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Geothermal reservoir characteristics and geothermal resource evaluation of Mesoproterozoic Wumishan Formation in Xiong'an New Area, China

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ABSTRACT

In order to deepen the large-scale development and utilization of the middle and deep geothermal resources in Xiong'an New Area, based on the outcrop, core, rock slice, drilling data and seismic line interpretation results, the buried depth, thickness, petrology and reservoir space characteristics of the thermal reservoir of Wumishan Formation of Jixian System in the Mesoproterozoic are analyzed, the thermal reservoir sedimentary microfacies model is established, and the fault distribution, porosity, permeability distribution characteristics and diagenesis controlling karst development factors are studied. The characteristics of karst thermal reservoir and caprock, geothermal gradient and hydrodynamic conditions of Wumishan Formation are clarified, the geothermal resource accumulation model in this area is established, and the favorable exploration target area of Wumishan Formation thermal reservoir is optimized. Finally, geothermal water reserve and recoverable geothermal water amount in the reservoir of Wumishan Formation with the roof buried no more than 5000m both in Xiong'an New Area and in the main construction of Xiong'an New Area are evaluated.

The research results show that the Wumishan Formation in Xiong'an New Area is the main geothermal reservoir at present. The geothermal resources of this formation are a large-scale conductive hot water storage system enriched in the Rise belts under the normal heat flow background, with atmospheric precipitation as the water source, weathered crust karst and deep faults as the migration channels, mainly through the long-distance supply of Taihang Mountain and Yanshan mountain. The wellhead water temperature of Wumishan Formation thermal reservoir is generally 57 ℃ ~ 83 ℃, up to 109 ℃, the water flow is generally 80 ~ 120 m^3/h, and the mineralization is 1900 ~ 3100 mg/L; The buried depth of thermal reservoir is relatively shallow in Rongcheng Rise and Nutuozhen Rise, with a roof of 700m ~ 2600m and a thickness of 800m ~ 1400m; In Gaoyang low Rise, the depth is relatively deep, the roof is generally 3000m ~ 4000m, the thickness is generally 700m ~ 1000m, and the temperature is relatively Rise. The thickness of the caprock is generally greater than 700m, and the geothermal gradient is between 3 ℃ ~ 8 ℃/100m in the Rise areas. The lithology is mainly dolomite, and the sedimentary microfacies are characterized by the development of dolomite tidal flat and algae dolomite tidal flat, which are easy to develop various dissolution and fractures; The karst development period is mainly Early Yanshanian - Himalayanian; 61.3% of the porosity is between 1% and 6%, and 87.8% of the permeability is between 0.01 and 100mD. The thermal reservoir of Wumishan Formation can be divided into the most favorable area, the second favorable area, the third favorable area, the general favorable area and the unfavorable area, according to the structural development, the porosity and permeability properties, the geothermal gradient, the buried depth of the top surface and the sedimentary microfactors, etc. For the Wumishan Formation thermal reservoir with the roof buried no more than 5000m, according to the principle that the recoverable geothermal water in 100 years accounts for 50% of the total storage water reserve, the recoverable geothermal water is 142.68×10^8 m^3, which content recoverable

heat 33.25×10^8 GJ, converted into standard coal 1.136×10^8 t；Among them, the recoverable geothermal water in the main construction area of Xiong’an New Area is 42.476×10^8 m^3 , the heat content of recoverable geothermal water is 7.928×10^8 GJ, equivalent to standard coal 0.2708×10^8t , the annual heating area can meet accounting for 30.1% to 48.6% of the actual demand . The geothermal resource endowment of Wumishan Formation in Xiong’an New Area is very good, which could not meet the actual energy demand of the main construction area alone.

1. INTRODUCTION

Hebei Xiong’an New Area, as China's national event and a millennium plan, scientific and rational development and utilization of geothermal energy is of great significance to reduce environmental pollution in Xiong’an New Area, improve energy structure, and become a new energy application demonstration area. The thermal reservoir of geothermal energy resources in Xiong’an New Area is mainly carbonate rocks.

The research on carbonate reservoirs at domestic and foreign is mainly aimed at oil and gas exploration (Alsharhan, 1995; Wang et al. 2002; Esrafili-Dizaji and Rahimpour-Bonab, 2009; Liu Bo et al., 1999; Qian YiXiong et al., 2007; Zhao Zongju et al., 2007; Wu KongYou et al., 2010; Lu ShiKuo et al., 2011; Wu WeiTao et al., 2015; Duggan P et al,2001; He DengFa,2018;He ZhiLiang et al., 2016). The carbonate reservoirs in Jizhong Depression belong to the karst weathering crusts, and are mainly buried hill-type karst reservoirs formed by large-scale rifting during the Himalayan period. However, it is relatively limited to discuss the distribution characteristics of karst reservoirs for the purpose of geothermal resources (Chen MoXiang et al. 1982; Zhou RuiLiang, 1987; Yan DunShi and Yu YingTai, 2000). Based on the interpretation of drilling cores, outcrops and seismic lines, the paper intends to analyze the types of reservoir spaces in Xiong’an New Area, discuss the characteristics of thermal reservoir, and analyze its influencing factors, combined with geothermal data (Chen MoXiang et al., 1982, 1988; Zhou RuiLiang, 1987 , 1989; Yan DunShi and Yu YingTai, 2000; Guo ShiYan et al., 2013; Chang Jian et al., 2016; Dai MingGang et al., 2019) optimizing favorable targets for the exploration. It provides an important basis for the exploration and large-scale exploitation of carbonate Wumishan Formation thermal reservoir in Xiong’an New Area.

The geographical scope of Hebei Xiong’an New Area covers three counties of Xiongxian, Rongcheng , Anxin and some nearby areas in Hebei Province. The starting area is about 200 km^2, and the total area of the new area is about 2000 km^2. Geologically, it is located in the Jizhong depression of the Bohai Bay Basin (Du JinHu, et al., 2002; Oil and Gas Resources Strategic Research Center of the Ministry of Land and Resources, etc., 2014; Dai MingGang et al., 2019), the geothermal resources in the region have a good geological foundation (Chang Jian et al., 2016), and the secondary structural units mainly involved are Rongcheng Rise, Niutuozhen Rise, Gaoyang low Rise and Lixian Slope, Bazhou Sag, Xushui Sag, Anxin Transition Zone, Raoyang Sag, Baoding Sag, etc. (Fig. 1), the main faults involved are Rongcheng Fault, Xushui fault, Niudong fault, Rongxi fault, Niunan fault, Anxinnan fault, Gaoyang-Boye fault, Baoding-Shijiazhuang (Taihang Mountain eastern foot) fault, Renxi fault, Renqiu fault, etc.(Dai MingGang et al., 2019).

2. STRATA FEATURE

The main strata from bottom to top in the study area are Archaeozoic, Changcheng System（same as international chronostratigraphic name Calymmian System）, Jixian System（same as international chronostratigraphic name Statherian System）, Paleogene, Neogene and Quaternary. There are also Paleozoic and Mesozoic in small local areas. The thermal reservoirs are mainly Wumishan Formation of Jixian System and Gaoyuzhuang Formation of Jixian System. There is a thin layer of Yangzhuang Formation of Jixian System as the interlayer between the two layers; The caprocks are mainly Paleogene and Neogene. Neogene is mainly Minghuazhen Formation and Guantao Formation (Fig. 2). Minghuazhen Formation is distributed in the whole area, with a deposition thickness of 400-650m. Guantao Formation is distributed in the south of Dawangzhen line (Fig. 3). Paleogene is distributed except for the axis of Niutuozhen Rise and Rongcheng Rise; The Quaternary is distributed in the whole area, with a thickness of about 300 ~ 450m.

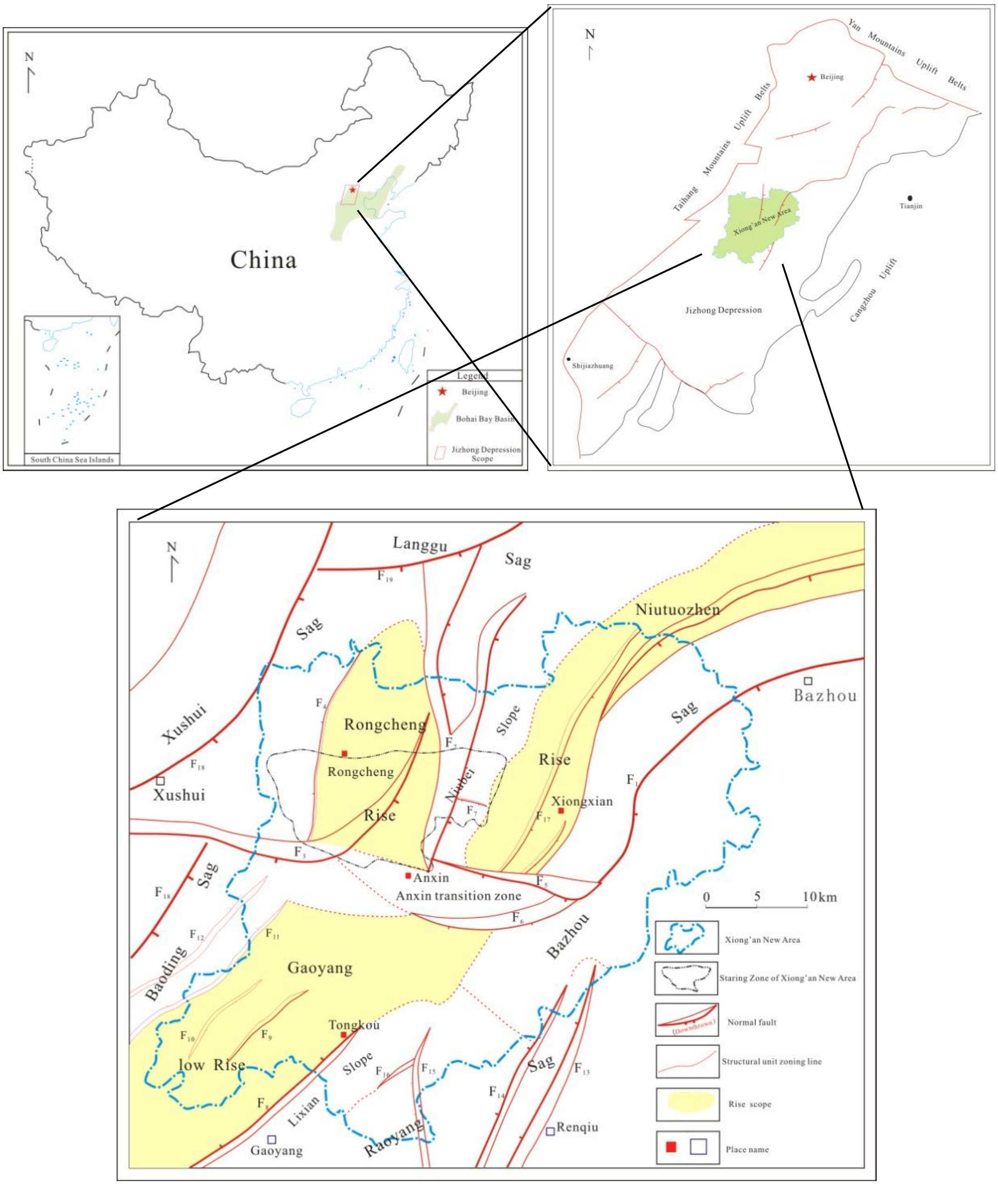

Fig. 1 Distribution of structural units on top of Wumishan Formation of Jixian System in Xiong'an New Area (after Dai MingGang et al.,2019a)

Wumishan Formation is distributed in the area, with a normal thickness of 700 ~ 1400m. It is the main thermal reservoir stratum in the area, which is basically distributed in the whole area except for part of the fault surface. The buried depth of the roof is shown in Fig. 3. The strata of this formation are basically denuded in the Rise, and the residual thickness increases from the center of the Rise to the two wings. The Niubei slope (also known as Niuxi slope) on the northwest side of Niutuozhen Rise has a buried depth of about 700 ~ 2200m at the top boundary, which gradually deepens from east to west; The thickness gradually increases from about 300m to 1100m. In Rongcheng Rise, well Rong1 and well D14, 400m north of Rong1, form the center of the local dome, and the buried depth of the roof is about 700 ~ 1000m. Its Wumishan Formation leans around, but the main axis of the Rise basically maintains a near north-south trend; The buried depth of the east side of the main axis roof from the north to the south is deepened from about 800m to about 2500m, with a thickness of 1100m ~ 600m; The west side of the main axis is adjacent to the Xushui Sag, and its buried depth of the roof is

Table 1 Regional strata of Xiong'an New Area

Era	System	Formation	Code	Thickness (m)	Lithological characteristics	Remarks
Cenozoic	Quaternary	Pingyuan	Q	300~500	Grayish yellow, yellowish brown, brownish red loam, clay, grayish yellow siltstone and fine sandstone	
Cenozoic	Neogene	Minghuazhen	N*m*	338~1000	It is mainly interbedded with sandstone and mudstone. The upper section is light purple and mottled mudstone, grayish green and grayish yellow sandstone and pebbly sandstone, and the lower section is mudstone and grayish green sandstone.	Forbidden reservoir
Cenozoic	Neogene	Guantao	N*g*	82~800	Brownish red and greyish green mudstone with greyish green sandstone ,and variegated conglomerate at the bottom	Distributed to the South and east of the pinch out line. Restricted reservoir
Cenozoic	Paleogene	Dongying Shahejie Kongdian	E	500~6000	Brownish red and purplish red mudstone and shale interbedded with grayish white and light gray sandstone	Mainly distributed outside the pinch out line
Mesozoic	Triassic-Cretaceous		Mz	0~200	The Upper Cretaceous is composed of purplish red and brownish red mudstone and variegated medium basic volcanic rock and conglomerate, and the Lower Cretaceous is composed of purplish red and brownish red mudstone, sandstone conglomerate interbedding , volcanic breccia and carbonate rock. The Jurassic system is mainly composed of mudstone and various sandstones, and locally intercalated with coal seams. Triassic system is also dominated by mudstone and sandstone.	
Paleozoic	Carboniferous-Permian		C-P	0~200	The upper part is interbedded with sandstone and mudstone, and the lower part is gray sandstone and sandy mudstone with coal seam	
Paleozoic	Cambrian-Ordovician		ϵ-O	0~1000	The Ordovician is mainly composed of light gray, brown limestone, Oolitic Limestone, dolomitic limestone, calcareous dolomite, dolomite with gray mudstone. Cambrian is mainly composed of grayish yellow, gray limestone, brownish gray fine-grained dolomite and calcareous dolomite, mixed with purplish red mudstone and silty mudstone, containing variegated chert	
Upper Proterozoic	Qingbaikou System		Qn	0~350	The upper part is marl and grey white quartz sandstone, and the lower part is black plus grey green and brownish red shale	
Mesoproteroz	Jixian System	Tieling Hongshuizhuang	J*xt* - J*xh*	0~200	Tieling Formation is composed of light gray and grayish brown dolomite, dolomitic limestone and brown and variegated shale. Dolomite contains more brown chert blocks. Honghongzhuang Formation is brown and variegated shale with thin layers of light gray dolomite and sandstone.	
Mesoproteroz	Jixian System	Wumishan	J*xw*	760~1400	Gray dolomite, gray white band dolomite containing flint, extremely thick stromatolite dolomite and silty	Main geothermal

				argillaceous dolomite with thin layers of brown red and gray green mudstone.	reservoir
	Yangzhuang	Jxy	38~206	Purplish red mudstone, intercalated with dolomite or gray fleshy red dolomite, and gray gray green sandy argillaceous dolomite at the bottom.	
	Gaoyuzhuang	Jxg	860~1040	Gray grayish black dolomite and argillaceous dolomite interbedded with mottled basalt.	Important spare geothermal reservoir
Changcheng System	Dahongyu	Chd	75~106	Quartz sandstone with grey siliceous dolomite	Spare geothermal reservoir
	Tuanshanzi	Cht	23~186	Gray siliceous dolomite, argillaceous dolomite, intercalated with a small amount of fine sandstone and silty shale	
	Chuanlinggou	Chcl	80~340	Dark gray shale and mudstone, intercalated with argillaceous dolomite	
	Chanzhougou	Chcz	50~300	The upper part is gray white quartz sandstone, and the lower part is flesh red pebbly arkose and glauconite sandstone	Spare geothermal reservoir
Archaeozoic		Ar		Gray flesh red granite gneiss, granulite, granulite, etc	

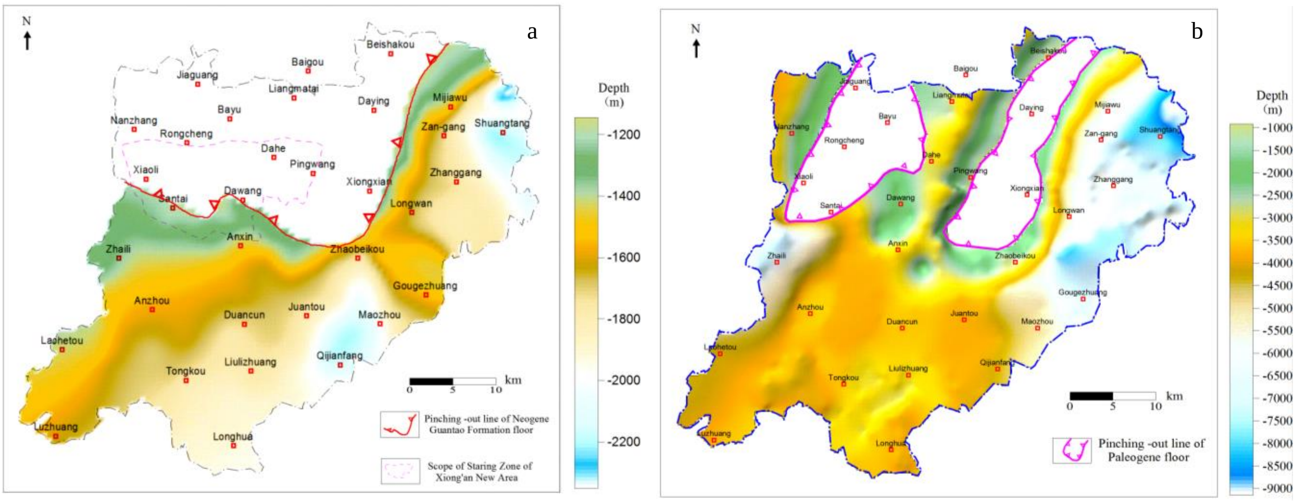

Fig. 2 Distribution diagram of buried depth of main thermal reservoir caprock floor in Xiong'an New Area

a. Distribution of buried depth of Neogene Guantao Formation floor; b. Distribution of buried depth of Paleogene bottom plate.

about 1000m ~ 2500m and the thickness is about 1000m. The axis of Gaoyang low Rise is distributed in the northeast direction, and its buried depth of the roof of Wumishan Formation is 3000m ~ 3500m, and gradually deepens to both sides, with an average thickness of about 900m.

Gaoyuzhuang Formation is distributed in the whole area except for part of the fault surfaces. According to the drilling data of 6 exposed Gaoyuzhuang Formation, the buried depth of the roof of this formation in the middle of Rongcheng Rise is about 900m ~ 1700m, and in the south is about 2075m; in the east of the main axis is about 2600m, but in the west of the main axis is about 2000m ~ 2600m, with a thickness of about 1000m. In Niutuozhen Rise of Xiongxian, the buried depth of the axis roof is 1200m ~ 1400m, and the east side of the axis gradually deepens to 1700m, with a thickness of about 1000m. In the downthrow side of Niudong Fault in

Bazhou depression, the buried depth of the roof of Gaoyuzhuang Formation is more than 7000m. In Gaoyang low Rise, the buried depth of the roof is mostly below 4000m.

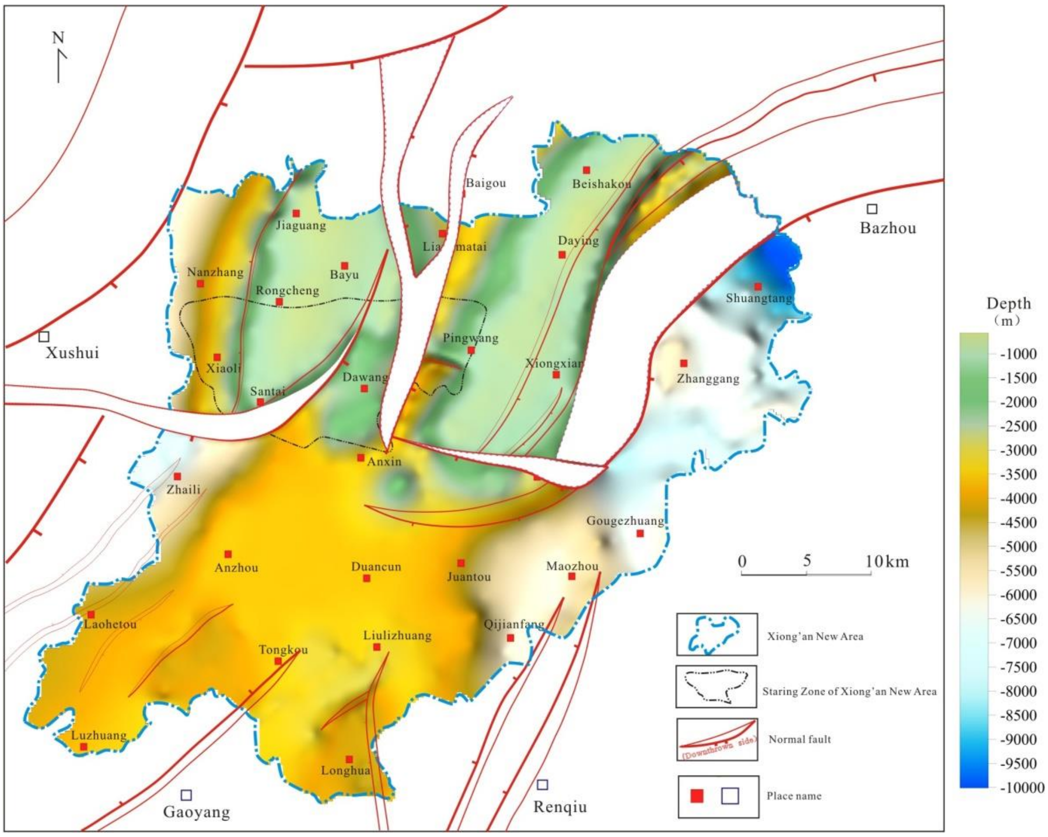

Fig. 3 Distribution of buried depth of roof of Wumishan Formation of Jixian System in Xiong'an New Area

3. FAULTS FEATURE

Jizhong Depression is mainly a secondary tilting block, dustpan depression and buried hill structural unit formed by a series of normal faults or reverse normal faults formed by Mesozoic compression and Cenozoic extension (Wan TianFeng, 2004) (see Fig. 1 and Fig. 4). Therefore, there are many faults developed in and around the study area, and the more important faults are(see Table 2):

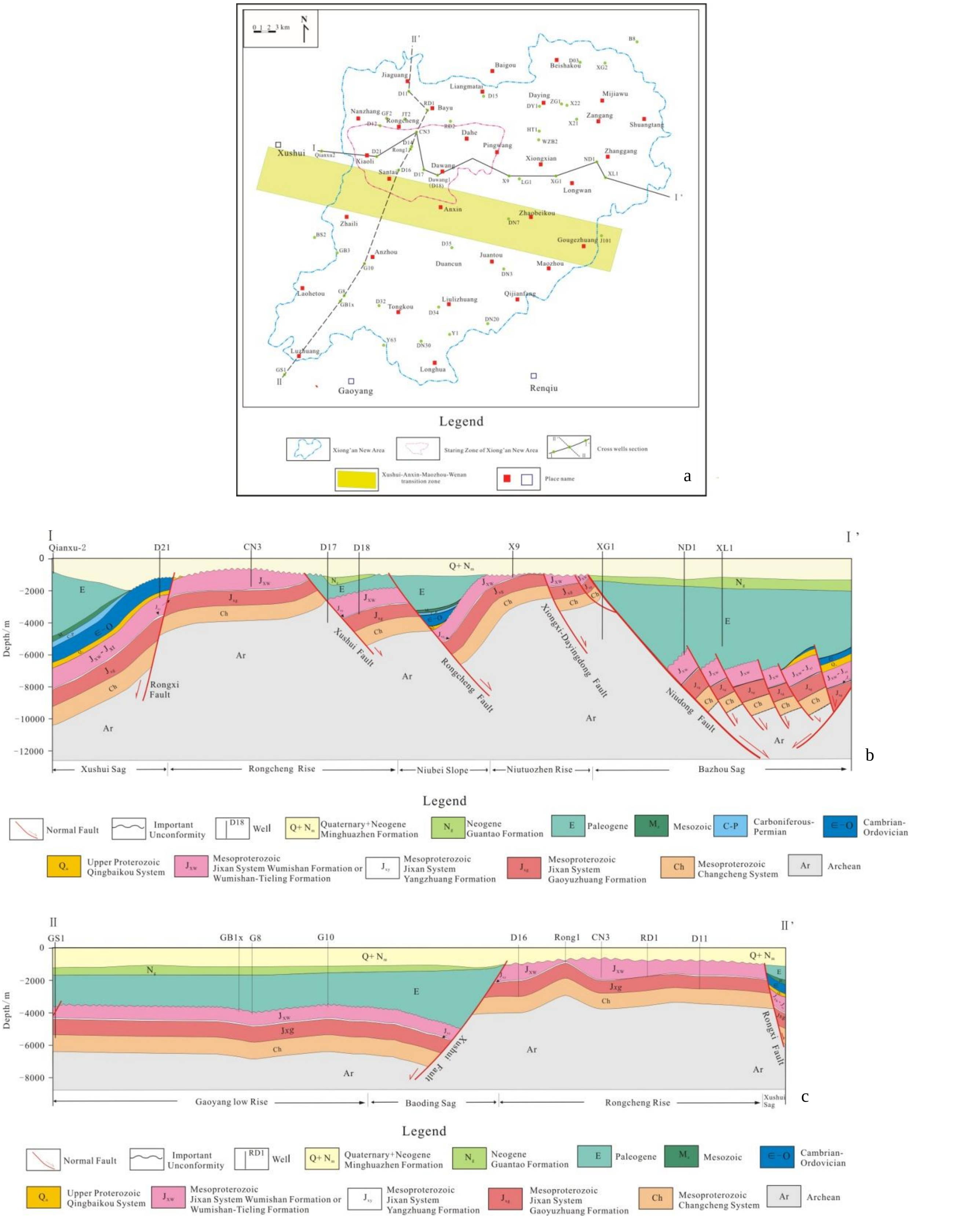

Fig. 4　Stratigraphic structure profiles of Xiong'an New Area

a. Location distribution of profiles and transition zone;　b.　Geological structure of I-I' section near W-E direction;　c. Geological structure of Ⅱ-Ⅱ' section near S-N direction.

Table 2 Characteristics of main faults on the roof of Jixian System in Xiong'an New Area

Number	Fault name	Length /km	Trend	Dip direction, Dip angle	Horizontal separation /m	Vertical separation /m
F1	Niudong	28+	NNE-NE	SSE~SE、40°	5000~7000	5000~7000
F2	Rongcheng	20	near N-S	E,45°	1300~3200	1000~3000
F3	Xushui	25+	E-W to NE	S,62° to SE,25°	100~2000	1500~2500
F4	Rongxi	21	near N-S	W,68°	200	3000
F5	Niunan	17	near E-W	S,75°- 45°	200~2000	1000~2500
F6	Anxinnan	17	E-W to NEE	S,25° to SE,65°	200~1400	600~3000
F8	Gaoyang-Boye	7+	NE	NW,60°	700	500

In addition to the main faults in the above table, there are two large faults outside the study area that have an important impact on the thermal storage in the study area:

Taihang piedmont fault (Baoding -Shijiazhuang fault): in the west of the outer part of the study area and along the NNE-SSW direction at the eastern foot of Taihang Mountain, it is a large fault deep into the upper crust. It inclines to SEE, and the fault surface is steep up and gentle down (Shan ShuaiQiang, 2018a). The dip angle of the upper steep section is about 45 °, and the gentle slope section extends to the bottom of the upper crust of Bazhou Sag.

Daxing fault: it is a boundary fault that controls Langgu Sag (Gui BaoLing et al., 2012; Shan ShuaiQiang, 2016,2018b). It is divided into multiple sections from north to south. The section closest to the area is distributed along NEE, inclined to SSE, with an inclination of 60 ° in the upper part and 30 ° in the lower part. It is also a gravity detachment fault with a horizontal fault distance of 20km and a vertical fault distance of 5-6km. It makes the Mesozoic and Cenozoic in the sag overlap the Proterozoic or Paleozoic in the South or East, and is also an important geological fluid transport channel.

The faults in Xiong'an New Area and the nearby faults structures outside the area control the distribution of karst development areas and the overall pattern of karst paleogeomorphology in the area. Structural fractures and deformation generate faults and fractures, forming the storage space and seepage channel of geothermal reservoir, effectively improving the seepage performance of which. The generation of fracture systems is conducive to pore water and groundwater activities and the development of dissolution holes. The larger the amplitude of fracture structures, the deeper the karst action, The greater the thickness of the seepage zone, the karst process is promoted to form a unified pore-fissure-cave system, and it is possible that the deep heat source can reach the shallow layer more easily, resulting in local Rise-temperature anomalies in the shallow layer. Therefore, these fault development zones are often the areas with the most developed thermal reservoirs in the study area.

4. CHARACTERISTICS OF MAIN GEOTHERMAL RESOURCES

4.1 Geothermal Reservoir Characteristics of Wumishan Formation of Jixian system

4.1.1 Lithology, Buried Depth and Thickness

The geothermal reservoir of Wumishan Formation in the study area is mainly dolomite (Fig. 4), including stromatolite dolomite, algal agglomerate dolomite, granular dolomite, fine-grained dolomite and chert banded dolomite. They are distributed in the working area except for some fault surface areas. The Wumishan formation in this area is divided into four members, which match the sedimentary cycle background of the Wumishan Formation (Mei MingXiang, et al., 1999). From the bottom to the top, they are the first, second, third and fourth members of the Wumishan Formation. Rongcheng Rise and Niutuozhen Rise generally lack Wu-4 member, and some even lack Wu-3, only a few areas retain Wu-4 . The residual thickness of the Wumishan Formation is generally reduced from northeast to southwest, from more than 1200 meters to more than 600 meters. The effective geothermal reservoir of this formation is mainly distributed within 300m from the top of Wumishan Formation, sometimes up to 500m.

4.1.2 Sedimentary Microfacies

The Wumishan Formation in the study area mainly develops tidal flat facies sedimentation (Fig. 5), which is further divided into five types of sedimentary microfacies: dolomite tidal flat, algae dolomite tidal flat, argillaceous dolomite tidal flat, limestone dolomite tidal flat and grain shoal. Among them, algae dolomite tidal flat is mainly stromatolite dolomite, which is mostly silicified; dolomite tidal flat is mainly micrite dolomite or micrite containing dolomite; The argillaceous dolomite tidal flat is mainly composed of muddy dolomite, argillaceous dolomite or intercalated stromatolite dolomite; Algae dolomite tidal flat is widely distributed, which provides a good material basis for the development of Rise-quality karst reservoirs in the later stage。

4.1.3 Reservoir Space

According to the core, outcrop and microscopic observation, the thermal reservoir space in the study area can be divided into three systems: fractures, pores and caves.

Fracture system: mainly including structural (corrosion) fractures and suture lines. Structural (corrosion) fractures are fracture systems generated under the action of structural stress, which are mostly vertical or oblique to the strike of the bedding plane. In the field, there are 4-5 groups of fractures with different occurrence. The fracture trends are mainly NNE-SSW, NW-SE and NWW-SEE. At the initial stage of formation of structural fractures, they are straight, smooth and uniform in width. After dissolution, the fracture surface is uneven and the fracture width varies greatly (Fig. 6f and 6g). The fracture width is generally 0.1-3mm, The maximum width can be more than 5mm with less filling. Sutures are mostly found in argillaceous dolomite, which can be seen in all horizons, and are generally distributed in broken line bedding. The fillings are argillaceous or dark materials, which contribute relatively little to the reservoir space (Fig. 6h).

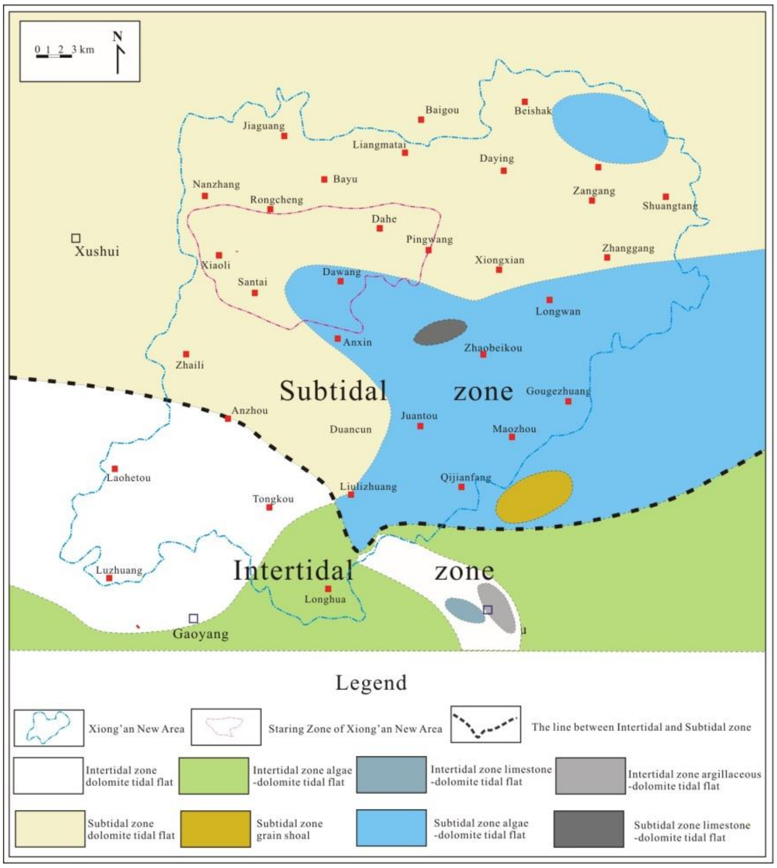

Fig.5 Lithofacies paleogeography map of Wumishan Formation in Xiong'an New Area (Dai MingGang et al.,2020)

Pore system: it mainly includes algal shelf pore, intergranular dissolved pore, and intragranular dissolved pore (mold pore). Algal shelf pores and intergranular pores are primary pores, while intragranular dissolved pores (Fig. 6a) are secondary pores. Intergranular pores are widely developed between dolomite crystals and mainly show as intergranular dissolved pores (Fig. 6b).

Cave system: mainly refers to dissolved pores and caves. Solution pores are distributed in all kinds of lithology, mostly bedding; Most of the karst caves are irregular oval in shape (Fig. 6c), with different sizes. The large diameter can reach tens of meters, and most of them are semi-filled. The filling materials are mostly collapse breccia, terrigenous debris, calcite and dolomite. According to field observation, most of the karst caves are developed in the middle and upper part of the Wumishan Formation. They are dissolved along the bedding plane along the interlayer fractures (the intersection with the through bedding fractures), and they are distributed in a "string of beads" and appear in groups and belts. The caves are mainly distributed in bedding and near horizontal. The caves distributed in bedding are lithologically selective (Fig. 6d), and the caves distributed in near horizontal are non selective (Fig. 6e).

According to Zhu JiangWei (2016) fracture data statistics, most of the fractures in Wumishan Formation of Jixian System are distributed between 70 ° and 90 °, belonging to Rise angle fractures; The fractures of buried hill reservoirs in Jizhong depression are filled with minerals (mainly calcite and dolomite), accounting for about 35%, of which half-filled fractures account for 12.5% of the total, and fully-filled fractures account for 22.5%. The rest of the fractures are basically not filled with minerals.

The combined composite space of fractures and karst pores is the main thermal reservoir space of Wumishan Formation in this area (Fig. 7), and the separately developed fractures and karst caves are the secondary thermal reservoir spaces.

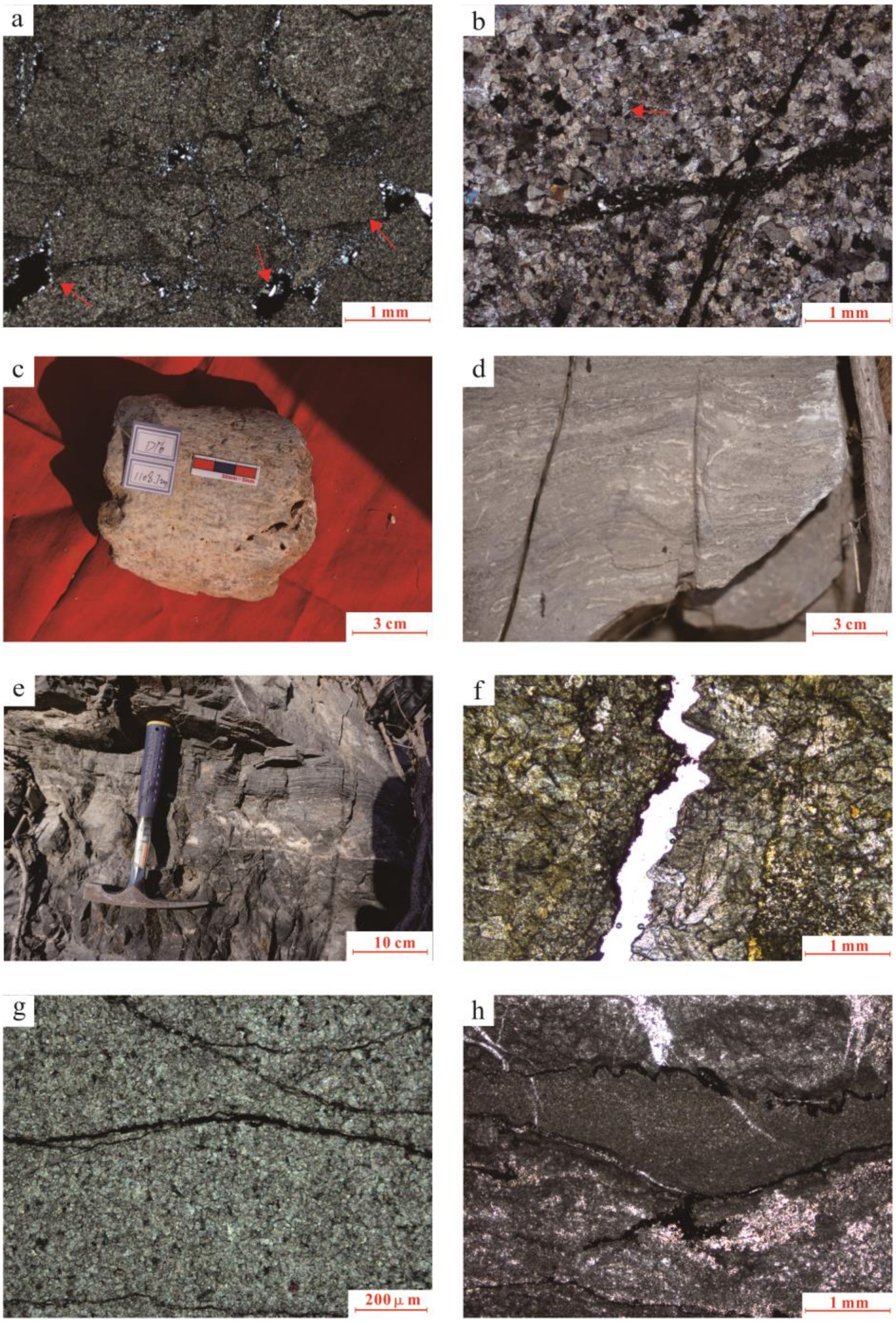

Fig. 6   Karst geothermal reservoir space type of Wumishan Formation in Xiong'an New Area

(Dai MingGang et al.,2020)

a.   sand-clastic dolomite, filled with quartz, well GS1, 3760.53m, (+);   b.   Fine crystal dolomite, dolomite intergranular pore, well MJ1, 2617.54m, (+);   c. Fine crystal dolomite, selective dissolution pore, well D16;   d. Laishui profile in Taihang Mountain, corrosion pores distributed along the stratum;   e. In Laishui profile, the corrosion holes are distributed nearly horizontally;   f. Fine crystalline dolomite, structural dissolution fracture, Jixian profile;   g. Muddy silty dolomite, unfilled fractures, well GS1, (+);   h. Muddy silty dolomite, suture, well D16, (-) .

Through logging interpretation, it is found that the linear density of fractures in dolomite is the Riseest, reaching nearly 0.7 piece /m, the linear density of fractures in calcareous dolomite is the second, reaching 0.4 piece /m, the linear density of fractures in siliceous dolomite is about 0.34 piece /m, the linear density of fractures in argillaceous dolomite is less developed, and the linear density of fractures is only 0.17 piece /m. fractures are the least developed in mudstone, and the linear density of fractures is less than 0.1 piece

/m (Fig. 8). Therefore, fractures are most developed in dolomite, followed by calcareous dolomite, and least developed in argillaceous dolomite(Dai MingGang,2020).

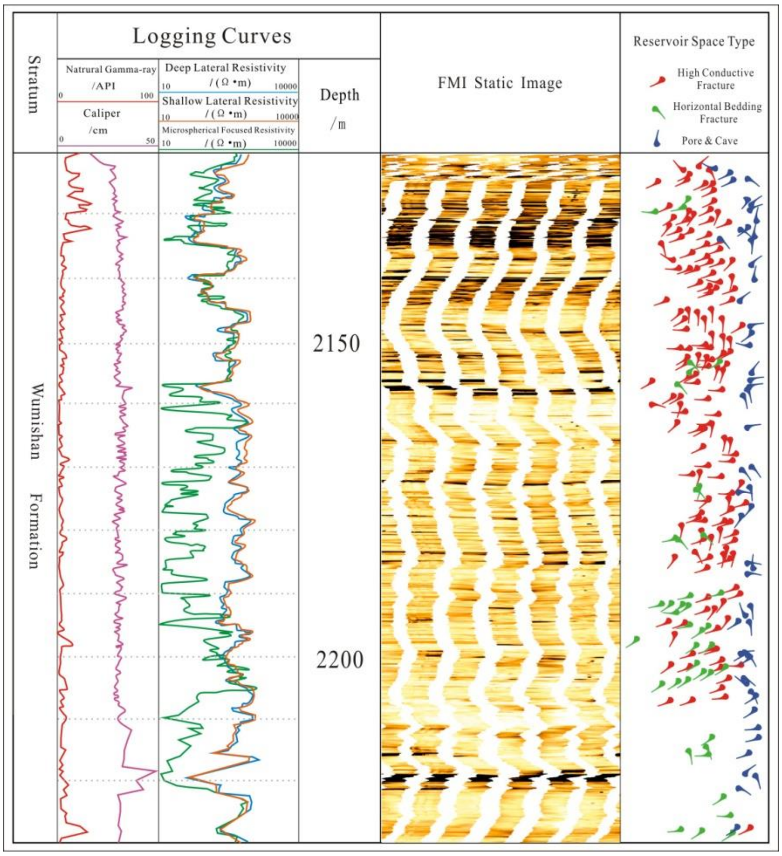

Fig. 7　Statistical diagram of thermal reservoir space development in typical interval of Wumishan Formation of Well Dawang-1 (D18) in Xiong'an New Area

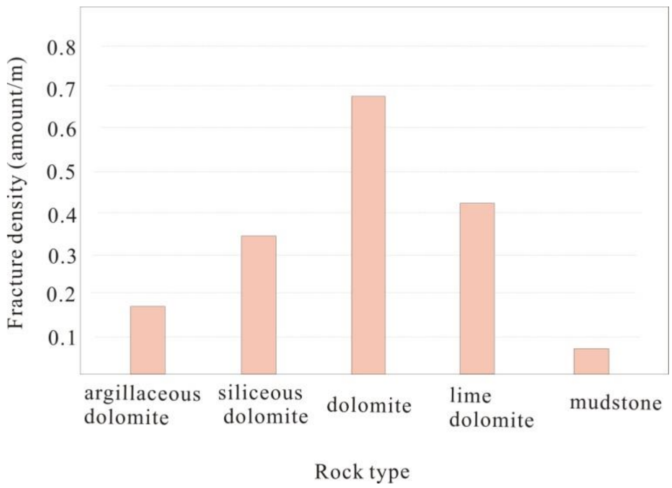

Fig. 8　Fracture development density of different rock types in Wumishan Formation, Xiong'an New Area

4.1.4　Porosity and Permeability

According to the 235 porosity and 230 permeability data of the small rock plug in the Proterozoic Wumishan Formation (as shown in Fig. 9) found that the reservoir thickness ratio of this formation is 20% ~ 40%, and the rock porosity is mainly distributed within 6.0%, accounting for 85.9%, of which 61.3% is porosity distributed between 1 and 6%, the maximum porosity can reach 22.4%(Dai MingGang et al.,2019a, 2019b, 2020), the average porosity is 3.39%, and the permeability distribution range is large, It is distributed from 0.01 to 1000md and above, and mainly from 0.01 to 100 mD, accounting for 87.8%, with an average permeability of 23 mD.

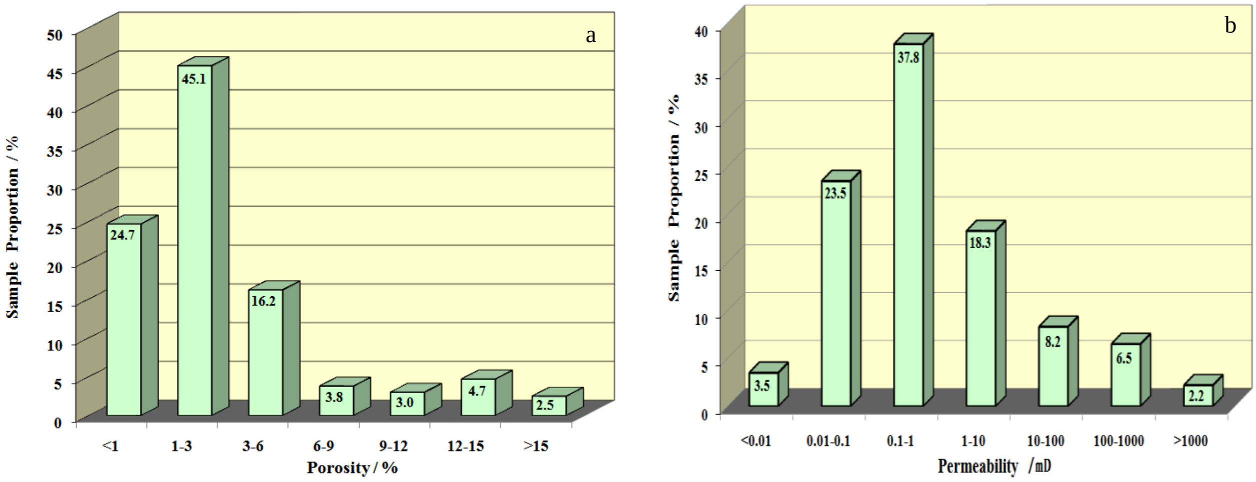

Fig. 9 Geothermal reservoir properties porosity(a) and permeability(b) of Mesoproterozoic Wumishan Formation in the study area and surrounding in Jizhong Depression (Dai MingGang et al.,2019a)

The current porosity and permeability properties of the Wumishan Formation thermal reservoir in Jizhong Depression are the result of the development and evolution of the Wumishan Formation diagenesis:

In the early Caledonian, that is, the syngenetic period (as shown in FIG. 10), the study area settled and received the carbonate rock deposition of the Middle Proterozoic Wumishan Formation. The sedimentary environment is mostly tidal flat subfacies and reef shoal microfacies. The main diagenesis types include cementation, quasi-syngenetic dolomitization, microbial dolomitization, quasi-syngenetic dissolution and short-lived weak compaction in the later stage. Cementation and compaction in this stage are the main diagenesis affecting the pores, and the original porosity is usually more than 30% and rapidly decreases to less than 3%.

From the Mid-Caledonian and Hercynian to the Indosinian and Yanshan movements, that is, the early, middle and late diagenesis, the Wumishan Formation was buried deep first and then subjected to intense denudation. At the end of Indosinian, due to the large-scale plate convergence in the eastern hemisphere and the near NE expansion of the Tethys ocean, the principal stress gradually changed from near NE to near E-W (Wan TianFeng, 2004), forming a Horst graben alternating pattern dominated by strong large folds and partial thrust faults in the study area. The multi-fold faults of the Wumishan Formation lifted the surface to receive the leaching of atmospheric fresh water and suffered weathering and denudation. In the fault-horst area, the Paleozoic was almost denuded, The Proterozoic Wumishan Formation was also strongly denuded. In the fault-graben area, part of the fault graben denuded to the Proterozoic Wumishan Formation. The main diagenesis of Wumishan in this stage includes supergene karstification, buried dissolution, fracturing, cementation and recrystallization. In addition, there are continuous compaction and pressure dissolution and metasomatism. The dissolution holes and karst caves formed in this stage, as well as the development of large-scale faults and solution fractures, have effectively reformed the thermal reservoir properties, increasing the porosity by about 10%.

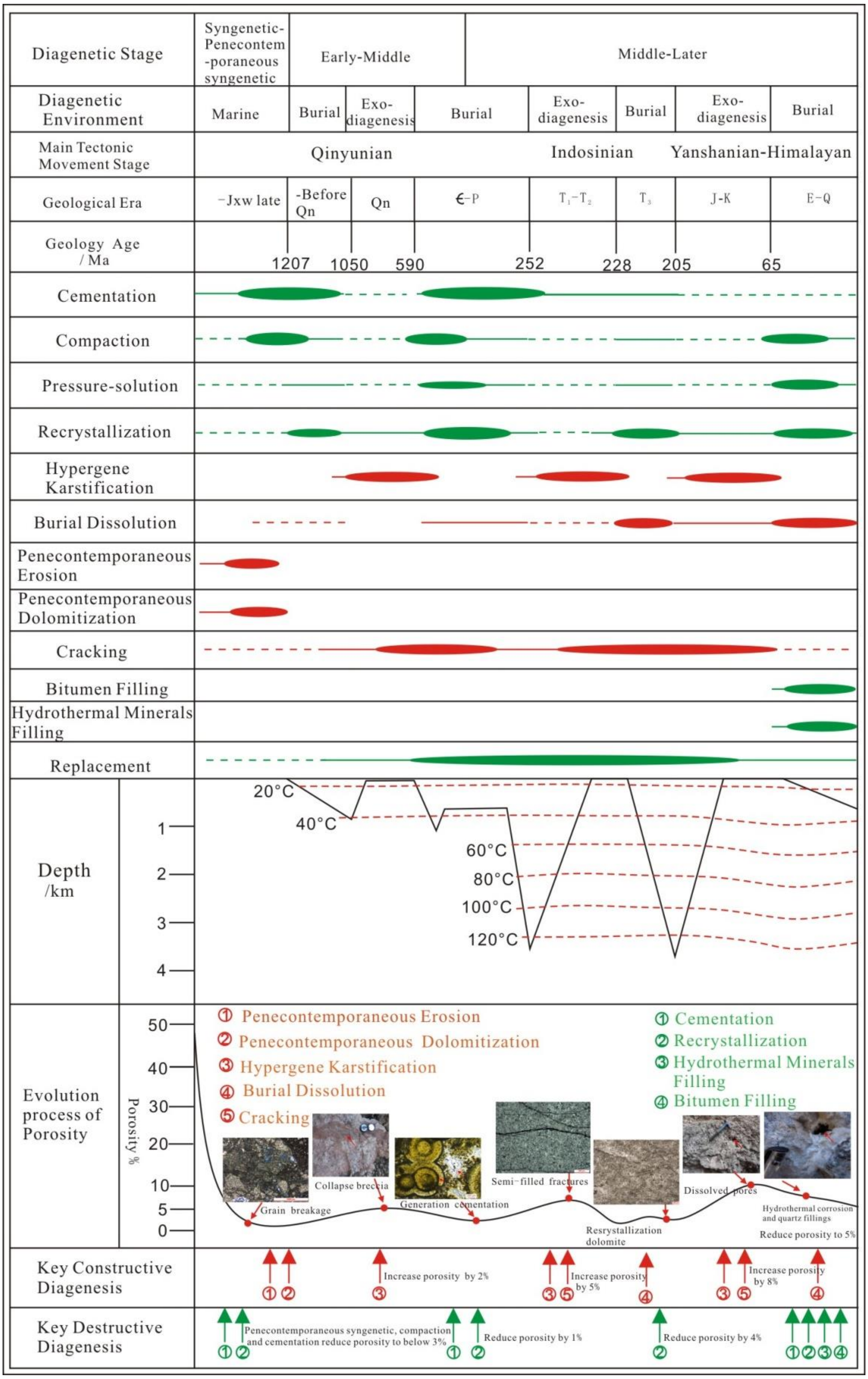

Fig. 10 Reservoir diagenesis-porosity evolution history of Mesoproterozoic Wumishan Formation rocks and porosity in Xiong'an New Area　(Dai MingGang et al.,2019a)

In the Yanshanian, the North China block underwent two large-scale extension compression activities, with the principal stress nearly EW (Wan TianFeng, 2004). Especially in mid-Yanshanian (late Late Jurassic - Early Cretaceous), the tectonic regime in the eastern part of North China changed from compression to tension (Zhai MingGuo et al., 2004; Zhu RiXiang et al., 2011). Under this background, the Taihang mountains piedmont fault began to extend (MA XingYuan et al, 1983), the basement fault activity is strong, the NE and NNW strike slip faults are developed, and the NE thrust fold structure is developed. The study area generally inherits the Rise and Sag pattern of the Indosinian, but the landform difference is more significant, the dissolution is more intense and deeper, which is still mainly developed in the Proterozoic algal reef shoal and algal flat.

During the late Yanshanian-Himalayanian, the study area was dominated by extensional movement and rapidly entered the development stage of faulted basin. The carbonate strata of the Wumishan Formation entered the burial stage again, forming a large-scale normal fault in the same period. The thrust fault in the early stage was also converted into a normal fault, forming the current fault structure pattern (Fig. 1 and Fig. 3). A large number of fault horsts formed in Indosinian- Yanshanian period evolved into fault grabens. A set of thick layer clastic rocks was deposited on the buried hills, which became a good cover for the underlying carbonate thermal reservoirs. There were multiple sets of thick layer source rocks, which had undergone large-scale hydrocarbon generation before Neogene. Diagenesis includes fracturing, cementation, buried dolomitization, buried dissolution, pressure dissolution, hydrothermal dolomitization and hydrothermal dissolution; At the same time, the reverse fault is transformed into a normal fault, which increases the pore space of the fracture. The Cenozoic hydrocarbon source rocks generated hydrocarbon on a large scale in the Paleogene, and the generated organic acids dissolved the thermal reservoir, which improved the thermal reservoir performance. In general, the filling of hydrothermal minerals in the early stage reduced the porosity to a certain extent, and the hydrothermal solution, organic acid solution and structural fracture increased the porosity.

In this process, cementation, compaction pressure solution and so on play a destructive role in the thermal reservoir property, while quasi-syngenetic dissolution, burial dissolution, supergene dissolution and fracture play a constructive role in the thermal reservoir property, of which supergene dissolution is the main role. Supergene karst is developed in the period of stratum exposure and denudation and is associated with the unconformity surface of the stratum. The combined effect of these factors makes the overall porosity decrease first and then increase to about 5%. In this way, the current porosity of the Wumishan Formation thermal reservoir in the study area is formed.

4.1.5 Fluid Feature

At present, according to the statistics of geothermal wells targeting the geothermal reservoir of Wumishan Formation, the water temperature at the wellhead is generally 57℃ ~ 83℃, up to 109℃, the water flow is generally 80 ~ 120 m^3/h, the mineralization is 1900 ~ 3100 mg/L, and the water quality is mainly Cl • HCO_3 - Na.

According to the analysis of water inspection in the study area and surrounding wells, the main cation in the carbonate geothermal water is Na+, the content of Na+ accounts for more than 80% ~ 90% of the total cation content, and the main anion is Cl^- - HCO_3^- , which accounts for more than 60% ~ 90% of the total anion content. The average pH value of the hot water is about 7.4, so it is classified as neutral water. It belongs to brackish water, for its hydrochemical type is Cl • HCO_3 - Na type . The geothermal water's mineralization increases from northwest to Southeast (Zhou RuiLiang, 1987; Chen MoXiang, et al., 1988; Yan DunShi, et al., 2000), indicating that the water source is located in the Taihang Mountains in the west of the study area, and it migrates through the mountain piedmont fault, unconformity and other dominant migration channels, and the salinity is positively related to the length of the fluid migration distance.

Figure 10 shows the δD and $\delta^{18}O$ correlation of geothermal water in the study area and the surrounding Jizhong Depression area, the values are between - 90.4 ‰ ~ - 57.36 ‰ and - 12.45 ‰ ~ - 6.99 ‰ respectively, and the average values are - 75.72 ‰ and - 9.99 ‰ respectively. Part of the geothermal water has obvious oxygen drift, which is located on the right side of the atmospheric precipitation line. It is verified that the geothermal water of carbonate rock thermal reservoir in the study area and the surrounding Jizhong area is from atmospheric precipitation, but some of the geothermal water is enriched in oxygen isotopes due to the Riseer interaction between water and rock.

Zonal comparison found that the eastern part of the study area δD and $\delta^{18}O$ is Riseer, while the west is close to the Taihang Mountains δD and $\delta^{18}O$ is lower, which is consistent with the results of predecessors (Zhou RuiLiang, 1987; Yan DunShi, et al., 2000), reflecting that the carbonate rock geothermal water mainly comes from the Taihang Mountain Area in the West. The ^{14}C isotopic dating results show that the ^{14}C age of the hot water in the carbonate reservoirs in the study area and the surrounding Jizhong area is roughly between 10000 and 27000 years.

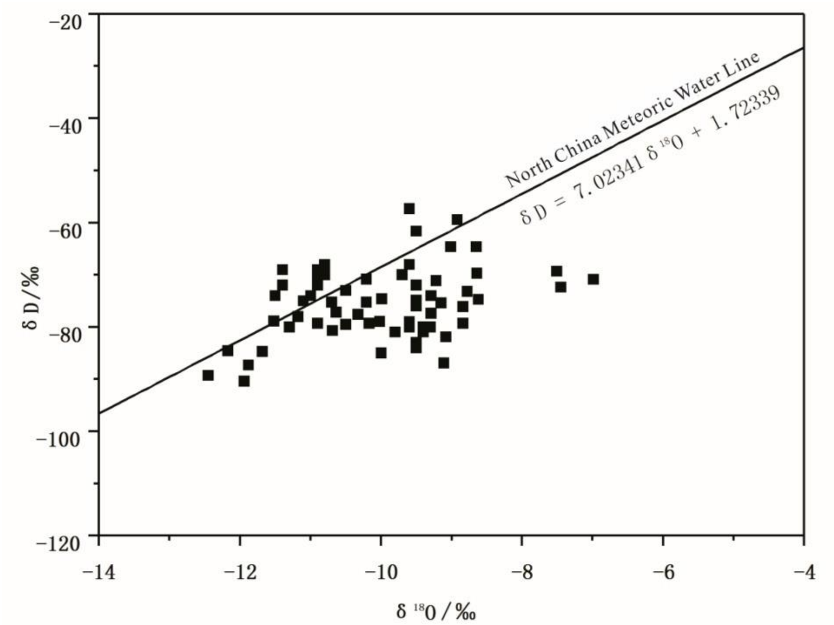

Fig. 11 δ D and δ ^{18}O correlation diagram of Geothermal water in reservoir of Wumishan Formation in Xiong'an New Area (Dai MingGang et al.,2019a)

4.2 Thermal Reservoir Caprock and Geothermal Gradient Characteristics

The Cenozoic is thermal reservoir caprock of the study area, and its thickness is basically the same as the buried depth of the top surface of Jixian System in terms of numerical value, and the overall thickness is about 700-2400m. The Cenozoic geothermal gradient in the study area is between 2℃～6℃/100m (see Fig. 12). Its distribution characteristics on the Rises are similar to the thickness distribution characteristics of the Cenozoic (Dai MingGang et al.,2019a). It is generally as Rise as 6℃/100m in the middle and gradually decreases to 2℃/100m around. Rongcheng Fault has an important influence on the geothermal field in the study area. In the southwest of Dawang Town, there seems to be an island of geothermal gradient, which is obviously Riseer than the trend line of the surrounding geothermal gradient.

The geothermal gradient of Wumishan Formation is 0.2℃～1℃/100m.

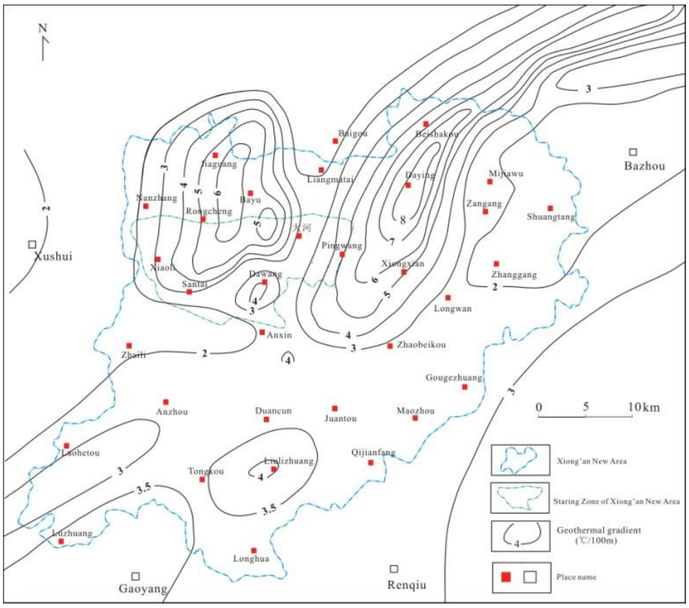

Fig. 12 Geothermal gradient map of Cenozoic in Xiong'an New Area **(Dai MingGang et al.,2019a)**

4.3 Feature of Geothermal Resources in Gaoyuzhuang Formation of Jixian System

Six wells in the study area were drilled to the Gaoyuzhuang Formation of Jixian System. According to these wells, the top depth of the thermal reservoir of the Gaoyuzhuang Formation is 1425 ~ 3600m, and the general thickness is not less than 1000m. the lithology is mainly gray dolomite with argillaceous dolomite and siliceous dolomite, containing flint blocks or strips (Oil and Gas Strategic Research Center of the Ministry of Land and Resources, etc., 2014). The porosity of Gaoyuzhuang Formation is 1.2% ~ 3.5%, whose the maximum is 13.2%, and the permeability is 0.1 ~160mD, mainly distributed in 0.3 mD ~7.9 mD. The formation temperature is generally about 75℃~95℃, the geothermal water flow is about 45~80 m3/h, and the mineralization is about 3000 mg/L. The geothermal gradient of Gaoyuzhuang Formation is not clear. The wellhead water temperature in the north of the Xushui-Anxin-Maozhou-Wen'an transition zone is generally 60℃~86℃, and geothermal water flow of a single well is 40~80 m3/h, where in the south the wellhead water temperature is generally 64℃~123℃, and the geothermal water flow of a single well is 20~95 m^3/h, and the mineralization is about 3000 mg/L. As the burial depth is only about 1000m deeper than that of Wumishan Formation, under the current economic and technical conditions, this layer is the most important backup geothermal reservoir in the New Area and will be gradually developed and utilized on a large scale in the next two decades.

4.4 Influencing Factors and Accumulation Model of Geothermal Resources in Wumishan Formation

4.4.1 Influencing factors

The geothermal resources in the study area are mainly sedimentary basin type, and the main influencing factors are: structure, deposition, water source hydrodynamic conditions, etc. among them, the heat source and water source hydrodynamic conditions lay the foundation of the geothermal resources in the area, and the structure and deposition factors determine the spatial shape and physical characteristics.

1) Heat Source

The heat source is the heat of the upper mantle and the radioactive heat generation of granite in the crust (Zhou RuiLiang, 1987; Chen MoXiang et al., 1982, 1988; Yan DunShi, et al., 2000). The average heat flow of the whole Jizhong Depression is 63.1mW/m2, which is close to the average heat flow of 61.5 mW/m^2 in North China (Chen MoXiang, 1988). The average heat flow of Rongcheng Rise is 63.81 mW/m^2, and the surrounding concave area is a low heat flow area; The heat flow of Niutuozhen Rise ranges from 66.3 to 113.8

mW/m^2 (Yan DunShi et al., 2000), and some parts in this area ranges from 68 to 90 mW/m^2. These data show that the study area belongs to the normal heat flow area in general, except that the heat flow is "redistributed" on the common depth surface of the base of the Rise and the Sag. Due to the small thermal resistance of the Rise area (Xiong LiangPing et al., 1984, 1985, 1988), the Rise in this area is affected by the structure under the normal heat flow background and becomes a Rise-value heat flow area.

2）Hydrodynamic Conditions of Water Source

The carbonate geothermal water in this area comes from the atmospheric precipitation in the Taihang Mountains in the West (Zhou RuiLiang, 1987; Yan DunShi, et al., 2000). The hydrodynamic conditions belong to the semi open-and semi-closed confined area and the open confined area. The hydrogeological environment of the semi-open and semi-closed confined area is more favorable to the formation of geothermal resources, which not only makes the groundwater continuously reduce the water salinity alternately, but also does cause less heat loss. If the structural and sedimentary conditions are suitable, a geothermal field with Rise economic value can be formed.

3）Combination of Thermal Reservoir, Caprock and Ground Water Channel

As mentioned above, the hot water migration channels in the area are faults and unconformities of different scales formed by various tectonic movements. The atmospheric precipitation from the Taihang Mountains in the West and the Yanshan Mountains in the north of the area is transported to Rongcheng, Xiongxian and other places through these faults and unconformities. In particular, the Shijiazhuang -Baoding fault (Taihang Mountains piedmont fault) communicates the surface water and geothermal reservoir. The groundwater originating from the Taihang Mountains is connected with the heat source through this fault, heated and then transported in the later stage.

The Proterozoic Rise porosity and permeability thermal reservoir in this area, together with the overlying clastic rock with appropriate thickness, forms a favorable reservoir cap combination, laying a reliable material space foundation for the formation of valuable geothermal fields in the study area.

4.4.2 Accumulation model

According to the above influencing factors of geothermal reservoir formation, the accumulation model of geothermal resources in the study area can be summarized as follows: the heat source is mainly the earth heat flow of the crust and mantle, the heat flow value in the Rise area is Rise, and in the sag area is low, which constitutes the heat source foundation of the study area; About 10000-27000 years ago, atmospheric precipitation flowed through the valleys, and rivers in the Taihang Mountains and Yanshan Mountains, and flowed down through the deep and large faults in the Taihang mountains such as Shijiazhuang-Baoding and other faults. It was gradually heated into hot water by the earth's heat flow (Fig. 7). At the junction of the fault and the unconformity surface, it encountered an unconformity Rise porosity and permeability layer.The deep pressure field and fluid potential were far greater than the shallow, most of the hot water flows through the unconformity through redirection. Because the strata in the depression are deeply buried, the Rise-pressure force field and Rise fluid potential are not conducive to the effective migration of fluids therein, so the unconformity in the Rise area becomes one of the dominant migration channels. Fluids first migrate in the unconformity in the Rise area.

In this process, deep and large faults in the hinterland of the basin mostly intersect with unconformities, and these faults are mostly normal extension faults. Therefore, fluids not only migrate in the unconformity, It also migrated in deep and large extensional faults. In the Rise area, the heat flow value is Rise, the hot water mineralization is low, and the water source is sufficient; in the Sag area, the heat flow value is low, the hot water mineralization is Rise, and the water source is limited; The geothermal water type is mainly $Cl^-+HCO_3^-$ -- Na^++K^+. The Meso-Upper Proterozoic carbonate rock strata experienced three periods of structural uplift in Caledonian, Indosinian and Yanshanian. Reef shoal, algal flat and tidal flat facies are favorable sedimentary factors. They were exposed to and received the corrosion of atmospheric precipitation and coastal mixed water for a long time. The further dissolution of acid fluid

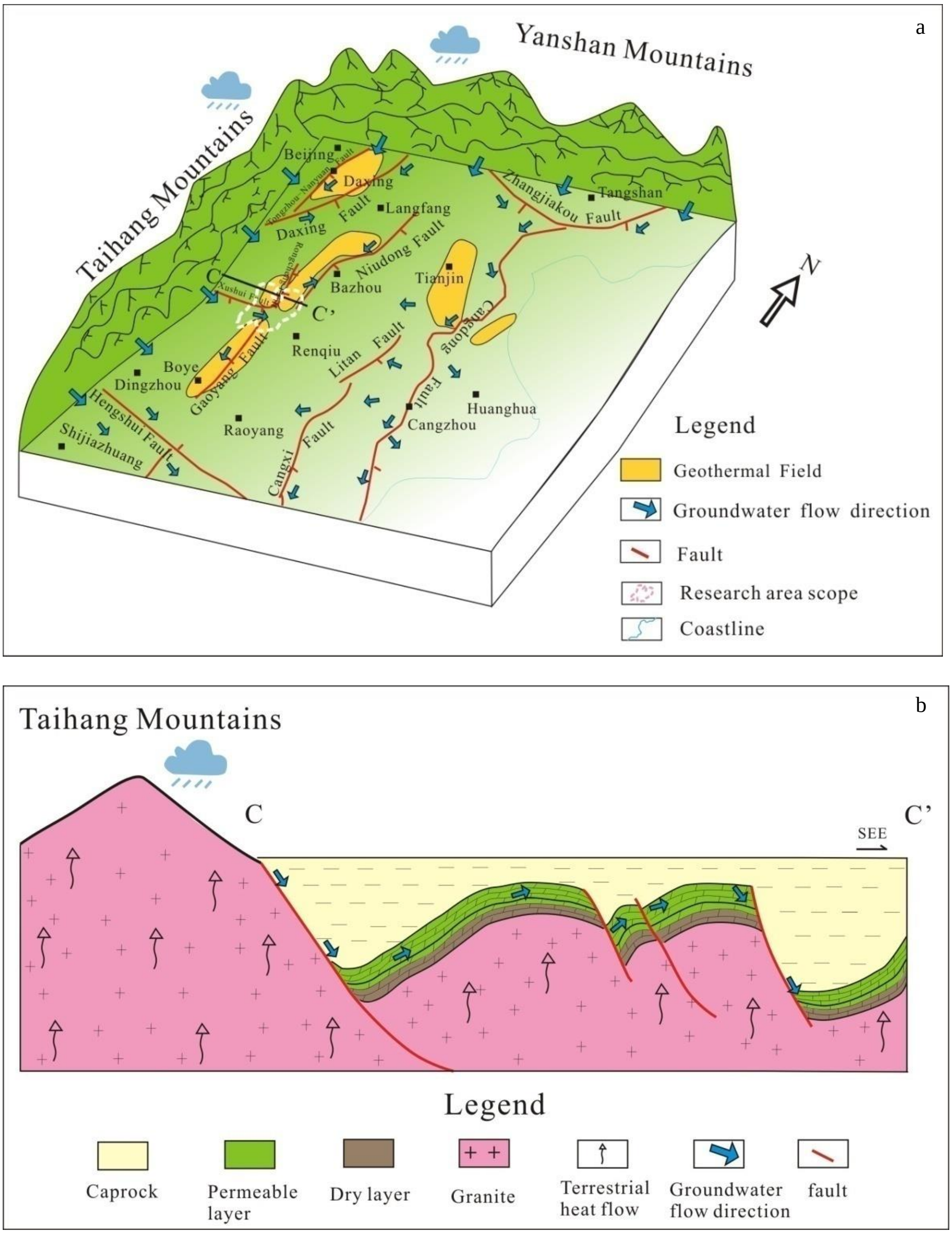

Fig. 13　Conceptual model of geothermal resources genesis in Xiong'an New Area (Dai MingGang et al.,2019a)

a.　Schematic position of mode section C-C ;　　b.　Conceptual model of geothermal origin

superimposed by burial in the later period constituted favorable fluid factors. These carbonate rock strata were transformed by quasi-syngenetic karst, interlayer karst and supergene karst, The karst thermal reservoir is developed, with large thickness and good physical properties. The effective thickness of the thermal reservoir is more than 300m, and the porosity is more than 3%. It provides good geological conditions for the migration and storage of geothermal fluid. In this way, the meteoric water is transported to the favorable sedimentary facies zone of the Mid-Upper Proterozoic carbonate strata in the forward structural units such as the Rise through faults and unconformities. During the process of migration and storage, it is continuously heated by the heat from deep sources, and pools in this trap to form a geothermal field with exploration and development value.

5 FAVORABLE GEOTHERMAL RESOURCE AREA AND RESOURCE EVALUATION OF WUMISHAN FORMATION

5.1 Favorable Geothermal Resource Area of Wumishan Formation

The favorable area for geothermal resources of Wumishan Formation in Xiong'an new area is mainly determined by the lithology, karst landform distribution, sedimentary microfacies type, porosity and permeability distribution, geothermal gradient of the caprock, development of deep and large faults, and buried depth of the top surface of the thermal reservoir in the study area.

The most favorable area: the lithology is mainly dolomite, algal dolomite and calcareous dolomite. The facies belts are mostly distributed in the microfacies of algal dolomite flat or granular shoal. The fractures are very developed. The paleogeomorphology is in the Indosinian and Yanshanian, which are karst highlands, karst sub highlands or karst slopes or their superimposed zones. The porosity and permeability are Rise today, and the burial depth of the top surface is generally shallower than 1500m, which is close to the zone of deep and large faults;

The better favorable area: the lithology is mainly dolomite and calcareous dolomite. The facies belts are mostly distributed in the micro-facies of algal dolomite tidal flat and dolomite tidal flat. The fractures are developed. The paleogeomorphology in Yanshanian was karst Riseland, karst sub Riseland or karst slope. Today, the porosity and permeability are medium-Rise values, and the burial depth of the top surface is generally shallower than 2500m, close to the zone of deep and large faults;

Good favorable area: the lithology is mainly micrite dolomite and calcareous dolomite. The facies belts are mostly distributed in the microfacies of dolomite tidal flat and calcareous dolomite tidal flat. The fractures are moderately developed. The paleogeomorphology in Indosinian is a karst Riseland, a karst sub Riseland or a karst slope; While, in Yanshanian is a karst basin or a region where the landform is reversed in the second period. Today, the porosity and permeability are medium and Rise values, and the top surface is buried in shallower than 3500m, which is not too far from the ascending plate of deep and large faults;

Compared with good favorable area, the general favorable area is basically the same except that the buried depth of the top surface is different, generally less than 4000m;

Unfavorable exploration area: the lithology is mainly argillaceous dolomite. The facies belts are mostly distributed in the microfacies of the mud dolomite tidal flat, and the fractures are not very developed or even not developed. The paleogeomorphology in Indosinian and Yanshanian were karst basins. The porosity and permeability are low values, and the burial depth is generally greater than 4000m. It is an area far away from the ascending wall of deep and large faults.

According to this principle, the favorable exploration target area of Wumishan formation thermal reservoir in this area can be selected (Fig. 14). The red scope is the most favorable target areas ,and the orange scope is the better favorable area ; The shallow yellow scope is good favorable area,and the shallow green scope is the general favorable area ;The shallow blue scope is the unfavorable area ,and the white scope is the missing zone of Wumishan Formation in fault surface.

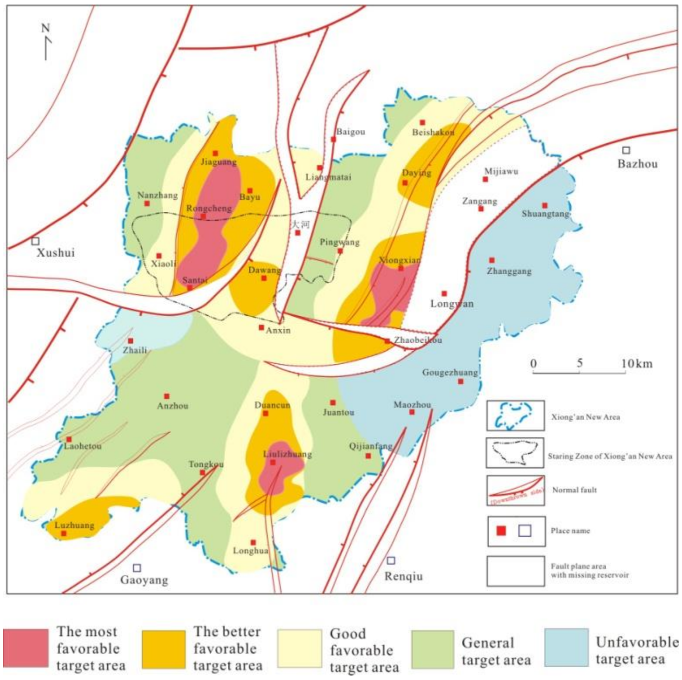

Fig. 14 Distribution of favorable exploration targets of Wumishan Formation thermal reservoir in Xiong'an New Area

(after Dai MingGang et al.,2020)

5.2 Evaluation of Geothermal Resources in Wumishan Formation

The geothermal resource in Proterozoic reservoir with roof no more than 3500m in Xiong'an New Area had been estimated(Dai MingGang et al. (2019b). For the carbonate geothermal resources with a top surface of 5000m and shallow in this calculation, the thickness of the target reservoir is generally greater than 800m, which means that the actual calculated bottom buried depth of the target reservoir can be greater than 5800m, or even 6000m. Considering that the current geothermal technology mainly utilizes geothermal water directly, only the geothermal water resources in the new area are calculated.

The calculation scope is divided into three blocks: the Rongcheng Rise block, including the Rongcheng Rise and Xushui Sag west area, corresponds to most of the starting area of the main ground construction area, Rongdong zone, Rongcheng cluster, Rongxi zone, Anxin cluster and a small area in the north of Zhaili cluster(see Fig. 15); Niutuozhen Rise block, including Niutuozhen Rise and Niubei Slope area, corresponds to a small part of the starting area of the main ground construction area and a large part of the Xiongxian cluster; The Gaoyang low Rise block, including the Gaoyang low Rise and the slope area of Lixian, corresponds to some characteristic towns on the ground (China Xiong'an Official Website, 2018).

The Volume Method is used to omit the release of elastic water from the rock, and the hot water storage capacity and the heat stored by the hot water in Xiong'an New Area are calculated according to formula (1) and (2):

$$Q_w = A \cdot d \cdot \phi \qquad (1)$$

$$E_w = A \cdot d \cdot \phi \cdot \rho_w C_w \cdot (t_r - t_0) \qquad (2)$$

Qw :Total hot water reserve, unit is m^3 ; Ew : Heat content of total hot water reserve,unit is GJ;

other parameter codes and meanings see Table3 and Table4 .

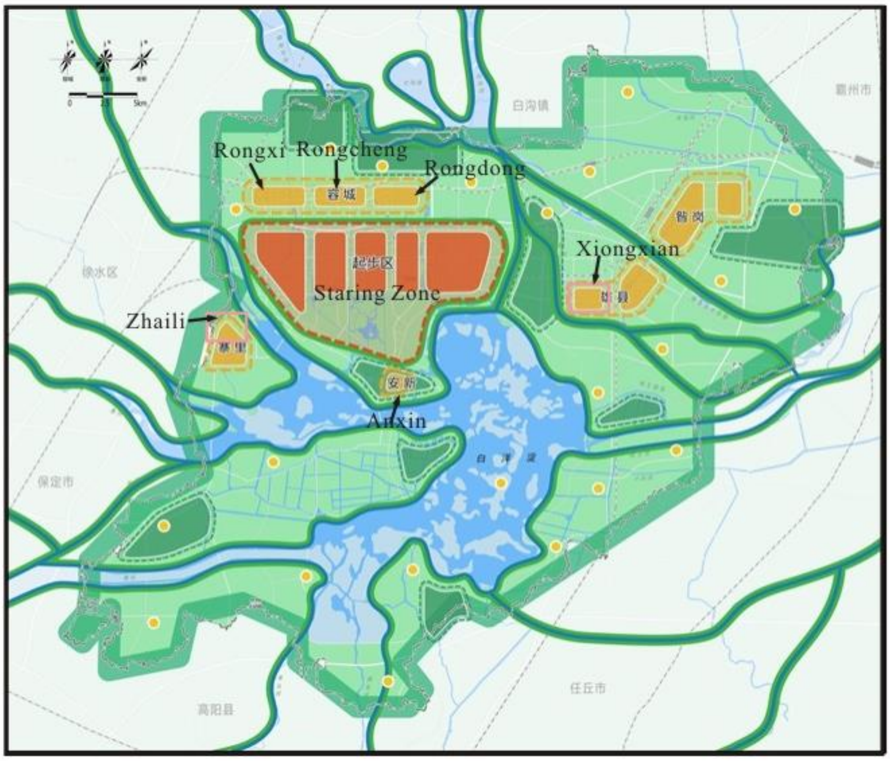

Fig. 15 Distribution Map of Main Construction Zone in Xiong'an New Area
(after China Xiong'an Official Website, 2018)

Hot water exploitation shall be based on the following principles: the available water for one hundred years is 50% of the maximum water storage(NathensonM and Muffei L,1975); The well spacing is 500m, and the well layout mode is "three production and two injection" ; The maximum water flow of a single well is no more than 110 m^3/h. This principle can meet the China national regulations that the groundwater depth of Xiong'an New Area should not exceed 30m and the thermal reservoir temperature prohibit exceed 2 ℃ in 100 years, and it can ensure that no thermal breakthrough will occur in 100 years (Dai MingGang et al., 2019b). See table 3 and table 4 for values of relevant parameters and table 5 for calculation results:

The potential of geothermal resources in Wumishan Formation reservoir with the roof no more than 5000m of each zone and cluster in Xiong'an New Area main construction area (See Table 5). Based on the annual energy consumption per unit area of 0.32GJ/ y·m2, the annual heating areas of Wumishan Formation is 2478×10^4 m^2.

It is assumed that the recoverable geothermal resources in Gaoyuzhuang Formation are about 90% in Wumishan Formation. Under the normal annual unit energy consumption of 0.32 GJ/ y·m^2, the energy supply-demand ratio of geothermal water resources in the main construction area of the New Area is 30.4%. Under the condition that the annual energy consumption per unit area is reduced to 0.2 GJ/ y·m^2 by adopting advanced energy conservation and thermal insulation measures, the total energy supply-demand ratio of geothermal water resources is only 48.6% (Figure 16)

This shows that under the condition that 50% of the total stored geothermal water is used in 100 years, the energy provided by the middle and deep geothermal resources in the main construction area of the new area is limited. Even if 100% of the total stored geothermal water is used in 100 years, it could not meet the energy demand of the main construction area alone. At this stage, it is necessary to develop a "multi energy complementary" system based on the middle and deep geothermal resources.

Table 3 Unified parameter values in Xiong'an New Area

Parameter Name	Production Time ΔT	Reference Temperature t_0	Minimum Tailwater Temperature t_T	Geothermal Water Density ρ_w	Geothermal Water Specific Heat C_w	Dolomite Density ρ_r	Dolomite Specific Heat C_r	Dolomite Thermal Conductivity k_r
Parameter Unit	Production-year	℃	℃	kg/m^3	J/(kg.℃)	kg/m^3	J/(kg.℃)	W/(m.℃)
Value	100 (12000 Days)	15	25	980	4180	2700	810	5.28

Table 4 Values of zoning parameters in Xiong'an New Area

Estimated Unit	Reservoir	Scope A (km^2)	Average Thickness d (m)	Average Wellhead Temperature t_r (℃)	Average porosity of thermal reservoir φ (%)	Discharge of a s ingle well q_{wh} (m^3/h)	Total hotwater reserve (×10^8 m^3)	Heat content of Total hot water reserve (×10^8 GJ)	Converted into standard coal (×10^{4}t)
Rongcheng Rise Block	J*xw*	314	1000	57	3.39	110	106.446	18.314	6257
Niutuozhen Rise Block	J*xw*	357	900	70	3.7	110	118.881	26.784	9151
Gaoyang low Rise Block	Jxw	435	800	102	2.3	70	60.03	21.394	7309
Total	Jxw	1106	/	/	/	/	285.357	66.492	22717

Table 5 Calculation results of geothermal water reserves and recoverable geothermal water in the main construction area of Xiong'an New Area

Calculation unit	Reservoir	Scope (km^2)	Total hotwater reserve (×10^8 m^3)	Heat content of Total hot water reserve (×10^8 GJ)	Heat content of Total hot water reserve Converted into standard coal ×10^4t)	Recoverable geothermal wate reserve (r×10^8 m^3)	Heat content of Total recoverable hot water reserve (×10^8 GJ)	Average Annual recoverable geothermal water volume in 100 years (×10^4m^3)	Annual recoverable heat from recoverable geothermal water in 100 years (×10^4GJ)	Annual recoverable heat Converted into standard coal from recoverable geothermal water in 100 years (×10^4t)	Annual heating area (×10^4 m^2)
Staring zone	Jxw	176.5	59.68	10.72	3662.51	29.84	5.36	2984	536	18.31	1675
Anxin cluster	Jxw	7.5	2.54	0.7811	266.87	1.27	0.3905	127	39.05	1.33	122
Rongdong zone	Jxw	13	4.407	0.7582	259.04	2.204	0.3791	220.35	37.91	1.3	118. 5
Roncheng cluster	Jxw	22	7.458	1.283	438.38	3.729	0.6415	372.9	64.15	2.191	200. 5
Rongxi zone	Jxw	14	4.746	0.8165	278.97	2.373	0.4083	237.3	40.83	1.39	127.6
Xiongxian cluster	Jxw	14	4.662	1.050	358.85	2.331	0.525	233.1	52.5	1.79	164
Zhaili cluster	Jxw	4.3	1.458	0.4478	153.01	0.729	0.2239	72.9	22.39	0.77	70
Total	Jxw	251.3	84.951	15.8566	5417.63	42.476	7.9283	4247.55	792.83	27.081	2478

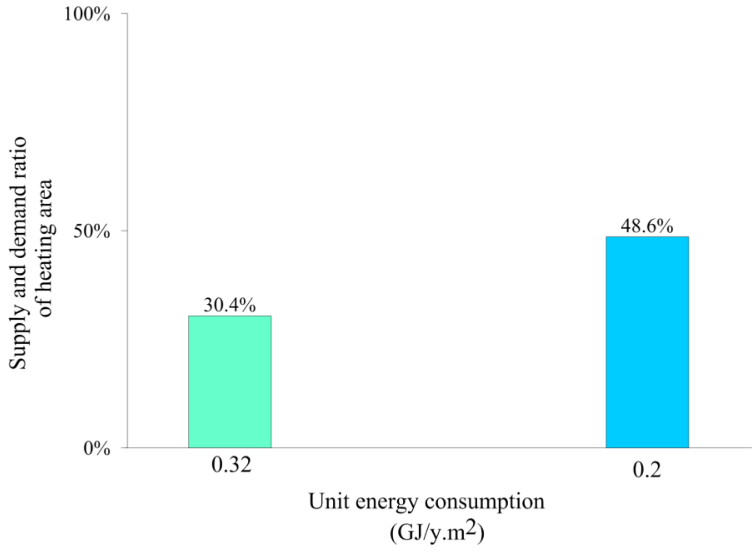

Fig. 16 Proportion of supply and demand area of mid-deep geothermal water heating with different unit energy consumption in the main construction area of Xiong'an New Area

6 CONCLUSION

(1) Wumishan Formation of Jixian System in the Mid-Proterozoic in Xiong'an Xew Area is the main thermal reservoir at present, with Rise temperature geothermal water and Rise water flow. The burial depth is relatively shallow in Rongcheng Rise and Niutuozhen Rise, with a roof of 700m ~ 2600m and a thickness of 800m ~ 1400m; In Gaoyang low Rise, the depth is relatively deep, the roof is generally 3000m ~ 4000m, the thickness is generally 700m ~ 1000m, and the temperature is Riseer.

(2) The lithology of Wumishan Formation is mainly dolomite, and the sedimentary microfacies are characterized by the development of dolomite tidal flat and algae dolomite tidal flat. Among them, the algae dolomite tidal flat microfacies and reef shoal microfacies are easy to develop all kinds of dissolution, and the dolomite tidal flat is easy to develop fractures; The main karst development period is Yanshanian-Early Himalayanian, and the diagenesis that plays a constructive role in the development of thermal reservoir porosity and permeability of Wumishan Formation mainly includes dissolution and structural cracking.

(3) Many faults formed the thermal reservoir space and percolation channel ,so three types of reservoir space: fractures, pores and karst caves are developed in Wumishan Formation in the study area. The composite space of fractures and karst pores is the main thermal reservoir space, and the single fractures and pores are the secondary thermal storage space.

(4) The carbonate geothermal resources in the study area are a large-scale conductive geothermal water reservoir system enriched in the Rise belt under the background of normal heat flow, with atmospheric precipitation as the water source, weathered crust karst and deep faults as the migration channels, mainly through the long-range supply of Taihang Mountain and Yanshan Mountain. The thermal reservoir of Wumishan Formation can be divided into the most favorable target area, the second favorable target area, the third favorable target area, the general target area and the unfavorable target area according to the structural development, the porosity and permeability properties, the geothermal gradient, the buried depth of the top surface and the sedimentary microfacies level.

(5) For the Wumishan Formation thermal reservoir with the roof depth no more than 5000m in Xiong'an Xew Area, the recoverable geothermal water is 142.68×10^8 m^3, based on the geothermal water recoverable utilization rate of 50% in 100 years, which content recoverable heat 33.25×10^8 GJ, converted into standard coal 1.136×10^8 t； Among them, the recoverable geothermal water in the main construction area is 42.476×10^8 m^3, the heat content of recoverable geothermal water is 7.928×10^8 GJ, equivalent to standard

coal 0.2708×10^8t , the annual heating area that can be met accounts for 30.1% of the actual demand, which could not meet the actual clean energy demand alone.

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