Fracture Characteristics and Heat Accumulation of Jixianian Carbonate Reservoirs in the Rongcheng Geothermal Field, Xiong’an New Area

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Abstract: Geothermal energy plays an important role in urban construction of the Xiong’an New Area. Geothermal reservoir fracture distribution of the Mesoproterozoic Jixianian Wumishan Formation (Fm.) carbonate reservoir in the Rongcheng geothermal field are evaluated based on FMI log from Wells D19 and D21. The results show carbonate reservoir fracture density of Well D19 is 15.2/100 m, greater than that of Well D21 with a value of 9.2/100 m. Reservoir porosity and permeability of Well D19 are better than that of Well D21, and the water saturation is bimodally distributed. The movable fluid volume ratio (BVM) of Well D19 is 2% to 8% with some zones exceeding 20%, while the value of Well D21 is less than 4%. Therefore, reservoir fractures in Well D19 are more conducive to fluid flow. Reservoir fractures have a similar occurrence to normal faults, indicating that the tensile stress field controlled the formation of such fractures. Developed reservoir fractures provide a good channel for groundwater convection. The circulation of regional groundwater and the heat exchange between water and rock and the multiple heat accumulation patterns form a stable and high potential heat reservoir in the Rongcheng geothermal field.

Key words: geothermal resource, carbonate, reservoir fracture, FMI log, in-situ stress

1 Introduction

With the development of economy and society, global environmental changes caused by climate change are extensively and profoundly affecting all aspects of human life. Energy shortage and environmental pollution have become important problems restricting sustainable global development. As one of the important substitutes for fossil fuels, geothermal energy is a green, low-carbon and recyclable renewable energy source. It has the characteristics of large reserves, wide distribution, clean and a high utilization rate (Fridleifsson, 2001; Axelson, 2012; Ghassemi, 2012; Guo and Li, 2013; Long et al., 2019, 2021). The exploitation and utilization of geothermal resources are not only a necessary means to alleviate haze and control air pollution, but also an effective way to adjust the energy structure and fulfill carbon discharges reduction (Wang G et al., 2018a; Wang S et al., 2018; Wu et al., 2018; Guo et al., 2019). The study of the formation mechanism of geothermal resources plays an important role in the evaluation and exploitation of geothermal resources, and provide strong support for the protection of the whole ecological environment (Wang et al., 2017a; Salihu et al., 2017; Feng et al., 2019).

The construction of the Xiong’an New Area (XNA) is one of China’s major strategies, and the concept of green energy development needs to be applied in infrastructural projects and people's livelihood engineering. Meanwhile, because of its unique geological structure, the XNA exhibits rich geothermal resources and is regarded as a world-class transparent digital platform and global model for geothermal resource utilization (Pang et al., 2018; Guo et al., 2019; Liu et al., 2019). Therefore, investigation into geothermal resources will be of great importance in the low-carbon construction of the XNA, and provide a good opportunity to achieve the goal of ‘carbon neutrality’. With the continuous development of Enhanced Geothermal Systems (EGS) technology, the engineering technology of deep geothermal energy extraction through artificial reservoirs can be extended to rock masses that are easier to reform. So, thick carbonate rocks under a high-temperature geothermal background are suitable to be target reservoirs. There are large areas of Middle Proterozoic carbonate rocks distributed in the North China
Plain, and such geothermal resources have huge potentiality. The subduction of the Pacific Plate in Neopaleozoic caused the destruction of the North China Craton (NCC), and under the local mantle thermal erosion from bottom to top, high-quality geothermal ‘sweet spots’ were formed in northern China (Li et al., 2014; Wang et al., 2016). Located in the central Jiuzhong Depression of the North China Plain, the XNA is rich in hydrothermal geothermal resources and has the best conditions for the development and utilization of these resources in central and eastern China (Li et al., 2017; Yu et al., 2017). The XNA consists of five tectonic units: Niutuozhen Uplift; Rongcheng Uplift; northern Gaoyang Low Uplift; part of the Baxian Depression; and the Raoyang Depression. Here, the geothermal resources can be divided into shallow, deep and ultra-deep geothermal energies according to depth boundaries of 200 m and 3000 m (Pang et al., 2017). The deep geothermal energy is composed of a sandstone reservoir in the upper part and a carbonate reservoir in the lower part. The carbonate reservoir is one of the hot spots of geothermal research in China due to the characteristics of developed karst fissures, large resource quantity, high fracturing success ratio and high recharge rate (Gu et al., 2019; Yue et al., 2019; Zhu et al., 2019; Chen et al., 2021). Similarly, the prerequisite for rational and efficient utilization of the deep karst geothermal resources is to ascertain the characteristics of reservoir space and fracture distribution in the geothermal reservoirs.

At present, the main scientific research focus is on the Niutuozhen geothermal field, where the geothermal temperature is controlled by the concave–convex geological structure, forming a favorable deep heat source (Pang et al., 2017). The exploration level of the Rongcheng geothermal field is low; hence, in recent years, the China Geological Survey has gradually increased the exploration intensity in this field. In 2018, the largest geothermal well was discovered in the Rongcheng geothermal field, with a single well heating capacity of 300,000 m². In 2019, a high-productivity geothermal well with 113 m² of water and a wellhead temperature of 71°C was drilled and the Archean Metamorphic basement was exposed. Currently, the Archean metamorphic rocks and other strata have also been drilled near the southern fault zone of the Rongcheng geothermal field (Ma et al., 2020a; Wang et al., 2020). Wu et al. (2018) summarized the main parameters of the karst heat reservoir at a depth of 3500 m based on well log data from Well D18, and concluded that the complex geological structure in the southern part of the Rongcheng–Niutuozhen geothermal field is a favorable target area for geothermal exploitation. Dai et al. (2019) evaluated the shallow Mesoproterozoic geothermal energy above 3500 m in the XNA, indicating that the Wumishan Formation (Fm.) could meet the requirements of geothermal field development for 100 years. Lu et al. (2019) conducted a deep study on the karst heat reservoir of the Wumishan Fm. by comprehensively using geological and geophysical data such as field profiles, cores and well logs, finally identifying the origin of high-quality reservoirs and optimized sweet spots. Ma et al. (2020a) studied the influence of the development of carbonate heat storage in the buried hill tectonic belt of the XNA based on ground subsidence, and considered that geothermal development was not the main factor, and provided theoretical support for the prevention and control of ground subsidence and an energy plan. Wang et al. (2020) analyzed the characteristics of the heat reservoir in the Wumishan thermal reservoir and karst thermal reservoir through pumping and water sample tests, which provides a basis for the search for high-quality geothermal resources.

In this paper, the geothermal reservoir of the Mesoproterozoic Jixianian Wumishan Fm. in the Rongcheng geothermal field is taken as the research object. Using the drilling data of two geothermal wells D19 and D21, the physical properties and fracture distribution of the geothermal reservoir in the study area are studied by means of multiple geophysical log interpretation. Finally, through a comprehensive study of regional structures, the strata system and geothermal reservoirs, we hope to reveal the heat accumulation patterns of the Rongcheng geothermal field.

2 Geologic Setting

2.1 Regional tectonics

The XNA is located in the central part of the Jiuzhong Depression in Bohai Basin and tectonically on the eastern block of the NCC. During the Archean–Paleoproterozoic, the crystalline basement of metamorphic rocks in the NCC formed, experienced intracontinental rifting in Mesoproterozoic and deposited thick strata (Zhao et al., 2005, 2015; Santosh, 2010). During the Indo-Australian movement, the N-S compression resulted in nearly E–W geologic structures in the study area. In the early Yanshanian stage, extensive formations in the structural high part were denuded. In the late Mesozoic, the closure of the Mongolian–Okhotsk Ocean and the subduction of the Paleo-Pacific plate transformed the NNW–SSE compression in the NCC into NWW–NEE stretching (Cabral et al., 2015). Under this background, the lithosphere in the eastern NCC has undergone large-scale thinning (Zheng et al., 2006; Chen, 2010), strong extensional block fault activity continued until the end of the Paleogene. From the Neogene to the Quaternary, under the strong tension of back-arc extension, the study area entered a stage of depressional evolution (Allen et al., 1997; Wang et al., 2018b; Liu et al., 2019). Since the Neoproterozoic, multi-stage tectonic movements have led to the formation of a concave–convex geological structure in the study area (Fig. 1). N–E and E–W strike faults were developed, such as Rongxi, Rongcheng, Gaoyang and Niudong faults. These faults serve as secondary structural unit boundaries to divide the structural units in the region (Yu et al., 2017).

According to the geotemperature isopleth and carbonate distribution at a depth of 3.5 km on the mainland of China (Pang et al., 2017), the reservoir temperature in the XNA is in the range of 100°C to 150°C, and over 150°C in the Bohai Basin area, which is only lower than the Gonghe Basin in Qinghai Province. Besides, small amounts of Cenozoic volcanic rocks and Yanshanian granite
intrusions were found during the geological survey. Therefore, it can be speculated that the heat flow in the XNA is mainly derived from upper mantle heat generation and radioactive element heat generation in granite. The depth of faults in the study area differs, some of them being as deep as the crystalline basement, which provides an upward channel for deep heat transfer. The carbonate rocks in the XNA have the following advantages in geothermal exploitation: first, the carbonates are sedimentary rocks, which are generally stratified and have obvious bedding, and can be dissolved; second, the strong compressive Indosinian and Yanshanian stress led to the wide distribution of tectonic fractures (Li et al., 2017; Wu et al., 2018). Geothermal wells D19 and D21 are deployed in the south of the Rongcheng Uplift, and the strikes of the normal faults in the well location are E–W and N–E respectively. Rose diagrams seen in Fig. 1 represent the orientation of induced fractures based on Formation MicroScanner Image (FMI) log interpretation, which can be regarded as the direction of maximum horizontal principal stress.

2.2 Strata system

The basement of the XNA was formed during the Archean–Paleoproterozoic and continuously expanded during structural thermal events, finally forming a unified crystalline basement (Ar) (Wang et al., 2017b; Lu et al., 2019). During the Meso–Neoproterozoic, the basement received platform type deposition, and the Jixianian carbonate strata (Jx), predominately the Wumishan Fm. (Jx\textsubscript{w}), were deposited and formed at this stage. The Changchengian (Ch) and Jixianian (Jx) systems of the Mesoproterozoic saw the deposit of numerous extremely thick dolostones, limestones, dolomitic sandstones and quartz sandstones (Table 1). During the Meso–Neoproterozoic to Mesozoic, the uplift of strata led to the denudation of the Qingbaikouan (Qm) and Sinian strata, which formed an angular unconformable contact with the overlying Carboniferous–Permian strata (C–P). In the Paleogene, the whole Bohai Bay basin entered a stage of post-rift thermal subsidence. The Carboniferous–Permian strata experienced strong denudation, resulting in a near-absence of Mesozoic strata in this area (Ma et al., 2020a; Tang et al., 2020). The Neogene (Nm) and Quaternary (Q) strata entered a post-rift thermal sag phase, and the calorific values of fluvial sandstone and mudstone return to normal (Tang et al., 2020). The regional geothermal background is characterized by high heat flow and a hot basin was formed in eastern North China (Ma et al., 2020b).

3 Methods and Materials

3.1 Bedding and fracture characterization with FMI log

Fractures are important seepage channels and contribute to the development of geothermal reservoirs. The FMI log interpretation, shown in Fig. 2, is crucial for understanding the fracture network and identifying potential seepage pathways.

![Geological map of the study area.](image)

Fig. 1. Geological map of the study area.

![FMI log interpretation of the study area, including conductive fractures, induced fractures and beddings.](image)

Fig. 2. FMI log interpretation of the study area, including conductive fractures, induced fractures and beddings.

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to reservoir space (Davarpahan et al., 2019; Zhu et al., 2020). The FMI log is generally applied to identification of fracture and bedding (Olson et al., 2007). In FMI interpretation, conductive fractures are interpreted as natural fractures (Laubach et al., 2019; Chen et al., 2021) that are generated during the geological process, providing storage spaces and migration channels for oil and gas (Ukar and Laubach, 2016). Induced fractures are generated while drilling, giving the direction of maximum horizontal principal stress. Techlog software is used to process the FMI log data (Fig. 2). The length, width and porosity of fractures are related to the fluid migration ability of reservoirs. These three fracture attributes are correlated to the quality of fractured reservoirs. The calculation methods are as follows:

(a) Fracture length (1/m) refers to the fracture length per square meter of wellbore;

(b) Fracture opening (W, mm) usually refers to the average width of various fracture paths in a unit length section (Fig. 3d). The empirical formula is as follows:

$$W = a \times A \times R_{so} \times R_m^{1-b}$$  \hspace{1cm} (1)

where $A$ is the area of conductivity anomaly caused by the fracture; $R_{so}$ is the formation resistivity of the flushing zone; $R_m$ is the mud resistivity; $a$ and $b$ are the constants correlated to the instrument ($b$ is close to 0).

(c) Fracture porosity ($\phi$, %) refers to the ratio of the fracture area from the wellbore wall to the wellbore area, per unit length interval. The calculation formula is as follows:

where $W_i$ and $L_i$ are the average width of the No. $i$ fracture and its length within the statistical window length $L$; $R$ is the borehole radius; $C$ is the coverage rate of the electric imaging well.

3.2 Log inversion of reservoir physical properties

Reservoir physical property parameters can be calculated by using geophysical log data based on empirical formulas. Although the values calculated based on an empirical formula cannot be equal to the absolute values measured in the laboratory, the calculated results are still of great significance for summarizing and comparing the distribution laws of reservoir physical property parameters in the vertical direction (Ma et al., 2019). Empirical formulas have been embedded in the Techlog program, and will be used for the calculation of physical properties. In this work, permeability (PERM), effective porosity (PORE), PORP, water saturation (SW) and movable fluid volume ratio (BVM) of the target reservoirs will be discussed.

4 Results and Discussion

4.1 Distribution of reservoir beddings and fractures

The identification of reservoir fracture geometric features plays an important role in the study of fluid conductivity and heat transfer law in any hydrothermal reservoir, and quantitative analysis of reservoir physical properties is an important prerequisite for revealing the rules of heat transfer and accumulation. Therefore, the FMI log information of two wells (locations shown in Fig. 1) are interpreted in detail. The target interval is 2940–3760 m of the Wumishan Fm. dolomite in Well D19 and 2200–3100 m of Wumishan Fm. muddy sandstone and limestone at 2200–2450 m in Well D21.

The lower part of Wumishan Fm. in Well D19 (Fig. 3a) has a larger bedding density than the upper part. The occurrences of the beddings are uniform with a SW dip direction (Fig. 3b) and dip angle ranging from 40° to 50° (Fig. 3c). The carbonate in Well D19 has extremely well-developed fractures (Fig. 4a), in total 125 fractures have been interpreted at depths of 2940–3760 m, and the fracture density reaches 15.2/100 m. The occurrence of the fractures exhibits a strong anisotropy, the dip direction is mainly S–N supplemented by E–W (Fig. 4b), and the dip angle is generally greater than 45° (Fig. 4c). The natural gamma ray (GR) curve (Fig. 3a wellbore) shows a sharp increase between 3250 m and 3300 m. The occurrence of the beddings of the Wumishan Fm. in Well D21 is similar to that of Well D19, but bedding density in the upper to middle part is significantly higher than that in the lower part. From the GR curve (Fig. 5a wellbore), there is a sudden increase in the middle of the reservoir from 2400 m to 2450 m, and the bedding cannot be identified in this position. Generally, the GR value is mainly controlled by the formation radioactivity, and one possibility is that, due to the dense distribution of fractures, the intrusion of magmatic hydrothermal fluid/liquid/gas or the infilling of clay minerals will lead to enrichment of radioactive elements. Fracture density in Well D21 is low (Fig. 6a), with a total 65 fractures interpreted; dip direction is mainly NE (Fig. 6b) and dip angle of most fractures is more than 45° (Fig. 6c). In the dolomitic part of the section (2450–3100 m), fracture density is 9.2/100 m, whereas in the muddy sandstone and limestone part (2200–2450 m), the value is only 2/100 m.

The strike of the reservoir fractures in the Wumishan Fm. is close to the deep and large faults in the study area, such as the Niudong fault and the Rongcheng fault. This trend reflects the consistency of the fracture orientation and faults in the Rongcheng field. N–S horizontal extrusion in the Caledonian and Hercynian periods led to the formation of NW and NNE strike structures. During the Yanshanian Movement, the main tectonic stress is NW–SE compressive stress, and the fault strike is NE and NW. In the early Himalayan period, the regional tectonic stress field was compressional in a NEE–SWW direction, forming NNW–SSW fractures. In the late Himalayan period, tension became the main stress and formed a series of fault depression structures. The main strike of the fractures in the regional reservoir is basically consistent with the strike of faults in the well control area. We can speculate that tensile stress plays an important role in the formation of fractures. At present, the in-situ stress is mainly tensile, which may still have an important influence on the later propagation of fractures.

4.2 Vertical distribution of reservoir physical properties

As can be seen from the vertical distribution of
Fig. 3. Bedding occurrence of Well D19, Rongcheng geothermal field, XNA. (a) GR curve; (b, c) dip direction.

Fig. 4. Reservoir fracture occurrence of Well D19, Rongcheng geothermal field, XNA. (a) GR curve; (b, c) dip direction.
Fig. 5. Bedding occurrence of Well D21, Rongcheng geothermal field, XNA.
(a) GR curve; (b, c) dip direction.

Fig. 6. Reservoir fracture occurrence of Well D21, Rongcheng geothermal field, XNA.
(a) GR curve; (b, c) dip direction.
reservoir physical property parameters of Well D19 (Fig. 7), eleven weathered layers, three cataclastic zones and one fragmented zone have been recognized. The reservoir in Well D19 can be vertically subdivided into three parts based on the fracture occurrence: the upper part within fractures characterized by similar occurrence; the middle part of dense, small non-directional fractures; and the lower part of fractures characterized by various occurrences. Especially in the middle part (3220–3300 m), the average BVM and PERM exhibit high values, the SW is low, small non-directional fractures are well-developed, and well temperature inversion occurs. According to the existence of a high GR value in this section (Fig. 3a), it can be inferred that the dolomite in this section has experienced obvious tensional stress, with primary fractures formed during the rock formation and subsequently destroyed. Therefore, the matrix porosity and PERM were significantly improved, and the low SW in this section also indicates the development of a seepage network. The BVM and PERM values of the upper part are higher than those of the lower part (Fig. 7). Combined with the characteristics of low density of the upper bedding, it can be concluded that the phenomenon of reservoir stratification easily leads to irregular fracture extension, which is not conducive to seepage of geothermal fluid.

No well temperature inversion has been observed in Well D21, but again three parts can be classified vertically from 2450 m and 2800 m: the upper part with sparse fractures; the middle part with fractures of similar dip angle; and the lower part with dense fractures. Very few fractures are developed in the upper part, but the values of PERM, PORE and BVM show that the reservoir at this depth interval has good petrophysical properties. This characteristic is because the lithology is mainly medium-coarse sandstone, with the matrix itself regarded as a good place for fluid transport and storage. In the middle part, the carbonate has high PERM, high PORE, uninterrupted BVM and low water saturation (Fig. 8). In the lower part, the PERM and PORE decrease, WS increases and BVM becomes discontinuous (Fig. 8). From the vertical values of fracture length, fracture width and PORP we can see

![Fig. 7. Vertical distribution map of reservoir physical parameters in Well D19.](image)

Lithology: red, fragmented zone; blue, cataclastic zone; yellow, weathered zone; BVM, movable fluid volume ratio; PERM, permeability; PORE, effective porosity; PORP, fracture porosity; SW, water saturation; TEMP, temperature.
that in general fractures in the middle part are larger than those in the lower part. This phenomenon caused a change in petrophysical property. The development degree of primary fractures in the reservoir is necessary for the migration and accumulation of thermal fluids, but its effect is reflected in the reasonable combination of fracture occurrence and fracture scale. The petrophysical property changes generated by the later reservoir reconstruction also have a controlling effect on the seepage flow.

4.3 Reservoir space characteristics

There is no linear correlation between fracture length vs. fracture width (Fig. 9a) and fracture length vs. PORP (Fig. 9b). The high values of fracture width and PORP are basically concentrated in the median interval of fracture length, whereas PORP is proportional to fracture width (Fig. 9c). The hydrothermal reservoir in the study area is dominated by dolomite, which is prone to dissolution, reconstruction, cementation and filling under long-term tectonic and hydrothermal action, which can promote the closure of original fractures. Therefore, although the ductility of fractures is positive for fluid migration, if the fracture width is small, it is more likely to be blocked later. The fracture width of Well D21 is less than 10 µm, and the PORP is less than 0.1%; the fracture width of Well D19 is more than 30 µm, and the PORP is up to 0.3% (Fig. 9c). Therefore, in the region, the dolomite fractures in the formation where Well D19 is located are more developed than those in Well D21, and so the former is

Fig. 8. Vertical distribution map of reservoir physical parameters in Well D21.
Lithology: blue, cataclastic zone; yellow, weathered zone; BVM, movable fluid volume ratio; PERM, permeability; PORE, effective porosity; PORP, fracture porosity; SW, water saturation; TEMP, temperature.
more conducive to hot water circulation.

The PORE frequency distributions of both wells share similar characteristics (Fig. 10a, b). With the increase of PORE, the counts decrease monotonously, but the counts of Well D19 have a lower rate of decline (Fig. 10a), indicating that the reservoir pore fissure space of Well D19 is generally better than that of Well D21 (Fig. 10b). The SW distributions of the two wells are similar, as both are bimodal (Fig. 10c, d). The double peak trend of SW in Well D21 is more obvious, and the proportion of the saturated water reservoir is as high as 23.4%. The BVM and PERM distributions of the two wells are very different. Well D19 has BVM values of 2% to 8%, with some zones exceeding 20% (Fig. 10e). Well D21 has an overall BVM value of less than 4%. The ratio of low permeability strata ($K < 0.1$ mD) in Well D19 is 5.8% (Fig. 10e), and the value in Well D21 is 15.1% (Fig. 10f). The PERM distribution of both wells is unimodal. The permeability peak of Well D19 is in the range of $10^2$ to $10^3$ (Fig. 10g), and that of Well D21 is in the range of $10^2$ to $10^3$ (Fig. 10h). Overall, the permeability of Well D19 is slightly better than that of Well D21. The distribution rules of PORE and SW of the two wells are consistent, indicating that the PORE and fracture volume and water content characteristics of the dolomite reservoir of the Wumishan Fm. in the Jixianian system are similar within the study area. The difference in reservoirs is mainly manifested in the distribution of BVM and PERM. The pore and fracture space in Well D19 is more conducive to fluid flow.

4.4 Geothermal reservoir formation model

The temperature curves of the two Rongcheng field wells are segmented (Fig. 11). Compared with the upper sedimentary cap strata, the geothermal gradient value of the deep thermal reservoir is clearly reduced, and even negative in some strata. The lithology of the upper sedimentary cap is mainly sandstone, conglomerate, shale, etc., and so probably the thermal conductivity of the rock is smaller than that of the dolomite. The lithology of the lower thermal reservoir is mainly dolomite, which has good water capacity and permeability. The thermal convection within the reservoir makes the temperature distribution in the reservoir relatively uniform and the geothermal gradient small due to its high heat transfer efficiency. At the same time, the multi-stage tectonic action causes the development of faults in this area, and the depth of faults can reach the crystalline basement. These fractures serve as good channels for the rapid transfer of heat from below (Fig. 11). The maximum principal stress direction of the two wells is roughly parallel to the nearby normal fault, which proves that the latest tectonic movement is still dominated by tensile action, which has positive significance for the development of regional heat reservoir fractures. High-angle fractures are developed and tend to form vertical migration channels for groundwater, which is conducive to recharging the reservoir from bottom to top. Following the destruction of the NCC, heat from the deep travelled to the surface through heat conduction, then thermal refraction occurred in the Middle Proterozoic carbonate rocks with high thermal conductivity, and, finally, when the heat conduction to the shallow surface encountered a low-thermal conductivity clastic sedimentary cap, a thermal reflection formed. At the same time, under the circulation of regional groundwater and the exchange of water and rock heat, stable and high potential thermal reservoirs were formed under multiple heat accumulation modes. In general, surface water permeates from deep fault structures and enters the deep heat storage of the XNA through lateral runoff. After a long groundwater runoff cycle, the water flow slowly seeps into the bedrock heat storage, and the deep heat storage resources are formed through heating from the deep heat storage rock temperature. Faults are good channels for heat conduction and water flow, and part of the heat in the deep crust is transported to the surface by water through deep faults in a...
hydrothermal convection mode. Another part of the heat is transferred to the surface through various strata in the form of heat conduction, all of which eventually supports/ offers/allows us to develop a hydrothermal model for the Rongcheng geothermal field (Fig. 11).

5 Conclusions

Through the above discussion, the following conclusions can be obtained:

(1) Carbonate in Well D19 has extremely well-developed fractures, the density of which reaches 15.2/100 m. A total of 65 fractures in Well D21 have been interpreted, with fracture densities of dolomite and sandstone of 9.2/100 m and 2/100 m, respectively. According to the fracture occurrence and density, the reservoirs in Wells D19 and D21 can be vertically subdivided into three parts. Fracture width of Well D21 is less than 10 µm, and the PORP is less than 0.1%; fracture width of well D19 is more than 30 µm, and the PORP is up to 0.3%. Therefore, in this region, the dolomite fractures in the formation where Well D19 is located are...
more developed than those in Well D21, so the former is more conducive to hot water circulation;

(2) Well temperature inversion occurs in the middle part of Well D19, where the average BVM and PERM exhibit high values, the SW is low, and small non-directional fractures are well developed. In Well D21, in general, fractures in the middle part are larger than those in the lower part, causing the petrophysical property of the middle part to be better. The BVM values of Well D19 range from 2% to 8% with some zones exceeding 20%, whereas the values of Well D21 are less than 4%. The percentage of low permeability formation in Well D21 is 15.1%, higher than in Well D19 with a value of 5.8%. The pore and fracture space in Well D19 is more conducive to fluid flow;

(3) Faults are good channels for heat conduction and water flow; part of the heat in the deep crust is transported to the surface by water through deep faults in a hydrothermal convection mode. Another part of the heat is transferred to the surface through various strata in the form of heat conduction.

The data obtained form the new hydrothermal model of the Rongcheng geothermal field in Xiong’an.

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Fig. 11. Hydrothermal model of the Rongcheng geothermal field based on Wells D19 and D21, XNA.

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