

## Method for groundwater research in bedrock of mountainous area of Hebei

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**Abstract:** In recent years, the mountain springs in the bedrock mountainous area of Hebei are decreasing in terms of both quantity and flow rate, which have affected the domestic water and production water supply for people in this area, due to which driven wells have been built with the expectation to relieve the problem. However, this work doesn't achieve much success due to the complex geological conditions in the bedrock mountainous area and tends to cause huge economic losses. In order to improve the success rate of this work, the authors of this paper made a summary about the type of reservoir structure, water storage conditions and characteristics, by drawing experience from the former practices of digging wells in the mountainous area of Hebei to search for water to relieve drought in 2011, referring to the research results about bedrock summarized by former researchers, employing the reservoir structure theory and by considering the stratum condition of the bedrock mountain area of Hebei. Based on the summary, the authors figure out the major reservoir structure and water research methods for mountainous regions where have metamorphic rocks, carbonate rocks and volcanic rocks distributed, which may offer some valuable guidance to future water researches in the bedrock mountainous area of Hebei.

**Keywords:** Mountainous area; Bedrock groundwater; Water research method

During the past a few years, the water environment in the mountainous area of Hebei changed a lot, mountain springs decreasing gradually and flow rate dropping sharply. As a result, people living in these regions are under threaten of water shortage and thus resort to well digging expecting to relief the strain on domestic water supply. In 2011, Hebei suffered from drought. Thus the work of water research and well digging for drought relief had been jointly carried out in the mountainous area of Hebei by China Geological Survey and Hebei government. Based on the result achieved during this work and drawing experience and lessons from the previous water researches, the authors summed up and analyzed the occurrence regularity of groundwater in the

bedrock mountainous area of Hebei and worked out a water research method for the bedrock mountainous area with metamorphic rocks, carbonate rocks and volcanic rocks distributed.

### 1 Overview

The bedrock mountainous area of Hebei includes the Bashang Plateau, Yanshan Mountain and Taihang Mountain area, covering an area of  $11.46 \times 10^4$  km<sup>2</sup>. The stratum of this area has developed well, showing the characteristics that on the base of the metamorphic series of Archeozoic-Early Proterozoic era, the slightly metamorphic platform-type Middle-upper Proterozoic Erathem covered in unconformity firstly, then the relatively stable marine sediment of Cambrian system and Ordovician deposited on the upper layer, then the

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stratigraphic gap occurred from Upper Ordovician to Early Carboniferous Epoch, and finally on the surface the Quaternary loose deposited.

According to the differences of the aquifer type, lithology characteristics and the groundwater occurrence conditions in the research area, the aquifer formation of the mountainous area of Hebei can be divided into three major types, namely, the aquifer formation with pore water in loose rocks, aquifer formation with fissure water in the fissures of metamorphic rocks, igneous rocks and clastic rocks and the aquifer formation with fissure karstic water in carbonate rocks (CHEN Wang-he *et al.* 1999).

Pore water in loose rocks: distributed in the intermountain basin and broad valley of Yanshan Mountain and Taihang Mountain as well as the Quaternary system distribution range in Bashang region. The thickness of the quaternary system is usually meters to tens of meters in the intermountain river valley, while 300-500 m in the intermountain basin. The lithology and thickness of this aquifer tend to change largely.

Bedrock fissure water: widely distributed in the mountainous area of Hebei. The aquifer formation with fissure water in the fissures of metamorphic rocks, igneous rocks and clastic rocks is of this type. The fissure water exist in reticular weathering fissures, structural fractures, diagenetic fracture, fracture zone of the structure and the contact zone of magmatic rocks. Except for the water in weathering fissure which is in reticular distribution, the water in other fissures is in zonal distribution. Although, the bedrock fissure water is widely distributed, it has poor water abundance in general, except for the zones with well developed fractures, such as the crushed zone of the structure, where the water shows good water abundance.

Karstic fissure water in carbonate rocks: mainly existing in the limestone and dolomite of Changchengian Group, Jixianian Group, Cambrian

Group and Ordovician. Major distribution regions include Wuan, Shexian, Xingtai, Jingxing, Laiyuan, Mancheng and Yixian in the Taihang Mountain area as well as Zunhua and Qian'an in Yanshan Mountain area. Additionally, it is also distributed sporadically in Chengde, Kuancheng, Xinglong, Pingquan, Qinglong and Qinhuangdao. The outcropping area reaches about  $1.72 \times 10^4 \text{ km}^2$  and the thickness can reach 500-1 500 m. The Karstic groundwater develops in uniformity, some being undeveloped and some being well developed such as that of Ordovician which shows good water abundance. The aquifer formations of different periods form a uniform aquifer system though they are also independent to each other.

## 2 Reservoir structure enriched with groundwater

If we want to search for the water in bedrock mountainous area, we have to find the reservoir structure. According to the definition of reservoir structure by LIU Guang-ya (LIU Guang-ya, 1979), all the geological structure that can accumulate and store water are called reservoir structure. The basic elements of reservoir structure include the permeable stratum or rock mass which is the storage medium of the reservoirs structure, the impermeable stratum or rock mass which forms the water-blocking boundary, the proper supply resources which provides the conditions for groundwater recharge and discharge since only when the recharge condition is better than the discharge condition can the reservoir start to store groundwater. According to the difference of water storage conditions as well as the difference and the convergence of the distribution pattern of groundwater, the reservoir structure can be classified as below (Table 1).

**Table 1** Type of reservoirs and the characteristics

| Type            | Formation conditions                                                                                                                                                                                                                      | Sub-class                                                                                                   | Characteristics of water control                                                                                                                                                                        |
|-----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Blocking type   | 1. Permeable stratum;<br>2. Water-blocking body perpendicular to the flow direction.                                                                                                                                                      | large scale intrusive rock mass, Rock dyke (wall)-blocking type, stratum-blocking type, fault-blocking type | In the permeable stratum, the groundwater is blocked; the groundwater gathers in the permeable stratum of the upstream of the block body.                                                               |
| Stagnating type | 1. Horizontal or gentle permeable stratum;<br>2. Relatively impermeable stratum buried under.                                                                                                                                             | Upper stagnating type, platform-stagnating type                                                             | Rainfall infiltrates through the permeable stratum; resisted by the water-blocking layer, the infiltration stagnates or gathers on the water-blocking layer.                                            |
| Fold type       | 1. Stratum in stratiform;<br>2. Permeable and impermeable strata existing.                                                                                                                                                                | Monocline type<br>Syncline type<br>Anticline type                                                           | There is a permeable stratum with storing space; the water in outcropped area recharges the groundwater; the groundwater gathers in the shaft area or wing area.                                        |
| Fracture type   | 1. Brittle and soluble stratum;<br>2. Having water storage space in the fault zone or fault-affecting zone.                                                                                                                               | Fault-storing type<br>Fault block-storing type                                                              | The storing space forms in the fractures or pores in the fracture zone of fault zone or fault-affecting zone; the infiltration gathers here and forms an area with good water abundance.                |
| Contact type    | 1. Having contact zone between the rock mass (dyke) and the surrounding rocks;<br>2. Having water storage fractures or permeable stratum in the contact surface or the surrounding rocks;<br>3. Having certain space for water gathering. | Intruding type (intruding into the contact zone)<br>Dyke-storing type<br>unconformable contact type         | During the intruding of dyke or rock body, the surrounding rocks or dyke form fractures for storing water.                                                                                              |
| Weathering type | 1. In the bedrock zone with weak permeability and well developed weathering fissures;<br>2. Having the unweathered bedrock with impermeability under;<br>3. With terrain facilitating water gathering.                                    | Reservoir structure with weathering crust                                                                   | The bedrock with weak permeability form fractures under the action of weathering; area with good water abundance forms in the low-lying zone with water-gathering conditions.                           |
| Karst type      | 1. Soluble rocks;<br>2. Well developed karst rocks.                                                                                                                                                                                       | Stratiform type<br>Zonal type                                                                               | Under the water table, the karst rocks are well developed; these rocks form the reservoir structure when having recharging conditions; in the karst structure, it is easy to form a strong stream flow. |

### 3 Major research methods in bedrock mountainous area (LIU Zhi-gang *et al.* 2012)

#### 3.1 Major research methods for metamorphic rocks

##### 3.1.1 Weathering fissure zone

The metamorphic rock is usually well developed in weathering zone, where the reservoir structure forms only under the terrain condition and structure condition for water gathering. Analyzing from the aspect of terrain condition, the proper place shall facilitate water gathering rather

than water seepage. The location of well shall be set at the cropped area of the weathering zone in the central of the low-lying land or in the bottom of the slope with argillaceous deposits to block water, from where we can exploit the groundwater from both the weathering fissures and the superficial quaternary system so as to increase the water yield. Analyzing from the aspect of lithology, the brittle metamorphic rocks possess a high content of quartz while the weathering zone is of high permeability, and thus the wells here may have a high water yield. By contrast, the gneiss and schist with high content of mica is of weak permeability in the weathering zone and thus the wells here may have a low water yield. In gneiss area, we usually dig large opening wells. For example, in Quyang County of Hebei, we have made a 10 m-depth large opening well in the low-lying area with a thick weathering zone and a large space for water gathering. The water yield of this well reaches up to 46 m<sup>3</sup>/h.

### 3.1.2 Fissure water in fault zone

Water research in fault zone is one of the major methods since the fault zone is generally well developed in the fault zone of metamorphic rock area. The extension fracture usually leads to the formation of fault breccia in the fault zone and thus makes the rocks in the two sides of the fault break. The pressure-tension fault usually causes mylonite of poor permeability and thus to make the rocks in the two sides of the fault zone break. Regardless of the property of the fault, the fissure development zone will form in the fault zone or in the two sides of the fault zone. In the extension fault zone forms the reservoir structure while the original rock in the two sides and the pressure-tension fault forms the water-blocking boundary of the reservoir structure and the fault-affecting zone forms the water storage zone. These formations are all good reservoir structures with good condition for well making, when provided with recharge conditions. Therefore, the fault zone of the gneiss area is suitable for digging well to search for water. For example, in Xingxiu Village of Wentang Town in Pingshan County, we have drilled a well on the amphibole biotite plagiogneiss gneiss fault with thickness of 140-150 m, drilling depth of 152.3 m and water yield of a single well at 92.4 m<sup>3</sup>/h. When

choosing the well location in fault zones, the occurrence and scale of the fault are factors to be considered. Proper distance between the well location and the fault shall be well determined. The fracture zone may not be reached if the distance is too long while it may be passed through before reaching the water table if the distance is too short. During practice, we should consider the fault occurrence, surface slope and the planned well depth comprehensively (LI Chuan-sheng *et al.* 2009).

### 3.1.3 Zonal fissure water in intrusive rock dyke

There are many intrusive rock dykes in the metamorphic rocks which have the functions of water gathering, water diversion and water blocking since the fissures in the metamorphic rock with weak permeability are generally well developed. Generally, the well developed rock dyke can gather water and transfer water while the undeveloped one may block water. If the rock dyke and surrounding fissures are undeveloped, the area will be deemed as lacking water containing conditions. For well spacing in the reservoir structures of rock dyke type, the following problems shall be considered: only the rock dyke stretching parallel to the contour line has the function of water blocking, the length and width of the rock dyke shall be of certain scale and the upstream shall have enough recharge space; the location of well in structure of rock dyke type for water blocking or water diversion shall be set in the upstream face of the rock dyke and the rock dyke shall be kept intact; the well location in the rock dyke for water gathering or water diversion can be set on the rock dyke to make the enter through the rock dyke and the rock walls of its two sides. For example, the well in Guanghua Village of Lingshou County is set on the quartz rock dyke in gneiss, with water yield of a single well reaching 30 m<sup>3</sup>/h.

## 3.2 Water research method in carbonate rock karst fissure zone

### 3.2.1 Perched water in limestone

The key to search for the perched water in limestone area is to find the water-blocking stratum in the area. The water-blocking stratum is required to be gentle, with the dip angle less than

10°, the larger area the better. Make sure the water-blocking stratum is not penetrated. The key of searching for perched water lies first in the research of permeable stratum in the bottom of the limestone, including the igneous rock sill and laccolite of shale, mudstone, sandstone, and marlstone. For example, the well of Malu Village of Pingshan County with depth of 5 m has the under stratum formed of the shale of Cambrian system while the outcropped layer formed of limestone of Ordovician, showing smooth formation occurrence, and gathering perched water due to the blocking function of shale. The water yield of the well is 5 m<sup>3</sup>/h (No. 4 Hydrogeology Team of Hebei Geological Survey and Hebei Bureau of Geology and Mineral Resources Exploration, 1974).

### 3.2.2 Karstic fissure water in the limestone fault zone

The karstic fissure water in the limestone fault zone sets a major water searching direction in the mountainous area, which is also a comparative method for water searching in limestone area at current. The groundwater in the limestone fault fracture zone is characterized by large water yield and high possibility of well completion. The strong karstic runoff always develops along the fault fracture zone. Brittle rocks, extension faults and active faults are proper area for water gathering. Searching for water in the fracture zone of limestone area shall be analyzed from the following four aspects: first, analyze the recharge conditions of the fault to find out whether the fault has enough recharge area or not; second, determine the buried depth of water table in the region to make sure that the depth of the completed well is enough to reach the fault zone under the water table; third, lay the well on the hanging wall of the fault; fourth, try to set the well in the intersection, elbow and pinch-out of the fault, the area with the fault displacement increasing, and faults concentrating, the area cutting the most aquifers, the fault-affecting zone of brittle rocks and the side toward water of the blocking fault, etc. For example, the well in Shijiatong Village of Yixian County is located in the fault zone of dolomite stratum of Wumishan Formation of Jixian System. In the area 40-150 m from the surface, the stratum is broken and shows developed fissures. The depth

of the completed well is 152 m, with water yield of 48.89 m<sup>3</sup>/h and with specific yield of 11.30 m<sup>3</sup>/m<sup>3</sup>h (ZHENG Xi-zhen *et al.* 1995; LI Guang-hong *et al.* 1991).

### 3.2.3 Karstic groundwater of blocking type

In the fissures of contact zone of the igneous rock dyke and rock mass and carbonate rock stratum (like limestone and dolomite), the karstic rocks develop well, with good permeability. When the blocking stratum is perpendicular to the flow direction of the groundwater or forms a large angle with the flow direction, the blocking type dyke reservoir structure forms. The well completion conditions in the upstream of the rock dyke are good for well completion. Taking the well of Xinji Village of Qianxi County for example, affected by the fault, the sandy conglomerate of Jurassic system contacts with the dolomite of Gaoyuzhuang Formation directly and thus the Jurassic stratum becomes a blocking body and generates the spring (ZHANG Tie-mei *et al.* 1990; LIU Zhi-gang *et al.* 1994).

### 3.2.4 Karstic groundwater in anticline and syncline extension zone

In the limestone area, the zones with good water abundance related to the fold are always distributed in such positions as the shaft of anticline and syncline, the pitching end of anticline and the hinge zone of fold where the tensile stress concentrates on. When these positions have beneficial terrain conditions for water gathering, they usually show good water abundance. These positions are exactly the right area for well completion.

### 3.2.5 Karstic groundwater in pure limestone stratum

The karstic stones in the limestone usually develop along the pure limestone stratum. In thick pure limestone area, abundant groundwater can be found. For example, there is a wide area of karst developing stratum in the Baiquan karstic spring field, Heilongdong Cave spring field, Weizhou spring field where the limestone of middle Ordovician are distributed. But the karst ground-

water in the karst area is distributed unevenly, thus the water yield may vary largely. The development degree of the karstic rocks is also affected by geological structure. Even in the karst recharge area with developed karstic rocks, the karstic water can not gather if there is no blocking stratum. Therefore, the key for water searching in the karst recharge area is to search for the blocking body that can gather the karstic water. For example, the water sources of Xingtai Steel Plant and Yangjiaopu of Handan City are exploited from the karstic ground water of Ordovician (ZHAO Ming-kun *et al.* 1991; WU Xing-li *et al.* 1985).

### 3.3 Water search method for ground-water in volcanic area

#### 3.3.1 Diagenetic fissure water

The diagenetic fissures develop in volcanic stocks, especially the basaltic rocks where the diagenetic fissures and pores are well developed due to the thermal contraction. Particularly, in the compact blocky basalt rock with thickness less than 15 m, the columnar jointing has fissures with large width and great permeability. When there is a water-blocking stratum under these fissures, or when these fissures are distributed between two impermeable strata, abundant groundwater can be stored here. Taking the Dejulong Farm in Zhangbei City for example, a large opening well has been completed in the andesite of Jurassic system where the stratum is thin, with diagenetic fissures well developed. The well is 10 m in depth, with specific capacity reaching 105 m<sup>3</sup>/h·m.

#### 3.3.2 Pore water in diagenetic rocks

The cement is formed of pozzolana volcaniclastic rocks including the tuff conglomerate and the coarse crystal tuff. When the cement is loose and with weak diagenesis, the diagenetic pores and fissures may develop well and possess good permeability. Under suitable geological structure conditions and terrain conditions, these pores and fissures can gather and store groundwater if there is water blocking stratum or they are distributed in the water-gathering landform. Taking the well in Neiboluo Village of Chengde City for example, it

is built on the stratum formed of conglomerate Houcheng formation of Jurassic system where the pores and fissures are well developed. The water yield of the well reaches 60 m<sup>3</sup>/h.

#### 3.3.3 Fissure water in interlayer diagenetic structure

In the brittle and rigid rocks like the andesite, trachyte, compact basalt, *etc.* the fissures are well developed under the tectonic force, while in the soft and plastic rocks like the tuff and tuffaceous shale, the fissures are undeveloped. When the two kinds of rocks are interbedding, the former becomes the aquifer while the latter becomes the water-blocking layer, forming the monoclinic or syncline reservoir structure thus to generate interlayer fissure water. For example, the Kuixing Mountain mineral water well in Chengde City is built on the fracture of the Mountain, and affected by the geological feature, the conglomerates of Houcheng formation of Jurassic system has well developed joint fissures. When the drawdown is 1.48 m, the water yield of the well will reach 80 m<sup>3</sup>/h.

#### 3.3.4 Fissure and pore water in interlayer sandy conglomerate

In the volcanic distribution area, where sedimentary rocks often interbedded in the volcanic rocks, the impermeable shale layer becomes the water-blocking boundary, while the conglomerate and sandstone layers with well developed fissures and pores form the aquifer, thus to generate the interlayer groundwater or sometimes form a fold-type reservoir structure. In the Mesozoic fault depression basin of Yanshan Mountain area, the fissure and pore water is well developed and even rich in water yield in some advantageous area. For example, the Dichigou Village of Xiahuayuan District lies on the anticline where the stratum is formed of andesite and andesite agglomerate with coarse sandstone imbedded, the anticline forms a ravine, the sand gravel outcrops, and the spring water flow out along the sand gravel layer. After being expanded, the spring has become the source of drinking water for the locals.

#### 3.3.5 Fissure water in fault fracture zone

The fault fracture zone in the volcanic rocks is similar to that of the other kinds of stocks. The fracture zone of brittle stocks, extension fault fracture zone, active fault fracture zone without cement filled in always contain water, especially in the intersection of two faults where the water is more abundant. The fault fracture zone in the plastic muddy and tufaceous stocks usually bears little water or even no water. The fault fracture zone in the Cenozoic basalt usually bears large quantity of water, because the fault was formed in later ages, the fractures have not yet cemented, and most of the faults in basalt are high-angle normal faults which connect the aquifers of different layers in the basalt, thus the groundwater in the fracture zone can be recharged sufficiently. However, the fault fracture zones on the discharge base level are permeable and not able to gather and store water.

### 3.3.6 Large pore water in plateau basalt

In some local district in the Cenozoic basalt area, the large pores which are distributed in the contact surfaces of the basalts generated during two times of eruptions connect with each other and with the diagenetic fissures. These pores are not formed during the eruption of basalt. They are much larger than pores and are in irregular tabular shape. The pores of this kind bear abundant water and the wells built here will have large water yield. For example, in the area of Xuqingfangzi Village and Wufulan Village of Zhangbei County, the water yield of wells built in stratum with large pores increase significantly which can reach to over 60 m<sup>3</sup>/h.

## 4 Conclusions

Considering the outcropping situation of major bedrocks in the mountainous area of Hebei, and based on the reservoir structure, the authors of this Paper figured out the method for bedrock groundwater research in the metamorphic rocks, carbonate rocks, and igneous rocks area. However, with further study that may be carried out on the distribution regularities of bedrock groundwater in mountainous area, the methods for water research in mountainous area will be enriched. Setting up a

model for water research in bedrock mountainous area of Hebei will provide basis for the future water research, and thus improve the success rate of the work and reduce the property loss of people. The burial conditions of groundwater are complicated and variable. Therefore, we should conduct relative researches in terms of the terrain, landform, geological condition, hydrogeological conditions of the working area shall be conducted during the process of water research and determine the area for water completion based on the comprehensive analyzing.

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