

## A study on the supply relations of different groundwater in Qingdao subway line R3

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**Abstract:** In this paper, the correlation between different groundwater in the study area is analyzed by using the hydrological data from the hydrogeological test holes and the long-term observation holes based on the hydrogeological data between the Jinggangshan Road Station and the Jianianhua Station on the Qingdao Subway Line R3. The conclusions are as follows. When the drills are near the seashore (less than 50 m) and the backfilled formation has a large permeability coefficient (the backfilled components being coarse particles), the Quaternary pore water is connected with the seawater and there is correlation between the two. When the drills are far from the seashore (more than 50 m) or the backfilled formation has a small permeability coefficient, there is no correlation between the two. When the drills are near the seashore (less than 50 m) with developed bedrock fissure, the bedrock fissure water is connected with the seawater and there is correlation between the two. When the drills are far from the seashore (more than 50 m), or when the bedrock fissure is undeveloped, there is no correlation between the two. There exists an aquifer (mainly marine muddy silt clay layers and partially silt clay layers) between the Quaternary pore water and the bedrock fissure water, which blocks the connectivity between the two. Consequently, there is no correlation.

**Keywords:** Qingdao subway; Hydrogeological conditions; Groundwater correlation

### Introduction

China's urban rail transit project began in Beijing in 1965, the goal of which was to solve such outstanding issues as traffic congestion and increasing population density. Urban rail transit projects have the following advantages compared with the ground transportation (HAN Li, 2005; WANG Jin-lin and WANG Nan, 2012): Its operation is environmentally friendly; it provides passengers with comfortable environment; it saves land because of its vertical space use. It has therefore become the preferred transportation mode for metropolis. Qingdao proposed to build subways in the 1980s. In order to explore the impact of Qingdao geological conditions on its subways, Qingdao municipal government built some pilot stations in the 1990s. Since the beginning of the 21<sup>st</sup>

century, Qingdao has witnessed rapid socio-economic development, and its population rose sharply. To solve such problems as traffic congestion and increasing population density, Qingdao has been developing its own urban rail transit system since 2008.

Located along the coast of the Yellow Sea, Qingdao bears the brunt of groundwater problems. The Groundwater affects the overall stability of the tunnel, the stability at the bottom of the tunnel with uplift structure, tunnel piping, quicksand and confined water on the bottom of the tunnel (XU Xing-xing, 2012). Subways are built deep underneath the ground, the majority of which is buried under the groundwater. It has numerous dots and long lines, and its construction is time-consuming. The ground subsidence should therefore be strictly controlled to ensure the safety of the surrounding buildings (structures) and the corresponding pipelines (YAO Juan, 2016; LI Yan-jun and YANG Mu-zhuang, 2007; LI Yu-xin *et al.* 2016).

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The Jinggangshan Road Station-Jianianhua Station on the Qingdao Subway Line R3, which is studied in this paper, passes through the Tangdao Bay, the closest part being just 20 m away. The groundwater is closely connected with the seawater in the area, which greatly affects the rail construction. Therefore, the study on groundwater correlation is an indispensable part to ensure the safety of subway construction.

## 1 Overview of the study area and research methods

### 1.1 Overview

In this paper, the interval of Jinggangshan Road (JGS Rd) Station-Jianianhua (JNH) Station depends on the Qingdao Hongdao-Jiaonan intercity rail transit engineering investigation section 1 (Project number 2014-146), this interval starts at the intersection of the two roads. The subway is laid out southward along the Jinggangshan Road, then westward from the Binhai Avenue, and to the intersection of the Emeishan Road and Binhai Avenue. The total length is about 3 756.0 m.



Fig. 1 Traffic position of the study area

### 1.2 Hydrogeological overview

The study area lies in the coastal accumulation area. The groundwater is principally composed of the Quaternary pore water and bedrock fissure water. The Quaternary pore water is then divided into the upper stagnant water and phreatic water. The groundwater in different layers is numbered in accordance with its nature: 1) Refers to the upper stagnant water; and 2) the phreatic water.

#### 1.2.1 The Quaternary pore water

##### 1) The upper stagnant water

It collects the precipitation, surface water and

sewage from the underground pipeline leakage (CHEN Guo-tan and YIN Yu-hua, 2012). The permeability coefficient of aquifers varies dramatically in different sections. Since the water supply is different in mode and in amount, the upper stagnant water is unevenly distributed with discontinuous and undulated water level. The aquifer consists principally of backfilled soil, shallow silt and sand soil.

##### 2) The phreatic water

It is mainly composed of lateral runoff and collects the vertical precipitation and the upper stagnant water. It is discharged through the lateral underground runoff and the downward supply to the bedrock fissure water.

### 1.2.2 The bedrock fissure water (the weathered and tectonic fissure water)

The weathered fissure water is mainly found in the weathered bedrock. The rock is brecciated and fragmented. The weathered fissures are developed in a stratigraphic form in the relatively low terrain. The tectonic fissure water is mainly found in the moderately and slightly weathered fractured zone and in the joint density area of the bedrock as veins and belts. The groundwater runoff is deep and flows to various directions. It can bear a certain amount of pressure and is distributed in the tectonic developed area.

### 1) Hydrogeological tests

The hydrogeological tests mainly refer to laying out hydrogeological test holes in the study area around the subway line, and conducting hydrogeological tests in different layers. On one hand, the permeability coefficient of the corresponding aquifer can be calculated. On the other hand, the water components can be determined by chemical analysis, thus laying a solid foundation for clarifying the supply relations of groundwater.

Sixteen hydrogeological test holes (Fig. 2) were evenly laid out in the study area. The results are shown in Table 1.

## 1.3 Research methods



**Fig. 2** Position of hydrogeological test holes and longterm observation holes

### 2) Hydrogeological longterm observation holes

In order to understand the characteristics of dynamic groundwater levels in key sections and the hydraulic relationship between the aquifer water level, the amount of water, and the aquifer or between the aquifer and the seawater, as well as the water content of the fault zone, hydrogeological

long-term observation holes were put in such typical sections as the Quaternary sandy areas, thick sections of highly weathered layer in the bedrock, and other sections that are close to the coastline. The observation holes can be divided into two kinds to watch the Quaternary pore water and the bedrock fissure water respectively. The observations holes

for the Quaternary pore water stop at the bedrock. The holes for the bedrock fissure water use  $\Phi 146$  mm steel pipes to stop water in the

Quaternary strata (steel pipes were put into the rock for about 0.5 m), and then use  $\Phi 108$  mm drills to dig into the bottom for observation.

**Table 1** Test results

| Drilling holes | Major pervious bed                                                           | Groundwater types                  | Permeability coefficient (m/d) |
|----------------|------------------------------------------------------------------------------|------------------------------------|--------------------------------|
| S01-1          | Plain fill                                                                   | The Quaternary pore phreatic water | 14.45                          |
| 12S            | Plain fill                                                                   | The Quaternary pore phreatic water | 120.62                         |
| S08-1          | Plain fill                                                                   | The Quaternary pore phreatic water | 28.24                          |
| 26             | Highly and moderately weathered lamprophyre                                  | The bedrock fissure water          | 0.35                           |
| 38             | Highly weathered diorite                                                     | The bedrock fissure water          | 0.46                           |
| S09-2          | Slightly weathered tuff-breccia (in fractions)                               | The bedrock fissure water          | 0.42                           |
| 10             | Moderately weathered granite porphyry                                        | The bedrock fissure water          | 0.22                           |
| S1             | Moderately and slightly weathered granite porphyry (in fractions)            | The bedrock fissure water          | 0.37                           |
| S2             | Moderately and slightly weathered granite porphyry (in fractions)            | The bedrock fissure water          | 0.03                           |
| S3             | Moderately and slightly weathered granite porphyry (in fractions)            | The bedrock fissure water          | 0.10                           |
| S4             | Moderately and slightly weathered granite porphyry (in fractions)            | The bedrock fissure water          | 0.05                           |
| S10-2          | Highly and moderately weathered tuff-breccia                                 | The bedrock fissure water          | 0.14                           |
| 03             | Highly and moderately weathered tuff-breccia and tuff-breccia (in fractions) | The bedrock fissure water          | 0.17                           |
| S07            | Highly and moderately weathered tuff-breccia                                 | The bedrock fissure water          | 0.16                           |
| S08-2          | Moderately weathered tuff-breccia                                            | The bedrock fissure water          | 0.60                           |
| S12            | Weathered tuff-breccia (in sandy clays and fraction blocks)                  | The bedrock fissure water          | 0.05                           |

Twelve long-term observation holes were arranged in the study area for 24-hour continuous observation (with 1 h interval). The water level and the corresponding tide level were measured. Then the coordinate system was drawn with time as the x-axis and water level as the y-axis to deduct the connectivity between the seawater and the groundwater in the holes.

## 2 Results and analysis

### 2.1 Overview of long-term observation holes

Twelve longterm observation holes (Fig. 2) were laid out in the study area, including 4 holes for the Quaternary pore water and 8 holes for the bedrock fissure water. Refer to Table 2 for details.

## 2.2 Analysis of major ion concentration between the groundwater and the seawater

Ten groups of groundwater samples were used for quality analysis in the supplementary survey stage. The results of ion concentration were compared with those of 12S water samples (equivalent to seawater). Refer to Table 3 for details.

## 3 Analysis of the supply relations between the groundwater and the seawater

According to existing data, the supply relations can be categorized into the following three scenarios (Fig. 3).

### 3.1 The correlation between the Quaternary pore water and the seawater

Four of the 12 longterm observations holes are to monitor the Quaternary pore water level and the tide, namely 12S, S01-1, S08-1, S09-1. The results can be seen in Table 4.

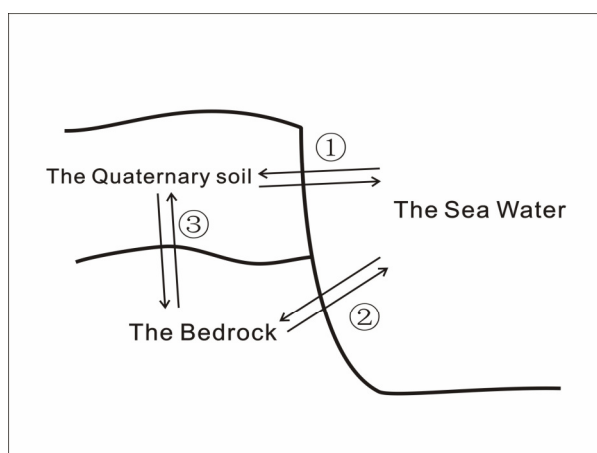
**Table 2** Summary of longterm observation holes

| Drill No. | Distance from Tangdao Bay (m) | Types of groundwater      | Water height (m) | Permeability coefficient (m/d) | Major aquifers and other geological conditions                                                                                                                                                    |
|-----------|-------------------------------|---------------------------|------------------|--------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 12S       | 20                            | The Quaternary pore water | 3.9              | 120.6                          | Plain fill (saturated, loose, mainly composed of stones whose diameter is 10-30 cm)                                                                                                               |
| S01-1     | 50                            | The Quaternary pore water | 4.1              | 14.4                           | Plain fill (slightly wet, slightly dense, composed of clays, silty clays, weathered sand with some gravels whose diameter is 2-6 cm)                                                              |
| S08-1     | 1 300                         | The Quaternary pore water | 3.0              | 28.24                          | Plain fill (slightly wet, slightly dense, composed of clays, silty clays, weathered sand with some gravels, principally backfilled 4.0-7.6 m gravels whose diameter is 3-7 cm, 10 cm the maximum) |
| S09-1     | 150                           | The Quaternary pore water | 5.8              | No water                       | Plain fill (slightly wet, slightly dense, composed of clays, silty clays, weathered sand with some gravels)                                                                                       |
| S01       | 35                            | The bedrock fissure water | 3.1              | 0.37                           | Moderately and slightly weathered granite prophyry, joint density area (fractured core)                                                                                                           |
| S02       | 100                           | The bedrock fissure water | 3.7              | 0.031                          | Moderately and slightly weathered granite prophyry, joint density area (fractured core)                                                                                                           |
| S03       | 100                           | The bedrock fissure water | 3.9              | 0.10                           | Moderately and slightly weathered granite prophyry, joint density area (fractured core)                                                                                                           |
| S04       | 100                           | The bedrock fissure water | 8.4              | 0.052                          | Moderately and slightly weathered granite prophyry, joint density area (fractured core)                                                                                                           |
| S07       | 1 200                         | The bedrock fissure water | 3.9              | 0.16                           | Highly and moderately weathered tuff-breccia (fractured core)                                                                                                                                     |
| S08-2     | 1 300                         | The bedrock fissure water | 5.3              | 0.60                           | Moderately weathered tuff-breccia (fractured core)                                                                                                                                                |
| S09-2     | 150                           | The bedrock fissure water | 11.8             | 0.42                           | Highly and moderately weathered tuff-breccia (fractured core)                                                                                                                                     |
| S10-2     | 10                            | The bedrock fissure water | 4.8              | 0.14                           | Highly and moderately weathered tuff-breccia (fractured core)                                                                                                                                     |

**Table 3** Comparative study on groundwater ion concentration

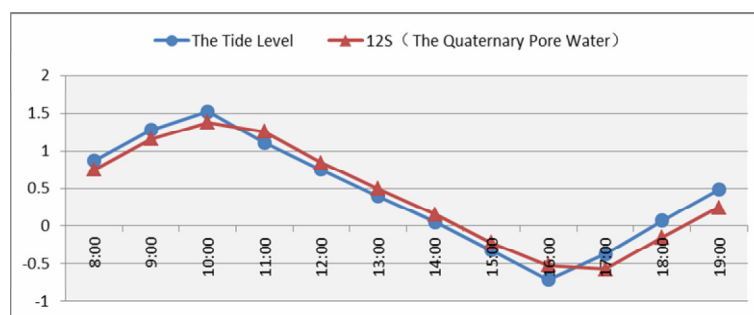
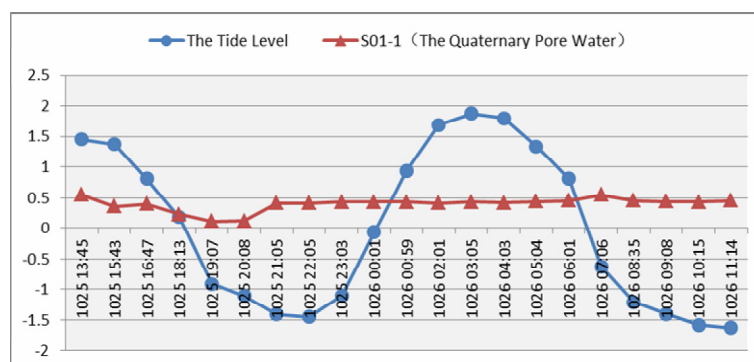
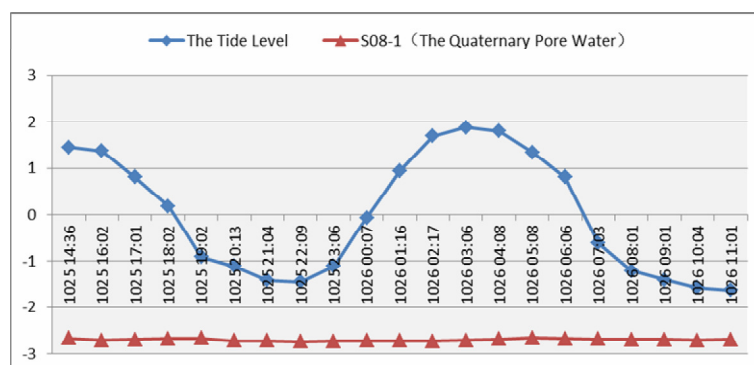
| Types of groundwater      | Drill No.                | SO <sub>4</sub> <sup>2-</sup> (mg/l) | Total mineralization (mg/l) | Cl <sup>-</sup> (mg/l) | Similarity to seawater |
|---------------------------|--------------------------|--------------------------------------|-----------------------------|------------------------|------------------------|
| The Quaternary pore water | 12S                      | 3 303.1                              | 33 645                      | 17 979.3               | 100%                   |
| The Quaternary pore water | S08-1                    | 696.44                               | 4 105.24                    | 1 789.66               | 21%                    |
| The bedrock fissure water | S08-2                    | 432.27                               | 9 904.2                     | 5 539.42               | 31%                    |
| The Quaternary pore water | S09-1                    | 836.87                               | 8 980.04                    | 4 601.98               | 27%                    |
| The bedrock fissure water | S09-2                    | 480.3                                | 8 151.03                    | 4 516.76               | 25%                    |
| The bedrock fissure water | S10-2                    | 2 020.86                             | 20 536.84                   | 10 652.73              | 61%                    |
| The bedrock fissure water | S07                      | 557.15                               | 10 228.18                   | 5 692.82               | 32%                    |
| The bedrock fissure water | S02                      | 76.08                                | 373.62                      | 109.08                 | 2%                     |
| The bedrock fissure water | S03                      | 45.65                                | 255.85                      | 61.36                  | 1%                     |
| The bedrock fissure water | S04                      | 513.54                               | 5 735.42                    | 9 097.54               | 51%                    |
| The Quaternary pore water | S01-1 (high water level) | 912.57                               | 5 833.17                    | 2 556.65               | 28%                    |
| The Quaternary pore water | S01-1 (low water level)  | 1 104.69                             | 6 818.59                    | 3 025.37               | 33%                    |
| The bedrock fissure water | S01 (high water level)   | 2 020.86                             | 29 214.79                   | 16 533.03              | 92%                    |
| The bedrock fissure water | S01 (low water level)    | 1 450.27                             | 27 816.22                   | 16 106.92              | 90%                    |

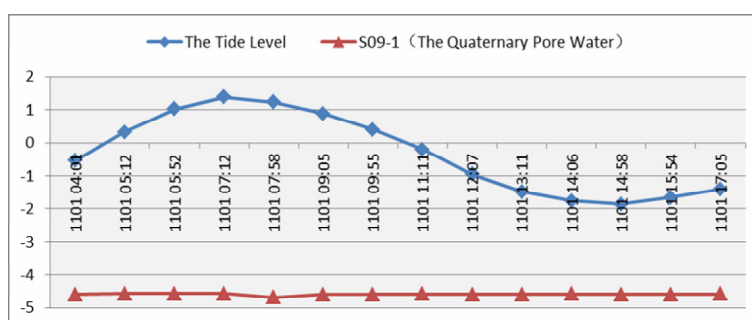
Note: The similarity to seawater refers to the maximum percentage of major groundwater components in different holes over the corresponding seawater components.

**Fig. 3** The supply relations between seawater and groundwater

**Table 4** Summary of the correlation between the Quaternary pore water and the seawater

| Drill No. | The corelation with the tide                        | Distance from the Tangdao Bay (m) | Major components of groundwater and their similarity to seawater | Causes                                                                                                                                        |
|-----------|-----------------------------------------------------|-----------------------------------|------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| 12S       | Positive correlation (time lag, weakened amplitude) | 20                                | 100%                                                             | The drill is near the sea (about 20 m) and its aquifer is principally made of boulders. The tests show it has large permeability coefficient. |
| S01-1     | Unrelated                                           | 50                                | 33%                                                              | The backfilled components consist mainly of particles, which block the correlation between seawater and groundwater.                          |
| S08-1     | Unrelated                                           | 1 300                             | 21%                                                              | The drill is far from the sea (about 1 500 m) and has no correlation with seawater.                                                           |
| S09-1     | Unrelated                                           | 150                               | 27%                                                              | The tests show the drill has no water. It is far from the sea (150 m). There is no correlation with the seawater.                             |

**Fig. 4** Plots of groundwater level and tide level at 12S (Jun. 5<sup>th</sup>, 2014)**Fig. 5** Plots of groundwater level and tide level at S01-1 (Oct. 25<sup>th</sup> – 26<sup>th</sup>, 2015)**Fig. 6** Plots of groundwater level and tide level at S08-1 (Oct. 25<sup>th</sup> – 26<sup>th</sup>, 2015)



**Fig. 7** Plots of groundwater level and tide level at S09-1 (Nov. 1<sup>st</sup>, 2015)

**Table 5** Summary of the correlation between the bedrock fissure water and the seawater

| Drill No. | The correlation with the tide                       | Distance from the Tangdao Bay (m) | Major components of groundwater and their similarity to seawater | Causes                                                                                                                           |
|-----------|-----------------------------------------------------|-----------------------------------|------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|
| S01       | Positive correlation (time lag, weakened amplitude) | 35                                | 92%                                                              | The drill is near the seashore (about 35 m) and it unveils developed bedrock fissure.                                            |
| S04       | Positive correlation (time lag, weakened amplitude) | 50                                | 51%                                                              | The drill is near the seashore (about 50 m) and it unveils developed bedrock fissure.                                            |
| S10-2     | Positive correlation (time lag, weakened amplitude) | 10                                | 61%                                                              | The drill is near the seashore (about 10 m) and it unveils fractured core. Therefore it has developed bedrock fissure.           |
| S02       | Unrelated                                           | 100                               | 2%                                                               | The drill is far from the seashore (about 100 m) and it unveils undeveloped bedrock fissure.                                     |
| S03       | Unrelated                                           | 100                               | 1%                                                               | The drill is far from the seashore (about 100 m) and it unveils undeveloped bedrock fissure.                                     |
| S07       | Unrelated                                           | 1 200                             | 32%                                                              | The drill is far from the seashore (about 1 200 m) and it unveils undeveloped bedrock fissure.                                   |
| S08-2     | Unrelated                                           | 1 300                             | 31%                                                              | The drill is far from the seashore (about 1 500 m) and it unveils undeveloped bedrock fissure.                                   |
| S09-2     | Unrelated                                           | 150                               | 25%                                                              | The drill is far from the seashore (about 150 m) and there is no correlation between the bedrock fissure water and the seawater. |

It can be seen from the aforementioned analysis that when the drills are near the seashore (less than 50 m) and the backfilled formation has a large permeability coefficient (the backfilled components being coarse particles), the groundwater has the same composition as that of the seawater. The Quaternary pore water level changes with the tide, showcasing a time lag and weakened amplitude (Fig. 4). It is therefore inferred that the Quaternary pore water is connected with the seawater and there

is correlation between the two. When the drills are near the seashore (less than 50 m) and the backfilled formation has a small permeability coefficient, the backfilled particles block the connectivity between the Quaternary pore water and the seawater. There is no correlation (Fig. 5). When the drills are far from the seashore (more than 50 m), it will not be affected by seawater. There is no correlation between the two (Fig. 6 and Fig. 7).

### 3.2 The correlation between the bedrock fissure water and the seawater

Eight of the 12 longterm observations holes are to monitor the bedrock fissure water level and the tide, namely S01, S02, S03, S04, S07, S08-2, S09-2, S10-2. The results can be seen in Table 5.

It can be seen from the aforementioned analysis that when the drills are near the seashore (less than 50 m) with developed bedrock fissure, the bedrock fissure water component is similar to that of the seawater (more than 50%). The bedrock fissure water level is also positively correlated with the tide (Fig. 8 to Fig. 10), showcasing a time lag and weakened amplitude. It is therefore inferred that the bedrock fissure water is connected with seawater and there is correlation between the two. When the drills are far from the seashore (more than 50 m), it will not be affected by seawater. Or when the bedrock fissure is undeveloped, there is no correlation between the two (Fig. 11 to Fig. 15).

### 3.3 The correlation between the Quaternary pore water and the bedrock fissure water

Three of the 12 longterm observation holes were chosen to compare the correlation between the Quaternary pore water and the bedrock fissure water, namely S01-1, S01 (Fig. 16); S08-1, S08-2 (Fig. 17); S09-1, S09-2 (Fig. 18).

It can be seen from the aforementioned data that there exists an aquifer (mainly marine muddy silt clay layers and partially silt clay layers) between the Quaternary pore water and the bedrock fissure water, which blocks the connectivity between the two. There is no correlation between the two. The Quaternary pore water level remains steady when the bedrock fissure water level changes (Fig. 19).

## 4 Conclusions

1) When the drills are near the seashore (less than 50 m) and the backfilled formation has a large permeability coefficient (the backfilled components being coarse particles), the Quaternary pore water is connected with the seawater and there is correlation between the two. When the drills are far from the seashore (more than 50 m) or the backfilled formation has a small permeability coefficient, there is no correlation between the two.

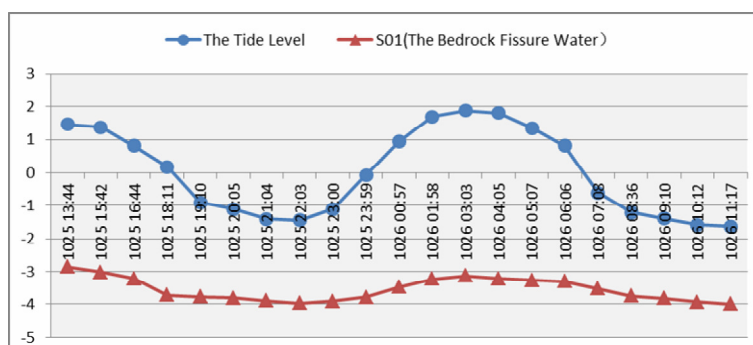


Fig. 8 Plots of groundwater level and tide level at S01 (Oct. 25<sup>th</sup> – 26<sup>th</sup>, 2015)

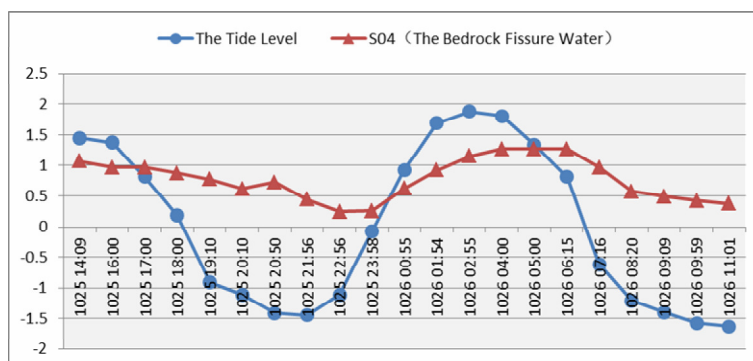


Fig. 9 Plots of groundwater level and tide level at S04 (Oct. 25<sup>th</sup> – 26<sup>th</sup>, 2015)

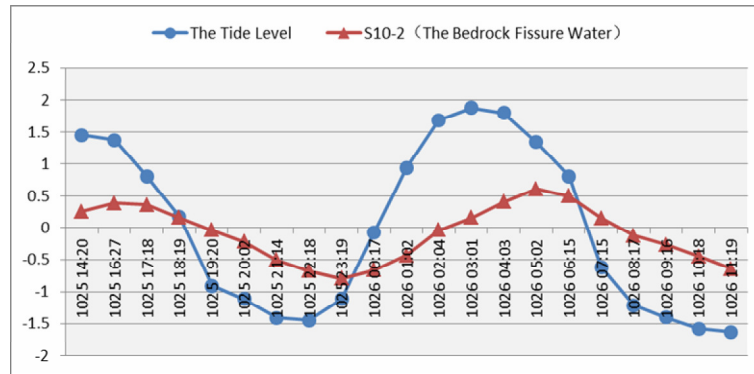


Fig. 10 Plots of groundwater level and tide level at S10-2 (Oct. 25<sup>th</sup> – 26<sup>th</sup>, 2015)

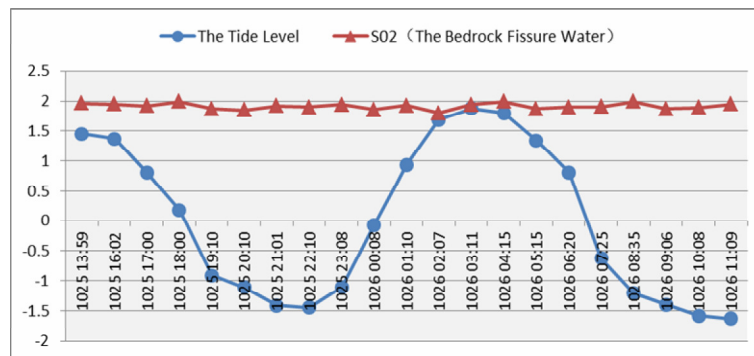


Fig. 11 Plots of groundwater level and tide level at S02 (Oct. 25<sup>th</sup> – 26<sup>th</sup>, 2015)

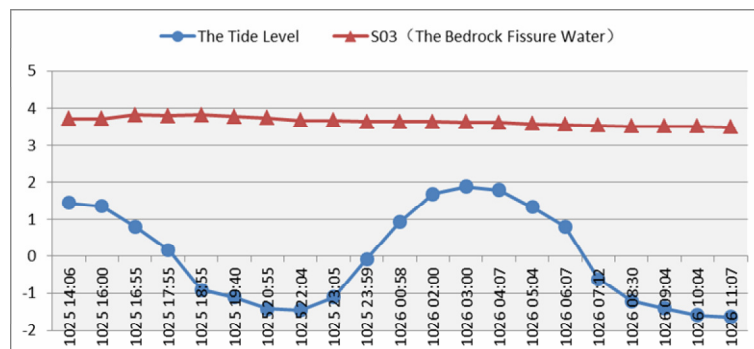


Fig. 12 Plots of groundwater level and tide level at S03 (Oct. 25<sup>th</sup> – 26<sup>th</sup>, 2015)

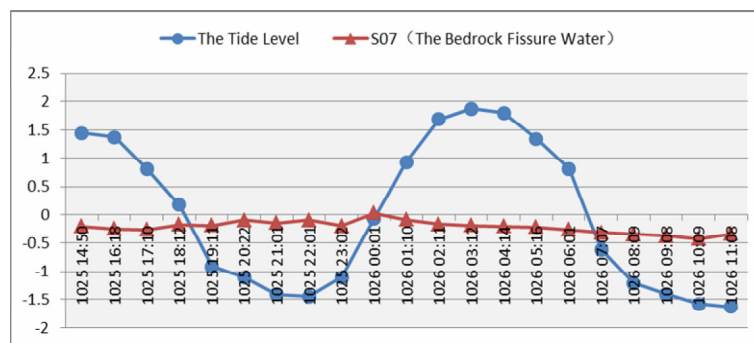


Fig. 13 Plots of groundwater level and tide level at S07 (Oct. 25<sup>th</sup> – 26<sup>th</sup>, 2015)

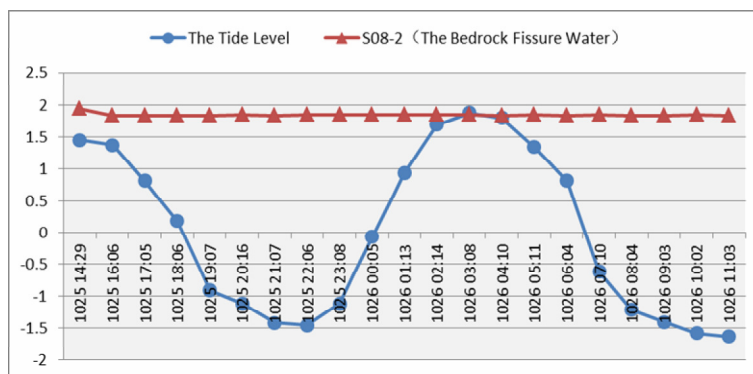


Fig. 14 Plots of groundwater level and tide level at S08-2 (Oct. 25<sup>th</sup> – 26<sup>th</sup>, 2015)

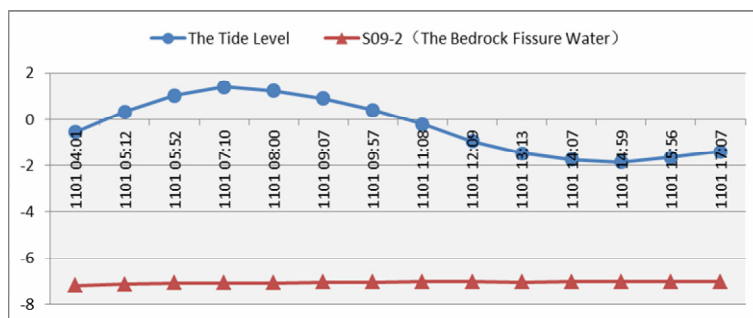


Fig. 15 Plots of groundwater level and tide level at S09-2 (Nov. 1<sup>st</sup>, 2015)

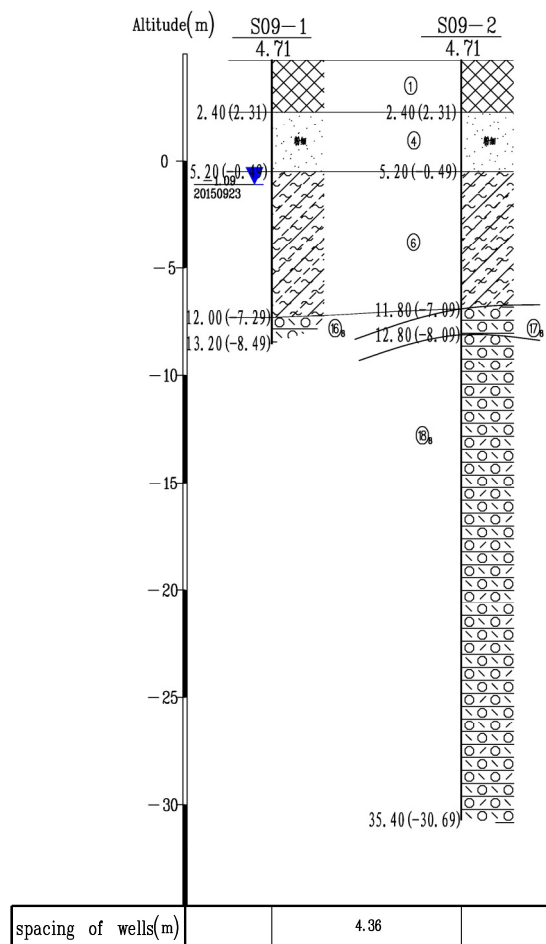


Fig. 16 Profile 1

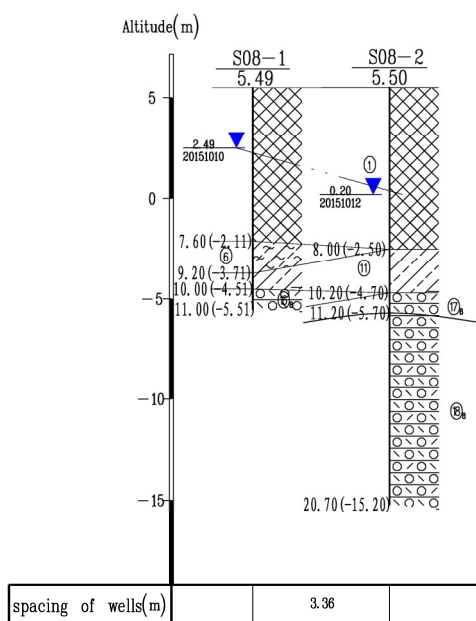


Fig. 17 Profile 2

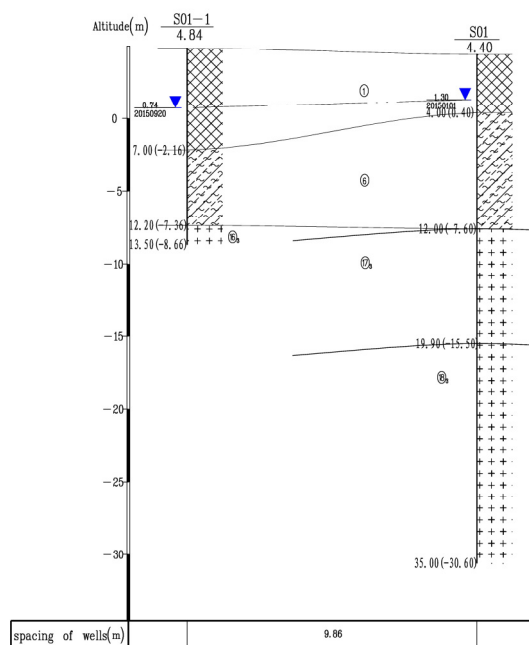


Fig. 18 Profile 3

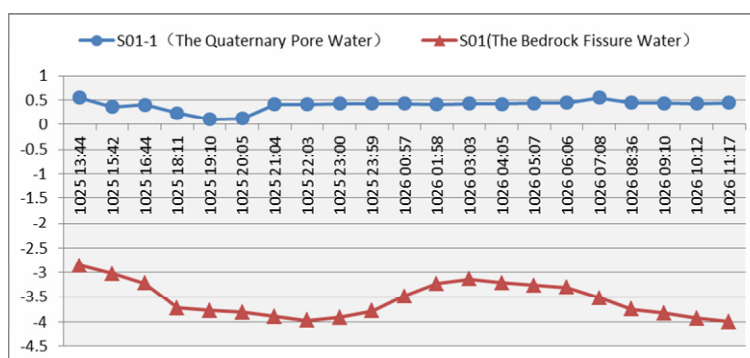


Fig. 19 Plots of dynamic groundwater comparison between S01-1 (Quaternary pore water) and S01 (bedrock fissure water) (Oct. 25<sup>th</sup> – 26<sup>th</sup>, 2015)

2) When the drills are near the seashore (less than 50 m) with developed bedrock fissure, the bedrock fissure water is connected with the seawater and there is correlation between the two. When the drills are far from the seashore (more than 50 m), or when the bedrock fissure is undeveloped, there is no correlation between the two.

3) There exists an aquifer (mainly marine muddy silt clay layers and partially silt clay layers) between the Quaternary pore water and the bedrock fissure water, which blocks the connectivity between the two. Consequently, there is no correlation between the two.

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