Analysis of earth temperature field and geothermal hazard evaluation at Gaoligong mountain tunnel

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Abstract

This paper analysis the geothermal hazard that may encounter during the construction of Gaoligong mountain tunnel located in the Southern part of Gaoligong Mountains.

1. Introduction:

Gaoligong Mountain tunnel goes through the south part of Gaoligong Mountain. The research part of the tunnel is about 13.5 kilometers long (C12K197+337~C12K+868). The tunnel begins from the Huitong Bridge locating in Nujiang River, and ends near to the Long ling village. The maximum burying depth of this tunnel is about 1400 meters.

Many warm springs appear in this area, some locate the north part of the tunnel, and some locate the south area of the tunnel. The temperature of warm springs can reaches to 100 ℃. This deeply buried tunnel may meet the warm groundwater or highly warm rock. The geothermal hazard can influent the construction safety, so much as make the tunnel route design impossible. For selecting reasonable and safety route design, researchers must predict the high geothermal distribution and analyze geothermal hazard which tunnel construction may meet.

2. Geological environment:

Gaoligong Mountain locates in collision belt between Eurasian plate and Indian Ocean plate. The main tectonic extending direction is south to north and east to west. The research area includes Baoshan Mountain fold and Tengcong fold. These two folds are multiple ones. The main tectonics includes Nujiang fracture (F1-1) and Lushui – Ruili fractures (F2-1). But the extending direction of F1-1 changes to NNW extends at the Longling village, and F2-1 changes to SW extending near Longling village showed in figure I. These two main fractures are composed of many small- size fractures.

The part between these two main fractures is Gaoligong multiple fold belong to Baoshan multiple fold. It is the main fold near to route area. The fold was crashed heavily, so there are many smaller folds belong to it. Many small-size fractures of east to west extending locate between the main fractures, cut the main fractures, and form many fault blocks. The north part of whole research area is narrower than the south part; the form of the research area is like triangle.

The landform goes down from the north to south, and two big rives locate aside of the research area. The Nujiang River locates the east boundary, and the Longcuan River locates the west boundary. To the south of the route line, there is another river called Shupo River.

This tunnel locates to the south of the Huangcao dam fracture, and was cut by some small size fractures belong to the main fractures showed in figure 1.

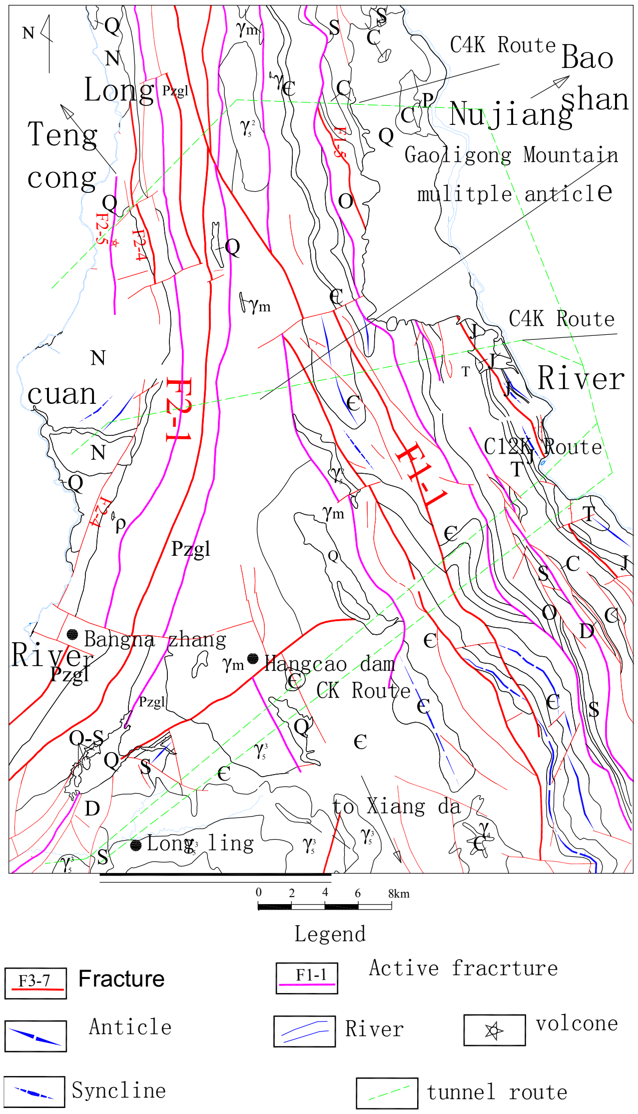


Figure 1 The main tectonic map

3. Warm groundwater system division:

3.1 Groundwater appearing characteristics:

The statistic datum shows that the appearing height and temperature of Nujiang River geothermal system is the lowest, the average height is 854m, and the average temperature is 31℃. The warm groundwater of this area mainly appears in the each banks of the Nujiang River. Some warm springs almost appear in Q_4, and mixed by shallow groundwater. The mixing may be the main reason why temperature of the warm groundwater is the lowest.

The warm groundwater area of Hangcao dam-Bangna zhang system is about 1436m high, average temperature is 62°C, and the highest temperature is 102ºC. Almost of them appear in the section location of fractures. The important warm springs – Bangna zhang warm spring and Huangcao dam warm spring locate in the south part of the C12K tunnel route.

The south part of Huangcao dam fracture is divided into two parts. The warm springs of east part appears interfaces between granites and fractures. The average temperature is near to Huangcao dam-Bangnazhang system. The height of the west part is about 906m, and the average temperature of it is about 36℃. Many of them appear in fractures, and some of them are buried by Q_4.

2.2 Geochemical and isotope characteristics of warm groundwater:

2.2.1 Geochemical characteristics:

For analyzing the groundwater division, researchers select about 176 water to analyze the geochemical and isotope characteristics. Their geochemical characteristics are showed in Pipe figure.

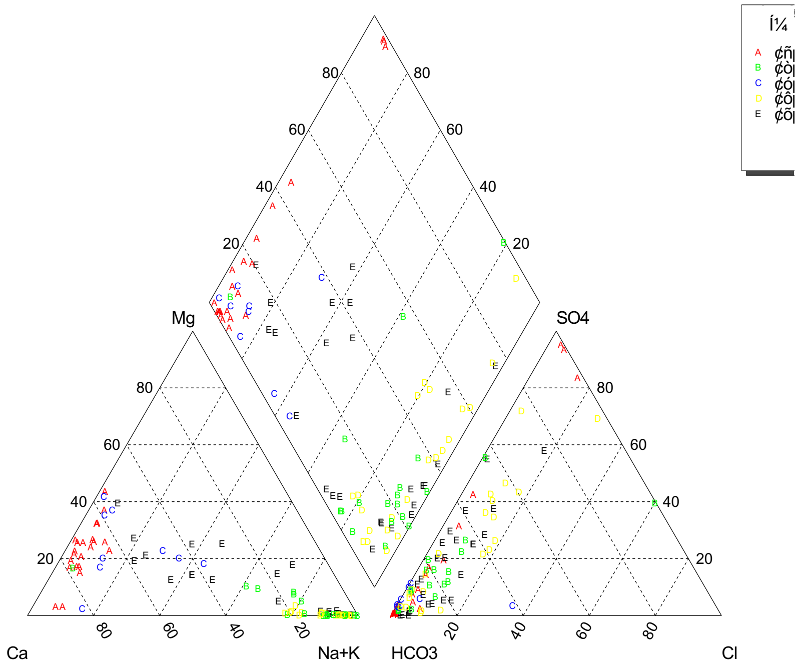


Figure 3 The pipe figure of water examples
I. Nujiang River system II.Hangcao dam-Bangna zhang system III. Luxi Basin system IV. Caoyang-Pingda system V. Longcuan River system

Pipe figure shows that the main cations are Ca^{2+} and Na＋K and the main anion is HCO_3^{-}. The percent of Na+K is about 60%, it shows the warm groundwater is deep groundwater. The TDS of warm groundwater is higher than shallow water. It shows that in deep stratum, the temperature and pressure are both high the rock-water reaction is strong. Although the TDS of the warm groundwater is high, but the range of the TDS is wide: 100～1230mg/l. The geochemical type is HCO_3^{-}-Na^{+}、HCO_3^{-}.SO_4^{2-}－Na^{+} for groundwater of higher TDS, and the lower TDS is HCO_3^{-}－Ca^{2+}.The TDS and the type are influent by the groundwater appearing type. For warm groundwater appearing in the banks of Nujiang River and Luxi basin, many of them are mixed by the shallow water, so their TDS are lower than the other warm groundwater, and the geochemical characteristics is similar to shallow water.

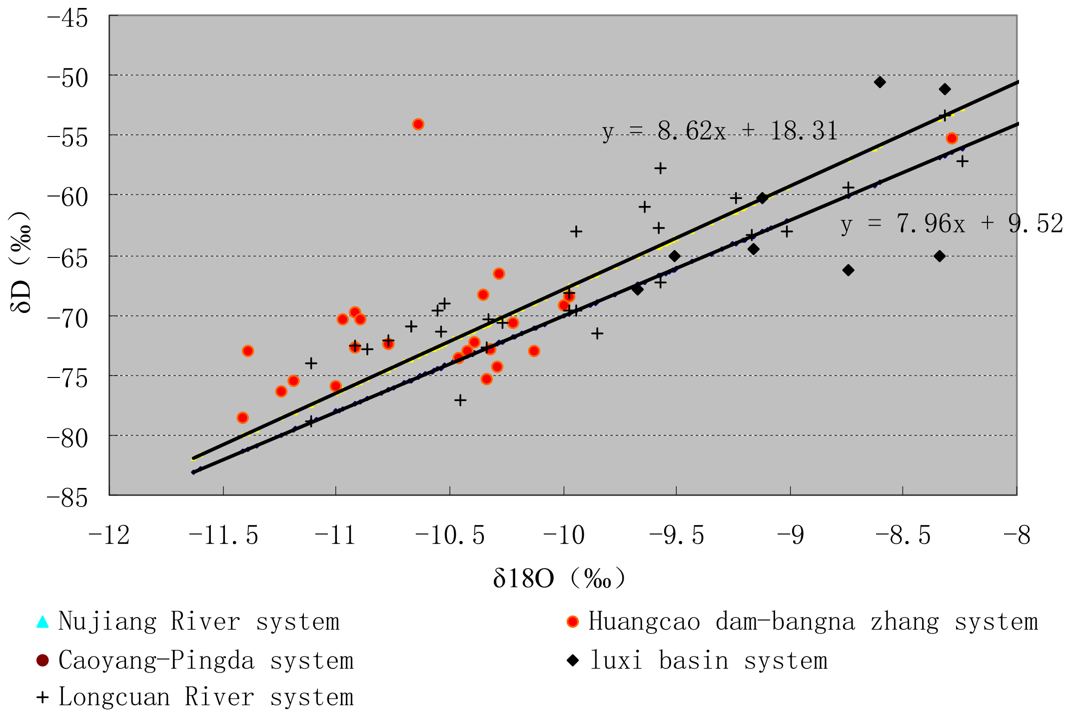


Figure 3 The isotope relationship of $\delta D \sim \delta^{18}O$

3.2.2 Isotope characteristics:

The relationship of $\delta D \sim \delta^{18}O$ shows that all warm springs of research area is supplied by the rain fall. But water samples of Luxi basin locate under the rain line, and are different from the Huangcao dam-Bangna zhang geothermal system. If these two systems is same one, the relationship of $\delta D \sim \delta^{18}O$ should be in the right location of rainfall line.

The geochemical and isotope characteristics can show the mixing phenomena with shallow water. Comparing to the Nujiang River geothermal system, the content of heavy isotope is less. So it can be concluded that Hangcao dam is absolute with Luxi basin system.

Except for little samples, the distribution of $\delta D \sim \delta^{18}O$ is concentrated because the warm groundwater is pure and not mixed by shallow water. The relationship of $\delta D \sim \delta^{18}O$ is connected with supply height; it shows that supple area is concentrated.

The $\delta D \sim \delta^{18}O$ relationship of Caoyang-pingda systerm almost locates on the rain line, but the distribution is dispersed, the range of δD is −60.3‰∼−78.4‰, and the range of $\delta^{18}O$ is −9.21‰∼11.28‰. Judgying from the high TDS and temperature, the warm groundwater is almost pure warm water.

The δD~δ^{18}O distribution of Longcuan River and Nujing River is dispersed, the water of these two systems is mixed by shallow water, and this characteristic is according to the TDS and temperature characteristics.

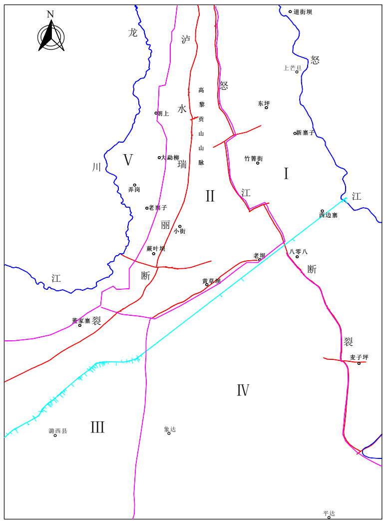


Figure 4 the geothermal system division
Ⅰ Nujiang River system
Ⅱ Hangcao dam-Bangna zhang system
Ⅲ Luxi Basin system
Ⅳ Caoyang-Pingda system
Ⅴ Longcuan River system

4. The groundwater system divisions:

Judging from geological environment, the geochemical and isotope characteristics, the researchers divide the research area into five parts showed in figure Ⅳ, they are described as follows:

3.1 Nujing River system:

The north boundary is Daojie dam, the east boundary is Nujiang, the west boundary is Nujiang Fracture (F1-1), and the south boundary is Pingda. The geochemical characteristics are different because of the appearing style of warm groundwater.
The temperature and TDS of this system is low because many springs are mixed by shallow water.

4.2 Huangcao dam-Bangna zhang system:

The south boundary of this system is Huangcao dam fracture, the east boundary is Nujiang Fracture (F1-1), and the west boundary is F2-4.

The north part is higher than the south of this system, the content of Na^+ is higher than other systems, and the content of Ca^{2+} and Mg^{2+} are lower. The temperature is the highest of all these systems.

4.3 Luxi Basin system:

This system is located in Luxi basin near to Mang shi. The number of springs in the basin is many, and distribution is intensive. But the temperature is lower than other systerm because the warm groundwater is mixed by shallow water, the geochemical style of this system is HCO_3^--$Ca^{2+}\cdot Mg^{2+}$

4.4 Caoyang-pingda system:

The east boundary of this system is Nujiang river Fracture (F1-1), the north boundary is Haungcao dam Fracture, the west boundary is Luxi Basin, and the south boundary is Pingda.

The landform of this system is gentle, the north is higher than south. The springs appear in Xiangda. The volume is small, and the temperature is similar to Hangcao dam system. The content of Na^+、Cl^-、SO_4^{2-} is higher and the geochemical style is HCO_3^--Na^+.

4.5 Longcuan River system:

The system locates the west to Hangcaodam system. The west to north part is higher than east to south part, the groundwater flows from north to south, and appears in each bank of river and fractures.

The content of Na^+ is higher than Ca^+、Mg^{2+}, the temperature is low because of mixing by shallow water, and TDS is also low.

5. Geothermal reservoir characteristics:

4.1 Reservoir construction:

The warm groundwater system in research is controlled by fractures. Because of the main fractures south to north extending are deep and long, the crush belt of the them have much space supplied for warm groundwater flowing. Nujiang River fracture named F1-1 and Lushui-ruili fracture named F2-1 forming two warm groundwater storerooms locating west and east parts. The Huangcao dam fracture cuts the F2-1, divides the west storeroom into two smaller warm groundwater storerooms.

The warm springs which appear in fractures directly doesn't be coved by relax deposit or is covered by thin deposit. Some fractures which can wicking groundwater is covered by relax deposit. The warm groundwater appears in relax deposit, and is mixed by shallow water. Some warm groundwater of the system IV appears in the sections between granite and rocks. The granite covers on the fracture, can makes groundwater heating.

The depth of warm groundwater going is controlled by pressure, the scale and landform. The geothermal reservoir construction is showed in table 1.

Table1
The tectonic of geothermal reservoir

Part		Control part	Stratum	Cover characteristics
Geothermal-reservoir	Nujiang Fracture	I	J_2l	Q_4 is cover on some fractures, it has heat insulation inflution
			J_2m^1	
			T_2h	
	Lushui-ruili Fracture	II	Pz_1gl	No cover or cover is thin on the fracture
		III, IV	Pz_1gl	
			P_1s	Q_4 is cover on the fracture
			γ_5	The fracture goes into the granite， and the granite have well heat insulation inflution

5.2 Reservoir temperature and depth:

The equilibrium of minerals of geothermal system is basement of evaluating geothermal scale. It uses the K-Na-Mg map from Giggenbach to evaluate the mature degree of anion. Judgying from the results of K-Na-Mg mature, it can get that all water sample can't reach in mature. Nujiang system and Caoyang-pingda system is not be mature because of shallow groundwater mixing. The water samples of III, IV and V locates at the Mg angle, about 40%~50% is near to be mature. Selecting mature sample to predict the reservoir temperature and depth of warm groundwater.

Table 2
The reservoir temperature and depth of warm groundwater

System	Samples	SiO_2	Na/K	Equilibrium	Reservoir temperature	Reservoir depth
II	S5074	149.57	171.72	157	157	2554
	S6001－1	115.30	95.69	110	110	2995
	6003	72.04	64.08	77	77	2406
	S6003－2	106.74	45.39	106	106	2406
average					134	2614
III	7005	104.55	200.25	90	105	1415
IV	5058	80.50	107.71	85	90	2220
	S5065－1	127.11	99.60	105	105	2195
	6020	120.76	97.21	110	110	1877
	7030	99.92	141.29	130	130	2031
	8020	108.02	124.89	125	125	2103
average					100	1863

	1033	79.41	46.90	75	75	1292
	1077	40.85	57.17	85	85	1108
	3028	89.43	76.95	90	90	1108
	3100	67.06	80.23	90	90	1169
	3103	93.85	92.65	90	90	1169
	5011	97.16	313.13	95	95	1662
average					86	1241

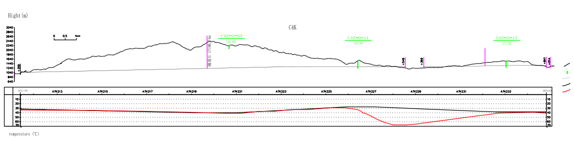
6. Tunnel geothermal hazard analysis:

The important tunnels going through Gaoligong Mountain were chosen as C4k (39.6km), C1K (21km), CK (39.6km) and C12K (36.4km) to evaluate the geothermal hazard. The paper uses datum of geotemperature field to get these four geotemperatrue sections, evaluates the geotemperature distribution at tunnel high and chooses the most appropriate route. The results show that C12K route goes through the common and low temperature zone, it is the best appropriate tunnel route showed in figure 5

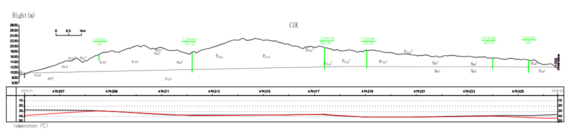
The geo-temperature distribution shows that the geo-temperature of the C4K and C1K is higher showed in figure 5.

Table3
Grade division of geothermal hazard

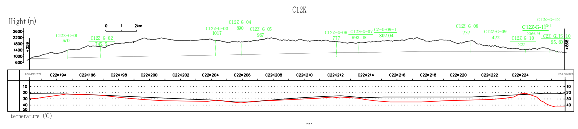
First	Second	Temperatue range（℃）
High geotemperature zone I		>60
Middle and high geotemperature zone II	Middle and low Q_1	>50~<=60
	Middle and high Q_2	>37~<=50
Lowe geotemperature zone III		>28~<=37
Common geotemperature zone IV		<=28



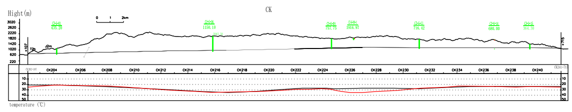
(1)C4K tunnel



(2)C1K tunnel



CK tunnel



C12K

Figure 5 the geo-temperature distribution with tunnel mileage

6.1 C4K:

Except of the import and export of C4K route（C4K225+600~C4K228+546）, the two route designs (C4K and C1K) of tunnel underside temperature are basically same.

The middle of tunnel is oppositely low（C4K211+350~C4K225+600, the percent is 78%, the temperature range is 28~40ºC, and the average temperature is 35ºC. The part between C4K225+600~C4K227+800 is controlled by warm water.

The temperature of tunnel zone C4K passing is high, especial to C4K225+600~C4K228+546, the temperature grade belongs to Q_1. The geothermal hazard is serious.

6.2 C1K:

The import of this route is influent by warm groundwater, the percentage is about 34,5%. The percentage of high and middle temperature is 54.3%, the range of temperature is 28~40℃, belong to Q_1 the geothermal hazard does harm to construction.

It can be get that the C1K is better than C4K, but more than half of tunnel belong to Q_1,

6.3 CK:

The mileage between CK224+900 and CK230+900 of CK is controlled by warm water, It belongs to Q_1, and the percentage of it is about 15.2%, the temperature range is 35-42℃. The other part of it belongs to low temperature zone, the temperature range is 25-35℃, belongs to common geothermal zone.

For CK route, the geothermal hazard can happen at middle part of tunnel, but the percent is small. And the temperature of some part of can reach in 40℃, can influent on construction.

6.4 C12K:

There are five parts of C12K is controlled by warm water. But except for the import part, the influence to warm groundwater is weak. Affected by warm groundwater, the temperature can reach to 35-40℃, but the percentage is only 5%, belongs to low temperature part. So the tunnel goes through common and low temperature zone, it is the best reasonable route design.

7. Results:

Basing on the analysis of the geothermal characteristics, it can draw some conclusions about geothermal system and tunnel geothermal hazard:

1. Judging from the geochemical and isotope characteristics and geological environment, the area may be divided into five geothermal activity areas. The Huangcao dam can insulate geothermal and cut down water flowing.
2. Bangna zhang warm spring appearing because Hangcao dam fracture cute down the Lushui-ruili fracture (F2-1), and also block off the warm groundwater flowing, so the area the fracture going through is opposite low temperature area.
3. The temperature and depth of geothermal reservoir show that the system of Hangcao dam – Bangna zhang system is the deepest geothermal system.
4. The bore temperature change with tunnel mileage increasing show than the C12K is the best reasonable route, 95 % part of the tunnel is low and common temperate area, it is similar to the results of the low geo-temperature results of geochemical and isotope analysis.

Reference:

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2. Wang jun & Hang shangyao[A], Basical characteristics of geothermal distribution of China. Beijing:earthquake publisher,1990