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The Chemical Characteristics of Geothermal Fluids in the Wumishan Reservoir, Tianjin Area, China

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ABSTRACT

The Wumishan reservoir of the Jixian System (JXW) is one of the most exploited geothermal reservoirs in the Tianjin area. In this paper the characteristics of formation and existence of the reservoir is studied, based on regional geological data. The JXW or Jixian System covers all over the plain and mountain areas in Tianjin with continuous stable distribution, thick deposition, rich fissures and good water quality etc. Chemical and isotopic analysis indicate that the type of thermal fluids in JXW changes from HCO_3-Ca·Mg in the north to Cl·SO_4-Na in the south and takes on horizontal zoning characters, which is mainly influenced by the runoff and discharge of thermal fluids.

1. INTRODUCTION

Geothermal resources are abundant in the Tianjin area, especially in Tianjin city and vicinity, which have been used widely so far and play a more and more important role in the city's development. JXW is the most exploited reservoir in the Tianjin area with favorable utilization conditions. The development of the system will result in the change of geochemical characteristics of the reservoir fluid. Therefore, it is very important to study the formation and migration conditions of geothermal fluids to maintain sustainable development of geothermal energy.

2. CHARACTERISTICS OF JXW IN THE TIANJIN AREA

2.1 The Distribution Characteristics of JXW

Generally, JXW with the area of 4200 km2 covers both in the mountain and plain area in Tianjin, which has become the most important bedrock reservoir for its continuous and stable distribution, large sediment thickness, rich fractures as well as good water quality etc. The mass flow from a single well in this reservoir amounts to 100~200 m3/h, with the maximum of 380m3/h; geothermal water temperature is ranged from 79 °C to 115 °C. The Baodi fault divides the geologic structure into two areas – the south and the north. North of the Baodi fault, a bedrock denuded zone is located between the north of Jixian mountain fault and Baodi fault. South of the Jixian fault is a shallow bedrock disposal zone. The cap rock of JXW is Quaternary sediment. JXW lies mainly between the Tianjin fault and Cangdong fault, JXW imbeds shallowly in the west of Baitangkouxi fault, Hexi and Dasi town in the Tianjin city, the depth is around 1500~2000 m, but it gets deeper in the structure depressed zone, e.g., more than 4000 m in the Jizhong depression. It is difficult to develop depressed zones under current conditions.

2.2 The Characteristics of JXW

JXW is divided into four segments from top to bottom, which are the forth, the third, the second and the first segment in sequence, the main water storage segments are the third and the forth segment, the lithology of which are coarse crystalline dolomites and flint stone straps. According to sound wave logging, the porosity of the fracture segment is 5~13.4%, and the mass flow of a single geothermal well drilled in this segment is 100~200 m^3/h, and amounts to 380 m^3/h in an area close to fault zone, the water temperature is 79~115 ℃ from a high temperature zone which corresponds to the convex part of bedrock in geothermal anomalous areas, this is the main water storage segment of JXW.

The water type of JXW gradually changes from HCO_3-Ca·Mg type in the north part to Cl·SO_4-Na type in the south part, with TDS 1000~3400mg/l and total hardness 120~170 mg/l.

3. THE CHEMICAL CHARACTERISTICS OF GEOTHERMAL FLUIDS IN JXW

3.1 The Chemical Type and Distribution of Geothermal Fluids

The geochemical component of the reservoir is determined by the lithology, stratum structure, groundwater recharge, runoff conditions and discharge conditions, and chemical characteristics are determined by the condition of groundwater runoff and discharge. Tianjin as a whole is the groundwater runoff and discharge area, the geothermal fluids contained in JXW have obvious horizontal zoning characters, the TDS of geothermal fluids gradually increases from the north east to the west south, the chemical type of geothermal fluids also changes from simple HCO_3-Ca·Mg type to complicated Cl·SO_4-Na type and shows horizontal zoning characters from the mountain to the basin center.

From Figure 1, it can be seen that the content of Cl^- and SO_4^{2-} increases gradually, the chemical type changes from HCO_3^- Ca·Mg and HCO_3·SO_4^- Na type in the north to Cl·HCO_3·SO_4^-Na type in the middle and east, then to Cl·SO_4^-Na type in the south, the TDS also rises from north to south, the TDS increases from 1.008g/l in the Wang2 well in the northern most part to 5.91g/l in the Tanggt well in the southern most part. Figure 1 also shows that chemical characteristic vary with different areas along the fault formation.

3.2 Chemical composition analysis of geothermal fluids

The TDS of most geothermal wells in JXW concentrates between 1.6g/l and 2.3g/l (Table 1) and is of little relevance to the average depth of reservoir top and bottom, which indicates that much convection exists between top and bottom layer of JXW. The water pH in JXW is 6.89~8.49, and Na^+ is the main cation, occupying between 68.76% and 91.76% in molar concentration. The mol percent of main anion changes with the TDS increasing of TDS, the main water type is Cl·SO_4-Na. Eighty percent (80%) of geothermal wells in Tianjin were drilled in this layer. As mentioned above, Na^+ and Cl^- are the main cations and anions, respectively, the content of F^- is around 10mg/l, the content of SO_4^{2-} and HCO_3^- differs between areas.

The Tianjin area is the drainage area of groundwater runoff, the main cation of JXW geothermal fluids is Na^+ in the Tianjin city and suburb, the main anion is HCO_3^- in the north, the water gradually transits to complex Cl^- and SO_4^{2-}. The Larson Index takes on gradual augmentation from the north to the south, and the hydrochemistry type shows zonation along the direction of groundwater runoff.

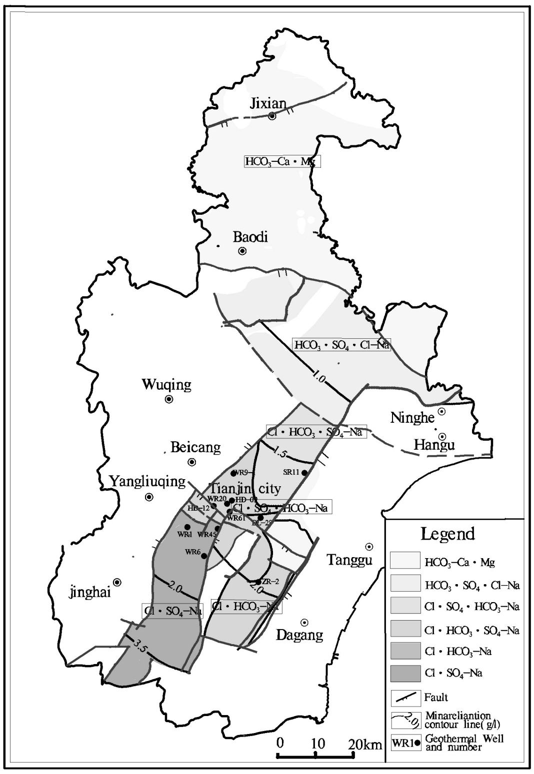

Figure 1: Chemical distribution of geothermal fluids in JXW in Tianjin

There is a big difference between the chemical composition of geothermal fluids in JXW and ancient preservative seawater (Table 2), The TDS of geothermal fluids is only 5 % of seawater (34.4g/l), ,Na+ and Cl-, the main ions of TDS, are only 3.3% to 10% of the seawater, the content of F- is 5~6 times more than that of seawater, whereas the content of Br- is 65 times lower than the average value of seawater, which further indicates that atmospheric precipitation comes from thermal groundwater. Therefore, it can be see that the seawater of primary deposit has been largely desalinated and has typical leaching characteristics.

Table 2: Element comparison of geothermal fluids in JXW and seawater

Elements	Seawater(mg/l)	ZR-2 well(mg/l)
I^-	0.05	0.10 ~ 0.15
F^-	1.4	10.6 ~ 11.0
Br^-	65	1.0 ~ 1.2
CL^-	18980	430.7 ~ 436.0
Na^+	10560	529.6 ~ 536.6
Na/CL	0.5564	1.21 ~ 1.25
Br/CL×10^3	3.42	2.29 ~ 2.75
Br/I	1300	6.67 ~ 10
CL/I	3.8×10^5	2.87×10^5 ~ 4.36×10^5

3.3 Study of Solid and Liquid Equilibrium

3.3.1 Simulation of solid and liquid equilibrium

Table 3 shows the test data of microelement of geothermal fluids in JXW in 2008, water type data is analyzed by Watch method and activity coefficient of 48 types of ions contained in geothermal fluids in JXW are calculated. Log (Q/K) value of various wall rock minerals and corresponding curve of log (Q/K) vs. T is shown in Figure 2.

Table 1: Chemical composition of geothermal fluids in JXW

Elements \ Well		WR45	WR20	WR6	WR61	WR1	SR11	SR9-1
Cation (mg/l)	Na^+	480	500.0	562.5	487.5	575.5	487.5	500.0
	Ca^{2+}	44.1	37.1	40.1	34.1	44.1	41.1	41.1
	Mg^{2+}	12.2	14.0	14.6	12.2	14	12.8	11.6
Anion (mg/l)	Cl^-	425.4	439.6	538.8	425.4	524.7	427.2	446.7
	HCO_3^-	408.8	421.0	378.3	399.7	393.6	408.8	491.2
	SO_4^{2-}	329.2	360.2	393.8	345.8	401.1	345.8	333.8
	F^-	10.2	11.2	10.0	11.6	10.0	10.04	8.95
Others (mg/l)	Soluble SiO_2	67	65	56.5	67	59	66.5	65.5
	TDS	1842	1906	2052	1841	2077	1863.5	1971
	Total Alkalinity	335.3	345.3	310.3	327.8	322.8	335.3	402.9
	Total hardness	160.1	150.1	160.1	135.1	167.7	155.1	150
	PH	7.8	7.5	8.29	7.75	8.18	7.45	7.6

Table 3: Chemical composition of geothermal water from production well in JXW

Well No. / Elements(mg/l)	HD09	HD12	DL28
Na^+	455.1	476.9	380.4
K^+	79.9	67.8	78
Ca^{2+}	29.9	30.9	35
Mg^{2+}	12.8	13.3	9.3
Fe	0.48	0.16	0.32
Cl^-	398.8	437.8	352.7
HCO_3^-	393.6	396.2	408.8
SO_4^{2-}	313.1	324.2	273.9
F^-	10.6	10.5	10.5
HBO_2^-	29.11	28.43	27.03
Soluble SiO_2	65	61.5	74
CO_2	11.32	13.2	13.06
H_2S	3.31	1.15	1.67
NH_4^+	0.93	1.17	0.87
Total TDS	1748.2	1806	1612.1
PH	8.0	7.5	7.09

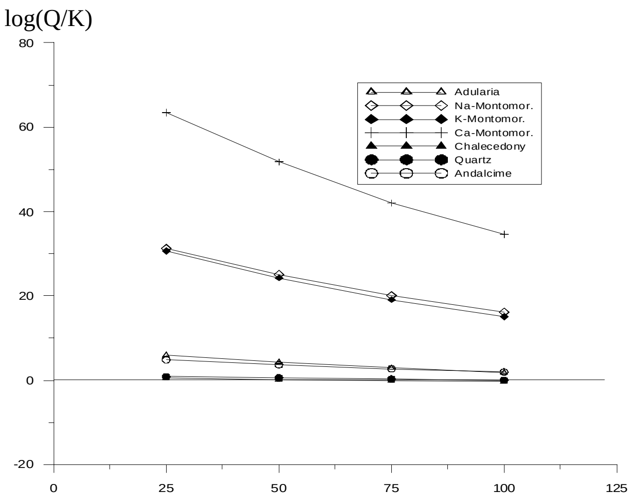

Figure 2: Log (Q/K) vs. T curve of geothermal fluid in JXW

Figure 2 shows that quartz and chalcedony are saturated or close to saturation, other altered mineral and geothermal fluids are not saturated, which means equilibrium is not achieved yet between deep geothermal fluids and rock, the reaction between them won't stop until geothermal fluids reach saturation.

3.3.2 Giggenbach triangle schematic

Figure 3 shows the geothermal wells in JXW are located in the shallow water area, far from the balance line and local balance zone, which indicates that the geothermal fluids are not in balance. Shallow groundwater mixed with geothermal fluids indicates that geothermal fluids were recharged from atmospheric precipitation in some way.

Table 4: Chemical composition of geothermal water from production wells in JXW

Sample No.	SR30D	HX-25	JN-07	XQ-07
Reservoir	JXW	JXW	JXW	JXW
K^+ (mg/l)	78.6	71.6	48.2	68.2
Na^+ (mg/l)	387.1	469.7	519.1	543.8
Mg^{2+} (mg/l)	9.2	12.2	6.7	13.4
Cl^- (mg/l)	352.7	432.5	428.9	538.8
SO_4^{2-}(mg/l)	277.1	324.4	265.8	351.9
HCO_3^- (mg/l)	396.6	372.2	491.2	369.2
TDS(mg/l)	1603	1778.3	1864	1979.4
PH	7.31	7.52	7.87	7.55

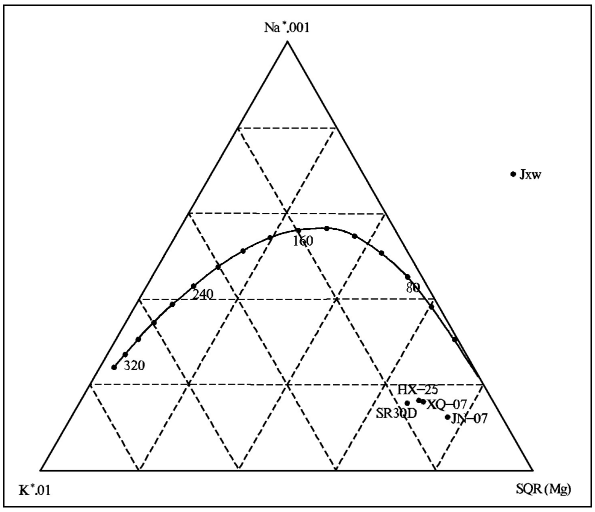

Figure 3: Na-K-Mg triangle schematic of geothermal fluids in JXW

3.4 The Isotopes Characteristics of Geothermal Fluid

Isotopes test results of δD and $\delta^{18}O$ from typical geothermal wells are shown in Table 5 and are plotted in Figure 4. It can be seen that geothermal water points are close to atmospheric line precipitation and geothermal fluids come from atmospheric precipitation after circular heating due to general geothermal gradient, the north mountainous area is the main recharge source of groundwater for the whole Tianjin plain.

Table 5: Isotope content of δD, $\delta^{18}O$ of geothermal fluid in JXW

Sample No.	ZL-2	DL-19	DL-28	DG-01
Reservoir	JXW	JXW	JXW	JXW
Water stored layer(m)	2244.8 ~2695.8	1655 ~2327.1	2754 ~3450	2349 ~2601
$\delta^{18}O$(‰)	-9.9	-9.1	-8.6	-8.6
δD(‰)	-69	-68	-66	-67

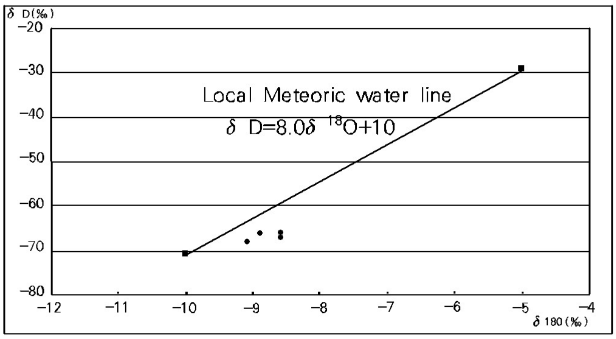

Figure 4: Precipitation line versus the content of δD and $\delta^{18}O$

4. THE FORMATION AND MOVEMENT OF GEOTHERMAL FLUIDS IN JXW IN TIANJIN

The formation and movement of geothermal fluids in JXW could be determined according to the analysis of geothermal fluid isotopes, chemical characteristics and ground water movement. The recharge of geothermal fluids is mainly from atmospheric precipitation, the recharge regions are in the north and northeast of the Yanshan mountain area, whereas discharge regions are in the downtown and southwest regions, which can be seen in Figure 5.

Tianjin area was in relatively stable sediment phase during Proterozoic and Paleozoic time, marine carbonate strata with the thickness of thousands of meters were deposited, and stratum bulges were denuded by the Indian movement, the terrain was crushed and fissures grew due to several fold and rupture activities until the Neogene period. Carbonate rock mass chronically exposed to the surface long time, suffered weathering denudation, leaching and erosion, and formed rich reserving space of landform, cavity and crevice system. This provided the space for groundwater movement. That the surface water and groundwater alternated strongly lead to the ancient karst water with high salinity, gradually turning into fresh water of Mesozoic karst. Until the Neogene period, the Tianjin area started to accept sediment and take on embedding seal status, but the Cenozoic stratum is still exposed to the surface and composes the half open hydrogeology structural system, during long development of lengthy geologic history, atmospheric precipitation infiltrates continuously in the northern mountainous area and moves deeper along the terrain layers, fault fracture zones, joints, fissures, and karst cavities etc. to recharge the insidious bedrock groundwater for this extensive plain.

Under the features of specific geological structure, there is high geothermal background, and especially the Cangdong fault that runs through Tianjin area that has good channels to the geothermal sources in the deep curst. After the groundwater recharges through the northern mountains, the groundwater flows from the north and northeast to the south and northwest and encounters physical chemistry effects and exchanges heat with the rock in the process of deep circulation. The runoff condition of the study zone is controlled by the structural condition of the area and study zone, the main groundwater movement is lateral runoff in accordance with the structure spread, the next is the vertical movement of a good open fault zone.

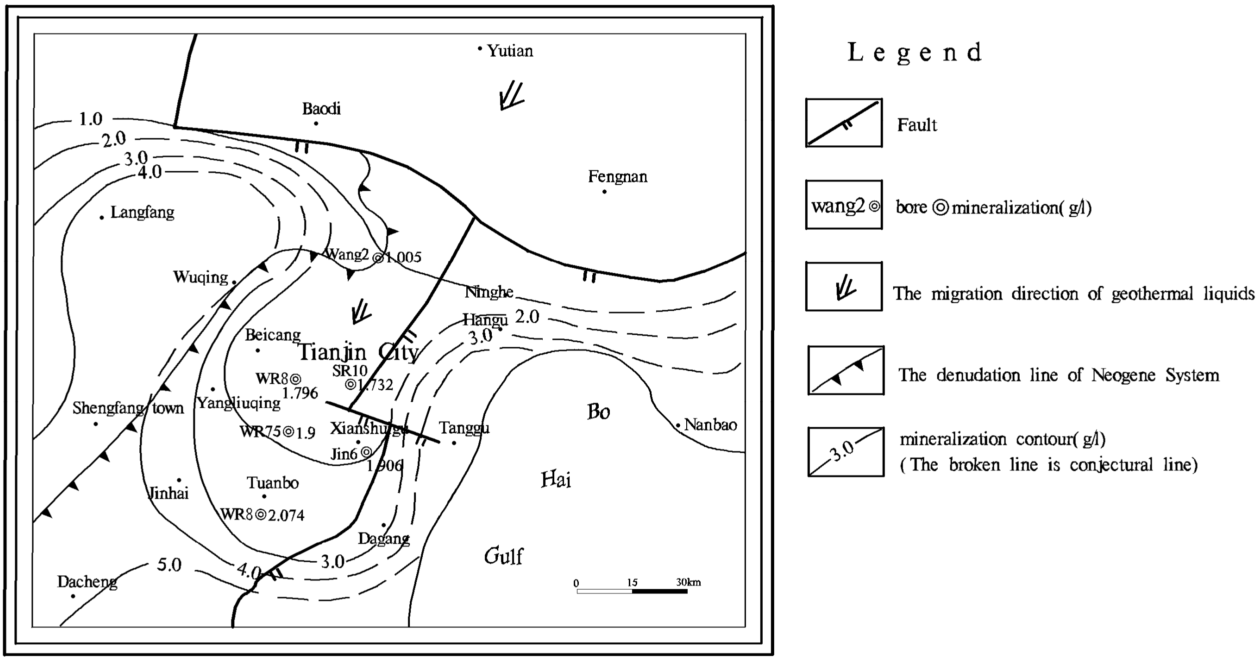

Figure 5: TDS isoclines of geothermal fluids in JXW

5. GEOTHERMAL FLUID ASSESSMENT FOR JXW

5.1 Water Quality Evaluation of geothermal fluid

Geothermal fluids in JXW have rich microelements, but these can't be used as drinking water before being processed. The processed geothermal fluids could be used for producing mineral water, which has good utilization prospects. The geothermal fluids are neither used directly for fishery nor for agricultural irrigation.

5.2 Corrosion and Scaling Evaluation of Geothermal Fluid

The corrosion of geothermal fluids can be evaluated by the Larson Index (LI), geothermal fluids in JXW with a LI over 0.5 in the Tianjin area indicates the geothermal fluids are corrosive, geothermal fluids with LI of 2 - 4 are acidic.

The chemical components of scaling are generally complex in geothermal utilization systems. The main components are $CaCO_3$, $CaSO_4$ and silicate. Calcium carbonate deposits are not easy formed in JXW, calcium sulfate deposits would probably occur, but without silicate scaling.

6. CONCLUSIONS

The chemical characteristics are mainly controlled by the runoff and discharge condition of groundwater and have zonation along the fault structure, which transformed from HCO_3-Ca·Mg type in the north to Cl·SO_4-Na type in the south, and takes on horizontal zoning character from the mountain to basin center. The geothermal fluids originated from atmospheric precipitation and the runoff direction is from the north to the south.

The reservoir is still in a transitional environment even if it is close to a reductive one. According to the analysis of chemical characteristics and dynamic tendency of geothermal fluids in JXW, the formation and movement of geothermal fluids are further studied. The results can be used for guiding geothermal exploitation & reinjection and providing information for geothermal sustainable development and management.

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