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Hydrogeochemical Properties of the Tianjin (China) Geothermal Field

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ABSTRACT

The Tianjin low-to-medium temperature geothermal field is located in the North China Hua Bei Plain. Up to now from 1930, approximately 350 wells have been drilled into porous sandstone reservoirs (including 2 major productive zones) or karst/fractured basement rock reservoirs (including 3 major productive zones), to depths between 700 and 4041 m for their exploration, exploitation or reinjection. At present, about 300 of the total number of wells are in production and 52 are used for reinjection. A lot of water samples were analyzed in the past several decades, the discharge temperatures range from 40 to 102 C; the total dissolved solids (TDS) are between 453 and 8000 mg/l, and they also contain high contents of silica and boron. The TDS is generally controlled by the geological structures, faults, the hydrogeological properties of reserviors, lithologies, and the supply and circulating conditions. In general, the TDS increases gradually along the fluid flowing direction from NE to SW, and the water quality types vary from HCO_3-Na, HCO_3·ClNa , to Cl·HCO_3 - Na, Cl·SO_4 - Na, etc. The paper collected a large number of data of water examinations from wells of various reserviors in Tianjin for better understanding of the hydrochemical properties and their evolutive laws.

1. INTRODUCTION

Tianjin is located in the northeast of the North China Plain, with the Bohai Bay at its east, and 120 km southeast of Beijing. The total region area is 11305 km^2, about 94.6% of it is covered by Quarternary (Huyan at el., 2007) rocks. Tianjin is the most important geothermal field by artifical-exploitation in China. Geothermal resources are widely applied to industry, greenhouses, aquacultures, spas, space heating, and so on. From 1930, when the first geothermal well was drilled until now, there have been more than 350 shallow and deep wells for exploration, exploitation and reinjection. The exploitation amount reached to 2604*10^4 m^3, and reinjection amount to 586*10^4 m^3 in 2008 (Zeng, et al., 2008). These wells respectively distribute in porous sandstone reservoirs or karst/fractured basement rock reservoirs to depths between 700 to 4041 m, and discharge temperatures range from 40 to 102 C. From 1980, chemical analysis of water samples from geothermal wells were carried out for K^+, Na^+, Ca^{2+}, Mg^{2+}, Al^{3+}, Fe^{2+}, Fe^{3+}, NH_4^+, Cl^-, SO_4^{2-}, HCO_3^-, CO_3^{2-}, F^-, NO_3^-, PO_4^{3-}, Br^-, I^-, S^{2-}, O_2, free CO_2, pH, total hardness, total alkalinity, TDS, and so on to investigate the geochemical properties and their changes under conditions of long-term exploitation.

2. GENERAL GEOLOGY IN THE STUDY AREA

2.1 Structure Units

Tianjin is a part of North China Platform. Bordering the Baodi Fault, the northern part belongs to Yanshan Platformal Fold Belt (North Region); and the southern part belongs to Huabei Downfaulted Basin(South Region) which area is 8700 km^2 (Huyan et al.). Tianjin geothermal wells are mostly located in the South Region that contains three third-order structure units: Jizhong Depression, Cangxian Uplift and Huanghua Depression. They are cut into many sub-tectonic blocks by faults which mainly strike NE and NWW. The most important and largest faults are Baodi Fault, Tianjin Fault and Cangdong Fault (Fig.1).

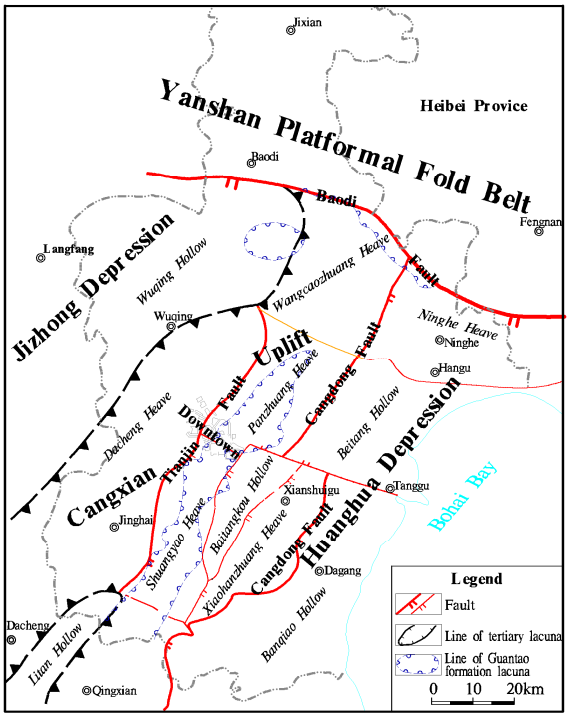


Figure 1: Division map of geological tectonics in Tianjin.

2.2 Strata

The geological strata from top to below are presented in Table 1. On the uplift area, the buried depth of bedrock roof is generally 900 to 1600 m with stratigraphic lacunae of Paleogene to Carboniferous; and deeper than 3500 m in the two depression areas.

2.3 Major Geothermal Reservoirs and Well Status

There are two kinds of geothermal reservoirs in Tianjin. The porous sandstone reservoirs mainly include both Minghuazhen Formation and Guantao Formation; the basement rock reservoirs mainly include Ordovician System, Cambrian System and Wumishan Formation

(Table 1). Almost only bedrock geothermal wells are located in the Cangxiang Upheaval area, Guantao Formation wells are mainly located in the two depression areas, and Minghuazhen Formation wells distribute the overall South Region.

3. GEOTHERMAL FLUID'S HYDROCHEMICAL PROPERTIES

For geothermal waters of all reservoirs, their chemical properties follow similar evolutionary laws: from northeast to southwest and from top to bottom, the TDS gradually increases; and the water quality types evolve from simple to complex (Gao, at el. 2007). The results of analysis for TDS, total hardness, total alkalinity, pH, and discharge temperatures are shown in Table 2. The detailed account of every different geothermal reservoir is separately shown as follows:

Table 1: The general strata and major geothermal reserviors in Tianjin

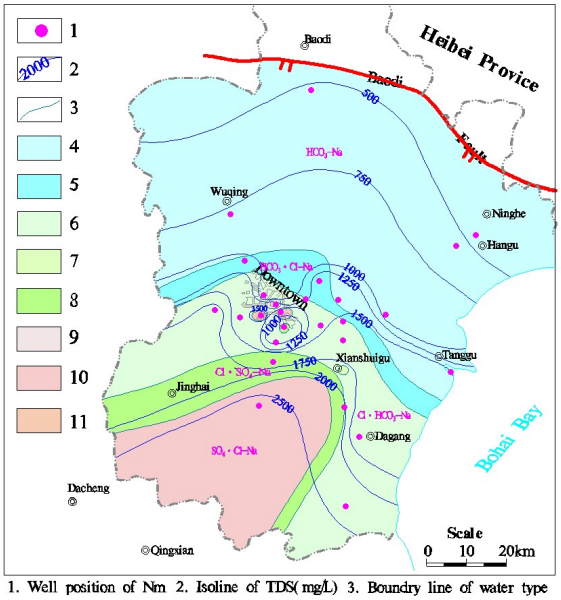
Geological Stratum			Main Lithology
Era	System	Geothermal Reservior	
Cenozoic	Quarternary (Q)		Alluvial arenaceous clay, sandstone, clay and some marine deposites.
	Neogene (N)	**Minhuazhen Formation**	Fluvial and inland lacustrine sandstone , clay.
		Guantao Formation	
	Paleogene (E)	Dongying Formation	Inland lacustrine clay and sandstone.
Mesozoic	Cretaccous (K)		Mudstone, gompholite, pyroclastic rocks.
	Jurassic (J)		Carbonaceous mudstone, pebbled sandstone, volcanic rock, coal-bearing formation.
	Triassic (T)		Sandstone, siltstone, mudstone.
Late Paleozoic	Permian (P)		Mudstone, fine-stone, oolite mudstone, volcanic rock, coal-bearing formation.
	Carboniferous (C)		Coal-bearing formation, sandstone, mudstone, siltstone.
Early Paleozoic	Ordovician (O)	**Ordovician System**	Limestone, dolomitic limestone.
	Cambrian (□)	**Cambrian System**	Oolite, argillized zone and dolomitic limestone, mudstone, breccia.
Late Proterozoic	Qingbaikou (Qb)	Longshan Formation	Marlite, glauconite siltstone and silty shale, quartz sandstone.
Middle Proterozoic	Jixian	Tieling Formation **Wumishan Formation**	Dolomite.
	Changcheng	Gaoyuzhuang Formation	Siliceous zone and stromatolitic dolomite, volcanic.
Archeozoic	Ar		Old crystalline rock.
Remark: The words with overstriking and underline are the major geothermal reservoirs in Tianjin.			

Table 2: Statistics of some chemical analysis items of major reservoirs in Tianjin

reservoi r	TDS (prevalent)	Total Hardness	Total alkalinity	pH	Discharge temperature (℃)
	(mg/l)				
Nm	392.5--3781.4	7.5--663.0	89.98--530.50	7.32--8.7	40--77
Ng	771.2--2074	1.54--115.1	26.64--625.6	7.44--8.82	40--87
∈	1029.3--1798.8	125.1--162.1	292.8--345.3	6.86--7.81	80--96
O	1011.2--4689.7	79.1--1701.5	152.6--472.95	6.95--8.12	51--76
Jxw	1008--5830.7	82.6--1198.6	33.3--420.4	6.88--8.28	73--102

3.1 Minghuazhen Formation (Nm)

The Nm geothermal reservoir is the uppermost one in Tianjin. According to the water examination results of Nm wells, its chemical characters on two depression areas show (Figure 2): from northeast to southwest, the TDS gradually increases from 435 mg/L to 2260 mg/L; and water quality types evolve from HCO_3 - Na to HCO_3·Cl - Na and Cl·HCO_3 - Na. On the core region of Cangxian Uplift, its water qualities are affected by waters from different underlying bedrock reservoirs (include: O,∈ , Jxw). The minimum TDS is 690 mg/L, and the maximal TDS can reach to 3710 mg/L. Water types mainly include: HCO_3 - Na, HCO_3·Cl - Na, Cl·HCO_3 - Na, Cl·SO_4 - Na, and SO_4·Cl - Na.



1. Well position of Nm 2. Isoline of TDS(mg/L) 3. Boundry line of water type 4. HCO_3–Na 5. HCO_3 • Cl–Na 6. Cl • HCO_3–Na 7. Cl • HCO_3 • SO_4–Na 8. Cl • SO_4–Na 9. SO_4 • HCO_3–Na 10. SO_4 • Cl • HCO_3–Na 11. SO_4–Na

Figure 2: DS isoline and distribution of chemical types of Minghuazhen Formation geothermal reservoir.

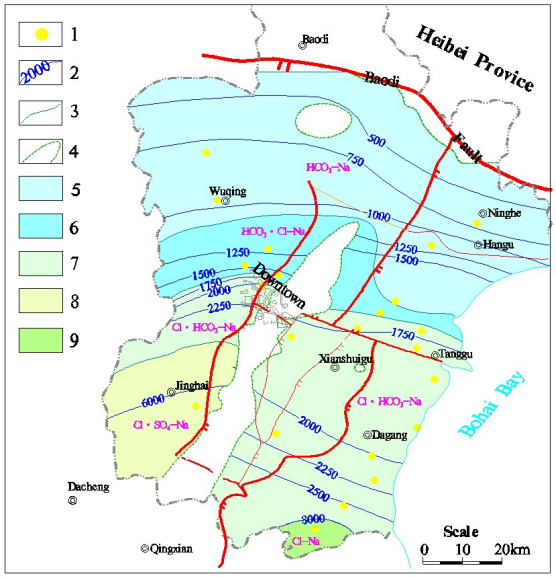
3.2 Guantao Formation (Ng)

The Guantao Formation geothermal reservoir mainly distributes on the two depression areas, and it lost on the most area of Cangxian Uplift area. In the Jizhong Depression area, from northeast to southwest, its TDS gradually increases from 800 mg/L to 6000 mg/L (Figure. 3); and the water types evolve from HCO_3 - Na to Cl·SO_4 - Na; In the Huanghua Depression area, the TDS gradually increases from 800 mg/L to 2770 mg/L, and the water types evolve from HCO_3 - Na to Cl·HCO_3 - Na. On local region of the south most part, the TDS can reach to 8437 mg/L with water type Cl - Na.

3.3 Ordovician System (O)

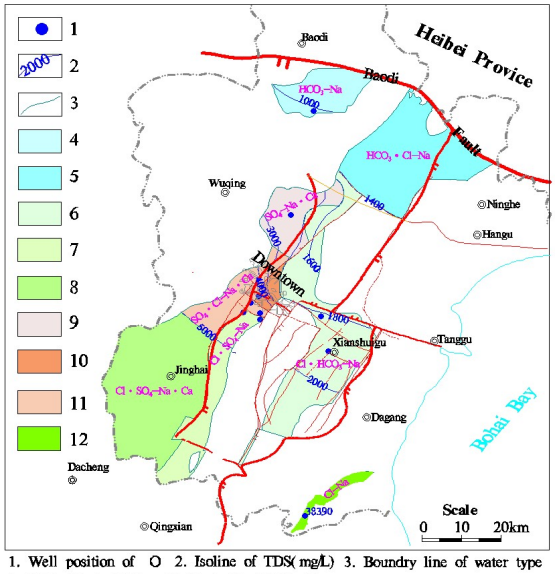
The Ordovician System was denuded on the most area of Cangxian Uplift area. Its wells are mainly located in downtown Tianjin (the western part of the Cangxian Uplift), secondly in the Dongli district (the eastern part of the Cangxian Uplift). Its water qualities are obvious depending on whether it is from the eastern part or western part.

In the eastern part, the TDS is between 1600 and 2000 mg/L with dominating water type Cl·HCO3 - Na. In the western part, the TDS varies between 2952 mg/L and 4600 mg/L, and the water types include Cl·HCO3 - Na , SO4 - Na·Ca, SO4·Cl - Na·Ca, SO4·Cl - Na, and etc. (Figure 4). In the local region of the south most part, the TDS can reach to 39380 mg/L with water type Cl - Na. Its waters with high TDS consisting of a large amount of SO42- may be affected by overlying stratum C - P which usually contains high sulphur elements.



1. Well position of Ng 2. Isoline of TDS(mg/L) 3. Boundry line of water type 4.Line of Guantao formation lacuna 5. HCO_3–Na 6. HCO_3 • Cl–Na 7. Cl • HCO_3–Na 8. Cl • SO_4–Na 9. Cl–Na

Figure 3: TDS isoline and distribution of chemical types of Guantao Formation geothermal reservoir.



1. Well position of O 2. Isoline of TDS(mg/L) 3. Boundry line of water type 4. HCO_3–Na 5. HCO_3 • Cl–Na 6. Cl • HCO_3–Na 7. Cl • SO_4–Na 8. Cl • SO_4–Na • Ca 9. SO_4–Na • Ca 10. SO_4 • Cl–Na 11. Cl • SO_4–Na • Ca 12. Cl–Na

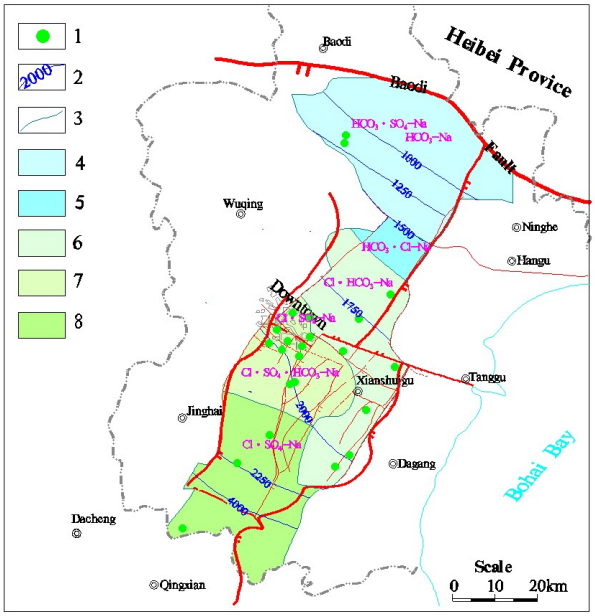
Figure 4: TDS isoline and distribution of chemical types of Ordovician System geothermal reservoir.

3.4 Cambrian System (∈)

Cambrian System only scatters on Cangxiang Uplift area. Up to now, there were only 7 Cambrian wells drilled, they are located on Wangcaozhuang Heave, Pangzhuang Heave and Shuangyao Heave. Their water qualities are similar with that of the local Wumishang Formation.

3.5 Wumishan Formation (Jxw)

The Wumishan Formation is the most important geothermal reservoir in Tianjin. Up until now, there are about 110 Jxw wells all located in the Cangxian Uplift area (Figure 4). The wells are as deep as 988 m to 3500 m. From northeast to southwest, the TDS gradually increases from 1000 mg/L to 6000 mg/L; and water types evolve from HCO_3 - Na to Cl HCO_3 - Na, and Cl·SO_4 - Na. The water quality in the eastern part is better than that in the western part.



1. Well position of Jxw 2. Isoline of TDS(mg/L) 3. Boundry line of water type 4. HCO_3–Na 5. HCO_3 • Cl–Na 6. Cl • HCO_3–Na 7. Cl • SO_4 • HCO_3–Na 8. Cl • SO_4–Na

Figure 4: TDS isoline and distribution of chemical types of Wimishan Formation geothermal reservoir.

4. THE RELATIONSHIP OF MAJOR IONIC CONCENTRATIONS WITH TDS

Generally, the major ionic concentrations of geothermal waters in Tianjin are quite well correlative to TDS (Figure: a-k). With increase in TDS, the concentration of Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-} increases; HCO_3^- increases when TDS is under 1500 mg/L, but declines when TDS is over 1500 mg/L; K^+ from basement rock wells is obviously higher than from porous rock wells. High TDS geothermal waters from the Ordovician System reservoir, have high Ca^{2+} , SO_4^{2-} and low HCO_3^- concentrations, i.e. they show distinctly different water types from other reservoirs.

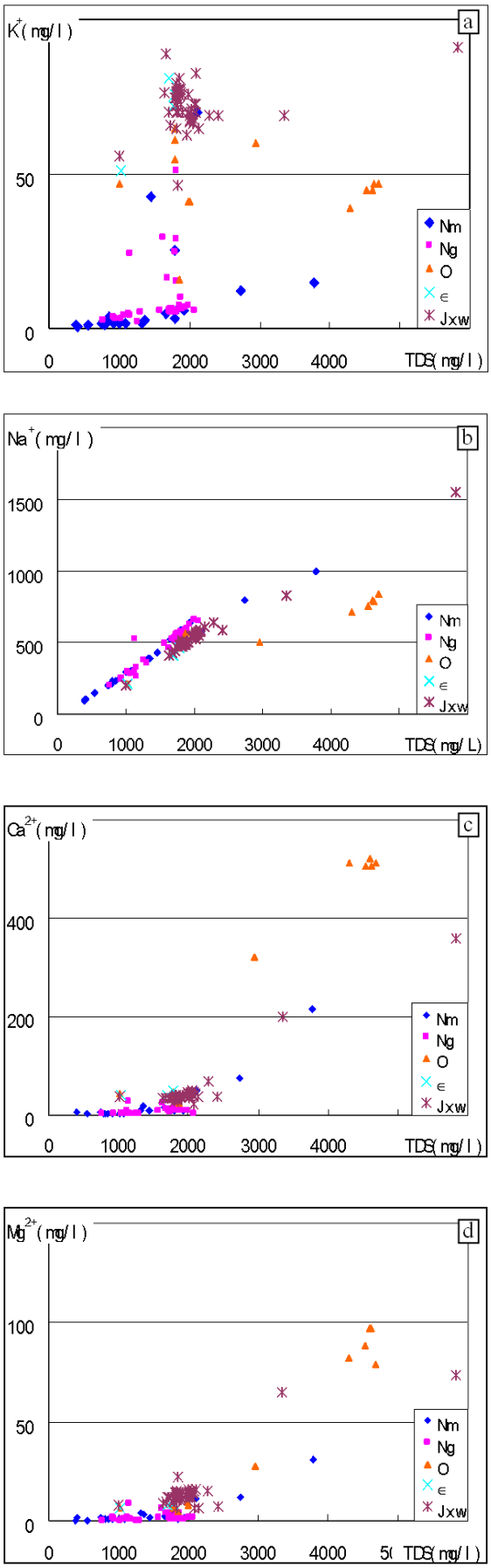


Figure 5: Ion concentrations plotted versus TDS for geothermal waters from different reservoirs in Tianjin.

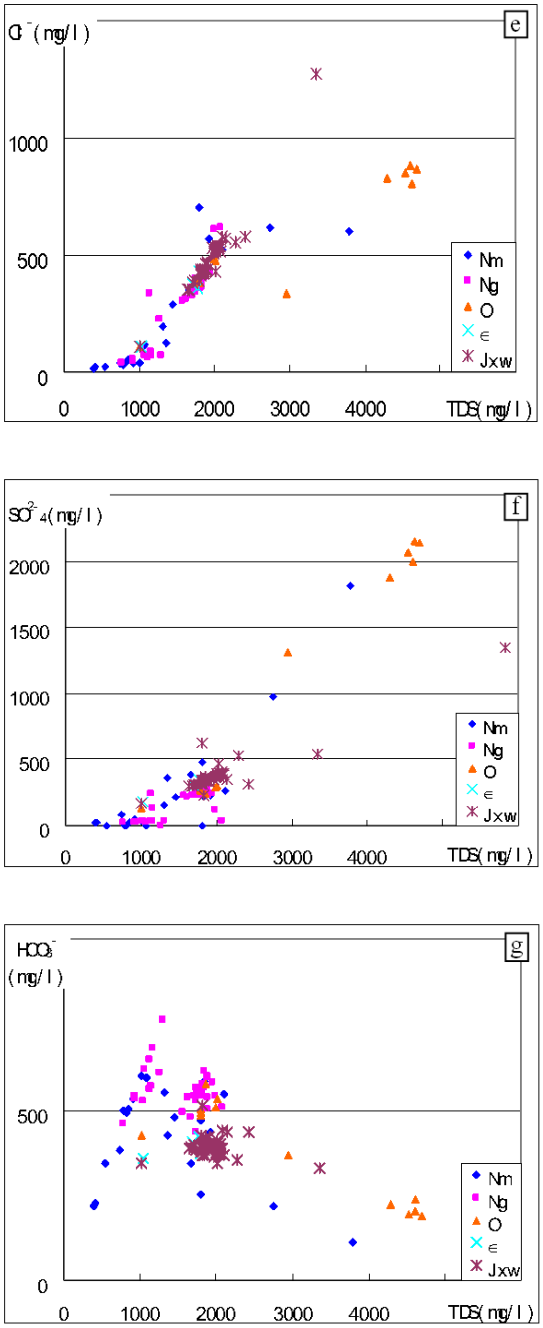


Figure 5 (continued): Ion concentrations plotted versus TDS for geothermal waters from different reservoirs in Tianjin.

5. SECONDARY OR MICROELEMENTS

There are many kinds of secondary or microelements in geothermal waters. Among those, the soluble SiO_2 and F^- are the major ones in Tianjin.

5.1 Soluble SiO_2

Many water geothermometers were developed in the mid-1960s to the mid-1980s. The most common ones are the silica (quartz and chalcedony), Na/K and Na-K-Ca geothermometers (Atefán Arnórsson, 2000). At an early stage in exploitation of geothermal resources, Tianjin made use of soluble silica concentrations from geothermal fluids to calculate reservoir temperature. But with more and more wells being drilled, we can acquire accurate aquifer temperatures by logging, so the method has almost lost its application value in Tianjin. Now we pay attention to it, because it is one of the important indices of medical treatment by hot mineral water. Tianjin geothermal waters show quite good relationship between soluble silica concentration and temperature (Figure 6).

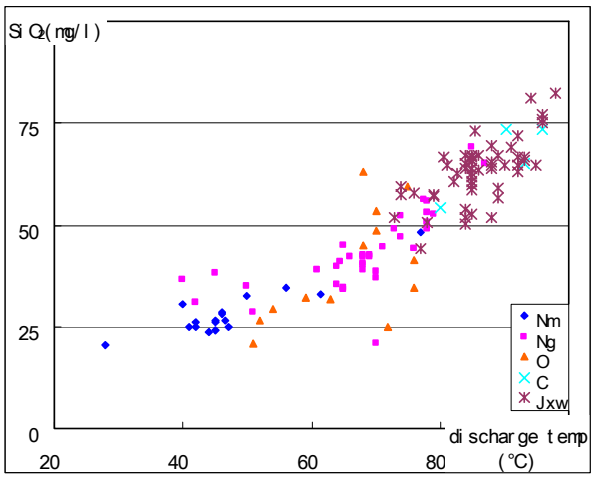


Figure 6: Soluble SiO_2 concentrations plotted versus discharge temperature for geothermal waters from different reservoirs in Tianjin.

5.2 Fluorite (F-)

Besides SiO_2, F^- is another important index with regards to medical treatment with hot mineral water. Unlike SiO_2, the relationship between F^- concentration and temperature is not good, but it is good with TDS (Figure7) if water specimens from the high TDS Ordovician System wells are excluded.

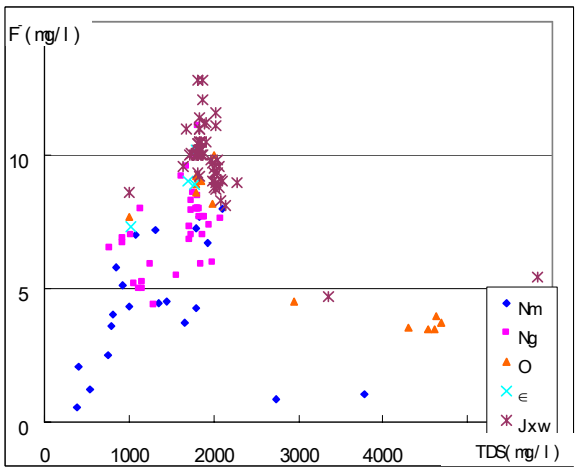


Figure 7: F^- concentrations plotted versus TDS for geothermal waters from different reservoirs in Tianjin.

6. WATER-QUALITY CHANGES BY TIME

The longest duration of water-quality monitoring is at the Ordovician System well, which spans over 20 years (Figure 8). In a general way, the concentrations of all the major ions from various reservoirs change slightly during long-term exploitation.

7. CONCLUSION

- Geothermal fluids in Tiajin possess typical lixiviation characteristics. Generally, TDS gradually increases along the flowing direction of ground waters, from northeast to southwestern; and from top to bottom, it increases with depth in geothermal reservoirs.

- Na^+ is the dominating cation in all geothermal fluids in Tianjin, its percent in mmol is usually over 80%, even to 98%; Ca^{2+} is the secondary one. Only in higher TDS' Ordovician System fluids, will Ca^{2+} percent in mmol exceed 36%. Anionic components are much more complex than cationic's. In lower TDS geothermal waters, HCO_3^- is the dominating component; with TDS increasing, the absolute contents and percent contents in mmol of Cl^- and SO_4^{2-} all get higher and higher.

- Tianjin geothermal waters show direct linear relationship between soluble silica concentration and temperature, and between F^- concentration and TDS.

- The high TDS of Ordovician System waters with high content SO_4^{2-}, is mainly affected by overlying stratum C-P.

REFERENCES

Gao, at el. 2002: The studies of Tianjin geothermal fluids on origins, ages and supply-runoff-drainge's conditions. Tianjin Institute of Geothermal Exploration and Development Design (in Chinese).

Huyan, et al., 2007: The Evaluate of Geothermal Resource's Continuable Exploiture Potential in Tianjin, Tianjin Institute of Geothermal Exploration and Development Design (in Chinese).

Stefán Arnórsson, 2000: Isotopic and chemical techniques in geothermal exploration development and use, international atomic energy agency vienna.

Zeng Mei-xiang, et al., 2008: The report of dynamic monitoring of geothermal resource in Tianjin, sponsored by Tianjin Bureau of Land and Housing Administrative (in Chinese).

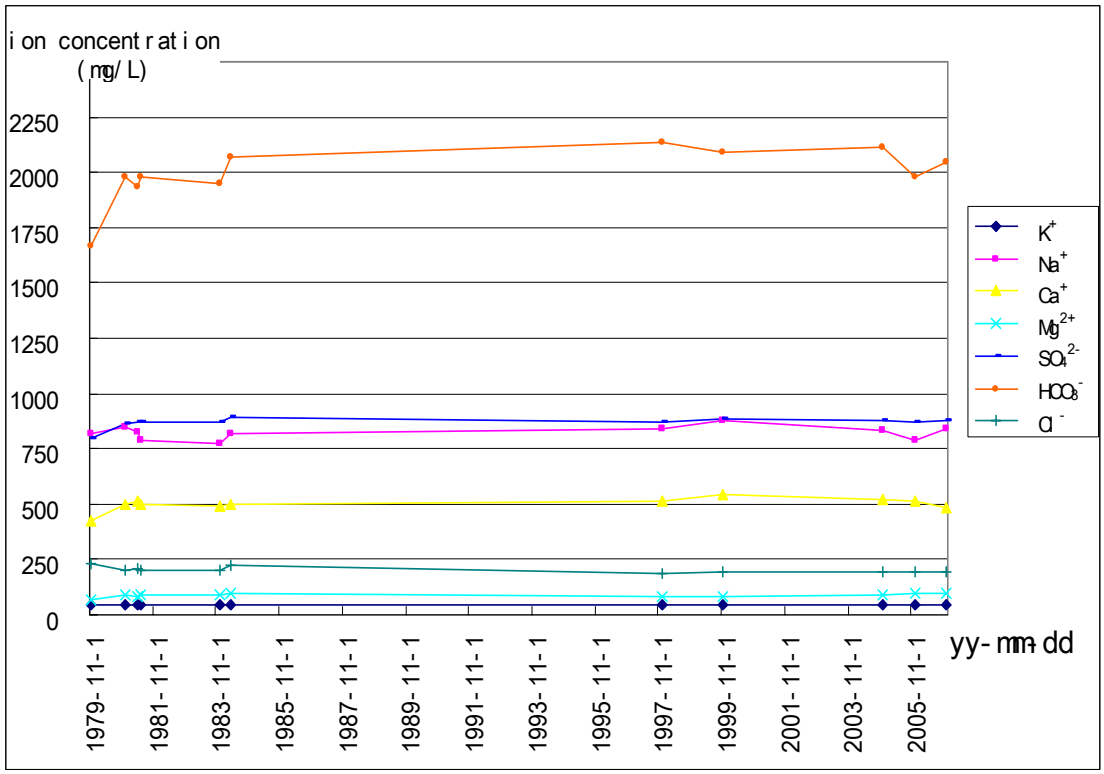


Figure 8: Duration curves of major ionic concentrations with TDS of a Ordovician well.