CHEMICAL INTERPRETATION OF THERMAL WATER FROM THE TIANJIN LOW TEMPERATURE AREA, NORTH CHINA AND THE YANGBAJING HIGH TEMPERATURE AREA, TIBET

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ABSTRACT

China is very rich in geothermal resources. This includes both high temperture and low temperature activity. The thermal activity has been divided into regional zones. The chemistry of these zones is briefly described. The chemistry of the Tianjin and the Yangbajing areas is dealt with in detail.

The Tianjin geothermal field is of the low temperature type with dilute water of meteoric origin. Two systems exist in the field. One is at shallow depth in Tertiary sediments. The thermal water is mainly mixed with cold groundwater. The other system is at greater depth in Sinian (Pre-Cambrian) bedrock. A mixing model suggests temperatures of 140 °C of the parent water. The heat source is the regional heat flow.

The Yangbajing geothermal field is of the high temperature type. From a geological and geochemical point of view, it is located in a tectonically active rift valley, with an underlying heat source, probably magmatic intrusion. The underground temperatures estimated by mixing models are 200-230°C. The water is saturated with respect to calcite, and becomes supersaturated during cooling, which may cause scaling.

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1 INTRODUCTION

1.1 Scope of work

The author of this report was awarded an UNU fellowship to attend the 1980 UNU Geothermal Training Programme held at the National Energy Authority in Iceland. After about four weeks of introductory lecture course on all aspects of geothermal energy the author received specialized training in the chemistry of thermal fluids. This included lectures and practical exercises on sampling techniques and methods of analysis of major components (4 weeks), field excursions to geothermal areas in Iceland (3 weeks), lectures and practical exercises in calculating geothermometers, mineral equilibria and mixing models (5 weeks). This report is an outcome of the research project carried out mainly during the last 4 months of the training.

Besides an introduction to the geothermal activity of China, the report will deal with some chemical problems of geothermal waters of the Tianjin area in North China and the Yangbajing area in Tibet. This includes reservoir temperatures, the application of chemical geothermometers and the calculation of mixing models for hydrothermal systems. Models are presented for the geothermal fields and calculations made for mineral deposition. These two areas represent two different types of geothermal activity in China. The first one is a low temperature geothermal field, the other is a wet steam geothermal field. The author brought 4 samples of thermal water from China to Iceland, which were analysed during the laboratory practical exercise. The report is based on these data together with data brought from China.

Special geothermal exploration in Tianjin started in 1970. The low temperature water was then used on small scale for house heating, for green houses and in industry. This area was discovered earlier in connection with water and oil exploration.

The exploration of the Yangbajing geothermal field in Tibet started in 1976 and in 1978 a small (1 MV) experimental geothermal power station was set up there.

1.2 Geothermal activity of China

The geothermal activity of the country is partly reflected by the number of hot springs, their temperature and the distribution density. According to incomplete statistics there are over 2000 hot spring localities in China (Fig. 1). Two problems rise when defining a hot spring. One is how to deal with groups of hot springs which occur within the same geographical area. Some areas cover several km^2 and even over ten km^2. In Fig. 1 such areas may be shown as one spring (example Yangbajing area). The other problem is the temperature limit when defining hot water. In China there are two methods to define the lower temperture limit; one is 2-4°C above local annual mean temperature or the temperature of local groundwater, the other is 20°C in northern China and 25°C in the southern China.

The distribution of hot spings was first presented in 1926 by Zhang hong Zhao at an international conference in Tokyo in Japan. There he connected the hot springs with regional structure. He published the book "Annals of hot spings of China". After liberation (1949) attention was mainly focused on medical treatment by using mineral water. For this purpose the hydrogeologist An Ke Shi published "The map of mineral springs of China". The first drillhole for geothermal research was drilled in 1962 at Dr. Li Siguang's suggestion. Then heat flow data were obtained for the first time in China. Since 1970, at Dr. Li Siguang's suggestion, geothermal exploration and utilization of geothermal water has increased widely. Exploration has been undertaken in more than 2/3 of the countries provinces, municipalities and autonomous regions . Even in areas where there are no hot springs at all, marked results have been obtained. In the provinces of Guangdong, Hebei and Tibet a number of small experimental geothermal power stations have been set up. In 1978 a symposium on geothermal energy in China was held. Then Wang ji Yang et al (1978) submitted some typical measurements of heat flow in North China. The author has compiled "The map showing the distribution of geothermal water in China" (Yao 1979) which is based on the results of a survey of hot springs and geothermal water prospecting. The map mainly shows the distribution characteristics of the temperature at a depth of 1-2 km, and the quality of the geothermal waters.

From a geological point of view China is in many ways special. It is joined by two orogenic systems the Peri-Pacific orogeny and the Tethys. A special sediment unit from Pre-Cambrian time is very important as a geothermal reservoir rock in North China. This is the Sinian subgroup, 8-10 km thick. This was thought to be a geosyncline, but a real platform has not be found. The thickness of the Chinese crust is everywhere more than 30 km, and it reaches 70-75 km thickness in Tibet. It is common knowledge that the Qinghai-Xizang (Chinghai-Tibet) Plateau is unique on the Earth.

There are different schools of thought in China in geotectonics e.g. the theory of geosynclines, rhombic fault blocks, mobilized platforms, mosaic crust, geomechanics and the plate theory. These can explain one´s views on each geologic phenomenon, but some macroscophic phenomens are universally acknowledged although the understanding of the mechanism varies. It is commonly recognized in China that two groups of crustal movement exist on the Chinese continent, one is heading towards the Pacific, another towards the Indian Ocean. The nearer the crustal movement to the front, the more violent it is. This is the "land wave" as Li Siguang designated.

In his study the author has found out that the temperature of springs are not only indicative of the springs themselves. If a great number of springs within a large area are taken into account as a whole, it is a specific item indicating the characteristics of the whole area (Yao, 1979). On this base the thermal activity has been designated into groups as follows:

(1) Areas with intense tectonic activities and a great number of hot springs of high temperature. Springs exceeding 80°C are commonly concentrated together, for example in Guangdong, Fujian, Taiwan in the southeast coastal area, west Yunnan, northwest Sichuan and Qinghai-Xizang (Chinghai-Tibet).

(2) The youngest geologic areas with the most intense tectonic movements contain hot springs with temperatures up to boiling point, for example in Taiwan, west Yunnan and Qinghai-Xizang (Chinghai-Tibet).

(3) In the so called "platform" areas with relatively weak crustal movement and less magmatic activity, the water temperature is low, generally 40-60°C. Example are thermal springs in the Sichuan and Guizhou provinces.

(4) Hot springs with temperatures below 40°C are sporadically scattered all over the country and have commonly no evident relations to regional structures.

On the basis of available data and the present understanding, the thermal activity has been grouped into water zones. These water zones may be grouped into two categories, i.e. areas with no sedimentary cover in the mountains and the areas with thick sediments. The location of these zones is shown in Fig. 2 and they are listed in Table 1.

Li Siguang suggested that there are three subsided zones in East China. The first is in the eastern sea area, the second from the Songliao Plain in the north southwards to the sea area of Beibu Gulf, and the third from Hulunboir southwards to the Sichuan basin. Exploration indicates that these three subrided zones have different heat flow characteristics. Because of much less intensive studies in the western part of the country, we call the whole sediment covered western areas the "west basin". This is not a classification with a strict meaning, merely emphasizing the difference between these basins and the eastern part.

The thermal water in the mountain areas reaches the surface in hot springs, but in the sediment covered areas no thermal manifestations are seen on the surface. There the surface is covered with Mesozoic and Cenozoic formations, which are different in occurence and hydrogeochemistry, but the heat source is the same, i.e. the regional heat flow. The exploration of the sediment covered areas reveals the existence of similar zonality.

The difference between geothermal water zones can be seen on thermal profiles (temperature-depth relationship). The water temperature at 1000 m depth is 50-60°C in the second subsided zone, while in the third zone the temperature is about 40°C. The average thermal gradient in these zones are 33°C/km and 21°C/km respectively. West of these zones the water temperature at 1000 m is 33°C on average, but there the thermal gradient varies greatly.

As a conclusion, the whole country may be divided into three regions: north, east and west with the dividing lines extending about Tianshan mountain - Shenyan city and a line of Lanzhou-Kandging-Kunning. The heat content of the north region is relatively lower than that of the east region and the heat content of the west region is still relatively higher. These three regions conform with the gravitational data obtained from satellite measurements, therefore, generally speaking we can say that the temperature of geothermal water is reflected by the mantle's thermal condition.

2 GEOLOGY AND GEOTHERMAL ACTIVITY OF THE TIANJIN AND THE YANGBAJING AREAS

2.1 The Tianjin area

Tianjin city, which is located on the North China Plain by the Bohai Gulf about 100 km southeast of Beijing, is the third most important city in China after Beijing and Shanghai. The terrain of the area is low and flat, the nearest mountains, Taihang shan, are 150 km west of Tianjin.

The North China Plain is built chiefly of argillo-arenaceous continental sediments of Cenozoic time, inserted with some thick basalt series and some marine deposits. Before Cenozoic time tectonic movements occured in the area. This can be seen as series of grabens and horsts and faults in the rocks of the Sinian subgroup of Pre-Cambrian and Palaeozoic age. The thickness of Cenozoic sediments on top of the Sinian formation is about one thousand meters in the horst areas and 2000-8500 meters in the graben areas. The Tianjin area is located on the Cang Xian horst. A simplified geological map of Tianjin is shown in Fig. 3.

The North China Plain is located in the peri-Pacific belt, the curstal movements there are commonly violent and earthquakes greater than 7 degrees on Richter scale have occurred twice in the last decade, Xing Tai 1966, and Tang Shan 1975. Movements with the velocity of about 1 millimeter per year have been observed on some faults. There are some different views about the structural form of the North China Plain. One is the theory of rift-valley system of peripacific. In general the underground temperature is rather high with heat flow 1.5 HFU. Most of the area has a geothermal gradient of 33-35°C/km, which is similar to the temperature gradients in the Tertiary system (34-37°C/km). The gradient in the Palaeozoic group is lower and in the Sinia-limestone it is notably low, 9.5-19°C/km.

A great deal of sophisticated field exploration has been undertaken in the Tianjin area. As a result of this work, geological strata in the area have been identified and grouped into three main formations:
a. Uppermost is the lowerQuarternary system and the upper Tertiary system. It is buried at 500-1000 m depth. The permeability is good compared with the other groups, the quality of water is good but the temperature is low. b. In the middle is the lower Tertiary system. The permeability is low, the quality of water is bad with dissolved solids 20.000-70.000 ppm, mostly calcium chloride, which is distributed in grabens and reflects relatively closed-system conditions. c. Lower is the bedrock from Palaeozoic and Sinian time. The limestones of the main reservoir have very high karstic and fissure permeability . The water has higher temperature than in the upper formations and the water is of relatively good quality with dissolved solids 2800-4000 ppm, mostly sodium chloride.

The thermal water in the Tianjin area is belived to belong to a very large hydrothermal system. The system can be divided into 5 regions extending from the Taihang shan mountains to Tianjin as follows: water supply region (recharge area),region with strong replacement of water, region with weak replacement of water, regional water confined to formations at depth,and discharge region. Every region has its own characteristic parameters such as underground temperatures,quality of water, pressure of fluid and content of heavy water. According to the ratio of helium and argon the calculated age of the thermal water in Beijing (which like Tianjin belongs to a "confined region") is 1.07-1.65 M.y. and is meteoric water.

A great deal of geological and geophysical work (including magnetic, gravimetric and seismic) has been undertaken for oil exploration in Tianjin and the nearby areas. Electrical exploration has not been undertaken within Tianjin because of the disturbance of the city's electricity network and pipelines.

The well temperature measurements indicate that the main thermal activity is connected with NE faults going through the city. Many of the drillholes are used by factories. The wells are drawing water from the same aquifers and pumping causes a general draw down of the water table in the geothermal reservoir. Therefore the measured temperature data is not very accurate. The thermal water has been analysed with respect to industrial utilization. Therefore, the analyses of the water may not be accurate enough for the geothermal research work.

2.2 The Yangbajing area in Tibet

The Qinghai-Xizang Plateau (Chinghai-Tibet), the highest and largest plateau on Earth, was formed only a few hundred thousand years ago. The average altitude of the plateau is 5000 meters. At its southern edge is the highest mountain in the world, Qomolangma Feng, 8848 meters. In the early Tertiary period about 40 millon years ago, the entire area was at the bottom of an ocean.

From the early Tertiary period to the Miocene, the Qinghai Xizang region was a large plain with no Himalaya or Kunlun mountains. By the middle of the Miocene the strong mountain-forming movement of the Himalayas had radically changed the terrain into many faulted basins and mountains. At the same time the entire region was slowly rising.

A strong upthrust occurred in the highlands between the middle and the late Pleistocene. The old faults reappeared along with new ones. Magma was active and hot springs were everywhere. Fine sulphur ore deposits were formed at the foot of the mountains. When the plateau reached 4000 meters altitude, the Himalayas tovering in the south began to block the wet Indian Ocean monsoons from entering the plateau. The weather became cold and dry, and there was very little precipitation above the snowline. The glaciers stopped growing and even bacame smaller. Former maritime glaciers became continental ones. The Qinghai-Xizang Plateau had a similar appearance as at present.

As previously mentioned, it is very difficult to estimate the number of hot springs. Recorded numbers of hot springs in the Xizang Plateau vary from less than 200 to over 600. The hot springs are scattered over six main areas. They are from north to south: (1) Tanggulashan area, (2) North Xizang lake area, (3) Niangintanggulashan area (including Yangbajing)

(4) Gangdisishan-Yaluzangbu area, (5) North foot of Himalaya mountains and (6) North sector of Hengduan mountain. The elevation of the hot springs ranges from 4000 to 5000 m, and most of them have water temperatures of 60-70°C. Eight thermal spring areas are at present known to have temperatures over the local boiling point. All of these appear in the areas numbered (3) and (4) above.

The hot spring localities of the Niangintanggulashan area are aligned in NE direction and the springs occur in groups a few tens of km apart along the faulted valley at the southeastern foot of the mountains. Many of these are gaseous springs. The Yangbajing field belongs to this group.

The Yangbajing field is located in central Xizang (Tibet), about 91 km north of Lhasa. The geology of the field has been described by the author (Yao 1980). It is located in a fault belt which is on the eastern flank of the Niangintanggulashan anticline (Fig. 4). There are pre-Devonian paragneisses in the axis area of the anticline. The oldest rocks are pre-Devoninan, but the age of the metamorphism is 22.1 M.y. (Miocene). The fault belt trends NE and forms an important structural line. It is a dividing line between the North Xizang block and the Lhasa-Bomi fold belts. The Tertiary rocks are distributed mostly northwest of the line. The fault belt is possibly an abyssal fault and magma has intruded along it. The Yangbajing geothemal field is located in the Yangbajing granite-stock, which stretches along the fault belt. The age of the granite-stock has been determined 35.6-27.8 and 65.6 M.y., and thus shows indications of multiple activity. The fault valley is also a strong earthquake zone.

The Yangbajing basin formed in middle Pleistocene and is covered with glacial sediments. These sediments are more than 300 m thick at the centre and less than 200 m thick at the border of the basin.

The Yangbajing field is at an altitude of 4300 m, which means that the boiling point is at 86°C. Numerous hot springs and fumaroles, indicating abnormally high heat flow, are located along the faults in the basin. The ground is heavily altered (kaolinisation) and native sulphur is common.

From a geological point of view, the Yangbajing geothermal field is located in a tectonically active rift valley. No recent volcanism is known on the surface, but recent volcanics may be covered with sediments.

In the Yangbajing field the geological and geophysical work includes magnetic, gravimetric and electric surveys. The geological interpretation of the electric measurments is difficult because of the absence of cores from the drillholes.

3 GEOCHEMISTRY OF THERMAL WATER

3.1 Chemical geothermometers and mixing models

Chemical geothermometers have been widely used in geotherml exploration for the last 20 years. The quantitative techniques currently available require chemical analyses of thermal water from springs or wells. Two types of chemical geothermometers have been quantitatively calibrated, the silica geothermometer and the cation geothermometers.

The silica geothermometer is based on experimentally determined solubility of quartz and chalcedony respectively. The unionized silica in the geothermal water is correlated with the solubility of these minerals. Equations for the silica geothermometer are listed in table 2. Equilibrium with quartz is preferred above 150°C, but at temperatures higher than 225°C silica is likely to be deposited during ascent of the water (Fournier, 1977). At lower temperatures other silica species such as chalcedony, cristobalite or amorphous silica may control the dissolved silica (Fournier and Row 1966, Arnorsson 1975, Fournier 1977).

Equilibrium constants for exchange and alteration reactions are temperature dependant. In such reactions, the ratios of dissolved constituents change with changing equilibrium temperature. This is the case for Na/K ratios and Na-K-Ca relations in thermal waters. A few different empirical equations have been used for the cation geothermometers.

The Na/K geothermometer has been considered to be applicable at temperatures above 100°C only. The equation most widely used to calculate Na/K temperature is given in table 2.

Studies of thermal water from deep wells in Iceland (Palmason et al, 1978) suggest a good fit with equilibrium between alkali feldspars to temperature as low as 30°C, if thermodynamic data of Helgeson (1969) is used. The equation for temperature based on feldspar equilibrium is given in table 2.

Fournier and Truesdell (1973) observed that the Na/K geothermometer often yields anomalously high temperatures for water of high calcium content and low temperatures. They therefore proposed an empirical Na-K-Ca geothermometer (see table 2). Paĉes (1975) recommends a correction factor for waters less than 75°C with partial pressure of CO_2 in aquifer above 10^{-4} to be added to the expression for the Na-K-Ca geothermometer.

The water in hot springs may consist of a mixture of deep hot water and shallow cold water. This changes the chemical composition of the geotermal water and affects the results of the chemical geothermometer. Mixing models have been described by Truesdell and Fournier (1974, 1975), and Fournier (1977, 1979). These mixing models are mainly of two types, the silica enthalpy model and the chloride-enthalpy model. For the first type the temperature of the mixed water must be below boiling. To apply this type of model the silica concentration and the temperature of the warm spring and the cold water must be known. The deep water may boil before mixing, but all the steam condense in the cold water. The original silica content and the temperature of the deep water is obtained from a silica-enthalpy plot.

The second type of mixing models can be applied to boiling springs. It makes use of a plot of enthalpy versus chloride, and it works best where the initial temperature of the hot-water component is above 200°C (Fournier 1977).

In the following chapters the chemical geothermometers and the mixing models are used to estimate underground temperatures in China.

3.2 On the chemistry of thermal waters in China

The thermal water in hot springs in China outside the basins can be divided into 10 main types on the basis of chemical analyses, table (3). Six of the types occur outside the basins (I-VI in table 3) and four within the basins (PI - PIV in table 3). Outside the basins, in general, the first type occurs in the Xizang-Yunnan zone, the Kangding-Yushu zone and the Qilian-Qinghai zone in west China; the second type in the Taiwan-Guangdong-Fujian zone in Southeast China, and the third type in the Hebei-Liaoning belt, North China, and the Qinling belt. The fourth type occurs in the Huayin-Xuefeng zone and the East Yunnan zone in Southwest China, and the fifth type in the "concentrated zone" including the three regions, (table 4). The sixth type is saline water of marine origin.

The chemistry of water is mainly controlled by three factors, i.e. the temperature, the origin of water and the rock type.

The chemistry of thermal water in the Chinese basins is quite complicated. Because of this, the thermal water in the basins is numbered differently in table 3. Most of the basins, covering large areas in China, are of continental type. Chemically, the water is quite different from that in marine basins in other countries. This is characerized by the lower contents of sodium and bromide ions, but higher content of heavy water etc. The water chemistry of continental basins may vary greatly, because of different basement, different stages of development and different evoluation processes. Sometimes the water chemistry within the same basin may vary greatly with depth.

The water chemistry at the depth of 1-2 km in the basins of East China may be connected to the latitudal Qinling and Nanling tectonic zones. North of Qinling, the total dissolved solids in the thermal water is low, generally about 7000 ppm in Songliao Plain with maximum values not exceeding 2000 ppm. In the North China Plain (including the Tianjin area), the total dissolved solids are 2000-7000 ppm, and less than 37000 ppm and 63000, ppm in the Subei Plain and the Ordos basin respectively. The water in the North China Plain, and the Subei Plain is predominantly of sodium bicarborate type but sometimes of sodium chloride type. In the Sichuan and Jianghan salt brine north of Nanling and south of Qinling, the water contains on average 270000 ppm of total dissolved solids and the highest being 340000 ppm, mainly sodium chloride and sodium sulfate types. The water becomes more diluted in the south part of the Nanling zone. It is mostly of sodium bicarbonate type, containing 1000-2000 ppm of total dissolved solids. The water in the basins in west China has higher total dissolved solids, commonly 5000-25000 ppm. Thermal water in drillholes in this area generally contains higher concentrations of lithium and boron similar to the hot springs in this area.

3.3 The Tianjin geothermal field

3.3.1 Distribution of drillholes

In the Tianjin field there are no hot springs at the surface but a large number of drillholes has been drilled. Their location is shown on Fig. 5. The drillholes can be divided into three groups:

a) Drillholes 300-400 m deep. These were drilled to supply the industry in the city with water.

b) Drillholes more than 1000 m deep, drilled for seismic, geothermal and oil exploration.

c) Shallow drillholes, drilled for water supply in the country.

Water in the drillholes in the last group are interfered by many factors, so the analytical data is mainly from the two first groups.

3.3.2 Chemical analyses and underground temperatures

The analytical methods used in China for chemical analyses of thermal waters are listed in table 5.

Available chemical analyses from Tianjin are listed in table 6 (new analyses) and Appendix A. From a chemical point of view there is a difference between the water from drillholes in the Tertiary sediment represented by drillhole 8 and in the Sinian bedrock represented by drillholes 17 and 18. The drillholes reaching Sinian bedrock tap another hydrothermal system which is deeper seated and hotter than the hydrothermal system represented by drillhole 8.

In table 7 the measured temperatures are compared to the calculated chemical geothermometers. It is not possible to calculate the cation temperature for the old analyses because sodium and potassium were not analysed, just estimated.

The measured temperatures reach 50°C in the shallower drillholes, but 96°C in the deepest drillhole. The calculated silica temperature for the new analyses supposing chalcedony equilibrium compares rather well with the measured temperature. An exception is well number 17, which has higher measured temperature than the chalcedony temperature. The old analyses usually have lower chalcedony temperature than the measured temperature. This may be due to inaccuracy in the silica determination.

Although the chalcedony temperature equilibrates at lower temperatures than the quartz temperature and is recommended up to 180°C (Arnorsson, 1975) equilibrium with quartz may exist to a much lower temperature, especially if the rock is old continental crust. Therefore quartz temperature may exist in the Tianjin area.

Marked discrepancy exists between the silica temperature and the cation temperature for the four new analyses from Tianjin. This difference may be explained by the mixing of cold water with the hot water. Cold water often yields anomalously high cation temperatures. In the case of mixing the water would not have reached equilibration after mixing and the estimated underground temperature would lie between the silica temperature and the cation temperature.

In order to obtain further evidence for mixing in the area, the distribution of chemical components such as chloride, sulphate, fluoride, calsium and magnesium as well as the calculated silica geothermometers were plotted on maps (Fig. 6, 7 and 8).

All the elements show increasing concentration from northwest to southeast along the Hai-Ho river. The chloride and the sulphate isolines have very similar trends which suggests good positive correlation between these elements (Fig. 9). These figures indicate a cold water tongue to exist at least in the uppermost 600 m.

Temperature measurements in the Tianjin area show that the highest water temperatures follow a NE-SW line, which coincides with an anticline structure in the bedrock (see Fig. 3) with decreasing temperatures in all directions from the axis. Figure 10 only shows a small part of the area. The water in the Tertiary sediments is groundwater that has been heated by an underlying thermal system mainly by mixing.

Chemical equilibrium has not been obtained in these waters.

An attempt was made to use a mixing model to estimate the temperature of the hot water in the lower system before mixing. The temperature at the surface is below boiling so the silica versus enthalpy graph described by Truesdell and Fournier (1977) was used. This model suggests a temperature of 140°C (Fig. 11).

3.3.3 The heat source and a model of the Tianjin field

As earlier mentioned the temperature of the water in the upper system is mostly due to conduction from the Sinian bedrock and mixing with cold groundwater. But what is the heat source for the Sinian system? According to data for geothermal gradient, the temperature of 140°C would be reached at 3500 to 4000 m depth. Therefore, if water penetrates to that depth it would reach temperature of 140°C by conduction.

On the basis of this, a schematic model of the Tianjin low temperature area is suggested (Fig. 12). As described in the geological section the bedrock is folded and faulted. Under Tianjin is an anticline and therefore the young sedimentary layers overlying the top of the anticline are thinner. The water is expected to be rainwater from the Taihang shan mountains. Some of this water penetrates to the depth of 3000-4000 m, and is heated up to about 140°C. This water flows through faults and fissures to shallower depth where it mixes with less heated water or cold ground water.

3.4 The Yangbajing geothermal area

3.4.1 Introduction

The Yangbajing geothermal field in Tibet has abnormally high heat flow which gives rise to conspicuous surface manifestations. Fumaroles, solfataras, hot springs and steaming ground is common. The bedrock is heavily altered and native sulphur is common. Large areas are characterized by hot soil, sometimes revealed by anomalous snow melting and siliceous sinter deposits are common. The hot springs and the sinters are mainly distributed in the southeast part of the field along the

Zang-bu river. This part covers about 9 km^2. The main activity, the fumaroles, the solfataras, the alteration and the native sulphur, is mainly at higher elevation in the northwest basin covering an area of 4 km^2. The drillholes are mostly distributed on the low ground. The location of the thermal springs and the drillholes are shown in Fig. 13. The drillholes are shallow (see table 8) and only well number 5 (427 m) reaches the bedrock.

3.4.2 The hydrothermal system and underground temperatures

The thermal water in the Yangbajing area is mainly of sodium chloride type characterized by a high content of boron and lithium. Average Cl/B atomic ratio and Li/Na weight ratio is 1.8 and 0.02 respectively. Chemical analyses of representative samples are listed in table 9 and analyses of other samples in Appendix 2. The gas consists mainly of nitrogen, hydrogen sulphide and hydrogen. The maximum measured temperature in the drillholes is 170°C. The chemistry of the drillhole water is slighty different from the chemistry of the spring water probably partly due to the difference in temperature. This can be seen in higher silica, boron and chloride, lower calcium and magnesium, and the slight alkalinity of the drillhole water.

Chemical geothermometers have been calculated for these samples (table 8). Some discrepancy exists between the silica temperature in equilibrium with quartz and feldspar equlibrium temperature (Fig. 14) for water from the springs. The cation temperature is always higher. Cold groundwater often yields extremely high cation temperature because equilibrium is not reached. As an example of this is the river water in table 9. Calculated cation temperatures would yield temperature in excess of 300°C. This discrepancy between calculated silica and cation temperatures may therefore be due to mixing of cold groundwater to the hot water.

A positive correlation exists between the concentration of chloride and silica (Fig. 15) indicating that the water comes from the same reservoir.

Figures 16, 17 and 18 show isotherms based on measured temperature, silica temperature and temperature based on Na-K feldspar equilibrium respectively. Isotherms based on the chemical geothermometers, especially the Na-K feldspar temperature, indicate cold water flowing from the mountain.

Figure 19 shows a temperature profile through the Yangbajing geothermal field. The highest temperature at the surface is at well 9. Compared to the geological map this coincides with a SW-NE fault.

Isolines for potassium, calcium, chloride and fluoride are shown on figures 20, 21, 22 and 23 respectively. These maps show a NE-SW trend which coincides with faults on the geological map (see Fig. 13).

Mixing models have been applied to the Yangbajing geothermal field in order to estimate the temperature of the hot water before mixing. Figure 24 shows silica-enthalpy graph (described by Truesdell and Fournier 1975 and 1977) for non-boiling water from the Yangbajing field. This model supposes boiling before mixing. In Yangbajing the boiling point is at 86°C because of the high elevation. According to this model the temperature of the hot water before mixing would be 190°C for most samples and as high as 225°C if extreme samples (2) are used.

The other mixing model is based on enthalpy chloride relations (Fig. 25). This model can be applied to boiling springs. This model has been described by Truesdell and Fournier (1975) and Fournier (1977 and 1979). According to this model, the water temperature before mixing would be 205°C based on the calculated silica temperature. If Na-K feldspar equilibrium temperature is used as a reference temperature the temperature of the parent water would be 230°C. It should be kept in mind that this model supposes that the sample with the highest chloride concentration is not mixed water, but that its chemical composition has only changed due to adiabatic cooling. The estimated temperature before mixing may therefore be regarded as a minimum temperature. The water in well 9 has a chemical composition closest to the unmixed hot water. These two mixing models are consistent, one indicating 190-225°C and the other 205-230°C for the deep water before mixing.

3.4.3 The source of heat and a model of the Yangbajing area

The Yangbajing geothermal field is located in a rift valley. From a geomorphological point of view it is unlikely that this high temperature (190-230°C) calculated for the deep water can be obtained only by regional heat flow. It is therefore believed that the wet steam reservoir extends to a great depth and is mainly heated by some heat source, possibly magmatic intrusions,at depth. It is possible that some juvenile steam also ascents to the reservoir, although it can not be seen from the chemical analyses.

From the chemical analyses and the geological knowledge of the area, the following model is submitted (Fig. 26): The water is assumed to be of meteoric origin and to have mainly precipitated in mountainous areas and subsequently been heated up in the bedrock (Cainozoic granite) by some hidden heat source (possibly magmatic intrusion). It is supposed that the water reaches a temperature of about 230°C. The heated water flows through faults with NE-SW direction to the surface. The bottom of the valley is covered with Quaternary sediments. Within the sediments the hot water mixes with cold groundwater or slightly heated water. It is difficult to calculate the composition of the deepwater before mixing, but according to this model well 9 has chemical composition closest to the chemistry of the deepwater before mixing.

3.4.4 Mineral equilibria and deposition

Mineral deposits associated with the utilization of geothermal water and steam are mainly calcium carbonate, silica and several iron bearing minerals. Deposition is caused by the physical and chemical changes that accompany boiling and cooling of the geothermal water.

Calcium carbonate deposits are mostly calcite. They are most intense at the level of first boiling. The degree of calcite supersaturation caused by boiling, and presumably also deposition rates, only depends on the temperature of the reservoir water and its ionic strength. Strongest supersaturation occurs at the lowest temperature and the highest ionic strength.

From the chemical analyses some mineral solubilities have been calculated. Table 10 lists the solubility of calcite, anhydride and fluorite for analyses from Yangbajing. These results are shown on Figures 27, 28 and 29. The plots show that the water is undersaturated in respect to anhydride, close to saturation in respect to fluorite and is near saturations in respect to calcite at silica temperature but most samples become supersaturated during cooling. It is therefore likely that calcite scaling may occur in the wells. The saturation in respect to fluorite indicates that the fluoride in the water is controlled by the solubility of this mineral. Other elements in the water may be controlled by other minerals. This has not been studied closely, because the waters are mixed with cold water, but feldspars seem to control the sodium and potassium together with some clay minerals.

The silica is truely controlled by the quartz solubility. Precipitation of amorphous silica may occur at lower temperatures. If the water contains 250 ppm silica, the amorphous silica would precipitate at about 70°C. This is the reason for the silica sinter around springs in the Yangbajing area.

Because of the low concentration of iron in the water, the deposits of iron bearing minerals is very limited and would not make any utilization problems.

4 CONCLUSIONS AND RECOMMENDATIONS

1. In this study chemical geothermometers have been used to indicate underground temperatures in various hydrochemical zones in China. These zones have earlier been described by the author (Yao, 1979). The calculated underground temperatures are preliminary because of the inaccuracy in the old silica determinations.

2. The study of the Tianjin low temperature geothermal field indicates that the thermal water reaching the surface is a mixture of hot parent water and cold groundwater. The temperature of the thermal water before mixing has been estimated 140°C by using a mixing model based on silica-enthalpy relations. The water is expected to be heated by the rock by conduction. Considering the thermal gradient of the region the temperature of 140°C should be reached at 3500-4000 m depth.

3. The Yangbajing geothermal field is a high temperature area. The maximum measured temperature is 170°C. A study of the chemistry of the thermal water from drillholes suggests that the hot water has mixed with cold water. Both silica-enthalpy and chloride- enthalpy mixing models suggest a temperature of 225°C-230°C before

mixing. The water is calcite supersaturated so calcite may cause scaling in wells during utilization.

The author would like to point out a few recommendations for further studies in the field of geochemistry of thermal waters in China.

1. Some analytical methods have to be revised in order to obtain better analytical results. The interpretation of the chemistry based on mineral solubility and ionic exchange requires very accurate determinations.

2. The collection techniques have to be revised, especially in drillholes in the high temperature fields like Yangbajing. There collection of both water and gas at the same pressure, using a separator, would produce valuable data for further evaluation of the chemical equilibria taking place.

3. To be able to get samples of the deep water before mixing it is necessary to drill deeper wells and case off the cold surface water. Information from the unmixed thermal water would add further knowledge and understanding of the thermal field.

So far we have only been dealing with the geochemistry in primary exploration. Further utilization of geothermal water also requires a chemical study to provide chemical data on fluid composition relevant for construction, design and monitoring the chemical composition of the well discharge. The work of the geochemist in the geothermal exploration and utilization is therefore endless.

Whether geochemical methods or others, individual surveys are used to answer specific questions.Valid conclusions can only by reached by evaluating all relevant data within the framework of the geological environment. During the training I have been using geochemical methods. I think they are advanced and effective and should be given attention.

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TABLE 1. THERMAL WATER ZONES IN CHINA

Mountain areas:

1. Xizang-Yunnan high-temperature zone
    - 1.1 high-temperature water-steam subzone
    - 1.2 high- and moderate-temperature thermal water subzone
2. Taiwan-Guangdon-Fujian high-temperature zone
    - 2.1 high-temperture water-steam subzone
    - 2.2 high- and moderate-temperature thermal water subzone
3. Hebei-Liaoning high- and moderate temperature thermal water zone
4. Qilian-Qinghai high- and moderate temperature thermal water zone
5. Kangding-Yushu high- and moderate temperature thermal water zone
6. Qinling moderate- and low-temperature thermal water zone
7. Wuayin-Xuefeng moderate- and low-temperature thermal water zone
8. East Yunnan moderate- and low-temperature thermal water zone
9. North-Shanxi moderate- and low-temperature thermal water zone
10. Tancheng Lujinag thermal water zone
11. Tianshan thermal water zone
12. High-temperature and carbonic acid water concentrated zone
    - Taiwan-Guangdon region
    - Shandong-Liaoning region
    - Daxingganling-North Shanxi region
13. Low-temperature and deep burial thermal water zone
    - Heilongjiang-Jilin region
    - Shanxi-West Shandong region
    - Zhejiang-North Fujian region

Covered areas:

1. Relatively high underground-temperature zone
2. Relatively moderate underground-temperature zone
3. Relatively low underground-temperature zone

TABLE 2. EQUATIONS FOR CHEMICAL GEOTHERMOMETERS

chalcedony (0-250°C) 1)

$$t\ ^\circ C = \frac{1032}{4.69 - \log SiO_2} - 273.15$$

quartz (0-250°C) 1)

$$t\ ^\circ C = \frac{1309}{5.19 - \log SiO_2} - 273.15$$

quartz (0-250°C) after steam loss 1)

$$t\ ^\circ C = \frac{1522}{5.75 - \log SiO_2} - 273.15$$

amorphous silica 1)

$$t\ ^\circ C = \frac{731}{4.52 - \log SiO_2} - 273.15$$

In all these four equations SiO_2 is in mg/l and represents unionized silica.

Na-K (100-275°C) 2)
Na and K in mg/l

$$t\ ^\circ C = \frac{855.6}{\log (Na/K) + 0{,}8573} - 273.15$$

Na-K (25-300°C) 3)
feldspar equilibrium

$$\log Na/K = -10.96 + 1709/T\ ^\circ K + 3.18 \log T\ ^\circ K$$

Na and K in moles/kg

Na-K-Ca (4-340°C) 4)

$$t\ ^\circ C = \frac{1647}{\log Na/K + \beta \log (\sqrt{Ca}/Na) + 2.24} - 273.1$$

Na, K and Ca in moles/kg

$\beta = 4/3$ for $\sqrt{Ca}/Na > 1$ and $t < 100\ ^\circ C$

$\beta = 1/3$ for $\sqrt{Ca}/Na < 1$ and $t > 100\ ^\circ C$

Paĉes 5) correction for Na-K-Ca geothermometer for water less than 75°C and partial pressure of CO_2 above 10^{-4} atm is:

$$I = 1.36 + 0.253 \log P_{CO_2}$$

References,

1) Fournier (1977), 2) Truesdell (1975), 3) Arnorsson (1979), 4) Fournier and Truesdell (1973) and 5) Paĉes (1975).

TABLE 3. CHEMICAL TYPES OF HOT WATER IN CHINA

No.	pH of water	total dissolved solids (mg/l)	Characters of component
I*	weak alkaline - alkaline	moderate (1500-4000)	Sodium water containing considerable amount of boron and lithium.
II	weak alkaline	low (500-1000)	Sodium water containing considerable amount of fluoride and silica, predominantly bicarbonate type.
III**	weak alkaline	low (500-2000)	Sodium water containing considerable amount of fluoride and silica, predominantly sulfate type.
IV	Neutral-weak alkaline	low (500-1000)	Alkaline-earth water, predominantly bicarbonate and sulfate type
V	weak acidic	——	Carbonic water containing considerable content of iron
VI	——	——	Sodium chloride water in coastal areas.
PI	——	1.000- 4.000	Predominantly sodium bicarbonate
PII	——	4.000- 10.000	Predominantly sodium bicarbonate
PIII	——	10.000- 35.000	Sodium bicarbonate and chloride
PIV	——	35.000-200.000	Chloride and sodium sulphate

*Yangbajing area belongs to this type

**Tianjin area belongs to this type

TABLE 4. CHEMISTRY OF THERMAL WATER ZONES IN CHINA

Name of thermal water zone	Chemical type	Location	Measured Temp. (°C)	Diss. solids	pH	Chemical composition. Concentration in ppm																	Undergr. temp ** (°C)
						K	Na	Ca	Mg	Fe	Al	Cl	SO_4	HCO_3	CO_3	NO_3	B	Li	F	SiO_2	Sr	CO_2	
Xizang - Yunnan high-temperature zone	Moderately mineralized weak alkaline-alkaline sodium water containing boron and lithium (Alkaline earth bicarbonate water and sodium chloride water in some areas)	Gulu, Xizang	56	5650	8.8	135.00	1090.00	0	0	0	0.05	880.97	27.60	1291.66	185.82	0	38.0	22.8	16.0	95			125
		Tanggula, Wenquan, Qinghai	53	1960	7.4	75.00	395.00	114.22	14.66	trace	0.15	131.62	655.98	563.38	0	0	11.5	2.0	6.0	90			131
		Tongmai, Xizang	94	1790	9.5	115.00	610.00	0	0	0	0.12	361.51	259.00	96.19	344.61	0	19.0	3.0	6.0	-			-
		Nagqu, Xizang	59	3910	8.0	84.00	1090.50	4.26	6.32	trace	0.10	224.63	101.90	2143.6	263.52	0	8.4	3.0	7.0	90			131
		Tengchong, Yunnan	105	2180	9.0	56.50	640.00					329.02	20.00	956.83				3.5	12.0	77			121
Kangding - Yushu high- and moderate-temperature zone		Kangding, Sichuan	92	1410	7.6	50.8	370.3	48.1	15.6			289.0	36.00	792.6	0		5.6		2.6	158		23.8	155
		Ganzi, Sichuan	58	2000	6.8	62.6	717.5	14.00	1.8			37.6	39.90	1963.6	0		15.5		8	113		128	144
Qilian - Qinghai high- and moderate-temperature zone		Reshui, Qinghai	94	1560	6.9	431.25		59.12	0	0		331.69	499.75	68.43	0	0	4.1	14*	8.8	115			139
		Qunaihai, Qinghai	88	1970	8.0	642.16		38.0	0	0		783.37	255.45	44.68	33.93	0	1.4		9.0	129			148
Taiwan - Guangdong - Fujian high-temperature zone	Slightly mineralized weak alkaline sodium water containing fluoride and silica, mainly of bicarbonate type (alkaline earth water of sulphate type and sodium chloride water in some areas).	Dengw'u, Guangdong	92	430	7.1	99.27		7.62	2.07	0.49	0	12.41	7.20	255.16	0	0			12.4	54		23	105
		Nangong, Guangdong	48	850	7.9	142.58		101.60	7.30	0	0	7.09	303.57	262.38	0				20.0	104		135	139
Huaying - Xuefeng moderate- and low-temperature zone	Slightly mineralized neutral- weak alkaline, alkaline earth water, bicarbonate and sulphate types.	South Wenquan, Sichuan	43	2880	6.8	155.71		544.49	123.67			33.73	1933.21	177.57									-
		Xifeng, Guizhou	56	390	7.1	4.15	14.84	54.35	22.06	0.02	0	2.97	103.88	168.77	0	3.0			1.4	10		34	-
East Yunnan moderate- and low-temperature zone		Anning, Yunnan	43	440	7.5	0		52.17	18.48	1.20		10.44	2.59	216.55	0	2.0			0.2	5		18	-
Hebei - Liaoning high- and moderate temperature zone	Slightly mineralized weak alkaline sodium water containing fluoride and silica, mainly of sulphate type.	Ningcheng, Liaoning	100	1010	8.5	21.4	294.9	0.30				49.6	493.1	75.5	6.3	0			15.0	71			117
		Wulongbei, Liaoning	69	300	8.7	3.04	65.75	1.80				22.66	33.6	42.09	22.8				12.7	81			126
		Xiaotangshan, Beijing	54	610	7.3	99.55		40.54	14.97	trace	0	32.62	72.53	292.88	0	0.40	0.10		6.5	40		5.3	92
Qinling moderate- and low-temperature zone		Lintong, Shanxi	44	960	7.6	248.29		40.83	3.62	0.03	0.02	156.15	249.89	194.53	0	2.10	0.9		5.8	40	0.1*	4.4	92
		Linru, Henan	63	2060	7.9	506.00		108.64	9.85	trace	0.02	327.21	621.02	350.67	0	0		9*	6.0	96	0.9*		135
		Yingshan, Hubei	70	430	8.4	3.8	89.6	17.0	0.50	0	0	7.4	196.9	49.2	0	0	0.10	0.1*	3.0	54	0.2*	26	105
	(Low mineralized neutral alkaline earth water containing strontium, sulphate type).	Xianning, Hubei	52	2130	7.2	24.15		466.58	80.09	0	0.04	7.09	1340.25	163.69	0	trace	0.04	1.0*	3.8	35	6*	22	86
		Tangshan, Jiangsu	60	1710	7.3	37.3		386.00	60.30	0		14.9	1090.3	166.0		0	0.11	0.6	3.5	25	16	17	72
High temperature - carbonic acid water concentrated zone	Weak acidic carbonate water containing more iron	Wuniarshan, Neimongu	10	610	6.4	20.71		81.30	22.48	0.05	2-4*	10.0	1.07	402.0	0	0	0.1	2-4*	2.8	52	0.2-0.4*	2193	(104)
		Lisui, Guangdong	33	4210	6.2	150.00	1000.00	45.89	8.76	1.52	0.02	34.96	134.6	2760.00	0	0.06			5.4	58		1483	(109)

* Semiquantitative spectral analysis ** Quartz equilibrium temperature

TABLE 5. THE ANALYTICAL METHODS USED IN CHINA

Component	Analytical method
SiO_2	Colourimetric with ammonium molybdate 2)
B	Colourimetric with quinalizarin 2)
Na	Flamephotometry
K	Flamephotometry
Na + K 1)	Estimated from the difference between total anions and calcium + magnesium
Ca	Titration with EDTA
Mg	Titration with EDTA
CO_2	Titration with hydrochloric acid
H_2S	Titration with thiosulphate
SO_4	Titration with benzedinechloride
Cl	Mohr titration (with silver nitrate)
F	Colourimetric with zirconium-alizarin 2)

1) Estimation used for samples form Tianjin.

2) Colour compared by eyesight.

TABLE 6. CHEMICAL COMPOSITION OF THERMAL WATERS IN TIANJIN, CONCENTRATION IN ppm

(Analysed at the UNU Geothermal Training Programme in Reykjavik)

Sample	Depth of well (m)	Type of rock	Measured temp. (°C)	pH/20°C	SiO_2	Na	K	Ca	Mg	CO_2 1)	SO_4	Cl	F	B
Well 8	803	R 2)	50.4	8.33	31.9	235.5	1.5	2.6	0.44	397.1	7.7	21.0	4.3	0.68
Well 18	2017	Zn 3)	96	7.20	73.4	654.6	65.7	37.1	6.8	376.4	316.4	569.0	9.4	10.40
Well 17	1406	Zn	84.5	6.98	52.4	602.0	71.3	38.4	13.0	315.1	355.4	1036.4	8.9	9.15
Xiaotangshan spring		Zn	54	7.3	35.7	489.0	15.4	41.7	13.7	216.5	69.2	129.6	6.5	0.32

1) CO_2 total carbonate = $H_2CO_3 + HCO_3^- + CO_3^{--}$

2) R = Tertiary sediments

3) Zn = Sinian bedrock

TABLE 8. COMPARISON BETWEEN MEASURED TEMPERATURES AND CALCULATED TEMPERATURE BY THE CHEMICAL GEOTHERMOMETERS FOR WATERS FROM YANGBAJING

No. of sample	Type of sample & depth of well (m)	Measured T	Silica T		T_{Na-K}		$T_{Na-K-Ca}$
			chalcedony	quartz	Na-K	feldspar equ	$\beta = 1/3$
W2	Well, 72	170	178	186	191	190	225
W3	Well, 311	137	123	147	121	140	173
W4	Well, 68	153	166	179	227	215	255
W5	Well, 457	146	144	162	141	154	179
W9	Well, 87	161	178	187	204	200	230
2	hot spring	66	139	163	217	208	220
12-2	"	62	130	163	169	175	219
19-1	"	56	122	149	200	197	213
20	"	68	117	149	152	161	205
21-2	"	62	126	151	193	191	205
26	"	66	141	164	220	210	204
28	"	30	130	154	210	203	209
29-8	boiling spring	89	146	159	197	195	206
29-23	hot spring	76	148	171	206	201	215
30-23	"	42	162	183	202	197	213
31	"	50	97	125	149	160	168
33	boiling spring	84	150	162	220	210	234
35	hot spring	56	140	163	193	191	208
37	"	49	135	159	226	215	215
38	boiling spring	85	121	145	190	189	215
42	hot spring	46	151	173	220	210	212
22	spring	-	127	152	228	217	214
25	"	-	142	165	224	214	212
32	"	-	95	123	185	183	184
40	"	-	135	159	212	205	208
41	boiling spring	-	130	148	184	183	204
44	spring	-	90	119	201	196	194
47	"	-	79	109	248	233	191
48	"	-	116	142	213	205	197

TABLE 9. CHEMICAL COMPOSITION OF REPRESENTATIVE SAMPLES OF THERMAL WATER IN YNAGBAJING

Concentration in ppm

No. of sample	Type of sample & depth of well	Measured Temp. °C	pH	SiO_2	Na	K	Ca	Mg	CO_2 1)	SO_4	Cl	F	B	Fe	Al	Li	Diss. solids
W2	72 m	170	8.40	273.7	470.3	49.8	2.5	0	123.4	30.0	556.7	6.2	102.8	0	0.05	–	1698
W3	311 m	137	8.15	135.2	470.3	25.1	8.5	0.30	323.2	34.3	382.4	8.0	64.4	0	0.10	–	1526
W4	68 m	153	8.60	243.2	488.1	68.1	1.0	0.91	157.7	50.0	562.3	8.0	91.2	0	0.08	–	1849
W5	457 m	146	8.20	180.7	344.2	22.9	8.0	0.30	239.0	22.5	280.3	5.6	44.7	0.05	0.08	–	1142
W9	87 m	161	8.30	275.3	608.3	71.6	5.0	1.52	160.3	35.0	596.9	12.0	101.1	0	0.16	–	1929
28	hot spring	30	6.45	134.3	357.6	44.2	15.5	1.52	223.1	20.0	352.9	8.0	64.0	0.16	0.08	–	1270
42	"	46	6.70	180.5	313.1	41.5	14.5	1.52	195.6	32.5	318.3	9.0	56.2	0.30	0.16	–	12.07
20	"	68	8.85	122.8	465.9	34.7	2.0	0.30	80.4	40.0	543.3	11.0	89.1	0	0.08	9.50	1576
29-23	"	76	7.05	174.8	436.2	52.3	11.5	0.91	213.2	27.5	481.0	5.4	81.1	0	0.08	–	1585
38	boiling spring	85	8.55	128.6	382.8	40.4	4.0	0.30	156.7	27.5	422.1	8.3	70.5	0	0.10	–	1339
29-8	"	89	7.00	169.8	453.3	50.5	19.5	0	233.9	25.0	487.9	5.8	80.2	0.25	0.08	8.50	1637
River water		6	7.00	4.0	3.0	1.5	14.2	1.09	34.8	6.0	1.3	0.5	–	–	–	–	74

1) CO_2 total carbonate = $H_2CO_3 + HCO_3 + CO_3^{--}$

TABLE 10. CALCULATED SOLIBILITY OF CALCITE, ANHYDRIDE AND FLUORITE AT MEASURED TEMPERATURE AND QUARTZ TEMPERATURE FROM ANALYSED WATER FROM YANGBAJING

Sample	T Measured	log K $CaCO_3$	log K $CaCO_3$	log K CaF_2	T quartz	log K $CaCO_3$	log K $CaSO_4$	log K CaF_2
2	66	-7,50	-7,53	-10.248	163	-10.339	-7.839	-10.448
12-2	62	-7.88	-8.465	-12.037	163	-10.241	-8.826	-12.327
19-1	56	-7.64	-7.571	-10.846	149	-9.406	-7.920	-11.127
20	68	-7.93	-8.256	-11.203	149	-10.203	-8.497	-11.388
21-2	62	-7.47	-7.397	-10.674	151	-9.761	-7.728	-10.926
26	66	-7.46	-7.704	-10.775	164	-10.214	-8.021	-10.975
28	30	-7.52	-7.557	-10.507	154	-10.154	-7.914	-10.762
29-8	89	-10.34	-7.541	-10.817	169	-12.446	-8.024	-11.829
29-23	76	-7.45	-7.680	-11.071	171	-9.814	-8.103	-11.409
30-23	42							
31	50	-7.71	-7.459	-11.059	125	-9.479	-7.683	-11.227
33	84	-7.73	-8.084	-11.162	173	-12.319	-8.575	-11.786
35	56	-7.57	-7.701	-10.749	163	-9.814	-8.114	-11.082
37	49	-7.26	-7.328	-10.583	159	-9.942	-7.691	-10.837
38	85	-9.33	-8.144	-11.172	152	-11.883	-8.424	-11.487
42	46	-7.40	-7.385	-10.444	173	-10.029	-7.836	-10.779
W2	170	-8.54	-8.660	-11.901	202	-10.705	-8.849	-12.052
W3	137	-7.83	-8.074	-11.181	155	-9.228	-8.194	-11.286
W4	153	-8.72	-8.831	-12.075	194	-10.865	-9.086	-12.282
W5	146	-7.89	-8.206	-11.455	173	-9.548	-8.379	-11.604
W9	161	-7.86	-8.354	-11.058	195	-10.257	-8.566	-11.226
22					152	-11.897	-8.087	-11.315
25					165	-13.180	-7.941	-12.175
30-20					167	-12.497	-7.908	-11.504
32					123	-11.749	-7.825	-11.543
40					159	-11.622	-7.864	-11.392
41					155	-12.961	-7.384	-11.242
44					119	-9.079	-7.441	-10.808
47					109	-10.463	-7.573	-14.285
48					142	-12.400	-7.632	-11.726

APPENDIX 1. Analysis of thermal water from Tianjin (in ppm)

Sample No.	Depth of well (m)	Measured temp. (°C)	pH	SiO_2	Na	K	Ca	Mg	CO_2 1)	SO_4	Cl	F	B 3)	Fe 2)	Diss. solids
Well 1	700	31	7.9	15	202.79		4.05	0	310.05	0	37.83	4.5	–	0.40	502
Well 2	440	34.2	7.7	15	413.16		9.10	3.67	135.64	451.06	184.53	5.5	–	0.08	1124
Well 3	735	30	7.9	15	227.24		6.35	0.32	317.86	31.27	67.78	2.8	–	0.08	588
Well 4	760	31	7.9	20	346.66		4.99	1.22	390.37	0.48	197.25	5.0	–	0.24	848
Well 5	614	31.6	–	15	220.79		4.05	0.30	327.55	8.12	45.81	4.5	–	0.12	548
Well 6	627	40.4	–	20	247.26		4.05	0.91	352.93	19.36	63.75	4.5	–	0.08	616
Well 7	700	32.8	7.7	20	396.10		8.60	0.91	327.74	161.09	221.11	4.5	–	0.16	1046
Well 8-1	803	50.4	7.9	20	233.54		3.17	0.04	437.93	1.31	30.63	5.0	0.69	0.12	588
Well 9	644	41.5	–	20	266.50		5.29	0	376.76	26.22	79.25	4.0	1.98	0.04	730
Well 10	529	43	–	25	285.22		5.81	1.61	341.75	75.89	108.11	2.5	1.98	0.14	722
Well 11	340	34	7.7	15	392.38		9.52	1.29	318.59	171.02	233.38	4.0	1.48	0	1062
Well 12	372	31.5	7.9	15	374.02		8.06	3.68	315.12	166.52	207.18	4.0	–	0	982
Well 13	300	21.8	7.7	18	326.46		12.68	6.76	302.27	142.51	180.38	5.0	2.47	0.04	888
Well 14	538	30	–	15	372.41		8.46	0.52	295.80	154.08	219.59	3.5	–	0.50	996
Well 15	708	52	8.3	25	373.26		4.89	1.24	317.37	155.58	199.14	4.0	–	1.07	970
Well 16	839	46	7.8	25	325.04		6.01	0.30	383.18	2.26	175.30	6.0	–	0.24	828
Well 17	1406	84	6.98	52.4	602.0	71.3	38.4	13.0	315.13	355.4	1036.4	8.9	9.15	–	–
Well 18	2017	96	7.2	73.4	654.6	65.7	37.1	6.8	376.42	316.4	569.0	9.4	10.40	–	–
Well 8-2	803	50.4	8.33	31.9	235.5	1.5	2.6	0.44	397.12	7.7	21.0	4.3	0.68	–	–

1) $CO_2 = HCO_3 + CO_3 + CO_2$ 3) $B = HBO_2$

2) $Fe = Fe^{++} + Fe^{++}$

APPENDIX 2. Analysis of thermal water from Yangbajing (in ppm)

Sample No.	Depth of well (m)	Measured (°C)	pH	SiO_2	Na	K	Ca	Mg	CO_2 1)	SO_4	Cl	F	B 3)	Fe 2)	Diss. solids
2	-	66	6.7	153.22	409.51	53.30	10.52	0.61	115.34	38.00	531.14	14.40	91.99	0	1554
12-2	-	62	8.95	154.97	497.5	43.33	1.50	0	126.18	35.00	565.74	5.00	99.04	0	1749
19-1	-	56	7.80	122.00	436.21	49.81	10.02	0.61	185.12	37.50	505.19	7.30	94.13	0.18	1545
20	-	68	8.85	122.83	465.89	34.70	2.00	0.30	80.39	40.00	543.25	11.00	89.05	0	1576
21-2	-	62	6.75	126.95	479.24	51.47	18.04	1.22	227.34	32.50	517.30	6.70	89.09	0.80	1694
22	-	-	8.30	192.66	483.69	68.07	9.02	0.91	253.94	40.00	522.29	9.00	81.93	0.04	1760
25	-	-	6.70	160.05	212.41	29.06	10.02	0.61	139.08	37.50	210.38	6.50	34.23	1.80	876
26	-	66	6.50	157.77	225.53	30.05	17.03	2.74	141.49	12.50	245.67	5.50	38.74	0.40	920
28	-	30	6.45	134.37	357.58	44.16	15.53	1.52	223.14	20.00	352.94	8.00	64.03	0.16	1270
29-8	-	89	7.0	169.81	453.28	50.47	19.54	0	233.89	25.00	487.89	5.80	80.19	0.25	1637
29-23	-	76	7.05	174.76	436.21	52.30	11.52	0.91	213.20	27.50	480.97	5.40	81.13	0	1585
30-20	-	-	7.0	164.04	420.57	50.47	18.04	0.61	239.69	35.00	470.59	9.00	80.25	0.21	1576
30-23	-	42	4.12	207.73	557.14	64.50	18.54	4.25	0	509.68	597.92	15.00	108.65	0.30	2212
31	-	50	6.85	79.14	216.62	15.61	18.04	2.13	227.12	20.00	186.85	3.80	31.55	0	788
32	-	-	7.0	76.66	151.34	14.78	9.52	2.13	156.27	22.50	131.49	3.80	25.32	0.16	585
33	-	84	8.10	179.70	510.40	68.07	5.01	0.30	231.51	30.00	581.31	8.00	95.74	0	1843
35	-	56	7.0	154.97	409.51	44.16	10.52	0.30	217.19	25.00	463.67	7.80	77.66	0	1498
37	-	49	6.70	145.63	330.87	45.98	16.03	1.22	184.26	35.00	377.16	7.50	59.06	0.04	1300
38	-	85	8.55	128.60	382.80	40.35	4.01	0.30	156.66	27.50	422.14	8.30	70.46	0	1339
40	-	-	8.05	145.91	325.68	40.35	15.03	1.52	229.81	35.00	361.59	5.80	62.37	0.25	1241
41	-	-	6.70	135.01	557.88	54.21	15.03	1.22	138.14	120.00	626.99	14.00	115.71	0.60	2039
42	-	46	6.70	180.53	313.06	41.51	14.53	1.52	195.64	32.50	318.34	9.00	56.15	0.30	1207
44	-	-	7.35	70.89	229.98	26.07	18.04	1.52	184.80	35.00	238.75	6.20	40.26	0.30	868
47	-	-	6.50	57.70	55.64	9.13	13.03	0.91	60.13	17.50	60.55	0.10	9.84	0	274
48	-	-	6.75	109.64	216.62	27.06	22.04	0.61	135.68	22.50	237.02	3.80	41.15	0	890
W 2	72	170	8.40	273.68	470.34	49.81	2.51	0	123.42	30.00	556.74	6.20	102.81	0	1698
W 3	311	137	8.15	135.19	470.34	25.07	8.52	0.30	323.24	34.29	382.35	8.00	64.38	0	1526
W 4	68	153	8.60	243.18	488.14	68.07	1.00	0.91	157.74	50.00	562.28	8.00	91.20	0	1849
W 5	457	146	8.20	180.70	344.22	22.91	8.02	0.30	239.00	22.50	280.28	5.60	44.72	0.05	1142
W 9	87	161	8.3	275.34	608.33	71.56	5.01	1.52	160.27	35.00	596.88	12.00	101.06	0	1929

1) $HCO_3 + CO_3 + CO_2$

2) $Fe^{+++} + Fe^{++}$

3) $BO_2 + H_3BO_3 + B_2O_3$