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ISOTOPE AND GEOCHEMICAL TECHNIQUES IN GEOTHERMAL INVESTIGATIONS IN CHINA: AN OVERVIEW

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ABSTRACT

A general background of geothermal systems and resources in China is provided to show the current understanding of the systems on which integrated geoscientific investigations are based, for which isotope and geochemical techniques are essential tools. Progress in this aspect of geothermal studies in China is reviewed with emphasis on recent development. The scope of this review includes theoretical aspects; methodology development; and field investigations covering different types of geothermal systems, low temperatures and high temperatures. Some future tasks are outlined in light of the current geothermal development activities and the planned growth of utilisation in the country.

1. INTRODUCTION

China is rich in geothermal resources and has a long history of utilisation. There are more than 2700 thermal springs and, if thermal wells and mine outflows are counted, more than 4000 thermal features. Around 200 geothermal systems have been mapped to date and still more are under investigation and planned for exploitation. As shown in Figure 1, two major global geothermal belts, namely, the Circum-Pacific and the Mediterranean geothermal belts extend to Chinese territory. These are where the high-temperature systems are found. There are many other intra-plate geothermal anomalies where the low-to medium- temperature geothermal resources are located.

Isotope and geochemical techniques as an integral part of geoscientific tools in geothermal exploration have been extensively applied in the process of geothermal development in China. Methodologies have been and are being developed or improved to best suit the needs with regard to the diverse geological conditions in the country.

At present, total installed capacity in the country is 32.17 MW (Ren et al., 1995). This number is growing at a rate of 12% annually and continuation of this trend is planned. In addition to power generation, geothermal resources are widely used for space heating, industry processing, agriculture,

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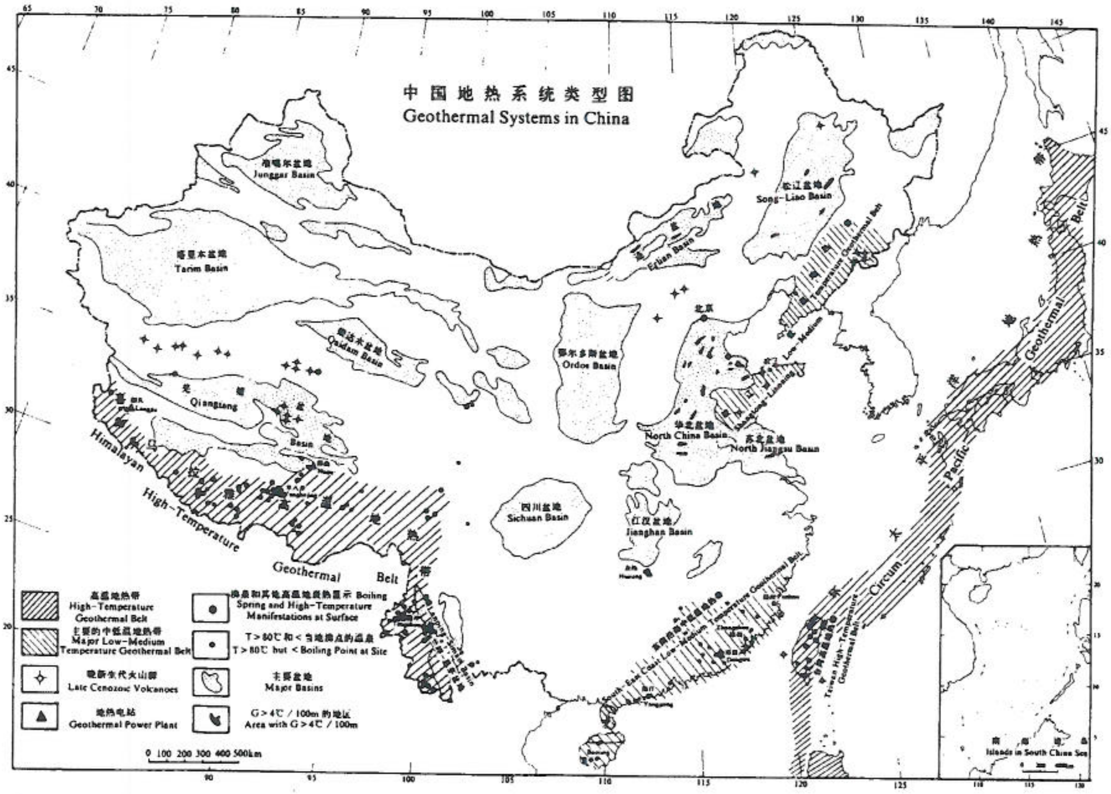

Figure 1: Distribution of major geothermal regions in China (from Wang et al., 1995)

bathing and spas. In 1990, the total flow rate of thermal water for direct use amounted to 9534 kg/s, which provides of thermal power of 2143 MW and the equivalent of 5527 GWh of thermal energy. These figures show that China nowadays is the second largest user of geothermal energy, for non-electric purposes, in the world.

With the rapid development of the economy, the central government of China pays greater attention to renewable energy including geothermal resources. A number of interested groups is emerging to utilise geothermal resources to which they have access. In this context, it is important to further develop and apply isotope and geochemical techniques including the most advanced ones that have become available only very recently.

This paper provides a brief overview of the past achievements in this field in China, and emphasis on the recent ones. Research efforts for theoretical and methodological advancement will be reviewed, and some field investigations will be cited to demonstrate the usefulness of the techniques. An outlook for future activities will also be included at the end.

2. THEORETICAL ASPECTS

2.1 General

Stable isotopes are good tracers of the origin of geothermal waters. Chinese geothermal waters originate from meteoric water, like most geothermal waters in the world. With the efforts of many researchers, isotope composition of geothermal waters as well as that of precipitation has been measured and interpreted for most of the geothermal regions. An early review was published by Fan and Wang (1988). Similarity of geothermal and meteoric waters in China was demonstrated in their review.

Isotopically, geothermal water in China can be grouped into two extreme types, i.e. the cyclic waters which have contact to some extent with the atmosphere, and the other type being basin brines (Wang and Wang, 1996). There are then different transitional types between the two. As far as geothermal development is concerned, we are mainly interested in the former type, the cyclic waters. This type of geothermal water is very similar in isotopic composition to that of the average global precipitation. As shown in Figure 2, cyclic waters plot in the vicinity of the Global Meteoric Water Line (GMWL) (also called World Meteoric Line - WML) on a δ^2H vs $\delta^{18}O$ graph.

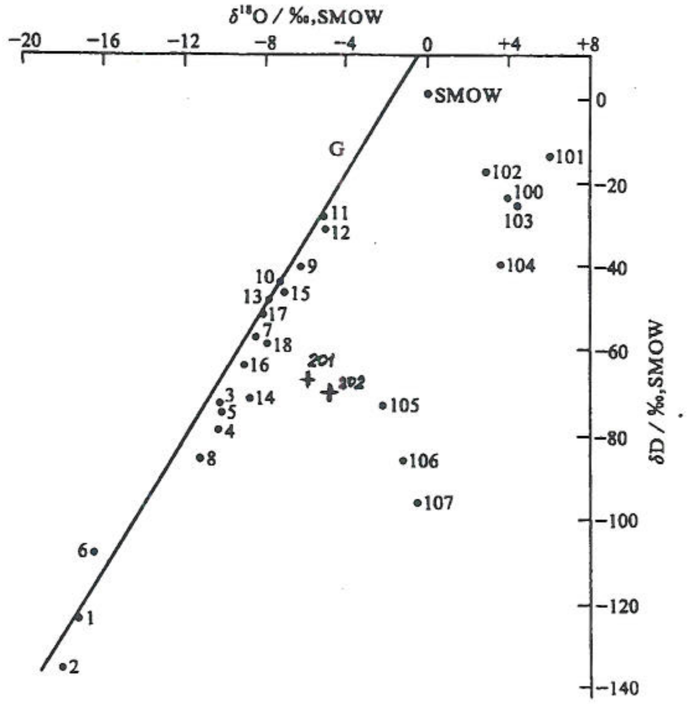

Figure 2: Isotope composition of geothermal waters in China (Wang and Wang, 1996 with new data from North China Basin added); Points 1-18 are for geothermal waters from regions including Yangbajing of Tibet (1-2), Yunnan (3-4), and other areas of China; Points 101-107 are for basin brines from Sichuan Basin; Points 201 and 202 are our recent data from North China Basin

However, the use of isotope signatures in precipitation in the investigation of individual systems is still hampered by the lack of baseline data or input functions of local meteoric waters. Long-term monitoring of local precipitation is very much needed. This will benefit from the recent efforts made by the IAEA to further strengthen the global network for isotopes in precipitation (GNIP) (Pang et al., 1998).

2.2 Contribution to the genesis analysis and potential assessment of geothermal systems in China

As mentioned above, a general picture of geothermal systems in China, their genesis types, energy potential and possible uses is quite clear now. In this process, isotope and geochemical techniques have played a key role in providing evidence on the origin and recharge, age and dynamics, and most importantly, reservoir (deep) temperature estimation.

2.3 Contribution to understanding of water-rock interaction processes

Oxygen shift, a common phenomenon found in most high-temperature geothermal systems, does not seem obvious in the systems with relatively high temperatures in China, as has been indicated by many authors, and as is shown in Figure 2, except for the hot springs in Tengchong, Yunnan Province, where a slight shift up to 2‰ has been reported by Shen (1988) and 1‰ by Zhao et al. (1996). Experiments have shown that water rock interaction may be responsible for the oxygen shift found in the ore forming fluids of the fossil geothermal system in Jiangxi Province (Zhou et al., 1995) (Figure 3).

Enrichment in O-18 and deuterium relative to Local Meteoric Water Lines is encountered in many geothermal systems in China, where processes like the mixing of different waters are identified by isotopic and other geochemical techniques. This will be discussed with examples later.

2.4 Tracing the origin of geothermal gases, Yunnan and Jiangxi Provinces

Noble gas (He) isotopes have been used to trace the origin of geothermal gas discharges (Wang, et al., 1993). Results have shown that a mantle contribution of CO_2 is found in both high and low temperature systems (Tengchong, Yunnan and Hengjin, Jiangxi).

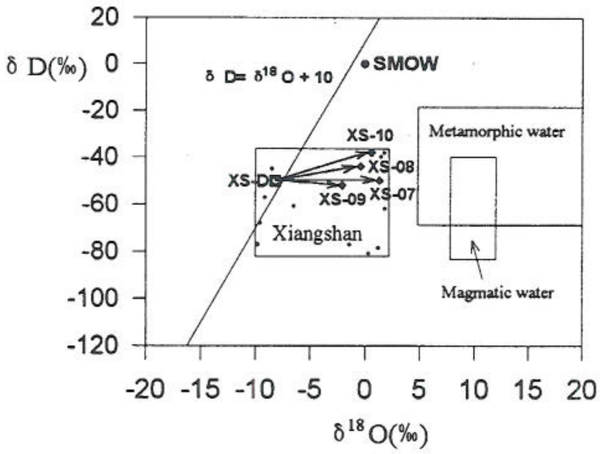

Figure 3: Oxygen-18 shift in the Xiangshan fossil geothermal system (after Zhou et al., 1995)

3. METHODOLOGY DEVELOPMENT

3.1 Geochemical modelling

The understanding of chemical equilibrium of water-rock interaction is the key to the successful application of chemical geothermometers. Efforts have also been made to improve the existing methods for this purpose. Recently, a new approach named FixAl that entails the construction of a modified Q/K graph has been proposed (Pang and Reed, 1998). This technique eliminates problems with water analyses with Al data lacking as erroneous. In addition to Al concentration errors, degassing of CO_2 and dilution of reservoir water interfere with computed equilibrium geothermometry. These effects can be distinguished in a Q/K graph by comparing curves for non-aluminous minerals to those for aluminous minerals and then correcting for CO_2 loss and dilution by a trial and error method.

Type geothermal waters from China, Iceland, and the USA that are used to demonstrate the methods show that errors in Al concentrations are common, and some are severe. The FixAl approach has proved useful for chemical geothermometry for geothermal waters with data on Al lacking as incorrect. The equilibrium temperatures estimated by the FixAl approach agree well with quartz, chalcedony, and isotope geothermometers.

3.2 Calibration of chemical and isotope geothermometers

Conventional geothermometers involve significant uncertainties in prediction of the reservoir temperature of geothermal systems. The difference in the reservoir temperatures given by different silica and cation geothermometers can be as great as 50-100°C without calibration to the specific geothermal conditions. The calibration method was illustrated by the Southeast China geothermal belt in which a reference geothermal system is selected for calibration and to which the chemical equilibrium modelling is applied. Suitability analysis of conventional chemical geothermometers is based not only on the measured down-hole temperature but also on the fluid-mineral equilibrium state of the reference system (Pang, 1992).

4. FIELD APPLICATIONS TO GEOTHERMAL EXPLORATION AND PRACTICAL IMPACT

4.1 Tracing the origin of geothermal water and salinity: Zhangzhou geothermal field, Fujian

Most of the hot spring waters in Southeast China are dilute. However, thermal waters from some geothermal systems close to the seashore are saline. The total dissolved solids in thermal waters in the Zhangzhou geothermal field is as high as 10,000-12,000 mg/l. The mixing of meteoric water with sea water is evidenced by the close correlation of the chloride concentration with that of bromide (Figure 4). This is also supported by the close linear correlation between chloride concentrations and the oxygen–18 ratio (Pang et al., 1995).

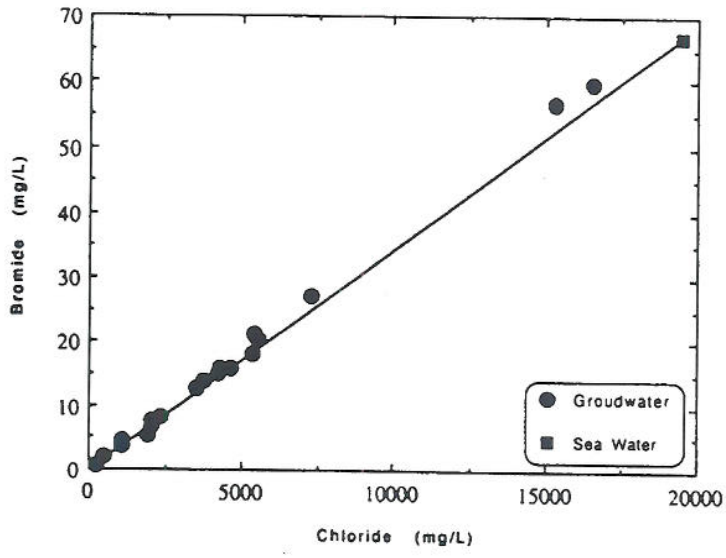

Figure 4: Mixing of meteoric water and sea water to produce high salinity geothermal water in the Zhangzhou geothermal system, Fujian Province, China

Sea water entered the systems during a period of high sea level, which occurred, for Southeast China, 6,000-7,000 years ago according to some geological evidence. The dilute waters from other systems have chemical features derived from the dissolution of the granite country rocks. Knowledge of the mixing processes have deepened the understanding of the genesis and origin of the systems. For instance, for Zhangzhou geothermal field, two mixing episodes are postulated: 1) Primary mixing at a depth of 3-4 km; 2) Secondary mixing between the ascending saline thermal water and the dilute ground water in the shallow Quaternary aquifer.

4.2 Vertical migration of geothermal formation waters, East Hebei

In a recent investigation in North China Basin, isotope and geochemical evidence has shown that vertical migration of geothermal formation waters from deeper aquifers to shallower aquifers has taken place to produce a unique geothermal anomaly, the geothermal gradient which is as much as 3 times higher than the background in the same area. This may be considered a new type of geothermal system in large sedimentary basins such as North China Basin.

4.3 Estimation of deep temperature in the geothermal systems using chemical and isotope geothermometers, Southeast China and West Yunnan

It is found that both the chalcedony and the Na-K-Ca geothermometers are suitable for the geothermal systems with meteoric water, but the chalcedony geothermometer yields better results for the coastal geothermal systems with seawater-modified water. For most of the geothermal systems in the geothermal belt, the reservoir temperatures obtained are within the range 100-120°C and the highest is 150°C (Pang, 1992) (Figure 5).

The use of ^{18}O (SO_4) isotope geothermometers, especially for low- to medium-temperature geothermal systems, was in doubt before it was carried out in the Zhangzhou geothermal system (Pang et al., 1995). However, it turned out to be still applicable in a geothermal system like this one. The water and dissolved sulfate show good equilibrium at 150°C, which serves as a very good indicator of the reservoir temperature (Figure 6).

Gas geothermometers have been used recently to estimate the deep temperatures in the Rehai geothermal system, Tengchong, Yunan province and for the Yangbaijing geothermal system, Tibet (Zhao et al., 1996; Zhao et al., 1998). This study has provided more evidence for, and refined, the conceptual model of the system proposed earlier.

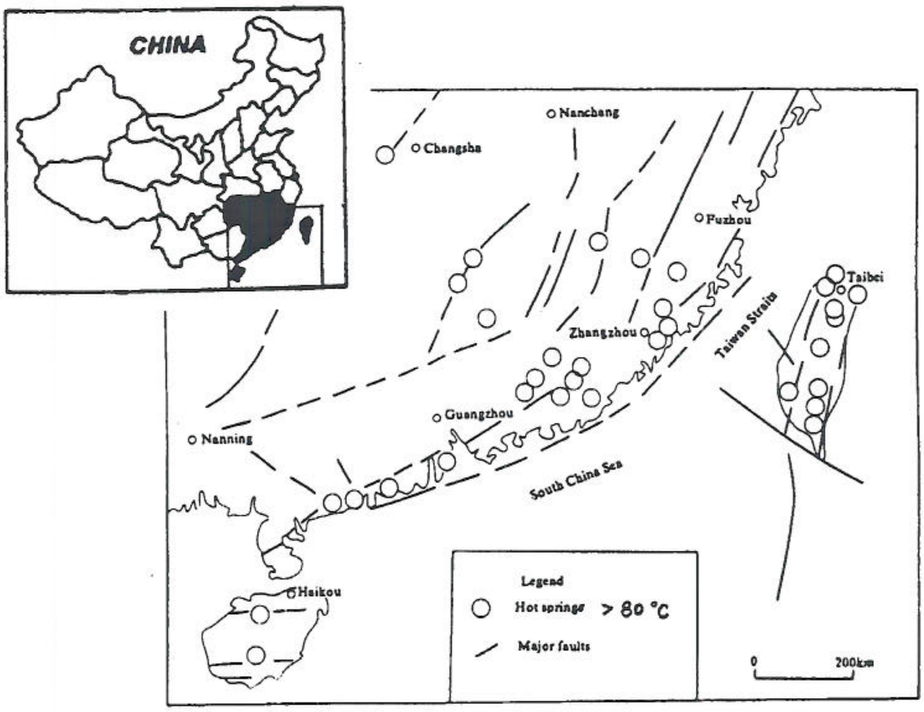

Figure 5: Distribution of geothermal systems with emerging temperatures higher than 80°C in Southeast China

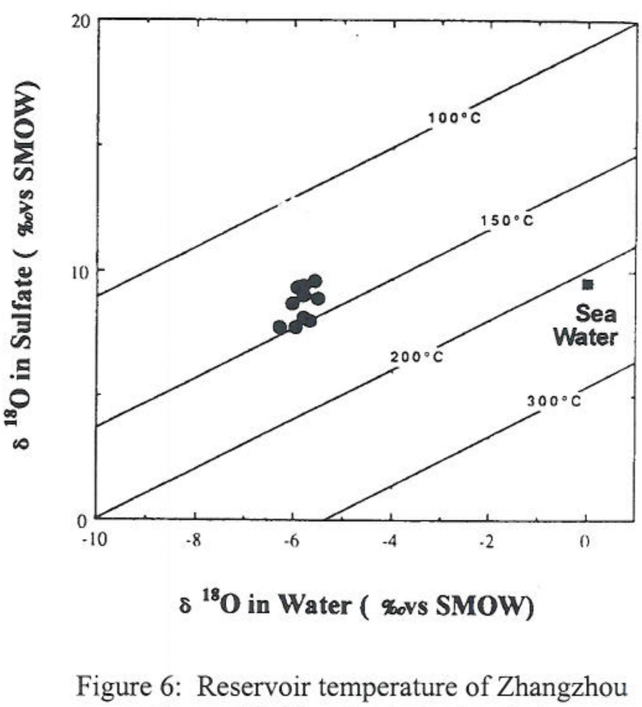

Figure 6: Reservoir temperature of Zhangzhou geothermal field estimated using isotope geothermometer based on aqueous sulfate

The major gas in geothermal steam in the Rehai geothermal field of Tengchong is CO_2, the minor gases are N, H_2S, H, and CH_4; the trace gases are He and Ar. The CO_2/H_2S ratios in steam are rather high. Magmatic fluid has probably invaded the geothermal reservoirs to keep up an internal pressure. This steam presumably comes from individual reservoirs at different depths. The estimated temperatures by gas geothermometers are in the range of 180-210°C for the upper reservoir and around 250°C for the lower one.

Comprehensive geological, geochemical and geophysical investigations and exploration including large numbers of drillhole measurements and well testing, have yielded a remarkable understanding of geothermal systems in China. Major types of geothermal systems have been identified and their energy potential assessed. The contribution of isotope and geochemical techniques has been considerable.

5. FUTURE OUTLOOK

Estimates of the geothermal power potential are 1000 MWe in South Tibet, 570 MWe in West Yunnan, 170 MWe in West Sichuan and up to 100 MWe in the Tatun region of Taiwan. However, the installed capacity is only 25 MWe. There is still a lot to be tapped. Drilling is under way in Tengchong field of Yunnan and in Yangbajing of Tibet, where a possible deep reservoir has been encountered with temperatures of 250°C at wellhead and 330°C at the bottom-hole. Some of the low-temperature reservoirs utilized have experienced serious drawdown.

In this context, it is still not clear which are the most urgent future tasks. The following topics are probably of relevance for future efforts in the field of isotope and geochemistry of geothermal fluids.

- Improve the understanding of geothermal systems; such as to develop or apply additional isotope tools such as, dating tools and noble gas isotopes.

- Understanding the origin of acidic fluids, like the reasons for and finding solutions to scaling and corrosion. For example corrosion problems are encountered in Zhangzhou geothermal field which is being exploited mainly for direct uses, with economic benefits to the local people that are quite promising. However, corrosion caused by high Cl concentration in the geothermal water has shortened the life time of pumps and pipes a lot, and this has increased the cost.

- Reservoir response to long-term exploitation. Both from the resource conservation point of view and the environmental point of view, reservoir monitoring and re-injection of waste water are very important for sustainable development of a geothermal system or area.

- National network for information system on isotope geochemistry of geothermal fluids. This has been in operation for about two years within the framework of the IAEA regional geothermal project for Asia and Pacific and progress has been made.

- Evaluation of the environmental impact of geothermal development. Geothermal energy is, in general, environmentally friendly compared to fossil fuels. But the discharge of waste water which contains heavy metals and other poisonous elements should be placed on the agenda. Assessment is necessary before any concrete measures can be taken.

Enhanced co-operation and training of professionals are needed to fulfill these tasks.

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