GEOTHERMAL POTENTIAL IN SE CHINA ASSESSED BY GEOCHEMICAL AND ISOTOPIC METHODS — A REVIEW

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SUMMARY - A review is given of the main results obtained from geochemical and isotopic studies for geothermal exploration and potential assessment for development in the low temperature geothermal areas of southeastern China. Emphasis is on the applicability of the various techniques to the areas concerned and the results obtained for them. Approaches used include chemical analysis on both major and trace elements; isotope determinations for oxygen, hydrogen and carbon in the water of interest; chemical geothermometry - the calibration and application. Discussions are included for the geochemical study on saline geothermal water and recommendations made.

1. INTRODUCTION

Hot springs are widely distributed in the coastal areas of southeastern China (Fujian, Guangdong and Hainan Provinces). There has long since been intensive dispute about the genetic origin of these hot springs. Some workers suppose that these hot springs are the surface manifestations of high temperature geothermal systems with abnormal heat sources. The Occurrence of geysers, high salinity and other chemical features of the thermal waters were taken as indicators for subsurface high temperatures. In this context, appropriate exploration and assessment of the systems become necessary, Therefore, since 1985, the present authors and others have initiated and carried out a multi-disciplinary project (Wang et al., 1989). This included a detailed investigation of the chemistry and isotopic composition of the thermal waters in order to understand the crucial problems such as the origin of the thermal fluids, recharge sources of the systems, the chemical characteristics and the dominant factors and/or processes that control them, the age of the fluids, the chemical equilibrium state of the fluid with the reservoir rock(s) and the range of the reservoir temperatures, etc. Items under investigation include the major and trace elements, oxygen, hydrogen and carbon isotopes. Computer modeling of the fluid-mineral equilibrium was also carried out for some of the systems.

2. ORIGIN OF THE THERMAL FLUIDS AND RECHARGE OF THE SYSTEMS

A local meteoric water line was determined based on the study of different types of present-day meteoric waters including rainwater, river water and shallow ground waters (Pang & Wang, 1990). This line was found to be identical to the world line. The data points from isotopic analyses of the thermal waters plot in the close proximity to the meteoric line, which implies their meteoric origin. According to the "elevation effect" principle, the elevation of the recharge areas for the hot spring systems were determined. Results show that for the recharge areas of the systems this is usually 800 to 1000 meters higher than that of the discharge areas. In most cases, recharge areas are the periphery of the groundwater basins. With some reference to modelling the mass and heat transport and conservation in the systems (Hu, 1989, Hochstein and Yang, 1990), it is concluded that these hot spring systems are most likely to be formed by the deep circulation of groundwater within the basins by forced convection induced by topography.

3. PROCESSES GOVERNING THE FLUID COMPOSITIONS

Most of the hot spring waters are dilute. However, thermal waters from those geothermal fields close to the sea are saline. The total dissolved solids in these waters may be as high as 10 to 12 g/l (Pang, 1987). The mixing with sea water of the recharged meteoric water is evidenced by the close linear correlation of the chloride with bromine contents. This is also supported by the close linear correlation between the chloride concentrations and the Oxygen-18 and Deuterium values (Pang et al., 1990). The Zhangzhou-Xiamen geothermal zone was selected as the sampling area for a detailed investigation on this sea water mixing with process. Samples at increasing distance and with different salinities were collected for chemical and isotopic analyses and interpretation. The sea water in most cases is connate sea water that entered the systems in the local high sea level period about 6,000 to 7,000 years ago. The dilute waters from other systems have chemical features derived from the dissolution of the granitic wall rocks. A knowledge of the mixing processes has benefited the understanding of the systems. For the Zhangzhou Geothermal Field, it is found out that two steps of mixing takes place in the system: the mixing of meteoric water with with the connate sea water at depth is the first step and the mixing between the ascending saline hot water with the dilute groundwater in the shallow aquifers is the second (Pang & Wang, 1991).

4. AGE OF THE WATERS

The age (residence time) of the geothermal fluid is defined as the time since it was last isolated from the atmosphere. Radioactive isotopes tritium and carbon-14 were used for dating of geothermal and other natural waters in the study areas (Pang et al., 1990a). Geothermal parent waters are tritium free. The presence of tritium in the thermal water is an indicator of dilution by the "young" shallow groundwater. Tritium was found to be quite effective for the investigation of the relationship of different types of natural waters and especially the relationship of geothermal water with them. However, it is not a good dating method because the age of geothermal waters is far beyond the range (about 100 years) of tritium method. Thermal water from Nanjin hot spring to the west of Zhangzhou basin was dated using Carbon-14 dating method and was calculated to be about 1,755±360 years old. However, carbon-14 dating was not successful when applied to the saline hot water because of its low carbon content,

5. WATER-ROCK INTERACTION AND GEOTHERMOMETRY

Modeling studies on the fluid-mineral equilibrium state of the geothermal systems were carried out for selected systems typical of different kinds (Pang, 1988; Pang & Armannson, 1989). Calibration on conventional chemical geothermometers was done in the light of this modeling (Pang, 1991). And the study on alteration mineralogy was also done to match with the modeling output.

Results show that for most of these low temperature systems, equilibrium between the thermal fluid and the wall rock(s) does not exist. The implication of this conclusion is essential to the application of conventional chemical geothermometers. For this reason, mixing models for geothermometry should be used where necessary.

Hydrothermal minerals are frequently encountered by drillholes in the geothermal fields like Zhangzhou, Fuzhou and others. The alteration minerals in Zhangzhou Geothermal Field are: epidote, quartz, calcite, laumontite, prehnite, pyrite, opal, fluorite and chlorite, etc. Assemblage with some of these minerals were predicted by the equilibrium modeling.

Based on the measured downhole temperature and the fluid-mineral equilibrium modeling, conventional geothermometers are calibrated for their suitability in the area with granite as the representative reservoir rock. For the geothermal system selected for calibration that resulted in equilibrium from modeling, conventional geothermometers seem to be in good agreement with the measured temperatures, and those inferred from fluid-mineral equilibrium. Chalcedony seems to control the amount of dissolved silica in the thermal waters. Different geothermometers agree with the common trend of the reservoir temperatures for the hot springs from the south of Fujian Province though a discrepancy exists among them when used for a particular system. Na-K geothermometers should be used with great care for they tend to give temperature much higher than those by other methods. For saline thermal water from the coastal systems, cation geothermometers are not applicable because the relative ion ratios among them tend to be dominated by those of the sea water rather than the equilibrium process. Fortunately, the silica geothermometers show only minor effect due to salinity of this magnitude and still yield satisfactory temperature estimates for the saline waters.

By applying suitable chemical geothermometers and appropriate mixing models, the reservoir temperatures of the geothermal systems were calculated. The results for most of the systems range from 100 to 120°C. For the Zhangzhou Geothermal Field where the highest downhole temperature was measured, the reservoir temperature was found to be around 140°C by adopting a silica mixing model (Pang et al., 1990b). Studies (Xiong et al., 1990) have shown the water here has to circulate down to a depth about 3.5 to 4 km to get heated to that temperature.

6. DISCUSSION AND CONCLUSIONS

Geochemical and isotopic methods have been found to be very effective for the geothermal exploration and potential assessment of the low temperature geothermal systems in the southeast of China. It can be concluded from these studies that the hot springs are fed from low temperature systems formed by the deep circulation of meteoric water. The reservoir temperatures of these hot systems ranges from 100 to 120°C and is unlikely to be considerably higher than 140°C within the depth of interest. Since the sea water in the saline water systems is most likely to be connate sea water, the salinity of the water will drop with their long-term exploitation.

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