GEOLOGY AND GEOCHEMISTRY OF REHAI (HOT SEA) GEOTHERMAL FIELD IN TENGCHONG, YUNNAN PROVINCE, CHINA

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ABSTRACT

Rehai (Hot Sea) in Tengchong is an important hydrothermal area in south-west China. It is a Cenozoic volcanic area produced by the convergence of the Indian and Eurasian Plate.

The surface activity is spread over 7.5 km^2 and the natural heat flow from the area is of ca. 125 MW. The majority of springs in the area discharge near-neutral bicarbonate-chloride-sodium water. The alkali thermometers suggest general reservoir base temperature of about 230°C. Dissolved gas in the water is mainly CO_2. D/H values in the water indicate that a high proportion of hot water is derived from a meteoric source, but might contain a small amount of abyssal water. 'Finally, we calculate the heat content of the field as ca. 8.1×10^{12} MJ.

INTRODUCTION

Rehai (Hot Sea) geothermal field (N42° 57.5'/ E98° 26.5') is a high temperature hot water system in, West Yunnan Province near the border between the People's Republic of China and Burma.

The arresting feature of Rehai (Hot Sea) to the traveller visiting, or passing through, is the multitude of vapour plumes ascending from the hot springs. More than 300 years ago, in 1639, the great Chinese geographer of the Ming Dynasty, Xu Xia-ke, travelled all the way across many mountains and set foot there; his detailed account of Tengchong Geothermics is given in his book of "Xu Xia-ke Travel Notes".

In 1973/74 we made a reconnaissance of the geology, volcanoes and geothermics in detail, and submitted a comprehensive report'.

THE REGIONAL SETTING

Tengchong is a Cenozoic volcanic area including basalt, andesite and dacite produced by the under-thrust convergence of the Indian Plate and the Eurasian plate. The Cenozoic volcanoes can be subdivided into four: Pliocene alkaline basalt and dolerite, E. and M. Pleistocene calc-alkali andesite and dacite, Late Pleistocene alkaline basalt and Holocene calc-alkali andesite-basalt (Fig. 1).

The basement of pre-volcanic rocks consists of a metamorphic Palaeozoic group and Mesozoic granite. The Molasse-like Neogene system is locally distributed.

The regional trend of the range is tectonically meridian, but is curved into a series of arcuate structures towards south-east, because of strike-slip movement along the Wandin fault with an E-W strike. Rehai geothermal field is situated just at the top of the Lianghe-Guyong arc fault zone.

The basement of the geothermal field is Late Cretaceous granite with a K-Ar age of 68.8 m.y; these were covered by the Miocene granopatic sand-stones and conglomerates which are altered into kaolinite and a mixture of illite and montmorillon-ite at the surface. An anticline with N-S strike developed in the Miocene, on the crest of which there are many longitudinal crest faults with dextral rotation, joints, fissures, veins, and so on, which may be passages for thermal fluids and which are important locally in controlling hydro-thermal activity including thermal springs and quartz veins.

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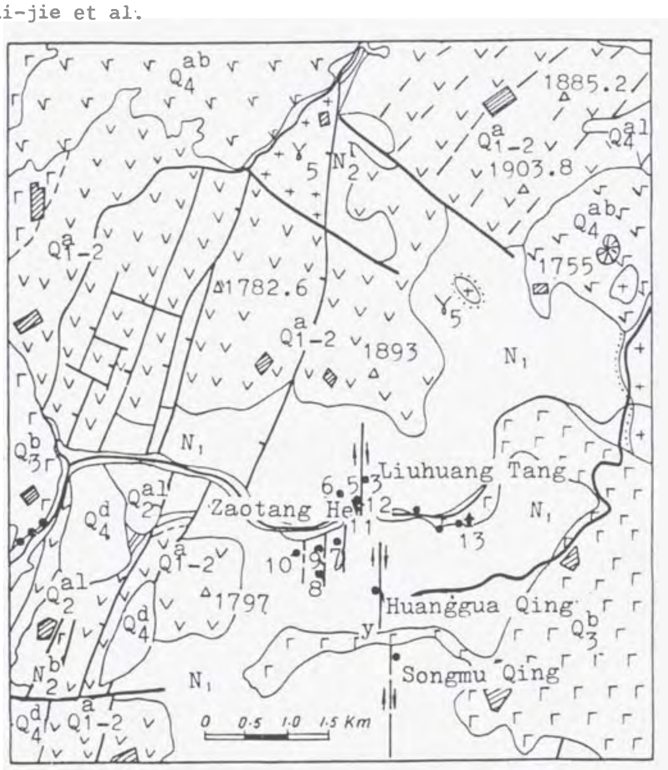

Q_4^{al} Holocene alluvium
Q_4^{d} Holocene debris
Q_4^{ab} Holocene andesite-basalt
Q_3^{b} U.Pleistocene basalt
Q_2^{al} M.Pleistocene alluvium
Q_{1-2}^{a} M-L.Pleistocene andesite-dacite
Pliocene basalt
N_1 Miocene conglomerates
γ_5 Mesozoic granite
f Faults
⊛ Crater
• Thermal areas

Fig.1, Geological map of Rehai Geothermal Field

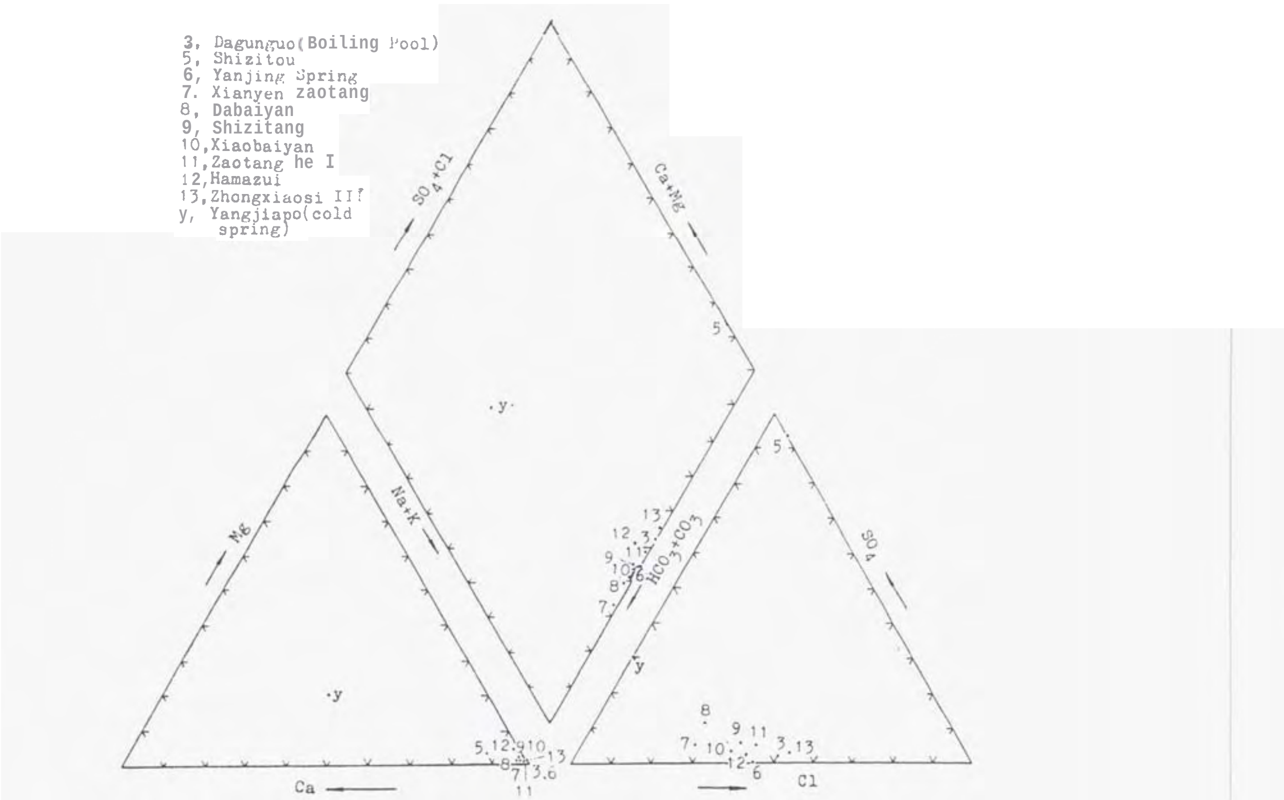

Fig. 2, Hydrothermical characteristics of thermal waters from Rehai (Hot Sea) geothermal field

SURFACE MANIFESTATIONS

The thermal activity covers an area of ca. 7.5 km^2 estimated from the distribution of hydrothermal minerals.

There are three main thermal areas in Rehai: Liuhuang Tang, Huanggua Qing and Zaotang He Falls which are located just at the crest of the anticline. The hot springs emerge from the fault on the crest. Other areas appear on the flanks and emerge from some minor longitudinal faults.

Huanggua Qing (Cucumber Gully), at the highest altitude, in reality merely represents a zone of steam condensation without any hot springs. Many needle-like sulphur crystals are frequently found around the small fumaroles. The temperature gradient reaches 2.36°C/m in shallow hole of 3.63 m depth.

Liuhuang Tang (Sulphur Pool) is celebrated for its big boiling pool with a temperature of 89°C, which has a small outflow of 0.91 l/s and which has been chemically enriched. On the other hand, the thermal area is characterised by steaming ground, over which widespread surface and near-surface sulphur deposit and white alunogen and gypsum occur.

Zaotang He (Bathing River), at the lowest altitude, is a stream from east to west across the field. There are varieties of hot springs of different sizes along the shore. Viewed from the floor of the valley the falls, formed by a quartz vein 1.5 m thick, with springs, is indeed a spectacle. The Bathing River is raised in temperature by about 7.5 or 17.5°C passing over the Fall in the monsoon season with a flow rate of 1000 l/s, or 340 l/s in the dry season, and an equivalent heat input of 31 MW. The natural heat flow from the field has been measured and found to be of ca. 125 MW.

CHEMISTRY

The majority of springs in the area discharge near-neutral bicarbonate-chloride-sodium water containing generally between 57 and 295 ppm chloride, 250 and 637 ppm bicarbonate, 18 and 56 ppm sulphate, and 130 and 440 ppm sodium. With a few exceptions, the carbonate concentrations are in the range 770 to 1168 ppm and chlorides are in the range 559 to 698 ppm in the No. 3 (Sulphur Pool) and No. 6, respectively. Acid sulphate spring with 16 ppm chloride and 303 ppm sulphate are located at higher altitudes. The cold water at 23°C contains 44 ppm bicarbonate and 16 ppm sulphate (Fig. 2). Low boron of ca. 4 ppm in Tengchong's hot water is quite unlike fields in Xizang (Tibet).

The linear relationship between the temperature and chloride is obtained from a least square fit: $T = 0.2\ Cl + 30.3$ which could reflect the degree of the mixing of hot and cold waters.

On the other hand, 3 points enormously deviate off the oblique line, as the No. 5 is steam heated low-chloride water, and No. 3 and No. 6 have enriched chemical contents due to surface evaporation and impediment of running water (Fig. 3).

The linear relationship is present inbetween temperature and TDS. The TDS of cold water is about 107 ppm, but the TDS of the hottest springs has a maximum value above 1300 ppm. It goes without saying that the TDS of concentrated water in the boiling pool (No. 3) is considerably higher with 2799.4 ppm.

The contents of SiO_2 and the Na/K ratio were used to determine the minimum underground temperature. The geochemical thermometer, as indicated by Na/K and Ca/Na/K ratios, which is generally found to be higher than that indicated by SiO_2, suggests a general reservoir base temperature of 230°C. Obviously, the changes of the chemical composition in the spring waters are mainly due to dilution and cooling by mixing with cold water entering near-surface aquifers from the margin of the thermal area. Mixture with cold water has a considerable effect on silica content.

The greater part of the non-condensable gases accompanying the hot spring fluid consists of CO_2, being approximately 40-85.6% by volume. The average H_2S concentration is approximately 10-30% by volume. Other gases include CH_4, N_2 and O_2.

Fig. 4 shows the results obtained from a survey of the D:H and ^{18}O : ^{16}O ratios in hot and cold

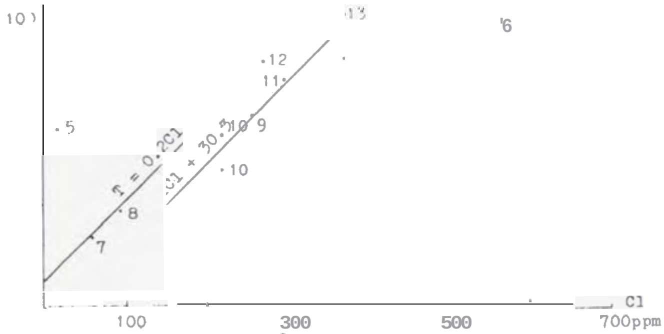

Fig.3, Plot of $T^{o}C$ versus Cl from Rehai Field.

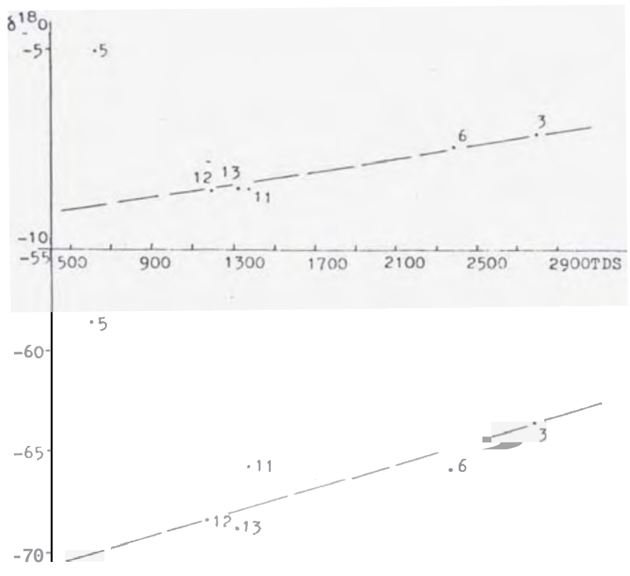

Fig.5, Plots of $\delta^{18}O$ and 6 D versus salinity.

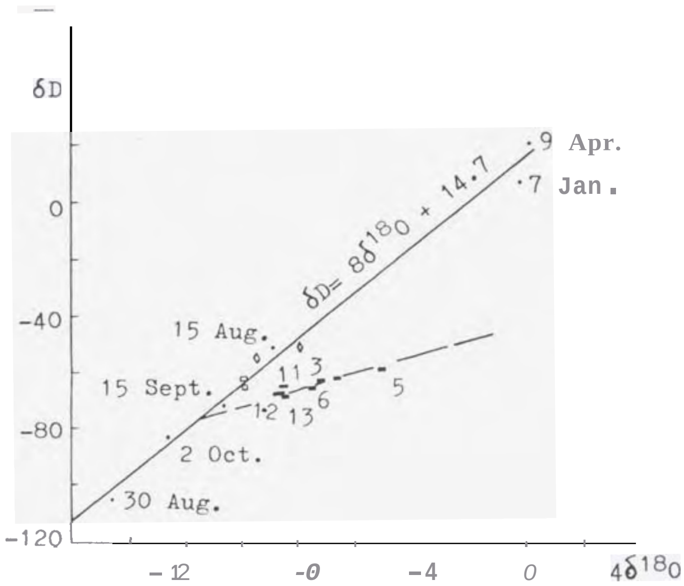

Fig.4, Values of 6D and $\delta^{18}O$ for samples of the thermal(-), cold spring(◊), surface waters(▫), and rainwaters(*) in Rehai Field.

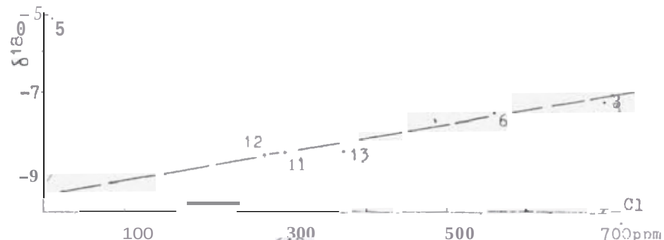

Fig.6, Plot of $\delta^{18}O$ versus Cl from Rehai Field

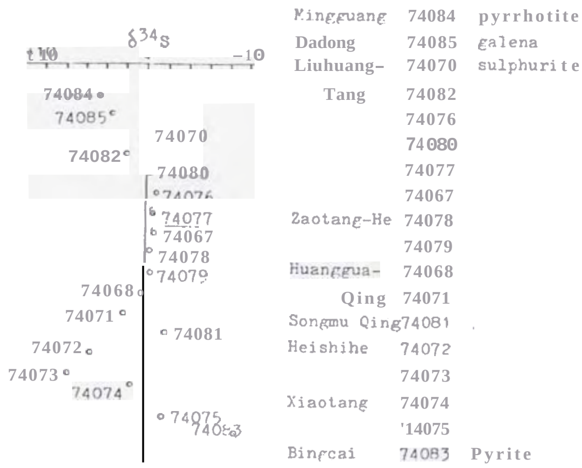

Fig.7, The $\delta^{34}S$ values of Rehai Field and other areas in Tengchong waters in and around Rehai field. Similarly, the ^{18}O and D contents increase with TDS (Fig. 5).

Figure 4 also reports the isotopic composition of the local cold waters and shows a straight line with a slope of 8, which represents the actual meteoric waters falling in Tengchong region. The following linear relationship is obeyed by precipitation and by most surface waters:

$$\delta D_{SMOW} = 8\delta^{18}O_{SMOW} + 14.7$$

The hot waters fall on a line which approximately intersects the local meteoric water composition and has a slope of the value of 3, indicating significant boiling and condensation effects. The fact that the value for the cold water springs is larger than that of recharge water shows that the local water catchment area of the hot water is far away.

In terms of the positive correlation between $\delta^{18}O$ contents and variations of Cl of the hot water (Fig. 6), the waters are predominantly meteoric in origin but might contain a small amount of NaCl-rich deep fluid with a higher, heavier isotopic ratio.

Studies of sulphur isotope have been made on 9 samples taken from natural sulphur in the hydrothermal area. The results of these analyses are plotted in Fig. 7 and indicate that the $\delta^{34}S$ of these samples are very close to the $\delta^{34}S$ of CDT. There might exist, therefore, abyssal heat recharge for the high temperature hydrothermal system.

ROUGH ASSESSMENT OF HEAT CONTENT

The information that will enable us to assess reservoirs should come from the following series of measurements: scientific exploration, geochemistry and geophysics; well drilling - downhole measurement; well discharge and field production results.

It is a pity that the geophysical measurements and drilling have not yet been done in this field. But based upon the method of assessment of geothermal resources of the United States[2], we can try to roughly assess the heat content of the Rehai Field.

The subsurface area, assumed to be underlain by a reservoir of the indicated average temperature of 230°C, is about 7.5 km^2 and is derived from the following data which includes the surface area containing springs, spring deposits and hydrothermal alteration.

The heat reservoir for the Rehai convection system is arbitrarily assumed to extend to 3 km in depth, which is the current limit of geothermal drilling. Though there is no data on depth available about the top of the convective reservoir, the top is generally assumed to have an average depth of 1 km.

If the volumetric specific heat is assumed to be 0.6 $cal/cm^3\ ^{\circ}C$, and the mean annual surface temperature is about 14°C, the heat content of Rehai (Hot Sea) geothermal system will be 8.1×10^{12} MJ.

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