THE BONGBENG (PEAFOWL SPRING) GEOTHERMAL PROSPECT, RUILI COUNTY, YUNNAN PROVINCE, P.R. CHINA

Jia Xiyi, Duan Dingyong, Liao Zhijie[1] and Ren Xiang[2]
2nd Hydrogeological Team of Yunnan Province
[1]Department of Geology, Peking University
[2]Geothermal Committee of China Energy Research Society

SUMMARY

This paper describes the geological setting, the hydrogeology of the Bongbeng geothermal field in Ruili County, and the geochemistry (including isotopic chemistry) of discharged thermal waters. It also discusses the geothermal prospects in Ruili County.

Geological Setting

The Bongbeng (Peafowl Spring) geothermal prospect (97° 53.7'E/24° 01'N), at an elevation of about 755 m, is located in the eastern part of Ruili Basin at the border between China and Burma. It is the largest Cenozoic basin at the border of Yunnan and Burma covering an area of about 1400 km^2, 15% of which lies in China, with the remaining 85% in Burma. Geological formations in the region can be classified into several stratigraphic units, namely:

Q_4 Holocene alluvium: pebble and sand;
Q_3 Upper Pleistocene alluvium: sand and pebble.
Q_2 Middle Pleistocene alluvium: sand and clay.
Q_1 Lower Pleistocene alluvium: conglomerate.
N_2^2 Upper Pliocene: clay rock and sandstone;
N_2^1 Lower Pliocene: conglomerate.
T_3^s Upper Triassic: dolomite.
T_3^n Upper Triassic: slate and siltstone.
P_1^s Lower Permian: limestone and dolomite.
Є Possible Cambrian: migmatite and gneiss.

Granites intruded the area during the Late Cretaceous (Fig. 1).

The Palaeozoic metamorphic and sedimentary rocks and the Cretaceous granites outcrop in peripheral areas of the basin. The central part of the basin is covered by 150 to 500 m thick Cenozoic sediments. Judging from the cores of some drillholes, the basement rocks beneath the Cenozoic formation are mainly of Triassic age. The Bongbeng prospect is at the junction of the Longling-Ruili Fault with NE strike, and the Wanding Fault which trends E-W.

The Longling-Ruili Fault separates two microplates and is a ductile shear belt (Lin Wenxing, 1990) along which rocks have been thrusted from north west to south east. The western hanging wall exposes Gondwanaland sedimentary and metamorphic rocks, and the strata on the opposite wall are similar to those of the Shan massif (Liao Zhijie, 1988). The granites intruded along the Longling-Ruili Fault during the Late Cretaceous.

The Wangding Fault in the Shan massif is older than the Longling-Ruili Fault. It is still uncertain whether the Wanding Fault merges with the Longling-Ruili Fault or is cut off by this fault beneath the Ruili Basin.

Hydrogeology

The Occurrence of the Bongbeng boiling spring and associated natural hot water ponds is an expression of the high thermal activity of Ruili County (PLA 00939 unit, 1979; Tong Wei et al., in press). Three boiling pools are located near the northern bank of the Ruili River. The temperature of the hot water discharged from pools is between 60 and 96°C; the total flow is about 5.43 l/s. These boiling pools could be the result of hydrothermal explosions. A recent explosion took place in April or May 1966, June or July 1966, and in February 1970. In addition, many seepages issue from the bed of the Ruili River in the dry season.

Exploration Drilling

In order to look for groundwater in the Ruili Basin, 18 wells with depths between 80 and 300 m were drilled by the 2nd Hydrogeologic Team of the Yunnan Geological and Mineral Resources Bureau during the period 1989 to 1990. From the measurement of downhole

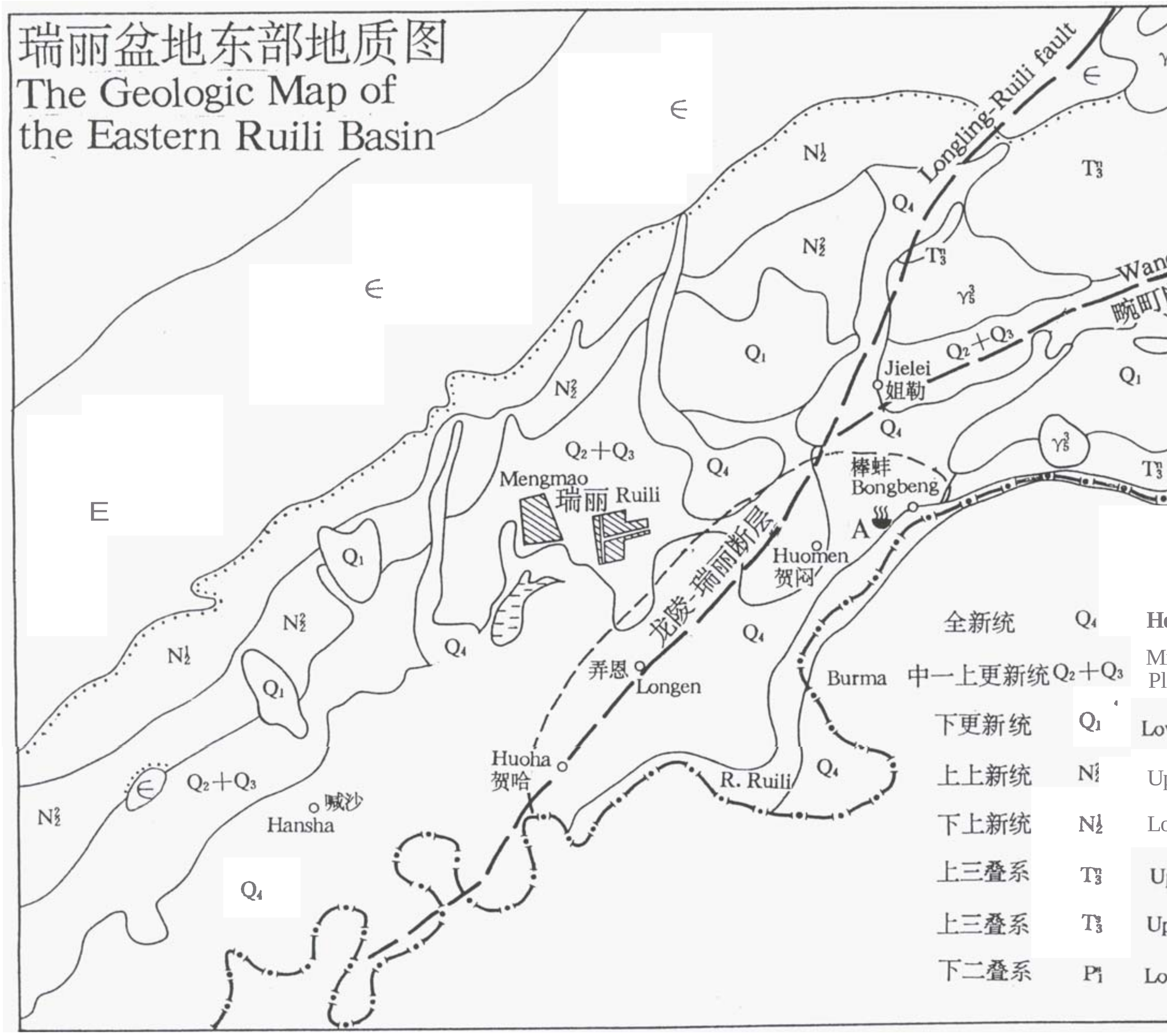

Figure 1: Geological map of the eastern Ruili

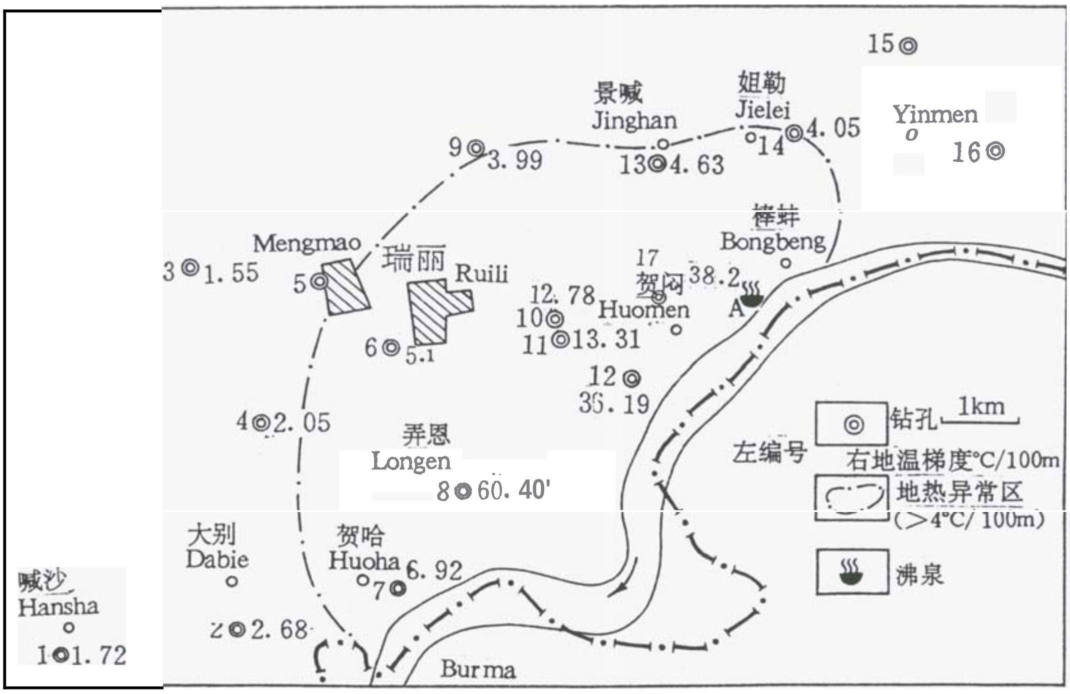

Figure 2: Temperature gradient contour (4°C/100m) of the Bongbeng Field.

temperature in the wells it was noted that the temperature at the bottom was between 60 and 97.5°C in nine wells. The results of drilling indicate that the Bongbeng thermal area could be as large as 11.8 km^2 based on the 4°C/100 m gradient contour (Fig. 2). Based on the anlysis of temperature profiles for six wells shown in Fig. 3, the following conclusions can be drawn:

(1) There are anomalous temperature gradients in the Cenozoic strata, but T profiles of three wells near the Longling-Ruili Fault (N8, N12 and N17 in Fig. 3) show the largest gradient.

(2) The temperature gradient in basement rock is close to zero (N12); in well N17 there is even a small temperature inversion near the top of the basement.

(3) The measured maximum temperature is only 97.5°C (N12), which is far lower than that given by geothermometers (see Table 2).

According to pumping tests (Table 1), there are three aquifers in the Bongbeng field, here termed the shallow Upper Pleistocene aquifer, the Upper Pliocene aquifer, and the basement fractured aquifer.

The shallow 'Q_3 aquifer' consists of sand and pebble of Upper Pleistocene age with a thickness of 60 to 120 m. This unconfined aquifer is recharged by infiltrating rain water, the Ruili River, or some thermal upflow. The flow rates are between 53 and 1172 m^3/d for different drawdown level. The waters are generally of calcium - sodium bicarbonate type with TDS of 0.2 to 0.5 g/l. An exception is well N8 with a TDS of 1.37 g/l and a temperature of 82°C. A local impermeable layer in the Cenozoic stratum acts as a cap rock.

The Upper Pliocene 'N_2^2 aquifer' consists of sandstone with a thickness between 90 and 160 m. Recharge still takes place by direct infiltration. The water in this aquifer is also of calcium - sodium bicarbonate type with total mineralization of <0.3 g/l. Both Q_3 and N_2^2 aquifers are mixed waters containing some thermal fluids and mainly infiltrated surface water.

The fractured basement (T3) represents in part the geothermal reservoir of the Bongbeng Field and consists of Late Triassic slate and siltstones. Its permeability is predominantly secondary due to fractures. The permeability of the aquifer is highly anisotropic and variable. However, it can be assumed that secondary permeability is highest along the previously mentioned principal directions of faulting and fracturing. At present only two wells (N12 and N17) have been drilled into the basement, which probably did not encounter the deeper part of the fractured reservoir. The water in the fractured basement aquifer is a sodium bicarbonate type with TDS of about 1.3 g/l.

Table 1 Flow testing of drillholes in Ruili County

No.	elevation m	depth m	caliper mm	aquifer strata	aquifer superface m	aquifer base m	aquifer thick m	water table m	T °C	yield l/s	spec. capac. l/s/m	drawd. water level m	spec. yield m^3/d
11	765.61	110.48	146	N_2^2	46.21		64.63	3.75	34	6.165	0.22	28.35	532.85
10	764.11	250.56	172	Q_3	11.63	77.71	66.08	2.53	26	8.53 6.28 4.46	1.30 1.70 1.88	6.59 3.69 2.37	736.99 542.59 162.43
			130	N_2^2	85.27	244.14	158.87	3.05	40	15.14 9.73 6.14	2.18 2.21 2.56	6.59 4.41 2.40	308.1 840.67 530.49
12	764.67	200.94	172	Q_3	19.46	145.89	126.43	3.30	38	1.52 1.00 0.61	0.08 0.08 0.07	19.30 12.8 8.76	131.32 86.40 52.7
			130	T	145.89	200.941	55.05	0.8	63	1.35	0.05	27.57	116.64
a	761.30	88.21	172	Q_3	6.45		81.76	+1.08	82	13.57 10.04 7.50	1.39 1.54 1.72	9.80 6.50 4.75	1172.44 867.45 648.0
17	765.52	180.84	172	N_2^2	4.15	95.02	90.87	2.95	39	3.55 2.98 2.44	0.11 0.12 0.13	32.60 25.15 18.8	306.72 257.47 210.81
			130	T_3^n	143.93		36.91	+22.2	50	0.33 0.11	0.005 0.005	66.45 21.35	28.51 9.5

T is the temperature at wellhead during **pumping.**

Table 2 The main chemical compositions of thermal water in the Bongbeng field(in mg/l)

No.	A*	A	8	8*	12	10	17
°C	95	96	85	85	63	40	50
pH	8	8	6.7	8.1	7.2	7.1	6.9
K	31	25	37.5	37	20	3.0	20.27
Na	380	358	375	356	329	27.72	328
Ca	2.98	1.72	10.34	a.589	6.03	9.64	11.2
Mg	0.63	0.26	0.78	1.958	1.05	3.66	1.57
H_4	1.4	1.11	0.56	1.85	1.28	0.23	1.89
	nd.	nd.	nd,	nd.	nd.	nd.	nd
HCO_3	250	739.88	137.42	923	825.84	122.08	873.61
Cl	24.3	30.76	26.15	22.12	23.84	2.52	35.37
	54.2	25.0	0.5	4.67	0.5	nd	6.0
F	17	17.5	22.5	12.54	18.5	0.44	1.6
HBO_2	29	38.85	26.46	30.15	17.16		2.69
SiO_2	156	144.09	68.25	69.54	07.3	73.74	63.57
TDS(g/l)	1.10	1.38	1.51	1.01	1.33	0.24	1.35
$TSiO_2$	162	159	117	118	130	121	113
TNKC	202	196	200	205	181	61	171
Tkm (T_{K-Mg})	138	146	141	126	117	53	111
Tkn (T_{K-Na})	217	205	232	235	195	-	197

* analyses **by** Peking University.

Table 3 Isotopic compositions af the Bongbeng field

No.	Type of water	Location	Elevation	T(°C)	δD(‰)	$\delta^{18}O$(‰)	T(TU)
1	cold spring	Mengxuo	1440.0	18.5	−53.1	−7.45	13
2	cold spring	Mengmao	761.8	23.0	−50.8	−8.25	19
3	warm spring	Zaduo	860.0	38.0	−52.6	−8.22	14
4	cold spring	Namuguan	075.0	19.0	−50.4	−7.52	13
5	boiling spring	Bongbeng	764.9	96.0	−52.2	−6.44	6
6	drillhole	No.12	764.67	63.0	−55.3	−7.81	?
7	drillhole	Ko. a	761.3	85.0	−55.4	−7.96	7
8	rain(dry season)	Mengmao	780.0	-	−33.6	−5.81	13
9	cold spring	Gaoligongshan	2344.0	-	−56.8	−8.61	-
10	rain(rainy season)	Mengmao	780.0	-	−79.0	−11.41	15

Geochemistry (including isotope chemistry)

At the early stage of geothermal exploration, the chemical analysis of samples of water and gas can yield information about some field characterics at relatively low cost. The analysis of water samples from hot springs and wells was completed by the Yunnan Geological and Mineral Resources Bureau and the Department of Geology at Peking University. The results of analyses from 2 springs and 5 wells are listed in Table 2.

As an aid to assessing the energy potential of the field, the most important parameter is the estimated subsurface temperature, a parameter which cannot normally be obtained other than by costly deep drilling. The reservoir temperature of the Bongbeng field was estimated by the silica (quartz - no steam loss), Na-K-Ca, Tkn and Tkm geothermometers (Fournier, 1981; Giggenbach, 1986). The results are also given in Table 2. Different geothermometers give different temperature estimates because they involve different re-equilibration rates. The Tkm values usually represent the temperature field of the shallow reservoir while the Tkn data indicate the temperature range of very deep waters (Giggenbach, 1986). The lower equilibrium temperature calculated from the silica geothermometer, which is close to the Tkm value, is thought to be affected by the mixing of hot and cold waters.

The water-rock equilibria of thermal waters in the Bongbeng field is shown by the triangular diagram of Giggenbach (1986) representing relative Na, K and Mg contents (Fig. 4). Samples A*, A and N8 lie below the 10 times dilution, indicating some partial equilibrium. Samples N12 and N11 are close to the shallow water area, indicating significant mixing.

The isotope studies in the Bongbeng field include analyses of D, ^{18}O and T. Concentration of stable isotopes deuterium (D) and oxygen-18 (^{18}O) in waters from different sources (Table 3) can be used to characterize origin and mixing patterns of thermal waters. A plot of isotope data in standard δ values (‰) relative to SMOW for the data listed in Table 3 is shown in Fig. 5. Cold spring waters, indicated by a black solid dot in Fig. 5, represent local present-day meteoric water. Water from the Bongbeng hot spring (No. 5) exhibits a significant 'oxygen isotope shift', i.e. enrichment of ^{18}O. The isotope compositions of thermal waters from two drillholes (Nos. 6 and 7) lie close to the meteoric water line and indicate significant mixing with cold water.

Two samples of rainwater collected in dry and rainy seasons of 1989 contain 13 and 15 TU

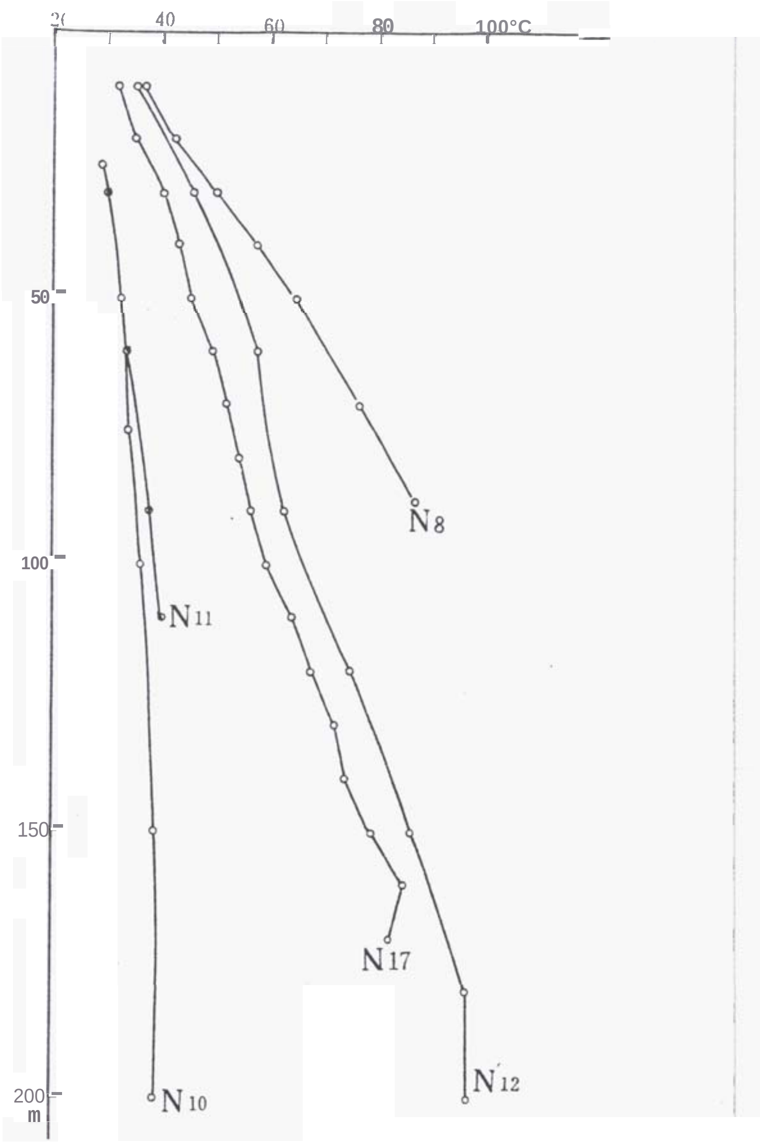

Figure 3: Downhole temperature in wells of the Bongbeng Field.

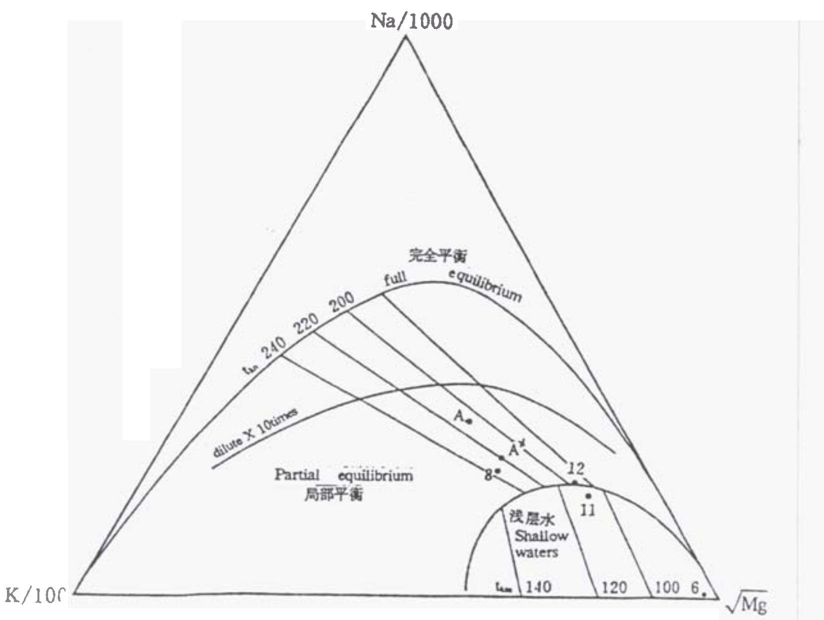

Figure 4: Relative Na, K, Mg contents of Bongbeng geothermal waters.

respectively. They represent the tritium background in those years. Three cold springs contain tritium concentrations ranging from 13 to 19 TU, indicating that they are of recent age. The Zaduo warm spring has a similar tritium content (14 TU). Three samples of thermal waters from the Bongbeng Field have lower tritium values between 6 and 9 TU, indicating that they contain a significant proportion of 'older' water.

Future potential and utilization

It appears to be feasible to produce geothermal fluids with temperatures as given by the T_{K-Mg} values (i.e. 120 to 140°C) from a set of deeper wells in the Bongbeng prospect. Whether the resource is sufficient to allow utilization and to produce electricity using binary plants will depend on the outcome of further studies.

There is a ready market for any locally generated electricity since Ruili County, with a population of 81,500, has only an installed capacity of 3 MW_e. The hydro power potential of the Ruili River is almost nil. The local government has shown great interest in exploration of the Bongbeng geothermal field.

References

Fournier, R.O., 1981. Application of water geochemistry to geothermal exploration and reservoir engineering. In: L. Rybach and L.J.P. Muffler (eds.) Geothermal Systems: Principals and Case Histories, 109-144, John Wiley & Sons.

Giggenbach, W.F., 1986. Graphical techniques for the evaluation of water/rock equilibration condition by use of Na, K, Mg and Ca contents of discharge waters. In: Proc. NZ Geothermal Workshop 1986, 37-41.

Liao Zhijie, 1988. Yunnan-Burma-Thailand tectonic domain and its characteristic Cenozoic volcanisn. Acta Scientiarum Naturalium Universitatis Pekinensis, v.24, No. 4,494-503.

Lin Wenxing, 1990. Rock features and types of ductile shear belt, western Yunnan, Yunnan Geology, v.9, No. 3, 200-209.

PLA 00939 Unit, 1979. Report of Regional Hydrogeological Reconnaissance in Ruili (G-47-32), Luxi (G-47-33) and Nongdao (F-47-2) of P.R. China (Scale 1:200000) (in Chinese).

Tong Wei and Zhang Mingtao (Eds), Geothermics in Mts. Hengduan. Science Press (in press).

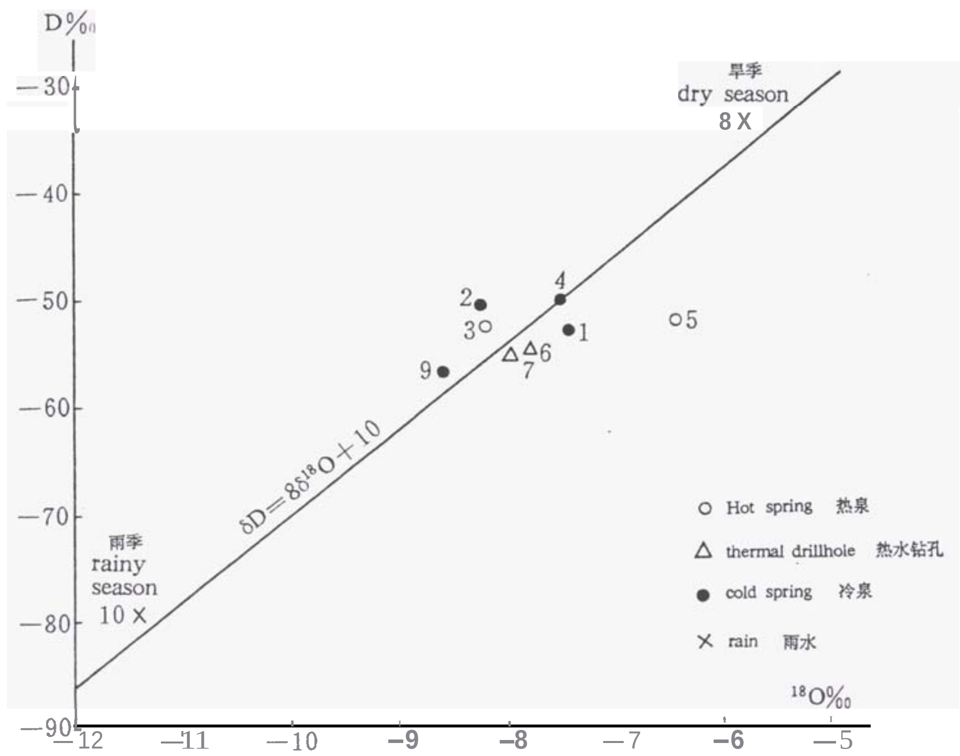

Figure 5: Deuterium-oxygen 18 relations for the Bongbeng Field.