HEAT SOURCE CHARACTERISTICS OF SOME WARM AND HOT SPRING SYSTEMS IN CHINA AND THAILAND

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ABSTRACT

The conductive heat flow associated with some warm and hot spring systems in China and Thailand has been modelled. Using simplified 2D thermal conductivity models for the Beijing graben (China) it was found that about half of the observed anomalous flux can be explained by the geometry and the low thermal conductivity of the graben. Since the observed flux within the deepest part of the graben in significantly lower than that predicted by the conductivity model, it is proposed that fluid movement at the base of the graben transfers heat to the flanks. The high heat-generating capacity of massive granites in northern Thailand causes anomalously high heat flows; modeling of the heat flow associated with the granites showed that high temperatures between 150 and 175° C can occur between 4 and 5 km depth beneath most hot spring systems in that region. These temperatures are near to resource base temperatures as inferred from the Na-K-Ca geothermometer.

INTRODUCTION

The normal conductive heat flow can be significantly modified by the topography (Lachenbruch, 1968) and by the regional distribution of rocks with different thermal conductivities (Blackwell and Chapman, 1977). An anomalous heat flow can also be caused by massive granites with a high heat-generating capacity and which is also affected by the geometry of these bodies (Lachenbruch and others, 1976).

It was the aim of this study to investigate the likely range of the anomalous heat flow and temperatures beneath some warm and hot spring systems in China and Thailand; the effect of granitic bodies was also considered in the latter case. For modelling of the conductive heat flow the algorithm and the finite-element analysis as developed by Lee, Rudman and Sjoreen (1980) was used. A two-dimensional structure of idealized sections was assumed throughout. Where available, representative means of the thermal conductivities (K) of saturated rocks were used; observed means were also used for the heat-generating capacity (A) of granites from northern Thailand. Data from Toulonkian and Ho (1981) were used where thermal rock parameters had not been reported. Changes of thermal conductivities with temperature were neglected.

The term "warm springs" is used here to describe springs with generally low mineralization and with discharge temperatures that do not exceed 50° C; the term "warm spring system" is used to describe a geothermal resource that can be associated with warm springs but with a low rate of heat discharged at the surface (rarely exceeding 0.5 MW per prospect). In contrast, the term "hot spring system" is used to describe a system where somewhat higher mineralized hot water is discharged at the surface at temperatures between 50 to 100° C; the total heat discharged lies within the range of 1 to 10 MW.

The chemistry of warm and hot spring systems described in this paper has been summarized (Table 1); some analyses are incomplete and the chemical data are only used with reference to similarity of fluids from different systems and their likely resource base temperatures.

THE BEIJING GEOTHERMAL PROSPECT

Thermal water with temperatures between 40 and 70° C occurs in a dolomite aquifer between 500 to 2500 m depth respectively beneath the city of Beijing (P.R. China). The aquifer occurs near the interface of the Sinian dolomites and overlying Tertiary and Cretaceous sediments which infill the Beijing graben (see Figure 1). Small temperature anomalies at depths of 70 m led to the discovery of this project. Two warm springs (35 and 50° C)

Table 1. Geochemistry of Selected Warm and Hot Spring Systems in China and Northern Thailand (all constituents in mg/kg)

Locality	T(°C)	pH	Na	K	Ca	Mg	Cl	SO_4	HCO_3	F	SiO_2
Beijing System[1]											
Xiaotangshan (62m)	52	7.3	84	14	42	15	32	75	240	6	37.5
Beijing, No. 15 (660m)	40	7.9	142	6	27	10	59	111	255	6	19
Beijing, No. 8 (1135m)	54	7.4	85	12	55	19	55	118	220	5.5	33
Beijing, No. 15 (1260m)	59	7.3	168	17	47	18	96	144	270	6.5	37.5
Beijing, No. 20 (2550m)	70	8.4	179	18	46	16	103	161	280	6	55
Hot Spring System (W. Yunnan)[2]											
Dakongbeng, No. 5	96	9.0	177	23	<	<1	33	31	329	16	201
Hot Spring Systems (N. Thailand)[3]											
Group A											
Ban Pong Nam Ron (CR4)	99	8.6	127	20	5	<1	10	18	n.a.	21	101
Huai Paeng (MH8)	82	8.3	108	5	6	<1	5	24	n.a.	n.a.	90
Group B											
Fang (CM3)	96	9.4	128	9	2	<1	27	44	n.a.	21	180
Pong Kum (CM2)	81	8.6	108	11	8	<1	5	16	n.a.	9	112
Group C											
San Kampaeng (CM1)	99	8.7	151	12	4	<1	10	14	600	17	109
Ban Pong (CM10)	75	8.3	122	8	9	<1	2	17	n.a.	11	96
Group D											
Mae Chok (PR2)	78	6.9	176	18	26	<1	13	62	n.a.	n.a.	68
Ban Pong Nam Ron (LP3)	60	8.8	80	5	9	<1	3	3	n.a.	n.a.	45

Sources: [1] Analyses of Beijing waters taken from Gunnlaugsson, E. (1982). [2] Analysis of Dakongbeng hot spring system from Zhang, Z. and others (1984). [3] Analyses of hot spring system in northern Thailand from inset of map by Department of Mineral Resources of Thailand (1984); n.a. = data are not available.

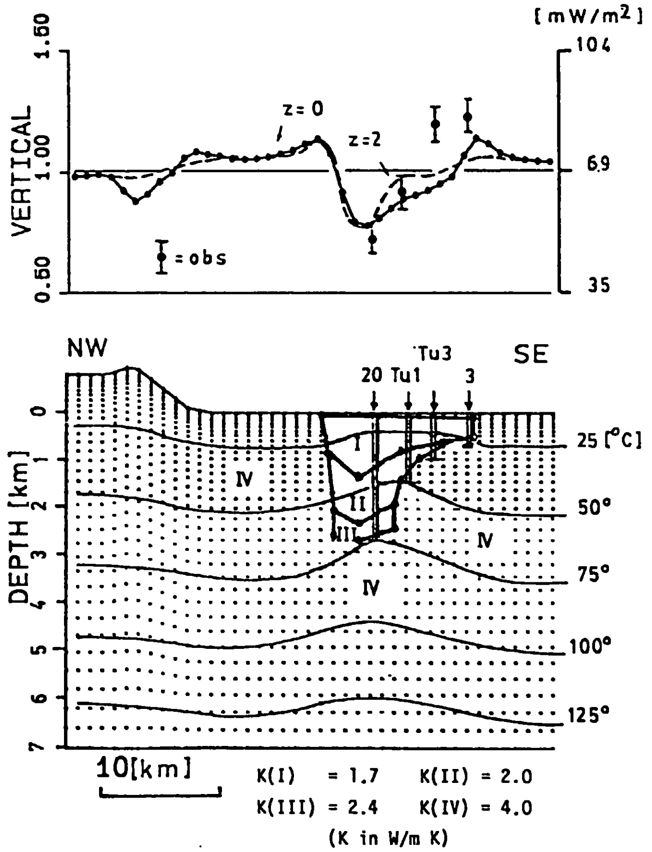

Figure 1. Heat flow model of Beijing graben. Theoretical heat flows are shown in the upper half and were computed at the surface (z = 0) and at 2 km depth (z = 2); superimposed are observed heat flow values. In the section, body I represents Neogene sediments, body II Paleogene and Cretaceous sediments, body III Jurassic andesites, and body IV Precambrian rocks and Sinian dolomites. Computed isotherms are shown by solid lines in the section. The uniform heat flow at a depth of 7 km is 69 mW/m^2.

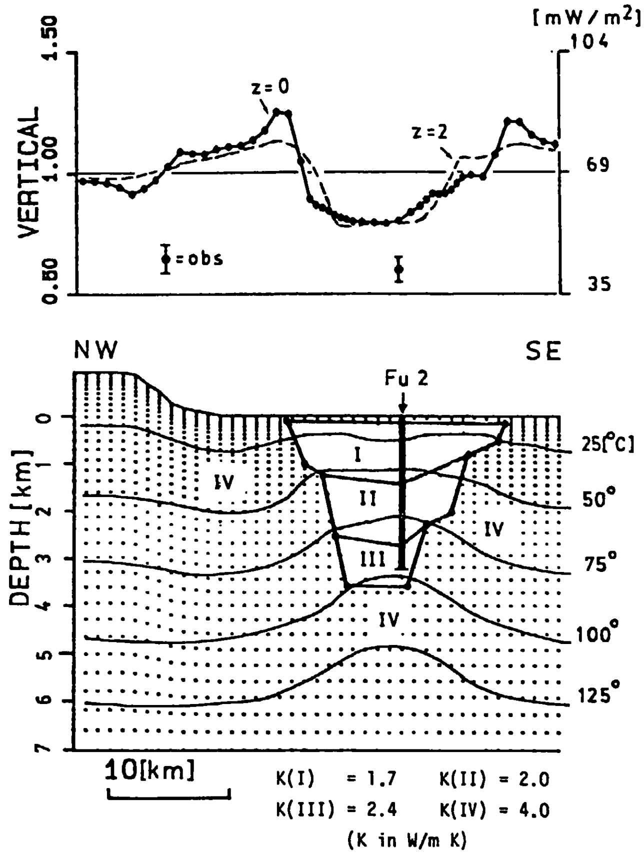

Figure 2. Heat flow model of Beijing graben; section lies 15 km southwest of that shown in Figure 1. For explanation of symbols see caption of Figure 1.

exist near basement contacts about 25 km to the northwest and 30 km to the north respectively from the centre of the graben shown in Figure 1. No thermal springs have been found over the southeast flank where most of the drilling activity has been concentrated.

The Tertiary and Cretaceous sediments in the graben are almost impermeable and exhibit mean thermal conductivities of 1.7 and 2 W/mK respectively (Zhang, 1981). Jurassic andesites were encountered in the deepest part of the graben (assumed conductivity of 2.4 W/mK). The thick Sinian dolomites and other Precambrian rocks, which constitute the basement, have a mean conductivity of 4 W/mK. The approximate cross-sectional structure of the graben beneath Beijing and the regional heat flow for the North China Region (about 65 ± 5 mW/m^2) are known (Zhang, 1981).

The interpretation of temperature gradients of a few deep wells near the sediment/dolomite interface (over an interval of about 200 m within sediments and the dolomites) showed that the present-day heat flow over the southeast flank reaches values of 80 to 85 mW/m^2 whereas in the centre of the graben it decreases to about 50 mW/m^2 (Hochstein, McKibbin and Yang, 1984).

The conductivity model of the Beijing graben along a northwest-southeast trending profile across Beijing is shown in Figure 1; the heat-generating capacity of the sediments and the basement rocks was assumed to be zero. The vertical component of the conductive heat flux near the surface and at 2 km depth was computed and is shown in Figure 1.

A least squares analysis showed that a regional heat flow of 69 mW/m^2 produces the best fit for the observed heat flow data. Theoretical temperatures based on this value are shown in Figure 1, which shows that the isotherms are updomed beneath the graben. This effect is more pronounced in the section of Figure 2, which depicts a wider and deeper portion of the graben about 15 km southwest of the profile shown in Figure 1. The slightly anomalous temperatures at shallow depth, mentioned previously, can be explained by the shape of the 25°C isotherm shown in Figures 1 and 2. The mean annual surface temperature was taken as 11°C; for the higher standing topography a lapse rate of -7°C/km was assumed.

The computed heat flow pattern in Figure 1 shows the same trend as the observed heat flow although the observed values shown in Figure 1 are significantly higher over the southeast flank (85 mW/m^2 versus 77 mW/m^2) and lower over the centre of the graben (48 mW/m^2 versus 57 mW/m^2) than the computed flux values. The theoretical temperatures beneath the southeast flank are about 10 to 15°C lower than the observed temperatures; at the floor of the graben both temperatures agree within 5°C. To check whether the magnitude of the anomalous heat flow is significantly affected by the geometry of the graben we computed the heat flow for another section (Figure 2) where the graben is about 5 km wider and about 1 km deeper. The temperature within the central part of the graben in Figure 2 is known from one deep well (Fungcan No. 2); the observed heat flow near the bottom of this well is even lower (40 mW/m^2) than that in well No. 20 lying in the centre of the graben as shown in Figure 1. The minimum theoretical heat flow in Figure 2 is still 55 mW/m^2 in the centre of the graben, and the theoretical temperatures at the bottom of the deep drillhole are about 25°C higher than observed.

To explain the discrepancies between theoretical and observed heat flows and temperatures, we propose that some heat has been transferred laterally from the dolomite aquifer beneath the graben to the aquifer beneath the southeast flank. A process that would reduce the heat flux beneath the graben by about 10 mW/m^2 and increase the flux over the southeast flank by about the same amount would explain the observed data.

The chemistry of Beijing thermal waters is listed in Table 1; the sites are widely spaced, and the first two sites in this table are about 30 km apart. A certain degree of homogeneity of the chemical constituents is clearly indicated, and this can be explained by the heat flow model. Independent evidence for secular fluid movement is given by the isotope characteristics of the thermal waters (Zheng and others, 1982). Any significant recharge occurs only via infiltration of the exposed Sinian and Precambrian rocks cropping out at the northwest end of the profiles shown in Figures 1 and 2. Because the temperatures beneath the exposed basement rocks are rather low (typically around 100°C at about 6 km depth), it can be inferred that the highest equilibrium temperatures of the thermal waters should be close to the temperatures in the deepest part of the graben, i.e. no greater than about 75°C. The maximum values given by the chalcedony geothermometer are close to this value. The application of sodium geothermometers is probably not justified because of the lack of sodium-bearing minerals in the dolomite aquifer.

HOT SPRING PROSPECTS IN NORTHERN THAILAND

A total of 40 hot spring areas have been mapped by the Geothermal Exploration Project, Department of Mineral Resources of Thailand (1984). About 20 percent of these areas lie within exposed, mainly Triassic granites (group A), 30 percent in the immediate vicinity of exposed granite contacts (group B), 20 percent of the hot spring systems occur 5 to 10 km from the nearest exposed granite contact (group C), and the rest lie further away (group D). About 40 percent of the hot springs in groups A, B, and C discharge hot water near or at boiling point temperature; the geochemistry of all waters is remarkably similar (see Table 1) although the prospects occur over an area of about 2×10^5 km^2. In addition, the resource base temperature as indicated by the Na-K-Ca geothermometer falls for most springs in groups A, B and C within the rather narrow range of 140 to 180°C. The natural heat output lies within the range 1.5 to 10 MW. All points taken together indicate similar conditions for the deeper reservoir of these systems.

Unfortunately, there are no data available that can be used to construct a realistic cross section for any of these systems; deep well temperatures are also not available. For this reason we modeled an idealized setting for the hot spring systems A, B and C as shown by the section of Figure 3. It was assumed that the sediments in contact with the granites are dominantly Paleozoic rocks. Representative thermal conductivity values were taken from Ramingwong

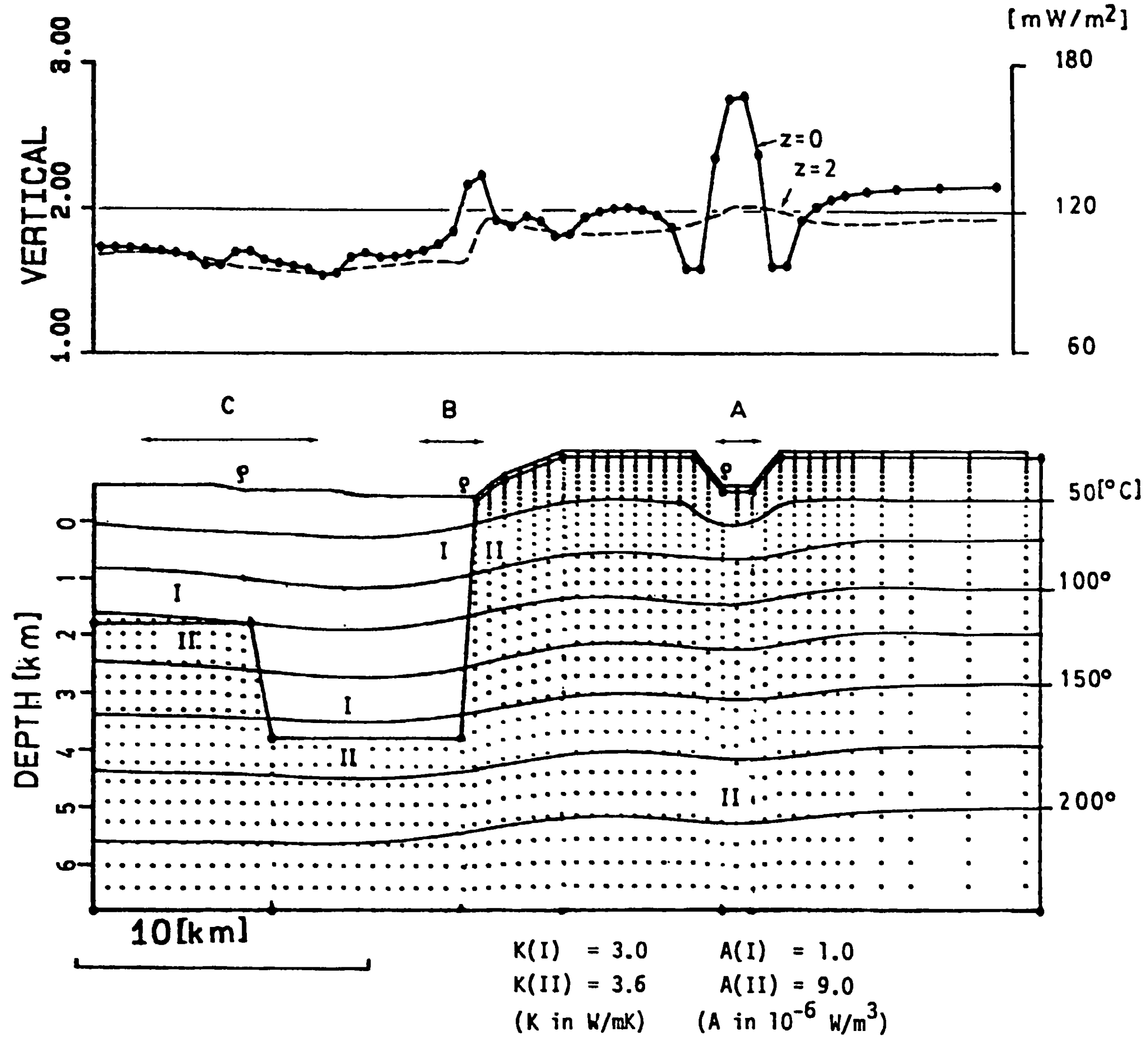

Figure 3. Heat flow model for an idealized section of hot springs in northern Thailand. In the section, body I represents Paleozoic sediments, and body II the granites. The uniform heat flow at 7 km depth is 60 mW/m^2. For explanation of other details in the figure see caption of Figure 1.

and others (1980) for granites, and from Thienprasert and Raksaskulwong (1984) for Paleozoic rocks. Analyses by the University of Chiang Mai (Ramingwong and others, 1980) have shown that the heat-generating capacity of N. Thailand granites is anomalously high; a mean value of $9 \pm 3 \times 10^{-6}$ W/m^3 is indicated for three large granite massifs associated with hot springs. For the deeper crustal heat flow a value of 60 mW/m^2 was assumed. The lower boundary of the granites was put arbitrarily at 8 km depth, and the thickness of the granites was adjusted to produce an undisturbed flux at the surface between 90 and 120 mW/m^2; these values are similar to those shown in the Department of Mineral Resources map (1984). The section in Figure 3 is an idealized section through the San Kampaeng (group C) and Pong Kum (group B) prospects near Chiang Mai. The mean annual surface temperature was taken as 25°C at 500 m elevation, and for the lapse rate a value of -7°C/km was assumed.

Computed heat flows at the surface and at 2 km depths for this idealized section are shown in Figure 3. These heat flows would be observed in the absence of any infiltration of the jointed granites and of any convective heat transfer within the granites. It can be seen that at the surface a significant heat flow anomaly is associated with the valley structure (i.e. for group A springs). At 2 km depth the zones near the contact and beneath the valley in the granites still exhibit a significant anomalous heat flow.

The isotherms are much less distorted than those beneath the Beijing section; temperatures of about 150 to 175°C prevail at 4 to 5 km depth throughout the section. Convection cells would be more likely to develop over small temperature highs near a granite contact, or within a granite body beneath a valley, than elsewhere. Recharge by infiltration would decrease the temperature of the well-jointed granites outside the zones with convective heat transfer.

It is unlikely that all the heat within the granites will be swept into a few, highly permeable fracture zones; if, say, 50 percent of the heat were collected, a base resource area of about 15 km^2 per MW heat discharged at the surface is indicated. Resource areas of the order of 30 to 150 km^2 would be required to supply a heat discharge of 2 to 10 MW, which is typical for the natural discharge of the N. Thailand hot spring systems.

The results of our models cannot be used to prove that all hot spring systems in N. Thailand are fed by deep systems within the granites. It can be inferred, however, that the deep temperature field is favourable for the development of such systems. The geochemistry and the small natural heat discharge of the hot spring systems support this inference. It is possible that most of the systems start as convecting cells within granites and near granite contacts, where the heat flow is enhanced, and that thermal fluids are driven to discharge points under the influence of natural hydraulic gradients involving some lateral flow.

A few of the hot spring systems are associated with nearby fluorite deposits; because of the rather high fluorine content of the thermal waters it is likely that these deposits were associated with ancient thermal springs, thus pointing to a long geological history of some of these systems.

The granite belts of N. Thailand continue northward into east Burma and west Yunnan (China). At least 20 hot spring systems have been mapped in west Yunnan, most of which appear to be associated with granite contacts. The Dakongbeng hot spring system at a granite contact has recently been described (Zhang, Liao and Zhang, 1984). The geochemistry of a hot spring from Dakongbeng is listed for comparison in Table 1. It can be seen that its chemistry shows close affinity to that of the Thailand hot springs listed in Table 1. The natural heat discharged by the Dakongbeng system is of the order of 10 MW.

SUMMARY

Modelling of the conductive heat flow over the Beijing thermal prospect has shown that the temperatures within the Beijing graben are elevated with respect to those of the surrounding basement. This effect and the geometry of the graben reduce the heat flow (about 18 percent) over the center of the graben and increase the flux (up to 12 percent) over its southeast flank. Observed anomalous heat flow, however, is about two times greater, which explains why observed temperatures are higher over the flanks and lower over the center of the graben than those given by the heat flow model. It is proposed that some secular movement of thermal fluids from the graben floor to the flanks is required to explain the observed anomalous temperatures and heat flow data.

The anomalous heat flow near the surface and at depth is modulated by the geometry of granites. Modelling of the heat flow over and within an idealized setting of hot spring systems in northern Thailand has shown that anomalously high temperatures (about 150° C at 4 km depth) can exist beneath each of these systems if these granites with high heat-generating capacity extend to 8 km depth. These temperatures are similar to minimum resource base temperatures as indicated by the Na-K-Ca geothermometer. The rather homogeneous geochemistry of all hot spring systems in northern Thailand and their low natural heat discharge support our inference that the enhanced heat flow within the granites is the most likely heat source for these systems.

Hot spring systems associated with granites are quite common; the hot spring systems in west Yunnan have already been cited in this paper, but there are also numerous hot and warm spring systems near granite contacts in the province of Fujien (China). The phenomenon that many of these hot springs discharge hot water at boiling point should not be used to classify these systems as hot water systems (i.e. Wairakei type), which have quite different heat source and reservoir characteristics.

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