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# LECTURES ON GEOTHERMAL RESOURCES AND DEVELOPMENT IN CHINA

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# PREFACE

Since the foundation of the UNU Geothermal Training Programme in Iceland in 1979, it has been customary to invite annually one geothermal expert to come to Iceland as a UNU Visiting Lecturer. The UNU Visiting Lecturers have been in residence in Reykjavik from one to eight weeks. They have given a series of lectures on their speciality and held discussion sessions with the UNU Fellows attending the Training Programme. The lectures of the UNU Visiting Lecturers have also been open to the geothermal community in Iceland, and have always been well attended. It is the good fortune of the UNU Geothermal Training Programme that so many distinguished geothermal specialists with an international reputation have found time to visit us. Following is a list of the UNU Visiting Lecturers during 1979-1991:

| | | |
|---|---|---|
| 1979 | Donald E. White | United States |
| 1980 | Christopher Armstead | United Kingdom |
| 1981 | Derek H. Freeston | New Zealand |
| 1982 | Stanley H. Ward | United States |
| 1983 | Patrick Browne | New Zealand |
| 1984 | Enrico Barbier | Italy |
| 1985 | Bernardo S. Tolentino | Philippines |
| 1986 | C. Russel James | New Zealand |
| 1987 | Robert Harrison | United Kingdom |
| 1988 | Robert O. Fournier | United States |
| 1989 | Peter Ottlik | Hungary |
| 1990 | André Menjoz | France |
| 1991 | Wang Ji-yang | P.R. China |

The UNU Visiting Lecturer of 1991, Dr. Wang Ji-yang, is professor and head of the Laboratory for Geothermics at the Institute of Geology of the Academy of Sciences in Beijing, People's Republic of China. China has in a short time span become one of the leading users of geothermal water for space heating, horticulture, fish farming and industry in the world. It is therefore of great value for the participants of the UNU Geothermal Training Programme to learn from the experience of the Chinese experts who have gradually been adapting western technology to their geothermal fields. We are grateful to Prof. Wang Ji-yang for giving us an insight into the various aspects of the exploration and exploitation of the geothermal resources of China in his five lectures in Reykjavik in August 1991, and for preparing the lecture notes that are presented here.

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United Nations University
Geothermal Training Programme.

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# 1. INTRODUCTION

China is rich in geothermal resources and has a long history of using hot springs for agriculture, bathing and therapeutic purposes. Since the early 1970's, extensive exploration and development of geothermal resources have been launched and quite good results were obtained. At present, a geothermal power plant with installed capacity of 25.18 MW was set up in Yangbajing Geothermal Field, which supplies about 40% (52% in the winter time) of the electricity to the Lhasa city, the capital of Xizang (Tibet) Autonomous Region. Two other geothermal power plants (Langjue and Naqu) are being planned in Tibet with the hope of meeting the growing needs for electricity and to help solve energy shortage problems in this remote area. Except for power generation, geothermal resources are widely used for space heating, industrial processing, agriculture, bathing and spas. In 1990, the total flow rate of thermal water for direct use amounted to 9534 kg/s, which provided the thermal power of 2143 MW and thermal energy of 5527 GWh equivalent. These figures show that China nowadays is the second largest user of non-electric geothermal energy in the world (Ren et al., 1990; Freeston, 1990).

With increasing interest in geothermal energy and recognizing the importance of this kind of new and renewable energy sources, studies, investigations and exploration for geothermal resources become more and more intense. To date, hundreds of wells and boreholes have been drilled and used for producing thermal fluids. Thousands of hot springs have been reconnaissanced and investigated. In addition, some theoretical research such as geostructure interpretations, subsurface temperature measurements, heat flow studies, numerical modelling of geothermal systems, isotope and geochemical methods have been attempted with the purpose of better understanding the distribution and potential of geothermal resources in our country. As a result, a report on "Geothermal Resources in China, Distribution and Potential Evaluation" has recently been completed by the Lab for Geothermics, Institute of Geology, Academia Sinica and will be published by Science Press in the near future. To promote the research and development of geothermal energy, a nationwide project for the period 1991-1995 on resource assessment, reservoir engineering, and technical aspects of development and utilization is in progress. It may be expected that so-called "Geothermal Flower" in the energy field can bloom fully and bear rich fruits for China's economy.

It must be pointed out that the rapid development of geothermal energy in our country seems to be impossible without outside assistance. In the last decade, UNDP has supported geothermal development projects in Beijing, Tianjin area and Yangbajing geothermal field. Since 1988, International Atomic Energy Agency (IAEA) has supported a research project on the application of isotope and geochemical techniques in geothermal exploration in Zhangzhou Geothermal Field, Fujian Province. Now the target area has been extended to geothermal areas of Guangdong and Hainan Provinces in SE China. During the period 1980-1991, many Chinese experts were trained in the UNU Geothermal Training Programme at ORKUSTOFNUN (Iceland), the UNDP Geothermal Diploma Course of Geothermal Institute of Auckland University (New Zealand), the UNESCO Group Training Course in Geothermal Energy in the Research Institute of Industrial Science of Kyushu University (Japan) and the UNESCO Course in Geothermal Exploration of the International School of Geothermics (Italy). These geothermal training programmes and/or courses are sponsored by U.N. organizations with part contribution from the host countries. In September 1991, the author had the great honour to be the Visiting Lecturer of the 1991 UNU Geothermal Training Programme in Reykjavik. Five lectures were given on various aspects of geothermal resources and developments in China. These lecture notes are intended to summarize the above mentioned lectures and give readers a general picture on that subject.

## 2. TECTONIC SETTINGS AND GEOTHERMAL BACKGROUND

Being located in the southeastern corner of the Eurasian plate, the continental area of China is both influenced by the Pacific plate from the east and Indian-Australian plate from the south (Figure 1). As a result, two geothermal belts are formed. One is the so-called "Himalayan Geothermal Belt" in SW China, which is the eastern extension of the worldwide Mediterranean Geothermal Belt and another is the so-called "Circum-Pacific Fire Ring" or "Circum Pacific Geothermal Belt" in the southeast. The famous high-temperature geothermal fields such as Kizildere in Turkey and Puga in India are located in the former belt and Paratunka in Russia, Matsukawa and Otake in Japan plus Tiwi in the Philippines are situated in the latter Belt. In China, Yangbajing Geothermal Field in Tibet and Tengchong volcanic area in Yunnan Province belong to the Mediterranean-Himalayan Belt, whereas Datong (Tatun) geothermal area in Taiwan occurrs in the Circum-Pacific Belt (Figure 2).

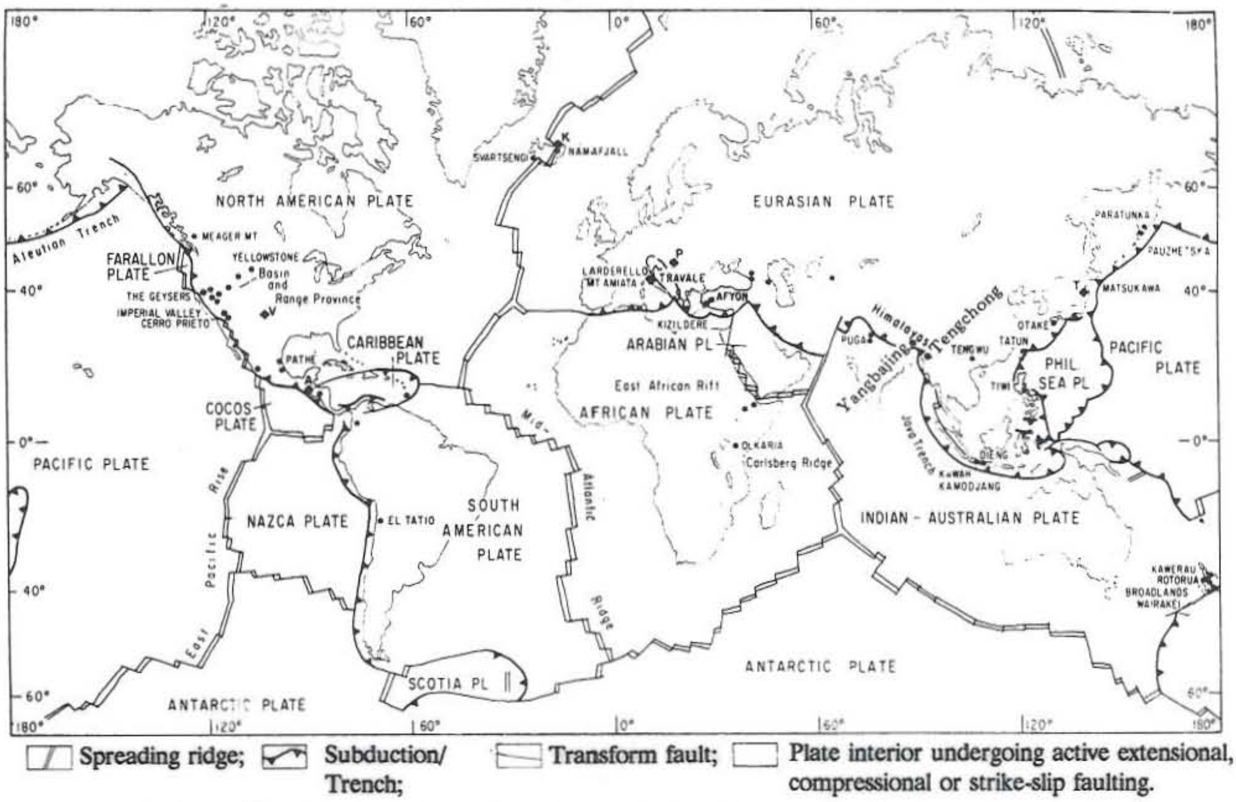


FIGURE 1: Global distribution of major geothermal systems related to plate tectonics (according to Rybach, 1981, with supplementary data from China)

Geothermal background for the above mentioned two geothermal belts turns out quite high. Heat flow studies (Wang and Huang, 1990) indicate that average heat flow in S-Tibet appears around 80-100 $mW/m^2$ with the highest up to 364 $mW/m^2$, and for Tengchong volcanic area, >80 $mW/m^2$. Taiwan is generally characterized by high heat flow (>80 $mW/m^2$) and in the high-temperature geothermal areas, heat flow appears to be > 120 $mW/m^2$ (Lee and Cheng, 1992).

Statistics show that the representative average heat flow for the whole continental area of China lies between 63-68 $mW/m^2$ by different approaches of statistic analysis, varying from 25 to 364 $mW/m^2$ (Wang and Huang, 1992) (Figure 3). Generally, heat flow values are increasing from West to East and from North to South. This is understandable because the plate boundaries in China are located in the South and East, with the increasing distance from these boundaries to the North and West, the tectonic activity and, correspondingly, the geothermal background decreases too. Therefore, the highest heat flow is observed in Taiwan, S-Tibet and Tengchong volcanic area

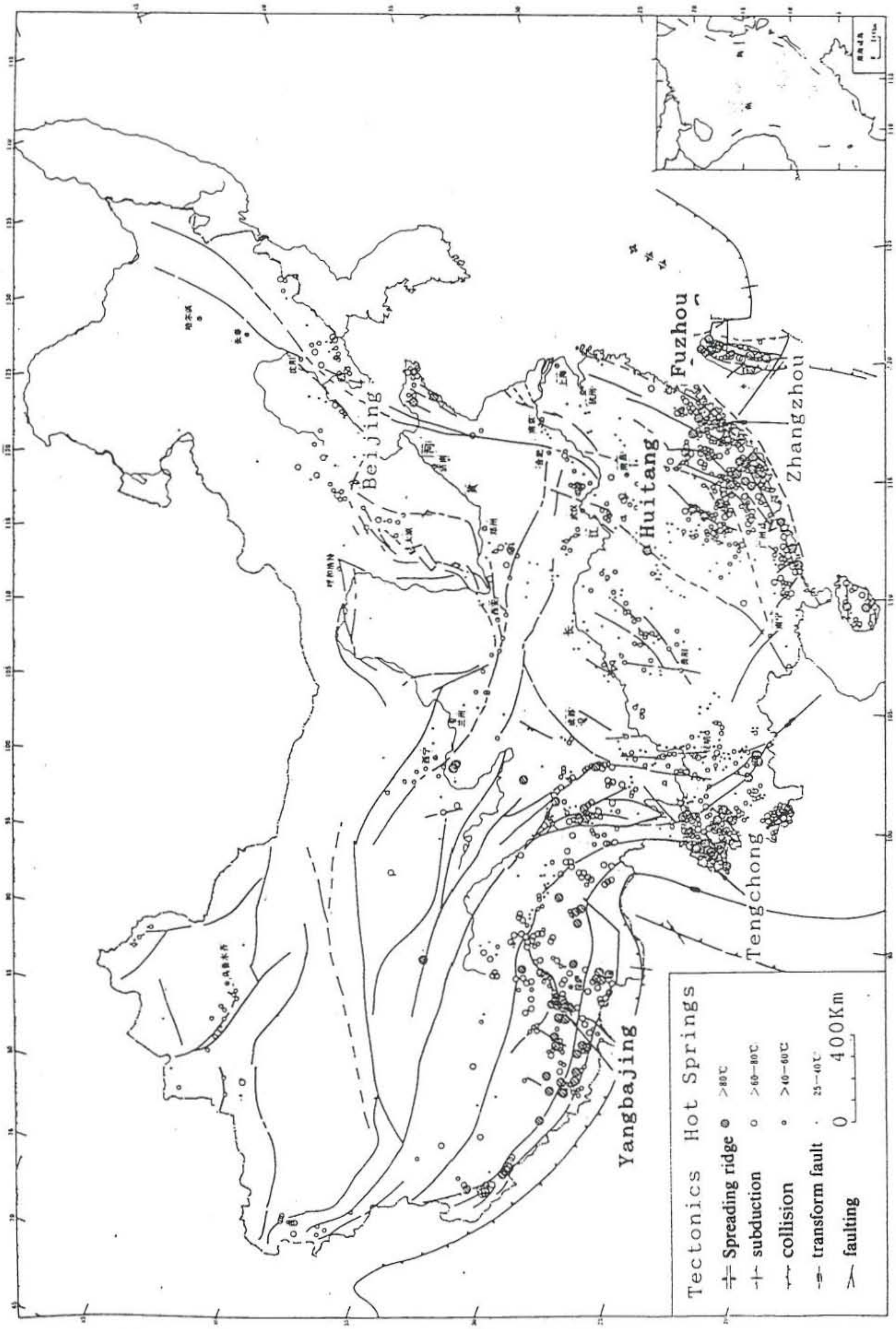


FIGURE 2: Distribution of major convective type geothermal systems in China

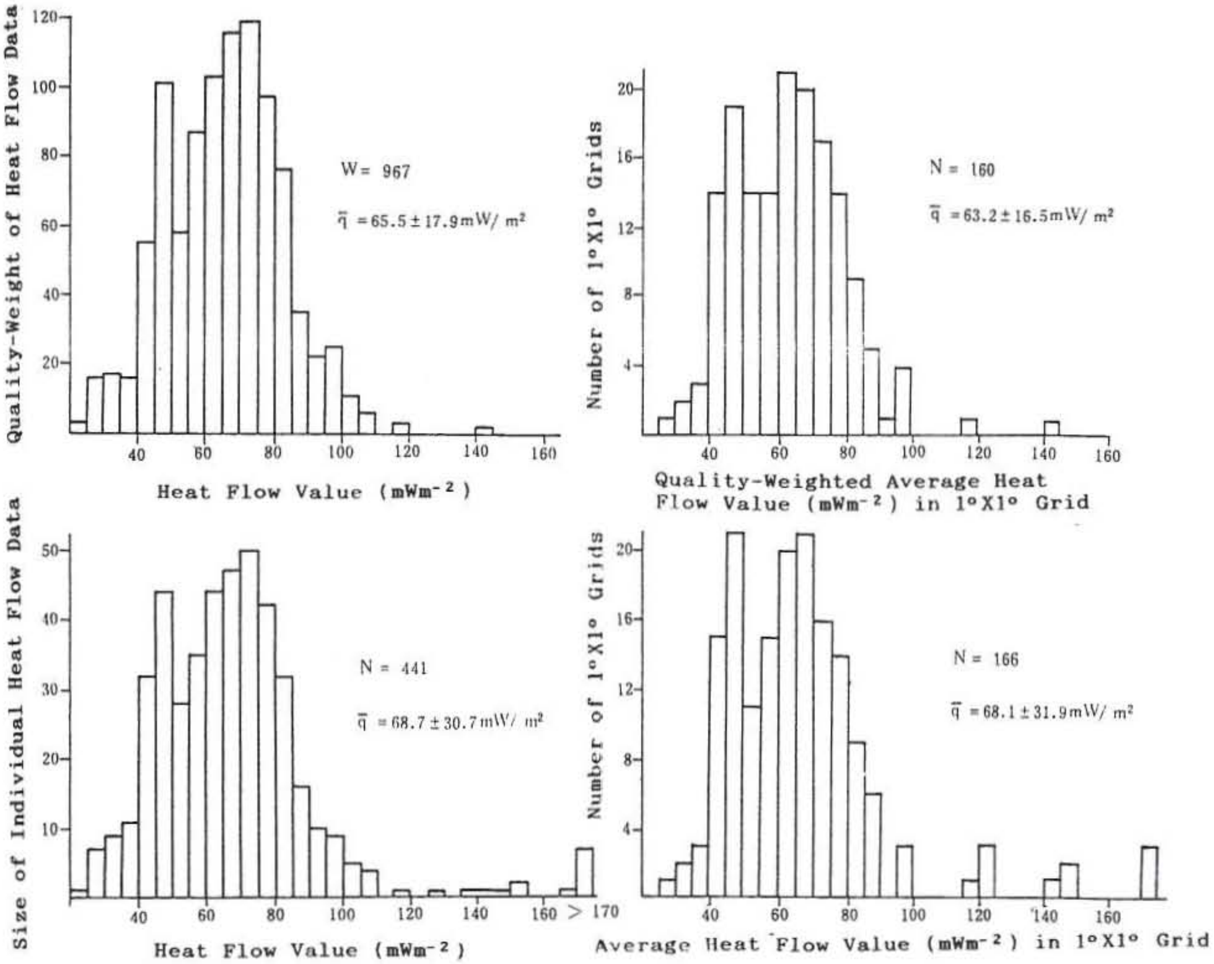


FIGURE 3: Histograms of frequency distribution of heat flow data in China

and the lowest (about 40 mW/m$^2$) in Talimu Basin and its surroundings of NW-China (Figure 4). A similar pattern is also valid for geothermal gradient (Wang et al, 1990) (Figure 5).

China's geothermal background is closely correlated to its tectonics. Generally, the younger and more active the region, the higher the geothermal background (both heat flow and geothermal gradient), and vice versa. Thus in Tibet, Tongcheng and Taiwan, which are active tectonic units of Cenozoic age, the geothermal background is high. On the contrary, the old stable terrains such as Yangtze fault block of Proterozoic age and Archean Sino-Korean fault block are characterized by low heat flow and low geothermal gradient. Relatively high heat flow (63 mW/m$^2$) and geothermal gradient (35°C/km) are observed in North China Basin because by the end of Mesozoic and extending into the early Cenozoic era, the North China Basin had undergone a rift development stage. During that time, magmatic activity was extensive and high thermal regime appeared. However, since Late Paleogene, the rift development stage was terminated owing to a change in the tectonics of the entire West Pacific, which led to the decay of the high thermal regime established in the earlier period. Nevertheless, the present-day North China Basin still retains relatively high geothermal background due to the "blanket effect" of the thick (up to 12 km) Cenozoic sediments and the rather short time interval of decay since Late Paleogene. Consequently, a special geothermal background similar to neither tectonically stable nor to active units was thus observed in the North China Basin (Wang et al., 1989a).

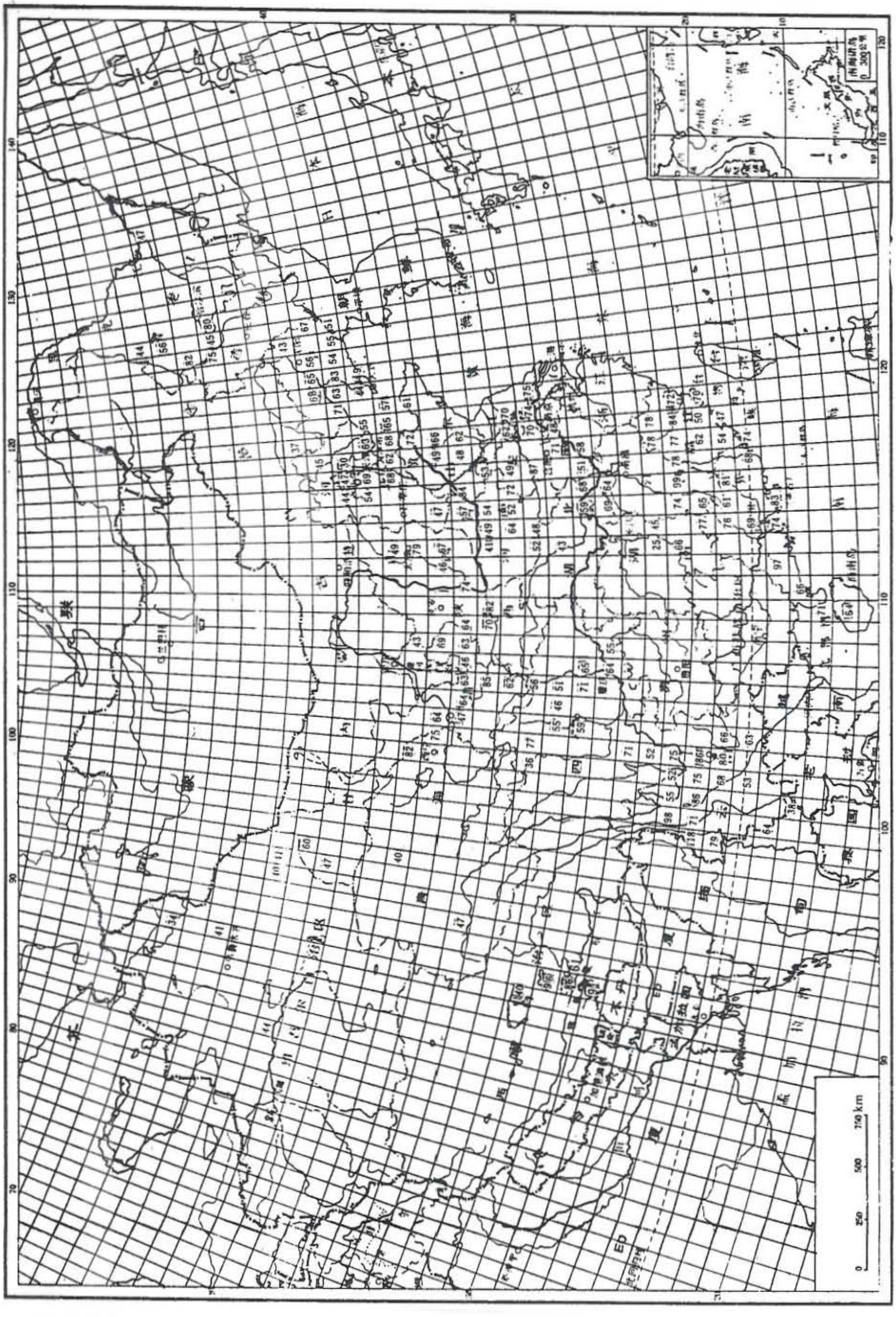


FIGURE 4: Heat flow distribution for the continental area of China, in a 1°x1° grid with a quality weighted average value in each note

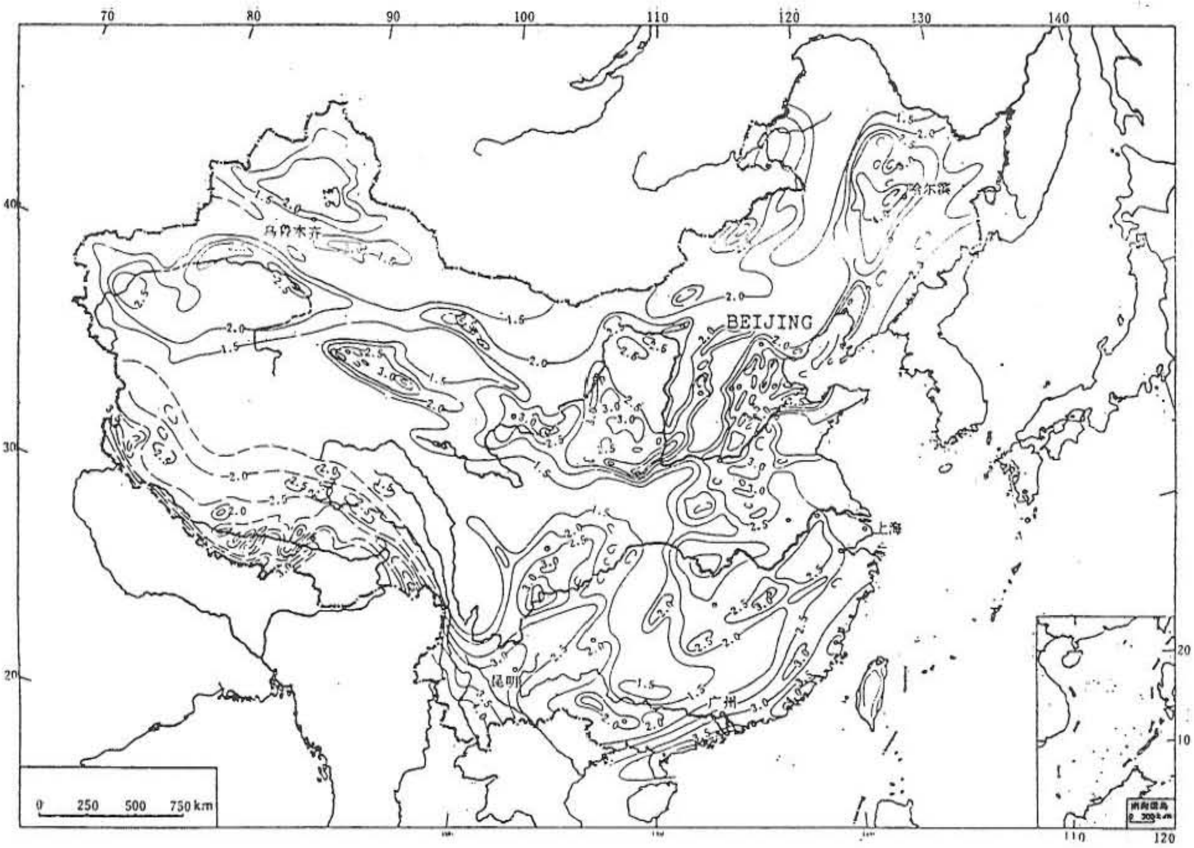
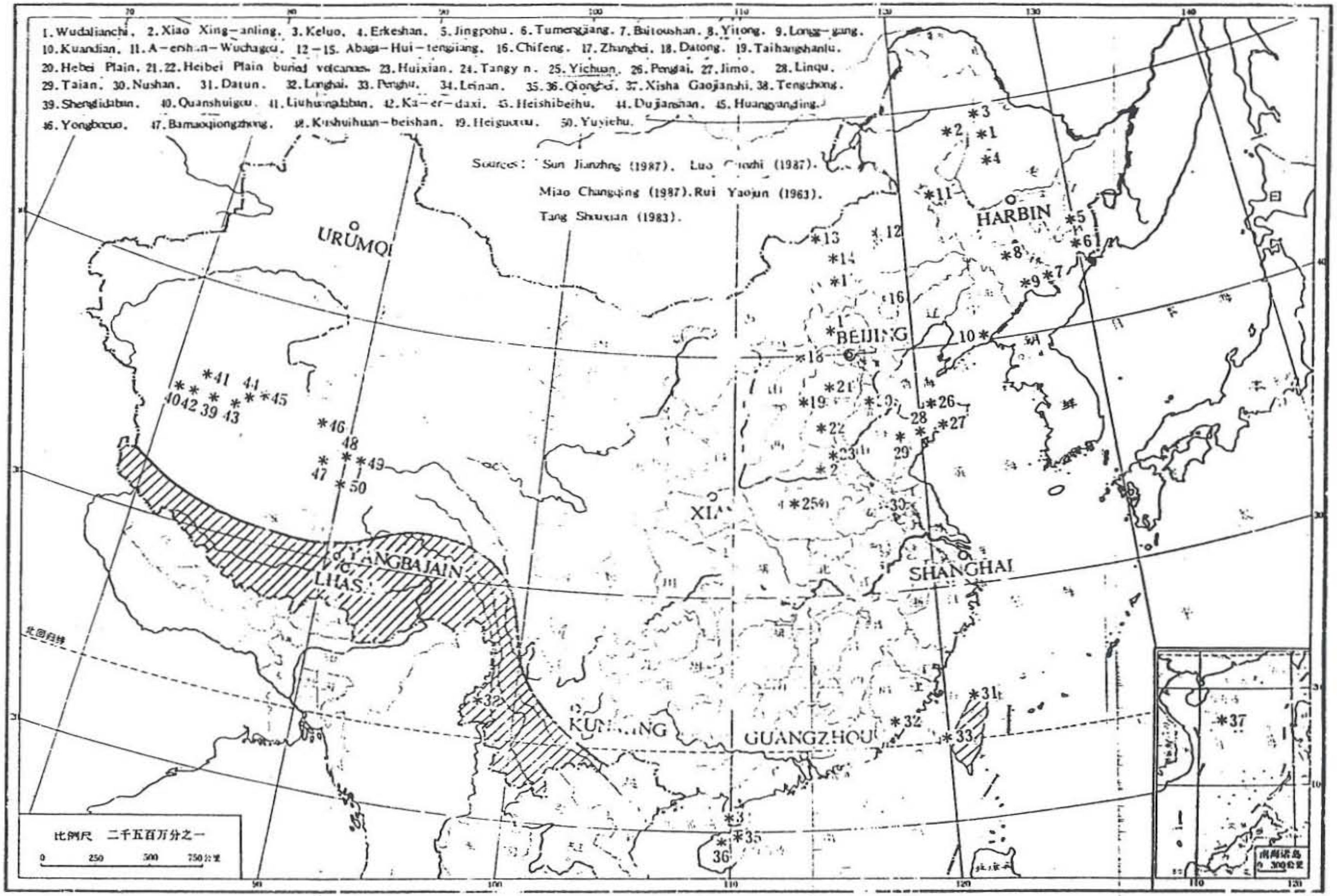


FIGURE 5: Geothermal gradient map of China (°C/100 m)



1. Wudalianchi. 2. Xiao Xing-anling. 3. Keluo. 4. Erkeshan. 5. Jingpohu. 6. Tumenjiang. 7. Baitoushan. 8. Yitong. 9. Longg-gang. 10. Kuandian. 11. A-ersh..n-Wuchagou. 12-15. Abaga-Hui-tengjiang. 16. Chifeng. 17. Zhangbei. 18. Datong. 19. Taihangshanlu. 20. Hebei Plain. 21. 22. Heibei Plain buried volcanos. 23. Huixian. 24. Tangy n. 25. Yichuan. 26. Pengai. 27. Jimo. 28. Linqu. 29. Taian. 30. Nushan. 31. Datun. 32. Longhai. 33. Penghu. 34. Leinan. 35. 36. Qiongbei. 37. Xisha Gaojianshi. 38. Tengchong. 39. Shengdidaban. 40. Quanshuigou. 41. Liuhuangdaban. 42. Ka-er-daxi. 43. Heishibeihu. 44. Dujianshan. 45. Huangyanding. 46. Yongbocuo. 47. Bamaoqiongzhong. 48. Kushuihuan-beishan. 49. Heiguoqu. 50. Yuyiehu.

Sources: Sun Jianzhng (1987). Luo [illegible]oizhi (1987). Miao Changqing (1987). Rui Yaojun (1963). Tang Shuxian (1983).

FIGURE 6: Distribution of high temperature geothermal systems (shaded areas) and Cenozoic volcanoes (stars) in China

## 3. HIGH TEMPERATURE GEOTHERMAL RESOURCES

High temperature geothermal resources in China are concentrated in recent volcanic and tectonically active areas (Figure 6). In southern Tibet, there are more than 600 hydrothermal manifestations including high temperature geysers, hydrothermal explosions, steaming grounds, fumaroles, boiling springs etc., among which 345 have been reconnaissanced and investigated by the Scientific Expedition Team under Commission for Integrated Survey of Natural Resources, Academia Sinica in the late 1970's (Tong et al., 1981) (Figures 7, 8). Results indicate that most of the thermal water in S-Tibet are of $Cl^-$-$HCO3^-$-$Na^+$ type with enhanced contents of Li, Rb, Cs and B. The total dissolved solid appears between 1-3 g/l and the water is of meteoric origin as evidenced by isotope and geochemical studies. The estimated reservoir temperature varies from 170 to 270°C and the total natural heat discharge at the Earth's surface amounts to $4{,}900\times 10^{13}$ J/a (Shen and Chen, 1992).

FIGURE 7: Tagejia geyser in S-Tibet, the biggest geyser in China during eruption at 15:20, August 2, 1975 (photo courtesy of Tong Wei)

FIGURE 8: Crater caused by hydrothermal explosion in Gangba County, S-Tibet; diameter of crater is about 7 m; water temperature is 85.5°C

Strong hydrothermal activity in S-Tibet is the surface manifestation of an extraordinarily high temperature regime at depth which resulted from the collision of the Eurasian and Indian plates. Recent studies (Shen, 1991) demonstrate that the thermal structure in S-Tibet seems to be rather complicated and multilayered (Figure 9). From the bottom to the top, it is composed of: 1) dislocation of the Moho surface where the lower crust and upper mantle are partially superimposed upon each other; 2) the lower crust with mushroom-shaped partially remelted bodies; 3) a partially melted layer of regional scale in the middle crust; and 4) subcrustal magmatic chambers or partially melted bodies at diverse (10-12 km) depths in the uppercrust. So far as geothermal resources are concerned, the last point is most important because the subcrustal magmatic chambers and/or partially melted bodies with temperature up to 600-800°C are the direct heat source supporting intensive hydrothermal activity at the Earth's surface and the relevant high temperature geothermal systems. Consequently, many high temperature geothermal systems in S-Tibet are, indeed, situated in the vicinity of young granitic batholith (Tong et al., 1981).

Tengchong volcanic area is located at the border with Burma, which, tectonically and geothermally, is the southern extension of the Himalayan Geothermal Belt (Figures 1, 8). The main difference between the Tengchong area and other parts of the Belt is that, in Tengchong there exists extensive Cenozoic volcanic activity. According to Liao (1989), Mu and Curtis (1989), the Tengchong volcanism can be divided into four stages ranging from Miocene to Pleistocene with the K-Ar age of 2.93, 0.81, 0.31 and 0.13 Ma correspondingly. The climax of eruptions occurred in late Pleistocene. The parent basaltic magma is believed to have originated from the partial melting of the upper mantle but progressively contaminated by radiogenic Sr-enriched crustal material on the way upwards to the Earth's surface. It is evident that Tengchong volcanoes may not be extinguished but only dormant. In this context, the magma body at shallow depth may behave as the heat source of its overlying hydrothermal system in this area.

A total number of 58 hydrothermal areas were identified in Tengcheng among which the Rehai (Hot Sea) Geothermal System is the most promising one. Investigation revealed that the reservoir temperature in this system may reach 230-240°C. The heat source might be a cooling magma body which intruded into a shallow depth of about 5-7 km and created the circular area of surface manifestation. The input of magmatic heat at depth may have set the groundwater into motion in this geothermal system. However, the groundwater is meteoric in origin as evidenced by isotopes (D, $^{18}O$). Summarizing all the above mentioned, a conceptual model of Rehai Geothermal System was proposed by Zhang et al. (1989) (Figure 10).

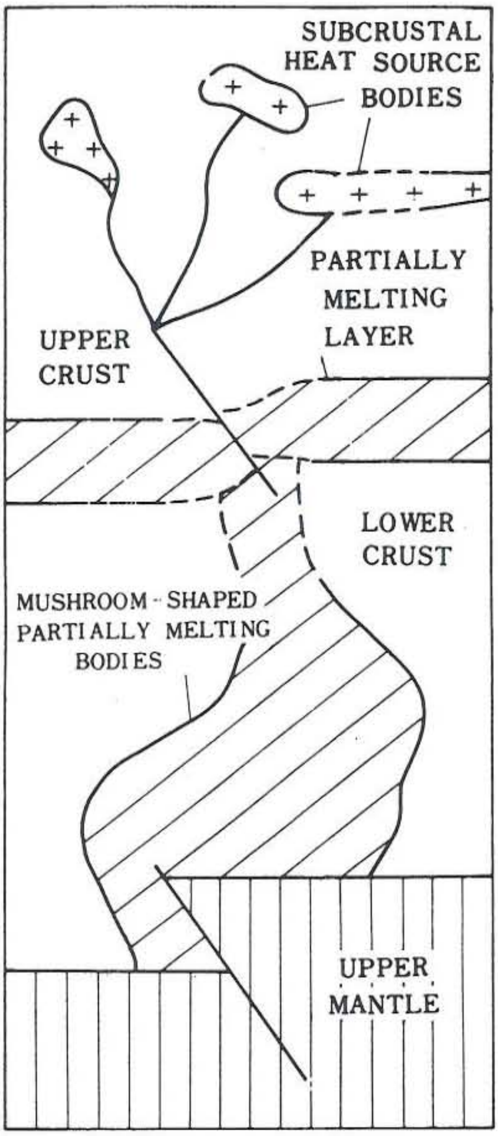


FIGURE 9: Conceptual model of multilayered crust and upper mantle thermal structure of Tibet (acc. to Shen, 1991)

High temperature geothermal resources are mainly used for power generation. Except for Yangbajing geothermal power plant, two other plants are being planned in Tibet. In Tengchong volcanic area, a project on the development of geothermal resources for generating electricity will be started in the near future in cooperation with AQUATER from Italy (Ren Xiang, personal communication). It is estimated that the power generation potential from the Tibetan section of Himalayan Geothermal Belt is nearly 1000 MW (Shen and Chen, 1992), and the Tengchong section alone takes up about 450 MW (Zhang et al., 1989).

About 80 hot springs and fumarolic areas have been reported from Taiwan. Datong (Tatun) and Tuchang are the two explored geothermal fields. The former lies in a volcanic region and the latter, in a slate formation. The deep reservoir of Datong Field contains acid sulphate chloride

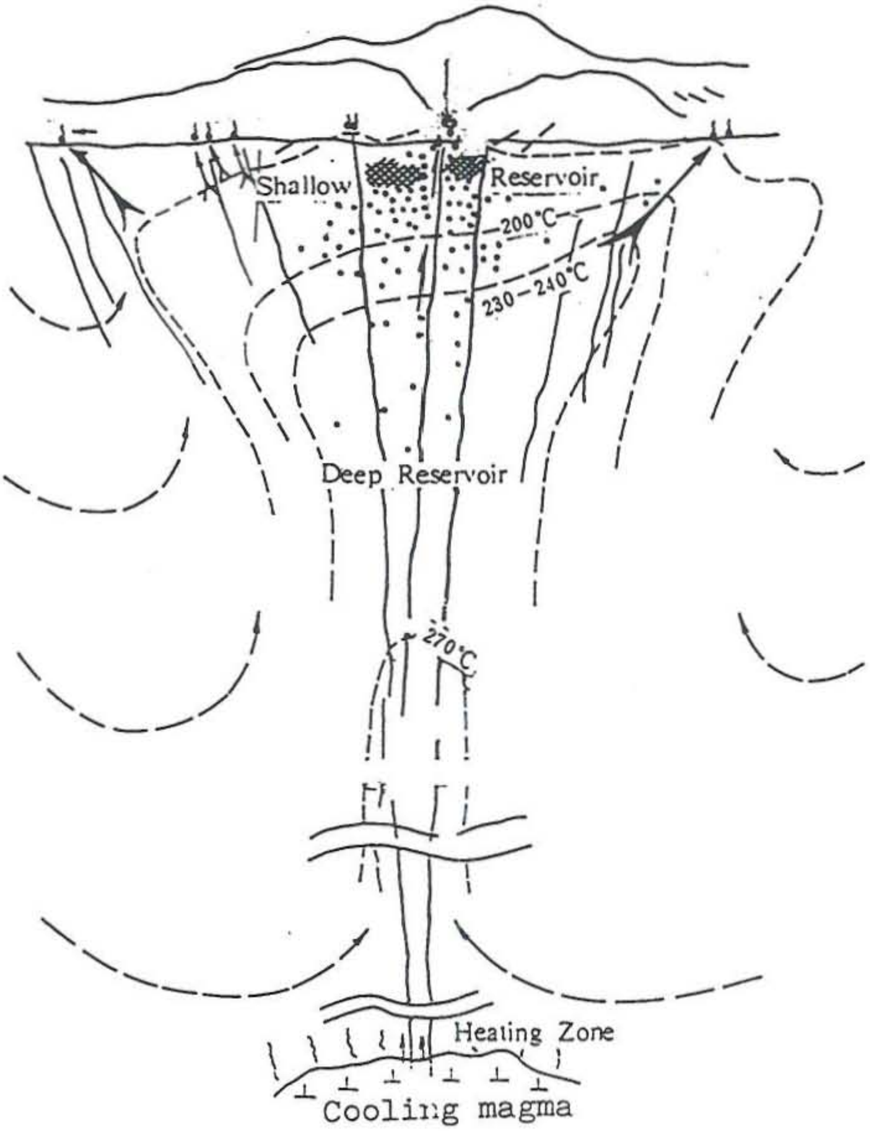


FIGURE 10: Conceptual model of Rehai Geothermal System in Tengchong volcanic area (After Zhang et al., 1989)

water with pH around 2 and temperature up to 293°C. The Tuchang Field produces $HCO_3^-$-$Na^+$ water having Ph around 8.5 and temperature up to 173°C. The estimated potential for power generation in Datong is between 80 to 200 MW (Chen, 1970; 1975).

## 4. LOW-MEDIUM TEMPERATURE GEOTHERMAL RESOURCES

There are two types of low-medium temperature geothermal resources in China. One is thermal water from the low-medium temperature convective type geothermal systems, not related to young magma bodies but heated by normal to relatively high regional heat flow, such as the Zhangzhou and Fuzhou geothermal systems in SE-China. Another is the thermal fluid connected with the low-medium temperature conductive type geothermal systems in large-scale sedimentary basins, such as North China Basin, Sichuan Basin and Talinu (Tarim) Basin (Wang et al., 1992a).

It can be seen from Figure 2 that the geothermal resources of the first type are concentrated in the following areas:

1) The coastal area of SE-China including Fujian, Guangdong, Eastern Jiangxi and Southern Hunan Provinces. There are more than 600 hot springs mostly with temperature of 40-80°C, some having temperature 80-95°C. Several systems such as Zhangzhou and Fuzhou in Fujiaan Province, Dengwu (Tengwu) and Yangjiang in Guangdong, Baoting in Hainan and Huitang in Hunan have been explored during the past 20 years.
2) The E-Shangtong, E-Liaoning Peninsula to the East of Beijing along Tancheng-Rujiang deep-fault zone. There about 70 hot springs exist with temperature of 40-70°C. Higher temperatures (80-90°C) are observed in several springs.
3) The Fen-wei (Shanxi-Shaanxi) graben area to the west of Beijing. The distribution of hot springs is somehow "S" shaped reflecting the graben configuration. Hot springs from the northern and southern parts of the graben are of higher temperature (60-80°C) whereas those from the middle part are of lower temperature ( 40-60°C). It might be a result of the different circulating depths of hot spring water.
4) The W-Sichuan - N-Yunnan area to the northeast of Tengchong along the "South-North" tectonic (or seismic) zone. A total number of 270 hot springs are recorded in this area. The temperature of springs is quite low (40-50°C), only a few appear to be more than 80°C.

Geothermal background for these areas varies from 40 to 75 Mw/m$^2$ (Figure 4). It is obvious that there is no particular heat source (magma body) underneath those systems. The temperature of the thermal water in these systems depends mainly upon the circulating depth of the water. The deeper the water penetrates, the higher its temperature will be and vice verse. For instance, the circulating depth of thermal water in Zhangzhou Geothermal System is quite large (3.5-4.0 km), so the highest temperature (121.5°C at a depth of 90 m) is observed along the coastal area of SE-China (Wang et al., 1989b).

Isotope and geochemical studies show that the thermal water in these systems originates from meteoric water. Along the coastal area, the thermal water in some systems was revealed to be mixed up with sea water. As a result, the TDS and $Cl^-$ content were increased. The reservoir temperature for this type of geothermal systems ranges from 40 to 150°C calculated by using different geothermometers. For example, the reservoir temperatures for Zhangzhou and Yangjiang systems are of 140°C, for Dengwu 135°C and for Baoting 120°C (Wang et al., 1992b).

It must be pointed out that Zhangzhou geothermal system has been studied in detail and may be considered to be representative for low-medium temperature geothermal systems of convective type. A genesis model is illustrated in Figure 11, and a brief description is stated as follows:

On a relatively high (73 mW/m$^2$) regional heat flow background, meteoric water ($\delta D = -52.29$, $\delta^{18}O = -7.66$)) penetrated downwards from the recharge area in the periphery of Zhangzhou

System with an elevation of 800 to 1000 m in Tianbao Mountain. On the way from recharge to the discharge area with increasing depth, groundwater "extracts" heat from the surrounding rock strata, heats itself up and becomes thermal water in the central part of the System. The abnormal convective heat flow in the centre of Zhangzhou Geothermal System appears to be 359 mW/m$^2$. The reservoirtemperature is about 140°C and the thermal water circulating depth, 3.5-4 km. At depth, the "fresh" thermal water mixed with sea water at a ratio of 2:1 which led to the increase of TDS and salinity of thermal water. As upwelling from depth along high-permeability conduit, saline thermal water mixed again with the cold fresh water accumulated in Quaternary aquifer and/or in fissure-fracture networks of granodiorite bed rock at shallow depth. Finally, the low-medium temperature thermal water resources were thus formed in Zhangzhou Geothermal System (Wang et al., 1989).

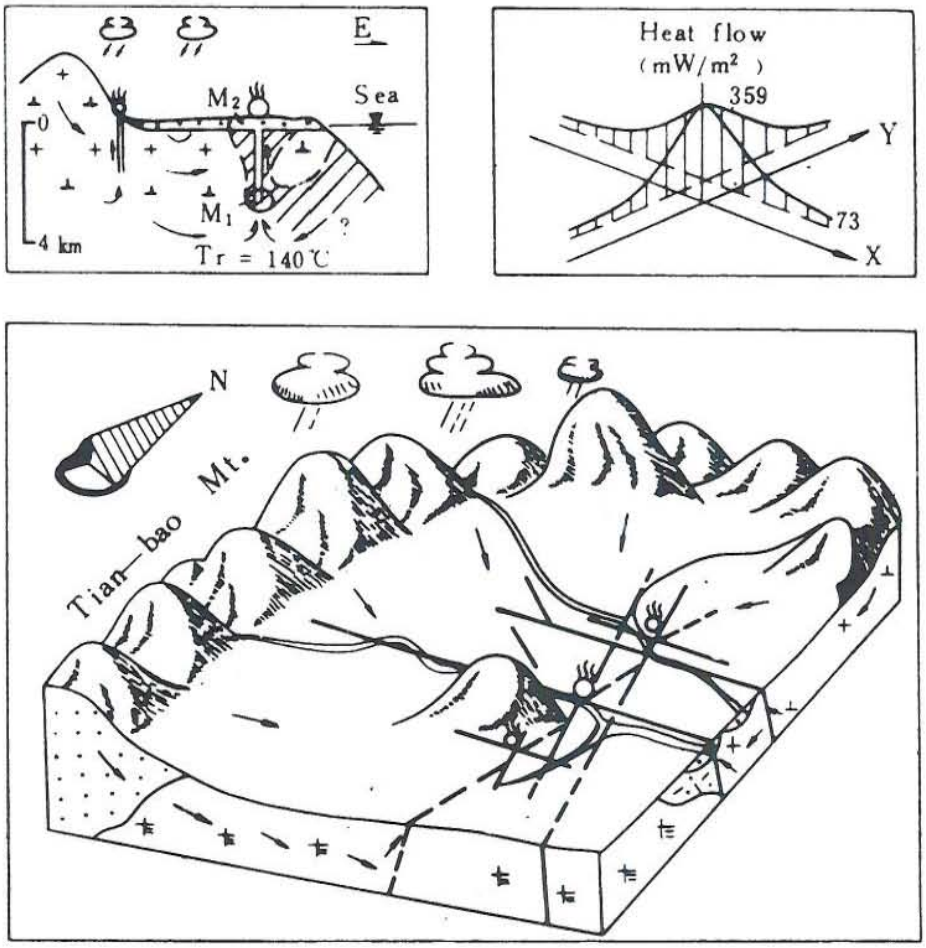


FIGURE 11: Genesis model of Zhangzhou Geothermal System

Altogether 26 low-medium temperature geothermal systems in SE China have been investigated in detail. The results are summarized in Table 1, and the geographical distribution is shown in Figure 12.

Geothermal resources in low-medium temperature geothermal systems of conductive type mainly occur in large-scale sedimentary basins. In China, there exist a number of such basins among which nine basins have an area of more than 100,000 km$^2$. They are: Songliao, North China, Eerduosi, Erlian, Jianghan, Sichuan, Talimu, Chaidamu and Zhungaer Basin. A total area of approximately 3.5 millions square kilometres is reached if the sedimentary basins with an area more than 200 km$^2$ are taken into consideration. It accounts for 36% of the total area of the continent of China. In Figures 13, 21 major sedimentary basins of Meso-Cenozoic age are presented.

Investigation and exploration demonstrate that sedimentary basins located in the eastern and central parts of China are most promising areas for development of low-medium temperature geothermal resources. Basins from western China such as Talimu, Chaidamu and Zhungeer are

TABLE 1: Summary of major low-medium temperature geothermal systems in SE-China

| Site no. | Location and name (Figure 10) | Temperature of spring water (°C) | Flow-rate (l/s) | Salinity (g/l) | Type of water chemistry | Reservoir rock | Cal. temp. (°C) | Well depth (m) | Obs. temp. (°C) | Wellhead temp. (°C) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Huitang | 88 | 4.0 | 0.32 | $HCO_3$-Na | Granite | 125 | 616 | 102 | 89 |
| 2 | Rucheng | 91.5 | 10 | 0.17 | $HCO_3$-Na | Granite and clastic rock | 115 | 200 | 92.2 | 91 |
| 3 | Suichuan | 82 | 20 | 0.40 | $HCO_3$-Na-Ca | Granite | 115 | 520 | 87.9 | 82.1 |
| 4 | Qingliu | 84 | 13 | 0.55 | $HCO_3$-$SO_4$-Na | Granite | 110 | | | |
| 5 | Datian | 81 | 6.0 | 0.65 | $HCO_3$-$SO_4$-Na | Granite | 128 | | | |
| 6 | Dehua | 89 | 3.5 | 0.33 | $HCO_3$-Na | Volcanic tuff | 120 | | | |
| 7 | Anxi | 87 | 3.7 | 0.24 | $HCO_3$-Cl-Na | Granite | 115 | | | |
| 8 | Xinglin, Amoy | 82 | 7.9 | 13.5 | Cl-Na | Granite | 125 | | | |
| 9 | Tangan, Amoy | 85 | 11 | 9.1 | Cl-Na | Granite | 110 | | | |
| 10 | Fuzhou | 50-70 | 17.3 | 0.5 | $HCO_3$-Na | Granite | 130 | 530 | 107 | 97.5 |
| 11 | Zhangzhou | 55-72 | | 12 | Cl-Na | Granite | 140 | 91 | 121.5 | 105 |
| 12 | Dongshanhu | 82 | 1 | 1.12 | Cl-Na | Granite | 140 | 227 | 104 | 102 |
| 13 | Dengwu (Tengwu) | 87 | 4.45 | 0.33 | $HCO_3$-Na | Granite | 135 | 806 | 94 | 92 |
| 14 | Fenglian | 92 | 10.9 | 0.45 | $HCO_3$-Na | Volcanic ro. | 135 | 620 | 94 | 92.5 |
| 15 | Jieyang | 83 | 1.8 | 0.53 | $HCO_3$-Na | Sandstone | 95 | | | |
| 16 | Wuhua | 82 | 4.55 | 0.89 | $HCO_3$-$SO_4$-Na | Sandstone | 110 | 100 | | 90 |
| 17 | Xingning | 81 | 3.76 | 1.10 | $HCO_3$-$SO_4$-Na | Granite | 130 | 100 | | 85 |
| 18 | Heyuan | 82 | 1.7 | 0.31 | $HCO_3$-Na | Granite | 115 | 100 | | 86 |
| 19 | Heping | 88.5 | 11.28 | 0.38 | $HCO_3$-Na | Granodiorite | 135 | 100 | | 91 |
| 20 | Longchuan | 83 | 4.6 | 0.40 | $HCO_3$-$SO_4$-Na | Granite | 135 | | | |
| 21 | Shixing | 84 | 2.17 | 0.26 | $HCO_3$-Na | Granite | 130 | | | |
| 22 | Zhongshan | 73-90 | 1-1.5 | 5.92 | Cl-Na | Granite | 125 | 93 | 95 | |
| 23 | Yangjiang | 97 | 16.4 | 3.0 | Cl-Na | Granite | 140 | 309 | 104 | 102 |
| 24 | Yangxi | 81 | 5.34 | 8.32 | Cl-Na-Ca | Granite | 110 | | | |
| 25 | Baoting | 88 | 8 | 0.26 | $HCO_3$-Na | Quartz and monzonite | 120 | 168 | 90 | 90 |
| 26 | Danxian | 83 | 4.33 | 0.32 | $HCO_3$-Ca-Na | Sandstone and andesite | 110 | | 90 | |

TABLE 2: Summary of geothermal resources for nine sedimentary basins from eastern and central China

| Basin name | Reservoir | | | Extent | | Resources stored in reservoir | | Recoverable thermal water resources | |
|---|---|---|---|---|---|---|---|---|---|
| (see Figure 11) | Strata | Temperat. (°C) | Salinity (g/l) | Area (x$10^4$ km$^2$) | Depth (m) | Water (x$10^8$ m$^3$) | Heat (x$10^{18}$ J) | Water (x$10^8$ m$^3$) | Thermal energy (Standard coal in billion tons) |
| N-China basin | N | 30-70 | 1-3 | 9.0 | 350-2000 | 194300 | 2880 | 1240 | 0.54 |
| (N-part) | PZ, Pt | 50-90 | 0.5-15 | 1.8 | <3000 | 1700 | 37 | 424 | 0.36 |
| (S-part) | N | 30-40 | 1-3 | 6.8 | 350-1300 | 987007 | 840 | 1000 | 0.287 |
| N-Jiangsu | N | 34-57 | <1 | 3.2 | 350-1600 | 39800 | 500 | 428 | 0.16 |
| Lower Liaohe | N | 34 | <1 | 0.34 | 800-1100 | 2340 | 19 | 50 | 0.013 |
| Songliao | K | 30-50 | 1-5 | 14.4 | 300-2000 | 32000 | 370 | 320 | 0.126 |
| Fen-Wei | Cz | 33-40 | <1 | 2.0 | <1000 | 60500 | 448 | 300 | 0.077 |
| Eerduosi | K+J+T+P | 27-39 | 1-5 | 16.0 | 400-1500 | 90750 | 668 | 907 | 0.228 |
| Sichuan | J+T+P | 25-69 | 1->50 | 13.6 | <2400 | 75100 | 1380 | | |
| Chuxiong | K+J | 45 | <1 | 3.5 | <1000 | 28000 | 176 | 140 | 0.03 |
| Leiqiong | N+E | 32-59 | 0.5-1 | 0.51 | <1600 | 5400 | 43 | 108 | 0.028 |
| Total | | | | 70 | | 628500 | 7361 | 4917 | 1.854 |

less promising because the water quality is not so good and the salinity seems to be too high (up to 30 g/l). In addition, W-China is less populated and, in fact, there is no user for the vast desert areas except for a few big cities and towns. Recently, an evaluation of the potential of thermal water resources for 9 basins from eastern and central China has been attempted and the results are listed in Table 2 (Deng et al., 1992a).

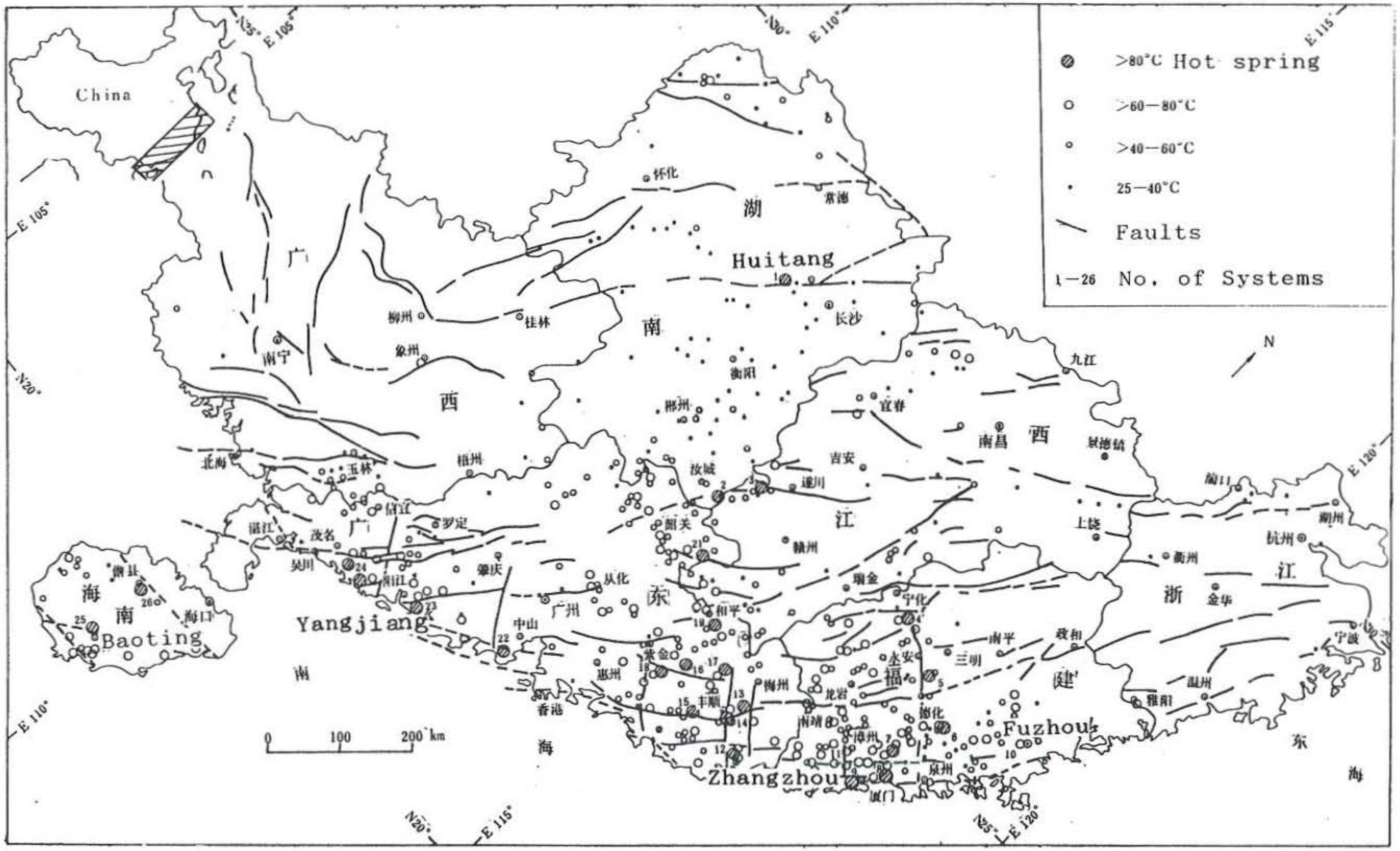


FIGURE 12: Hot springs and major geothermal systems in SE-China

It must be noted that the potential of geothermal resources in these basins is quite good and the recoverable thermal water resources amount to 1.854 billion tons of standard coal equivalent. The recoverable resources in North China Basin and N-Jiangsu Basin take up 73% of the total and thus, these two basins are the most promising areas for the development of low-medium temperature geothermal resources in China. Although the extent of Feng-Wei Basin and Lei-Qiong Basin is not so large, these two basins are still quite promising for development because the water quality is good and the flow rate is large enough for exploration. Except for Chuxiong basin, the water quality for other Mesozoic basins such as Sichuan, Eerduosi and Songliao appears to be not as good. Therefore, these basins are not very promising for geothermal development.

In the northern part of North China Basin, there exist two thermal water reservoirs: one is the reservoir of Neogene sediments and another is the so-called "Buried Hill" reservoir of Lower Palaeozoic and Mid-Upper Proterozoic carbonatite rocks. The Neogene sediments are a thick series of inter-bedding mudstone and sandstone of alluvial origin. The sandstone layers are the main aquifers in the Neogene system with good water quality. The buried depth of aquifers varies from 400 to 2000 m and the water temperature ranges from 30 to 85°C. The chemistry of thermal water is of $HCO_3^-$-$Cl^-$-$Na^+$ type with low salinity (1-3 g/l). $^{14}C$ dating revealed that the "age" of thermal water in Neogene sediments is about 10,000 to 30,000 years old. That means the thermal water seems to be quite stagnant in the reservoir, and the water resources should be considered to be unrenewable. "Buried Hill" has been named by Chinese petroleum geologists to describe the karst-fissure reservoir of carbonatite rock strata in the basement of North China Basin. Thermal water with temperatures up to 105°C at a depth of 2000-3000 m has been found in this reservoir but the water quality appears to be changeable. Sometimes saline water may be encountered. For this reason, utilization of thermal water from this reservoir should proceed with caution (Deng et al., 1992b).

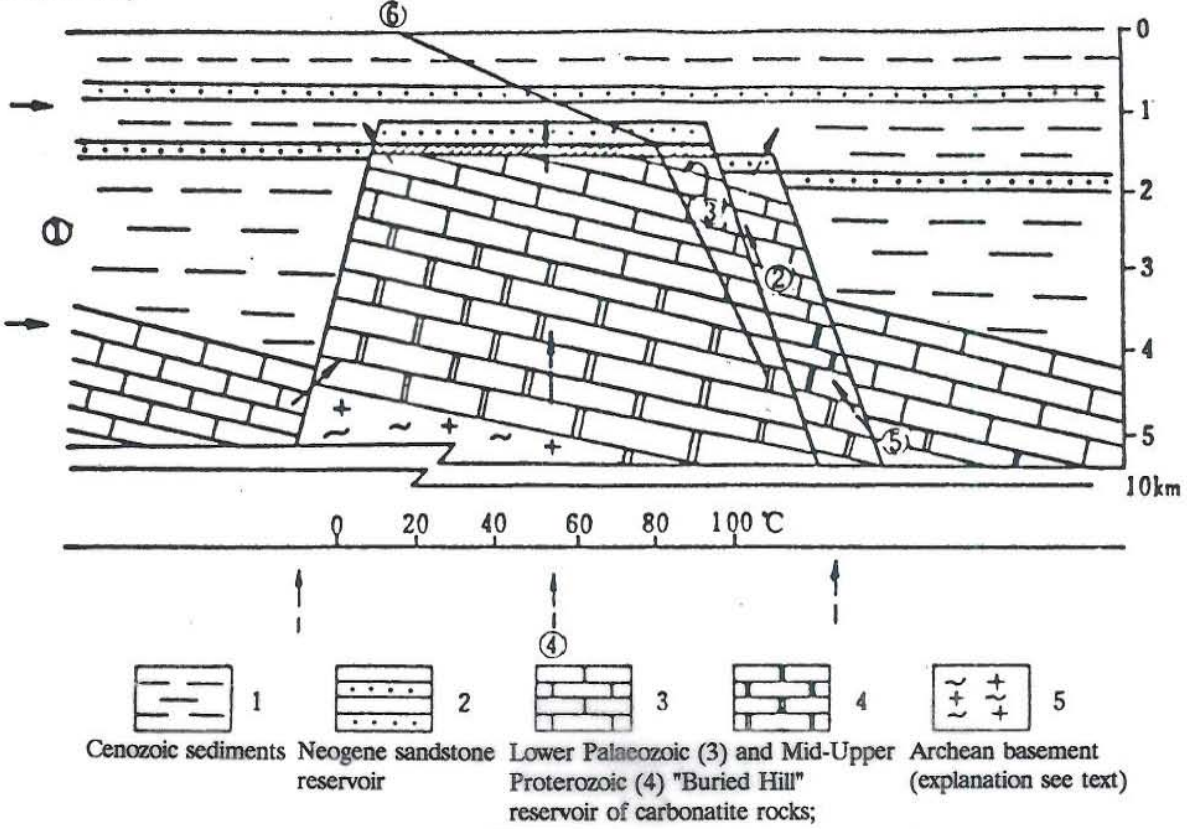


FIGURE 14: Formation mechanism of geothermal resources in North China Basin (according to Deng et al., 1988)

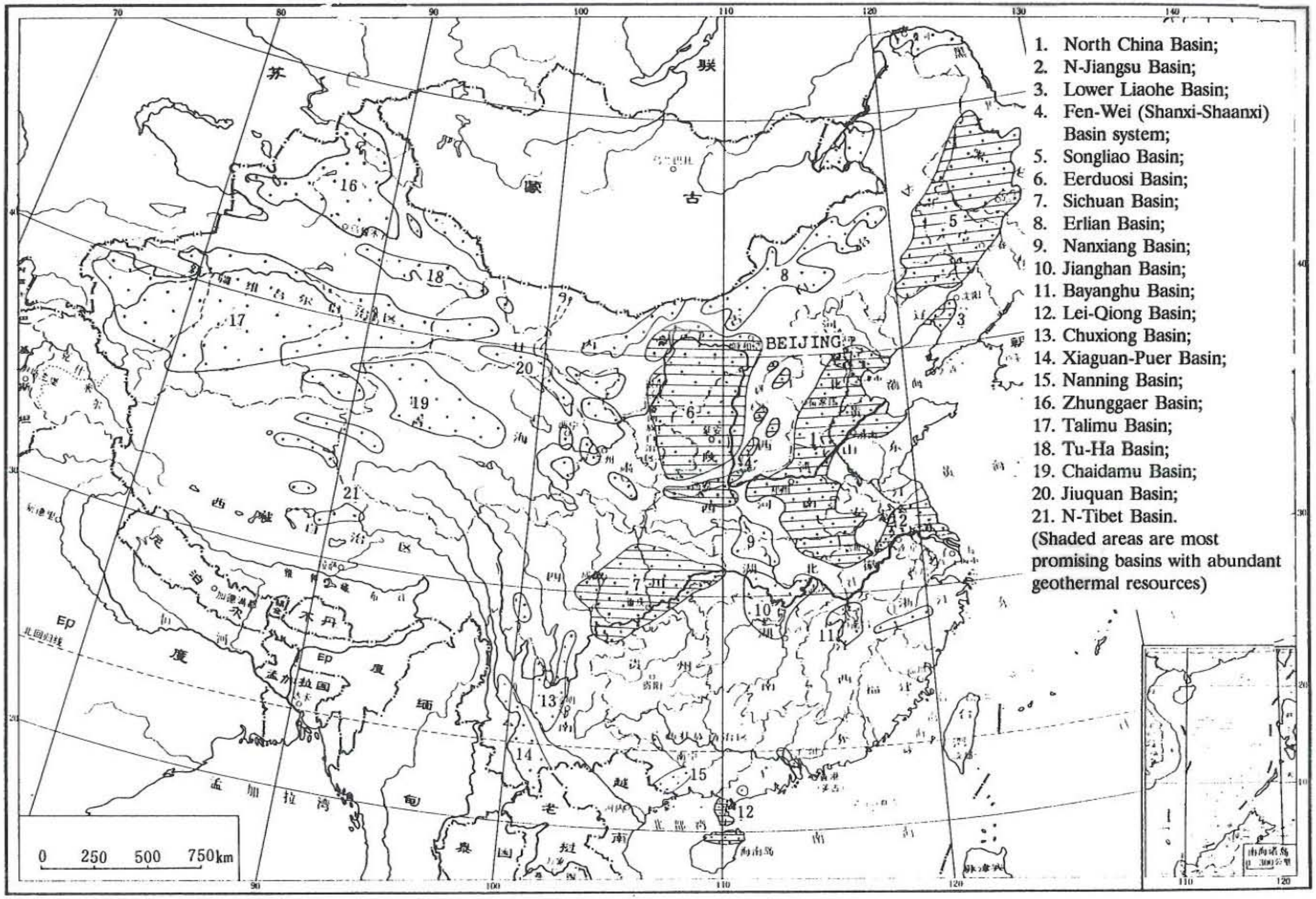


FIGURE 13: Distribution of major sedimentary basins with Meso-Cenozoic age in China

The formation mechanism of geothermal resources in North China Basin is illustrated in Figure 14. It can be seen that on the relatively high regional geothermal background (62 $mW/m^2$) (4), two reservoirs exist in the Basin. Lateral flow of cold water heats up on the way from the recharge area to the discharge area and supplies the reservoirs with thermal water of different temperatures (1). In the central part of an uplift, heat flow increased due to the refraction and concentration of heat (5), which led to the occurrence of high geothermal gradient (up to 50-60°C/km) in the sedimentary cover strata on the top of a basement uplift (6). Along the faults and/or fracture zones, deep circulating thermal water arises and sometimes makes up the occurrence of local small convection cell in certain parts of the reservoir (3). Finally, the low-medium temperature geothermal resources in North China Basin are thus formed (Deng et al., 1988).

It must be stressed that the formation of thermal water in North China Basin seems to be quite typical and may be regarded as representative of the geothermal resources connected with the low-medium temperature geothermal systems of conductive type.

## 5. GEOTHERMAL RESOURCES DATABASE

To facilitate the data acquisition and promote the development and utilization of geothermal energy, the first geothermal resources database system has recently been set up (Xiong et al., 1991). The system provides original data for the evaluation of the quality and quantity of thermal water, its genesis analysis, assessment of geothermal resources and methods for the routine processing of data. The whole system can be divided into three subsystems: 1) Geotemperature and thermo-physical properties of rock; 2) Hydrogeological parameters and 3) Thermal fluid chemistry in geothermal areas. Altogether there are 25 base files, 89 items, 39 command files and 3 applied programs. The three subsystems are closely connected with each other through CdBASE-III but can also be used separately as a subsystem software (Figures 15, 16).

The system emphasizes the scientific nature of the input data. Only original data from field and/or laboratory measurements can be stored. A software package is prepared for integrated data useful to the geothermal resources assessment. The semifinal data can be stored in the transition base. The items stored in the database are as follows:

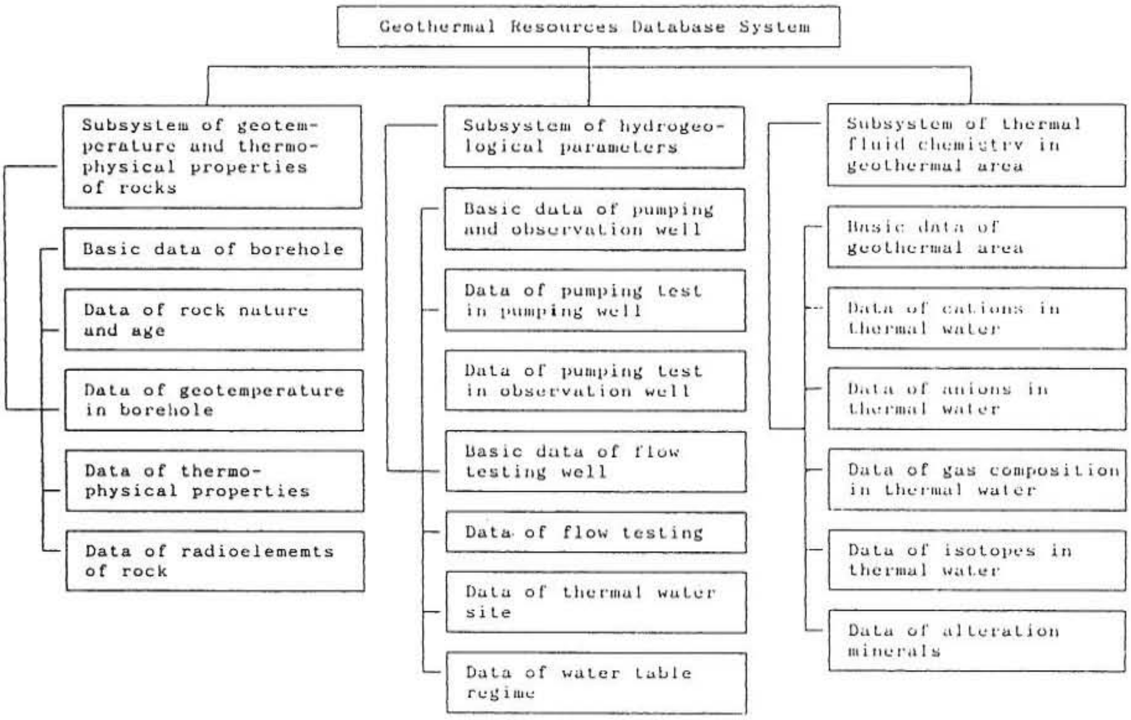


FIGURE 15: Base file structure of the database system (acc. to Xiong et al., 1991)

1. Subsystem of Geotemperature and Physical Properties of Rock
    (1) Basic data of borehole: Name of borehole; Location; Tectonic setting; Longitude and latitude; Coordination; Starting time of drill; Completion time of drill; Time of temperature measurements; Elevation of borehole; Elevation of water table.
    (2) Data of rock nature and age: Borehole depth; Rock nature and age.
    (3) Data of thermo-physical properties and radioelement of rock: Depth of recovered

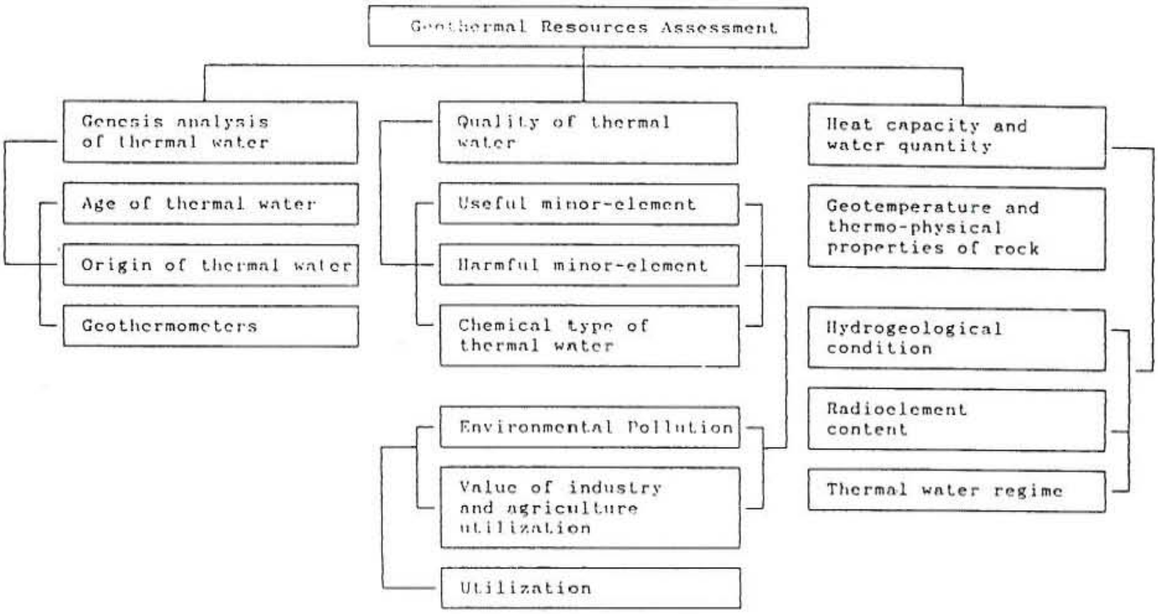


FIGURE 16: Requirement analysis for the geothermal resources assessment (according to Xiong et al., 1991)

rock sample; Thermal conductivity; Specific heat; Density; U, Th, K contents; Measurement equipment.

(4) Data of geotemperature in borehole: Name of borehole; Measurement organization; Depth of measurement; Geotemperature; Measurement time; Data source.

2. Subsystem of Hydrogeological Parameters

(1) Basic data of pumping well and observation well: Well name; Longitude and latitude; Location; Well depth; Coordination; Elevation of ground surface; Elevation of well head; Depth of infiltration tube; Aquifer type; Reservoir depth; Time of well completion; Data source; Organization of well completion.

(2) Data of pumping test in pumping well: Name of pumping well; Starting and completion time of pumping test; Water temperature; Pumping equipment; Well radius; Test method; Distance between pumping well and boundary; Boundary condition; Water table of non-pumping wells; Drawdown; Aquifer thickness; Pumping water rate; Permeability; Hydraulic transmissibility; Water storage coefficient; Number of observation well; Pressure transmissibility; Organization of pumping test; Data source.

(3) Data of pumping test in observation well: Name of observation well; Distance between pumping and observation well; Distance between observation well and boundary; Observation time.

(4) Basic data of flow-testing well: Name of well; Longitude and latitude; Well depth; Elevation of well head; Well radius; Casing depth; Radius of case tube, Infiltration tube depth, Body tube depth and netted tube depth; Cement material; Cement depth; Mixed water table; Water table of confined and unconfined aquifer; Depth and thickness of cover layer; Depth and thickness of reservoir; Time of well completion.

(5) Data of flow-testing: Temperature and pressure at certain depth; Temperature and

pressure at well head; Pressure of shut-in well; Inner radius of discharging well; Total amount of steam and water; Specific heat of thermal water; Specific heat of steam; Thermal water enthalpy; Vaporization heat; Test method; Number of observation well; Depth of precipitation tube; Bottom-tube radius; Test organization; Test time; Infiltration tube depth; Body tube depth and netted tube depth; Depth and thickness of cover layer; Water table of confined and unconfined aquifers; Mixed water table; Maximum temperature at certain depth; Power generation potential; Temperature after dilatation; Dryness.

(6) Data of water table regime: Name of observation well; Time of observation; Maximum water table; Minimum water table; Average water table.

(7) Basic data of thermal water site: Province name; Location; Longitude and latitude; Type (Well or spring ); Well head elevation ; Well depth ; Thickness of reservoir; Depth and elevation of water table; Flow-rate or pumping flow-rate; Well head temperature; Maximum and minimum water table; Water quality.

3. Subsystem of Thermal Fluid Chemistry in Geothermal Area

(1) Basic data of geothermal area: Area name; Location; Longitude and latitude; Coordination; Elevation; pH value; Flow-rate; Type(well or spring); Water temperature; Depth of basement layer; Well depth; Well head temperature and well bottom temperature; Data source; Average ambient temperature.

(2) Data of cations in thermal water: Na; K; Ca; Mg; Li; Rb; Cs; Al; Analytical method;

(3) Data of anions in thermal water: $CO_3$; $HCO_3$; $SO_4$; Cl; F; $HBO_2$; As; $SiO_2$; Analytical method;

(4) Data of gas composition in thermal water: $CO_2$; $H_2S$; $H_2$; $CH_4$; $N_2$; $O_2$; Analytical method;

(5) Data of isotopes in thermal water: $^2H$; $^3H$; $^{18}O$; $^{14}C$; $^{34}S$; Analytical method;

(6) Data of alteration minerals: Calcareous sinter; Kaoline; Chlorite; Opal; Quartz; Pyrite; Analcite; Pyrophyllite; Alum; Sphene; Apatite; Silica; Illite; Epidote Apatite; Chlorastrolite; Zoisite; Chalcedony sinter; Anhydrite; Montmorillonite; M-I mixed clay; Laumontite; C-M mixed clay; Muscovite.

The functions of the database system can be divided into two categories: database and data processing.

1. Database

Data input; Data correction; Data compilation, etc.

2. Data processing

(1) Calculation of geothermal gradient (total interval of well; designed interval of well; designed stratigraphic unit).

(2) Calculation of heat productivity.

(3) Calculation of hydraulic transmissibility; pressure transmissibility; water storage coefficient.

(4) Calculation of total amount of steam and water; water quantity; steam quantity, dryness, power generation potential.

(5) Calculation of reservoir temperature by geothermometers.

(6) Correction analysis of thermal water ions.

(7) Identification of thermal water chemical type.
(8) Plotting geotherm and water table regime.
(9) Plotting triangular diagram of water analysis.
(10) Plotting lithological unit.
(11) Plotting histogram.
(12) Plotting isolines of geotemperature, geothermal gradient and water analysis results etc.
(13) Geothermal resources assessment by using finite element method.
(14) Data output form: chart; table; geological map; statistical map, etc.

## 6. DEVELOPMENT AND UTILIZATION

As stated before, China has a long history (over 2000 years) of utilization of geothermal resources. Early people used hot springs for irrigation and clothes-washing. During the Han dynasty (206 BC to 220 AD), salt was extracted from thermal water in Zigong area of Sichuan Province. In the Ming dynasty (1368-1644 AD), Lishizheng, a famous medical doctor at that time, used hot spring water for disease treatments. He persuaded people: "If you got ill, go to hot spring area and take a bath". As a result, numerous bathing houses and spas were spread over hot spring areas throughtout the country. In Xiaotangshan (means "a little warm hill") hot spring area (25 km to the NW of Beijing), two thermal water pools were sunk in 1666, the 5th year of Emperor Kangxi of the Qing dynasty. And a bathing tank was constructed for the famous Empress Dowager Cixi (Figure 17). In Huaqingchi hot spring area near Xi'an city, the ancient capital of Tang dynasty, a quite fancy bathing house was built up for the Imperial Concubine Yang. However, all these uses were mainly for "health" and /or "recreation" purpose, rather than for energy.

Since the early 1970's, with recognition of the importance of geothermal energy as an alternative new and renewable energy source, geothermal resources have started to be used for energy purpose. The experimental geothermal power station was set up in Dengwu (Tengwu on Figure 1), Fengshun Country, Guangdong Province in 1970 and followed by Wentang and Huailai in 1971, Huitang in 1975 and finally, Yinkou in 1977 (Table 3, Figure 18).

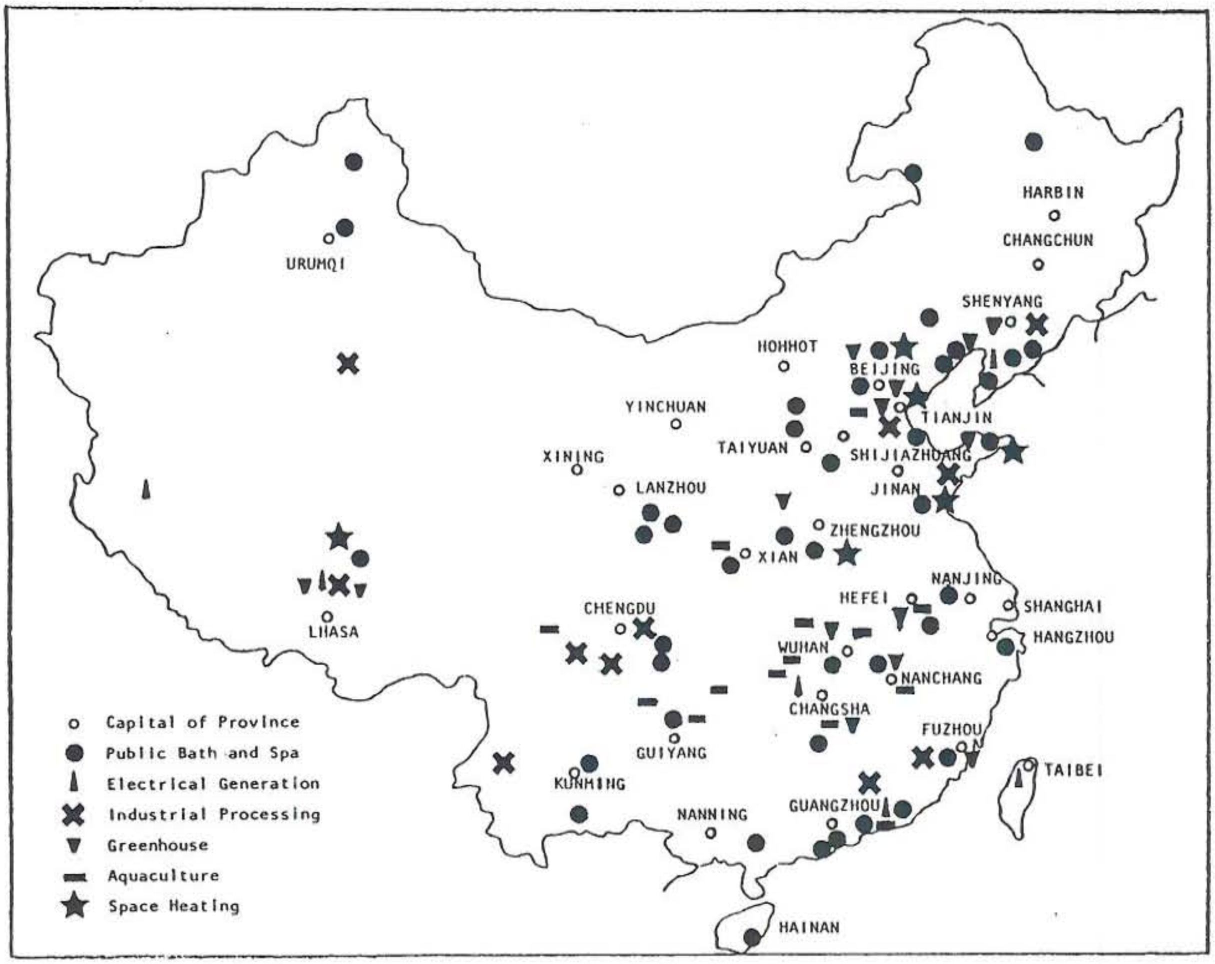


FIGURE 18: Geothermal utilization sites in China (acc. to Ren and Tang, 1989)

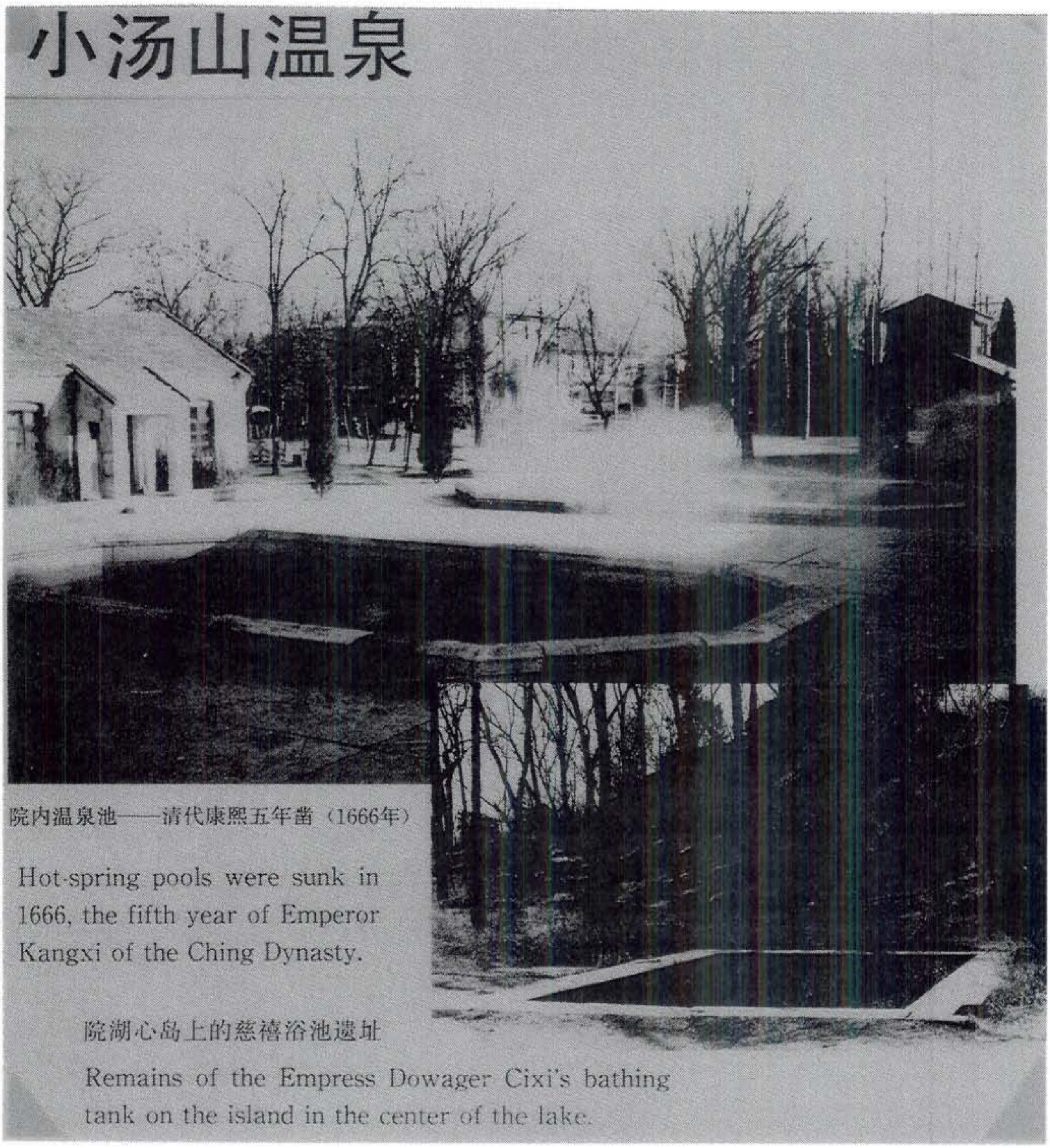


FIGURE 17: Thermal water pools and bathing tank for Emperor Dowager Cixi in Xiaotangshan hot spring area

It is clear that the capacity of all the experimental geothermal power stations is too small and the efficiency is too low owing to the low temperature of thermal water for power generation. At present, only Dengwu, Huitang and Yichun are still in operation (part time), and the other two were shut down several years ago. In 1977, a geothermal power plant was set up in Yangbajing Geothermal Field using thermal water with 5-20% vapour of temperature up to 202°C. By the end of 1990, the installed capacity reached 25.18 MW (Wu Fangzi, personal communication). As high temperature geothermal resources are concentrated in Tibet, Tengchong volcanic area and Taiwan, geothermal power generation is mainly conducted in these areas. Current plans are to have 50 MW on line by 1995, but only 7 MW are in design and/or construction phases at Yangbajing and Naqu (Ren et al., 1990; Huttrer, 1990). It is obvious that more funds and assistance are needed.

TABLE 3: Experimental geothermal power stations in China

| No. | Name | Location | Therm.water temperature (°C) | Design capacity (kW) | System type | Working medium | Generation date |
|---|---|---|---|---|---|---|---|
| 1. | Dengwu | Guangdong | | | | | |
| | Unit no. 1 | | 91 | 86 | Flashing | Water | Oct.1970 |
| | Unit no. 2 | | 91 | 200 | Binary cycle | Iso-butane | Sep.1971 |
| 2. | Yichun | Jiangxi | 67 | 50 | Binary cycle | Chlor-ethane | Sep.1971 |
| 3. | Huailai | Hebei | 85 | 200 | Binary cycle | Cholor-etane, butane | Sep.1971 |
| 4. | Huitang | Hunan | 92 | 300 | Flashing | Water | Oct.1975 |
| 5. | Yingkou | Liaoning | 75-84 | 100 | Binary cycle | Nor. butane, freon | Apr.1977 |

Taiwan started to investigate the possibility of using geothermal resources for power generation in the 1960's. An experimental power plant was set up at Tuchang geothermal area with a capacity of 0.15 MW in 1977 (Chen et al., 1992).

The state-of-the-art and further development of geothermal power production in China is demonstrated in Tables 4, 5 (Ren et al., 1990).

TABLE 4: Utilization of geothermal energy for electricity production as of December, 1989 (after Ren et al., 1990)

| Location | Year | No. of units | State | Type of unit | Unit rating ($MW_e$) | Tot.installed capacity ($MW_e$) | Und.const. or planned ($MW_e$) |
|---|---|---|---|---|---|---|---|
| Yangbajing (Tibet) | 1977 | 7 | In operation | Condenser | 6 x 3.0<br>1 x 1.18 | 19.18 | 2 x 3.0 |
| Langjue (Tibet) | 1984 | 1 | Work on and off | Testing | 1.0 | 1.0 | |
| Nagu (Tibet) | 1990 | 1 | Under constr. | Binary cycle | 1.0 | | 1 x 1.0 |
| Dengwu (Guangdong) | 1970 | 1 | Work on and off | Flashing, binary cycle | 0.3 | 0.3 | |
| Huitang (Hunan) | 1975 | 1 | Work on and off | Binary cycle | 0.3 | 0.3 | |
| Yichun (Jiangxi) | 1971 | 2 | Work on and off | Binary cycle | 2 x 0.05 | 0.1 | |

It must be pointed out that although the total amount of geothermal power production at present and in the near future seems to be too small, it still may be a big step in solving the energy shortage problem of remote areas in Tibet, West Yunnan etc. Thus, we are going to continue our efforts with the hope of contributing more electricity from geothermal energy.

TABLE 5: Present and planned production of geothermal electricity (after Ren et al., 1990)

| | Capacity ($MW_e$) | Utilization (GWh/yt) |
|---|---|---|
| In operation in Jan. 1990 | 20.88 | 50.0 |
| Under construction in Jan. 1990 | 1.00 | |
| Funds committed but not yet under construction, Jan. 1990 | 6.00 | |
| Total projected use by 1995 | 50.0 | |

As mentioned at the very beginning of these lecture notes, China nowadays is the second largest user of non-electric geothermal energy (Table 6) and "is showing out as a prospective leader in direct uses" (Freeston, 1990). There are about 49 projects using thermal water for industrial processing such as dyeing, drying fruits and vegetables, paper and hide processing, air conditioning and preheating boiler feed water, etc., with a net energy consumption of 171 GWh.

TABLE 6: Direct uses for the countries identified as having a capacity above 100 $MW_{thermal}$

| Country | Flow rate (kg/s) | | Power (MW) | | Energy (GWh) | | Load (%) | |
|---|---|---|---|---|---|---|---|---|
| | 1985 | 1990 | 1985 | 1990 | 1985 | 1990 | 1985 | 1990 |
| Bulgaria | | 2647 | | 293 | | 770 | | 30 |
| China | 3540 | 9534 | 393 | 2143 | 1945 | 5527 | 56 | 29 |
| Czechoslovakia | | 728 | | 105 | | 276 | | 30 |
| France | 2340 | 2971 | 300 | 337 | 788 | 886 | 30 | 30 |
| Hungary | 9533 | 12155 | 1001 | 1276 | 2615 | 3354 | 30 | 30 |
| Iceland | 4579 | 4595 | 889 | 774 | 5517 | 4290 | 71 | 63 |
| Italy | 1745 | 1520 | 288 | 329 | 1365 | 1937 | 54 | 36 |
| Japan | 26101 | 31311 | 2686 | 3321 | 6805 | 8730 | 29 | 33 |
| New Zealand | 559 | 252 | 215 | 258 | 1484 | 1763 | 79 | 78 |
| Romania | 1380 | 1380 | 251 | 251 | 987 | 987 | 45 | 45 |
| USSR | 2735 | 7722 | 402 | 1133 | 1056 | 2978 | 30 | 30 |
| Turkey | 1355 | 2012 | 166 | 246 | 423 | 625 | 29 | 29 |
| USA | 1971 | 3355 | 339 | 463 | 390 | 1420 | 13 | 35 |
| Yugoslavia | | 806 | | 112.7 | | 602 | | 61 |
| Others | 1965 | 2393 | 142 | 343.4 | 582 | 1761 | 47 | 58 |
| Totals | 57803 | 83381 | 7072 | 11385.1 | 23957 | 35906 | 39* | 36 |

* Based on total thermal power and energy. All other countries are together under "others".

Tianjin is the largest user of industrial processing mainly in dyeing. The energy consumption takes up 47.5% of the total. Yinshan County in Hubei Province, using thermal water of temperature 42-50°C for tannin extract, saved 12,800 ton of standard coal per well within 12 years. The energy saving through the use of thermal water for hide processing at Xiongxian County, Hebei Province is equivalent to more than 5,000 tons coal annually. The local people at Tenchong County, Yunnan Province are using 92°C thermal water for soaking pulp and paper drying and make quite a lot of money by exporting these products (Ren et al., 1990).

Space heating is mainly applied in North China where a severe cold winter is usual. With an energy utilization of 334 GWh, the heating area is totalling to 1,313,800 $m^2$. Geothermal space heating systems in Tianjin are concentrated in Tanggu, Hangu and Dagan districts. About 50 wells provide a maximum flow of 300 t/h of up to 97°C water to heat an area of 805,000 $m^2$. This is the largest single spacing heating project in China so far. The space heating projects in Beijing are spread over a large area of the city, but there are no central heating systems, usually one well for one unit only. The largest one is at Xiaotangshan sanatorium, where 4 wells provide 137 t/h of 50°C water to heat a total area of 4,000 $m^2$.

Greenhouses also feature as major users of thermal water in China. In 1990, China had a greenhouse area of 1,159,156 $m^2$ in 17 Provinces and/or Autonomous Regions, of which 258,129 $m^2$ is in Hebei Province , amounting to 22.3% of the total. Two standard designs of greenhouses are used to produce fresh vegetables, the main crops being cucumbers, tomatoes and lettuce. The farmers in Xiaotangshan County have built up 43,290 $m^2$ greenhouses and supply the grand hotels and fancy restaurants in Beijing with ten different kinds of special vegetables. In 1984, when President Reagan of the United States visited China, instead of getting vegetables by air from California, a variety of fresh vegetables from Xiaotangshan geothermal greenhouse were put on the table for the farewell banquet at the Great Wall (Beijing Sheraton) Hotel, which surprised and was enjoyed by the guests and host very much. Fish farming by thermal water appears to be another fast growing application in China. At present, a total area of 1.6 million square meters of fish ponds was reported in 17 provinces and cities. The products include African carp, eels, shrimps, turtles, snails etc. In Fujian Province, a large number of eels have been raised in geothermal fish ponds and the products are partly exported to Japan.

Currently, there are 594 baths, 23 swimming pools and 179 sanatoriums, with many more local pools at hot spring sites. The swimming pools and baths using thermal water for athletic training have rapidly developed in recent years. The famous training centre for female volleyball team using thermal water is located in Zhangzhuo City, Fujian Province.

It is interesting to note that the 4 provinces making major use of thermal water for non-electrical processes are Hebei, 24% of the county total; Tianjin, 15%; Shandong, 12% and Tibet, 10% (Ren et al., 1990; Freeston, 1990). The general information on the non-electrical utilization of geothermal energy in China is summarized in Table 7.

It must be pointed out that although geothermal energy in China has been developed and utilized quite rapidly during the past 20 years, we are looking forward to finding out and using more "high-energy-level" geothermal resources such as geopressured geothermal resources in deep parts of oil-gas fields and hot dry rock, even magma energy, in recent volcanic areas. There are some indications of the existence of geopressured geothermal resources in Bohai Bay area of North China and in Beibu Gulf at South China Sea (Zhang Qiming, personal communication). A research project on geopressured geothermal resources has just been approved and some results may be expected in the near future.

TABLE 7: Utilization of geothermal energy for direct heat as of Dec. 1989
(after Ren et al., 1990)

| Location | Type | Maximum utilization | | | Average annual utilization | | |
|---|---|---|---|---|---|---|---|
| | | Flow rate | Temperature (°C) | | Flow rate | Temperature (°C) | |
| | | (kg/s) | Input | Outlet | (kg/s) | Input | Outlet |
| Beijing | B+G+D<br>F+I+C | 285 | 70 | 40 | 237 | 52 | 33 |
| Tianjin | F+D+I<br>B+G | 1580 | 98 | 42 | 1426 | 51 | 35 |
| Fujian | F+B<br>G+I+A | 197 | 105 | 42 | 171 | 59 | 38 |
| Hubei | F+G<br>B+I | 389 | 77 | 43 | 245 | 62 | 30 |
| Shanxi | B<br>G+F | 277 | 86 | 38 | 113 | 44 | 30 |
| Liaoning | F+B+G<br>D | 250 | 96 | 43 | 188 | 70 | 34 |
| Henan | F+B+G | 214 | 63 | 40 | 143 | 38 | 30 |
| Sichuan | F+B<br>G+I | 382 | 98 | 39 | 366 | 48 | 36 |
| Jiangsu | B | 154 | 72 | 41 | 90 | 52 | 38 |
| Guizhou | B | 66 | 57 | 43 | 34 | 53 | 37 |
| Yunnan | B+F<br>I+A+C | 431 | 103 | 42 | 323 | 52 | 36 |
| Anhui | B | 110 | 63 | 41 | 83 | 51 | 35 |
| Hebei | F+B+G<br>D+I+A | 2121 | 104 | 41 | 1697 | 61 | 40 |
| Guangdong | B<br>F+I | 1268 | 98 | 40 | 840 | 59 | 38 |
| Hunan | F+B+I<br>G | 170 | 93 | 41 | 130 | 46 | 30 |
| Shandong | F+B | 711 | 103 | 46 | 521 | 64 | 42 |
| Jiangxi | F+B | 288 | 82 | 40 | 216 | 41 | 30 |
| Tibet | G+D | 260 | 154 | 78 | 214 | 135 | 62 |
| Qinghai | F+B | 61 | 93 | 45 | 52 | 42 | 30 |
| Shaanxi | B | 232 | 70 | 45 | 127 | 53 | 34 |
| Jilin | B | 53 | 75 | 38 | 42 | 49 | 32 |
| Xinjiang | B | 28 | 80 | 40 | 23 | 45 | 34 |
| Inner Mongolia | B | 7 | 48 | 35 | 7 | 48 | 35 |

Type of use:
I = industrial process heat
D = district heating
C = air conditioning
B = bathing and Swimming
A = agriculture drying
G = greenhouses
F = Fish and other animal farming

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