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DEVELOPMENT OF GEOTHERMAL ENERGY IN CHINA

1980?

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The Government of the People's Republic of China which pays great attention to the energy resources research and development has recently established the National Energy Committee as the nationwide special organization with responsibilities for planning, coordination and management of research and development of energy for the whole country. Geothermal energy, as a new source of energy, though at present has only made up small part of the country's total energy mix, is a promising potential energy, to which the Government of China attaches great importance. It can be foreseen that the geothermal energy will hold more and more important position in a country's total balance.

Follows are a brief introduction of the distribution, development and multipurpose utilization of the geothermal energy resources in China as well as the near future plan in this field.

DISTRIBUTION OF GEOTHERMAL ENERGY RESOURCES IN CHINA

Taking it into consideration the physico-geographical and geological conditions in China, and the multipurpose utilization of thermal water, the lower temperature limit is set at 25°C. Thermal water may be grouped into three classes as follows:

the low temperature is 25-60°C, medium temperature is 60-100°C and high temperature is over 100°C (Huang Shangyao et al.,1979-80).

China is rich in geothermal resources. To date, more than 2000 locations, including hot springs, geothermal wells and geothermal water in mines, have been discovered. Based on physical state of geothermal energy resources China has mainly natural hydrothermal convective systems: the geothermal water system and the wet-steam system while the dry steam system is not known yet. The geopressured and hot dry rock systems remains to be investigated.

More than half of the hot springs in China are located in Xizang (Tibet) Autonomous Region, Yunnan, Taiwan, Guangdong and Fujiang Provinces, where the hot springs occur in the most large numbers (Fig. 1). Hot springs are apparently concentrated in 4 zones --- Xizang-Yunnan, Taiwan, Southeastern Coastal and Yunnan-Sichuan. Next to the 4 zones, hot springs occur in Liaoning, Shangdong, Jiangxi, Hunnan, Hubei and Sichuan Provinces, each numbered over 50. Futhermore there are abundant geothermal resources in the country's vast plains as hidden geothermal fields and have been encountered by oil-gas wells.

All above show that the unique geological structure of China, the geothermal regime of the earth's crust and hydrogeological conditions in China are favorable to the formation and distribution of varied types of geothermal water and steam, and has provided natural cinditions for development and utilization of geothermal energy resources (Huang Shangyao et al., 1978).

largest one in China (Jin Chen Wei, Chou Yunshen, 1978), which reaches the upper mantle of the earth. Its associated magmatic activity and remelting process have provided the excellent channel and powerful heat source. Therefore' the Xizang-Yunnan Geothermal Zone is of most active on the mainland of China. In this zone more 400 sites of active hydrothermal outcrops have been found with abundant hot springs geysers, fumaroles and hydrothermal explosion orifices. Most of them in Xizang are exposed at an altitude of over 4000m. Among them over 100 sites have the temperature 86-94°C which are higher than local boiling point (Tong Wei et al., 1979-1980). At present the Yangbajing geothermal field in Xizang is under development. This field is located on middle segment of Xizang-Yunnan Geothermal Zone. A maximum temperature of 170°C is mearured at the depth of 150m. The well head temperature is 150°c. The pressure is about 3-4 atm.. The maximum flow rate of geothermal fluid is 400 tons/hour (Geothermal Team of Xizang Autonomous Region). The base temperature calculated from geochemical thermometer is 180-230°C (An Keshi at al.,1980). In 1977 an experimental power station with the capacity of 1000kw was built. The well-known Tengchong volcanic hot spring area, associated with Pliocene volcanic activi is located at the southeastern end of this zone. The hydrothermal activity is very strong. The temperature of geothermal water is, in most circumstances, over 96-98°C, exceeding the local boiling point. There are many geothermal manifestations, such as boiling spring clusters and fumaroles. The hydrothermal alteration and mineral deposition are developed. The well head temperature of a [illegible] borehole on the left side of Zaotang River is 96°C. The water-steam spouted at a height of about 15m with a discharge of 23 tons/hour (Geological Bureau of Yunnan Province). The downhole temperature at the depth of 12m reached 145°C. The exploration and development of the geothermal resources is orientated to power generation.

Taiwan Geothermal Zone lying in the suture line between Pacific Plate and Eurasian Plate is a part of Circum-Pacific Island Trough Belt. The ophiolite zone is well developed along the Dachonggu geofracture belt which suggests the geofracture has already reached deeply into the upper mantle. The recent crustal movement is intense on the Island, with the relatively violent Quaternary volca[nic] activities and frequent earthquakes. Thereare more than 100 active hydrothermal sites in this region, six of them with temperature ove[r] 100°C. In the volcanic area which is near Beitou of northern end of Taiwan there are many fumaroles, the highest temperature of them is 120°C.(C. H. Chen, 1970). In a 1005m deep well high-temperature steam of 294° is obtained. Owing to the low pH value, thier development and utilization ran up against difficulties. In addition, the reservoir temperature of the Tuchang-Qingshui geothermal area in the southwest part of Yilan County is as high as 220°C. A 1500 kw turbo-generator has been installed and test run started in Octo[ber] 1977 (Geothermal World Directory, 1978-79).

Distribution of Medium and Lower Temperature Energy Resources in C[hina]

The medium and lower temperature geothermal water is widely di[s]tributed on mainland of China in the interior part of the plate.

In the uplifted regions of the earth's crust, the geofracture [zones] formed in different ages undergoing tectinic movements after thier formation. Some of them become active only recently. In gener[al] they are good channels for the movement and ascendance of deeply circulating ground water, which is heated by normal underground temperature. At the low-lying places of the uplifted regions (usually valleys or intermountain basins) geothermal water occurs in form of hot springs. According to the concentration of hot springs in these regions, two medium and lower geothermal zones can be preliminarily divided up, namely the Southeastern Coastal Geothermal zone and Yunnan-Sichuan Geothermal zone (Huang Shangyao et al., 1979-80, An Keshi and Huang Shangyao, 1980).

The Southeastern Coastal Geothermal Zone lies in the west from the suture line between the Eurasian Plate and the Pacific Plate, including east Jiangxi, south Hunan, Fujiang, Guangdong and Hainan Island. There is no recent volcanic process in this zone, but since Mesozoi the crustal movement is intence and the geofractures are developed. Associated neutral and acid magmatic activity formed volca[nic] rock zone of southeast coast and largequantity of granite bodies. The NNE and NE folded zones and geofractures of different nature ha[ve] been formed. The hot springs of medium and lower temperature are m[ain]ly concentrated in the Southeastern Coastal Geothermal zone, 250 o[f] them are located in Guandong and 150 in Fujiang. Water temperature ranges from 40°C to 80°C and sometimes over 80°C. Hot springs are generally located along the geofracture zones and on the fringes o[f] Yanshan granite bodies. Several hot spring regions, such as Deng[...] [...] in Guangdong (93°C), Dongshanhu, Shantou in Guangdong(a[nd] [...] in Fujiang (98°C) have been explored not long before. Here is the favorable region for the development of medium and lower temp[...]

rature geothermal resources in China.

Yunnan-Sichuan Geothermal Zone lies in the east from the sutur line between Indian Plate and Eurasian Plate, extending from south to north along the active tectonic zone. The tectonic movement is intense there with remarkable ground deformation and frequent earthquakes. In this zone there are over 100 hot spring locations, which are relatively concentrated along south segment. Most of them have a temperature of over 60°C, sometimes up to 90°C. The hot spri along north segment of this zone are less than that of south, with the temperature below 60°C.

In other areas, such as Yanshan, Taihangshan, Qinling, the nor foot of Tianshan, southeast Sichuan and west Chaidamu basin, there are also a lot of hot springs, more or less concentrated, extendi generally along the folded and fractured zones. The temperature is mostly less than 60°C. Some of them have the temperature about 80-90°C.

In the depressed regions of the earth's crust with Mesozoic an Cenozoic sedimentary formations in interior part of the plate, which is widely developed in China, there exist medium-lower temperature geothermal water. At the relatively uplifted parts of the basement in faulted depressed basins, the geofracture systems are usually more developed. Deeply circulating ground water, heated by normal geothermal temperature, ascends along the channels of fractures and is accumulated at the top of the basement rocks, usually forming the hidden geothermal reservoirs. In depressed basins where the tectonic movement is comparatively mild, the geothermal water-bear strata have extensive areal distribution, but the temperature is the same as that of surrounding rocks. In Huabei, Jianhan, Sichuan, Shanganxin, Chaidamu, Talimu and Zhungeer oil and gas-bearing basins, geothermalwater or brine have been discovered from time to time along with the oil-gas exploration. Among them the Huabei (NorthChina) basin has the best potential. Ther are over 100 boreholes encountred geothermal water with the temperature of 70-90°C. Some wells of Renqiu Oilfield have tapped geothermal water with the temperature of over 100°C and the flow rate of 4300 tons/day(Xie Jiasheng, 1978). At Zhongshan Park in Beijing a 2600 m deep well has been drilled. The temperature of geothermal water is 69.5°C (Geological Bureau of Beijing). At Wanjiamatou in Tianjing, the geothermal water from 1100-1400 m depth has a temperature of 94°C (Geological Division of Tianjing). Leiqiong basin in south China is also abundant in geothermal resources. In most cases, at the depth of 300-500 m, geothermal water with the temperature of 30-50°C can be encountered. In Jianghan and Sichuan basins, the oil-gas exploration wells with the depth of 2000-3000 m have obtained geothermal brine . The temperature of the highly mineralized (180-330 g/l) geothermal brine is over 80-90°C.

North China is on the east margine of the Eurasian Plate. Under the influence of Pacific Plate basins of grabentype are developed. The terrestrial heat flow is measured as slightly over 1.5 HFU (Geological Institute of Sinica, 1978). Analyzing the temperature data collected from oil-gas fields, the geothermal gradient in large depressed basins of China has the general tendency to decrease gradually from east to west.

Recently, the regions of depressed basins in the interior part of the plate with comparatively high geothermal gradient are considered as the favorable areas for the development and utilization of medium-lower temperature geothermal water.

To summarize, the geothermal activity decreases regularly from east to west, along with the weakening of recent tectonic mobility from plates boundaries to interior part of the plate. As a result, the geothermal temperature, gradient and the density of hot springs are gradually lowered.

CURRENT STATUS OF GEOTHERMAL ENERGY RESOURCES EXPLORATION AND DEVELOPMENT IN CHINA

Historical Description

Geothermal energy development in China could be dated back in ancient times. The history of development and utilization of geothermal energy resources in our country may be summarized in two stages (Huang Shangyao et al., 1979).

Before Liberation

Ancient chinese utilized hot springs for bathing, irrigation, medical treatment and sulfur production as early as 500-600 years B.C.. Since Han Dynasty, deep wells had been drilled to withdraw geothermal brine for salt recovery. There are many accounts in chronicles about hot spring utilization in medical treatment and seedling overwintering. Actual development of geothermal resources, however, stagnated before liberation, except the very limited construction of some hot spring sanatoriums.

After Liberation

Along with development of national economy and progress of science and technology in the fifties and sixties, the exploration and development of geothermal resources was put on the agenda.

A lot of hydrogeological and other related investigation teams of different provinces, municipalities and autonomous regions began to investigate thier indigeneous geothermal resources, some exploration had been done at hot springs to meet the requirement of newly constructed or existing sanatoriums. The process of development as a whole, however, was rather slow.

Since 1970, at the suggestion of the late geologist prof. Li Siguang, many provinces, municipalities and autonomous regions have carried out geothermal prospecting, exploration and multipurpose utilization. In Beijing, Tianjing, Xian, Kunming and other large cities deeply hidden geothermal reservoirs had been explored for bathing, heating, industrial processes and other purpose. At the same time, at Fengshun of Guangdong Province, Huailai of Hebei Province, Huitan of Hunan Province, Yichuen of Jiangxi Province and Yangbajing of Xizang (Tibet) Autonomous Region, geological exploration work was directed specially to electrical power generation. Seven experimental geothermal power stations have been constructed successively. The number of geothermal bathing houses, space heating systems and green houses utilizing geothermal energy increased rapidly and partially substituted conventional energy resources. To date, geothermal prospecting has been undertaken in more than 20 provinces, municipalities and autonomous regions. In recent years, along with the regional hydrogeological mapping and prospecting, the investigation of geothermal resources has been also started in remote border regions.

At this stage, the exploration, development and utilization of geothermal resources advanced rapidly. Geothermal exploration is conducted not only near the known hot spring regions, but also in plain regions, including some large cities such as Beijing, Tianjing Xian, Kunming and Huabei Oilfield, providing valuable experiences for geothermal prospecting in areas covered by thick sedimentary formations with the geothermal fields of medium or lower temperature. Such geothermal energy is suitable for direct utilization rather tha electrical power generation. Obvious progress has been obtained in th area of multi-stage and multi-purpose utilization of geothermal water

In mainland of China, high-temperature geothermal resources are distributed only in south- west border regions. Exploration, develop ment as well as experimental geothermal power generation are being carried out at Yangbajing in Xizang Autonomous Region. Tengchun volcanic hot spring area is also under exploration.

Multi-Purpose Utilization

Geothermal resources are, sometimes, composite resources, which provide not only thermal energy but also some industrial minerals.

Electrical Power Generation Utilizing Geothermal Energy

The utilization of geothermal energy forelectrical power generation has the advantage that it requires neither conventional boil fossil fuel, nor heavy transportation and does not cause environmen troubles. Rational utilization of geothermal energy can improve in future the energy resources distribution. Since the known geotherma fields of higher temperature are located mostly in south-west remot border regions, where development conditions are rather sever, the first experimental geothermal power stations had to be constructed in some areas of east China in the early 70s. Such as the experime power plant at Dengwu, Guangdong Province which was completed in

1971. Five other ones had also been constructed successively. All these power plants utilize geothermal water of medium or even lower temperature. They are operated with binary system or flash steam system. It has been evidenced by practice that geothermal water of low or medium temperature is generally unsuitable for electrical power generation with present technology. In vast area of China this type of geothermal fields are dominant . Only at geothermal fields of relatively high temperature, the power generation utilization is feasible. So the focal point has been later shifted to remote border regions, such as Yangbajing of Xizang Autonomous region, Tengchun of Yunnan Province and so on. In particular, the experimental power plant at Yangbajing is already in operation, making use of wet vapor from boreholes. The experiment seems to be successful and is now in expansion. Electricity production utilizing geothermal energy will be significant for these remote border regions.

Different Industrial Processes Utilizations

Geothermal energy resources have wide applications in various branches of industry. It can save conventional fossil fuel for heat and chemicals for water treatment. Nowadays, geothermal water is utilized as hot water supply for boilers, tannin extraction, paper-making, textile, printing and dyeing, concrete components curing, leather drying, air conditioning etc.. Good results have been obtained in these fields. At Guanghua Dyeing and Weaving Mill in Beijing, for example, the 48°C geothermal water is used directly on calendering-dyeing machines, giving an economy of steam estemated as 15000 tons per year (equivalent to 2500 tons coal) (Yang Qilong et al., 1976)

A certain concrete components plant in Liaoning Province makes use of 71°C geothermal water, attained a save in coal of about 2800 tons annually. Fuzhou Tennery utilizes 93°C geothermal water in boiler an leather-drying machines. Over 1000 tons of coal is saved every year.

Utilization for Agriculture

In rural areas of China, geothermal energy is utilized in accor dance with local conditions. Some experiences have been accumulated in this field. Geothermal water can regulate the temperature of irri gating water, preventing the seedling of rice from rotting in cool early spring, which is of benifit to grain yield. Somewhere in Hebei Province, fresh or waste geothermal water from local sanatorium is used to irrigate more than 800 mu rice field, grain yield was incre by 100-200 jing per mu. In Nanxiong Basin of Guangdong Province, 39 geothermal water is used to irrigate 70 mu field, which improved lo laterite soil and a grain yield of 300 jing per mu was registed (G dong Hydrogeological Observation Station, 1972). In some hot sprin area of Hubei Province, some station of rice seed multiplication ha been built, and good results have been obtained. At Jingshan, Yinch and Yincheng, green houses covering an area of 3 mu have been built Geothermal water saved 3000 tons of coal per year (Tian Doufeng, 1 8). At certain duck farm of Tianjing, geothermal water is utilized in incubators instead of electrical heating. The save in electrici is about 570,000 kilowatt hours per year. At Xiongyue District o Liaoning Province, geothermal water is used for green house heating. Besides, it is also used to grow seedling of sweet potatos. Every year, some 3500 tons of coal is saved. Geothermal water is also us in overwintering of some water plants. It in turn brings about an advance in pig farming. Somewhere, geothermal water is circulated i. fishponds at winter time (Guangdong Hydrogeological Observation Station, 1972, Yang Qilong et al., 1976, Zheng Keyan, 1979).

The Utilization of Geothermal Water in Dayly Life

In this field, geothermal water is utilized for space heating, resort bathing, washing and drinking. It saves coal and manpower, r. duces pollution. For example, at Beijing People's Art Press House a. Xiaotangshan Hot Spring Sanatorium, geothermal water (58°C and 51°(respectively) heating covers a floor space of 18,000 m^2. Annual saving of coal is estimated at 400 tons. In Beijing Renming Machine Works, geothermal water is for public bathroom. This alone saves 600 tons of coal per year (Zheng Keyan, 1979). Haikou City on Hai. Island, Guangdong Province, has some wells tapped geothermal reservoir, yielding geothermal water of 35-42°C. A water tower and distr. bution system has been built for townpeople. In Fujian Province, ge. thermal water also used in local public bathhouses. All these examples show that beside electricity generation, direct use is an important aspect of geothermal energy utilization, which might seem to have little worth in one case, it plays a great part as a whole in saving fossil fuel and reduction of pollution and deserves recommendation in densely populated areas, wherever exist the conditions for geothermal reservoir occurence.

Medical Treatment

Geothermal water has the value in medical treatment because of ... higher temperature and special chemical composition. At prese.

there about one hundred sanatoriums built in hot spring areas. According to investigations and experimentations of public health office, some geothermal water has obviously curative effect on diseases as a arthritis, certain skin diseases (psiriasis, eczema) , intestines and stomach diseases as well as early heart and artery diseases. Many hot spring sites are famous to tourists for there scenic beauty, in such areas care must be taken when drilling programme is under consideration, to prevent any possible damage to natural sight.

Recovery of Mineral

Bromine, iodine, boron, lithium, strontium, potassium and compounds of other elements are extracted from geothermal brine in Sichu Hubei, Qinhai, Shangdong, Guizhou and other provinces, providing chemical and nuclear industries with raw materials. In particular, i Jianghan Basin of Hubei Province, the highly mineralized geothermal brine is utilized by a salt-chemical plant to produce annually more than 10 thousand tons of table salt, 18.8 tons of bromine, 0.5 ton of iodine, 40 tons of boron, 70 tons of potassium and 480 tons of ammonia water (6%) (Tian Doufong, 1978). Tengchun volcanic hot sprin produce certain amount of sulfur.

In brief, in the field of multi- purpose utilization, some expe riences have been accumulated in regard to lower and medium temperat geothermal water as a cheap and clean substitutes for conventional energy resources. Geothermal energy will play ever increasing part i our nation's economic development.

TENTATIVE PROFRAMME OF GEOTHERMAL ENERGY DEVELOPMENT

Considering the geothermal energy resourcesdistribution in our country and current status of exploration and development technology a tentative programme of geothermal energy development has been formulated as follows:

1, Geothermal energy resources investigation and assessment

Thorough investigation of economically exploitable geothermal resources distribution and potential. Indication of prospective area as the basis for overall planning of geothermal energy development i period 1900-2000.

1) Compilation of geothermal resources catalogue and maps of geothermal energy resources distribution.

2) Investigation of ground temperature and heat flow, compilation of the maps of ground temperature, heat flow and gradient.

2, Exploration and assessment of major geothermal regions, investigation of occurence and spatial distribution of geothermal reservoirs mechanism of thier origin and potential of resources.

1) In medium and lower temperature geothermal regions.

Prior development in large and medium cities, oilfields or industrial and mining areas for direct utilization, such as space heating, hot water supply, industrial and agricultural utilization.

2) In high temperature wet steam geothermal regions.

Experimental development on one or two selected points with the purpose of electricity generation.

3) Experimental research of geopressured geothermal resources.

4) Hot dry rock geothermal resources research.

3, Exploration techniques.

1) Infra-red remote sensing.

2) Terrestrial heat flow measurement.

3) Electrical methods of exploration (natural potential and audi frequency magnetotelluric method).

4) Microseismic method.

5) Geochemical method.

6) Isotop-geochemistry method.

7) Numerical simulation of geothermal reservoirs.

8) Thermo-physical properties measurements (thermal conductivity specific heat).

9) Measurement techniques (of temperature, pressure, flow rate e

10) Downhole geothermal water sampling equipment.

11) Deep well drilling technology, including grouting and preventing.

4, Development of geothermal reservoirs

1) Artificial recharge.

2) Scale deposition.

3) Anticorrosion.

4) Long-distance transport.

5) Artificial stimulation

6) Environmental aspects.

7) Land subsidence.

8) Life prediction of geothermal field.

5, Geothermal energy utilization.

1) Electricity generation.

Binary cycle system

Total flow system.

2) Other applications.

CONCLUSION

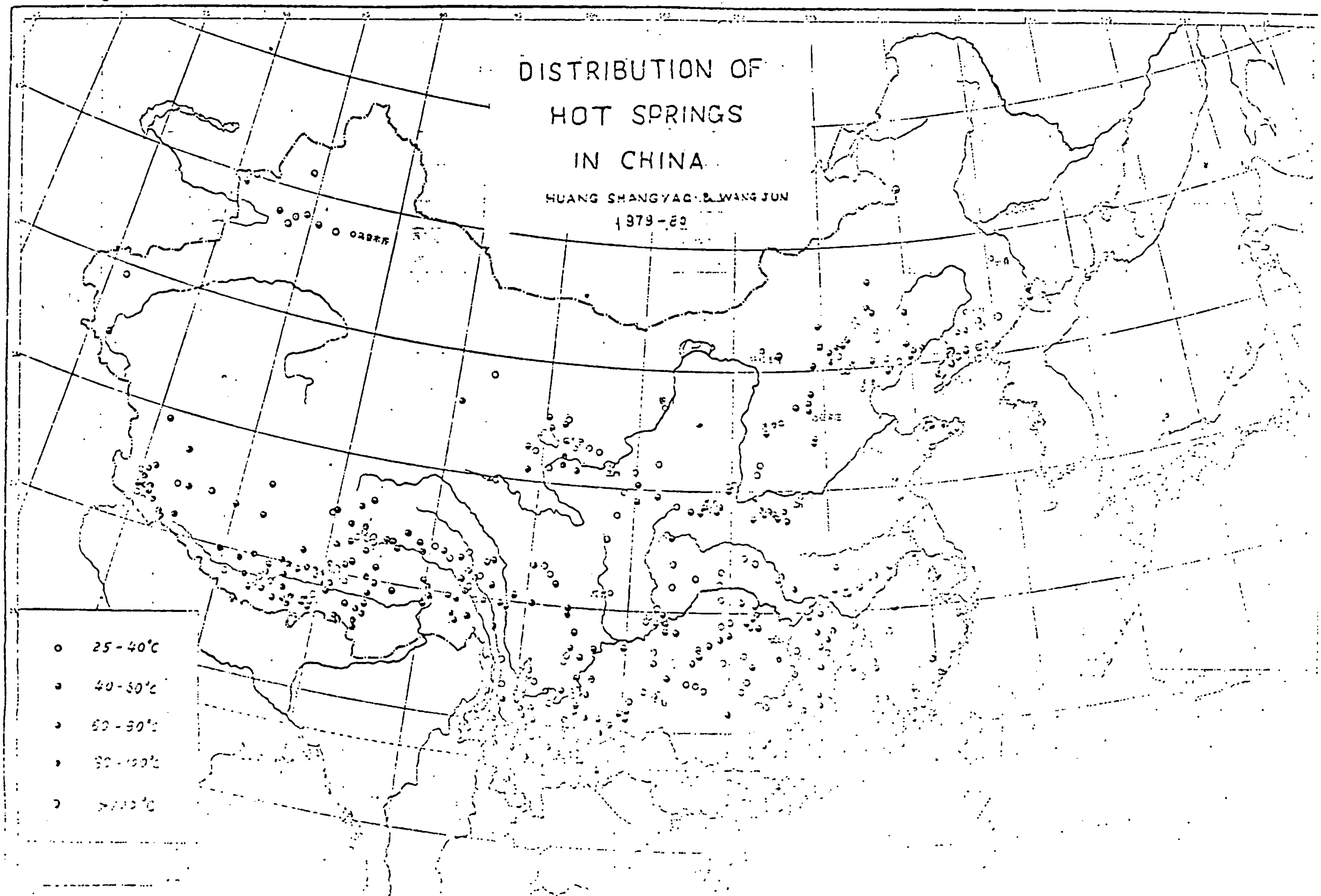
In recent years, the Chinese Government attaches great importa to geothermal energy development and obvious progress has been achi in this field, especially in multi-purpose utilization of lower and medium temperature geothermal water, while the utilization of geothermal energy for electrical power generation is at start point.

Since United Nations Conference on New Sources of Energy (Rom 1961), a series of worldwide or regional symposiums on geothermal energy development have been held. I believe this Seminar held by ESCAP will promote geothermal development in participant countries. We are glad to have the opportunity to exchange experiences with asian and pacific countries, in particular, the abundant experience of host country -- New Zealand, is very valuable for us.

ACKNOWLEDGEMENT

I am indebted to Dr. Zhang Hongren, senior geologist of Minist of Geology, for his encouragement and assistance in preparation of this paper. Appreciation is expressed to Dr. Xin Kuide, deputy chie of Hydrogeology and Engineering-Geology Bureau and Mr. Li Zhiji of the same ministry for thier valuable comments on the paper.

Fig. 1


DISTRIBUTION OF
HOT SPRINGS
IN CHINA
HUANG SHANGYAO & WANG JUN
1979-80
25-40°C
40-60°C

Translation from the original Chinese arranged through auspices of CHINA CONSULTING GROUP, INC.

Published October, 1980 by:

CHINA CONSULTING GROUP, INC.
Oak Cliff Bank Tower, Suite 1320
400 South Zangs Blvd.
Dallas, Texas 75208

(214)941-8800

Price: $95.

GEOTHERMAL RESOURCES AND DEVELOPMENT
IN THE PEOPLE'S REPUBLIC OF CHINA

1980

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Part 1

PRESENT STATUS OF THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL ENERGY IN THE PEOPLE'S REPUBLIC OF CHINA

Part 1 - PRESENT STATUS OF THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL ENERGY IN THE PEOPLE'S REPUBLIC OF CHINA

China has abundant geothermal resources. According to China's natural geographic and geological conditions, and considering the practical conditions of geothermal water's comprehensive utilizations, we have defined the lower limits of the geothermal water temperature to be 20°C in the north and 25°C in the south. Based upon this criterion, China has already discovered nearly 2,500 thermal water points covering all of China's 30 provinces, municipalities, and autonomous regions. More than half of these are located in the southeastern coastal area and in parts of western China, such as Yunnan and Xizang (Tibet). They form two concentrated belts and most of them contain thermal water over 80°C.

The concentrated belt of the southeastern coast covers Guangdong, Fujian, Taiwan, Jiangxi, and southern Hunan. The province that has the most number of thermal water emergences is Guangdong, with more than 250 locations. Fujian has more than 150 locations, and Taiwan has more than 100 locations. This concentrated belt has a total of more than 650 thermal water emergence locations. Quite a few of those locations have water temperatures exceeding 90°C; for example, 102°C at Dongshanhu in Shantou, Guangdong; 93°C at Dengwu in Fengshun; 98°C in Fuzhou, Fujian; and 92°C in Huitang, Hunan. In Zhangzhou, Fujian, there is a seismic hole 265m deep at the bottom of which the temperature exceeds 120°C. In Taiwan Province, there are 103 active regions of thermal waters. Six of these have temperatures that exceed 100°C. Among these is the Pingdong hot spring in Gaoxiong County, which reaches water temperature as high as 140°C. The Datun volcanic hot spring region's steam temperature reaches 294°C in a geothermal borehole over 1,000m deep. The southeastern coastal geothermal water belt is a favorable region for the development of high temperature thermal water in China.

The Yunnan-Xizang concentrated belt covers the southwestern plateau of China in Xizang region and Yunnan Province. There are a total of more than 700 thermal water emergence locations. Among these, Yunnan has more than 480 locations and Xizang has more than 200 locations. From the northern foothills of the Himalays to western Yunnan, there are many thermal water fountains and steam fountains. Of those discovered, there are over 40 thermal water active regions with water temperatures higher than the local boiling points. The Yangbaqing geothermal field in Xizang has more than 10 geothermal boreholes sunk, and has yielded a steam temperature above 150°C. The flow rate per well reached 400mt/hr. Western Yunnan is the province's main region of high temperature thermal water with 9 locations where the temperature of the thermal water exceeds the local boiling points. Included is the well-known Tengchong volcanic hot spring. Based upon temperature measurements in shallow boreholes, the water temperatures have reached 135°C at 10m depth, and 145°C at 12m. The Yunnan-Xizang concentrated belt is China's most promising region in developing the high enthalpy (i.e. greater than 150°C) geothermal energy.

In addition to the southeastern coast and the southwestern Yunnan-Xizang concentrated belts, there are also large numbers of hot spring emergences in other places of China, such as along the northern foothills of Tianshan, Qilianshan, Taihangshan, Luliangshan, the Weihe graben, the eastern Qinling, the Hebei and Rehe mountainous regions, Liaodong, the Shandong peninsula, Dabieshan, Ningzhenshan, western Hunan, and the eastern Guizhou heave. Among these, there are more emergences in Liaodong, Shandong, Sichuan, and Hubei Provinces. Each of these provinces has more than 50 locations. The water temperatures of these areas are lower than the above-mentioned concentrated belt, averaging between 25-60°C. However, some of the hot springs have temperatures higher than 80-90°C. For example, the temperature is 93°C at Jimo, Shandong; 90°C in Zhaoyuan; 87°C at Xiongyue, Liaoning; and 96° at Ningcheng's Reshuitang.

Also, within the Mesozoic and Cenozoic deposit basins of China, there are extensive geothermal water resources. The northern China region has the greatest potential. Because of the development of the Huabei Oil Field, thermal water with temperature above 90°C has been found in many oil and gas exploration boreholes. There are also many thermal water wells with temperature exceeding 30°C in the Beijing-Tianjin area. There are nearly 200 wells in Tianjin. Tianjin's geothermal resource is extensive with its thermal anomaly region having an area of 590km2. Part of this is in the urban area. The core region of the thermal anomaly region has a geothermal temperature gradient of above 8°C per 100m. There are two types of geothermal water in Tianjin. One is the overburden thermal water, which has a depth of about 700-1,200m with a water temperature not exceeding 55°C. Another is the bedrock crevasse water, which has a depth of about 1,200-1,800m with a water temperature of more than 70°C. The thermal well at Wanjiamatou in Tianjin region has a withdrawal section between 1,100-1,400m with a water temperature of as high as 94°C. In addition to the northern China region, the Qionglei basin in southern China also has abundant geothermal water. Even at 2-3km depth, thermal brine has been obtained in Jianghan Basin in Sichuan (Note: should read Hubei). The mineral content reached 180-330g/liter.

To summarize, from the south to the north in China, from Changbaishan to Yuanshan, and from the southeastern coast to the Qinghai-Xizang Plateau, there are extremely extensive distribution of geothermal resources. This shows that China has a special and unique geological structure where the thermal condition of the earth's crust and hydro-geological conditions are all favorable to the formation and distribution of various types of geothermal water and steam. This has created favorable natural conditions for China's development and utilization of geothermal resources.

China is one of the world's earliest countries to develop and utilize geothermal energy. This was recorded over two thousand years ago. But large-scale development and utilization was only made in the last ten years. During the period of the 1950's and 1960's, China's geothermal resource development was limited to develop hot springs for therapeutic purposes. In the 1970's, the emphasis of developing geothermal energy was shifted to the comprehensive use for industry and agriculture in addition to therapeutic uses. More than two-thirds of China's provinces, municipalities, and autonomous regions have now started reconnaissance surveys and exploration work for utilizing geothermal resources. Cities without thermal water emergences, such as Beijing, Tianjin, Xian, and Kunming have also engaged in the exploration and development of geothermal resources.

Research work on geothermal power generation started in 1970. China's high temperature geothermal resources had not been developed at the time; hence, all the research performed dealt with the low temperature geothermal water in seeking geothermal power generation technology. The purpose of the research was to accumulate experience for future large-scale power generation by using the medium-and high-temperature geothermal resources. China's first small experimental geothermal power station was completed in October of 1970 in Fengshun County of Guangdong Province. The station has a capacity of 86kw and uses a single stage flashed-steam cycle system. In September of 1971, two small experimental geothermal power stations were built, one in Yichun, Jiangxi, and another in Huailai, Hebei. Both used a dual-fluid circulation system. The working medium was chlorethane (C_2H_5Cl). The capacities were respectively 50 and 200kw. Now, there are six such small experimental power stations. Their types and parameters are summarized in the following table. Starting in 1976, China has been carrying out high temperature geothermal fluid exploration and development in Yangbajing, Xizang. In September, 1977, the first unit of the Yangbajing experimental geothermal power station began operation. The geothermal wet steam temperature was approximately 150°C. The station adopted the single-stage flashed-steam cycle and had a capacity of 1,000kw. It was used to acquire experience in utilizing Yangbajing's geothermal fluid for power generation. It is planned that a 3,000kw unit will be installed in Yangbajing by the end of 1979.

TABLE 1 - EXPERIMENTAL GEOTHERMAL POWER STATIONS

Name of Experimental Geothermal Power Station	Location	Thermal Water Temp. (°C)	Design Capacity (kw)	System Type	Working Medium	Generating Date
Fengshun	Fengshun (Dengwu), Guangdong					
No. 1 Unit		91	86	Flashed-Steam Cycle	Water	1970, 10
No. 2 Unit		91	200	Dual Fluid Cycle	Iso-Butane	1971, 9
Wentang	Yichun (Wentang), Jiangxi	67	50	Dual Fluid Cycle	Chlor-Ethane	1971, 9
Huailai	Huailai (Houduyao), Hebei	85	200	Dual Fluid Cycle	Chlor-Ethane, Normal Butane	1971, 9
Huitang	Ningxiang (Huitang), Hunan	92	300	Flashed-Steam Cycle	Water	1975, 10
Yingkou	Xiongyue, Liaoning	75-84	100	Dual Fluid Cycle	Normal Butane, Freon	1977, 4
Yangbajing	Yangbajing, Xizang	150	1000	Flashed-Steam Cycle	Water	1977, 9

The economics of power generation using low and medium temperature geothermal water is very poor, especially when using geothermal water with temperatures of less than 100°C. China's building of those experimental geothermal generating units in the 1970's is aimed at researching the technology and system for geothermal power generation. It was also based upon the principle that "according to the local conditions, fully utilize China's plentiful energy sources of all kinds"; a search was made for the feasibility and economics of the low- and medium-temperature thermal water which exists almost all over China.

For example, the Hydrological-Geological Team of Jiangxi Province, in a joint effort with the Research Group on Energy Sources of the Tianjin University experimentally researched the utilization of a hot spring water of 67°C in Yichun, Jiangxi. A small experimental geothermal power station of 50kw adopting a dual-fluid circulation system was built. The working medium was chlorethane. The unit was of the axial-flow type turbine with a relative internal efficiency of about 70%. Later, a unit of the radial-flow type was developed and built. The relative internal efficiency was increased to more than 80%. The condenser used low-winged spiral thread tubing in place of bare tubings in order to enhance heat transfer. This almost doubled the efficiency of the condenser heat transfer. There are two tube-and-shell type standing evaporators. These can be used in parallel or can be operated in series as in a two-staged evaporation type. Originally, the production well was not artisian. After recharging the nearby well with river water, the production well became artisian. The head was then about 5m, and the flow rate increased to 90-100mt/hr. The water temperature also increased slightly. This eliminated the need for a deep-well pump. The condenser cooling water flowed by gravity. The topography of the mountainous region was utilized by building a dam of one-meter height across the river, and the water was drawn through a concrete pipeline to the power station. The station had a lower elevation and hence obtained a head of about 3m. This eliminated the need for a condenser cold-water pump. Thus, in this 50kw experimental power station, there was very little power consumption within the plant. Only the pump for the chlorethane working medium required about 6-7kW. Because of these factors, this tiny power station which used 67°C thermal water could supply power to the local residents continuously over the years. This also made the power station independent of outside power sources for its start-up. The effluent thermal water from the station was sent to several large geothermal greenhouses, nearby hot spring sanatoriums, and hospitals. This opened the research into seed breeding and health therapy experiments. The end effluent was sent to rice paddies to raise the soil temperatures, to promote early maturing of the crops, and to raise the yield. This enabled the full use of the thermal water which previously had been wasted by flowing away.

The direct use of the low temperature geothermal water is more economical and is more effective. Many places in China have started experiments in this field. Many cotton, wool, and dyeing textile factories in Beijing, Tianjin, Guangdong, Yingkou have used geothermal water for cloth dyeing and washing, and for adjusting shop humidity and temperature. Not only has this simplified the processes and improved the working environment, but it also improved the cleanliness, brightness, and color of the textile product. Yinshan and Jingshan, two counties in Hubei, used geothermal water to establish two seed-breeding bases. From 1971 on, Yinshan has cultivated more than 500 varieties of early, middle, and late rice strains. More than 100 of these strains have entered their fifth or sixth generation. Many of the good strains have gone through winter propagation in the geothermal greenhouses and raised its propagation coefficient, and subsequently propagated over the whole county. The yield has reached more than 1,000 jin per mu per crop. (Note: 1 jin=0.5kg, and 1 mu=0.067 hectare). These strains were welcomed by the masses. Hunan, Jiangxi, Liaoning, Shandong, Tianjin and many other places have used geothermal water to protect the floating lotus (a pig feed in southern China) through the winter, to help in curing concrete products, in leather-making, in cultivating African carp, for vegetable planting, seedling raising, and for poultry incubation. Industries in Sichuan, Yunan, Guizhou, and Xhandong Provinces have extracted iodine, potassium, lithium, sulfur and other useful elements from geothermal waters. The Jianghan Basin in Hubei has two high temperature brine wells. On top of an annual salt production of more than 10,000 tons; 0.5 ton of iodine, 18.8 tons of bromine, 40 tons of boron, 70 tons of potassium chloride, 5.8 tons of aluminum carbonate, and 480 tons of 6% ammonium water were extracted from the brine every year. The use of hot springs for therapeutic purposes has a long history in China. There are over 80 hot spring sanatoriums established by the state alone, such as world-famous sanatoriums at Conghua in Guangdong, at Lushan in Jiangxi, and at Xiaotangshan in Beijing. Furthermore, the use of geothermal water in space heating and as a hot water supply is also emphasized.

Even though the history of China's development and utilization of her geothermal resources is still rather limited, the prospect is bright. At present, our foundation in this field is rather weak. Our technologies in the field of geothermal resource exploration, evaluation and development are, as yet, unable to satisfy the needs. Thus, as we continue to strive for more data and better results, we must learn extensively from good foreign experience and strive for assistance from our foreign colleagues in this field, such that the so-called "Geothermal Flower" in the energy field can bloom fully and bear rich fruits at an early date in China.

Part 2

GEOTHERMAL ENERGY IN BEIJING (PEKING): PRESENT STATUS AND PLAN OF DEVELOPMENT AND UTILIZATION

BEIJING MUNICIPAL BUREAU OF GEOLOGY

May, 1979

Foreword

Full utilization of geothermal resources is a strategically significant measure. It helps to broaden the energy sources, to accelerate the pace of the Four Modernizations of the capital city and shift the emphasis of the Party's tasks.

Geothermal resource in Beijing refers to the stored hot ground water within a specific depth. Since the start of planned exploration and study in 1970, a geothermal water zone has been found in the southeastern urban region and 20 geothermal wells have been sunk. Many of the wells were utilized with good results. The exploration covered: Chaoyangmen, Tiananmen, and those regions east of Yongdingmen such as Hujialou, Shilibao, Shuangjing, Dajiaoting, and Tiantan, etc.--an area of about 50 square kilometers.

Full utilization of geothermal resources in Beijing's construction means: changing the urban fuel composition, reduction of coal consumption as well as transportation requirements, and more importantly, reduction of environmental pollution. This will have significant economic benefit and political meaning in terms of transforming the capital into a clean modern city and improving the health of its residents.

For the sake of better management and utilization of the capital's new geothermal resources and to achieve a planned and orderly development; the Bureau of Geology, Bureau of Planning, Bureau of Housing Administration, Municipal Unified Building and Public Utilities Bureau, and Institute of Architecture Design jointly developed this plan under the unified leadership of the Municipal Committee. This serves as an implementation plan as well as a reference for the leadership and planners.

I. PRESENT STATUS OF GEOTHERMAL GEOLOGICAL WORK AND MUNICIPAL BUILDING PLAN

1. History of Geothermal Geological Work in Beijing

Geothermal geological work in Beijing started early in the 1950's with a geothermal geological exploration in the suburb Xiaotangshan. Afterwards, the work moved toward the urban area. Since 1970, geophysical exploration and reconnaissance survey by boring were systematically carried out to determine the geothermal geological structure and the thermal water distribution. A great amount of new results were thus obtained in the southeastern urban area above the 1,000m depth range, clearly defining a geothermal core region about $50km^2$ in area. This will provide a reliable basis for the present development and utilization of the geothermal water. (See attached Chart 1.)

A. Geophysical Exploration

1) Exploration by Electric Methods

Factory No. 646 of the Ministry of Oil performed gravity and electric exploration work (scale 1:100,000) in urban Beijing between 1966 and 1970, and reported its findings. From 1970 to 1978, based upon the above findings, the Hydrology and Engineering Geology Team of Beijing Municipal Bureau of Geology explored the urban Beijing and the northwestern suburb, covering a total area of about $500km^2$. The exploration was by the electric method (scale 1:50,000) in search of geothermal energy and a solution to a municipal water supply problem. A report was subsequently published. The report provided basic information for geothermal geological exploration work, including deductions on: the structural outline of the Beijing graben, the burial and distribution of Sinian subgroup dolomitic limestone and the secondary structural rift.

2) Gravity Exploration

In 1972, a gravity exploration (scale 1:10,000) was carried out in the urban area covering $220km^2$, producing maps on Bouguer gravity anomaly, gravity gradient, and residual gravity anomaly. The exploration also defined the extent of basalt and structural outline of the Beijing graben, thus enriching the results of geothermal geological exploration.

3) Artificial Seismic Exploration

Team 217 of the Bureau of Physical Exploration, the Ministry of Oil, and Team 104 of Beijing Municipal Bureau of Geology performed many controllable source seismic tests during 1976 and 1977 (scale 1:50,000). These tests were for gas and oil as well as geothermal water in the nearby Fengtai area covering $70km^2$. The exploration uncovered the convex structure of Wujiachang. The results were important to the study of the thickness of the deposits and rift structure within the Beijing graben.

B. Geothermal Geological Reconnaissance Survey and Exploration

1) Geothermal Survey

The Hydrology and Engineering Geology Team of Beijing Municipal Bureau of Geology surveyed water temperature in shallow wells over urban and neighboring suburban areas of about 600km^2 from 1970 to 1976. A total of 1,000 wells were surveyed, and the results were used to define the geothermal anomaly region (now it is called "geothermal core region") of southeastern urban Beijing. This significant finding clearly pointed out the direction of geothermal exploration and boring.

2) Geothermal Exploration and Boring

Based upon various previous findings, the Hydrology and Engineering Geology Team and Team 104 of the Beijing Municipal Bureau of Geology, carried out exploration drilling in the geothermal core region from 1970 to 1979 covering an area about 50km^2. A total of 20 geothermal water wells were sunk. Part of these have already been used for industrial manufacturing, therapeutic bathing, and winter heating. Final reports and related charts and maps on the geothermal exploration of southeastern urban Beijing were prepared. The report included a comprehensive summary of various geothermal geological information obtained from 1970 to 1976 and a preliminary evaluation on geothermal water.

The achievements mentioned above on geothermal geological work provided significant information toward the understanding of the geological structure and composition of deposits, and represented a breakthrough in the discovery of geothermal resources. But, due to certain reasons, there remain the following problems in the geothermal geological exploration work:

(1) The level of investigation was lower in the outlying region and relatively higher in the geothermal core region. This limits the extent of geothermal development and utilization to within the 50km^2 in the southeastern urban region.

(2) Depths of exploration were shallow. The exploration boreholes reached depths only around 1,000m except for a few individual holes. The characteristics of the boundary condition such as the thickness and distribution of the geothermal storage layer are not fully known. The condition of the geothermal resource needs further evaluation.

(3) Lack of confirmation. The level of physical exploration is relatively high in outlying regions, yet without confirmation by borehole. Lithological character of geological strata, distribution and governing laws on geothermal storage layers, etc., await confirmation by boring.

Exploration results obtained so far provide an important basis for both geothermal development and planning. The plan implementation will mean the expansion of the area of geothermal utilization from the southeastern urban area to the whole urban area, and from single-purpose use to multipurpose use. This will enable the geothermal energy, as an energy source, to contribute more benefits and become more versatile in the socialist construction of the capital.

2. Characteristics and Storage Conditions of the Geothermal Resources in the Southeastern Urban Beijing

A. Geothermal Geological Environment

The existence of geothermal resources in the southeastern urban region is closely linked to the particular geological structural condition of the Beijing graben.

The Beijing graben is between the Beijing Northwestern heave and the Daxing horst, spreading in a northeastern-southwesternly direction with a south-north width of about 15km. On each side of the Andingmen-Xibianmen-Fengtai line, there are three well developed rifts, roughly parallel to each other. The six rifts, from north to south, are the Yamenkou rift, Chegongzhuang rift, Lianhuachi rift, Qianmen rift, Chongwenmen rift, and Nanyuan rift. Their development process is also the formation process of the graben. Because of the differences in the lithological characters and the forces acting on them at different locations, the graben has an asymmetrical form, steeper in the north and milder in the south as shown in the attached profile. It also forms a local heave of the bedrock at its southern flank near Hujialou. Such a heave shows up clearly in the Bouguer gravity anomaly map of the physical exploration, as shown in Figure 1, and it has been verified by boring. Otherwise, all geothermal characteristics gradually spread out from this region. This forms Beijing's southeastern urban region's geothermal core region.

The deposit stratum in the Beijing graben is very complex. After boring, uncovering, and tests in the laboratory such as rock mineral analysis, differential thermal analysis, sporopollen analysis, and isotope dating, etc., it was finally determined that the foundation rock of the graben is a Sinian subgroup stratum. Successive strata above are: Jurassic, Cretaceous, Tertiary system strata as shown in the attached profile and in attached Chart 2. The Sinian subgroup stratum forms the thermal storage stratum of the region, and other strata form the upper cover.

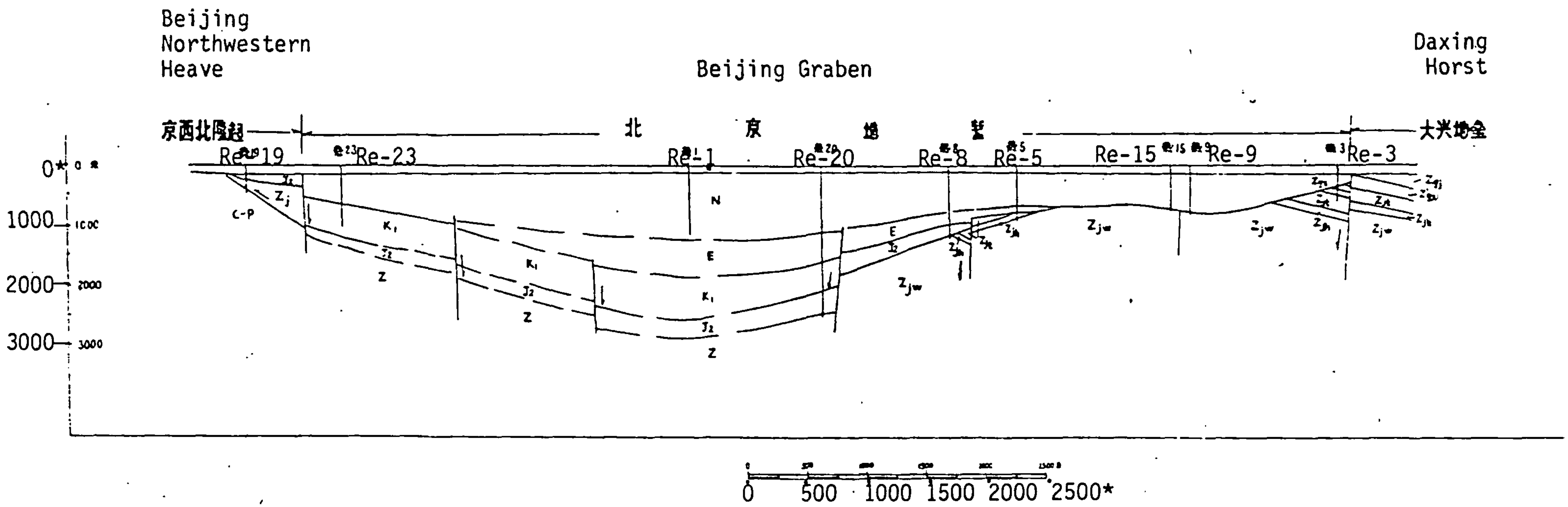
The Sinian subgroup stratum that exists in this region is formed by the Jixian and Qingbaikou systems. The Wumishan formation, Hongshuizhong formation, and Tieling formation are in the Jixian system. The Xiamaling formation and Jingeryu formation are in the Qingbaikou system. They jointly form the foundation base of the graben. The depth increases gradually from southeast to northwest, ranging between 392m at the No. 3 hole in the Oxygen Plant, to 2,456m at the No. 20 hole in Zhongshan Park. The lithological character of the upper part are thin siliceous and argillaceous limestone, dolomite, and shale. The lower part consists mainly of thick, stratum-like dolomitic limestone with well-developed karst crevasses. This is the only geothermal storage stratum and is about 1,000m deep.

The Jurassic system stratum is discordant over the Sinian subgroup stratum. The only Jurassic stratum is the Tiaojishan formation of the mid-Jurassic system. The formation exists to the west of Chongwenmen rift, with a roof depth varying from 517m, at No. 24 hole in Hujialou, to 2,101m at No. 20 hole in Zhongshan Park. The open thickness varies from 197m to 398m. It is composed of medium basic volcanic rock such as andesite, volcanic breccia, tuff, and tuffaceous sandstone, etc.

The Cretaceous system stratum exists in the middle section of the graben and is discordant over Jurassic system stratum. Depth of the roof is 1,567m at the No. 20 hole in Zhongshan Park, and the open thickness is 534.5m. It is composed of medium acidic volcanic rock fragments such as sandstone, breccia and tuffaceous mudstone.

The Tertiary system stratum exists over the whole region. The depth in the west is shallower and partially exposed at the ground surface. Most of

PROFILE



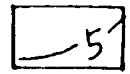
Beijing
Northwestern
Heave
Beijing Graben
Daxing
Horst
京西北隆起
北 京 凹 陷
大兴凸起
Re-19
Re-23
Re-1
Re-20
Re-8
Re-5
Re-15
Re-9
Re-3
0*
1000
2000
3000
N
E
K1
J2
Z
C-P
Zj
Zjw
0 500 1000 1500 2000 2500*

FIGURE 1 - BOUGUER GRAVITY ANOMALY OF URBAN BEIJING

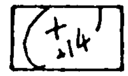
(scale 1:100,000)

1. Babaoshan
2. Balizhuang
3. Gongzhufen
4. Fengtaizhen
5. Ganjiakou
6. Xisi
7. Beihai
8. Tiananmen
9. Tiantan
10. Beijing Railroad Station
11. Hujialou
12. Minor convex structure in southeastern City
13. Dajiaoting
14. Jiuxianqiao
15. Gaobeidian
16. Nanyuan

LEGEND



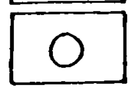
- Bouguer Anomaly Contour (milligal)



- Zone of Positive Bouguer Anomaly

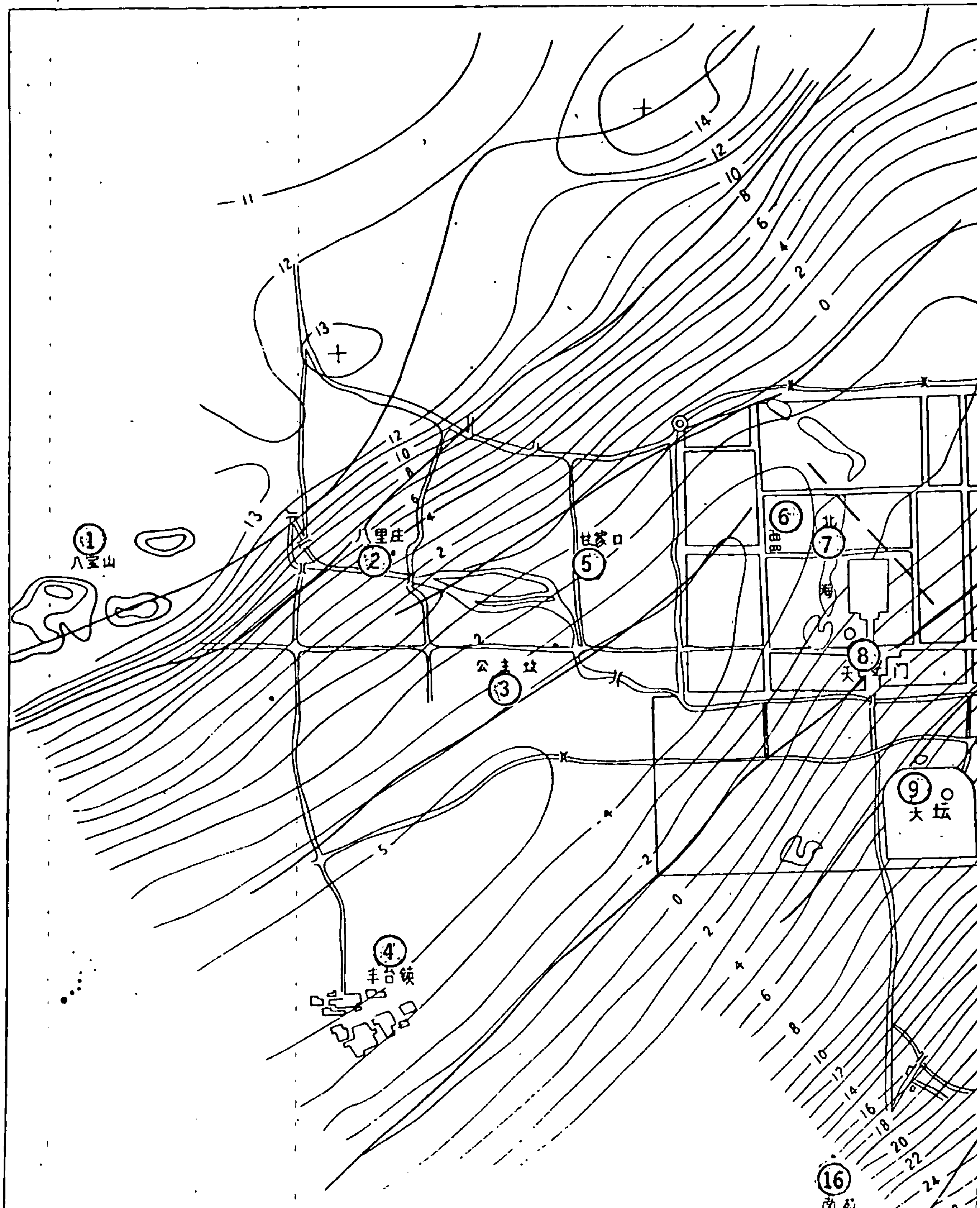
- Zone of Negative Bouguer Anomaly


- Rift (concealed)


- Thermal Water Well

北京城区布伽重力异

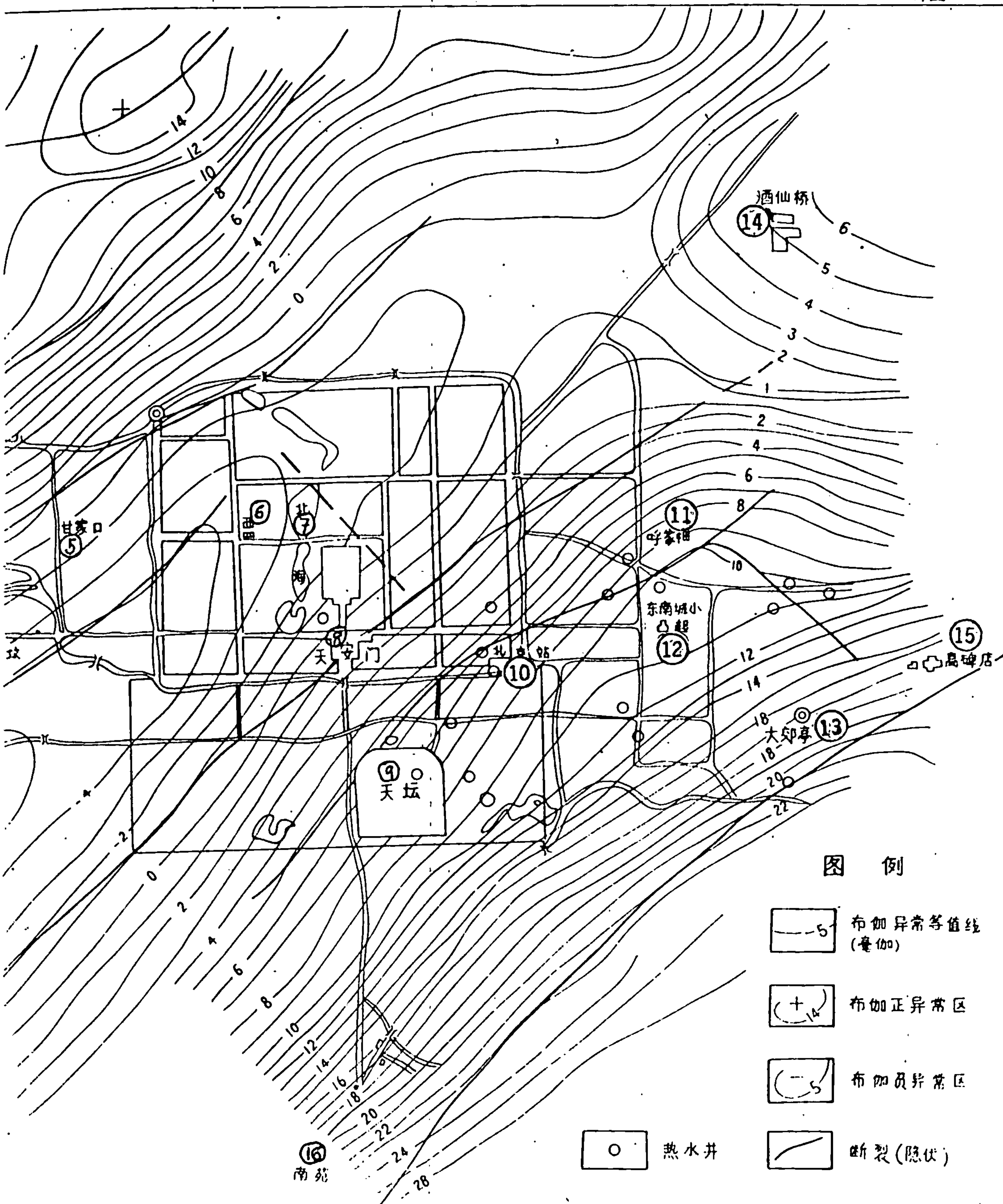
比例尺　　1：10万



京城区布伽重力异常图

比例尺　　1：10万

插图1



the rest is buried deeper than 80m. In general, the open thickness ranges from 500m to over 1,000m. The Chongwenmen rift serves as a boundary. The southern part covers directly over Sinian subgroup stratum, and the northern part is discordant over the Cretaceous system stratum or the Jurassic system stratum. It is composed of mudstone, sandy mudstone, sandstone, and breccia. Lithological characters are fine in the upper parts and coarse in the lower part and with alternating fine and coarse layers. Permeability is extremely low, which reflects the characteristics of terrestial deposits. This stratum is distributed over a wide region. It is thick and structurally dense and thus becomes an excellent impermeable, thermal insulating stratum.

The Quaternary system deposit covers the top and is seen over the whole region. Its thickness grows from west to east, from 50m to 150m in general. Its formation is due to stream deposition. It is composed mostly of the clay soil stratum, sand, and gravel. Permeability and water-bearing characteristic are good. The water in this stratum can be used as a supplementary water source for the thermal water recharge wells. In addition, during the formation of Beijing graben, there was volcanic activity accompanying the crust movement and deposition of the Tertiary system stratum. Basalt magma in the deep part of the earth sprayed out, following the outlet of the Chongwenmen rift covering an area of more than 40km^2. All boreholes had uncovered this except those near Shuangjing. For example, the No. 7 hole near Hujialou at the Guanghua Dyeing and Textile Factory has five layers of basalt with a thickness of 264m. The thinnest is near Tiantan Park and even then it is thicker than 20m. Because of this, favorite conditions are present in this region for heat flow by radiation, conduction, and thermal convection.

B. Hydro-Geological Characteristics of the Geothermal Region

1) Geothermal and Thermal Anomaly Region

The internal heat of the earth, under the action of a differential thermal condition, is continuously dissipating its heat through the ground surface. It exhibits itself in different ways through different rock strata at the ground surface and at specific depths. Based upon this fact, a water temperature survey was made in shallow wells within a 600km^2 area in urban and suburban regions. It was discovered that at about 70m depth, water temperature begins to gradually rise because of the terrestial heat. Under normal conditions, shallow ground water temperature is generally 13^o to 14^o. But in the southeastern urban area the water temperature is all above 15^{o}C. The area east to Shilibao, west to Qianmen, north to Chaoyangmen, and south to Dajiating covers several tens of square kilometers as shown in Figure 2. It was confirmed by boring that this thermal anomaly was entirely due to geothermal influences. When such influences are expressed in terms of the geothermal gradient, then its distribution is approximately centered at the convex structure of the bedrock at Hujialou, and spreads outward in elliptic contours. The maximum thermal gradient reaches above 5^{o}C east of Hujialou. From there, the gradient drops from 4^o to 5^{o}C and 3^o to 4^{o}C as shown in attached Chart 3.

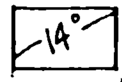
2) Distribution and Depth of Thermal Water

Geological boring found that, in this region, the geothermal energy is stored in Sinian subgroup's dolomitic limestone. This kind of

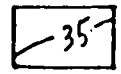
FIGURE 2 - ISOTHERMS OF DEEP AND SHALLOW GROUND WATERS IN URBAN BEIJING

1. Xiyuanzhen
2. Eight Institutes
3. Wali
4. Jiuxianqiao
5. Beiwa
6. Balizhuang
7. Yuyuantan
8. Fengtaizhen
9. Beihai
10. Beijing Railroad Station
11. Tiantan
12. Dahongmen
13. Nanyuanzhen
14. Dajiaoding
15. Gaobeidian

<u>LEGEND</u>

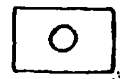


- Isotherms of water at 70m depth

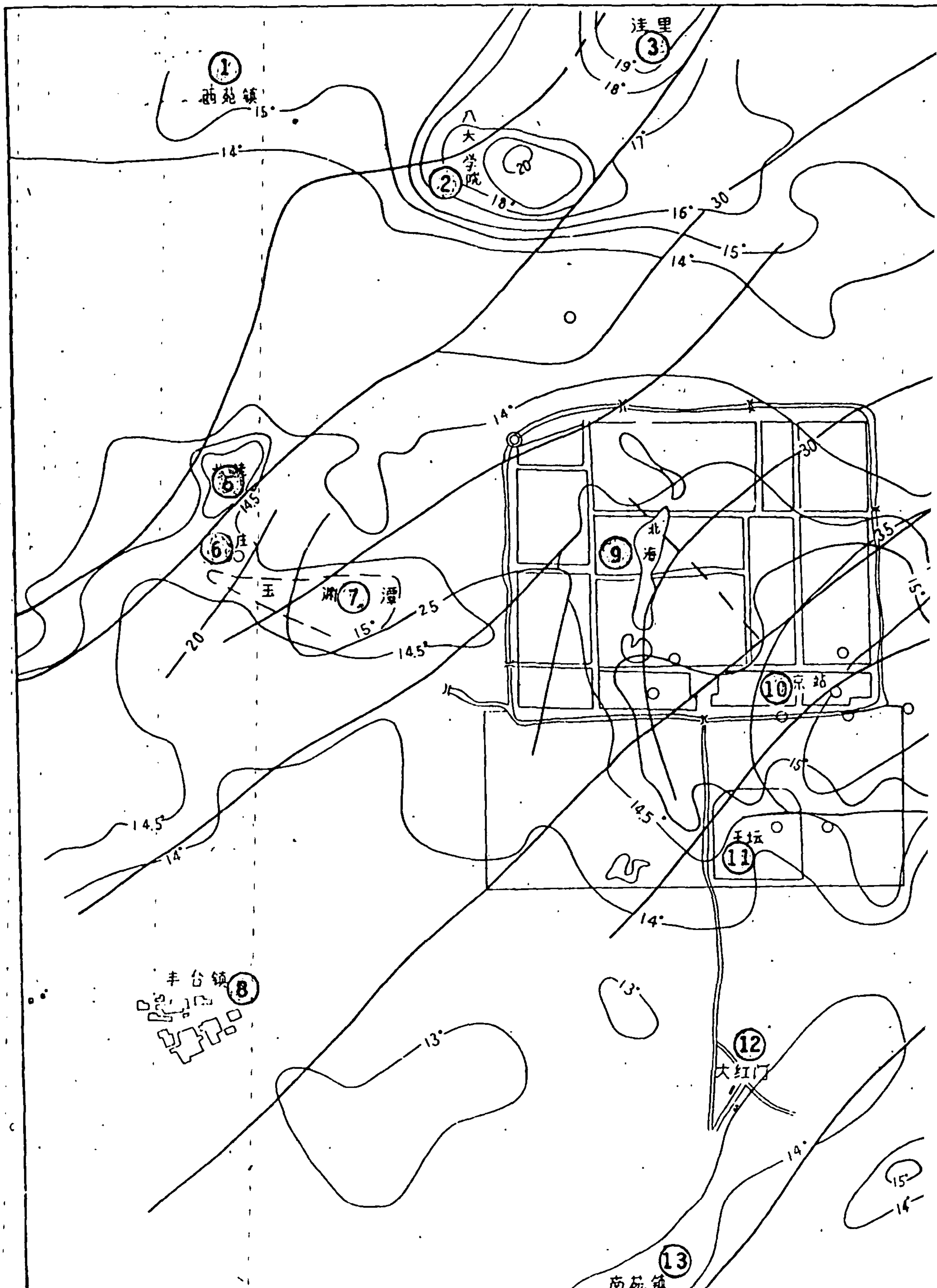


- Isotherms of water at 700m depth


- Rift (concealed)

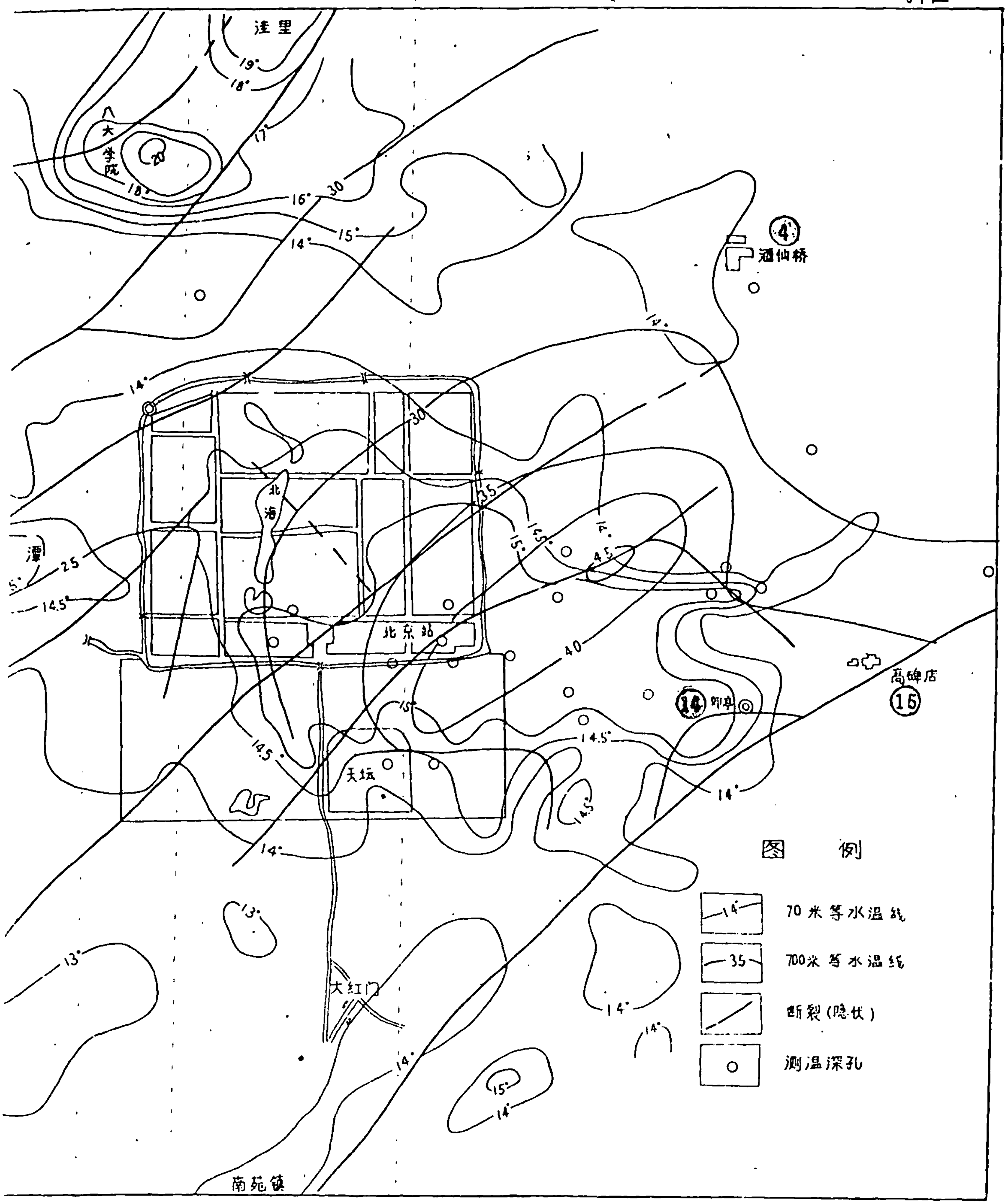

- Deep boreholes for temperature survey

北京城区深、浅层地下水温



·京城区深、浅层地下水温等值线图

插图2



carbonatite stratum, because of its brittleness and high dissolvability, has well developed karst and crevasses during the continuous structural movements. This has provided favorable conditions for the storage and movements of geothermal water. Such crevasses and karst strata have exposed thicknesses of more than 9,000m at the ground surface. Among those, the limestone of the Wumishan formation, which has better water-bearing capacity, is 670m to 3,518m. But up to the boring depth, the open thickness was only 40m with a maximum open portion of only 200m. It can be seen that the yield potential of this aquifer is great.

The geothermal water in this region is of the confined or artesian type. After the borehole opened up the aquifer, the water stage soon rose to near the ground surface, and sometimes it overflowed. The magnitudes of the head are as shown in Chart 3, with a maximum elevation of 30m at the convex structure of bedrock near Chongwenmen rift, paralleling the direction of the rift. Thermal water output per well can reach 1,000 metric tons per day. In Chart 3, it is shown that most of the high yield wells are close to the Chongwenmen rift zone. Such variations of water stages and flow rate indicate that the Chongwenmen rift may be the vital passageway for the rise and movement of geothermal energy in this region.

3) Physical Property and Chemical Composition of the Thermal Water

Thermal water is transparent in general with a slightly rusty yellow color. It sometimes exhibits a bluish gray color, which was caused by the oxidation of elements (such as ferrous iron) when the thermal water comes out of the ground with a reduction of pressure and temperature. Furthermore, because of the release of gases such as hydrogen sulfide, the water appears to have a rotten-egg odor and rusty taste. The most outstanding characteristic of the thermal water is still its temperature. Measurements at the wellheads showed a minimum temperature of 38.4°C and a maximum of 69.5°C with a normal temperature of about 50°C. The Chongwenmen rift serves roughly as the boundary for the variation of water temperature in the horizontal direction. Water temperature is greater than 50°C north of the rift and drops gradually to 40°C and less toward the south side. The water is classified to be low to medium temperature thermal water.

Thermal water normally exhibits neutral to weak alkalinity, with a dissolved solid content of 500-600 mg/1 and a holo-hardness number of 7 to 12 German degrees. Water chemistry classification is based upon normal ion content in the water as tabulated in Table 1. The thermal water of this region belongs to carbonic acid--sulfuric acid--sodium type water. In addition to those main chemical components listed in Table 1, there are those special chemical components as tabulated in Table 2. In shallow ground water, the content of those special components were either small or nil. Among those, the contents of flourine (F'), radon (Rn), radium (Ra), boric acid (HBO_2), and hydrogen sulfide (H_2S), have all reached the standards of mineral water, and some have met the concentration requirement for therapeutic purposes. In addition, the effect of geological structure on the chemical components of thermal water is more pronounced. For example, water in the No. 5 well at the Beijing Railroad Station and water in the No. 8 well at the Xinqiao Hotel, both near Chongwenmen rift, belong to the carbonic acid-sulfuric acid-sodium-calcium water chemistry type. Radon, soluble

TABLE 1: SUMMARY TABLE OF CONTENTS OF MAIN CHEMICAL COMPONENTS OF GEOTHERMAL WATER

Water Source	Chemical Component (in mg equivalent %)							
	HCO'_3	SO''_4	Cl'	K'+Na'	Ca"	Mg"	Holo-Hardness (German Deg)	Solids (mg/1)
Geo-thermal Water	40-56	23-35	14-23	49.5-77.1	18-32	9.7-22	7-12	500-600

silicon dioxide, boric acid, and hydrogen sulfide contents are relatively high. The No. 13 well at the Beijing 3rd Cotton Textile Factory and No. 15 well at Santongyun, both are far from the rift. They belong to carbonic acid-sulfuric acid-sodium type water and carbonic acid-sodium type water. Radon and silicon dioxide contents are both low. This illustrates that the Chongwenmen rift has significant impact on both the formation and existence of the thermal water.

The above description shows that the thermal water of this region is not salty, has low hardness and good water quality.

TABLE 2: COMPARISON OF SPECIAL CHEMICAL COMPONENTS BETWEEN GEOTHERMAL WATER AND SHALLOW GROUND WATER

Chemical Components	Unit	Water	
		Geothermal Water	Shallow Ground Water
F'	mg/1	5-6	0.5-0.6
Soluble SiO_2	mg/1	30-60	20
HBO_2	mg/1	0.4-3.76	Minute
H_2S	mg/1	0.19-1.91	Nil
Fe	mg/1	0.5-5.8	0.04
Li	mg/1	0.3	Nil
Sr	mg/1	1/53	0.4
Rn	eman/1	4/6-43.2	4.4-4.9
Ra	g-rad/1	10^{-10}-10^{-9}	10^{-12}
U	g/1	10^{-6} -10^{-9}	--
Total	Curie/1	3.8x10^{-1}	3x10^{-12}
K^{40}		(1.95±0.23)x10^{-11}	(2.01±0.92)x10^{-12}
$D(H^2)$	δd	-6.3 to -9.78	-6.9 to -7.48
$T(H^3)$	TU	2 to 34±4	144 to 861

On the other hand, the water has high contents of special chemical components and with moderate temperature; hence, it has good potential to be used in building heating, water supply for industrial and agricultural production, and therapeutic bathing, etc. But because of the high contents of flourine, radon, and iron exceeding the drinking water standard, it cannot be used for drinking water.

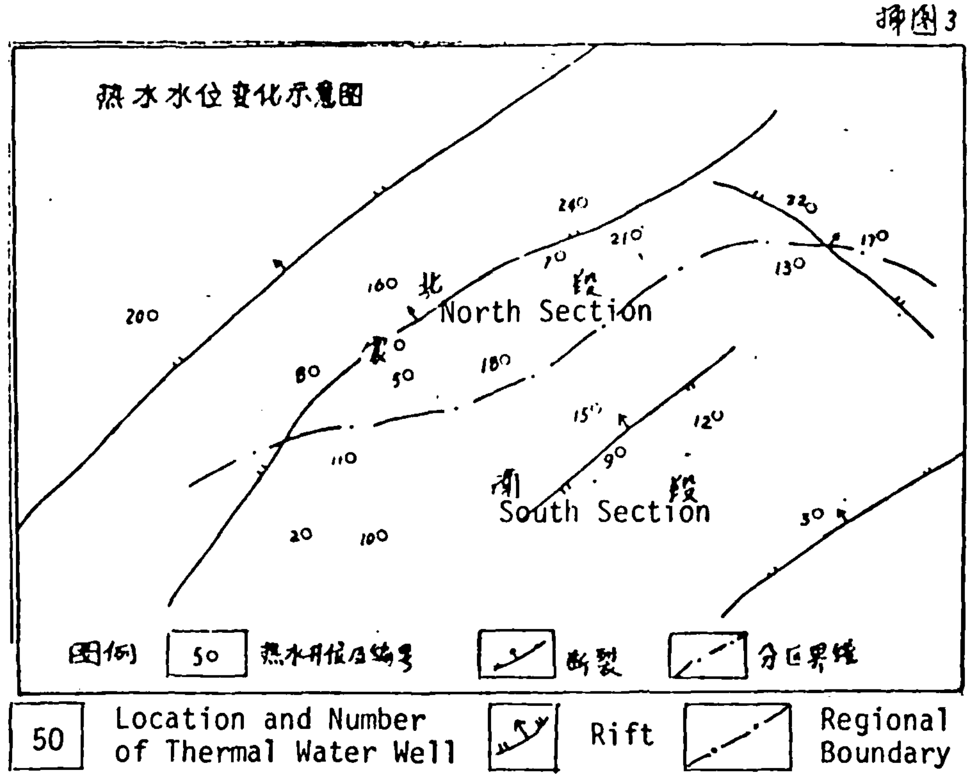
4) Dynamics of the Thermal Water

The dynamic changes of thermal water's important parameters, such as temperature, stage, quality, flow rate, etc., are increasing every year with the increasing number of production wells and the increasing amount of water use based upon periodic observation. Dynamic parameters of the thermal water have changed differently. The stage variation was most pronounced. Observed data showed that there is quite a difference in stage variation between north and south sections as shown in Figure 3. For example, in the south section, starting and shutdown of the No. 13 well at the Beijing 3rd Cotton Textile Factory can influence those wells 7km away, such as the No. 2 well at Tiantan, No. 3 well at the Oxygen Plant, and No. 12 well at the Main Glass Factory. However, this has only minor effect on the No. 17 well of the Beijing 1st Cotton Textile Factory within 1 km. On the other hand, pumping of the No. 17 well can affect the No. 16 well at the Art Press 6km away, but have very little effect on the No. 13 well at the Beijing 3rd Cotton Textile Factory. This shows that the dynamic conditions and hydraulic connections of north and south sections are different. Withdrawal rate has significant impact on both the north and south sections. There are eight production wells in the south section. Stage was generally 10 to 12m before 1974. As the withdrawal rate increased, the stage fell. From 1971 to 1976, the accumulated withdrawal amount was 2,080,000 metric tons. At the end of 1976, the stage fell to 15.2-22.4m The average annual rate of the stage drawdown was 0.45 to 0.89m in 1976, as shown in Table 3. In the north section, the stage drawdown rate was even greater. In this section, there are 11 thermal water wells. Before October 1976, the withdrawal amount was less than 600,000 metric tons. Average annual rate of stage drawdown was around 1m. After that, because of the increase of withdrawal rates of Nos. 16, 17, and 22 wells, stage fell drastically. Total withdrawal was 2,760,000 metric tons from 1971 to 1976; the corresponding stages were 2.54-11.56m in 1971 and dropped to 9.4-16.6m in 1976. Annual rate of stage drawdown was 2.15-4.98m.

The above description shows that the trend for the stage is to move downwards year after year. If the withdrawal rate increases continuously or proper measure is not undertaken, then the geothermal water stage will consistently fall at an even faster rate, and eventually will have the situation that the geothermal medium--water--is no longer usable.

Over the years of withdrawal, the temperature variation of the thermal water has been small. For example, the No. 3 well at the Oxygen Plant has maintained its water temperature at 600m at 40.93° to 40.54°C over a two-year survey period. Amplitude of variation was only 0.4°C. The variation of the chemical components should be a slow process and it is presently under observation.

FIGURE 3 - SCHEMATIC DIAGRAM ON VARIATION OF THERMAL WATER STAGES



C. Preliminary Analysis on the Formation of the Thermal Water and Thermal Water Resources

Thermal water resources and their formation are still under study. Based upon results obtained so far, the preliminary conclusions are: (1) geothermal water under Beijing has been formed over the long geological history, (2) the formation is controlled by local topography, geology, and structural conditions, (3) thermal water is produced in conjunction with a combination of factors such as terrestial heat storage, heat sources, water sources and passageways.

In the mountainous region with exposed bedrock in western Beijing, precipitation and surface runoff percolates continuously into the ground under gravitational action. Water infiltrates into the deep parts through all possible ways, such as pores, bedding surface, joints, crevasses, karst rifts and fracture zones, etc. The temperature of the water rises as it flows along under the action of radiation, conduction and convection from the deep heat source of the earth. When this thermal fluid reaches the dolomitic limestone in the graben, it forms the thermal water resource of this region under the impermeable cover and thermal insulation of Cenozoic era stratum. Under high pressure, the deep high temperature geothermal water rises rather rapidly through Chongwenmen and other rifts into shallower parts. It is stored in the dolomitic limestone thermal storage stratum and in any favorable position such as a convex structure of the bedrock. Hence, it is possible to obtain relatively high temperature geothermal water in shallow parts (e.g., around 1,000m) of the geothermal core region.

The above-mentioned condition can be illustrated from water quality. In general, it is recognized that the stable isotope of hydrogen in

TABLE 3 - SUMMARY OF GEOTHERMAL WATER STAGES AND RATES OF DRAWDOWN

Well Number and Location	Before 1974		End of 1974		End of 1976	
	Date	Stage (m)	Stage (m)	Average Rate of Drawdown (m/yr.)	Stage (m)	Average Rate of Drawdown (m/yr.)
South Section						
No.2 Tiantan	72.2*	12.6	21.0	3.60	22.40	0.70
No.3 Oxygen Plant	74.5	9.5	14.5	5.00	15.60	0.55
No.9 Remin Mach.	72.12	8.9	(13.9)	2.72	15.60	0.85
No.10 Nat'l Comm. on Phys. Ed.	73.8	9.5	15.2	4.55	16.75	0.89
No.12 Main Glass Factory	74.1	11.1	16.0	4.90	15.20	-
No.13 Beijing 3rd Cot. Tex. Fac.	-	-	15.1	-	16.20	0.45

Remark: Those excluded are: No.11 at Langanshi and No.15 at Santongyong.
*78.2 in the original

North Section	Before 1975		October 1975		End of 1976	
No.5 Beijing Railroad	73.7	2.54	4.00	0.67	9.40	4.98
No.7 Guanghua Dye-ing Factory	73.2	5.10	7.93	1.09	11.83	2.93
No.8 Xingqiao Hotel	72.12	0.20	-	-	9.15	-
No.16 Renmin Arts Press	74.9	11.56	12.70	1.14	16.60	4.20
No.17 Beijing 1st Cot. Tex. Fac.	74.8	7.00	8.00	1.00	(8.36)	(0.36)
No.18 Yuan Xili	75.2	8.85	(8.68)	-	14.26	3.35
No.21 Dongfanhong Auto Fac.	75.6	8.40	8.00	-	13.40	4.32
No.22 Beijing 3rd Cot. Tex. Fac.	75.12	9.95	-	-	12.10	2.15

Remark: Those excluded are: No.24 at Hujialou, No.20 at Zhongshan Park, and No.1 of Beijing Railroad Bureau

water--deuterium--will not undergo any pronounced change during the ground water flow process. Based upon chemical analyses, concentration of deuterium in the thermal water has a δd value of -6.33 to -9.78, which is very close to the rainwater value of -6.33 to -7.48, river water value of -6.9 to -7.48 and the shallow ground water value of -6.9

to -7.48 and the shallow ground water value of -6.9 to -7.48. Viewed from the gas composition, the main gas component of the thermal water is nitrogen with an argon-nitrogen ratio of 1.96 to 2.37%. This is fairly close to rainwater's value of 2.49% and shallow ground water's value of 2.12 to 2.14%. In addition, the thermal water also consists of special elements and components such as radon, helium, fluorine, soluable silicon dioxide, lithium, strontium, radium, etc., which shows that the thermal water is formed in the deep part and rises through the rift. In general, the atmosphere does not contain radon which tends to concentrate near certain rifts. In this region, the wells near Chongwenmen rift often have higher radon contents. The helium content of the thermal water is 0.077 to 0.134%, while in shallow ground water no helium is detectable. These facts indicate that after precipitation and surface water percolate into the ground, the water captures helium from the deep part of the earth's crust during its circulation. Moving through the Chongwenmen rift as a passageway, it obtains radon, flourine, boron, sulfur and silicon dioxide which correspond to the material in the deep part of the earth's crust. The dolomitic limestone of the water-bearing stratum of this region has very little silicon dioxide and sulfur, yet the basalt's content of these substances are five times of those in the dolomitic limestone. This implies that the formation of the thermal water is more closely related to the magma in the deep part.

As far as the question of thermal water resources is concerned, because of limited extent and depth of exploration, boundary conditions such as the thickness of the aquifer and the extent of distribution, are still unclear. To determine these factors, the geothermal resource requires further study. However, based upon the existing information, the preliminary estimate is that the permissible daily withdrawal rate is about 50,000 metric tons. The quantity is not large, yet with the advance of exploration techniques, application of the recharge technique and continuous perfection of evaluating methods, data will be obtained in the future, covering accurate amount of water, heat, etc.

3. Near-Term Municipal Building Plan and Analysis of Geothermal Space Heating for Southeastern Urban Beijing

A. Municipal Building Plan and Implementation Scheme

Based upon the requirements of the layout of our city's building plans, the existing urban region will be modified and rebuilt gradually but completely. Those buildings in the near suburban area will be adjusted so that they form functional groups, and there will be extensive development in the far suburbs. Both above and underground construction will be guided by the principles of the overall plan. On fuel structure, coal will be gradually replaced by gaseous and liquid fuel. Use of geothermal water for winter heating should be promoted and expanded rapidly so as to reduce smoke and soot and improve the environmental condition.

The two categories in the municipal building plan for which geothermal heating has been proposed are new building areas and rebuilding areas. This will be implemented around 1982. The locations for these buildings will be: (1) Tuanjiahu near Erdaogou outside Chaoyangmen, (2) Puhuangyu, south of Tiantan, and (3) Jingsongqu near Longtanhu. As shown in attached Chart 4, there will be a total building area of 3,180,000m^2 with a land area of 318 hectares. The new building area will be 2,670,000m^2 with a land area of 267 hectares. The work will begin in 1979 and be completed in 1982. The building area to be rebuilt is 510,000m^2.

B. A Preliminary Analysis of the Application of Geothermal Heating in Urban Buildings

In our country, the application of geothermal energy as a heating source is recent. It has been confirmed in practice to be both technologically feasible and economically justifiable. As an example, a 1,299m deep thermal water well was sunk in September, 1975 at Renmin Art Press inside Jiaguomen. The aquifer was dolomitic limestone. The depth of its roof was 1,257.9m and 42m of the stratum was opened. During the pumping test, the drawdown was 15.53m. The daily flow rate was 985 metric tons with a temperature of 59^{o}C. After the test and the shutting down of the pump, the static water stage was 10.38m. It was used for heating beginning in the winter of 1976 with a heating area of 4,400m^2 during the year. It was then increased to 14,300m^2 in 1978, and the result has remained good since then. In the winter season, as in January, when the outdoor temperature dropped to around -10^{o}C, the room temperature was maintained between 16^o to 22^{o}C, with an effluent water temperature of 41^{o}C. To utilize the thermal energy of the well more efficiently, variable flow rate tests were performed in January of 1979. Room temperature was between 18^o to 22^{o}C when the flow rate was 36 metric tons per hour and was still between 16^o to 18^{o}C when the flow was reduced to 9 metric tons per hour. Based upon this fact, it was recognized that the heating capability of this well could reach more than 50,000m^2. The heating area could be further increased by improving the pipeline network and further adjustment of building layouts.

Geothermal heating can be justified in comparing economic benefits with boiler heating. Table 4 shows that the initial investment for geothermal heating is RMB 37,000 dollars (Note: US $1-RMB 1.6) more than boiler heating, but the operating cost is RMB 17,000 dollars less. The heat supply of boiler heating is considered on 10^6 kcal/hour basis with a heat area of 20,000m^2, and the geothermal heat area is also considered on a 20,000m^2 basis. In this case, the extra investment can be recovered in a little more than two years. This example illustrates that geothermal heating is economical.

The above analyses show clearly that geothermal heating is completely feasible on both technical and economic terms. If the pipeline network system can be further improved, new heat exchange components designed, heat pumps adopted, effluent water temperature lowered, and the utilization rate of thermal water increased, then the heating area per well can increase significantly.

To turn geothermal energy into a reliable source of thermal energy, the requirements on geothermal geological work from the viewpoint of utilizations are:

1) To satisfy the needs of the capital city on geothermal heating, various characteristics of the heat storage strata of the geothermal core region should be further clarified. These include the governing laws on the variation of the strata in both vertical and horizontal directions, heat storage conditions, and the distribution and depths of thermal water in different strata. Geothermal resources should also be evaluated.

TABLE 4 - COMPARISON OF INVESTMENTS BETWEEN GEOTHERMAL HEATING AND BOILER HEATING

	Initial Investment (RMB 10^3)					Operating Cost (RMB 10^3)			
Heating Method	Civil Construction	Well Construction	Heating Elements	Material	Sub-Total	Coal	Labor	Electricity	Sub-Total
Geothermal	0.14	4.43	4.6	2.72	11.89	-	0.05	0.27	0.32
Boiler	1.2	-	3.3	3.67	8.17	1.2	0.09	0.72	2.01

Note: US \$1 = RMB 1.6

2) To expand the region of the thermal water use, the storage, movement, and possibility of utilization of the thermal water on both west and east regions next to the geothermal core region should be understood.

3) To provide a basis for long-term geothermal utilization, the possibility of geothermal water reserves under the northwestern urban region and its value should be studied.

II. PRELIMINARY PLAN FOR DEVELOPMENT AND UTILIZATION OF GEOTHERMAL ENERGY

The geothermal resources of Beijing should be well managed and protected, to make them a reliable and stable energy source. To achieve this, one should use the geothermal geological work of the previous years as the foundation, dealing directly with the previous unresolved problems, and should integrate the three requirements by the Municipal Building Plan on geothermal geological work. In addition, the following work should also be carried out well.

1. The Development and Utilization of Geothermal Energy in Southeastern Urban Beijing

A. A Basic Guideline on Development and Utilization of Geothermal Energy

To maximize the use of the limited local geothermal resources in the capitol city's construction, a balanced emphasis must be on drilling both shallow and deep, production and exploration wells. In addition, the technique of ground water recharge must be investigated as a way to guarantee future production. A balanced emphasis should also be made on production and recharge. We should carry out exploration and recharge while producing, and use the benefit brought by production to promote exploration. Only in this fashion, can existing geothermal resources be a reliable and long-lasting heat energy supply.

B. Plan for Development and Utilization of Geothermal Energy

The geothermal resources of this region should first be utilized for urban building heating purposes, with consideration of industrial, agricultural, and therapeutic bathing purposes in a comprehensive development. This will be the underlying principle in defining the production well field and the stage implementation scheme.

1) Defining the Geothermal Production Well Field

The number of production wells should be determined by the heat supply per well and the heat requirement of the building area. As mentioned above, the thermal water temperature of the Beijing geothermal core region is usually around 50°C, and the daily flow rate per well is 1,000 metric tons. Because of the increase in both the depth of exploration and the well diameter, it is estimated that the water temperature can be raised up to around 60°C and the daily flow rate up to 1,500 metric tons. Based upon the state of the art on heating equipment and technology, it is possible to utilize 30° to 40°C of heat from the thermal water. Under this assumption, the heat supply per well and the required number of wells can be determined. The related parameters are tabulated in Table 5.

·Determination of the Building's Heating Standard. Coal supplies over a heating season are specified at 22 kg/m^2 of building area. Coal's heating value is 101,200 kcal, based upon a unit heating value of 4,600 kcal/kg. The heating season is 120 days long, giving an average building heating requirement of 35 kcal per m^2 per hour.

·Determination of the Heat Supply and the Heating Area per Well. Based upon a flow rate of 1,500 mt/day per well (62.5 mt/hr), with a

TABLE 5 - SUMMARY OF NUMBER OF WELLS FOR GEOTHERMAL HEATING PLAN

Flow Rate Per Well		Thermal Water Temperature °C		Heat Output Per Well	Building Heating Standard*	Heating Area Per Well	Building & Rebuilding Area	Number of Wells Required
mt/day	mt/hr	At Well-Head	Utilized	10^6kcal	kcal/m^{2}hr	10^3m^2	10^6m^2	
1500	62.5	60	40	2.5	35	70	3.18	45
"	"	"	"	"	50	50	"	63
"	"	"	30	1.875	35	54	"	58
"	"	"	"	"	50	38	"	83

*The heating standard is derived by the specified 22kg of coal at a heating value of 4,600 kcal/kg.

thermal water temperature of 60°C and with 40°C of which can be utilized, the heat output per well is 2.5 x 10^6kcal. Using this heat output and the building heating standard of 35 kcal (Note: Per m^2 per hour), the heating area per well is thus 70,000m^2.

·Determination of the Number of Production Geothermal Wells. Since the heating area per well is 70,000m^2 and the total building and rebuilding area to be heated by geothermal energy is 3,180,000m^2, then a total of 45 thermal water wells are needed. If the building heating standard is raised from 35 to 50 kcal, then the heating area per well will drop to 50,000m^2, and a total of 63 wells will be required.

We shall further consider the case for either heating standard, the flow rate remains at 62.5 mt/hr per well and the water temperature remains at 60°C, but the heat energy that can be extracted is reduced from 40° to 30°C with the increase of the heating standard from 35 kcal to 50 kcal. The possible heat supply is calculated to be 1,875,000 kcal/hr per well. Considering that the total planned building area is 3,180,000m^2, then a total of 58 wells are required. If the building heating standard is at 35 kcal, then the heating area can reach 54,000m^2 per well. If the standard is raised to 50 kcal, then the heating area will drop to 38,000m^2 corresponding to 83 wells for the planned buildings.

These conditions illustrate that the number of required wells varies between 45 to 83, depending upon the portion of thermal water temperature utilized and the building heating standards. In accordance with the principle of gradual and orderly expansion of wells, a total of 65 production wells are tentatively scheduled.

2) Distribution and Construction of Geothermal Wells for Heating

The distribution of geothermal wells should be integrated organically with the building's heating needs and natural conditions. In attached Chart 4, geothermal energy exists in all building zones except near Dongzhimen and Zuojiazhuang where the geothermal condition is still not clear. Hence, the geothermal energy distribution basically matches the three building zones at Tuanjiehu, Jingsong, and Puhuangyu.

The planned depths of geothermal production wells are classified by geological conditions into three categories: 1,500m, 1,500-to-1,800m, and 1,800-to-2,000m. The southern Tuanjiehu zone is close to the convex structure of bedrock near the Chongwenmen rift, and has a temperature gradient of more than 5°C (Note: Per 100m). Drilling down to 1,500m will get a higher water temperature; however, both Jingsong and Puhuangyu zones are further from the Chongwenmen rift, so the geothermal temperature gradient is low. Hence, drilling to deeper than 1,500m will be required to obtain a higher water temperature. The Zuojiazhuang building zone outside Dongzhimen is close to the center of the graben. This means that the depth of the heat storage layer is great, so that the drilling depth should also be increased. Based upon these depths, for total of 65 geothermal production wells, the drilling footage will be 113,500m. Among those wells, 25 are 1,500m deep, 25 are 1,500 to 1,800m deep, and 15 are 2,000m deep.

In construction, the Tuanjiehu zone will have first priority, but both Jingsong and Puhuangyu building zones will also be covered. It is planned that the construction of these geothermal production wells will be started in 1980 and will be completed in three years, ending in 1982. An average of 21 wells should be completed each year. The actual progress depends upon the availability of boring equipment and piping.

C. Application of Recharge Techniques

Geothermal energy is extracted through the ground water medium and it cannot be utilized if there is a deficiency in water. As mentioned above, the geothermal water stage of this region has been dropping gradually over the years following the increase of the withdrawal rate. If this trend continues, the stage may drop so low as to be beyond the capability of the pumps. According to some foreign experience, the application of recharge techniques can ensure the continuous production of geothermal resources. For example, in the Huitang geothermal field in Hunan, artificial recharge tests were carried out in a geothermal well from September 6 to October 21 in 1973. The thermal water maintained a temperature of 85° to 89°C with no reduction observed while the well was recharged with 23°C river water for 47 days at an average recharge rate of 1,850 metric tons per day. This nearly doubled the productive reserve of the thermal water, and a geothermal power station has been built there. In France, the design of one production well with one recharge well in geothermal utilization was able to maintain the thermal water temperature for 30 years. Based upon these experiences and the geothermal condition in Beijing, it is planned to adopt the recharge technique.

1) Conceptual Number and Location of Recharge Wells

The ratio between recharge and production wells can be 1:1, 1:2, or 2:3... Since parameters such as the rational spacing between wells, recharge rate and recharging methods and effects are still under study, it is impossible to provide the economical and rational number of recharge wells at this time. If it is tentatively assumed that for every three production wells there will be two recharge wells, then a total of 43 recharge wells will be required. As far as the locations of the recharge wells are concerned, in addition to maintaining proper distance from the production wells, they should be at regions with internal hydraulic connections and rather concentrated withdrawals. According to this concept, groups of recharge wells should be placed at Hujialou, Tiantan, and Shuangjing. Each group consists of 5 to 8 recharge wells. In addition, there will be individual recharge wells for local pressure boosting in the Chongwenmen and Beijing Cotton Textile Factory regions. The planned depths of the recharge wells are greater than those of the production wells by 50 to 100m to increase the flow path of the recharge water and its depth, thus obtaining more thermal energy. Computing based upon an average well depth of 1,800m, the total drilling footage for the 43 recharge wells is 77,400m. It is planned to have two drilling rigs working in 1980. Starting from the three groups of recharge wells mentioned above, three recharge stations will be established. Recharge wells will then be increased and constructed in stages in order to gain experience while expanding.

2) Method of Recharge

The recharge will be done centrally, with each recharge station as a unit. Recharge water will be transmitted through a pipeline network to the three recharge stations at Hujialou, Tiantan, and Shuangjing, and then recharged by natural head or by applying pressure. Recharge water is mainly coming from the tailings of the geothermal water after heating use. The consumption will be made up by shallow stratum water.

Recharge can be carried out at any time of the year, but will be centered in two periods, namely "withdrawal in winter, recharge in winter" and "withdrawal in winter, recharge in summer." In the winter heating season, the consumption of heat and thermal water is great, thus recharge in winter should be of the first priority to ensure meeting normal heating requirement. During non-heating seasons, it is proposed that cold water or cold water which has warmed up in heating ponds under the sun in the summer season, be recharged so that thermal water of a certain temperature is stored in an aquifer for use in winter.

D. Preliminary Prevention of Thermal Water Corrosion

The geothermal water of this region is commonly corrosive to metals and pumps. Because of the hydrogen in the hydrogen sulfide there will be seepages into the metal of the pump shaft, and the surface of the shaft will always blister and form 0.2 to 0.2mm pits and freckles. The thread of the pump shaft support is occasionally completely corroded, sometimes causing the shaft itself to break. The cause is none other than water chemical corrosion (or electric corrosion) or biological corrosion. One problem is that the present water-lifting equipment and various carbon steel materials are suitable only in cold water. In addition, the off-and-on nature of the pump operation will also cause mechanical fatigue and increase corrosion. To prevent thermal water corrosion, increase the life of water-lifting equipment, and obtain cheap thermal energy, the following measures should be taken before the large-scale development of geothermal energy.

1) To satisfy the need of geothermal energy development and utilization, water-lifting equipment and materials suitable to the thermal

water of this region should be developed and produced as soon as possible. To meet the immediate needs, the sections of mechanical parts for most easily corroded (i.e., at the stage fluctuation zone) can be chrome-plated or replaced by a chrome nickel material so as to be more corrosion-resistant.

2) Corrosion-Prevention by Coating

Epoxy resin can be applied to the easily corroded part. This high-polymer substance is odorless, tasteless, alkaline-resistant, insoluble in water, and heat-resistant (melting point 145° to 155°C). Its adhesion to metal is strong. Coating the pump shaft with epoxy resin will protect the pump shaft from water and thus strengthen the corrosion resistance of the pump shaft. In addition, plastic or silicon sprays are also effective corrosion-resistant materials.

3) Sterilization and Elimination of Bacteria

There are iron bacteria and sulfate salt-reduction bacteria (Sr bacteria). Strontium bacteria can reduce the sulfate salt in the water to sulfides or can oxidize the hydrogen sulfide into sulfuric acid, thus accelerating corrosion. To eliminate the bacteria and neutralize the hydrogen sulfide in the thermal wate,r a proper amount of liquid chlorine, hypochlorides and other exidizers should be added in the recharge water to minimize the corrosiveness of the thermal water.

4) Based upon electro-chemical principles, the method of sacrificing the anode for protecting the cathode has already been applied in corrosion-prevention of oil pipelines. The method should be tested to find out its applicability to thermal water corrosion problems.

2. Reconnaissance Survey and Exploration of Geothermal Resources in the Deep Part and Outlying Areas of the Geothermal Core Region

To locate new geothermal resources and to expand the scale of geothermal development and utilization, reconnaissance survey and exploration work on geothermal resources must be extended to the deep part of the geothermal core region and outlying areas. Geological structure and heat storage conditions should be explored and determined for planning purposes.

A. Deep Geothermal Exploration of the Geothermal Core Region

Three geothermal boreholes will be used to determine the thickness of the Sinian subgroup dolomitic limestone aquifer in the southeastern urban region, i.e., the geothermal core region. These boreholes will also be used to understand the development of deep karst crevasses and to understand deep high temperature geothermal conditions. They are located near Hujialou, the Beijing Railroad Station, and the Longtanhu area, where the geothermal temperature gradients exceed 5°C, shown as C_1, C_2, and C_3 in attached Chart 5. The planned borehole depth is 2,500m with a total drilling footage of 7,500m. Large drilling rigs are to be used. The construction work will start in 1980 and will be completed in 1981.

B. Geothermal Reconnaissance Survey and Exploration of the Outlying Areas

1) Extent of the Survey and Exploration

The survey and exploration will include both the east and west sides next to the core region from Jiuxianqiao to Dingfuzhuang and Yongdingmen to the Nanyuan area. It will also include the northwestern urban region and both the east and west sides next to the region. The total area is about 250km^2. The objectives are to verify and investigate in detail, the geological characteristics of the Beijing graben and its relation to geothermal energy, to locate a new geothermal region and its possible utilization. This will serve as a basis for expanding long-term geothermal development and utilization.

2) Geophysical Exploration

Because of the relatively high degree of geophysical exploration and study of this region, it is unnecessary to duplicate the work. The physical exploration will emphasize the application of comprehensive physical exploration techniques in verifying the distribution laws of underground geological structure and heat storage of the Beijing graben. Hence, it is proposed that physical exploration should be carried out along four transects by using a non-blasting seismic source with a digital seismograph and magnetic, gravitational, and infrared survey techniques. The exploration will be from Babaoshan to Fengtai, Zizhuyuan to Nanyuan, Zijiahuozi to Dajiaoting, and Jiuxianqiao to Dingfuzhuang; these being designated respectively as CI, CII, CIII, and CIV, with a total length of 64km. This plan calls for initiating work on the transects CII and CIII first in 1980, with work on the other two transects later; and the verified work will be completed in 1981.

3) Geological Boring

With the physical exploration verification as the basis, geological structure will then be studied further in detail; the governing laws of the thermal water storage and its distribution will be defined. A total of eight geothermal reconnaissance survey boreholes will be sunk, designated as C_4 to C_{11}. The planned borehole depths vary from 1,500 to 2,500m. Three of those holes will be 1,500m deep, two will be 1,800m, one will be 2,000m, and two will be 2,500m deep, with a total footage of 15,100m. The plan calls for the boring to start in 1982 and to be completed in 1983.

In all the regions above, a total of 119 wells, including reconnaissance survey holes, boreholes, etc., are proposed. The total footage will be 213,500m and six to eight drilling rigs will be required. The work will begin in 1980 and will be finished in 1983. Table 6 is a summary of all the different kinds of well and borehole work.

3. Research Topics on Geothermal Energy

Our present geothermal exploration technology and equipment are outdated, our methods are limited, the productivity is low, and the construction period is extended. All these are incompatible with the requirements posed by the large-scale development and utilization of geothermal resources, and incompatible with serving the needs of the capital city's four modernizations. To change the present situation, it is urgent to introduce the necessary advanced technology and equipment, and to quickly determine all the information related

TABLE 6 - SUMMARY OF THE WORK FOR GEOTHERMAL HEATING DRILLING, SURVEY, AND EXPLORATION

Work Region	Classification	Number of Wells	Drilling Footage 10^3m	Number of Drilling Rigs Planned	Planned Construction Date
Core Region	Production Well	65	11.35	3	1980 to 1982
	Recharge Well*	43	77.4	2	Start in 1980
	Borehole	3	7.5	1	1980 to 1981
Outlying Area	Survey Borehole	8	15.1	2	1980 to 1983
Subtotal		119	213.5	6-8	1980 to 1983

*Establish three recharge stations first. With this experience, then go into full swing.

to the geothermal resources by various methods. In addition to accomplishing the exploration work previously discussed, the following research work should be carried out.

A. On Basic Theory

1) Research on the Evaluation Methodology on Geothermal Resources

A basic understanding has been achieved on geothermal resources' formation, replenishment, and heat storage boundary conditions. Based upon this knowledge, we should search step-by-step for an evaluation methodology for geothermal resources that fits the practical condition of this region. The approach is by trying and repeatedly testing and comparing various techniques such as the natural flow rate method, heat storage method, or analogy comparison method. In addition, a correct evaluation should be made on this region's geothermal resources.

2) Theoretical Research on the Utilization of Geothermal Heating

By selecting pertinent parameters of low- and medium-temperature geothermal heating systems, and research and testing for defining the economic and technological standards, an economical and a rational system model for geothermal heating should eventually be established.

B. On Application

1) Research on the Prevention of Geothermal Corrosion

Although much research has been performed over the past years on geothermal corrosion, there is still a lack of quantitative information on corrosion mechanisms and its main causes. Corrosion prevention measures are still not very effective. This plan calls for a continuation of past efforts, utilizing previously obtained results, and expanding, as well as deepening, the corrosion prevention research on a mass basis. The research should find the main causes of corrosion and propose feasible corrosion prevention measures. The electro-chemical corrosion prevention methods that sacrifice the anode to protect the cathode should be further tested. Better results should be obtained before the end of 1980.

2) Research on the Impact of Geothermal Energy on the Environmental Pollution and Human Health

The thermal water contains radioactive elements, such as radon, radium, uranium, etc. Although the amounts are small, the radioactive substances tend to concentrate because of frequent use. They either remain in the pipeline or are discharged over the ground surface. The effect of its accumulation over the years on human health and the environment remains unclear. To safeguard human health and reduce environmental pollution, research work should be emphasized while earnestly developing and utilizing geothermal energy. By checking for potential dangers and proposing safety methods, a safe utilization of geothermal resources will be achieved.

3) Research on the Comprehensive Utilization of Geothermal Energy

The economic and technological feasibility of heat pumps or heat exchangers should be tested in the winter heating projects to investigate increasing the thermal energy levels of both the thermal water and effluent. The effects of this increase of thermal energy on corrosion prevention shoudl also be studied. Summer use of geothermal energy for refrigeration, such as in air conditioning, industrial, agricultural and sideline business and applications in people's daily living needs, should be studied. This will expand the domain of geothermal utilization.

C. On Exploration Technology

1) Research on Geothermal Boring Machinery

The emphasis of this research is on the medium depth (1,500m) and deep well (2,500m) drilling rigs especially made for geothermal exploration. The requirements for the machinery are to be easily movable and operable, and have a large diameter (greater than 6 or 8 inches), and high efficiency. In addition, the existing boring equipment should be rapidly modified as to fully utilize their potential. The emphasis for modification is on enlarging the diameter, so that a well can be completed by using a single diameter drill. Improving the well-completion technology will insure the quality of the completed well.

2) Research on New Techniques and Methodologies

Emphasis is placed on development of well video recording, stereographic photography techniques, and equipment to improve the efficiency and quality of completed wells.

4. TECHNICAL TRAINING

To meet the needs of the four modernizations, a technical force should be established in geothermal geology, exploration and design, and technical management. Training courses on physical exploration, boring, chemical analysis, heating design and technical management are planned. Such comprehensive training should produce a group of management and technical cadres who possess social consciousness and advanced technology. Various training methods would be utilized to produce trained personnel as soon as possible.

A. On Job Training

Under the guidance of responsible personnel, the trainees will study while remaining on their productive jobs. Priority will still be on the production of geothermal wells but will integrate study with production. After three months' practice in production, the trainee should be skillful in operating advanced equipment. He should also understand general maintenance. Within six months, the trainee should thoroughly understand the principal technical capability of commonly used equipment. He should also be able to work independently.

B. Short Training Courses

Those professional engineering and technical cadres presently engaged in the fields of geothermal geology, physical exploration, heating technology, design, and management, should be trained in rotation. Special lecturers will be invited to teach the courses. The training will enrich the cadres' basic understanding of geothermal theory, enable them to solve concrete problems in production, and apply new techniques. All these will raise the present technical and management levels.

Each class will last three months. The course will mainly consist of new techniques on geothermal resource research, application of electronic techniques in geothermal exploration and technical management, theory of their comprehensive utilization, determination of technical parameters, installation of automatic control systems for geothermal heating, and the advanced evaluation techniques in chemical analyses.

C. Foreign Visits and Study

Geothermal technical study groups, consisting of selected geothermal professional engineering and technical personnel, will be sent abroad to study exploration, engineering and utilization of geothermal resources. After a particular place has been chosen, the group will directly participate in the local exploration and construction effort and learn advanced techniques and management experience. The main content will include basic theory on geothermal energy, new techniques and methods, and experience on technical and economic management. Each session will last six to nine months.

GEOTHERMAL ENERGY IN BEIJING

CHARTS 1-6

CHART 1 - EXTENT OF GEOTHERMAL GEOLOGICAL WORK IN URBAN BEIJING

A Brief Explanation of the Chart

Item	Work	Legend	Description
Geophysical Exploration	Gravity		In 1972, a gravity exploration (scale 1:10,000) was carried out over an area of 200km^2 in urban Beijing. Reports and related charts were issued.
	Electric Method		Two electric method explorations were carried out in urban and northwestern suburb regions (scale 1:50,000) in 1970 and 1978. Summary reports and charts were issued. From 1966 to 1970, Factory No. 646 of the Ministry of Oil performed gravity and electric exploration work (Scale 1:100,000) in urban Beijing. Reports charts were issued.
	Artificial Seismic Tests		Controllable source seismic tests were performed in the exploration of a 70km^2 area in Fengtai region during 1976 and 1977 (scale 1:50,000). Reports and charts were issued.
Geothermal Survey and Exploration	Temperature Survey		Well water temperatures were surveyed over the urban and neighboring suburban areas of about 600km^2. A total of 1,000 wells were surveyed and the results were used to define the geothermal anomaly region in southeastern Beijing. It provided the basic information for geothermal exploration.
	Boring		20 geothermal boreholes were completed over an area of 500km^2 in southeastern region. Geothermal exploration reports and related charts were issued.

Note: Above work was mostly performed by Beijing Municipal Bureau of Geology and those units under the Ministry of Oil.

SITES SHOWN ON CHART

1. Qinghezhen
2. Beiyuan
3. Laiguangying
4. Yuquanshan
5. Kunminghu
6. Haidianzhen
7. Jiaoxianqiao
8. Huangshi
9. Baishiqiao
10. Balizhuang
11. Beihai
12. Babaoshan
13. Hongmiaocun
14. Shuangqiao
15. Gaobeidian
16. Dajiaoting
17. Tiantan
18. Lugouqiao
19. Fengtaizhen
20. Laojuntang
21. Dahongmen
22. Changxindianzhen
23. Henjiecun
24. Nanyuanzhen

CHART 2 - ANTE-TERTIARY GEOLOGICAL MAP OF URBAN BEIJING

Legend

Era	Period	Symbol	Description
Mesozoic	Jurassic	J_{2d}	Mid-Jurassic volcanic rock
		J_1	Lower Jurassic sandstone, shale and breccia
Palaeozoic	Permian	P	Sandstone
	Carboniferous	C	Shale, sandstone and coal
	Ordovician	O	Limestone
	Cambrian	Є	Limestone
Sinian Subgroup	Qingbaikou	Z_{qj}	Jingeryu siliceous marlite
		Z_{qx}	Xiamaling shale, siltstone
	Jixian	Z_{jt}	Tieling siliceous, argillaceous dolomitic limestone
		Z_{jh}	Hongshuizhuang shale
		Z_{jw}	Wumishan flint belt dolomitic limestone
	Yanshan	Y	Granite

- Reverse fault
- Normal fault
- Unclear, speculated to be a rift
- Stratigraphical divide
- 200 — Sinian subgroup roof depth contours (m)
- Divide between the mountainous and plain regions
- ○ Hole No. / Hole Depth
- ○ Depth of the bedrock (lithological character and age)....
- 1074 — Historical epicenter and date of occurrence

Note: $\overline{J_{2d}}$ Showing that there are Cretaceous layer over mid-Jurassic volcanic rock in boreholes in Beijing depression.

SITES SHOWN ON CHART 2

1. Beijing northwestern heave
2. Yamenkou rift
3. Chegongzhuang rift
4. Lianhuachi rift
5. Beijing graben
6. Qianmen rift
7. Chongwenmen rift
8. Nanyuan rift
9. Daxing horst
10. Jiaoxianqiao
11. Zizhuyuan
12. Beihai
13. Dinfuzhuang
14. Babaoshan
15. Gugong
16. Lianhuachi
17. Tiantan
18. Yamenkou
19. Fengtaizhen
20. Nanyuanzhen
21. Kunminghu
22. Re 4
23. Re 25
24. Mei 2
25. Re 19
26. Mei 1
27. Re 23
28. Re 24
29. Re 7
30. Re 16
31. Re 22
32. Re 17
33. Re 13
34. Re 15
35. Re 12
36. Re 9
37. Re 3
38. Re 11
39. Re 10
40. Re 2
41. Re 8
42. Re 1
43. Re 6
44. Re 14
45. Re 20
46. Re? 1
47. Dingshui 2
48. Tie 1
49. Gaobeidian

CHART 3 - DISTRIBUTION OF GEOTHERMAL ANOMALY IN SOUTHEASTERN URBAN BEIJING

Legend

GEOTHERMAL TEMPERATURE GRADIENT

- 6°C/100m
- 5°-6°C/100m
- 4°-5°C/100m
- 3°-4°C/100m

(6°C/100m to 3°-4°C/100m: Geothermal Anomaly Region)

- 2°-3°C/100m
- 2°C/100m

WATER TEMPERATURE AND OTHERS

- 50°C (Max. wellhead temperature)
- 40°-50°C (Max. wellhead temperature)
- 37°-40°C (Max. wellhead temperature)
- Stage Elevation Contours (m)
- Depth Contour of Aquifer Roof (m)
- Fault Line (concealed)
- Hole Number / Aqu. Roof Depth — Stage Elevation (m) / Unit Flowrate (1/s-m)

SITES SHOWN ON CHART 3

1. Chegongzhuang rift
2. Lianhuachi rift
3. Qianmen rift
4. Chongwenmen rift
5. Shuangjing rift
6. Nanyuan rift
7. Houhai
8. Beihai
9. Gugong
10. Tiantan
11. Taoranting
12. Longtanhu
13. Zhen 1
14. Zhonghai
15. Nanhai

CHART 4 - NEARTERM MUNICIPAL BUILDING PLAN FOR SOUTHEASTERN URBAN BEIJING

Explanation of Municipal Building Plan

New Building Zone					Rebuilding Zone				
No.	Location	Building Area 10^3m^2	Number of Wells Planned	Heating Area 10^3m^2	No.	Location	Building Area 10^3m^2	Number of Wells Planned	Heating Area 10^3m^2
1	Zuojia-zhuang	520	10	500	1	Xingfu-xiaoqu	50	1	50
2	Tuanjiehu (1st stage)	300	6	300	2	Guangming-xiaoqu	60	1	50
3	Tuanjiehu (1st stage)	190	4	200	3	Banchang-xiaoqu	30	1	50
4	Anhualou	100	2	100	4	Longtan-xiaoqu	100	2	100
5	Jinyuchi	100	2	200	5	Tiantan-dongli	60	1	50
6	Jinsong (1st stage)	270	8	400	6	Tiantan-gaoceng	40	1	50
7	Jingsong (2nd stage)	360	8	400	7	Tiantannan-lidongqu	50	1	50
8	Puhuang-yubei	170	3	150	8	Tiantan-nanli	60	1	50
9	Liujiayao	220	4	200	9	Puhuangyu dongqu	30	1	30
10	Puhuang-yunan	80	2	80	10	Puhuangyu-xiqu	30	1	30
11	Dahongmen	40	1	40					
12	Dongsibei-dajie	50	1	50					
13	Donghuamen	50	1	50					
14	Taoranting	100	2	100					
	Sub-Total	2,670	54	2,670		Sub-Total	510	11	510

Legend

☐ New Building Zone

☐ Rebuilding Zone

SITES SHOWN ON CHART 4

1. Dongzhimen
2. Shizipo
3. Chaoyangmen
4. Jianguomen
5. Erdaogou
6. Jianguomen Waidajie
7. Chongwenmen

CHART 5 - LAYOUT OF GEOTHERMAL EXPLORATION, DEVELOPMENT, AND UTILIZATION PROJECTS IN URBAN BEIJING

Legend

Existing geothermal well and its number

Borehole

Reconnaissance survey borehole

Borehole No. / Planned Depth (m)

Physical exploration profile line and its number

Recharge station

Region of geothermal development and utilization

Concealed normal fault

SITES SHOWN ON CHART 5

1. Yamenkou rift
2. Chegongzhuang rift
3. Lianhuachi rift
4. Zianmen rift
5. Chongwenmen rift
6. Nanyuan rift
7. Mountainous region
8. Zinghezhen
9. Beiyuan
10. Yuquanshan
11. Kunminghu
12. Haidianzhen
13. Jiaoxianqiao
14. Bazhen
15. Yongdinghe
16. Baishiqiao
17. Ditan
18. Balizhuang
19. Diaoyutai
20. Beihai
21. Gaobeidian
22. Shuangqiao
23. Dajiaoting
24. Roller
25. Lugouqiaozhen
26. Fengtaizhen
27. Henjiecun
28. Nanyuanzhen

CHART 6 - GEOTHERMAL BOREHOLE COLUMNAR SECTION CHART

Part 1: Borehole at Guanghua Dyeing and Textile Plant

BOREHOLE NO.			Beijing Re-7	Borehole Depth	824.84m	Static Stage	3.26m
LOCATION			Guanghua Dye. & Textile Pl.	Ground Elevation	39.42m	Water Temp.	48^{o} C
STRATUM	Depth (m)	Thickness (m)	STRATIGRAPHIC PROFILE AND BOREHOLE STR.	DESCRIPTION OF LITHOLOGICAL CHARACTER		Flowrate 925 mt/d Drawdown 13.38m	
Quaternary System	171.60	171.60		Clay, sand and gravel			
Tertiary System	697.00	525.40		Mainly of sandy mudstone which is mottled, reddish brown and semi-cemented. Younger tertiary system is above 402m with older tertiary system below The latter has many layers of green or purplish red basalt and is 200m thick.			
Qingbaikou-Jixian System	824.84	127.84		Dolomitic limestone which is brownish grey-white with flint belt. There are caverns and karst phenomena at hole depth 737-742m. The caverns are filled with sand.			

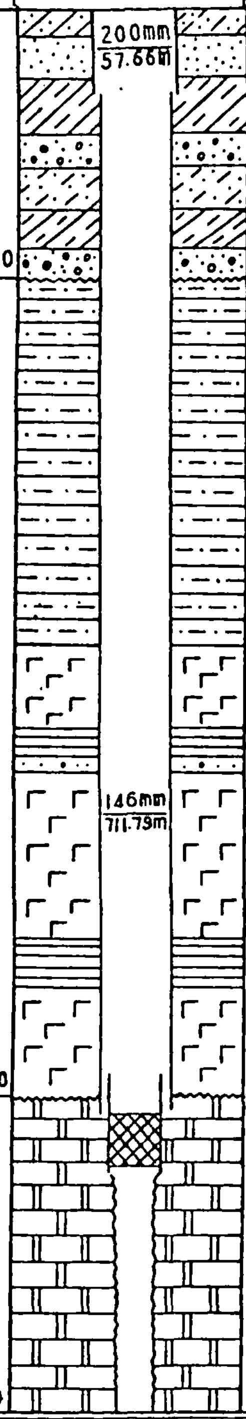


CHART 6 - GEOTHERMAL BOREHOLE COLUMNAR SECTION CHART

Part 2: Borehole at Renmin Art Press

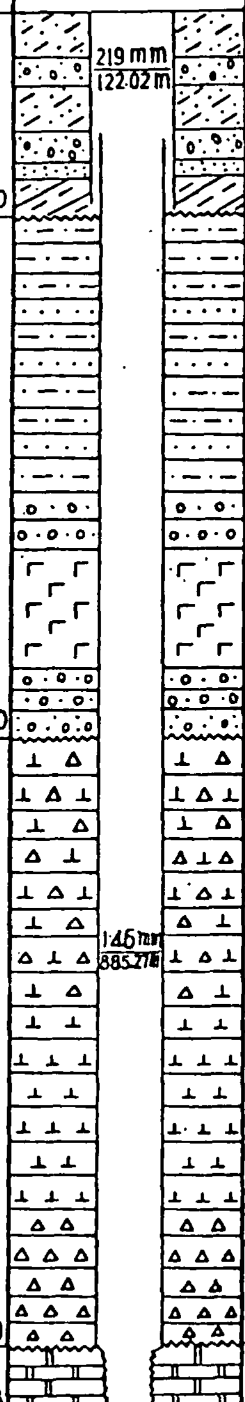
BOREHOLE NO.		Beijing Re-16	Borehole Depth 129.08m	Static Stage	10.38 m
LOCATION		Renmin Art Press	Ground Elevation 43.44m	Water Temp.	58° C
STRATUM	Depth (m)	Thickness (m)	STRATIGRAPHIC PROFILE AND BOREHOLE STR.	DESCRIPTION OF LITHOLOGICAL CHARACTER	Flowrate 1000 mt/d; Drawdown 12 m
Quatenary System	129.00	129.00		Alternating layers of clay sand, sandy clay, sand and gravel.	
Tertiary System	859.50	730.50		Younger tertiary system from 129.00-739.00m, mainly of reddish brown sandy mudstone with thin layers of sandstone. Bottom part consists of semi-cemented sand and gravel. Older tertiary system is from 739.00-859.50m, mainly of basalt with sand and gravel at the lower part.	
Jurassic System	1257.90	398.40		Upper part consists of grey, purple and brown andesite volcanic breccia. Middle part is mainly of purplish black andesite. Lower part is purplish red breccia.	
Qingbaikou-Jixian System	1299.08	41.18		Siliceous dolomitic limestone, fractured and with karst.	

CHART 6 - GEOTHERMAL BOREHOLE COLUMNAR SECTION CHART

Part 3: Borehole at Zhongshan Park

BOREHOLE NO.			Beijing Re-20	Borehole Depth 2600.5	Static Stage	7.5 m
LOCATION			Zhongshan Park	Ground Elevation	Water Temp.	69.5^{o} C
STRATUM	Depth (m)	Thickness (m)	STRATIGRAPHIC PROFILE AND BOREHOLE STR.	DESCRIPTION OF LITHOLOGICAL CHARACTER	Flowrate	1000 mt/d
					Drawdown	55 m
Quaternary	78.00	78.00		Clay sand, powdery fine sand, gravel.		
Tertiary System	1567.00	1489.00		Younger tertiary system is 1033m thick. Both upper and lower parts are mainly reddish grey, greyish white and greyish green sandstones. Middle part is mainly red mudstone. Older tertiary system is 456m thick. Upper and middle parts consist of three basalt layers with green mudstone and shale. Lower part is mainly brown mudstone and shale with sandstone.		
Cretaceous System	2181.50	614.50		Upper part is mainly purplish brown, greyish brown shale. Middle part is mainly brownish grey sandstone with sandy mudstone and shale layers. There are gypsum and plant fossils. Lower part is mainly purplish grey and mottled breccia with sandy shale. There is gypsum.		
Jurassic System	2456.60	274.50		Upper part is a deposit of volcanic fragments, mainly of purple sandstone and breccia. Middle part is a set of volcanic eruption rocks--mainly andesite & tuff.		
Jixian System	2600.5	144.5		Dolomitic limestone with well developed karst in the middle part.		

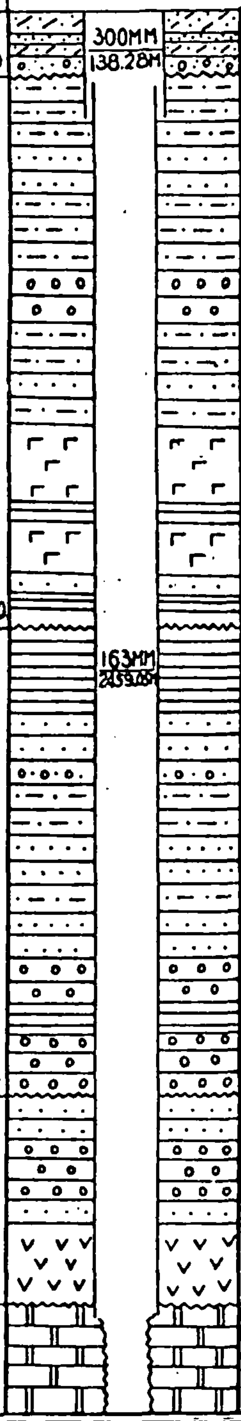
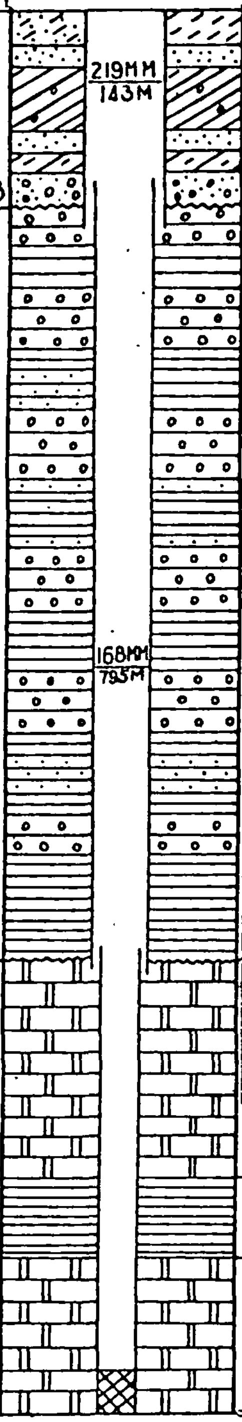


CHART 6 - GEOTHERMAL BOREHOLE COLUMNAR SECTION CHART

Part 4: Borehole at Roller Factory

BOREHOLE NO.				Borehole Depth	1082m	Static Stage 15.80 m
LOCATION			Roller Factory	Ground Elevation		Water Temp. 51^{o} C
STRATUM	Depth(m)	Thickness (m)	STRATIGRAPHIC PROFILE AND BOREHOLE STR.	DESCRIPTION OF LITHOLOGICAL CHARACTER		Flowrate 1399 mt/d Drawdown 11.2 m
Quaternary System	126.13	126.13		Alternating layers of clay, sand and gravel.		
Tertiary System	789.00	662.87		Alternating layers of mottled, semi-cemented sandstone, conglomerate rock and shale. More sandy shale in the lower part.		
Qingbaikou-Jixian	946.25	157.25		Greyish white dolomite and dolomitic limestone with layers of green or purple shale at the top part.		
	979.00	32.75		Black shale.		
	1082.00	103.00		Grey dolomitic limestone with 7 crevasses between 1076.00-1079.22m. Severe water leakage.		



Part 3

GEOTHERMAL RESOURCES IN THE TIANJIN AREA AND OUR CONCEPT FOR THEIR RECONNAISSANCE SURVEY AND EXPLORATION

TIANJIN MUNICIPAL GEOLOGICAL OFFICE

1980

FOREWORD

The municipality of Tianjin, with a population of 7 million and an area of 11,305 km^2, is 120 km southeast of Beijing (Peking) and in the northeastern section of the North China Plains. One of China's chief industrial bases, it has a number of growing industries, including steel, rubber, machine building, chemicals, textiles and food processing, of which many products are exported.

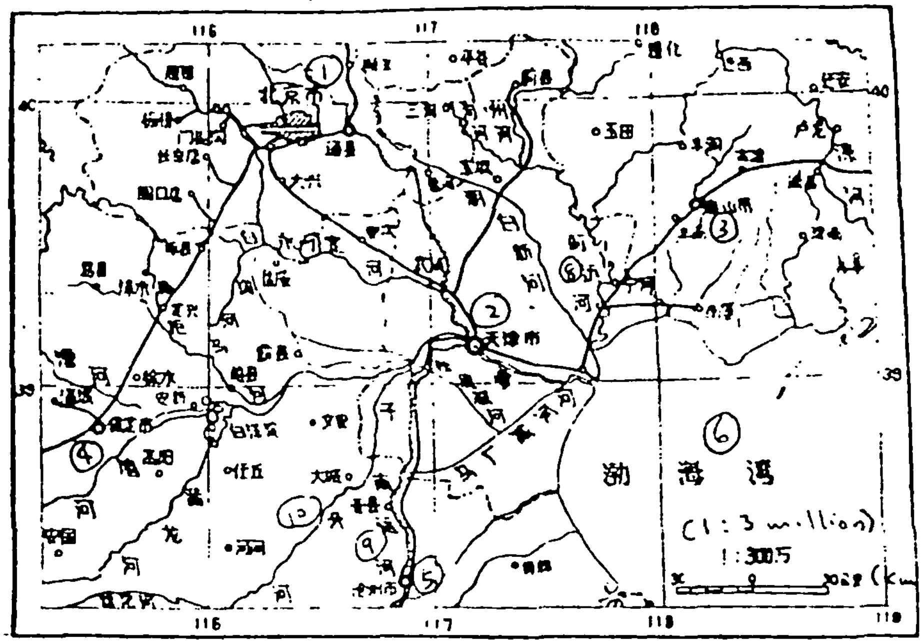
Tianjin has rich underground resources, which include, besides extensive oil and gas fields in Dagang and the Bohai Bay, large geothermal reserves in the city and its environs. The maximum water temperature observed to date in the three large geoheat anomaly regions of the area (covering 700 km^2) is 96°C. Thermal water here falls into two types: that found in the pore spaces of the Tertiary System thermal storage stratum at shallow depth and that in the karst crevasses of the bedrock thermal storage stratum at a depth exceeding 1,200 m. The former is already being utilized.

Full exploration and utilization of these resources to serve the area's residents and its industry and agriculture is a necessary step to its modernization.

FIGURE 1: GEOGRAPHIC POSITION OF TIANJIN

附天津地理位置图 图-1

1. Beijing
2. Tianjin
3. Tangshan
4. Baoding
5. Cangzhou
6. Bohai Bay
7. Yongding River
8. Jiyun River
9. Grand Canal
10. Ziya River



I. LEVEL OF INVESTIGATION OF GEOTHERMAL WATER IN TIANJIN

Geothermal geological work in the Tianjin area started in the early 1970's, centering chiefly on thermal water (30° -53° C) stored in the pore spaces of the Tertiary System thermal storage stratum at shallow depth, extensive use of which is now being made. However, comprehensive exploration of deep thermal water (above 60° C) in the karst crevasses of the bedrock thermal storage stratum has not yet been made.

Hydrogeological, petrogeological and seismic and thermal geological work to improve the area's water supply in the past decade have yielded the following:

<u>In physical exploration</u>:

1. Airborne magnetic and gravity anomaly map of the North China Plains (scale 1:1 million);

2. Tianjin high magnetic and gravity anomaly overlay map (scale 1:100,000);

3. Summary report on gravity exploration in urban and suburban Tianjin (urban 1:50,000, suburban 1:100,000);

4. Our concept and evaluation of the oil-bearing characteristics of the Huanghua depression and the peripheral (Tianjin included) Guqian Mountain (1:50,000 and 1:100,000);

5. Report on findings of aerial magnetic surveys of the Beijing-Tianjin area;

6. Aerial infrared remote sensing (1:10,000 to 1:30,000).

In thermogeological exploration:

1. Summary Report on the stage of geothermal exploration;

2. Preliminary discussion of the relation between the distribution and structure of geoheat anomaly regions in Tianjin;

3. Summary of preliminary investigations of the Wanglanzhuang-Guanjiabao geoheat anomaly region;

4. Investigation Report of geoheat resources in the Wanjiamatou geoheat anomaly region;

5. Investigation Report on geoheat in the eastern suburbs of Tianjin;

6. Overall Plan for geothermal water survey and exploration in the environs of Tianjin.

The above have given us some idea of the extent of geothermal water storage in the Tianjin area and the broad prospects for its future utilization. Overall development and utilization at this stage, however, is still premature, due to insufficient knowledge of the volume of deep high temperature karst crevasse water, the technical conditions involved in artificial recharge and the computation of the heat balance, as well as the corrosiveness of the hot water. Only when these questions are answered can we really make use of these resources to serve the livelihood of the people and for production and construction.

II. GEOLOGICAL AND HYDROGEOLOGICAL CONDITIONS OF THE GEOTHERMAL WATER

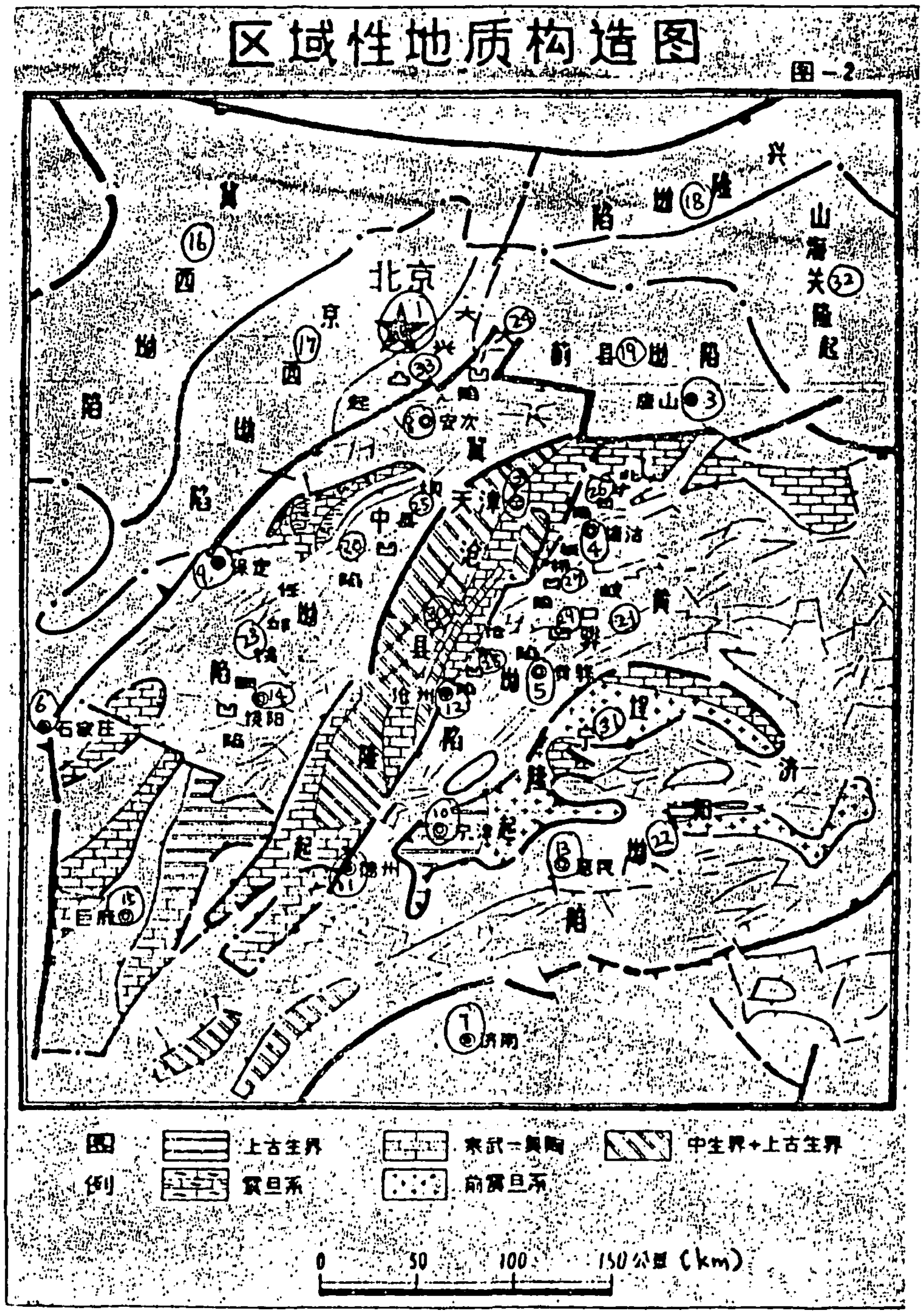
1. Characteristics of the geological structure of the Tianjin area

The Tianjin area belongs to the North China Plains Subsidence Zone of the Late Cathaysian Structural System. Its geothermal resources are stored chiefly at the northern tip of the secondary structure Cangxian Anticline. Its southeastern and northwestern flanks are, respectively, the Huanghua Depression and the Jizhong Depression, and its northern side is the Mt. Yanshan Folded Zone aligned in an east-west direction. (See Figure 2.)

The Cangxian anticline can further be classified as a secondary structural unit, being a succession of north-north-east concave and convex structures formatively connected with different fault zones. It consists of the Shuangyao, Xiaohanzhuang, Ziaodongzhuang, Dadongzhuang and Panzhuang convex structures and the Baitangkou Trough. The structural faults can be classified under two formations, the first a north-north-east fault zone including the Cangdong, Xiaoyingpan, West Baitangkou, North Tianjin, Lingtou, and Tongcheng Faults, and the other a north-west-west fault zone including the Haihe Fault Zone, the North Guanzhuang, Zengfutai and Chenglinzhuang Faults (See Figure 3).

FIGURE 2: GEOLOGICAL STRUCTURE AERIAL MAP

1. Beijing
2. Tianjin
3. Tangshan
4. Tanggu
5. Huanghua
6. Shijiazhuang
7. Jinan
8. Anci
9. Baoding
10. Ningjin
11. Dezhou
12. Cangzhou
13. Huimin
14. Raoyang
15. Julu
16. Jixi Depression
17. Jinxi Depression
18. Xinglong Depression
19. Jixian Depression
20. Jizhong Depression
21. Huanghua Depression
22. Jiyang Depression
23. Renqiu Raoyang Trough
24. Dachang Trough
25. Baxian Trough
26. Beitang Trough
27. Banjiao Trough
28. Cangdong Trough
29. Zhikou Trough
30. Cangxian Anticline
31. Chengning Anticline
32. Shanhaiguan Anticline
33. Daxing Convex Structure

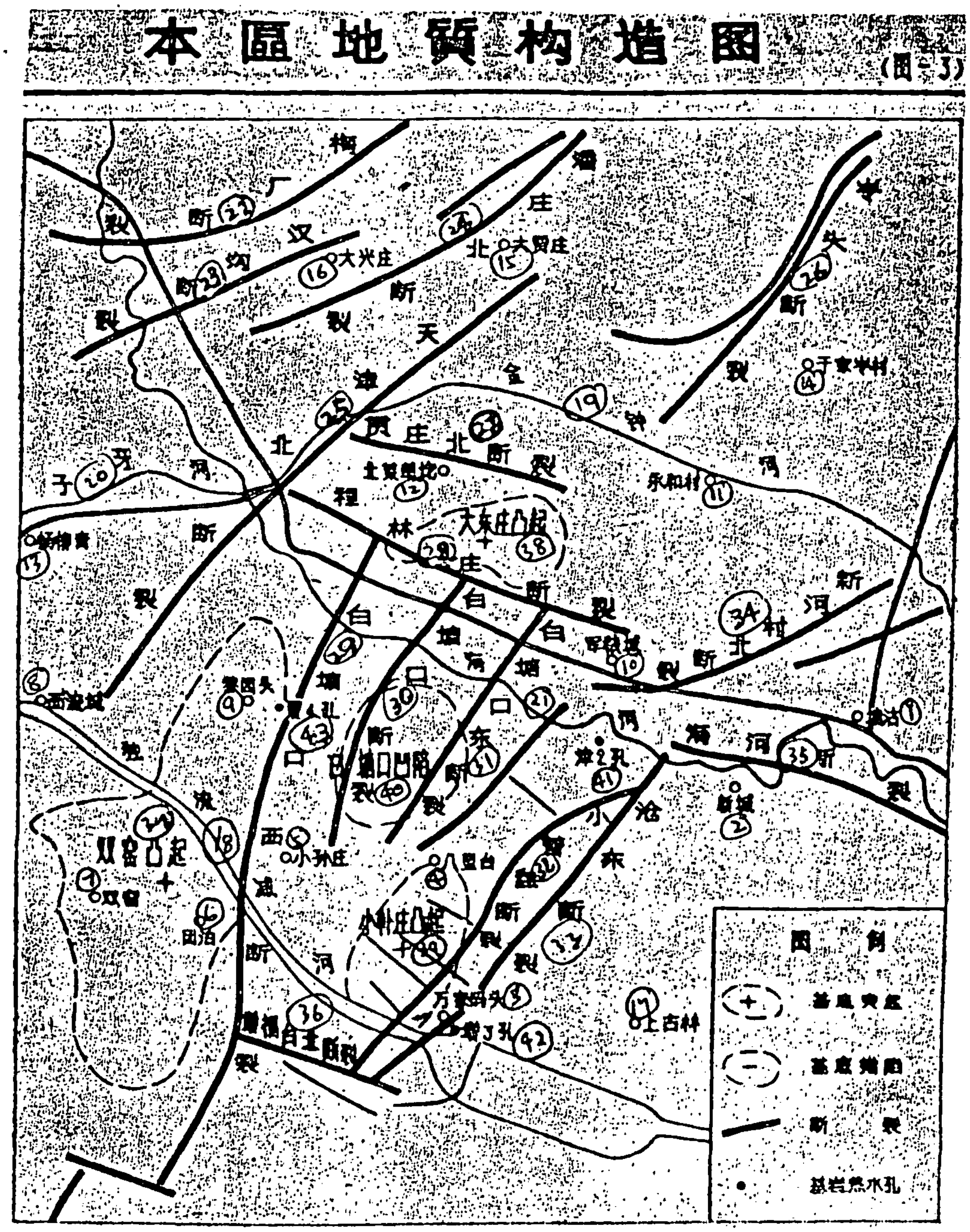


LEGEND

-Upper Palaeozoic -Cambrian-Ordovician -Mesoizoic and Upper Palaeozoic
-Sinian -Early Sinian

FIGURE 3: GEOLOGICAL STRUCTURE MAP

1. Tanggu
2. Xincheng
3. Wanjiamatou
4. Balitai
5. Xiaosunzhuang
6. Tuanbo
7. Shuangyao
8. Xiliuyu
9. Liyuantou
10. Junliancheng
11. Yonghecun
12. Bei Huangcaotuo
13. Yangliuqing
14. Yujialingcun
15. Dajiazhuang
16. Daxingzhuang
17. Shanggulin
18. Duliujian River
19. Jinzhong River
20. Ziya River
21. Haihe River
22. Meichang Fault
23. Shuanggou Fault
24. North Panzhuang Fault
25. North Tianjin Fault
26. Lingtou Fault
27. North Guanzhuang Fault
28. Chenglinzhuang Fault
29. West Baitangkou Fault
30. Baitangkou Fault
31. East Baitangkou Fault
32. Xiaoyingpan Fault
33. Cangdong Fault
34. North Xinhecun Fault
35. Haihe Fault
36. Zengfutai Fault
37. Shuangyao Convex Structure
38. Dadongzhuang Convex Structure
39. Xiaohanzhuang Convex Structure
40. Baitangkou Trough
41. Jin 2 Hole
42. Zeng 3 Hole
43. Zhen 4 Hole



LEGEND

- Bedrock convex structure
- Bedrock depression
- Fault
- Bedrock thermal water hole

Scale 1:500,000

The positive structure of the north-north-east late Cathaysian System structure is steep in the east and mild in the west. The eastern flank, which is anticlinal and has some convex structures, is generally steeper than the western flank. The larger thrust fracture zones generally occur in the steep eastern flank, as is demonstrated by a higher gravity gradient on the Bouguer gravity map. The convex structures in this area possess the same characteristic, as for instance the Cangxian Anticline, which dips from east to west. The Cangdong Fault Zone developed on its eastern flank, with a greater depth and displacement. Artificial seismic T_1 Reflection Stratum Tests show the displacement to be 200 m, which means that it would have a displacement of over 1,000 m in the Lower Palaeozoic Group roof. The gravity gradient therefore is great. Its southeastern wall (literally "disk" in Chinese), that is, the Huanghua Depression, has a thick layer of early Tertiary deposit, but in its northwestern wall--the Cangxian Anticline--the early Tertiary stratum is often missing. The Cangdong Fault Zone extends for over 100 km from south to north, being the major fault in this area.

The Shuangyao Convex Structure is the chief secondary structure on the Cangxian Anticline, being also steep in the east and flat in the west. On its steep eastern flank is the West Tangkou Fault Zone, another belt of Bouguer gravity gradient concentration. Its fault point (epicenter) is comparatively shallow in Wanglanzhuang and Guanjiabao, the burial depth being 360-380 m, and is markedly active at the present time.

There are, in addition, the Xiaoyingpan Fault Zone on the eastern part of the Beizhakou-Xiaohanzhuang Convex Structure and the Lingtou Fault Zone on the eastern part of the Panzhuang Convex Structure. (See Attached Map 1.)

2. Stratification

Observations and drilling have revealed that Tianjin, on the northern tip of the Cangxian Anticline, consists geologically of a thousand-meter-thick Cenozoic Group deposit in the upper part and a Palaeozoic Group stratum in the lower part. The distribution is as follows:

(1) Cenozoic Group

The thickness of the Cenozoic Group is very uneven in this area, being markedly influenced by the structure of the bedrock. The deposit is relatively thin in the convex roof of the secondary structure, the thinnest part estimated at 750-800m at Guanjiabao of the Shuangyao Convex Structure. The burial depth at the Zhen 4 Borehole near Wanglanzhuang is 1,032m, 1,072m at the Zeng 3 Borehole on the Xiaohanzhuang Convex Structure, and over 2,500m at the Baitangkou Trough in the center of the three convex structures. Generally speaking, only Quaternary and Upper Tertiary System strata are found on the convex structures, but the Lower Tertiary System stratum found in the Baitangkou Trough leads to the deduction that there may also be a Mesozoic Group deposit here.

The lithological characteristics and distribution are:

1) The thickness of the Quaternary System stratum here is around 600m. Apart from the littoral plains which have interbedded marine and terrestial deposits, the rest are loose terrestial deposits.

2) Tertiary System. The distribution thickness is generally 500-600m.

The Minghuazhen Formation is at the lower part of brownish red purplish mudstone with some sandstone and the upper part of greyish yellow and light brown mudstone with some fine sandstone.

Guantao Formation: greyish white gravelly sandstone with some mudstone.

Dongying Formation: alternate layers of light grey and greenish grey sandstone and mudstone.

Shahejie Formation: mainly dark grey and brownish grey with gravel and sandstone and fossiliferous limestone stratum, in upper part, and extensive oil shale below.

Kongdian Formation: greyish, brownish red mudstone with some sand, shale and oil shale.

(2) Mesozoic Group

There is in this area a thick layer of terrestial volcanic extrusive and pyroclastic rocks bearing a coal stratum formed in the course of many volcanic eruptions in the Jurassic and Cretaceous Periods.

(3) Palaeozoic Group stratum is mainly distributed over the following locations in this area:

Carboniferous Permian System: thickness 36m at the Re 1 Borehole in Liqizhuang.

Ordovician System: about 300m, as seen from many boreholes.

Cambrian System: thickness 150-300m, as seen from boreholes.

Sinian Subgroup: widespread in this area, the thickness reaching as much as several thousand meters. (See Attached Chart 3.)

3. Definition and Distribution of Geoheat Anomaly Regions

According to Tianjin Weather Bureau statistics, the annual mean temperature of Tianjin is 12.2°C, with the lowest temperatures occurring in January, when the monthly average is 8°-10°C, and the highest in July, averaging 28°-30°C.

With the depth of the constant temperature stratum as the dividing line, the ground temperature can be divided into two spaces:

(1) The Variable Temperature Zone (from ground surface to the depth of the constant temperature stratum);

(2) The Heat Increment Zone (from the depth of the constant temperature stratum down).

Within the Variable Temperature Zone, due to solar radiation, the temperature varies from day to night and season to season. Data gathered by the

the Tianjin Weather Bureau demonstrate that, despite these periodic changes involving different temperature ranges, the annual mean value of the temperature at different depths is close to a constant, i.e., it is 13.6°-13.9°C at a depth of 0.20m to 3.2m, or 1.5°C± above the average subsurface temperature.

The base line of Tianjin's Variable Temperature Zone is also the depth and temperature paramaters of the Constant Temperature Stratum. According to observations made at that stratum and numerous deep well tests, in the Tianjin area it is buried at a depth of 32m, with a temperature of 13.6°C and an average thermal temperature gradient of 3.5°C/100m. By classifying those areas with a gradient exceeding 4°C/100m as anomaly regions, there are three such areas in the vicinity of Tianjin (See Figure 4) with a total area of 700 km^2. Their locations are as follows:

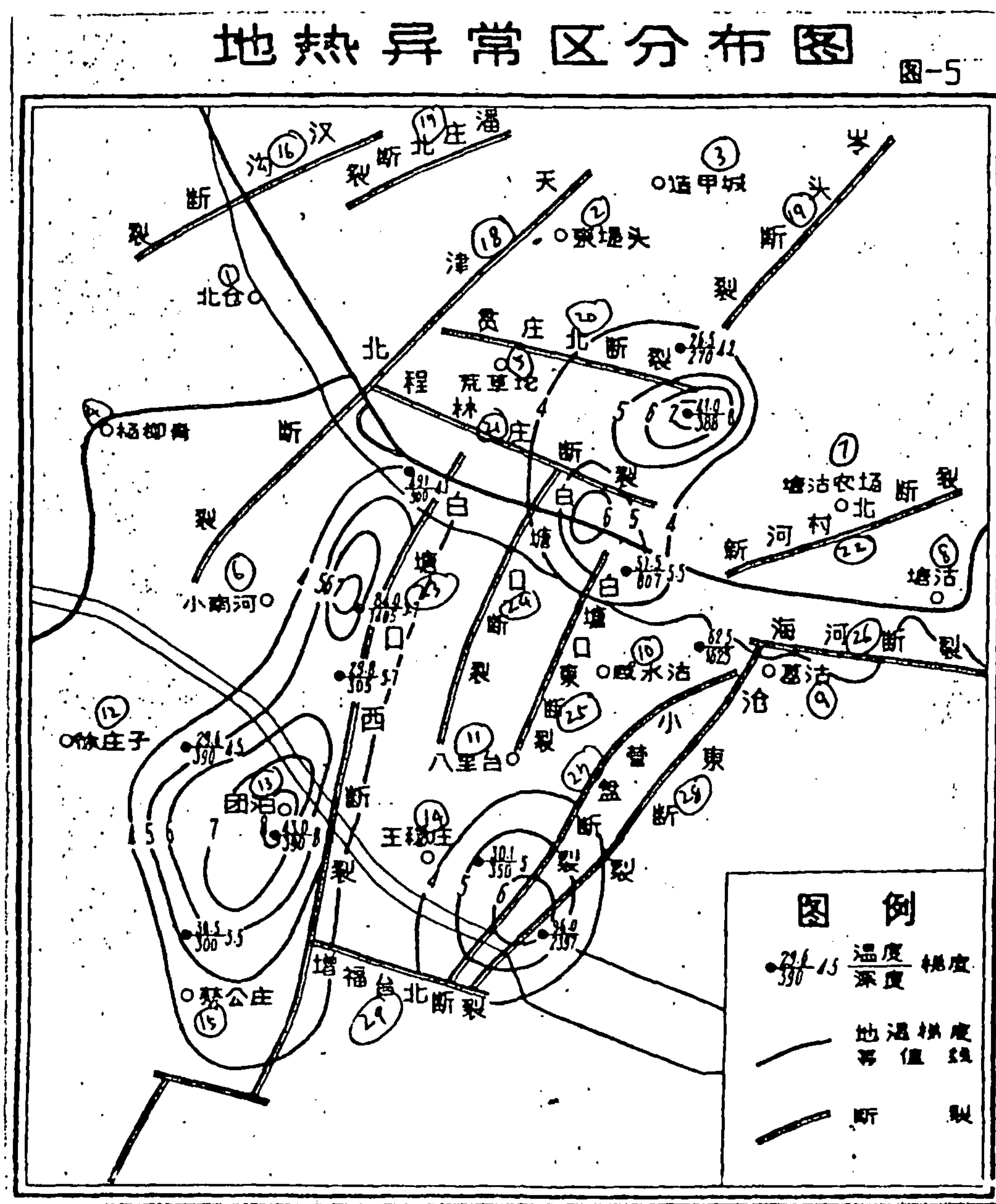
(1) The Wanglanzhuang Heat Anomaly Region: In the southwestern part of Tianjin, starting at Chentangzhuang, through Liqizhuang and Qingbowa to Guanjiabao in Jinghai County, with an area of 409 km^2. There are two geo-heat anomaly cores: the one in the north at the Wanglanzhuang Brick Factory, with a gradient of 7.25°C/100m, and the southern core near Guanjiabao, with a gradient of 8.3°C/100m.

(2) The Wanjiamatou Heat Anomaly Region: Located near Wanjiamatou and Xiaohanzhuang in the southern suburbs, over an area of 119 km^2, with the core at Wanjiamatou with a gradient of 8.3°C/100m.

(3) The Shanlingzi Heat Anomaly Region: At the eastern suburb's Zhonghe Chemical Plant, Xiaodongzhuang and Shanlingzi, over an area of 171 km^2. There are two cores, the southern one at the Zhonghe Chemical Plant, with a gradient of 6.25°C/100m and the northern core at the Shanlingzi Production Brigade, with a gradient of 8.10°C/100m.

FIGURE 4: DISTRIBUTION OF GEOHEAT ANOMALY REGIONS

1. Beicang
2. Dongtitou
3. Zhaojiacheng
4. Yangliuqing
5. Huangcaotuo
6. Xiaonanhe
7. Tanggu State Farm
8. Tanggu
9. Gegu
10. Xianshuigu
11. Balitai
12. Xuzhuangzi
13. Tuanbo
14. Wangyinzhuang
15. Caigongzhuang
16. Hangou Fault
17. North Panzhuang Fault
18. North Tianjin Fault
19. Lingtou Fault
20. North Guanzhuang Fault
21. Chenglinzhuang Fault
22. North Xinhecun Fault
23. West Baitangkou Fault
24. Baitangkou Fault
25. East Baitangkou Fault
26. Haihe Fault
27. Xiaoyingpan Fault
28. Cangdong Fault
29. North Zengfutai Fault



LEGEND

$\frac{29.6}{390}$ 4.5 $\frac{\text{temperature}}{\text{depth}}$ gradient

- Thermal temperature gradient contour line
- Fault

4. Basic Factors Controlling Geothermal Conditions in Tianjin

(1) Crust Structure: The vicinity of Tianjin is located on the anticline of the North China Plains. According to statistics published by the Geological Institute of the Chinese Academy of Sciences in 1979, the representative heat flow value of the Cenozoic Geological Depression Area of the North China Terrace is 1.5 HFu (including Tianjin), which is appreciably higher than the mean world value for similar geological regions. The reason for this is closely related to the deep crust structure. According to seismic records and artificial seismic tests, the crust structure here is:

TABLE 1

Stratum	P-Wave Velocity (km/sec)	Density (g/cm^3)
Sedimentary Rock Stratum Crystalline Basement Plane	VP = 4.52	2.64
Sial Stratum Kraton Plane (K-plane)	VP = 5.91	2.72
Sima Stratum Mohorovicic Plane (M-plane)	VP = 6.83	3.0
Upper Earth Mantle	VP = 7.99	3.27

The thickness of the North China Crust is around 30-45 km, the trend being thinner in the east and increasingly thicker to the west. The M-plane of the Tianjin area is 32-33 km, which is thin compared to other parts of north China. It is understandable, therefore, that its heat flow would be relatively high.

FIGURE 5: KRATON BOUNDARY ISOBATH MAP OF BEIJING, TIANJIN AND THEIR VICINITIES

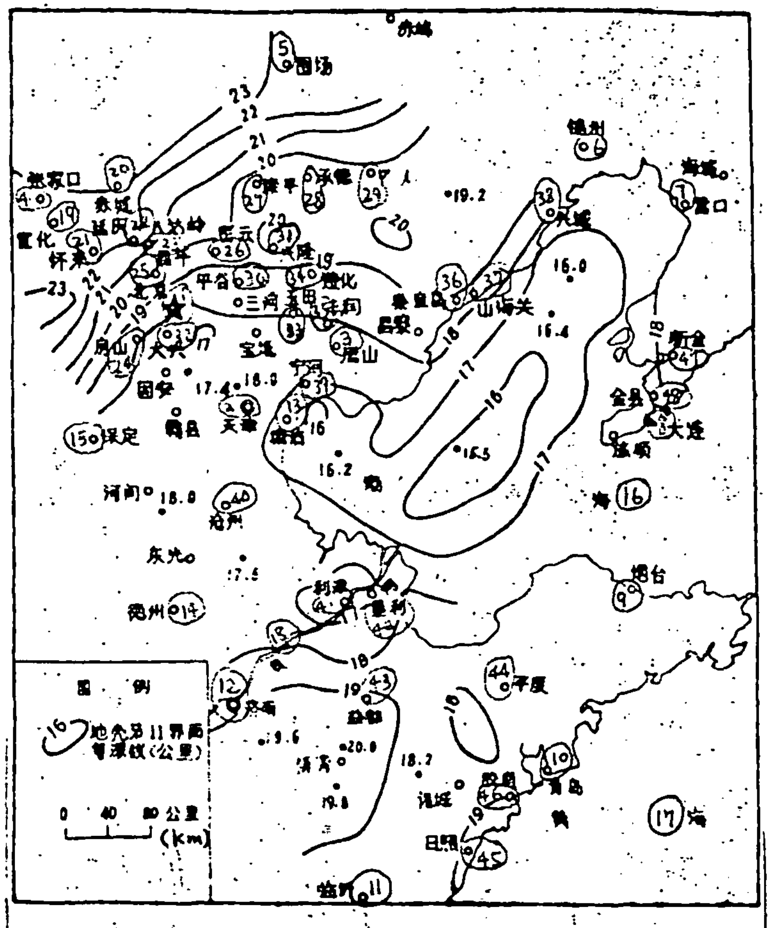


图-6 北京—天津及其邻近地区地壳康氏界面等深线图

LEGEND Crust No. 11 Interface Isobath (km)

FIGURE 6: MOHOROVICIC BOUNDARY ISOBATH MAP OF BEIJING, TIANJIN AND THEIR VICINITIES

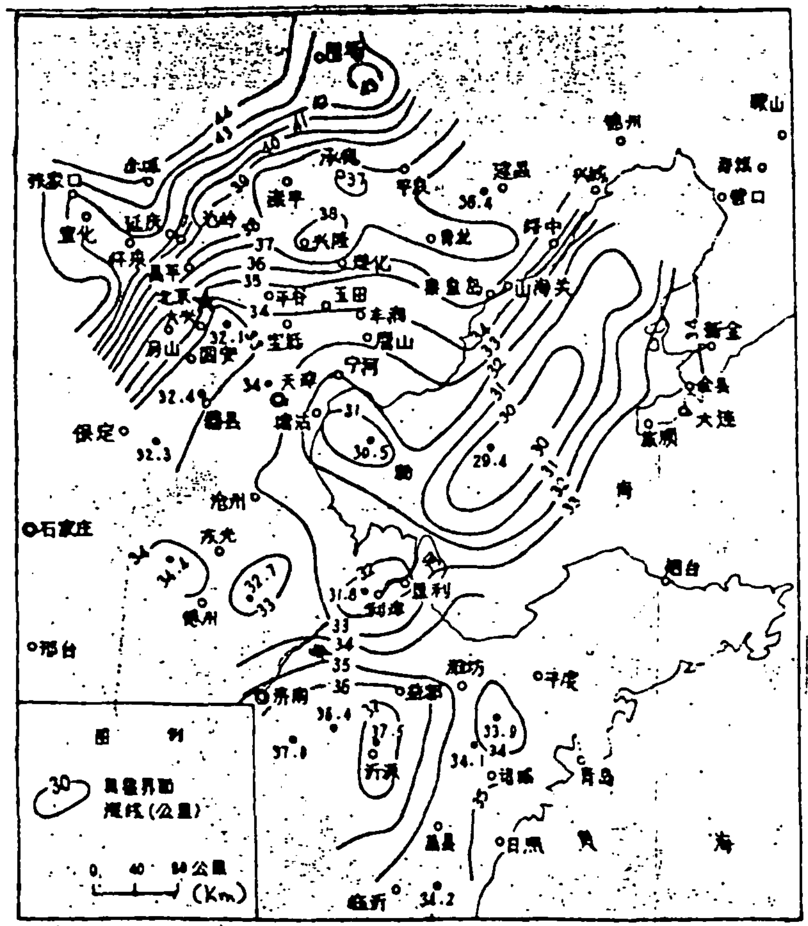


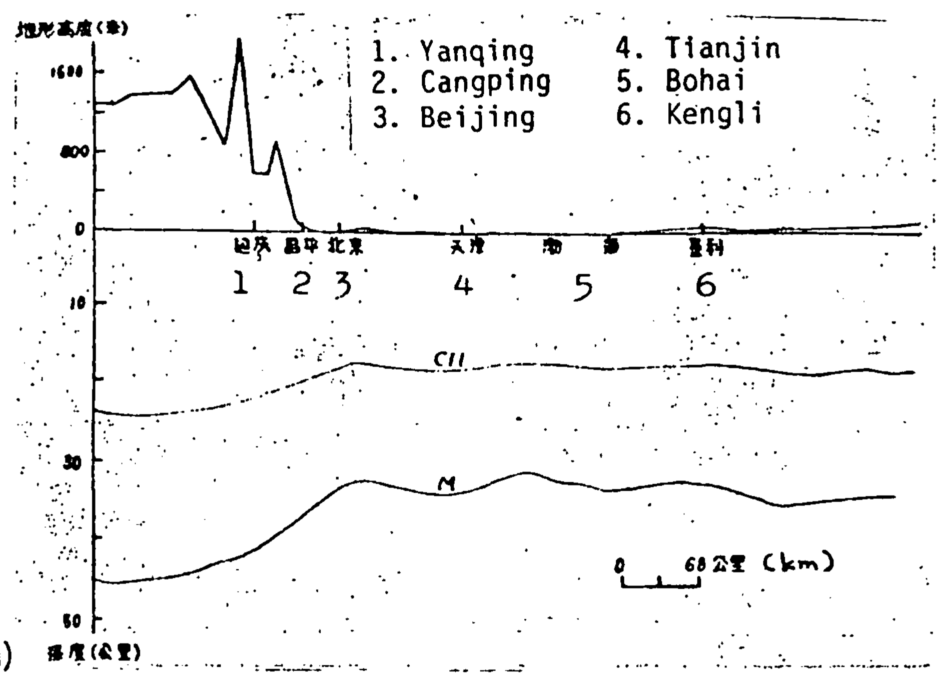
图-7 北京—天津及其邻近地区莫氏界面等深线图

LEGEND Mohorovicic Boundary Isobath (km)

(Same for Both Maps)

1. Beijing
2. Tianjin
3. Tangshan
4. Zhangjiakou
5. Weichang
6. Jinzhou
7. Yingkou
8. Dalian
9. Yantai
10. Qingdao
11. Linyi
12. Jinan
13. Tanggu
14. Dezhou
15. Baoding
16. Bohai Gulf
17. Yellow Sea
18. Yellow River
19. Xuanhua
20. Chicheng
21. Huailai
22. Yanqing
23. Badaling
24. Fangshan
25. Changping
26. Miyun
27. Luanping
28. Chengde
29. Pingchuan
30. Pinggu
31. Xinglong
32. Daxing
33. Yutian
24. Zunhua
35. Fengrun
36. Qinghuangdao
37. Shanhaiguan
38. Xingcheng
39. Ninghe
40. Cangzhou
41. Lijin
42. Kengli
43. Yidu
44. Pingdu
45. Rizhao
46. Jiaonan
47. Xinjin
48. Jinxian

FIGURE 7: CRUST STRUCTURE OF YANQING-BEIJING-TIANJIN-KENGLI



(2) Morphological Types of Basement Structure: The relation between the structural location of Tianjin's three geoheat anomaly regions and geoheat is as follows:

TABLE 2: RELATION OF STRUCTURAL MORPHOLOGY AND GEOHEAT GRADIENT

Geoheat Region		Structural Location	Depth of Basement (m)	Gradient (°C/100 m)
Heat Anomaly Regions	Wanglan-zhuang	Shuangyao Convex Structure	800-1050	4-8.3
	Wanjia-matou	Xiaohanzhuang Convex Structure	960-1100	4-8.3
	Shanlingzi	Xiaodongzhuang & Dadongzhuang Convex Structures	1100-1200	4-8.1
Baitangkou Low Temperature Region		Baitangkou Depression	exceeding 2500	2.0-2.5

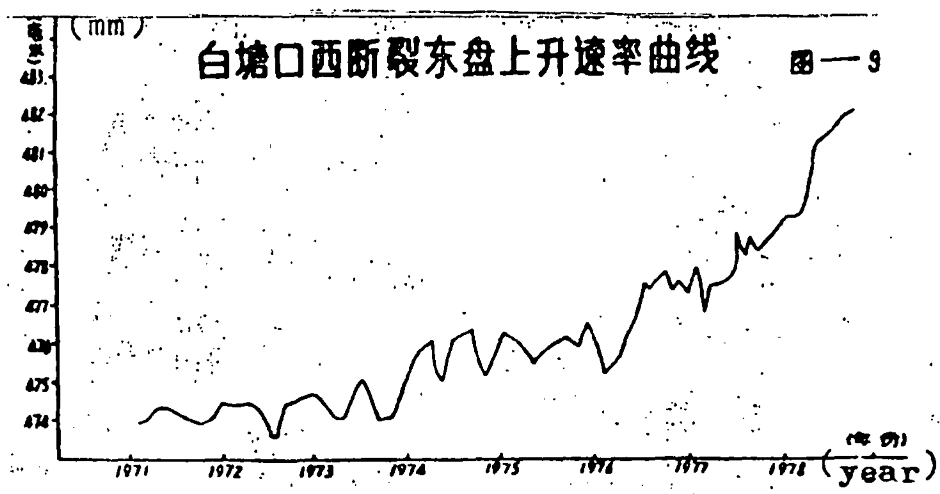
An important characteristic of Tianjin's ground temperature is that its distribution in the Upper Cenozoic Overburden is chiefly controlled by the structure of its basement. That is, the temperature is relatively high in the convex areas of the basement and low in the depressed regions. This is decided by the difference between the heat conductive abilities of the rocks in the overburden and the basement. The Cenozoic deposit is generally composed of loose mud and sand, being very thick with a low heat conductivity (less than 4×10^{-3} cal/cm.sec.degreeC). The Lower

Paleozoic dolomite has a higher heat conductivity (7×10^{-3} cal/cm.sec. degreeC), which is twice that of the former. The thicker the overburden (1000-2000m), the better the heat insulation characteristic and the smaller the ground temperature gradient, making for better heat storage capacity.

(3) Deep, Large Faults: The formation and activity of the three Tianjin Heat Anomaly Regions are controlled by deep, large faults. The Wanglanzhuang Anomaly Region is controlled by the West Baitangkou Fault, the Wanjiamatou Region by the Cangdong Fault Zone, and that in Shanlingzi by the Lingtou Fault. The West Baitangkou Fault, for instance, extends in a north-north-east direction, which is basically parallel to the major axis of the Wanglanzhuang Anomaly Region. The cores are not on the top of the anticline but near one flank of the trunk fault. According to artificial seismic data analyses of that fault zone, the fault points (epicenters) are usually buried at a depth of 700-1100m, but those at the two central positions of the heat anomaly region are noticeably shallower (360-380m), conforming exactly with the heat anomaly cores.

According to observations made by the Zhangdaokou Seismological Station of the deformation movement of the upper and lower walls of the West Baitangkou Fault, the situation was basically stable from 1971 to 1973, but in late 1973 the eastern wall began to rise sharply, from 1 m/m to 2 m/m yearly, reaching at the present time a total difference between the upper and lower walls of 10 m/m and over. This demonstrates the correlation between this fault and geoheat, and that the fault is active. (See Figure 8.)

FIGURE 8: RISE CURVE OF THE EASTERN WALL OF THE WEST BAITANGKOU FAULT



5. Storage Conditions and Distribution of Geothermal Water

There seems to be a certain areal law governing the distribution of geothermal water in the North China Subsidence Zone. According to petrogeological data, the water temperature of the Sinian Subgroup Wumishan and Gaoyuzhuang limestone formations is rather high (70°-96° C), that of the Ordovician and Cambrian System limestone somewhat lower (55°-70° C), and that of the upper overburden much lower (30°-53° C). The ground water temperature in this region has a trend of rising gradually from northwest to southeast. The hot water is replenished by that from the Taihang and Yanshan Mountains, with the characteristic of deep circulation.

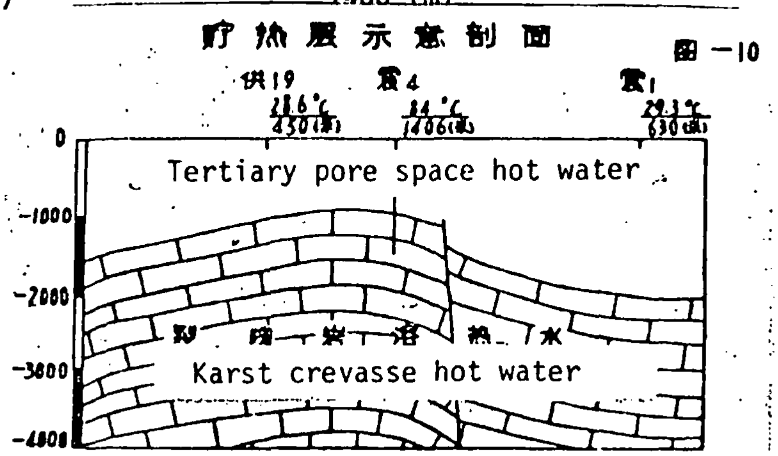
Tianjin's geothermal water is a part of that of the North China Plains Subsidence Zone and is located in the Cangxian Anticline, where geothermal conditions are superior to elsewhere in the zone. According to the characteristics of the geothermal water stratum and the distribution of the geotemperature field, it can be classified into two types:

(1) Tertiary Group Storage Stratum Pore Space Water: Stored in the Cenozoic overburden, the stratum belongs to the Upper Tertiary System's Minghuazhen Formation. Lithologically it is a semi-colloidal fine sandstone, generally buried at a depth of 600-1000m, the depth of the withdrawal section being at 600-850m, and the water temperature 30^{o}-53^{o} C. The flow rate of a single well is 700-1400 tons/24 hr. The water quality is HCO_3-Na or CL-HCO_3-Na type, and the degree of mineralization is less than 1.0 g/1.

(2) Bedrock Storage Stratum Karst Crevasse Hot Water: Distributed in the bedrock below the Cenozoic overburden, with a depth of 1000-1200m. The burial condition being controlled by the basement structure, the depth is relatively shallow in the convex parts of the bedrock, such as at the Zhen 4 Hole at 1032m. That in the depressed parts is relatively deeper, such as in the Baitangkou Depression, where it exceeds 2500m. (See Figure 9.)

FIGURE 9: SCHEMATIC PROFILE OF THE THERMAL WATER STORAGE STRATUM

Gong 19 Hole	Zhen 4 Hole	Zhen 1 Hole
$28.6^{o}C$ / 450 (m)	$84^{o}C$ / 1406 (m)	$29.3^{o}C$ / 630 (m)



The hot water storage stratum as exposed at the Zeng 3, Zhen 4 and Jin 2 Holes (which are now production wells) is mainly Ordovician System limestone and silica-bearing banded dolomitic limestone of the Sinian Subgroup Wumishan and Gaoyuzhuang Formations. The temperature is 55^{o}-$96^{o}C$, and a single well's natural flow rate is 1500 tons/24 hr. (See Table 3.)

TABLE 3 DATA OF BEDROCK HOT WATER WELLS

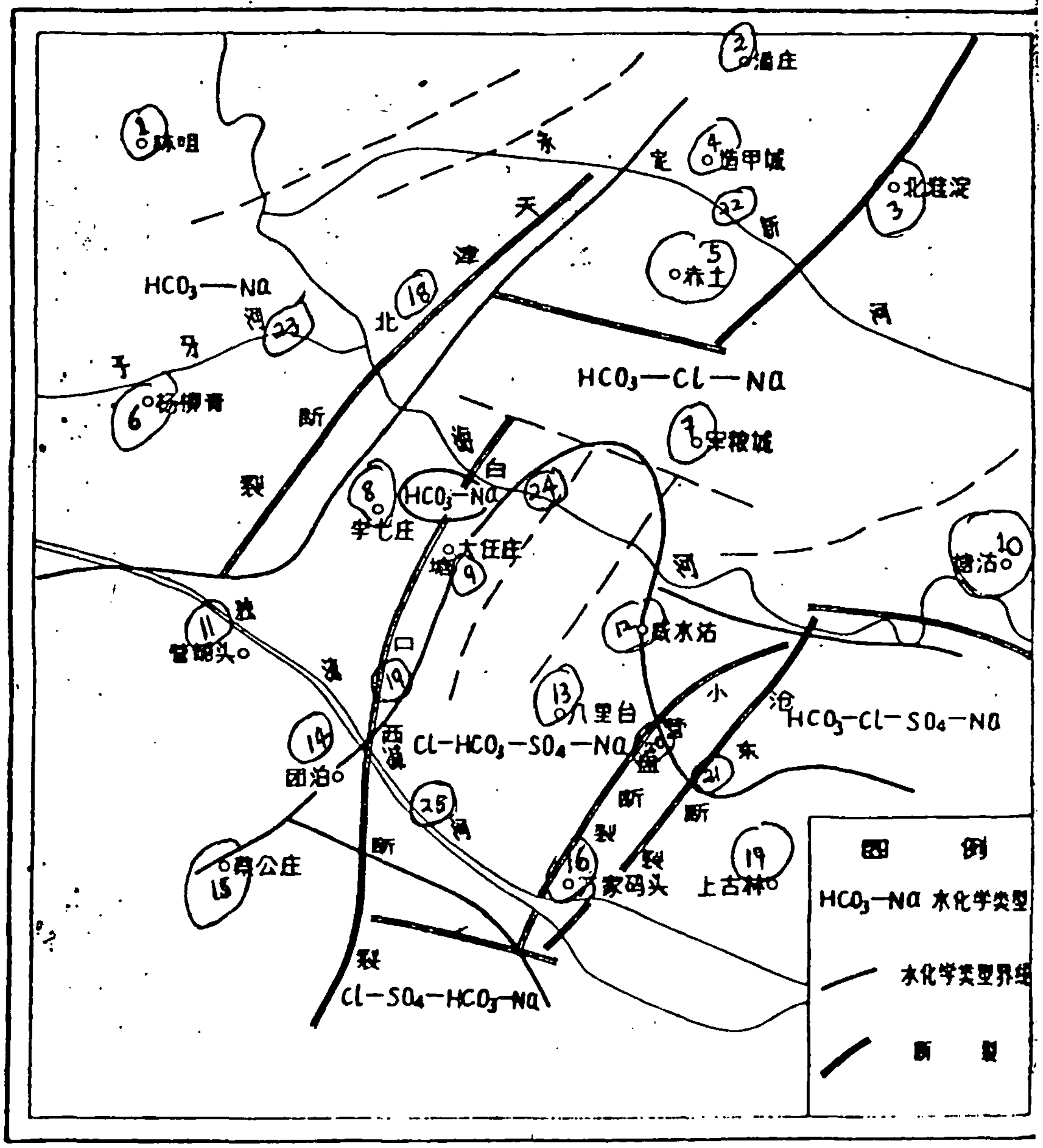
Borehole	Structural Position	Depth of Well (m)	Withdrawal Section (m)	Aquifer (Age)	Temp. (°C)	Gradient °C/100m	Mineralization g/1
Zhen 4	Shuangyao Convex Structure	1405	1150-1400	Zn	84	6.0	1.80
Zeng 3	Xiaohan-zhuang Convex Structure	2377	1400-1600	Zn	96	5.8	1.90
Jin 2	"	1625	1260-1500	Oz	62.5	3.8	1.50

6. Chemical Characteristics of the Hot Water: The chemical composition of the Tertiary System pore space hot water is closely correlated with geological structure and hydrogeological conditions. Of the sodium bicarbonate type, it has a low hardness, high alkalinity, a slightly high F. SiO content, and a 0.4-1.2 g/1 degree of mineralization.

The horizontal zonal division of this water is most evident, having at its northwestern part (with the North Tianjin Fault as boundary) HCO_3-Na type water with a 0.4-0.6 g/1 degree of mineralization, at the central part (between the North Tianjin Fault and West Baitangkou Fault) either HCO_3-Cl-Na or Cl-HCO_3-Na type water and a mineralization degree of 0.6-1.0 g/1, and at the southern part (to the southeast of the West Baitangkou Fault) Cl-SO_4-HCO_3-Na type water with a mineralization degree exceeding 1.0 g/1. (See Figure 10.)

FIGURE 10: HYDROCHEMICAL CLASSIFICATION OF THE HOT WATER

热水水化学类型图 图-11



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LEGEND

- HCO_3-Na Hydrochemical Type
- Boundary Line of Hydrochemical Types
- Faults

1. Chenchui
2. Panzhuang
3. Beiwadian
4. Zhaojiacheng
5. Chitu
6. Yangliuqing
7. Junliangchen
8. Liqizhuang
9. Darenzhuang
10. Tanggu
11. Yingputou
12. Xianshuigu
13. Balitai
14. Tuanbo
15. Caigongzhuang
16. Wanjiamatou
17. Shanggulin
18. North Tianjin Fault
19. West Baitangkou Fault
20. Xiaoyingpan Fault
21. Cangdong Fault
22. Yongdingxin River
23. Ziya River
24. Haihe River
25. Duliujian River

The content of soluble SiO_2 increases with the rise in water temperature, being generally less than 15 mg/1 but increasing in the anomaly regions from 16 mg/1 to 28 mg/1 at the cores. The change of SiO_2 content therefore is evidently a sign of thermal water.

The hydrochemical composition of Paleozoic karst crevasse hot water is slightly more complex. It belongs to the sodium chloride sodium bicarbonate type, the degree of mineralization being less than 2 g/1, hardness at 3-5 German degrees, soluble SiO_2 content around 25-50 mg/1 and a relatively high F content, 6-8 mg/1. (See Table 4.)

TABLE 4

Tianjin Hotel					Zeng 3 Hole				
		Content Per Gallon					Content Per Gallon		
Ion		Mg	Equivalent	Equiv.%	Ion		Mg	Equivalent	Equiv.%
Cat-ions	K+N'a	238.28	10.36	97.64	Cat-ions	K'+N'a	699.43	30.41	92.40
	Ca"	3.41	0.17	1.60		CA"	38.48	1.92	5.83
	Mg"	0.97	0.08	0.76		Mg"	7.05	0.58	1.77
	NH'4	0.14				NH'4	1.04		
	Mn"	0				Mn"			
	Total	242.80	10.61	100		Total	746.00	32.91	100
Anions	Cl	64.17	1.61	17.06	Anions	Cl	656.94	18.53	56.30
	SO"4	15.20	0.32	3.02		SO"4	314.12	6.54	19.87
	HCO'3	436.29	7.15	67.39		HCO'3	449.72	7.37	22.40
	CO"3	39.91	1.33	12.53		CO"3	0		
	NO2	Traces				NO2	Traces		
	F'	4.32				F'	9.00	0.47	1.43
	Br'	0				Br'	1.50		
	HPO4	0				HPO4	0		
	Total	559.89	10.61	100		Total	1431.43	32.91	100
	Grand Total	802.69	21.22			Grand Total	2177.43	65.82	

	German Degree		Mg/1		German Degree		Mg/1
Total Hardness	0.70	Solubility SiO_2	17.75	Total Hardness	7.01	Solubility SiO_2	65.00
Temporary Hardness	0.70	O. Consumption	2.64	Temporary Hardness	7.01	O. Consumption	1.63
Negative Hardness	23.08	Solids	602.30	Negative Hardness	13.66	Solids	2017.57
Total Alkalinity	23.78	pH	8.40	Total Alkalinity	20.67	pH	7.65

(Table 4 continued next page)

TABLE 4 (Continued)

Zhen 4 Hole						Jin 2 Hole					
Ion		Content Per Gallon				Ion		Content Per Gallon			
		Mg	Equivalent	Equiv.%				Mg	Equivalent	Equiv.%	
Cations	K'+N'a	750.26	32.62			Cations	K'+N'a	567.41	24.67	94.02	
	CA"	42.89	2.14				Ca"	26.05	1.30	4.95	
	Mg"	10.94	0.90				Mg"	3.28	0.27	1.03	
	NH'4	0.18					NH'4	0.24			
	Mn"	0					Mn"	0			
	Total	804.27	35.66				Total	596.98	26.24	100	
Anions	Cl	519.39	14.65			Anions	Cl	426.85	12.04	45.88	
	SO"4	711.32	14.81				SO"4	238.71	4.97	18.94	
	HCO'3	378.32	6.20				HCO'3	563.21	9.23	35.18	
	CO"3	0					CO"3	0			
	NQ2	0					NQ2	0			
	F'	10.40					F'	10.40			
	Br'	0.25					Br'	1.00			
	HPO4	0.01					HPO4	0			
	Total	1619.69	35.66				Total	1240.17	26.40	100	
Grand Total		2423.96	71.32			Grand Total		1837.15	52.48		
		German Degree		Mg/1				German Degree		Mg/1	
Total Hardness		8.52	Sol.SiO2	28.00		Total Hardness		4.40	Sol.SiO2	29.25	
Temporary Hardness		8.52	O.Cons.	4.62		Temporary Hardness		4.40	O.Cons.	3.79	
Negative Hardness		8.86	Solids	2262.80		Negative Hardness		21.48	Solids	1584.80	
Total Alkalinity		17.38	pH	7.39		Total Alkalinity		25.88	pH	7.60	

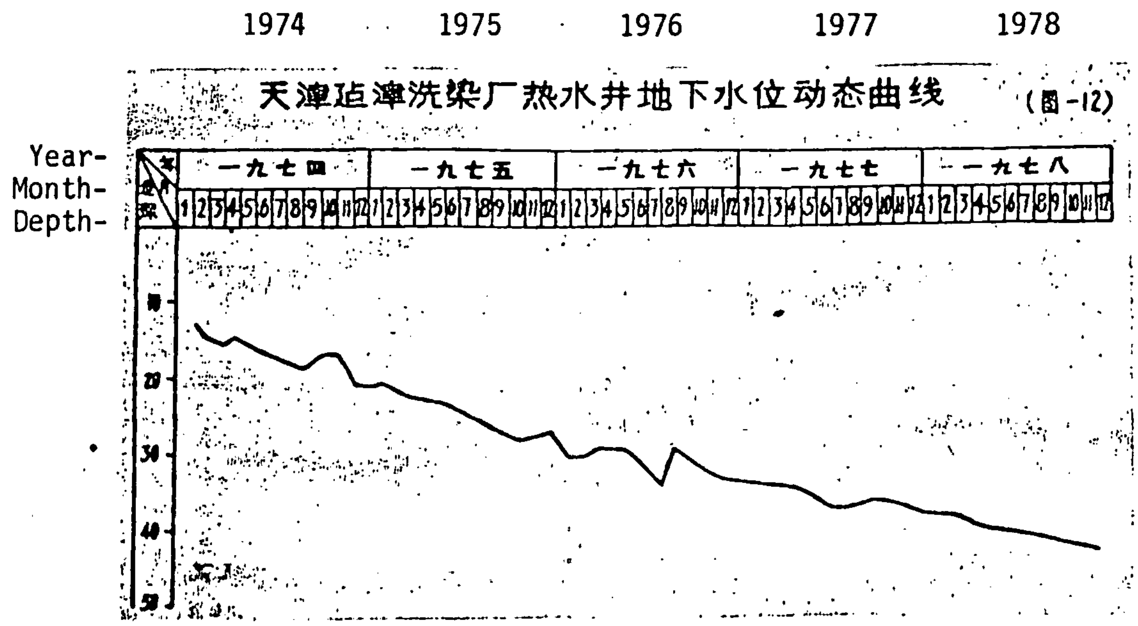
Tianjin Woolen Mill

Ion		Content Per Gallon		
		Mg	Equivalent	Equiv.%
Cations	K'+N'a	331.89	14.43	97.17
	CA"	6.01	0.30	2.02
	Mg"	1.46	0.12	0.81
	NH'4	0.02		
	Mn"	0		
	Total	339.38	14.85	100
Anions	Cl	158.47	4.47	30.10
	SO"4	107.59	2.24	15.09
	HCO'3	444.84	7.29	49.09
	CO"3	25.51	0.85	5.72
	NQ2	0		
	F'	4.76		
	Br'	0		
	HPO4	0.07		
	Total	741.24	14.85	100
Grand Total		1080.62	29.70	
		German Degree		Mg/1
Total Hardness		1.18	Sol.SiO2	16.75
Temporary Hardness		1.18	O.Cons.	2.63
Negative Hardness		21.64	Solids	874.95
Total Alkalinity		22.82	pH	8.30

7. Dynamic Law of the Geothermal Water Regions

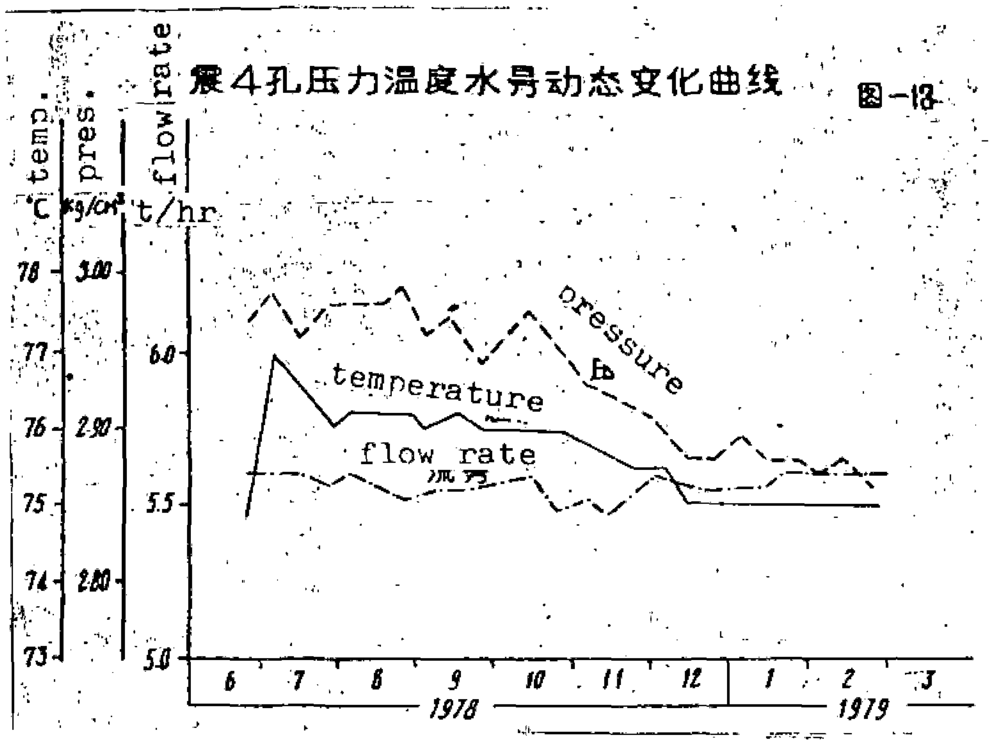
Withdrawal of the underground hot water having increased yearly due to city construction and production, the water stage fluctuated correspondingly. Prior to 1972, all Tertiary pore space water in the area was natural flow, but this stopped in the first half of 1972 to 1973. To date, in the urban areas, the water stage at a depth of 600-800m has dropped to 40-50m below ground surface and that in the suburban areas 30-40m below surface. The thermal water well at the Tianjin Jianjin Cleaning and Dyeing Works built in 1934 (depth of well 863m) had had a natural flow for nearly 40 years, which stopped in 1972. The stage elevation is now -49.34m, dropping at a rate of 5-6m a year. (See Figure 11.)

FIGURE 11: STAGE FLUCTUATION CURVE OF HOT WATER WELL AT JIANJIN CLEANING AND DYEING WORKS



Due to the fact that Paleozoic karst crevasse thermal water has not been developed on any scale, that in the urban areas is still natural flow. When the well was sunk at the Zhen 4 Hole in 1975, the water head was fairly high, being 40m above ground, and the natural flow rate exceeded 200 tons/24 hr, with the temperature being 84^{o}C at the well head. Since systematic observations were made in 1978, the flow rate has been controlled at 5.5 tons/hr. The hydrodynamic pressure dropped from 2.97 kg/cm^2 to 2.86 kg/cm^2, showing the water head to be dropping.

FIGURE 12: ZHEN 4 HOLE PRESSURE TEMPERATURE FLOW RATE FLUCTUATION CURVE



8. <u>Utilization of Thermal Water</u>

The Tertiary pore space hot water now being utilized for the city's livelihood and production is playing an increasingly larger role in conserving coal, petrol and other energy sources and reducing environmental pollution. Its low hardness (that of the Tertiary System is less than 1.0 German degree) makes it useful in industrial boilers, saving both fuel and the industrial salts needed to soften the water. Its high alkalinity (20-25 mg/l) can be used to add whiteness, luster and color fastness to the fabrics dyed. The Tianjin Woolen Mill, for example, utilized 49°C geothermal water to save yearly 2,400 tons of coal and 15,000 kw/hr of electricity. The improved products are now extensively exported. Geothermal water is also being used in papermaking, timber processing, chemical technologies, food processing, and the machine building and cement industries. Many farms are using this water in vegetable nurseries. The Zhangdaokou Production Brigade in the western suburbs, for instance, utilized the limited amount of geothermal water generated through seismic observations to build a small greenhouse which yields three crops of vegetables yearly, and a larger nursery bed, netting for the brigade over 10,000 yuan a year.

The Tianjin Hotel is using 42°C hot water to supply more than 1,000 baths in the summer and in winter after some heating, to warm the entire hotel. This enables them to save 3,000 tons of coal yearly.

The geothermal water in this area has also been put to therapeutic use, relieving skin diseases and arthritic pains.

III. CONCEPT OF THE EXPLORATION AND DEVELOPMENT OF GEOTHERMAL WATER IN THE TIANJIN AREA

To sum up, the research done up to date on geoheat in the Tianjin area has enabled us to learn something of its storage conditions and to define three anomalies. Tertiary hot water has already been developed to a fairly large extent but overall development will have to come after the following problems are resolved, namely, first the evaluation of geothermal water resources, and secondly, the conditions for their utilization. The first also includes sources for artificial recharge. We need to further investigate:

1. The law governing the distribution and burial conditions of the heat storage stratum. In the urban areas, boreholes control the Tertiary storage stratum, but no engineering control has yet been set up outside of the urban areas. In regard to the Paleozoic and Sinian Subgroup strata distribution, we now possess some knowledge, but mostly deductions, and will need confirmation through physical exploration and borehole control.

2. The heat storage and hydrogeological characteristics of the storage stratum.

3. Technical conditions and artificial sources for recharge.

4. The relation of geological structure and magmatic water movement with the formation of thermal water.

5. Formative conditions for the geoheat resources and geothermal water.

6. Problems related to the utilization of these resources, such as water corrosiveness and precipitation, etc.

We plan to complete the exploration in two stages:

First Stage, 1979-1982: To complete exploration over an area of 200km^2 including the city proper and its vicinity. During that stage to obtain a detailed evaluation of the Tertiary System storage stratum and preliminary investigations and evaluation of those in the Paleozoic and Sinian Subgroup.

Second Stage, 1983-1985: To explore areas outside of the city proper, covering 500km^2, to make an overall evaluation of the Tertiary as well as Paleozoic and Sinian Subgroup resources.

After the above, to put forth a plan for overall development. The city has already organized a force of specialists to do this work, but needs to solve problems of investment, equipment and technology.

Maps and Charts Attached:

(1) GEOLOGICAL STRUCTURE AND DEPTH OF BURIAL OF BEDROCK ROOF IN THE VICINITY OF TIANJIN

(2) HYDROGEOLOGICAL PROFILE OF THE VICINITY OF TIANJIN

(3) COLUMNAR PROFILE OF THE PALEOZOIC GROUP STRATUM IN THE NORTH CHINA BASIN

CHART 1 - GEOLOGICAL STRUCTURE AND DEPTH OF BURIAL OF BEDROCK ROOF IN THE VICINITY OF TIANJIN

Note: Chart 1 has been delayed at the printer's and will be available early in January, 1981. It will be sent to you at that time.

CHART 2 - HYDROGEOLOGICAL PROFILE OF THE VICINITY OF TIANJIN

Note: Chart 2 has been delayed at the printer's and will be available early in January, 1981. It will be sent to you at that time.

Proceedings of the New Zealand Geothermal Workshop 1980

PREDEVELOPMENT STUDY OF YANGBAJAIN GEOTHERMAL FIELD IN XIZANG (TIBET)

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ABSTRACT

Yangbajain geothermal field in Xizang (Tibet) is a wet-steam field with a natural heat flow of 485 MW and subsurface temperature of 200-270° C.

Based on geological, geochemical and geophysical data, the gross hydrological model of thermal system beneath Yangbajain is discussed. The sodium bicarbonate·chloride water in shallow reservoir is a mixed water which is formed by mixing of deep sodium chloride water with melt water from elevated catchment zones. Sulfur Mine has undergone extensive hydrothermal alteration beneath which a high temperature heat source might exist, and which is an important area for hot water and steam production.

Yangbajain geothermal field (30°.09N/90°.5E) is situated 90 km northwest of Lhasa with elevation of 4260-4684 m. Authors undertook a geological and geochemical survey of this field during 1975-1976 and the results of prior surveys indicated that it is a wet-steam field suitable for exploiting with a natural heat flow of 485 MW and subsurface temperatures of 200-270° C.

GEOLOGICAL SETTING

Yangbajain field is a major one in the Himalayan Geothermal Belt and is situated in a Quaternary rift basin of the foot of Mt. Nyainqentaglha consisting of Precambrian gneiss with a last metamorphism age of 21 m.y. Along the foot of this mountain, there is the Nyaingentaglha Fault with the strike of NE40°, along which many geothermal areas are manifested (Fig.1). In the early stage of developing, it was a sinistral transverse fault, as the gneiss of northwest hanging wall is a anticline with about E-W strike and strata of Carboniferous-Eocene sediments and volcanic rocks in the southeast hanging wall appear to be large drag sliding owing to its slide along the fault. In fact, the fault consists of a set of sliding planes, but relative vertical movements along which since Pleistocene have caused a rift where the moraines of 3 glacial ages including middle and upper Pleistocene and Holocene were deposited.

Nyainqentanglha Fault is intersected by a normal fault with N-S strike at Yangbajain which is an important condition for development of this field. There are some minor faults with NW strike.

Presently there are no active volcanoes nearby and the youngest granite is about 37 and 60 m.y. old at southwest and east of the field, respectively.

SURFACE MANIFESTATION AND NATURAL HEAT FLOW

17 surface manifestation areas occur in the field (Fig.2). MA.1 is a famous hot lake with an area of 7350 m^2 and with maximum depth of 16.1 m. Its surface temperatures are about 45-57°C changing with season and the temperature below remains almost constant because of convection; outflow rate is about 33.25 l/s. It is possible that the lake was formed by ancient hydrothermal explosions.

MA. 11 is a Sulfur Mine located in the northwest corner of this field that in fact is a strongly altered area at an altitude of 4400-4700 m. There are no springs over there, steam with high temperature has altered the moraines into the kaolin and alunite, and strong silicification has taken place. There are many solfataras with significant sulfur deposition which was mined for producing sulfuric acid. In some places, the surface temperature is about 20°C, whereas the bottom temperature of some shallow holes at 0.8m depth is about 85.2°C.

Other areas contain vigorous hot spring and fumarole manifestations with sinter or less travertine which are located south of Sulfur Mine along the Zangbo Qu River at altitude of 4270 m. In the dry season, white salts encrustations appear throughout the field, its mineral assemblage includes common salt, alunogen, kernite and hungtsaoite. Both artificial hydrothermal eruption and geysering wells were triggered by drilling in this area since 1975.

The total natural heat loss of this field has been assessed in 1975-1976. The results of various heat surveys [1] over different types in the field are listed in Table A on page 2.

FLUID GEOCHEMISTRY

The geochemical composition of 40 hot springs and some wells were sampled for detailed chemical analysis. The modified trilinear plot of water collected for detailed analysis is shown in Fig.3.

The chemical types of most hot waters discharging from Yangbajain field are a near neutral pH(6-8), sodium chloride-bicarbonate water rich in boron which contains varying amount of chloride (500 ppm) and bicarbonate (400 ppm) as the major anions, and sodium (310 ppm) as the major cation.

The high chloride content indicates that they are associated with a hot-water system. These waters are formed by dilution of high temperature sodium chloride water with cold ground water. When dilution is further enhanced by meteoric water, the sodium chloride bicarbonate waters change into sodium bicarbonate-chloride type, which always occur above, or at the perimeter of the reservoir. But when some springs or pools have a sluggish flow, an acidic sodium sulfate chloride water forms by the oxidation of H_2S.

The sodium chloride-bicarbonate water discharging from Yangbajain field is characterized by fluorine (18 ppm), lithium (6-18 ppm) and arsenic (3 ppm).

Ratios of Cl/B are almost constant (2.5-3.7) for most of the hot springs due to discharge from the same aquifer. Springs along the Zangbo Qu River have higher Cl/B ratios.

If the thermal waters issue from the same aquifer, then the difference in chloride concentration are a function of the extent of mixing. Calculations based on the mixing model of Fournier et al. [2] and assuming a mean annual temperature of fresh water of 2.5°C with possible silica concentration about 10 ppm, indicate that the cold-water portion is between 0.6-0.7 and that reservoir temperature is about 228°C for the hot springs in the field, which is greater than the temperature of 127-188°C estimated from the silica concentration (79-275 ppm) of the hot springs.

The Na/K molar ratios are rather constant, about 13-18, found in most springs and which may represent the equilibrium value for water in contact with the country rocks at temperature of between 190-220°C. The same results were obtained by using Na-K-Ca geothermometers.

Gas escaping from hot springs is CO_2, H_2S, O_2, N_2 and minimal methane, argon, helium, and hydrogen. From centre to perimeter of field, CO_2 content of gas escaping from hot springs tends to decrease, but N_2 content shows the opposite trend.

Isotopic data for deuterium and oxygen 18 (Fig.4) are given in the SMOW, parts per mil (o/oo). Hot springs in the field range from -15.5 to 20.5 in $\delta^{18}O$ and from -142 to -150 in δD. The six surface waters range from -112 to -122 in δD and from -15.5 to -17 in $\delta^{18}O$. It seems that the waters recharging hot springs are not the surface water nearby Yangbajain Basin, but might be melt waters with lower value of δD and $\delta^{18}O$ coming from far away.

Based on the linear relation between $\delta^{18}O$ and Cl of the hot waters, the waters are predominantly meteoric in origin but contain a small amount of NaCl rich deep fluid with a high heavy isotopic ratio. [3].

The samples for sulfur isotopic analysis of this field are mainly from natural sulfur and the nardite, tschermigite, alunogen, epsomite, red orpiment and metallic sulfides. The results indicate that the $\delta^{34}S$ of these samples are considerably close to the $\delta^{34}S$ of CDT. Therefore an abyssal heat recharge for the high temperature hydrothermal system might exist. It is probable that the magma pocket originates from intracrustal partial melting.

It is also obvious that recent mineralization such as blende, mercury, haematite and stibnite occurs in the field.

HYDROLOGICAL MODEL

Investigation of surface manifestation, heat flow measurements, and a combination of other geophysical works made by Geological Bureau of Xizang including vertical electrical sounding, gravity and magnetic surveys have been used to outline the system. Unfortunately, these geophysical surveys are not sufficient to outline the northwest boundary of this field as the relief is too rugged.

The results for each probing depth along northwest direction have been superimposed on a section to give a two-dimensional model of the southeast part of this reservoir (Fig.5), which have been partly verified by drilling except at Sulfur Mine. The gravity, magnetic and self-potential data have been added in this figure.

In the south of the field, the cap-formation is made up by the fine glacial varve layer of about 40 meters, below which there is the shallow reservoir consisting of relatively lossened pebbles with a low resistivity layer in the pseudo vertical section plotted using the data of soundings. The shallow reservoir is absent in the north of this field. Self potentials less than -130 mV have been recorded indicating a minor local path for the recharge of hot water.

Based on the drilling data, a silicified layer has been deposited as mixing of the ascending sodium chloride water with the downward moving melt water has taken place. The silicified layer with thickness of about 250 m is present below 140 m in hole of N.13 (altitude of W.H. 4333.7m); towards the south, it thins out as indicated by a thickness of 100 m below 70 m in hole N.2 (altitude of W.H.

TABLE A. HEAT LOSS OF YANGBAJAIN GEOTHERMAL FIELD

Discharge type	Heat loss by	heat loss (MW)	%
Steaming ground	Convection, evaporation	177	36.5
Warm ground	Conduction	27	5.6
Hot springs, lake	Direct discharge and evaporation	230	47.5
Seepages	Direct discharge	51	10.5
Total		485	100.0

[illegible]4.7m) near Zangbo Qu River.

The maximum temperature in N.13 is 172°C at 160 m and the maximum temperature in N.6 (nearby N.2) is 161.4°C at 70 m. Therefore, the maximum temperature within these wells occurs within the silicified layer.

The dryness falls from 15 to 10.9 in the same section.

The analysis of the hot water discharging from N.13, shows a chloride concentrations of [illegible] ppm, accompanied by bicarbonate and sulfate concentrations of about 434 and 114 ppm, respectively.

The distinct decrease of both gravity and magnetic values might indicate intense alteration and presence of a deeply buried igneous intrusion, and the local gravity and magnetic high in the profile might indicate a basalt body below [illegible] m, which is not the heat source of Yangbajain field.

Based on these data, a possible hydrological model of the Yangbajain system can be made up (Fig. 6). The hot water from the deep sodium chloride water reservoir flows up into a near-surface aquifer along the Sulfur Mine Fault which is parallel to Nyainqentanglha Fault. Melt waters flowing into the system from elevated catchment zones in Mt. Nyainqentanglha move southwards and downwards into the system and towards the local cold water sink which is represented by Zangbo Qu River. The descending cold meteoric water diverts the ascending chloride water, which changes into horizontal flow, and a variable mixed water occurs to the south of Sulfur Mine. As mixing of the hot water with melt water occurs, silica is deposited in the zone of mixing.

Sulfur Mine has undergone extensive hydrothermal alteration, beneath which high heat flow presumably remains. The hydrological model suggests that wells for the production of hot water should be as near to the source as possible.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the enthusiasm and help given by Mr. Tong Wei, Mr. Zhang Zhifei, Mrs. Zhu Meixiang, Mrs. Shen Minzhi, and Mrs. Zheng Shuhui.

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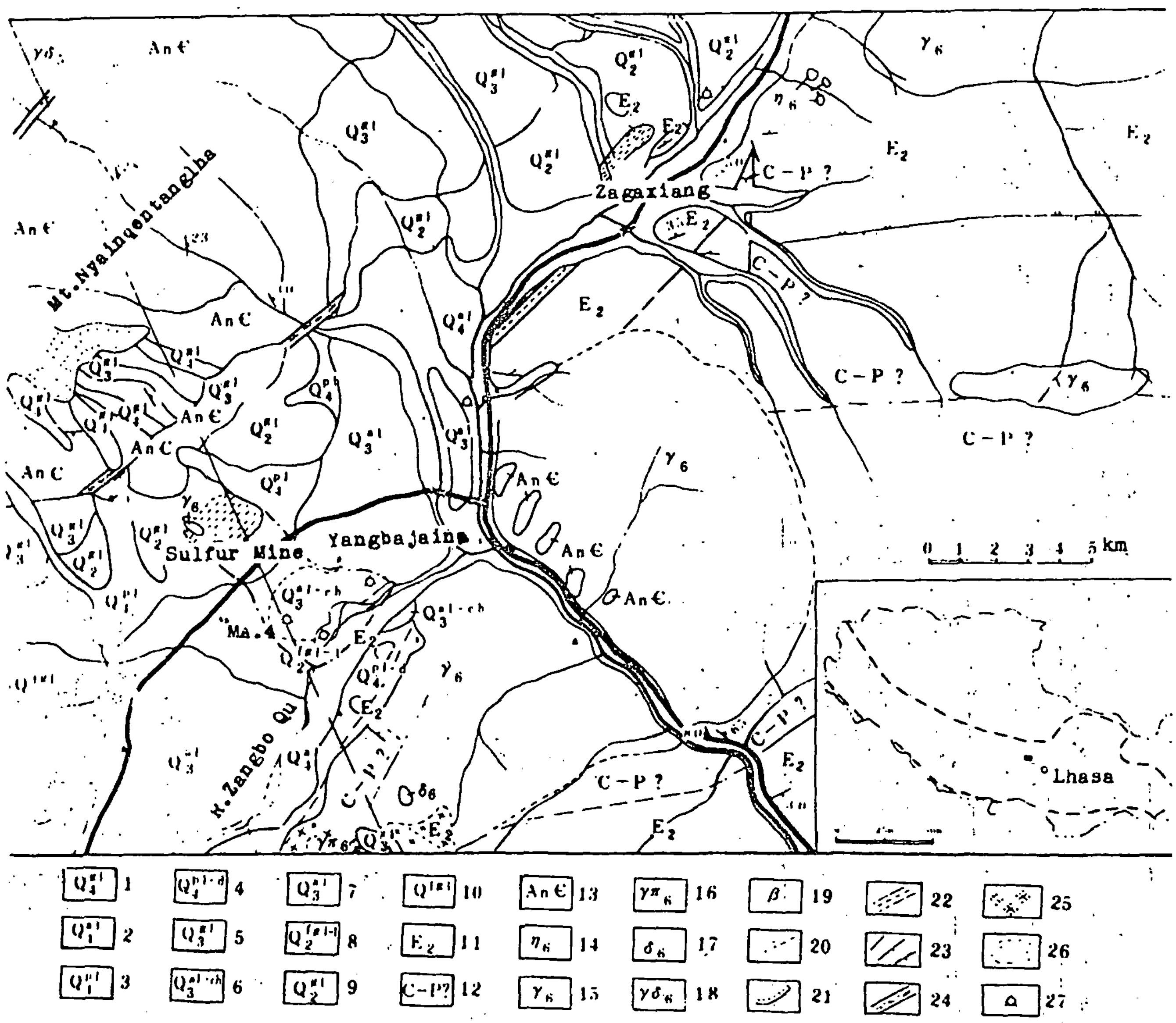
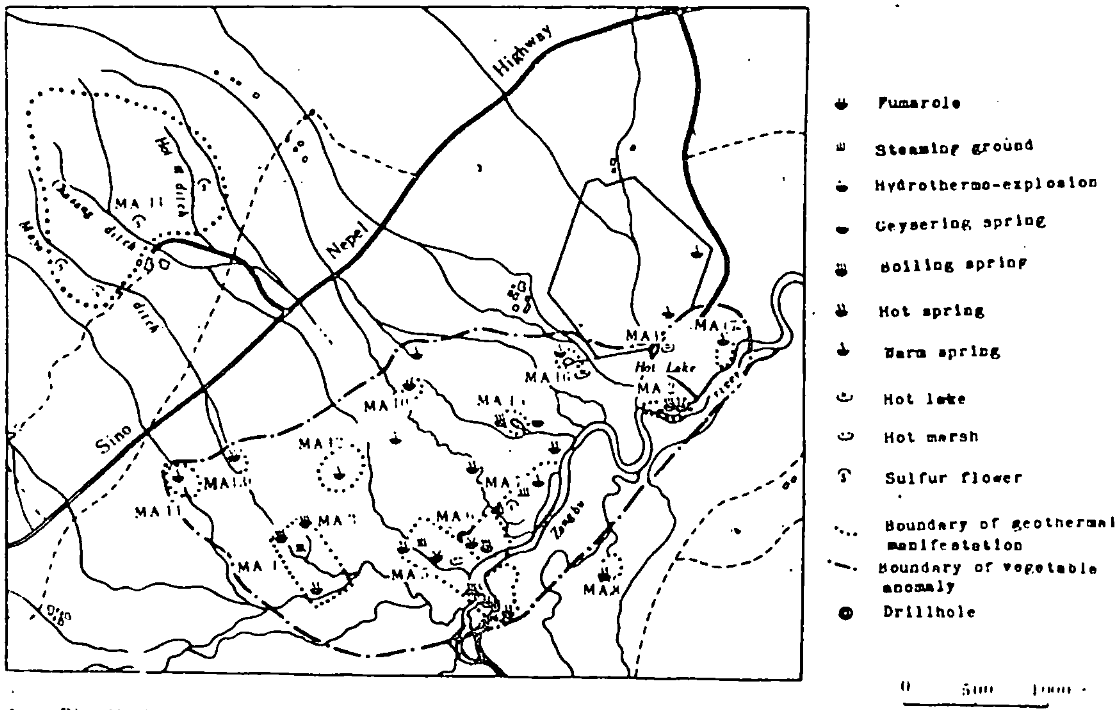


Fig 1: THE GEOLOGIC MAP OF YANGBAJAIN GEOTHERMAL FIELD

1. Holocene moraine bed; 2. Holocene alluvial bed and swamp deposits; 3. Holocene pluvial bed; 4. Holocene fluvial and talus accumulation; 5. Late Pleistocene moraine bed; 6. Late Pleistocene alluvial bed and sinter; 7. Late Pleistocene alluvial bed; 8. Middle Pleistocene fluvioglacial deposits and lacustrine deposits; 9. Middle Pleistocene moraine bed; 10. Pleistocene fluvioglacial deposits; 11. Eocene volcanic tuff, dacite, trachyte, volcanic breccia; 12. Cabroniferous-Permian slate, quartz-schist, marble; 13. Pre-Cambrian biotite gneiss, migmatite; 14. alkali-intrusive rock of Himalayan period; 15. granite of Himalayan; 16. granite porphyry of Himalayan; 17. diorite of Himalayan; 18. granitic diorite of Yenshanian Period; 19. basic hypabyssal rock of Late Himalayan Period; 20. geologic boundary (surveyed and deduced); 21. angular unconformity; 22. fault fractured zone; 23. fault, normal fault, thrust; 24. mylonitization zone; 25. contact metamorphic zone; 26. hydrothermal alteration zone; 27. geothermal manifestation spots.



2. Distribution of geothermal manifestation at Yangbajing geothermal field

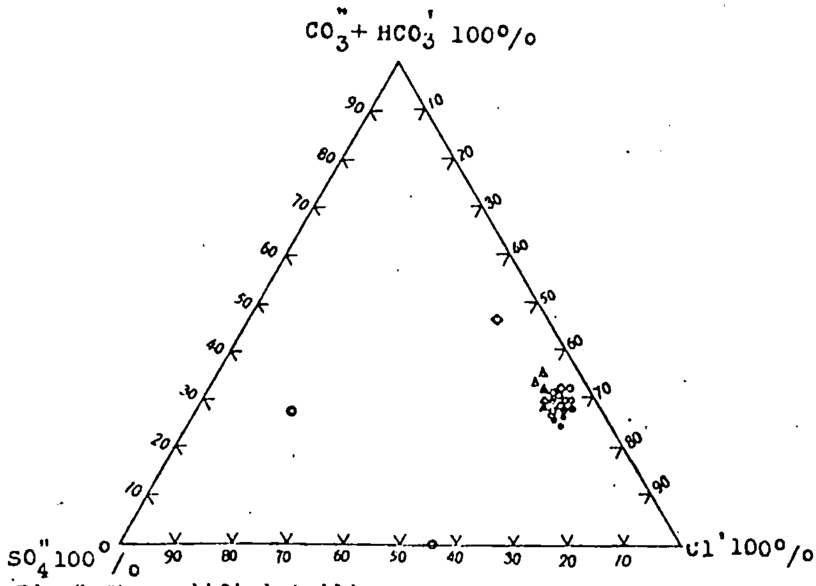


Fig.3 The modified trilinear plot of water discharging from Yangbajain field (MA: Geothermal manifestation areas)
▲ MA.1,2, ○ MA.3,4, • MA.5,6,7,9, ◇ MA.8, △ MA.12,13,

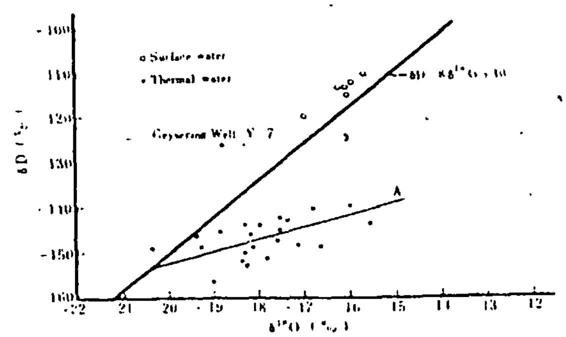


Fig.4 δD vs $\delta^{18}O$ plot of thermal waters in Yangbajain geothermal field

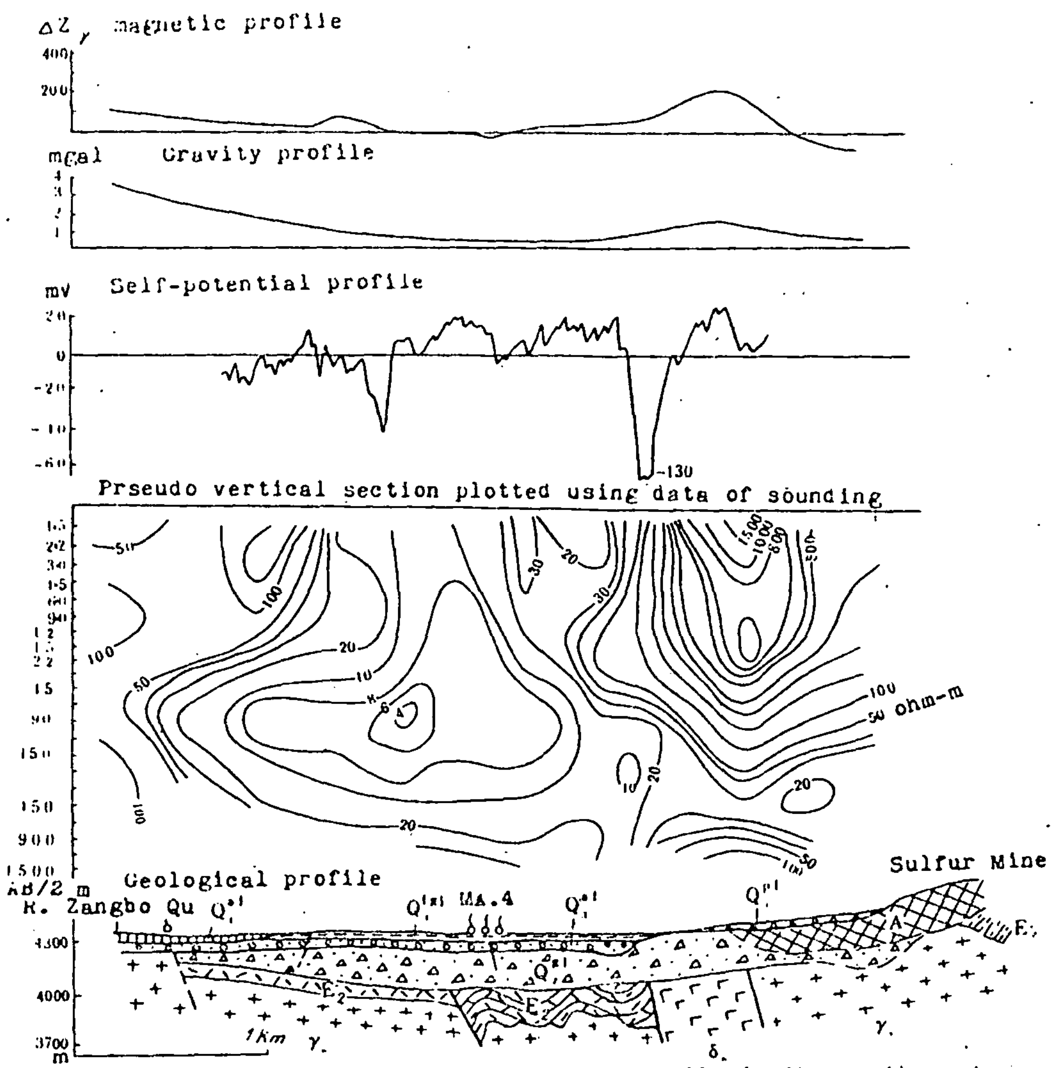


Fig.5 The geological and geophysical profile in the south part of Yangbajain field

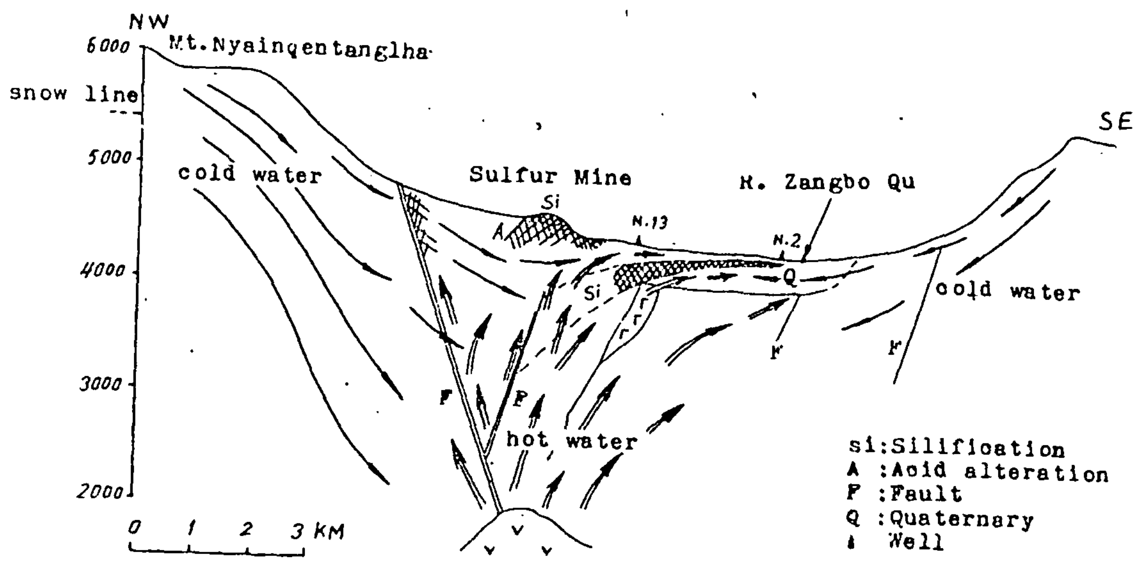


Fig.6 Hydrological model of Yangbajain field

PROSPECTING AND UTILIZATION OF THE GEOTHERMAL RESOURCES OF TIANJIN

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MAR. 1981

Contents

Prospecting and Utilization of the

Geothermal Resources of Tianjin

Located in the north-east of North-China Plain, near the Bohai Gulf to its east, about 150 kilometers from the Taihang Mountain to its west, 120 kilometers from the Yan Mountain to its north, and 120 kilometers from Beijing to its north-west, Tianjin, with a population of about seven million, is one of the three main municipalities directly under the Central Government and, also, an important industrial base as well as a main harbour of our country (Fig. 1).

天津地理位置图 附图-1

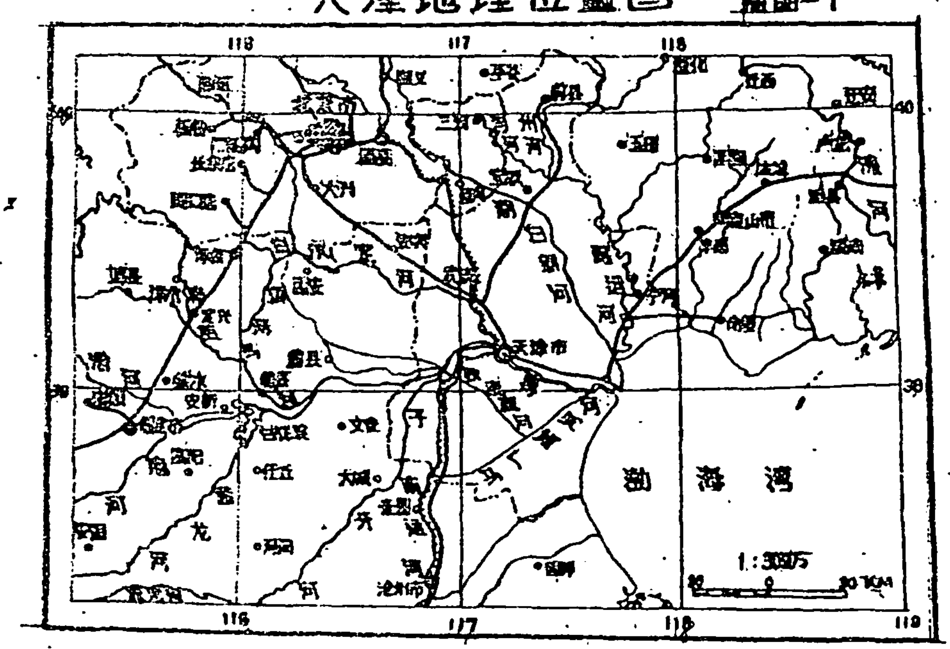


Fig. 1 Geographical Position of Tianjin

The prospecting of the geothermal resources of Tianjin was undertaken in the beginning of the seventies with the main effort put on the prospecting and development of the shallow tertiary void thermal water (30-50°C) which has been being extracted for use on large scale, while the reconnaissance for the deep bedrock, fracture and karst water resources (above 60°C) was initiated by the end of the seventies. For carrying out the investigation work regarding the hydrogeology for Tianjin urban water supply, petroleum geology, seismic geology and geothermal resources, regional prospecting, to a certain extent, has since ten years been conducted by using the aviation geophysical (1:200,000), gravitational, magnetic (1:50,000 & 1:100,000), seismic geophysical methods as well as the airborne infrared remote sensing technique (1:10,000 & 1:30,000). In the meantime, efforts have also been devoted to the geological reconnaissance of the geothermal resources as well as to the prospecting tests for the corresponding hydrogeology, petroleum geology, seismic geology and geothermal geology. As a result of these works, the superior geological condition of the Tianjin geothermal resource is ascertained and the fact that Tianjin is abundant in geothermal water resource is brought to light to a certain extent. This clearly shows the good and broad prospects for the utilization of the geothermal resources of Tianjin.

I. Geological and tectonic features of the Tianjin geothermal area

1. Tectonic features

The Tianjin area is situated at the northern end of the Cangxian upwarp which is of proximate grade tectonics in the subsidence zone of North-China Plain belonging to the Neocathaysian structural system, with its south-east side and north-west side adjacent respectively to Huang Hua and Ji Zhong downwarps (Fig.2).

区域性地质构造图 图-2

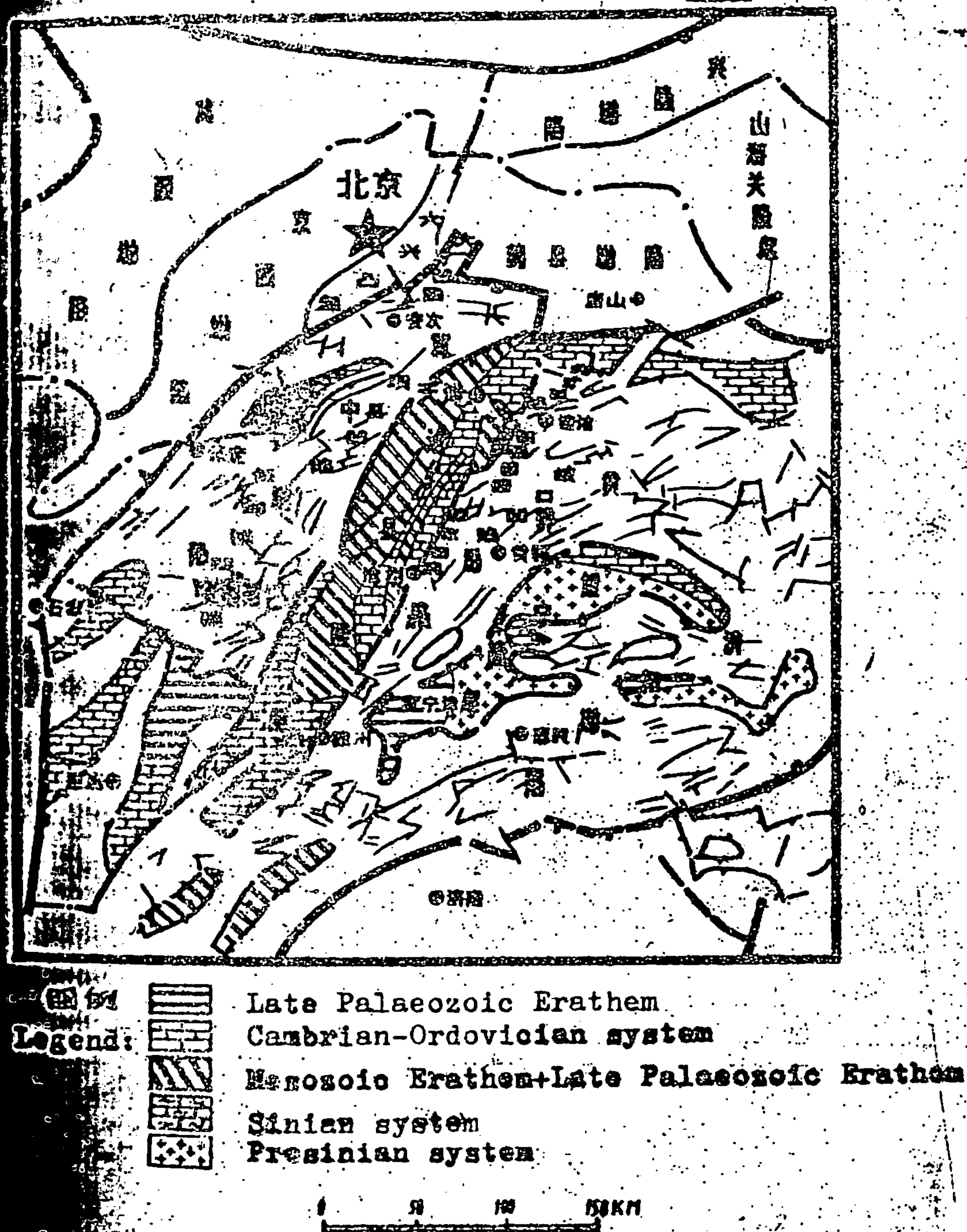


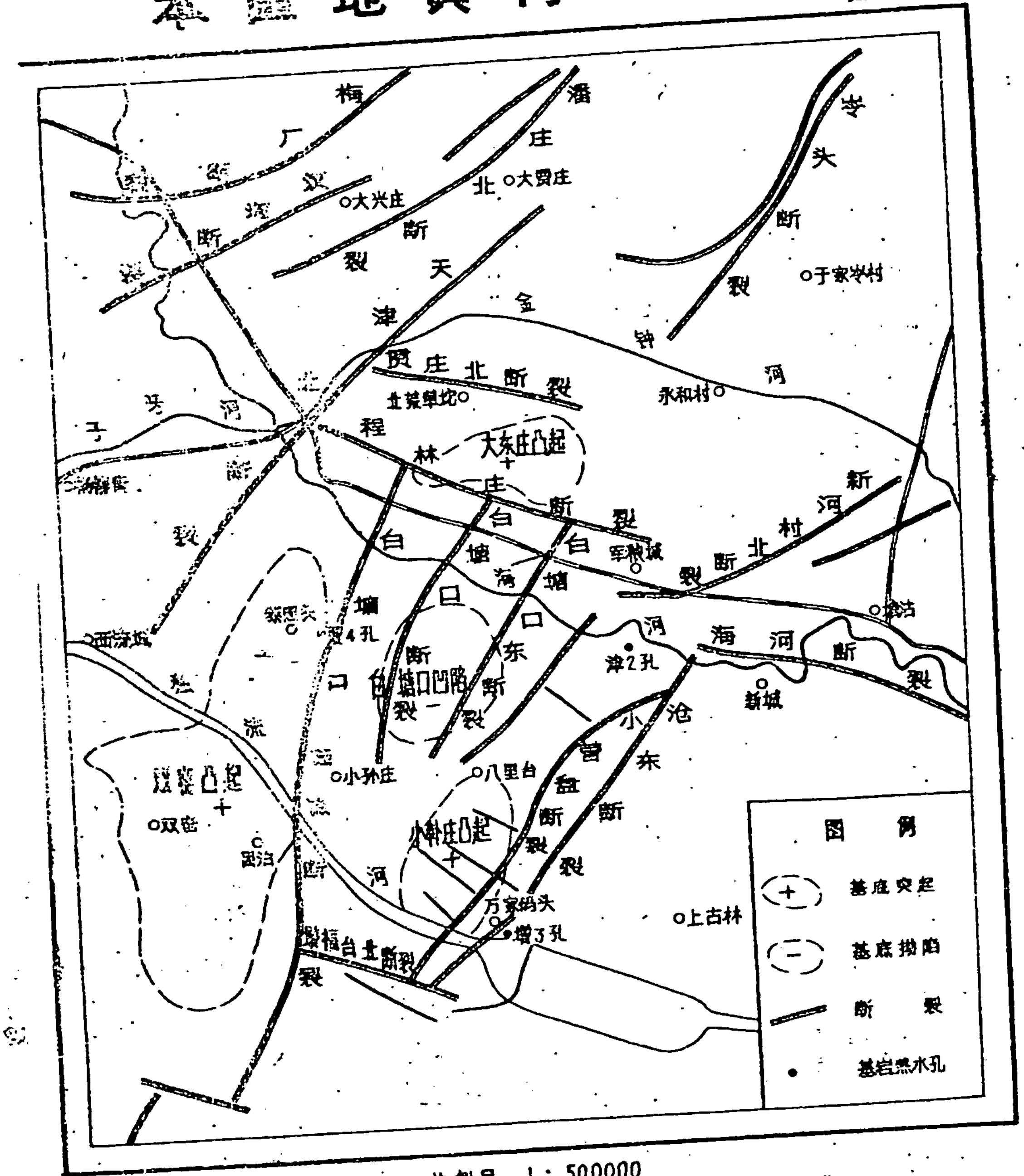
Fig. 2 Regional Geological Structure Map

there develop two groups of zone of structure: the one is north-north eastwise, composed of uplifts and subsides and parallel fractures; the other is west-northwestwise, composed of fractures. The former group consists of Shuang-Yao uplift, Bai-Tang-Kou subside, Xiao-Han-Zhuang uplift, Cang-Dong fracture, Xiao-Ying-Pan fracture, east-of-Bai-Tang-Kou fracture, west-of-Bai-Tang-Kou fracture north-of-Tianjin fracture, etc, while the latter, mainly of Zeng-Fu-Tai, Ha-He, Cheng-Lin-Zhuang and Guan-Zhuang fractures etc. (Fig. 3)

Another structural feature of this area lies mainly in its forward structure whose slope is steep in the east and gentle in the west. Fractures of larger dimensions mostly are on the steeper side of the upwarped east, such as the Cang-Dong, west-of-Bai-Tang-Kou and Xiao-Yin-Pan fractures which are respectively situated in the east sides of Cang-Xian upwarp and Shuang-Yao and Xiao-Han-Zhuang uplifts.

Still another feature is mainly the new tectonic movement of the geofracture. According to the observation made on the west-of-Bai-Tang-Kou fracture for the earth deformation of the upper and lower walls, the data of 1971-1973 are fundamentally firm and stable. The east wall began to uplift gradually from 1973 and more drastically from 1976 due to the Tangshan megaseism, with an average rate of 1 - 2 mm per year. Up to present, the upper wall movement relative to the lower one has already attained a height difference of more than 10mm (Fig. 4).

本區地質构造图 插图-3



Scale 比例尺 1 : 500000

Legend:

(+) Basement uplift

(−) Basement downwarp

═ Fracture

• Bedrock thermal water hole

Fig. 3 Map of Geological Structure of Tianjin Area

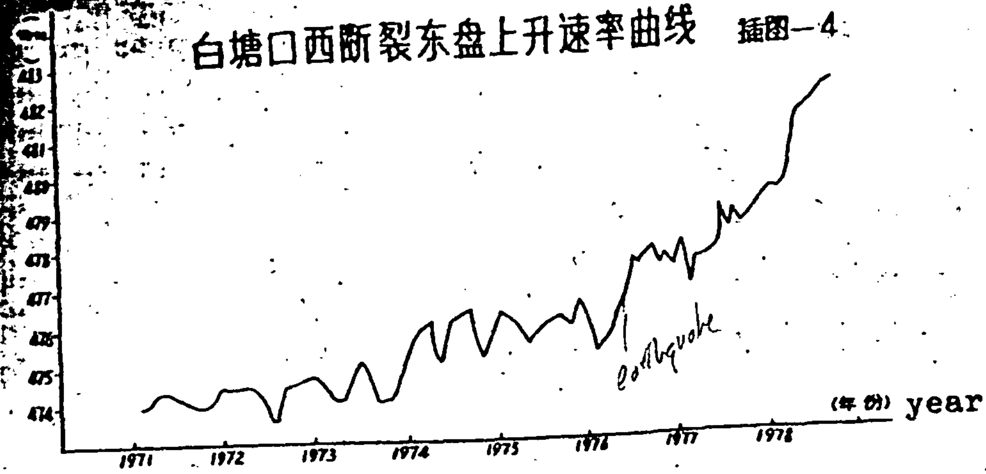


Fig. 4 Rising rate of the East Wall of the west-of-Baitangkou Fracture

2. The Stratum

Owing to the fact that this area had been subjected to serious denudation for a long period before the Palaeozoic Era due to the repeated tectonic movements, only the lower Palaeozoic Erathem stratum and upper Palaeozoic Erathem thinner stratum remain in the northern part of the Cang-Xian upwarp. However, in some subsides (e.g. Bai-Tang-Kou subside), there remain not only the Palaeozoic Erathem stratum but also probably the Mesozoic Erathem stratum.

(1) Cenozoic Erathem

This area has been in a condition of severe subsidence since Cenozoic Era. In the basement upwarp, the Cenozoic Erathem stratum directly tops the Palaeozoic Erathem stratum. Due to the influence of the paleotopography of the basement, thickness of being relatively (about 800 - 1000m), while the Bai-Tang-Kou sub-side part being up to more than 2500m.

Quarternary system: This system is mainly composed of a series of sandy and clay soil strata with a thickness of about 550 - 600 m. Both of them are of continental sediment except the stratum of the littoral plain which is of marinecontinental alternating sediment.

Tertiary system: The thickness is 500 - 600 m in general.

Ming-Hua-Zhen Formation: The lower part is composed of reddish-brown and reddish-purple sandstone-mudstone alternating beds, while the upper one, of greywish-yellow, greywish-green and light brown sandstone-mudstone alternating beds.

Guan-Tao Formation: This is composed of psephitic sandstone bedded with a few mudstone.

(2) Palaeozoic Erathem

Carboniferous system: The thermal water hole No.1 has an revealed thickness of 42 meters and lithological characters of greywish-black carbonaceous mudstone bedded with thin layers of fine-grained sandstone and coal line, with brown hematite and bauxite in the bottom.

Ordovician system: The normal thickness is about 300 meters and the lithological character is of light grey limestone bedded with mudstone and dolomitic limestone.

Cambrian system: The normal thickness is about 150-300 meters and the lithological character is mainly of grey violet mudstone and argellaceous limestone bedded with thin layers of limestone.

(3) Sinian Suberathem: The normal thickness may be up to several thousand meters. As to lithological characters, the most are dolomite, dolomitic limestone and siliceous limestone bedded with mudstone and sandstone.

II. Features of geothermic field of Tianjin area

One of the features of distribution of the geothermic field in the region of North China Plain is that the geothermal temperature and the geothermal gradient are low in the western and northern parts of the plain and high in its central part. On the basis of a geothermic field situated in an area of 300 m deep, the former case is 20 - ~~23~~ 25°C in geothermal temperature and ~~1 - 2~~ 2-3.5°C / 100 m on average in geothermal gradient, while the later one is respectively 20 - ~~23~~ 30°C and 2 - ~~4~~ 5°C / 100 m.

Another feature of the regional geothermic field is that there are four apparently high-value areas, extending respectively from Tianjin to Qingxian, Raoyang to Guantao, Jingxiang to Fuyang and over the north of Binxian. At the depth of 300 meters of these areas, the normal geothermal temperature is 23 - 25°C with a maxi-

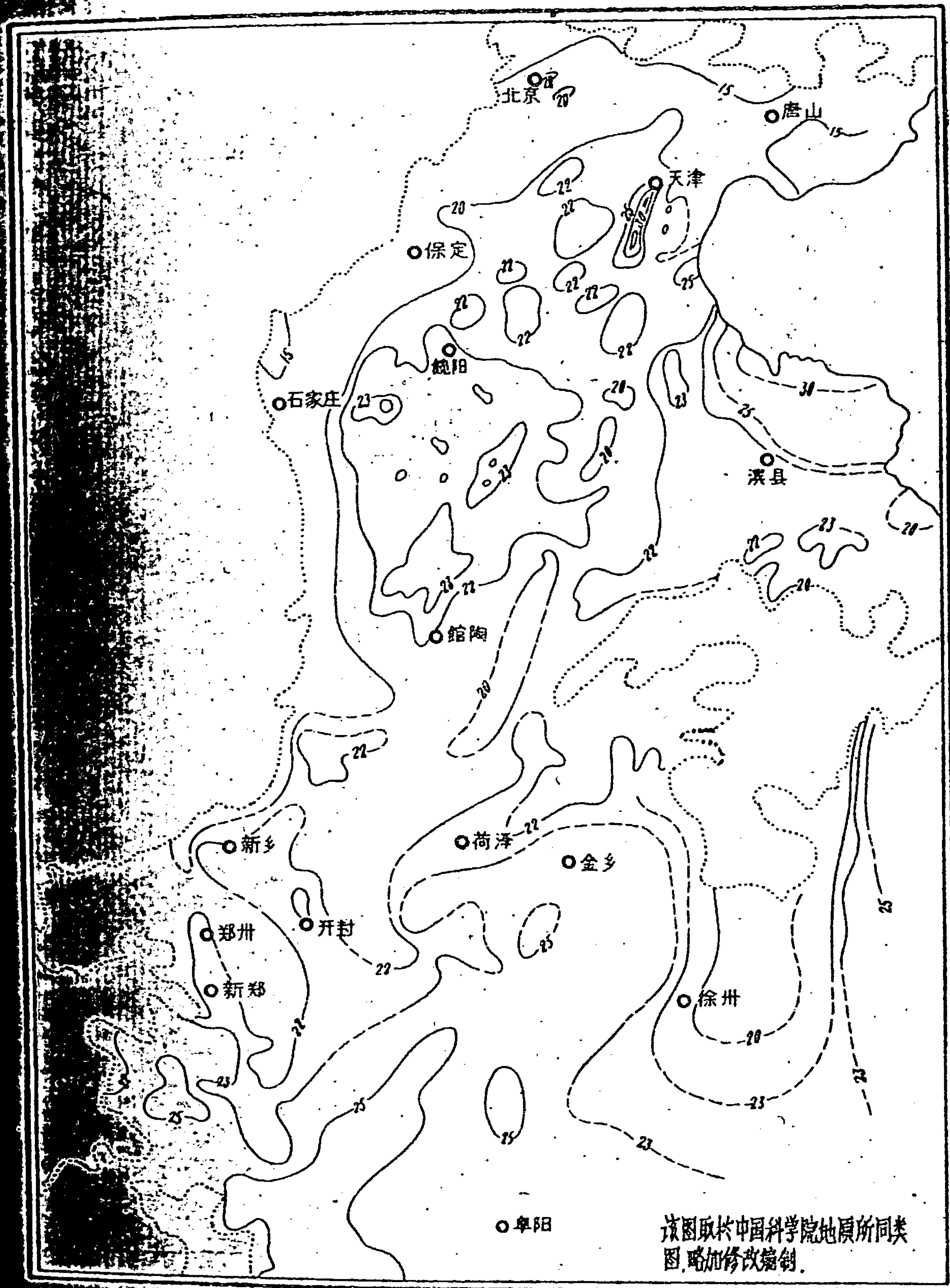
... the geothermal gradient averages 4 - 5 °C per hundred meters. The Tianjin geothermal area just finds itself in the high-value area of the regional geothermic field (Figs.5 and 6).

At the 300 m depth, the geothermal temperature of the geothermic field of Tianjin area is 20 - 22°C in general in the northern part and 22 - 25°C in the urban and south suburban with an average geothermal gradient of 4 - 6°C / 100m and maximum of 6 - 9°C / 100m. The geothermic areas having an average geothermal gradient higher than 4°C/100m extend over 700 square kilometers (Fig. 7).

It is seen from above that the geothermal temperature and average geothermal gradient of Tianjin geothermal area are 2 - 5°C and 1 - 2°C / 100 m higher respectively than those of other areas in North China Plain.

Viewing from the longitudinal variations of the regional and Tianjin geothermal temperatures, the fact is that in the rock strata of tertiary and quaternary systems, the geothermal temperature increases with the depth, while the geothermal gradient is fundamentally constant, generally at 3.2 - 3.7°C / 100m and that in the thermal reservoir of bedrock prevails the general rule that the geothermal temperature increases but the geothermal gradient significantly decreases (less than 2°C/100m) (Fig. 8).

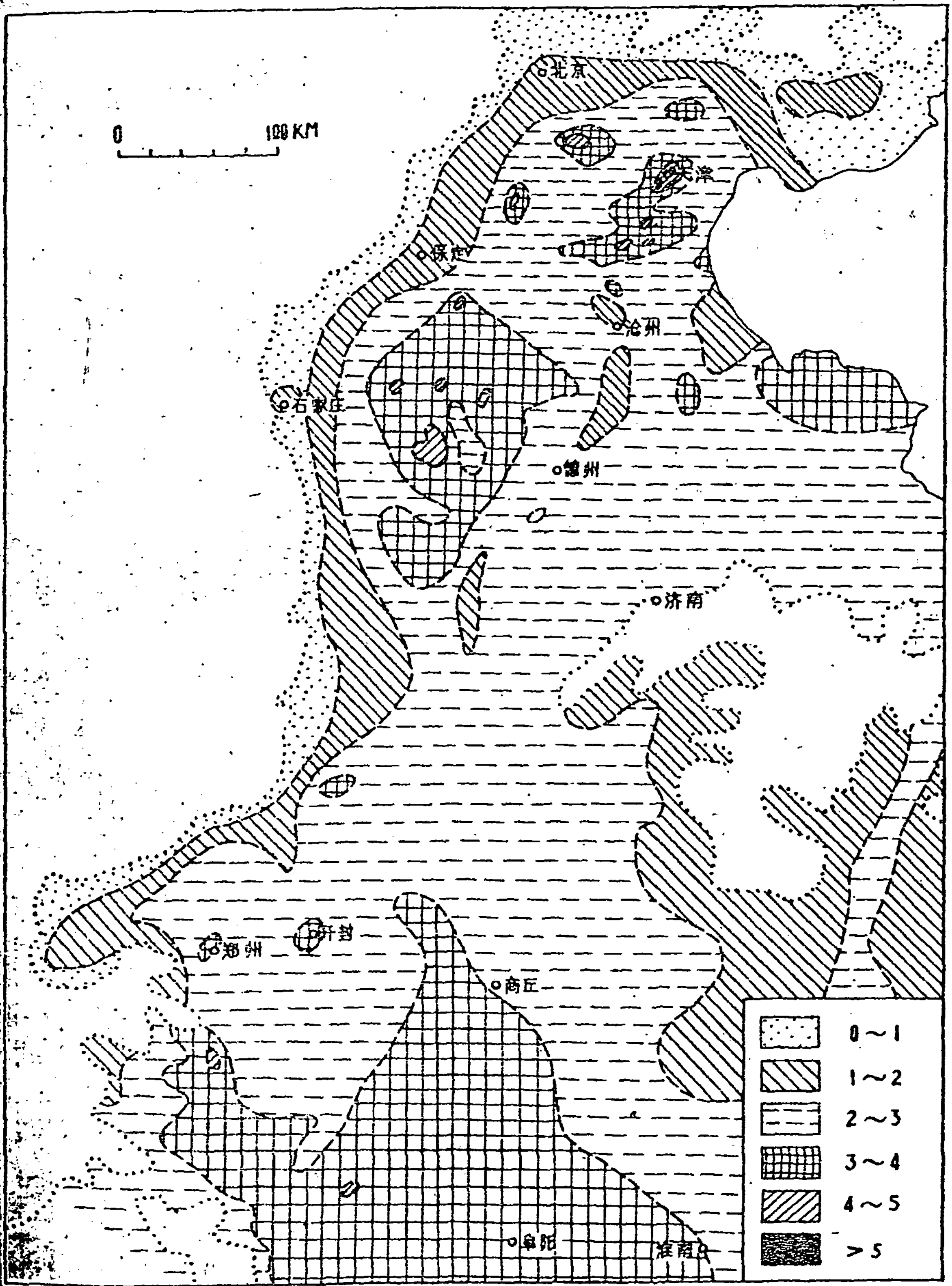
From the above, it is obvious that the Tianjin geothermal area is situated in a place of North China Plain where excellent geothermal condition exists and that the spread of its geothermic field is quite advantageous to the exploration and utilization of the geothermal resources.



Scale 1:4000000

Fig. 5 Geothermal Isogram of 300 m Depth of North China Plain (unit: C)

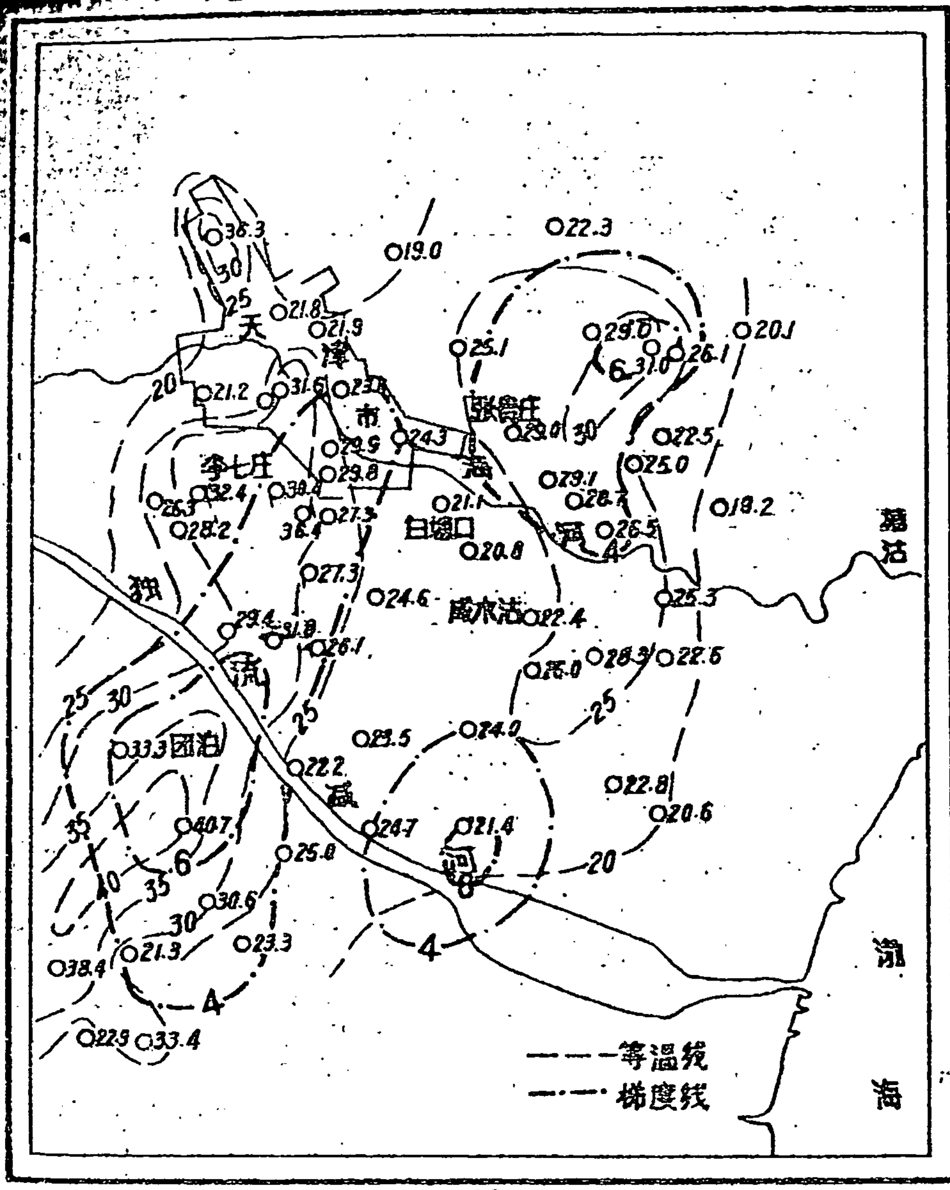
华北平原300米深度内平均地温梯度图 插图 6



注：该图取于中国科学院地质所同名图略加修改绘制

Fig. 6 Average Geothermal Gradient of 300 m Depth of North China Plain (unit: °C)

天津地热田300米深处地温等值线图 （数值为温度℃）



Scale 1:500000 插图 7

——— isotherms

—·—· isogradient

Fig. 7 Geothermal Isogram of 300 m Depth of the Tianjin Geothermal area (unit: °C)

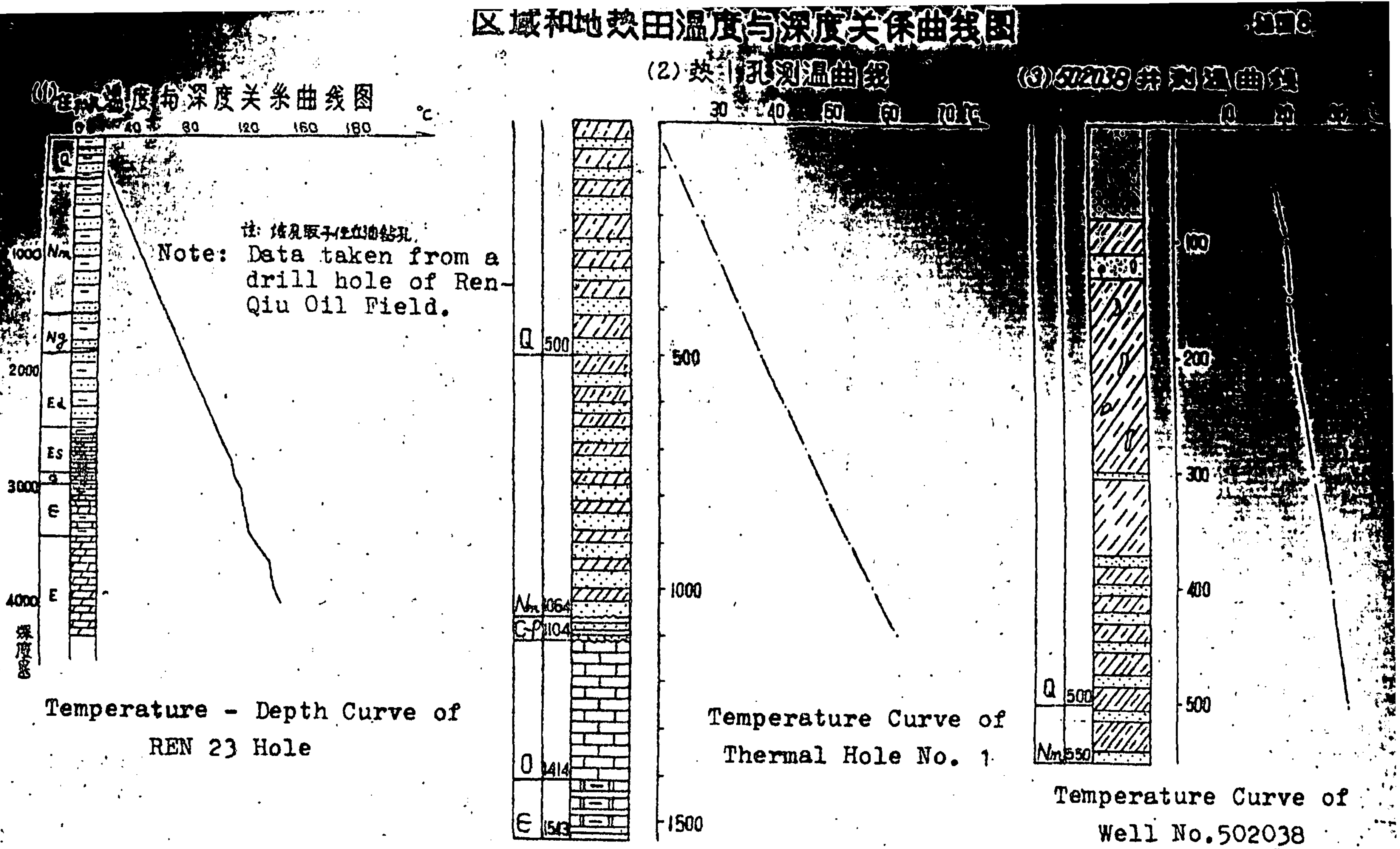


Fig. 8 Regional and Geothermal Area Temperature v. Depth

anjin geothermal area is a hydrothermal resource in subsidence nd mainly has the following features.

Distribution of the geothermal anomaly zone

The Tianjin geothermal area is mainly composed of two types rmal reservoirs, namely, the shallow reservoir of tertiary and the deep-seated bed rock reservoir. The spread of the l anomaly zone of the former type is delimited according to tual temperature measured in drill hole, while that of the type is roughly determined according to a few drill holes eir tectonic positions.

allow thermal reservoir extends over three thermal anomaly namely, Wang-Lan-Zhuang, Wan-Jia-Ma-Tou and Shan-Ling-Zi, total area of 700 square kilometers (Fig. 9), a geothermal nt higher than 4°C/100m and a center gradient up to 8.3°C 1).

Type of geothermal water

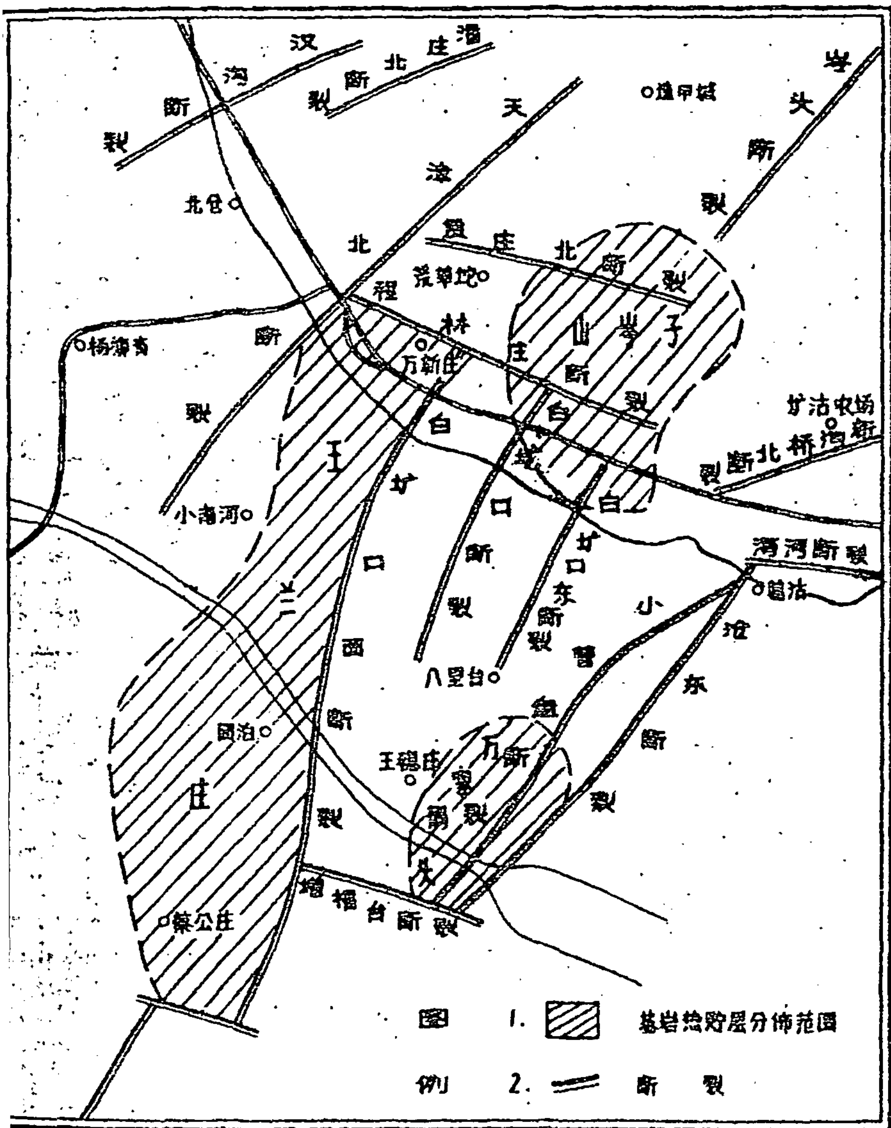
According to the condition of the buried water, lithologi- aracters of thermal water layer and distribution features of eothermal field, the geothermal water can be classified into pes, namely, the void water of tertiary system and the frac- karst water of Ordovician system and Sinian Suberathem 3).

层热水资源分布图　　插图9

Zone of thermal anomaly

... of Distribution of the Shallow Geothermal Water Resources

深层基岩热水資源分佈图 插图10



Spread of the bedrock thermal reservoir

Fracture

Fig. 10 Map of Distribution of the Deep-seated Bedrock Geothermal Resources

Table [illegible] Distribution of the Shallow Thermal Anomaly Zone of Tertiary System

Name of zone	Location	Area of distribution (km^2)	Geothermal gradient of the center of anomaly zone ($^oC/100m$)	Burial depth of the basal plate of tertiary system (m)	Burial depth of the roof of tertiary system (m)
Wang-Lan-Zhuang	Urban, South-west suburb	409	8.3	800 - 1400	550 - 600
Wan-Jia-Ma-Tou	South suburb	119	8.3	1000 - 1300	600 ±
Shan-Ling-Zi	East suburb	171	8.1	1100 - 1300	600 ±

The deep-seated bedrock thermal reservoir extends over a total area of about 900 square kilometers (Fig. 10) and the geothermal gradient averages 1 - 2^oC/100 m (Table 2).

Table 2. Distribution of the reservoir of deep-seated bedrock

Name of reservoir	Location	Area of distribution (km^2)	Average geo-thermal gradient (^oC/100 m)	Burial depth of bedrock	Litholog characte bedrock servoir
Wang-Lan-Zhuang	Urban, South-west suburb	609	1 - 2	800 - 1400	Limeston Sinian S berathem Limeston Ordovici system
Wan-Jia-Ma-Tou	South suburb	119	1 - 2	1000 - 1300	Limeston Sinian S berathem
Shan-Ling-Zi	East suburb	171	1 - 2	1100 - 1300	Limestone Ordovici system

Table 3. Types of geothermal water of Tianjin Geothermal Area

Type	Burial depth (m)	Lithological characters of thermal water layer	Water temperature (^{o}C)	Water head (m)
Void thermal water of tertiary system	600 - 1000	Semi-colloidized limestone	30 - 53	Burial depth 30 - 60
Fracture and karst thermal water of limestone of Ordovician system and Sinian Suberathem	Below 1000	Limestone	58 - 96	Above surface 10 - 30

Table 4. Hydrochemistry of the underground thermal water of Tianjin Geothermal Area

Type of water		Hydrochemistry	Mineralization (g/l)	Total hardness (German)	Alkalinity (German)	Fluorine content (mg/l)	pH value
Tertiary system thermal water		HCO_3 - Na	0.6 - 1.0	0.7 - 1.0	20 - 25	3 - 5	8 - 8.5
Bedrock thermal water	Ordovician system	Cl.$HCO_3(SO_4)$-Na	1.58 - 4.4	4.4 (higher in particular)	25.88	10.40	7.116
	Sinian Suberathem	Cl. HCO_3-Na	1.8 - 2.0	5 - 7	17 - 20	6 - 10	7.5-8.0

characterized by its high alkalinity and low hardness and mineralization, while that of bedrock by its relatively high mineralisation, alkalinity and fluorine content, and relatively low hardness in general (Table 4).

4. Single well thermal water output

Regarding the single well water output, it varies significantly with different thermal water layers; the output of the single well in bedrock thermal water layer is higher than that in tertiary system layer (Table 5).

Table 5. Variations of Water Output relative to different thermal water layers

Thermal Water Layer	Single Well Output (t/h)
Tertiary system	30 - 60
Ordovician system	80 - 120 (artesian)
Sinian Suberathem	60 - 100 (artesian)

5. Dynamic Range of discharge of geothermal water

Due to the developments of both agriculture production and urban construction in recent ten years, the extraction volume of the geothermal water of tertiary system has been increasing year after year. Accordingly, the water level changes greatly and, in the urban area, deteriorates gradually. Before 1972, the void thermal water of tertiary system in the urban area flowed by itself, but stopped to flow automatically from the first half of 1972 to 1973. At present, the level of geothermal water of the of 600 - 800 meters in urban area has already dropped to 40 - 60 meters below earth surface. Taking as an example the thermal water well of Tianjin Jianjin Washing and Dyeing Factory, it was built in 1934 (863 m deep) and ran for 40 years. From 1972, it stopped to flow and, in 1979, the elevation dropped to -49.34 meters with a dropping rate of 4 - 6 meters per year (Fig. 11).

Fracture and karst water of Palaeozoic Erathem and Sinian Erathem are all artesian, but are not yet extracted on large scale. According to the data obtained from seismic observation well, the dynamic range of discharge is such that under artificial control of the flow, at 5.5 t/h, the dynamic water pressure is reduced from 2.97 kg/cm^2 to 2.86 kg/cm^2 with the head showing a little downward trend (Fig. 12).

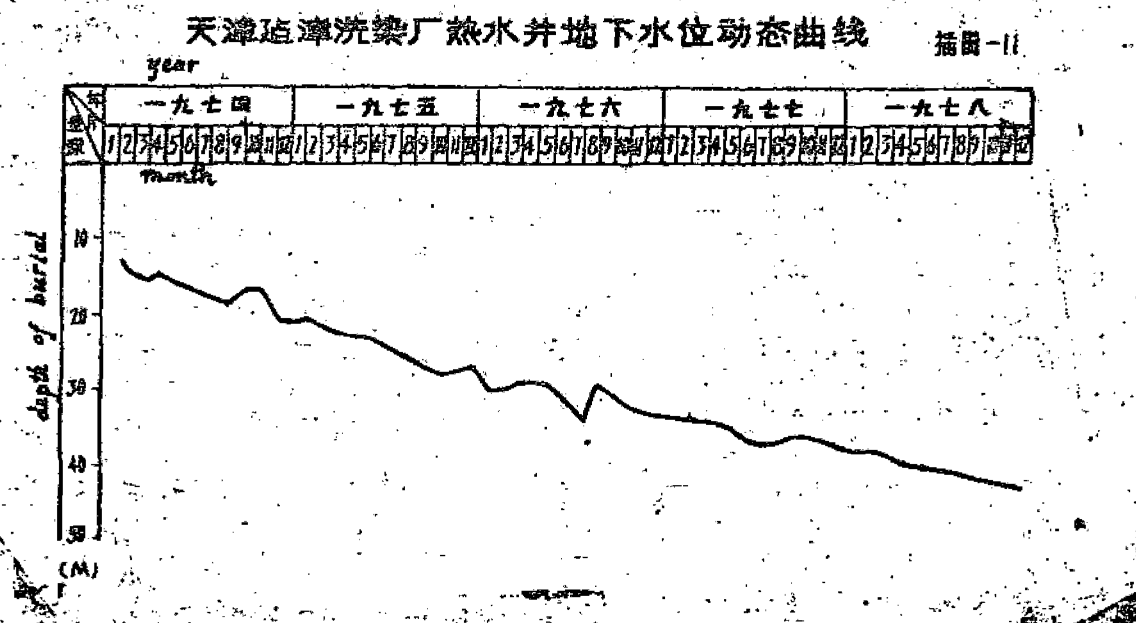


Fig. 11 Variations of Underground Water of the Geothermal Well of Tianjin Jianjin Washing and Dyeing Factory

震4孔压力温度水易动态变化曲线 插图—12

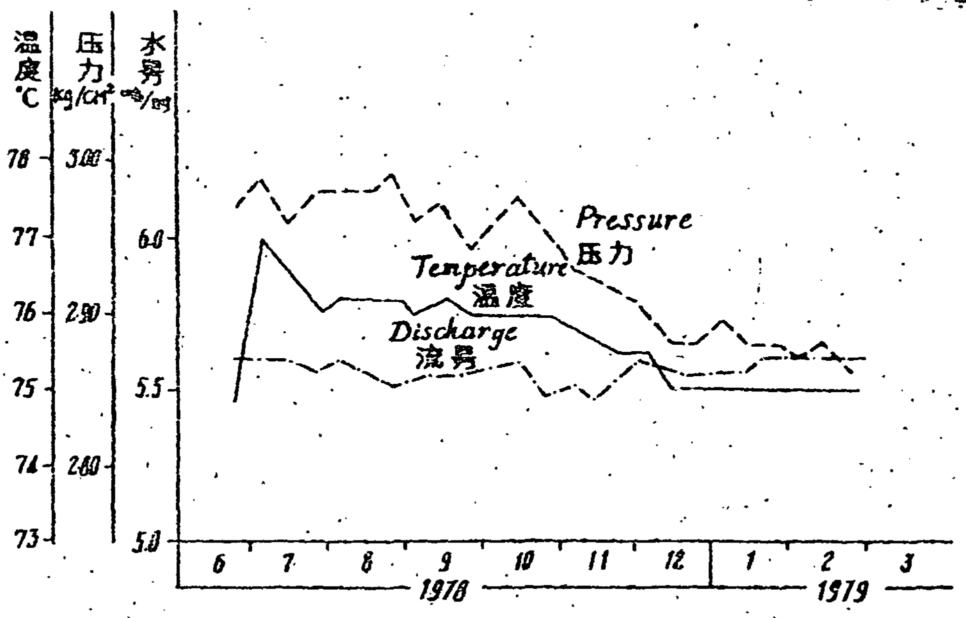


Fig. 12 Pressure - Temperature - Flow Dynamic Variation Curves of Seismic Hole No.4

IV. Fundamental mode of geothermal water system of Tianjin geothermal area

For reconnaissance, appraisal, extraction and utilization of the geothermal resources, of paramount importance is the research of the mode of thermal water system of geothermal area. The research work for the fundamental mode of geothermal water system embraces mainly three aspects: geothermal system, thermal water system and heat-controlling system.

Geothermal system: Of the geothermal system of Tianjin geothermal area, the heat originates mainly from the energy released by the decay of radioactive elements contained in the depths of the crust and in the mantle. According to the survey made in 1979 by competent authorities, in the North China Plain, the representative value of heat flow is q=1.5HFU (Heat Flow Unit). Taking a surface temperature of 15°C as basis, the calculated total amount of crust heat flow and mantle heat flow are respctively $q_u = 0.93 \times 10^{-6}$ $cal/cm^2/sec.$ and $q_m = q-q_u = 0.57 \times 10^{-6}$ $cal/cm^2/sec.$ Say roughly, within this area 62% heat flow originates from the depth of the crust and 38% from the mantle. According to the process of action, the geothermal system can be divided into heat producing layer (lower part of crust and mantle), thermal reservoir (upper part of crust, Sinian Suberathem and Palaeozoic Erathem strata) and heat detaining stratum (stratum of tertiary system). (Fig. 13)

Thermal water system: In Tianjin geothermal area, the sources of thermal water system are atmospheric water and paleo-sedimentary water. From the data of stable isotope and dynamic range of discharge, it is known that the void thermal water of tertiary system is preliminarily considered as the heated mixture of atmospheric water, surface infiltration water and paleo-sedimentary water, and that the recharge of contemporary atmospheric water is less intensive. The deep-seated bedrock water, fracture water and karst thermal water are deep-seated circulation water which is originated from the atmospheric water, recharged to a certain extent by contemporary atmospheric water from mountain recharge area and heated under high temperature and pressure during deep circulation.

Heat-controlling system: Four aspects concerning the heat controlling system of the Tianjin geothermal area, are crustal tectonics,

天津地热田热水系统基本模式示意图

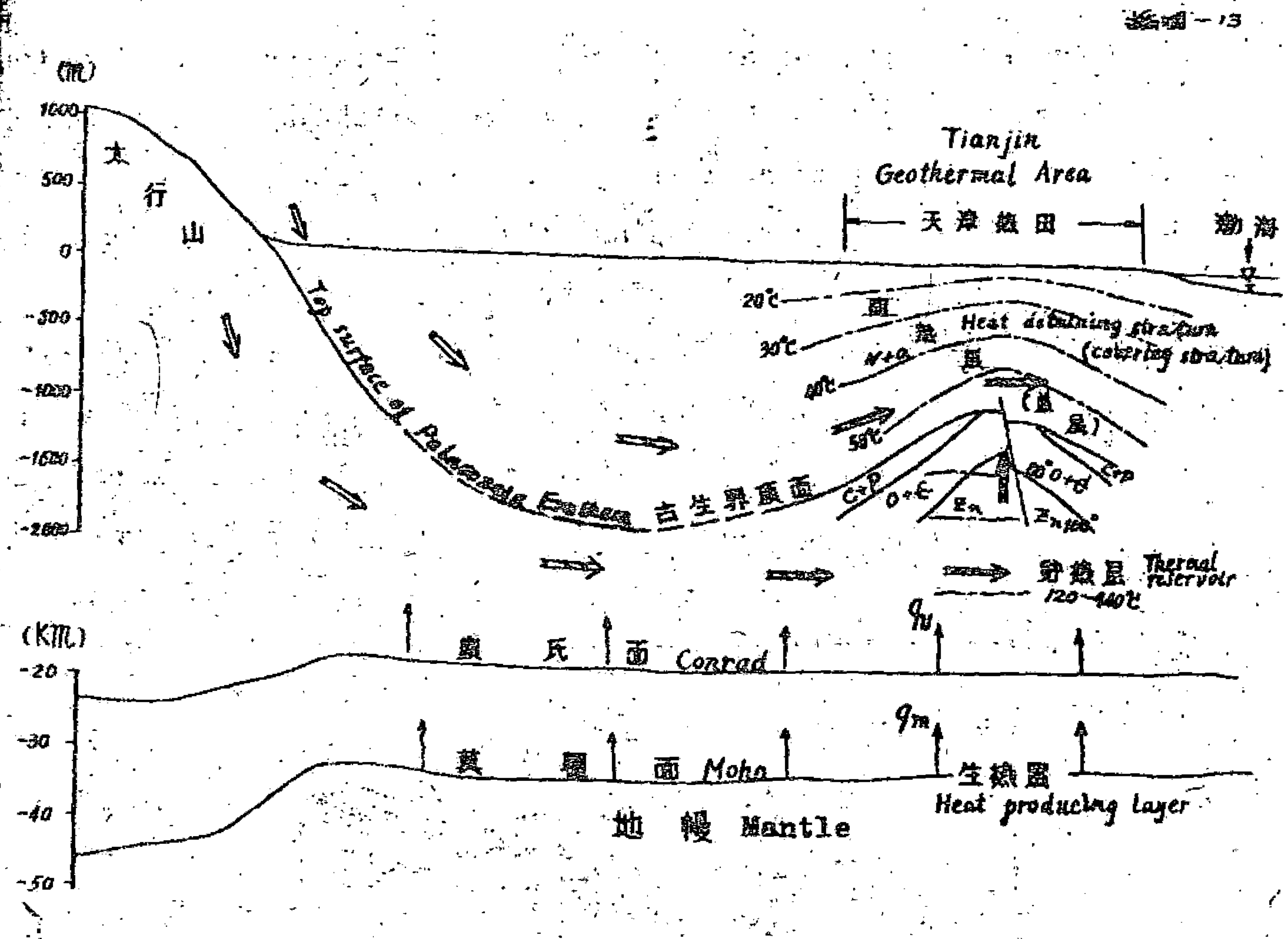
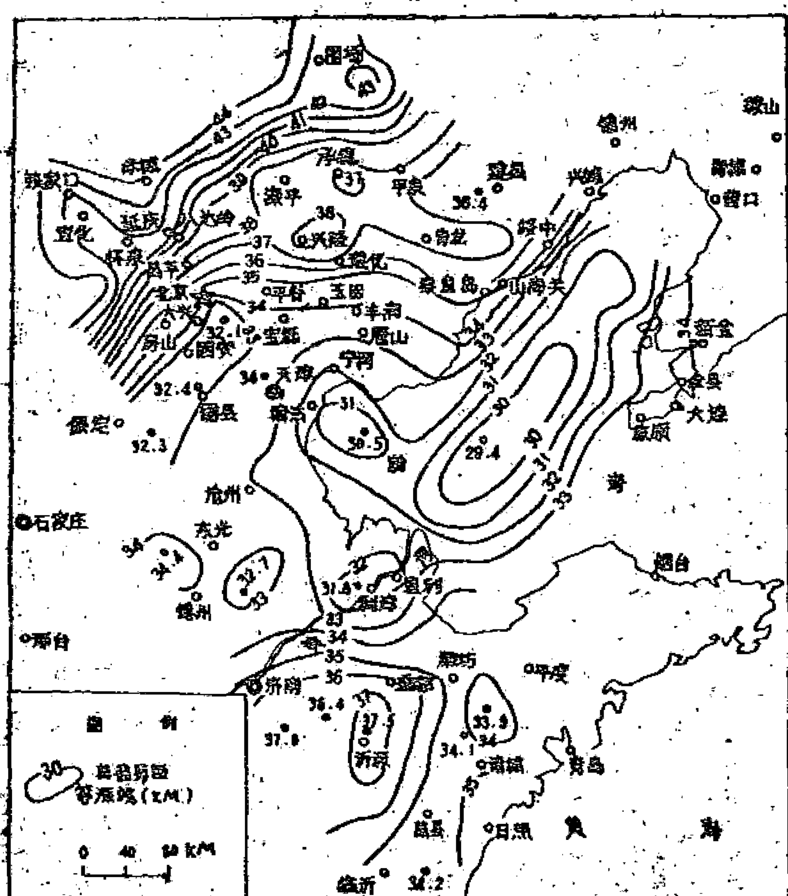


Fig. 13 Schematic View of the Fundamental Mode of Thermal Water system of Tianjin Geothermal Area

pattern of basement tectonics, tectonic fracture, strata and lithological characters.

1. Crustal tectonics

According to the seismic record and observation data of artificial earthquake, the crust thickness of North China region is approximately 30 - 45 kilometers, with the trend generally being thin in the east and relatively thick in the west. The neighbourhood of Tianjin, having a Conrad and a Moho respectively of about 17 and 32 - 33 kilometers, is a region which is relatively thinner in the North China Plain and consequently has a heat flow value higher than the representative value of North China Plain. According to calculation, the earth heat flow value of the neighbourhood of Tianjin is 1.77 HFU ($1.77 \times 10^{-6} cal/cm^2/sec.$). This is an internal factor of the geothermal anomaly of the Tianjin geothermal area (Figs. 14, 15, 16).



插图—14 北京—天津及其邻近地区莫氏界面等深线图

Fig. 14 Moho Isobaths Map of Beijin-Tianjin Region and Neighbourhood

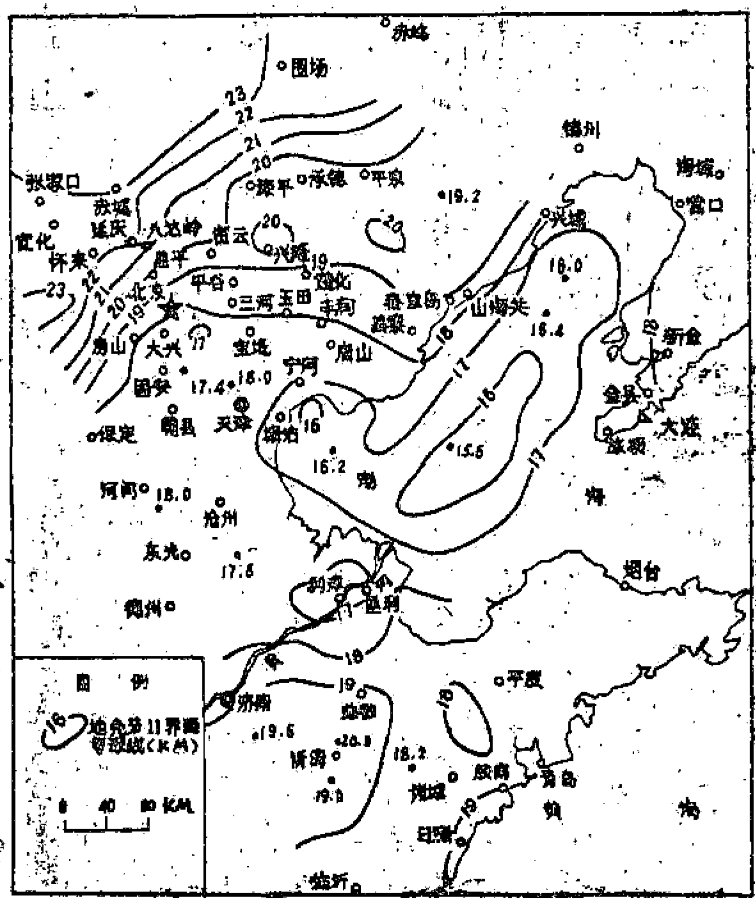


插图-15北京—天津及其邻近地区地壳康氏界面等深线图

Fig. 15
Conrad Isobaths Map of the Crust of Beijing-Tianjin Region and Neighbourhood

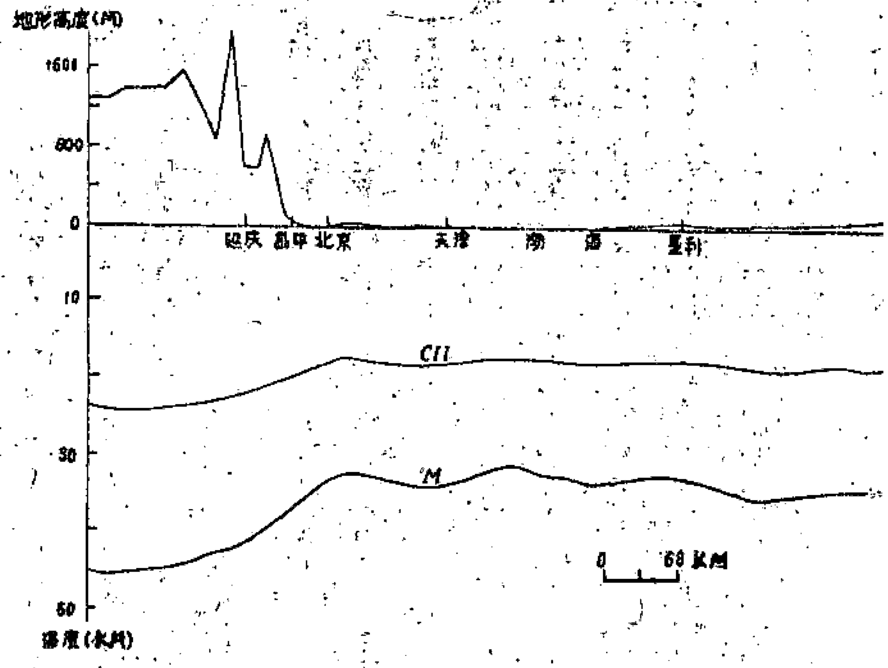


插图-16延庆—北京—天津—垦利的地壳构造

Fig. 16 Crust Tectonics of Yanqing-Beijing-Tianjin-Kenli Region

The Tianjin geothermal area mainly spreads over the northeastwise uplift of proximate grade tectonics of the Cangxian upwarp. The bedrock uplift part is featured by dense isolines and high geothermal gradient (above 4°C/100 m), whereas the gradient of subsidence part is low. This is mainly due to the fact that the heat flow originating from the deep-seated part concentrates along the uplift part with a low heat resistance and increases the geothermal temperature, hence the geothermal gradient. Actually, the uplift of the basement tectonics functions redistribution of the deep-seated heat flow.

3. Tectonic fracture

Within the sphere of the Tianjin geothermal area, there develop two groups of zone of fracture of north-northeast and west-northwest directions, such as west-of-Bai-Tang-Kou and east-of-Cang-Dong fractures. These fractures, all being geofracture, consitute on the one hand the main thermal channel and on the other hand create a condition favorable for the convective circulation of the deep-seated thermal water, due to the effect of the repeated tectonic movement on them, especially that of the new tectonic movement. Such an inference can be evidenced by the coincidence of extending direction of long axis of Wang-Lan-Zhuang geothermal area with that of the fracture and by the remarkably increased geothermal gradient in the region nearby the fracture. For instance, in the west-of-Baitangkou fracture, the geothermal gradient of the east-of-Baitangkou subsidence is 2.3°C/100 m, while that of the west side (nearby the Shuan-Yao uplift) which under normal condition should be 4.2°C/100 m is actually as high as 7.2°C/100 m. The fact

... within so short a distance is chiefly due to the function of thermal channel of the west-of-Baitangkou fracture.

4. Strata and lithological characters

The spread of the geothermic field is directly influenced by the strata and lithological characters chiefly due to the different thermal conductivities of different rocks. The thermal conductivity is inversely proportional to porosity. In this region, since the average porosity of the sandstone and mudstone of tertiary system is 15-30% and that of the carbonate rock of Ordovician system and Sinian Suberathem is only 1-5%, the thermal conductivity of the bed rock is 2-3 times higher than that of the rock formation of tertiary system, while the geothermal gradient of the bedrock is significantly lower than that of the rock formation of tertiary system. Therefore, the rock is a good thermal conductor which forms a thermal reservoir of the geothermal area and the rock formation of tertiary system is relatively a confining lid of thermal reservoir which forms a covering stratum of thermal reservoir.

V. Present status of the utilization of geothermal water resources of Tianjin and long-range planning

1. Present status of the utilization of geothermal water

In Tianjin, the geothermal water resources of tertiary system were put into common use since the beginning of the seventies and have been being extracted for use on large scale. Fundamentally, the bedrock thermal water has not yet been developed up to present. By the end of 1979, there are in total 381 geothermal wells of which 259 wells are actually utilized with a total extraction volume of about 48.94 million tons per year of which about 70% is used in industries, 25% in life requirements and 5% in agriculture. The details of utilization are as follows.

Industrial use: The geothermal water of tertiary system is mainly used as processing water for cotton and wool spinning, knitting and dyeing works and as supply water for industrial boilers with the advantages of economization of coals and industrial salt for water softening and sensible enhancement of the lustre, whiteness and fastness of color dyeing and printing of their products. For example, by using the tertiary system thermal water of 49°C, the Tianjin Wool Weaving Factory not only saves yearly 2400 tons of coal, 15,000 kw-hr of electricity and cost of salt for water softening, RMB¥120,000, but also considerably improves the product quality. In addition, attractive results have been derived from utilization of geothermal water in papermaking, wood-processing, food-processing and chemical processes.

Life requirements and space heating: The Tianjin Guesthouse utilizes the geothermal water of 42°C for tubs in more than thousand rooms and space heating in winter after properly reheating it, thus economizing more than one thousand tons of coal per year. In addition, the Zhang-Dao-Kou Seismic Observation Station situated in the west suburb utilizes the bedrock thermal water not only for seismic observation but also for directly heating the dwellings and office buildings in winter time.

Agricultural use: Satisfactory results have been obtained from

... ...ing, etc. For instance, by using a small quantity of bedrock water drained from the Seismic Observation Station, the Zhang-Dao-Kou Production Brigade of west suburb established a greenhouse of one mu land gathering three crops of vegetables per year and cultivated ten mu land of seedlings under polyethelene film shelter, netting a yearly total production value of more than RMB¥10,000.

2. Orientation and long-range planning of the utilization of geothermal water resources of Tianjin

In Tianjin city, there is an appreciable increase of energy consumption as a result of the development of urban construction and the progress of industrial and agricultural productions, as well the improvement of the living standards of the people. To cope with this situation, it is important to economize the energy on the one hand and develop the local energy sources on the other.

In Tianjin city, the geothermal energy is a constituent part of the local energy sources and brilliant prospects exist for its utilization in this city in light of the experiences in actual utilization of geothermal energy both in this city and foreign countries. According to the features both of the geothermal water and distribution of resources, in the days to come the main uses of the geothermal water of Tianjin area will be oriented as follows. In principle, the shallow thermal water of tertiary system found in the neighbourhood of urban area will be directly used in the technological processes involved in the industries such as wool and cotton weaving, knitting and printing and dyeing factories. Thermal water of tertiary system in the suburban area will be arranged mainly for use in greenhouses and for planting, breeding and poultry hatching and gradually developed as a main part of energy sources for agriculturel and side-line production. The bedrock thermal water will be used in urban area for space heating, partially or totally.

As for the general envisage of the exploration, development and utilization of the Tianjin geothermal resources, emphasis will be laid on the reconnaissance of the deep-seated bedrock water resource and a corresponding appraisal turned out in 1982 with the appraisal of the whole geothermal area to be turned out with best efforts in 1985. Our main objects are as follows:

1980 - 1982:

(1) Reconnaissance and appraisement of the bedrock water resource in the urban area;
(2) Investigation of the possibility of recharge and comprehensive utilization and putting forward a program for the utilization of geothermal water;
(3) Intensification of the control of tertiary system thermal water in the urban area.

1983 - 1985:

(1) Programatical development and utilization of the bedrock geothermal in the urban area;
(2) Reconnaissance and appraisement of the deep-seated bed rock thermal water resources of the whole geothermal area.

After 1985, all geothermal resources of Tianjin area will be programmatically explored and utilized to enable Tianjin to become gradually a city where the geothermal energy is utilized to the fullest extent.

In Tianjin area, in spite of its excellent geothermal potentialities, earlier geothermal investigation work and a given basis for utilization of the geothermal energy, up to present, due to various reasons, the investigation is slow in progress, the existing geothermal water is not yet fully utilized, the reconnaissance of the deep-seated bedrock thermal water resources is only in its infancy, the geothermal resource of this area is not yet evaluated as a whole, a great deal of problems pertaining to geothermal energy, hydrogeology and geological structure yet remain to be solved and a working plan for the economical and scientific exploration and utilization of geothermal resources elaborated. Therefore, what we have mentioned above is only preliminary in character and indeed not a few contents yet remain to be added or corrected correspondingly.

. . . The end . . .

AREA
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GEOTHERMAL RESOURCES IN CHINA

by
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April, 1981

This paper is prepared on the basis of special articles and reports on geothermal investigation and development, with references to the status of geothermal work and the results of scientific research, also some published treatises.

In China, geothermal water is generally divided according to its temperature as: low-temperature (20-40°C), medium-temperature (40-60°C), high-temperature (60-100°C), and superheated (over 100°C). However, as there are several kinds of classification and no standardized one so far, it should be pointed out that in this paper the concept of high-, medium-, and low-temperature waters are considered mainly from the economic benefit of their utilization and in accordance with traditional divisions in foreign countries as follows:

High-temperature water: Steam and water, over 150°C, used for electricity generation and other comprehensive uses, e.g. geothermal fields in Yangbajing, Xizang (Tibet), and in Tengchong, Yunnan.

Midium-temperature water: 90-149°C, mainly used for heating, refrigerating, drying, and other non-power uses in some geothermal fields along the southeastern coast of China.

Low-temperature water: Thermal spring or thermal water having a temperature less than 90°C, mainly used for greenhouse, sanatorium, heating and other non-power uses as in the thermal fields at Yingshantang River, Hubei province, and Hsiaotangshan, Beijing. Geothermal energy has been used to its maximum in the above-mentioned areas according to the local demands and the properties of the thermal water.

Geologically, the tectonic movements since the Mesozoic and Cenozoic, especially since the Yanshanian movement, have produced a great influence on nearly the whole territory of China. The most violent is represented by the extensive foldings and faultings in East China, Xizang and West Yunnan, accompanied by strong magmatic intrusions and volcanic eruptions. However, Himalayan movement has been obvious in the souteast coastal region, Taiwan, Xizang and West Yunnan terrain, and fairly common in the northwest where extrusive basalts and intrusive basic, utra-basic and acidic rocks can be seen.

All these regional structural activities, especially the Neotectonic movements determine the formation and distribution of the geothermal fields within the territory of China.

I. CHARACTERISTICS OF GEOTHERMAL DISTRIBUTION

According to its geological conditions and occurrence, geothermal resources in China are generally related with the recent volcanic and magmatic activities, structural fractures in mountainous areas, and Cenozoic artesian basins. Moreover, the thermal water from underground has distinct regional differences either in quantity or in quality and temperature, according to the data on natural thermal springs, boreholes and mining pits at 2000 places or more.

1. Geothermal System Mainly of Wet Steam

Wet-steam thermal system is distributed mostly around South Xizang, West Yunnan and Taiwan, among which the former two have shown to be the most active hydrothermal areas in the interior of China, where over 400 or more thermal springs and nearly a hundred hydrothermally active points have been found to have a temperature higher than the local boiling point. In this Xizang-Yunnan terrain there are various geothermal indications such as hydrothermal explosion, geyser, boiling spring, hot spring, warm spring, hot pool, etc. Various kinds of sinter deposits can be seen, such as siliceous and salt sinters, sulphurite, and others. At some places are precipitated stibnite, cinnabar, pyrite, and realgar. Another feature of hydrothermal activities in this terrain is strong hydrothermal alteration.

Hydrothermal explosion as known is an important evidence for the intensity of geothermal activity. The Qinghai-Xizang Plateau Comprehensive Survey Team of Academia Sinica have found some ten hydrothermal explosion areas along both sides of the Yaluzangbu River in Xizang, among them Qupu hydrothermal area in Pulan county is supposed to be the largest. The rare hydrothermal phenomenon can only be found around Xizang, e.g., the Gulu geyser at the eastern flank of the Nianqingtangula Mts. and the tagejia geyser of Ang-ren county at the southern side foothills of the Gandisi Mts.

The origin and characteristics of this geothermal system can be represented by the typical thermal springs in Yangbajing, Tengchong and Taiwan.

1.1. The Yangbajing geothermal field in Xizang is the first wet steam field under exploration and exploitation in China's inland region, where an experimental power plant of 1000kw is built.

The geothermal field lies in the middle part of the Yangbajing basin. On both sides of the basin are mountain peaks approximately 5500-6000m above sea level. The geothermal field is mainly controlled by the deep fracture in NE direction along the fringe of the basin. A series of NW fractures together with minor faults in other directions provide the channels and passageways for thermal fluids.

The Nianqingtanggula Mts. is a gentle anticline composed of Pre-Devonian(?) gneiss, which is probably the oldest rock in the region. On the periphery of the basin occur slate, siltstone, and schist of Permo-carboniferous period, and red and volcanic rock series of Cretaceous period.

Around the basin, granitic rock masses produced by the Himalayan movement are distributed over large areas, their isotopic age may be dated back to 37 m.y. for Xuegula rock mass, and 61-68 m.y. for Yangbajing rock mass.

Within the basin are deposited Quaternary glacial drift, fluvioglacial sand and gravel, and alluvio-diluvial sediments, with an accumulated thickness of 300m or so. The basement of the basin is mainly constituted by granite, and possibly volcanic rocks in the southern part of the field.

After the basin was formed, new foldings and faultings continued to cause changes in Quaternary sediments, resulting in intricate fissures and fractures in the covering strata of the geothermal field. Besides, the Yangbajing basin is at the same time an active earthquake zone of high intensity and frenquency. All these have provided the most favourable conditions for the upward movement of the thermal fluid, consequently various geothermal features on the ground surface are formed.

The chemical types of the Yangbajing geothermal fluids are mainly of sodium chloride which is the typical water type in the geothermal reservoir of Yangbajing field. The total dissolved solids in hot water ranges between 1.5-2.0 g/l. There are lithium, boron, and rubidium contained in hot fluids, and the gaseous composition is mainly carbon dioxide. As well as hydrogen sulphide, nitrogen, oxygen, etc. Occasionally hydrogen.

From the characteristics above, Yangbajing geothermal field occurs in the fault basin controlled by the huge fracture which is still active in the piedmont belt of the Nianqingtanggula Mts. It is a thermal field that yield high-temperature water. Though neither outcrops of intrusive rock body nor traces of volcanic eruption since the Neogene period can be observed in the field and its vicinity, the evidence of the strong hydrothermal alteration, the deposits of sulphurite, and the stibnite on the walls of the old fumarole, also the results of geochemical analyses of the thermal fluids, show that there must be at a certain depth under the earth's crust a recently cooling magma body. This magma body must be the huge source that supply heat to the geothermal field.

1.2. The geothermal indications on the ground surface in the Tengchong volcanic zone can be well compared with that in Xizang. Big fumaroles, boiling springs and cluster of hot springs appear in groups everywhere. Within a belt of about 110km long in N-S direction and 60km in width, 79 groups of springs have been found. Among them, 10 groups have a temperature over local boiling point. Steam indications are chiefly distributed in the southern part. Occasionally there can be noticed sulphur tufa, niter tufa and hydrothermal mineralizations.

The geothermal fluid at Tengchong has a fairly complex chemical constituents. It is mainly chloride-bicarbonate-sodium and bicarbonate-chloride-sodium types of thermal water with a content of total dissolved solids ranging from 0.2 g/l at the minimum to 2.5 g/l at the maximum. The gaseous composition generally involves CO_2, O_2, N_2, H_2S, CH_4, among which CO_2 is the most predominent.

The geothermal phenomena at Tengchong are directly related to the activities of volcanic eruption. According to the shallow hole measurement at Rehei thermal field, the temperature may reach 145°C at the depth of only 12m. This shows that there must exist a high temperature geothermal fluid body at deeper depth.

1.3. Taiwan province is also one of the quite active geothermal zones in China. There are altogether 103 places of geothermal indications such as fumaroles, warm springs, etc. The terrain of Datun volcanic groups lying in the north of the island would be the most typical, having totally 11 geothermal areas. In Macao area, an exploration well shows that the highest temperature may reach 293°C. Yilan, Wulai and some other places are also very promising.

2. Geothermal System Mainly of Medium- and Low-Temperature Hot Water

Medium- and low-temperature thermal waters are very common in China. It can be found in many fold zones in the mountains, and in the basins as well.

In the folded mountainous areas, thermal water is buried in water-bearing rock formations of different periods, and often exposed in the form of warm springs in the areas of Mesozoic intrusive rocks. These springs are mainly controlled by structural fractures. In many thermal areas, strong silicification can be observed in the surrounding rocks. Geothermal water is mainly of atmospheric origins, it contains dissolved solids generally less than 1 g/l except for that in the western part of China ranging from 1 to 4 g/l. Whereas in the eastern part of China largely less than 0.5 g/l.

The coastal region in East China (including Fujian, Guangdong, and part of Hunan and Jiangxi provinces, and Shandong and Liaodong peninsulas) is one of the terrains where medium- and low-temperature waters are mostly distributed, especially in Guangdong and Fujian which are the most representative regions of the folded mountainous type for thermal water. For example, the Dengwu geothermal water area in Guangdong lies within the Mesozoic granitic intrusion, the rock mass is generally trending northeastward, corresponding with the structural line. The structural system is mainly constituted by a NE trending compresso-shear fracture zone and a NW tenso-shear one. At the top of the former zone is a Yanshanian granitic intrusion, while at the bottom are late Jurassic rhyolite and rhyoporphyry, with strong silicification. Geothermal water occurs at the intersection part of the faulting, with a temperature of 90°C. It belongs to low-mineralized bicarbonate-sodium type water with a total dissolved solids less than 0.4 g/l. It contains fluorine and silica, and gaseous composition mainly nitrogen, and also radioactive radon. The characteristics of the geothermal water in the eastern folded mountainous zone, especially in the magmatic rock zone is on the whole similar to that in the Dengwu zone.

Besides, numerous springs can also be found in East Yunnan and West Sichuan provinces, and in Yinshan, Chinling, Qilian and Tianshan mountains.

In China, there are a number of plains and basins constituted by the Mesozoic and Cenozoic strata, such as Songliao, North China and Jianghan plains, and Sichuan and Caidamu basins. Since the recent twenty years, considerable geothermal resources have been discovered in the course of geological exploration and oil prospecting. In some of the basins the thermal waters are high-mineralized hot brine, containing various trace elements. In Tianjin district, three anomaly zones have been detected, totalling nearly 700km^2 in area. Hot water of 30-53°C generally can be drawn from wells penetrating the covering sediments at the depth of 600-1000m. In Beijing, a 50km^2 anomaly area has been delineated, where 50°C hot water can be extracted at the depth of 1000m. In Jianghan plain, a 3000m well produces artesian hot brine at the temperature of 95-100°C. Some wells at Penglai in Sichuan basin has tapped artesian hot brine of 74°C, with a discharge of 3000 tons diurnally.

From the temperature of the geothermal wells in various districts, the geothermal regimes are quite different in different basins. In short, the geothermal gradient is generally higher in the basins in the eastern part than that in the western part. 3-4°C/100m in North China region, 2.5-3°C/100m in Sichuan basin, and still lower in the western part.

The distribution of geothermal water in the basin is considered to have a close connection with oil and gas fields. The hydrochemistry of the water is of sodium chloride or calcium chloride type. It is highly mineralized, normally has a content of total dissolved solids over 10 g/l, the highest may reach 380 g/l. The elements contained in water are usually bromine, iodine, boron, strontium, lithium, barium, etc. The gaseous compositions are mainly methane and hydrogen sulphide.

North China plain is one of the basins which are rich in geothermal resources. In addition to Tianjin and Beijing districts, the oil fields of Dagang, Renqiu, and Shengli are also areas where hot water occurs. In central Hebei depression nearly a hundred geothermal water wells have been drilled, covering an area of 1500km^2. Within the depression, the geothermal gradient in most of the districts is 3.5°C/100m, sometimes exceptionally high up to 6-13.7°C/100m. In some high anomaly areas, 50-70°C may be reached at the depth of 1000m. Water that has the highest temperature occurs in the depression is about 118°C (well depth 2303-2700m). Geothermal water wells in this zone is particularly productive. The water has a high temperature and good quality. Normally the yield of a single well is about 50-2000 t/d, the highest being 4000 t/d. According to the statistics on 91 wells the daily production of hot water is up to 80900 tons.

II. GEOTHERMAL ZONATION

From the geothermal distribution in China, either the temperature or the geochemistry of warm springs has certain regularities and regional characteristics. Based on the data available and according to the genesis, controlling factors, distribution of the geothermal phenomena, six zones may be divided for the time being, except for the hot ground water in basins and sporadic warm springs in some districts.

1. Xizang-Yunnan Geothermal Zone

This zone includes largely the Gandisi Mts. and extends to the south of the Nianqingtanggula Mts., especially along the Yaluzangbu River easterwardly to the Nujiang river and the Lancang River, then turn southward in an arc shape into the Tengchong volcanic zone, Yunnan, possibly stretching to the Ailaoshan Mt. This terrain is the most active hydrothermal zone with the most concentrated geothermal features. Tectonically it belongs to the Yanshanian and Himalayan fold zones. In Xizang, magmatic intrusion can be noticed some 800m long along the north bank of the Yaluzangbu River. In Tengchong area not only Yanshanian granites but also traces of multi-volcanic activities can be seen. Neotectonic movement is very active there. Due to the continual uplifting of the earth's crust, volcanic activity and earthquake are very frequent and violent, caused by the force of mobile magma.

This zone is part of the Mediterranean-Himalayan zone, belonging to the convection type of high-temperature hydrothermal system. The hydrothermal explosions and geysers are all concentrated here, especially in the Nianqingtanggula and Gangdisi mountains, and on both sides of the Yaluzangbu River as well. In West Y unnan, high-temperature thermal springs are mainly distributed around the zone of volcanoes in Tengchong.

It is expected to develop geothermal resources mainly of wet steam over 150°C in some of the major geothermal fields. This is possibly the largest zone of geothermal potential in the continent of China.

2. Taiwan Geothermal Zone

Taiwan, a Cenozoic geosynclinal fold zone, being part of the Circum-Pacific island arc system, is situated at the region where the two arcs of Ryukyu and Phillippines join together. The lively volcanic activities on Taiwan island may be linked to the volcanic zones of Ryukyu in Japan and the eastern coastal region of the Phillippines. Taiwan is one of the seismic belts where earthquakes occur most intensly and frequently. It is an area with concentated strong quakes in Chin. Geothermal resources in Taiwan, which is mainly of high-temperature hydrothermal convection type, mostly concentrate on the eastern and western seismic belts. Taiwan is one of the terrains on China which is very promising in geothermal potentials.

3. Southeast Coast Geothermal Zone

This zone includes Fujian and Guangdong provinces and part of Jiangxi and Hunan, where occur more than 500 thermal springs. Most of the springs are densely distributed in the coastal regions of the former two provinces and have higher temperatures than that in other areas. Among them, hot water points with a temperature over 60°C occupy 35% of the total number pf springs in these two provinces. The geothermal resources in this zone are mainly medium- and low-temperature thermal waters. The occurrence of thermal water is controlled by a series of NE trending tectonic fractures, and is also related to the existence of magmatic intrusions and volcanic rocks.

According to the temperature in thermal springs and boreholes, it is a little lower in the west and higher in the east. Approximately, the temperature of the geothermal water increases in the regions on the eastern side of the line along the Lianhuashan fracture within the boundary of Guangdong province northwards to Zhangzhou, Fujian. There are several thermal springs which have a temperature more than 90°C, and in some thermal areas the water temperatures in boreholes may reach over 100°C. For example, the temperature of Dongshan Lake, Guangdong and in some boreholes of Fuzhou, Fujian, are 102°C and 100°C respectively. This is another geothermal prospect in China.

4. Tancheng-Lujiang Fracture Geothermal Zone

Tancheng-Lujiang fracture is the greatest and longest deep fracture trending NNE in East China. It starts from the south of the Yangtzi River, passes northernly through Shandong, Liaoning, Jilin and Heilongjiang provinces, and stretches straight into the USSR territory of the Far East. This is not only a deep fracture braking off the crust of the earth and still active up to now, and is a seismic belt as well. Along the fracture from south to north, largely occur the Mesozoic and Cenozoic intrusive and extrusive rocks.

It is this very fracture that controls the geothermal distribution in this terrain. Though along the fracture thermal springs are not predominant and in general their temperatures are not very high, yet in accordance with geothermo-measurements in a number of mines in the vicinity and the temperatures of thermal water in the geological exploration holes, the geothermal gradient ranges from 3.42-4.57°C per meter. For example, the temperature in a borehole of 545m deep in Donghai thermal spring area, Jiangsu, reaches 94°C. This indicates that relatively high-temperature water may exist at depth.

5. Chuan-Dian (Sichuan-Yunnan) N-S Geothermal Zone

The zone is an elongated belt extending southnorthwardly along a line from Kunming to Kangding, where occur a great many thermal springs of lower temperatures generally between 30° and 60°C. The spatial distribution of the thermal springs are leadingly determined by the N-S structure system consisting of a group of strong compressive and compresso-shear folds and faults. It is an active tectonic zone as well as one of the areas of strongearthquakes in China. As a result, along these fracture zones a lot of thermal springs can be found as many as 100 or more spots densely clustered, such as in the Hsiaojiang and Anning fracture zones. However, these thermal springs have generally low temperatures, with only a few exceptions such as Kangding.

6. Qi-Lu (Qilian-Luliang) Arc-Shape Geothermal Zone

This zone includes Ji-He mountainous area, Luliang Mts, Fen-Wei Valley, Chinling and Qilian mountains, etc. Tectonically the zone belongs to the Qilian-Luliang-Helanshan epsilon type (according to the geomechanic theory established by the late Prof. J.S. Lee), which shows obviously the tectonic movement in the Neoid period. It is a recent active zone where earthquake has a high frequency and intensity. In this arc-shape zone, thermal springs are very common, their temperatures being relatively low, generally 40°-60°C. Some of the springs on the east and west flanks of the zone, for example, in the eastern part of the Yingshan Mt. and in Qinghai region, have relatively high temperatures which may reach about 90°C or so. These areas are the composite part for several sets of fractures, where thermal water has been found in some valleys and basins like Fen-Wei Valley, Longdong Basin and the piedmont of Hexi Corridor plain. The ground temperature in Longdong Basin is relatively low, while in Sian, it is about 55°C/1000m. On the whole, the prevailing temperature of thermal water is low, therefore this zone belongs to low-temperature thermal water type.

III. ANALYSIS OF GEOTHERMOGENESIS

From the distribution of geothermal water in China, it occurs largely in the coastal region along the shore of the Pacific Ocean in East China and in the Zang-Dian region of southwest China. The water has fairly high temperature, compared with that in other regions. This characteristics has a close connection with the geotectonic position, the concrete feature of geologic structures and magmatic and seismic activities in China. Geotectonically, the major part of China belongs to the Eurasian plate. The eastern side of the continent is influenced by the movement of the Pacific plate. Taiwan province lies just on the junction part between the Eurasian plate and the Pacific plate. Whereas Southwest China is affected by the movement of Indian plate. On the collision belt between the Indian and the Eurasion plates lies the Himalayan tectonic zone.

Zang-Dian geothermal zone is the eastward extended part of the Mediterranean tectonic belt. Its extension follows the seismic belt that passes from the middle of the Atlantic, eastwardly through the Mediterranean Sea and then the Middle East, finally into Xizang of China. The formation of the Zang-Dian geothermal zone is probably related to the collision between the Indian and the Eurasian plates. Since the Indian plate is continually moving northward and downthrusting, the thickness of the crust in Qing-Zang plateau must have been increased, and consequently intense compression and fracturing have taken place. Meanwhile under the action of heat, part of the crust might be again turned into a molten state, forming a kind of remelted granitic magma, which may go up along the fractures. This seems to be the explanation for the new magmatic activity appearing so frequently deep under the plateau. In West Yunnan, which should be on the eastern side of the upthrusting part of the Eurasian plate, also happened a series of fracturing and magmatic activities which lead to intermittent volcanic eruptions since the Tertiary and the Quaternary. Besides, the structural fractures produced since the Cenozoic often provide favourable passages for hydrothermal activities. All the above mentioned are the major causes and factors for the intense geothermal activities in Zang-Dian region.

The eastern part of China is mainly influenced by the westward movement of the Pacific plate. In southeast China, Taiwan which lies in the boundary zone between the two great plates Pacific and Eurasian is at the same time subjected to the northwestward compression of the Phillippine plate. A series of Neotectonic movement accompanied by earthquakes and volcanic eruptions often take place there. The recent volcanic eruption and magmatic activity no doubt have provided the conditions for intense hydrothermal activities, and also imposed some effects on the southeast coastal region of the continental part of China, where a series of NE trending fractures produced by Neotectonic movement control the spatial geothermal distribution. In addition, the coastal region and the adjoining sea area where the earth's crust is relatively thin (25-30km) is the place where the upper mantle materials may force upwards along the fractures. So the heat value is quite high in the realm of continental shelf and offshore area, according to incomplete statistics. However, as the recent boundary between the two plates has already moved to the eastern side of the Phillippines, comparatively remote from the continent, the hydrothermal activity in the southeast coastal region becomes weaker than that in Taiwan.

Magmatic activity is also considered to be the main cause for the thermal anomaly in China. For instance, volcanic eruption and magmatic activity in West Yunnan, Taiwan and

Xizang have directly induced the hydrothermal activities in these regions. In other areas, the occurrence of many thermal springs has a direct relationship to magmatic rocks. For example, in the southeast coastal region such as Guangdong, Fujian, etc., magmatic activity has been very frequent since the Mesozoic. Volcanic rocks and intrusive masses are distributed in large areas where numerous thermal springs gush out with relatively high temperatures. In Fujian, especially in its coastal area, more than 90% of the thermal springs occur in the Jurassic volcanic rocks and Yanshanian granites. About 40% of the thermal springs in Guangdong is related to the occurrence of rock mass.

As for the magmatic activities in Fujian and Guangdong, there is a gradual migration, either in space from northwest to southeast or in time from the ancient to the recent; similar for the sedimentary formations and volcanic eruptions of different geological times; as well as for the metamorphosed rocks which show a tensency of increase in metamorphism from northwest to southeast. All these imply that in this region the structural activities are intensified from the northwest inland towards the southeast coast, and the active zone migrates gradually eastward. It can noted that not only the distribution of geothermal water coincides with that of rock masses, but temperatures of thermal springs increase in NW-SE direction as well.

IV. THE DEVELOPMENT OF GEOTHERMAL RESOURCES

Geothermal energy is one of the important new energy resources in China, which is taken to be very promising. But up to now, it is still under preliminary investigation, its production and utilization are still of relatively small scales. Studies on geothermal resources have to be taken more intensely in respect to their distribution rules, forming conditions and potentials.

To take into consideration the characteristics of the geothermal resources in China, the demands of national economy and the financial possibility and technical feasibility at present, geological investigation and geothermal development have been undertaken in a planned way according to an order of priority.

At present, a number of geothermal areas favourable in various cinditions and accessible for exploitation and utilization in the near future, such as the thermal areas in Beijing, Tianjin, Xizang, Yunnan, Fujian, Guangdong, etc., have been determined the priority areas where direct and comprehensive uses of geothermal energy have been stressed.

In Beijing and Tianjin districts, geothermal water is mainly used for space heating and hot water supply. Within the range of known anomalies, exploration is being carried on and rational exploitation of thermal water at the depth interval between 1000m and 2000m is underway. Beyond the range, however, searching for new geothermal anomalies is emphasized. Meanwhile, artificial recharge has been practised, as well we the investigation and study on environment protection.

In Zang-Dian region, geothermal steam is mainly used for generating electricity whereas thermal water is used for other purposes. The priority of prospecting and development is focussed on thermal resources over 100°C. The major projects in this region are the geothermal fields in Yangbajing, Xizang; and in Tengchong, Yunnan.

In Fujian and Guangdong, thermal water is commonly used for industry, agriculture and civil purposed. In other promising areas, geothermal development are to be initiated, e.g., in North China Plain and other areas, thermal water encountered during oil exploration is going to be put into full use to meet partly the agricultural and domestic needs. In Dengwu, Guangdong; Huitang, Hunan; Yichun, Jiangxi; Huailai, Hebei; etc., thermal water less than 100°C have been used, to build six experimental geothermal power stations of several tens to hundreds of kilowatts by using the flashing or media methods. Some of the power stations have been put into operation for several years, and data on these pilot plants are available for solving the electricity problem in remote areas which are rich in geothermal energy but lack of common energy sources and far beyond the reach of power network.

For the guarantee of the exploitation and utilization of geothermal energy, the following measures have been adopted:

1. The priority research work and development of the major areas are put under the national plan and financed by the government; the funds for other areas are involved in respective local plans. During the preliminary reconnaissance, geological survey, geochemical and geophysical prospecting undertaken simultaneously in a planned way. On this basis, those fields that are of good prospects and have favourable conditions will come into the second phase, the phase of exploration and drilling. An exploitation plan can only be made when the geothermal potential is ascertained.

2. Specialized personnels engaged in geothermal geology are assigned to work in different areas and in different departments, in order to stimulate theoretical geothermal study and regional investigation, to make clear the characteristics, distribution and potential of the geothermal resources, and to improve the prospecting techniques, appraisal methods and

utilization technology. The possibility of geostatic heat existing in Bohai Gulf, Beibu Bay (Tonkin Gulf), etc., are being investigated by relevant units. Also hot dry rocks are payed attention to.

3. Based on the occurrence of geothermal resources, the financial and technical possibilities in China, the priority is laid on the geothermal potentials within the depth of 2000m. They are chiefly for direct use in a comprehensive way suitable to local conditions, so as to obtain the benefits to its fullest.

4. Emphasize the protection of geothermal resources and pay attention to the intense study especially on geothermal fluid, make comprehensive use of it as a mineral resource form which industrial raw materials can be extracted, and by which diseases can be cured.

5. Require rational exploitation of the recoverable but not unlimited geothermal resources. Overdrawn would lead to exhaustion and environmental problem. Practise and expand the use of artificial recharge in order to increase the replenishment and reduce or eliminate thermal pollusion, land subsidence, etc.

Geothermal energy development is quite a complicated problem that need thorough study. Difficulties especially technological problems would emerge with time and need to be tackled to bring about a further advancement in the development and utilization of geothermal energy in China.

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Geothermal Resources and Their Present State of Research in China

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ABSTRACT

The distribution of geothermal resources in China is controlled by tectonic plate movement. A good many high-temperature geothermal fields have been found in Tibet, Yunnan, and Taiwan. All are situated on suture lines. Elsewhere in China they consist mainly of thermal water of medium or low temperature. So far, geothermal resources are being employed in industry, agriculture, the people's daily life and other fields. Geothermal energy has begun to be used for power generation.

Methods of exploitation and research are varied. Successful temperature measurements of shallow bores in Beijing were conducted in 1970. On the strength of temperature data obtained from shallow bores at a depth of 70 m., we found underground hot water southeast of the city, and marked out an geothermal abnormal area of 30 square kilometers there. So far it has been tapped by more than 20 wells with depth ranging from 650 to 2600 m. and water temperatures from 38°C to 69°C. Meanwhile gravity, radon analysis and other methods are being used to detect geothermal faults in the abnormal heat area.

Since 1975 geothermal exploration has been carried on in the Yang-bajan wet steam geothermal field in Tibet. A number of geothermal wells with depths ranging from 68 to 1007 m. have been drilled and the maximum temperature in the bores reaches 172°C. China's first 1000 kw. experimental wet steam power station was built in Yangbajan in 1977, and

now a 6000 kw. power station is under construction. On the basis of analyses of rock strata, temperature and the chemical composition of geothermal flow we arrived at the important conclusion that thermal flow does not come from beneath the southern part of the field, where many hot and boiling springs can be seen, but from beneath the area further north the south-eastern foot of the Ngaingentanglha Mountains.

INTRODUCTION

China is rich in geothermal resources. More than 2000 thermal outlets are known so far. They are mainly concentrated in the Tibet Autonomous Region and Yunnan Province in the south-western part of China, in Taiwan, Fujian and Guangdong provinces in the east. Fig. 1 shows the main geothermal fields in China. There are 110 in number. They have a fairly high temperature in each locality. Some of them have been investigated and explored. According to their known temperatures these fields are classified in three categories: 1. Wet steam geothermal fields (with temperatures exceeding the local boiling point, which ranges from 82°C to 100° C in relation to altitudes from 5500 m. to 0 m. above sea level); 2. High temperature water fields (with temperatures from 65°C to the local boiling point); 3. Medium temperature water fields (with temperatures from 40°C to 65°C).

Geothermal surface manifestations in Tibet and Yunnan are most impressive with many hot or boiling springs and geysers. For instance, in the Yangbajan geothermal field there are the West Boiling Spring (photo 1), the Hot Water Lake (photo 2) and so on. Hydrothermal explosions occur in these areas. On the fourth of December 1977 I saw with my own eyes a hydrothermal explosion at well no. 1 at Yangbajan. I went outside my house as soon as I heard an explosion. I looked at the sky, and saw steam and hot water mixed with stone and earth flying into the air to a height of one hundred metres and then falling over

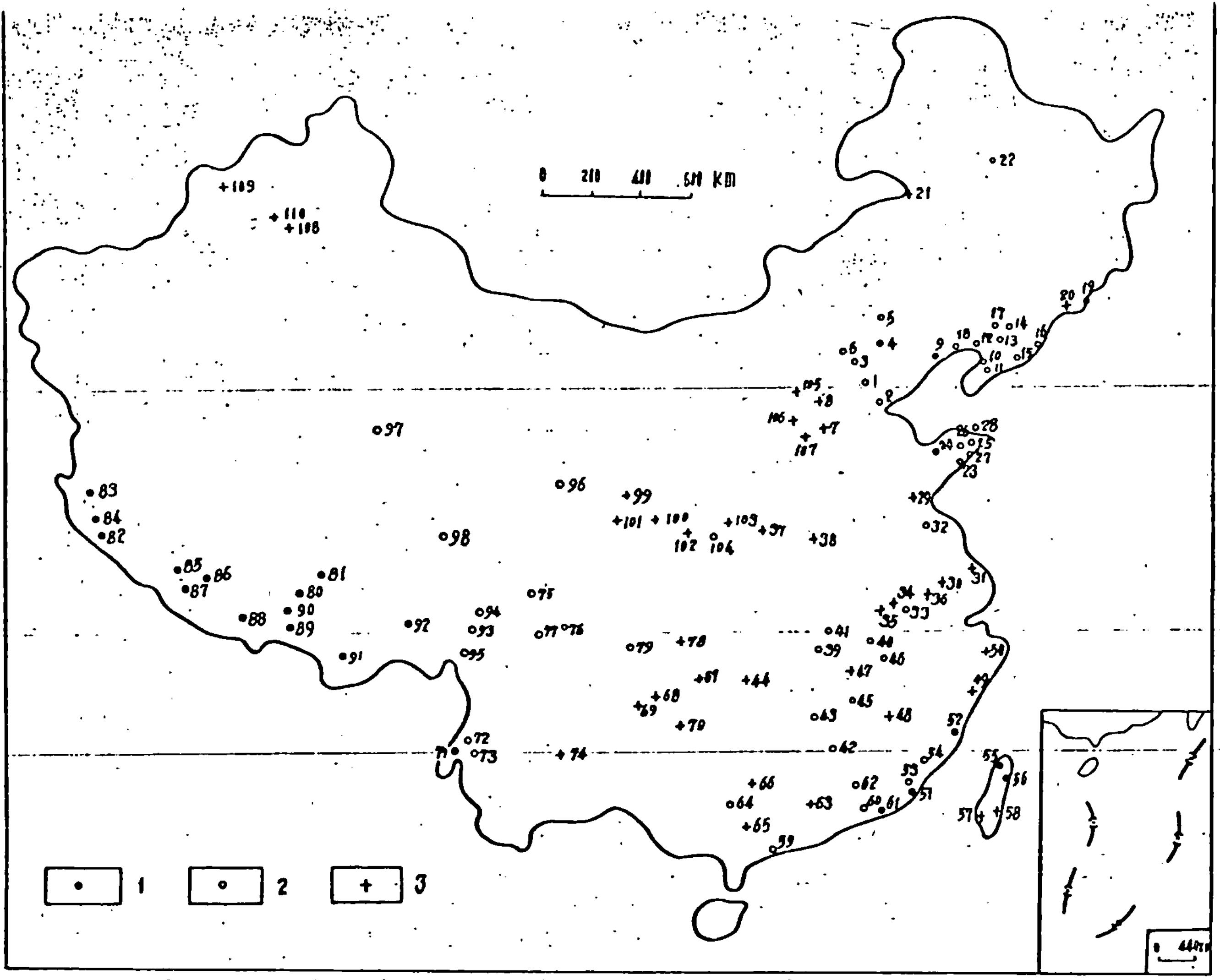
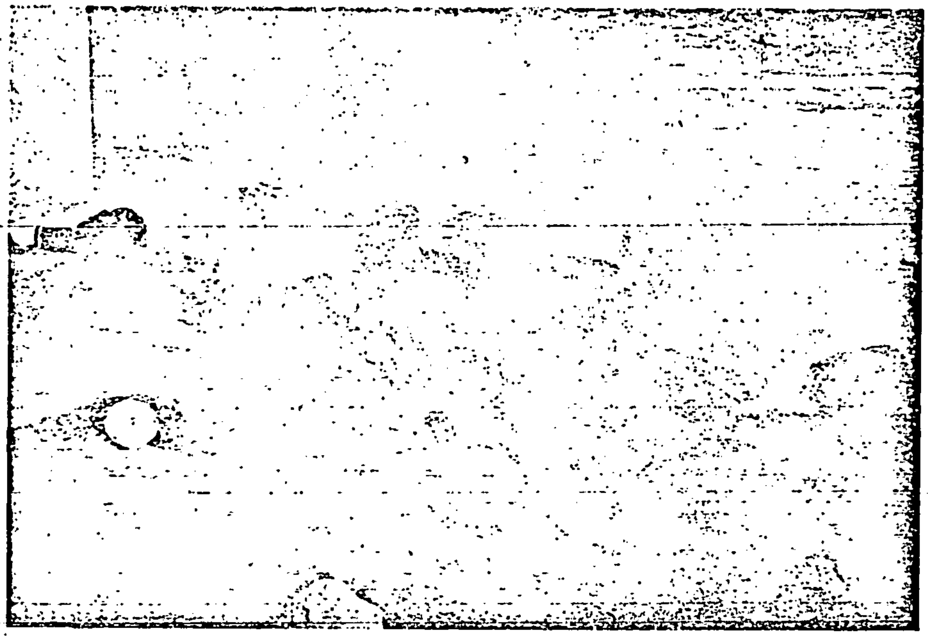


Fig. 1. Distribution of main geothermal fields in China

1 — wet steam geothermal fields; 2 — high-temperature water fields; 3 — medium-temperature water fields.

1- Beijing city 73°c	2- Tianjing city 82°c	3- Huailai 89°c	4- Longhua 79°c	5- Weichang 74°c
6- Chicheng 68°c	7- Pingshan 74°c	8- Fuping 61°c	9- Ningcheng >100°c	10- Gaixian 88°c
11- Xiongyue 80°c	12- Panshan 98°c	13- Danggangzi 72°c	14- Benxi 71°c	15- Fengcheng 70°c
16- Dandong 70°c	17- Liaoyang 71°c	18- Xingcheng 70.5°c	19- Antu 76°c	20- Hunjiang 62°c
21- Arxan 48.5°c	22- Songliao 83.8°c	23- Dongwenquan 89°c	24- Tangdonggou >100°c	25- Hongshui 71°c
26- Gilitang 77°c	27- Hulutang 68°c	28- Weihaitang 79°c	29- Linyi 56°c	30- Tangshan 60°c
31- Xiaohai 62°c	32- Tangmiao 94°c	33- Lujiang 67°c	34- Shucheng 63°c	35- Yuexi 50°c
36- Hexian 45°c	37- Sanmenxia 61°c	38- Linru 63°c	39- Shashi 97°c	40- Yingshan 72.5°c
41- Tangchi 73.2°c	42- Rucheng 91.5°c	43- Huitang 91°c	44- Yongshun >60°c	45- Suichuan 82°c
46- Xingziyiekou 72°c	47- Xiushui 62°c	48- Jinyi 56°c	49- Jiaxi 62°c	50- Ninghai 50°c
51- Zhangzhou 120°c	52- Fuzhou city 106°c	53- Nanjing 80°c	54- Dehua 89°c	55- Datun 293°c
56- Yilan 226°c	57- Binan 51°c	58- Pingdong 47°c	59- Yangjiang 97°c	60- Fengshun 92°c
61- Chaoan 103°c	62- Xingning 82°c	63- Conghua ~45°c	64- Quanzhou 88°c	65- BeiLiu 52°c
66- Pingie 45.5°c	67- Wuchuan 56.5°c	68- Huahuai 50.5°c	69- Jinsha 50°c	70- Xifeng 56°c
71- Rehan 145°c	72- Ruizhen 90.4°c	73- Panzhi 96.9°c	74- Anning 46.9°c	75- Ganze 90°c
76- Kangding 92°c	77- Litang 80°c	78- Beibei 45°c	79- Sichuan Basin 99.1°c	80- Yangbajan 172°c
81- Gulu 86°c	82- Pulan 86°c	83- Soduo 85.5°c	84- Qupu 95°c	85- Angren 86°c
86- Chabu 96.4°c	87- Kenglan 88°c	88- Kayu 88°c	89- Nyemo 86.5°c	90- Burou 87°c
91- Tuduo 88°c	92- Tongmai 94°c	93- Chapu 78.5°c	94- Badong 75°c	95- Bazong 73°c
96- Guide 93.5°c	97- Qaidam Basin 65°c	98- Yueshui 72°c	99- Dongyui 60°c	100- Qingshiu 53°c
101- Wushan 42°c	102- Meixian 59.8°c	103- Lingdou 43°c	104- Xian city 69°c	105- Hunyuan 63°c
106- Yuxian 54°c	107 Qixian 52°c	108 Shawan 52°c	109- Wenquan 48°c	110- Wusunan 45°c



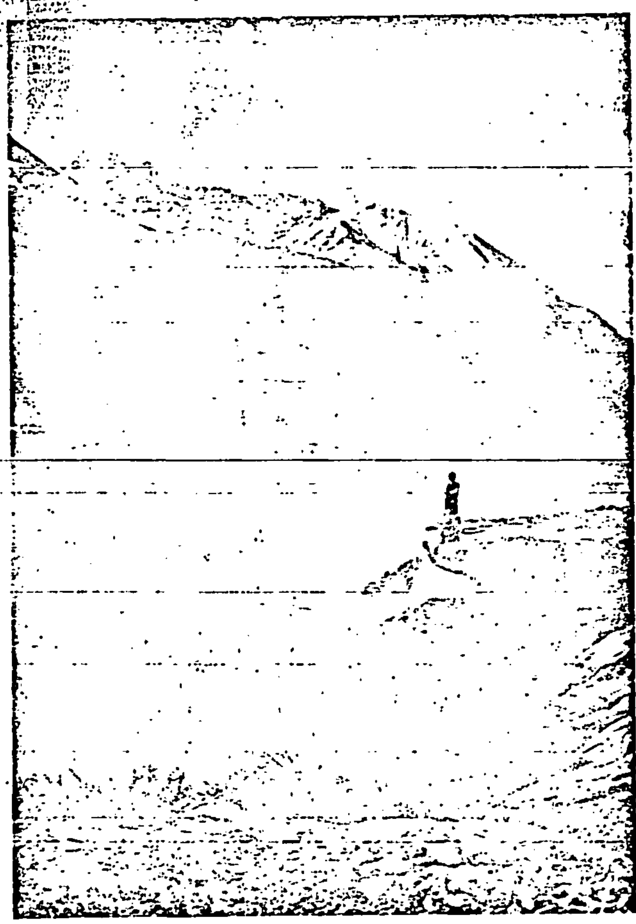


Photo 1. (Top). West Boiling Spring ($92^{o}c$). The boiling point at that altitude is only $86^{o}c$.

Photo 2 (left). Hot Water Lake ($50^{o}c$), surface area 7,350 square meters.

an area almost one hundred metres in diameter. The explosion lasted three minutes. One person was injured. A hot water pool was formed there (photo 3). Tibet has the world's highest geothermal field (Angren), with an altitude of 5500 m. and a fumarole temperature of 86°C.

Exploration and utilization of geothermal energy has been done in China for more than 2,000 years, but wide spread geological exploration and utilization have begun only since the early 1970s. Prof. Li Siguang who died in 1971 did much to push geothermal work forward. He said, "The tapping and utilization of geothermal energy is as important an event as the discovery that coal and oil can burn." Explorations by hydrogeologists in Beijing and other places have brought to light underground hot water resources. In 1970 the first experimental geothermal power plant was built at Fengshun, Guangdong province. Since 1975 geothermal exploration has been carried out in Tibet's Yangbajan. So far well no. 9 has the best parameters: depth 87.25 m., 169 tons of water and 21 tons of steam per hour at a wellhead temperature of 148°C and pressure of 4.62 atm. The estimated electricity potential is 1978 kw (photo 4). In 1977 the first experimental wet steam power plant was built there. (photo 5).

Geothermal water is also used in the glue, paper-making, spinning and weaving, cement-making and tanning industries and supplies boilers and heaters for workshops. For example, a geothermal well yielding over 1,000 tons per day at 48°C was sunk in 1973 at the Guanghua Dying and Weaving Plant in Beijing. It serves 4 dying and 2 desizing machines, and saves 2,500 tons of coal and 135 tons of salt annually. In less than one year the money economized was equivalent to the cost of the well. The chemical industry extracts I, K, Li and other substances from hot brine. Some geothermal areas produce sulphur.

Hot water is widely used in agriculture and sideline production,

Photo 3 (left). Hot Water Pool (56°c), surface area 100 square meters, formed as a result of a hydrothermal explosion.

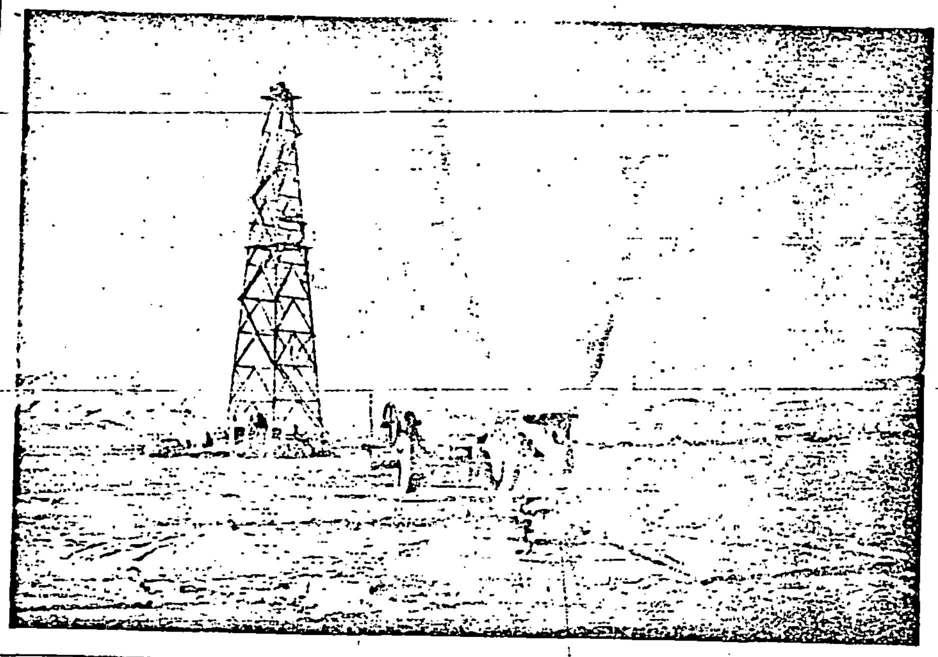


Photo 4 (right) Bore No 9 discharges vertically. Beside it, a new geothermal well is being drilled

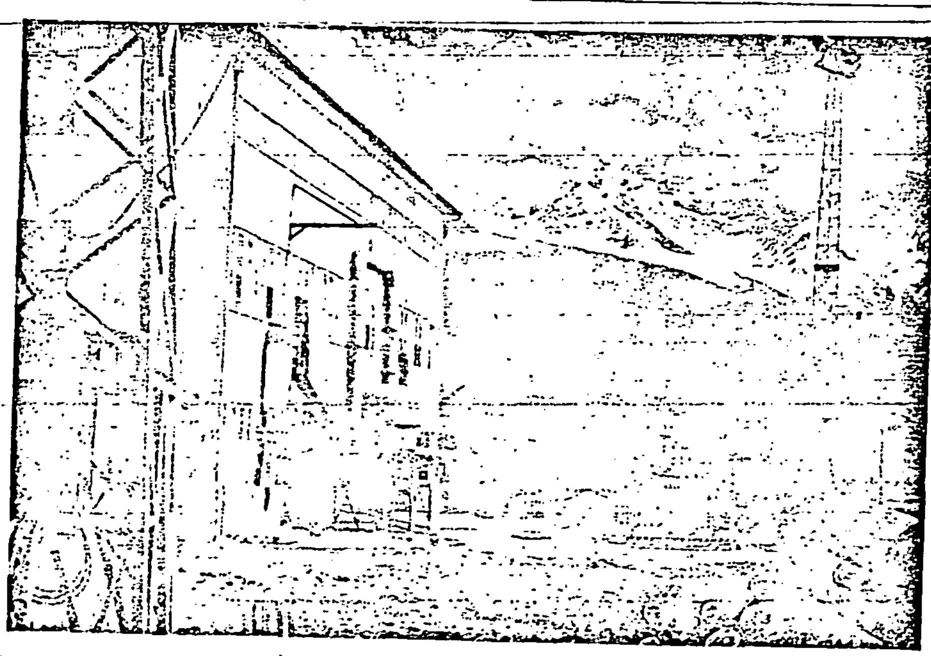


Photo 5 (left). The Yangbajan experimental geothermal power plant with a designed generating capacity of 1,000 kilowatts.

as for instance in cultivating paddy rice, heating hothouse and chicken and duck hatcheries, raising tropical fish, watering cabbages and hyacinths. In Rucheng Hunan, a greenhouse with an area of 4,000 square meters has been built.

The widest application of underground hot water is in people's daily live. The city of Beijing has established over 20 geothermal public bathhouse, where 30 to 40 thousand persons can take a bath every day. Hot water containing radon, sulphur and other useful elements has been shown to have a curative effect on suffers from dermatosis, rheumatism and arthritis. China has more than 100 sanatoriums with warm springs. Recently, more and more houses are using underground heat for heating. In Beijing 50,000 sq.m. of indoor floor space is now being heated with geothermal water with a temperature of 53° - 59°C, maintaining room temperature at between 15°C and 20°C even in the coldest time of winter.

Undoubtedly, the direct use of geothermal water is the most efficient way of obtaining heat and water.

DISTRIBUTION OF GEOTHERMAL RESOURCES AND THEIR ZONATION

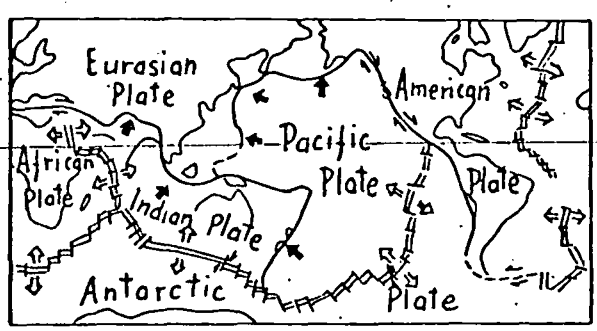


Fig 2 Scheme of six big plates in the World

It is a widespread conception that the world can be divided into six big plates. (Fig. 2) The thick lines are suture lines between the plates. The distribution of geothermal belts is connected with these suture lines.

Prof. Zhang Bosheng in his article "Chinese Wavelike Inlaid Structure" points out: "In China it is obvious that there are two series of crustal waves, one is the Pacific wave series, the other - the Mediterranean wave series. These two groups of wave series are intermingled in

China. Thus oblique square net-like structures regularly occur." This means that the above mentiioned two wavelike series were the main controlling factors in the formation of the earth's structure in China. We believe that a similar condition exists so far as geothermic heat is concerned.

The Mediterranean geothermal belt goes through southern Tibet and western Yunnan and the Pacific Ocean geothermal belt passes through Taiwan. The geothermal distribution of other regions is obviously affected by these two geothermal series (Fig. 3).

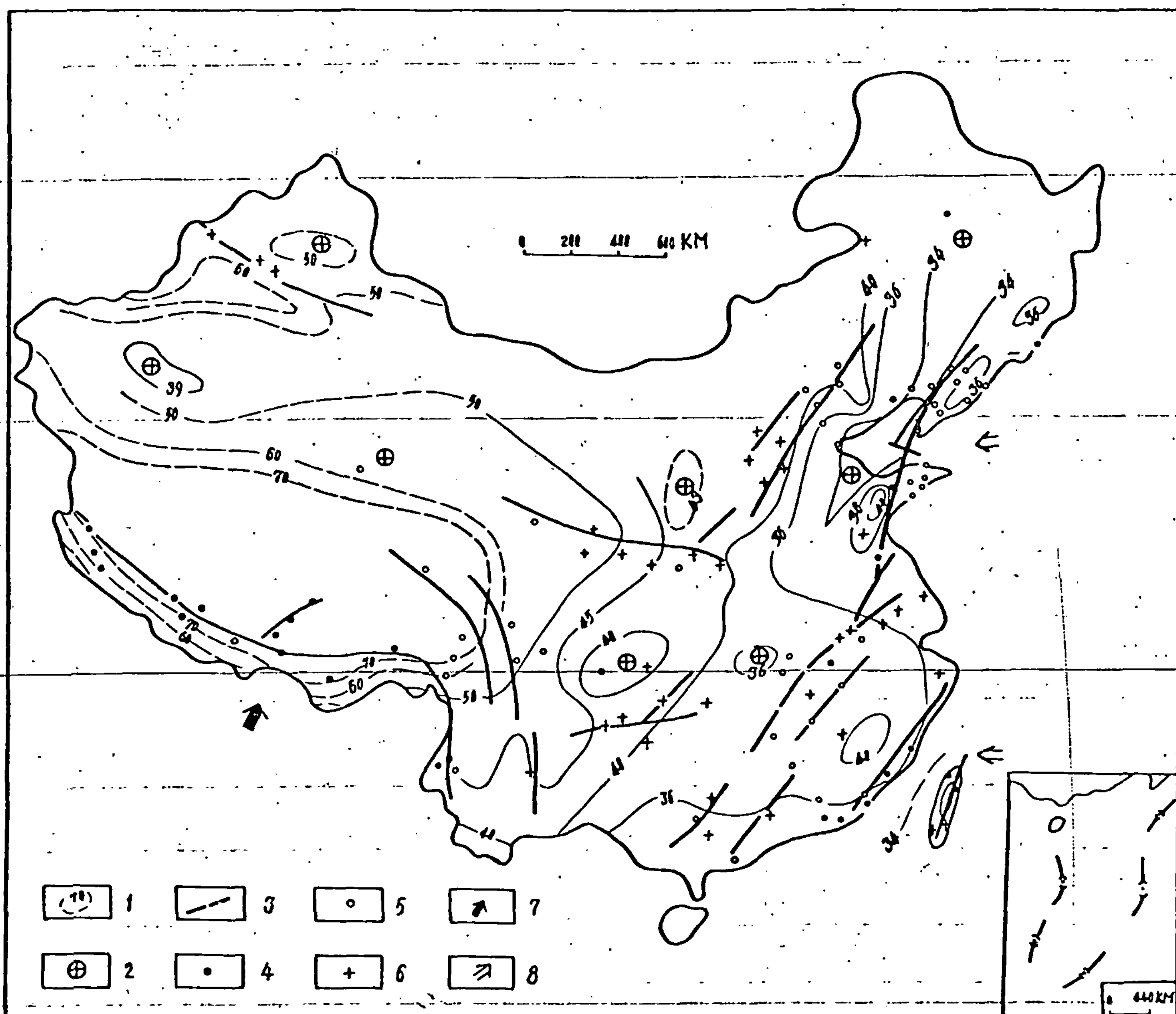


Fig. 3 Scheme of apparent thickness, gravity anomaly, geothermal faults of the crust in China and their relation to geothermal areas

1 – isopach of the crust (Km); 2 – gravity positive anomaly; 3 – geothermal fault; 4 – wet steam geothermal field; 5 – high temperature water field; 6 – medium temperature water field; 7 – direction of movement of Indian Plate; 8 – dive direction of Pacific Plate.

Figure 3 shows that the distributive direction of geothermal fields coincides with the direction of the main faults. The southern Tibet and Western Yunnan geothermal belt is situated along the Yarlung Zangbo River extending from west to east in Tibet and turns to the south in Yunnan. Both the faults and the distribution of geothermal fields are arc-shaped. Things are different in the eastern part of China. Both the faults here and the distribution go in a north easterly direction. The fact is, these directions coincide with the suture lines of tectonic plates.

In or near the suture lines of the plates, geothermal fields are characterised not only by quantity, but also by their high temperature. The maximum temperatures measured in the bores in Tibet and Taiwan are 172°C and 293°C respectively, and there are wet steam geothermal fields. The regions sited near the belts - Sichuan and Qinghai in the southwest and Liaoning, Shandong, Fujian and Guangdong in the east - are also comparatively rich in geothermal resources. In these provinces there are a lot of high temperature water fields. In the central or north-western part of China, further away from the sutures, there are a few medium or low temperature water fields.

It is common knowledge that geothermal distribution is controlled chiefly by new geotectonic movements and magma activity. Geothermal heat itself is a reflection of this fact. Since the Cenozonic Era, the Qinghai - Tibet Plateau has been uplifting to become the "roof of the world", as a result of the Indian Plate moving up into the Eurasian Plate, accompanied by a huge amount of granite intrusion. It is apparent that the geothermal fields in Taiwan and along the eastern coast of China have been formed by the Pacific Plate plunging into the Eurasion Plate since the Mesozoic Era. Magma explosions and intrusions have taken place in these areas. There is no doubt that the formation of geothermal areas is closely connected with the above facts.

From Fig. 3 we can also see another feature of geothermal distribution.

Geothermal area can be divided into two types. One type is the foremountain type, the other -- the basin type. Some geothermal fields are located on the border between mountains and plains. The chief characteristic of the fore mountain type is that hot springs appear directly on the basement rocks or in places where there is little caprock. They are located in the zones where the thickness of the crust varies greatly. The most typical place is the Wet Steam Geothermal Zone in southern Tibet and western Yunnan, which is situated right where the isopach of the crust ranges from 50 to 70 km. Other examples are the eastern high-temperature water zones. These are concentrated on one side of a fore mountain or hill, where the crust is thicker. In the case of the basin type, the thermal flow is covered by overlying sediment, and gravity positive anomaly can be found.

In view of the above points, firstly, China's geothermal resources can be divided into two regions, the Western geothermal region and the Eastern geothermal region. Secondly, each geothermal region can be divided into several zones and basins (Fig. 4).

It should be noted that the geothermal fluids in China differ in their contents. The geothermal fluids on fore mountains or on the coastal line usually have a lower degree of mineralization: from $>$ 1 g/l to 3-5 g/l, mostly of the types $HCO_3 \cdot Na$, $HCO_3 \cdot SO_4 - Na \cdot Ca$ and so on, and containing more F, HBO_2, SiO_2, Li, Sr, etc. But in the confined basins of the interior regions of China another condition prevails: For example, in the Qaidam basin some geothermal fluids have a mineralization as high as 386.5 g/l and contain K (28.75 g/kg) and Sr (2.5 g/kg), higher than the contents of K (25 g/kg) and Sr (2 g/kg) in the Salton Sea and Potash-oil test in the United States, said to be the highest in the world. Furthermore, the Ba content (2.87 g/kg) of the fluid from artesian wells in the Sichuan basin is the highest in the world.

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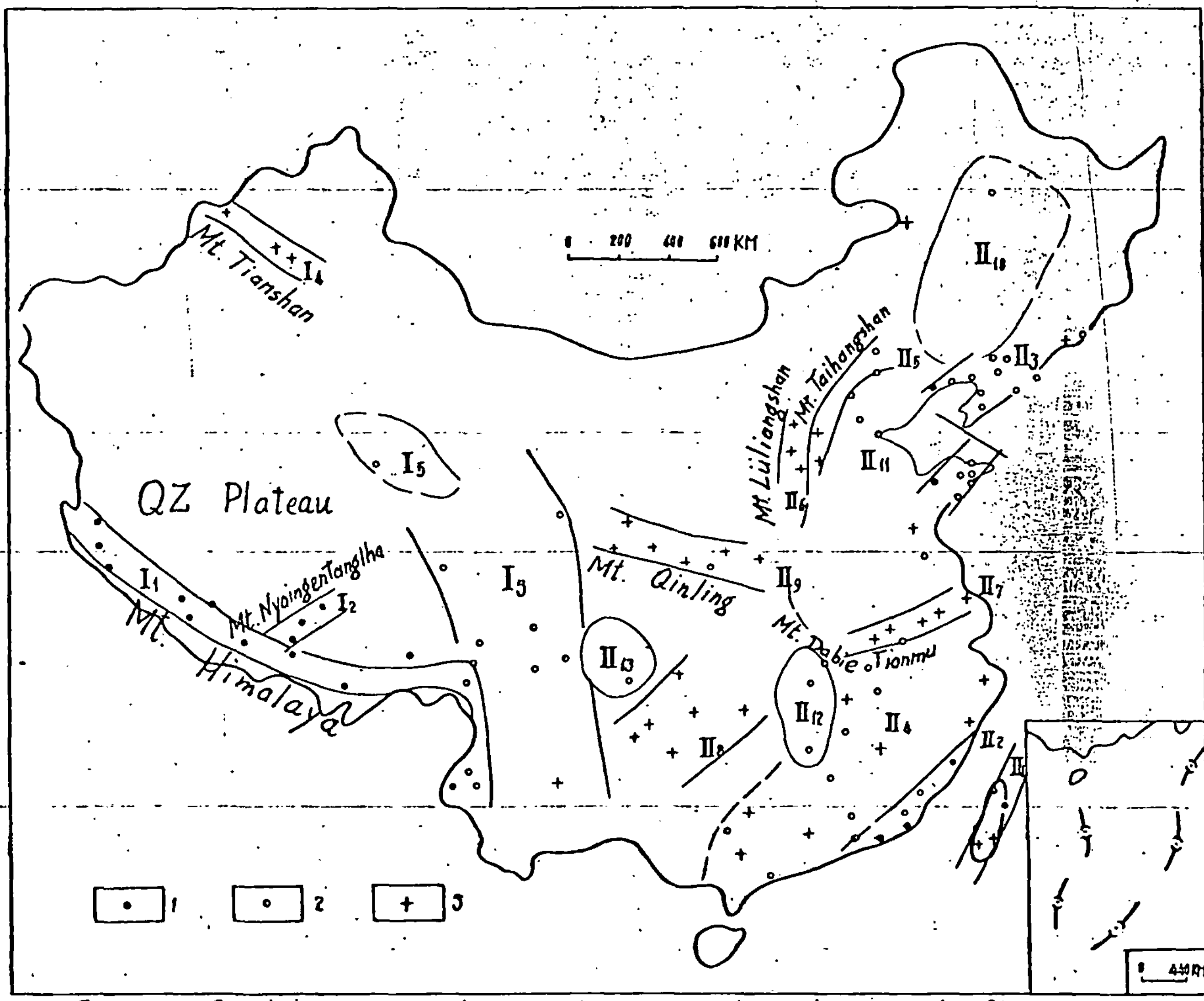


Fig. 4 Sketch map of the zonation of geothermal areas in China

1 – wet steam geothermal field; 2 – high temperature water field; 3 – medium temperature water field.

I – Western geothermal region (the Mediterranean geothermal belt and area affected by it):
I_1 – Southern Tibet – Western YN wet steam geothermal zone; I_2 – West steam geothermal zone on foremountain Nyaingentanglha; I_3 – High temperature water zone on the eastern margin of QZ Plateau; 4 – Medium temperature water zone on foremountain of Tianshan; I_5 – medium and low temperature water basin in Qaidom.

II – Eastern geothermal region (the Pacific geothermal belt and area affected by it):
II_1 – Taiwan steam geothermal zone; II_2 – FJ-GD high temperature water zone; II_3 – LN-SD high temperature water zone; II_4 – Medium and high temperature water zone on south-eastern hill; II_5 – Medium and high temperature water zone on foremountain of Taihang; II_6 – Medium and low temperature water zone on foremountain Lüliang; II_7 – Medium temperature zone on foremountain of Dabie-Tianmu; II_8 – GZ medium-low temperature water zone; II_9 – Medium temperature water zone on foremountain Qinling; II_{10} – Songliao high temperature water basin; II_{11} – Huabei medium-high temperature water basin; II_{12} – Jinghan high temperature water basin; II_{13} – SC medium temperature water basin.

Finally, about the geopress-geothermal resources on the eastern coast and the continental shelf, I would like to mention that oil drilling in these areas at a depth of about 3,000 m. has revealed temperatures of around 142°C. This is a problem which needs further research.

GEOTHERMAL EXPLORATION AND RESEARCH

Geothermics is a complicated subject, and geothermal exploration requires the use of various methods. Those applied or tested in China include geological investigation, temperature measurement in shallow holes, geophysical and geochemical explorations, drilling, airborne infrared surveys, micro-earthquake measurement, reinjection of cold and waste hot water, and studies of "harmful heat" in mines.

It is impossible to give a detailed description here of all these aspects, and to introduce some aspects it may be better to give two examples to show how some methods of exploration are used in practice.

The first example - Beijing Geothermal Field. Beijing City is situated in the Huabei plain. There were no springs on the surface, so that the first problem was finding a geothermal anomaly in Beijing City. In the early 1970s after studies on the geotectonic geology in Beijing Professor Li Siguang pointed out that underground hot water resources should be explored. At that time we have some gravity material and knew that the city of Beijing was located on the graben. On the basement there were some very thick sediments in which there might be a temperature rise. So the first exploratory bore was made on the central part of the garben. At a depth of 1000 m. shale and sandstone of the Upper-Tertiary period was met, and their temperature was only 30.6°C (54 m/°C on the average), therefore this bore was given up. Meanwhile, the temperature in shallow bores at the depth of about 100 m. (in wells that supply cold water to the city) and detailed geophysical surveys of gravity and electricity were carried out. After measuring the temperature of hundreds of shallow bores using heat-variable resistors, the maximum depth influenced by weather and other factors was determined to be no more than 70 m.

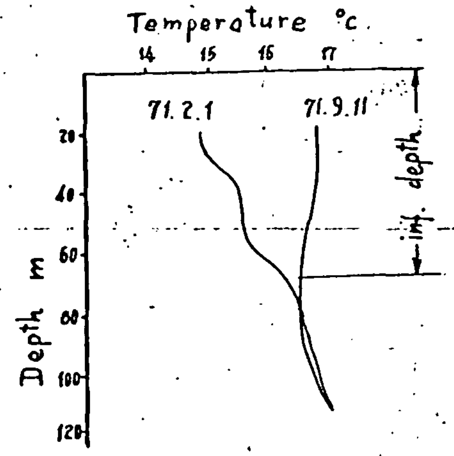


Fig. 5 The maximum depth influenced by weather in shallow bores

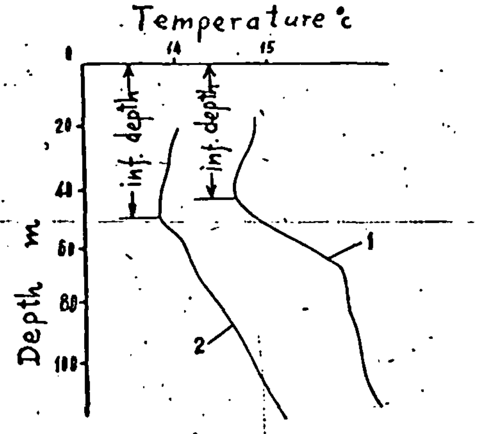


Fig. 6 Typical temperature curves in shallow bores

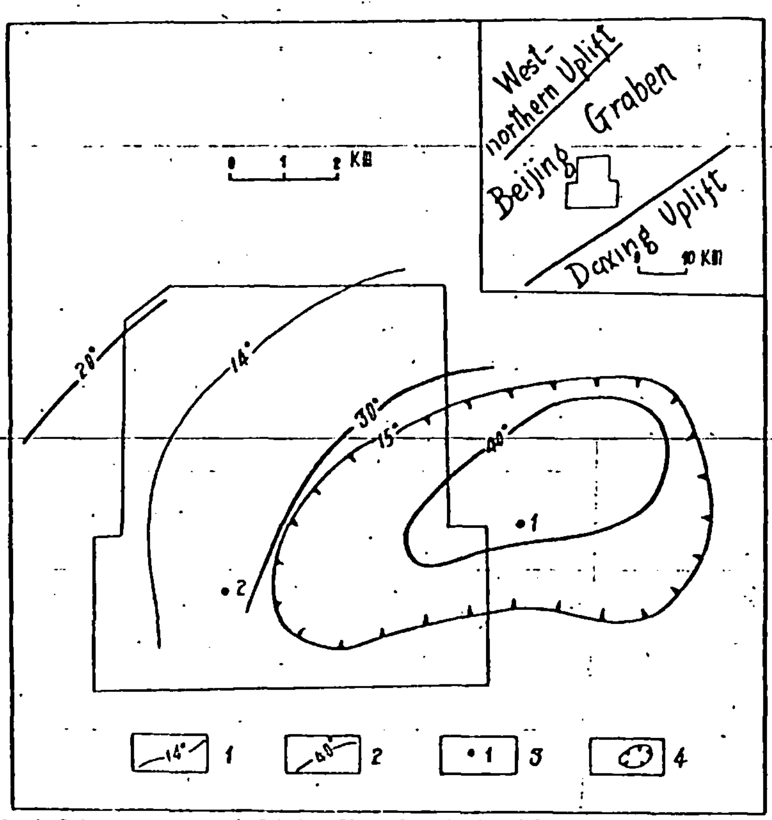


Fig. 7 Temperature map at depth 70m and 700 m in the city of Beijing

1- isotherm, at depth 70m ; 2 - isotherm at depth 700m
3 - typical shallow bores ; 4 - geothermal anomalous area.

(Figs. 5, 6). Then temperature data from every bore at this depth were chosen, and a temperature map at the depth of 70 m. was drawn (Fig. 7). The map showed that in the South-eastern part of Beijing there was a geothermal anomalous area (about 30 sq. km.), where the temperature at the depth of 70 m. exceeded 15°C, in some places reaching 16°C, or 1-2°C higher than in surrounding areas. Further drilling proved that temperature anomalies at a depth of 70 m. reflected the deep geothermal conditions of this area. Because the geothermal gradient in the anomalous area is higher (about 20 m/°C) than in other areas, the temperature at a depth of 700 m. may reach 30-40°C or more. To date, more than 20 geothermal wells have been sited in this area. Each of them brings up about 1,000 tons of hot water every 24 hours, with temperatures of 38-69°C at the well head. This hot water comes from limestone of the Sinian period at about 1,000 m. depth (photo 6).

It should be noted that the gravity survey was successful. The map of gravity anomaly (Fig. 8) shows the geothermal anolamous area in relation to positive gravity anomaly, where max. residual gravity anomaly reaches over 2 mg. It has been proved by drilling that there is a local uplift on the graben, where limestone can be met at the depth of only 400 m., and the limestone is overlaid with basalt of the lower Tertiary period and other layers. This means that about 40 million years ago an active volcano erupted here and basalt lava flowed over the surrounding country side.

Besides, on the northwestern side of the anomaly toward the centre of the garben there are two dense isogradients of gravity (>4 mg/km). The depth of limestone on one side of this zone differs greatly from the depth on the other side. On the other hand, distribution of radon is very useful for the detection of the fault, where the content of radon (max. 43.2 eman/1) is higher than in other places (Fig. 9). In addition, the water level

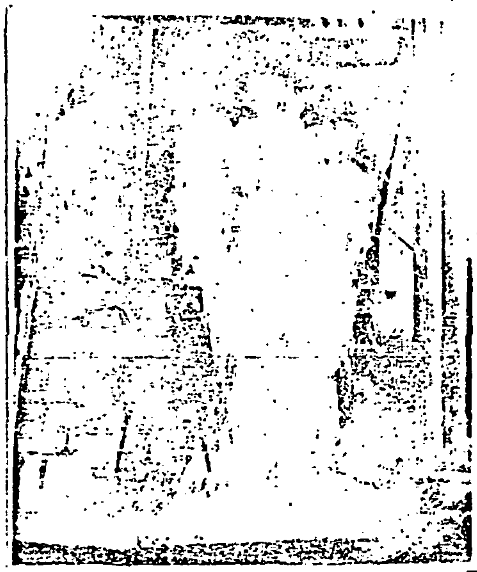


Photo 6. 1,200 m.-deep geothermal well in Xinqiao Hotel with a wellhead temperature of 56.5°C. (photo by Zhen Ke yan)

in the bores in this zone is high in comparison with others, and reduces slowly during exploitation. There is no doubt that this is a deep fault, which may be the main passage for thermal fluids.

Finally, it should be noted that the geothermal anomalous area is the best place for exploiting geothermal energy, i.e. where the best effect can be gained with the least capital outlay. However, geothermal water can also be obtained from the central part of the garben, outside the anomaly. For instance, a bore sited near the central part of the garben met limestone-basement at 2440 m. depth, temperature at the bottom of the bore was 73°C.

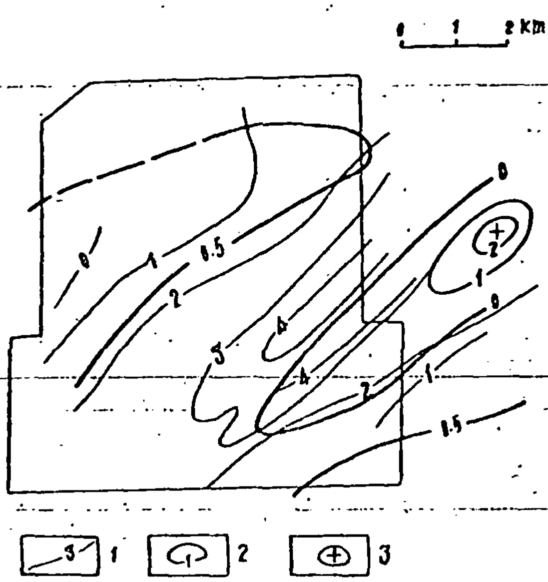


Fig. 8 Gravity anomaly in the city of Beijing
1 - isogradient of gravity anomaly (mg/Km);
2 - residual gravity anomaly (mg);
3 - positive gravity anomaly.

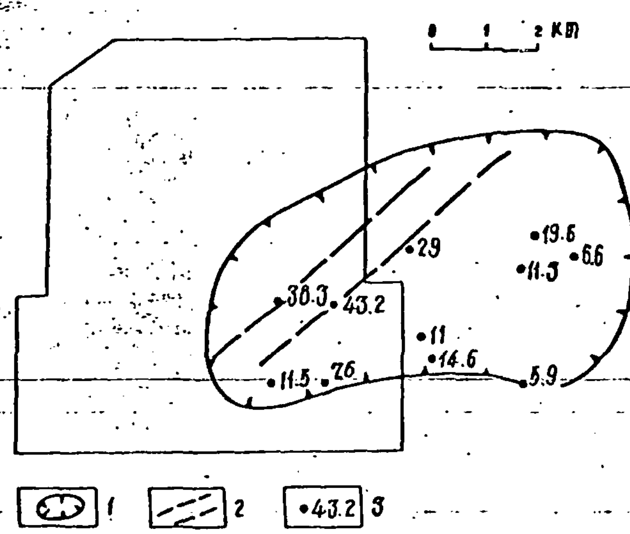


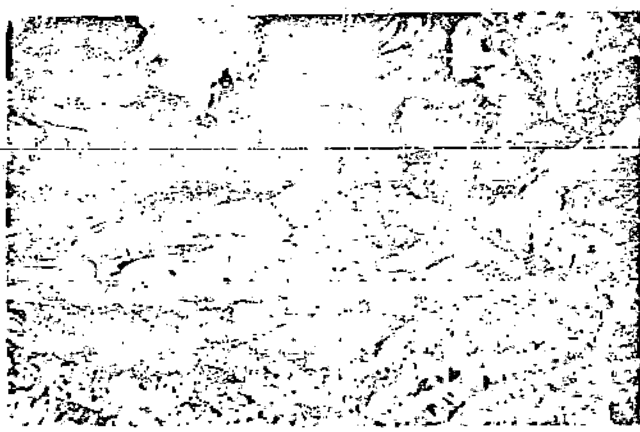
Fig. 9 Radon in geothermal wells in the city of Beijing
1 - geothermal anomalous area; 2 - deep fault;
3 - bores and radon content (эman/L).

Data obtained from drilling indicates that the Beijing Graben was formed during the Cretaceous and Tertiary age.

The second example - Yangbajan wet steam geothermal field in Tibet

This field is located in the elongate basin about 5 km wide and 100 km long at the foot of Mt. Nyaigentanglha, where there are many geothermal fields (Fig. 4). New tectonic movement is very active here. Folds and faults can be seen in the Quaternary layers. The Max. altitude of Nyaigentanglha is over 6,000 m., whereas the altitude of Yangbajan basin is about 4300 m. The main rocks in Yangbajan and surrounding area are gneiss, slate, clastic rock, tuff and granite. Some spectacular thermal manifestations can be seen in the Yangbanjan geothermal field. There are many hot or boiling springs, most of them distributed along the bank of the Zhanbu River. There are also boiling mud pools (photo 7), steam fumaroles (photo 8) and silica sinters (photo 9).

A temperature survey was done to outline the geothermal anomalous area. According to longterm temperature measurement at depths of 0 m. - 3.2 m., we calculated the depth influenced by weather at about 5 m. Therefore, dozens of shallow holes were drilled (Fig. 10). Basing on data from exploration, we came to the important conclusion that the geothermal flow



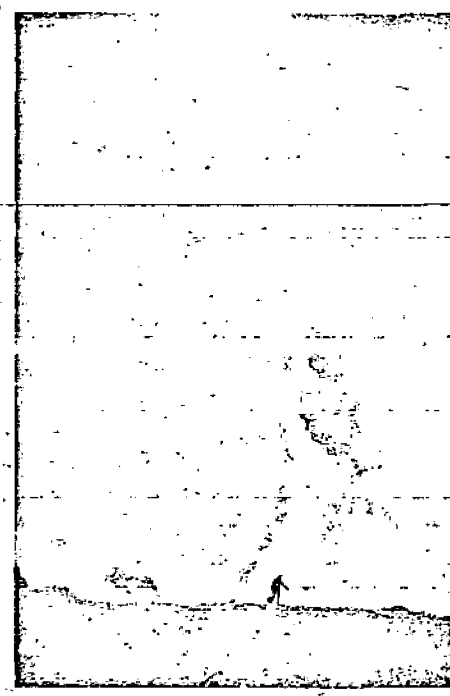


photo 7 (top). The mud pool

photo 8 (right) The steam fumarole

photo 9 The silica sinter

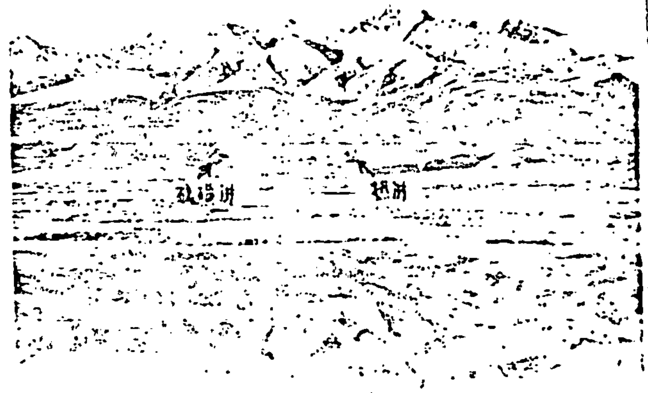


photo 10 View of the Yangbajan geothermal field. Background: Mount Nyaigentanglha Forehill is an alteration area with two gullies which are called "sulphur gully" and "hot gully".

does not come from beneath the southern part of the field, although many springs are there, but from beneath the northern alteration area at the south-eastern foot of Mount Ngaingentanglha. The facts are as follows.

First, between the northern alteration area and Zangbu River to the south one indurated layer of sediments and several fractures filled by veins of opal were found (photo 11). The top of this silicified aquifer varies from a depth of 150 m. in the north to a depth of 70 m. in the south, and from about 250 m. to 100 m. in thickness. As there are a lot of fractures in it, the permeability of the silicified acquifer is high. The geothermal well no. 9 and other wells are productive because of the high permeability of this layer.

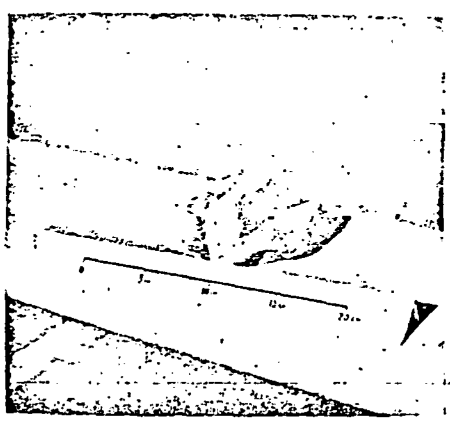


Photo 11 Core from bore no. 13 at 142 m. depth, silicified quaternary sandstone

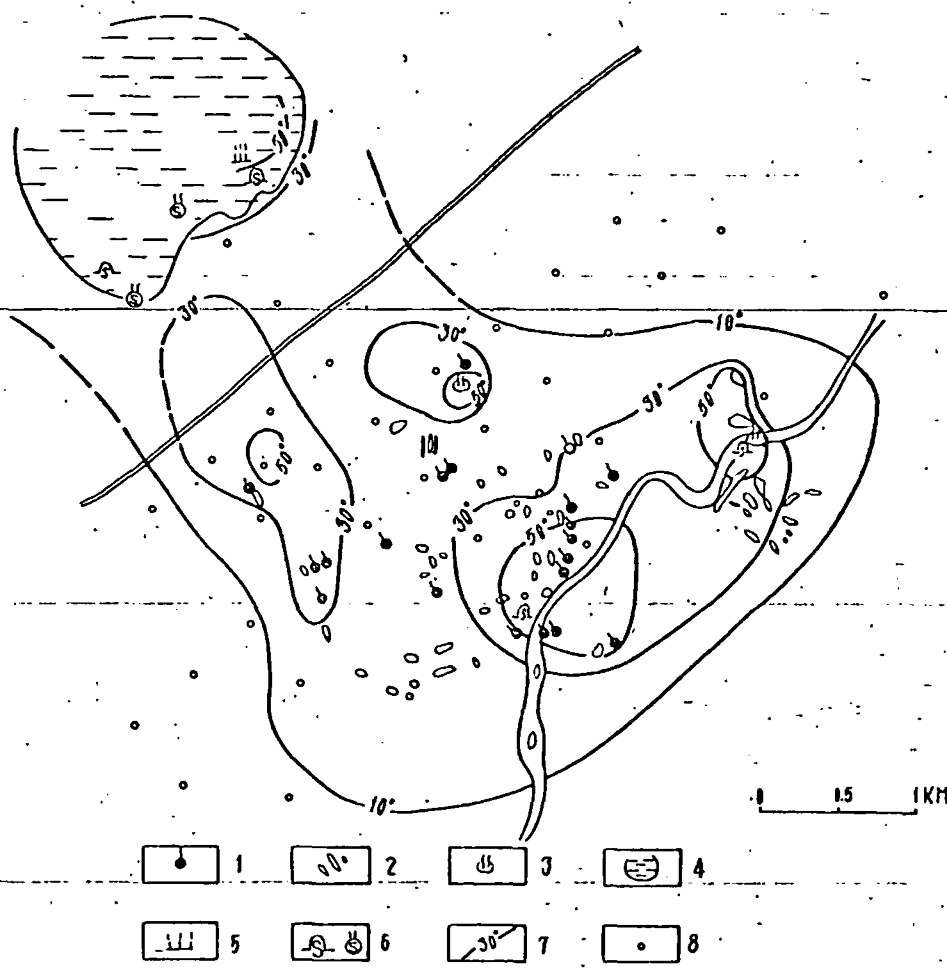
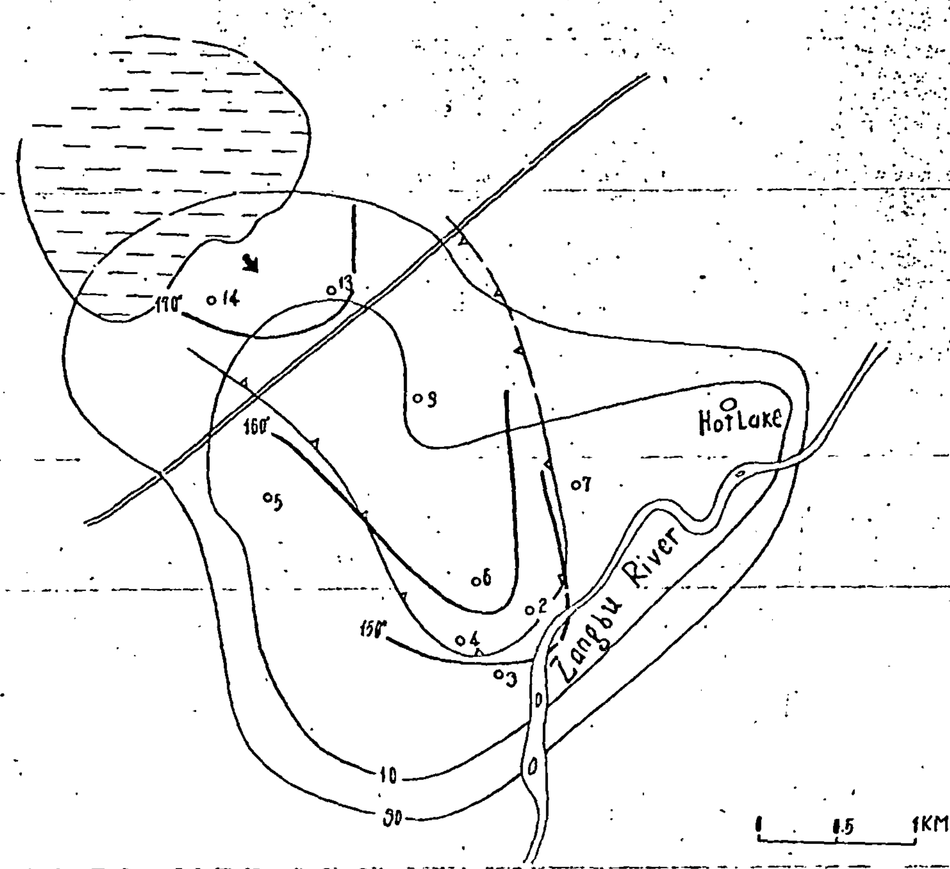


Fig.10 Surface manifestation and temperature at 5m depth in Yangbajan
1 - hot or boiling spring; 2 - silica sinter; 3 - steam fumarole; 4 - hydrothermal alteration area; 5 - steaming ground; 6 - sulfur flower and solfatara; 7 - thermal isoline at 5 m depth (°C); 8 - measuring point of temperature.

Second, this silicified aquifer has a high temperature in comparison to the surrounding area (172°C in the north and 160°C in the south). And the temperature in the southern bores at first rises with increase of depth reaching its highest point in the silicified aquifer, and then falling with further increase of depth (Fig. 11, 12). In passing, I



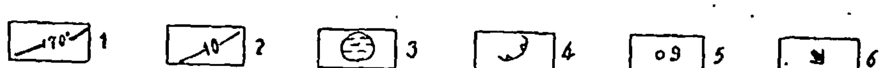


Fig. 11 Complex map of geothermal reservoir in Yangbajan
1 - isoline of maximum temperature in boreholes; 2 - isoline of minimum apparent resistivity (om.m); 3 - hydrathermal alteration area; 4 - distributive area of silicified strata; 5 - boreholes; 6 - direction of movement of geothermal flow.

should mention something about electric survey. This is used to determine the geothermal reservoir, because high temperature often causes low apparent resistivity of aquifer rock. For instance, bores no. 13 and no. 14, which have temperatures of 171°-172°C, are sited out of the area with a minimum apparent resistivity of less than 10 Om.m. From

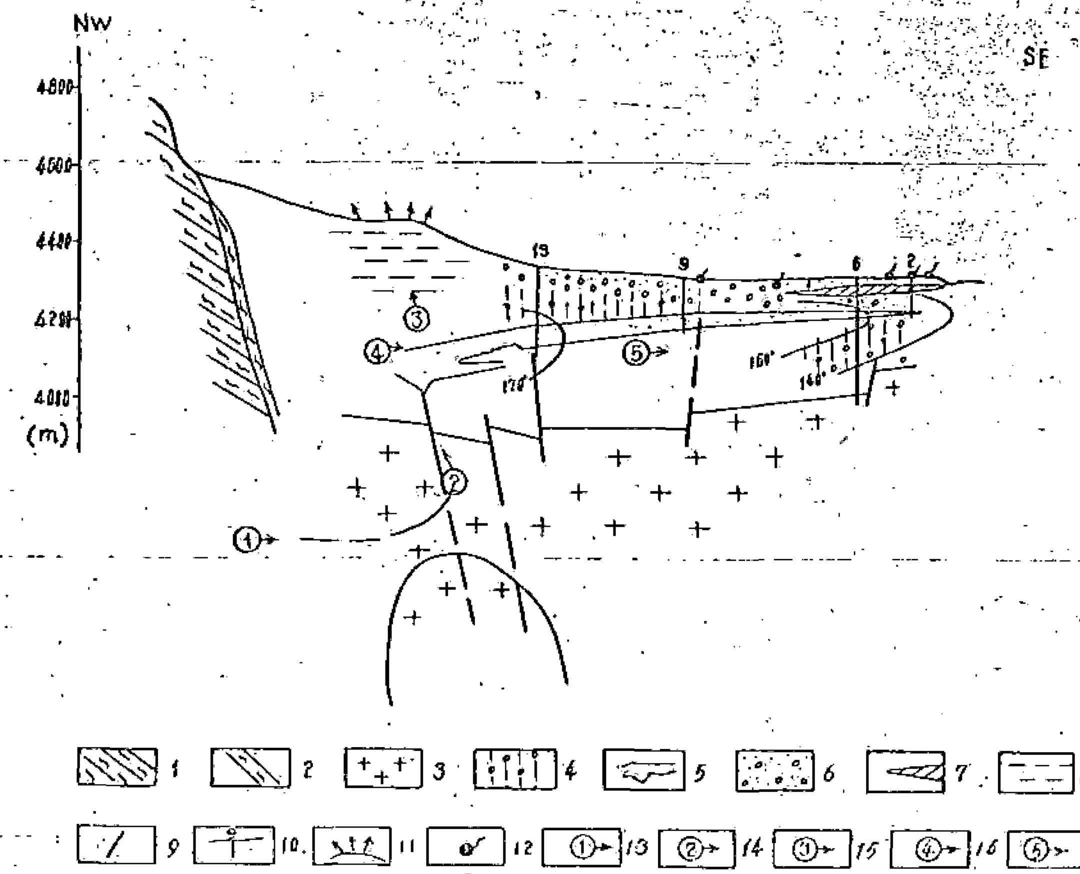


Fig.12 Schematic diagram of the hydrological features, of the Yangbajan hydrothermal system

1 - gneiss of Paleozoic Era; 2 - breccia; 3 - granite; 4 - till of Quaternary; 5 - silicified grit controlled aquifers; 6 - grit; 7 - clay; 8 - alteration area; 9 - fault; 10 - boreholes; 11 - steam ground; 12 - hot or boiling springs; 13 - cold recharge water; 14 - deep thermal flow; 15 - sulfur steam; 16 - cold water at the foot of Mount Nyaingentanglha; 17 - mixed geothermal flow.

the well log we learned that the northern silicified aquifer has a higher resistivity.

Third, the mineralisation and ions of geothermal fluids decrease progressively from the alteration area to the Zangbu River and from the "tongue" to the surrounding area. The fluid from Bore no. 13 contains mineralisation 2.21 g/l, Cl 651 mg/l and HBO_2 297.6 mg/l,

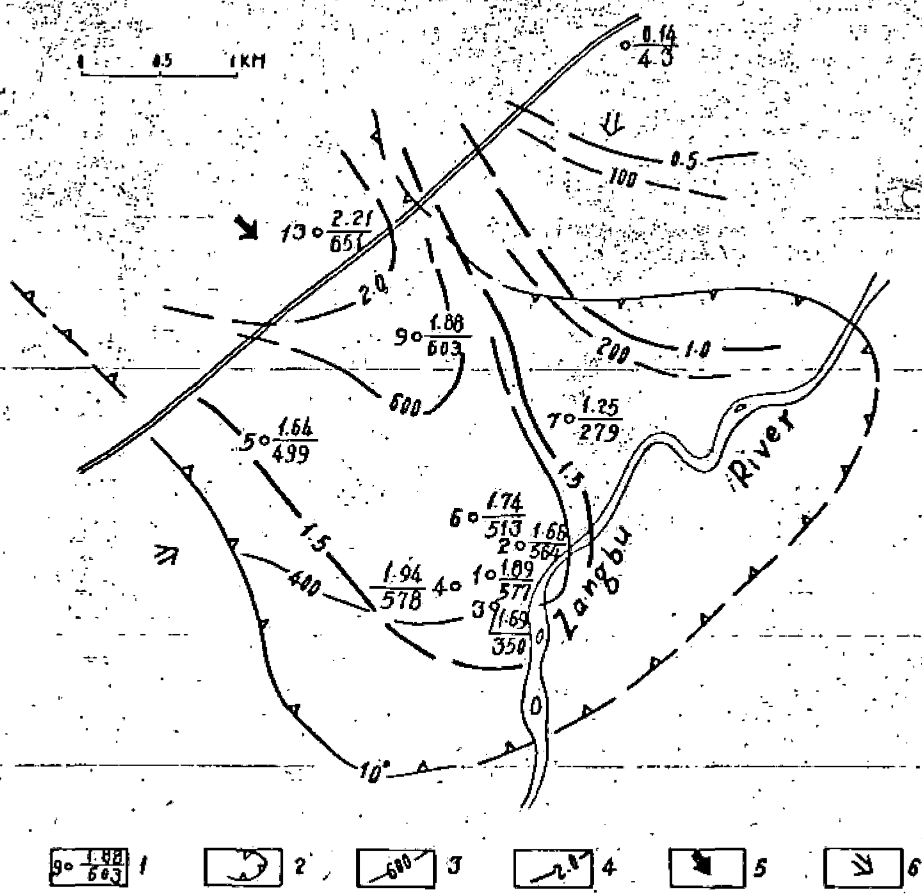


Fig.13 Mineralization and Cl content in geothermal boreholes
1 – bores $\frac{\text{mineralization (g/L)}}{\text{content Cl (mg/L)}}$; 2 – geothermal anomalous area ; 3 – isoline of content Cl (mg/L) ; 4 – isoline of mineralization (g/L) ; 5 – direction of thermal flow ; 6 – direction of cold flow.

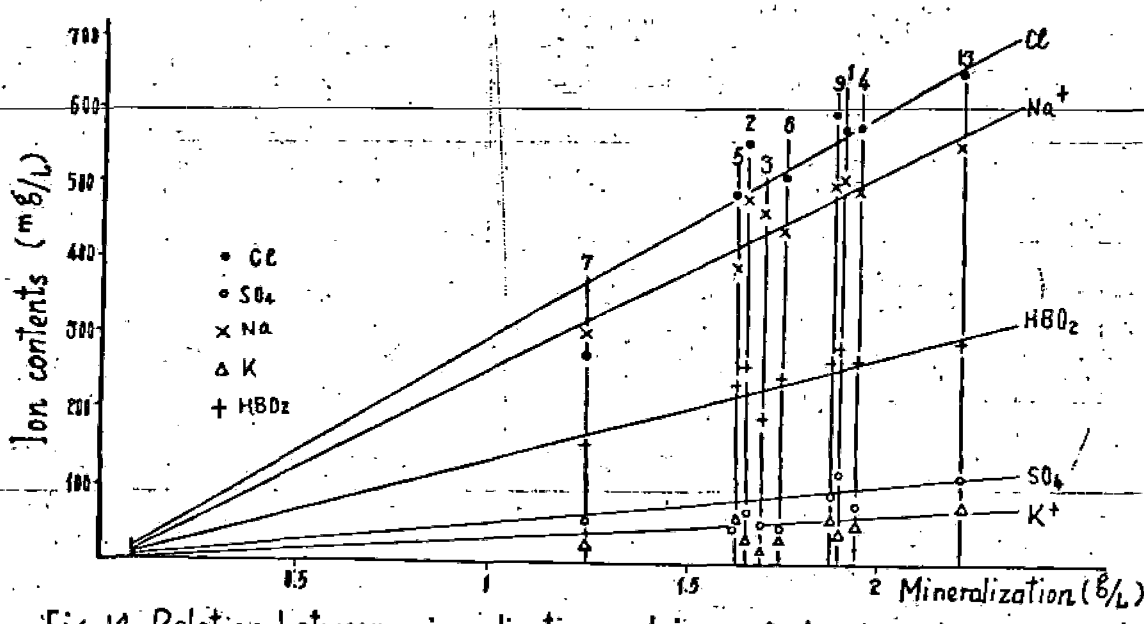


Fig. 14 Relation between mineralization and ion contents of geothermal fluids sampled from boreholes in Yangbajan

the highest among all existing boreholes and springs (Fig. 13). It appears that hot water with high mineralisation and Cl, B, etc. comes from the deep thermal flow connected with magma activity. This kind of thermal flow mixes cold water with low mineralisation and high HCO_3 from outside the field, and Cl-HCO_3 mixed water is formed. Fig. 14 shows the mineralisation and ion content in boreholes are proportional.

Accordingly, it is presumed that the present activity of the Yangbajan geothermal field is the post-intrusive action of magma, which caused the uplift and hydrothermal alteration of the sulphur deposit in the north of the field. The passage through which the deep geothermal flow passes may be the fault at the foot of Mount Ngaingentanglha beneath the sulphur deposit. Cold recharge water (1) passes a nearby heating volume and mixes with juvenile water from cooling mamga (Fig. 12), rising in temperature and decreasing in density and forming a deep thermal flow (2) which rises along the fault beneath the sulphur deposit. Due to pressure reduction and changes in the oxide-reductive condition, sulphur steam, (3) mercury, etc. are separated and produce hydrothermal alteration and sulphur deposit. Then as it is pushed by cold water at the foot of Mount Nyaingentanglha (4) the deep thermal flow turns to horizontal movement to be a mixed thermal flow (5).

It is concluded that the Yangbajan geothermal field was formed in the Quaternary period, with its hydrothermal alteration and sulphur steam remaining active up to now.

PRESENT STATUS OF THE UTILIZATION OF GEOTHERMAL ENERGY IN THE PEOPLE'S REPUBLIC OF CHINA

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Abstract

Our country is comparatively abundant in geothermal resources. The geothermal outcrops only are 2500 in number, spreading all over thirty provincial, urban and autonomous regions. There are about thirty geothermal fields which have already been and are being explored in our country and still great potentialities for further development, The high temperature geothermal resources are utilized mainly for power generation, while the medium temperature ones, besides being directly used, are utilized for the development of small power generating stations mainly for comprehensive use according to local conditions. The low temperature geothermal resources are developed mainly for direct uses. At present, the geothermal energy has already been extensively utilized in our country for both agricultural and industrial productions. As a result, excellent advantages have already been obtained from such uses,

such as economization of coals, reduction of transportation of coal ashes and alleviation of environmental pollution, etc.

Introduction

The existence of geothermal energy has been known to all since early years. In our country, the utilization of geothermal energy can be traced back to two thousand years ago and, in fact, records of such utilization can be found from the writings of ancient times and many local chronicles. However, till the fifties of the present century, the use of the geothermal energy was limited to few purposes only, such as bathing and medical treatment. It was in the sixties that we began to utilize the geothermal energy to agricultural and industrial purposes, but not on large scale. Since the seventies, the geothermal energy has been explored and utilized in our country as a new energy source and a research group built up accordingly. However, up to present, a national unified developing plan yet remains to be elaborated. As the eighties will mark a new epoch in science and technology progress in our country, the geothermal energy as a part of the energy source will no doubt have our government's best attention for its development. At present, the geothermal energy has already been extensively utilized in our country for both agricultural and industrial productions and for the well-being of the masses, such as power generation, refrigeration, space heating and conditioning, aquaculture, medical treatment and washing, etc. As a result, excellent advantages have already been obtained from such uses, such as economization of coals, reduction of transportation of coal ashes and alleviation of environmental pollution, etc.

Table I. Distribution of Experimental Geothermal Power Station

Name of Experimental Geothermal Power Station (EGPS)	Location	Water Temp. C	Design Capacity Kw	System Type	Working Medium	Generating Date
Fengshun EGPS	Dengwu, Fengshun, Guangdong					
No.1 unit		91	86	Flashed Steam	Water	Dec. 1970
2 unit		91	200	Binary Cycle	Isobutane	Sept.1977
Wengtang EGPS	Wengtang, Yichun Jiangxi	67	50	Binary Cycle	Ethyl chloride	Sept.1971
Huailai EGPS	Houheyao, Huailai, Hebei	85	200	Binary Cycle	Ethyl chloride, Normal butane	Sept. 1971
Huitang EGPS	Huitang, Ningxiang, Hunan	92	300	Flashed Steam	Water	Oct. 1975
Yingkou EGPS	Xiongyue, Yingkou, Liaoning	75	100	Binary Cycle	Normal Butane, freon-11	Nov. 1977
Zhaoyuan EGPS	Zhaoyuan, Shandong	91	200	Flashed Steam	Water	
Yangbajing EGPS	Yangbajing, Xizang					
No.1 unit		137	1000	Flashed Steam	Water	Sept. 1977
No.2 unit			3000	"	"	1981, estimated
No.3 unit			3000	"	"	"

Remark: Stations in Taiwan Province not included.

I. Electric Generation

The geothermal resources we have hitherto discovered are mainly hydrothermal in type. Presently, there are two main types of systems for generating electric power with geothermal water, namely, the flashed steam system and the binary cycle system. The former one is comparatively ripe in technological sense, while the latter yet remains to be further studied and developed. For investigating the feasibility both technical and economical in the utilization of the geothermal water for power generation, we have since 1971 successively built a lot of experimental geothermal power stations (see Table 1.) for carrying out researches in these two systems. Appreciable achievements have already been obtained in this respect.

Presently in our country, the Xizang Yanbajing geothermal field which is 91.8 kilometers far from Lasa and 4300 meters above sea level is the main field we are developing. A survey made within the delimited geothermal field having an area of 8 square kilometers reveals that there exists volumes of surface geothermal display. A jet of vapor-water mixture having a temperature above 140°C gushes out when drilling up to a depth of about 30 meters, while temperature measured at a depth between 70 - 130 meters is as high as 170°C. Calculation shows that, at the place which is 1100 meters deep, there is probably another reservoir the temperature of which ranges from 190 to 240° C. In September 1977, an experimental geothermal power generating unit having an output of 1000 Kw was put into operation. It employs a single-stage flashed steam system supplied with vapor-water-mixture of 131 - 137° C (vapor 10.9%) drawn from two production wells. Inasmuch as the hot water was not up to the designed temperature 145 - 165° C, the actual stable output was only 500 Kw with a maximum of 700 Kw. Up to the end of 1980, the accumulated operating time of the said unit was 15,000 hours, yielding a total electric power of 5.50 million Kw-hr.

For further developing the Yanbajing geothermal field in order to satisfy the power requirements of Lasa area, two power generating units, No. 2 & 3, each delivering an output of 3000 Kw, and 91.8 kilometers of 110 v power transmission lines are now under construction and scheduled to be put into operation in 1981.

Although the economics of the high temperature geothermal power generation is acceptable, there are different views about the fixation of the lower water temperature limit both technically and economically reasonable for use in power generation. As a matter of fact, resources of high temperature are less than those of medium low temperature. This means that the lower the hot water temperature can be used for power generation, the more geothermal resources we can utilize. Therefore, it is of paramount importance to work out an energy conversion technique which permits to lower the economic temperature for geothermal power generation. Since 1971, we have conducted a series of experiments in the utilization of geothermal water for power generation and successfully obtained a great deal of experiences and technical knowledges. Although the employment of lower temperature hot water for power generation is not necessarily resonable in economical sense, these researches permit us to push forward the scientific exploration of the geothermal energy for power generation. The Huitang Experimental Geothermal Power Station of the Hunan Province is relatively a successful one compar ing to other small scale power stations. It also employs a flashed steam system supplied with hot water of 91° C by one production well deep to 560 meters. The construction work was completed in 1975. With its designed output, this station operates on two-shift/day basis and delivers power to neighbouring areas by paralleling with other networks. In 1979, its yearly operating time was 4744 hours, yielding a total power of 1.16 million kw-hr. The expense invested in this station is RMB¥1460 per Kw exclusive of the drilling charge. According to the estimate made, this figure can be considerably levelled down to less than that for coal-burning plant of same capacity, if the plant is furnished in a complete set. Presently, the electricity charge collected by the station is RMB¥0.55/Kw-hr which lies between the charge for the coal-burning plant and that for the water-power plant. Should this station be operated on three shift basis, it can be expected that even a slight surplus could be derived from the electricity charge only after the deduction of the equipment depreciation and the operating costs covering the maintenance, management and labor payment. Furthermore, for comprehensive utilization, drain water of 68° C off the power station is channelled to various places, such as agricultural greenhouse, sanatorium, hospital, bathroom, fishpond, etc. Cooling water is used for the gravity irrigation of 800 mu farmland. Taking into consideration these gains and incomes and estimating the possible recovery of the drilling charge, the economical benefits to be developed from the comprehensive utilization could be attractively significant.

The Wentang Experimental Geothermal Power Station of Jiangxi Province is one of the power generating units using the binary cycle system in our country, and has certain prominent features in technical arrangement. The geothermal water having a temperature of 67° C is drawn from two geothermal wells which are 70 meters deep and supply the water at a rate of 90 tons/hour with the ethyl chloride (C_2H_5Cl) as the working medium. The power generation of this station is technologically featured by the use of a two-stage vaporization thread tube type condenser to intensify the transfer of heat and a radial flow type turbine of high efficiency, the low local power consumption (about 15%) and its capability of being started without external power source. By using the hot water of 67° C, it can deliver a total net power of more than 40 kw for external use. Besides being used by the inhabitants for their daily life requirements, the hot water, after being used for power generation, is drained and used in 553 square meters of agricultural geothermal greenhouse, 10000 square meters of hot water fishpond, nine indoor high density running water fishponds and a hot spring sanatorium consisting of more than hundred beds. After such comprehensive utilization, the water is further drained off for use in farm irrigation. Evidently, the effect of energy economization and the economical benefits which can be derived from the medium - low temperature geothermal resources should not be underestimated, inasmuch as the fact that so many purposes as mentioned above can be satisfied by only two thermal wells having a temperature of as low as 67^{o} C and by extraction and utilization of the heat by stages and sectors.

In light of the aforementioned two examples, it is therefore inadvisable to make a simple comparison of investments between the coal-burning power plant and the geothermal power plant and take it as the basis for fixing the lower limit of the temperature of the hot water to be used for power generation without taking into consideration the factors such as the optimum use of the energy resource, the economical benefits to be derived from the comprehensive utilization of geothermal water, the elimination of fuel requirements, the saving of the transportation of coal ashes and the alleviation of environmental pollution. Such being the case, it is of paramount importance to work out a comparative criterion of economical feasibility for the geothermal power generation and in the meantime to elaborate for such feasibility a technique for its improvement.

II. Industrial Processing Space Conditioning and Space Heating

In cities and towns where geothermal resources exist, fuels can be considerably saved and city environment improved by supplying the geothermal water directly to the industrial processes requiring hot water and the buildings in northern areas for space heating. Of equal economical importance is the use of the geothermal water for refrigeration and space conditioning in south areas. In our country, the geothermal energy is now being used in different industrial fields, including spinning and weaving, printing and dyeing, stoving, leather processing, silk reeling and papermaking industries, as well as in chemical technology and extraction of elements from minerals. By using the geothermal water of 49° C for washing woollen cloth, Tianjin Woollen Mill has saved 2400 tons of coal and 15000 kw-hr of electricity per year and remarkably improved the product quality. Beijing Guanghua Dyeing and Weaving Mill employs the geothermal water of 48° C for washing and dyeing cloth, the result being an economization of 2500 tons of coal and 135 tons of table salt per year. In the Fengshun County of Guandong Province and the Xiongyue County of Liaoning Province, printing and dyeing mills, by using the geothermal water, have rendered their products bright and lustrous, hence selling favorably in markets. In addition, the Fengshun County makes use of the geothermal water for a stoving room of 37 square meters for stoving wheat, paddy, leaf tobaco, medicinal materials, milk powder and other agricultural by-products, For these purposes, only two tons of hot water of 79° C are required to be replenished per hour. The construction co st of this room is RMB¥ 73.00 per square meter and can be recovered in one year if it is fully utilized. This stoving technique is featured by iys convenience in use and easiness in controlling the temperature. It consumes no fuel and causes no burnt defect and no smell after stoving. What is more, it permits us to reduce the stoving time and increase the working efficiency. By using this geothermal stoving technique, only a time of six hours is required for stoving the paddy and 36 - 48 hours for accelerating the germination, whereas a time of three days is generally required in this respect when using the sun heat. The May 7th Oil Field and the Jiannan Gas Field of the Hubei Province have since many years extracted some industrial raw materials from the high temperature geothermal brine. For instance, the No. 2 & 7 Gao wells, besides a yearly production of more than 10 thousand tons of table salt, have also yielded yearly 0.5 ton of iodine, 18.8 tons of bromine, 40 tons of boron, 5.8 tons of aluminum carbonate, 480 tons of 6% ammonia water and other trace elements for use in agricultural and industrial production as valuable raw materials.

There is a good prospect for the utilization of geothermal water for space heating in the northern areas of our country, In Beijing, there are two geothermal resources of 53 - 59° C which solve the space heating problem for a building area of 50,000 square meters. The Tianjin Guesthouse is now using the geothermal water of 42° C for space heating after properly reheating it. An economization of more than three thousand tons of coal per year can thus be saved. At present, in the Xingcheng County and the Xiongyue County of Liaoning Province, the Weihai City and Jimo County of Shandong Province, the Yingcheng County of Hubei Province and many other areas, the geothermal energy has already been utilized by many factories, official organizations and hospitals for space heating, but not yet developed on large scale for use in central heating. Tianjin is now carrying out an extensive research work in this respect.

As for the utilization of geothermal water for ice-making and space conditioning, the research work has already been undertaken by the Experiment Station for Geothermal Energy Utilization of Fuzhou City. A set of experimental equipment was built up in January 1980. This set uses a two-stage ammonia absorption refrigerate system supplied with geothermal water of 87° C and has been operated continuously and intermittently for seven months. Test runs show that, by using geothermal water and cooling water respectively of 87° C and 25° C and at rates of 8.5 t/h and 58.7 t/h, an evaporation temperature of -24° C and a refrigerating capacity of 23363 Kcal/hr. can be obtained. It can produce 4 tons of ice per day and, in addition, offer its refrigerating capacity to a cold storage which is 50 square meters in area and below -12° C in room temperature and a vegetable freshness keeping storage of same size. The geothermal water drained off after refrigeration is further delivered to farmland for use in greenhouses and fishponds. When the cooling water temperature is up to 32° C during summer time, an evaporation temperature of -32° C can be obtained. According to a preliminary calculation, the initial investment for this type of geothermal refrigerate system being supplied with the thermal water of above temperature is RMB¥2100 per 10^3 Kcal/hr. which is higher than that for the compressor refrigerator of same capacity.

However its operating cost is lower than that for the compressor refrigerator. The time required for recovering the high investment cost with the low operating costs is 4.3 years. The Fuzhou city is abundant in geothermal resources. Geothermal fields are found within the urban area which is five kilometers across from north to south and one kilometer from east to west. Here, great potentialities exist in the utilization of geothermal energy, Since within a zone rich in geothermal water and at a depth of 200 meters, the water temperature measured exceeds 90° C.

III. Agricultural and Aquacultural Uses, etc.

There are broad prospects for the utilization of geothermal energy in the fields of agriculture, fishery, forestry and animal husbandry. Since most of the medium-low temperature geothermal resources are dispersed over the vast farmlands and remote regions, so they are not ideal for power generation and practically impossible for use in the urban industries. In fact, should these resources be used for the purpose of establishing the greenhouse and sanatorium breeding the tropical fishes, irrigating the farmland, producing the forage and green manure and supplying the inhabitants with hot water for bath and other life requirements, then part of the energy required by the rural areas can be resolved not only for developing the rural production and economy but also for improving the rural living condition and the well-being of the masses.

The geothermal greenhouse, as a matter of fact, can play a very important role in the field of agriculture. In our country, many villages endowed with geothermal resources have already built up different types of geothermal greenhouses of various sizes. Mainly, they are used for cultivating improved varieties, raising rice seedlings, growing seedlings, as well as for cultivating vegetables. By raising the seedlings in the geothermal greenhouse, the Jingshan County of Hubei Province reproduces in same year a quantity of 4508 kgs of rice seedlings with 250 grams of improved rice variety and, besides, supply other parts of the country with 100,000 kgs of this variety as seedlings. They have also utilized the greenhouse to cultivate cucumber and tomato. The productivity of each is about 25,000 kgs per mu, being several times higher than those planted in the field. With a geothermal greenhouse of 1129 square meters, the Yingshan County Scientific Experiment Station has since 1971 successively raised about 500 types of rice seedlings, among which more than 100 types have already been brought to their fifth or sixth generation. Within only four years the whole county is spreaded with these new breeds and the productivity is generally 400 kgs per mu. This station utilizes the geothermal greenhouse to raise the seedlings by layers, germinate the early rice and grow the sweet potato seedlings, thus creating a condition favorable for the production brigade to sow in time. Using a geothermal greenhouse of one fen land (66 square meters) to raise the seedlings by layers can meet the seedling requirement of 1000 mu (660 thousand square meters) rice field. The Agricultural Science Institute of Hunan Province established in 1974 in Huitang, Ningxiang County a geothermal greenhouse of 330 square meters to replace the original coal-burning greenhouse of 200 square meters. This has not only resulted in an economization of 1398 tons of coal per year but also accelerated the alteration of generations of the improved varieties. Three year amount of work can thus be accomplished in one year and the newly raised high yield hybrid rice varieties have already been propagated on a nation-wide scale. In the year of 1979, the 76 million mu of land planted with such varieties yielded an increase of 3.9 billion kgs, amounting to one-third of the national total increased production.

The use of geothermal water for raising the red and green duck-weed and the water lettuce can not only winter the seedlings but also accelerate their growth, thus resulting in high production. In the Yingshan County, pigs fed with the water lettuce are generally 10-15 kgs heavier than those fed with ordinary forages. According to the incomplete statistics made by the Hubei Province for Yingshan, Tanchi and Jingshan regions, a plantation of more than 200 mu of water lettuce can give a yearly crop of 15 million kgs for use in the province and supply to other parts, resulting a yearly income of about RMB ¥400,000 . The Suichuan County of Jiangxi Province and Lintong

County of Shanxi Province and many other regions also utilize the geothermal water for breeding the water lettuce by the use of which the pig-raising is developed. In our country, quite a few regions possess geothermal water of good quality, the drain of which can be directly used to irrigate the farmland and increase the soil temperature for obtaining early mature and bumper crops. Experiments made by the Nanjing County of Fujian Province, Yingchen County of Hubei Province and Xiongyue County of Liaoning Province show that the growth period of the paddy grown out of the seedlings irrigated with geothermal water can be reduced by about 20 days and a good crop can be obtained. Some regions in the Zunyi County of Guizhou Province utilize the geothermal water to irrigate the seedlings and , as a result, obtain an increase of food production by 20 to 30%.

Recently, the use of geothermal water for breeding and wintering the tropical fishes has been fairly developed in our country. In 1974, the Jiexi fishing ground of the Guangdong Province used 25 mu (16,600 square meters) hot spring fishponds to start an experimental breeding of four main carps. Further, they discovered that a proper temperature of pond water (20 - 30° C) would make the fish to absorb more food and therefore speed up their growth. In the winter of 1979, as the climate of the Guangdong Province was persistently microthermal (below 7° C), cloudy and drizzly, quantities of dace perished, while the Jiexi hot spring fishing ground was successful in holding the immature fishes and providing different places with volumes of fry. In cooperating with other organizations, the Yingshan County Scientific Experiment Station and the Changjiang Institute of Accquatic Products of the Hubei Province have been successful in using the geothermal water for carrying out the Zanzibar tilapia breeding, sex reversal and hybridization experiments, as well as those on production scale. Through the sex reversal experiment, they have obtained 100% all-male fish. These experimental all-male fish, being rapid in growth and 40.4% higher in productivity than the natural colonial fish, are now being propagated. In few years, they have gathered about 1.5 million fry and provided other parts of the country with improved varieties. The acquatics breeding base of the Fuzhou City, by utilizing the geothermal water for breeding the African crucian carp, enables the fry to safely pass the winter and provides different regions with a total of two million fry per year. In 1980, the Research Institute of Acquatics of the Hubei Province constructed a 2000 square meter geothermal fishpond with plastic roof for breeding eel. This pond can supply 80 tons of immature eel and fry.

In addition to what we have mentioned above, some districts and regions are using the geothermal water to heat the methane-generating pits and hatch the chickens and ducks. The Yingshan County Scientific Experiment Station uses a geothermal piping system for heating a methane-generating pit of 30 cubic meters. As a result, the fermentation speed is accelerated and the gas generating rate incresed. This pit can produce gas even under an outdoor temperature of - 7° C. The Institute of Agricultural Science of the Fujian Province has utilized the geothermal water for hatching chickens for the purpose of making a comparison with the electrical incubation technique. Tests show that, in contrast to the electrical incubation technique, the geothermal technique is featured by its lower equipment expenses, higher incubation rate, sound chicken rate and survival rate and no need of electricity. Furthermore, chickens after shelling are heavier in weight, more rapid in growth and higher in price. The equipment expenses can be recovered within a period of three to four months.

The medical treatment and health recuperation with hot springs have been practiced since very early years and fairly popularized in our country. Up to the present time, there are about one hundred hot spring sanatoria built by the state as well as research organizations of mineral spring therapy built in the more important mineral spring regions. Much experiences have been gained in this respect. For instance, sanatoria of comparative large scale have already been built in Xiaotangshan of Beijing, Lushan of Jianxi, Conghua of

Guangdong, Xingcheng of Liaoning, etc. Basing on the warming effect, chemical effect and mechanical-physical effect of the geothermal water and with the state of illness, period of treatment and patient's physique condition in view, These sanatoria use different water temperatures for applying either wholly-immersing or half-immersing treatment. For certain diseases, sensible curative effect has been obtained by the dietectic treatment which is even more effective especially for arthritis, dermatosis, quasi-rheumatism, etc. The Dongtangyu Hot Spring Sanatorium, Lantian County, Shanxi Province has realized a curability of more than 90% in the treatment of dermatosis and arthritis. In Hubei, a staff member of a designing institute, due to sufferance from the rheumarthritis, difficulty in moving about and longtime but fruitless medical treatment, has received a bathing treatment in the Tangyanfan Sanatorium of the Jingshan County. Three months after , he can straighten his waist and half a year after, he returns to normal and resumes his work. The Dangxiong, Ali and Nagu regions of Xizang Autonomous Region have utilized the hot spring water to build up bathing pools for the stocks aiming at protecting their health, treating the dermatosis and wiping out the blood-sucking parasites. The hot spring bathrooms are now more common in our country. Almost all of the residential districts where hot spring exist are provided with different types of hot spring bathrooms. In Fuzhou City, the state-owned hot spring bathrooms only number thirteen, consisting of more than 4000 beds and entertaining four to five million person-time per year. In some districts, there are also swimming pools using hot spring water. The open hot spring swimming pool established in the Lingtong County of Shanxi Province not only starts earlier but also terminates later than the cold one, thus extending the time of utilization by two to three months per year.

Conclusion

Our country is comparatively abundant in geothermal resources. According to the survey made, the geothermal outcrops only are about 2500 in number, spreading all over thirty provincial, urban and autonomous regions. In our country, the geothermal resources of high temperature mainly lie in Xizang, Yunnan and Taiwan, while those of medium-low temperature extend, for a greater part, over the eastern maritime provinces and from the north including the Songliao Plain and North China Plain up to the south including the Jianghan Plain and the vast sedimentation type basin of Beihaiwan sea waters. The high temperature geothermal resources are used mainly for power generation, while the medium temperature ones, besides being directly used, are utilized in remote areas short of electricity or in areas having special requirements or further, to suit the local conditions, in small power generating station with the development of comprehensive utilization as the main purpose. The low temperature geothermal resources are developed mainly for direct uses. At present, there are about thirty geothermal fields which have already been or are being explored in our country and still great potentialities for further development. However, in light of the present condition that a greater part of the geothermal resources in our country are of low temperature type, emphasis will henceforth be laid on both direct and comprehensive utilizations. For the years to come, we shall use our efforts to intensify the research work of geothermal energy, speed up the exploration and development of the geothermal resources and in the meantime enhance the mutual understanding and cooperation between countries, in order to advance the development of geothermal energy to a new phase.

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Energy

NOTES ON NEW ENERGY SOURCES IN CHINA

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Prepared for Local Coordiantors of the
New Energy Sources Delegation
May - June, 1979

Not for quotation or reprint

Notes on New Energy Sources in China

"Communism equals Soviet power plus electrification."

-- V. Lenin

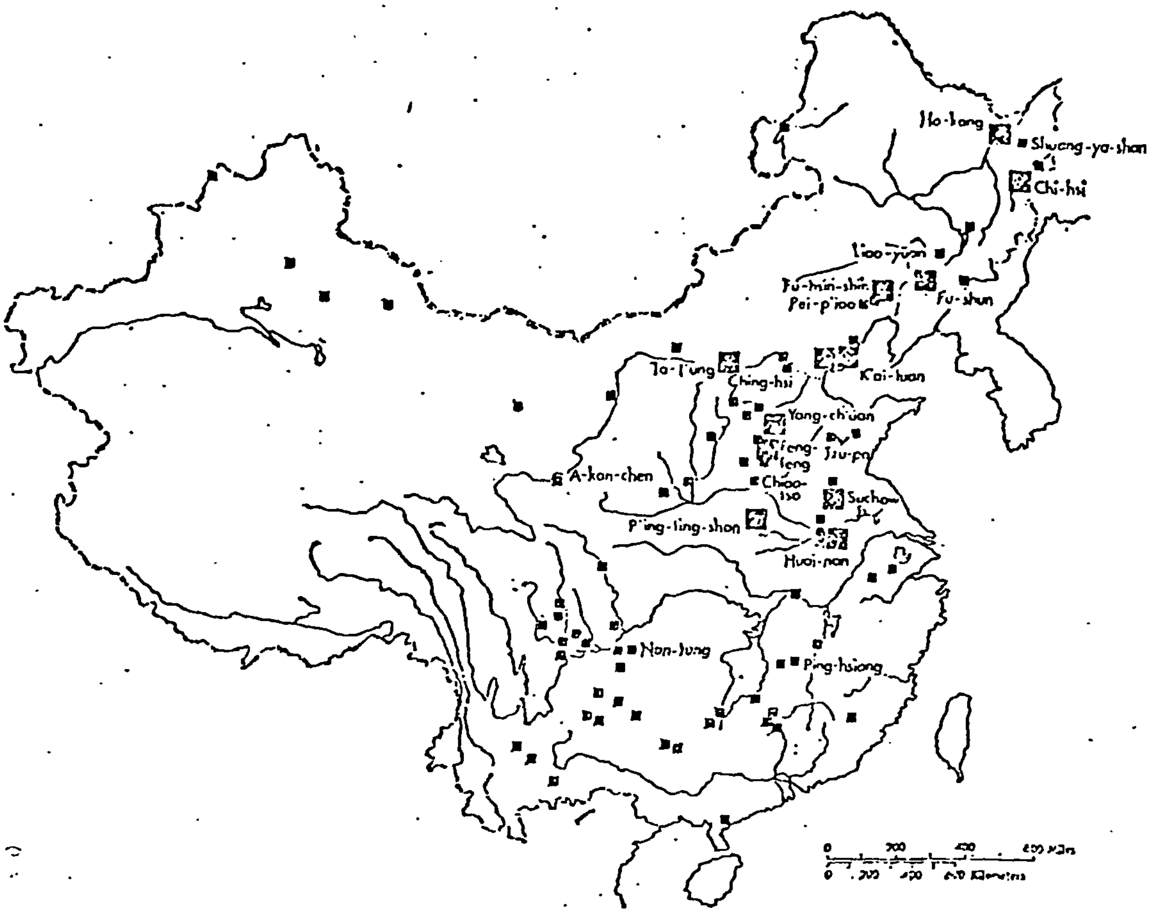
China's economy has been characterized as a "predominantly solar economy." Vaclav Smil was referring to the conversion of solar radiation by edible plants. By a solar economy, then, Smil meant an agrarian or pre-industrial economy. A modern economy, in energy terms, is one that has undergone a transition to "functioning on auxiliary energies," that is, fossil fuels and electricity.

However, solar energy and the solar economy are also ultramodern. Solar energy cannot be branded as the energy of agrarian societies because it spans the distance between pre-industrial and industrial economies and may, indeed, assume more importance in future civilization. Solar energy also bridges the gap between the high and low level technology approaches of the Maoist and post-Mao eras. It is not ironic but intrinsic to the subject that solar energy application was first stressed in the time known as the Great Leap Forward (1959), and is being emphasized again now. Solar energy is suitable for a labor-intensive, small-scale, locally-managed and low technology approach associated with the Maoist or Yenan model of development. It may be equally sensible when speaking of high technology, large-scale, capital-intensive projects to include solar energy. It is the potential of solar, wind, ocean, geothermal, biomass and magnetohydrodynamic energy sources that makes us call them new.

Like the United States, China has no energy plan. But the People's Republic does have an energy strategy: research and development on all fronts, at all levels, "attaching equal importance to production and frugality." Large, mechanized coal mines and tiny, one-horse coal works, huge hydropower stations and small water wheels, oil refineries, nuclear power plants and manure pits all form part of China's energy strategy.

China is already the fourth largest producer of energy. Only the United States, the Soviet Union and Saudi Arabia produce more and only the United States and Russia consume more. The Chinese are quite aware that their drive for "four modernizations" -- in agriculture, industry, defense, and science and technology -- will keep them near the top in consumption and will require substantial, rapid increases in output. Peking's enthusiasm for modernization of the petroleum industry is well-known. Kang Shien, Minister, the State Economic Commission, announced that China intends to "catch up with and overtake the United States" in oil industry production. Yuan Baohua, Vice Minister of the State Planning Commission has stated that China plans to develop all modern forms of energy production, including nuclear power stations. Yuan further maintained that China would devote serious effort to solar, wind and ocean energy.

Over five hundred million tons of coal are dug out from China's coal mines year. This total places (or shows) China the third largest producer of coal behind only the United States and the Soviet Union. Two-thirds of this output comes from the Northeast. Fully one-third of the total is extracted from small-scale mines. Plans to step up coal use and production extend to using waste coal as a significant part of the fuel supply.

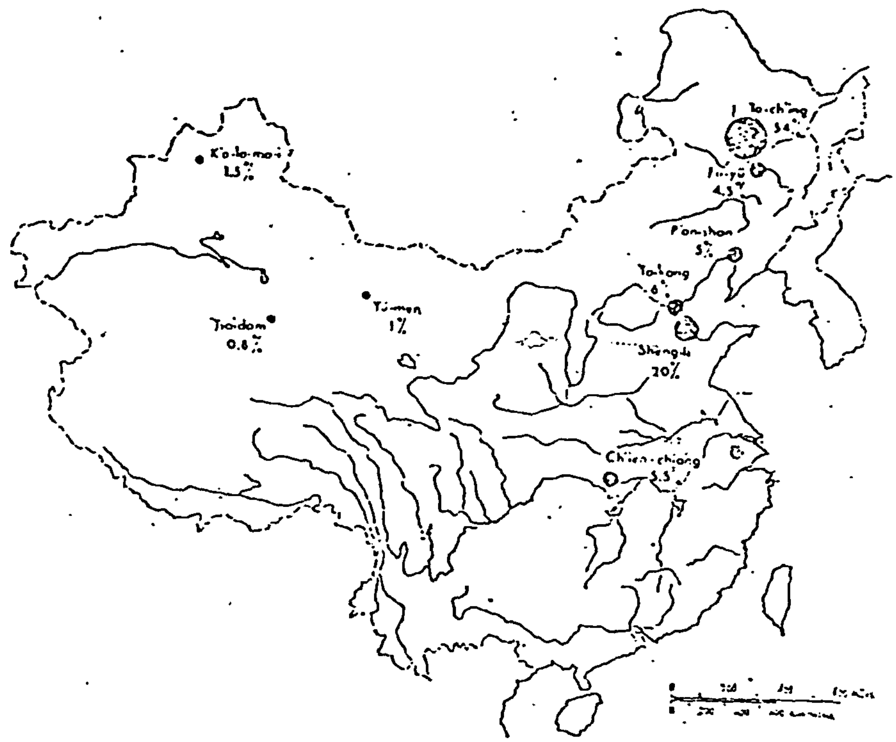


—China's major coalfields. Large squares show collieries with more than 10 mmt of annual raw coal production in the mid-1970's.

(Smil)

The modernization of China's petroleum industry is intended to enable her to keep up with domestic demand, not to make her into a major oil exporter. The extent of her oil reserves are unknown, but estimates are mounting. Smil estimates "certainly no less than 3 bmt and most likely no more than 10 bmt." At present the People's Republic has mounted an intensive effort to upgrade the technology of its oil (including shale oil) and natural gas production.

"The Use of Atomic Energy to Generate Power Has a Promising Future" is a title from a magazine, Popularization of Science (普及科学). The article argues that nuclear energy for power generation has less of an effect on the environment than conventional fuel

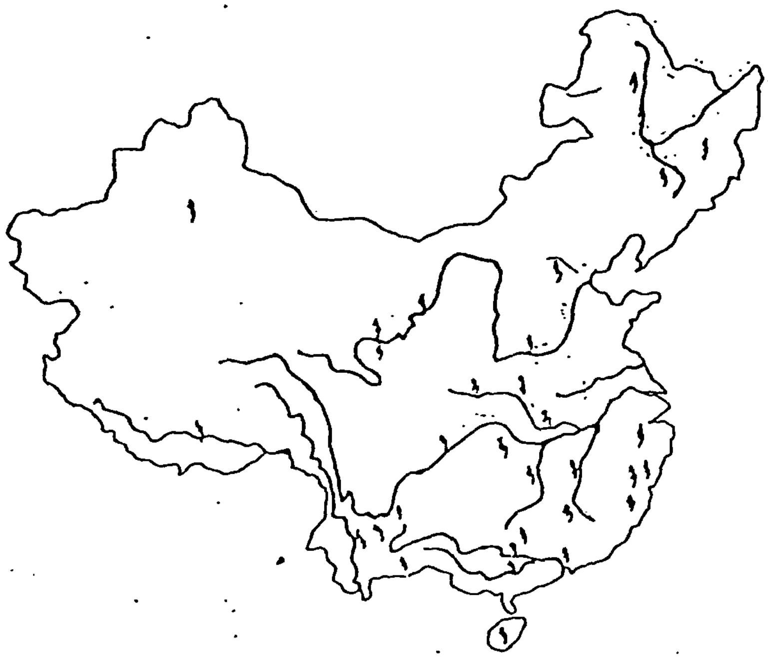


—China's major oilfields. Shares of the 1975 crude oil production (according to the CIA, "Economic Indicators," op. cit., pp. 28–29) are shown for nine major fields which provided 98.3 percent of the aggregate output of 74.261 mmt.

(Smil)

plants, which belch enormous amounts of sulfur dioxide and other poisonous gases into the air every day. In December, 1978 Vice Premier Deng Xiaoping announced that China had signed to buy two nuclear power stations from France. In January of this year, a three year scientific cooperation agreement on basic research was signed in Peking between the Chinese Academy of Sciences (Academia Sinica) and the French Atomic Energy Commission. China has the natural uranium resources and technology to support a nuclear power industry, but her emphasis in the nuclear field still falls on weaponry. Some scientists have expressed reservations as to nuclear power generation and power plants.

Hydroelectric power accounts for very little of China's total energy production, but China is potentially the richest hydropower in the world. The government is well-aware that "with its total resources ranking foremost in the world, China abounds in water resources. ... A vast amount of energy resources is needed to achieve our country's four modernizations. If water resources are not fully developed, supplies of coal and oil for other construction projects will be reduced." (People's Daily) China's experience with water management projects predates the ancient sage, Yu, who, it is written, wore the hair off his legs about 2000 BC, taming the temper-mental Yellow River. The Yellow River



Rivers
hydro-electricity stations

Major Chinese hydroelectric systems

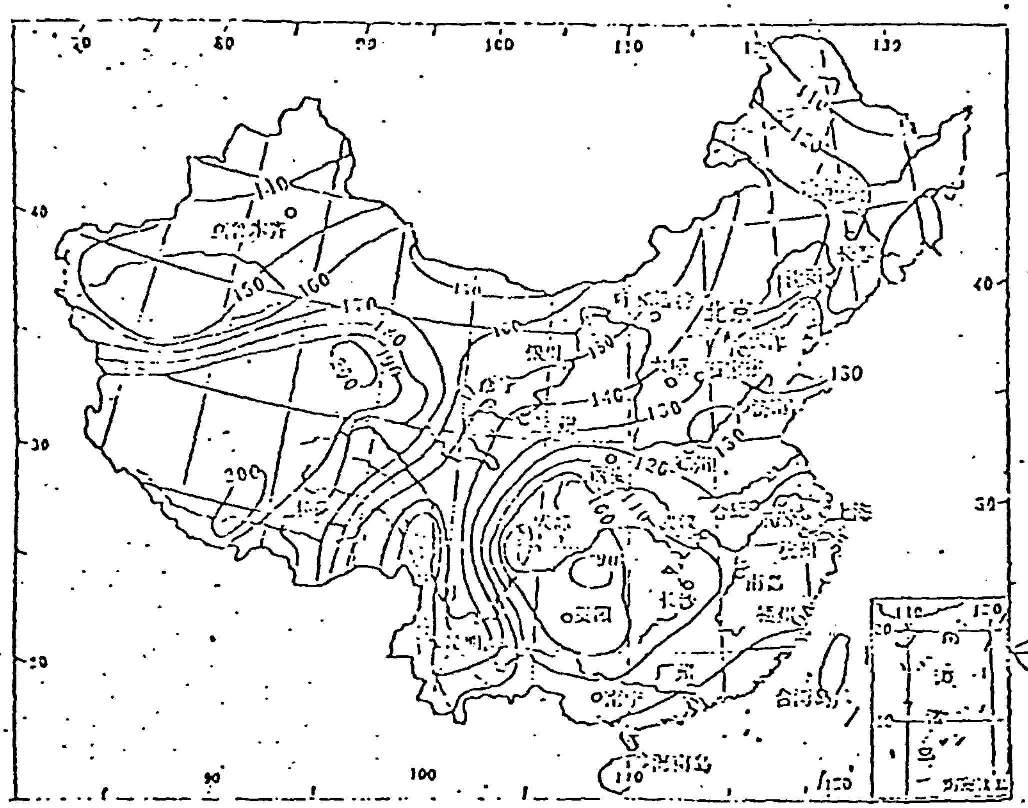
	Megawatts
Yellow River (moving upstream):	
Sanmen, Honan	[1] 150.0
Tienchiao Shensi	[1] 50.0
Shihtsuishan, Ningsia	(2)
Chingtung, Ningsia	225.0
Papan, Kansu	180.0
Yenkuo, Kansu	300.0
Liuchia, Kansu	1,225.0
Lungyen, Tsinghai	(2)
Yalu River (moving upstream):	
Supung Dong Sui, Liaoning	700.0
Hulutao Unbong, Kirin	400.0
Sungari River: Tafengman, Kirin	590.0
Han River and tributaries (moving upstream from the Yangtze River):	
Tanchiangkou, Hupeh	900.0
Huanglungtan, Hupeh	150.0
Shihchuan, Shensi	135.0
Tatu River: Kungtsui, Szechwan	508.0
Yangtze River: Three gorge area, Szechwan/Hupeh	(2)
Fuchun River and tributaries (moving upstream):	
Fuchun, Chekiang	260.0
Chililung, Chekiang	420.0
Hsinan, Chekiang	652.5
Cascade systems:	
Kutien, Fukien (4 stages)	158.0
Maotiao, Kweichow (6 stages)	250.0
Lungchi, Szechwan (4 stages)	108.0
Ili, Yunnan (4 stages)	172.0

[1] Partial capacity.
[2] Under construction.

(Clarke)

is one of seven major hydroelectric river systems that include 1600 large rivers. Before China was seen as a "solar-dominated ecosystem," it had been inaptly characterized as a "hydraulic" society. (Wittfogel)

"New" or "renewable" energy sources span the panorama of time, space and political vicissitudes within China. Local, small-scale new energy projects were sponsored in the most Maoist of times, and are still being popularized during deMao-ization. China's labor force is underemployed. Projects which require high labor utilization and a small capital investment make sense. Individual and family consumption is low priority; per capita energy consumption is one-half that of Mexico. On



Islands in the South China Sea

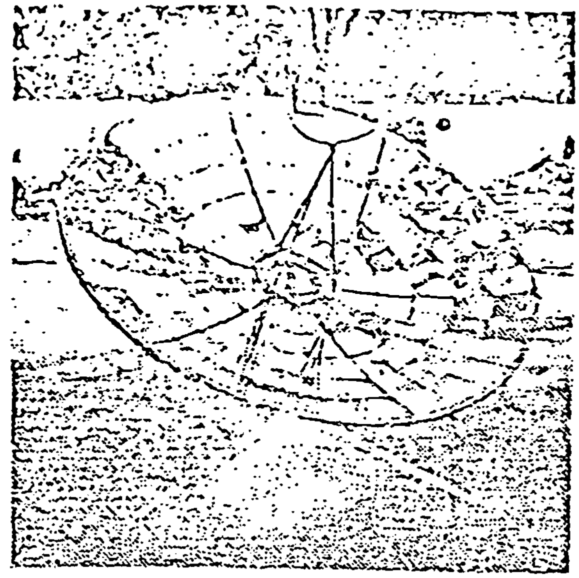
我国太阳辐射的年总量分布图

Total Annual Distribution of Solar Radiation in China (DL75, 12, 77)

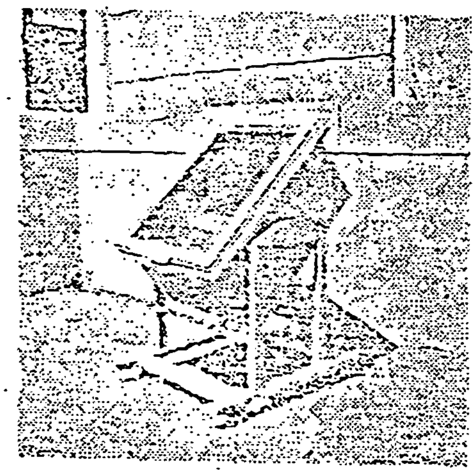
[The isolines indicate the number of kilocalories per square centimeter per year] the road to industrialization, the government is perfectly willing to accept programs which divert coal and oil away from household and agricultural use. Above all, China seems acutely conscious of the ever-intensifying geopolitical significance of energy independence. Not all peoples, in terms of energy resources are created equal. Peking hopes to mobilize the sum total of its potential to meet the challenge.

"Solar energy is a huge resource. It is inexhaustible and creates no pollution. Moreover, research on equipment for utilizing solar energy is becoming increasingly successful. The cost of such equipment is decreasing gradually. ... At present, many nations throughout the world, including China, are paying more attention to research and utilization of solar energy." (Geographical Knowledge 地理知识)

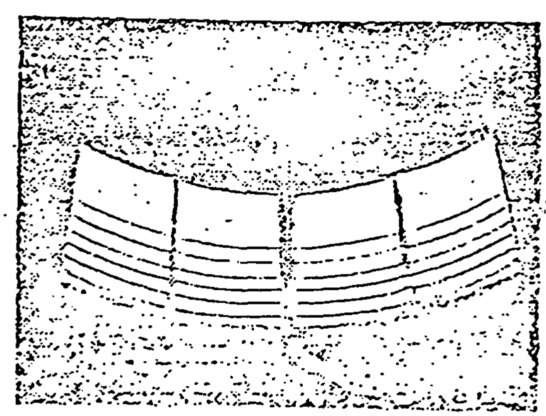
The distribution of solar radiation divides China into four regions: a southern region, a north-



Umbrella-type Light-focusing Solar Cooker



Box-type Light-focusing Solar Cooker



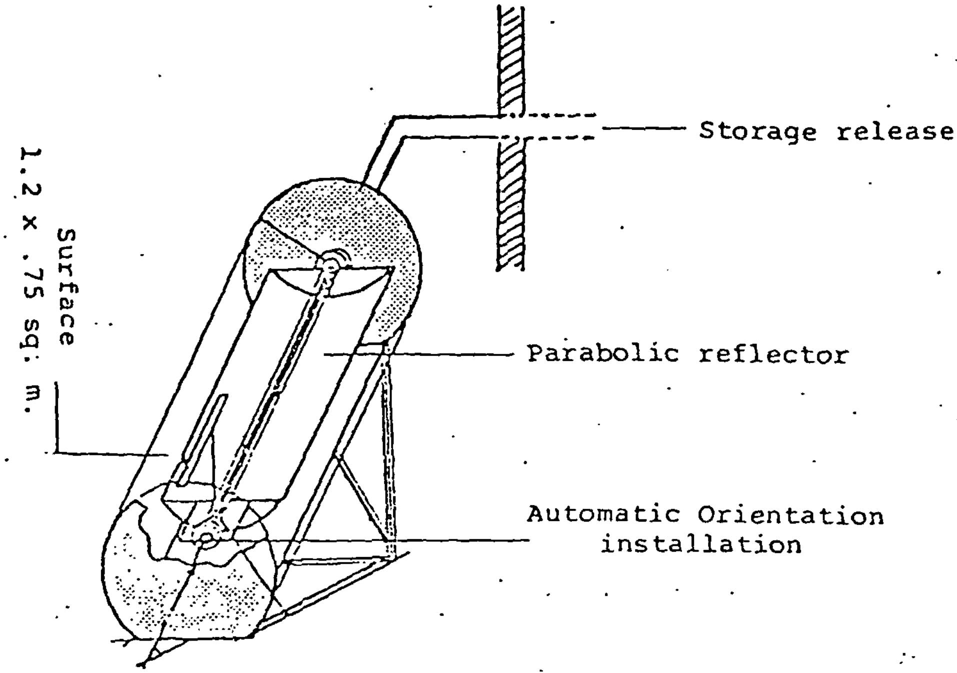
Inflectional-type Light-focusing Solar Cooker

(DLZS, 12, 77)

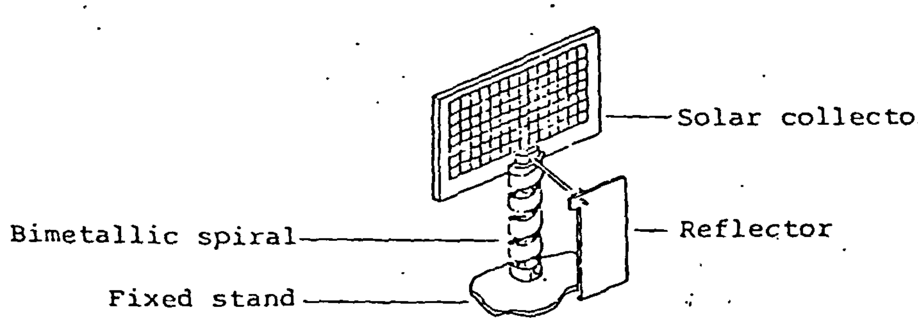
east region, a northern region and the western Tibet-Cinghai region, which is the most remote, sparsely populated, and with its clear skies, most suitable for collecting solar radiation. The annual amount of sunshine varies roughly from 80 to 200 kilocalories per square centimeter per year.

China has expressed interest in photochemical, photoelectric and photothermal conversion. Photothermal conversion has made greater strides toward popular understanding, acceptance and utilization in China than in America. Solar water heaters are commonly installed for bathrooms, barber

Universal Solar Cooker

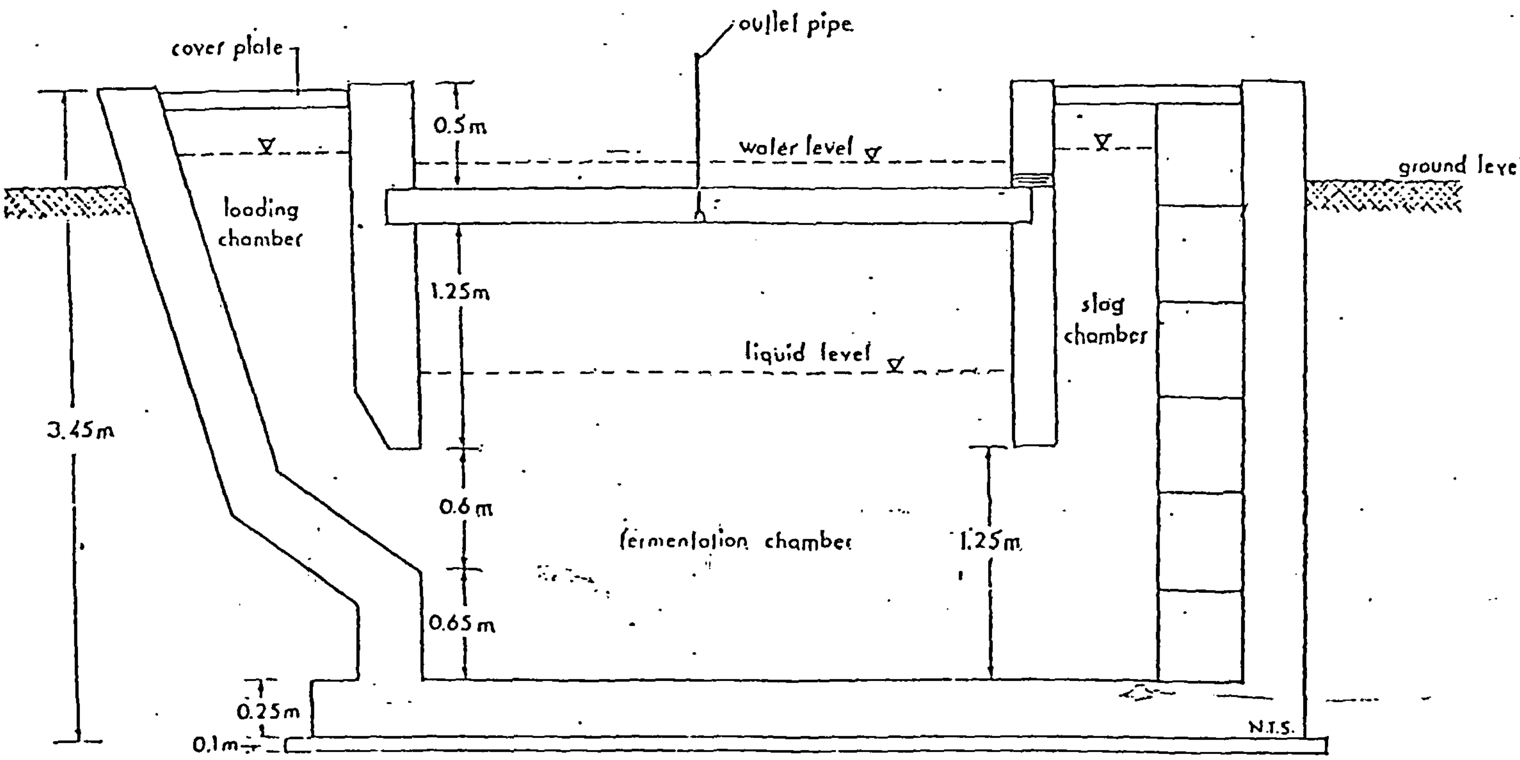


Automatic Control



(National Council for US-China Trade)

A conference in Honan summarized the Chinese attitude toward solar energy and new energy sources in general in its "ten advantages of developing methane and making use of solar energy." The conference concluded that solar and biomass energy sources can help "save fuel, which is beneficial for supporting socialist construction... save the labor force... save firewood and grass which is beneficial for expanding manure resources... save... crops and turn them into fodder... reduce the expenditure [of the commune for consumption and invest energy resources into production]... lighten women's household labor, which is beneficial for liberating the labor force of women... eliminate insect pests and disease... solve difficulties in fuel... promote the development of agricultural mechanization." Finally, exploitation of solar and biomass energy resources are "beneficial for preparedness against war, developing science and culture in the



—Typical Szechwanese biogas digester. This cross-section, originally published in K'o-hsueh Shih-yen, No. 5 (May 1973), p. 32 is not drawn to scale. Flow of the water through a small hole in the wall separating the gas and the slag chamber maintains a relatively stable pressure inside the digester.

(Smil)

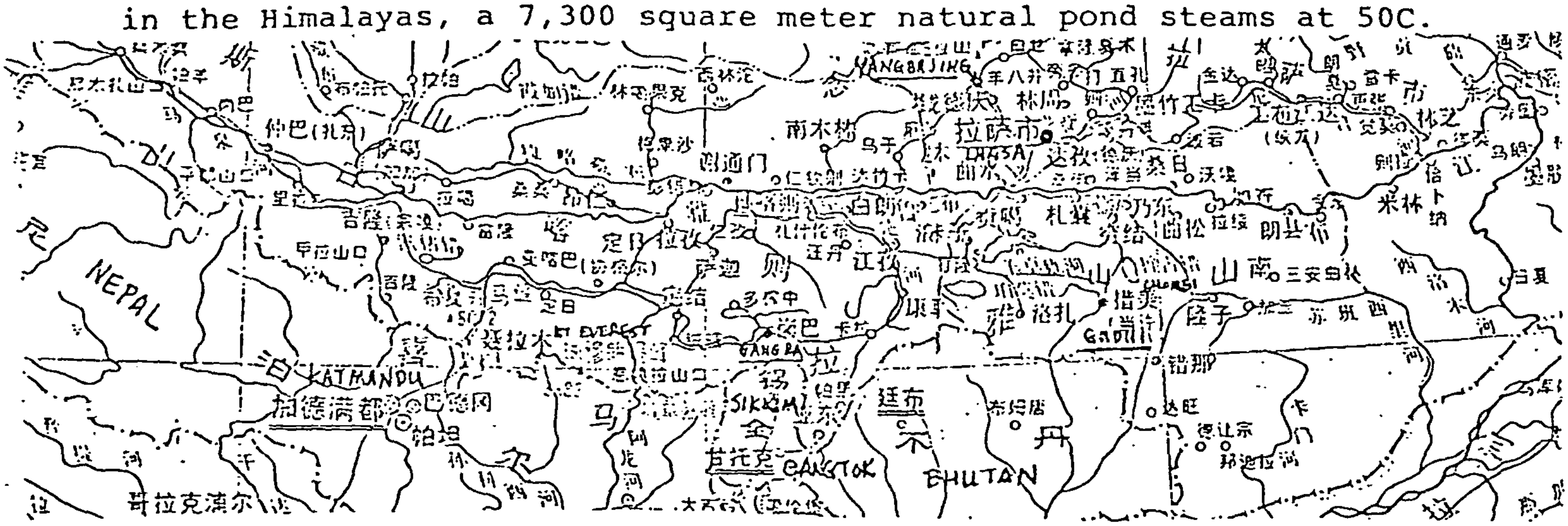
shops, hotels and factories. Solar cookers of three types are common. Umbrella-type light-focusing cookers, box-type light-focusing cookers and inflectional-type light-focusing solar cookers. One plastic, pillow-type solar energy water heater is composed of three layers of polyvinyl chloride membranes. The space between the upper and middle layers is filled with gases for heat insulation, and the space between the middle and bottom layers is filled with water to be heated by the sun. The contraption weighs only 1.5 kilograms and is collapsable, but can hold 60 liters of water. Some of the more 'sophisticated' cylindrical types use a transfer medium, have automatic control, and can heat up to 850C. Solar distillers are used for desalting ocean water or for heating and treating polluted water. When the weather is hottest, solar energy coolers of a very simple design can be efficient. Solar heat evaporates ammonia from solution. The ammonia is recondensed, concentrated and can itself absorb heat and produce ice in solar energy freezers. Recently, the grain bureau of the Xinjiang Uyigur autonomous region announced the development of a solar drying machine that can achieve 180C and which can dry up to one ton of grain per hour.

The Chinese have begun serious research into photovoltaic apparatus and process. The satellite that China produced and launched in 1968 carried silicone solar batteries which supplied the power to broadcast the music "the East is Red" through space. In 1977, a navigational signal light powered by batteries charged by solar energy was successfully tested.

rural areas, narrowing the three big gaps and building socialist new rural areas and so on." (JPRS 23 Dec 75) The masses receive an education, basic training in applied science through participation and conscious involvement in small energy projects.

The Chinese can, Smil writes, claim world leadership in biogas utilization. Over four million biogas digesters are currently in operation. The sealed insulated digesters produce a biogas, approximately 2/3 methane, 1/3 carbon dioxide, hydrogen sulfide, hydrogen and nitrogen. The gas is fomented through the controlled anaerobic fermentation of animal and human excrements, grass or other vegetable matter, garbage and waste water. A ten cubic meter digester costs only forty reminbi or so to build and can supply much of one Chinese family's needs in summer and autumn months. The result is not only a savings of fossil fuels, the digester yields agricultural fertilizer, and promotes a psychology of anti-waste. Some digesters also provide gas to generate electricity or pump water.

China is one of fifty nations active or interested in geothermal exploration and development, and one of less than ten nations using geothermal energy for power generation. Recently Tianjin (Tientsin) municipality reported "initial success" in developing geothermal resources on the outskirts of the city. Underground water in a 590 square meter area reaches 30 - 96C at 700 - 1000 meters. Over 190 geothermal wells have been drilled in Tianjin, producing annually 27 million tons of water heat. Fengshun County in Guangdong Province has a geothermal power station opened in 1971. After degassing, 103.5C water (91C at the well opening) is introduced into an expansion container to produce low-pressure steam and drive an 86 kw turbogenerator. Huailai County near Beijing (Peking) is the site of a station which uses hot water to heat a secondary power fluid (isobutane?) of lower boiling point in an evaporator. In 1975 a station was opened in Ningxiang County, Hunan Province, where hot springs bubble at 92C. In 1978 China's first experimental geothermal steam power station began operation at Yangbajing, near Lhasa in Tibet. Geothermal resources in Tibet seem most promising. Underground water can reach temperatures above 300C and, 4,300 meters above sea level in the Himalayas, a 7,300 square meter natural pond steams at 50C.



It is well-known that the Tibetan plateau was uplifted within a relatively recent historical period. New structural movements are severe, there is frequent magmatic activity, also volcanic and earthquake activity. Gudui Commune in Cuomei County, near the border with Bhutan is situated in the middle of a high temperature hydrothermal activity area as promising as the Yangbajing site.

The potential for generation of tidal power on the China seacoast is reportedly small. (R. Carin) The qiantong estuary in Zhejiang Province -- famous for its "angry tide" -- is said to be the most suitable location for ocean energy installations.

But the economic importance of this estuary has been enhanced through land reclamation more than tidal energy projects. Still a 7000 MW project is under study. Small stations in Guangdong and Shandong utilize a tidal variation of .4 to 1 meter to generate power.

Tidal energy is one of three energy sources which constitute "over 99.99% of the earth's energy resources." The Chinese recognize that the sun's radiant energy, geothermal and atomic energy, and tidal energy dwarf conventional sources as a volcano next to a match. Still with regard to the crisis in conventional energy supplies, Peking places the bulk of the blame on the "bourgeois-democratic" system or "capitalist" method of production.

Secretary Schlesinger said: "As a result of our discussions, a substantial agenda for cooperation between our two countries has been established." Instead of a signed document on joint projects, this rather vague "agenda for cooperation" represented a "highly enthusiastic" Chinese response to talks which preceded normalization of diplomatic relations.

The New Energy Sources Delegation from the People's Republic of China embodies the current Chinese approach to energy -- omni-faceted. With regard to these "new" or "renewable" energy sources, the Chinese will investigate all avenues, and they will "walk on both legs" -- high and low level technology. This all-encompassing commitment to meeting the challenge of energy resources is, perhaps, something that the American government can learn from the Chinese.

Some institutes in the People's Republic of China concerned with new energy sources

Beijing Academy of Architectural Materials, State Capital Construction Commission, Beijing (Peking), China

Beijing Institute of New Energy Application, Beijing, China

Bureau of Geology, Beijing Municipality, China

China Science and Technology University, Hefei, Anhui Province, China

Dalian Insitute of Combination Machine Tools, Lüda, Liaoning Province, China

Guangzhou Institute of Energy Sources, Guangzhou (Canton), Guangdong Province, China

Guangdong Provincial Institute of Geothermal Energy Research, Guangzhou, Guangdong Province, China

Hebei Provincial Plant Protection and Local Fertilizer Institute ?

Institute of Electric Engineering, Academia Sinica (Chinese Academy of Sciences), Beijing, China

Institute of Geology, Academia Sinica, Beijing, China

Jilin Institute of Applied Chemistry, Academia Sinica, Changchun, Jilin Province, China

Lanzhou Institute of Chemical Physics, Lanzhou, Gansu Province, China

Nanjing Institute of Technology, Nanjing (Nanking), Jiangsu Province, China

Qinghua University, Beijing, China

Sichuan Provincial Institute of Biology, Chengdu, Sichuan Province, China

Tianjin University, Tianjin (Tientsin), Hebei Province, China

A few articles on new energy sources in China (this office will not be able to supply xeroxed copies of the articles, much less of translations)

Geothermal Research Group, Institute of Geology, Academia Sinica, "Report on the Data of Terrestrial Heat Flow in the North China Plain and Adjacent Regions, SGS, (No 1, Jan 79).

The heat flow in northern China has higher values (o.6 u $cal/cm^2 . s$ to 1.84 u $cal/cm^2 . s$) than other similar tectonic elements of the world.

Chen Zongyong, "Morning and Evening Tides of Infinite Variety," Haiyang (Oceans), (No 1, Jan 79).

Periodicy of tides in Shijiu, Shandong, Dongfang of Hainan Island and at Shanwei, Guangdong -- all of which wait for no man.

Fu Kezhun, "Wind," KXSY, (No 2, Feb 73).

Very brief treatment of the use of wind for power generation.

Chen Gang, "Hot Springs of China," DLZS, (No 2, Apr 73)

Distribution of various types of hot springs.

Gu Yehong, "Exposing Zhu Xi's True Face Under His Mask as the Vanguard of Geological Paleontology," KXSY, (No 11, Nov 74).

Zhu Xi, a NeoConfucian philosopher, is famous for his emphasis of ge-wu (the investigation of things) which he would have extended even to a blade of grass. For this reason, he has been called a forerunner of the scientific approach that never took off in China. Because he was what the current government refers to as an "idealist Confucian," his philosophy has been harshly criticized, especially under the "Gang of

Four."

Huang Shengnian, "On Atomic Energy," KXSY, (No 12, Dec 74)

General discussion which extends as far as the control of thermal nuclear reaction by strong magnetic field and internal laser detonation.

(Tianjin University), "Fuel-less Electric Power Station: Solar Thermal Electric Generation," KXSY, (No 7, Jul 77).

General discussion of simple gadgets and introductory concepts.

Wang Dasi, "Marsh Gas Bacteria," KXSY, (No 3, Mar 77).

Use of two different types of bacteria, importance of controlling the carbon/nitrogen ratio, addition of human and animal feces to the "fermentation bath."

Wang Taichuan, "Desalinization of Sea Water by Solar Energy," KXSY, (No 9, Sep 77).

Anti-waste psychology at its finest -- retrieve residual chemicals, use of industrial residual heat to supplement solar energy, etc.

Wang Zhanmin and Shi Zhun, "Prospection of Hot Ground Water in Peking and its Bearing on the Struggle in Epistemology Between the Confucian and Legalist Schools of Philosophy," SGS, (No 4, Nov 74).

The political possibilities of science can boggle the mind.

Ya Chun, "Solar Energy Utilization," KXSY, (No 11, Nov 74).

Solar ovens, distillers, freezers, thermal engine, air heater, furnace, power generators, and the use of satellites to collect solar energy for power generation.

Yan Jiaqi, "The Earth's Energy Sources," KXSY, (No 6, Jun 74).

First one to learn to use it wins.

Zhang Mingtao, "Hydrothermal Explosions," DLZS, (No 7, Jul 77).

4. Popularization of solar energy devices.

[illegible] "Umbrella-Shaped Solar Disks," KXSY, (No 10, Oct 74).

Thermal Engineering Laboratory of Tianjin University

(anon), "Solar Energy Water Heater," KXSY, (No 12, Dec 74).

Questions and answers on concrete problems.

(anonymous), "On the Use of Marsh Gas," KXSY, (No 7, Jul 74).

The Qiantang estuary.

DLZS (No 2, Feb 77).

Do [illegible], "[illegible] Declamation on the Seasons of Zhejiang Provin-

of the nineteenth century.

disaster, even by the supposedly feminist Taiping rebels

This, in Chinese culture, has been taken as an omen of impend

mel[illegible] develops into a testis, the hen becomes a cock.

[illegible] reading. If the left ovary malfunctions and if the

[illegible]u Zhun, "The Mystery of the Crowing Hen," KXSY, (No 2, Feb 73).

Why not a windmill on the Empire State Building?

[illegible] Ruizhao, "How Do Winds Vary With Altitudes?" DLZS, (No 2, Feb 77).

[illegible]tiny, and we could not decide which to choose.

[illegible]rhening article. "The mountainfall of samples made us

[illegible] 5, May 77).

[illegible] Survey of t[illegible]

Gangba County, Tibet.

Zhang Mingtao, "Preliminary Survey of the Gudui Thermal Field," DLZS, (No 5, May 77).

Fascinating article. "The mountainfull of samples made us dizzy, and we could not decide which to choose."

Zhu Ruizhao, "How Do Winds Vary With Altitudes?" DLZS, (No 2, Feb 77).

Why not a windmill on the Empire State Building?

Zhu Zhun, "The Mystery of the Crowing Hen," KXSY, (No 2, Feb 73).

Must reading. If the left ovary malfunctions, and if the medulla develops into a testis, the hen becomes a cock. This, in Chinese culture, has been taken as an omen of impending disaster, even by the supposedly feminist Taiping rebels of the nineteenth century.

Zo Zhongmou, "Land Reclamation on the Seashore of Zhejiang Province," DLZS, (No 2, Feb 77).

The Qiantang estuary.

(anonymous), "On the Use of Marsh Gas," KXSY, (No 7, Jul 74).

Questions and answers on concrete problems.

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The popularization of solar energy devices.

ABBREVIATIONS:	DLZS	Dili zhishi	(地理知识)	Geological Knowledge
	KXSY	Kexue shiyan	(科学试验)	Scientific Experiment
	SGS	Scientia Geologica Sinica	(地质科学)	

[illegible]

岐阜県春日村の接触変成帯に発達する特異な交代変成岩と脈について

鈴 木 和 博*

(1975 年 1 月 6 日 受理)

I. 序

岐阜県揖斐郡春日村の古生層は白亜紀末の貝月山（かいづきやま）花こう岩の熱変成を被り，緑色片岩相から角閃岩相までの程度に変成している．当地域の古生層は未変成の砂泥質岩・塩基性火山岩・石灰岩・ドロマイト岩などから構成され，さらにこれらの岩石がそれぞれ花こう岩に直接している．筆者は，この点に着目し，特に珪質ドロマイト岩の累進変成と泥質岩・塩基性岩の累進変成との関係ならびにスカルンの形成に代表される交代作用の性格を明らかにする目的をもって，この地域の接触変成帯を研究中である．

この研究途上，花こう岩接触部近傍にざくろ石−単斜輝石−斜長石脈を伴う黒雲母−斜長石岩その他の岩石が顕著に発達することに注目し，これを調べた．その結果，黒雲母−斜長石岩は，接触変成作用末期のカリウム交代作用により，塩基性岩源の角閃岩から生成したものであることが明らかになった．また脈はこの交代作用によって解放される成分が濃集した部分であることが判明した．均質な角閃岩が黒雲母−斜長石岩と石灰質な脈に分化していくこの交代作用は，Korzhinskii (1959)・Orville (1969)・Vidale (1969) などによって詳しく論じられた化学的に平衡でない岩石の接触面に起きる相互交代変成作用とは異なったものである．

このような交代変成岩は春日村の接触変成帯以外にもしばしば存在するようである．しかし，この種の岩石は一般に，詳しい記載が行なわれないままに，原岩組成の不均質に原因するものとして片付けられたり，あるいは混成作用と決めつけられることが多かった．春日村の交代作用は小規模ではあるが，源岩石からの交代変化を逐次たどることができる．この記載と物質移動の定量的な追求とは報告に値すると筆者は考えた．なお本稿では，春日村の接触変成帯の等化学的な熱変成岩や泥質岩源・石灰質岩源交代変成岩については，簡単に記載するだけにとどめたい．これらについては別稿で報告する予定である．

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II. 地 質 概 略

春日村には Fig. 1 に示すように古生層・貝月山花こう岩および両者を貫く時代未詳の岩脈類が分布する．

1. 古生層

古生層は砂泥質岩・塩基性火山岩類・石灰岩・ドロマイト岩・チャートから構成される．その一般走向は調査地域の北東部および中部において N50°〜70°E であるが，南西部では N30°E になり，全体として北西に突出した湾曲構造を呈する．地層傾斜は南東 (40°〜80°SE) である．当地域の古生層の層位・古生物については関(1939)・5 万分の 1 図幅「近江長浜」(礒見, 1956)・Miyamura (1967) らの詳細な研究があり，それによれば時代は二畳紀である．

泥質岩には粘板岩といえる細粒部分もあるが，大部分はやや粗粒のシルト岩である．これらは数 mm〜数 cm の厚さで互層し，さらに細〜中粒砂岩と数 cm〜数10 cm の規模で互層する．粗粒砂岩は層厚 1〜10m の塊状層を成す．

塩基性火山岩類として一括したものには玄武岩・玄武岩質火山礫凝灰岩・凝灰岩などが含まれる．量的には玄武岩が圧倒的に多い．玄武岩は主に板状溶岩として産するが，枕状溶岩・迸入岩として産することもある．個々の溶岩の層厚は 1〜10 m であり，これが凝灰岩・石灰質岩・泥質岩の薄層を挟んで反復している．

石灰岩やドロマイト岩は層厚数 m〜10 数 m のレンズ状岩体として産出することが多い．これらの岩石はしばしば数 mm〜数cm 大のチャート様ノジュールを含む．しかしノジュール部以外は比較的純粋であり，大部分の石灰岩やドロマイト岩の SiO_2 含有量および Al_2O_3・Fe_2O_3 含有量はそれぞれ 1 %以下である（上治・貞本, 1954）．

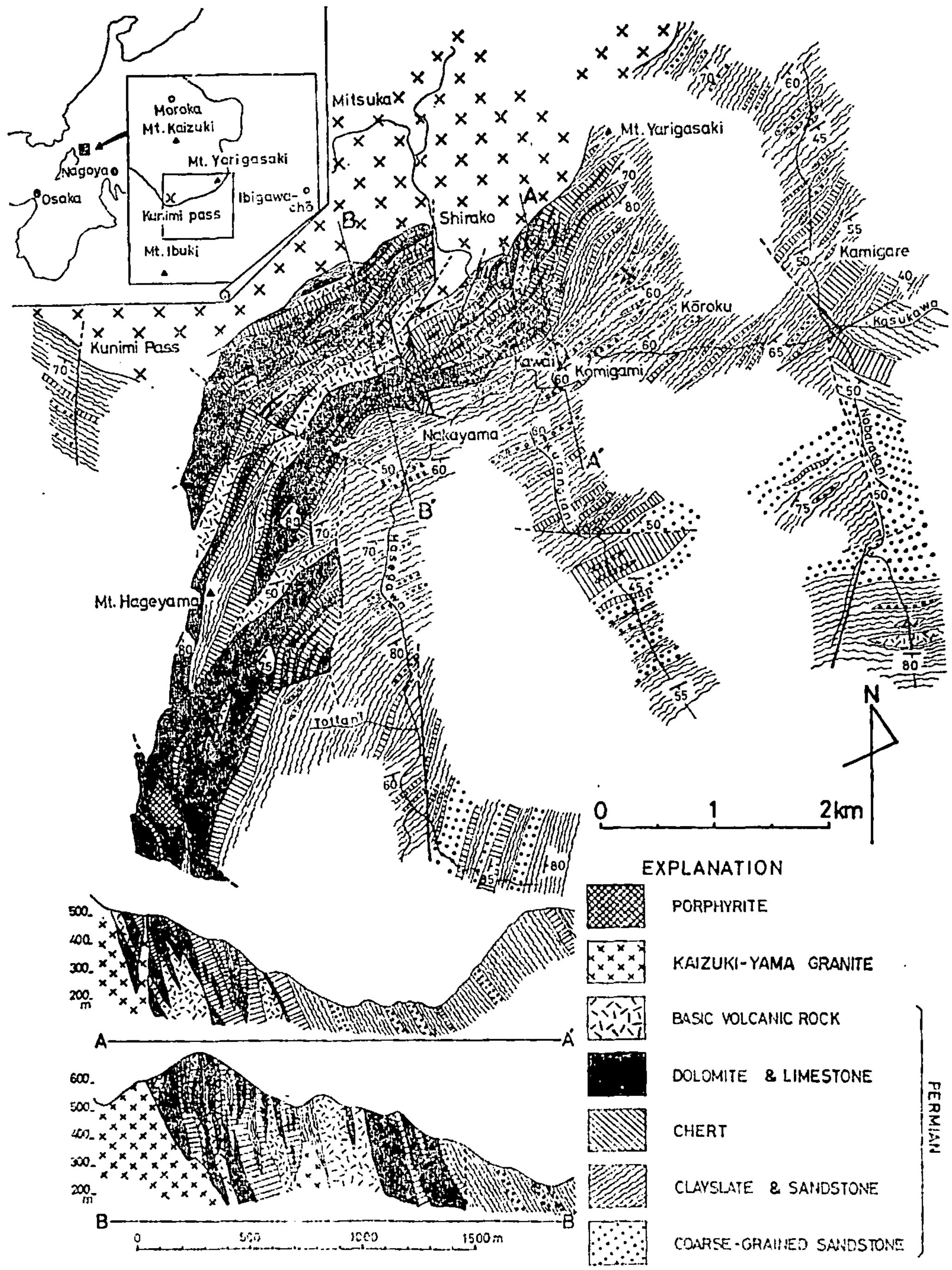

Fig. 1. Geologic map and cross sections of Kasuga-mura.

2. 貝月山花こう岩

春日村から北方にかけて10×15kmの楕円形状に露出する花こう岩体は[illegible]ほか (1965) によって貝月山花こう岩と命名された．この花こう岩体の固結年代はK-Ar法で73m. y. である（河野・植田，1966）．河井ほか (1970) は，有色鉱物の量が岩体中心部に向って漸次減少すること，面構造が同心円状になっていることを報告した．

春日村では花こう岩と接触変成岩は明瞭な境で接し，その接触面は外側（南）に60°〜80°傾斜する．接触部近傍の変成岩中には幾つかの岩枝が貫入している．また地質図には示してないが，花こう岩中および変成岩中にはアプライト脈やペグマタイト脈が多数存在する．調査地域内の主要な岩相は中〜粗粒・塊状の花こう閃緑岩ないし石英モンゾニ岩であり，主成分鉱物は斜長石 (30〜40%)・石英 (25〜35%)・カリウム長石 (20〜25%)・黒雲母 (8〜14%)・角閃石 (0〜2%) である．

斜長石の核部は An 45〜28 の範囲の振動状累帯を成し，縁部は An 26〜21 の正規累帯を成す．縁部にはしばしばミルメカイトが発達する．石英は 1〜4 mm の不規則な輪郭をとるものが多いが，一部の岩石では 5〜8 mm の粒状結晶を成す．カリウム長石には不定形の小結晶と 1 cm 内外の斑晶がある．両者とも 2Vx=63°〜68° であるが，パーサイト構造を示すものもある．斑状カリウム長石の三斜度は 0.00〜0.26 である．黒雲母は Z 軸色=褐色，γ=1.649〜1.661 である．角閃石には緑色種と無色〜淡緑色種がある．岩枝の部分では角閃石がオパサイト化していることがある．

3. 玢岩類

玢岩は主に幅数 10 cm〜数 m の南北走向・垂直の岩脈として産するが，戸谷（とったに）付近には岩株も見られる．大部分の岩脈を構成するものは角閃石玢岩であるが，単斜輝石玢岩もある．岩株は単斜輝石玢岩から構成され部分的に斑れい岩質に成っている．玢岩脈は花こう岩を切って貫入し，弱いながら急冷周辺相を持つ．また花こう岩体近傍のドロマイト岩中に貫入している場合でも，両者の間に反応帯が見られない．これらの事実は花こう岩や接触変成岩がかなり冷却した後に玢岩が貫入したことを示す．

III. 接触変成作用

基性火山岩や泥質岩に黒雲母が出現し始める黒雲母アイソグラッドから花こう岩体までを接触変成帯と呼ぶ．黒雲母アイソグラッドは花こう岩体から2.5〜3kmの所に位置する．この接触変成帯は，変基性岩の鉱物組合わせに基づいてアクチノライト帯・青緑色角閃石帯・緑色角閃石帯の3帯に分帯することができる (Fig. 2)．

1. 変基性岩

変基性岩の主要な鉱物組合わせは次のようである．アクチノライト帯；アクチノライト―アルバイト―緑泥石―緑れん石―黒雲母(±方解石±石英)，アクチノライト―アルバイト―オリゴクレース―緑泥石―緑れん石―黒雲母(±方解石±石英)．青緑色角閃石帯；角閃石―斜長石―黒雲母―緑泥石(±単斜輝石±石英)，角閃石―斜長石―黒雲母(±単斜輝石±石英)．緑色角閃石帯；角閃石―斜長石―黒雲母(±単斜輝石±石英)．いずれの組合わせも少量のスフェン・チタン鉄鉱・燐灰石を伴う．

接触変成帯外側の基性岩は斜長石・単斜輝石・緑泥石・方解石・石英・スフェン・チタン鉄鉱・燐灰石などから成る．斜長石は An 69〜43 であり，これは割目などに沿ってアルバイト化している．本地域南西方の滋賀県長浜市東部産の岩石にはパンペリー石が含まれるが，春日村からはこのような低度変成作用を特徴づける鉱物を見つけていない．

アクチノライト帯の岩石はアクチノライト・緑レン石・アルバイトの共存で特徴づけられるが，本帯高温部では緑れん石が減少しアルバイトとオリゴクレースが共存する．アクチノライト・緑れん石・黒雲母の出現は同時である．残存単斜輝石は，この帯の中温部まで認められる．黒雲母は1〜2%含有されるのみであり，そのZ軸色は緑褐色〜褐色である．

青緑色角閃石帯の岩石はZ軸色が青緑色の角閃石の存在で特徴づけられる．本帯高温部の代表的な岩石の化学組成とモードをTable 1；1・2に示す．本帯低温部では青緑色角閃石はアクチノライト集合体の縁部に存在し，緑泥石と共存する．緑泥石の量はアクチノライト帯より著しく少ない．低温部の斜長石は An 0〜41 の逆累帯を成すものが多い．高温部の斜長石はほとんど累帯構造を示さず，組成は An 35〜24 である．緑泥石は本帯中温部まで存在する．この緑泥石の消滅に伴ってスフェンの減少とチタン鉄鉱の増加が見られる．なお幾分石灰質な岩石では緑泥石の消滅以前に単斜輝石が出現する．

緑色角閃石帯の岩石はZ軸色が緑色〜緑褐色の角閃石の存在で特徴づけられる．代表的な岩石の化学組成とモードを Table 1；3・4 に示す．斜長石は An 53〜28 である．

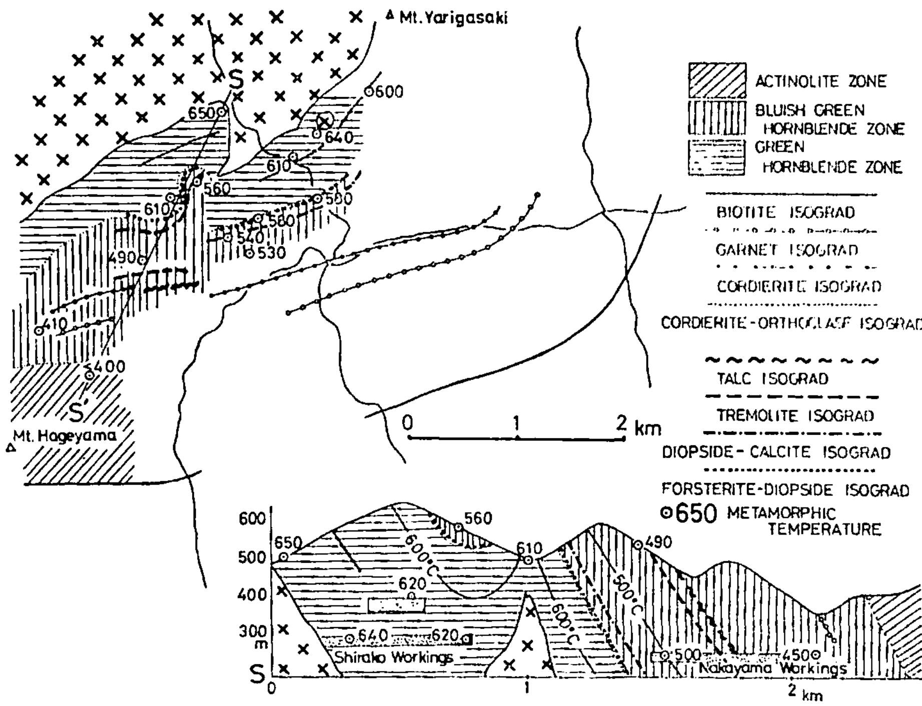

Fig. 2. Zones, isograds and temperatures of the progressive contact metamorphism in Kasuga-mura.

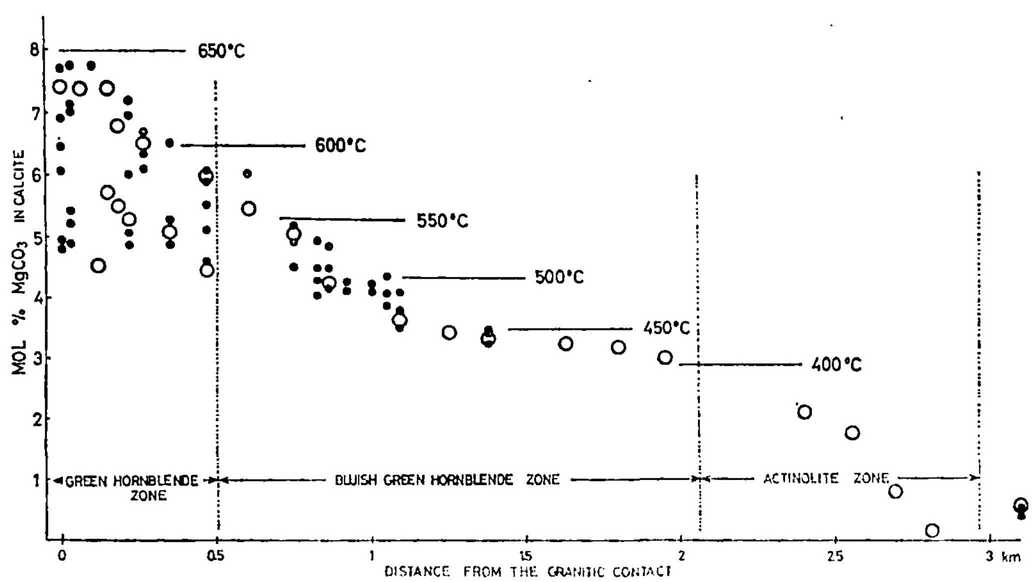

Fig. 3. Mol % $MgCO_3$ in calcite and temperatures as function of the distance from the granitic contact. Solid circles show the composition of calcite determined by EPMA and open circles by cell dimension.

2. 変泥質岩

変泥質岩の鉱物組合わせは，①黒雲母－白雲母－緑泥石；②黒雲母－白雲母－緑泥石－ざくろ石；③黒雲母－白雲母－菫青石(±ざくろ石)，黒雲母－白雲母－紅柱石，紅柱石－菫青石－白雲母；④黒雲母－オルソクレース－菫青石(±ざくろ石)，紅柱石－オルソクレース－菫青石である．いずれの組合わせも石英・斜長石を含む．組合わせ①はアクチノライト帯に，②は青緑色角閃石帯低温部に，③は青緑色角閃石帯中温部～緑色角閃石帯中温部に，④は緑色角閃石帯高温部に出現する．

非変成泥質岩の基質部は石英・緑泥石・白雲母・斜長石・炭質物・鉱石鉱物から成り，やや粗粒な砕屑粒として石英・斜長石・カリウム長石が存在する．

黒雲母アイソグラッドは塩基性岩において黒雲母・アクチノライト・緑れん石が出現し始める所に位置する．ざくろ石アイソグラッドは菫青石アイソグラッドより幾分低温側に位置する．この両アイソグラッドに囲まれる領域では，ほとんどすべての変泥質岩にざくろ石が出現し，緑泥石と共存している．しかし菫青石アイソグラッドより高温側ではざくろ石の出現が極めてまれになる．紅柱石は菫青石とは共存するが黒雲母とは共存しない．緑色角閃石帯の高温領域すなわち花こう岩体から 200m 付近で白雲母が減少し，オルソクレースと菫青石の共存が見られる．一般には白雲母が分解すると Al_2SiO_5 鉱物が出現してくるが，春日村の大部分の変泥質岩では Al_2SiO_5 鉱物を含まない黒雲母・オルソクレース・菫青石（±ざくろ石）の組合わせが出現してくる．この組合わせを持つ岩石は，同様な化学組成の含白雲母岩に比べて，著しく黒雲母が少なく菫青石が多い．菫青石はざくろ石と共存するものでは $\beta=1.561$，しないものでは $\beta=1.548\sim1.556$ である．また黒雲母はざくろ石と共存するものでは $\gamma=1.646$・$Mg/Mg+Fe+Mn=0.36$ (Table 2：1)，しないものでは $\gamma=1.628\sim1.643$ である．産出例は少ないが，菫青石－オルソクレースアイソグラッドより花こう岩体側に，紅柱石－オルソクレース－菫青石の組合わせが存在することより，白雲母の分解反応は紅柱石の安定領域で生じていることが推察される．花こう岩から約 50m の所では紅柱石が安定に存在している．しかし，これより花こう岩体側からは Al_2SiO_5 鉱物を含む岩石を見つけていないため，春日村の接触変成帯で紅柱石→珪線石の反応が生じたかどうか不明である．

3. 石灰質岩源変成岩

珪質ドロマイト岩およびドロマイト岩中のチャート様ノジュールの周囲には石英・ドロマイト・方解石・滑石・透閃石・透輝石・苦土かんらん石より成る多様な3相・4相および5相の鉱物組合わせが生じている．鈴木(1975)は $CaO-MgO-SiO_2-CO_2-H_2O$ 系におけるこれらの鉱物組合わせを解析して，厚い塊状の珪質ドロマイト岩の変成作用は，近似的に閉じた系と見なせること，滑石と透閃石の出現は温度と H_2O・CO_2 などから成る流体およびその CO_2 の分圧に依存するが，その CO_2 の割合は極めて狭い範囲に限られること，一定の流体圧下においては透輝石－ドロマイトアイソグラッドと透輝石－苦土かんらん石アイソグラッドが特定の温度を示すこと，を明らかにした．滑石アイソグラッドと透閃石アイソグラッドは，青緑色角閃石帯の中温部に位置し，透輝石－ドロマイトアイソグラッドは青緑色角閃石帯の高温部に位置する．透輝石－苦土かんらん石アイソグラッドは青緑色角閃石帯と緑色角閃石帯の境界に位置する．

石灰岩の場合には緑色角閃石帯の中温部からチャート様ノジュールの周囲に珪灰石が生じ始める．珪灰石－石英－方解石の組合わせは接触部近傍まで存続する．

4. 変成条件の推定

接触変成帯外縁部の変基性岩においてアクチノライト・緑れん石・黒雲母が同時に出現し始めることは再結晶が緑色片岩相の高温領域（黒雲母帯，Fyfe and Turner, 1958, p. 167）から開始したことを示す．他方花こう岩接触部近傍では，変泥質岩が黒雲母－オルソクレース－菫青石(±ざくろ石)の組合わせを持ち，変基性岩が角閃石－斜長石の組合わせを持つ．これは島津(1958)・Rose (1958)・Compton (1960) らが論じているように，花こう岩接触部近傍の変成度が角閃岩相の高温領域であることを示す．青緑色角閃石帯低温部の角閃石と緑泥石の共存する岩石は緑色片岩相と角閃岩相の境界を表わすのであろう．なおこの温度領域付近に角閃石・緑れん石・アルバイトの共存で特徴づけられる緑れん石角閃岩相の岩石は存在しない．

ドロマイトと共存する方解石中の $MgCO_3$ 含有量を EPMA と格子定数の変化（Goldsmith and Graf, 1958）で決定し，Sheppard and Schwarcz (1970, p. 161) の関係式：

$$\log MgCO_3 \text{ mol\% in calcite} = 1.727\times10^{-3}T-0.223$$
$$(400°C < T < 1075°C)$$

で変成温度を推定した (Fig. 2, Fig. 3)．方解石および共存するドロマイト中の $FeCO_3$ 含有量や $MnCO_3$ 含

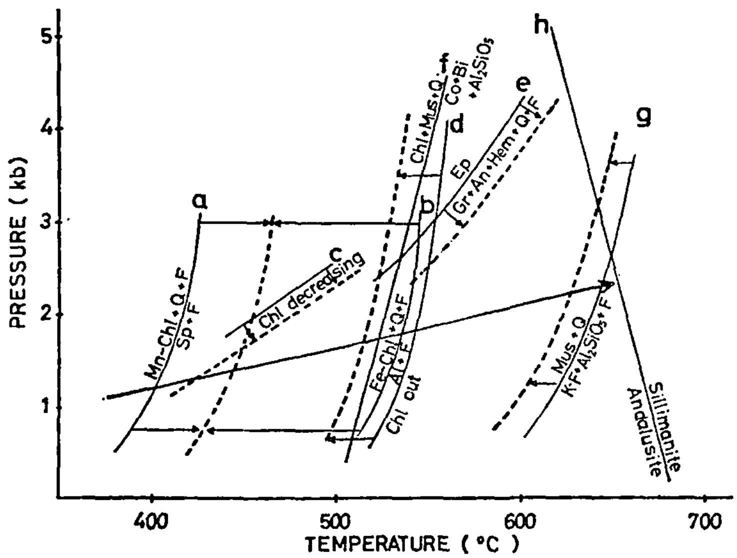

Fig. 4. P-T phase diagram of experimentally determined equilibria.
a : Mn-chlorite+quartz+fluid=spessartine+fluid (Hsu, 1968). b : Fe-chlorite+quartz+fluid=almandine+fluid (Hsu, 1968). c : Chlorite decreasing reaction; albite+epidote+chlorite+quartz=oligoclase+tschermakite+Fe_2O_3+H_2O (Liou *et al.*, 1974). d : Chlorite out reaction; chlorite+sphene+quartz=aluminous amphibole+ilmenite+H_2O(Liou *et al.*, 1974). e : Epidote=grossular+anorthite+hematite+quartz+fluid (Liou, 1973). f : Chlorite+muscovite+quartz=cordierite+biotite+Al_2SiO_5 (Hirschberg and Winkler, 1968). g : Muscovite+quartz=K-feldspar+Al_2SiO_5+H_2O (Evans, 1965). h : Andalusite=sillimanite (Althaus, 1967).
The dashed curves show the probable shift of experimental equilibrium curves by decreasing P_{H_2O}/P_{total} ratio, increasing P_{O_2}, etc.

有量は 0.1 モル%以下である．緑色角閃石帯の方解石は Fig. 3 に見られるように多様な $MgCO_3$ 含有量を示し，またドロマイトの微細な結晶 (5～20 μ) を含んでいる．一般に $MgCO_3$ 含有量の小さい方解石中ほどドロマイトの微細粒が多く含まれている．Mg 質方解石からドロマイトの離溶は 600°C 以上では容易に生じるが，600 °C 以下では離溶しにくく約 5 モル%の $MgCO_3$ を含有したまま冷却する (Goldsmith, 1960)．緑色角閃石帯において方解石中の $MgCO_3$ 含有量の下限が約 5 モル%であることは Goldsmith の記述と一致し，方解石中に見られるドロマイトの微細粒が離溶ラメラであることを示す．したがってドロマイトのラメラを持たない $MgCO_3$ 含有量の大きい方解石が最高の変成温度をより反映していると考えられる．500°C の等温線は青緑色角閃石帯の中温部に，600°C の等温線は緑色角閃石帯の低温部に位置する．

ドロマイト—方解石離溶温度計の示す変成温度と各種アイソグラッドの化学反応を近似する反応式の実験データたとえば Evans (1965)・Althaus (1967)・Hirschberg and Winkler (1968)・Hsu (1969)・Liou (1973)・Liou *et al.* (1974) を比較することによって接触変成帯の水蒸気圧を推定することができる (Fig. 4)．この図では，平衡曲線に対する鉱物の固溶体の効果および酸素分圧の効果を適当に考慮して，それぞれ破線で示してある．

白雲母と石英の反応 g が紅柱石の安定領域の約620°C で生じていること，緑れん石角閃岩相下限を示す平衡曲線 d および e に囲まれる温度圧力領域の岩石が存在しないことなどから，水蒸気圧は 2.5kb 以下であることが推定される．Skippen (1974) の CaO–MgO–SiO_2–CO_2–H_2O 系の実験によると，滑石を含む鉱物組合せは，流体圧 ($P_{H_2O}+P_{CO_2}$) が 1kb 以下の場合には出現しないが，2kb になると比較的 CO_2 の割合が大きい条件下で存在し，この流体圧の増加に伴って存在し得る温度領域が拡大

[illegible]

IV. 交代変成岩の産状と記載

1. 基性交代変成岩

春日村の接触変成帯には，淡緑色の不規則脈を伴った，黒褐色～灰黒色の岩石が顕著に発達している．この優黒質の岩石は角閃石を含まず著しく黒雲母に富むという特異な組成を持つものである．鉱物組成から，黒雲母－斜長石岩と黒雲母・磁鉄鉱・カリウム長石岩の2種に識別される．黒雲母－斜長石岩に伴う脈は幅数 mm～数 cm のざくろ石－単斜輝石－斜長石脈である (Plate I; 1)．ざくろ石は幅の比較的広い脈の中心部に濃集しているが，小規模な脈には存在しない．また，この脈の周囲には 1 mm 内外の幅で角閃石が濃集していることが多い (Plate II; 5)．黒雲母－磁鉄鉱－カリウム長石岩に伴う脈はざくろ石を含まない単斜輝石－斜長石脈である (Plate I; 2)．

これらの特異な岩石の産出地点は，Fig. 5 に示すように，角閃岩相の変成度に達した変基性岩の層中であり，しかも断層沿いの場所であることが多い．Fig. 5 のそれぞれの地点では，例として Fig. 6 に模式的に示すように，角閃岩（A）が褐色角閃石－斜長石岩（B）を経て黒雲母－斜長石岩（C）に漸移している．角閃岩中には石灰質な脈やレンズは存在していないが，褐色角閃石－斜長石岩になると，ほとんど例外なく，0.5～1 mm 大の単斜輝石－斜長石集合体 (CPA) を作ってくる．この単斜輝石－斜長石集合体は，母岩中の黒雲母の増加に伴って，次第に脈状に連なりざくろ石－単斜輝石－斜長石脈(GCPV)に発達する．黒雲母－斜長石岩とざくろ石－単斜輝石－斜長石脈は，花こう岩（E）に直接する部分で，黒雲母－磁鉄鉱－カリウム長石岩（D）と単斜輝石－斜長石脈（CPV）になる．この場合，花こう岩にはほとんど変化がみられず，接触部から 1～3 cm の範囲が幾分優白質になっているにすぎない．なお，花こう岩から伸びるアプライト質な脈は単斜輝石－斜長石脈を明らかに切っている．

上記のような角閃岩からの一連の変化は同一層（溶岩流）内で層の延長方向に生じていることが多い(Fig. 7)．また黒雲母に富む岩石はブラストオフィチック組織や残斑状組織を呈する．これらの事実は黒雲母に富む岩石と脈が，カリウム交代作用によって，均質な基性火山岩から生成したことを暗示している．

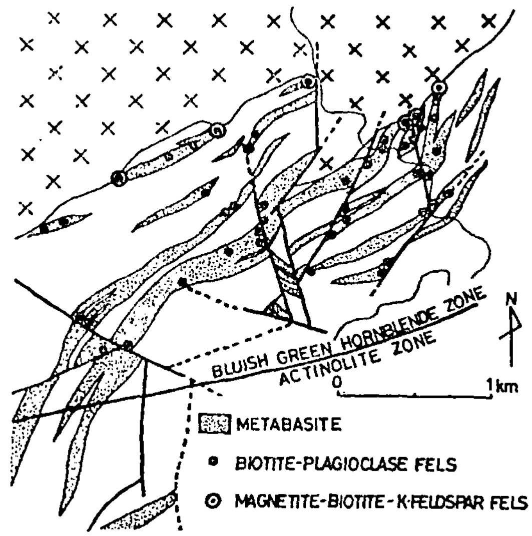

Fig. 5. Sketch map showing outcrops of basic volcanic rocks and localities where the unusual bands and veins are present.

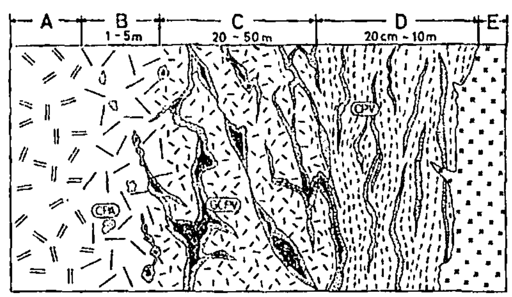

Fig. 6. Schematic illustration of the occurrence of the basic metasomatite.

A; amphibolite, B; brown hornblende-plagioclase fels, C; biotite-plagioclase fels, D; biotite-magnetite-potassium feldspar fels, E; granite, CPA; clinopyroxene-plagioclase aggregate, GCPV; garnet-clinopyroxene-plagioclase vein, and CPV; clinopyroxene-plagioclase vein. The size of the aggregates and veins is exaggerated.

A）褐色角閃石－斜長石岩

本岩石はブラストオフィチック組織および残斑状組織を呈する細粒岩 (0.08～0.15 mm) である (Plate I; 1, 2)．主成分鉱物は斜長石・角閃石・黒雲母・単斜輝石であり，副成分鉱物はチタン鉄鉱・スフェン・磁硫鉄鉱・

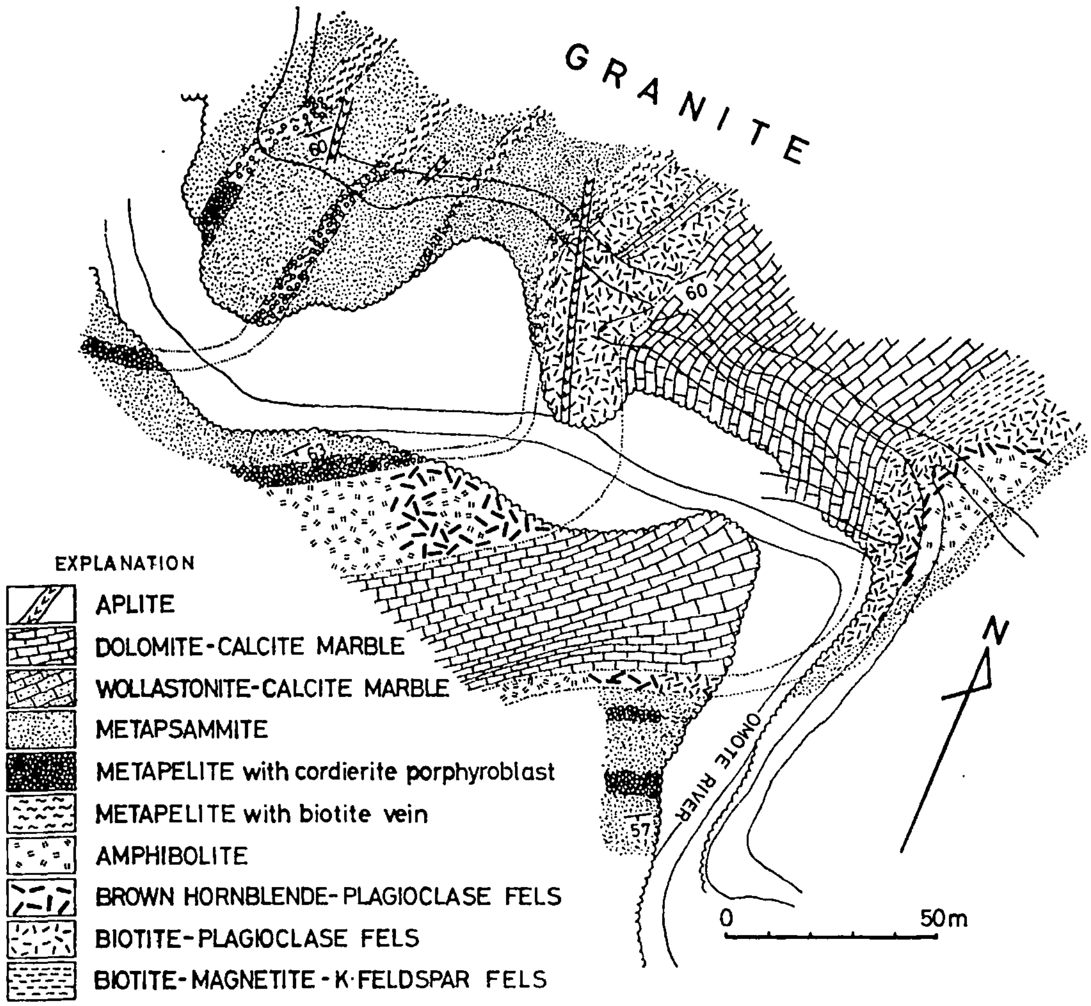

Fig. 7. Schematic sketch of the outcrop along the Omote-river, Kasuga-mura.

燐灰石である (Table 1: 5).

寄木状の斜長石は An 40～24，柱状の斑晶は An 48～37 である．角閃石はZ軸色＝緑褐色，2Vx＝60°，β＝1.673 であり，その組成は Al_2O_3 が少なく Fe_2O_3 が多い (Table 2; 4)．また一部の岩石にはZ軸色＝濃緑褐色，2Vx＝53°～42°，β＝1.710～1.715 の角閃石が存在する．このように Al_2O_3 が少なく Fe_2O_3 が多い角閃石は角閃岩相程度の変成度の接触変成岩からは知られていない．しかし，Durcha 産の縞状角閃岩 (FRANCIS, 1958) や Glen Tilt Complex 中の角閃石岩・角閃石片岩の捕獲岩 (DEER, 1938) など，いわゆる交代変成岩には普通にみられる．単斜輝石は 2Vz＝56°，β＝1.698 のサーラ輝石であり，これは斜長石と1mm大の集合体を形成していることが多い．

B）黒雲母－斜長石岩とざくろ石－単斜輝石－斜長石脈

黒雲母－斜長石岩は，残斑状組織の見られる細粒岩 (0.05～0.2 mm) であるが，黒雲母は 2～4 mm 大になっていることもある (Plate Ⅱ: 3)．主成分鉱物は黒雲母・斜長石・単斜輝石である (Table 1: 6).

黒雲母はZ軸色＝褐色～暗緑色，γ＝1.659～1.661 である．褐緑色の黒雲母は褐色角閃石－斜長石岩との境界の黒雲母，斜長石岩の黒雲母，磁鉄鉱－カリウム長石岩との境界付近の黒雲母…岩石に含まれる．褐色の黒

Table 1. Modes, chemical compositions and specific gravities of metabasites and basic metasomatites and associated veins.

	1	2	3	4	5	6	7	8	9	10
Quartz	3.4	4.2	tr	2.6	tr	-	-	-	3.8	-
Plagioclase	41.3	41.2	41.4	40.3	45.4	25.8	17.6	17.9	21.6	40.8
K-feldspar	-	-	-	-	-	-	-	-	23.1	-
Hornblende	46.4	46.1	48.7	45.9	38.8	1.6	80.2	1.9	5.0	2.1
Biotite	2.4	1.0	2.6	2.4	5.3	59.6	0.8	-	31.4	-
Clinopyroxene	-	-	-	0.9	4.7	9.8	-	40.5	2.6	47.2
Garnet	-	-	-	-	-	-	-	31.7	-	-
Sphene	1.1	2.7	2.1	1.9	3.2	1.7	0.4	4.2	3.1	4.1
Ore minerals	3.9	3.4	4.5	5.4	1.8	0.7	1.0	0.8	7.6	2.2
Others	1.5	1.4	0.7	0.6	0.8	0.8	-	3.0	1.8	3.4
SiO_2	51.33	51.32	50.02	50.52	50.95	48.16		46.34 *	50.79	46.38
TiO_2	2.20	2.56	1.68	2.85	1.85	3.05		2.59	2.44	2.31
Al_2O_3	13.76	13.54	14.72	14.12	14.34	13.31		10.28	13.48	10.63
Fe_2O_3	3.59	5.52	2.56	2.50	4.85	2.62		2.80	9.49	2.10
FeO	9.09	8.23	11.32	13.11	8.34	12.55		8.61	6.84	12.67
MnO	0.19	0.21	0.16	0.14	0.16	0.18			0.23	0.51
MgO	7.64	7.32	7.48	5.75	7.16	7.47		3.59	5.45	3.67
CaO	8.19	7.23	7.81	7.78	7.37	4.26		22.21	2.90	18.69
P_2O_5	0.31	0.27	0.23	0.35	0.48	0.39			0.71	0.56
Na_2O	1.95	2.48	2.67	1.88	3.30	2.06		1.64	2.30	0.82
K_2O	0.36	0.17	0.42	0.30	0.56	4.41		0.08	5.12	0.56
$H_2O^{(+)}$	1.01	0.54	0.43	0.36	0.37	1.36			0.48	0.45
$H_2O^{(-)}$	0.22	0.15	0.19	0.23	0.07	0.07			0.15	0.14
Total	99.84	99.54	99.69	99.89	99.80	99.89			100.38	99.49
Specific gravity	2.95_2	2.98_5	3.02_0	2.98_9	2.98_4	2.98_8		3.12_2	2.89_9	3.21_8

1. Bluish green hornblende-plagioclase hornfels. Ca. 560m above sea level, Mitani, Kasuga-mura.
2. Ditto. Ca. 480m above sea level, Hirosawa, Kasuga-mura.
3. Green hornblende-plagioclase hornfels. Beside a small waterfall, 100m north of Kawai, Kasuga-mura.
4. Brownish green hornblende-plagioclase hornfels. Shirako workings in Kasuga mine, Kasuga-mura.
5. Brown hornblende-plagioclase fels. Mitsuka workings in Kasuga mine, Kasuga-mura.
6. Biotite-plagioclase fels. Mitsuka workings in Kasuga mine, Kasuga-mura.
7. Hornblende-rich part between biotite-plagioclase fels and garnet-clinopyroxene-plagioclase vein. The southwest mountainside of Mt. Yarigasaki, Kasuga-mura.
8. Garnet-clinopyroxene-plagioclase vein. Road-cutting, 500m north of Kawai, Kasuga-mura.
9. Biotite-magnetite-potassium feldspar fels. Shirako workings in Kasuga mine, Kasuga-mura.
10. Clinopyroxene-plagioclase vein. Shirako workings in Kasuga mine, Kasuga-mura.

* calculated from the following mode; hornblende 7.4, plagioclase 21.0, clinopyroxene 37.5, garnet 25.7, calcite 3.7, and sphene 4.7.

雲母は Al_2O_3 が少なく，構造式に示されるように四面体層を満す量しか含まれていない (Table 2; 2). このような黒雲母は特異なものではあるが，北アイルランドの Mourne Mountains の著しく珪質な G2 花こう岩からも記載されている (Brown, 1956). 寄木状の斜長石は An24 前後になっているが，残斑晶斜長石は褐色角閃石—斜長石岩中のものと変化ない.

黒雲母・斜長石岩とざくろ石—単斜輝石—斜長石脈の境界の角閃石濃集部 (Plate Ⅱ; 5, Plate Ⅱ; 4) は角閃石と少量の斜長石・黒雲母・スフェン・磁硫鉄鉱から構成される (Table 1; 7). この部分の角閃石は，褐色角閃石—斜長石岩中の角閃石と同様，Z軸色が緑褐色であ

Table 2. Chemical compositions and structural formulas of the representative minerals.

	1	2	3	4	5	6	7
SiO_2	37.12	39.76	50.78	47.88	48.39	38.81	50.33
TiO_2	2.64	3.95	0.74	1.72	2.18	0.46	0.71
Al_2O_3	19.16	11.40	7.04	4.70	5.06	17.30	1.40
Fe_2O_3	1.70	1.78	0.26	6.72	5.68	6.83	0.90
FeO	20.88	19.53	12.58	12.92	13.37	3.92	16.69
MnO	0.30	0.18	0.28	0.28	0.30	0.47	0.36
MgO	7.08	11.34	13.75	11.19	10.85	1.03	6.51
CaO	0.28	0.16	11.28	11.56	10.90	30.38	22.41
P_2O_5	0.10	0.19	0.07	0.12	0.14	0.02	-
Na_2O	0.26	0.37	0.75	0.89	0.78	0.18	0.60
K_2O	6.96	7.29	0.10	0.33	0.59	-	0.16
$H_2O^{(+)}$	3.54	3.57	1.82	1.63	1.69	0.44	-
$H_2O^{(-)}$	0.16	0.29	0.09	0.17	0.20	0.10	0.03
Total	100.18	99.81	99.54	100.11	100.13	99.74	100.10
Si	5.541	6.032	7.312	7.070	7.128	6.026	1.962
Al^{IV}	2.459	1.878	0.688	0.818	0.822	-	0.038
Al^{VI}	0.914	-	0.507	-	0.007	3.166	0.026
Ti	0.297	0.459	0.080	0.192	0.241	0.054	0.021
Fe^{3+}	0.191	0.203	0.028	0.747	0.630	0.789	0.026
Fe^{2+}	2.608	2.478	1.515	1.597	1.647	0.509	0.544
Mn	0.038	0.023	0.034	0.035	0.037	0.062	0.012
Mg	1.576	2.565	2.952	2.465	2.382	0.238	0.378
Ca	0.018	0.026	1.740	1.831	1.721	5.055	0.937
P	0.013	0.024	0.009	0.015	0.017	0.003	-
Na	0.075	0.109	0.209	0.255	0.223	0.054	0.045
K	1.326	1.411	0.018	0.062	0.111	-	0.008

1. Biotite from biotite-cordierite-garnet-quartz-oligoclase-orthoclase hornfels. Omote-river, between Kawai and Shirako, Kasuga-mura. X colourless, Y・Z brown and γ 1.648.
2. Biotite from biotite-plagioclase fels (Table 1; 6). X colourless, Y・Z deep brown and γ 1.662.
3. Bluish green hornblende with some impurity of actinolite from bluish green hornblende-plagioclase hornfels (Table 1; 2). X pale green, Y green, Z bluish green, 2Vx 78°, α 1.642, β 1.651 and γ 1.659.
4. Brown hornblende from brown hornblende-plagioclase fels (Table 1; 5). X pale greenish yellow, Y brown, Z greenish brown, 2Vx 60°, C∧Z 16.3°, α 1.663, β 1.675 and γ 1.680.
5. Hornblende from hornblende-rich part (Table 1; 7). X pale greenish yellow, Y greenish brown, Z greenish brown. 2Vx 75°, C∧Z 17°, α 1.656, β 1.668 and γ 1.679.
6. Garnet from garnet-clinopyroxene-plagioclase vein (Table 1; 8). a_0 11.870Å and n 1.780 ±0.002.
7. Clinopyroxene from garnet-clinopyroxene-plagioclase vein (Table 1; 8). 2Vz 59～60°, α 1.701, β 1.711 and γ 1.732.

り，また Fe_2O_3 が多く Al_2O_3 が少ない (Table 2; 5)．斜長石は An37～28 である．

ざくろ石—単斜輝石—斜長石脈は少量の鉄ヘスチングサイト・スフェン・クリノゾイサイト・磁硫鉄鉱・黄鉄鉱を含む (Table 1; 8)．ざくろ石は脈の中心部に濃集し，その周囲に単斜輝石・斜長石が存在する (Plate Ⅱ; 5)．しかし脈の規模が小さい場合にはざくろ石が存在しないこともある (Plate Ⅱ; 4)．

ざくろ石は a＝11.862～11.901 Å，n＝1.763～1.783 のグランダイトであるが，その組成は脈によって若干異なり，また個々の結晶にも無色～褐色の色変化が認められる．Table 2; 6 に分析値を示したものは a＝11.870 Å，n＝1.780±0.002 であり，Gro 62.3%，And 25.8% となる．単斜輝石は Di 40% の鉄サーラ輝石である (Table 2; 7)．他の脈の単斜輝石も 2Vz＝58°～62°，β＝1.710～1.715 の光学性を持ち，組成は分析したものと大差ないと推定される．クリノゾイサイト (2Vz＝40° 前後) は脈の中心部で無色のザクロ石に接して産し，単斜輝石とは共存しない．鉄ヘスチングサイト (2Vx＝36°，β＝1.703，Z 軸色＝濃青緑色) は単斜輝石・斜長石の部分に存在する．方解石はざくろ石の粒間などに少量存在するのみである．

C) 黒雲母—磁鉄鉱—カリウム長石岩と単斜輝石—斜長石脈

黒雲母—磁鉄鉱—カリウム長石岩は，まれに Plate Ⅱ; 5 に示すような，残斑状組織を呈する灰黒色の細粒岩 (0.08～0.15 mm) である．主成分鉱物は黒雲母・カリウム長石・斜長石・磁鉄鉱である (Table 1; 9)．斜長石の量は岩石によって著しく変化し，ほとんど存在しないこともある．副成分鉱物としてしばしば電気石を含むことを特徴とする．

黒雲母は γ 1.643～1.655 であり，黒雲母—斜長石岩中のものより屈折率が低い．斑状の斜長石は An 28～24 である．残晶斜長石は An37～28 であり，部分的にカリウム長石に置換されていることが多い (Plate Ⅱ; 6)．またほとんど全体がカリウム長石に置換された斜長石の格子状外形も認められる (Plate Ⅱ; 1)．カリウム長石は 2Vx 64°±2°，d(131)−d(1$\bar{3}$1)＝0 のオーソクレースである．γ 1.522 なるカリウム長石の Ab, An 成分は[illegible]ないと推定される．[illegible]90% 以上は 0.1 mm 大の[illegible]．[illegible]鉱の離溶ラメラが[illegible]．電気石は黄褐色～無色の多色性を示し，ω 1.641，ε 1.618 [illegible]．

単斜輝石—斜長石脈 (Table 1; 10) は副成分[illegible]

トと共に、チタン石、スフェーン・磁硫鉄鉱・黄鉄鉱・白鉄鉱・閃亜鉛鉱を含む．一般に脈の中心部は周辺部に比べて粗粒である（0.4 mm -0.1～0.8 mm）．また斜長石が多い．斜長石は中心部分において An 60～50，周辺部分において An 75～60 である．光学性から推定した単斜輝石の組成は $Wo_{47}En_{17}Fs_{36}$～$Wo_{48}En_{37}Fs_{15}$ である．粗粒部分の単斜輝石の方が細粒部分のものよりヘデン輝石成分に富む傾向がある．

2. スカルン

春日村の接触変成帯にみられるスカルンには，石灰質岩と泥質岩・塩基性岩・チャートなどが反応して生じたものと，花こう岩あるいは花こう岩起源の流体と石灰質岩が反応して生じたものとの 2 種類がある．後者のなかで主要なものは次の 2 つである．

A）単斜輝石―苦土かんらん石累帯スカルン

このスカルンは花こう岩に直接するドロマイト岩中に数 cm～数 10 cm の幅で発達するほか，花こう岩体から約 50 m 以内のドロマイト岩中に幅数 cm～40 cm の脈状に発達する．これは例外なく花こう岩側あるいはスカルン脈の中心側に単斜輝石帯が存在しドロマイト岩側に苦土かんらん石帯が存在する累帯を形成している．単斜輝石帯は鉄サーラ輝石～透輝石・アクチノライト～透閃石・方解石・磁硫鉄鉱・黄鉄鉱・輝水鉛鉱などから構成される．苦土かんらん石帯には方解石の他に斜ヒューム石が存在する．この他に，花こう岩に直接したスカルンの単斜輝石帯には石英・斜長石・金雲母・灰重石が存在することもある．このスカルンに接した花こう岩はグライゼン化あるいは閃長岩化している．

B）珪灰石スカルン

珪灰石スカルンは，花こう岩に直接する石灰岩中に幅 10 数 m の規模で発達し，また花こう岩から約 200m 以内の石灰岩中に 1 m 内外の脈状に発達する．このスカルンは花こう岩に直接する部分では石英や長石を含むこともあるが，少し離れた所では石灰岩が珪灰石化していても石英を含まない．このことは SiO_2 が珪酸塩溶融体としてでなく流体に溶解した形で移動したことを示すのであろう．

3. 泥質岩源交代変成岩

塩基性交代変成岩に接している変泥質岩には Plate Ⅱ; 2 のような黒雲母脈が多数発達している．この岩石には，極めてまれではあるが，黒雲母に置換されかけた菫青石の斑状変晶が残存しており，ここから黒雲母脈が伸びていることも認められる．また黒雲母脈を持つ岩石を層の走向方向に追跡すると，角閃岩と接する部分で，菫青石ホルンフェルスになる (Fig. 7)．したがって黒雲母脈を含む岩石は，塩基性岩に作用したものと同じカリウム交代作用によって，菫青石ホルンフェルスから生成したと推定される．

V. 考　　察

1. 基性交代変成岩の原岩と交代作用の時期について

基性交代変成岩は原岩と考えられる角閃岩に比べ K_2O に富み CaO が乏しい．この差異は接触変成作用に伴う交代作用に原因すると推定されるが，接触変成作用以前に K_2O に富み CaO が乏しい基性火山岩が存在していたかどうかをよく検討する必要がある．

基性交代変成岩の産状で述べたように，同一溶岩流内で，層の方向に，角閃岩から連続的な黒雲母の増加が認められる．このことは基性火山岩が噴出時には同一組成であったにもかかわらず，その後 K_2O の増加と CaO の減少を被ったことを示す．

K_2O の増加と CaO の減少は斜長石の絹雲母化などの変質によって生じる可能性もある．しかし内帯古生層で一般に認められる斜長石の変質はアルバイト化作用であり，K_2O を著しく増加させる変質は知られていない (KATADA *et al.*, 1963；田中，1970)．春日村の場合も未変成岩およびアクチノライト帯の岩石をみる限り K_2O を著しく増加させるような変質作用を被った証拠はない．

K_2O を付加する交代作用の時期は，基性交代変成岩と互層する菫青石ホルンフェルス中に黒雲母脈が生じ菫青石が白雲母に変化していることより，角閃岩相の変成度に達した後であることが推定される．なお花こう岩体から伸びるアプライト質な脈は交代変成岩を切っているから，交代作用は花こう岩の最終的な貫入より前に起ったと考えられる．

2. 基性交代変成岩の交代反応について

基性交代変成岩の直接の原岩は角閃岩である．したがってここでは角閃岩 (Table 1; 1～4) の平均組成を原岩の組成とみなすことにする．交代作用に伴う体積変化がないと仮定した場合，岩石 1000 cm^3 中のグラム原子数で表現した交代変成岩と脈の組成変化は Fig. 8 のようになる．脈は，後に述べるように，交代作用によって解放された成分が濃集した部分である．それ故，岩石全体（交代変成岩＋脈）の組成変化は両者の割合にも関係し

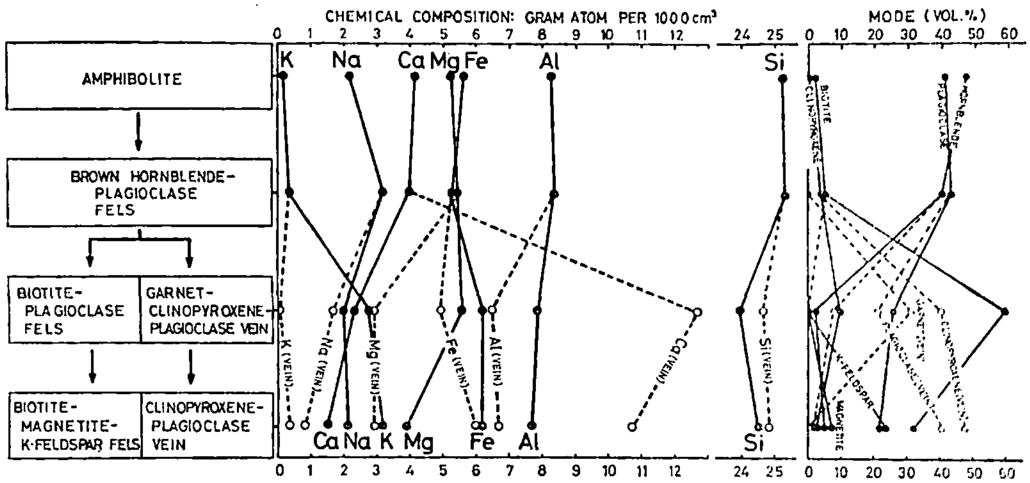

Fig. 8. Variations in respective chemical compositions and modes of the basic metasomatites and associated veins during the course of the metasomatism.

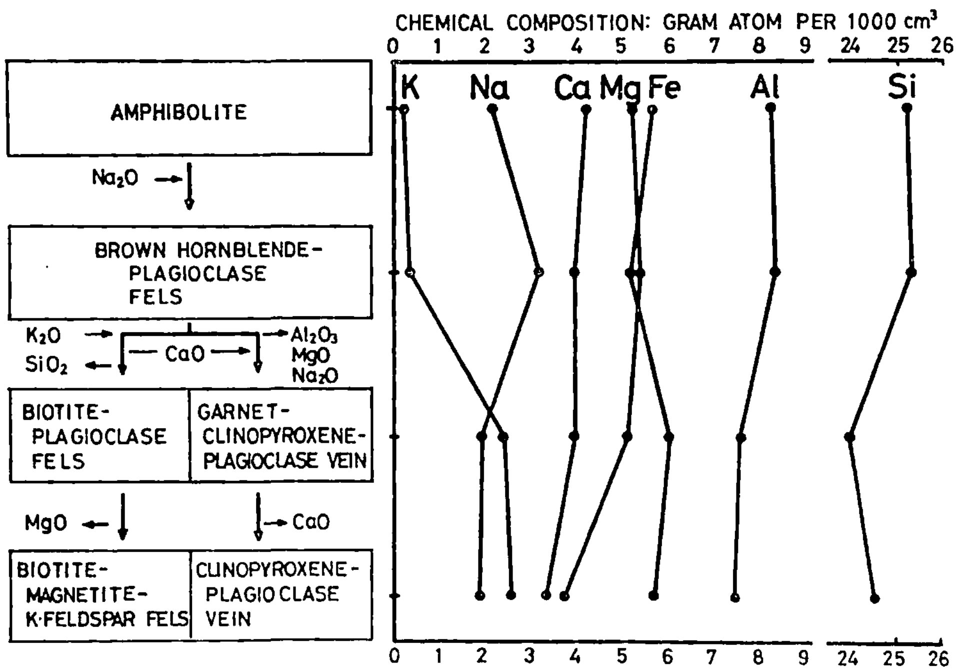

Fig. 9. Variations in chemical compositions of the bulk basic metasomatite plus vein during the course of the metasomatism.

ている．野外の観察に基づいて，黒雲母－斜長石岩とざくろ石－単斜輝石－斜長石脈の割合を 85：15，また黒雲母－磁鉄鉱－カリウム長石岩と単斜輝石－斜長石脈の割合を 80：20 とし，岩石全体の組成変化を 1000cm³ 中のグラム原子数で示すと Fig. 9 のようになる．

Fig. 8 および Fig. 9 の化学組成・モードの変化と Table 2 の記載の結果から，以上のような交代作用が漸次起ったことが推定される．なお，ここで岩体内の存

[illegible]することで[illegible]について述べる.

A) [illegible]

この段階では角閃石中の Fe_2O_3 の増加で代表され, [illegible] Table 2: 3 は $(Na,K,Ca)_{?.07}(Mg_{2.91}Fe^{2+}_{1.25}Fe^{3+}_{0.63}Al_{0.31})(Al_{0.69}Si_{7.31})O_{22}(OH)_2$ であり, [illegible] (Table 2: 4) は $(Na,K,Ca)_{2.15}(Mg_{2.10}Fe^{2+}_{1.60}Fe^{3+}_{0.75})(Al_{0.93}Si_{7.07})O_{22}(OH)_2$ である. 岩石中の鉄含有量は変化していないので, 角閃石中の Fe_2O_3 の増加は, 角閃石あるいはチタン鉄鉱の2価鉄が酸化し $2Mg^{2+}Si^{4+} \rightleftarrows 4Fe^{3+}$ の置換が生じた結果であろう. この角閃石は Glen Tilt Complex 中の捕獲岩の角閃石 (DEER, 1938) と同様に Fe_2O_3 が多いことは, 酸素分圧の大きい流体が花こう岩から供給されて, 壁岩の部分も花こう岩中と同様な高い酸素分圧を持ったことを示す. 花こう岩中の酸素分圧が比較的大きいことは, 岩枝の一部で角閃石がオハサイト化していることからも明らかである.

Na_2O の増加以外, 褐色角閃石—斜長石岩の化学組成は原岩とほぼ同じである. したがって角閃石の反応で解放される $CaO \cdot Al_2O_3 \cdot MgO \cdot SiO_2$ などは単斜輝石・黒雲母・斜長石を形成したと考えられる.

B) 黒雲母—斜長石岩の形成とそれに伴う反応

角閃石が減少し黒雲母が増加する反応は斜長石の減少を伴う. このように角閃石の黒雲母化に伴って斜長石が減少する例は Donegal の Curran Hill において花こう閃緑岩に接する変輝緑岩にもみられ, そこではもとの輝緑岩に 30% 以上存在していた斜長石が 10% 前後に減少している (HALL, 1965). この斜長石の減少によって, 角閃石の黒雲母化で不足する Al_2O_3 が補われるのであろう. 黒雲母形成反応は, 黒雲母が角閃石あるいは斜長石を直接置き換えて生じた証拠がないこと, 黒雲母が 2〜4 mm の大きさに生長している部分があること, 原岩にみられるブラストオフィチック組織が大部分消去されていることから, 角閃石や斜長石の構成成分が一旦流体中に溶けた後, 黒雲母として結晶し CaO が流体中に残る型の反応と推定される. このような鉱物の構成成分が一旦流体に溶けた後, 他の鉱物として結晶する反応は多くの実験で観察される (O'NEIL and TAYLOR, 1967; TSUZUKI *et al.*, 1973; 中川ほか, 1973 など).

黒雲母—斜長石岩では CaO が減少し, ざくろ石—単斜輝石—斜長石脈では CaO が増加している. 岩石全体の CaO 量は原岩の CaO にほぼ等しく, また CaO が外部から供給された証拠もないので, 角閃石の黒雲母化によって解放される CaO は脈を形成すると推定される. また, 後述するように褐色角閃石—斜長石岩中に見られるざくろ石—単斜輝石集合体を出発点として, すでに黒雲母化した部分を貫き長さを増して発達している. この脈の形成において, ざくろ石と単斜輝石は同時に生じるのではなく, まず単斜輝石が生じ脈の規模が大きくなった後ざくろ石が生じることが鏡下の観察から認められる. 脈の幅が増し Al_2O_3 が減少するのは, ざくろ石が生じるまでの間, 黒雲母が単斜輝石化することによって解放される Al_2O_3 が流体中に溶けて除去されるためであろう.

C) 黒雲母—磁鉄鉱—カリウム長石岩の形成とそれに伴う反応

黒雲母—斜長石岩中の黒雲母は黒雲母—磁鉄鉱—カリウム長石岩との境界付近でZ軸色が緑色を帯びてくる. これは黒雲母中で鉄の酸化が起っているためであろう. また磁鉄鉱とカリウム長石の出現は黒雲母の減少およびその屈折率の低下と対応する. したがって黒雲母—磁鉄鉱—カリウム長石岩は黒雲母—斜長石岩の黒雲母の一部(アンナイト成分)が磁鉄鉱とカリウム長石に酸化分解することによって生じたのであろう. なお斜長石の残斑晶を置換したカリウム長石は Ca・Na ⇄ K 置換で生じたのかもしれない.

単斜輝石—斜長石脈の中心部は, 周縁部に比べて, 斜長石が多く, また An 成分に富んでいる. この斜長石は花こう岩の貫入に伴う温度の上昇によってざくろ石—単斜輝石—斜長石脈のざくろ石が分解して生じたのであろう. ROY and ROY (1957) によればグロッシュラー・ハイドログロッシュラー系列のざくろ石は YODER (1950) の示した 850°C より 300°C 〜400°C 低い温度で分解する.

3. 脈の成因

基性交代変成岩と脈の関係は, 現象面から見れば CaO 量に応じて相律と矛盾しない鉱物組合わせを示す縞状構造であり (Fig. 10), KORZHINSKII (1959) や ORVILLE (1969) の論じた石灰質岩と長石質岩あるいは泥質岩の間の相互変成帯の関係に類似する. しかし成因的に見るならば, 脈は黒雲母—斜長石岩の形成に伴って生長しており, 角閃石の黒雲母化によって解放される CaO が濃集した部分と考えられる.

野外および鏡下の観察から, 石灰質の脈やレンズを含まない角閃岩が交代作用を被って, 脈が発達していく過程は次のようにたどることができる.

1. 褐色角閃石—斜長石岩の段階において0.5〜1 mm

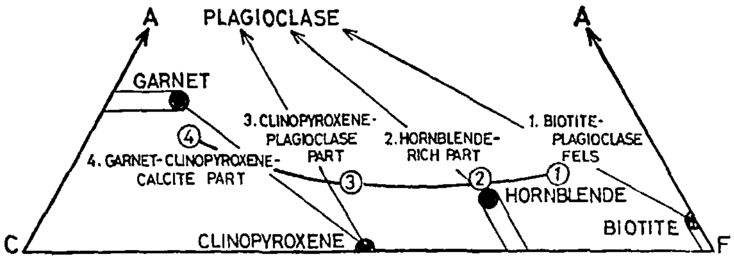

Fig. 10. ACF diagram showing the mineral assemblages of biotite-plagioclase fels and associated garnet-clinopyroxene-plagioclase vein. The compositions of 2, 3, and 4 are calculated from their modes. Solid circles represent the composition of minerals.

大の単斜輝石一斜長石集合体が形成される (Plate Ⅱ; 3).

2. 角閃石の黒雲母化に伴い単斜輝石一斜長石集合体は脈状に連なる (Plate Ⅱ; 4).

3. 黒雲母一斜長石岩の段階では脈の幅が 1 cm～数 cm になり，その中心部にざくろ石が出現する．また脈の周囲には角閃石が濃集する (Plate Ⅱ; 5).

4. 黒雲母一磁鉄鉱一カリウム長石岩が形成される段階ではざくろ石が消失し，その部分に An 成分に富む斜長石が増加する (Plate Ⅱ; 6).

春日村の基性交代変成岩に伴う脈は，部分的に石灰質な基性岩が変成して生じた縞状構造 (Shido, 1958; Green, 1964) とも成因的に異なることが，この脈の生長過程から示される．Shap granite の熱変成を受けた Borrowdale 火山岩では，CaO に富む花こう岩起源の流体が節理などに浸透することによって，ざくろ石脈が生じている (Firman, 1957). しかし春日村では流体が CaO に富んでいた証拠はない．したがって脈は先に述べたように，角閃石の黒雲母化によって解放される CaO が一種のセグリゲーション (分泌作用) (Harker, 1939, p. 75) で濃集した部分と考えられる．セグリゲーションで CaO が濃集したことは，岩石全体の CaO 量が原岩の CaO にほぼ等しいことからも裏づけられる (Fig. 9). 春日村で確認されたセグリゲーションは御斎所・竹貫地域の基性変成岩中の石灰質レンズの形成機構 (Miyashiro, 1958) や Dateless County の泥質変成岩中の石英一長石脈の形成機構 (Vidale, 1974) と同種のものと考えられる．

4. 流体相について

互層する基性岩・石灰質岩・泥質岩それぞれに先に記載したような交代作用が認められる．これらの交代変成岩が形成されるためには，基性岩において K_2O・Na_2O が，ドロマイト岩において SiO_2・FeO が，石灰岩において SiO_2 が，泥質岩において K_2O が供給される必要がある．大規模な固体拡散は考えられないので，これらの物質は流体を媒介として移動し，供給されたのであろう．

花こう岩体近くほど交代作用が顕在化することより，流体は花こう岩の固結時に放出される種々の成分を溶解した熱水あるいは超臨界の水溶液と考えられる．花こう岩の貫入に関係して K_2O を含む流体が活動することは広く認められている (Phillips, 1955; Firman, 1957; Beach and Fyfe, 1972).

交代作用で付加された成分は原岩の種類によって異なるが，同一花こう岩から異なる組成の流体が放出され，それぞれの源岩石に作用したとは考えられない．花こう岩起源のある組成の流体が小さな割目や結晶粒間を通って壁岩中に浸透すると，始め平衡でなかった流体と壁岩は平衡になるように反応し，壁岩に流入する流体と流出する流体では，化学組成が違ってくる (浸潤交代作用, Korzhinskii, 1959・1968). すなわち交代変成岩の化学組成で増加として現われる成分はこの反応で生じた鉱物に流体中から取り込まれたものであり，また減少として現われる成分は鉱物から流体中に溶けたものである．そしてこの交代反応によって生じる鉱物の種類は源岩石の組成にも支配されている．したがって，流体の組成は同一でも，岩石中に取り込まれる成分は源岩石の組成によって異なると理解される．

基性岩の交代反応で解放された CaO は脈に濃集されて岩石全体としては [illegible] 減少していない [illegible] 実際には CaO・MgO・Al_2O_3・SiO_2 [illegible] 減少している．これらの成分は流体中に溶けて [illegible]

の一部は青緑色～緑色角閃石帯の[illegible]岩と変成岩石の[illegible]、[illegible]・緑泥石・石英・方解石脈やドロマイト岩中の石英・トレモライト，緑泥石[illegible]（[illegible]，1974）の形成に関与したと考えられる．

VI. 結　論

（1）貝月山花こう岩による春日村の接触変成帯は2.5～3km の幅を持ち，緑色片岩相高温部から角閃岩相高温部までの変成度を示している．この接触変成作用の水蒸気圧は最大 2kb 程度と推定される．

（2）花こう岩の近傍に発達する特異な黒雲母―斜長石岩は角閃岩が褐色角閃石―斜長石を経て変化したものであること，また花こう岩に直接する部分に発達する黒雲母―磁鉄鉱―カリウム長石岩は黒雲母―斜長石岩の黒雲母の一部が酸化分解して生じたものであること，を明らかにした．そしてこの一連の変化はカリウム交代作用がおもに働いて起ったことを示した．

（3）また，これらの交代変成岩に伴うざくろ石―単斜輝石―斜長石脈や単斜輝石―斜長石脈は角閃石の黒雲母化によって解放された CaO が濃集した部分であることを，定量的な物質収支によって明らかにした．

（4）上記以外の交代変成岩の考察をも加えると，花こう岩起源の H_2O を主成分とする流体は $K_2O \cdot Na_2O \cdot SiO_2 \cdot FeO$ を少なくとも含んでいたことが結論される．

謝　辞

本研究は名古屋大学理学部地球科学教室の渡辺武男先生（現秋田大学）の御存命中に始まった春日村の接触変成帯の研究の一部を成すものであり，石岡孝吉先生の指導を頂いた．また，諏訪兼位先生・都築芳郎先生からは実験上の教唆と有益な助言とを，山本敬一博士・湯佐泰久氏からは化学分析の教示を，愛知教育大学化学教室の杉浦孜先生・地学教室の浦野集臣先生からは原子吸光法による分析の教示を頂いた．野外調査に際しては清水工業株式会社，個別的には同社春日鉱山の岡際鉱山長を初めとする多くの方々のお世話を頂いた．以上の方々に心より感謝する．

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On some unusual bands and veins metasomatically developed in the contact aureole in Kasuga-mura, Gifu-ken

Kazuhiro SUZUKI

(Abstract)

The Paleozoic sediments and volcanics in Kasuga-mura have been intruded by the Cretaceous Kaizuki-yama granite and converted into hornfelses over 2.5 km from the granitic contact. On the basis of the progressive mineralogical changes in metabasites, the contact aureole can be divided into three zones; the actinolite zone, the bluish green hornblende zone, and the green hornblende zone, in order of increasing metamorphic temperature. The actinolite zone belongs to the higher-grade part of the greenschist facies and the other zones to the amphibolite facies. Four bulk analyses of rocks and two analyses of bluish green hornblende and biotite were carried out. Metamorphic temperature estimated by the dolomite-calcite solvus geothermometry ranges up to 640°C. H_2O-pressure, less than 2.5 kb, is indicated by muscovite plus quartz reaction occurring approximately at 620°C.

Remarkable bands and veins spotted with large brown crystals of garnet are developed in the bluish green and green hornblende zones. They are biotite-plagioclase fels bands and garnet-clinopyroxene-plagioclase veins occurring in a roughly alternated fashion, and so also biotite-magnetite-potassium feldspar fels bands and clinopyroxene-plagioclase veins. Through brown hornblende-plagioclase fels the metabasites in the field grade into those felses and eventually into veins, which under the microscope reveal surviving ophitic and porphyritic textures of the original basites. Five bulk analyses of the bands and the vein, with analyses of a clinopyroxene, a biotite, a garnet and two brown hornblendes, indicate potassium metasomatism and associated higher oxygen fugacity in the late stage of the contact metamorphism. With the oxidation of biotite to magnetite+potassium feldspar+Mg-rich biotite, the biotite-plagioclase fels changes futher to the biotite-magnetite-potassium feldspar fels at the immediate granitic contact.

The lime liberated by the conversion of hornblende into biotite almost accounts for that which was fixed metasomatically in the garnet-clinopyroxene-plagioclase vein and the clinopyroxene-plagioclase vein.

Similar bands and veins, though known to occur in varying amounts in other granitic contacts, have been lightly dismissed as attributable to the inhomogeneity of the original chemistry, or arbitrary hybridism has been invoked. The present study makes it clear that bands and veins in Kasuga-mura have been brought forth, in fact, from homogeneous metabasites through metamorphic differentiation accompanied by potassium metasomatism arising probably from granite intrusion.

Explanation of Plates

PLATE I

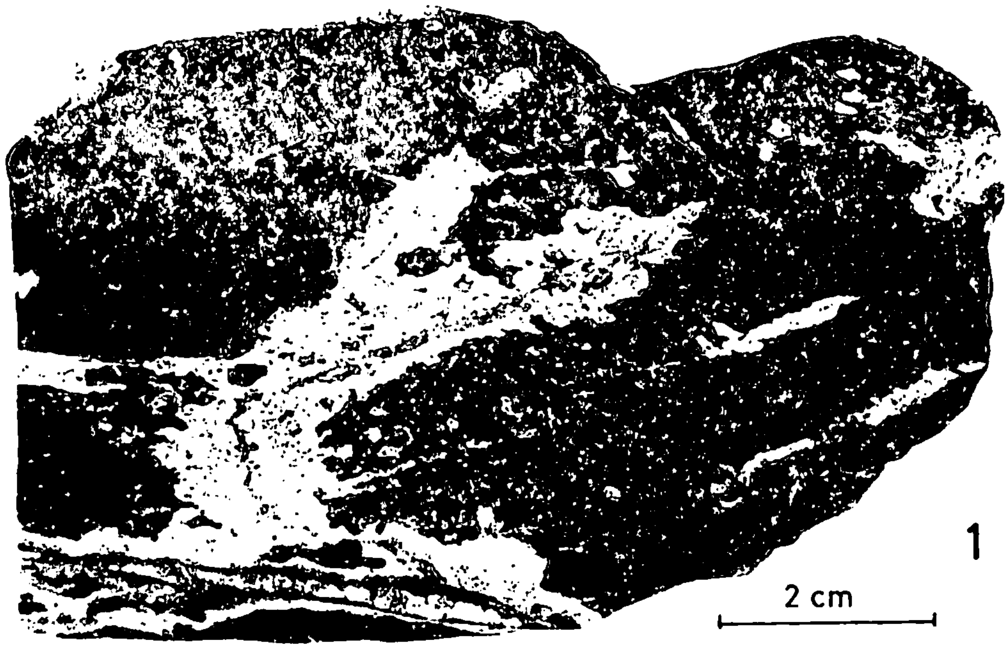
1. Biotite-plagioclase fels and garnet-clinopyroxene-plagioclase vein. Garnet is seen in the central part of the below vein.
2. Biotite-magnetite-potassium feldspar fels and clinopyroxene-plagioclase vein. Central light portion of the vein is bytownite formed by decomposition of the garnet in garnet-clinopyroxene-plagioclase vein.

PLATE II

1. Brown hornblende-plagioclase fels with the ophitic texture surviving. Large leucocratic patches below represent original vughs. One nicol.
2. Relict phenocryst of plagioclase showing Carlsbad twinning in brown hornblende-plagioclase fels. Nicols crossed.
3. Biotite-plagioclase fels. One nicol.
4. Hornblende-rich part (below) and biotite-plagioclase fels (above). Relict phenocryst of plagioclase is recognized. One nicol.
5. Relict phenocryst of plagioclase in biotite-magnetite-potassium feldspar fels. One nicol.
6. Relict phenocryst of plagioclase showing an incipient stage of transformation into an aggregate of potassium feldspar. One nicol.

PLATE III

1. Relict phenocryst of plagioclase in an advanced stage of transformation into an aggregate of potassium feldspar. One nicol.
2. Biotite vein in cordierite-muscovite-biotite-quartz-plagioclase hornfels. One nicol.
3. An aggregate of clinopyroxene and plagioclase in brown hornblende-plagioclase fels. One nicol.
4. Clinopyroxene-plagioclase vein in biotite-plagioclase fels. One nicol.
5. Garnet-clinopyroxene-plagioclase vein in biotite-plagioclase fels. One nicol.
6. Clinopyroxene-plagioclase vein in biotite-magnetite-potassium feldspar fels. One nicol.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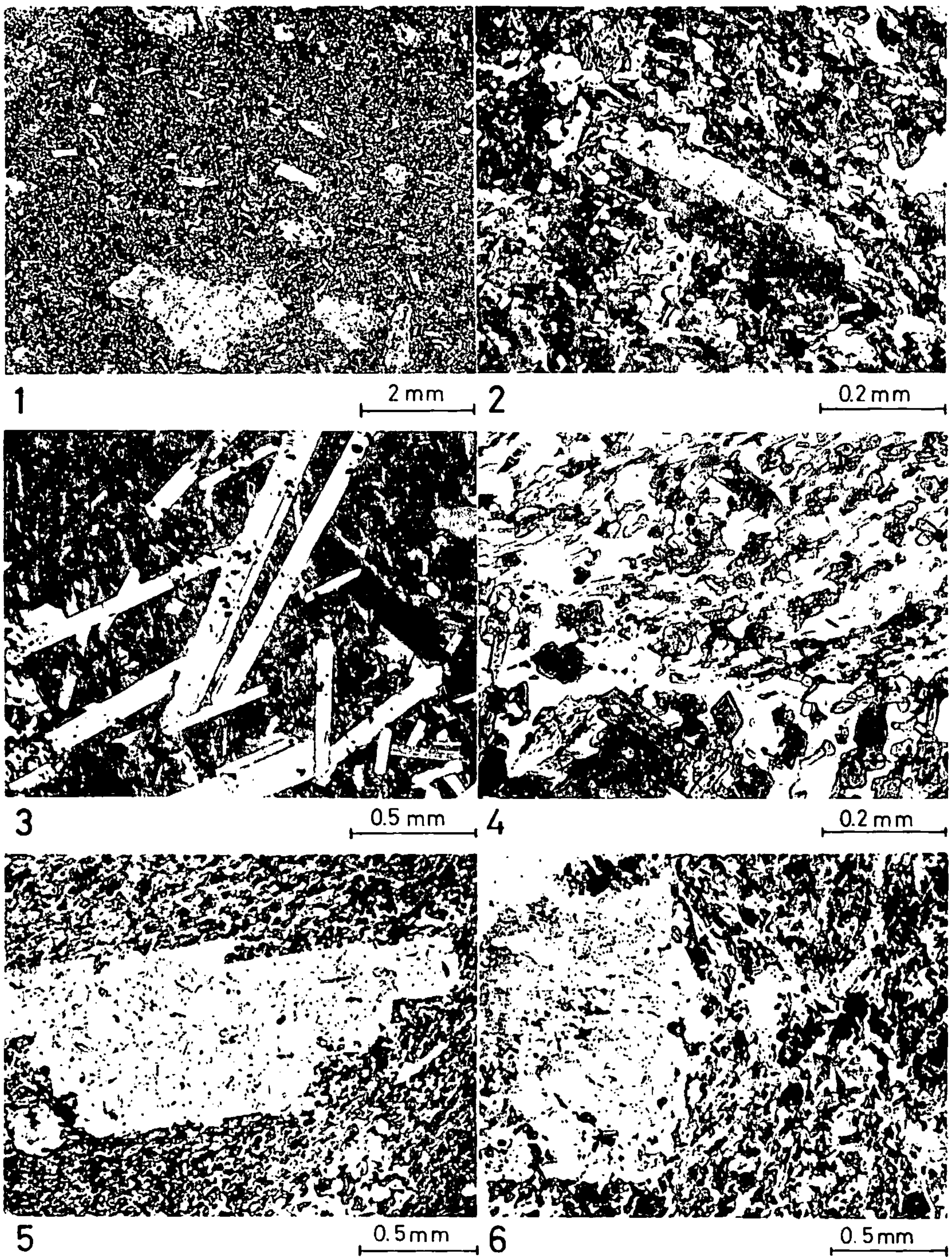

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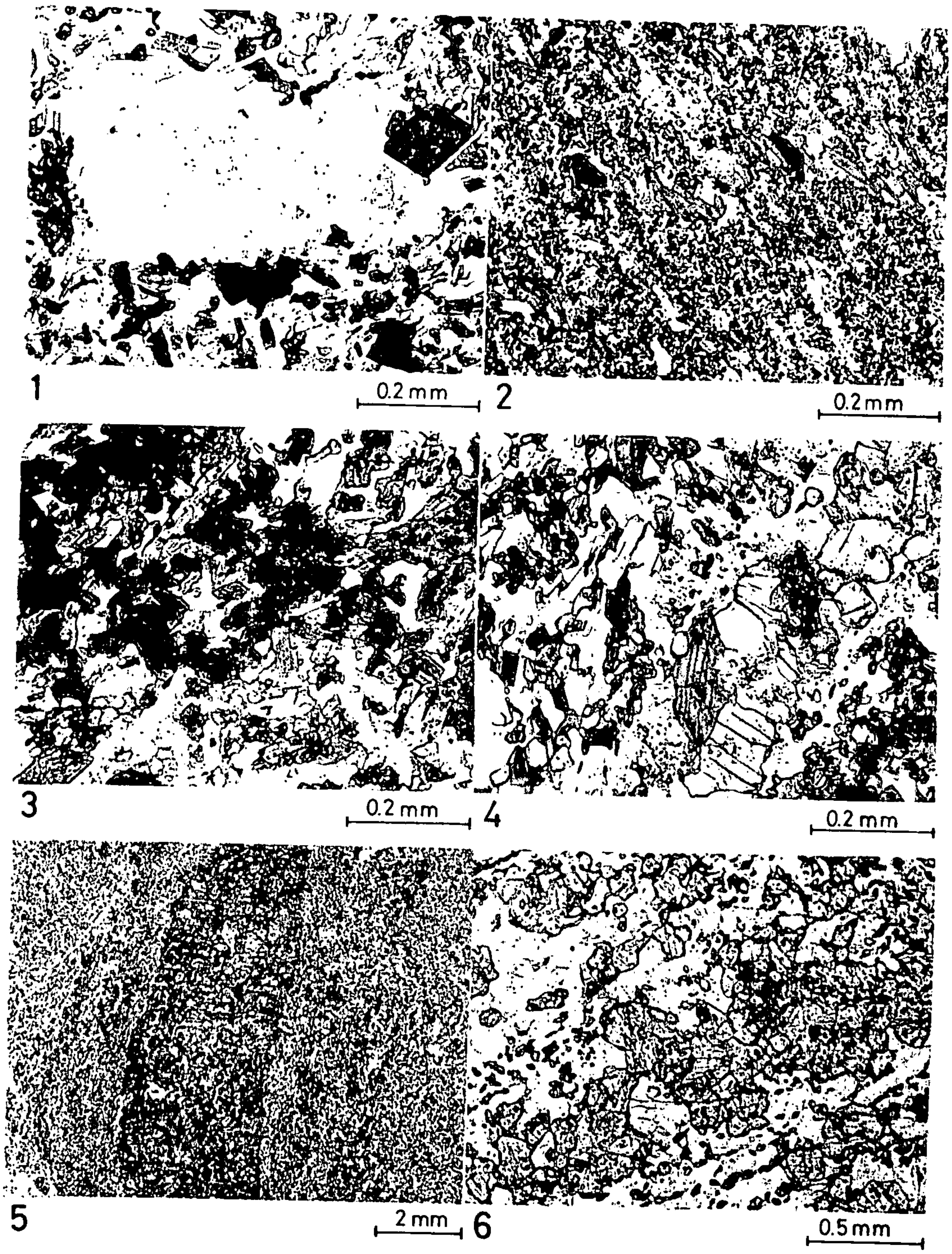

For Dr. Wright,
with compliments of the
authors,
Shen Hsien-chieh
Apr. 9, 1981

Journal of Volcanology and Geothermal Research, 9(1981)57—76
Elsevier Scientific Publishing Company, Amsterdam — Printed in Belgium

GEOTHERMAL STUDIES IN CHINA

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(Accepted June 10, 1980)

ABSTRACT

Wang Ji-yang, Chen Mo-xiang, Wang Ji-an, Deng Xiao, Wang Jun, Shen Hsien-chieh, Hsiung Liang-ping, Yan Shu-zhen, Fan Zhi-cheng, Liu Xiu-wen, Huang Ge-shan, Zhang Wen-ren, Shao Hai-hui and Zhang Rong-yan, 1981. Geothermal studies in China. J. Volcanol. Geotherm. Res., 9: 57—76.

Geothermal studies have been conducted in China continuously since the end of the 1950's with renewed activity since 1970. Three areas of research are defined: (1) fundamental theoretical research on geothermics, including subsurface temperatures, terrestrial heat flow and geothermal modeling; (2) exploration for geothermal resources and exploitation of geothermal energy; and (3) geothermal studies in mines.

Regional geothermal studies have been conducted recently in North China and more than 2000 values of subsurface temperature have been obtained. Temperatures at a depth of 300 m generally range from 20 to 25°C with geothermal gradients from 20 to 40°C/km. These values are regarded as an average for the region with anomalies related to geological factors.

To date, 22 reliable heat flow data from 17 sites have been obtained in North China and the data have been categorized according to fault block tectonics. The average heat flow value at 16 sites in the north is 1.3 HFU, varying from 0.7 to 1.8 HFU. It is apparent that the North China fault block is characterized by a relatively high heat flow with wide variations in magnitude compared to the mean value for similar tectonic units in other parts of the world. It is suggested that although the North China fault block can be traced back to the Archaean, the tectonic activity has been strengthening since the Mesozoic resulting in so-called "reactivation of platform" with large-scale faulting and magmatism.

Geothermal resources in China are extensive; more than 2000 hot springs have been found and there are other manifestations including geysers, hydrothermal explosions, hydrothermal steam, fumaroles, high-temperature fountains, boiling springs, pools of boiling mud, etc. In addition, there are many Meso-Cenozoic sedimentary basins with widespread aquifers containing geothermal water resources in abundance. The extensive exploration and exploitation of these geothermal resources began early in the 1970's. Since then several experimental power stations using thermal water have been set up in Fengshun (Fungshun),

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Province Guangdong (Kwangtung), Huailai, Province Hebei (Hopei) and other locations. In 1977 a new power station using high-temperature (150°C) hydrothermal fluids and steam was constructed in the Yangbajing (Yangpachain) geothermal field north of Lasa (Lhasa) in Xizang (Tibet). Since 1970 in Beijing (Peking), Tianjin (Tientsin) and other cities thermal water of 40—60°C has been used for space heating, industry, agriculture, medical sanatoriums, etc.

High temperatures which may prevail in shafts and galleries of deep mines constitute a so-called "geothermal hazard". According to the geothermal conditions, six types of mines can be defined each requiring particular facilities for safe and efficient working.

INTRODUCTION

Geothermal studies have been conducted in China continuously since the end of the 1950's. However, there has been renewed activity since 1970 with the development of the national economy and the consequent advance of theoretical studies in geosciences.

Geothermal studies in China involve three basic aspects: (1) fundamental theoretical research on geothermics, including study of the regional subsurface temperature field, the determination of terrestrial heat flow, and geothermal modeling; (2) prospecting and exploration for geothermal resources, and exploitation and utilization of geothermal energy; and (3) geothermal studies in mines.

REGIONAL GEOTHERMAL STUDY

In recent years systematic measurements have been made of subsurface temperature in North China and more than 2000 values were obtained. These data are plotted in Figs. 1 and 2 showing the distribution of temperature at a depth of 300 m and the corresponding variation of the geothermal gradient in the region studied. The temperature at 300 m generally varies from 20 to 25°C and the geothermal gradient varies from 20 to 40°C/km. These values may be regarded as average for this region. Nevertheless there are some anomalies. For example, the temperature at a depth of 300 m in the region to the south of Tianjin (Tientsin)* is 25—30°C whereas the temperature at the same depth along the eastern piedmont of Taihang Shan (Taihang Mountains) is no more than 15—20°C.

According to the preliminary results of our research the geological factors that control subsurface temperatures in North China are as follows:

(1) Structural relief on the crystalline basement. Depth to crystalline basement in North China varies because of differential movement of fault blocks. This affects the distribution of subsurface temperature. Generally the shallower the depth to basement the higher the temperature. For example, the high-temperature region to the south of Tianjin (Tientsin) is associated with the Cang Xian (Tsangnsien) uplift and the low temperatures in Huanghua region

*The geographical names in this paper are translated according to the Chinese phonetic alphabet with English spelling in parenthesis.

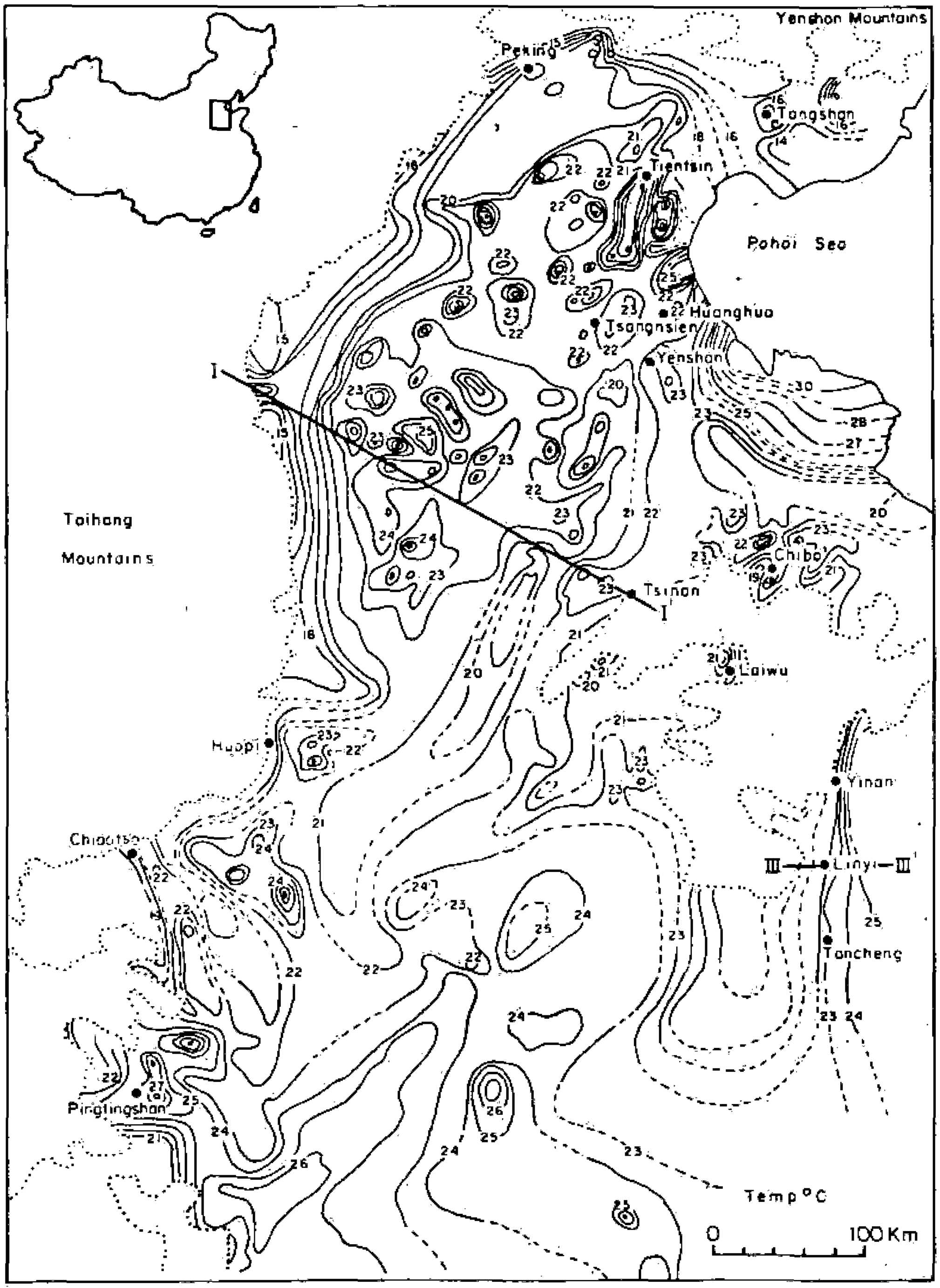


Fig. 1. Temperature distribution at a depth of 300 m in North China.

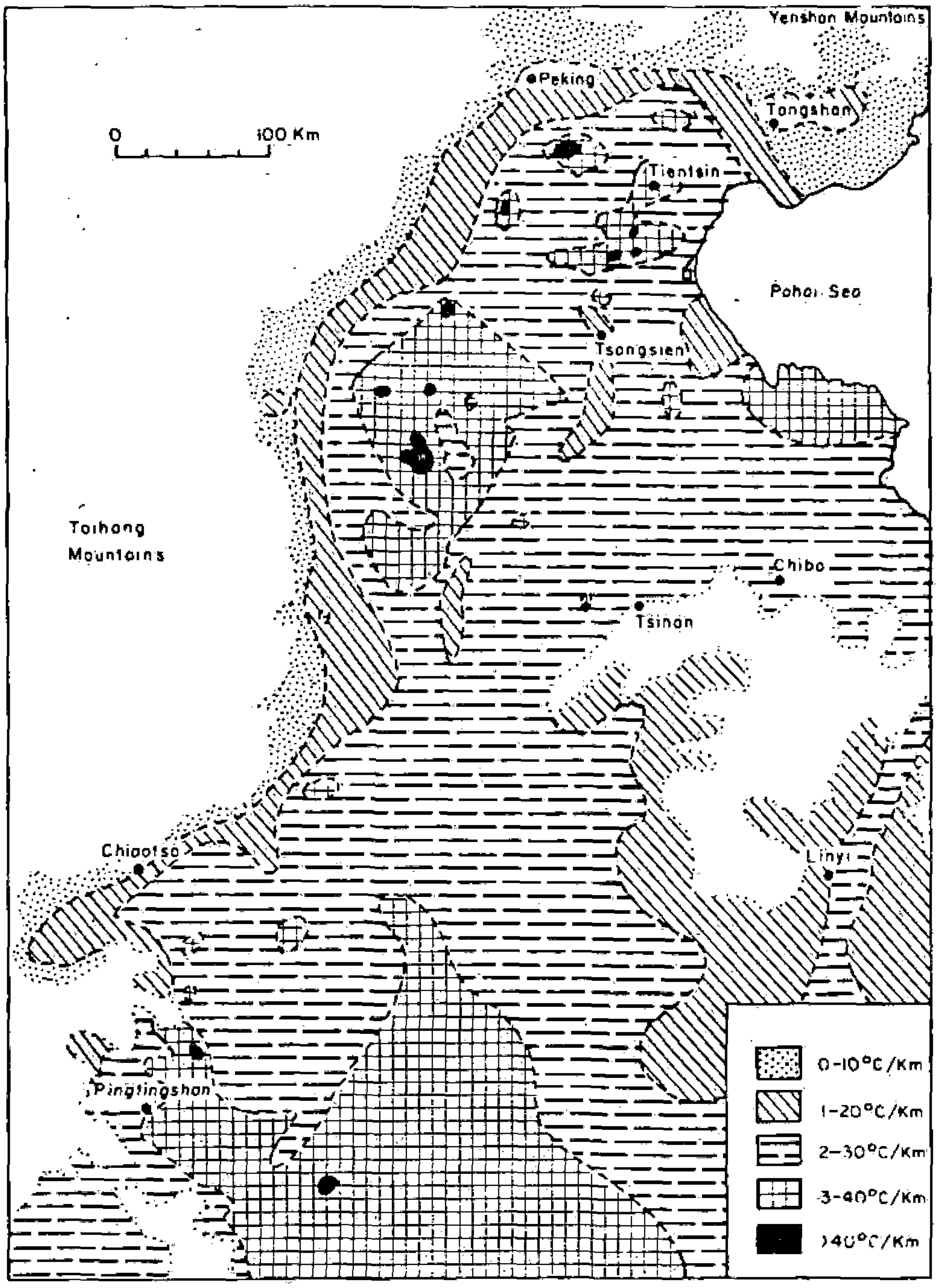


Fig. 2. Variation of geothermal gradient over the depth interval 0—300 m in North China.

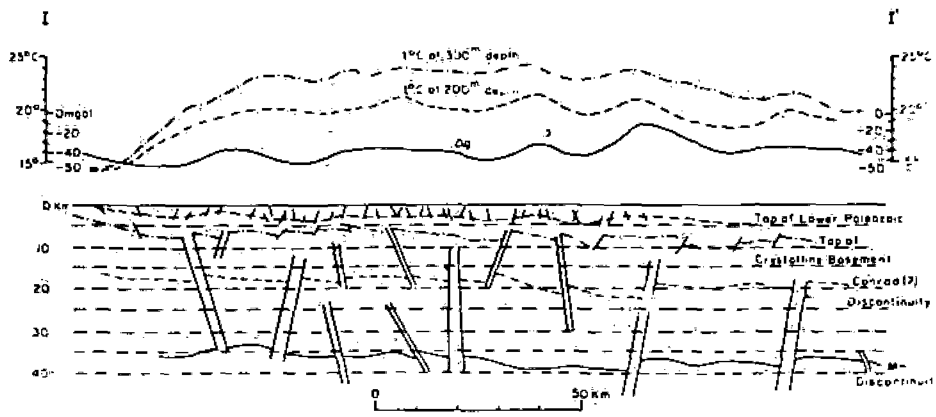


Fig. 3. The Yuanshi-Jinan geotemperature profile.

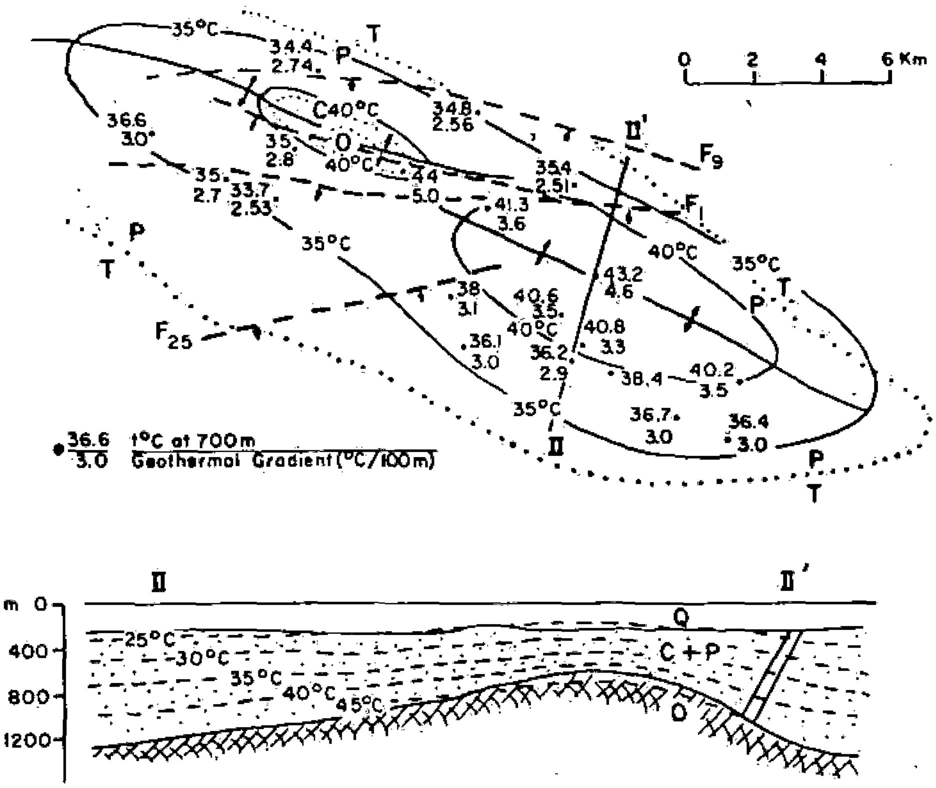
may be related to a depression. If we compare Figs. 1 and 2 with the tectonic map of the basement, a good correlation is apparent in the Yuansni-Jianan (Yuansnih-Tsinan) geotemperature profile (Fig. 3).

It is well known that the thermal conductivity of crystalline rocks is often higher than that of overlying sedimentary rocks, so that heat flow is concentrated in the uplifted region making it a region of high temperature. Similarly, because of contrasts in thermal conductivity causing a concentration of heat flow, higher temperatures may also be observed over an anticline (Fig. 4). In order to verify the results obtained, geothermal models were formulated for the uplift associated with the Pingdingshan (Pingtingshan) coal mine, Province Henan (Honan). Preliminary results (Fig. 5) show satisfactory qualitative agreement with the contour trends in Fig. 1.

(2) Faults and fractures. The Tancheng-Lujiang (Luchiang) fracture zone trending NNE and extending over East China is an active deep-seated fault zone penetrating to the upper mantle. Several strong earthquakes such as the 1668 Tancheng earthquake of magnitude 8.5, the 1969 Po Hai (Pohai) Sea earthquake of magnitude 7.4 and the 1974 Haicheng earthquake of magnitude 7.3 occurred along or near this deep-seated fracture zone. Furthermore, a number of hot springs have been found along this zone. Temperature measurements in drill holes indicate that the temperature at a depth of 300 m along the fault zone is 2—4°C higher than that outside the zone (Fig. 6).

The higher temperatures along the Tancheng-Lujiang (Luchiang) fracture zone are in part due to the regional geological setting. From the results of magnetotelluric soundings on the middle part of this zone near Linyi of Province Shandong (Shantung) the M-discontinuity is at a depth of about 30—35 km; accordingly, the asthenosphere is elevated to about 70 km, so that the conductive heat flow component is increased leading to higher subsurface temperatures here (Fig. 6). In addition, the fracture zone is favourable for the convective transport of heat (magma, hydrothermal fluid, etc.) from the deep interior of the earth.

Similar examples are also observed in some regions of North China. It is



Q–Quateruary
T–Triossic
P–Permion
C–Corboniferous
O–Ordovicion
F–Foults

Fig. 4. Temperature distribution above an anticline.

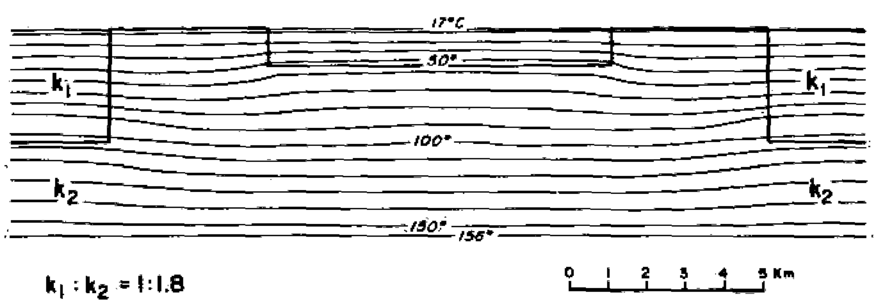


Fig. 5. Geothermal model for uplift.

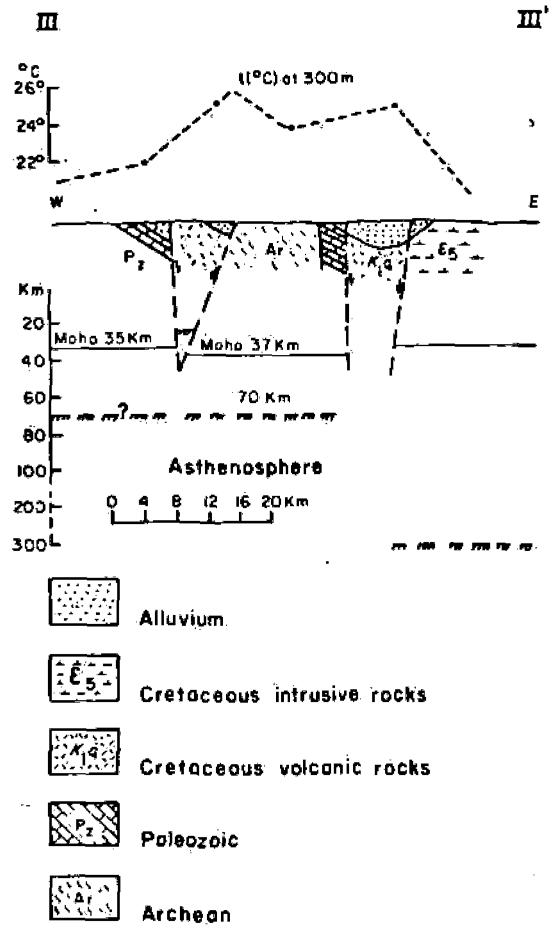


Fig. 6. Geotemperature profile across the Tancheng-Lujiang fracture zone at Linyi.

interesting that the high-temperature zones shown in Fig. 1 do not fall exactly at the uplifted center but always occur on the boundaries of different fault blocks, being deep-seated fracture zones.

(3) Magmatic activity. In the North China Plain, intrusive igneous rocks have been found by drilling and geophysical surveys in Yanshan (Yenshan), Qingyun (Chingyun), etc. These are areas with higher near-surface temperature. Moreover, in metal mines such as Jinling (Chinling), Laiwu, Yinan, Province Shandong (Shantung) where felsic magmatic bodies have also been observed, the temperature at a depth of 300 m in this region is about 3—5°C higher than that in surrounding regions. This indicates that granitic rocks high in heat-producing elements (U and Th) could exert a strong effect on subsurface temperatures.

(4) Groundwater activity. There are three different cases of groundwater activity which influence near-surface temperatures.

In areas of active recharge, discharge and subsurface flow, groundwater would transport heat from the surrounding rocks causing a decrease in near-surface temperatures. The low temperatures in the eastern piedmont of Taihang Shan (Taihang Mountains) and the southern piedmont of Yanshan (Yenshan Mountains) are an example.

A second case is the large artesian groundwater basin such as the oil-gas fields and coal basins in North China where confined aquifers are common. The water, whether it is of sedimentary or meteoric origin, is in thermal equilibrium with surrounding rocks. The geothermal gradient in these regions in North China ranges from 20 to 30°C/km (the south Shandong (Shantung) coal basin, 23—25°C/km; the north Anhui (Anhwei) coal basin, 21—26°C/km; the south Anhui (Anhwei) coal basin, 25—30°C/km).

The third case is deep circulation of groundwater that results in a local geothermal anomaly such as are associated with anomalies in some metal and coal mines in North China.

DETERMINATIONS OF TERRESTRIAL HEAT FLOW

To date, 22 reliable heat flow values from 17 sites have been obtained in North China. The geological and geographical setting of these sites are shown in Fig. 7 and summarized in Table 1.

The data can be categorized according to the fault block tectonics theory; from 17 heat flow sites there are 13 in the Hebei-Shandong (Hopei-Shantung) fault block (sites 1—9, 13—16), 3 in the Henan-Anhui (Honan-Anhwei) fault block (sites 10—12), and only one (site 17) value falls in eastern Qinling (Chinling) folding block to the south. The average heat flow value at the 16 northern sites is 1.3 HFU, varying from 0.7 to 1.8 HFU. It is apparent that the North China fault block is characterized by a relatively high heat flow with wide variations in magnitude compared with the mean value for similar tectonic units in other parts of the world.

The heat flow data can be divided into two groups, depending on the geological framework, as follows:

(1) Regions of recent tectonic uplift with extensive exposures of Pre-Cambrian basement include Yanshan (Yenshan), the central mountainous areas of Province Shandong (Shantung) and the Funiu-Dabie (Tapieh) Mountains; the average heat flow at 13 sites is 1.17 HFU. In the central part of Yanshan (Yenshan) which is considered to be the "core" of Chinese continental crust, rocks of Archaean age are widely exposed. The heat flow is low (about 0.7 HFU), whereas in the neotectonic areas such as Huailai and Yanquing (Yenching) basins the heat flow is higher (1.3—1.8 HFU).

(2) Recent areas of subsidence with wide development of Cenozoic sediments, geographically are equivalent to the North China Plain; the heat flow is significantly higher and varies from 1.45 to 2.0 HFU. The heat flow is much higher than the average world values for similar areas. It is suggested that the higher heat flow in these areas can be explained as follows: since the late

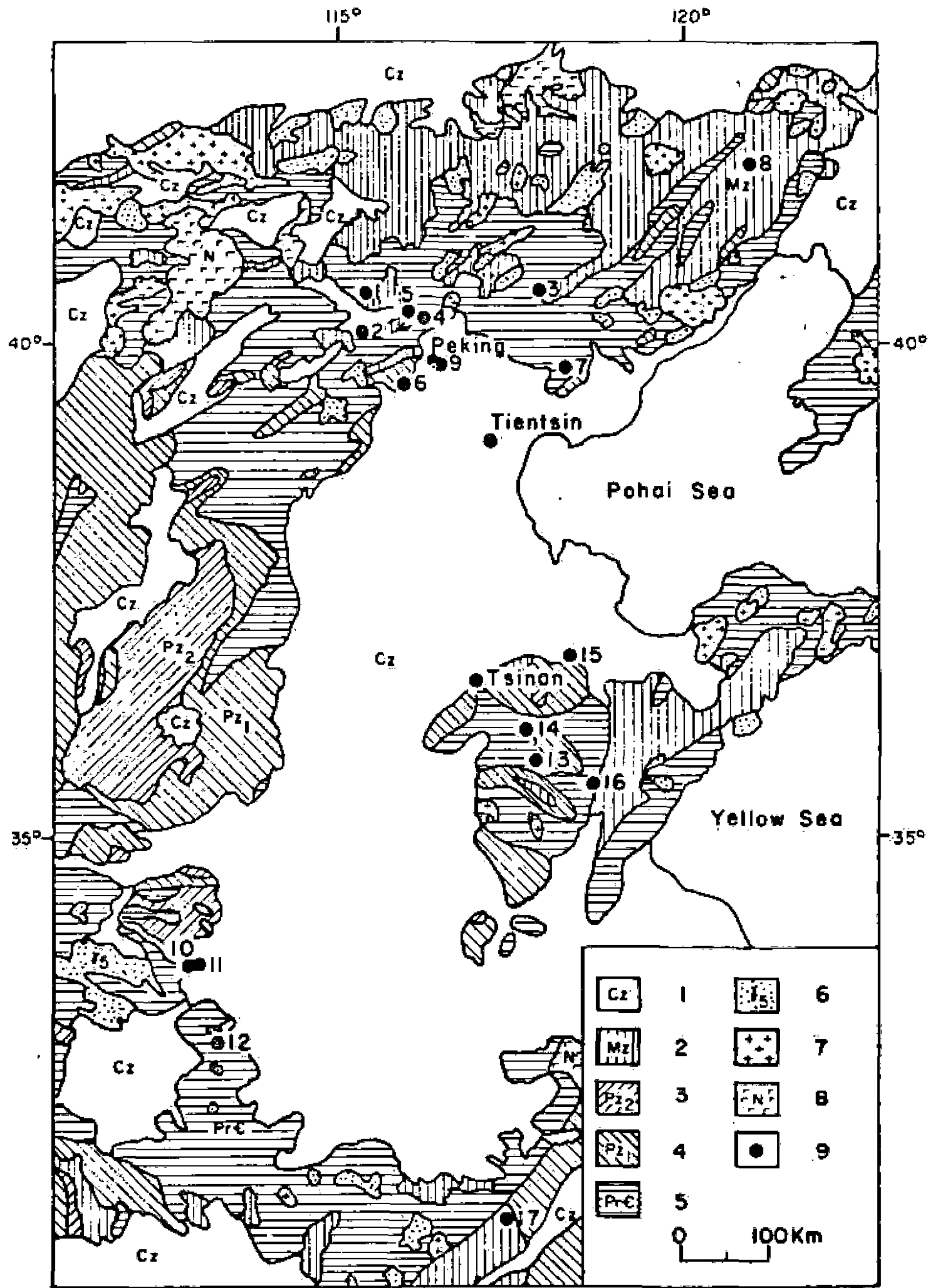


Fig. 7. Location map of heat flow determinations in China.
1 = Cenozoic (mainly Quarternary), 2 = Mesozoic (mainly volcanic and clastic rocks of Jurassic-Cretaceous), 3 = Paleozoic (mainly coal sequence of Carboniferous-Permian), 4 = Paleozoic (mainly carbonate rocks, in South China clastic rock of Silurian), 5 = Precambrian (metamorphic rocks of Sinian and Precambrian), 6 = Mesozoic acid-intermediate intrusive rocks, 7 = pre-Mesozoic acid-intermediate intrusive rocks, 8 = Neotertiary basalts, 9 = number and sites of heat flow determinations.

TABLE 1

Heat flow data in China

Site No. (cf. Fig. 7)	Bore hole	Location		Elevation (m)	Depth of borehole (m)	Time for equi-librium
1. Chicheng (Chihcheng) Province Hebei (Hopei)	13	40°41'N,	115°30'E	1300	529	7 days
2. Fanshan (Fanshan) Province Hebei	103	40°12'N,	115°26'E	750	733	45 months
	46	40°10'N,	115°26'E	875	418	15 days
3. Chengde (Chengteh) Prov. Hebei	10	40°35'N,	117°51'E	~700	627	16 months
4. Yanging (Yenching) Beijing (Peking)	72-7	40°24'N,	116°16'E	525	369	14 days
	72-5	40°25'N,	116°15'E	528	683	3 days
5. Yanging Beijing	2	40°27'N,	115°56'E		533	10 days
6. Fangshan (Fangshan) Beijing		39°44'N,	115°57'E	~200	507	2.5 years
7. Luan Xian (Luan County) Prov. Hebei	59	39°49'N,	118°30'E	57	348	21 days
8. Beipiao (Peipiao) Prov. Liaoning (Liaoning)		41°48'N,	120°44'E	172	in mine	
9. Beijing (Peking)	21	39°55'N,	116°27'E	36	700	3.5 months
	22	39°55'N,	116°29'E	36	1030	1 month
	24	39°55'N,	116°27'E	36	940	1.5 months
10. Pingdingshan (Pingtingshan) Prov. Henan (Honan)	101	33°47'N,	113°12'E	~100	581	3.5 months
11. Pingdingshan Prov. Henan	18-1	33°47'N,	113°23'E	80.7	683	23 days

Research interval			K (mcal/cm s °C)			Q, uncorrected (HFU)	
depth range (m)	nature of rocks	gradient (°C/km)	N	harmonic means	arith-metic means	individual	mean
168~330	tuffaceous quartz sandstone	14.38±0.22	3		6.56±0.53	0.94±0.08	
183~733	pyroxenolite	13.76±0.05	20	5.8±0.23		0.80±0.03	0.72
200~274	dolomite,	7.06±0.62	1		9.19	0.65	
274~400	granodiorite	10.77±0.38	4		5.69±0.23	0.61±0.03	
441~620	granodiorite, hornstone	12.68±0.07	7		5.71±0.16	0.72±0.02	
160~340	granodiorite	16.36±0.27	7		7.85±0.47	1.21±0.08	1.28
480~610	marble	19.88±0.30	8		6.81±0.49	1.35±0.10	
335~502	andesite	38.00±0.54	15		4.84±0.09	1.84±0.04	
300~500	porphyritic granite	12.70±0.23	1		5.68	0.74	
130~348	weak gneissic migmatite granite	11.74±0.07	8	6.02±0.14		0.71±0.02	
729~859	andesite	42.03±1.24	8		4.05±0.12	1.70±0.07	
506~700	dolomite	19.42±0.35	15		10.33±0.34	2.01±0.08	1.77
860~1030		13.70±0.53	8		10.57±0.48	1.45±0.09	
837~940		19.54±0.50	5		9.46±0.24	1.85±0.07	
148~326	dolomitic limestone	26.44±0.28	14	6.46±0.23		1.71±0.06	
217~295	limestone	29.59±0.75	6	5.80±0.16		1.72±0.07	1.76
360~419		30.67±0.54	7	5.92±0.24		1.81±0.08	
603~683		27.65±0.70	5	6.35±0.28		1.76±0.09	

TABLE 1 (continued)

Site No. (cf. Fig. 7)	Bore hole	Location		Elevation (m)	Depth of borehole (m)	Time for equi-librium
12. Queshan (Chuehshan), Prov. Henan	33580-1	32°50'N,	113°39'E	135	117	1.5 months
13. Xinwen (Hsinwen), Prov. Shandong (Shantung)	350	35°52'N,	117°40'E	173	735	6 days
14. Laiwu (Laiwu)	576	36°10'N,	117°39'E	~150	502	20 months
Prov. Shan-dong	6-2	36°13'N,	117°41'E	~140	500	23 days
15. Jinling (Chinling)	11	36°48'N,	118°11'E	< 50	736	9 months
Prov. Shan-dong	73-2	36°48'N,	118°07'E	< 50	335	10 months
16. Yinan (Yinan) Prov. Shandong	10-1	35°40'N,	118°37'E	~140	505	3 days
17. Lujiang (Luchiang) Prov. Anhui	56	31°00'N,	117°19'E	38.5	750	8 months
(Anhwei)	135	31°00'N,	117°19'E	41.5	700	7 days

Mesozoic, especially Cenozoic time, these regions were separated apart from surrounding uplifted areas and have been strongly subjected to a subsidence. As a result, block faulting took place in a non-equilibrium mode, faulting of the crystalline basement occurred, and neotectonic and magmatic activity was extensive. In addition, eruption of Cenozoic basalts occurred in many places. This resulted in high heat flow in this region.

It is clear that the heat flow pattern in North China is determined by tectonics and the history of geological evolution of the region studied. Although the age of the formation of the North China fault block can be traced back to the Archaean, being part of the oldest continental crust in China, the tectonic activity has been strengthening since the Mesozoic, that is, so-called "reactivation of platform". This eventually led to the appearance of relatively high heat flow with a large range of data scatter in North China.

Heat flow determinations in China are few, but the first values have shown the close relation with the geologic framework of the region. A knowledge of

Research interval			K (mcal/cm s°C)			Q, uncorrected (HFU)	
depth range (m)	nature of rocks	(°C/km)	N	harmonic means	arith-matic means	individual	mean
30~110	gneiss	18.17±0.19	3		6.43±0.18	1.17±0.04	
645~735	limestone	16.37±0.28	4		7.04±0.41	1.15±0.07	
180~210	marble	20.00	3	5.77		1.15	1.18
320~390	marble, diorite	21.00	2	5.7		1.2	
200~240	diorite, clastic rock	28.0	2	5.5		1.65	1.57
110~210	diorite limestone	22.0	2	6.7		1.48	
100~300	hornstone, diorite	24.50	5	6.07		1.49	
100~308	trachyandesite, syenite-porphyry	41.14±0.27	7	4.57±0.16		1.88±0.07	1.84
134~229	trachyandesite, syenite-porphyry	36.40±0.52	4	4.94±0.28		1.80±0.01	

regional heat flow will play an important role in prospecting for geothermal resources, especially in predicting areas for hot dry rock applications; it will therefore be useful to increase the effort in this regard.

PROSPECTING AND EXPLORATION FOR GEOTHERMAL RESOURCES

Exploitation and utilization of geothermal energy

China is rich in geothermal resources. To date, more than 2000 hot springs have been found (Fig. 8). It can be seen from Fig. 8 that the hot springs are concentrated in the following regions:

(1) Recent tectonically active regions involving both banks of the Yalu Zangbu (Yalu Tsangpo) River in South Xizang (Tibet) and the Tengchong (Tengchung) volcanic zone of the western Province Yunnan. Based on the data collected by the Qinghai-Xizang (Chinghai-Tibet) Scientific Expedi-

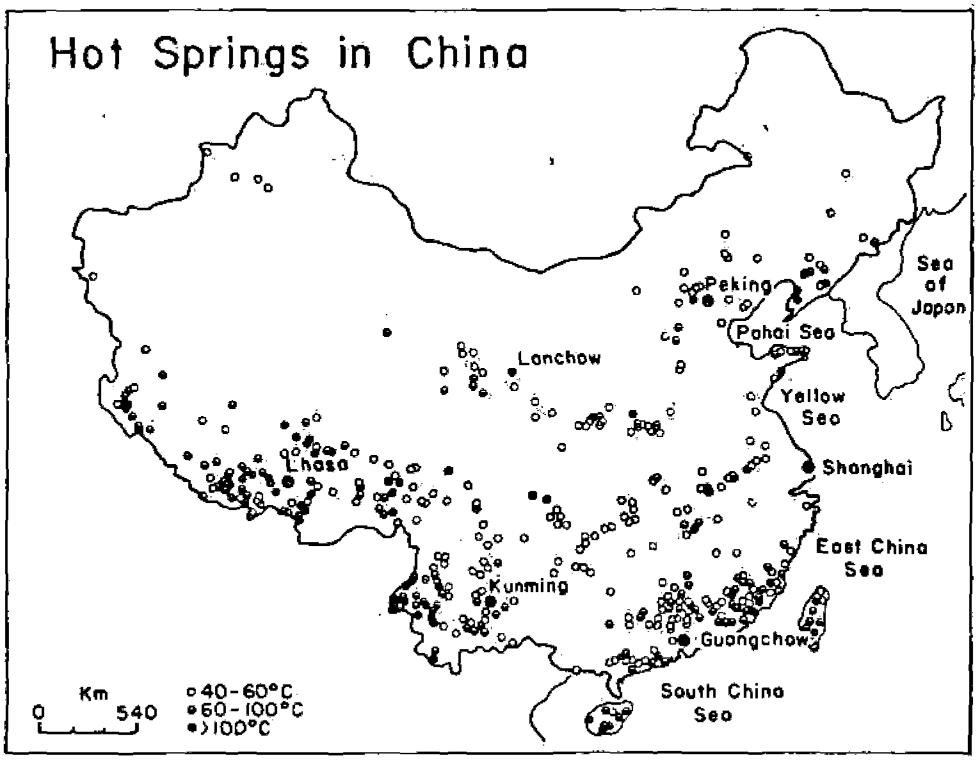


Fig. 8. Hot springs in China (by Huang Shang-yao, Wang Jun).

tion Group, Academia Sinica, there are more than 600 surface manifestations in the Xizang (Tibet) plateau demonstrating many types of hydrothermal activity including high-temperature geysers, hydrothermal explosion, hydrothermal steam, fumarole, high-temperature fountains, boiling springs, pools of boiling mud, hot springs, and thermal springs among which geysers and hydrothermal explosion were found in China for the first time (Figs. 9, 10).

The intensive hydrothermal activity in this region can be related to plate motions. It is suggested that between Cretaceous and Eocene time the Indian plate drifted northward and approached the Eurasian plate. Oceanic crust between these two plates was downthrusted along the geosuture zone of the Yalu Zangbu (Yalu Tsangpo) River. This movement finally led to the occurrence of intermediate felsic magmatic rocks in the Gandes (Gangdise) Arc belt. After the Eocene, the Indian and Eurasian plates fully collided with each other. As a result, the continental crust was thickened and partial melting began. Remelted magmas intruded and rose along fissures. Because of thickened crust at South Xizang (Tibet) the magma did not reach the surface of the earth. Consequently, heat is retained at shallow crustal levels causing hydrothermal activity with strong surface expressions in South Xizang (Tibet).

(2) Provinces Guangdong (Kwantung), Fujian (Fukien) and Taiwan along the coast of southeastern China constitute a zone where hot springs are con-

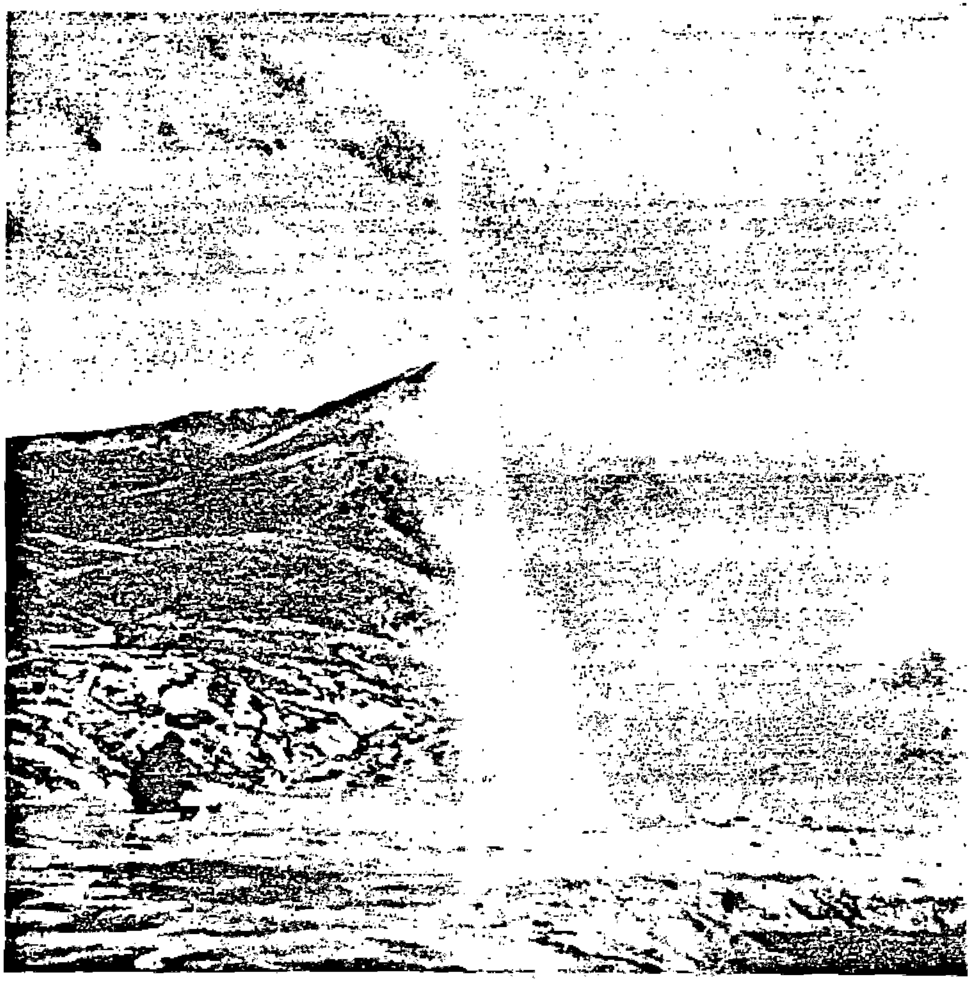


Fig. 9. Geyser at Ngamring County, Xizang (Tibet) — the largest geyser in China. (Photo courtesy of Zhang Ming-tao.)

centrated. Most hot springs have a temperature less than 100°C except for Taiwan where boiling springs have been found. Because Taiwan is located in a Cenozoic tectonically active zone, the hydrothermal activity there is strong. Along the southeastern coast of China, Mesozoic felsic intrusive rocks are widely distributed and the hydrothermal activity is correspondingly less strong.

(3) A North-South Tectonic Zone extends along Xichang (Hsichang)-Kunming at longitude of 104°E and is a zone of deep faulting. Along this zone are a series of Mesozoic-Cenozoic grabens with extensive magmatism and seismicity, so it may also be a high-temperature, high-heat flow zone with strong hydrothermal manifestations at the surface.

(4) In eastern Shandong (Shantung), mountainous areas of East Liaoning

Fig. 10. Hydrothermal explosion at Gamba County, Xizang (Tibet). (Photo courtesy of Zhang Ming-tao.)

and Yanshan (Yenshan) regions, hot and thermal springs mainly occur along the intersection of two sets of fractures. The temperature of the majority of the springs ranges between 40 and 60°C, and locally up to 100°C.

In addition to the hot springs, there are many Meso-Cenozoic sedimentary basins with widespread aquifers containing geothermal water resources in abundance. For example, thermal water having a temperature of 70—90°C was encountered in many oil and gas exploration drill holes in North China. In Beijing (Peking) and Tianjin (Tientsin) areas there are many thermal water wells of 1000—2000 m depth having temperatures of 40—60°C.

Extensive exploration and exploitation of geothermal resources in China began early in the 1970's. Since then several experimental power stations using thermal water have been set up in Fengshun (Fungshun) of the Province

Guangdong (Kwantung), Huailai of the Province Hebei (Hopei), and other locations (Fig. 11, Table 2). In 1977 a new power station using high-temperature (150°C) hydrothermal fluids and steam was constructed in the Yangbajing (Yangpachain) geothermal field north of Lasa (Lhasa) in Xizang (Tibet). At present, further prospecting and exploration of this geothermal field are in progress (Fig. 12).

Further utilization of thermal water for domestic heating and other purposes seems probable. Since 1970 in Beijing (Peking), Tianjin (Tientsin) and other cities, thermal water has been used for space heating, industry, agriculture, medical sanatoriums, etc. It is anticipated that these applications will be rapidly extended.

TABLE 2

Experimental geothermal power stations in China

Name of experimental geothermal power station	Location	Thermal water temperature (°C)	Design capacity (kW)	System type	Working medium	Generating date (year, month)
Fengshun	Fengshun (Dengwu) Guangdong					
No.1 Unit		91	86	flashed steam cycle	water	1970, 10
No.2 Unit		91	200	dual fluid cycle	iso-butane	1971, 9
Wentang	Yichun (Wentang), Jiangxi	67	50	dual fluid cycle	chlor-ethane	1970, 9
Huailai	Huailai (Houheyao) Hebei	85	200	dual fluid cycle	chlor-ethane, normal butane	1971, 9
Huitang	Ningxiang (Huitang), Hunan	92	300	flashed steam cycle	water	1975, 10
Yingkou	Xiongyue Liaoning	75—84	100	dual fluid cycle	normal butane, freon	1977, 4
Yangbajing	Yangbajing, Xizang	150	1000	flashed steam cycle	water	1977, 9

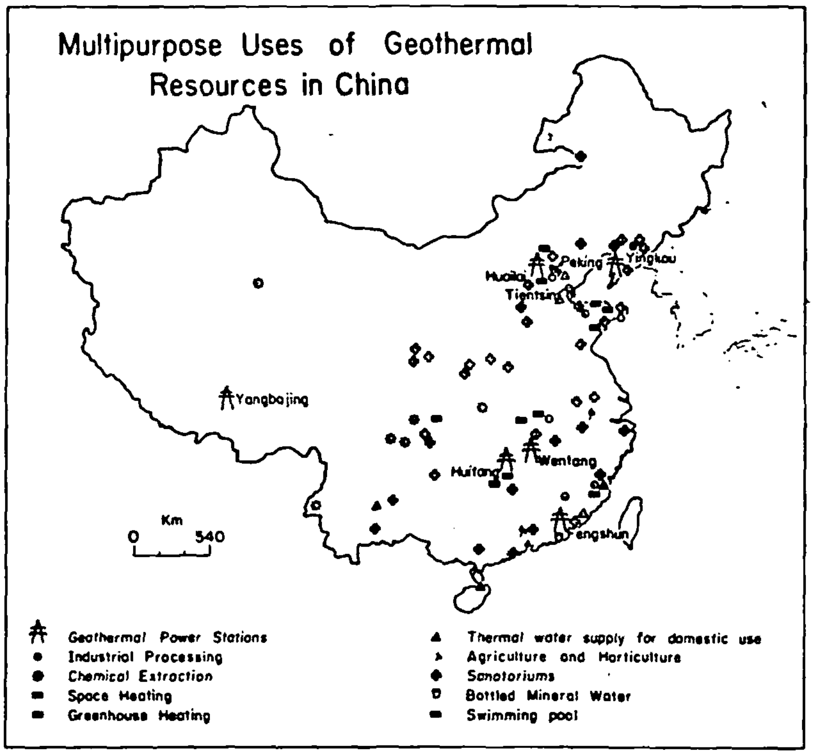


Fig. 11. Distribution of experimental geothermal power stations and multipurpose uses of geothermal resources in China.

GEOTHERMAL STUDIES IN MINES

It is well known that temperatures increase with depth; as a result the ambient conditions in shafts and galleries of deep mines sometimes exceed the limits tolerable to man. A so-called "geothermal hazard" is formed. For example, the rock temperature at a depth of 430 m in the Pingdingshan (Pingtingshan) coal mine, Province Henan (Honan) is up to 35°C and the air temperature at the same depth in the gallery is 30°C. Similar temperatures are reported in some coal and metal mines of East China. Based on geothermal investigations six types of mine can be defined.

(1) Mines with elevated basement. Geologically this type of mine is widely developed in the zone of uplift, where the geothermal gradient is about 30—40°C/km and the heat flow is greater than 1.3 HFU. The Pingdingshan (Pingtingshan) coal mine is of this type and seems to be typical.

(2) Mines in areas of basement subsidence with a normal geothermal gradient (20—30°C/km). The Yanzhou (Yenchou) coal mine in Province Shandong (Shantung) and coal mines in northern and southern Anhui (Anhwei) are of this type.

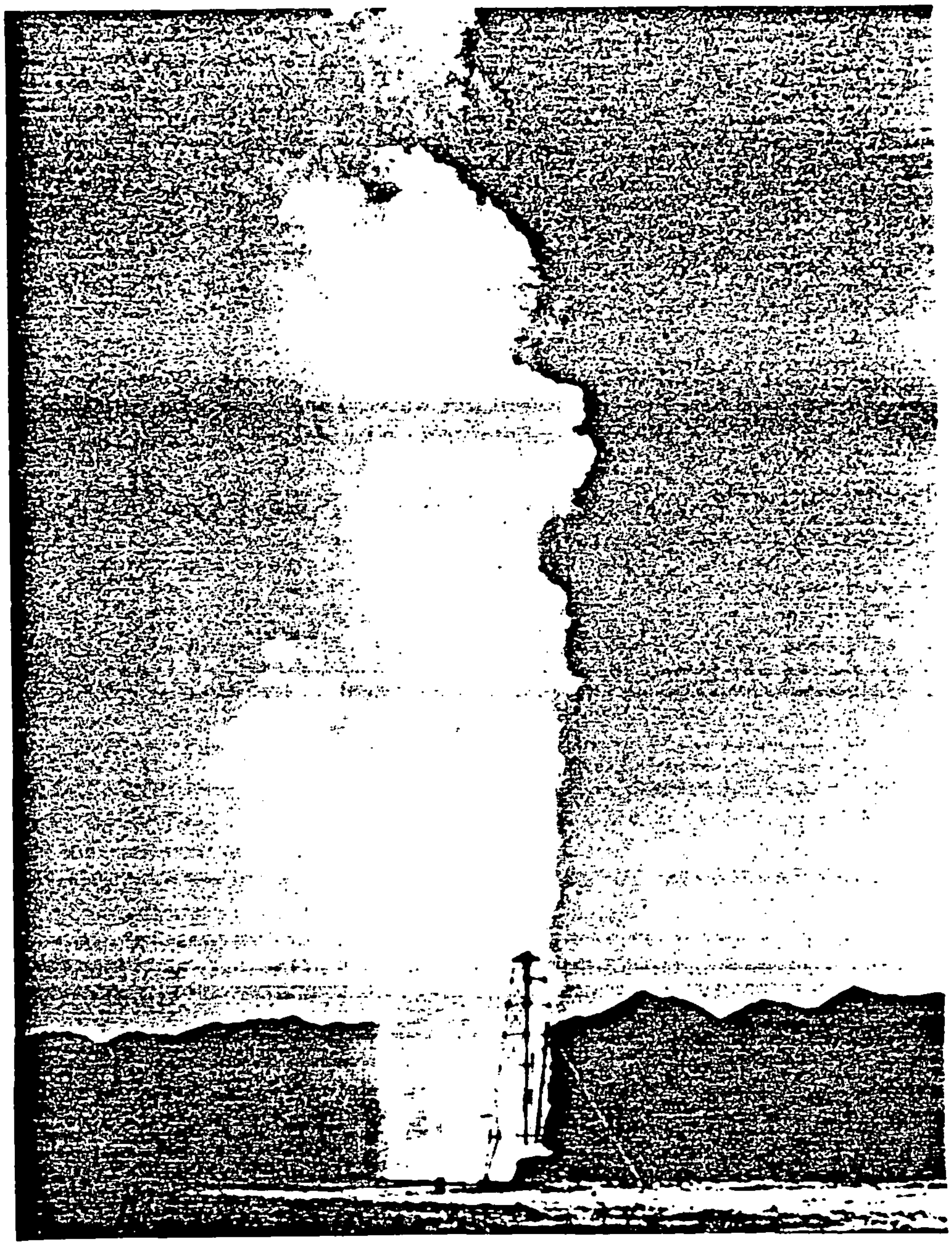


Fig. 12. Drilling at Yangbajing (Yangpachain) geothermal field, Xizang (Tibet). (Photo courtesy of Zhang Ming-tao.)

(3) Mines in deep fault zones such as those in Liaoyuan, Fushun, Fangzi (Fangchih), Linyi along the Tancheng-Lujiang (Luchiang) fracture zone. These mines are characterized by high rock temperature and sometimes by the occurrence of deep-seated circulation of hot water.

(4) Mines with intensive mixing of groundwater. These mines are located mainly in the piedmont of the Taihang Shan (Taihang Mountains) and Yanshan (Yenshan Mountains). Due to intensive mixing of groundwater the rock temperature of the deeper parts of the mines is lower, An example is the Kailuan coal mine, Province Hebei (Hopei), near the southern piedmont of Yanshan (Yenshan) where the rock temperature in the gallery at 1000 m depth is less than 28°C, and the geothermal gradient is less than 20°C/km. Similar temperatures are observed in the Jingxi (Kingsi), Fengfeng, Jiaozuo (Chiaotso), Hebi (Huopi), Zibo (Chibo) coal mines.

(5) Mines with deep circulation of hot water. These are characterized by local thermal anomalies with temperatures up to 50°C or higher as in the Weigang (Weigam), Xiuyan (Hsiuyen) metal mines in East and North China. Tectonically these mines are located in areas where the fractures and faults are intensely developed.

(6) Mines rich in sulphide ores. In these mines apparent temperature anomalies can be found because of the oxidation of sulphide ores, which may lead to the burning of the ores in some cases. Mining is dangerous and caution must be used.

It should be noted that different methods are required for different types of mines to safeguard the environment. For example, in order to lower the mine temperature for the first type of mine, adequate air ventilation is satisfactory, but for the fifth type, extensive discharge of hot water is required.

ACKNOWLEDGEMENTS

The authors wish to express their sincere thanks to Professor John K. Costain for helpful advice on the manuscript, to Sandra Long and Tish Glosh for typing, and Eric Raitch for the drawings.

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