CONTRIBUTING FACTOR OF GEOTHERMAL IN TIANJIN COMPARED WITH THE LOW TEMPERATURE FIELDS IN ICELAND, HUNGARY AND FRANCE

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ABSTRACT

This report deals with some aspects of low-temperature exploration and exploitation in four countries. An account is given of the main characteristics of the Tianjin low-tempreature fields. In Iceland a general geothermal picture is presented and the Selfoss and Urridavatn low-temperature fields are described, with a special reference to the cooling problem experienced in these areas. An outline is given of the geothermal activity in Hungary and that of France. The geothermal areas in the two countries are in some respects akin to that in Tianjin, in that the low-enthalpy fluid is extracted from deep seated sedimentary layers where the temperature of the fluids appear to be controlled by the normal thermal gradient.

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INTRODUCTION

This report is a part of the authors work during six months training at the United Nations University Geothermal Training Programme held from April to October 1985 at the National Energy Authority in Iceland. This programme was sponsored by the United Nations University and the Icelandic Government.

The training started with a 5 weeks introductory lecture course covering various aspects of geothermal sciences. Following the introduction course the special training started with a training in reservoir engineering and borehole geophysics (5 weeks). This was followed by one week field excercise to the Tertiary central volcano of Geitafell in SE-Iceland. The author also went on a one week excursion to the Selfoss, Urridavatn and Glerardalur low temperature areas. The author further received some practical training in running temperature and caliper logs.

In other field excursions the author visited various geothermal localities, studied district heating services, low and high temperature areas, power stations, greenhouses etc.

The rest of the training time was used to read relevant reference books on geothermal energy and writing this report.

2 TIANJIN GEOTHERMAL OUTLINE

2.1 Introduction

Tianjin is situated in the North-China plain east of Bo-hai Gulf, about 120 km southeast of Beijing (Fig. 1).

The Tianjin area covers a total of 11.000 km^2 and has a population of about 7 millions. It is one of the three main municipalities directly under the Central Goverment, and is furthermore an important industrial base. It serves as the main harbour for North-China. Geothermal resources in Tianjin are similar to those in Hungary and France in being of low temperature affinity and are in areas of normal gradient condition (Wan, 1984). The thermal reservoirs are found in permeable formations at deep levels, and surface thermal manifestations are absent. Drilling and geothermal utilization in Tianjin started in 1934. The depth of the first deep well was about 860 m and temperatures of 34-36°C. Up to 1970 the shallow thermal system in Tertiary rocks was utilized on a big scale. A reconnaisance for a deeper reservoir contained in bedrock fractures and karst limestone formations (50-100°C) was initiated at the end of the seventies. Geothermal prospecting work has for the last ten years been a reconnaisance survey, which has demonstrated abundant geothermal resources in Tianjin.

2.2 Geological setting

According to the plate tectonic theory the main part of China belongs to the Eurasian plate as seen in Fig. 2. Eastern China (including Tianjin) lies near to the boundary of the Pacific plate (Fig. 3), whereas the southeastern China is affected by the movement of the Indian plate. The plate tectonic theory further postulates that the tectonic activity should intensify towards the east coast, i.e towards the plate boundary. Neotectonic movements are believed to be related to these and they are undoubtedly providing the conditions for the intense hydrothermal activity. It also imposes some effects on the east coastal region and the continental part of China (including Tianjin) such as a series of NE-trending fractures produced by neotectonic movements. These movements control the spatial distribution of geothermal activity (Xin and Zhang, 1981). The Tianjin area is situated at the northern end of the Canxian uplift. It is a subsidiary structure in the subsidence zone of the North-China plain belonging to the Neocathaysian structural system. Its southeast side and northwest side lie adjacent to Huang Hua and Jizhong depression respectively (Fig. 4).

According to oil prospecting information, one of the main structural features of the Tianjin area is that two groups of tectonic zones have developed (Fig. 5) (Qin, 1981). One trends NNE and is composed of uplift and subsidence structures and parallel fault systems. The other is a WNW trending fault zone. The former group consists of the Shuang-Yao uplift, Bai-Tang-Kou depression, Xiao-Han-Zhuang uplift, Cang-Dong fault, west of Bai-Tang-Kou fault, north of Tianjin fault etc., while the latter, mainly of Zeng-Fu-Tai, Ha-He, Cheng-Lin-Zhuang etc.

2.3 Stratification

The Tianjin region has been subjected to a marked denudation over a long period before the Upper Palaeozic Era due to repeated tectonic movements. This is evidenced by that only the Lower Palaeozoic strata and Upper Palaeozoic thinner strata remain in the northern part of the Cang-Xian upwarp. However, in some depressions (e.g. Bai-Tang-Kou depression), there remain not only the Palaeozoic strata but probably also the Mesozoic strata.

2.3.1 Cenozoic formations

Due to the influence of the Paleotopography of the basement, the depositional thickness of the Cenozoic strata is not uniform, the uplifted part being relatively thin (about 800-1000 m) while within the Bai-Tang-Kou depression it is more than 2500 m thick.

Quarternary system: The succession is mainly composed of a series of sandy and clay soil strata with a thickness of about 550-600 m.

Tertiary system: The rock thickness is in generally 500-600 m and can be divided into two parts, i.e. the Ming-Hua-Zhen formation, which is composed of sandstone-mudstone alternating beds, and the Guan-Tau formation, with psephitic sandstone interbedded with a few mudstone layers.

2.3.2 Palaeozoic formations

These can be divided into four main units:

Carboniferous: Lithological character of grey and black carbonaceous mudstone bedded with thin layers of fine-grained sandstone and coal line, with brown hematite and bauxite at the base of the formation.

Ordovician: The normal thickness is about 300 m and the lithology is mainly of light grey limestone.

Cambrian: The thickness is about 150-300 m and the rocks are mainly of grey violet mudstone bedded with thin layers of limestone.

Sinian: The thickness may be up to several thousand meters. The rock sequence consists mostly of dolomite and dolomitic limestone.

2.4 Thermal distribution

Fig. 6 shows the ground temperature of the North-China plain to be lower in the western and northern part near the mountainous area, and high in the central part, on the basis of regional temperature and gradient at 300 m depth. The former case is 15-20°C and 1-2°C/100 m on the average gradient, while the latter one is respectively 20-23°C and 2-4°C/100 m (Fig. 6 and Fig. 7).

The temperature at 300 m depth in the northern part of the Tianjin geothermal field is in general 20-22°C and 22-25°C in the urban and south suburban part with an average gradient of 4-6°C/100 m and maximum of 6-9°C/100 m. The geothermal areas having an average gradient higher than 4°C/100 m extend over 700 km^2.

According to measured data, the average depth to a zone of constant temperature in Tianjin is 32 m and its mean temperature is 13.6°C. The average temperature gradient in Tianjin is 3.5°C/100 m deduced from deep well data. In those areas in Tianjin, where the temperature gradient exceeds 4°C/100 m, are considered as geothermal anomalies. Three anomalies have been recognised (Fig. 8). The features of the three anomalies are shown in Table 1.

Ren 23 (Fig. 9) is a good example for the Tianjin region in verical temperature variation of the regional temperature in wells. In the Tertiary and Quaternary succession, the temperature of the thermal system increases with depth, and shows a stable geothermal gradient of 3,2 -3,7°C/100 m. In the lower thermal reservoir the gradient is a little less or 2 - 1.5°C/100 m.

The geothermal reservoir can be classified into two types according to depth, lithological character and distribution feature of the geothermal reservoir, i.e. the porous Tertiary system and the fracture, karst aquifers in Ordovician and Sinian strata (see Table 2).

Hydrochemically (c.f. Table 3), the porous water of the Tertiary system is characterized by high alkalinity and low hardness and salinity, while that of the fracture karst water (Ordovician and Sinian strata) by its relatively high salinity, alkalinity and fluorine content, and relatively low hardness (Qin 1981).

2.5 Discussion

The benefit the author has had from the study of geothermal in Iceland and from literature survey of geothermal in Hungary and France, has contributed much to his understanding of the geothermal activity in the Tianjin region. Based on these, the author is able to make the following model of the Tianjin geothermal area.

Tianjin is situated in the eastern part of China, which according to the plate tectonic theory, is mainly influenced by the westward movement of the Pacific plate. This is mainly observed as tectonic activity which increases from west to east. The geothermal activity increases also towards east, as observed in a generally higher geothermal gradient in the east (3-4°C/100 m) than in the west (1.5-2.5°C/100 m).

According to the seismic data the crustal thickness of northern China is approximately 30-45 km, with a general thinning towards east. In the neighbourhood of Tianjin the Moho is found at about 32-33 km depth (Fig. 11). The heat flow value in the neighbourhood of Tianjin is 1,77 HFU (1,77 x 10-6 cal/cm-/sec). This is a higher heat flow value than the representative value of the north China plate.

The ground temperature distribution in the Cenozoic cover in Tianjin is controlled by the basement structure. Generally, the temperature is higher where the underlying basement is uplifted, and lower where the basement is depressed. What is more important is that deep active faults have a great effect on the ground temperature.

The faults of Cang-Dong and West-Bay-Tang-Kan do not reach the surface as a caprock covers the fault escarpments. Surface thermal manifestations in these areas are not strong. The contours of isothermic gradient, however, deliniate the geothermal field. They are all controlled by NE-NNE trending faults, which were formed in the Mesozoic (Wan, 1984).

Observations have been made on the west Bay-Tang-Kou fault regarding the earth deformation of the upper and lower walls. The east wall has been observed to have been uplifted gradually from 1973, but from 1976 a more rapid uplift has occurred due to the Tangshan megaseismicity with an average rate of 1-2 mm per year. Up to 1981 the upper wall movement relative to the lower one has already attained a height difference of more than 10-15 mm (Fig. 11).

The study of the geothermal fields in Tianjin has shown that they are a low enthalpy resource. The spatial location and the deep groundwater cycles of these geothermal systems are all controlled by active faults (Wan, 1984). The faults are all active and they are believed to create favourable conditions for the convective circulation of the deep-seated thermal water. Such an inference can be evidenced by the coincidence of the alignment of the Wang-Lan-Zhuang geothermal area with a fault (Qin 1981).

TABLE 1: Distribution of the shallow thermal anomaly zone

Name of zone	Location	Distribution of area (km^2)	Gradient of the center of anomaly zone (1°C/100 m)
Wang-Lan-Zhuang	Urban South-west Suburb	409	8.3
Wan-Tia-Ma-Tou	South Suburb	119	8.3
Shan-ling-Zi	East Suburb	171	8.1

TABLE 2: Types of geothermal water in Tianjin

Type (m)	Depth	Lithology of thermal reservoir	Temperature (°C)	Water head (m)
Porous water of Tertiary system.	600-1000	Semi-cemented limestone	30-63	-30 to -60
Fracture and Karst water of Ordovician and Sinian strata	>1000	Limestone	55-98	Above surface +10 to +20

TABLE 3: Hydrochemical characteristics of geothermal water

Type of water	Hydro-chemistry	Salinity (g/l)	Total hardness (German)	Alkal-inity (German)	Fluorine (mg/l)	pH
Tertiary thermal water	HCO_3-Na	0.6-1.0	0.7-1.0	20-25	3-5	8-8.5
Ordovician thermal water	Cl $HCO_3(SO_4)$ - Na	1.58-4.4	4.4	28-88	10.4	7.1
Sinian strata thermal water	Cl HCO_3 - Na	1.8-2.0	5-7	17-20	6-10	7.5-8.0

3 THE LOW ENTHALPY GEOTHERMAL RESOURCES IN ICELAND

Iceland is an island situated in the central North-Atlantic ocean. It is about 103,000 km^2 and inhabited by about 228,000 people. It is rich in the geothermal resources. Due to its location on a divergent plate boundary where high volcanic activity prevails the country has a very high geothermal potential. About 80% of the population of Iceland enjoys geothermal district heating.

3.1 Geologic and geothermal setting

Iceland lies astride the mid Atlantic ridge. The axial rift zones are divided into two parallel volcanic rift zones in South-Iceland and one in North-Iceland (Fig. 12). These zones are characterized by several fissure- and fault swarms, which often pass through a central volcano.

The volcanic rift zone is charcterized by a high heat flow in the crestal region, but falling off with increasing distance symmetrically away from the ridge crest until it reaches an average level for the oceanic plates. The regional heat flow varies from about 80 mW/m^2 furthest away from the active volcanic zones crossing the country to about 300 mW/m2 in some regions at the margins of the Reykjanes-Langjokull axial rift zone. In over 100 m deep wells outside known geothermal fields and outside zones of active volcanism the geothermal gradient ranges from 37°C/km-165°C/km. Hot springs are very abundant in the country as a result of the high heat flow. The temperature of thermal springs varies from a few degrees above the mean annual temperature to boiling springs. The steam fields or the high temperature areas are confined to the active zones of rifting and volcanism (Fridleifsson, 1979).

The geothermal areas in Iceland are divided into high and low temperature areas. The former are characterized by temperatures exceeding 200°C at depths of $<$ 1000 m. They are always found within the Neo-volcanic zone. The heat source is assumed to relate to a magmatic heat at shallow levels in the crust. Most of the major low temperature areas are found just outside the Neo volcanic zone in rocks of Quaternary ages (Flovenz and Georgsson, 1982).

A comparison of the deuterium content of the thermal water and the local precipitation in the individual areas has shown that the thermal water in Iceland is of meteoric origin, in most cases a precipitation which has fallen in the highlands. Some of the precipitation percolates deep into the bedrock and flows laterally along faults and pervious horizons for distances of tens of km before it appears on the surface along dykes or faults on the lowlands. The water withdraws heat from the regional heat flow during its passage through the strata (Fridleifsson, 1979).

3.2 The low temperature areas in Iceland

According to seismic surveys the crustal thickness in Iceland varies from 8-15 km. The crust is formed almost entirely of igneous rocks. The uppermost 3-5 km are composed mostly of subaerial lavas in Tertiary regions but hyaloclastites and lavas in areas of Quaternary and Recent age. The low temperature areas are distributed mainly in the Plio-Pleistocene and Tertiary volcanics (Fridleifsson, 1979).

According to drilling investigations in Iceland, there are indications that aquifers encountered are mostly related to some near vertical structures such as dykes, faults or fractures. Hot springs are commonly found at the intersection between two such structures where one acts as an aquifer and the other as an aquiclude. The main problem of low temperature geothermal exploration in Iceland is to locate dykes, faults and fractures, and estimate their inclination and find out which of these structures are permeable (Flovenz and Georgsson, 1982).

The author had an opportunity to do a study, both in the field as well as of published data reports, of two low temperature areas, the Urridavatn and the Selfoss low temperature fields. The following account describes some of the important features associated with these areas.

3.3 The Urridavatn geothermal field

Urridavatn is situated within the Tertiary region of eastern Iceland. The geothermal area provides thermal water for district heating for the town of Egilstadir (1200 inhabitants).

Surface thermal manifestations are mostly found at the bottom of the Lake Urridavatn as evidenced by gas bubbles emerging through holes in the winter ice.

The lava succession at Urridavatn is about 9.5 m.y. old, dipping about 6° towards SSW. The dykes and faults trend generally NNE-SSW, and are a part of the dyke swarm from an extinct central volcano some 30 km to the south. The dip of the dykes is about 6° from vertical towards the east.

Figure 13 shows the area to be transected by a complicated system of faults and fractures with a NNE-SSW direction. Due to recent surface sediment cover within the grabens it is very difficult to trace the exact locations of the faults. Another fracture system is situated within the lake, east of the thermal area. It is not clear how the faults are oriented at the bottom of the lake, but the thermal area appears to be located just to the south of the intersection of these two fracture systems. Two other small faults with a NE-SW direction are located west of lake Urridavatn (Einarsson et al., 1982).

Dykes make up about 7% of the total volume of the exposed rock. Most of them trend N 10-20 E but a NW-SE direction is also common. The interpretation of the resistivity profiling indicates that the main aquifers follow a fracture with a NE-SW direction. At the intersection of the fracture and the dikes, water is routed towards surface. The dip of the fracture from vertical estimated from the drillhole data is between 2-6° to the east.

3.3.1 Utilization problems and possible solutions

After the district heating service started in January 1980, the water in the wells started to cool down. At the beginning the district heating utilized only well No.4 where the discharge was about 12 l/s of 64°C warm water. This water was mainly from shallow aquifers, and it was assumed that the water would start to cool down due to influx of cold water from the lake. In 1982 the water in the well had cooled down below 55°C. Utilization from well No. 5 started in 1981, and the discharge was 15 l/s of 53°C warm water. The well intersected some aquifers at shallow depths and a small one where the well intersected the dyke at about 600 m depth. In 1982 the water temperature in well No. 5 had lowered down to about 52°C (Einarsson et al., 1982).

It has been worked out that the exploitation of the shallower aquifers in wells No. 4 and 5 has resulted in an influx of cold ground water into the upper part of the geothermal system. In order to avoid the cooling problem the exploration methods used have been directed towards utilizing deeper aquifers (>400 m) and case off the shallower ones that have experienced the cooling.

The aquifer system at the Urridavatn geothermal field has been studied for some years. The effort has partly been to prove and to locate the connection between the cold ground-water system (e.g. Lake Urridavatn) and the geothermal system. In that respect a tracer has been put into the lake and its emergence monitored in the wells. Furthermore, as the chemical compositions in the two water systems are quite different, a study has been done in tracing the chemical change in the thermal water thus reflecting the extent of cold water intrusion.

3.4 The Selfoss low temperature area

The Selfoss low temperature geothermal field is situated in the Quaternary region in southern Iceland (Fig. 12). The geothermal water is used for domestic heating of the town of Selfoss which has a population of about 3000. The exploitation has resulted in a marked drawdown in the reservoir which in turn has led to an intrusion of cold ground water and a gradual cooling in the upper part of the reservoir.

The lithology can be dividid into three separate formations: The uppermost formation consists of about 30 m thick and highly permeable postglacial lava flow. The chlorine content of the cold groundwater in the lava is very low.

A 50-80 m thick and impermeable tillite horizon underlies the lava and lies unconformably on top of a Quaternary basement. The tillite acts as a cap rock separating the overlying cold ground water system and the geothermal system in the Quaternary rock sequence (lavas, hyaloclastites and intrusives). The geothermal water has a much higher chlorine content than the cold groundwater system above.

The removal by pumping of water from the geothermal system decreases the hydrostatic pressure in the system, and in turn has caused inflow of cold ground water. This leakage is both through drillholes with cracked casing and also by seepage of the cold water through fractures in the tillite cap rock. There are five parameters which can to some extent indicate the intrusion of cold ground water into the geothermal system.

1) Direct temperature measurements of the water pumped from the area; 2) The amount of water pumped from the area; 3) Hydrological parameters which indicate the inflow of cold groundwater into the reservoir; 4) The chlorine content of the thermal water was originally about 10 times higher than that of the cold ground water. The changing chlorine content of the thermal water thus indicates the ratio of the cold groundwater in the thermal water; 5) The temperature change in observation drillholes indicates the rate of rock cooling with time.

The thermal water has a relatively high chlorine content (108-520 ppm). It varies, however, between drillholes and also with time in the same drillhole. The variation is believed to be caused by the inflow of cold groundwater with chlorine content of 5-10 ppm into the thermal system (Tomasson and Halldorsson, 1980).

In order to monitor the influx of cold groundwater, the sampling of the thermal water for chemical analyses has been more or less continuous since 1965. Hydrological observations show that the drawdown is less than expected in an infinite confined aquifer. The explanation is that it is a recharge area, where cold groundwater leaks down.

Table 4 shows how the changing chlorine content and the temperature in different aquifers can be used to calculate the ratio of the cold water intrusion into the thermal system. The chlorine content change gives much higher ratio of cold water intrusion than the temperature ratio. This is believed to be due to the heat transfer from the rock to the water.

The investigation of the Selfoss thermal field has been concentrated in latter years towards understanding the process of cooling and how best to minimize its effect on the utilization. Firstly, the older shallower drillholes, which had been causing an excape of cold groundwater into the thermal reservoir, were cemented up. Secondly, the uppermost aquifers in the reservoir which have experienced the cooling were either cemented or cased off. Thirdly, the emphasis in drilling has been to seek aquifers at deeper levels (>600 m).

TABLE 4: The temperature and chlorine content of the geothermal water. Temperature in °C

	Original Cl-content	Cl-content after invasion of cold groundwater	Ratio	Original temp.	Temp. after invasion of cold water	Ratio
Aquifer	500	250	0.51	90	81	0.11
	400	250	0.45	81	81	0
	500	116	0.78	90	55	0.41

4 THE GEOTHERMAL RESOURCES IN HUNGARY

Hungary is located in central Europe. It covers an area of about 93.000 sq km and has a population of about 11 million. It is rich in natural resources such as coal, oil, gas, manganese, uranium, and geothermal.

Up to 1977, 525 thermal wells had been registered, all of them giving water with a temperature higher than 35°C with a total output of 438.000 l/min. Of these 370 wells have temperature of 35-59°C, 125 wells have temperatures of 60-89°C and 30 wells have temperatures higher than 90°C. The following account is a summary of a paper by Ottlik et al. (1981).

4.1 Regional geology

The region is encircled by the Eastern Alps. The Carpathian area and the Dinarides is usually called the Carpathian basin. It is divided into three sub-basins, the largest being the Pannonian basin, but the lesser ones being the Vienna and the Transsylvanian basins.

Hungary lies according to the plate tectonic model just to the north of the Eurasian plate and African plate boundary, (Decker and Decker, 1982). The subduction of the "oceanic" lithosphere towards the Pannonian area led to thermal mantle diapirism under this region. The rising mantle material caused a lithospheric thinning where the thinned-out crust has an average thickness of 25 km. This crustal thinning has led to the formation of the Pannonian basin.

The Pannonian basin is filled with sediments of late Cretaceous-Paleogene age to Neogene-Quaternary age. The underlying basement is of metamorphic rocks of Precambrian age as well as formations of Palaeozoic and Mesozoic age. The Precambrian and Palaeozoic basement is usually of impermeable formations, but carbonate formations locally include fracture-fissured aquifers. Fig.14 shows a simplified geological cross section of the Pannonian basin.

The main mass of the Mesozoic rocks is made up of limestone and dolomite of wide areal extent, and up to 4000-5000 meters in thickness. These rocks are often karstic and highly fractured-fissured and constitute a regional thermal water reservoir.

The Pre-Neogene basement is characterized by normal faults. The rate of subsidence has varied in space and time resulting in a basin and range topography. The strike of the large-scale tectonics of the basin, is mainly NE-SW.

Seismic activity demonstrates that young tectonic movements have also taken place within the basin-filling sedimentary rocks, with faults in the brittle basement being reflected by mild flexures in the overlying sedimentary rocks.

The most important period of volcanism falls into the Miocene and Pliocene. Evidence of this volcanic activity is widespread, especially in the northern parts of the great Hungarian plain, where a tuff layer more than a hundred meters thick can be found underlying the Pannonian strata. Another period of volcanism occurred at the end of Pliocene-early Pleistocene times, although with a significantly weaker activity. During that period, basaltic lavas surfaced and formed isolated domes in several places. Today's cold CO_2-rich wells/springs are considered as a last phase of postvolcanic action.

4.2 Ground temperature and heat flow

Much temperature data have been obtained in oil and water exploration borholes. This data has been used to construct a geoisotherm map (Fig. 15).

The mean of 38 heat flow values for different parts of the Intre-Carpathian region gives 90,4 mW/m^2. A good negative correlation with the thickness of the basin-fill is observed.

4.3 Geothermnal activity

The following is a short account of the water bearing rock formations, temperatures and exploitation.

The dolomite of Devonian age is water bearing. One occurrence is known where the exploitation is 139 l/min with an outflow temperature of 58°C.

South of Lake Balaton a limestone of a supposed Carboniferous age was opened by drilling at a depth of 600-800 m, and water of 70°C was exploited with a slight overpressure.

South of Budapest, limestone of Permian age contained water of 100°C at a depth of 1000 m.

Carbonate rocks of Triassic age are widespread in the basement of the basin and they represent one of the main aquifer systems.

In the Transdanubian Central Range, 30-35 per cent of the precipitation falling on the uncovered and karstified Triassic rocks at the surface penetrates downwards thus assuring the continuous recharge of deep karstic water. Also the faulted structures enable the downward percolation of water and the development of large-scale convection. The existence of such circulation is indicated by thermal springs coming to the surface along fault traces.

The subsurface waters of the Pannonian basin are generally speaking not in hydrostatic equilibrium. A little surplus pressure exists as demonstrated by the artesian character of the wells. Considering the movement of water from the surface to depth in large, closed sedimentary basins, three zones are to be distinguished generally. In the Pannonian basin, these may be characterized as follows:

1. Zone of infiltration: The uppermost 300-700 m of sediments have a free communication between meteoric and subsurface waters. As a consequence fresh water at approximately hydrostatic pressure dominates in this zone. A slight hydraulic pressure is controlled by topography.

2. Zone of expellation: Below the zone of infiltration to a depth of 1-3 km, the water migration is controlled by the compression and consolidation of sediments, the water is remnant old sea-water expelled form the marine sediments by campaction and by consolidation and moves upwards and sideways. Artesian character of the waters is typical in this zone.

3. Zone of reinfiltration: At greater depths, the compaction of the rocks comes to an end, and the consolidated rocks are capable of a secondary infiltration. This zone exists in the Mesozic and older basement of the Pannonian basin. Hydrostatic pressures and mixed waters are supposed to be present.

5 THE LOW ENTHALPY GEOTHERMAL DEVELOPMENT IN FRANCE

5.1 Introduction

France, which is situated in the western part of Europe, covers an area of about 551,600 km^2 and has a population of about 53 million. France is a developed capitalistic country. The energy consumption depends mainly on import, but the exploition and utilization of geothermal energy has brought forth new ideas.

France has in the last decade developed a new way for using geothermal resources in normal gradient areas. This is due to the existence of wide and deep sedimentary basins in many parts of the country. Not only was it shown that geothermal energy resources exist in such areas, but also that it was technically possible and economically feasible to develop projects in applications of geothermal energy. Two major basins exist in France; the Paris Basin to the north and the Aquitaine Basin to the south-west (Lejeune and Varet, 1981). Other minor basins occur in the eastern part of the country but these are structurally more complex, with intensive faulting and lithological variations which make geothermal exploration more hazardous.

5.2 Geothermal geology in the Paris Basin

In the Paris Basin five geothermal reservoirs have been exploited.

1. Albian sands, bearing drinkable water at temperature of 30 - 45°C are exploited by several industries (washing mainly) and for the heating of the Broadcasting House in Paris.

2. Neocomian sands, bearing similar water as above and temperature of up to 50°C. It is exploited at Bruyeres le Chatel (30 km south of Paris) for the heating and the production of hot water for a research centre.

3. Lusitanien sands and limestones (Jurassic), with water over 60°C.

4. "Dogger" limestones (Jurassic) with temperatures over 80°C in the eastern Paris Basin. These provide district heating for Villeneuve la Garenne, Coulommiers, Cergy-Pontoise, la Courneuve, Aulnay, Clichy, (all sites less than 50 km N, E or S Paris).

5. Triassic sandstones, with temperatures above 100°C in the central part of the basin, the deepest and the less known reservoir of the Paris Basin are now exploited at Luneville, Nancy (swimming pools), and Melleary near Orleans (greenhouses).

5.3 Production system

Geothermal reservoir characteristics, mainly depth, lithology and composition of geothermal fluid, determine the appropriate technical scheme. The exploitation is done in three ways:

1. "Doublets" are coupled production and injection wells. They may be either vertical or inclined, depending on surface conditions (availability of land). Production and injection wells differ, due to the neccessity of introducing a pump in the production well. Rather than pressure interferences, which play advantageously in exploiting sedimentary aquifers, the distance between the production and injection wells in the reservoir is calculated according to cooling models of the reservoir with time due to the injection of colder water (Fig. 16).

2. Single wells can be used only when the chemical composition allows for its release in the natural surface drainage. Even when the chemistry of the fluid is favourable, reinjection may be requested in order to maintain the reservoir characteristics and allow for a better management of the geothermal resource on a regional scale.

3. Multiple well systems are used in densely urbanised areas, in order to optimize the production system, regarding both its economy and long term planning. The most adequate solution is found to be a hexagonal distribution,

with alternating production and injection wells. Such a system is used in Creil and is under construction in Meaux (Lejeune and Varet, 1981).

5.4 Heat demand in France

Development of low enthalpy geothermal application requires not only a good knowledge of the resources availability, but also of the energy demand expressed in terms of final use. In most European countries, a large part of the energy demand is for space heating, production of industrial or sanitary hot water, drying, cleaning etc. In France, nearly one third of the total energy demand falls in the low temperature range (below 100°C) i.e. of the order of 60 MTn/year (Lejeune and Varet, 1981).

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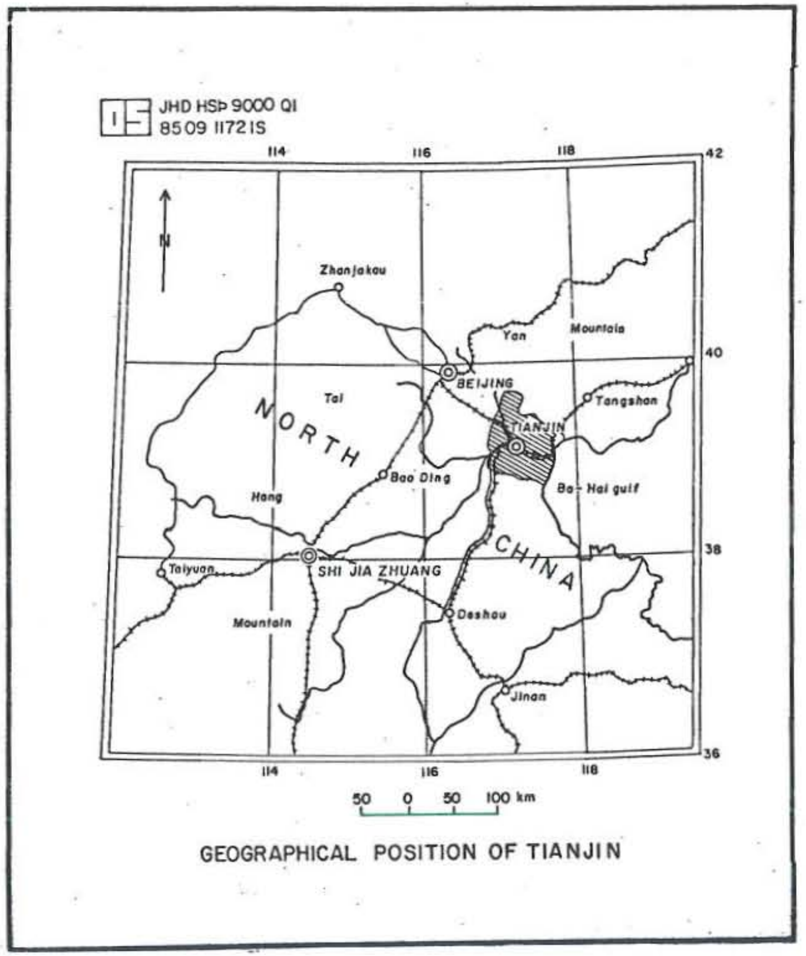

Fig. 1. Geographical position of Tianjin.
(from Lu Run, 1983)

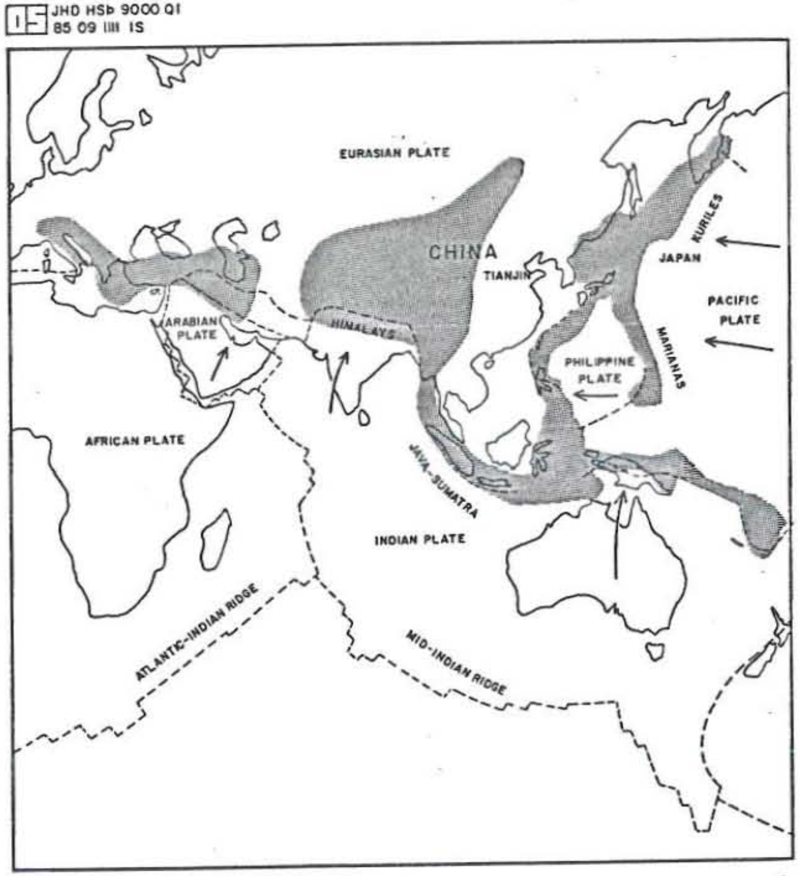

Fig. 2. Tectonic map of the Eurasian and Indian plate.

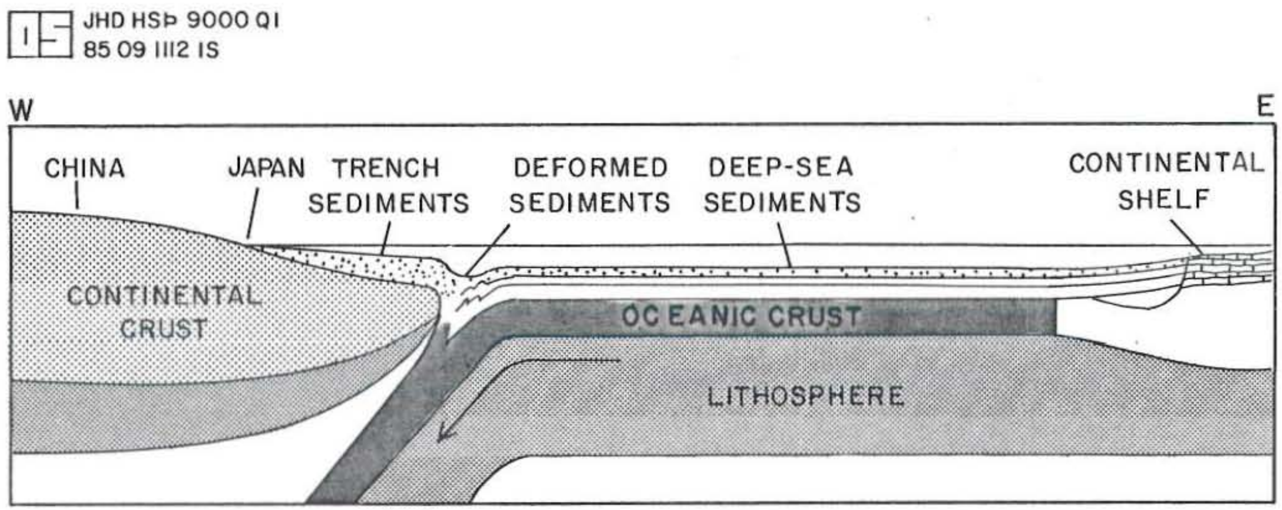

Fig. 3. Collision of the Eurasian and the Pacific plate.

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Geological map of Tianjin showing regional structure

(from Lu Run, 1983)

Fig. 4

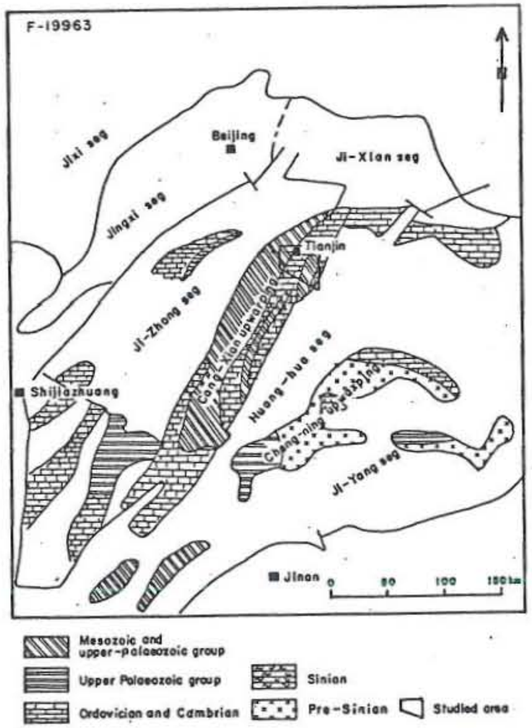

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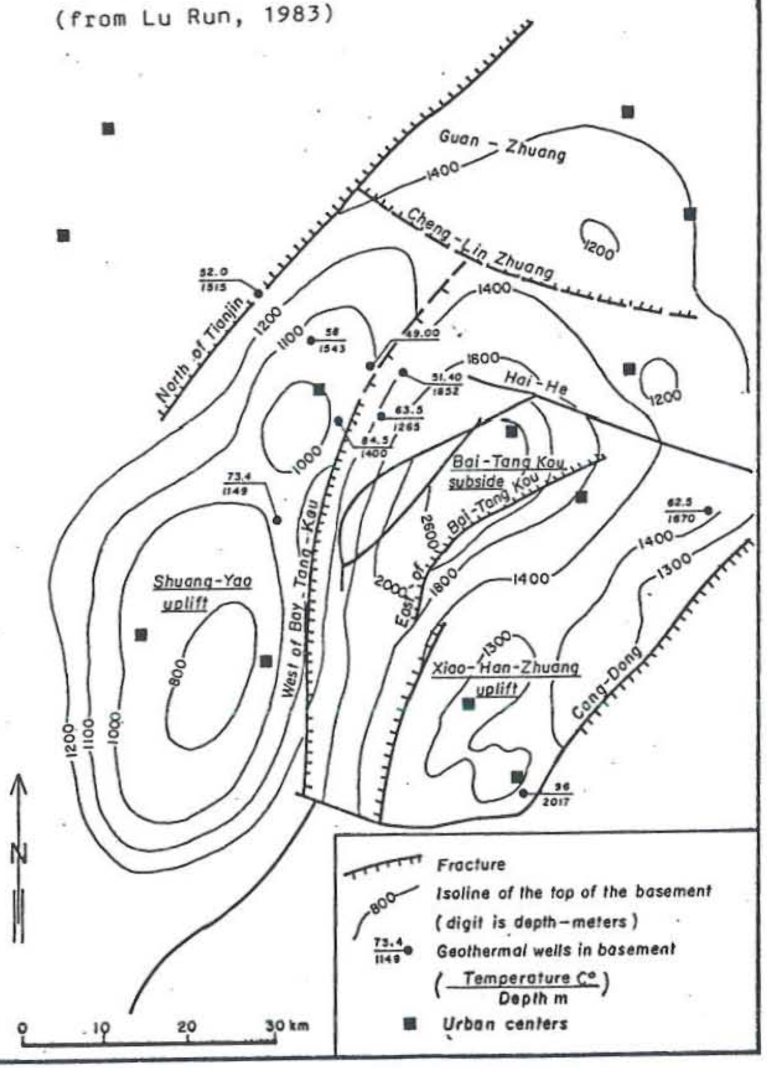
Fig. 5

MAP OF GEOLOGICAL STRUCTURES AND TOP OF BASEMENT IN TIANJIN GEOTHERMAL FIELD

(from Lu Run, 1983)



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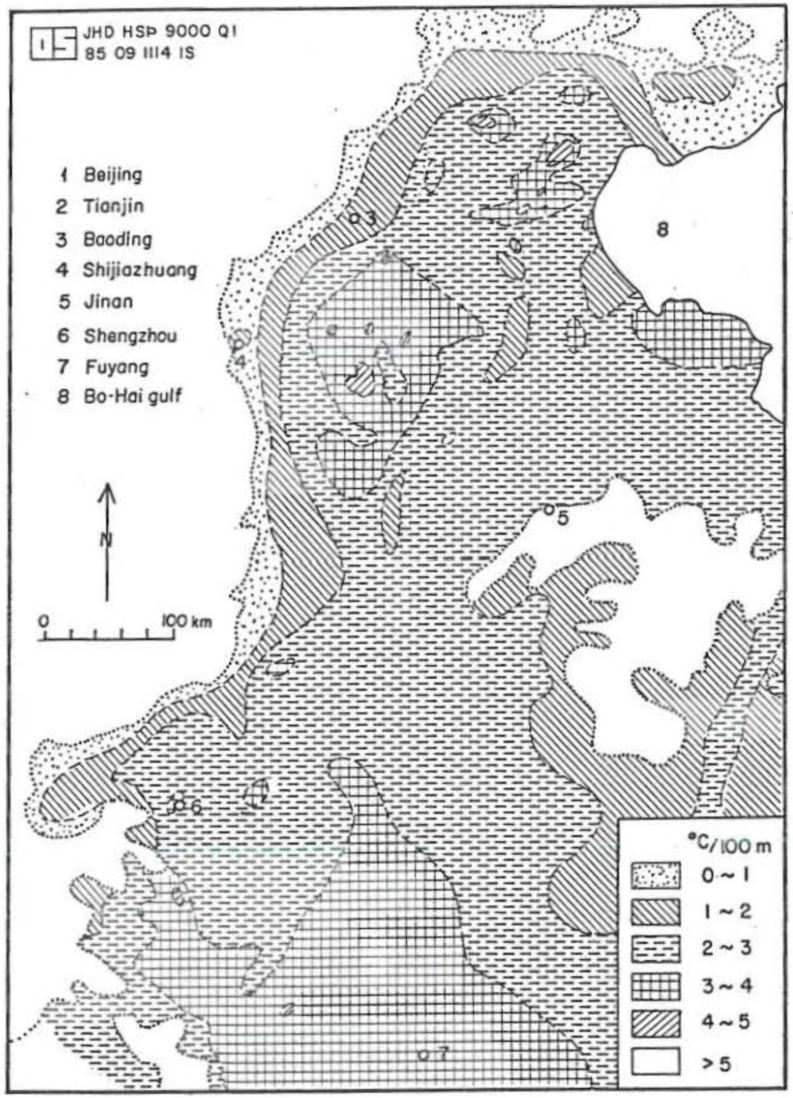

Fig. 6. Geothermal map of 300 m depth of the North China Plain.

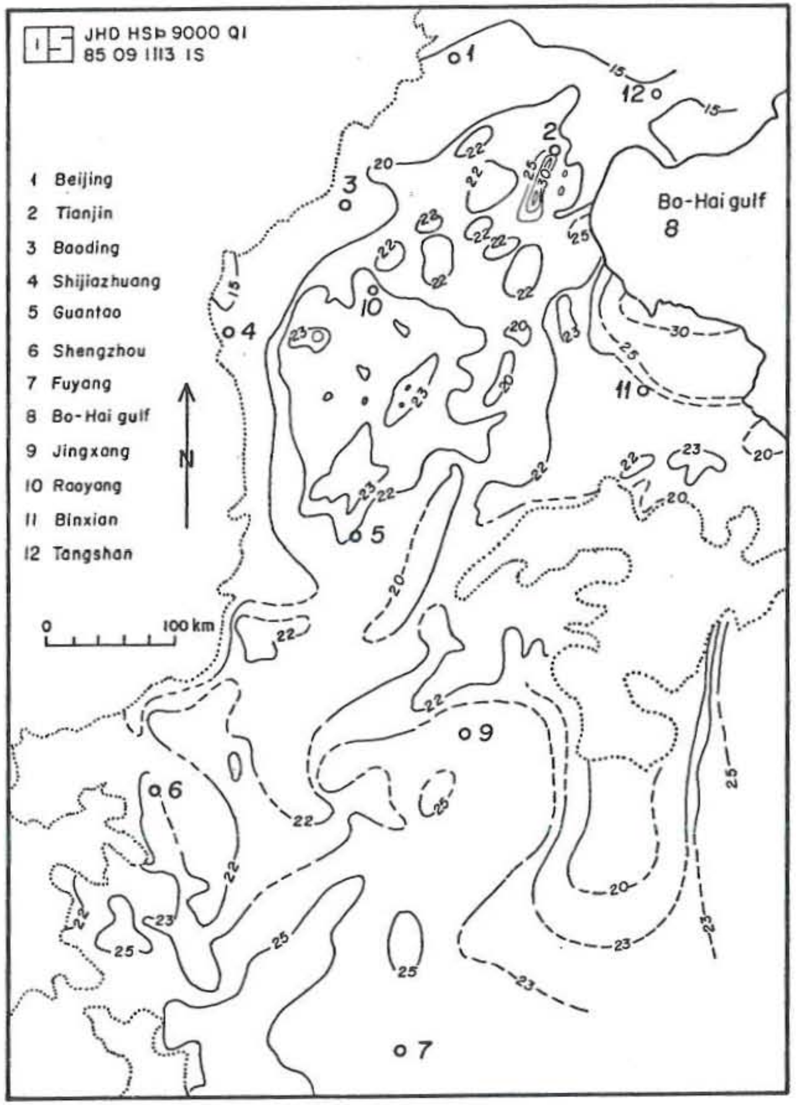

Fig. 7. Average temperature gradient of 300 m depth in the North China Plain.

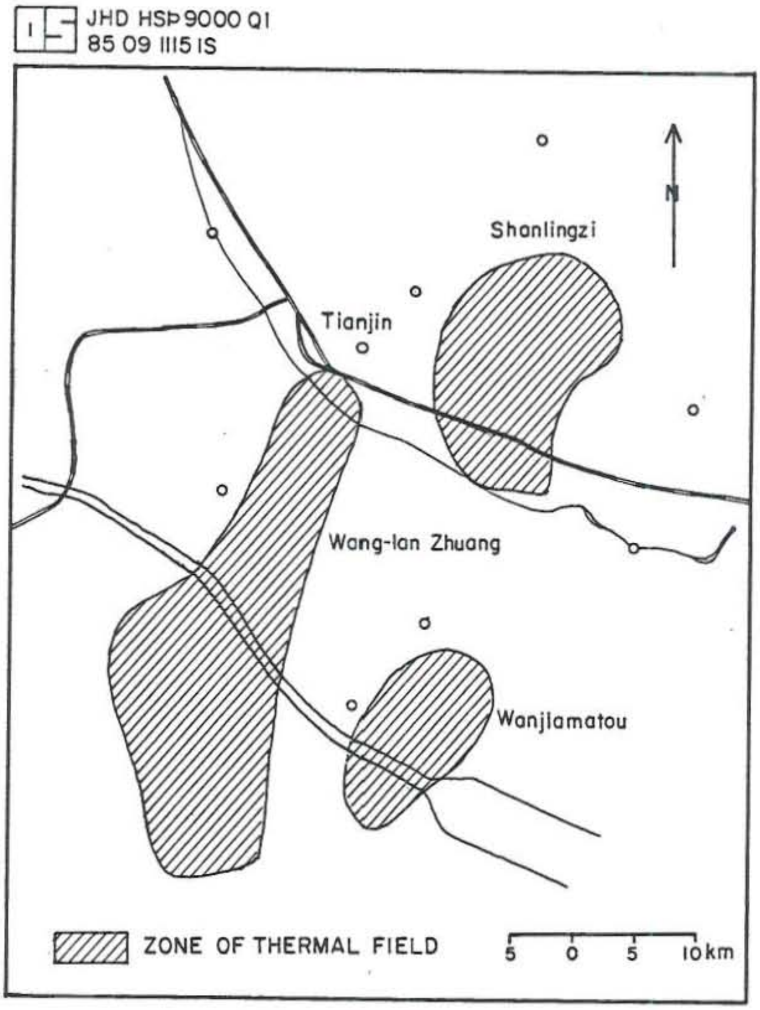

Fig. 8. Distribution of thermal fields in Tianjin.

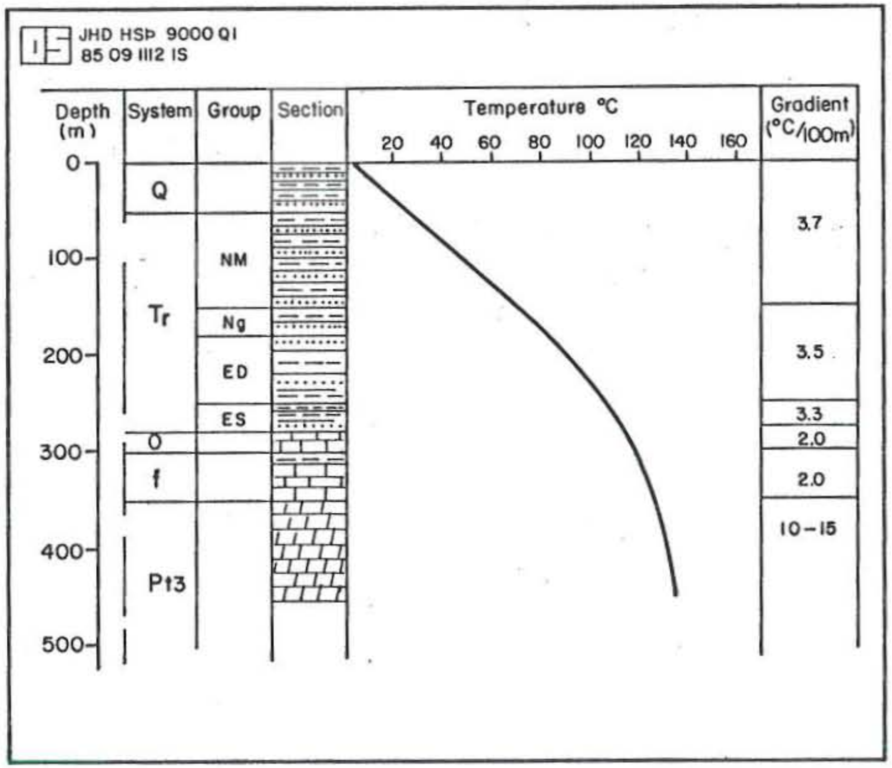

Fig. 9. Temperature depth curve of the Ren 23.

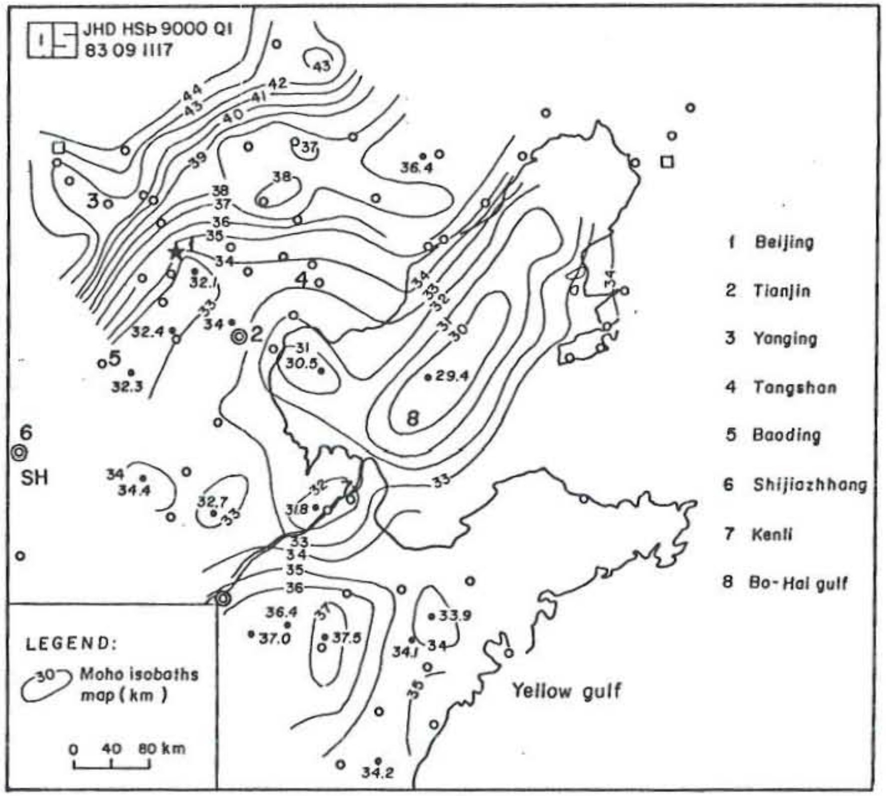

Fig. 10. Moho Isobaths map of the Beijing-Tianjin Region and neighbourhood.

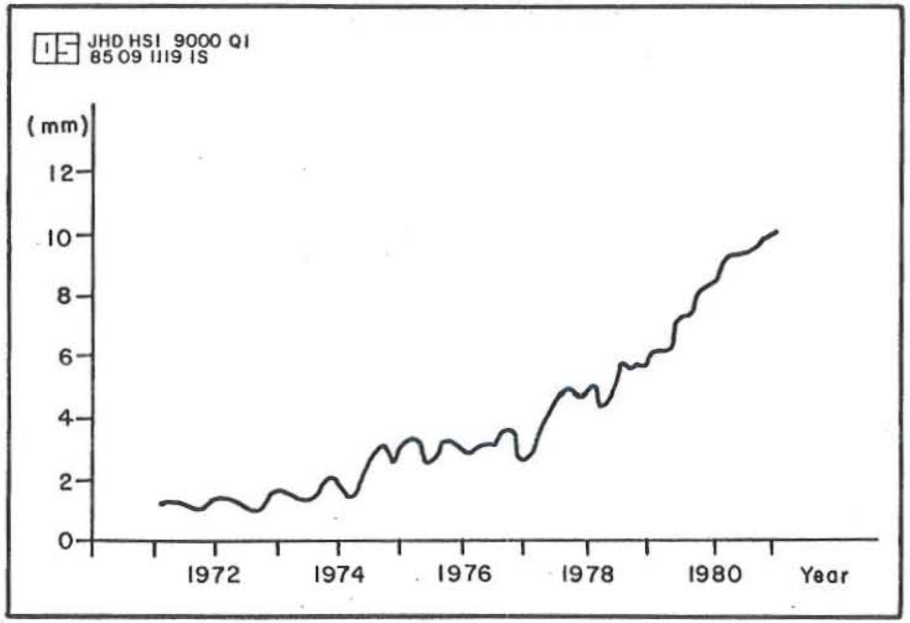

Fig. 11. Rising rate of the East Wall of the west-of-Paitangkon Fracture.

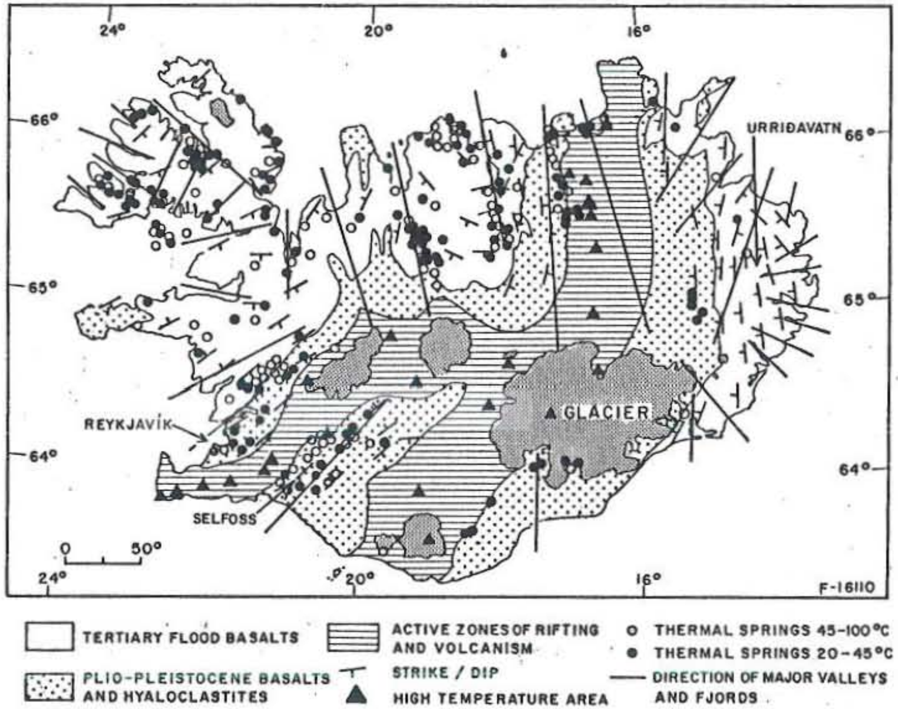

Fig. 12. Geological map of Iceland.

(Slightly modified from Fridleifsson, 1978)

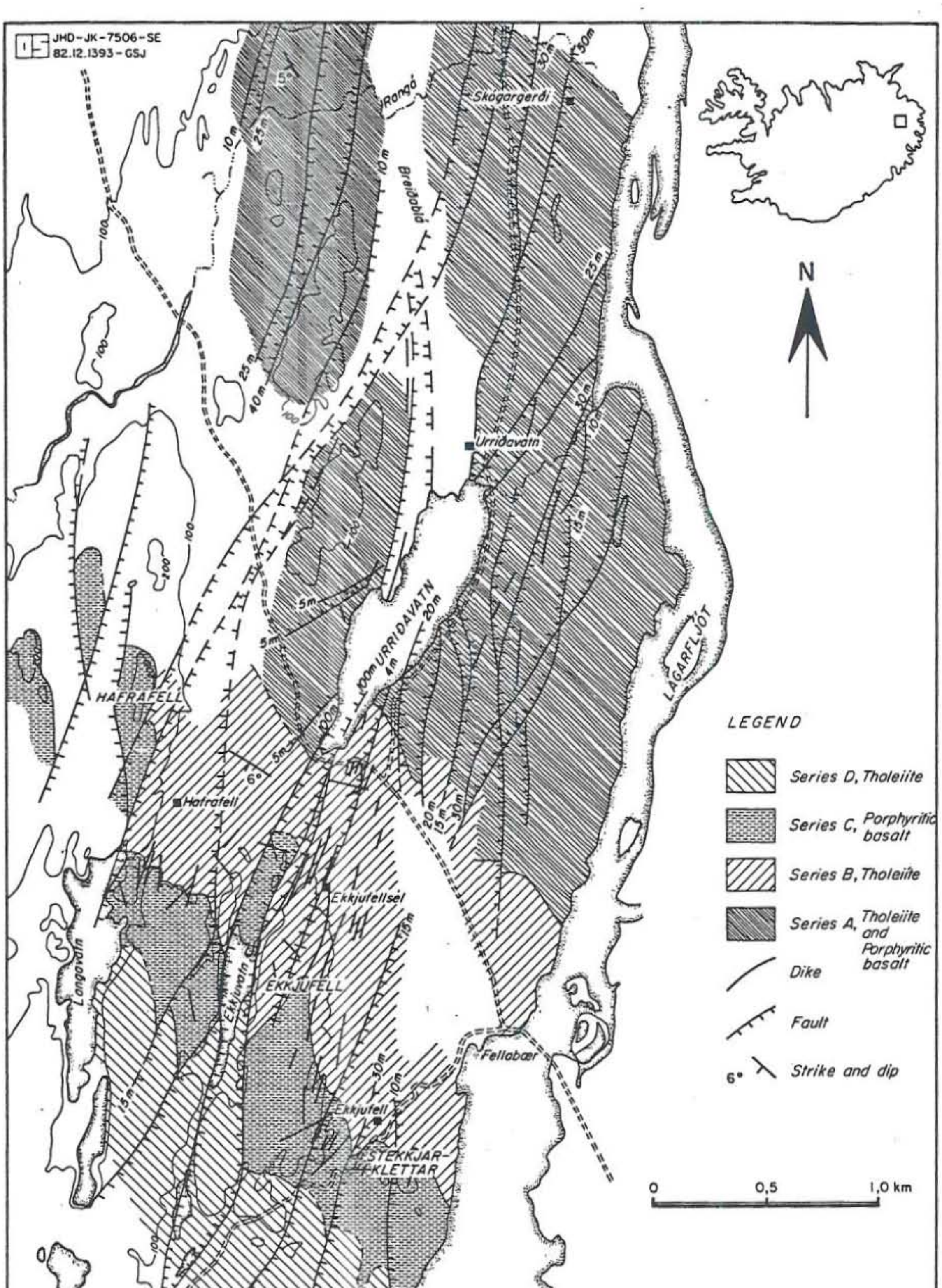

Fig. 13. Urridavatn geological map.

(from Einarsson et al., 1982)

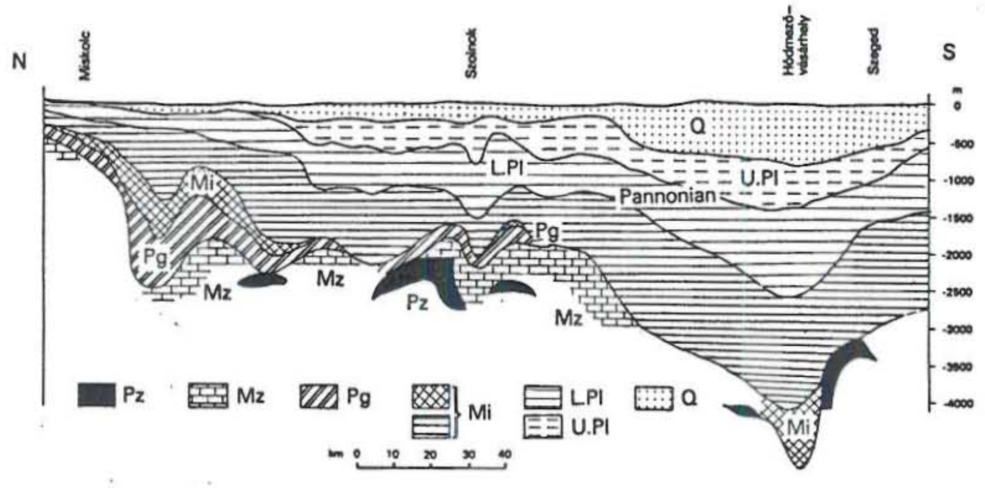

Fig. 14. Geological profiles of strike directions N-S across the Great Hungarian Plain.

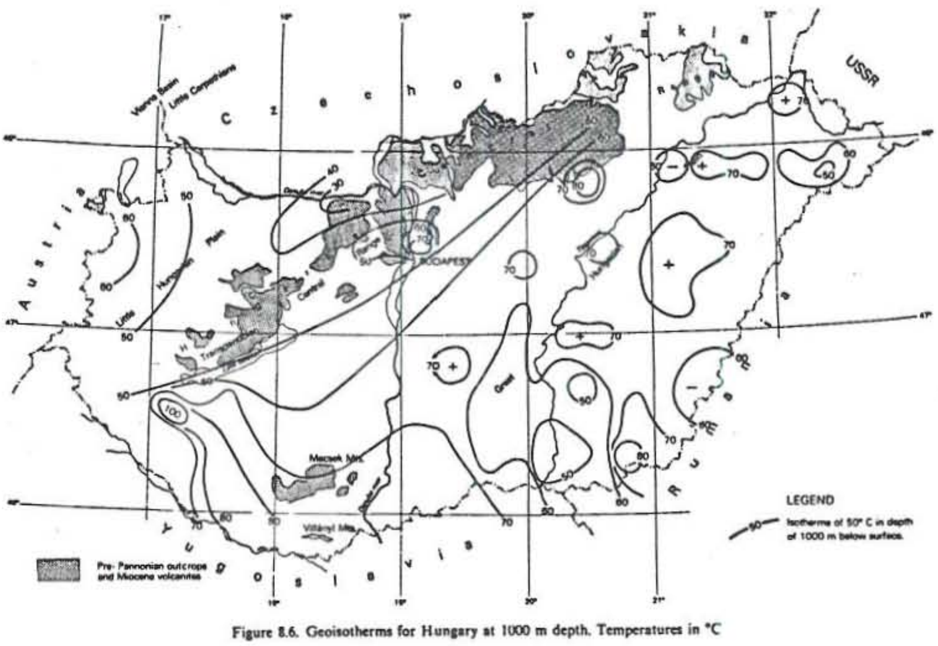

Figure 8.6. Geoisotherms for Hungary at 1000 m depth. Temperatures in °C

Fig. 15. Geoisotherms for Hungary at 1000 m depth. (from Ottlik, 1981)

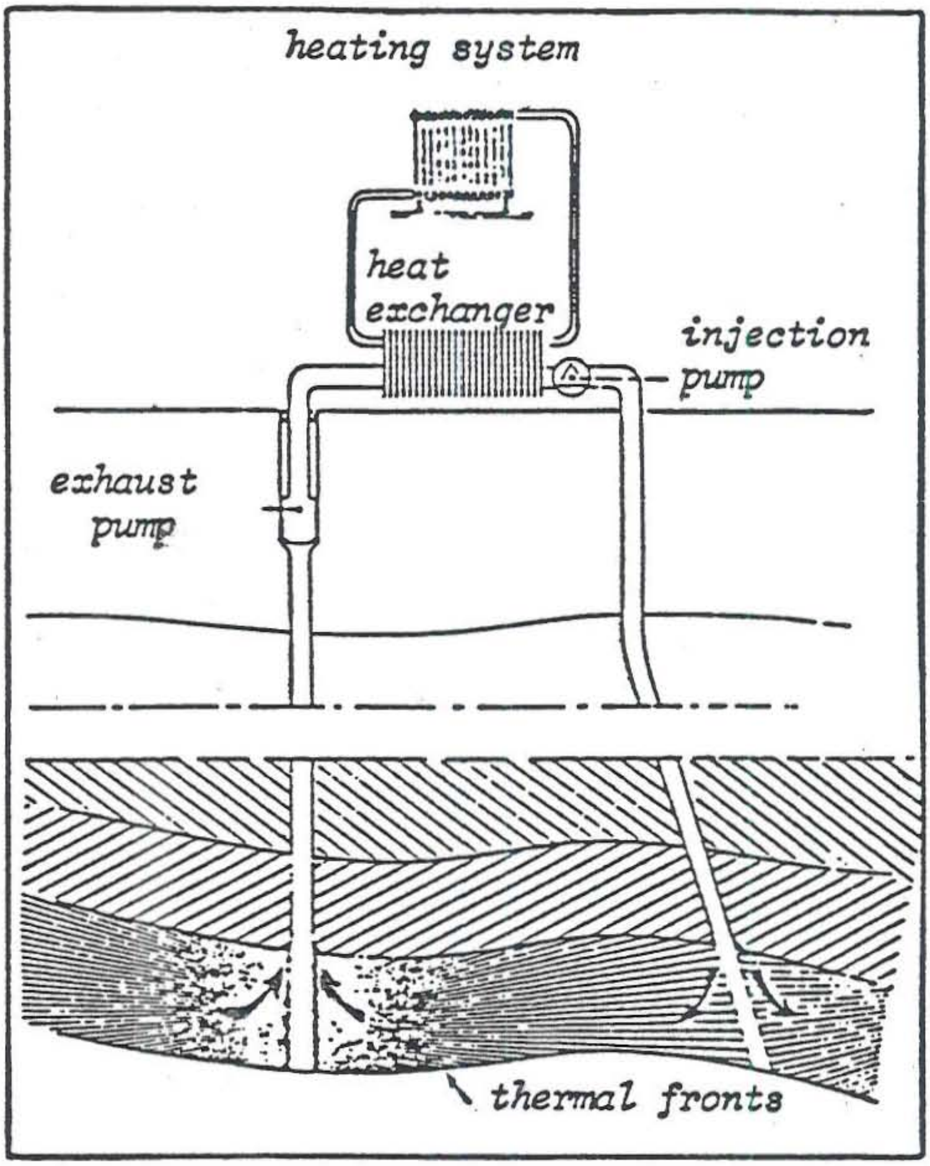

Fig. 16. Functional scheme of a "Dopublet" system.
(from Lejeune, 1981)