THE TIBETAN SECTION OF THE GLOBAL GEOTHERMAL ZONE, WITH SPECIAL REFERENCE TO YANGBAJAIN GEOTHERMAL FIELD

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ABSTRACT

This paper presents the preliminary results of a geothermal project executed by the United Nations through its Department of Technical Cooperation for Development.

The Himalayan geothermal zone is one of the most important components of the global geothermal framework. The Yangbajain area located in Tibet, China, is a typical example of this type of geothermal field. Research performed in the past years, and particularly during the Chinese-Italian geothermal project, promoted by the United Nations, has provided extensive knowledge on the geological structure, geophysics and geochemistray of the Yangbajain geothermal field. The temperature and pressure in the reservoir are slightly lower than the average values recorded in the other main geothermal field in the world. Geological, geochemical and geophysical features indicate that the geothermal system is connected to a fairly deep heat source and to convective circulation passing through a fault system. This heat source could be situated in the melting zone between the double crust formed by the collision of the Indian and Eurasian plates.

INTRODUCTION

Although there are extensive geothermal resources in the Himalayan area, investigation, development and exploitation have started only recently. A general geothermal investigation was carried out in Tibet from 1973 to 1976. Geophysical exploration in Yangbajain started in 1974, and more detailed exploration started in 1976 when the Tibetan Geothermal Geological Team was established. At present, 42 exploration and production wells have been drilled for a total drilling depth of 11,300 m. In 1982, the United Nations provided technical assistance to China and in 1983 a contract was stipulated between the U.N. and Aquater (ENI Group)-ENEL for geothermal research in the Yangbajain area. At this point, a cooperation started between Chinese and Italian experts, which resulted in richer and more accurate data, and more progressive data processing and interpretation. Although data processing and interpretation is still in progress, a clearer outline of the Yangbajain geothermal field and of the Himalayan geothermal zone has already emerged.

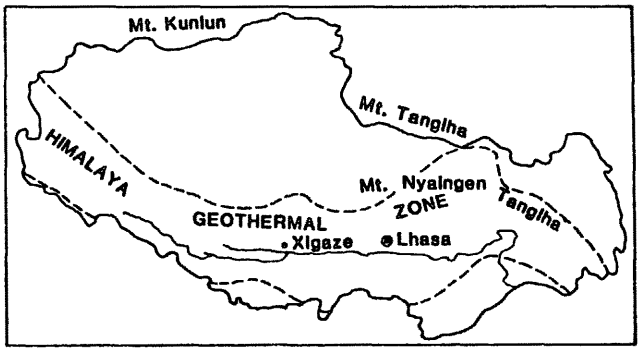

Figure 1. Himalaya geothermal zone (after Tong Wei and others, 1981)

YANGBAJAIN GEOTHERMAL ZONE

The Yangbajain geothermal field is a typical example of the geothermal zones in the Himalayan range.

The Himalayan geothermal zone is approximately 250 to 300 km wide and 2000 km long, and includes 400 active hydrothermal manifestations (hot and warm springs, fumaroles, geysers, etc.) (Figure 1) (Tong Wei and

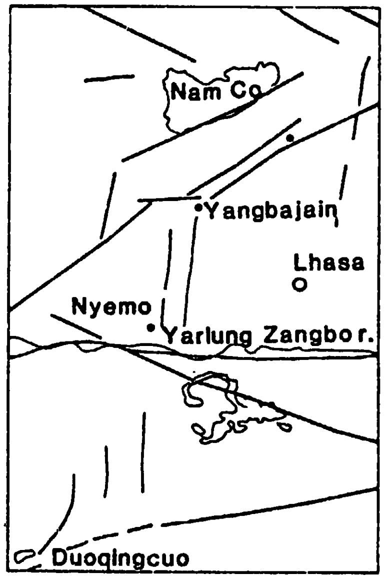

Figure 2. Damxung-Yangbajain-Douqingcue active structural zone

others, 1983). Middle-high temperature geothermal manifestations are concentrated mainly in the Yarlung-Zangbo ophiolite zone, and their occurrence is controlled by the active structure of the area (Han Tonglin, Tapponier, and Armijo, 1984; Han Tonglin and others, 1984).

The Yangbajain geothermal field is located in the Damxung-Yangbajain-Nyemo basin, which is a graben controlled by a series of faults with northeast-southwest and north-south directions (figure 2). The general features of the Yangbajain geothermal field are:

- various hydrothermal manifestations: sinter and hydrothermal deposits (Wang Daichang and others, 1984); phreatic explosion craters;
- heat flow: 110,000 kcal/sec (Tong Wei and others, 1981);
- low resistivity in the shallow Quaternary layer;
- Na-Cl-HCO_3 water with high boron concentrations in the center of the field;
- shallow reservoir located mainly in the Quaternary aquifer contained in loose sand and gravel;
- highest well temperature: 172° C and highest shut-in pressure at well-head is not in excess of 4.6 bars.

GEOLOGICAL-STRUCTURAL FEATURES IN THE YANGBAJAIN GEOTHERMAL FIELD

The Yangbajain basin can be classified as a recent graben since it was formed during the Quaternary period, and is presently controlled by active faults (Figure 3). During the regional Quaternary uplift, differential movements occurred on north-south, east-west and northeast-southwest faults. The intersections between these fault directions generate upwelling paths for geothermal fluids, thus creating the geothermal system in this area.

The northern margin of the Yangbajain basin is formed by the Nyainqentanglha mountains composed mainly of gneiss, probably of earlier Paleozoic age. The southern margin of the basin is formed by the Tang mountains where Cretaceous rocks (dated as Aptian-Albian) crop out with anticline structure.

Both intrusive and volcanic rocks form the basement of the valley and occur on the southern piedmont (Tang mountains). Absolute datings on biotite and sanidine gave a middle Eocene age. Volcanic rocks, generally products of explosive activity, have been dated as earlier Oligocene. A more recent, late-orogenic (Miocene) phase, has been recognized both along the valley (ash flow on the southwest side of the Yangbajain geothermal field) and in the Nyainqentanglha Mts. (granitic bodies at the core of the

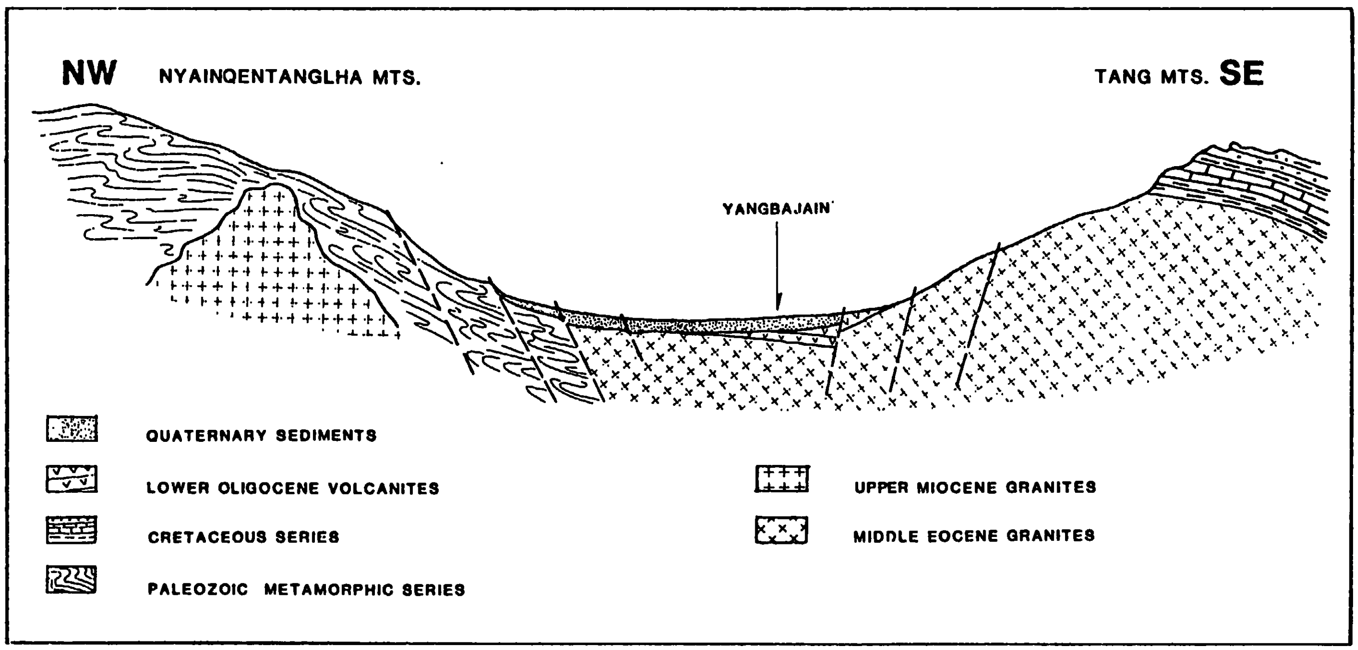

Figure 3. Schematic cross section through the Yangbajain graben

Table 1. Yangbajain Valley Absolute Datings

Sample	Rock Type	Mineral	K (%)	$^{40}Ar_{rad}$ (10^{-6}ml/g)	$^{40}Ar_{rad}$ / $^{40}Ar_{tot}$	Age (M.Y.)
1	Granite	Biotite	7.34	13.39	0.76	46.0± .6
5	Rhyolitic ash-flow	Groundmass	4.80	6.28	0.96	32.6± .5
7	Granitic dyke	Groundmass	4.33	5.87	0.90	33.8± .5
9c	Trachytic dyke	Biotite	7.70	4.50	0.65	14.8± .2
17	Rhyodacitic dyke	Groundmass	3.41	3.41	0.76	34.8± .5
49	Alkali trachyte	Sanidine	8.73	15.40	0.82	44.9± .6
96	Alkali granite	Biotite	7.49	2.24	0.36	7.6± .1
128	Rhyolitic ash-flow	Groundmass	1.93	0.55	0.37	7.3± .2
182	Alkali granite	Biotite	7.50	2.17	0.47	7.4± .2
ZK 308 well (483 m)	Granite	Biotite	6.86	13.41	0.90	49.6± 1

Analyses performed by Geochronology Laboratory - University of Pisa

range). An outline of the absolute dating results is provided in Table 1 and sample locations are shown in Figure 4.

The Quaternary sediments filling the basin have been divided into four phases:

— Q_1 dated by spore-pollen, formed mainly by lacustrine deposits;
— Q_2 formed mainly by glacial and fluvioglacial deposits;
— Q_3 formed mainly by glacial, fluvioglacial and alluvial-diluvial in the central basin;
— Q_4 dated by spore-pollen, is alluvial-diluvial.

The rapid uplift of the middle Pleistocene stage produced thicker deposits with a higher porosity and permeability, which form the shallow reservoir in the Yangbajain geothermal field. The upper Pleistocene includes sinter-cemented deposits that form the cap rock of the reservoir. This cap rock however is affected at times by fractures, which allow the passage of geothermal fluids to the surface, thus forming thermal surface manifestations.

GEOPHYSICAL FEATURES IN THE YANGBAJAIN GEOTHERMAL FIELD

The results obtained from temperature measurements in the 5-m-deep boreholes reflect the general outline of the thermal field. The temperature gradients obtained in the deep wells show a continuous increase in the northern part of the geothermal field. In the southern part the gradient is inverted after having crossed the shallow reservoir.

The geoelectrical survey carried out in the Yangbajain valley over a 100 km^2 area showed a low-resistivity area over the geothermal field. The area of apparent resistivity lower than 5 ohm.m measures less than 2 km^2, whereas the 10 ohm.m area is about 5 km^2. Based on drilling results, the boundaries of the thermal field extend to the apparent resistivity of 30 ohm.m (see Figure 5).

The interpretation along several electric profiles defined the resistant substratum behaviour beneath the alluvial deposits:

— beneath the geothermal field the granitic substratum presents a high, which separates two wide areas in a northeast and southwest direction, where the resistant substratum depth rapidly increases;
— lateral resistivity variations in the alluvial cover correspond to the assumed subvertical fault system in the substratum;
— in the southwestern basin, electrical soundings are disturbed by a tectonic accident (regional fault), also confirmed by magnetic and gravimetric data.

The gravimetric survey, through the Bouguer anomaly map, shows a positive anomaly aligned in a northwest-southeast direction over the geothermal field. Two relative highs, separated by a relative low, can be distinguished on

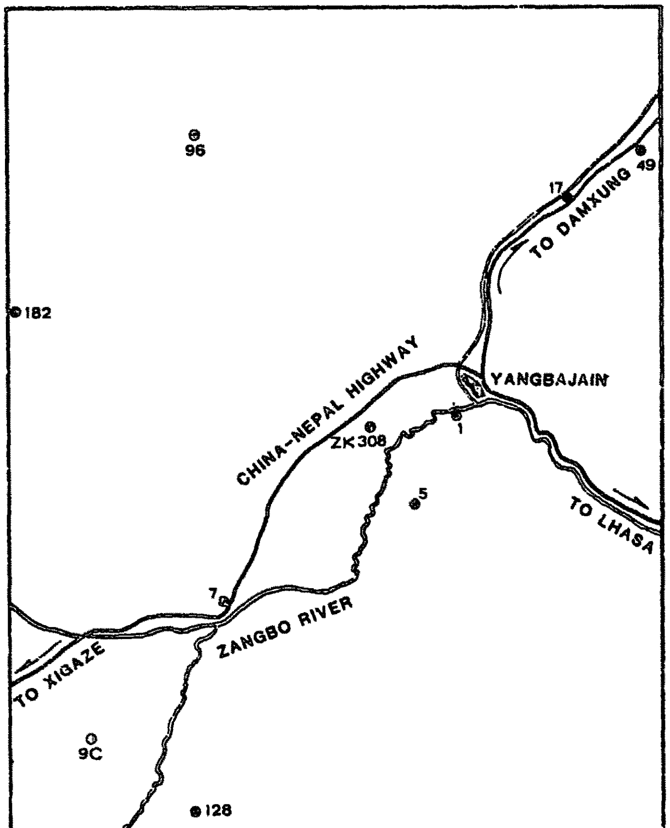

Figure 4. Sketch map showing locations of dated samples

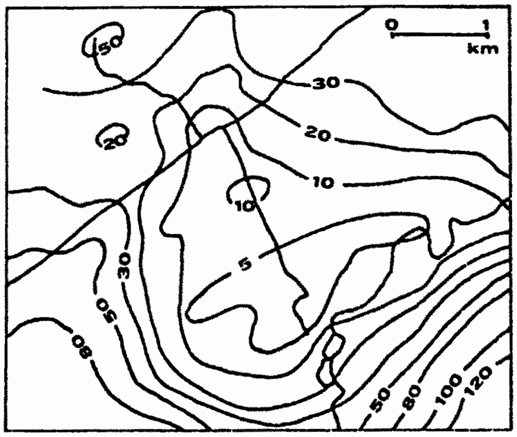

Figure 5. Isoline map showing the ρa of resistivity soundings in the Yangbajain geothermal field

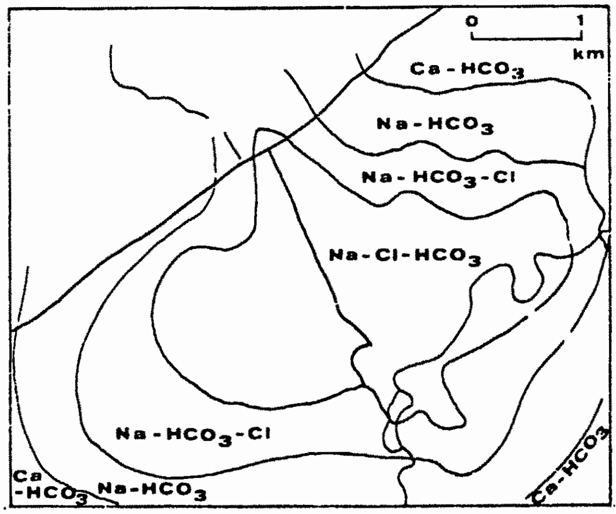

Figure 6. Hydrochemical map showing water type in the Yangbajain geothermal field and its adjacent area

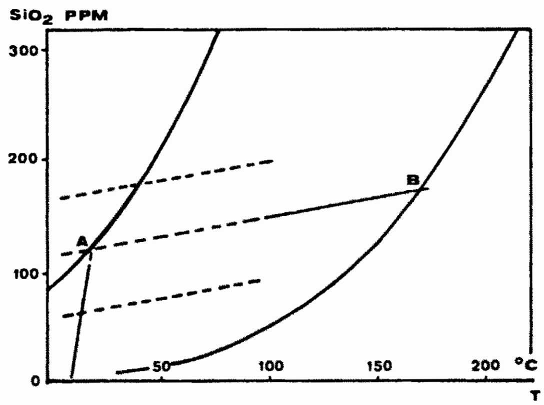

Figure 7. Silica-temperature plot of water samples from the Yangbajain geothermal field and its adjacent area

this anomaly. The positive anomaly can be interpreted as the top of the granitic body. This body is affected by several vertical faults that produce secondary highs and lows, and its depth rapidly increases towards northeast and southwest.

Outside the geothermal field, the gravimetric survey confirmed the regional trend of the main faults, and defined two important gravimetric minimums linked to the substratum depression located northeast and southwest of the geothermal field, and filled with light fluvio-lacustrine sediments.

The magnetometric survey in the same area confirmed the presence of susceptive rocks (tuffs and granites). In the geothermal field some weak anomalies in the eastern part may be linked to volcanic rocks, whereas the strong positive anomaly in the northwest can be explained by the presence of high susceptibility rocks in the substratum. Another strong magnetic anomaly is located in the southwestern part of the valley, probably linked to a regional fault.

The resistivity profiles the gravitic-magnetic results and geological evidences have indicated a network of buried faults, some of which were crossed by drilling.

A few magneto-telluric soundings showed that low resistivity (10 ohm.m) also exists at 10 to 20 km in depth, which probably corresponds to the melting zone along the obduction surface.

HYDROGEOCHEMICAL FEATURES IN THE YANGBAJAIN GEOTHERMAL FIELD

Figure 6 shows the distribution of hydrochemical water types in the Yangbajain thermal field area. The Na-Cl-HCO_3 water type was found in all production wells and thermal springs located near the production area. Moreover, the Na-HCO_3-Cl, Na-HCO_3 and Ca-HCO_3 types occurred in the surrounding areas. The last type represents cold waters. In the northern area of the thermal field a reduced outflow of deep waters seems to lead to an increase in the HCO_3-Cl and Na-HCO_3 water types.

In Figure 7 we observe that cold water recharge approaches point A to reach equilibrium with amorphous silica, thus becoming warm water. Then the sample values move along AB to reach the quartz equilibrium temperature of approximately 170° C.

The straight line AB can also be interpreted as the mixing phenomenon of reservoir hot water with recharge water. Na/K, Ca/Na, Ca/K and SiO_2 geothermometers give a calculated temperature of approximately 170 to 200° C. This is probably the highest temperature in the deep reservoir.

Stable isotopic compositions of D and ^{18}O indicate that some shallow springs are recharged from local meteoric water, whereas well water and boiling springs represent recharge of meteoric water from higher elevations.

Radioactive isotope tritium has only been found in shallow warm springs and cold water. Geothermal water from many wells is nontritium water. Deep circulation is characterized by a long turnover period.

RESERVOIR GEOLOGICAL FEATURES AND ANALYSIS OF THE ORIGIN OF THE YANGBAJAIN GEOTHERMAL FIELD

As stated previously, the reservoir is mainly contained in Quaternary deposits that overlie the basement. This

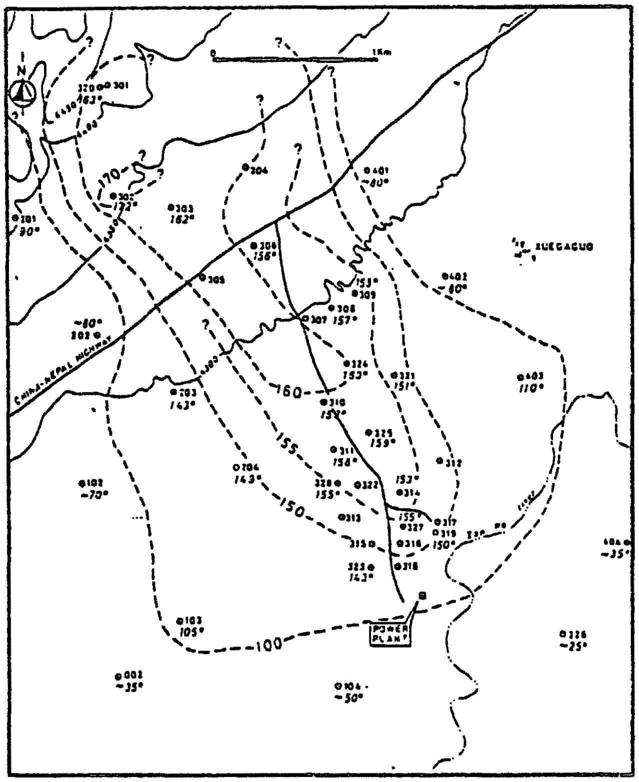

Figure 8. Map of the maximum recorded temperatures

basement is formed by a granitic body, locally (southeastern area) covered by pyroclastic rocks. The shape of the reservoir is outlined in the isotherm map (Figure 8). In the southern part the reservoir is a confined aquifer, sealed by lacustrine deposits and sinters. In the northern part the reservoir is an unconfined aquifer contained both in loose Quaternary deposits and basement fractures.

The reservoir overlies a structural high of the buried basement. The high is affected by a system of interesting faults. Hot fluids rise through these faults according to a typical hydrothermal convection pattern. In the areas northeast and southwest of the structural high, the temperatures decrease rather sharply because surficial cold water circulates through the Quaternary sediments.

The temperatures within the reservoir range from 150 to 160 °C; higher values (~172°C) are recorded in the northwestern sector. The most reliable temperature values recorded by the geothermometers range from 170 to 200°C.

The temperature profile trend of the deep exploratory well ZK308, under 1000 m in depth, defined the temperature gradient of the geothermal field area as 40°C/km. Based on this gradient the maximum temperatures measured in the wells or inferred from the geothermometers are related to a 4 to 5 km depth. The fluids originating from these depths emerge from the granitic basement in the area north of the China-Nepal highway, where wells 2K302 and 303 are located.

Based on the above we can infer that the Yangbajain geothermal field originated in an area with a slightly anomalous geothermal gradient. An explanation to this gradient could be found in the global tectonic model. According to this model, the south-Tibetan region includes the obduction surface of the Indian plate descending beneath the Tibetan plate. The obduction generates for the descending slab unstable temperature and pressure values, which lead to partial melting.

Experimental petrology has indicated that granitic magma begins to form under a pressure of 4 to 6 kilobars (corresponding to 15 to 20 km depth) and a temperature of 600 to 650°C (Tong Wei and others, 1981). The physical features of the partially molten mass and the area's tectonic situation determine an upwelling of this mass to various levels in the overlying crust, depending on the local geological conditions. Furthermore the collision between the Indian and Eurasian plates has formed a series of grabens (which are still active), orthogonal to the plate borders (Tapponier and others, 1981; Mercier and others, 1984). The faults and fractures inside the grabens have favoured the upwelling of hot fluids to the surface. In the grabens with favourable geological conditions, geothermal fields such as that of Yangbajain can occur.

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