A PRELIMINARY STUDY OF THE CHINGSHUI GEOTHERMAL AREA, ILAN, TAIWAN

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EXPLORATION

The Chingshui geothermal area is located about 20 km southwest of Ilan, a city in northeastern Taiwan. This area was first selected by the Mining Research Service Organization, Industrial Technology Research Institute for reconnaissance survey of geothermal resources in 1973 by means of geological and geophysical methods. A total of fifteen shallow test wells, ranging from 161 m to 501 m, were also drilled, penetrating aquifers with rather high temperatures of up to 175°C. However, further exploration has been subsequently undertaken by the Chinese Petroleum Corporation from 1976 to explore for a usable geothermal resource with greater production for power generation. Up to now, over eight geothermal wells, CPC-CS-4T, 5T, 9T, 12T, 13T, 14T, 15T, and 16T, have been drilled to various depths, ranging from 1505 m to 3000 m, having a roughly estimated thermal water flowrate of about 370 tons/hour under the flowing pressure of about 8 kg/cm^2 on the gauge.

Before or during the drilling, several geological, geophysical, and geochemical methods have been conducted by CPC. A reliable geologic feature was realized by geological and gravity data, while a geothermal activity was revealed by microearthquakes, resistivity, temperature gradients, and concentrated mercury data.

GEOLOGY

Geologically, this area is located just at the northeastern end of the submetamorphic zone, extending nearly N-S along the mountain backbone of Taiwan (Fig. 1). The slightly fractured submetamorphic slate of the Miocene Lushan Formation is the predominant rock widely cropping out all over this area. This formation can be lithologically divided into three members: the Jentse Member, the Chingshuihu Member, and the Kulu Member. Generally, the Jentse Member is mainly composed of metasandstone intercalated in slate, while the underlying Chingshuihu Member and Kulu Member consist mostly of slate.

The bedding of the Lushan Formation strikes approximately NE-SW and dips generally to the SE at angles from about 35° to nearly vertical. Local overturning is reported in places near faults.

Predominant joints, which are almost aligned perpendicular to the strike of the strata, are found densely developed in the sandy Jentse Member.

A southeast dipping monoclinal unit of the Lushan Formation, with which there exists a local steeply dipping anticline, is in fault contact on the west with the compact shaly Kankou Formation, Oligocene in age, and the massive, compact but well-fractured Szuleng Sandstone. The monocline is cut internally by numerous thrust and normal faults, trending principally parallel to the bédding (NE-SW) and slightly curved, while a few local faults, all normal, trend N-S around the manifestation area situated on the monocline.

HYDROTHERMAL SYSTEM

Figure 2 illustrates the generalized dynamic model of this area. Since no magmatic heat source is recognized and the water produced in this area is the so-called metamorphic water, it is evident that the heat at shallow depth is obtained as a result of deep circulation of ground water along faults in areas of high heat flow. High heat flow may be related to a thin crustal layer or to melting, beginning at depth along a descending slab of a plate boundary. Both convective and conductive heat transfers were possible in this area.

The possible model of the geothermal system may be water moving in the Jentse Member up-dip from the southeast along the thrust faults; and from the south and southeast along the normal fault (Fig. 2), or water moving within a more permeable sandy unit beneath the Jentse Member. Leakages to the surface occur where near vertical normal faults intersect these sandy units of the otherwise slaty formation. Cap rock is formed by the slaty units and perhaps locally by cemented faults.

Available subsurface data indicate that thermal water production in this area is largely from the fracture zone in the Jentse Member, which is evidently controlled by the predominant joints and active faults.

Surface meteoric water recharge may come from the two different sides of this area: the northwest and the southeast (Fig. 2). The former may occur along the western adjacent area which is characterized by a well-fractured Szuleng Sandstone of high porosity and permeability with a fault as well as a higher hydraulic gradient due to high elevation. The latter may occur along the eastern adjacent area, which is characterized by the highly deformed strata of high permeability, as well as by the high elevation with a high hydraulic gradient.

DRILLING

Due to the limitation for selecting suitable well sites in an area of very rugged terrain, all the deep geothermal wells were located along the Chingshui River, a longitudinally running river bed, which is also the main geothermal manifestation area where drilling rigs could be set. Except for the CPC-CS-15T well, which is an exploratory well drilled beyond the sandy Jentse Member, all the production wells, CPC-CS-4T, 5T, 9T, 12T, 13T, 14T, and 16T, were concentrated mostly at two suitable sites about 500 m apart around the manifestation area. Both vertical and directional wells were designed for penetrating the major fracture zone in the Jentse Member at the different position. Selected data relating to the deep geothermal wells are shown in Table 1.

TABLE 1: WELL DATA OF THE CHINGSHUI AREA

Well No.	4T	5T	9T	12T	13T	14T	15T	16T
Elevation (m)	257.95	269.54	260.67	260.67	269.54	281.50	220.5	272.58
Completion Data (m)								
Total Depth	1505	2005	2079	2003	2020	2003	2138	3000
Shoe of Liner	1503	1998	2074	1998	2015	1995		2990
Shoe of 9-5/8"	539	555	539	1097	574	1000		906
Liner Hanger	498	493	490	1048	505	947		830
Temperature at TD (°C)	201	220	205	223	219	215	148.7	225

Remarks: Well No. 15T is nonproductive.

As the subsurface fracture of thermal fluid reservoirs might have resulted from well-developed joints or faults, the hole deviation of the deep wells drilled in the Jentse Member, whether designed as a directional well or not, are inclined with a rather high angle up to 35°, and all are deviated almost parallel to the joints existing at the surface. Furthermore, some holes which have produced a greater amount of hot water changed their deviations abruptly, each at a certain depth, and turn back in direction with a loss of mud circulation when a recognizable reservoir zone has been encountered.

Bentonite slurry treated with chrome lignosulfonate chemical was used for drilling circulation. For preventing the hole from caving, the mud always maintains proper properties with a weight of 1.10 to 1.25 in specific gravity and 40 seconds in Marsh funnel viscosity. Heavy loss of circulation has occurred when a major fracture zone has been penetrated during drilling. Fresh water was finally injected into the well to replace the mud for well completion.

The casing program of the production wells is 20 in. conductor, 13-3/8 in. surface casing, 9-5/8 in. production casing, and 7 in. or 4-1/2 in. slotted liner. The depth of the slotted liner hanger varied from 490 to 1048 m, depending upon the depth of the high temperature production zone, while the length of the liner for each well varied from 950 to 2160 m. Cementing has been done for the conductor, surface, and production casings.

Temperature measurements of 8, 24, 48, and 72 hours in standing time were run for about every 500 m being drilled in each well for evaluating the original formation temperature in the well, as well as for determining the effective casing program of the production casing and slotted liner. In addition, both ES and LL7 electrical loggings have also been run for each well before setting casing for identifying the accurate depth and thickness of the production zone. The fracture identification logging (FIL) has been applied to several wells in this area with reasonable results.

INITIAL WELL PERFORMANCE

A large-scale and detailed well testing has been undertaken since early 1979, which includes well production rates and wellstream enthalpy measurements, pressure transient tests for drawdowns and buildups on wells of CPC-CS-4T, 5T, 13T, 14T, and 16T. In addition, temperature and pressure-depth survey, noncondensable gas content analysis, and interference testing were also performed.

Pressure transient data measured in producing and shut-in wells indicated: (1) the formation behaves like a homogeneous formation, (2) the flow conductivity of the formation is in the range of 2.4 to 3 darcy-meters (8,000 to 10,000 millidarcy-ft), (3) all wells have large positive skin effects of about 42, indicating serious damage, (4) the flow efficiencies average at 0.18, indicating the wells produce only 18% of the theoretical maximum for an ideal well, and (5) there is no apparent decline in average system pressure on production, indicating recharge and/or a large system size.

Important interference tests were performed which indicated an average flow conductivity of 3.7 darcy-meters (12,000 millidarcy-ft) and a porosity-thickness product of 600 m (2000 ft). The porosity-thickness product can be converted into estimates of the mass of hot water per unit area, or the equivalent power which can be installed for 35 years of life.

A study of the noncondensable gas indicated that the formation liquid water is essentially saturated with carbon dioxide, or slightly undersaturated. This seems to indicate that water from deeper wells may contain even higher amounts of noncondensables, and that it will be necessary to handle noncondensables when power generation is started, assuming success in future developments.

Another interesting result concerned temperature-depth data. Only well 14T shows normal temperature-depth behavior on production. Four other wells, 4T, 5T, 13T, and 16T, do not. The temperature of the produced fluids drops with increasing production rate, indicating a drop in enthalpy of wellstream at high producing rates. This appears to indicate that as flowrate increases and well pressure drops, colder fluid enters the well in some manner and blends with the hot water. In well 4T, the cold water enters at a depth of 700 to 800 m. In well 13T, there are many cold water entry points from 1400 m toward 574 m, the shoe depth of cemented 9-5/8 in. casing. There also appear to be many points of cold water entry between 1000 to 2000 m in well 16T.

The most obvious reason for cold water entry with reduced wellbore pressure would be a poor cement bond to the casing. This would allow colder water (from formations near the surface) to dumpflood the well. An inspection of cement logs did indicate a number of poor cement bonds.

Another reason for cold water entry would be that there is no good cap rock on top of the geothermal reservoir. Most wells drilled are along the bank of the Chingshui River. Thus it is also inferred that the fall in temperature could be caused by a vertical fracture inflow of cold water somewhere beneath the river bed.

PLAN FOR FUTURE EXPLORATION AND DEVELOPMENT

Drilling fluid will be changed from Bentonite slurry mud into fresh water for future operation. Well completions are also under study to find ways to avoid the large skin effects and thus avoid well damage. A more careful correlation of cement bond log results may indicate the reasons for the cold water entries, and possible remedial work.

Figure 1 is a geological map of the Chingshui geothermal district of northeastern Taiwan. Shown on the map are several fault systems and associated geothermal wells at Tuchang and Chingshui. There are hot springs and fumaroles at both places. Also shown is a fault system at Sanshing, where there are no surface signs of heat--no hot springs or fumaroles. A new well is under drilling at Hanhsi, Sanshing to test the possibility of hot water at depth.

It is natural to think that fractures exist only adjacent to faults. Actually, the entire band from Tuchang to Sanshing, and even beyond, could be a large geothermal fracture porosity reservoir. All well test data inspected in this study resemble homogeneous reservoir data. No nearby drainage limits were evident in the data. Chingshui could be a very large system. Thus it appears that it is worthwhile to consider drilling step-out wells normal to the faults at Chingshui. For this reason, more geothermal wells will be drilled along the band for a studied trial to exploit greater production for power generation in the very near future.

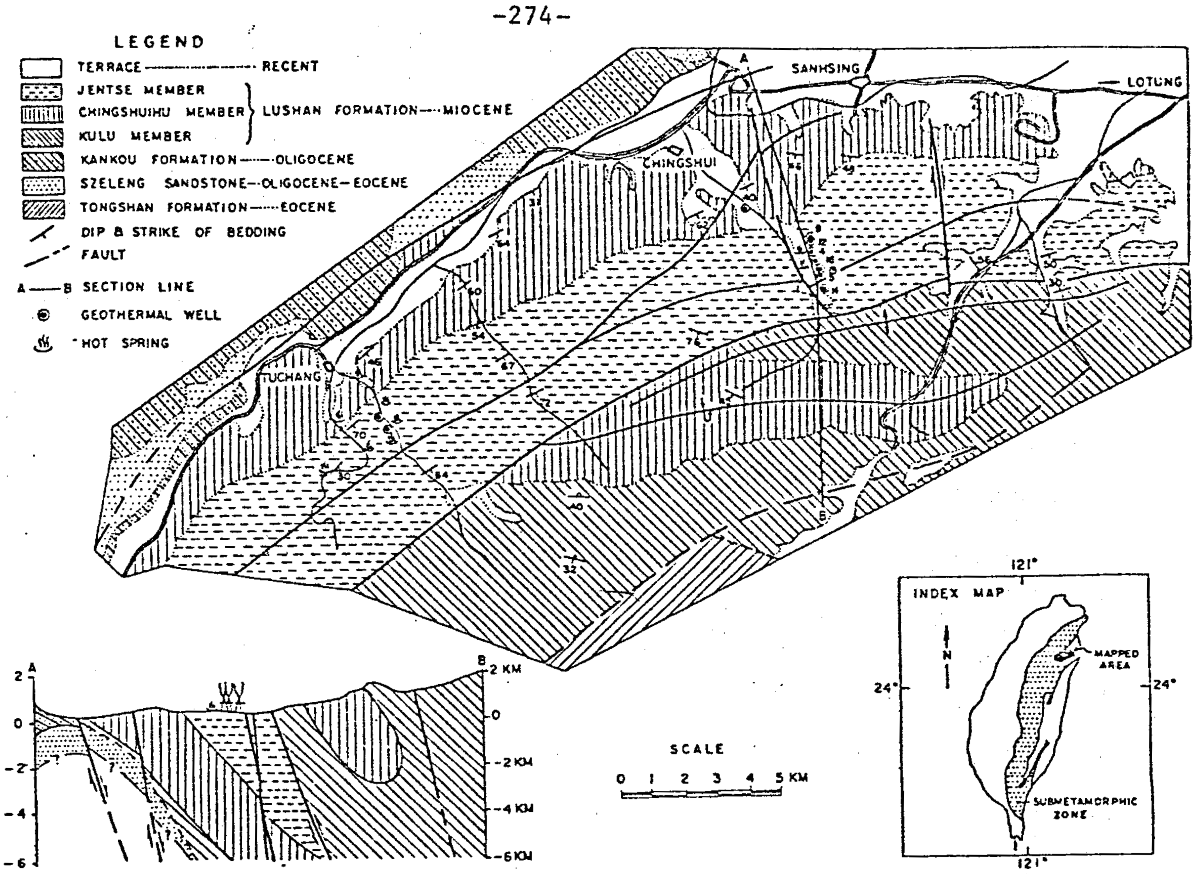

FIG. 1: GENERALIZED GEOLOGIC MAP OF THE CHINGSHUI GEOTHERMAL AREA

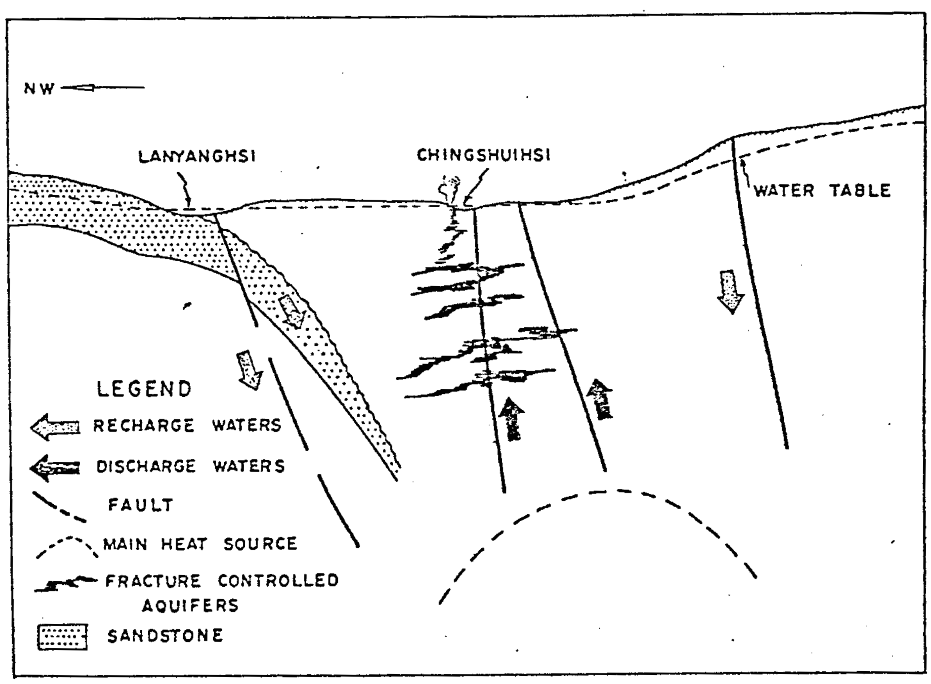

FIG. 2: SCHEMATIC DIAGRAM OF THE INFERRED HYDROLOGIC FEATURES OF THE CHINGSHUI HYDROTHERMAL SYSTEM