PROMISING GEOTHERMAL RESOURCES IN THE NEOGENE VOLCANITECTONIC DEPRESSIONS ALONG THE VOLCANIC FRONT OF NORTHERN HONSHU, JAPAN

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## I. INTRODUCTION

In Japan, the Quaternary volcanic areas have been the main target of prospecting for geothermal reservoir, because of appearance of meny geothermal manifestations on surface. The late Miocene to Pliocene sedimentary basins in a specific terrane are also candidated as deep and large geothermal reservoirs. Really the Sanzugawa basin, Akita Prefecture, is very promising as a result of prospecting by the Agent of Japan and a private company. The prospecting for geothermal reservoirs in these Neogene basins, however, is more difficult than those in Quaternary volcanic areas, as the former may be deeply seated and bring few geothermal manifestations on surface. In this paper, the writers describe the outline of surveyed volcanotectonic depressions(VTD) of Neogene age which are distributed along the volcanic front of northern Honshu, Japan. They also evaluate the possibility of each VTD as a geothermal reservoir in comparison with active geothermal areas in Quaternary calderas.

## II. GENERAL DESCRIPTION OF VTD

The volcanotectonic depression is defined as a kind of caldera that was formed under control of regional tectonics. Therefore, it is different from other types of caldera in morphology and dimension. A number of VTD's of Neogene age is distributed in a narrow terrane along the volcanic front of the Japanese Arc-Trench System as shown in Fig. 1. VTD's under consideration can be divided into three stages, according to fission-track age. Roughly speaking, most of them were formed at the earliest stage from 7 to 5 Ma.

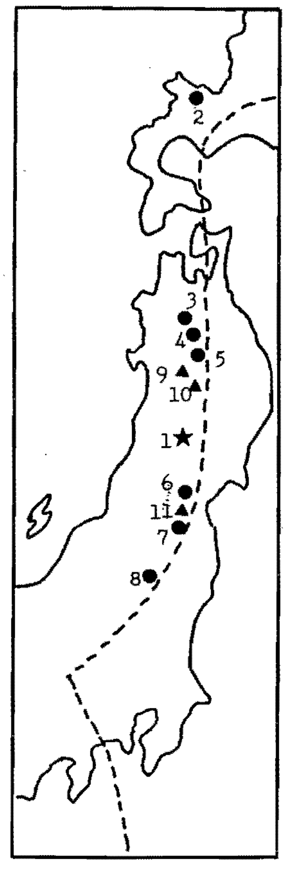
## III. VTD AS LARGE RESERVOIR OF FLUID

### (1) Constituted Material

The VTD is mainly constituted by large amount of vitic materials and clastic grains. Generally speaking , the lowest formation of VTD consists of thick pumice flow deposits which unconformably cover the basement rocks. The main part VTD-filling formation consists of lacustrine sediments containing a large amount of reworked vitric materials. Occasionally, they intercalate slump and sliding deposits and interfinger with talus deposits along marginal zones. Lava flows and dike rocks are found in various horizons. In some cases, the formation can be divided into two or three members, each having a sedimentary cycle. Local unconformities between them were probably caused by movements relating to volcanic activities such as eruption of mid-caldera pumice flows. Total thickness of VTD-filling formations ranges from several tens to several thousand meters. The sedimentation of each cycle is upward fining. Pumice flow deposits and coarse sediments at lower part are usually porous, while fine tuffites at upper part are rather dense. They are regarded as a set of possible fluid reservoir and cup rock. Porous rocks are also found in and around igneous rocks. A typical example is vent breccia.

### (2) Geologic Structure

The geologic structure of VTD's is unique and characterized by composite graben-horsts.




**Rank 1**

1 Sanzugawa

**Rank 2**

2 Akaigawa

3 Tobe

4 Ohyu

5 Yuze

6 Shirasawa

7 Kawarago

8 Ten,ei

**Rank 3**

9 Miyata

10 Tazawako

11 Kamafusako

**Fig.1** Locality and rank as possible geothermal reservoir of surveyed VTD. Broken line indicates the volcanic front at latest Neogene.

Many horst blocks are bounded on both sides by gravity faults with definite trends. This structure seems to have been developed through all stages. Though the original shape of VTD's has generally been modified, it can be roughly estimated by the distribution of the lacustrine sediments. The abuting relationship between the basal pumice flow and lucustrine sediments may indicate the margin of original caldera. Visible faults are not always recognized around there. The block movement at the mid-caldera stage is often demonstrated by existance of talus deposit along the newly-formed fault scarps. The faults of the post-caldera stage are well recognized in all VTD's. At present, most of caldera-filling sediments remain in the depression surrounded by these faults correlates to that of low Bouguer anomalies. On the other hand, the horst surrounded by these faults correlate to that of high Bouguer anomalies. A typical example of geologic structure of VTD is shown in Fig. 2.

The fault system in VTD's seems to be very important as both reservoir and passage of fluids. It is resonably thought that swarms of faults formed many fructure zones from nearly surface to the basement rocks through caldera-forming sediments. These high porous and high permeable zones, especially in deeper basement rocks are regarded as one of the most promising geothermal reseroirs. It is also certain that hydrothermal solutions uplifted at several stages through these faults as indicated by evidences of rock alterations in the following chapter.

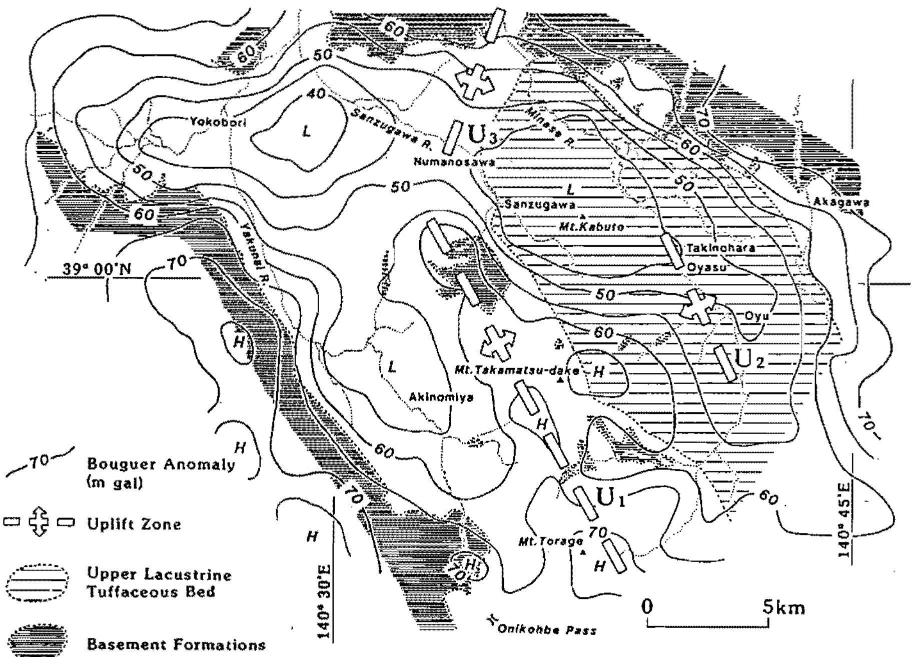



**Fig.2** Simplified geologic structure of the Sanzugawa caldera as a typical example of VTD

(3) Morphology and Dimension

Generally speaking, the original morphology and dimension of each VTD have not always clarified, because of erosion or thick cover of Quaternary volcanoes. As an estimation from distribution and thickness of VTD-forming sediments, most of VTD's may have been like a flat-bottomed pan in shape. The dimension of them is roughly n x $10^2$ $km^2$ in area and n x $10^2$ - $10^3$ m in thickness. Though each VTD was usually subdivided into several depressions at later stages, larger reservoirs are expected in them.

## IV. EVIDENCES OF GEOTHERMAL ACTIVITY IN VTD

(1) Igneous Activity

Igneous rocks relating to the VTD's under consideration are divided into three types, according to stage and character of igneous activity. The pre-caldera igneous activity seems to have been less important for the formation of VTD structure. The eruption of basal pumice flows may have been geneticaly related to the original depression on land. The volume is them are extraordinally large. Various kinds of lava flow are intercalated with caldera-filling lacustrine sediments. They range from rhyolitic to basaltic in chemical composition. Various kinds of dikes and sills intruded into the sediments locally and often accompanied by hydrothermal alterations. Among them, clots of vent breccia is conspicuous. Post-caldera igneous rocks are widely distributed in and around the VTD. They usually occur as lava flows or lava domes. They range from felsic to intermediate in composition. Lava flows and welded pumice flows cover a wide area within and outside of a typical VTD. On the other hand, intrusive rocks are mainly distributed inside of a VTD.

(2) Rock Alteration

The rock alteration appearing in the caldera formations is grouped into caldera-type and hydrothermal alterations.

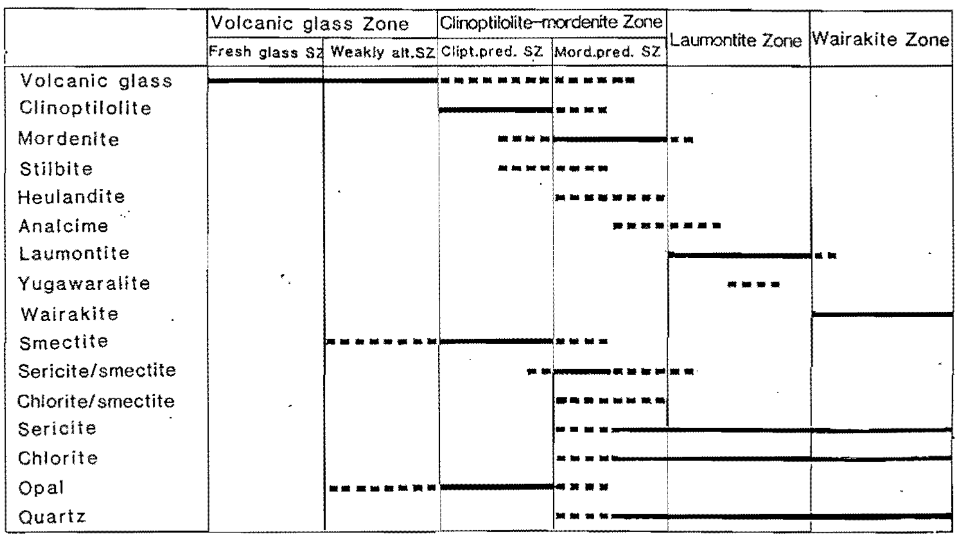
The caldera-type alteration is characterized by regional appearance of zeolites which are listed in Table 1. Among zeolites, wairakite appears rather rarely. Its appearance, however, is significant as an indicator of high temperature and low pressure conditions. Laumontite is pervasive, while analcime occurs only locally. Clinoptilolite and mordenite are very common. The clinoptilolite-mordenite zone is futher subdivided into a clinoptilolite-predominant subzone and a mordenite-predominant subzone. The volcanic glass zone is also subdivided into a fresh glass subzone in strict sense and a weakly altered subzone in which zeolites are absent. The mode of occurrence of zeolites and related minerals in higher-grade zones is similar to that in the corresponding zones of hydrothermal alteration, while that in lower-grade zones is simlar to that of diagenetic alteration. The alteration zones are mainly distributed in the caldera formations. They are not always surrounding an intrusive mass or a specific feeder. The boundaries between the zones are usually oblique to the stratigraphy. Thus caldera-type alteration is unique and different in manner of zonal distribution from other zeolitizations. It is noteworthy that most of economic mordenite deposits in Japan were formed by this type alteration. The high quality of mordenite from these deposits is partly caused by high content of vitric materials in the caldera formations and partly caused by a moderate temperature condition under high geothermal gradients.

Various alteration zones of hydrothermal origin appear locally in the VTD. They are grouped into three, accoding to chemistry of reacting solutions. The mineral assemblage of each alteration zone is almost same to that of generalized one (Utada, 1980). Zoning is various. Hydrothermal alterations are often superimposed upon not only the caldera-type alteration but also themselves. They mainly appear near actual or estimated faults and around intrusive masses.

(3) Geothermal Manifestation

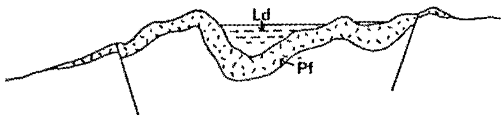
Abundance and distribution of geothermal manifestations are charactristic in each VTD. There are twelve hot springs and many fumaroles in the Sanzugawa Caldera which is regarded as one of the most promising geothermal reservoirs, while thereis no geothermal manifestation in the Miyata Caldera of which geological setting is very similar to the former. This difference may be partly caused by that in perservation of caldera structure. In the latter, the original structure was intencely modified and the Vtd was separated into several isolated blocks.

**Table 1 Mineral assemblage of alteration zones of "Caldera-type"**

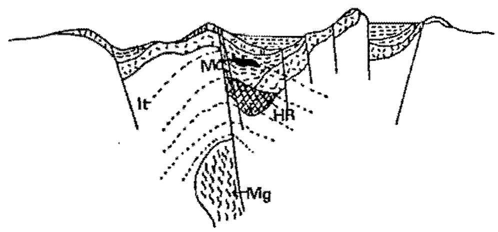


## IV. A MODEL FOR FORMATIVE PROCESS OF GEOTHERMAL RESERVOIR IN VTD

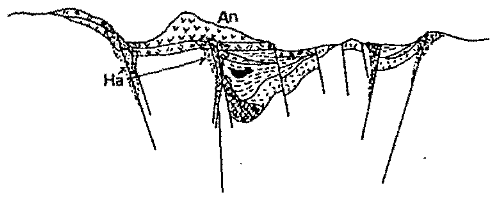
Development of VTD is roughly divided into three stages as shown in Fig. 3. The formation of characteristic VTD structure began at the eruption of large amount of basal pumice flow which was nearly compensated by deposition of caldera-filling sediments. Subsequent uplifting of magma caused a high geothermal gradient within and around VTD. The geothermal reservoir may have been formed under the highest temperature condition at this stage, in association with the caldera-type alteration. Most of the magma may have erupted out as a pumice flow or lava flow, which was favorable for keeping a hot reservoir. At the latest stage, a part of geothermal solution uplifted through the faults or dikes and made various hydrothermal alteration envelopes, mixing with circulating meteoric waters.




STAGE I. ERUPTION OF PUMICE FLOW(WELDED TUFF) AND FORMATION OF CALDERA LAKE DEPOSIT
Pf: Pumice flow, Ld: Lake deposit




STAGE II. UPLIFTING OF MAGMA AND ELEVATION OF GEOTHERMAL GRADIENT. FORMATION OF GEOTHERMAL RESERVOIR AND MORDENITE DEPOSIT, RELATING TO CALDERA-TYPE ALTERATION. HR: Hydrothermal Reservoir, Md: Mordenite deposit, Mg: Magma, It: Iso-geotherm line




STAGE III. FAULTING AND HYDROTHERMAL ALTERATION. ERUPTION OF PUMICE FROW(WELDED TUFF) AND ANDESITE LAVA. Ha: Hydrothermal alteration, An: Andesite lava

**Fig.3** A model for formative process of geothermal reservoir in caldera, relating to magma and geothermal activities

## V. EVALUATION OF EACH VTD AS GEOTHERMAL RESERVOIR

Comparing with active geothermal areas, the character of promising VTD as geothermal reservoir is listed as follows:

1) The dimension is large, though the morphology is various.
2) The original morphology and structure are preserved.
3) There are newly-formed depressions having low Bouguer's anomaly.
4) The depression is filled by a large amount of pumice flow deposits and thick pile of lacustrine sediments.
5) Post-caldera pumice flows or lava flows cover the depsession.
6) The main volcanism is felsic to intermediate.
7) There are many geothermal manifestations such as hot spring and fumarole.
8) The caldera-type alteration is widely distributed.
9) Hydrothermally altered minerals indicating high temperatures were formed.

According to these criteria, each VTD under consideration is evaluated as geothermal reservoir. All VTD's are ranked into three as shown in Fig. 1.

## VI. CONCLUSION

The VTD's under consideration have a unique geological setting. Some of them are very promising as geothermal reservoir, because they have several same characters to active geothermal ares in Japan.

# HEAT SOURCE AND HYDROTHERMAL SYSTEMS OF NON-VOLCANIC GEOTHERMAL RESOURCES IN NORTHEN THAILAND

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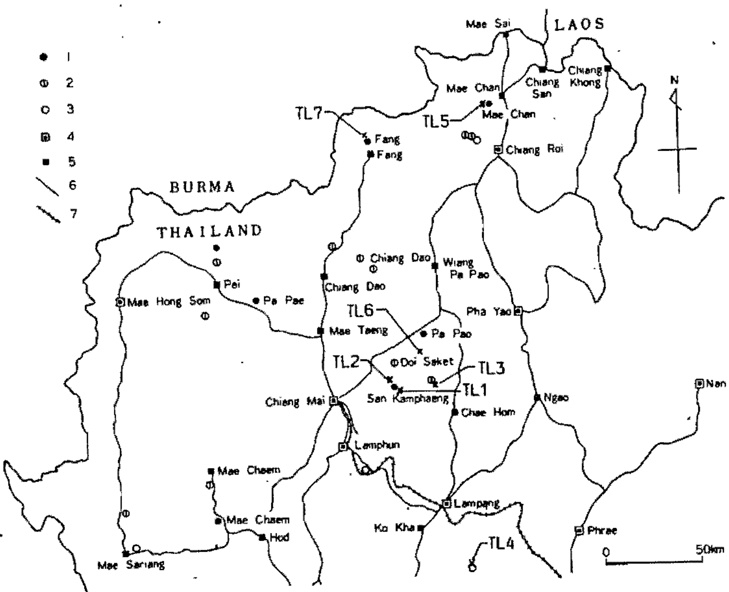
## INTRODUCTION

Geothermal waters of northern Thailand are considered as non-volcanic origin and characterized by high temperature and low concentrations of disolved chemical species (Takashima and Kawada, 1981). The water circulation system and heat exchange mechanism to form such geothermal waters are problems to be soluved.

In this paper, heat source, history of hydrothermal activity and water circulation system are discussed on the basis of heat generation data, thermoluminescence dating, fluid inclusion and alteration mineral studies and existing chemical data.

Figure 1 is the distribution of hot springs in northern Thailand. The study of heat generation and thermal history is covered whole area. However, the study of water circulation system is focused at the San Kamphaeng area where intensive exprolation had been carried out.




1 : Hot spring (over 90°C) 2 : Hot spring (70-90°C)
3 : Hot spring (below 70°C) 4 : City
5 : Town 6 : Main road
7 : Rail road

X : Location of thermo-luminescence (TL) dating samples.

Fig. 1 Location of hot springs in northern Thailand.

## HEAT SOURCE

There are no active volcanos in Thailand. Accordingly, the heat source of hot springs are considered as the decay of rocks, especally granitic rocks widely distributed in northern Thailand.

Sixty nine granitic rocks were collected from 7 areas (Fig. 2) and the number of samples of these areas are 4 to 19 as listed in Table 1. Analyses of the radiogenic elements were carried out by gamma-ray spectrometry on 1024 channel analyzer with 3x3 in. of NaI(Tl) crystal detector. The sample is powdered to 20 meshes under and 290 grams of it was packed into a cylindrical polypropylene container.

The results of analyses were grouped to 7 areas and listed in Table 1. The data of each area is not so dispersed as shown in the figures of standard deviation. The results were ploted on Fig. 2 in which distribution of granitic rocks and high heat flow areas were

Table 1 Summarized data of radiogenic elements and heat generation.

| Area No. | Area | U (ppm) | Th (ppm) | $K_2O$ (%) | Th/U | HG | HGU | Number of samples |
|---|---|---|---|---|---|---|---|---|
| 1 | North of San Kamphaeng | 9.9 (3.0) | 29.2 (5.3) | 5.02 (0.26) | 3.0 | 18.6 | 12.0 | 19 |
| 2 | Pa Pao-Prao | 10.2 (1.9) | 32.2 (4.4) | 4.87 (0.51) | 3.2 | 19.7 | 12.6 | 10 |
| 3 | Mae Chaem-Mae Sariang | 14.1 (7.0) | 49.3 (9.1) | 5.66 (0.53) | 3.5 | 28.1 | 18.1 | 8 |
| 4 | Pa Pae-Chiang Dao | 7.8 (1.9) | 27.4 (2.0) | 4.57 (0.45) | 3.5 | 16.0 | 10.3 | 13 |
| 5 | Fang-Chiang Rai | 8.4 (0.6) | 28.5 (1.3) | 4.48 (0.23) | 3.4 | 16.9 | 10.8 | 4 |
| 6 | Chiang Rai-Mae Chan | 12.3 (2.7) | 43.8 (7.4) | 4.46 (0.63) | 3.6 | 24.6 | 15.8 | 8 |
| 7 | Fang | 7.5 (2.1) | 19.1 (8.1) | 4.00 (0.51) | 2.5 | 13.4 | 8.6 | 7 |

HG: Heat generation ($10^{-10}$mW/g)
HGU: Heat generating unit (0.42μW/$m^3$)
Figure in parenthesis indicates standard deviation

drawn. Two high heat generation unit (HGU) areas , Mae Chaem-Mae Sariang and Chiang Rai-Mae Chan, were identified from Fig. 2. There are no good relation with the above HGU data and hot spring distribution (Fig. 1). However, heat from granitic rocks are largely contributed to the geothermal energy in northern Thailand.

Another problem of heat source in northern Thailand is the contribution of basaltic magma of Quaternary age. The newest age of a baslt is 0.6 Ma (Sasada et al., 1987). It may contribute some part of heat deep part. However, quantitative estimation is remained for further study.

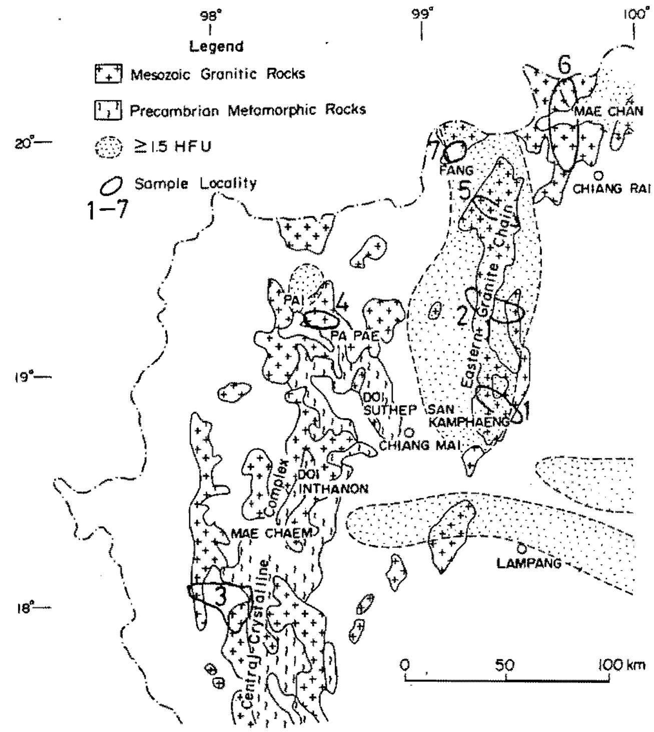



Fig. 2 distribution of granitic and metamorphic rocks, high heat flow region and sample locality in in northern Thailand.
(Geology is compiled by Kawada et al. (1987) with heat flow data of Thienprasert and Raksaskulwong (1984)).

## THERMAL HISTORY

Hydrothermal activity related to volcanism has a thermal history corresponds to the history of nearest volcano. However, thermal history of non-volcanic region may have long life and diferent process from volcanogenic geothermal systems.

In order to clarify the diference between the history of the above two geothermal systems and use it to geothermal exploration, thermoluminescence dating of altered rocks were carried out for over 50 samples collected from drilling cores, quartz veins and altered rocks.

Some age data obtained by present time are shown below (Other samples are now procesed for TL dating);

| | | |
|---|---|---|
| TL1 | (Core of 397m depth from GTE-6 well in the San Kamphaeng) | >0.5Ma |
| TL2 | (Quartz vein in altered rock collected from north San Kamphaeng) | 0.90Ma |
| TL3 | (Silicified rock collected from Chae Hom hot spring site) | >0.11Ma |
| TL4 | (Silicified rock collected from Wang Chin hot spring site) | 0.19Ma |
| TL5 | (Quartz vein in altered rock collected from Mae Chan hot spring site) | 0.085Ma |
| TL6 | (Silicified rock collected from forest road between R.1019-Chae Hom) | >0.46Ma |
| TL7 | (Quartz vein in altered rocks collected from north Fang) | 0.047Ma |

(Locality is plotted on Fig. 1)

It is difficult to discuss the detailed history of non-volcanic geothermal systems. However, young ages are identified at the presently active hot spring sites and old ages are found in the areas far away from hot spring sites or alteration halos with no thermal manifestations. After collecting all TL age data, thremal history of non-volcanic hydrothermal systems can be identified.

## HYDROTHERMAL SYSTEM MODEL

Figure 3 is a model of hydrothermal system of the San Kamphaeng area. In the isotope data low oxygen shift is identified. It indicates weak water-rock interaction. Long water circulation time is also identified from tritium data (Takashima and Jarach, 1987). The contents of chemical elements in hot spring waters are very low (Hirukawa et al., 1987). It also indicates the weak water-rock interaction.

Based on the above two data, it is considered that the reservoirs of the San Kamphaeng area is channel like shape and not so large.

Underground temperatures are calculated from chemical geothermometer. The results show that the temperature of the San Kamphaeng and other areas are relatively high temperatures upto 200°C. However, underground temperatures actually measured in exploration wells at the San Kamphaeng area are only 120°C at the depth of 500m (GTE-6 well), 90°C at the depth of 1000m (GTE-7 well) and around 100°C for other wells (Jivacate,1985).

Fluid inclusion study is very useful for obtaining the maximume temperature that the sample hed been reachrd. There are many quartz veins in drilling cores and surface altered samples. However, most of them are aggregate of small crystals and difficult to obtain the suitable samples. Only preliminary observation indicates that the subsurface temperature is not so high as expressed by chemical geothermometer data.

Figure 3 is combined all data which are already repoted and new data obtained from our study.

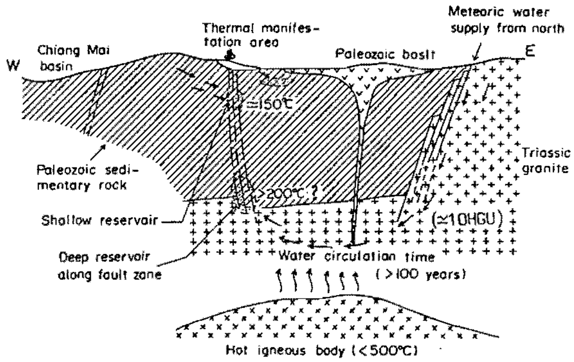



Fig. 3 Idealized reservoir model of the San Kamphaeng area. (Modified from Takashima and Jarach (1987)).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REFERENCES


Hirukawa, T., Jarach, W., Tangool, W. and Takashima, I. (1987) Preliminary study on the geochemical characters of major geothermal fields in northern Thailand. Bull. Geol. Surv. Japan, vol.38, p.21-31.

Jivacate, C. (1985) Well logging at the San Kamphaeng area, northern Thailand. Geothermal Resources Council, International Volume, p.549-555.

Kawada, K., Sasada, M. and Kanaya, H. (1987) Preliminary study on heat generation from the granitic rocks in northern Thailand. Bull. Geol. Surv. Japan, vol.38, p.7-12.

Sasada, M., Ratanasthien, B. and Soponpongpipat, P. (1987) New K-Ar ages from the Lampang basalt, northern Thailand. Bull. Geol. Surv. Japan, vol.38, p.13-20.

Takashima, I. and Jarach, W. (1987) Isotope geochemistry of six geothermal fields in northern Thailand. Bull. Geol. Surv. Japan, vol.38, p.33-40.

Takashima, I. and Kawada, K. (1981) Geothermal resources of Thailand. Chishitsu News, no.325, p.16-29 (in Japanese).

Thienprasert, A. and Raksaskulwong, M. (1984) Heat flow in northern Thailand. Tectonophysics, vol.103, p.217-233.