Proceedings 18th NZ Geothermal Workshop 19%

DRUSE AND HYDROTHERMAL VEINS AS FLUID FEED ZONES: EXAMPLES FROM SOME GEOTHERMAL FIELDS IN NORTHERN HONSHU, JAPAN

S. TAMANYU

Geological Survey of Japan, Tsukuba, Japan

SUMMARY - The morphological features of feed zones of geothermal fluids have been investigated based on previous studies which described the characteristics of drill core samples collected from the Uenotai, Ohnuma-Sumikawa and Okuaizu geothermal fields, Northern Honshu, Japan. These samples show that druse cavities and hydrothermal veins play an important role as feed zones.

The morphology of feed zones are greatly different at the micro and macro scales. The microscopic image of mm-order fractures taken by CT tomography shows that the cracks are three dimensionally connected in a very complicated manner. To the naked eye, core samples are characterized by druses and hydrothermal veins along fractures which have clear degrees of dip and strike. However, the accompanying hydrothermal alteration sometimes makes the dip and strike orientation ambiguous. The macroscopic image of feed zones on a reservoir scale is an assemblage of fractures whose locations are controlled normally by fracture zones, and density-contrasted geologic boundaries which are easily fractured. In general, the shapes of reservoirs tend to be nearly vertical if controlled by fractures, and nearly horizontal if controlled by stratigraphic boundaries. The different features of feed zones on different scales seem to be caused by different formation mechanisms. Macroscopic fracture features are mainly derived by brittle deformation under lithostatic condition, whereas, the microscopic features are caused by water-rock interaction under hydrostatic conditions.

1. INTRODUCTION

The morphological features of feed zones of geothermal fluids have been investigated based on previous studies which described the characteristics of drill core samples collected from the Uenotai, Ohnuma-Sumikawa and Okuaizu geothermal fields, Northem Honshu, Japan, respectively. These samples confirm that druses and hydrothermal veins play the role of feed zones. This paper describes the characteristics of these feed zones on different scales, and considers their formation mechanisms.

The Uenotai geothermal field is located in the southern part of Akita Prefecture, and the Uenotai power station has been operated as a 27.5 MWe plant since March 1994. The Ohnuma-Sumikawa geothermal field is located in northern part of Akita Prefecture, where the Ohnuma power station has been operated at 10 MWe since June 1974, and the Sumikawa power station at a 50 MWe since March 1995. The Okuaizu geothermal field is located in western part of Fukushima Prefecture, where the Yanaizu-Nishiyama power station has operated at 65 MWe since May 1995.

These three geothermal fields occur behind the Quaternary volcanic front, and have their own Quaternary volcanoes, believed to be their heat sources. The exploited geothermal reservoirs are mainly located in fracture zones in lower Tertiary rocks and the top of the pre-Tertiary basement. However, the top of pre-Tertiary basement in the Okuaizu geothermal field has not been proved as a potential reservoir because drill holes have not yet reached it.

2. DEFINITION OF DRUSE AND HYDROTHERMAL VEINS

Based on Glossary of Geology (Bates and Jackson, 1980), the term "druse" is defined as an irregular cavity or opening in a vein or rock, having its interior surface or walls lined (encrusted) with small projecting crystals usually of the same minerals as those of the enclosing rock, and sometimes filled with water. Hydrothermal veins are defined as the mineral deposits sealing fractures in altered wall rocks. The center of the vein is made of secondary minerals which can be classified according to two origins (Meunier, 1995). One is the deposition of clays transported by fluid suspensions which produce coatings on the fracture faces. In such cases, the wall-rock alteration, if it exists, has no genetic relation with the clay deposited in the fracture. Another is the precipitation from saturated fluid solutions which causes mineral growth on fracture faces. The altering fluid can have three different sources giving three different types of hydrothermal veins: injection, infiltration and drainage (Meunier, 1995). Hot springs and geysers in geothermal fields are typical of an injection regime: the hot fluid, coming from deep, rises to the surface and permeates the surrounding rocks. The hydrothermal veins studied in this paper, belong to the injection vein type.

3. FEATURES OF FEED ZONES IN EXPLORED GEOTHERMAL FIELDS

3.1 UENOTAI GEOTHERMAL FIELD

The Uenotai geothermal field, can be divided into a "structural high" zone in the central part with a transitional zone to the "structural low". The former is well correlated with the high temperature and vapor dominated zone, and the latter with the medium temperature and liquid dominated zone (Naka, et al., 1987, Robertson-Tait, et al., 1990, Naka and Okada, 1992). The characteristics of the feed zone at Uenotai, based on core studies, is as follows (Tamanyu et al., in preparation) (Fig. 1). The fractures developed in the "structural high" and its surroundings have essentially the same characteristics, although filling hydrothermal minerals vary according to differences in temperature. The identified reservoir fractures mostly have a high angle, though some low-medium angle fractures also play the role of feed points. Many of them are also related to dissolution features, druse and hydrothermal mineral deposits along the fractures. This means that these fractures have interacted with geothermal fluid after they formed, implying that reservoir-related fractures occur first by brittle deformation under lithostatic conditions initially, then relatively small fractures including the low angle fractures occur intermittently under hydrostatic conditions.

The reservoir can be regarded as an assemblage of fractures. The locations for the reservoir are controlled primarily by the structural high , and secondarily by fracture zones and geologic boundaries, in particular between Tertiary and Pre-Tertiary formations.

3.2 OHNUMA AND SUMIKAWA GEOTHERMAL FIELDS

The reservoir characteristics in these areas are described by Kubota (1985) as follows. Geothermal fluids have been stored generally in open fractures such as the druses observed in ore veins (Fig. 2). During drilling, lost circulations occur frequently in the high temperature zone suggesting it is fractured and permeable. However, fractures are self-sealed with vein materials in the low temperature zone. The reservoir characteristics based on well tests (Sakai et al., 1986) are described as follows. The transmissibility in Sumikawa is calculated as $2\text{-}3\times10^{-2}m^3$, which is a higher than in production wells in Ohnuma area. Loses of circulation during drilling occur on average every 300 m below the 200°C isotherm, suggesting the area is intensely fractured and permeable.

The reservoir-related fractures in the Sumikawa area have been analyzed by computer simulation, based on the assumption that the feed points are arrayed on fault planes. As a result, the fractures were recognized to be distributed along five planes (strike/dip N80°E, 54-66") (Bamba, et al., 1995)

3.3 OKUAIZU GEOTHERMAL FIELD

The features of reservoir fractures in this field are described as follows (Nitta et al., 1987). Two kinds of reservoirs have been modeled for geothermal exploration: one is a vertical reservoir developed along steep fractures, and the other is a horizontal reservoir developed on the top of pre-Tertiary basement. The former type has been proved by exploration, but the latter remains unproven because no drill holes have encountered pre-Tertiary basement. The vertical reservoirs were confirmed at the Chinoikezawa and the Sarukurazawa fracture zones, and their exact dips were calculated as 76" and 83" from drill hole data. The core sample obtained from 1232.5 m depth in the Chinoikezawa fracture zone, shows the fracture plane is covered with euhedral quartz and sphalerite crystals (Fig. 3).

4. MORPHOLOGY OF FEED ZONE

Three-dimensional images of mm-scale fractures from the Uenotai core sample (KU1) were examined by a computerized X-ray tomographic (CT) scanner (Nakano et al., 1992). Cracks regarded as the channels for geothermal fluids are indicated by symbols Q and R in Fig. 4. Microscope observations show that crack Q, less than 1 mm in width, is covered with euhedral quartz and zeolite, and that crack R is empty. Fig. 5(a-1 - a-4) show the distribution of the cracks (i.e., low density areas in the CT data), and Fig. 5(b-1 - b-4) show maximum sized clusters (networks) of connecting cracks. From these figures, it is clear that the cracks are connected in a very complicated manner, even when they appear discontinuous in a two-dimensional cross section. The cluster of the connecting cracks is not a simple planar shape as normally assumed in the modeling of cracks, but has blocky and convoluted string-like regions. The results also show that the density contrast between cracks and the surroundings is at least 0.5 g/cm^3.

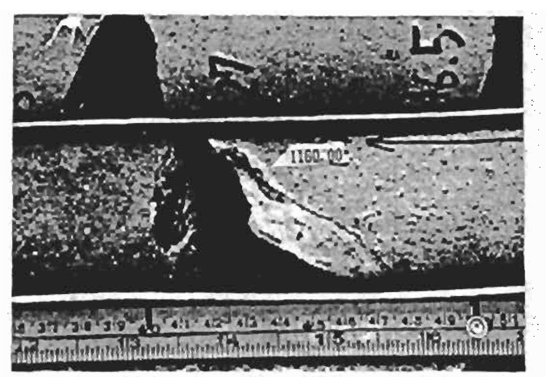
Fracture features in core size sample (–10 cm) and on a reservoir scale (–10-100 m) are somewhat different from the above mentioned microscopic features. The fracture features in cores are characterized by druses and hydrothermal veins along fractures which have clear dip and strike (Kubota, 1985, Nitta et al., 1987, Bamba, et al., 1995, Tamanyu, et al., in preparation). However,

Uenotai (Tamanyu et al., in preparation)

Liquid Dominated System

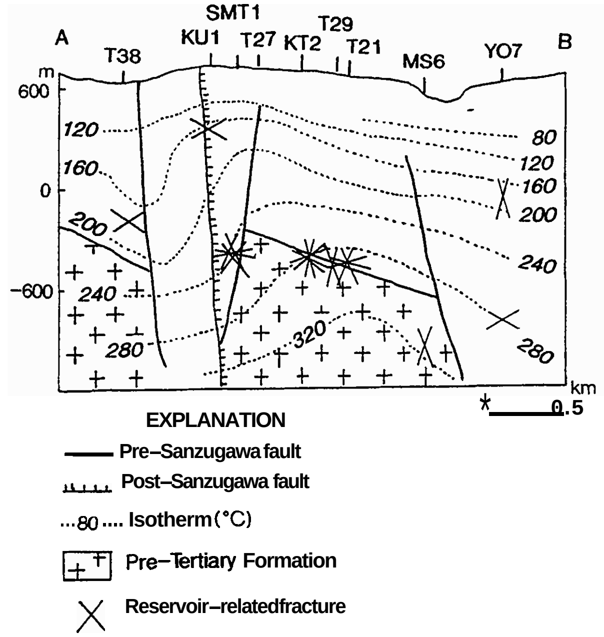
T38

KU1

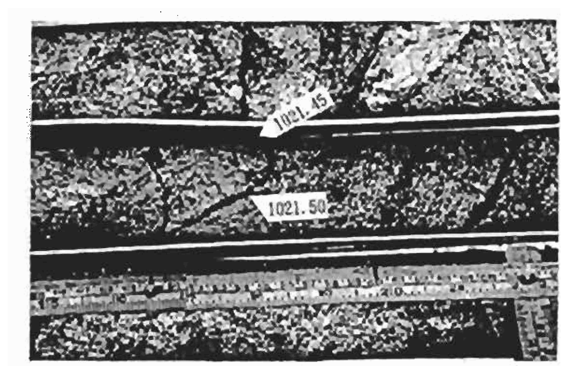


T27

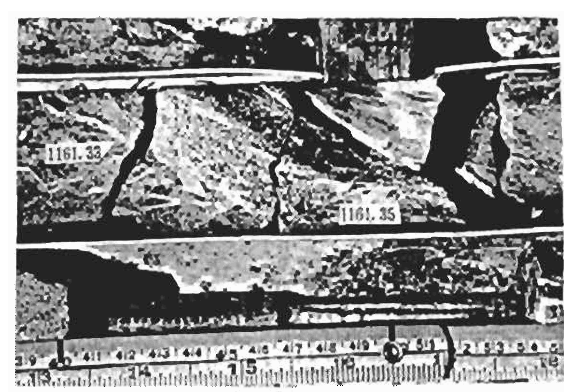
MS6



Vapour Dominated System



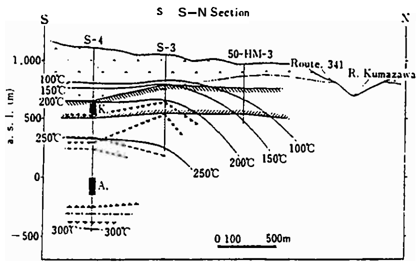
T29



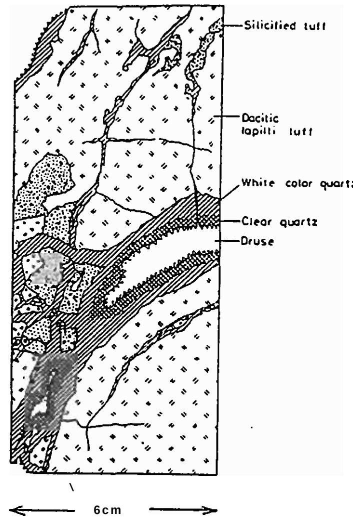
T21

Fig. 1: Examples of reservoir fracture in the Uenotai geothermal field, Northern Honshu, Japan (Tamanyu, et al., in preparation).

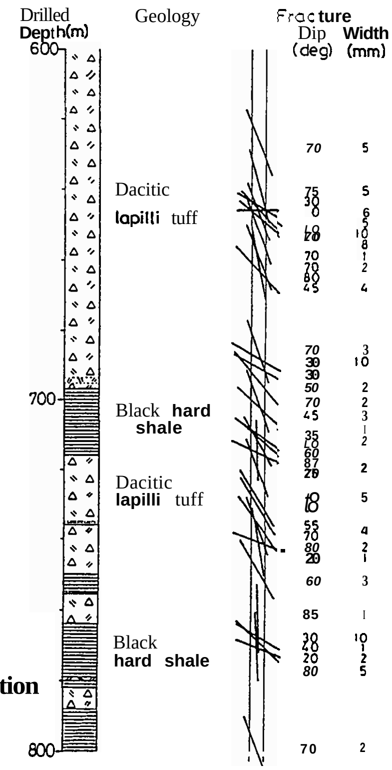
Ohnuma and Sumikawa (Kubota, 1985, Sakai et al., 1986)



Montmorillonite Lower Limit
Chlorite Upper Limit
Calcite Lower Limit
Epidote Upper Limit
Zeolite Appearance Zone
Wairakite Appearance Zone
A: Anhydrite G: Gypsum
K: Kaolinite P: Pyrophyllite
200℃ Isotherm



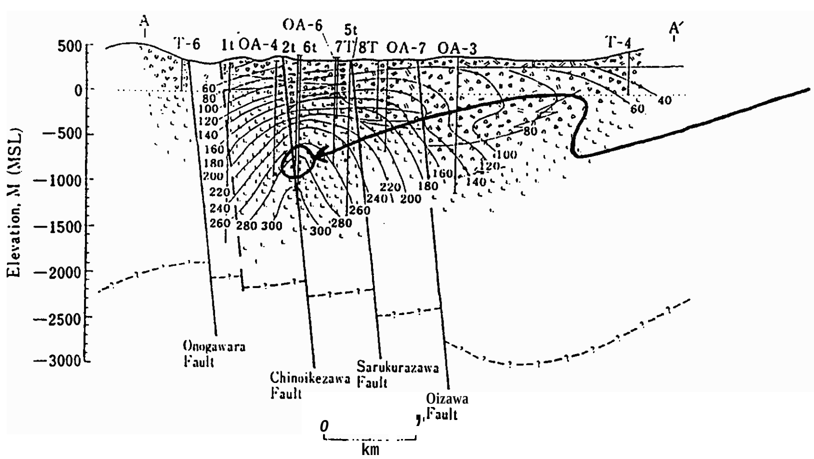
Sketch of open fracture in a core sample from **S-3** well



Open **fractures at the point of lost circulation**

Fig. 2: Examples of reservoir fracture in the Sumikawa geothermal field, Northern Honshu, Japan (Kubota, **1985**).

Okuaizu (Nitta et al., 1987)



Sunagohara Formation
Urushikubo Formation
Ogino Formation
Miyashita Mudstone Member
Forizawagawa

Basement (Determined from gravity)
Lost circulation drilling
—200— Temperature contour, ℃

The open fracture obtained by core-logging at **1232.5** m in depth, **covered with euhedral quartz and sphalerite,** crystals, corresponds to the Chinoikezawa fault.

Fig. 3: Examples of reservoir fracture in the Oku-Aizu geothermal field, Northern Honshu, Japan (Nitta, et al., **1987).**

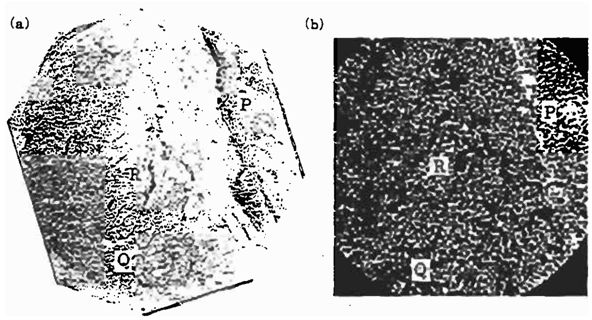


Fig. 4: Microscopic image and X ray CT scanning image on **sample** B from KU1 **in the Uenotai geothermal field** *(Nakano* **et al., 1992).**

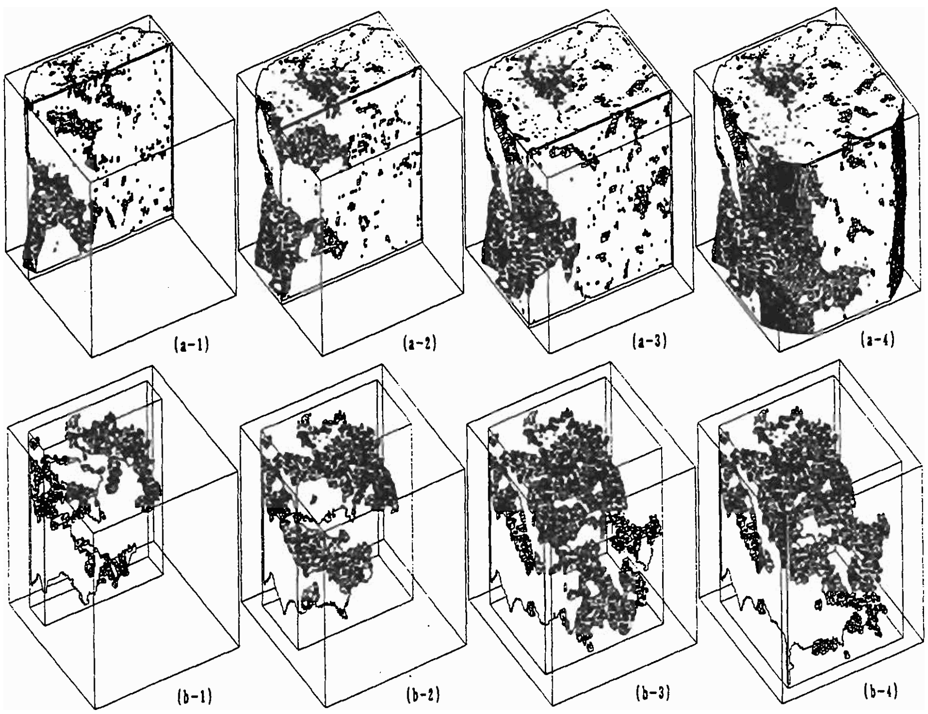


Fig. 5: **Distribution of the cracks and the maximum sized cluster of connecting cracks in sample A** from KU1 in **the Uenotai geothermal field** (Nakano **et al., 1992).**

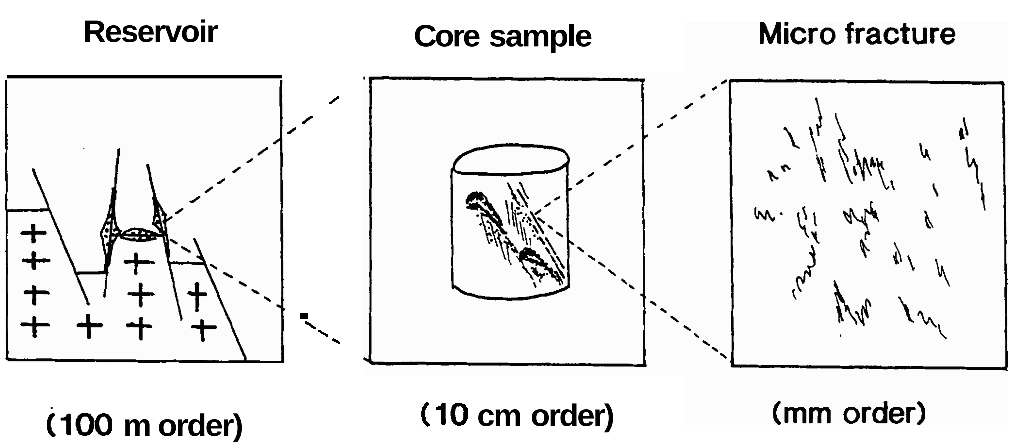


Fig. 6: **Reservoir features in different scales.**

the hydrothermal alteration accompanying with the **druse** and veins sometimes obscures the dip and strike.

The reservoir is an assemblage of fractures. The locations of the reservoir are controlled firstly by the structural high, because high temperature zone is generally concordant. They are controlled secondarily by fracture zones and geologic boundaries, in particular between Tertiary and pre-Tertiary formations because fractures are easily developed at the boundary of materials with different properties. Therefore, the shapes of reservoirs tend to be nearly vertical if controlled by fractures, and nearly horizontal if controlled by the top of the pre-Tertiary basement (Nitta et al., 1987, Tamanyu et al., in preparation). These morphological features on different scales, are summarized in Fig. 6.

5. FORMATION PROCESS OF FEED ZONES

The reservoir-related fractures occur first by brittle deformation under lithostatic conditions, the same as other general fractures in the initial stage, then relatively small fractures including the low angle fractures occur intermittently under hydrostatic conditions. Water-rock interaction has accompanied fracture formation, and resulted in dissolution features, druse and hydrothermal mineral deposits (Tamanyu et al., in preparation).

6. ACKNOWLEDGMENTS

The author expresses his appreciation to Dr. Peter Wood of IGNS, New Zealand for critical reading and important comments on this draft. The author is currently at the Institute of Geological & Nuclear Sciences in New Zealand as a senior research fellow funded by the Research Development Corporation of Japan. I thank these two organizations for their kind support for this study.

7. REFERENCES

Bamba, M., Kubota, Y., Ueda, A., Kihara, Y. and Yamagishi, Y. (1995). Fracture pattern simulated statistically in the Sumikawa geothermal system, northeast Japan. 1995 World Geothermal Congress, Florence, Italy, Abstract, 1709-1713.

Bates, R. L. and Jackson, J. A.(1980). ***Glossary of Geology.*** second edition, American Geological Institute. 749P.

Kubota, Y.(1985). Conceptual model of the North Hachimantai - Yakeyama geothermal area. ***Jour. Geotherm. Res. Soc. Japan,*** Vol. 7, 231-245.*

Meunier, A.(1995). Hydrothermal alteration by veins. In: ***Origin and mineralogy of clays,*** B.Velde (Ed)., Springer, pp. 247-267.

Naka, T. and Okada, H.(1992). Exploration and development of Uenotai geothermal field, Akita prefecture, northeastern Japan. ***Mining Geology,*** Vol. 42, 223-240.*

Naka, T., Takeuchi, R., Iwata, S. and Fukunaga, A.(1987). Exploration and exploitation of Uenotai geothermal field, Akita, Japan. ***Chinetsu,*** vol. 24, 113-135.*

Nakano, T., Nishizawa, O., Masuda, K., Inazumi, T. and Kasama, S.(1992). Three-dimensional distribution of cracks and minerals in a rock obtained by X-ray CT. ***The Society of Exploration Geophysicist of Japan (SEGJ) International Publication No.*** 2, ***Geotomography,*** 2, pp. 361-371.

Nitta, T., Suga, S., Tsukagoshi, S. and Adachi, M.(1987). Geothermal resources in the Okuaizu, Tohoku district, Japan. ***Chinetsu,*** vol. 24, 340-369*.

Robertson-Tait, A., Klein, C.W., McNitt, J.R., Naka, T., Takeuchi, R., Iwata, S., Saeki, Y. and Inoue, T.(1990). Heat source and fluid migration concepts at the Uenotai geothermal field, Akita prefecture, Japan. ***Geothermal Resources Council,*** vol. 14(II), 1325-1331.

Sakai, Y., Kubota, Y. and Hatakeyama K.(1986). Geothermal exploration at Sumikawa, North Hachimantai, Akita. ***Chinetsu,*** vol. 23, 281-302*.

Tamanyu, S., Fujiwara, S., Ishikawa, J. and Jingu, H.(in preparation) Fracture system related to geothermal reservoir based on core samples of slim holes -Example from the Uenotai geothermal field, Northern Honshu, Japan-.

*written in Japanese with English abstract