

# GEOLOGIC ANALYSIS OF THE FUSHIME GEOTHERMAL FIELD, KYUSHU, JAPAN

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## ABSTRACT

*Fushime geothermal system is characterized by high temperature (over 300), existence of temperature inversion around the depth of 1,000 m and high salinity of geothermal fluid. Geothermal structure of this field was geologically interpreted with data acquired from surface surveys and more than twenty wells. Two types of permeable zones are recognized in this field. One is related to a dacite intrusion which is distributed in the center of the field. The other is related to fault zones. The main reservoir exploited for the power station occurs in a fractured zone developed around the dacite intrusion and permeable zones related to faults are utilized for reinjection. One of these fault zones trending northwest to southeast is found to be associated with an andesite dike swarm related to the Takeyama volcano.*

## 1.0 INTRODUCTION

The Fushime Geothermal Field is located at the most southern part of Satsuma Peninsula (called the "Satsunan" area) in Southern Kyushu, Japan (Fig. 1). Japan Petroleum Exploration co., Ltd. (JAPEx) had carried out geothermal exploration work in this field since 1977. After JAPEx Geothermal Kyushu Ltd (JGK), a subsidiary company of JAPEx, took over the exploitation work of this field in 1988, "Yamagawa Power Plant" started operation in this field in March 1995 with a 30 MWe generation capacity.

During the exploration and exploitation phases, various surveys were carried out such as geological, geophysical and geochemical surveys as well as the drilling of over twenty wells. According to the survey results, the Fushime geothermal system is mainly controlled by geological structure. In this paper structural control of the field is briefly summarized based mainly on geological data.

## 2.0 REGIONAL GEOLOGY

Figure 2 shows collapse features and eruption centers which accompany major surface manifestations in the Satsunan area. The topographic feature of the Satsunan area is dominated by lava domes and flows which are related to the "Central Cones" of the Ata Caldera (Matumoto, 1943), extending between Yamagawa Bay and the Onkadobira Fault. All these lavas are post-Ata deposits. The Central Cones eruptive sequence is comprised of multiple andesitic lava and minor pyroclastic eruptions which spread over an interval of at least 20,000 years until about 5,000 years B.P.

The latest eruptions in the central cones area construct the part of the Ikeda sequence which is related to formation of the Krakatau-type Ikeda Caldera of 4 km in diameter (Ui, 1967). The latest explosion craters such as Narikawa, Unagi, Ikezoko and Matsugakubo are in alignment extending 5 km to NW direction from the Yamagawa Bay. To the south-west of the central cones, there is an alignment of well preserved lava domes such as Kasegidake, Tsujinodake and Kogawa.

The analysis of trends indicated by volcanic vent locations shows some NW-WNW trending lineations. It is the most clearly defined lineation which passes through the summits of Tsujinodake, Kogawa domes and the unexposed dome to the southeast. This NW trend directly continues through the summits of the Takeyama peaks to the Matagoshi Island (volcanic necks). This NW trend may suggest an important buried fault up which magmas have been extruded. The Ikeda-age craters of Matsugakubo and Ikezoko also define a NW trend which continues through small craters or collapse features to the fumarolic area on the northeastern shore of Lake Unagi.

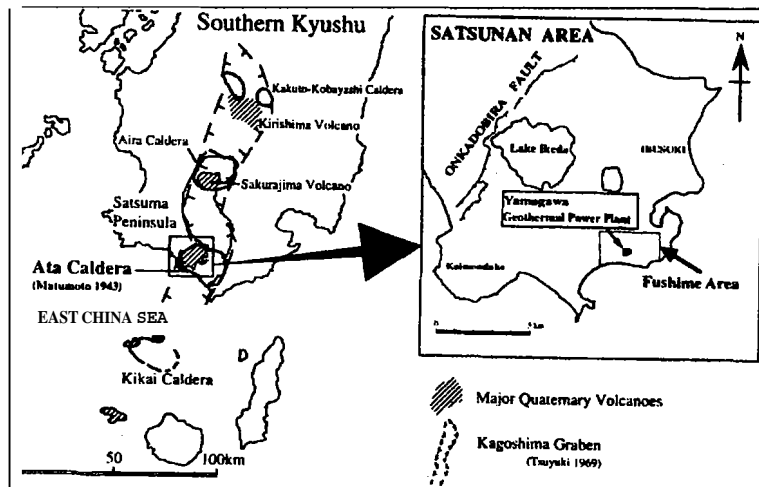


Figure 1. Location of Satsunan area and Yamagawa geothermal power plant (Fushime geothermal field).

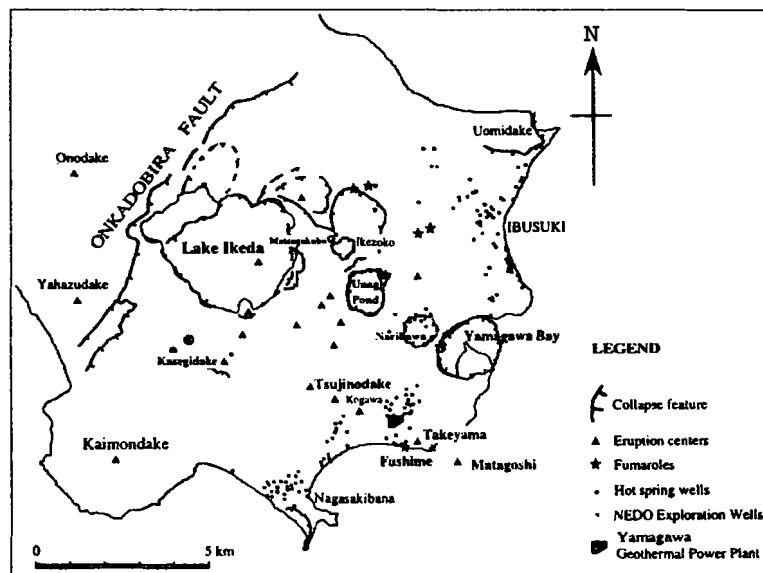


Figure 2. Topographic features and surface manifestations. Collapse features, eruption centers of young volcanoes, distribution of hot springs and fumaroles are shown. Most of hot springs are from boring

### 3.0 GEOLOGY OF THE FUSHIME FIELD

The geological structure of the Fushime geothermal field was interpreted based on the geologic correlations of over twenty wells in an area of approximately 4 km<sup>2</sup>, as well as the geophysical survey results. The Fushime geothermal field is located in a depression. In the depression there are some faults which are predominantly downthrown towards the center of the depression (Fig. 3).

Formations encountered in drilled wells are mainly consisted of pyroclastics (Fig. 4). Two types of intrusive rocks are recognized in addition. The largest one is a dacite intrusion which is distributed in the central part of the field and intrudes in the Upper Nansatsu formation. Another intrusive is an andesite dike swarm related to the Takeyama volcano. These andesite dikes has been encountered in three directional wells intersecting the NW-trend passing through Takeyama. This trend is also observed as a high resistivity axis (MT and Tubel surveys) and gravity high.

### 3.1 Intrusions and their Role to the Geothermal System

#### Andesite dike swam

Thin andesite layers are found only in the wells drilled in south or south-west directions. In well #15 at least five, possibly seven layers inferred from logging and drilling data, in well #7 five layers, and in well #23 eight layers of thin andesite appeared. Andesite layers are distributed at various depths. The horizontal projection of distribution of these andesites is very restricted as shown in Fig. 3. These andesite layers are clearly distributed along a zone, 100 to 120 meters in width, passing through Takeyama and Tsujinodake volcanoes, suggesting that these are the dikes related to the formation of Takeyama-Tsujinodake line.

To examine this feature, we carried out FMI<sup>1</sup> logging. FMI image data was acquired from well #23 over its completion interval between 811 and 1189 meters. As the borehole diameter for the interval is 12 1/4", the borehole coverage of the tool is about 52%. Most interval of the FMI image acquired indicated tuffbreccia. Each breccia could be recognized in the image. The andesite dikes appeared as high resistivity and high velocity zones with less internal heterogeneousness in the FMI image.

In the FMI analysis, more than 250 fractures/boundary features were identified, and classified into five categories; drilling induced fractures, open fractures, bed boundaries, healed fractures, and poor quality (uncertain) fractures. In Fig. 5 distribution of natural fractures is shown: namely fractures and healed fractures. It is evident that most of natural fractures show a NW-SE direction, and that the density of them clearly increase in the dike zone. Drilling induced fractures also displayed a NW-SE strike direction in the interval of dike occurrence.

The caliper data occasionally shows an oval shape, suggesting "break out" and is considered to be related to stress release. The FMI sonde has four arms, and gives caliper data. In the FMI of well #23, observed borehole elongation is more pronounced at pyroclastics zone than at andesite dike zones. The borehole elongation observed lay fairly consistently in a NE-SW direction. As the borehole elongation usually indicates the least principle horizontal stress direction, it is suggested that in the Satsunan area NE-SW direction is the least principal horizontal stress direction.

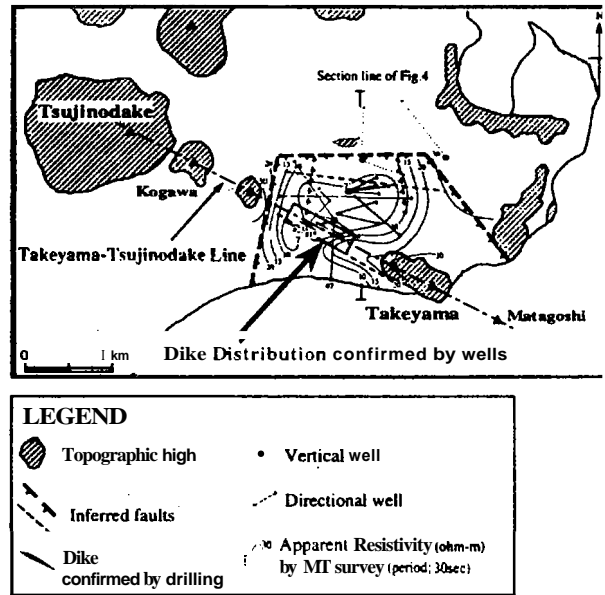


Figure 3. Geologic structure of the Fushime geothermal field with MT survey result. Wells, inferred faults and dikes confirmed by wells are shown.

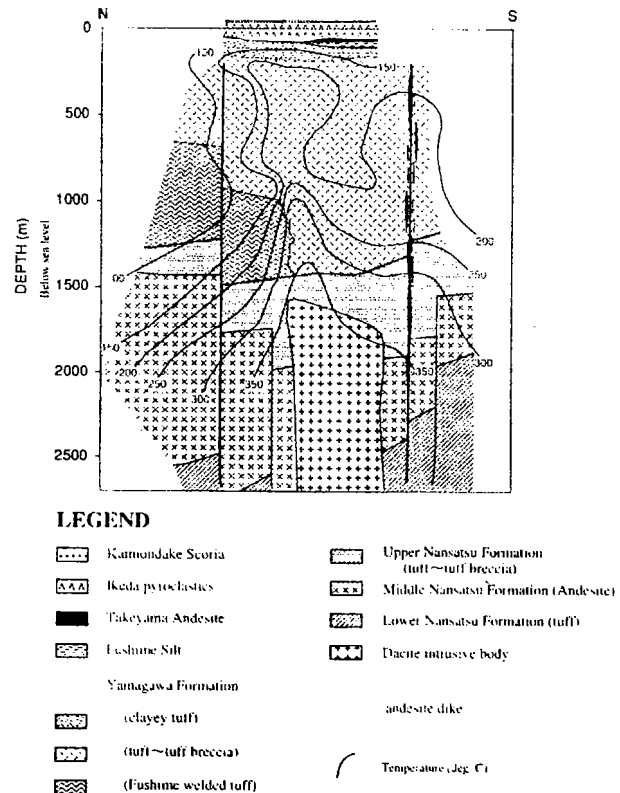


Figure 4. North to south geologic cross section with temperature distribution of the Fushime geothermal field. Section line is shown in Fig. 3.

<sup>1</sup>Trade mark of Schlumberger

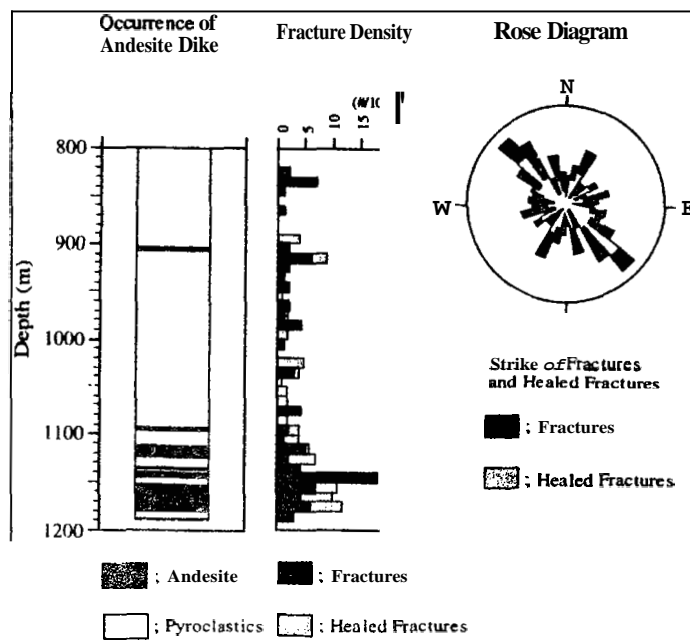


Figure 5. FMI analysis in the dike zone. Data are acquired from well #23.

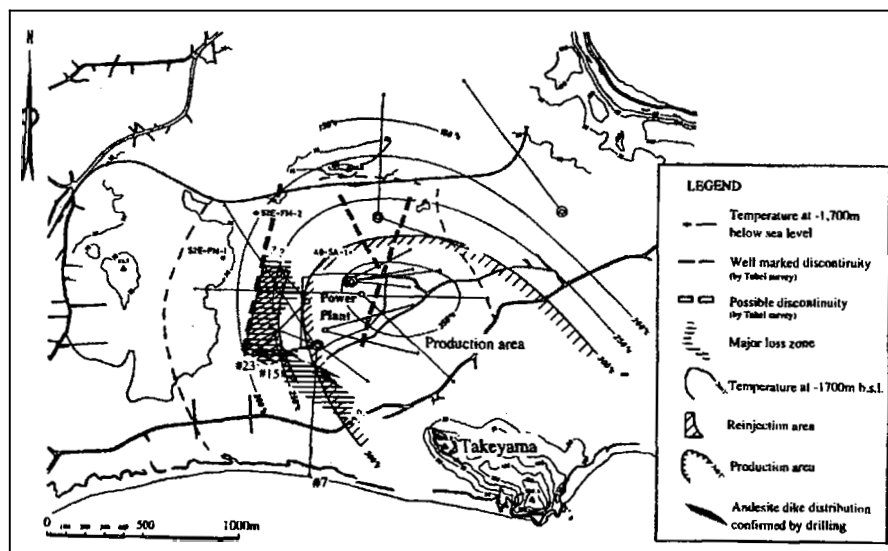


Figure 6. Production and reinjection areas in the Fushime field. Main production area is defined as the area of over 300°C at the depth of 1,700 m below the sea level and reinjection area is defined as the crossing area of the Takeyama-Tsujinodake line and NE trending fault zone detected by Tubel survey.

As the trend of dikes may concentrate in a direction normal to the minimum compressional axis (Nakamura, 1977), the observation of the andesite dike swarm direction consistently suggests that the least horizontal principal stress in this field is oriented in the NE-SW direction. Further it is consistent that the NE-SW direction of the least principle horizontal stress direction is approximately normal to the direction of volcanic dome and crater alignments in the Satsunan area such as the Takeyama-Tsujinodake line.

From the drilling fluid loss distribution pattern, one of the major loss zones identified extends along the Takeyama-Tsujinodake line. These loss zones show vertical distribution and high permeability and are currently utilized for reinjection (Fig. 6).

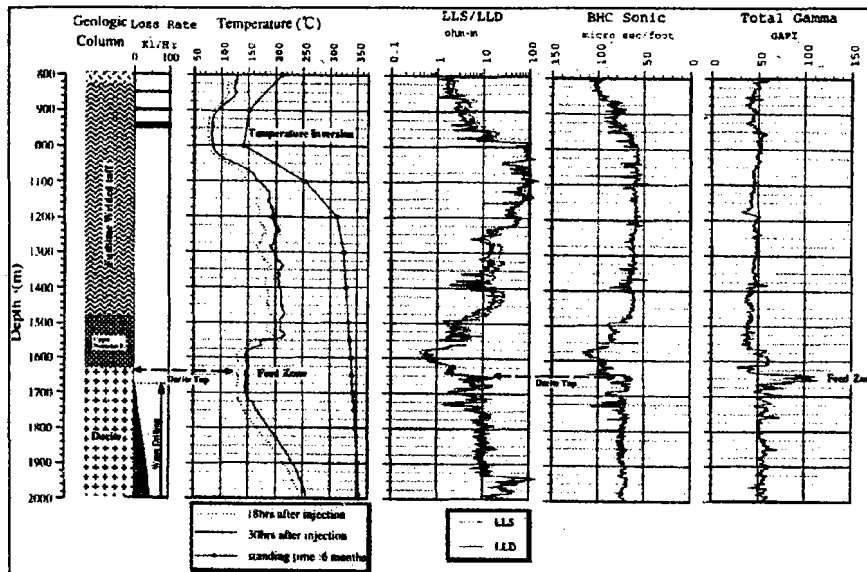


Figure 7. Log example from typical production well (#17). Main feed zone locates around the top of dacite. Total gamma increases in that interval

### Dacite intrusion

Dacite intruding into the Upper Nansatsu formation is distributed in the central part of the field. Major feed zones of production wells in this field usually exist around the dacite intrusion. Flowmeter logging and temperature surveys before and after cold water injection reveal the permeable zones in the completed section of production wells. An example of a series of logs from production well (#17) is shown in Fig. 7. As shown in Fig. 7, it is indicated to be permeable around the upper boundary of intrusive dacite.

The permeable zone around the intrusive dacite is the major production zone in this field. The tuffs surrounding the dacite intrusive body have commonly undergone particularly severe silicification, suggesting hydrothermal fluid circulation in this zone. In this zone K-feldspar is clearly enriched and plagioclase is depleted (Yagi, 1990). Further, the gamma-ray log shows a high anomaly in this zone. As shown by Browne (1978) and Elders et al (1981), enrichment of Potassium and K-feldspar indicates that this zone is the major production zone.

## 4.0 CONCLUSIONS

The geothermal system of the Fushime field is controlled by fracture systems. The main geothermal reservoir is in a fractured zone developed around a dacite intrusion distributed in the center of the field. The main production zone is located around the depth of 1700 m below sea level, the temperature of which, exceeds 300.

Other highly permeable zones arising from faults are utilized as reinjection zones. One of these zones is clearly associated with the NW-SE trending Takeyama-Tsujinodake line which is related to the andesite dike swarm. The NE-SW direction normal to the Takeyama-Tsujinodake line is consistent with the least principle horizontal stress.

## ACKNOWLEDGMENT

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