RESERVOIR POROSITY ANALYSIS AT THE DARAJAT GEOTHERMAL FIELD

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ABSTRACT

Lithology at the Darajat Geothermal Field consists of microdiorite intrusions, andesite lavas and sequences of pyroclastic rocks (bottom to top), with the majority of the Darajat reservoir being composed of andesite lavas.

Volcanic rocks typically give a wide range of primary matrix porosity, which can be enhanced by fracturing and leaching, or reduced by mineralization. Therefore, evaluation of the porosity in a geothermal reservoir can be very difficult.

The integration of Formation Micro Scanner (FMS), Accelerator Porosity Sonde (APS) logs, drilling data and core plug data were applied to assess matrix and fracture porosity. FMS and drilling data were used to identify fracture zones and lithology type, while APS and core plugs were used to identify porosity and mineralization.

The porosity distribution in the reservoir appears to be related to rock type. The average porosity of andesite lava from wells located on the margins of the field, which represents a non fractured zone, is much lower compared to the field center. The average porosity of this zone is approximately 2 %. Fracture related porosity was observed from wells penetrating major fault zones in the reservoir. The steam entry or loss zone related fractures are characterized by an average porosity greater than 13 %. Outside these steam entry or loss zones, the background porosity in the reservoir is 7 %. This appears to indicate that fracturing significantly enhances the primary matrix porosity of the host rock. It has also been observed that there is no apparent trend of decreasing porosity with depth at Darajat.

1. INTRODUCTION

1.1. Background

Reservoir porosity is one of the key parameters for reserves calculation and numerical simulation. Therefore, detailed porosity analysis was undertaken to distinguish porosity in an undisturbed and fracture zone of each lithology unit. Since most of the reservoir rock is composed of andesite lava, the study focused on the analysis of porosity in the andesite lava and microdiorite.

1.2. Location

The Darajat Geothermal Field is located on the eastern side of The Kendang ridge, part of a Quaternary volcanic range extending from Papandayan volcano in the southwest to the Guntur volcano in the northeast **(Figure-1)**.

1.3. Structural Geology

In general, structural features at the Darajat Field are NE-SW and NW-SE directions with the most prominent feature from air photography being the Kendang fault. This fault is trending N-S on the western side of the field and NE-SW toward the northern part of the field. Detailed subsurface fracture studies identified five major fracture zones in the Darajat field which includes the NE-SW trending Kendang, Gagak and Cibeureum faults, N-S trending fractures south of the Gagak fault and E – W trending fractures from DRJ-4/13 to DRJ-8 **(Figure-2)**.

1.4. Lithology Unit Subsurface

Based on analysis of well cuttings and cores integrated with Schlumberger Formation Micro Scanner (FMS) log; four lithology units can be observed in the Darajat Geothermal Field **(Figure-3)**. From bottom to top, these consist of:

1. The intrusive rock (microdiorite) unit - The shallowest intrusions of this unit were found to the north and to the south of the Gagak fault around wells S-1 and DRJ-4/13, respectively. Another deeper intrusive body was found at the bottom of wells DRJ-17 and DRJ-24.
2. The andesite lava unit - This unit was previously called the “Andesite Lava Complex” by past authors and consists of thick andesite lavas interbedded with thin layers of pyroclastics. This unit hosts the majority of the Darajat reservoir.
3. The interbedded andesite/pyroclastics unit – consisting of less thick sequences of andesite lavas interbedded with layers of pyroclastics.
4. The pyroclastics unit – characterized by thick pyroclastics interbedded with thin layers of andesite lavas, primarily found in the margins of the field.

2. DATA COLLECTION

The porosity data were obtained from core plugs and Schlumberger Accelerator Porosity Sonde (APS) logs. APS logs measure hydrogen ions in the rock formation pore space to detect porosity (Schlumberger, 1993).

Direct porosity measurements using Helium injection were applied to cores obtained from six slim hole wells (S-1 to S-6), one deepened well (DRJ-1B), and spot cores were taken from sixteen large bore wells **(Figure-4)**. Cores taken from slim hole wells located in the margin of the field, represent non-fractured or matrix porosity. Obtaining good representative data was difficult since the highly fractured intervals are difficult to core, and the slim hole well cores are mostly from above the reservoir zone. To obtain representative samples of fracture porosity in the reservoir, spot cores were taken from within or adjacent to the steam entry zones in large bore wells.

The APS tool was run in seven large bore wells (DRJ-15, 17, 18, 19, 20, 23 & 24) and one slim hole well (S-3B) **(Figure-4)**.

This tool was run in the reservoir section only, except in well S-3B where it was run to get a comparison between cores and APS log results. APS log readings appear to correlate well with FMS log and drilling information in identify permeable zones. High hydrogen signatures may represent a highly fractured zone, loss zone, drilling break and probable lithology changes. However, porosity readings from APS tools has to be assessed carefully, since there are several factors affecting the measurements of APS log, such as the presence of steam, gas (CO_2 & H_2S) and stand off corrections. In the presence of steam, as well as gas, the porosity reading will be depressed or close to zero.

3. ANALYSIS

All porosity data were integrated with FMS and drilling data such as fracture type and density, steam entries, drilling breaks and loss zones to define matrix and fracture porosity of different rock units within the reservoir. The porosity values were added up and averaged to get an estimate porosity number of each rock type.

Schematic diagram of porosity analysis is as follows:

Rock interpretation >> lithology correlation >> identify permeable zone >> identify matrix / fracture porosity >> assign porosity number from APS / Helium injection >> statistical calculation >> porosity value of each rock type

Two types of porosity were recognized in the Darajat reservoir **(Figure-5)**:

1. Matrix porosity or the porosity of the rock outside of the widely spaced fracture zones (porosity of a non-fractured zone).
2. Fracture related porosity or porosity of the rock that is located in the fractured zone.
   Fracture related porosity can be divided into 2 types:
   a. Steam entry / loss zone / drilling break related fracture porosity.
   b. Background fracture porosity.

3.1. Matrix Porosity

Matrix porosity was analyzed mostly by using data from slim hole wells located in the margins of the field and non-fractured zones found in the large bore wells. The slim hole wells were chosen to represent rock units with minimum structural impacts.

Andesite Lava

Matrix porosity of andesite lava was derived from core porosities obtained from wells S-3, S-4 & S-5. These slim hole wells are located within the current vapor reservoir and may represent matrix porosity of the reservoir rock. The average matrix porosity of andesite lava is 2.1 % **(Figure-6a)**.

A graph plot of porosity value with elevation indicates that there is no obvious trend of decreasing porosity with depth **(Figure-6b)**.

Microdiorite
Very limited data were available to analyze matrix porosity of microdiorite. Therefore, the results may or may not be representative. The core porosity from wells S-1, DRJ-13, 21 & 22 indicate that the average matrix porosity of microdiorite is 1.6 % **(Figure-7)**.

3.2. Fracture Porosity

Andesite Lava

Fracture porosities of andesite lava were obtained from wells DRJ-4, 7, 14, 15, 17, 18, 20 & 24. These wells penetrated major fault zones in the reservoir and are characterized by the presence of high-density open fractures, loss zones, drilling breaks and steam entries.

Two types of fracture porosity can be recognized from this analysis:

1. *Fracture porosity which is related to steam entry / loss zone / drilling break.*
   The APS logs response in this zone typically showed a relatively high hydrogen signature compared to the surrounding areas. The data from wells DRJ-15, 17, 18, 23 & 24 indicate that steam entry related fracture porosity of the andesite lava ranges from 6.7 – 23.5 %, with an average porosity of 13 % **(Figure-6c)**.

2. *Fracture porosity which are not related to steam entry / loss zone / drilling break.*
   This type of porosity can be assumed to be the background fracture porosity. Based on FMS log analysis, most of the Darajat reservoir is occupied by this type of fractures. The background fracture porosity of andesite lava ranges from 3.6 – 10.9 %, with an average porosity of 7 % **(Figure-6c)**.

<u>Microdiorite</u>
The available data from microdiorite unit is very limited. With the assumption that the microdiorite is more brittle than andesite lava, the fracture porosity of microdiorite is most probably higher than the fracture porosity of andesite lava (> 7 %).

4. CONCLUSION

The integrated study of geology for Darajat indicates that the reservoir is hosted primarily by andesite lava, overlaid by sequences of pyroclastic rocks. Two microdiorite intrusions penetrated this andesite lava in the north and south of Gagak Fault.

The reservoir is dissected by NE-SW, NW-SE, N-S and E-W faulting that creates high density open fractures or permeable zones.

These permeable zones produced a dual porosity that can be described as fracture and matrix porosity. Both matrix and fracture porosity in Darajat appears to be related to rock type. Comparing the porosity of non reservoir and reservoir rocks, the wide range of porosity in reservoir rocks suggests that the fracturing has enhanced the primary matrix porosity.

5. ACKNOWLEDGEMENTS

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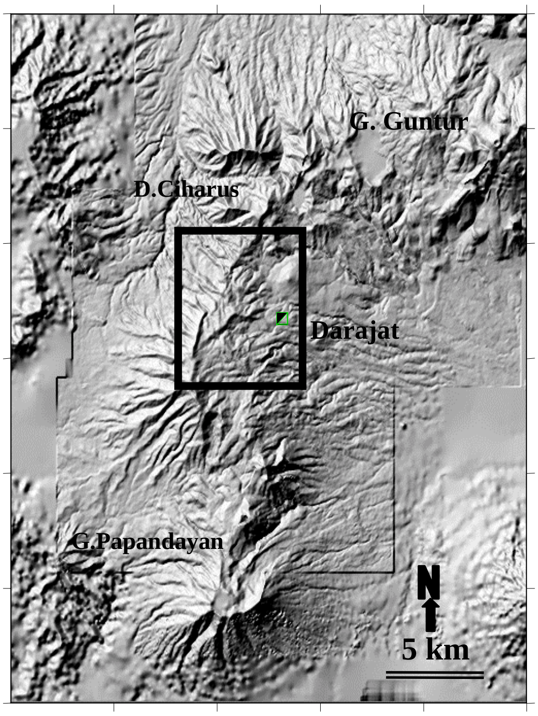

Figure 1.
Location map of the Darajat Geothermal Field

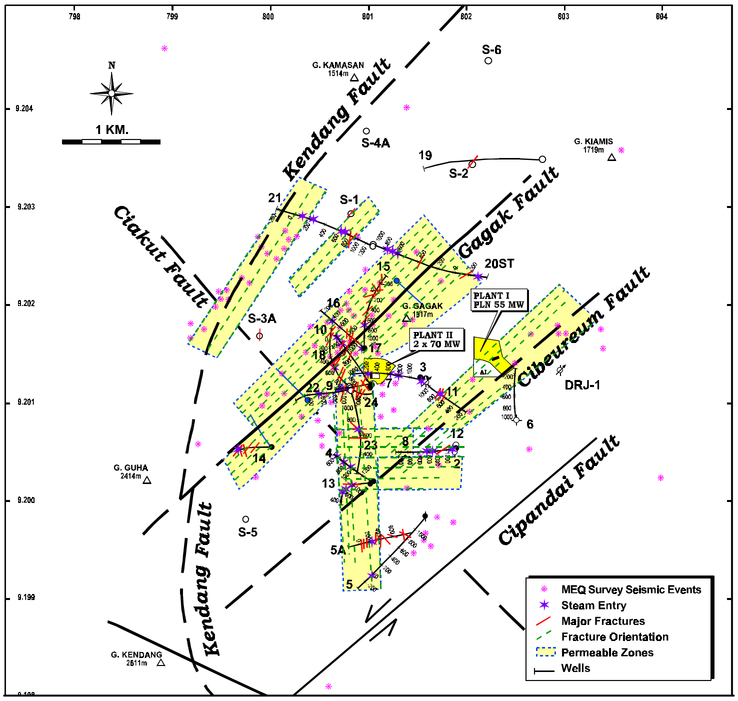

Figure 2.
Fracture zones interpreted from FMS log, MEQ and drilling information

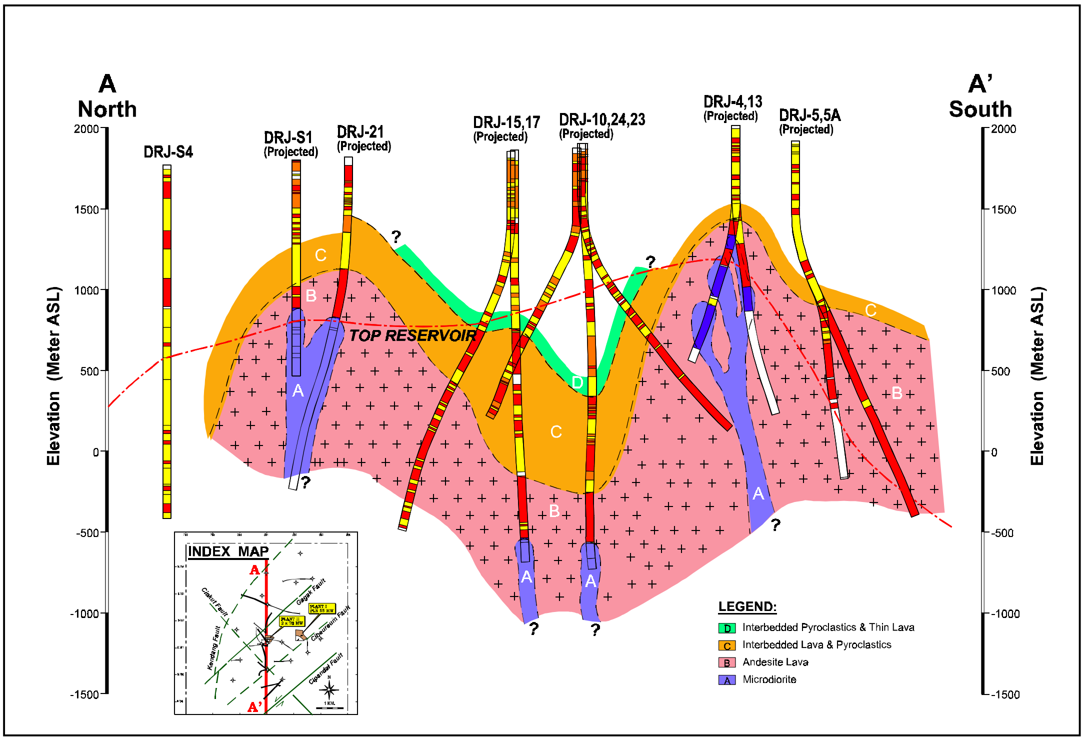

Figure 3.
N-S cross section showing the distribution of lithology within Darajat reservoir

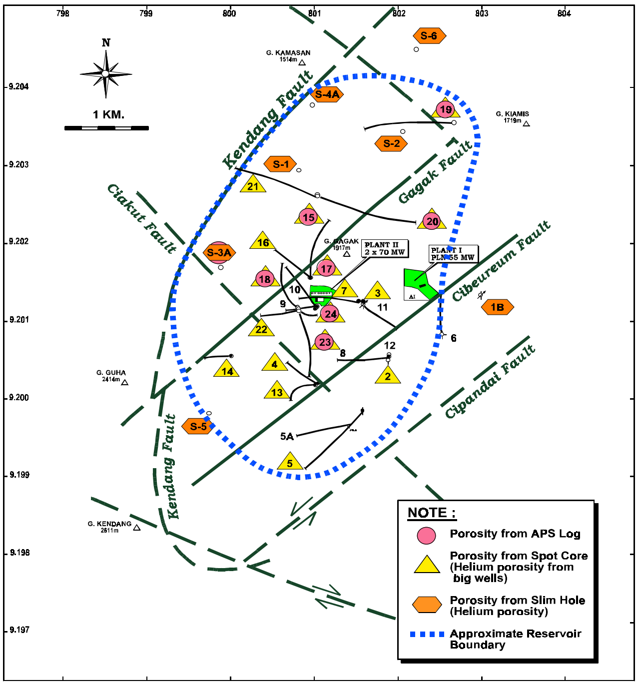

Figure 4.
Location of porosity data

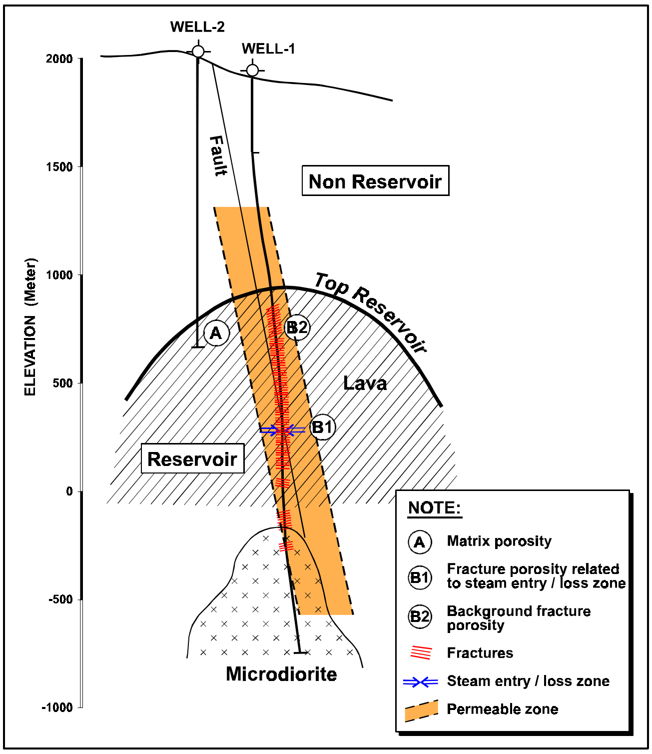

Figure 5.
Schematic diagram of porosity type recognized within Darajat reservoir

Figure 6a. POROSITY OF ANDESITE LAVA

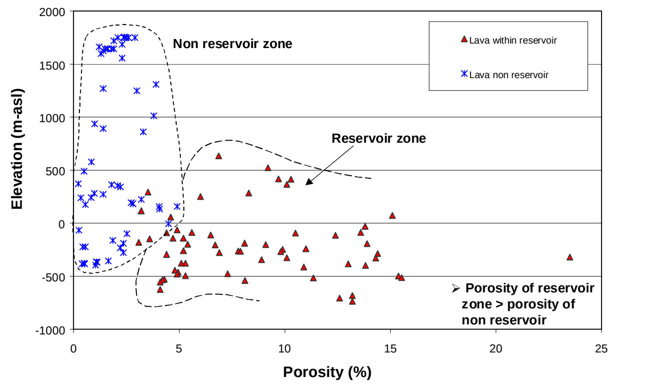

Figure 6b. POROSITY OF ANDESITE LAVA WITHIN RESERVOIR

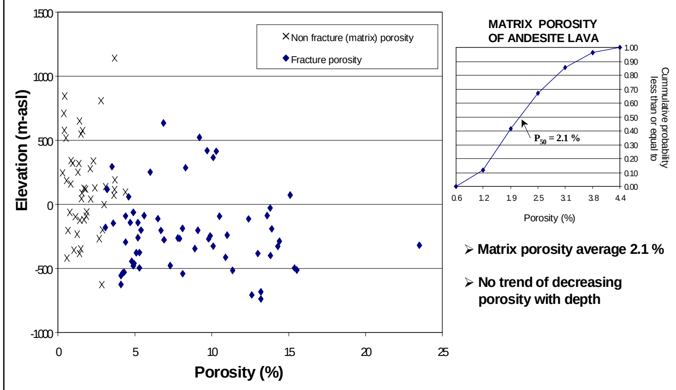

Figure 6c. FRACTURE POROSITY OF ANDESITE LAVA

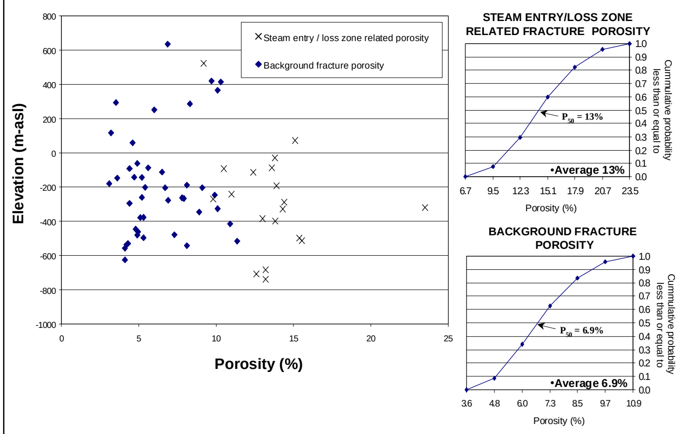

Figure 7. POROSITY OF MICRODIORITE WITHIN RESERVOIR