PETROLOGIC INDICATORS OF PERMEABLE STRUCTURES IN THE BOTONG SECTOR OF THE BACMAN GEOTHERMAL PRODUCTION FIELD

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Abstract

Well permeability and productivity in most geothermal wells are attributed to geologic structures. The diagnosis of structural permeability in the subsurface is thus critical in geothermal exploration and development. Petrologic data is used in the preliminary evaluation of structural permeability during drilling. The petrologic parameters currently used in identifying structures are 1) mylonites, 2) veins, and 3) increase in alteration intensity. The study which focuses on the Botong sector of the Bacman geothermal production field aims to assess the applicability of these petrologic parameters and to establish a set of petrologic criteria for structural permeability. OP-4D, the most permeable of the five Botong wells, is characterized by generally moderate amounts of drusy veins, and moderately to intensely altered rocks. In contrast, OP-3D, which has relatively poor permeability, has weak veins and veinlets and moderately altered rocks. It has also prehnite veins. Mylonites appear as an inconclusive permeability indicator.

1.0 INTRODUCTION

Petrologic data has long been used in determining well-fault intersections and predicting permeability especially during drilling when the rock samples are the critical clues to subsurface information. The petrologic data used are moderate to abundant mylonites and veins, and alteration intensity. Recently, however, some geothermal wells turn out to be poor producers or injectors because of low permeability despite the presence of interpreted structures. The present study will assess the use of mylonites in interpreting geologic structures and establish diagnostic indicators of structural permeabilities.

The study focuses on the five production wells,' OP-3D, 4D, 5DA, 6D and 7D, of the Osiao-Pangas, Botong sector of the Bacman II production field (Fig. 1). This area was chosen because 1) most of these wells are "perfect holes" and present a complete petrologic picture and 2) the structural geology is well defined. With the exception of the recently drilled OP-7D, these wells have an output ranging fiom 12.1 MWe in OP-4D to 1.7 MWe in OP-5DA and injectivity index of 12.3 in OP-4D and 8.4 l/s-MPa in OP-3D.

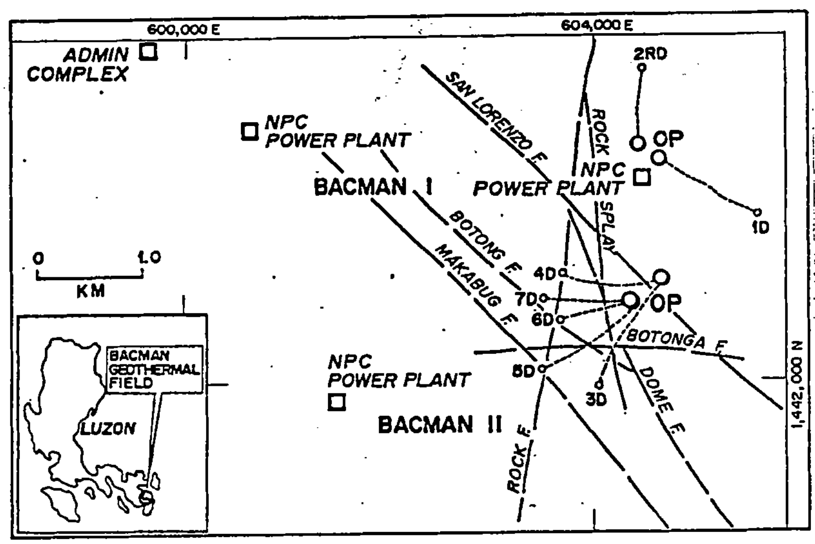


Fig. 1. Location Map of Bacon-Manito Geothermal Production Field.

Petrologic data on type and relative abundance of vein minerals, alteration intensity, and moderate to abundant mylonites were plotted for each well. Vein abundance is classified as rare, weak, moderate and abundant while vein morphology was described as veinlets or drusy. Activity diagrams for different temperature levels in the permeable zones were constructed for all the wells to establish the state of equilibrium between the observed minerals and the fluids presently circulating in the geothermal system. Alteration intensity, on the other hand, is grouped as weak, moderate and intense. Mylonites, identified by shearing features, were compared with 'bit-abraded' rocks. Well-fault intersections were calculated based on petrologic parameters. Actual permeability indicators such as drilling circulation losses and permeable zones detected during production completion tests were likewise plotted and compared with the postulated geologic structures. The corresponding diagnostic petrologic data were then used to establish the indicators of permeable structures.

2.0 DATA PRESENTATION

The classification scheme for the petrologic parameters used in the study is shown in Table 1A-C.

Classification	% Area in Thin Section
A. Veins	
Weak	
Moderate	**5-10**
Abundant	**> 10**
B. Alteration Intensity	
Rare	≤ 10
Weak	10-25
Moderate	25-95
Abundant	95-100
Classification	**Number of Sheared Cuttings**
C. Shearing	
Rare	**1-5**
Weak	**6-10**
Moderate	**11-15**
Abundant	**> 15**

Veins. Common vein-forming minerals calcite and quartz are rare to abundant fiom *the* production casing shoe **down** to the bottom *of* the five **Botong** wells (Fig. 2a-e). Dolomite and anhydrite are less common in rare to weak *amounts* in all the wells. Anhydrite, a common vein material in other geothermal fields, has a limited occurrence in OP-3D, 4D and 7D. Similarly, wairakite is weak at a single depth in OP-3D but weak to abundant at two depths in OP-7D.

Epidote and clinozoisite form at deep levels in OP-3D, 4D, 5DA and 7D. Weak to moderate and mostly drusy albite, actinolite, tremolite, with occasional garnet and illite, in addition to epidote are present in OP-4D near the well bottom.

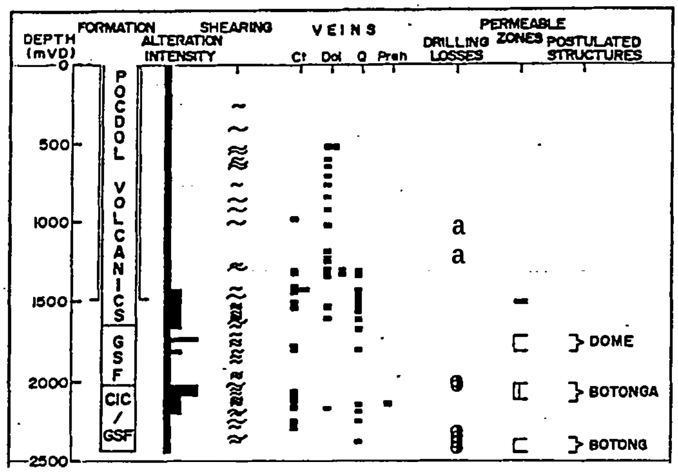


Fig. 2a. Petrology of Well OP-3D.

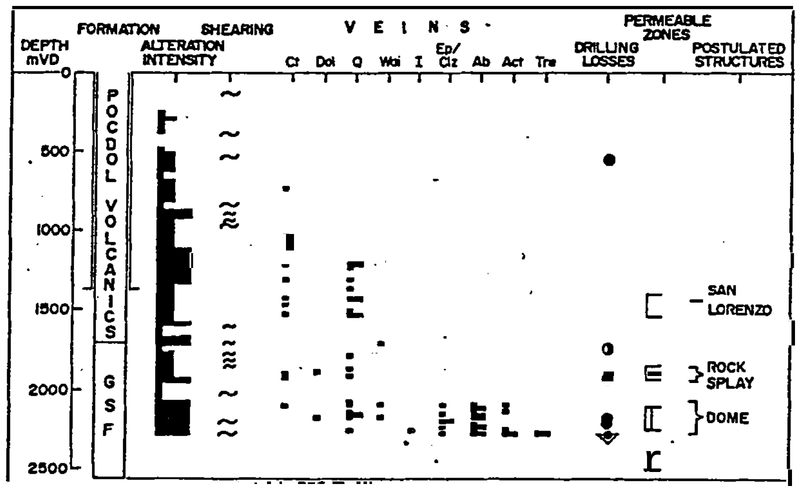


Fig. 2b. Petrology of Well OP-4D.

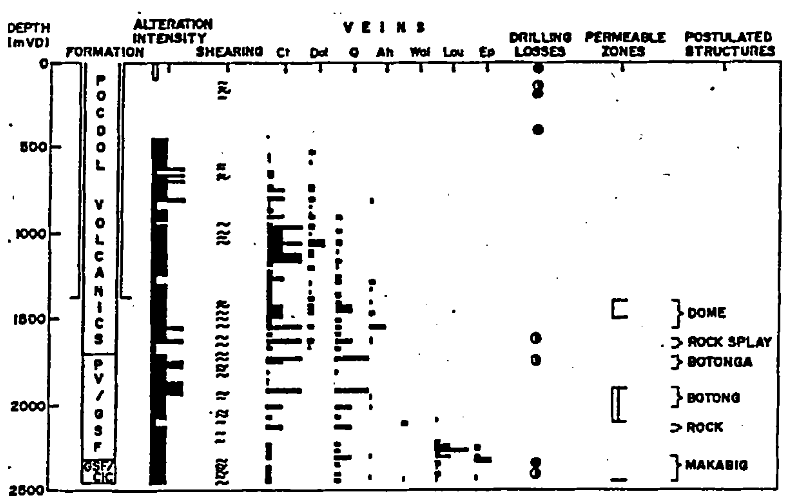
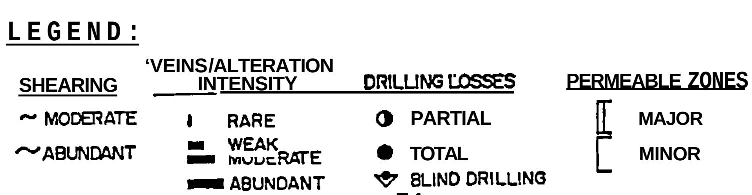


Fig. 2c. Petrology of Well OP-5DA.



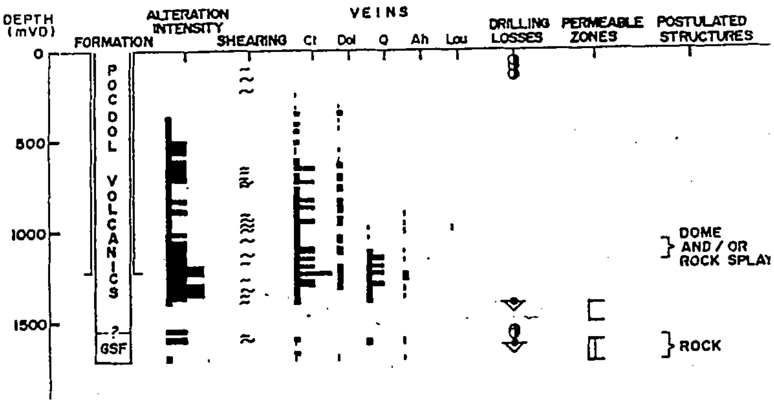


Fig. 2d. Petrology of Well OP-6D.

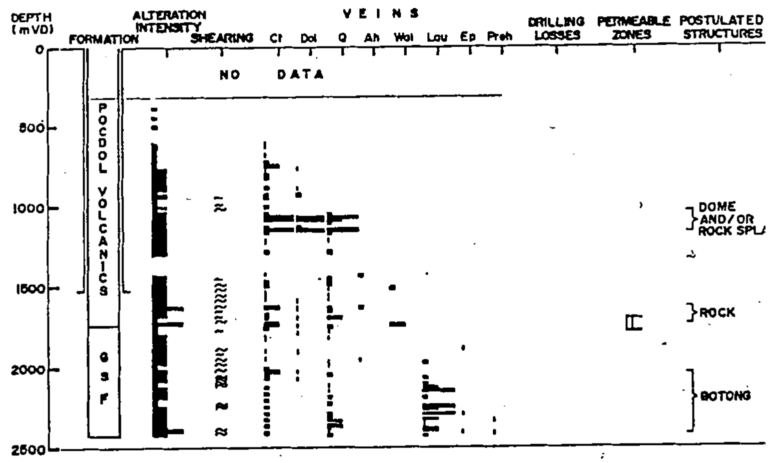


Fig. 2e. Petrology of Well OP-7D.

Laumontite veins and cement are rare to moderate and rare to abundant near the well bottom of OP-5DA and 7D, respectively. Prehnite is extremely sparse at deep levels in OP-3D and 7D.

Veinlets (Fig 3a) and drusy veins are generally observed in all the wells. However, drusy forms (Fig. 3b) are common near the bottom of OP-4D.

Fig. 3a. Quartz veinlet (v) in OP-4D.

Fig. 3b. Drusy veins of actinolite (V) in OP-4D.

Alteration Intensity. The rocks are mostly *oxidized* or weathered near the surface (Fig. 4a). However, alteration intensity generally increases from moderate to intense (Fig. 4b) at deeper levels in the five Botong wells. Alteration is also influenced by lithologic type. It is weak to moderate in the andesitic lava flows and more pronounced in the volcanic breccias or conglomerates.

Fig. 4a. Weakly altered andesite lava.

Fig. 4b. Intensely altered volcanic breccia.

Mylonites The term mylonites describes sheared and deformed rocks which are attributed to geologic *structures*. Well-site geologists, on the other hand, identify 'bit-abraded' cuttings which are produced by the mechanical abraded action of the drilling bit on the formation d a c e . A comparison of the two types of cuttings show similar petrologic features of shearing and deformation (Fig. 5a-b). The term shearing will thus be used in the ensuing discussions to avoid genetic implications.

Moderate to abundant sheared rocks are randomly distributed in all the wells except in OP-4D . where it is relatively sparse.

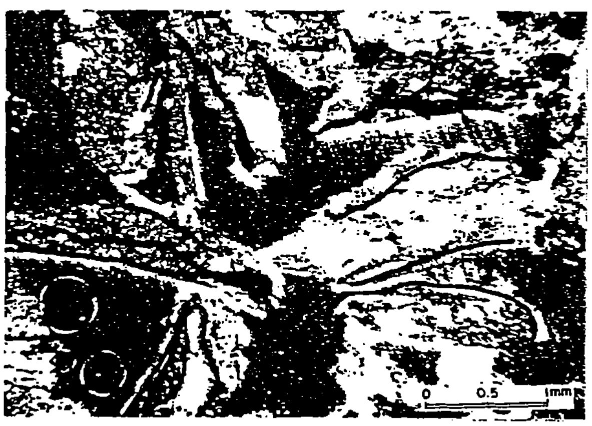


Fig. 5a. "Bit Abraded" Cuttings

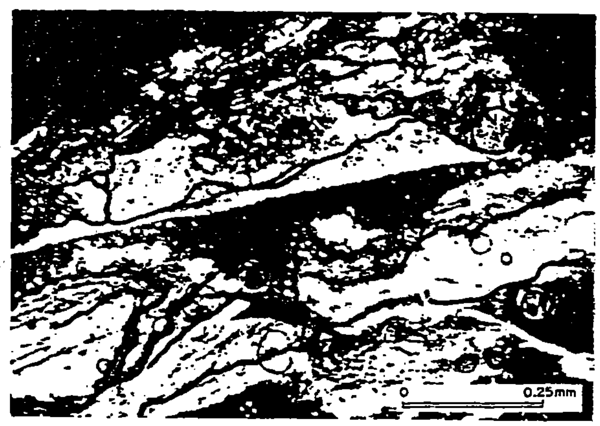


Fig. 5b. Mylonites

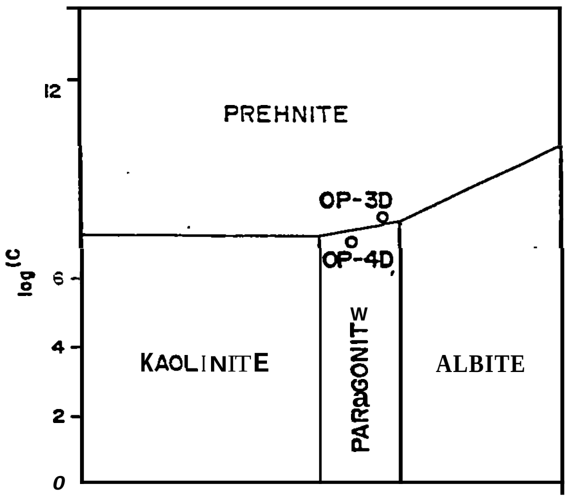
3.0 DISCUSSIONS

The major permeable zones in all the five wells are related to geologic *structures* (Fig. 2a-e). These are Botonga in OP-3D, Dome in OP-4D, Botong in OP-5DA and Rock in OP-6D and 7D. Except for OP-5DA and 7D, these zones likewise correspond to drilling circulation losses. OP-4D and 6D are the most permeable wells within the Botong sector with the the highest outputs of 12.1 and *4.8* MWe, respectively. Both had *total* drilling circulation losses and were subsequently blind drilled within the major permeable zones. OP-3D and 5DA are relatively low permeable wells with outputs of 8.4 and 1.7 MWe, respectively. The former has the lowest injectivity index of 8.4 l/s-MPa.

In OP-4D, the Dome fault intercept at ~ 2100-2300 mVD is characterized by intensely altered rock units and *drusy* veins of mostly moderate quartz together mith high temperature

paragonite stability field indicating the recent deposition of paragonite/illite.

OP-6D was blind drilled within the major permeable zone and has incomplete petrologic data (Fig 2d). Hence, the intersection of the Rock fault in this drillhole cannot be properly characterized.



associated

Mylonites, another petrologic parameter originally thought of as solely geologic in nature, shares common petrologic shearing and deformation features with the 'bit-abraded' cuttings. Thus, physical distinction could not be established between the two types. This similarity may explain the inconsistency of shearing distribution in the wells.

In OP-4D, shearing is *scarce* within the intercepts of Dome fault which *is* interpreted to be permeable based on other petrologic data. It is totally absent within the San Lorenzo fault intersection at 1400-1550 mVD which is defined by a minor permeable zone. In contrast, moderate to abundant shearing at shallow levels in almost all the wells do not correspond to fault intersections.

4.0 CONCLUSIONS

Vein mineral abundance, type and morphology, and alteration intensity appear as diagnostic indicators of permeable structures. Permeable structures are characterized by moderate to abundant drusy veins coupled with moderate to intense rock alteration. Impermeability, on the other hand, is indicated by contrasting petrologic features of weak veins and veinlets, weak rock alteration, and the presence of prehnite veins.

Based on the present *study*, permeability indicators using petrologic data is proposed below:

INDICATOR	DEGREE OF PERMEABILITY		
VEIN	POOR	MODERATE	HIGH
• Morphology	Veinlets	Veinlets and drusy	Drusy
• Abundance	Rare-Weak	Moderate	Moderate Abundant
• Mineral	Prehnite (Preh)	Any except Preh	*Any* except Preh
ALTERATION INTENSITY	Weak	Moderate	Intense-Complete

Table 2. Proposed Pctrologic Indicators of Pcrmcability.

The use of mylonites as an independent permeability indicator, on the other hand, appears inconclusive.

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