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STRUCTURAL CONTROL IS A STRATEGY FOR EXPLOITATION WELL AT KAMOJANG GEOTHERMAL FIELD, WEST JAVA, INDONESIA.

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ABSTRACT

Kamojang Geothermal Field is one of the best geothermal field in the world, explored since 1918. The field lies 33 km south-east Bandung, West Java. It is located in the centre of a volcanic chain which has progressively grown from WSW to ENE.

Three tectonic activities have created current Kamojang structures. Firstly, the circular collapse of Pangkalan, 2 km in diameter which occupies the central part of the Kamojang field; secondly, NE -SW flults of tensional and lateral origin, are parallel to the magmatic axis; and last, 5 km wide graben is a major expression of NW-SE tensional faults. The faults, having N60 strike in the southeastern part of the field have been identified as a very important structures related to the main target of reservoir Kamojang field. Even if the faults and fractures have been altered in the upper part of the surface and form non permeable seals, the bottom sections may still be highly permeable. Therefore for development drilling one must consider the deep structures instead of just shallow expressions and alteration.

Geological correlations between the several wells drilled up to date shows evidence that the structures correspond to the surface features as described above. Case study of well Kamojang denote that the structure identified as Citepus fault is founded in the depth of about 1400 m to 1700 m. v. d

I. INTRODUCTION

Geothermal development has been carried out by the State Oil and Gas Company of Indonesia (PERTAMINA) since 1972 .

Indonesia geothermal prospects are frequently located along the major volcanic island arcs of Sumatera, Jawa-Bali, Sulawesi and island at East Indonesia. About 70 high enthalphy prospects have been discovered, providing approximately 19,658 MW total energy potential. Sumatera has the highest potential of about 9,562 MW and followed by Java-Bali with 5,681 MW. Sulawesi is estimated to have 1.568 MW and the remaining potential is mostly located in the more remote island of east Indonesia.

The Kamojang geothermal field lies 33 km south-east of Bandung, West Jawa. It is located between Majalaya and Garut city on a hilly volcanic chain where the average elevation is 1500 m a.s.l. (figure 1).

The prospect of Kamojang was discovered 1926, but systematic investigations were just commenced in 1972 by GENZL, VSI and PERTAMINA. A geological mapping (Healy, 1975), a shallow electrical survey, AB/2 = 500 m (Hochstein, 1975) and a deep electrical survey, AB/2 = 1000 m, (PERTAMINA, 1980) have been carried out to delineate the possible geothermal field.

An area of about 14 km square has been estimated to have high geothermal potential. Five shallow exploration wells were drilled in this area giving positive indications. Until the end of 1995, 56 production wells have been drilled within a 4 km square area. Six of them supply steam for a 30 MW power plant unit I, 47 production wells for Unit II & III while the other with future additional drilling will supply unit IV & V (2 X 30 MW) power stations.

PERTAMINA has resently carried out a detailed geological interpretation of the Kamojang area which is presented in this paper.

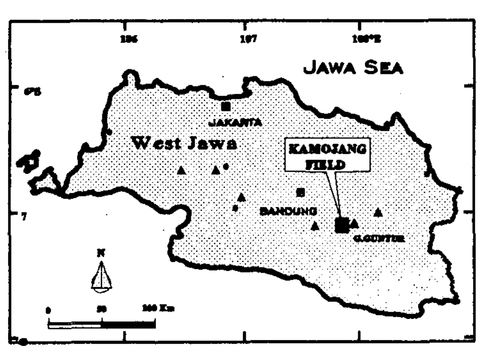

Fig 1: Location Map of The Kamojang Field.

II. GEOLOGY

A. REGIONAL GEOLOGY

The Kamojang Geothermal field is located on a large volcanic chain, 15 kilometres long and 4-5 kilometres wide, extending from Gunung Rakutak in the WSW part to Gunung Guntur in the ENE part. This chain is constituted by the following succession of volcanic complexes, from WSW to ENE : Gunug Rakutak, Ciharus complex, Pangkalan complex, Gandapuro complex, Gunung Masigit and Gunung Guntur. Erosion stage of these complexes and their structural relationship clearly appears that these volcanoes have progressively grown from the WSW to ENE.
The gunung Rakutak is the oldest and Gunung Guntur being still active, is the youngest.

This volcanic chain has been affected by a large NW-SE graben, 6 km wide, extending from Ciharus to Kamojang. The depression, clearly observed in the field, can be devided into several sub-structures corresponding to small grabens and horsts; thus two grabens have been defined, the first 1,5 km wide, crosses the geothermal field of Kamojang in its middle part whilst the second, 750 m wide, affect the Ciharus complex.

Both, the magmatic axis and the NW-SE depression, are affected by normal fractures oriented approximately N-S. Two structures have been distinguished: the first is a graben 500 m wide which goes through the part of Ciharus; the second is constituted by a fault bundle which extends into the eastern part of Kamojang area where surface manifestations lie.

Most of the volcanic complexes exhibit circular structures. Though all are circular, they do not seem to have the same origin; Rakutak structure, 2.5 km diameter, seem to be a small caldera while Ciharus and Pangkalan structures, respectively 1,5 and 2 km in diameter, are collapse pits and Guntur structure, 250 m in diameter, is a simple crater.

B. GEOLOGY OF KAMOJANG GEOTHERMAL FIELD

1. Volcanological units

The geological mapping of this area has been carried out by GENZL/VSI (1975), and PERTAMINA (1981).The area can be divided into the following two units:

- **The Pangkalan unit**, lies in the western part of Danau Pangkalan area, consists of weathered andesite.

- **The Gandapura unit**, located in the eastern part of Kamojang field, is formed by pyroxen andesite rocks. This formation is younger than the Pangkalan unit.

The Danau Pangkalan area, a large flat area located between the two previous volcanic units, is composed of volcano-sedimentary deposits.

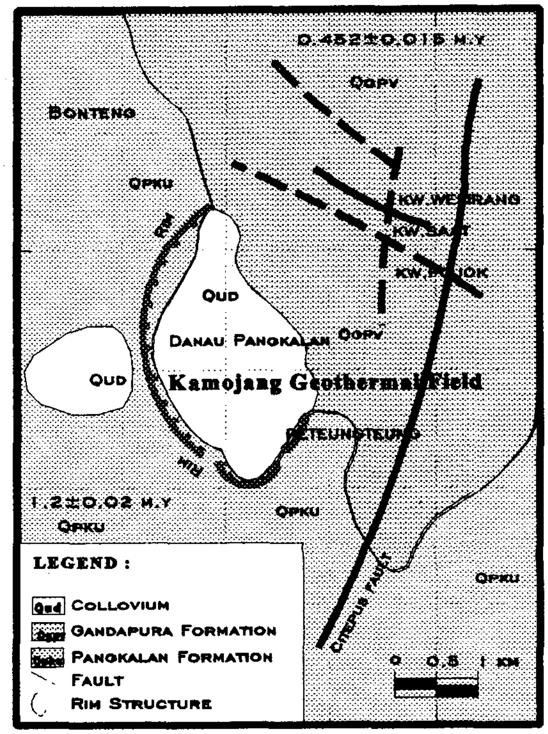

Fig 2 : Geological Map of Kamojang, West Jawa
Ref : Genzl 1974 - 1975).

2. **Structure**

A tectonic analysis of this area has been recently carried out by PERTAMINA (1981-1982). Five prominent tectonic features have been defined by BEICIP - PERTAMINA (1983) (Figure 3)

- The rim of the collapse pit of Pangkalan
- The faults striking N 60
- The faults strinking N 140
- The faults striking N 15
- The faults striking N 110

a. **The collapse pit of Pangkalan:**

This circular structure is located in the western part of Kamojang field. It is limited by a rim which outcrops clearly in the western and southern part only. In the northern and eastern parts, regional fracture collapse it and young lava flows conceals it. This rim delineates a circular area about 2 km long and 1.5 km wide. The collapse due to this subsiding structure is about 570 m deep in its western part.

b. **The faults striking N 60 :**

Two main fault bundles oriented N 60 have been detected. The first is located the south of Danau Pangkalan area and crosses the Kamojang. This fault bundle consists of left lateral strike-slip faults which shift the rim of Pangkalan structure by about 200 m. The second lies in the northern part of the Pangkalan structure which disappears in the northern block beyond these fractures. The role of these faults has varied during the geological history of Kamojang: firstly, they were of lateral type with small displacements; then, recently, they were of normal type downthrowing to the nort.

After the formation of the Pangkalan structure, small volcanic complexes or cones have along the second N 60 system which seem to represent a possible heat source for the geothermal field of Kamojang.

The more prominent electrical anomalies defined by GENZL (1975) and PERTAMINA (1981) are strongly controlled by these tectonic features.

c. **The faults striking N 140 :**

Numerous fractures oriented N 140 have been deteted, particularly in the eastern part of the Kamojang geothermal field. In the southern part of the field, these faults of tensional type delineate two narrow downthrown structures which clearly affect the rim of the Pangkalan structure. In the northern part, these grabens can be observed too; but in the central part where the N 60 shear system extends, they cannot be observed at the surface.

These tectonic feature seem to be contemporanous or slightly younger than the N 60 lateral fault. There is good concordance between these surface observations and the interpretation of electrical surveys carried out by PERTAMINA (1981).

d. **The faults striking N15 :**

In Kamojang, this direction of faulting is subordinate in comparison with the previously described systems. Only one fault has to be mentioned; it is a normal fault, running in the eastern part of the field, along whit surface manifestations pour out.

e. **The faults striking N 110 :**

They are of normal type and have a minor role with small down throuwn to the south.The fault features exist in the northern part only.

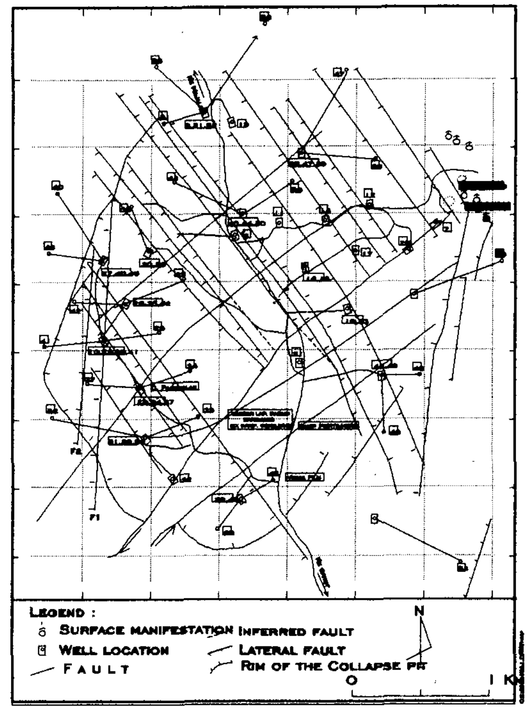

Fig 3 : Wells Location and Structural Pattern, Kamojang, West Jawa.

3. **Temperature distribution**

The temperature distribution is strongly controlled by the structures. The N 60° fault system near to K11 and K25 can be considered as the heat source of the field while the N 60° fault system close to K23 constitutes a permeability barries beyond which the temperature is low. The N 140° graben is an excellent permeable zone where the steam flows easily and from which a small convection cell develops towards the east.

4. **Hydrothermal alteration :**

Petrographical analyses of cores and cutting from well (BEICIP - PERTAMINA, 1983) show that the hydrothermal process has been active in Kamojang geothermal field.

Some layers in every well are completely altered and hydrothermal deposits like clays, silica, calsite, pyrite, etc ... have sealed these lithological units, changing them into true cap-rock. The self-sealing process has developed also along some old fractures which have not been reactivated; the southern lateral fault N 60° where the permeability was poor, is presently sealed and constitutes a permeability barries.

Sometimes, this self-sealing process has envolved until the di-self-sealing process. (Di-self-sealing process : is the transformation from an impermeable and plastic rock to a hard and fracturable). This process has been observed many times in layers located at relatively great depth where albite + epidote are present, giving to these layers a good secondary premeability.

From hydrothermal study, calculations of the temperature have been carried out. The calculated temperature is equal to or higher than 250^0 C in the reservoir. The maximum temperature measured in Kamojang field is only 240^0 C. thus, it appears that this field is cooling. Moreover, there is agreement with the structureal location of Kamojang along the magmatic axis which has migrated from the WSW to ENE

III. GEOCHEMISTRY

Surface thermal features in Kamojang geothermal fields consist of several fumaroles, steaming graund, mud pools and hot springs. Which is mosly hot acid sulfate springs associated with fumaroles in this area.

Looking for anomalous constituent geochemistry such as CO_2, Hg, Li, As and Cl during geochemical survey are very important.
Geochemistry investigation detail was done by jointly with the PT.Sumber daya Bumi - Pertamina and the first compilation geochemical map of CO_2, Hg, Li, As was made. (figure 4)

- Anomalous CO_2 , located in Nortern part of Danau Pangkalan , Cikateang and Sukarame. the anomalous indicating CO2 coming up into the surface through the permeable zone. The anomalous suppose controled by the fault stringking N 60^0

- Anomalous Hg, located in the Danau Pangkalan which are indicated that the area located over the steam heated zones. Anomalous are associated with the collapse pit of Pangkalan and also fault stringking N 60^0 .

- Anomalous Li located in the Eastern part of Kamojang which associated with fault stringking N 140^0, and anomalous As located around Danau Pangkalan and Pasir Jawa. which are connected with the collapse pit of Pangkalan and also fault stringking N 60^0 .

IV. GEOPHYSICS

Resistivity and gravity survey provide border geothermal prospect of Kamojang Geothermal field. Apparent resistivity 10 Ohm-m on AB/2 = 1000 m, Kamojang space prospect area is approximately 14.5 km^2. In the development of Kamojang survey CSAMT, the Kamojang space area prospect extends to be estimatedly 21 km^2 (figure 4). The extension has its means for developing of Kamojang field in the future until 300 MW.

Head-on method with 5% eror possibility provides datas of the existence of fault structure with strike and dip direction, e.g Citepus foult that detected with approximately stringking fault N 200^0 E and the dip of 69^0 $\pm$ 3.5^0.
Kendeng fault - detected that it has its direction of striking fault N 60^0 E/ 59^0 $\pm$3^0

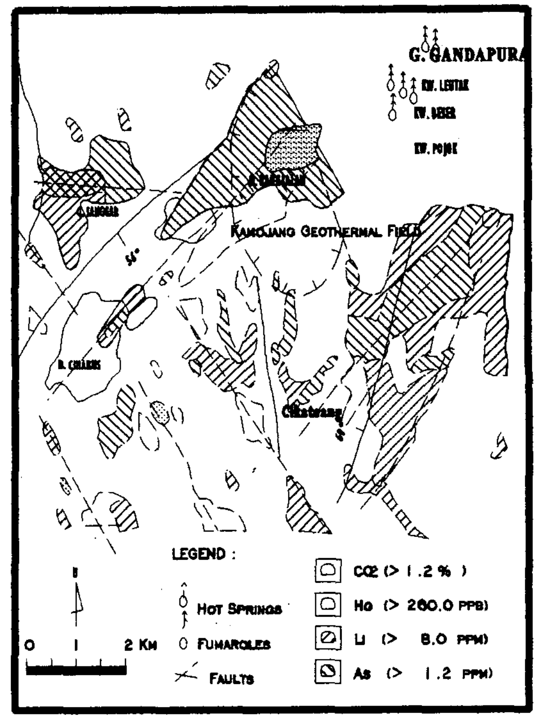

Fig 4 : Anomalous CO2, Hg, Li, As of Kamojang - Ciharus lake, West Jawa.

V. DRILLING CASE STUDY

Kamojang Well (KMJ - 54)

Pre - Drilling

Exploration well plan TVV - C/1 that will be called well Kmj-54 situated in the corner of North-East part of Kamojang field about 1 km to the south, the elevation of 1.374,22 m a.s.l.

The aim of well is to prove that there is the extension of the Kamojang geothermal field to the south-east part. This well is targeted to the depth 2000 m.d
with its direction N 112° E (S 68° E).

Lithology formation can be estimated close to the well

KMJ - 49, situated in the north part of TVV - C/1. The lithological log is constituted by the following formation :

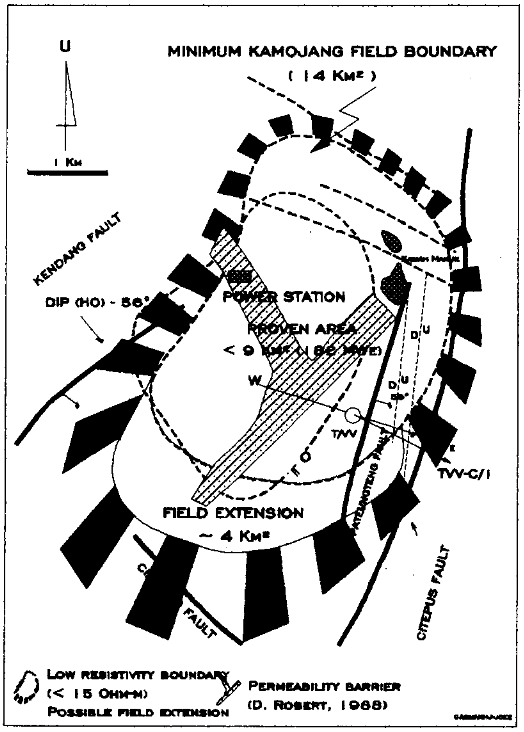

Fig 5 : The result of Geophysical survey, Kamojang, West Jawa.

1. Formation from the surface to the depth of about 600 m is pyroclastic rock that interbeds with altered andesite rock. The rock altered with intensity of about 25 - 80 %, argillitization altered process. Clay mineral that is altered mineral that is very dominant besides carbonate mineral, chlorite, iron oxide, pyrite and secondary silica.

2 Below 600 m the litholog is dominated by altered basaltic andesite (30 - 60%). Alteration minerals consist of secondary silica, iron oxide, chlorite, pyrite and clay.

3. Loss sirculation is estimated found on fault zone in the depth of 1300, 1505, and 1790 m.d. The first and the second fault is secondary fault of Citepus fault which is found in the depth of1790 m.d (figure 6).

After Drilling

TVV-C/1 becomes well Kmj-54 after drilling. The total depth is about1700 m.d. K.O.P set up in the depth of 450 m. Lithological analyses of cores and cutting from well show that the hydrothermal process is already active in this well. The first 600 metres consist of the monotonous sequence of tuffaceous breccias, than from 600 - 900 metres is intercalation of basaltic andesite and tuffaceous breccias.

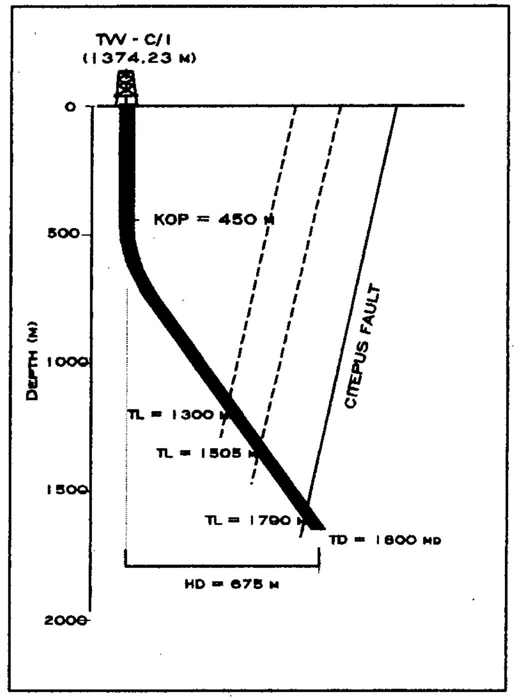

Fig 6 : Plan of TVV-C/I exploitation well, Kamojang, West Jawa.

The lower part of the formation 900 - 1700 metres are basaltic andesite.
Two feed zone are found in the depth of 1200 - 1375 t.v.d and 1400 - 1700 t.v.d. This zone can be interpreted of Pateungteng fault (dip of fault is 75 - 80°) and zone of Citepus fault (dip of fault is 75 - 80°). (figure 7).

VI. **Conclusion**

Target setting of both exploration and exploitation well at Kamojang are zone of reservoir. As far as we have to stick to the rule that reservoir geothermal must be a good porous and permeable, and have a good temperature (more than 225°C), analize of fault even came from geology, geochemistry or geophysical survey are very useful. Strike and dip of fault are olso useful for the obyection of the depth target of well or feed zone in the well. Intrusion evaluation and hydrothermal alteration proses are very important to fit the hot zone where the hot fluid come from.

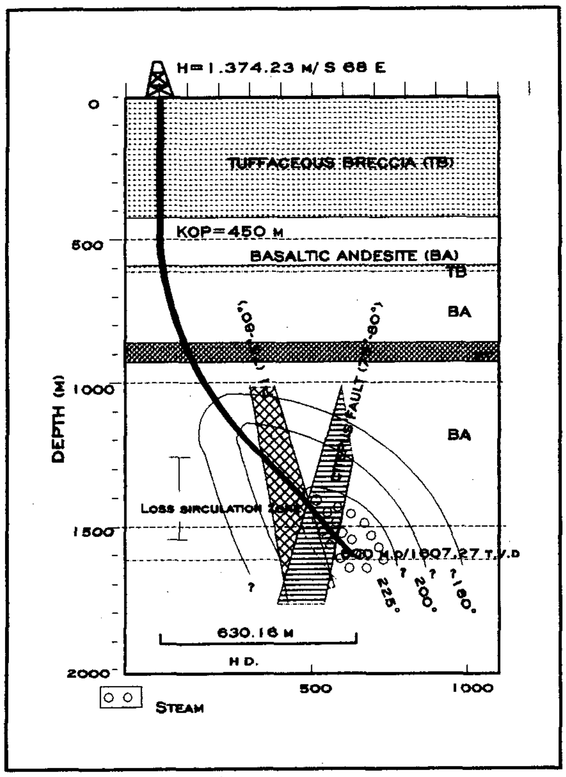

Fig 7 : Cross section of KMJ-54 well, Kamojang, West Jawa.

ACKNOWLEDGMENT

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