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MAPPING RESERVOIR PERMEABILITY WITH GEOELECTRICAL, FMS AND SPINNER DATA, KAMOJANG FIELD, INDONESIA

Sayogi Sudarman [1], Bambang Guntur [2], Doddy Setiadji [2] and Yos Sumantri [3]

[1]. PERTAMINA--Geothermal Division, Jakarta, [2]. PERTAMINA--Kamojang Field,
[3]. UPN-VY, Petroleum Engineering Department, Yogyakarta

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ABSTRACT

More than 60 wells have been drilled at the Kamojang field, a vapour-dominated resource with 140 MWe installed capacity. The resource is hosted by Quaternary volcanics, and fracture permeability is provided by horst and graben structures that intersect with volcanic collapse features. Resistivity data suggest that the resource covers 21 km^2. Production from wells in the northern and southern sectors of the field is reduced because of low permeability, although the wells encountered high temperatures.

The reservoir rocks are composed of the Rakutak basaltic andesite formation (~2 my) overlying the Gandapura andesite formation (~0.4 my). Petrographic studies of hydrothermal alteration in the reservoir rocks show that the Gandapura formation exhibits strong argillic alteration while the Rakutak formation exhibits low to moderate intensity propylitic alteration.

In order to map the permeability structure of the reservoir, geoelectrical data from CSAMT (Controlled Source Audio Magneto Tellurics) and MAM (Mise-A-la-Masse) have been analyzed together with bore hole data, including well production rates, permeability indications from lost circulation, and limited FMS (Formation Micro Scanner) and spinner data. The results are incorporated into a map of reservoir permeability. Good permeability extends to the NE and NW while moderate permeability extends to the south. A low permeability barrier is found inside the field. Spinner data indicate that higher productivity is associated with higher elevation reservoir feed zones. These studies of reservoir permeability indicate that both fault planes and the contact zone between the Rakutak and Gandapura formations provide important controls on reservoir permeability.

The permeability structure map can be used for planning the drilling strategy at the Kamojang field. In particular, these results support exploration drilling in the northeastern and northwestern sectors of the field.

INTRODUCTION

The Kamojang vapour-dominated field is located in West Java about 40 km south of Bandung, the provincial capital city. The field has been producing since 1983 and has 140 MWe installed capacity. Pertamina has drilled more than 60 wells in the field, and has drilled sufficient steam for a 60 MWe expansion. The production wells include a number of dry holes caused by low reservoir permeability, although reservoir temperatures are high.

To improve drilling performance, Pertamina has conducted several studies related to the permeability structure in the field. These include geological structure analysis, geophysical surveys, including CSAMT and MAM, and downhole surveys, such as FMS logs and spinner surveys in selected wells. These data have been integrated with production test data in order to develop a fracture permeability map of the field.

The mapping of permeability has two main objectives: first, to assist with selecting drilling targets and optimizing wellbore sizes, and, second, to provide a permeability distribution map that can be incorporated into the reservoir numerical model.

FIELD OVERVIEW

The Kamojang field is associated with a Quaternary andesitic stratovolcano. Geologic structures, which have been identified through field studies, include volcanic collapse structures forming crater walls and horsts and grabens associated with normal faults (Figure 1). The geothermal system is manifested by fumaroles, solfataras, boiling springs, mud pools and intensive hydrothermal clay alteration which occur at an intersection between the N-S trending Citepus fault and a series of NW-SE trending faults within the Gandapura formation (0.4 my). Clay alteration within the Gandapura formation forms a cap rock to the system, while the underlying Rakutak basaltic andesite (2 my) is the primary reservoir rock. Lost circulation while drilling is frequently found along the contact between the Rakutak and Gandapura formations. Reservoir entries are also believed to be associated with fracture permeability related to faults.

Sudarman et al (1990) interpret that the field has an areal extent of about 21 km^2 based upon the CSAMT resistivity anomaly (Figure 1). Exploration wells in the north and southeast have confirmed the size of the system. Only about 40% of the area has been intensively drilled, mostly covering the central part of the field. Nine of the production wells have low output due to inadequate permeability in the Rakutak formation.

The well output is divided into three catagories: low (<30 ton/hr), moderate (~30-55 ton/hr) and high (60 to >85 ton/hr) as shown in Figure 2. All of the wells are completed with 7 inch slotted liners, and the liners are set at an average depth of +250m asl (above sea level). Feed zones are found at average depth of about +400m asl, and they produce saturated steam with an average temperature of 240°C and pressure of 33 bars.

METHODS OVERVIEW

To map the permeability structure of the field, the CSAMT and MAM data were used as a base. Well productivity data were then compared to the resistivity anomalies identified with these two geophysical methods.

The CSAMT survey was conducted in 1989 with the data being collected in a radial configuration et 50-100m intervals (Sudarman et al., 1990). The data were interpreted by constructing pseudo apparent resistivity profiles. The profiles indicate that the reservoir rocks do not have a homogeneous resistivity distribution and that high permeability reservoir entries can be correlated to low resistivity anomalies <10Ohm.m (Sudarman et al., 1996).

P. Sumintareja et al. (1998) discuss the theory and the field procedure of MAM surveys. As injected electrical current flows from the bottom of the slotted liner into the reservoir rock, a current shortage will happen when the current flows into a permeable zone which contains geothermal fluids. This phenomenon produces a low resistivity value at surface monitoring stations.

The MAM surveys were conducted in two stages. Both adopted a radial configuration with a theta of about 22.50°, a radius of about 1.5 km, and a sampling interval of 200m. The first survey used two production wells as line electrodes, KMJ-63 in the west and KMJ-48 in the east. For the second stage, the directional well KMJ-47 was used as the line electrode in the northern area where the manifestations occur. As with the CSAMT data, resistivity profiles are constructed and evaluated with regards to permeability in the reservoir.

Additional information regarding the permeability distribution was provided by FMS and spinner logs obtained from some of the wells in the field. These data were particularly valuable for understanding variations in the distribution of vertical permeability. FMS surveys allow identification of the orientation of permeable features and can help distinguish between permeability associated with bedding planes versus fractures. The spinner surveys provide information concerning the relative contributions of fluid from the feed zones of a well.

RESULTS AND DISCUSIONS

Figure 3 shows the CSAMT pseudo apparent resistivity map (left) and the MAM anomaly map of DV/I<0(center). The inferred permeability map (right) was constructed by integrating the bore hole data with the resistivity maps. The CSAMT data produces three resistivity zones, high (>25

Ohm.m), moderate (10-25 Ohm.m) and low (<10 Ohm.m). The MAM data show only two zones, either a positive or negative anomaly. An overlay of one map onto the other shows that there is good agreement in the northeastern part on the reservoir, where the low CSAMT anomaly corresponds with the negative MAM anomly. Agreement between the two resistivity maps is not as good in the central part of the reservoir. The well production data help resolve this discrepency, by showing that the discrepency results from a low permeability region, or barrier, in the central part of the field. The field can thus be divided into three permeability zones: low, moderate and high. The low permeability barrier, which has been encountered by 9 wells, is located in the center part of the field, covering an area about 3.3 km^2. The permeability barrier is surrounded by a 12.2 km^2 high permeability zone. The moderate permeability region covers 5.5 km^2 in the southernmost part of the reservoir area.

The correlation between CSAMT resistivity, reservoir transmissivity and well production data is shown in Figure 4. These data indicate that resistivities less than 10 Ohm.m correspond to high transmissivity (30-80 Darcy-meter). Thus, low resisitivity values show a relationship to high well outputs (60 to >85 ton/hr steam).

The permeability map in Figure 3 (right) and the geological structure map (Figure 1) do not correlate well. The zone of high permeability is much wider than indicated by the mapped faults. The widespread nature of the permeability zone is interpreted to indicate that bedding contact zones are also an important control on the permeability distribution in the field. The FMS data support this interpretation. The FMS data show many low angle fractures (20-40°), such as in KMJ-63 (Figure 5). These low angle fractures may be related to the lithologic transition from the Gandapura to the Rakutak formations.

The spinner data also support the interpretation that there is a lithologic control on permeability (Figure 5). Major feed zones identified from the spinner data often occur at +400m asl, suggesting a horizontal control to the permeability.

Figure 5 also shows a vertical distribution of hydrothermal clay and major sealing minerals, eg. silica and carbonate for each permeability zone. The relative abundances of these minerals are estimated through petrographic descriptions. It is believed that these minerals also play a role in the quality of the reservoir permeability. The vertical profile indicates that the abundance of hydrothermal clay generally decreases with depth. The sealing minerals provide a different trend. In zones of high permeability, the sealing minerals amount to less than 30% of the alteration minerals. For zones with moderate and low permeability, the minerals tend to increase with depth from 10% to 40% and from 20% to 65%, respectively. Therefore, the abundance of sealing minerals suggests that the low permeability barrier at the center of the field is produced by self-sealing through the precipitation of hydrothermal minerals. This zone is interpreted to be a paleo upflow zone of the reservoir.

CONCLUSIONS

By combining geophysical data, bore hole logging surveys and well production data, insights have been gained into the nature of permeability in the Kamojang reservoir. The permeability can be incorporated into a permeability map that characterizes the reservoir. Reservoir permeability is found to be controlled by both steeply dipping faults and bedding planes along the contact of the Rakutak and Gandapura formations (Figure 5). The bedding planes impart a more widespread lateral high permeability zone than would be expected from the distribution of the faults. Spinner data reveal that permeability is higher in the upper entries. The permeability map (Figure 3 right) shows that the lateral high permeability zone extends to the northeast and northwest of the production area and therefore provides new targets for drilling.

A low permeability zone occurs at the center of the field and is interpreted to be caused by self sealing silica and carbonate minerals which can constitute as much as 65% of the total alteration mineral content of the rock (Figure 5).

The permeability map helps to categorize the permeability distribution into the following zones:

- High permeability zone: Area=12.2km^2, Kh=30-80 D.m, with average well production of 60 to >85 ton/hr steam at 15 ksc.
- Moderate permeability zone: Area=5.5 km^2, Kh=10 D.m and average well production at 30-55 ton/hr steam.

- Low permeability zone: Area=3.3 km^2, Kh=2.2 D.m and average well production of less than 30 ton/hr steam.

RECOMMENDATIONS

Future drilling success will provide further confidence in the permeability map. Step-out delineation wells are recommended for the northeastern and northwestern portions of the field. Slim holes should be drilled to 2 kilometers depth in these sectors, and if commercial permeability is discovered, the feasibility of drilling big hole production wells should be evaluated.

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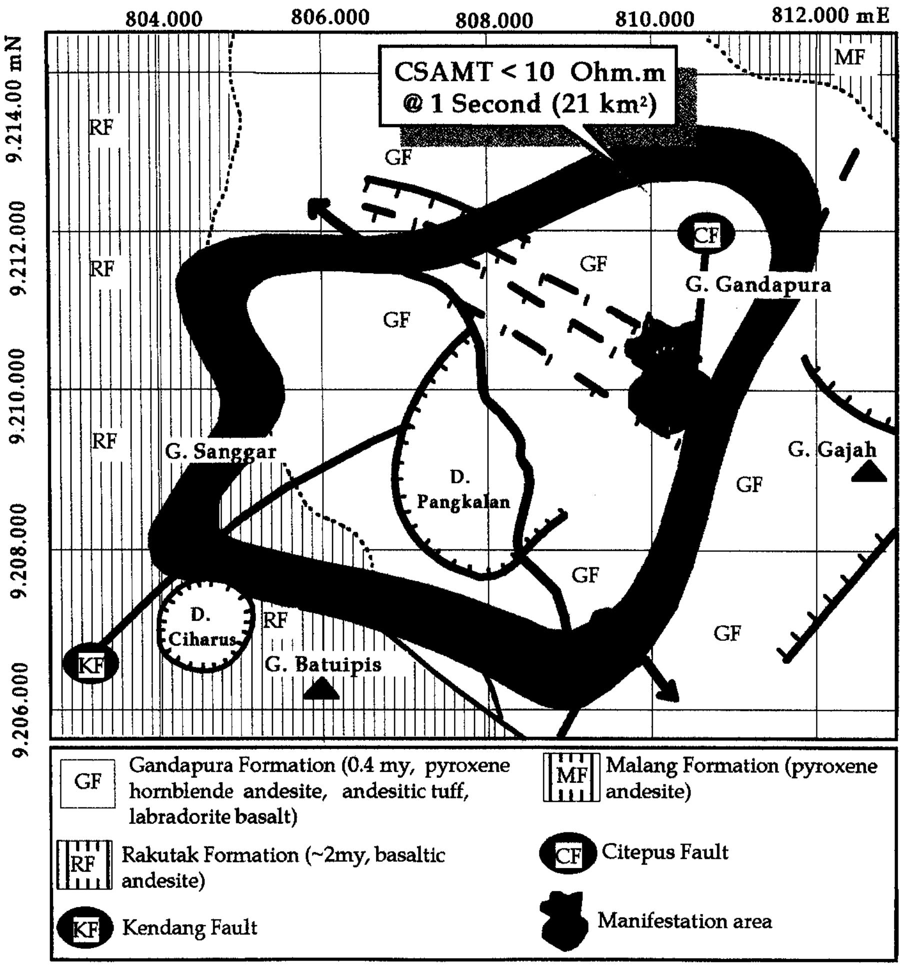

Figure 1 Geology, Manifestations and Field Boundary at the Kamojang Vapour Dominated Field

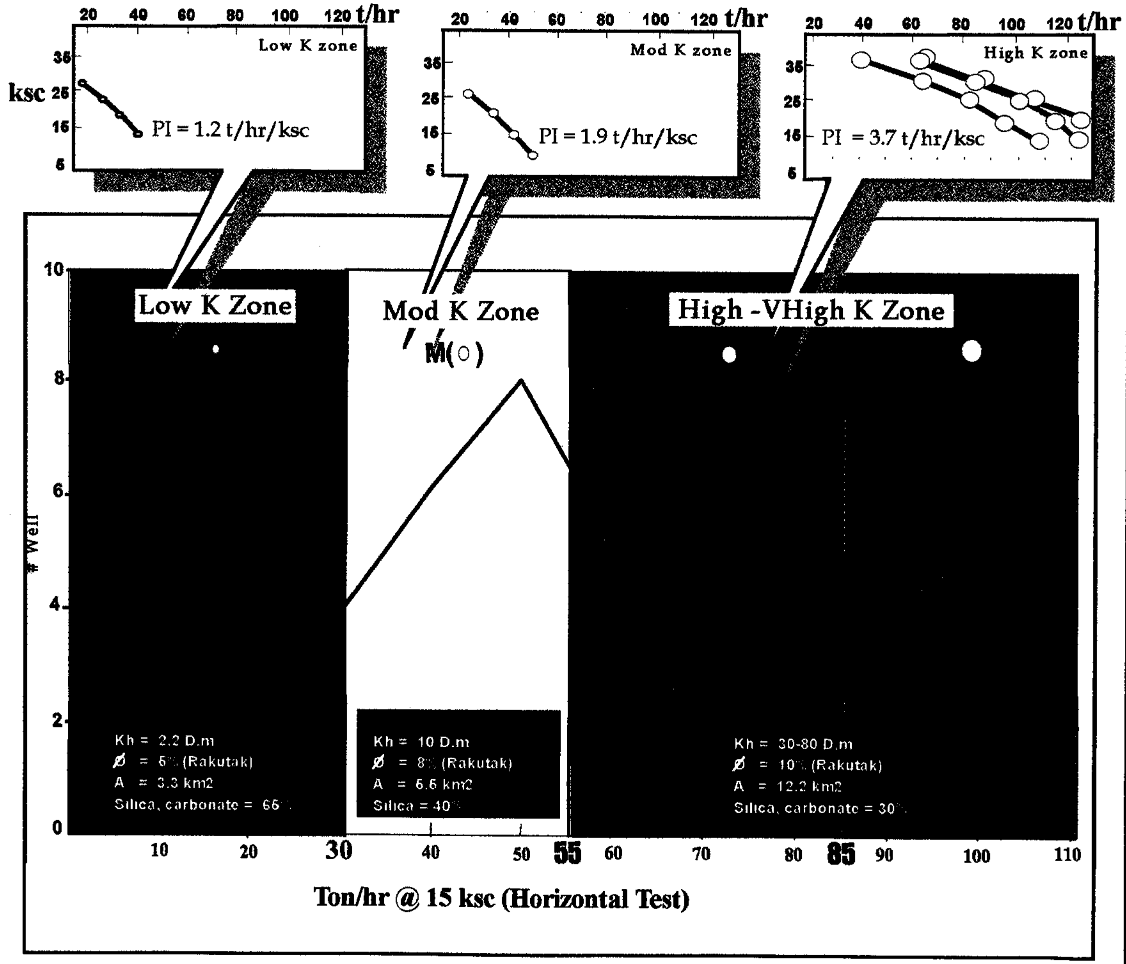

Figure 2 Kamojang Well Data (7 Inch Slotted Liner)

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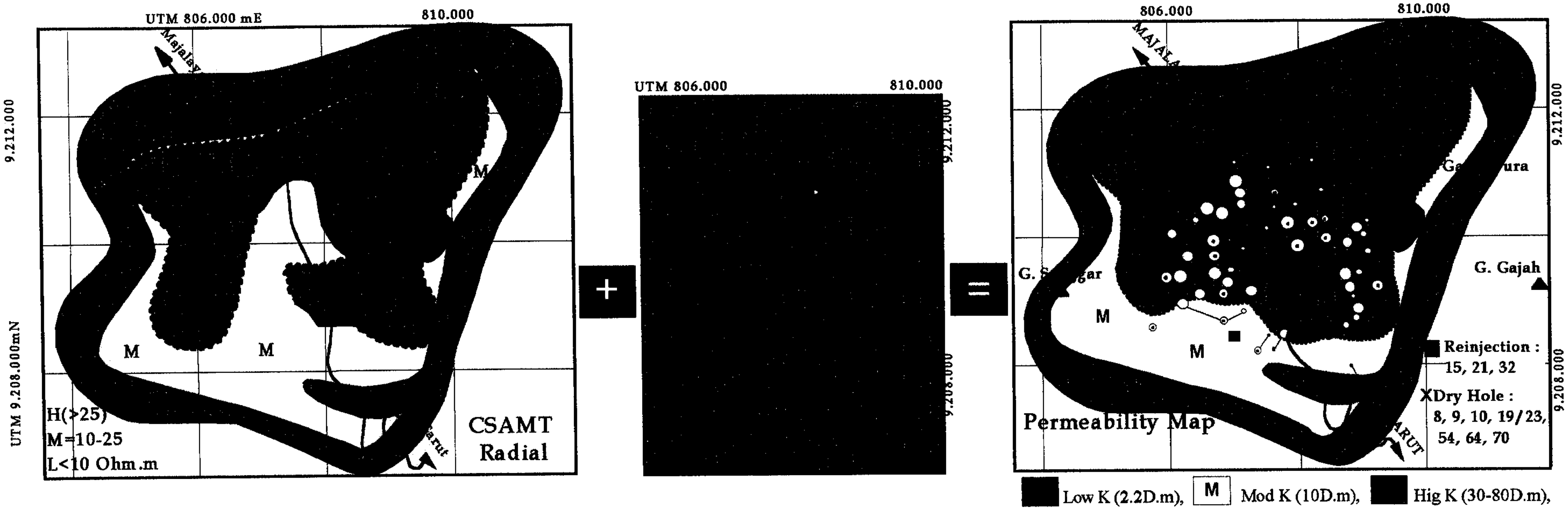

Figure 3. Permeability Map of the Kamojang Feed Zone @ +400m asl, Showing the Process and the Final Result

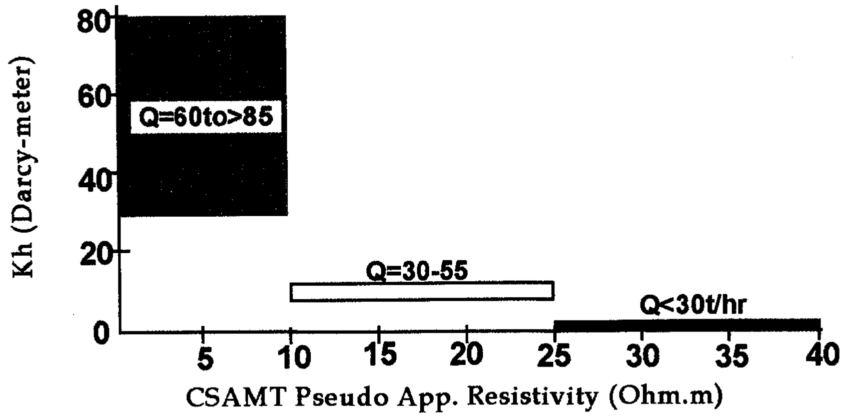

Figure 4. Resistivity--Permeability--Well Production Relationship of the Kamojang Vapour Dominated Field.

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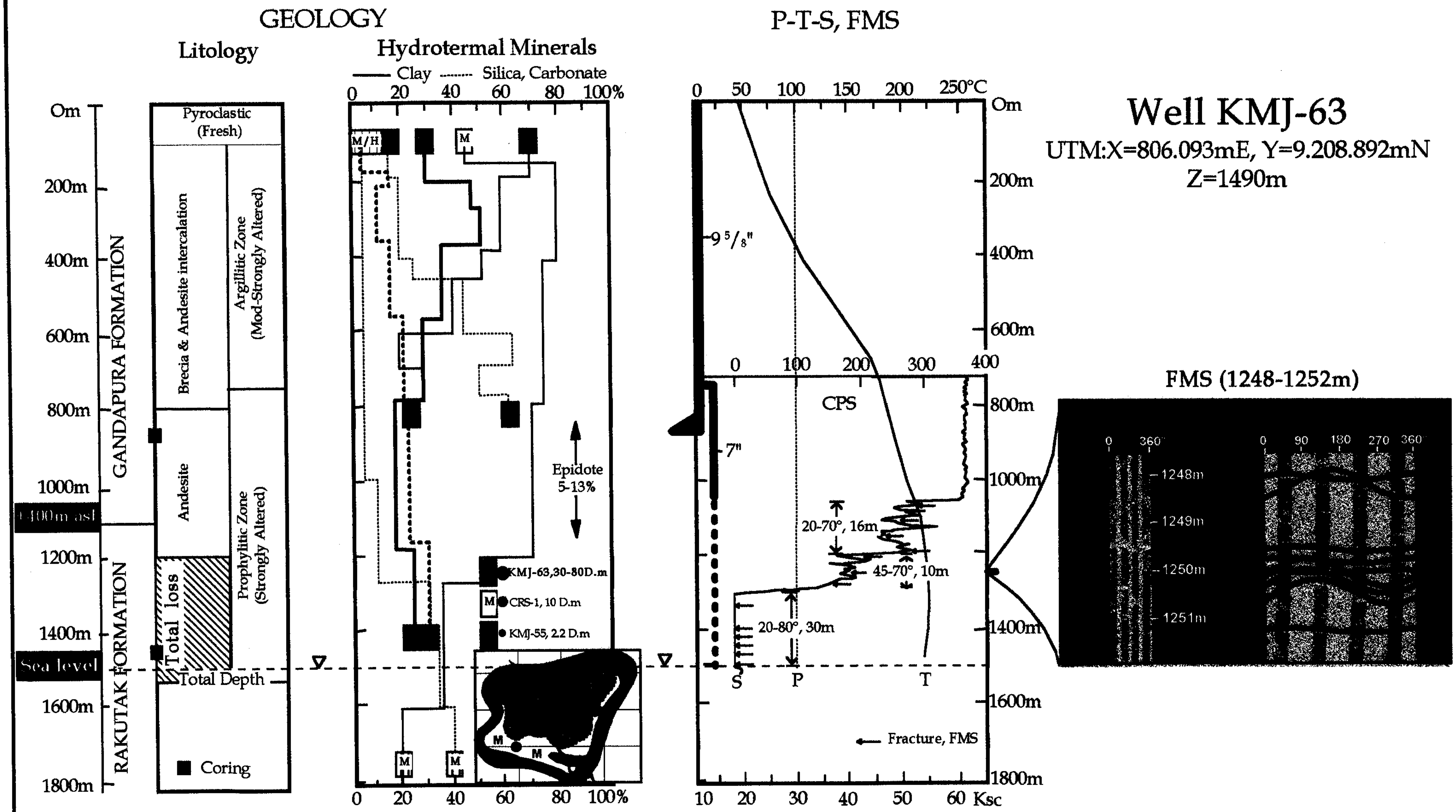

Figure 5 Subsurface Geology, P-T-S and FMS Data of KMJ-63 (High K Zone). Sealed Minerals From CRS-1 (Moderate K Zone) and KMJ-55 (Low K Zone) Are Also Drawn for Comparison.

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