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RESULTS OF I-I DEEP WELL: IMPACT ON THE CONCEPTUAL MODEL OF THE SALAK GEOTHERMAL SYSTEM

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ABSTRACT

I-I deep well, the last well of 2012-2013 Salak Drilling Campaign, was drilled at Pad I with two objectives, namely, (1) augment steam supply and (2) reduce the uncertainty of the base of reservoir (BoR) in the inferred upflow region southwest of Salak (also known as Awibengkok) Geothermal System. Although the well was completed about 20% shallower than planned to 10,402' MD (3,170 m) only, it is now the deepest well drilled in the Salak reservoir.

Interpretation of borehole image logs indicates that I-I deep well intersected predominantly pyroclastics (volcanics) with interbedded lavas and sedimentary rocks below 10,000' MD. These units appear to be a member of the Marine Sediments and Volcaniclastics (MSV) Formation which is now deeper than what were previously interpreted as continuous sedimentary rocks. Before, it was believed that sedimentary rocks (called Continuous Sediments Formation) underlie the MSV Formation to form the basement of the Salak reservoir.

I-I deep well successfully encountered the deepest permeable entry to date at ~6,350' BSL at Salak. It confirmed the presence of deep permeability (likely related to the geothermal system's upflow) in this part of the field and prompted a revision of the P10 BoR. Geology, geochemistry, and Pressure-Temperature (PT) data also support the interpretation of a high-temperature upflow in the Pad I area. However, both Qtz and NKC geothermometries don't work very well because brine injection at Pad I since 1994 has impacted the reservoir and has camouflaged the original chemistry of Pad I wells. These favorable results at I-I deep well confirm previous interpretations that the upflow of the geothermal system is beneath the southwest area. The presence of the deep feed zone in the MSV Formation indicates that this formation is not the basement of the geothermal reservoir and supports further drilling of deep wells in this area.

Keywords: Salak, Deep Well

INTRODUCTION

The Salak geothermal field is located in West Java, Indonesia along the Sunda Volcanic Arc (Figure 1). It is situated in a mountainous area with elevation ranging from about 950 to 1,500 m above sea level (ASL). The field is about 60 kilometers from Jakarta, capital city of Indonesia. Salak is one of the world's largest liquid-dominated geothermal fields with a current total installed capacity of 377 MWe. Six power plants are found in Salak with 180 MWe from the PLN Units-I/II/III and 197 MWe from the Star Energy Geothermal Salak Units IV/V/VI.

The Salak geothermal system lies in a highland on the southwestern flank of the Gunung Salak volcano (2211 mASL). The commercial resource is spatially associated with andesitic-to-rhyolitic volcanism that has occurred over the past 330 ka, especially silicic volcanics erupted in the last 280 ka along a major NNE-trending structure. It is fracture-controlled reservoir with benign chemistry, low-to-moderate non-condensable gas (NCG) content, moderate-to-high temperature (240–312°C) geothermal resource with high fracture permeability, moderate porosity (mean = 10.6%) and moderate-to-low matrix permeability (geometric mean = 0.026 md) (Stimac et al., 2007).

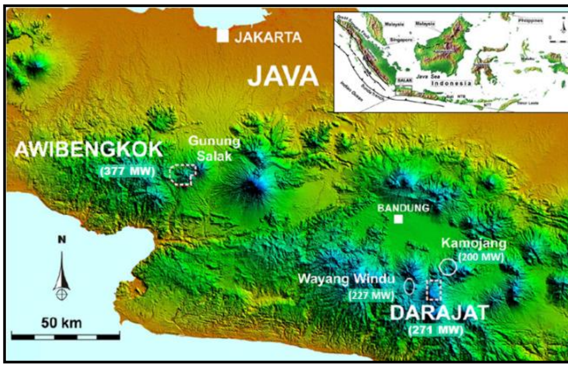

Figure 1: Map of West Java showing major cities and volcanic centers. Also shown are the Awibengkok/Salak and Darajat geothermal contract areas (dashed polygons) and other producing geothermal fields in the general area (Aprilina et al., 2015).

BACKGROUND OF I-I DEEP WELL DRILLING

Salak geothermal field is one of three geothermal fields operated by Star Energy Geothermal which has been produced for more than 20 years of commercial operations. In order to maintain steam supply to support full generation, one of the strategies is steam production program through drilling campaign. The latest drilling campaign in Salak field was conducted in 2012-2013 which has been completed 13 new drilling wells.

I-I deep well was targeted to the south from the I pad and was drilled primarily for steam supply and Value of Information (VOI) to test temperature and permeability at depth in the area of the inferred upflow region of the Salak reservoir, to reduce uncertainty about the Base of Reservoir in the southwestern area of the field, below elevation -5,500 ft.sl (Figure 2).

Pad I is located at area where the highest reservoir temperature was measured, with distinct fluid chemistry showing stronger magmatic influence, and petrographic evidence of intrusive rocks and contact metamorphism (Stimac et al., 2008). The MEQs directly beneath the I pad are believed to be related to injectate and/or pressure transients down a deeply extending vertical fracture system. These evidences support the interpretation of deep fluid convection and that the fracture system related to upflow of the geothermal system is in West Salak.

The base of a geothermal reservoir is defined when the permeability of the rock is not enough to sustain commercial production. This corresponds (more or less) to a permeability of 1 - 10 mD, which is the permeability assigned to the deepest active block layer at -6,000 ft.sl. in the Salak reservoir model (Kusumah et al., 2013). Data from recently drilled deep wells (O-CRD; I-G; I-H; and J-D) show potential for an extension of permeability at depth. Also, the depth of recorded MeQ / micro-seismicity events indicates the possibility that permeability could extend as deep as -13,000 ft. ASL in the southwestern area of the field in the vicinity of the I pad (Figure 3). In other geothermal field (e.g. Larderello, Italy; Bulalo, Philippines), substantial reserves have been found below what previously was thought to be a reservoir bottom. A very deep well at the I pad will help to reduce uncertainty about a possible deep reservoir at Salak.

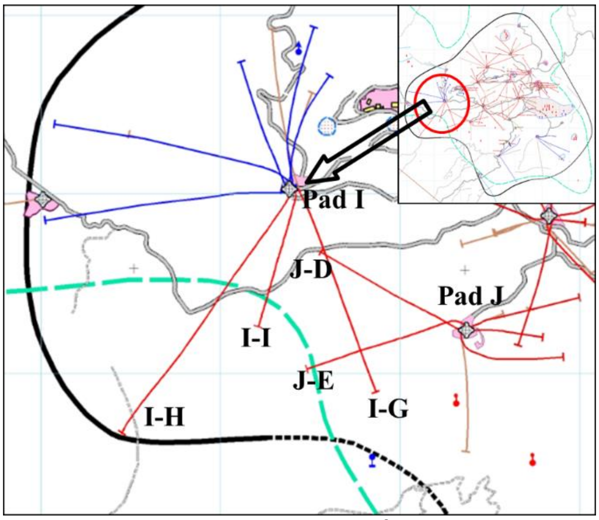

Figure 2. Map showing the location of Pad I, Pad J, I-I deep well, and surrounding wells. Upper right map showing well locations and commercial reservoir boundary of Salak Geothermal Field.

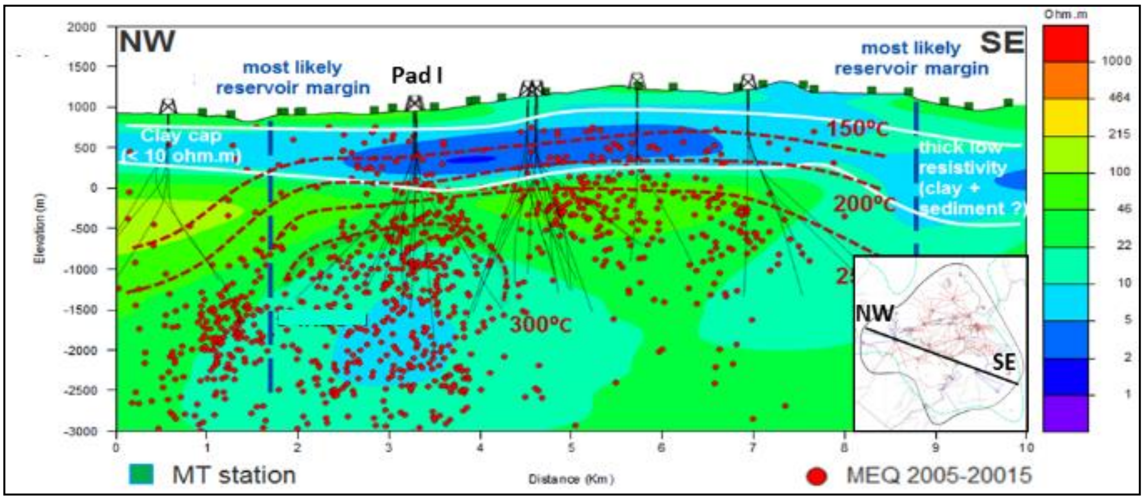

Figure 3. Cross-section across the seismicity zones in south Salak. Profile also showing the low-resistivity clay cap as defined by the 1D MT layered model (invariant mode; white dashed lines) and the 3D MT inversion model (colored background) with the isotherm contour. The low-resistivity body below the 200°C isotherm is an artifact of the 3D modeling.

I-I DEEP WELL DRILLING SUMMARY

I-I deep well was designed as a low inclination (17°) standard 2D directional well targeting production from the deep brine reservoir south of the I pad. I-I deep well was planned to be drilled to 13,000 ft.MD /12,481 ft.TVD (9,175 ft.BSL) and to be completed with 4 different diameter holes (26", 17-1/2", 12-1/4" and 9-7/8") and 1 contingency hole (7-7/8"). The drilling was started with 26" hole section to depth of 1798 ft.MD and then followed with 17-1/2" hole section to the top of reservoir depth at 4314 ft. The 13-3/8" production casing was set and cemented at 4304 ft.MD in altered (silicified) dacite tuff. Epidote was first observed in drill cuttings at 4309 ft.MD and became persistent below about 4960 ft.MD. Reservoir section was drilled with 12-1/4" hole section to the depth of 9702 ft.MD and followed by landing the 10-3/4" perforated casing to the bottom. This section was completed with 2 bit ran safely with no stuck pipe event and also during drilling those section were successfully managed the return to the surface. After drilled out 10-3/4" casing shoe, while continuing drilling about 300 ft.MD of 9-7/8" hole section, the well experienced big total losses that lead to hydrostatic column dropped significantly in the wellbore and followed by increasing wellbore temperature and pressure that lead to well control issue. Due to the high risk of wellbore phenomena uncertainty then the team decided to suspend drilling in order to be able to do study for better understanding the wellbore phenomena (Souvanir et al., 2015). I-I deep well actual schematic depict in Figure 4.

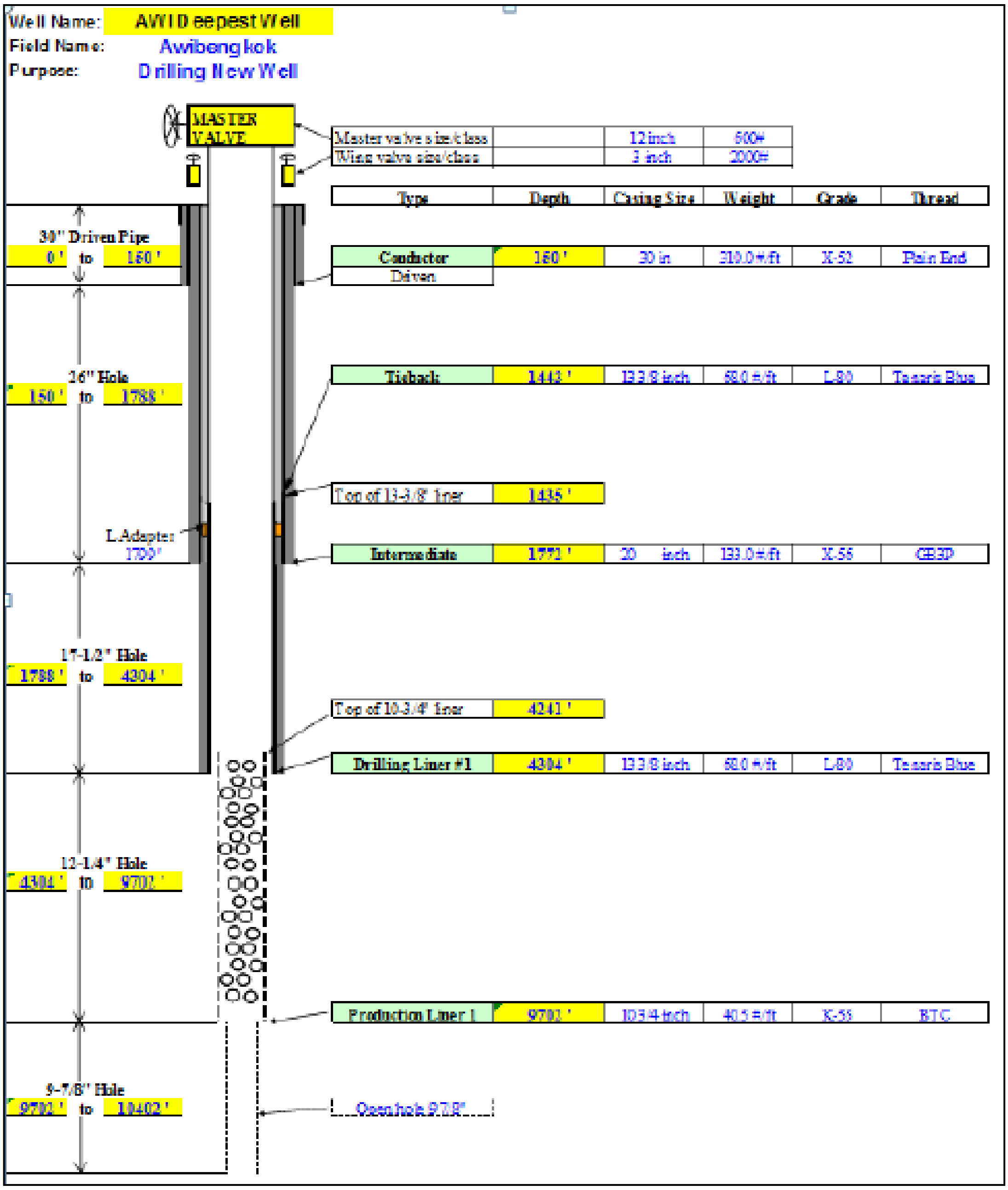

Figure 4. I-I deep well actual schematic.

I-I DEEP WELL RESULTS

The lithological sequence intersected by I-I deep well is similar to that encountered in offset wells I-G, I-H, and J-D especially above the reservoir hole section. In general, the lithological sequence of I-I deep well based on cutting description can be divided into six major formations, namely Upper Dacite, Upper Andesite, Middle Dacite, Middle Andesite, Rhyodacite Marker (RDM), and Lower Andesite. However this well was blindly drilled starting at 6,505' MD until TD. In this hole section which was drilled without mud returns, the only means of obtaining lithologic data were come from Total Count Gamma Ray (GR), Spectral Gamma Ray (HNGS), and borehole resistivity image logs which was conducted at 9734-10359 ft.MD (Figure 5). A previous study about identifying reservoir rocks using drilling data mentioned that the Rhyo-Dacite Marker (RDM) at Salak has a high GR response that is discernible in the GR log. In addition, the Marine Sediments and Volcaniclastics (MSV) Formation exhibits another increase in GR response (Pamurty et al., 2015).

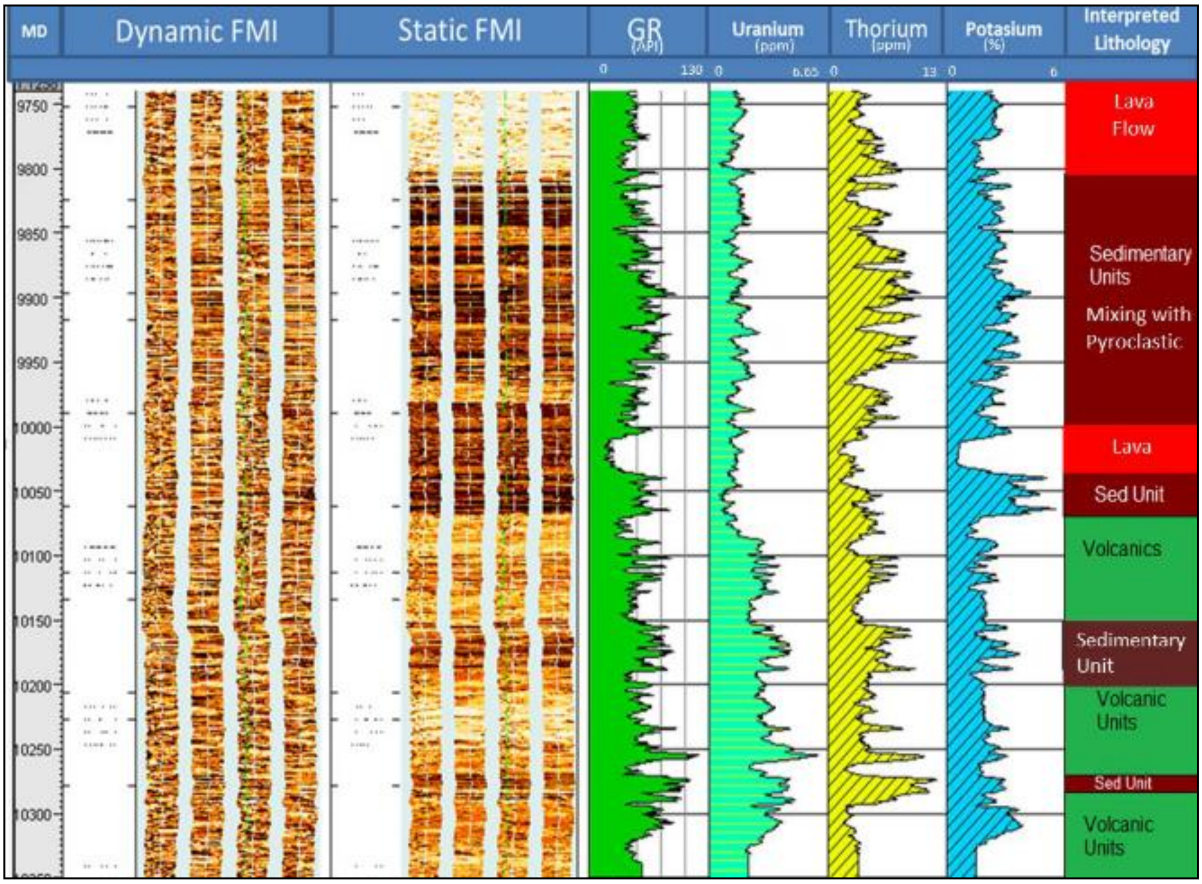

Figure 5. I-I deep well lithology interpreted from borehole resistivity image log, total count Gamma Ray (GR), and Spectral Gamma Ray (HNGS) showing occurrence of volcanic rocks (Marine Sediment Volcanic Formation) at depth.

Lithology interpreted in this blind drilling section predominantly consists of breccias interlayered with clastic sediments and carbonate rocks. The carbonate rocks are interpreted to be correlated with the Bojonglopang (or Bantargadung) Formation that has a similar Middle Miocene age. Volcanic rocks mixing with these sedimentary rocks are common in the deep wells. The deep section petrography suggests that the marine sediments and other sedimentary units are mixed with the volcanics instead of being deposited as a continuous sequence. The volcanic materials found in the sedimentary units are believed to be reworked materials due to natural sedimentation process and/or orogenic movement rather than volcanic activity. It is supported by image log interpretation which indicates that the sedimentary rocks at Salak are strongly folded (Figure 6). These bedded units have various strikes and dips, from gentle to steep, and are interpreted as folded and maybe faulted. Both Martodjojo (1984) and Clements and Hall (2007) theorized that sedimentation decreased due to uplifting or orogenesis in the southern part of West Java in Late Miocene. Volcanogenic materials were deposited by turbidity currents and debris flows (Bantargadung and Saguling Formations) in the middle part of the Bogor Basin (Clements and Hall, 2007). The Bantargadung and Saguling Formations are dominated by breccia with boulder-sized fragments of andesite and limestone.

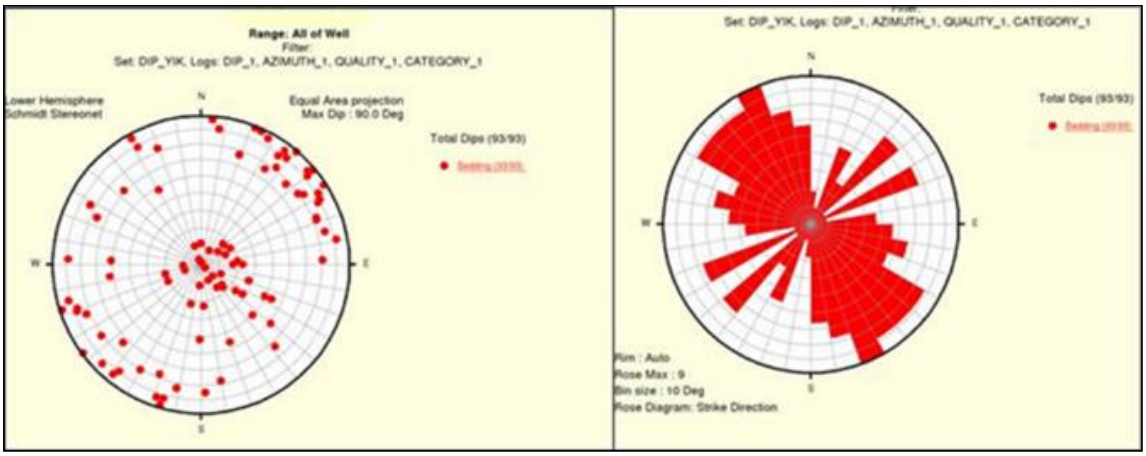

Figure 6. Dipmeter plot show that the dips of the bedded sedimentary rocks can be grouped into both shallow (<45°) and steep (>60°). The steeply dipping beds support the theory that these sediments may be folded.

Based on Pressure-Temperature-Spinner (PTS) and heat-up survey data, I-I deep well encountered three permeable zones at 6,150 ft.MD, 6,530-7,030 ft.MD, and 10,030 ft.MD (Figure 7). The deepest feed zone at 10,030' MD has high temperature (610° F), high pressure (1,300 psi), and high enthalpy inflow. Eventhough borehole resistivity image log indicates no direct correlation between the feed zone location to the structure data, the interval range of this feed zone to permeability indication (fractures/fault cluster , and significantly drop in pressure while drilling/PWD) is 67 ft.MD. This suggest that feed zone may still correspond to the large fractures occured at 9960-9965 ft.MD (Figure 8).

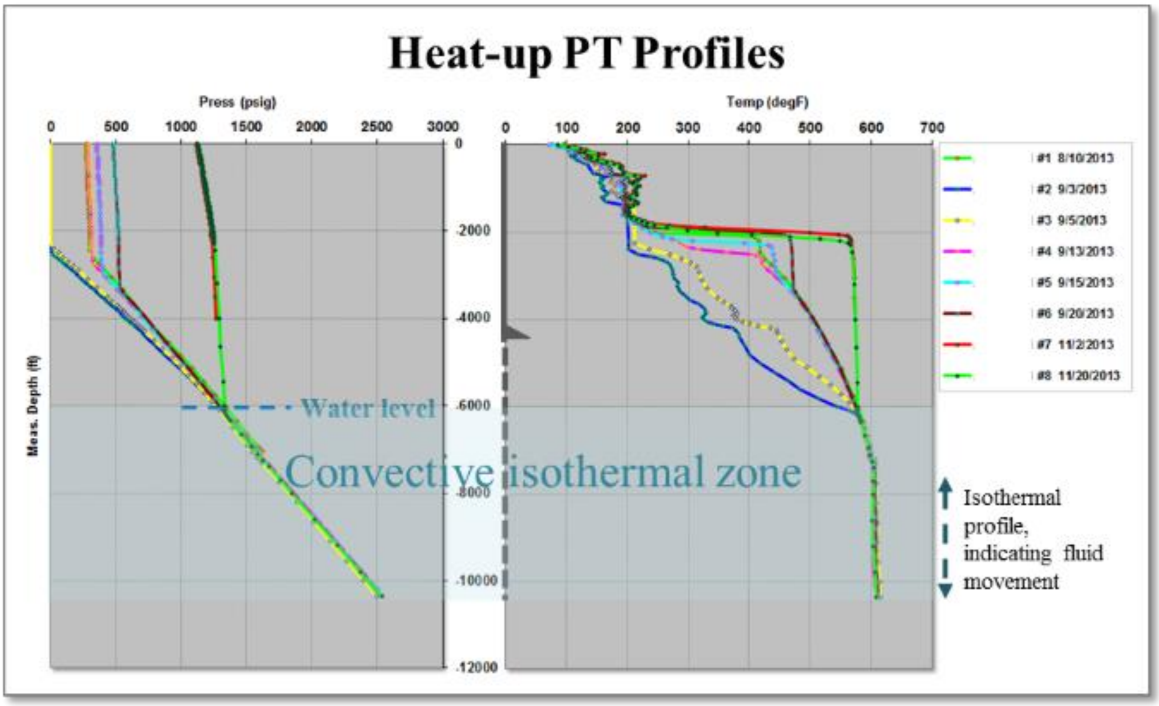

Figure 7. Heat-up PT Profiles of I-I deep well. Deep upflow creates convective isothermal zone that was undisturbed during completion test.

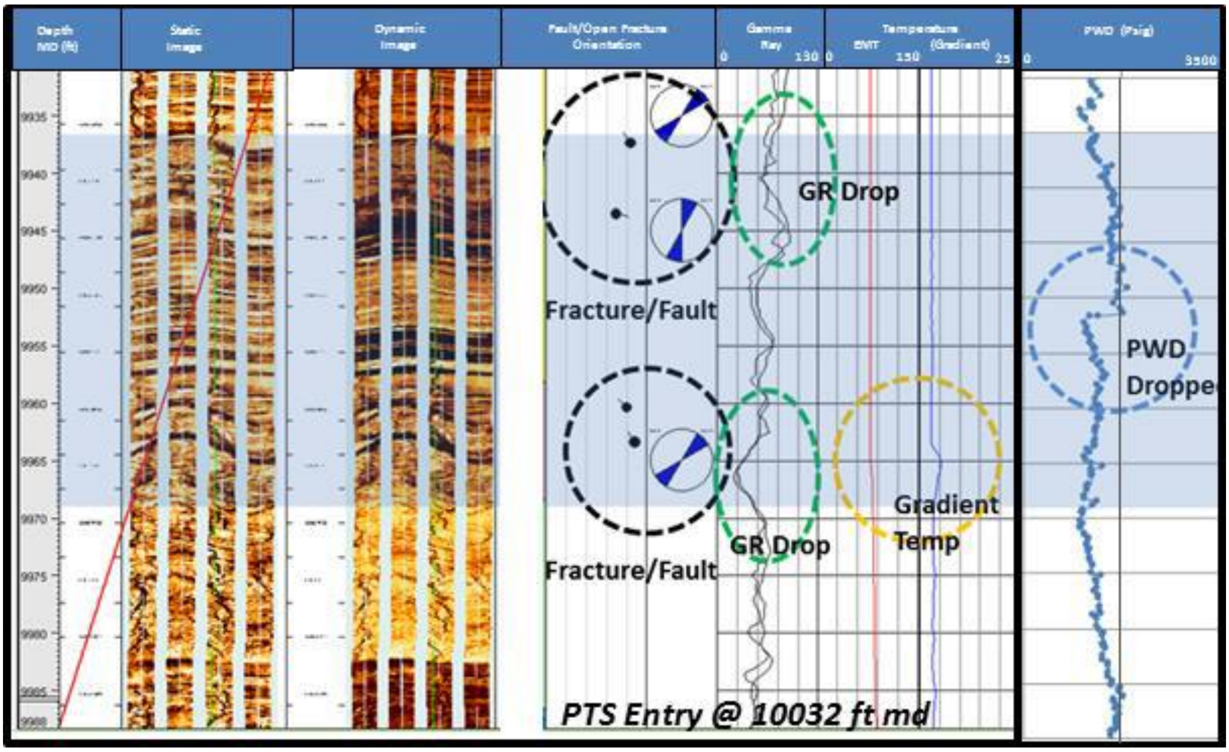

Figure 8. Borehole resistivity image log shows fractures/fault cluster at 9960-9965 ft.MD that coincident with significantly drop in pressure while drilling (PWD). These features may correlate with thee deepest entry in I-I deep well at 10,030 ft.MD.

IMPACT TO THE SALAK CONCEPTUAL MODEL

Interpretation of borehole image logs indicates that I-I deep well intersected predominantly pyroclastics (volcanics) with interbedded lavas and sedimentary rocks below 10,000 ft.MD. These lithology units are deeper than what were previously interpreted as continuous sedimentary rocks. Wells that penetrated the deeper, more continuous sedimentary sequence often show conductive temperature gradients suggesting that the sediments represent the basement of the Salak reservoir in some portions of the field. Before, it was believed that sedimentary rocks (called Continuous Sediments) underlie the Mixed Volcanics-Sediments (MVS) to form the basement of the Awibengkok reservoir. However, this deep sequence of pyroclastics and sedimentary rocks at I-I deep well suggests that the MVS is present deep in Salak. Furthermore, this new interpretation suggests that separating the sedimentary rocks into the Mixed Volcanics-Sediment (MVS) and Continuous Sediments (CS) based on the occurrences of volcanic materials and predominant carbonate rocks, respectively, is impractical now. It is probably best to combine the MVS and the carbonate-rich CS (now herein called the Marine Sediments and Volcanics or MSV).

The deep entry at 10,030 ft.MD (6,350 ft.BSL), now the deepest fluid entry identified to date at Salak, confirmed the presence of deep permeability (likely related to the geothermal system's upflow) in this part of the field and prompted a revision of the P10 BoR (low case). These favorable results at I-I deep well confirm previous interpretations that the upflow of the geothermal system is beneath the I Pad. The presence of the deep feed zone in the Marine Sediments Volcanics (MSV) indicates that this formation is sufficiently permeable to sustain commercial production and suggests that this formation is not the basement of the geothermal reservoir.

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