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Cold Water Downflow Identification in The Upflow Zone

Vivi Nusantara*[1], Muhammad Ikhwan[1], Tofan Sastranegara[1], and Dhanie Marstiga[1]

[1] Directorate of Exploration & Development, Pertamina Geothermal Energy, INDONESIA.

(E-mail: vivinusantara@pertamina.com)

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ABSTRACT:

This study presents a subsurface investigation to identify and mitigate cold water downflow within the upflow zone of a geothermal system. Despite intersecting a prominent reservoir, the risk of reduced well productivity remains due to cold water downflow below a “leaked caprock”. A thin conductive layer interpreted as caprock discontinuity may allow shallow cold water to intrude into the reservoir. Low smectite content and an extensive transitional alteration zone observed during drilling may serve as early indicators of a leaked caprock.

1. Introduction

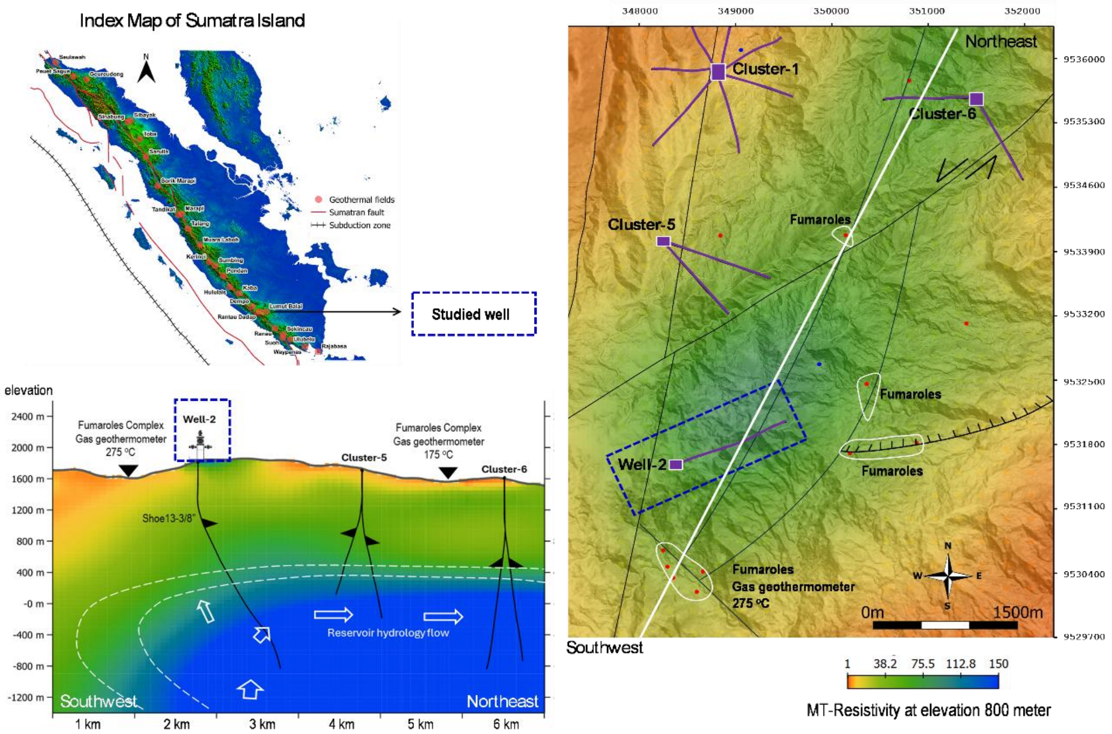
Wells targeting the upflow zone of a geothermal system are typically anticipated to deliver the best output. However, some wells exhibit low productivity despite reaching the sweet spot. One potential factor contributing to well underperformance is the intrusion of cold water downflow due to a poorly developed caprock. This paper presents a case from “Well-2” in the Lumut Balai Geothermal System, South Sumatra, Indonesia (Figure-1).

“Well-2” is a 3000 m well drilled at the upflow zone and successfully penetrated the permeable high-temperature reservoir [2]. Its production casing depth was determined primarily by the MT-Resistivity model, mineralogical observation, onsite Methylene Blue Dye Test (MBT), various drilling parameters, and PT data. All these datasets and evaluations were used for this study.

2. Results

The MT-Resistivity model characterizes the caprock as a conductive body below 60 Ωm, located at 1600 to 1100 masl. A pronounced thinning conductive layer was observed near Well-2, which is commonly associated with an active upflow regime. This model is further supported by the presence of a fumarole complex in the area, with geothermometer temperatures reaching up to 275°C (Figure-1).

Figure 1. Location map and MT-Resistivity profile of studied well.



Upon drilling, onsite MBT analysis from the caprock interval measures the smectite content ranging from 12 to 23%, significantly lower compared to other wells. Smectite concentration within the caprock are higher in Cluster-5 (48%), Cluster-6 (42%), Cluster-9 (72%), and Cluster-A (75%). First epidote in Well-2 was identified at 940 masl, coinciding with 6% smectite concentration. At greater depths, core samples revealed a mature reservoir system near the heat source, indicated by the presence of epidote, actinolite, and garnet (Figure-2).

During the drilling of the 17-1/2" hole section, severe Total Loss Circulation (TLC) conditions led to multiple cement plugging operations. A subsequent formation collapse occurred within the lava unit between 1210 to 1024 masl, likely due to the intensive natural fractures (sheeting joint). This hole problems caused several stucked-pipe and mechanical failure in the drill strings. As a result of these operational challenges, the production casing had to be set prematurely at 700 meters above the Top of Reservoir (TOR).

PT logs were acquired through a series of downhole measurements (Figure-2). Well-2 is characterized as a high-temperature, low pressure well. A convective trend is observed from -100 to -800 masl, suggesting active fluid circulation within the 262^{o}C reservoir. Four distinct feed zones were identified, each exhibiting unique temperature behavior (Table-1).

Figure 2. Detailed subsurface model and PT log interpretation of “Well-2”.

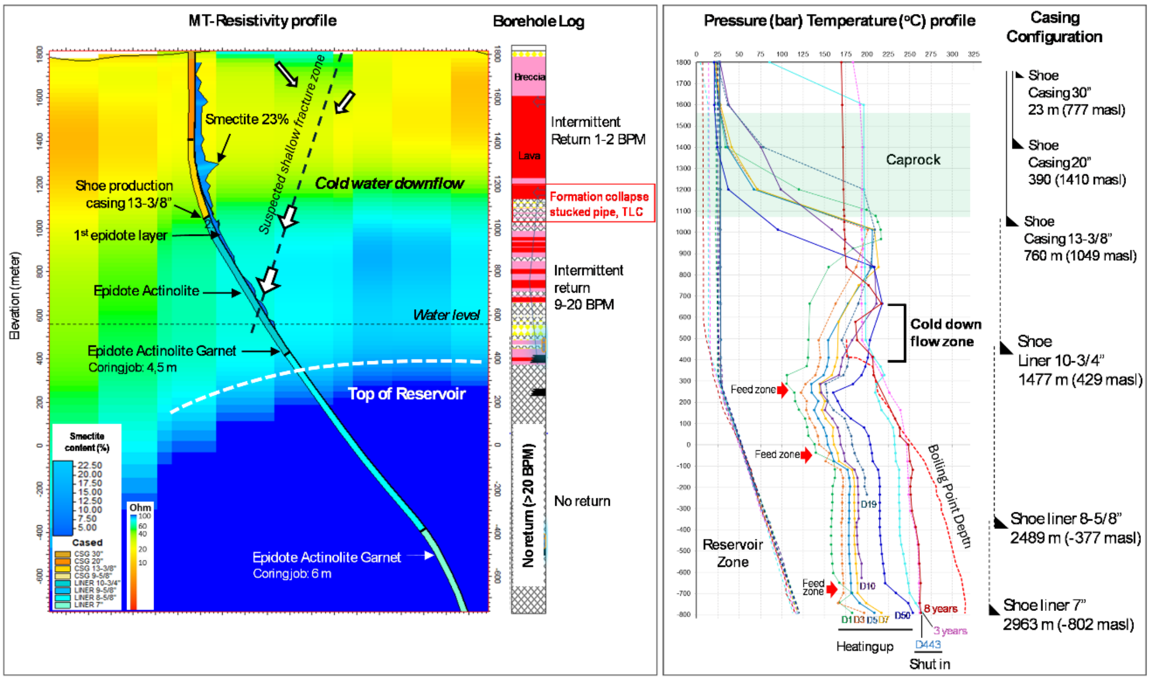


Table 1. Identified feed zone in Well-2.

Feedzone	Location (masl)		Alteration Type	Remarks
	Top	Bottom		
FZ-1	578	493	Transitional	Cold wáter downflow
FZ-2	328	246	Propylitic	Hot water
FZ-3	-38	-78	Propylitic	Hot water
FZ-4	-697	-744	Propylitic	Hot water

3. Discussion

The caprock is indicated at 1600 to 1100 masl (Figure-1). However, the low smectite concentration within this interval suggests that the caprock is poorly developed. The thinning feature at MT-Resistivity model was initially interpreted as an updoming signature that commonly observed in the upflow zone. However, in the case Well-2, this thinning structure likely represents a caprock discontinuity which facilitates shallow cold water downflow into the borehole.

Surface lithology near Well-2 is composed of the youngest ignimbrite, lava, breccia, and intrusion units from the Lumut Dome Formation [3], suggesting a central to proximal volcanic facies [1]. Garnet and intrusive rocks further confirm that Well-2 was drilled in the upflow zone, near to a diatreme breccia and magmatic heat source. Due to its brecciated structure, diatreme breccia is highly permeable and potentially allows meteoric water to percolate into the reservoir.

In high-rainfall and high-elevation areas where Well-2 sits, strong hydraulic gradients can drive cold water downflow through fractures, particularly where the caprock is poorly developed. This may cause thermal interference and partial cooling, as observed in Well-2. The coexistence of smectite with high-temperature minerals like epidote, actinolite, and garnet suggests past temperatures of ~240–300°C [4]. However, current cooler conditions have produced a thick transitional alteration zone (1000 to -400 masl). This finding implies that smectite and epidote do not serve as a reliable indicator mineral for reservoir delineation in this well.

Drilling operation in Well-2 encountered severe shallow TLC, forcing early casing at 1049 masl, 700 meters above the TOR. The operational issue is likely caused by sheeting joints in lava and diatreme breccia, as indicated by cuttings and loss rates. To isolate cold downflow and the transitional zone, the next production casing should be set deeper, at around 400 masl.

4. Conclusions

Despite positive subsurface indicators, drilling in the upflow zone near the heat source at the central volcanic facies carries the risk of cold-water intrusion. This cold water downflow is negatively affecting the productivity of Well-2. Therefore, isolating this zone could improve the reservoir pressure and well output.

A thinning conductive layer may indicate caprock leakage, moreover, its association with diatreme breccia can increase the risk of cold water downflow into the reservoir. Localized TLC and low smectite concentration at caprock depth may serve as early indicators of a potential cold water downflow zone.

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