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# Calcite Scale Deposition in Production Wells in Mindanao Geothermal Production Field, Philippines

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## ABSTRACT

Three production wells in Mindanao Geothermal Production Field, APO-1D, APO-3D, and SP-4D, have been plagued by calcite scale deposition. Drilled from the same pad, these wells are mainly drawing ~240-250°C neutral brine from the same aquifer at ~1100 m. Discharge tests showed their high potential for calcite scaling.

Even before the start of commercial utilization in March 1997, massive calcite scales already developed at ~1140-1170 m in APO-1D. These scales were likely formed when cooler (~220°C) brine near well bottom became heated as it rose inside the well during bleed conditions. In 1998, APO-1D was cement-plugged from ~1195 m down to the bottom.

During commercial utilization, flashing of brine caused deposition of calcite scales at 660-710 m in APO-1D, at 780-815 m in APO-3D and 610-700 m in SP-4D. After only four months of utilization, small subhedral calcite scales already formed total blockages in APO-1D and in SP-4D requiring two mechanical work-over jobs for each well between February 1998 and May 1999. In APO-3D, large well-developed calcite prisms formed after thirteen months of utilization. So far, these scales have not been detrimental to APO-3D's output.

Deposition of calcite scales during utilization can be detected by monitoring declining trends in mass flow correlative with decreasing calcite saturation index (CSI) values.

## Introduction

The Mindanao Geothermal Production Field (MGPF), with an area of ~30 km², is situated on the northwest flanks of Mt. Apo located in the southeastern part of Mindanao island (Figure 1). Commercial exploitation of the field started in March 1997 with the commissioning of a 52-MWe geothermal power plant (M1GP). A second 52-MWe power plant (M2GP) was commissioned in June 1999.

Production from three M1GP wells drilled from the same pad - APO-1D (6.2 MWe), APO-3D (5.5 MWe) and SP-4D (6.0 MWe) has been hampered recently by blockages caused by calcite deposition. In this study, the blockage history and petrology of calcite scales will be discussed. Mechanisms of calcite formation will be postulated based on observed data, and parameters for monitoring calcite deposition in M1GP production wells will be defined.

## Wellbore History

The first exploratory well in MGPF is APO-1D which was drilled in September 1987 down to a total vertical depth of 1852 m. Based on post-drilling tests, its main feed zone occurs at 1120-1185 m (Esberto, 1998) where neutral-pH fluids with chlo-

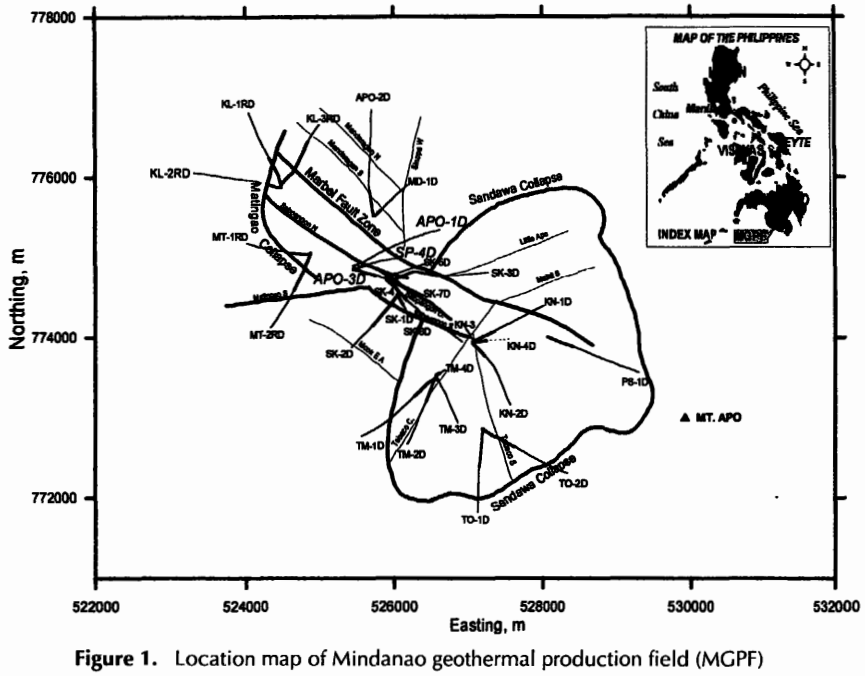


**Figure 1.** Location map of Mindanao geothermal production field (MGPF)

ride concentration of 4100 mg/kg and $T_{quartz}$ of 250°C are presently flowing. A minor feed zone near the bottom at 1807-1850 m contributes neutral brine with lower salinity of 3500 mg/kg and lower $T_{quartz}$ of 220°C (Parilla, 1988; PNOC-EDC, 1994).

Seven years later, APO-3D and SP-4D were drilled in the same pad as APO-1D. Both wells were drilled only down to ~1290 m to avoid the cooler, more dilute brine at ~1850 m intersected by APO-1D. Completion tests and medium-term discharge (MTD) results showed that these two wells are mainly drawing brine from the same aquifer of the major production zone in APO-1D at ~1120 m (Esberto, 1994; Nogara *et al.*, 1997; Salonga, 1994).

## Blockage Formation

### *Well APO-1D*

After the well's MTD tests in June 1988, a 1.25" sinker bar (SB) indicated the absence of blockage in APO-1D (Figure 2). The well was later put on bleed when exploration activities in Mt. Apo were suspended from 1989 to 1992. In January 1993, a SB survey already tagged a calcite blockage at 1173 m. The next surveys in March 1994 again detected massive calcite blockages at 1185 m and 1273 m which effectively sealed-off the bottom aquifer of APO-1D. In December 1994, a new calcite blockage at 659 m was confirmed by a 5" go-devil (GD) survey.

Before the start of commercial exploitation in March 1997, APO-1D and all production wells in M1GP were continuously utilized for power plant (PP) and FCDS (fluid collection and disposal system) testings from December 1996 to February 1997. In July 1997, after seven months of continuous utilization, massive calcite scales were detected in APO-1D at 628-732 m by 6" and 3" GD surveys. The well was finally cut off from the power plant in September 1997 because it could hardly produce any steam. Work-over (WO1) and acidizing jobs were performed in March 1998 to remove the calcite blockages and to cement-plug the bottom cold feed zone.

Calcite-inhibition experiments were conducted in APO-1D from August to September 1998; then, the well was put back on line in November 1998. After six months, calcite scaling was again severe, warranting a second work-over (WO2) operation in May 1999.

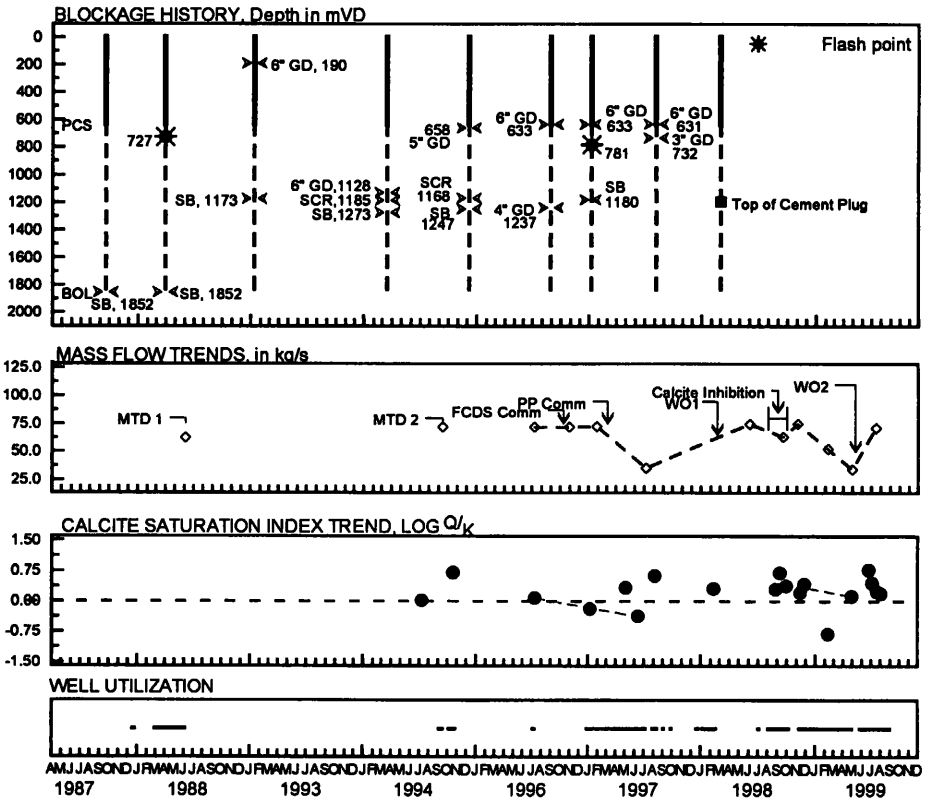


**Figure 2.** APO-1D wellbore history and calcite saturation index (CSI) trend

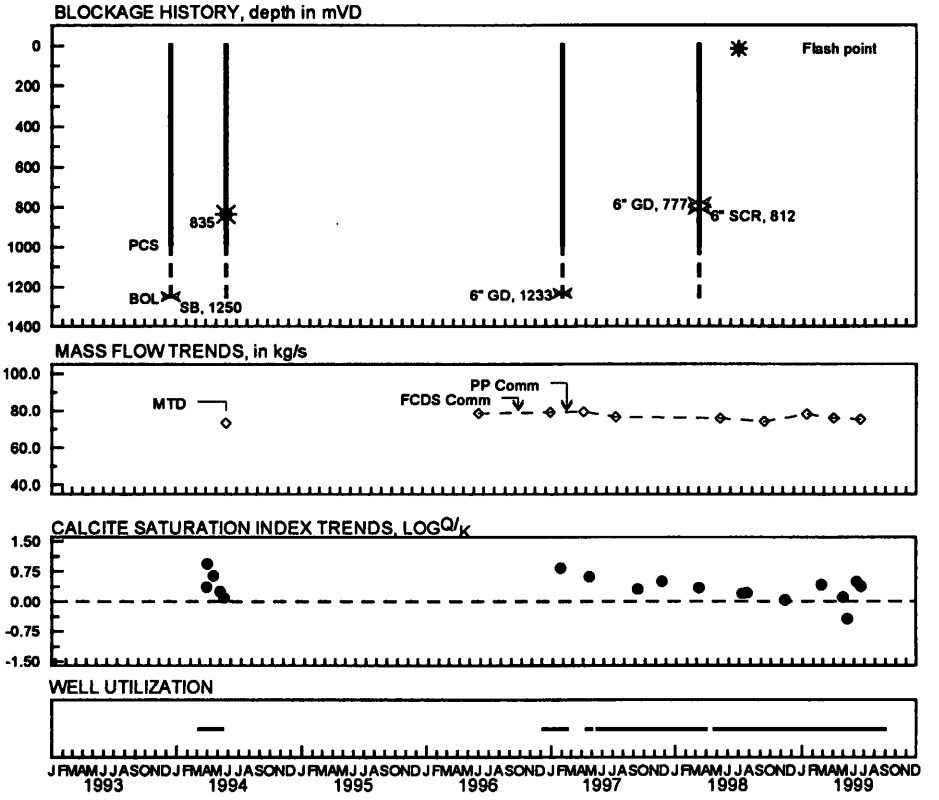


**Figure 3.** APO-3D wellbore history and calcite saturation index (CSI) trend

### *Well APO-3D*

A 6" GD survey in February 1997 showed that APO-3D was clear of any blockages after its MTD and power plant testing (Figure 3). Calcite scales were tagged by a 6" GD tool at 778 m in April 1998, thirteen months after the well was hooked up to the power plant. Despite the presence of scales, the output of APO-3D remained relatively stable in comparison to APO-1D and SP-4D.

### *Well SP-4D*

No calcite blockage was formed in SP-4D during its MTD from 1994 to 1996 based on GD surveys conducted in December 1996 (Figure 4). As in APO-1D, massive calcite scales were first detected in SP-4D in July 1997 at 697 m and 744 m. In February 1998, work-over operations were performed in SP-4D to remove calcite scales since the well could no longer supply steam to the power plant. After work-over, SP-4D was again utilized continuously causing another episode of massive calcite scaling which had to be removed by a second work-over job in April 1999. In May 1999, a calcite-inhibition system was successfully installed in SP-4D to prevent deposition of calcite scales.

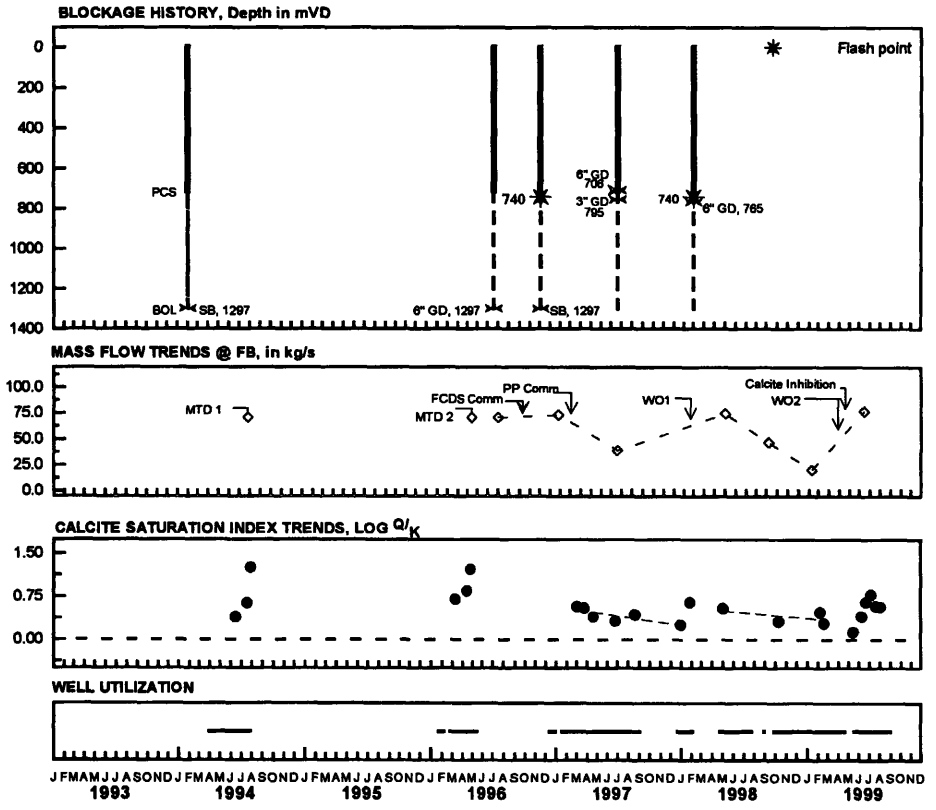


**Figure 4.** SP-4D wellbore history and calcite saturation index (CSI) trend

**Table 1.** Summary of Calcite Scales in Mt. Apo Wells

| | Shallow Scales | | | Deep Scales |
|---|---|---|---|---|
| | **APO-1D 660-710 m** | **SP-4D 610-700 m** | **APO-3D 780-815 m** | **APO-1D 1140-1170 m** |
| Flash point depth | 781 m | 740 m | 835 m | 781 m |
| Grain Size | Fine to medium (0.2-1.4 mm) | Fine to medium (0.2-3.6 mm) | Medium to coarse (2.0-10.0 mm) | Fine (0.02-0.6 mm) |
| Crystallinity | Subhedral mosaic | Subhedral mosaic | Well-developed prisms | Subhedral mosaic |
| FI Type | Liquid and vapor | Liquid and vapor | Liquid and vapor | Liquid with daughter minerals |
| FI Abundance | Extremely abundant | Extremely abundant | Few | Moderate |
| FI Occurrence | In multiple planar arrays | In multiple planar arrays | In rows or isolated | In rows |
| FI Average $T_h$ | No readings | 238°C | 238°C | 250-260°C |
| Flash point temperature | 235°C | 230°C | 234°C | 235°C |
| Flow regime during flashing | Annular | Annular | Bubbly | Annular |

## Petrology of Scales

### *Composition of Scales*

The mineral blockages which deposited in APO-1D, APO-3D and SP-4D consist mainly of calcite ($CaCO_3$). Aragonite ($CaCO_3$) and smectite [$(Ca,Mg)O.Al_2O_3.5SiO_2.nH_2O$] are also present in subordinate amounts (<10-40%). Based on textural relationships, aragonite is the initial scale deposit in these three wells. Because it is metastable, aragonite is eventually transformed to calcite which is the most stable form of calcium carbonate. Smectite scales are also present in the blockage as amorphous to fibrous layers, or rims around calcite and aragonite scales.

### *Calcite Morphology*

Two kinds of calcite scales occur in M1GP wells. The first kind is found at shallow depths, *i.e.* 660-710 m in APO-1D, 780-815 m in APO-3D and 610-700 m in SP-4D. The second kind exists at deep levels as seen in APO-1D at 1140-1170 m.

Shallow calcite scales in M1GP wells form right above the flash point (Table 1) (Esberto, 1997). These calcite scales in APO-1D and SP-4D form a mosaic of fine to medium (0.2-4.0 mm) subhedral crystals. In contrast, calcite scales in APO-3D consist of well-developed prisms of medium to coarse grain sizes (2.0-10.0 mm).

Deep calcite scales in APO-1D at 1140-1170 m occur in a mosaic of very fine (0.02-0.6 mm) subhedral grains. Their morphology is similar to that of the shallow calcite scales in APO-1D and SP-4D.