Chalcedony Scale Formation in a Production Well in Tiwi Geothermal Field

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ABSTRACT

With the growing global efforts in advancing geothermal energy development, several technologies are being introduced to capitalize on the full potential of geothermal resources. A critical aspect of these efforts is the understanding of the underlying mechanisms behind challenges encountered during resource utilization. Mineral scaling is one of the persistent challenges in the industry, which can cause significant generation losses and impact the overall performance of geothermal fields. Among the various types of mineral scales, chalcedony—although not commonly observed in production wells—has been identified in certain cases, such as in the Tiwi Geothermal Field in Albay, Bicol, Philippines. Unlike more prevalent scales like calcite and anhydrite, chalcedony typically does not form independently. Its formation is governed by a combination of factors, including reduced flow rate, declining pressure, and changes in wellbore geometry. Chalcedony is often found to crystallize following the initial deposition of primary scale minerals such as calcite or anhydrite. This study seeks to enhance the understanding of the formation mechanism of chalcedony in geothermal production wells. By acquiring clearer insights into its behavior, more effective mitigation strategies can be identified to address this scaling issue and maintain the efficiency of geothermal operations.

1 INTRODUCTION

Silica is one of the most common types of scale found in geothermal wells, along with calcite and anhydrite (Brown, 2003). It typically deposits as amorphous silica, while the formation of silica with a higher degree of crystallinity, such as chalcedony, is considered unlikely due to the high flow rate inside the wellbore as the fluid travels from the production zone up to the wellhead. To date, the formation of chalcedony as a scale mineral remains poorly documented and understood in geothermal literature.

However, despite these constraints, chalcedony scale has been observed in one of the production wells in the Tiwi Geothermal Field (TGF). This study aims to investigate the possible mechanisms that enable the formation of chalcedony scale in a production well. Factors identified by Brown (2003) that lead and may promote chalcedony scale formation – such as temperature, flow rate, saturation index, surface texture of the pipe, and the influence of other dissolved cations – are examined and have been correlated with actual wellbore conditions.

The scale sample used in this study was obtained during a workover of a production well in TGF to clear up blockages that formed along its production liner. The collected sample was first analyzed qualitatively through a series of physical tests and then quantitatively using X-ray Diffractometer (XRD) and Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy (SEM-EDS). To further support and validate the findings from both qualitative and quantitative analyses, fluid chemistry simulations were subsequently performed using SOLVEQ and CHIM-XPT.

Compared to amorphous silica, chalcedony has higher crystallinity, therefore harder compared to amorphous silica, which could lead to more persistent blockages, reduced flow efficiency, and costly maintenance. Understanding how and why chalcedony forms as scale in a production well is crucial for developing and identifying effective mechanical and chemical strategies to mitigate and manage silica-related scaling issues.

2 METHODOLOGY

The sample was collected during a broaching operation—a non-rig activity that utilizes a broaching tool to remove obstructions inside the well. Materials or mineral scales trapped between the tool's components were carefully retrieved. After collection, the sample was dried and initially examined using a binocular orthoscopic microscope for preliminary mineral identification. A series of qualitative tests—including effervescence, magnetism, and scratch tests—was then conducted. The morphology and texture of each selected scale sample were carefully examined, as this information is crucial for understanding the scale formation mechanism within the wellbore.

Selected samples with suspected chalcedony scale were analyzed using XRD and SEM-EDS. To support the XRD and SEM-EDS results, water and gas data from the same production well were simulated using SOLVEQ and CHIM-XPT, a commercially available DOS-based geochemical simulator. These are DOS-based geochemical modeling software: SOLVEQ performs pH correction, gas-add-back, and thermal simulations (cooling/heating) (Reed, Spycher, & Palandri, 2012), while CHIM-XPT handles more advanced processes such as boiling, fluid-fluid mixing, and water-rock interaction (Reed, 1992; Reed, Spycher, and Palandri, 2016).

The collected data were correlated to identify potential mechanisms of scale formation, with particular focus on chalcedony scale. Additional tests and methodologies were also proposed for future studies to validate the hypotheses presented in this study regarding chalcedony scale formation in production wells.

3 RESULTS AND DISCUSSIONS

The scale sample retrieved from the production well consists of banded calcite, anhydrite, and silica with pyrite crystals (Figure 1). Its elemental composition and mineralogy were confirmed by SEM-EDS (Figure 2) and through macroscopic and XRD analyses for mineralogical characterization. The sample is non-magnetic, and some portions reacted to 10% HCl during the effervescence test, confirming the presence of calcite. Anhydrite was identified through a scratch test. Pyrite, on the other hand, was observed based on its physical properties – luster, color, and crystal morphology. Aside from these identified minerals, a black scale that is banded with anhydrite and calcite is also observed. Based on the initial megascopic examination, it is suspected to be silica. The sample was subjected to XRD analysis; however, due to its relatively small quantity, the presence of chalcedony appeared to be masked by other dominant mineral phases (Appendix A). This posed a challenge for the researchers in confirming the presence of chalcedony in the sample. Consequently, SEM-EDS analysis was conducted to verify its mineralogical composition further. To further prove its mineralogy and composition, the sample was prepared and analyzed using SEM-EDS. As shown in T2 of Figure 2, the suspected scale is composed of Si, therefore confirming that it is a silica scale. Based on its morphology, it has a microcrystalline texture. This suggests that it has a higher crystalline structure than amorphous silica but is not yet considered quartz. Therefore, this silica scale could be chalcedony. However, silica scales are typically reported as amorphous in geothermal wells due to kinetic constraints (Brown, 2013; Utami et al., 2014).

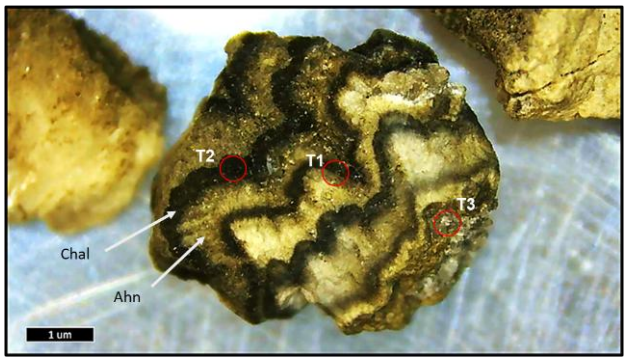


Figure 1. A photograph of scale minerals retrieved from the production well in the Tiwi Geothermal Field (TGF). Colloform banding texture is observed between the deposited anhydrite (Anh) and chalcedony (Chal). Points T1, T2, and T3 indicate target areas examined using SEM-EDS for morphology, texture, and elemental composition.

Chalcedony typically forms at temperatures below 200 °C, as stated by Barja (2014). Additionally, as summarized by Heaney (1993) from various researchers, chalcedony forms under these conditions: at 400 °C and 340 bars (White and Corwin, 1961), at 100–300 °C and 3 kbar (Oehler, 1976), and at 150–240 °C (Kastner, 1980). It also forms more slowly at a lower flow rate compared to amorphous silica (Barja, 2014). If the flow rate inside the wellbore decreases to a level conducive to chalcedony deposition, this mineral may form and deposit. These reported conditions were compared with the actual measured temperature and flow rate in the wellbore. The measured temperature inside the well where the scale sample was retrieved ranges from 189 to 276 °C based on a shut-in pressure-temperature survey. This temperature falls within the ranges identified by Barja (2014) and Heaney (1993) as suitable for chalcedony deposition. Given the temperature of the well, there is a strong likelihood that a significant decrease in flow rate could promote chalcedony deposition. Factors that might decrease flow rate include surface manipulations such as throttling or well shut-in, or the presence of progressing blockages that restrict or disrupt flow.

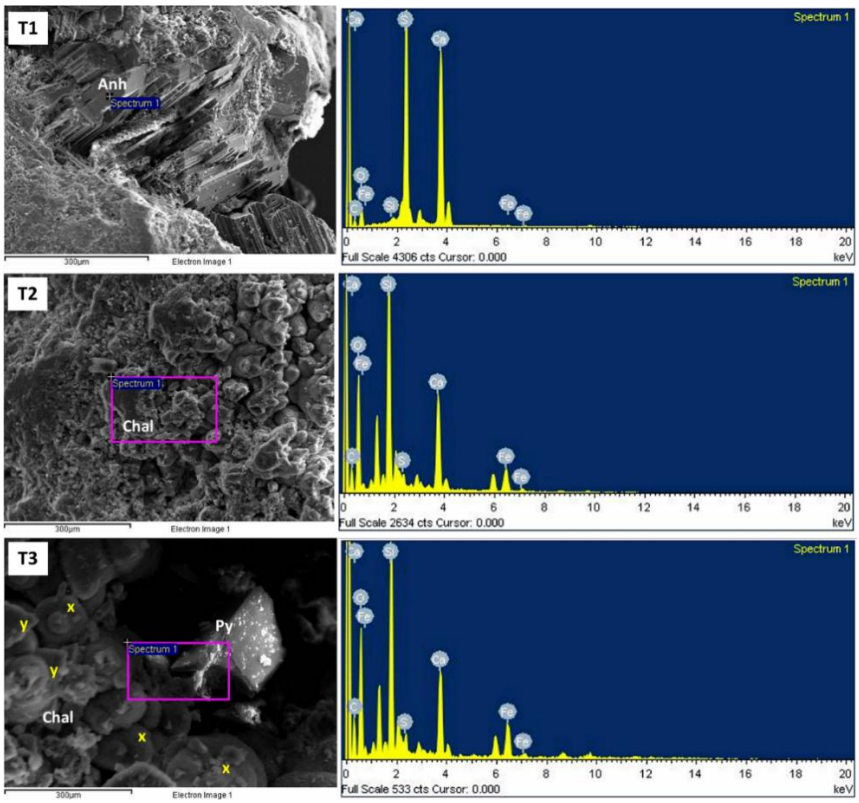


Figure 2. SEM-EDS photomicrographs of target points T1, T2, and T3, along with their corresponding elemental profiles on the right, show (T1) crystalline anhydrite (Anh) with well-defined cleavages with elemental profile of Ca, Si, O, Fe, C, and S ; (T2) microcrystalline chalcedony (Chal) with botryoidal texture and a chemical composition of Ca, Si, O, Fe, C, and S; and (T3) a subhedral pyrite (Py) grain with associated microcrystalline chalcedony, with chemical composition containing Ca, Si, O, Fe, C, and S, where x marks the pyrite and y indicates a globular chalcedony crystal.

There is also a possibility that chalcedony could have formed in the well section where mineral scaling is advancing. It might deposit on the surface of pre-existing minerals, creating a banded texture. It could also develop an initial crystal along the jagged surface of the wellbore. Additionally, as scale gradually grows inside the wellbore, it can further restrict flow and significantly reduce the flow rate (Allan et al., 2019) (Figure 3), promoting chalcedony formation. Another idea is that chalcedony may have formed through heterogeneous nucleation, seeded by grains of pre-existing crystals such as anhydrite, calcite, or pyrite. In some cases, as reported by Fournier (1985), it may also be seeded with amorphous silica grains. These chalcedony formation hypotheses are supported by the banded texture seen in the sample, suggesting it may have formed after the deposition of anhydrite or calcite during a low-flow period. However, these ideas need further investigation by examining the interior of the chalcedony with more advanced equipment, such as an Electron Probe Micro-Analyzer (EPMA).

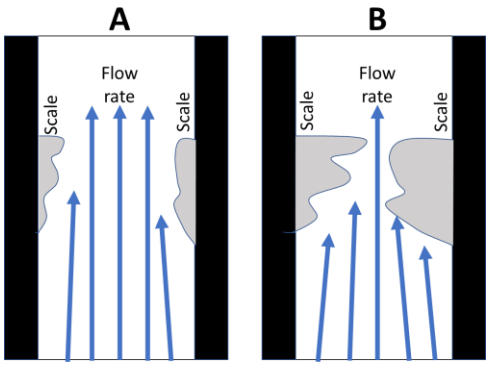


Figure 3. Effect of scale buildup on wellbore flow: (A) initial scaling shifts flow toward the center, reducing flow rate; (B) progressive scaling further restricts flow, causing greater reduction

Another hypothesis is that chalcedony formation might have been catalyzed by divalent and trivalent cations like Fe^{+2}, Mg^{+2}, and Al^{+3} (Brown, 2013). Silica might have bonded with these cations under suitable temperature and flow rate conditions, forming chalcedony crystals. This hypothesis could explain why the chalcedony scale present in the sample is black. Also, looking at the SEM-EDS result (T2 of Figure 2), the presence of iron (Fe) is detected in the sample.

Poiseuille's law, which states that in a pressurized condition, such as in geothermal wells, if the pressure decreases, the flow rate also decreases, assuming that all other conditions remain the same or constant. Based on the results of the simulation in five different temperature regimes, to evenly represent the section where the sample was retrieved, the resulting minerals – anhydrite, calcite, pyrite, and chalcedony – matched with the actual minerals that have been identified (Figure 4).

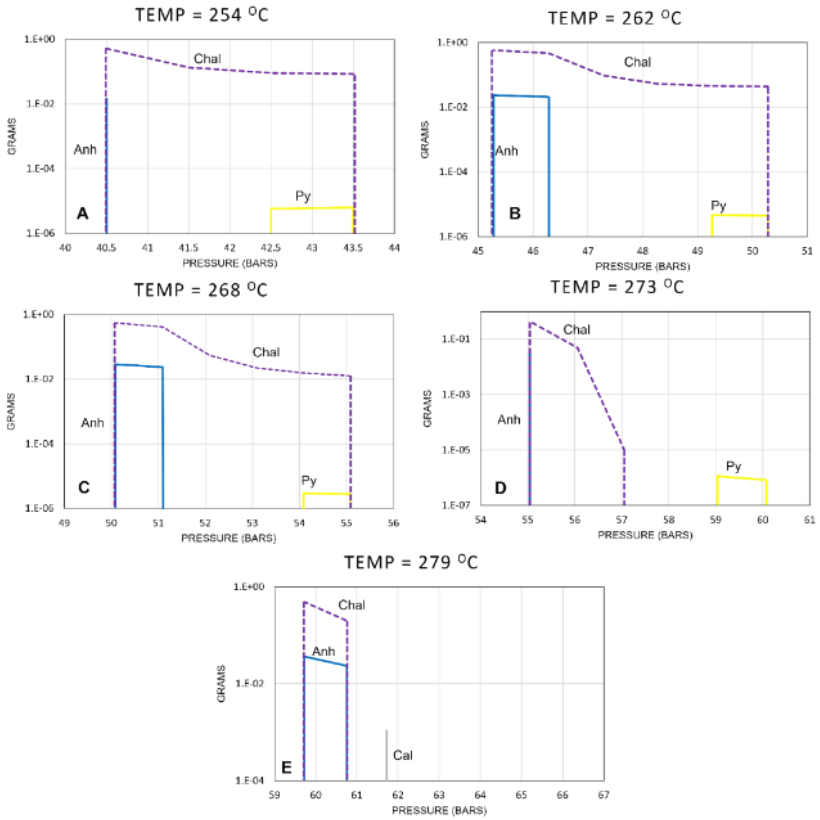


Figure 4. These graphs show the results of boiling simulations using CHIM-XPT, where pressure was decreased to simulate a reduction in flow rate. The graphs illustrate the results measured under varying temperature conditions: (A) 254 °C, (B) 262 °C, (C) 268 °C, (D) 273 °C, and (E) 279 °C. Calcite (Cal); Pyrite (Py); Anhydrite (Anh); Chalcedony (Chal)

This analysis provides a preliminary understanding of how and why chalcedony is present in the scale sample retrieved from one of the production wells in TGF. Recognizing the chalcedony formation mechanism is essential to identify wells that might be affected by scaling based on routinely measured parameters such as temperature, wellhead pressure, and flow rate. A clear understanding of its formation process will help develop proper mitigation strategies, especially as the geothermal industry continues to advance its knowledge and efforts in scaling.

4. SUMMARY AND CONCLUSION

SEM-EDS analysis, supported by textural and other physical properties, confirmed the presence of chalcedony as a scale-forming mineral. This crystal has a higher degree of crystallinity than amorphous silica. This finding was also supported by the results of geochemical simulation using SOLVEQ and CHIM-XPT.

This study proposes several possible scenarios to explain the formation of chalcedony scale in geothermal production wells:

1) Chalcedony may have formed under reduced flow rate and suitable temperature conditions. Flow reduction may occur due to surface manipulations such as throttling or well shut-in events. Additionally, as blockages form and progress, they can further restrict and lower the flow rate within the wellbore.
2) Chalcedony may have formed when silica particles are trapped along a rugged or jagged surface of the wellbore, promoting nucleation under high-pressure conditions.
3) Chalcedony may have deposited on the surface of pre-existing scale minerals, such as anhydrite or calcite, forming a banded texture. As these minerals continued to accumulate, they increasingly restricted flow within the wellbore, creating low-flow conditions favorable for chalcedony crystallization.
4) Chalcedony may have formed as a secondary scale mineral through heterogeneous nucleation, wherein it crystallizes on the surface of pre-existing scale minerals or other materials that act as nucleation sites or seeds.
5) Additionally, chalcedony formation may be catalyzed by the presence of divalent and trivalent cations, which can facilitate or accelerate the crystallization process.

These findings provide a first step for understanding the possible formation mechanism of chalcedony scale. Further investigations using more powerful techniques, such as Electron Probe Micro-Analyzer (EPMA), downhole pressure, temperature, and flow rate measurements coupled with improvements in sampling techniques and documentation, are recommended to better understand and examine the mechanisms behind chalcedony scale formation in geothermal production wells.

For mitigations, since chalcedony has a Mohs hardness of 6.5 to 7, mechanical methods like broaching may not be very effective. Alternative or improved procedures that can handle this hardness should be considered. For chemical interventions, developing new formulations specifically for chalcedony is advised, as its ordered crystalline structure makes it more resistant than amorphous silica.

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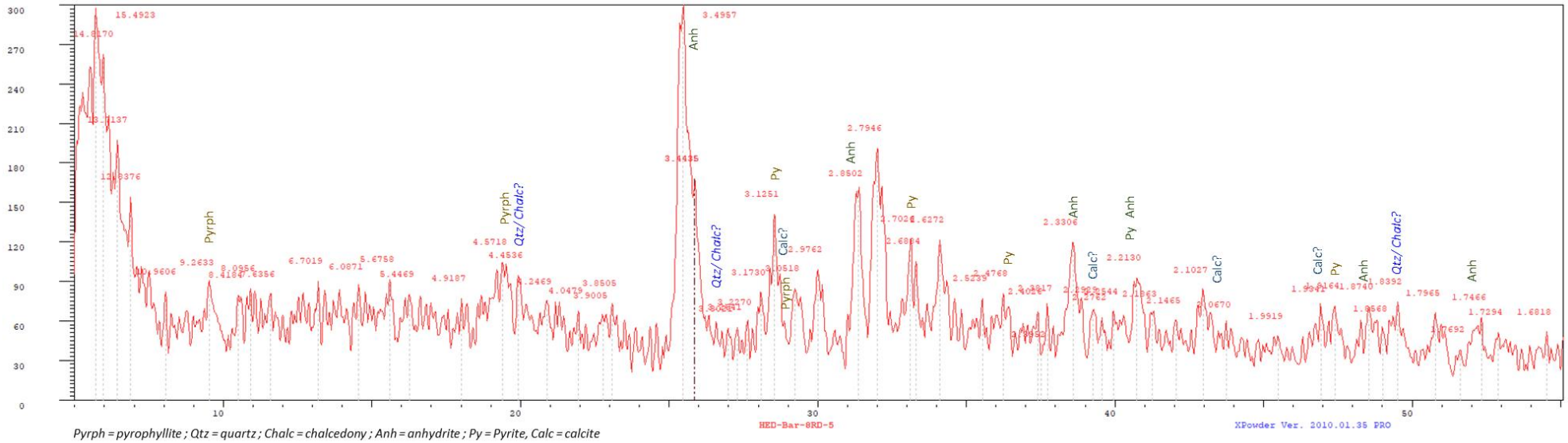
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Appendix A: XRD Result



Pyrph = pyrophyllite ; Qtz = quartz ; Chalc = chalcedony ; Anh = anhydrite ; Py = Pyrite, Calc = calcite