Microstructure of Sinter Deposit Formed at Hot Springs in West Sumatera

A Putra\(^1\), D Y Inanda\(^1\), F Buspa\(^1\) and A F Salim\(^1\)

\(^1\)Laboratory of Earth Physics, Department of Physics, Faculty of Mathematics and Natural Sciences, Andalas University, Kampus Unand Limau Manih, 25163, Padang

email: ardhee@fmipa.unand.ac.id

Abstract. Sinter deposit emerged and spread at several hot springs in West Sumatera is divided into three types, they are full silica, half silica-carbonate and full carbonate. This work intends to investigate the characteristic of each type by its crystalline structure and morphology and its correlation to surface temperature. The research is focused on Sapan Maluluang hot spring (full silica), Garara hot spring (half silica-carbonate) and Bawah Kubang hot spring (full carbonate). Crystalline structure is analyzed by X-Ray Diffraction (XRD) methods, it showed that deposit from Sapan Maluluang has opal-A structure, Garara has opal-CT structure and Bawah Kubang has crystalline structure. The Scanning Electron Microscopy (SEM) methods is applied to describe its morphology surface, in which spherical, almost rounded and irregular textured was formed at each deposit, respectively. Surface temperature of hot spring also has given impact on deposit texture.

1. Introduction
One of the mineral deposits present around hot springs is silica and carbonate sinter, material that is dominated by silica minerals (SiO\(_2\)) and carbonate (CaCO\(_3\)). The formation of silica sinter in hot springs indicates that geothermal reservoirs have high temperatures. Therefore, the presence of silica sinter is one of the important manifestations for the existence of geothermal reservoir. Silica is classified into three categories based on their atomic structure, ie opal-A, opal-CT, and opal-C [1]. At early formation, silica has noncrystalline (Opal-A) or amorphous properties. The change of noncrystalline mineral structure into Opal-CT and C-opal occurs after 10,000 years, this process is called diagenesis. Opal-CT has \(\alpha\)-cristobalite and \(\alpha\)-tridymite irregularities, and C opal has a neatly arranged \(\alpha\)-cristobalite [2].

The sinter is hypothesized as silica based on the color taken from the sediment around hot springs in Solok Selatan and Solok regencies, in Sapan Malulung hot springs, as well as hot springs Garara, and Bawah Kubang. Based on literature study, the district has hot springs with high silica content. The characteristics of silica sinter can be expressed by describing its structure and morphology. Each structure gives further explanation of the geothermal system. Therefore, X-Ray Diffraction (XRD) and Scanning Electron Microscopy (SEM) are used for this research.

2. Method
The material used in this research is sinter found in three hot springs, namely in Sapan Malulung, Garara, and Bawah Kubang. Samples were taken using a hammer and crushed using mortar and pestle until smooth. After forming a fine sample, it was sieved with a 100 mesh sieve. Further
characterization is done using XRD for identifying structure of samples and SEM for describing its morphology. For additional data, temperature measurements of the hot springs surface used a thermometer.

3. Results

3.1. Sinter Structure

XRD results from sinter sediment samples from Sapan Malulung, Garara and Bawah Kubang hot springs are shown in Figures 1 (a), (b) and (c), respectively. Figure 1 (a) shows that the sinter extracted from the Sapan Malulung hot springs is dominated by non-crystalline silica opal-A or commonly called amorphous, indicating a large peak (hump) produced between 2θ 18° to 30° with d-spacing between 2.97 Å - 4.92 Å. A silica having A-opal phase has a relatively young sinter life. Opal-A silica in Steamboat Spring, Nevada is described for 6500 years old, and opal-A silica at Mound, Utah is estimated for 1600 years old [3,4]. The structural change of noncrystalline (opal-A) to opal-CT and C-opal occurs after a period of 10,000 years [5]. Based on these data it can be estimated that the silica sinter found in Sapan Malulung hot springs is <10,000 years old.

Deposit from Garara hot springs shows different XRD patterns with Sapan Malulung hot springs or can be seen in Figure 1 (b). Garara hot springs have a sharper diffraction peak and higher intensity compared to Sapan Malulung hot springs. The resulting crystalline pattern is opal-CT, where there is a regular layered crystal structure that is tridymite and cristobalite. Based on the data ICCD 00-003-0271 tridymite and cristobalite are the phases of silica minerals (SiO₂). This pattern is a typical pattern of opal-CT.

The hot springs that produce the opal-CT structural silica, which has been formed in Atiamuri and Ohakuri have a silica age ranging from 50 to 40 000 years [6]. The opal-CT produced by silica sinter in Years, TVZ has a 14 500-year-old, and based on petrology data, the Geology Department of
University of Auckland, the CT opal produced from silica sinter at Umukuri has an age of 40 000 - 120 000 years [7]. Based on this data, it is estimated that silica sinter deposits in the Garara hot springs have an older age compared to Sapan Malulung hot springs.

Figure 1 (c) is the XRD result of sinter present in hot springs Bawah Kubang. Based on the figure, the peak of detected diffraction is aragonite, this is known based on ICCD data with the code 01-075-9984. Aragonite is a phase of mineral calcium carbonate (CaCO$_3$). Based on this data, it can be concluded that the sample of hot spring Bawah Kubang classified sinter carbonate. The common phrase used in geothermal systems is the emergence of silica sinter deposits on the surface, indicating that the hot springs have high reservoir temperatures.

### 3.2. Sinter Morphology

SEM results can be seen in Figures 2, 3, and 4. The magnification used is 5000x and 20 000x. Figure 2 is a SEM sample of sinter samples found in Sapan Malulung hot springs with the magnification of 5000x (left) and 20000x (right). Based on the image, it has a rounded texture neatly arranged together like a long chain, and has a particle diameter between 0.641 μm - 0.670 μm as indicated by the arrows. The diameter of this particle is much smaller than that of Herdianita (2000), that sinter having a crystalline phase has a round texture with a particle size of 4-8 μm and the smallest size of opal-A is 1-2 μm.

![Figure 2. The SEM result of Sapan Malulung hot springs sinter, magnification 5000x (left), magnification 20000x (right)](image)

Figure 3 left and right shows the sinter SEM results found in the Garara hot spring. This sinter has a slightly rounded texture, the slab, and conical shape. And has a particle size between 0.626 μm to 0.783 μm. This size is larger than the sinter found in Sapan Malulung hot springs. Based on research done by Herdianita (2000) that older sinters usually have an opal-CT phase with a slightly rounded texture (resembling opal-A), and a 20-30 μm particle size plate. Based on field data hot springs has a surface temperature of 58 °C. The conical, cone-like springs have a moderate surface temperature (35-59 °C) [8].
Based on Figure 4 left and right, sinter at Bawah Kubang hot spring has a texture like bubbles with a smooth and dense aggregate and has a particle diameter of 0.385 μm - 0.424 μm. The particle size is smaller than the sinter found at Sapan Malulung and Garara hot spring.

4. Conclusion
Deposit at Sapan Malulung and Garara hot springs contain silica sinter, but at Bawah Kubang hot spring contains carbonate sinter. Sapan Malulung sinter deposits have opal-A, rounded and connected structures that form like long chains. The sinter deposit at Garara has an opal-CT phase and is a slightly rounded texture and is in the shape of plates and cones. The identification of silica sinter in Sapan Malulung and Garara can be a reference for further research on geothermal research.

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