Identification Of Sinter Silica Evolutionary Manifestation As A Bicarbonate Travertine Based On Isotope $^{18}$O And $^2$H Review Of Local Meteoric Water Line Curves As Determinant Of Outflow Fluid Reservoir In Cisolok-Cisukarame Geothermal System

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Abstract. Cisolok geothermal system located in Cisolok district, Sukabumi regency has undergone an evolution. One of the indication is the transformation of its surface manifestation from Silica sinter to Bicarbonate travertine. The existence of this travertine indicates the presence of bicarbonate spring and reservoir systems temperatures below 150°C, which are the hallmark of two-phase liquid dominated geothermal systems. Analysis of stable isotopes ($^{18}$O and $^2$H) is used to identify the reservoir water’s source affecting the evolution of Cisolok’s surface manifestations. The stable isotopes are then compared with the global and local meteoric water line. The contents of isotope $^{18}$O and $^2$H, after being compared with the global and local meteoric water line, gives a visual data that’s adjacent and in line with the local meteoric line. This indicates that the hot water from Cisukarame manifestation originates from local meteoric water, which is the result of evaporation and precipitation from the local water. The evolution of the geothermal system in this area is indicated by the increase of isotope $^{18}$O content in water and a decrease of the same isotope among the rocks. Indication of the temperature reduction in this area, which is estimated to have happened over a period of 10,000-50,000 years, involves a diagenesis reaction and an amorphous silica hydrolysis that caused the increase of $^{18}$O and dD levels in the water. With two-phase liquid dominated geothermal systems, there’ll be many outflows that bring diverse manifestations. The results of the data analysis show that the evolution of the Cisolok geothermal system occurs due to the contact between reservoir fluid and limestone lithology at a depth of 350-600 meters which causes the Cl water content in the system to transform into HCO$_3$ water content and alter the surface manifestations of silica sinter containing amorphous silica into a travertine containing bicarbonate.

1. Introduction
The system geothermal in Cisukarame and Cisolok is considered as area with prospect of geothermal in West Java. All of manifestation of geothermal which appearance at 106°27'13.4" E and 6°56'0.5" S in River of Cisolok located about northern part of Cisolok with distance about 6 km. Recently, the manifestation of Cisolok geothermal is used as public bathing place.

Geothermal Systems is one of the geothermal prospect areas shown by an intensive geothermal surface manifestation of surface alteration and hot spring. The Cisolok River has very high temperature on thermal water discharging. In fact, the temperature of the boiling point is very high. It also has very high discharging rate and neutral pH. At the bank and the surface and Cisolok River
occurring Hydrothermal alterations which show a highly alteration intensity dominated by the availability of travertine and silica sinter which is thick.

Cisolok is one of the geothermal prospects at Sukabumi, West Java. Geothermal surface manifestations at Cisolok occurs along 300 m of the Cisolok River consisting of spouting springs, surface alteration, and deposits, such as prophylitic zone, argillic zone, silica sinter and dominated by travertine deposits. Temperature within the reservoir area range about 170-200 oC, with the composition of hot fluids typically is bicarbonate (HCO₃). The travertine deposit exhibits from the top to the bottom of the following characteristics such as Crustiform and colloform, Comb, saccharoidal and dogteeth Crustiform and stromalitic, and Brecciated.

2. Data and Method

Paper research has study using integrated of several methods such as, isotope analysis and observation of surface manifestation. Isotope stable such as oxygen and Hydrogen, utilizing to determined specific characteristic of geothermal fluid to meteoric water line and world water line. The results used for characterize the fluid origin of surface manifestation and geothermal system. Otherwise, observation of surface manifestation used to determine physical, texture and structure and can correlated to other result to get more understand about the geothermal field [5].

2.1. Geology Regional

Geomorphology of the Cisolok - Cisukarame region is composed of the morphology of hills produced by volcanic products with 150 - 900 meters above sea level, with the rather steep to steeper slope class. The physiography of the study area is included in the Bandung zone composed of dominance of the quartz volcanic products. The geology of the research area is composed of volcanic products, Quaternary and Tertiary sedimentary rocks. The stratigraphy and age of rocks exposed in the research area are; (Tmtl) of the early Miocene, followed by the intrusion of dacit (Tmda) of middle Miocene, Tuff Citorek (Tpv) fine grained dust deposited on Pliocene, and ending volcanic breccia (Qbv) and lesite andesite (Qvl) in Holocene overlapping Tuff Citorek.

The geological structures formed in the study area were Northeast - Southwest and North - South, based on the Cikadu River's fault mirror, with normal fault mechanism with pitch 85°. This fault is interpreted to be formed on Pliocene - Pleistocene, in the Cisukarame region the trace structure cannot be seen due to the closed volcanic sediment of the quarter.
2.2. Surface Manifestation

Geothermal surface manifestations at Cisolok River occur along 300 m consisting of spouting springs, surface alteration and deposits, such as prophylitic zone, argillic zone and silica sinter and dominated by travertine deposits. The large hot spring has a height about 3-4 m, flow rate 10 L/s, temperature 90° C and pH 7.3.

![Figure 2](image1)

**Figure 2.** (A) The figure above is Prophylitic zone cropped out at CSL-04 (B) The outcrop covered by travertine and silica sinter [2]

Hot springs along the river have smaller flow rates than large hot spring with temperature 90°-100° C and pH 8. The Cisolok hot springs is an artesian spouting spring, because the condition near the boiling point. Prophylitic zone distributed at NNW of the river covered by silica sinter and argillic zone was exposed at upper of the river predict as fossil of early hot spring activity.

![Figure 3](image2)

**Figure 3.** The figure is travertine deposits associated with silica sinter at CSL-05 [2]
3. Result and Discussion

The values of precipitation which come from \( d^{18}O \) and \( d^2H \) (dD) that has not been evaporated are linearly related by

\[
dD = 8 \ d^{18}O + 10
\]

Equation above, known as the "Global Meteoric Water Line" (GMWL), is based on locations around the globe which has precipitation data, and has an \( r^2 > 0.95 \). This high correlation coefficient reflects shows that the hydrogen and oxygen stable isotopes in water molecules are intimately associated; consequently, the fractionations and isotopic ratios of the two elements are usually together be discussed. The intercept and slope of any "Local Meteoric Water Line" (LMWL), which collected from a precipitation of single site or set of "local" sites where is the line can be derived, it could be significantly different from the GMWL. In general, most of these local lines have slopes of \( 8 +/- 0.5 \), but slopes in the range of 5 and 9 are not uncommon.
Figure 6. $\delta^2$H and $\delta^{18}$O compositions of hot and cold springs. Fault-hosted and volcano-hosted hot springs. Identification of enrichments in three stable isotope which are, i.e., combination of magmatic gas input with andesitic water input, evaporation, and evaporation [4].

Figure 7. $\delta^2$H and $\delta^{18}$O correlation lines between associated cold springs (open) from Java and hot springs (gray filled). The dashed lines are stable isotope correlations between respective meteoric waters from other locations around the world and thermal waters [4].

The Slope line of water meteoric shows value of correlation between $\delta^2$H and $\delta^{18}$O is caused by the same behavior during rainout on both isotopes, although the fractionation factor for 2 H is about 8 greater than for 18O:

$$s \approx \frac{\epsilon^{2H_{av}}}{\epsilon^{18O_{av}}} = 8.2 \text{ at } 25^\circ C$$

Thus, in rainy season, there was a progressive depletion of $^2$H is which takes about 8 times greater than for $^{18}$O. By plitting a $\delta^{18}$O vs. $\delta^2$H diagram, the result shows value that the correlation having linear with slope near 8. The average temperature of condensation that changes during rainy season, will vary in actual slope. A linear regression is then an average slope. The meteoric waters which unaffected by evaporation, the value is slightly greater than 8.

Slope of local meteoric water are affected by evaporation that happens after the condensation event. If pour rain is falling above the ground through a dry air column, some of it will evaporate.
Evaporation generally is a kinetic reaction, it is not reaction which needed an equilibrium, and will affect to $^{18}$O in the rain which imparting a preferential enrichment. Evaporation of rain as the amount effect precipitation on the isotopic composition. In arid regions, a slope line which is less than and closer to 7 in local meteoric water lines was calculated using data from all the rain events. In other words, based on data that having significant rain events (>20mm), the slope value are closer to 8. This condition can saturate the air column and minimize droplets on having evaporation.

There are a few processes can cause plot off the GMWL related with waters. Water which has mixed with water that evaporated typically plots under the meteoric water line along lines that intersected with the MW Line on the location of the original unevaporated composition of the water; range of 2 - 5 for slopes value are general. The exchanged in geothermal also increases the $^{18}$O content of waters as the rocks and decreases the $^{18}$O content of rocks and waters try to reach a new state at the elevated temperature which is equilibrium of isotopic. This causes a shift $\delta^{18}$O values, but not the $\delta$ D values of geothermal waters. The low temperature of diagenetic reaction which involves hydrolysis of silicate can occasionally cause rises in $\delta$ D values of the $\delta^{18}$O and waters.

There are two key factors which control the isotopic character of rainfall at a given location are the grade of rainout of the bulk air (the water vapor ratio has already condensed into precipitation to the original amount of water vapour in the bulk air) and the temperature of condensation of the precipitation. In the atmosphere, most water vapour is consequent from vaporization of low-latitude oceans. Precipitation that derived from this vapour that supplemented in D and $^{18}$O relative to the vapor, with the vapour a function of condensation temperature and fractionation among the rain.

![Figure 8. Development of $^{18}$O and $^2$H during rainout. The reduction begins in this example at 25°C with a rain that falls on the meteoric water line for precipitation](image)

Generally, rain in the summer isotopically is heavier than rain in the winter. This adjustment in average isotopic configuration is predominantly caused not only by seasonal temperature variances but also affected by periodic changes storm tracks and moisture sources.

Interaction between groundwater and surface water shall be traced by using stable isotopes of water because water that still remain at the surface for any length of time is usually exposed to vaporisation and is subsequently enriched in $^2$H and $^{18}$O relative to groundwater.

The results of isotope content $\delta^{18}$O and $\delta^2$H, then compared with meteoric and meteoric globally obtained visualization of adjacent data and the exact direction of local meteoric this indicates that the hot water from Cisukarame manifestation comes from meteoric water. Visible depleted compositions $\delta^{18}$O and $\delta^2$H when compared with local meteoric lines, resulting from the vaporization process. Based on the water type analysis, the resulting manifestation is a chloride-type hot water from the reservoir so that it can be interpreted that reservoir water has a fluid derived from meteoric water, the presence and enrichment of water meteoric in the reservoir is interpreted as a relatively old geothermal system because it has undergone intensive interaction so that the meteoric fluid can dominate. Then the similarity of the isotope content with cold springs (Cisukarame River) can be interpreted. The meteoric water in the reservoir comes from the run off of the fluid in the same region, with the control of the geological structure as recharge.
The isotope analysis shows the similarity of fluid characteristics $\delta^{18}O$ and $\delta^2H$ with local meteoric water, interpreted by the dominance of the meteoric waters controlling the reservoir. Based on this, it is assumed that the source of water comes from the area of Mount Halimun as run off and then enter through the fault that develop as a source recharge area.

This type of alteration is interpreted as the final result in which the weather control is more dominant and the precipitation of silica saturated is absorbed. So the acid pH characteristics and mineral temperature stability are lower <150 200 °C. Geothermometer analysis results Cisolok-Cisukarame geothermometer classified in the medium-temperature geothermal system 125 - 225 °C. Based on the existence of geyser manifestations and sintered silica fluid in the reservoir geothermal system is a system of water dominance system. The appearance of chloride type water manifestation indicates that Cisukarame area is a lateral flow area is a direct result of reservoir which is supported by the manifestation of sinter silica as saturated precipitate of reservoir fluid. While the more towards the Southwest the manifestations that appear in the Cisolok region are water sulfate-chloride. Based on the geochemical analysis the Cl- content is lower due to increased surface water mixing. SO4 content higher than the Cisukarame region, it is estimated that sulfate content is produced due to the influence of surrounding rocks containing pyrite. These water chemical differences indicate a change in water characteristics which increasingly leads to Cisolok surface water control is increasing, so it can be interpreted the source of heat comes close to the direction of Cisukarame. The lateral flow manifestation conditions indicate a distant fluid migration so that the heat source can be derived from the magmatic activity of Mount Halimun located in the northeastern of the research area. In addition, other possibilities based on geological conditions on the surface are assumed that the source of heat derived from andesit intrusion (Qvl) and dacit (Tmda) are still active.

Based on the alteration pattern occurring in Cisolok, the reservoir seems to have temperature of above 220 °C indicated by the occurrence of propylitic alteration, silica sinter and travertine deposit. The chemical compositions of thermal waters and study of indicates that the deep thermal water will flow laterally to Cisolok, but the steam will discharge directly up to Cisukarame. Steam produced from the sub surface boiling can then condense into groundwater and surface water and cause oxidation of CO2 to H2CO3 and H2S to H2SO4. These processes are also known as steam heating.
where the argillic alteration can occur. The argillic zone is dominated by kaolinite and smectite in association with chlorite and quartz, indicating that the alteration occurs at acid condition and temperatures of below 120 °C. A change in mineralogy of silica sinter from opal A to opal-CT, perhaps into microcrystalline quartz, according to, indicates that the activity of Cisolok geothermal system has been occurring more than 10,000 years.

Interaction between thermal water and surrounding rocks, one of the formations is limestone, causes the deep Cl water to change into HCO3 water. At the surface, the thermal water does not form silica sinter anymore, but travertine deposit. The travertine deposit will firstly cement the basement and alluvial materials to form pebbly travertine. Furthermore, the travertine will form crystalline crust and lithoclast above the pebbly travertine. Because the basement is dipping to SW, the travertine deposit seems to have only 1 slope, i.e. dipping to SW. Point, where the hot spring emerges, is about CSL-01 to 03 now. After that, dropping of water table likely occurs. Therefore, the hot spring activity shifts to SW. This can cause the CSL-01 hot spring to shifts to the oxidation zone and to be HCO3 water. The fluctuation of water table seems to occur until now. This cause a change in the chemical composition and type of Cisolok thermal waters.

4. Conclusion
The isotope analysis shows the similarity of fluid characteristics δ18O and δ2H with local meteoric water, interpreted by the dominance of the meteoric waters controlling the reservoir. Based on this, it is assumed that the source of water comes from the area of Mount Halimun as run off and then enter through the fault that develop as a source recharge area. Cisolok reservoir is higher than 200°C based on presence of prophylitic zone and silica sinter. The direction of outflow is lateral flow, but steam is up flow. Argillic zone caused by oxidation process (H2S → H 2SO4). And dominated by clay mineral, such as kaolinite and smectite associated with chlorite and quartz are formed by acid pH environment with temperature less than 120 °C. These conditions were happened over 10000 years ago, shown by silica sinter has changed from amorphous silica become quartz crystalline (stable form) and occur caused by interaction of hydrothermal and wall rock. Hot spring has been changing from chloride to bicarbonate water and the evidence is presence of travertine deposit on surface. Travertine deposit is filling alluvial and basement of river as pebbly travertine.

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