Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Lithological and Structural Control of the Geothermal System in the Nereidas Valley, Caldas- Colombia

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Keywords: Geothermal, structural control, Nereidas Valley, geology, Botero-Londoño.

ABSTRACT

The Nereidas Valley was described in the '60s. Its located in the SE of the municipal set of Villamaría, Caldas-Colombia, nearby to the Rio Claro river in the confluence with the Nereidas river. There are several geothermal manifestations like hot waters, steams, and formations of new minerals. These manifestations are located to the West from the Botero Londoño area in the Nereidas Valley. They are characterized by having high patterns of a deformative processes in the zone. There are several hydrothermal alterations like silicification, sericitization, and epidotization as a product of the ascension of the hydrothermal fluids. This area is influenced by structural control. These structural controls are produced by the existence of the Santa Rosa, La Telaraña and Nereidas faults mainly. Using kinematic indicators, it is observed that La Telaraña and Santa Rosa faults have a right-lateral strike-slip with an NNE-SSW orientation. On the other hand, the Nereidas fault has a left-lateral strike-slip with an NW-SE orientation. These faults have geomorphological evidence like triangular facets and the deflection of the Rio Claro river. In the area of the survey, the ascension of the geothermal fluids it is posed as a product of the secondary porosity by the brittle deformation due to the tectonic activity. Therefore, structural control is proposed throughout the thermal system. In addition, the area is affected by the emplacement of felsic intrusions probably associated with the volcanic system of Nevado del Ruiz (NRV).

1. INTRODUCTION

The geothermal systems can be found associated to volcanic centers or in structurally controlled areas (Ayaz et al., 2010; Faulds et al., 2010). In the San Diego – Cerro Machín Volcano Tectonic Province (SCVTP) near to Nevado del Ruiz Volcano in the Central Cordillera limited by departments of Caldas and Tolima, the volcanism associated to this area has a geodynamic environment dominated by an active continental margin CHEC (1983). The area of survey is influenced by a coupled of faults that are found in a transpressive deformational setting that helps the fracturing and deformation of the rocks as Toro and Osorio (2005) mentioned. Faults and associated fractures are important for the understanding of geothermal systems due to their influence on the stratigraphic structure and groundwater flow (Corbel et al., 2012). These faults behave as conducts that can also increase the permeability of lithological units that have been affected by them (Ferrill et al., 2004). According to Bohórquez et al. (2005), the current tectonic framework regimen of the area that encloses the northern volcanic system of Colombia (SCVTP) – which includes NRV-, is originated by the South American plate collision with the Panamá-Chocó Block and is dominated by a set of synthetic and antithetical structures. These structures respond in general to the regional strains tensor (with a $\sigma 1$ in direction NW-SE). The hydrothermal manifestations are at the intersection of the Telaraña and Nereidas faults with the respective orientations NNE-SSW and NW-SE that. These can be recognized by several geomorphological features. The basement, which is under a dilatational tectonic syntax regime, allows fluids to ascend by the dilatational zone and by secondary porosity they are found on the surface. The fault's location, orientation, geometry and magnitude of permeability contrast between the fault core and the damage zone define the behavior of faults as a pathway, barrier, or both, for geothermal fluids (Caine et al., 1996); Li et al., 2013). The influence of faults should be considered when exploring geothermal reservoirs, like at the Nevado del Ruiz (NRV) geothermal project in Colombia, Mejía et al., (2012). Colombia is however another country with similar volcanic environments to countries with high geothermal potential and could be in the future a reference in the geothermal power generation at a global scale.

2. GEOLOGICAL SETTING

2.1 Lithologies

Lithologies: The area of survey comprehends the following lithologies that are identified during the study and that are also previously reported in the literature (Figure 1).

2.1.1 Cajamarca Complex

It is a part of the central axis of the Central Cordillera of the Andes in Colombia. It is composed of a variety of metamorphic rocks like quartz-sericitic and actinolitic schists, marbles, quartzites, phyllites. The complex is recognized too as a polimetamorphic complex owing to many deformational events. The isotopic datings by Maya (1992) confirm that this complex has suffered 2 paleozoic metamorphic events and one cretaceous, indicating a paleozoic-cretaceous age for this complex according to Maya and Gonzalez, (1995). This explains the dynamic metamorphism that is a product of tectonic movements that happened in the Central Cordillera, resulting in the formation of mylonites, fracture and folding rocks (Monsalve and Mendez, 1997).

According to Nivia, (2001) and Gonzalez, (2001), nonconformity overlies ignimbrites of the Rio Claro, recently called pyroclastic density current (PDC). At a regional level, the complex has many granitic intrusions pre-Mesozoic to Cenozoic, according to Restrepo and Pace (1992).

2.1.2 Rio Claro Ignimbrites

According to Monsalve and Mendez (1997) are presented as a unit of massive volcanic floods with a local structure called a columnar disjunction, due to the faster cooling of the floods by thermal contraction. It is described as a chaotic deposit of different grades of compaction and is composed of vesicular fragments, accidental, and juvenile lithics. These contain volcanic and in a lower proportion metamorphic rocks, a lot of these are altered and embedded in a matrix of volcanic ashes. In addition, they have been recognized as deposits of debris floods of a minor magnitude by Velasquez and Sanchez (2016). These deposits were dated with fission prints proposing an age between 40.000 ma to 90.000 ma during the study of Grand and Handszer (1989). They are found in the zone filling the valleys of the Molinos, Rio Claro and Nereidas rivers. They are partially covered by lava floods of dacitic –andesitic compositions, according to Acosta and Quintero (2014).

2.1.3 Quaternary Deposits

Comprehend a group of pyroclastic rocks and mud floods, glaciers, and recent alluvial deposits. The origin of the floods is mainly provided by Cerro Bravo, Nevado del Ruiz, El Cisne, Santa Isabel Nevado, and El Tolima Nevado volcanoes according to Acosta and Quintero (2014). They are characterized by being found on the margins of the rivers, covering the oldest rocks mentioned previously. This unit has geomorphology that is represented by elevated plates highly dissected for the Molinos and Rio Claro rivers according to Diaz and Aguirre (2014).

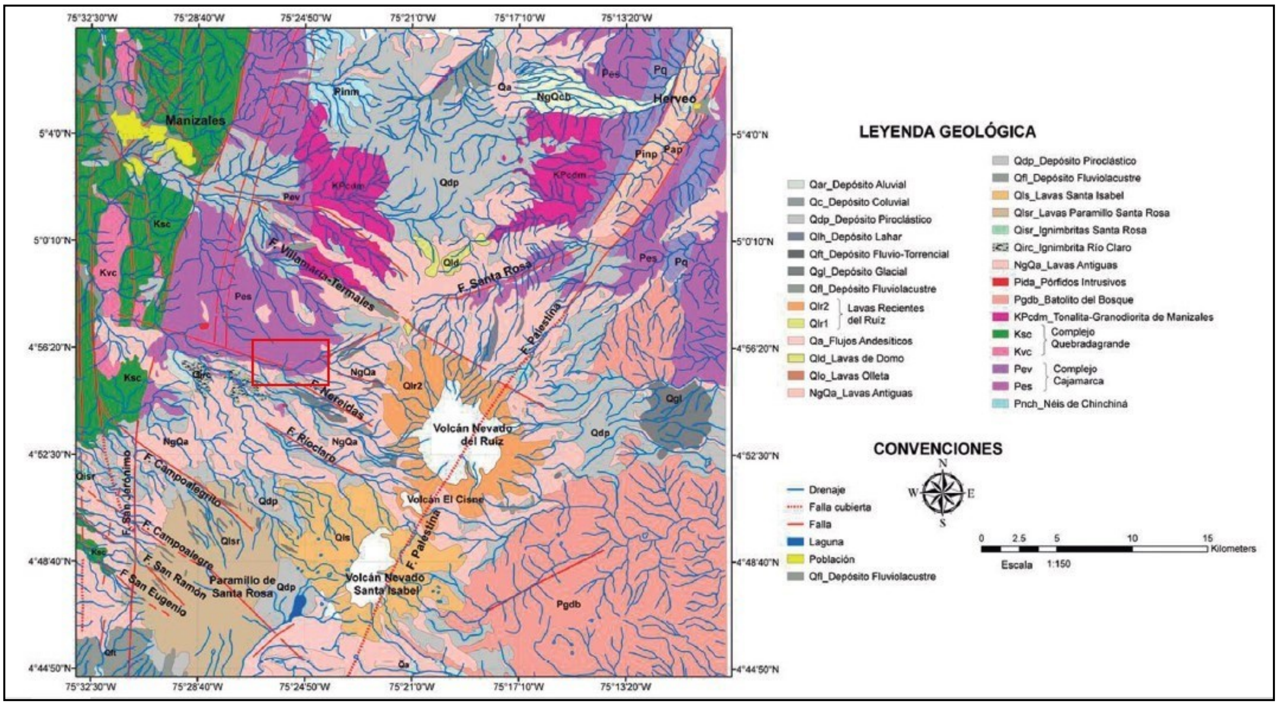

Figure 1: **Regional geological map of the area. The red box limits the survey area. Source: Modified from Mejía et al. (2012). Structural analysis to the northeast of the NRV, Colombia – input to the geothermal exploration.**

2.2 Structural Geology

In the survey area, there are two major fault systems that are part of the Nereidas Valley geothermal system (Figure 2). The first system has an NW trend and includes the Nereidas, Villamaría-Termales, and other local faults that do not have relevance in the present survey. The Nereidas fault is the most important fault in this system because most of the hot springs are located along this fault. According to Calvache Y Monsalve (1983), they established that the faults that belong to this system have a left-lateral strike-slip with a progressive sinking of blocks to the southeast. The second system has an NW-SE trend and includes the Santa Rosa, La Telaraña, Río Claro, and other local faults that don´t have relevance in the present survey. The Santa Rosa and La Telaraña faults are the most important faults in the system because they interact with the Nereidas and Villamaría-Termales faults producing a zone of dilatational tectonic syntax, increasing the secondary porosity, allowing the circulation of hot springs throughout the bedrock (Figure 3). The Santa Rosa Fault is defined as a reverse fault with a dextral-lateral strike-slip component for its parallelism with the Ibagué Fault.

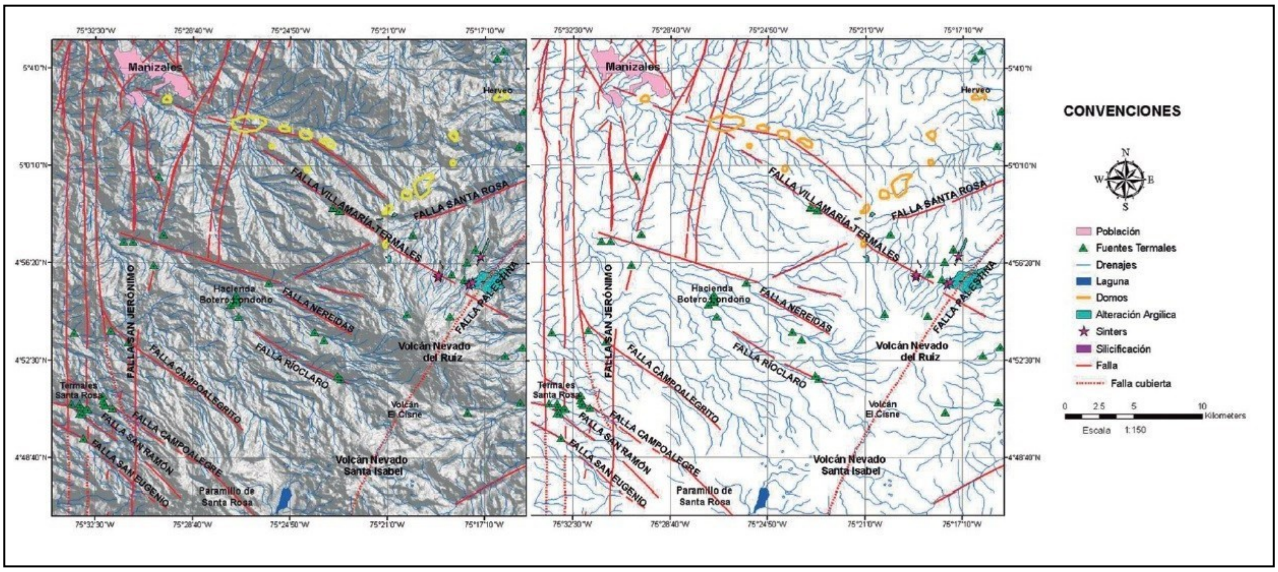

Figure 2: **Structural geology map of the survey area. Source: Taken from Mejía et al., (2012). Structural analysis to the northeast of the NRV, Colombia – input to the geothermal exploration.**

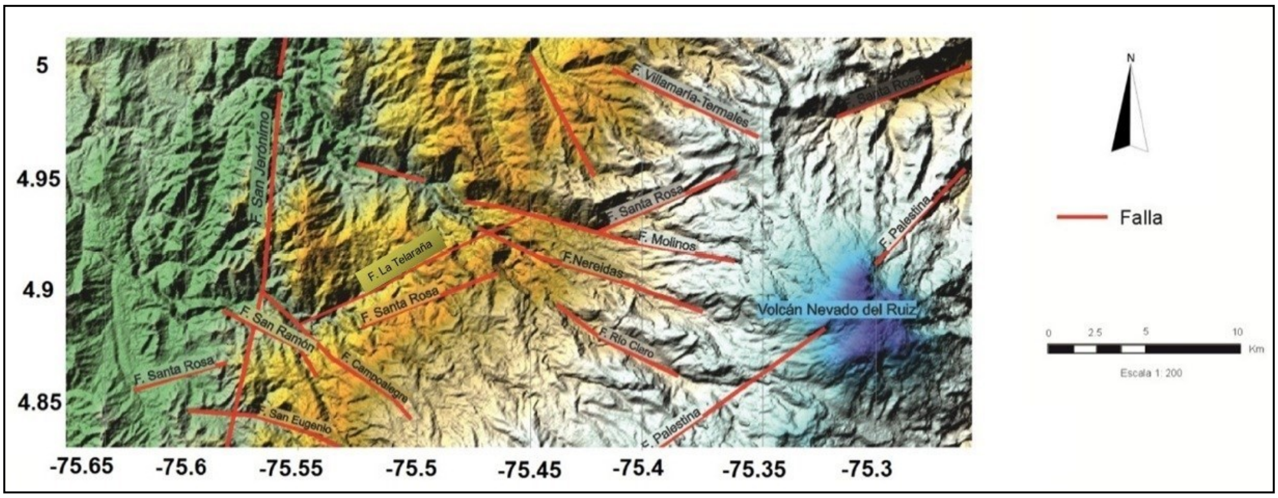

Figure 3: **Fault map of the survey area. Source: Modified from Acosta and Quintero (2014). Kinematic and deformation analysis of the Santa Rosa Fault between the municipalities of Santa Rosa Cabal and Villamaría (Caldas).**

It is located to the north of Pereira- Dosquebradas and passes through Santa Rosa de Cabal crossing the Central Mountain Range to the north of Nevado del Ruiz Volcano before joining to the Palestina Fault. Guzmán et al. (1998).

3. METHODOLOGY

It consisted of a previous revision of the literature that involves the main characteristics of the geological setting, followed by a stage of fieldwork. In this survey, the structural data, the recollection of rock samples, and the identification of the predominant lithology were done, the geothermal manifestations, and the alterations produced by the exposure of the rock to the heat of the water and its components (Figure 4).

Figure 4: Photography of the survey area, located on the Vereda Playa Baja, Villamaría, Caldas- Colombia. Source: Authors.

4. FIELDWORK

During the recollection of the data were found three hydrothermal manifestations, two of these are located along the margin of the Rio Claro river and the third one is on the margin of the Quebrada Nereidas. The first manifestation is found in an oligomictic breccia named according to Boggs (2009) that has a secondary porosity which provides the facility of the ascension of the warm water (Figure 5).

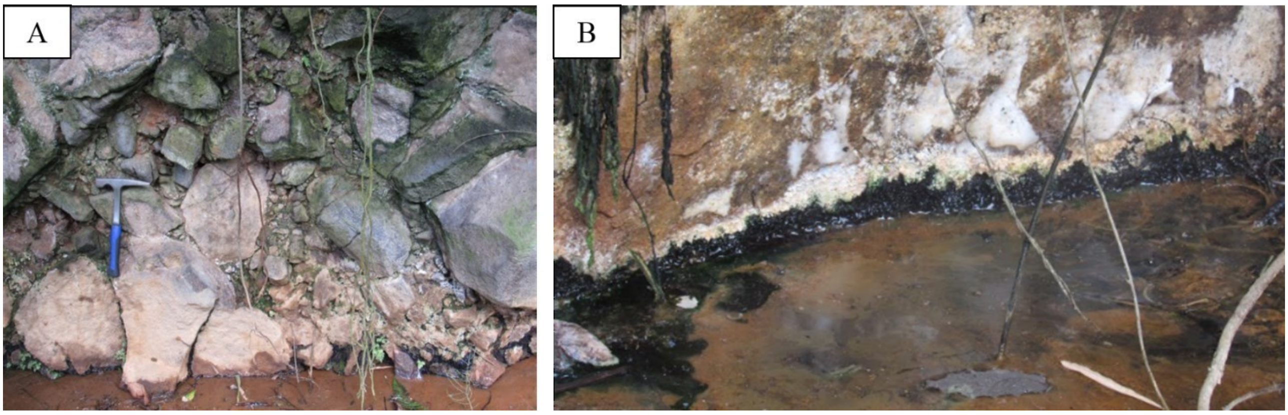

Figure 5: First station that presents hot water manifestation and steam. It was found in Quaternary Deposits. Source: Authors.

The Second manifestation is easier to recognize due to the bubbling of the heated water, presence of water vapor, and some biomarkers like algae of ochre color or orange-red kinds. These allow knowing that the temperature of the steams is in a range of (60º-71ºC), as mentioned in Waring (1983) (Figure 6).

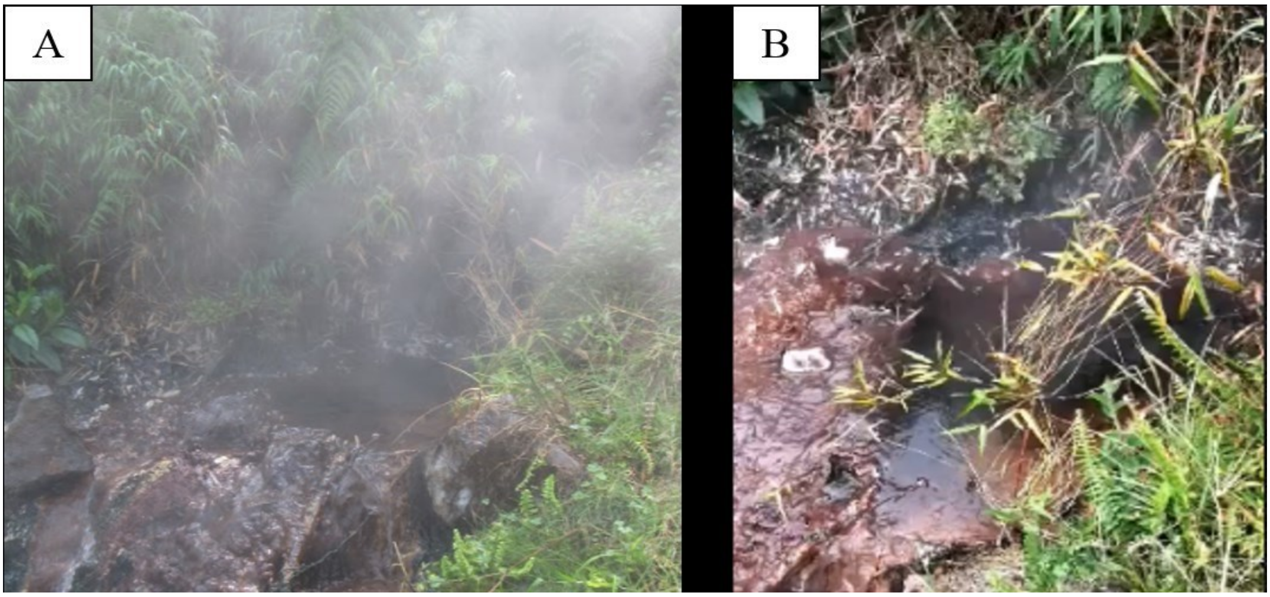

Figure 6: Second outcrop, which presents major temperature and steam emanation. Source: Authors.

In the front margin of the Rio Claro's river can be distinguished cataclastic foliation and a zone of the strain partitioning due to the different sides of the blocks presented in a tonalitic porphyry. The main joint family has the orientation N60W/ 82º NE proving the evidence that the Santa Rosa and La Telaraña faults are doing structural control in the zone (Figure 7).

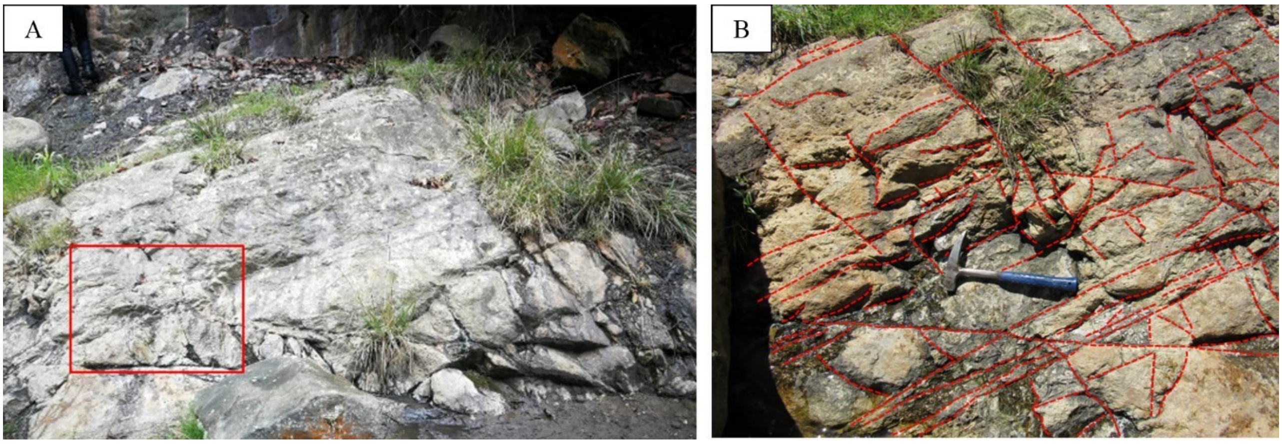

Figure 7: Two deformation events have a different origin. A) Ductile deformation due to strain partitioning. B) Is observed a brittle deformation associated with joints and fractures. Source: Authors.

The third manifestation is the most extensive and representative. It is on the Cajamarca Complex which presents many deformational events like mylonitization and an intrusion event, this intrusive body has not been correlated with the other intrusions reported in the zone because it is highly altered by deformational zone and presents silicification and epidotization as a product of the hydrothermal fluids-rock interaction being the main alterations that can be registered on this rock (Figure 8).

Figure 8: **A) Highly altered as a product of the interaction between the rock and the hydrothermal fluids. B) The Cajamarca Complex is been affected by mylonitization as it's showed associated with a shear zone. C) Intrusive contact among the schists belonging to Cajamarca Complex and a felsic igneous intrusion, which is not classified. Source: Authors.**

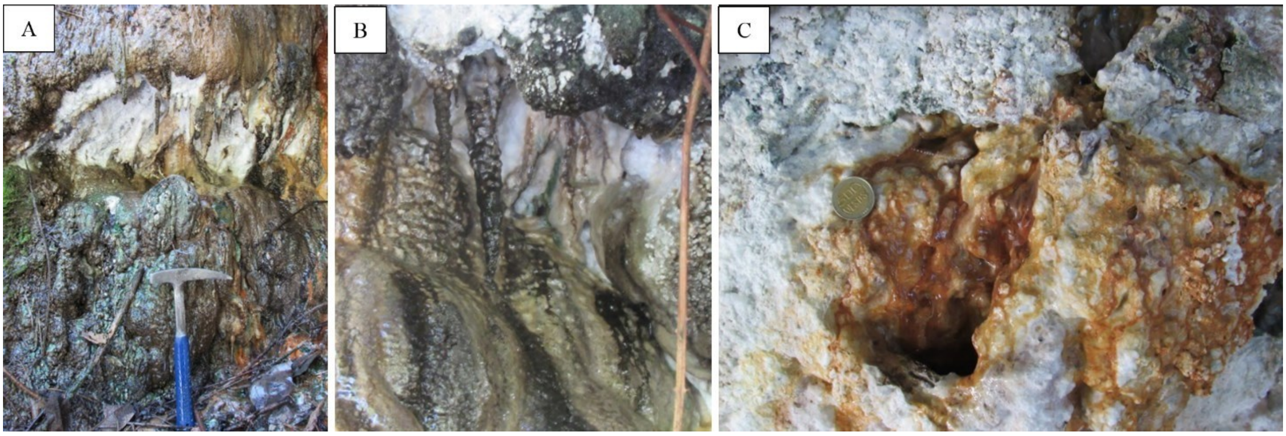

Figure 9**: A and B) Presence of stalactites and stalagmites composed by amorphous silica as shown in the figures. C) Silicification does the hydrothermal fluids. Source: Authors.**

5. CONCLUSIONS

According to the research carried out, an approximation is achieved based on the hydrothermal alterations presented in the geothermal system, placing them in a structural geological context, seeking in the future to perform petrographic studies, stable isotopes in fluid inclusions, geophysical methods and water chemistry and determine their viability as a geothermal source.

Based on the development of the study, we can assume that this system is connected to the hot springs manifestations in the Botero–Londoño area. The connection between those manifestations is a product of structural control among Nereidas and Santa Rosa and Nereidas and la Telaraña faults.

The basement of the area of the survey (Cajamarca Complex) is highly deformed evidenced in the anastomosed foliation superimposed in the original foliation on the schists. Also, the basement suffers brittle deformation that originates fractures and joints that allow to elevate the secondary porosity and permits the ascension and circulation of the hot water.

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