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New Areas of Geothermic Interest in the Central Cordillera of the Colombian Andes: Santa Rosa and Cerro Machín

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ABSTRACT

Colombia is part of the Pacific Ring of Fire, because of this has a privileged location to explore geothermal systems. Colombia has three cordilleras with trend N-NE. Recently volcanic activity and high enthalpy geothermal systems are recorded in the Central Cordillera. Colombian Geological Survey has begun the exploration of new areas with geothermal potential in this Cordillera, such is the case of Santa Rosa and Cerro Machín areas, which have been found geothermal superficial evidence. The Santa Rosa geothermal area is located in the western flank of Paramillo de Santa Rosa stratovolcano. It is compound by Paleozoic-Mesozoic metamorphic rocks, Cretaceous metavolcanics-metasedimentaries rocks and Quaternary volcanic deposits. Exits two regional fault systems are approximately perpendicular to each other. The first one in NNE-SSW and NE-SW directions, coincidences with the directions that are generally found in the tectonic systems of the Andean chain. The second system is in NW-SE to EW direction. In the area have been evidenced the thermal manifestations such as hot springs until to 90 °C with marked structural control and rocks with phyllic-propylitic alteration has been recognized. The Cerro Machín volcano geothermal area is located to 35 km to SE of Santa Rosa area. It has a very high explosive behavior. Geology consists in Triassic schists, green schists, phyllites and volcanic deposits with ages less than 50.000 years and dacite domes. The alteration rocks are almost restricted to the intercalderic domes result of the interaction between rocks with superficial steam, besides some volcanic lithics into volcanic deposits (less 10.000 years) have hydrothermal alteration. Locally, the structural trend is N-NE. Hot springs are restricted to the proximal crater area and controlled by main rivers and streams with northeast orientation, they are bicarbonate waters with temperature from 20°C to 90°C. In the other hand, gases emanations in the top of the intracalderic domes are found. New evidence of H2S were found in a stream near to the volcano and 5 km to east of main crater, indicating probably another magmatic chamber or a strong structural control which get these gases away to far of the crater. In order to enhance the exploration, structural geology characterization, geochemistry analysis in gases, potential methods and resistive methods (MT, TDEM) acquisition will be applied.

1. INTRODUCTION

Geothermal exploration in Colombia has been developed since the 1980s with the participation of OLADE (1982), in which it was identified that Colombia is a country with great geothermal potential. Colombia has three large N-NE oriented mountain ranges, corresponding to the Oriental Cordillera, Central Cordillera and Occidental Cordillera. It has been considered that the appearance and disappearance of the volcanic phenomenon in the Central Cordillera is closely related to the subduction angle of the Nazca plate (Bohórquez et al., 2005). On this mountain range is both active volcanism like the Cerro Machín volcano with activity less than 1,000 years, until inactive as the Paramillo de Santa Rosa with the last activity in the Holocene. Regardless of the volcanic activity, thermal manifestations associated with geothermal activity are found on the Central Cordillera. In this way, Colombia is considered has a high geothermal potential, so the Geothermal Resources Exploration work group of the Colombian Geological Survey (SGC) has prioritized geothermal areas over the Central Cordillera, taking into account volcanic activity and surface evidence such as springs and rocks with hydrothermal alteration.

2. LOCALIZATION

Among the new exploration areas are the geothermal areas of Santa Rosa and Machín; the first is located on the western flank of the Central Cordillera, while the second is on the eastern flank. The geothermal area of Santa Rosa is located east of the Santa Rosa de Cabal municipality, on the western flank of the Paramillo de Santa Rosa Volcanic Complex (CVPSR). While the geothermal area of Cerro Machín is located northeast of the Municipality of Cajamarca and northwest of the city of Ibagué. (Figure 1).

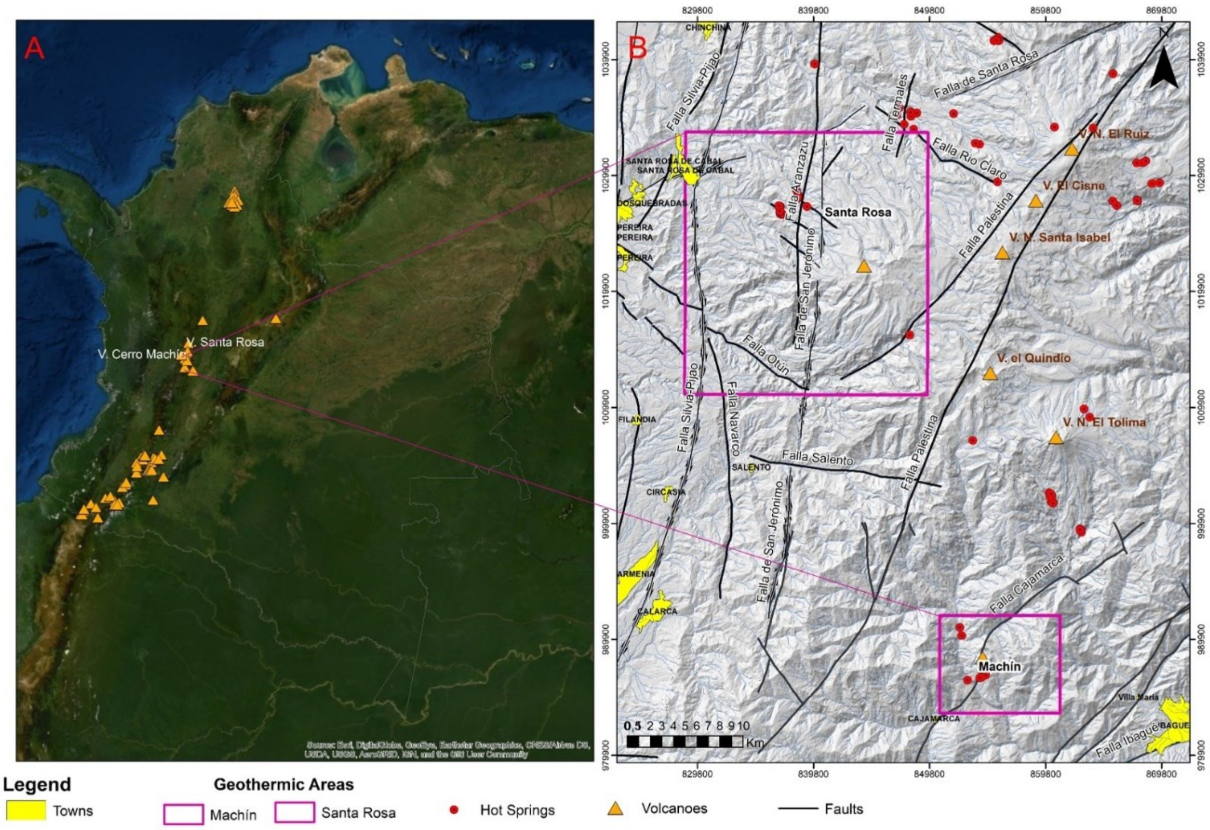

Figure 1: Localization of new geothermal areas in exploration by SGC. A) Volcanoes located in Colombian Cordilleras. B) Santa Rosa and Cerro Machín geothermal areas.

2. GEOLOGICAL FRAMEWORK AND BACKGROUND

According to Bohórquez et al. (2005) both geothermal areas are among the most northern volcanism in the country, between the volcanoes Romerales to the north and Cerro Machín to the south, limited by large fault systems that cross the country. Regionally, two main fault systems have been identified that are direct influence in these geothermal areas. The dominant faulting is the structural units with N-S to NNE direction, corresponding to the Romeral Failure System. It was established that the predominant stress regime during the Quaternary is mainly compressive and secondarily strike-slip, with a stress tensor ($\sigma 1$) in the NW-SE direction. Complementary to this regime and in an orthogonal sense, there are evidences of distension with the NNE-SSW to NE-SW direction. The probably active fault pattern has an N-S to NNE address, although additionally there are important structures in the WNW-ESE and NE-SW directions. Faults in the N-S to NNE direction have inverse type dynamics and sinestral components. The dynamics of structures with WNW-ESE address coincide with normal type and dextrolateral component, and NE-SE direction faults would adapt to a reverse type dynamic.

The CVPSR is classified as a stratovolcano very eroded by ice action and highly affected by a high density of tectonic lineaments, corresponds to a set of eruptive sources and volcanic deposits located in the central sector of the San Diego Cerro Machín volcanotectonic province. Two eruptive periods are proposed for the evolution of the CVPSR, the first one from 2.3 to 0.56 million years ago and the second one from 0.56 million years ago to the Holocene (Pulgarín, 2017). In addition, it is the westernmost volcano among the volcanoes of its study area, and is displaced westward along the axis of the active volcanic mountain range (CHEC, 1983; Pulgarín, 2017).

The geological units that make up this geothermal area consist of volcanic rocks mainly andesites to dacites overstating on Jurassic, Cretaceous and Cenozoic rocks that serve as a basement, with reservoir rocks being possible (?). Geological units, from the oldest to the most recent, are rocks of the Jurassic of the Cajamarca Complex, volcanic-sedimentary rocks of the Cretaceous of the Quebradagrande Complex and El Bosque Batholith of granodiorite to tonalite composition from Cenozoic. Overstating there is a thick layer of extrusive rocks, related to the intense activity in the Miocene and extends until recent times (Figure 2).

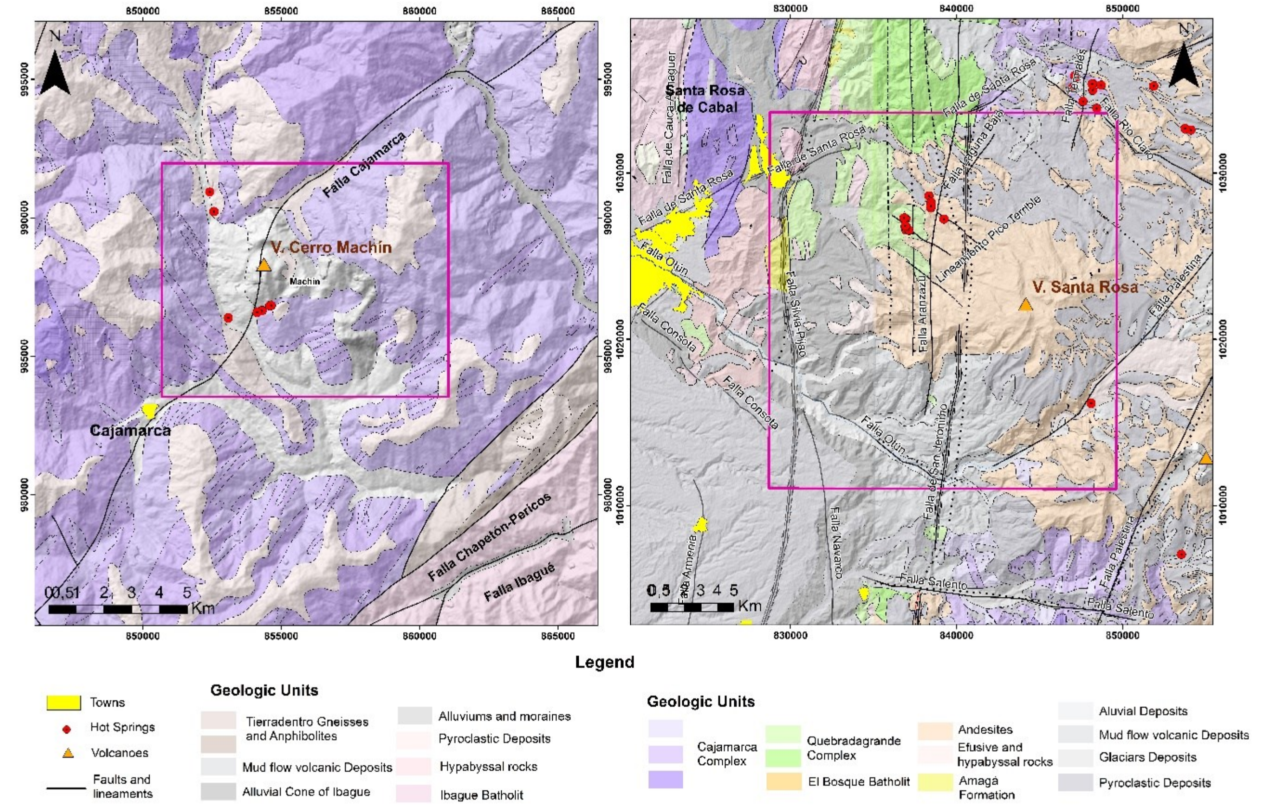

Figure 2: Geology maps of Santa Rosa and Cerro Machín geothermal areas.

According to González (2001), the Cajamarca complex refers to metamorphic rocks that constitute the core of the Central Cordillera, they are intensely folded so it has not been possible to determine the thickness, also varies widely in the composition resulting from several regional metamorphic events in those that superimpose thermal or dynamic effects. It has been divided into three compositional groups: pelitic group (phyllites, sericitic and michaceous and metasedimentite shales), quartz group (quartzites) and basic group (green schists and amphibolites). The Quebradagrande Complex has as its eastern limit the San Jerónimo Fault, which separates it from the metamorphic rocks of the Cajamarca Complex. Intercalations of volcanic rocks (such as basalts, flows of breccia and tuffs) and sedimentary (carbonated shales, feldspathic sands, greywacke, limolites and limestones) that are interspersed with volcanic rocks in concordance. El Bosque Batholith from Eoceno is part of a group of plutons of intermediate composition located on the eastern flank of the Central Cordillera, marking end of an orogenic activity initiated in the early Cretaceous.

Volcanic rocks with a great thickness that rest on this basement are flows of homogeneous composition mainly andesitic to dacitic, with an average content in K_2O, of calcoalkaline affinity (Pulgarín, 2017). Following the regional cartography made by González (2001), there are andesitic-dacitic flows from the Miocene to the Pliocene, effusive and hypoabisal rocks corresponding to andesitic flows from the Quaternary and alluvial vulcan-sedimentary Quaternary deposits, glaciers, volcanic mud flow and pyroclastic.

The Cerro Machín geothermal area is located within the Cerro Machín Volcano, classified as a complex pyroclastic ring that has a diameter of 2.4 km with domes plugging its crater (Figure 2). This volcano restricts its activity to the Holocene, in which its volcano structure is underlining the basement corresponding to the Cajamarca Complex. According by Mosquera, et al. (1982), this Complex composes more than 50% of this geothermal area, predominantly constituted by chloritic-actinolytic schists, phyllites and quartz-sericitic-graphitic schists, subordinates are quartzites, quartz schists, amphibolic schists and marbles. On the basement are located pyroclastic emissions of intermediate to basic composition represented by flows and fall of ash, lapilli and pumps have been maped and Quaternary sedimentary deposits from fluvioglacial origin are found, little or not at all, consolidated from volcanic rock cobble in a tobaceous matrix. Detailed cartographic studies in the Cerro Machín volcano have identified domic bodies between rhyolite-dacite and biolite-enriched rhyolites composition (Cepeda et al., 1995).

Main regional structures of this geothermal area have a NE direction corresponding to the faults of Ibagué, Chapetón-Pericos and Cajamarca, all of which have strike-slip behavior. IsCajamarca fault that has the structural control of this geothermal area.

2.1 Geothermal area of Santa Rosa

In this geothermal area there are a lot of rivers and brooks that are born in the Paramillo Volcanic Complex of Santa Rosa, with tours from east to west. On stretches of some of these water sources there are occurrence of hot springs grouped into two sectors known as San Vicente and Santa Rosa (Figure 3). The hot springs of San Vicente are along the line of the Campoalegrito river, with temperatures between 28 °C to 89 °C and a chlorinated chemical classification (Alfaro & Jaramillo, 2002). The springs of Santa Rosa are located on sections of the San Ramón river and the Santa Helena ravine, these hot springs have a temperature with ranges between 44 °C to 68 °C and a bicarbonated chemical classification (Alfaro & Jaramillo, 2002; Alfaro et al ., 2002). These variations in temperature and chemical composition suggest that the springs with the greatest direct contribution of the reservoir fluid are those of San Vicente (Alfaro & Jaramillo, 2002). In these two sectors there is a thermal anomaly reflected not only by the presence of hot springs, but by estimated values of geothermal gradients with values around 120 °C/Km and 130 °C/Km (Alfaro & Jaramillo, 2002).

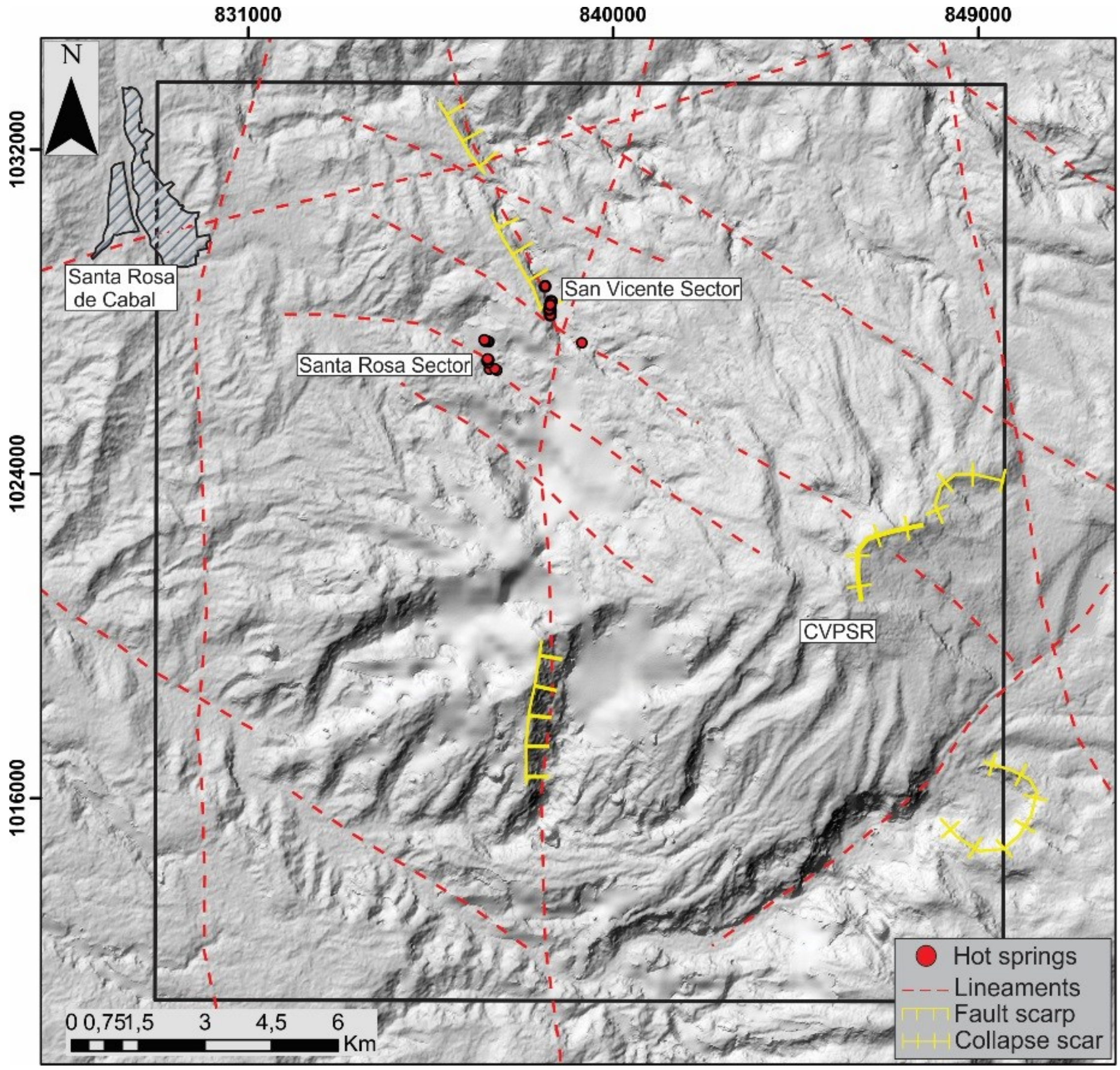

Figure 3: Morphotectonic map on a shadow relief in the geothermal area of Santa Rosa.

The geothermal area of Santa Rosa is part of the Parque de los Nevados, where, although numerous hot springs are found there are specific characteristics that make independent geothermal systems suppose. Hydrothermal calcium carbonate deposits that were previously silica (opal and chalcedony) (Fetzer, 1942) are frequently found in the Santa Rosa area, however these deposits are not found in the Nevado del Ruiz (Alfaro & Jaramillo, 2002). The above, coupled with the fact that the hot springs in the Santa Rosa area are located a great distance from those of the Nevado del Ruiz (25 km in a straight line) suggest, independence between these two geothermal systems (Santa Rosa and Nevado del Ruiz), where Santa Rosa's would be richer in CO_2. Fluid geochemistry works have suggested that the Santa Rosa geothermal system has a temperature above 250 °C (Alfaro and Jaramillo, 2002).

Recently the group of Exploration of Geothermal Resources of the Colombian Geological Service, has advanced studies related to the structural geology and characterization of hydrothermal alteration in the geothermal area of Santa Rosa (Figure 2). Although the results of this work are preliminary, structures in the NNE and NW direction have been identified mainly. The NNE strokes are the most regional with marked fault scarp, associated with the Sistema de Falla de Romeral; According to the data of the field, these are reverse faults with planes that dip east. The NW structures control the traces of the tributaries in which the area's hot springs are located, apparently these structure would be strike slip fault (Rodríguez et al., 2019). The volcanic building, the hot springs and some hydrothermally altered areas, is located on the interception of the NNE structures with the NW.

The hydrothermal alteration has been identified locally in the sectors of La Tigrera. It is possibly the fossil fumarole "El Disparate" referenced by Fetzer (1942), as well as in the occurrence of the hot springs of Santa Rosa and San Vicente, where there are minerals in the group of clays that do not allow to recognize the original characteristics of the rock (Rodríguez et al., 2019). To the west of the CVPSR in the La Sierra sector, the hydrothermal alteration presents greater extension, especially at the headwaters of the Campoalegrito and San Ramón rivers as well as the fossil fumarole now Azufrera Betania. In these places lavas of porphyritic texture outcrop, composed of phenocrysts of altered plagioclase, in addition to some mafic minerals that sometimes appear to be chloritized (Rodríguez et al., 2019).

Figure 4: Hydrothermal alteration and tectonic structures in the geothermal area of Santa Rosa. A. Hydrothermal alteration in the hot spring of Santa Rosa. B. Alteration in the possible fossil fumarole El Disparate. C. Slickenline. D. Reverse fault in NS direction. E. Overview of the Azufrera Betania in the La Sierra sector. F. Details of the alterations on the ravine Santa Helena.

2.2 Geothermal area of Cerro Machín

The importance of this geothermal area lies in the recent activity of the volcano whose last eruption is dated in 820 years (Thouret et al., 1995) with later intracalderic domes and due to the high discharge temperature of the hot springs (>90°C). Geoconsul (1992) evaluates the geothermal potential of the Ruiz volcanic massif, where a large part of the active volcanoes of the Colombian Andes are located, including the Cerro Machín volcano, and where a small dominant liquid deposit of about 250 ° C is proposed.

The geothermal activity in this area is represented by discharges of water and gas in the Toche river and the Aguatibia and San Juan streams (Figure xx). Recently, new outflows of gases (H2S?) were found in the Azufral stream and in the vicinity of the Tapias town, along with abundant deposits of travertines in the Corrales creek (Figure 5). According to Alfaro & Jaramillo (2002) the hot springs are bicarbonated with discharge temperatures ranging from 40 ° C to 94 ° C with an estimated temperature for the reservoir from 220 to 2240 ° C with the Na / K geothermometer. Based on the model Enthalpy-silica, the temperature of the reservoir is estimated at 245 ° C, but for some thermal and by the model of Enthalpy-Chlorides, the temperature of the reservoir could reach 300°C.

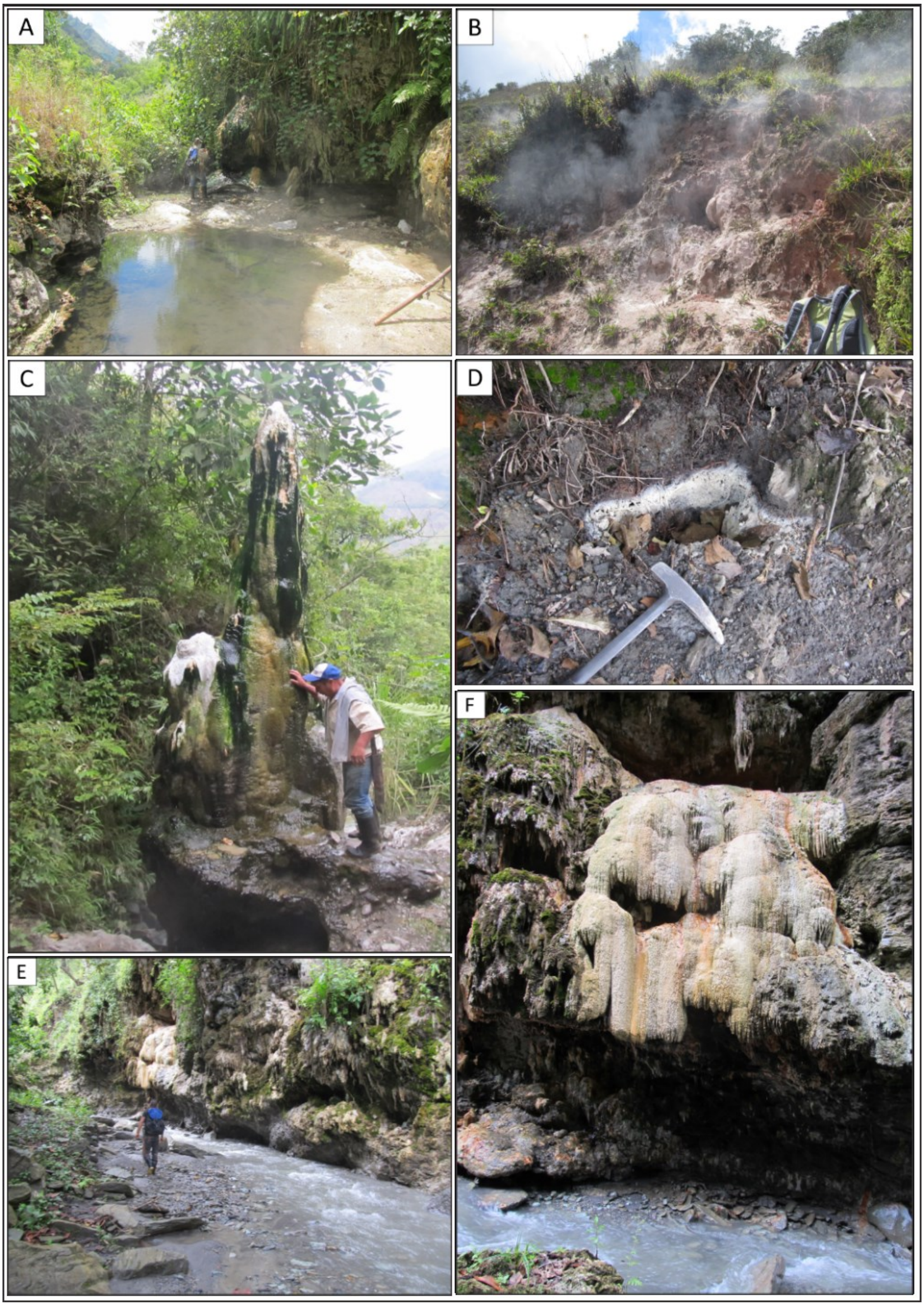

Figure 5: Thermal manifestations in Cerro Machín. A) Puente Tierra hot spring. B) La Macha fumarole. C) Travertino deposits in Aguatibia stream. D) Gas outlet in Tapias. E y F) Large deposist of travertine along the Corrales stream.

The preliminary field results carried out recently by the SGC allow us to reaffirm the structural control of the Cajamarca fault (Mosquera et al., 1982, Cepeda et al., 1995, Cuellar et al., 2014) in NE direction with dextral component. Although several authors have traced this fault right in the middle of the Cerro Machín volcano, until now no evidence has been found of the change in the orientation of the fault. In the sector of the Aguatibia stream, a fluted plane was found in the intracrateric domes, which together with the emergence of thermal springs in the same steam, would mean a plane of weakness in the same direction to the Cajamarca fault and the Ibagué fault system (Figure 6).

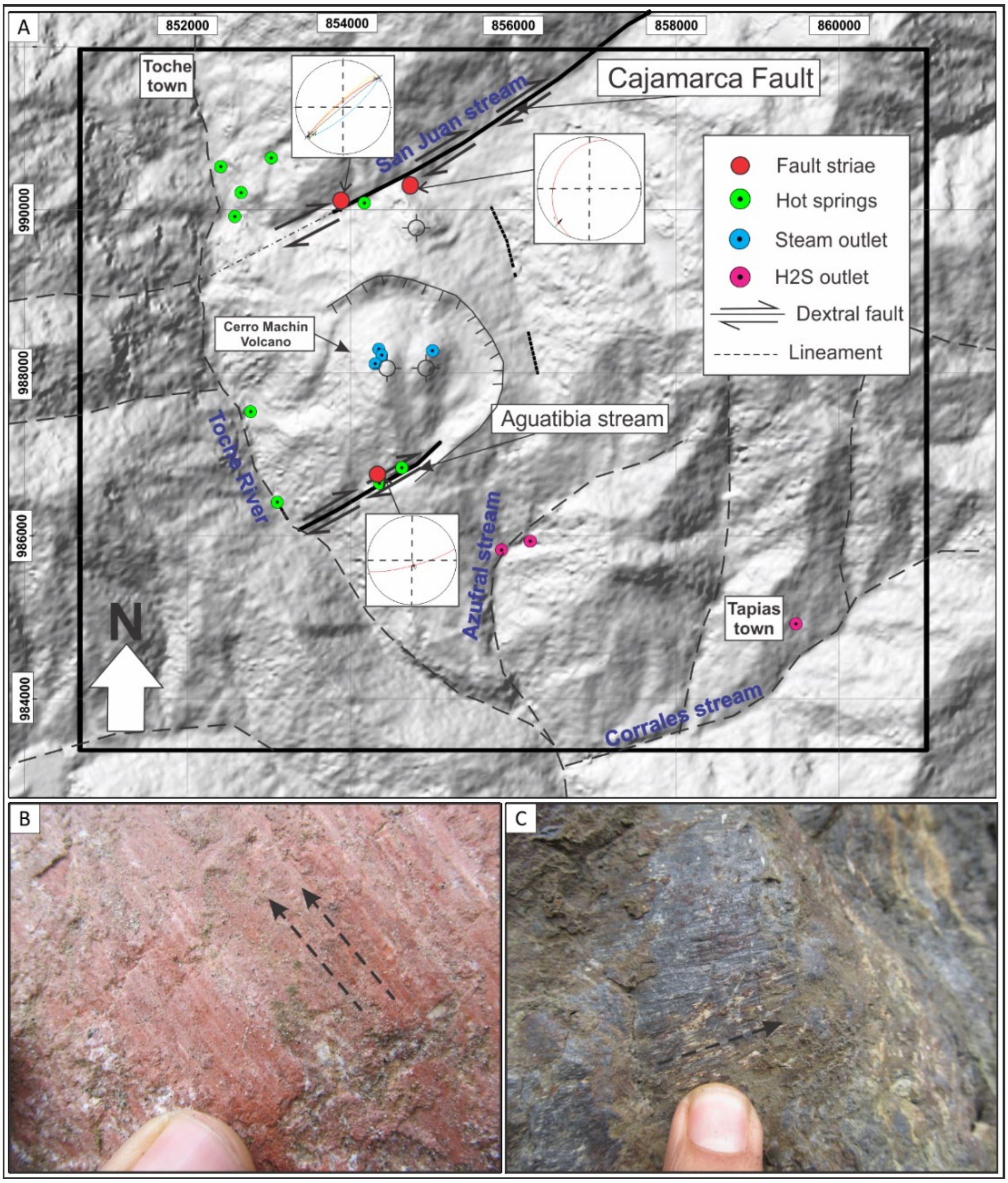

Figure 6: Structural expressions. A) Cerro Machín map with the main structures. B, C) Striae in dome a basement respectively.

Hydrothermal alteration is almost restricted to intracrateric domes that have a strong interaction with gases (Figure 7B). The argillic alteration predominates, although petrographic and geochemical analyzes have not been performed. Outside this area, a strong hydrothermal alteration is not expressed, but an intense weathering mainly from the metamorphic basement. Within the volcanic deposits, metamorphic and volcanic (lithic) fragments are observed with some degree of alteration in the matrix, evidencing the fluid-rock interaction through the different eruptions.

Given the aforementioned results and taking into account works such as Londoño (2016) who describes two swarm swarming areas (just below the main crater and in an area near to Tapias town), the exploration area has been expanded to the east. Thus, it is possible to acquire information from a possible magmatic focus different from the one that gave rise to the Cerro Machín volcano and its hydrotermal system, or on the contrary, to affirm that it would be a single magmatic source with domic expressions inside the crater and outside them.

The Geothermal Resources Exploration Group of the Colombian Geological Survey is conducting the studies of magnetoteluric, TDEM and potential methods (gravity and magnetism), along with a new stage of sampling of water and gases. These methods will be carried out during the years 2019 -2020 with the aim of recognizing the resistive structure of the subsoil and to create the conceptual model describing of this area.

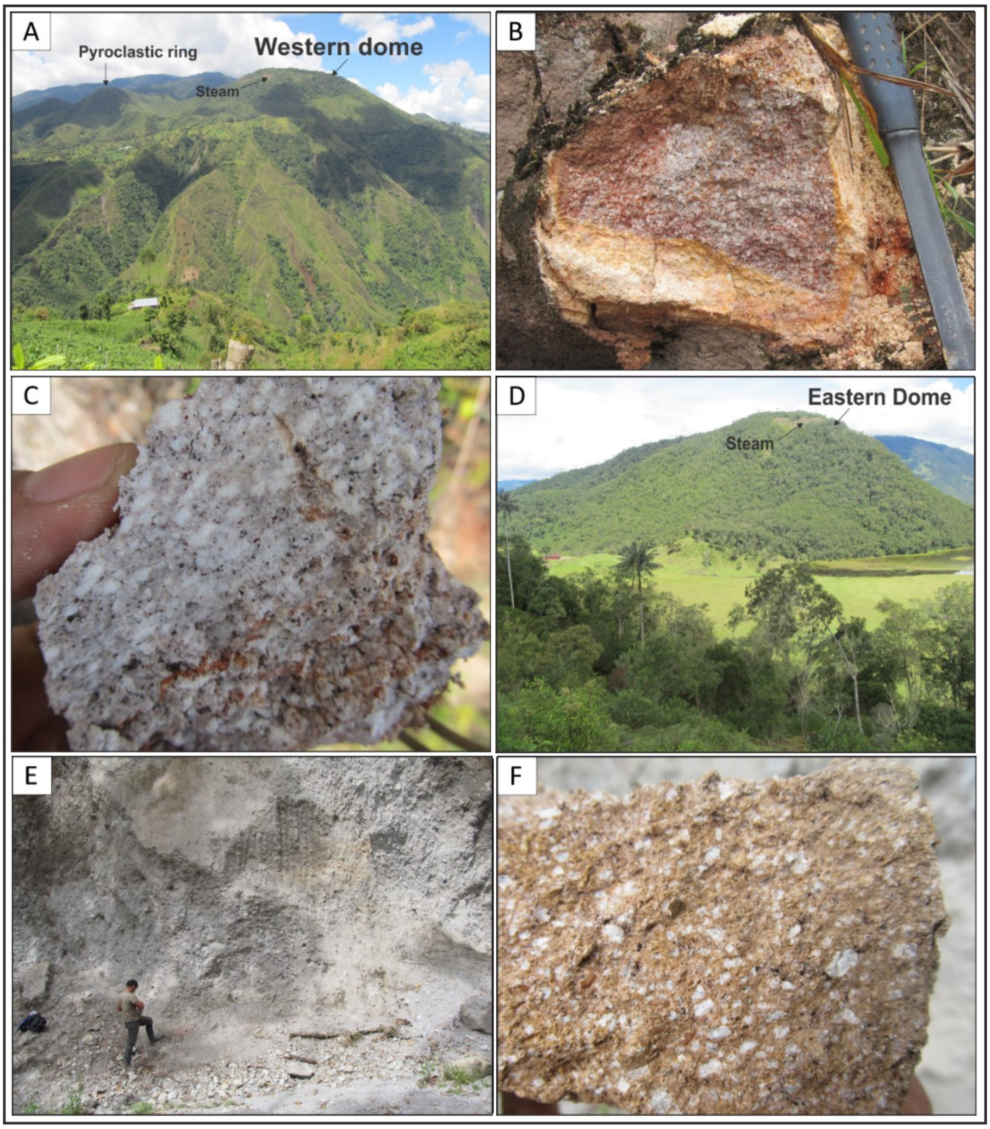

Figure 7: A) Cerro Machín volcano. B, C) Altered rock in the top of the dome. D) Intracrateric dome. E, F) deposits whit altered volcanic lythics.

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