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Hydrothermal Alteration and Fluid Inclusions Microthermometry Analysis of the Geothermal Exploratory Well N1 from EL Hoyo-Monte Galan Geothermal Area, Central Western Nicaragua, Central America.

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ABSTRACT

El Hoyo-Monte Galan is a geothermal prospect area in the Central Western Nicaragua. The current state of the project is feasibility stage with drilling exploration carried out in 2009. Hydrothermal activity in the surrounding area has been depicted by the hydrothermal alteration found in well N1 which comprises mineral phases such as quartz, chlorite, wairakite, alunite, epidote, and other high temperature minerals. Fluid inclusion microthermometry analysis was conducted on the well cuttings collected from the geothermal well N1 with homogenization temperature ranging from 178°C to 322°C, suggesting a good agreement with the hydrothermal mineralogy.

1. INTRODUCTION

Nicaragua is located between the Caribbean coast and the Central American trench on the Pacific side of the Central American Isthmus. The formation of the Central American Volcanic Arc (CAVA) is attributed to the subduction of the Cocos plate beneath the Caribbean plate, which has been occurring since the late Cretaceous period. The westward migration of the volcanic front occurred over time and ultimately settled in its current location approximately 8 million years ago, as shown by Ehrenborg (1996) (Figure 1 a). The Nicaraguan depression or Nicaraguan graben is the most important tectonic feature that host the Nicaraguan volcanic front and high enthalpy geothermal resources in the country, the graben started to subside in the Late Miocene (McBirney & Williams, 1964; Dengo et. al., 1985). The primary geological composition of the Nicaraguan Depression consists predominantly of unconsolidated pyroclastic materials. According to Henry R. Schmoll (1975), the entirety of the volcanic materials under consideration can be classified as being of Quaternary age, estimated to be approximately one million years old.

The Nicaragua Geothermal Master Plan 2001 (here after NGMP) encompasses a comprehensive analysis and assessment of the geothermal data available in the country for 11 specific areas with an estimated potential of 1,549 MW (Figure 1 b). El Hoyo-Monte Galan, our study area is a geothermal prospect area in the central western Nicaragua Quaternary volcanic chain. The geology of the area comprises volcanic and volcanoclastic products of volcanic complexes, ignimbrite shields and minor volcanic centers. centers that include products from the different volcanic centers, described as follow: (1) Malpaisillo Ignimbrite Shield which is a broad plateau of tuffs and pumice deposits located to the NE and SW of El Hoyo and Momotombo volcanic complexes. Comprises a succession of rhyodacitic ignimbrites and pumice lapilli fallouts of K-rich composition. (2) Minor Buildings in the Caldera de Galán Area. Includes Mount Montoso, a cone on the western edge of the Caldera Galan, consists mainly of andesitic lavas. Mount Colorado, a lithic tuffs and lava flow mainly composed of lithic tuffs and some lava flow, is deeply eroded, and deformed by N-S faults. Loma La Chistata, a small cone eroded and cut by faults, lies on cinereous and pomaceous deposits with similar characteristics to the Malpaisillo Tuff. (3) El Hoyo Volcano Complex. A composite edifice with a general morphology of an elongated NE-SW shield. The main edifice consists of two broad, partially overlapping cones, Cerro El Picacho and Volcano El Hoyo has been mainly effusive, of variable composition between andesitic and basaltic. The terminal portion of El Hoyo seems to have grown over an existing cone. An older structure, inferred in the most eroded portions and in morphological discordance with the present cones, is also observed at the base of the E slope.

The geothermal conceptual model of the area proposed in the Volume VI of the Nicaraguan Geothermal Master Plan 2001 has identified an up-flow zone below the NE slope of El Hoyo Volcano. Three flow patterns have been proposed: i) A N flow moving in direction to the valley of Malpaisillo. ii) A flow moving to the E towards the fumaroles of Mt. Colorado. iii) A SE flow, flowing below the phreatic aquifer of the valley located between the El Hoyo massif and Mt. Colorado (Figure 1 c).

The geothermal drilling program carried out in 2009 consisted of drilling two wells in the NE flank of El Hoyo volcano with the purpose of intercept the geothermal resource a relatively shallow productive zone, around 600-1,200 m.b.s.l. The well N1 was completed to 2,000 m.b.s.l (T.D) and the well N2 located approximately 1,400 m northwest from well N1 was completed to 1,630 m.b.s.l (T.D). Although the resource was not confirmed through the drilling program, the recovered drill cuttings provide the opportunity to reveal the signature of hydrothermal activity in the area.

This study focuses on analyzing the well cuttings of N1 throughout petrography, X-ray diffraction and fluid inclusions microthermometry to depict the hydrothermal signature in the surrounding area.

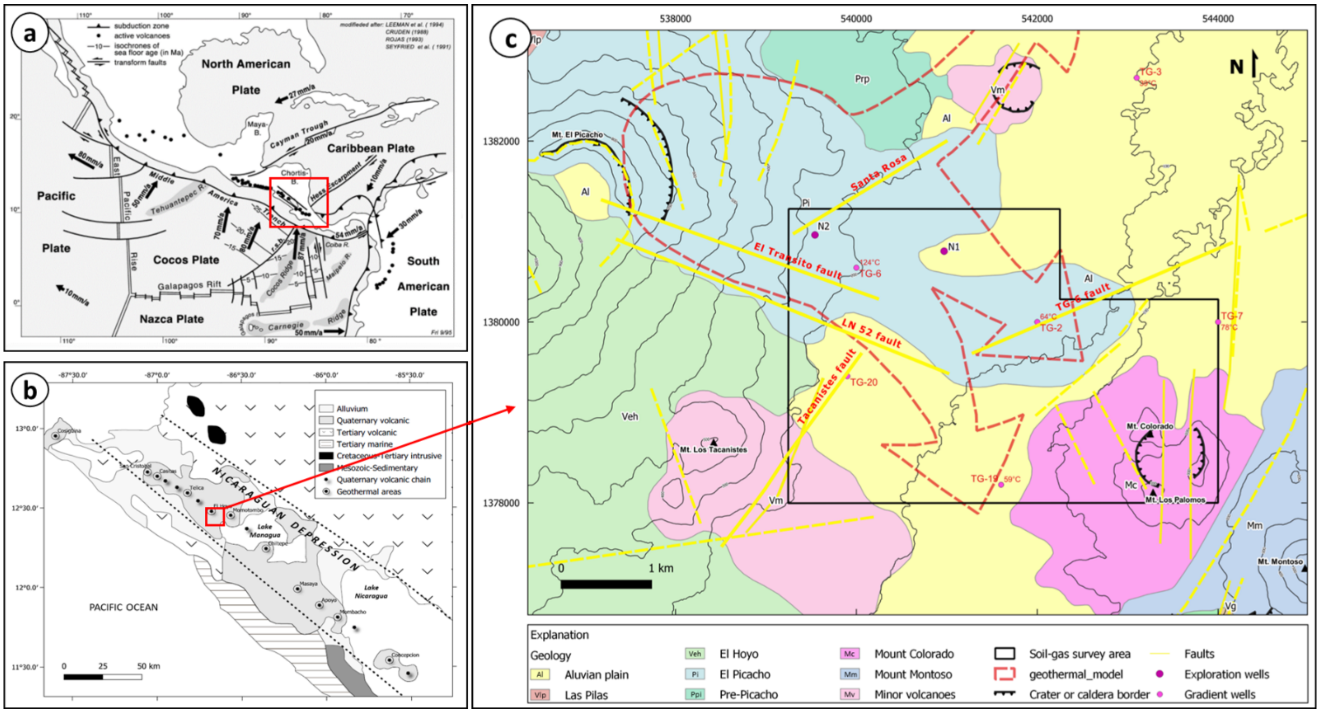

Figure 1. a. Sketch of the regional geological setting of Central America (Frischbutter, 2002). b. Nicaraguan depression geological units and geothermal areas (modified after Elming et. al., 2001; geothermal areas, NGMP, 2001) c. El Hoyo-Monte Galan geological map and geothermal model (modified after NGMP, 2001).

2. SAMPLES AND METHODOLOGY

Samples mainly used in this study were the well cuttings from N1. Along the depth, the cutting samples were collected with an adequate interval and used for the following analytical methods. First drilling cuttings were prepared into petrographic slides, to be analyzed with a polarizing petrographic microscope, using Plane-Polarized Light (PPL) and Crossed Polar (XPL) to examine optical properties of the minerals. As different minerals have its specific set of optical properties (Philpotts, 2003).

Second, X-ray diffraction (XRD) bulk analysis of drilling cuttings from well N1 and well N2 were conducted after grinding and hand grinding and powdering by a mortar and pestle to obtain the sample particles sizes <40µm, ideally randomly oriented with respect to each other (Alberta, 2023). The analysis was conducted using the Rigaku Ultima IV X-Ray diffractometer with a scanning from 2° to 65º as 2θ (degree), a step size 0.02º 2θ and a scanning speed per step of 1 s.

Third, fluid inclusions microthermometry measurements were conducted on quartz grains that were carefully selected and from the well cuttings. The analysis was conducted utilizing a Linkam LK600 heating-freezing stage. The measurable temperature range extends from -120 to 500°C. The rate of heating was controlled to fall within the range of 0.1 to 15 °C per minute. The temperature measurements throughout the heating process exhibited a precision of ±2 °C within the temperature range of 150-500 °C. The homogenization rate (Th) was measured at a rate of 2 °C per minute.

3. RESULTS AND DISCUSSION

3.1 Hydrothermal alteration

The main hydrothermal alteration minerals identified in the wells throughout petrographic analysis and X-ray diffraction include cristobalite and quartz as silica mineral, kaolinite, smectite, chlorite, chlorite/smectite mixed layer, illite as silicate, alunite calcite, pyrite, magnetite, and epidote. These alteration minerals were classified based on the hydrothermal alteration zone proposed by Hayashi (1973) to estimate a stable pH and temperature range of the minerals. Description of the alteration are given focusing on the more representative members for each and Figure 2 shows the results of the quartz index applied to well N1 which is the deepest well in the area.

Type I - Silica minerals: This type is important for the investigation of geothermal resources as it is created within reservoir cracks or along fluid conduits. The pH conditions span from highly acidic to alkaline, but it is most likely to be formed under strongly acidic condition. The silica members were identified by petrography and XRD analysis. For both wells N1 and N2, quartz is the dominant silica phase and is found in all depths with sporadic presence of cristobalite and tridymite based on XRD analysis. In well N1, quartz is identified from 150 m depth to the bottom of the well, with percentage of abundance from 0 to 20% according to quartz index.

Type II - Hexagonal sulfates: This type of alteration is an indicator of strong acidity and is characterized by the appearance of hexagonal sulfate as alunite in the most common in geothermal fields. Although XRD indicates alunite at 915m and later at 1701m, from petrography analysis, alunite occurs sporadic and is commonly associated with quartz and altered plagioclase.

Type III - Aluminum silicates: Characterized by the formation of aluminum silicate such as kaolinite, pyrophyllite and andalusite. The minerals of this type can coexist with those of type II and IV. Kaolinite is the most representative member of the group and occurs in two significate levels from 252m to 432m, and later 1245m to 2000m.

Type IV - Sheet aluminosilicates: Characterized by the formation of aluminosilicates clays minerals such as montmorillonite (smectite group), chlorite, sericite, and their interlayered stratified minerals. Montmorillonite is dominant in alteration zones formed at the surface and at shallow levels. The ratio of expandable layer (montmorillonite) increases with alteration temperature. At greater depths, where temperatures are above 200-240°C (Kristmanndóttir, 1979) chlorite and sericite are common aluminosilicate. Thus, the above-mentioned progressive changes in the clay minerals can be used for estimating underground temperature. Smectite layer have been identified from 150 m to 315m as the predominant alteration product that forms over and adjacent to most high temperature volcanic-hosted, neutral pH geothermal systems. Type III and IV play the role of cap rock at shallow levels, furthermore, the cap rock of the geothermal system is allocated from 150m to 432m, where kaolinite is present. This smectite clay cap is an active component of the geothermal hydrology. Clay alteration within the reservoir itself are chlorite + illite (Browne, 1978), however, which have been found form 315m to 1701m, with sporadic occurrence of kaolinite.

Type V- Framework of network silicates (zeolites and feldspars): Characterized by the presence of alkali or alkaline earth aluminum silicates, zeolites and feldespars, usually accompanied by the clay minerals of type IV. Ca-zeolites, such as heulandite, laumontite and wairakite, occur in lower temperature parts, Na-feldespar tends to appear with increasing temperature, and finally K-feldespar is found in the highest temperature parts. Wairakite occurs sporadic at shallow levels, and with higher intensity from 700m to 1245m. K-feldspar was observed at 915m.

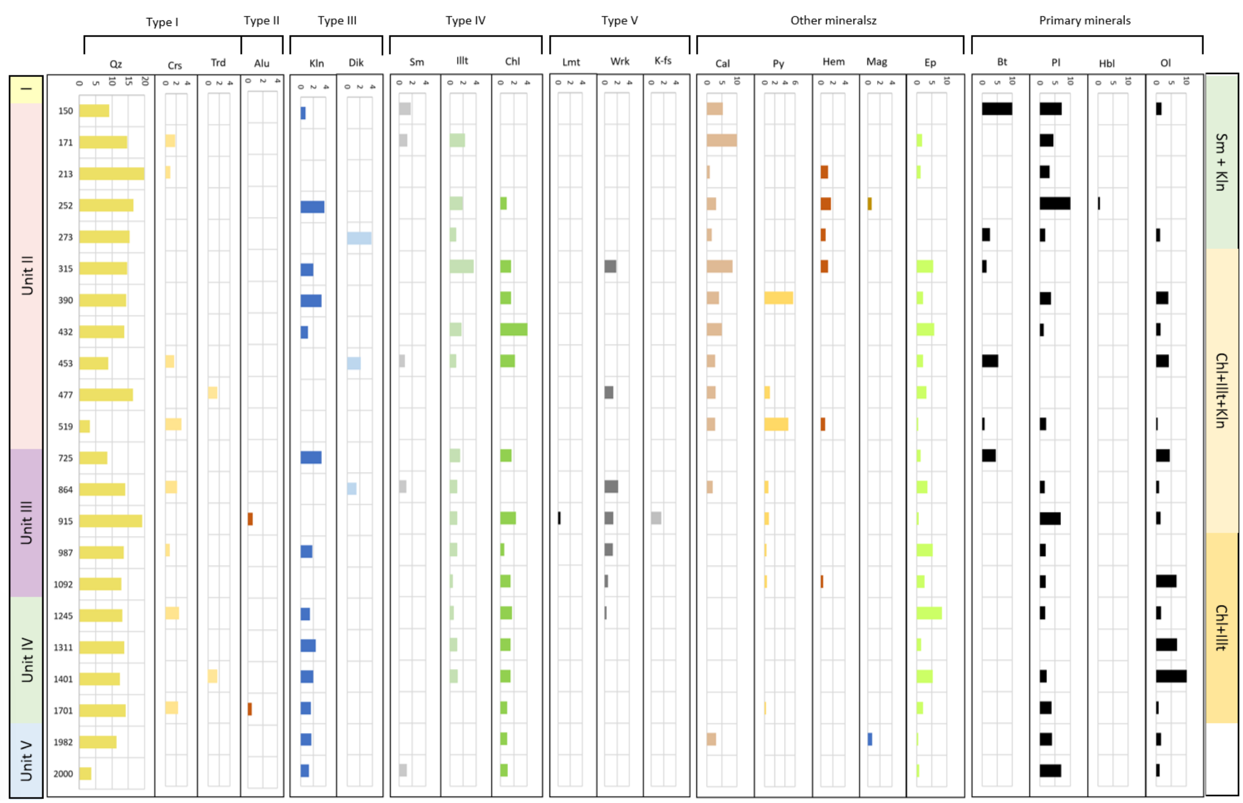

Figure 2. Hydrothermal classification and quartz index applied to X-ray diffraction data of well N1.

3.2 Fluid inclusion

Microthermometry measurements were conducted on quartz grains. Petrography shows that quartz occurs in aggregates (Figure 3 b), filling veins (Figure 3 c and d), voids (Figure 3 e), and in aggregates associated with other phases such as calcite (Figure 3 a). The crystals display an anhedral morphology predominately, with sporadic occurrences of euhedral and inequigranular size. They appear colorless when observed under plane-polarized light (PPL) and exhibit a light, tint yellow color when viewed under cross-polarized light (XPL). Quartz exhibits the following textures described by Dong et al. (1995), which is as follows:

• Mosaic quartz (Figure 3 a, b, c, and f) has been recognized in different levels of the well N1 samples. This texture is characterized by equigranular quartz grains that have highly irregular and interlocking grain boundaries. The most typical texture of recrystallization in quartz is mosaic.

• The comb texture (Figure 3 d) is formed by groups of elongate, parallel, or subparallel quartz crystals. The comb quartz displays a base of bands of mosaic quartz and euhedral termination. Under XPL microscopy the comb quartz. The most typical texture of primary growth in quartz is comb.

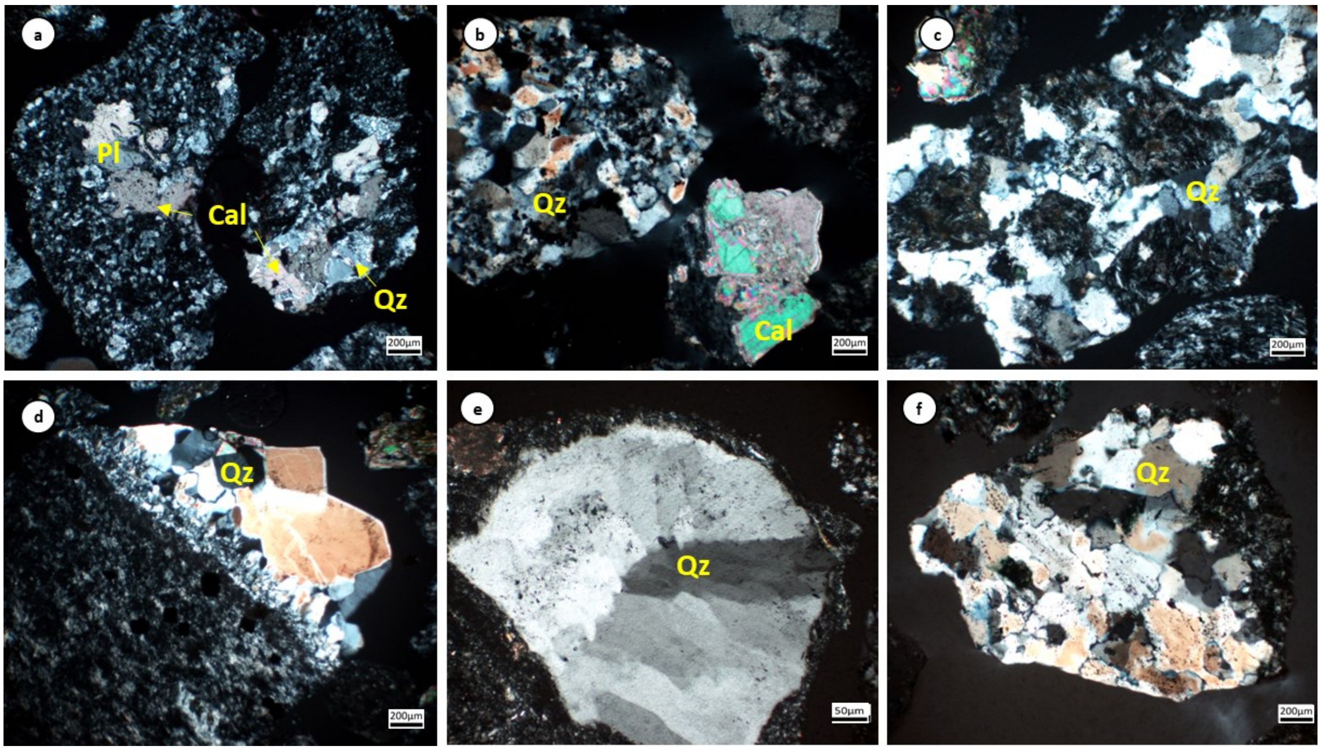

Figure 3. Microphotographs of quartz textures present in well N1 under cross-polarized light. a. Quartz occurring in association with calcite at 519 m depth b. Mosaic fined coarse-grained quartz at 587 m depth c. Mosaic coarse-grained quartz filling veins at 1179 m depth. d. Comb quartz at 1179 m depth. e. Void filled with quartz displaying massive texture at 1536 m depth f. Mosaic fined coarse-grained quartz at 1803 m depth.

According to Rodder (1984), fluid inclusions are classified intro three groups based on their mode of origin: primary, secondary and pseudosecondary. Primary inclusions are those that form by any process during crystal growth of a host mineral. They are generally large in size and isolated from fractures or are arranged in parallel with the growth plane of the crystal. Secondary inclusions are those that form by any process after the crystallization of the host mineral, they occur along fractures or cleavages. Pseudo-secondary inclusions are similar to secondary inclusions but are formed during crystal growth along fractures.

For the present study, secondary inclusions have been analyzed, the fluid inclusion assemblages (FIAs) identified in well N1 and N2 consist of coexisting liquid-rich and vapor-rich inclusions are indicative of boiling conditions during formation (Figure 4). The fluid inclusion microthermometry analysis of secondary inclusion was carried out at 603m, 642m, 915m, and 1048 m. The set of results obtained from depth 603 to 915 indicates temperatures ranges from 200°C to 360°C. However, for the inclusions measured at 1048 m ranges from 170°C to 310°C.

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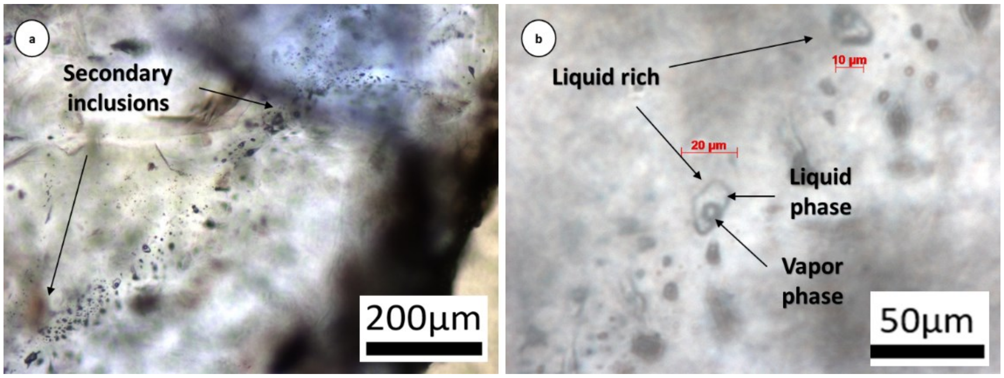

Figure 4. a and b. Microphotograph of secondary FI in quartz from N1 at 603m.

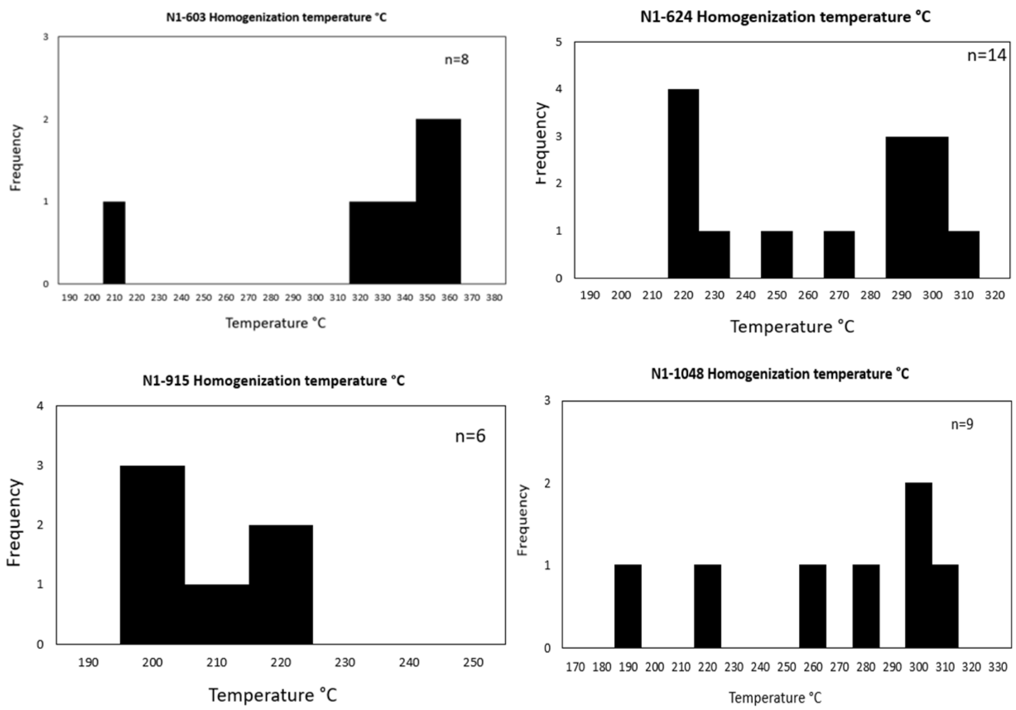

Figure 5. Histogram of the homogenization temperatures of well N1.

4. CONCLUSION

The analysis of the geothermal well cuttings has revealed the presence of mineral phases such as quartz, chlorite, wairakite, epidote and other significant minerals, which are characterized by hydrothermal processes occurring around the well. The cap rock of the geothermal system comprises of smectite clay and shallow occurrence of kaolinite found from 150m to 432m. The reservoir zone is depicted by chlorite + illite and alteration type V from 453m to 1245 m. Microthermometry measurements conducted suggests a good agreement between the mineralogy assemblages and the one recorded with fluid inclusions.

The hydrothermal mineralogy, hydrothermal zones, and temperature obtained in this study can be utilized as indicators to assess the thermal conditions that hold significance for subsequent research and investment in the given area.

5. ACKNOWLEDGMENT
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