Geology of the Well Nereidas 1, Nevado Del Ruiz Volcano, Colombia

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ABSTRACT

The geothermal well Nereidas 1, is located on the western side of Nevado del Ruiz volcano (Colombia), 3450 m above sea level, and was drilled to 4818 ft depth. The stratigraphy found during the drilling corresponds to a volcanic sequence, which includes pyroclastic rocks, pyroxene andesites, amphibole andesites and dacites, overlying metamorphic rocks from the Cajamarca complex composed of schists, phyllites and gneisses affected by a Tertiary thermal event. Secondary minerals found along the column, are the result of the weakly acid to alkaline fluid-rock interactions that occurred at different levels. This distribution allowed the identification of four hydrothermal alteration zones: argillitic (from 0 to 1300 ft); argillitic-sericitic (from 1300 to 2100 ft); sericitic (from 2100 to 3500 ft) and thermometamorphic or propylitic (from 3500 to 4818 ft depth).

Introduction

For three decades, Colombian authorities and scientists have been interested in evaluating the possibilities of the Nevado del Ruíz volcano, located in the Central Range of Colombia, to generate electrical energy, taking in to account the geothermal potential, given the abundance of hidrothermal manifestations nearby and inside its associated volcanic complex.

During the 70's, the whole territory was the subject of intense regional geothermal exploration, by the head of the Instituto Colombiano de Energía Eléctrica (ICEL). These studies led to select targets with potential to produce electrical energy from a geothermal source. One of these areas was named Volcanic Complex Ruiz-Tolima (Herd, 1974). Pre-feasibility studies undertaken by Central Hidroeléctrica de Caldas - CHEC (1983), allowed the identification of more specific areas of the complex to carry on the studies, including the Nereidas - Botero Londoño area, on the western flank of the Nevado del Ruiz volcano, where the first exploratory geothermal well was drilled during July and August of 1997.

The well is located in the place called Pirineos at 3450 masl, by the Nereidas creek, 26 Km to the SE of Manizales City, Department of Caldas (Figure 1). The well was planned to reach a depth of 2000 m (6000 ft), but it suffered a strong deviation, up to 42 degrees, reaching only a total depth of 1466 m (4818 ft). The work described here includes macroscopic and petrographic analyses, as well as electronic microscopy and XRD determinations in some cuttings and cores obtained from the well that were used to reconstruct the stratigraphy, identify minerals and hydrothermal alteration zones.

Geology of the Nereidas - Botero Londoño Area

The area is characterized by its underlying Paleozoic metamorphic basement, composed of very folded quartz rich graphitic schists, intruded by apophysis from the Manizales stock during late Tertiary. Subsequently, these schists and apophysis are covered by massive lava flows coming from the initial volcanic edifices of Pliocene age: Nevado del Ruiz, La Olleta, El Cisne and Nevado del Tolima, all of them in the Colombian central cordillera. Those edifices constitute the paleo-topography that canalized the most recent flows from the present volcanic complex, through channels of the Molinos and Río Claro rivers and the Nereidas creek, flowing in the direction E-W. These flows correspond to the Quaternary volcanic activity, and are represented by pyroclastic flow deposits, lava flows, mud flows and pyroclastic falls. The volcanic deposits eroded by the recent glacial and fluvial forces have changed the present topography of the region (Monsalve and Méndez, 1997).

The main geologic structures affecting the studied area, are the Palestina Fault System with NE trend, the Molinos-Rio Claro and Nereidas faults with WNW trend, whose present manifestations are represented by the occurrence of volcano-tectonic seismic activity, allowing the development of the fumarolic fields at Nereidas and La Olleta, and the Nereidas, Botero Londoño and El Recodo hot springs; interesting places for the planned geothermal exploration (Monsalve and Mendez, 1997).

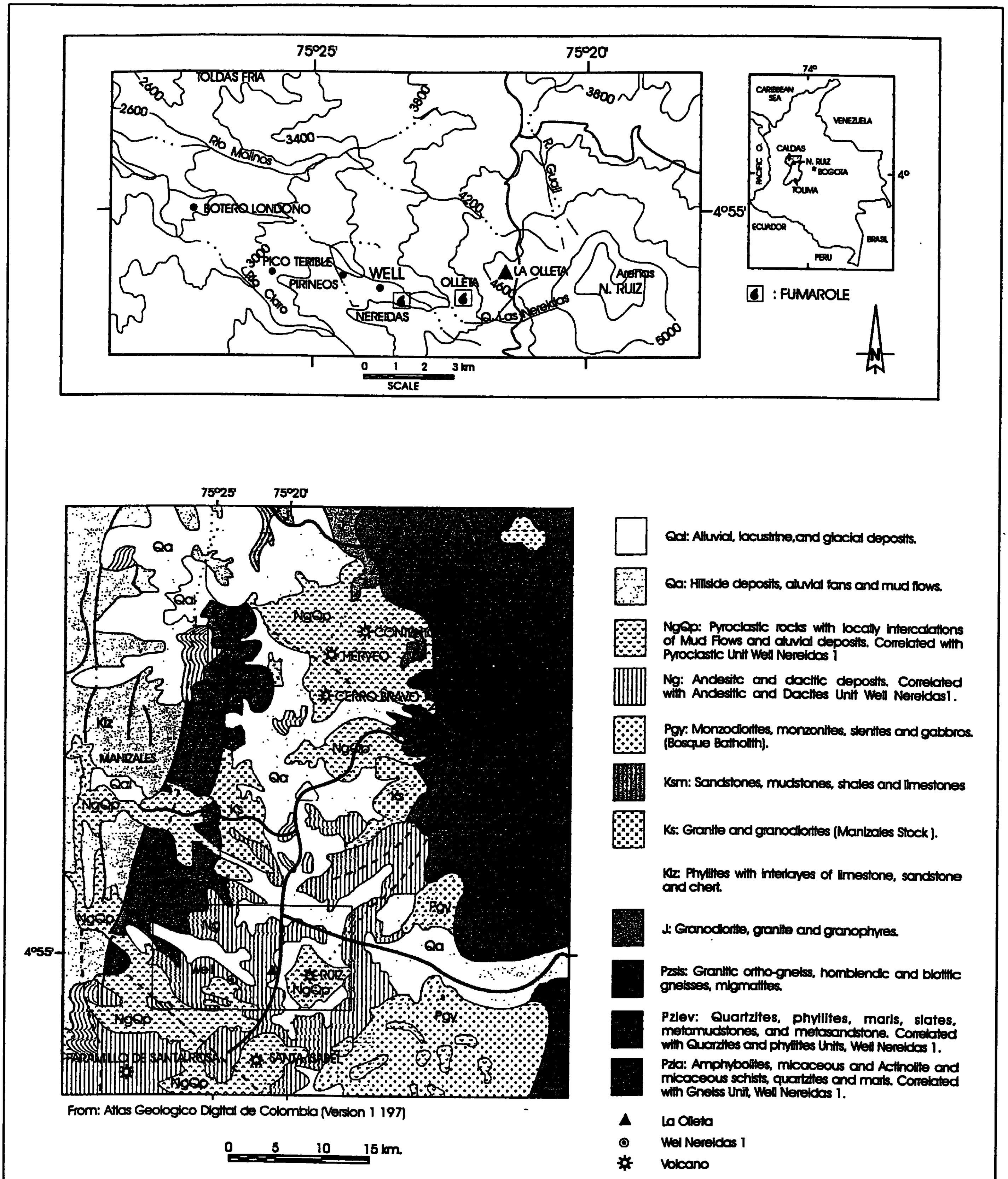

Figure 1. Nevado de Ruiz and Well Nereidas 1. Location and geological maps.

Geology of the Well Nereidas 1

The well Nereidas 1 was drilled to 4818 ft depth, through seven lithologic units. The unit boundaries are approximate and are based on changes observed in cuttings, using binoculars, and petrographic microscopes.

To prepare the stratigraphic column for the well (Figure 2) and to identify hydrothermal alteration zones (Figure 3), microscopic analyses of cuttings and core samples was done using thin sections and polarized microscopes. Some samples were selected for examination under a reflected light microscope, energy dispersion analysis EDAX was used to obtain the chemical composition of the minerals, and for XRD analysis for clay minerals determination. The mineral coinposition of cores samples and cuttings is given in figure 4.

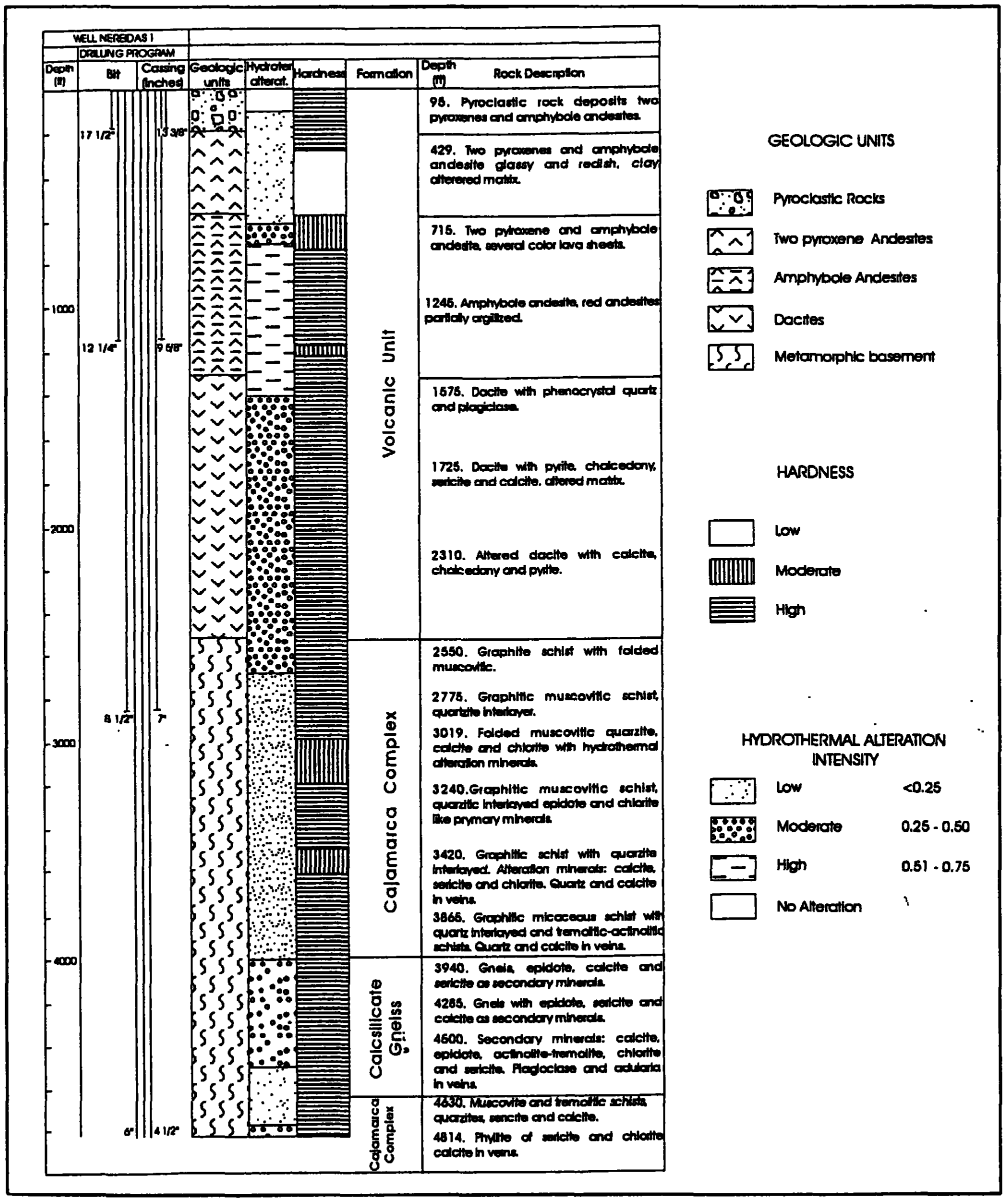

Figure 2. Well Nereidas 1. Stratigraphic column.

Pyroclastic Rokcs Unit

This unit corresponds to the upper part of the column, between 0 and 172 ft depth. It is a pyroclastic deposit composed of fragments of different types of andesites, some of them very oxidized, pumice and crystals. The alteration found near the surface is incipient. Oxides and clays are common and may be the result of superficial weathering.

Two Pyroxene Andesite Unit

This unit is found from 172 to 557 ft depth; it is characterized by grey to reddish colors, and composed of plagioclase phenocrysts, orthopyroxene, clinopyroxene, and accessory opaque minerals and amphyboles, in a partially altered clay matrix. The matrix is hypocrystalline with a pilotaxitic texture, composed of plagioclase microlites, disseminated opaque minerals, some pyroxenes and glass. The intensity of alteration in this unit is low.

Amphybole Andesite Unit

The main characteristic of this unit, encountered between 557 and 1290 ft, is the occurrence of fragments of different colors: green, white, reddish, and grayish, this could mean the existence of various packets of overlying lavas. Their fragments have porphyritic texture and contain amphybole, some plagioclase, accessory opaque minerals and biotite in a hypocrystalline matrix with aphanitic pilotaxitic texture. This unit is highly altered, it presents partial oxidation of the matrix and amphyboles; excluding the reddish andesites level where oxidation is complete. Partial argillization of the matrix and phenocrysts, silicification of the matrix, and slight replacement of plagioclase and matrix by calcite is observed. This is an argillaceous unit, which contents veins of calcite and smectite, chlorite, kaolinite, montmorillonite and chalcedony.

Dacite Unit

This unit is found from 1290 to 2490 ft depth. It is characterized by grey, white and greenish colors. The rocks are composed of plagioclase phenocrysts, quartz and accessory minerals like biotite, in a felsic matrix. The hydrothermal alteration is moderate to high, and is characterized by partial to total replacement of the plagioclase and matrix by calcite, clays and chalcedony.

Quartzite Unit

Found between 2490 and 3940 ft, this unit is constituted by deep grey to black folded quartzites and graphitic quartz-muscovitic schists, with quartz and calcite veins, with interlayered graphitic muscovitic and tremolite-actinolite schists. It can be correlated with the middle part of the Cajamarca Complex. It is composed of quartz, muscovite and graphite, plus accessory minerals like plagioclase, biotite, tourmaline, sphene and zircon. The quartzites are mineralized with pyrite, chalcopyrite and sphalerite. Within the unit there are intercalations of tremolitic-actinolitic schists, composed of chlorite, tremolite-actinolite, plagioclase and epidote. The hydrotermal alteration is low.

Plagioclase and Hornblende Unit

Encountered between 3940 and 4814 ft, the unit is composed of clear green and pink calc-silicate and biotitic gneisses. The calc-silicate rocks present diopside, plagioclase (labradorite-bytownite) altered to albite, hornblende, diopside, epidote, garnet in variable amounts and sphene as accessory mineral. The biotitic gneiss is composed of abundant actinolite (alteration of hornblende), biotite and plagioclase. Tourmaline and sphene are accessory minerals, with microveins of adularia and albite. In general, the hydrothermal alteration is moderated.

Sericitic Phyllite Unit

Towards the bottom of the well, between 4814 and 4818 ft depth, fine grained pale grey to white phyllites are found. The phyllites show two folding directions and are composed of sericite, quartz, chlorite and plagioclase (partially altered to calcite), with veinlets of quartz, calcite, pyrite and plagioclase. This unit is correlated with upper part of the Cajamarca Complex.

Hydrothermal Alteration

The identification of the hydrothermal minerals, led to determine the following alteration zones (Figure 3):

A) Argillitic zone (0-1300 ft): Showing a paragenesis of: smectite, calcite, kaolinite, montmorillonite and chalcedony.

B) Argillitic-sericitic zone (1300-2100 ft): Characterized by the appearance of sericite.

C) Sericitic zone (2100-3500 ft): Characterized by chlorite and quartz and diminishing kaolinite. Secondary minerals are sericite, quartz, kaolinite, calcite and smectite.

D) Thermometamorphic propylitic zone (3500-4818 ft): Recognized by the occurrence of albite, adularia, epidote, amphybole, sphene and sulfides. The zone presents: a) plagioclase (labradorite-bitownite), diopside and hornblende association. b) garnet, biotite and presence of diopside (and pyrite) in veins, and c) amphybole actinolization, albitization and epidotization of the plagioclase, indicating hydrothermal alteration. At 4814 ft depth, a strong change in intensity and range of alteration was observed. High-temperature minerals disappeared, only sericite, chlorite, pyrite, sphene and some calcite veins remained.

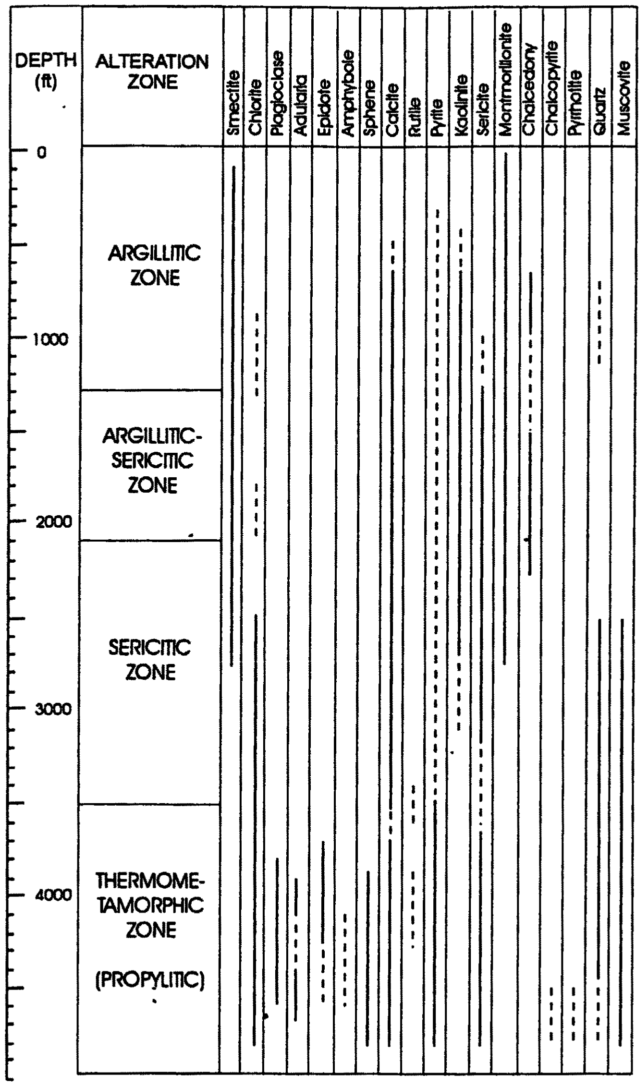

Figure 3. Well Nereidas 1. Distribution of hydrotermal alteration minerals and zones.

Discussion

The mineral composition of cutting and core samples from well Nereidas 1, allowed to characterize different events that gave place to the current lithology of the area. With just one well, the largest problem to solve at this stage of exploration, was to differentiate between metamorphic and hydrothermal processes. The contact metamorphism mineralization masks minerals generated by water-rock interaction associated with different periods of hydrothermal activity. Nevertheless, the thin section study and field correlation, were an important tool to determine the origin of the minerals found in cores and cuttings.

Based on the above observations, we can say that the hornblende gneiss recorded an overlapped thermal event associated with the Manizales Batholith intrusion (of granodioritic-tonalitic composition), dated 62.4 +/- 3.6 Ma (Jaramillo, 1978) or even by the El Bosque Batholith. This thermal event is inferred from the occurrence of diopside in veins; zoned garnet bands (an-

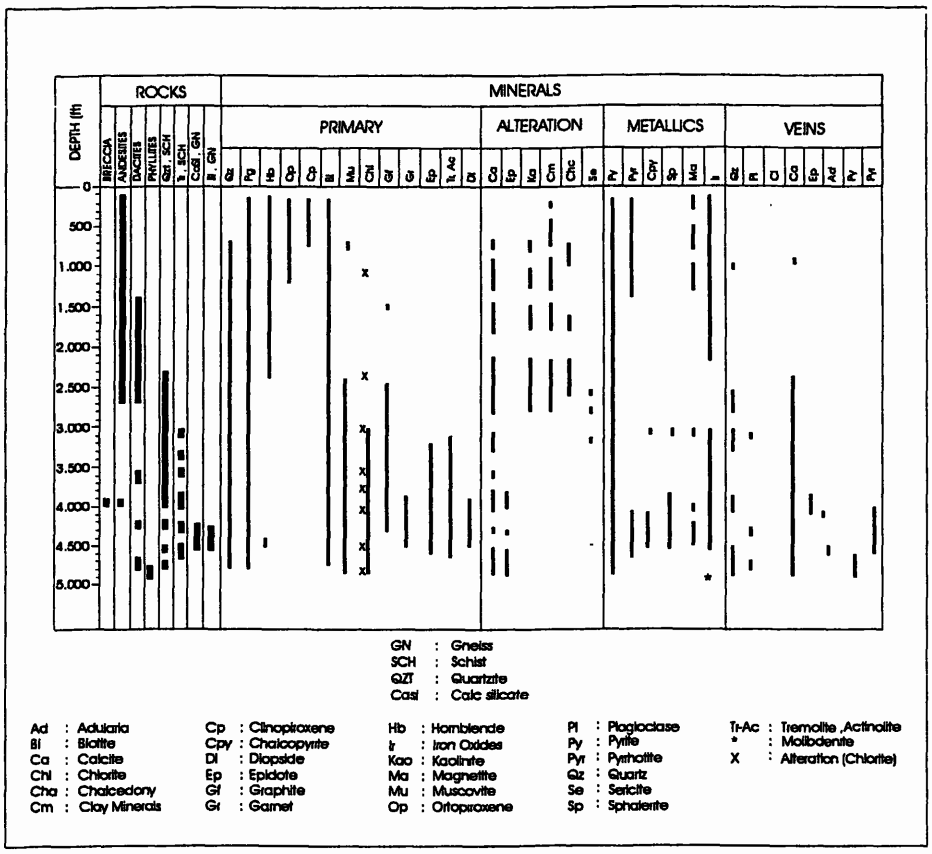

Figure 4. Well Nereidas 1. Mineral composition of cores and cuttings.

dradite), epidote replacing bands of intermediate plagioclase and the existence of red biotite within the micaceous bands of the gneisses. In the gneisses, the intrusion originated beside the thermal metamorphism and metasomatism, partial change in texture and primary minerals (hornblende and diopside actinolitization, intermediate plagioclase albitization), that possibly led to sulfide mineralization (pyrite, pyrrhotite, chalcopyrite and sphalerite).

Even though the well only reached 1466m depth, the measured bottomhole temperature was about 200 °C. If we consider the presence of epidote in the basement rocks, as an indicator of temperatures above 250°C, it is possible that the inferred geothermal reservoir is at temperatures higher than 200° C. The presence of adularia, calcite and silica suggests that boiling, mineral deposition and self sealing processes have taken place, and is reflected in the distribution of hydrothermal zones. A mineralized breccia with pyrite, at 4000 feet depth, suggests basement faulting probably related to a younger mineralizing event. Furthermore, the core recovered between 4500 and 4500 ft of depth, shows faulting in two directions, in rhomboidal shape. On the other hand, contact metamorphism veins of adularia and albite in schists and minerals, like pyrite, might indicate secondary permeability in the basement rocks and consequently in the reservoir.

Acknowledgments

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