Geothermal and volcanic field trip, Neuquén and Mendoza provinces, Argentina.

November 15 - 28, 2021.

Introduction

From November 15th to the 28th the UNLP SEG-SGA Student Chapter visited Neuquén and Mendoza provinces (Argentina) where important active hydrothermal systems are located. The schedule, detailed below, included Copahue hydrothermal system, Andacollo Ag-Au mine, Domuyo hydrothermal system, an asphaltite, and a puzzolana quarries.
The main objective of the field trip was to recognize active hydrothermal systems and compare them with epithermal deposits as their fossil counterparts.

Trip leader:
Dr. Gerardo N. Páez

Dr. Gerardo Paez graduated in Geology from the Universidad Nacional de La Plata in 2004. He did his Ph.D. studying the genesis of the Au-Ag deposit of the Martha Mine in the Deseado Massif.
He currently teaches in the Igneous Petrology Department and is a researcher of CONICET (National Council of Scientific and Technical Research). He also works as a consultant for the industry as a specialist in the relationship between volcanic systems associated with epithermal mineral deposits.
He is the author of more than 80 scientific publications, including refereed papers, conference presentations, book chapters, etc., and has participated in more than 16 research projects.
He was also one of the founding students of the Student Chapter of our University.

For more information about him or to be in contact with him go to the following links:
Google Scholar: https://scholar.google.com.ar/citations?user=HUNLQmQAAAAJ&hl=es
Research Gate: https://www.researchgate.net/profile/Gerardo-Paez-2
LinkedIn: https://www.linkedin.com/in/gerardo-nestor-p%C3%A1ez-0620157b/

Trip participants:
De Martino, Facundo J.
Palma, Diego S.
Galar, Amanda
Pagola, Morena L. S.
Lapcak, Bárbara
Rolando, Lucas
Marelli, Franco

Field trip financing

The field trip was financed with Stewart R Wallace funds obtained in 2019 and students' funds.

Copahue geothermal field

The Copahue-Caviahue volcanic complex is formed by the Agrio caldera and the Copahue volcano, located in the southern Andes at 38°S - 71°W. In this complex, there is an important volcanic and magmatic-hydrothermal system, whose surface manifestations are observed in the Copahue volcano building (37.9°S - 71.2°W, 2997 m) and in the surrounding geothermal areas that are located inside the caldera. This Caldera is characterized by the emission of fumarolic gasses and acidic waters (Fig. 1).

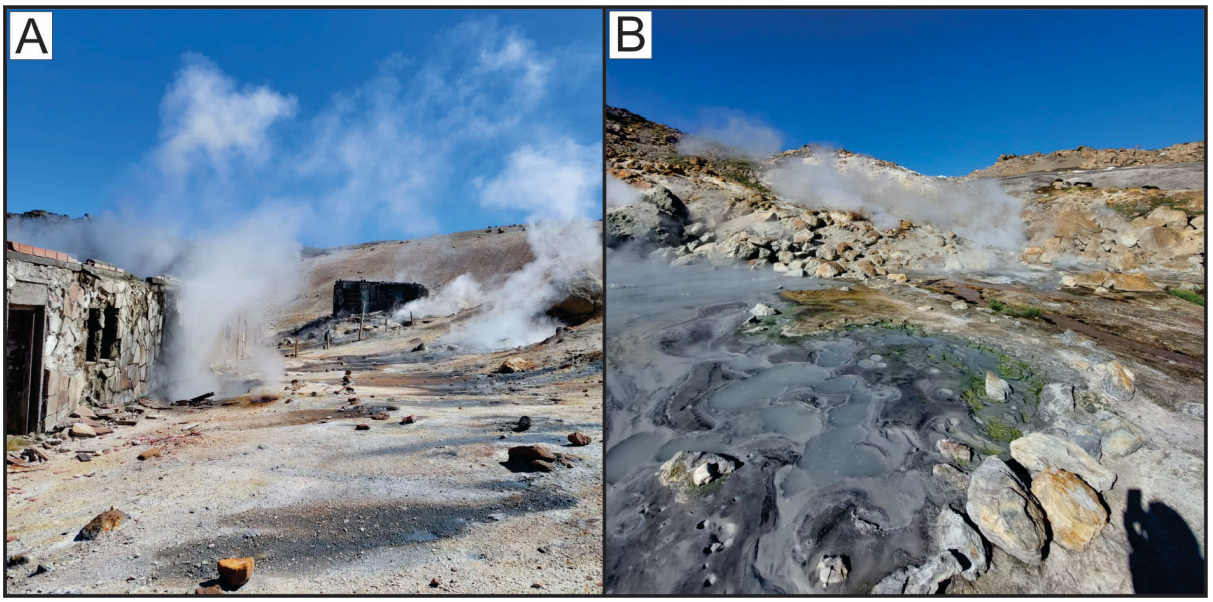

Figure 1. A) Thermal manifestation in "Las Máquinas". **B)** Mud spots and fumaroles in "Las Maquinitas".

The active hydrothermal system presents superficial manifestations that are developing hydrothermal mineralogical systems of different characteristics, according to their physicochemical parameters. From the fieldwork, the different formations, structures, and geoforms were recognized, related to the developed volcanic system.

In addition, the hydrothermal zones were evaluated, whose special characteristic is that these systems are currently under development. The Copahue geothermal reservoir has a structural type control, as secondary permeability (G. Mas et al. 1993, 1995, 2005; Mas et al. 2000), which is dominated precisely by a regional fault, bearing N 55o W, with a complex of associated faults. The active manifestations are the so-called Copahue, Las Máquinas, and Las Maquinitas hot springs in Argentina, and Chancho-Có on the northern flank of the volcanic edifice in Chilean territory (Fig. 2).

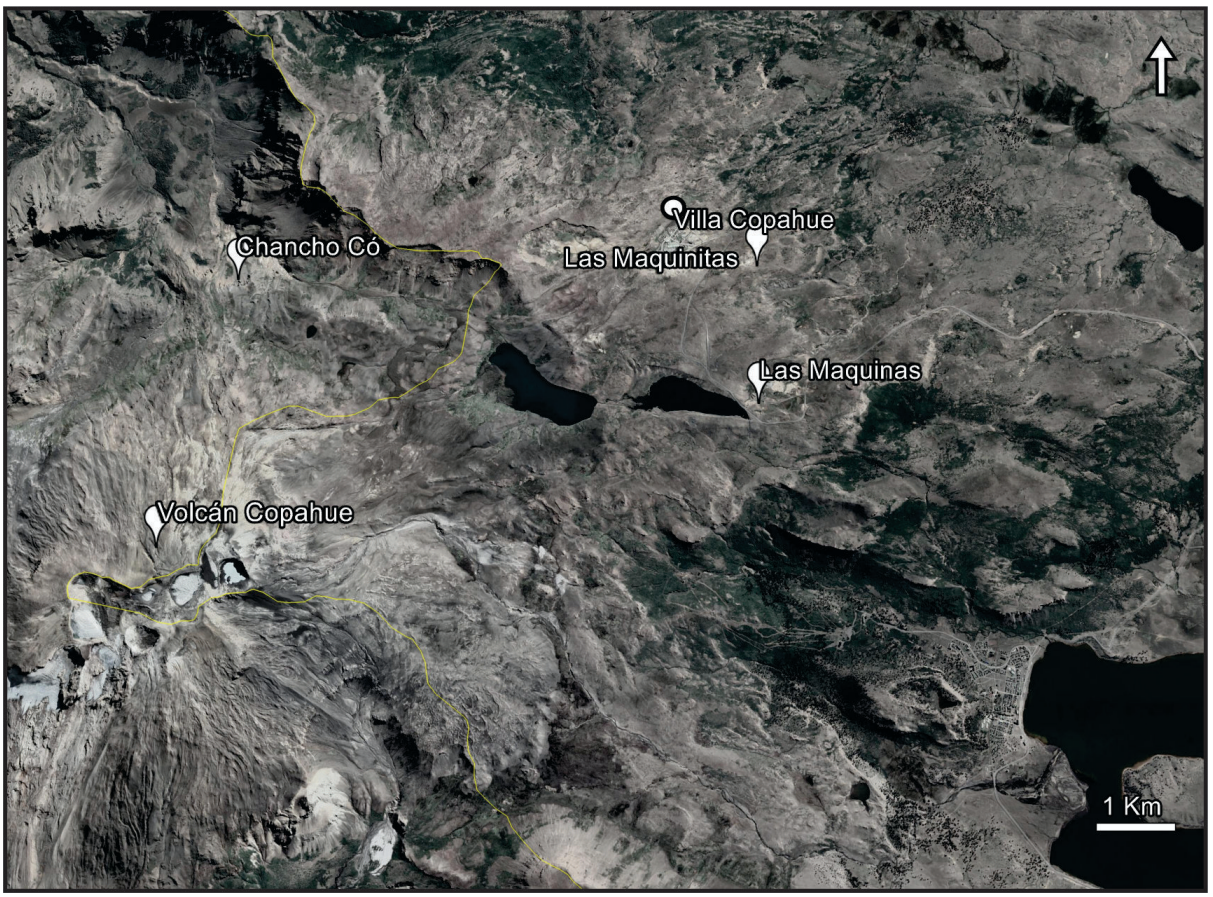

Figure 2. Location map of hydrothermal manifestations.

The solutions of the hydrothermal areas are characterized by very acidic waters with pH values between 1.60 and 3.6 and temperatures ranging from 24°C to 92.7°C. According to the content of anion content (SO_4^{2-}, Cl^- , and HCO_3^-), these waters can be classified as sulfate and immature acidic waters.

The temperature of the waters analyzed is acquired by the passage of deep source vapors (magmatic-hydrothermal) through them, which in turn control their anion content.

Andacollo Mine

The Andacollo mine, a low sulfidation epithermal deposit, is located in the northwest Neuquén. The Andacollo project is the only metalliferous exploitation (Au and Ag) that Neuquén province has had in its history, its exploitation would have started in the middle of the 19th century and it is not currently in production.

They are N 30°-45° and N 310°-330° strike veins of Carboniferous age and N 70°-90° strike veins of Permian age. The oldest veins have lengths of up to 1200 meters and a thickness that varies between 1 and 8 meters, with high-grade Au-Ag banded quartz texture (Fig. 3B). The Ag ore is composed of sulfosalts and electrum, and the Au is fine-grained free, in electrum, and disseminated in pyrite. The Au: Ag ratio in these veins is 1:100 to 1:200.

As for the Permian veins, they have lengths of up to 200 meters, and thicknesses ranging from 0.20 to 1.5 meters with quartz, carbonates, and sulfide. Au is found free of fine grain, and in pyrite, Ag is found as electrum and disseminated in sulfides such as pyrite, chalcopyrite, galena, and sphalerite. The Au: Ag ratio in these veins is 1:1 to 1:5.

The veins have been exploited through underground labors such as tunnels (Fig. 3C), and and less frequently, through shallow excavations (Fig. 3A). The extraction of metals was done by the flotation method, from a processing plant whose tailings were placed in a tailings dam located in an area adjacent to the mine.

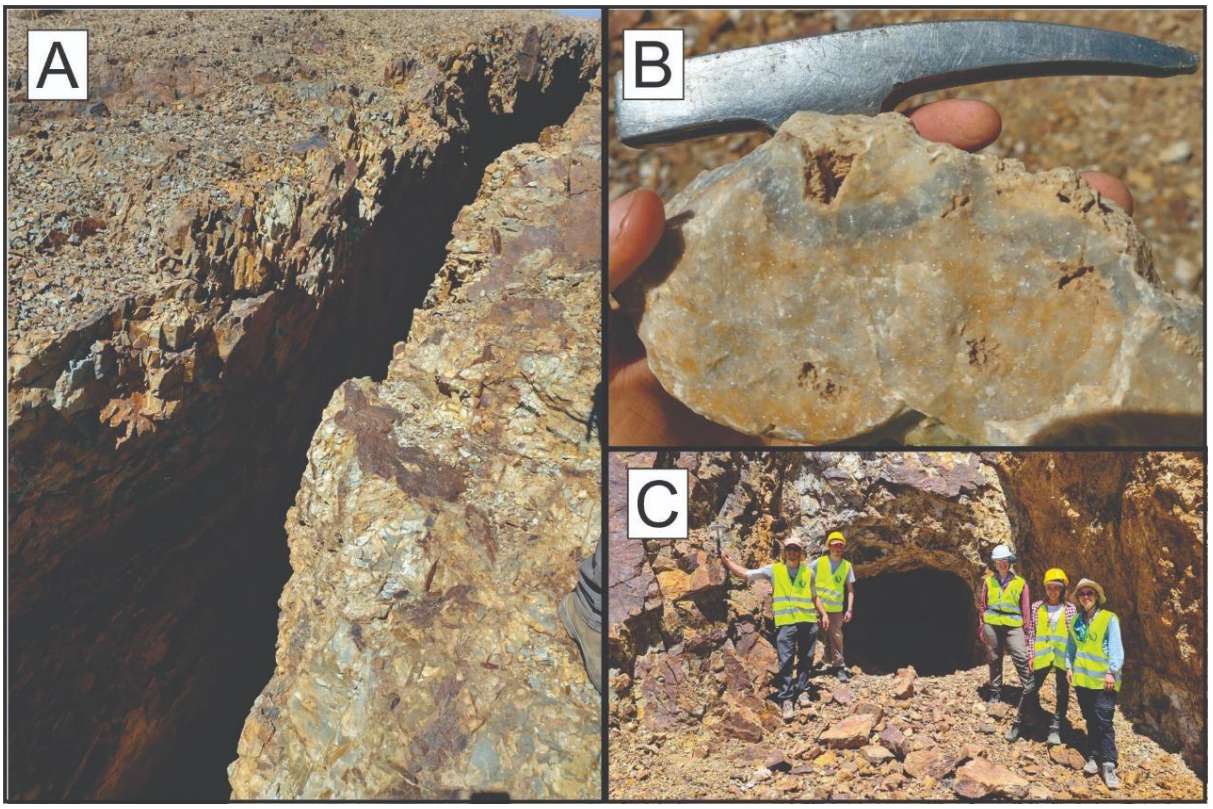

Figure 3. A) Shallow open cut **B)** Fragment of vein with colloform quartz texture. **C)** Old tunnel.

Puzzolana quarry, Zapala

The "Kuyumkura" quarry, located in the town of Zapala (Neuquén), has been exploited since 2000 for the extraction of pozzolana.
This material owes its name to the locality from which it was mainly extracted by the Romans, Pozsuoli, near Naples.

They are incoherent, loose pyroclastic rocks, formed by ashes, volcanic sands, coming from the disintegration of volcanic slag heaps, especially augite and olivine, together with an important amount of vitreous volcanic components and siliceous sedimentary rocks with the presence of opal, chalcedony and flint. They are constituted by hydrated silicates of alumina, iron, manganese, magnesium, lime, sodium and potassium.
The materials of this particular quarry are the result of Surge type deposits. These are a type of low density pyroclastic flow made up of very fragmented materials of coarse ash size. They present good lamination and many times with criss-cross stratification with reddish colors due to the oxidation of the ferrous materials. (Fig. 4A).
These materials are first organized and sieved (Fig. 4B). They are then ground together with clinker and gypsum to obtain pozzolanic cement. .
The addition of pozzolans prevents, or minimizes, the damaging reaction between cement and aggregates, allowing the reactive action of calcium and alkalis to be neutralized by the formation of stable silicates in the cement mass itself, thus preventing subsequent attack on the aggregates.

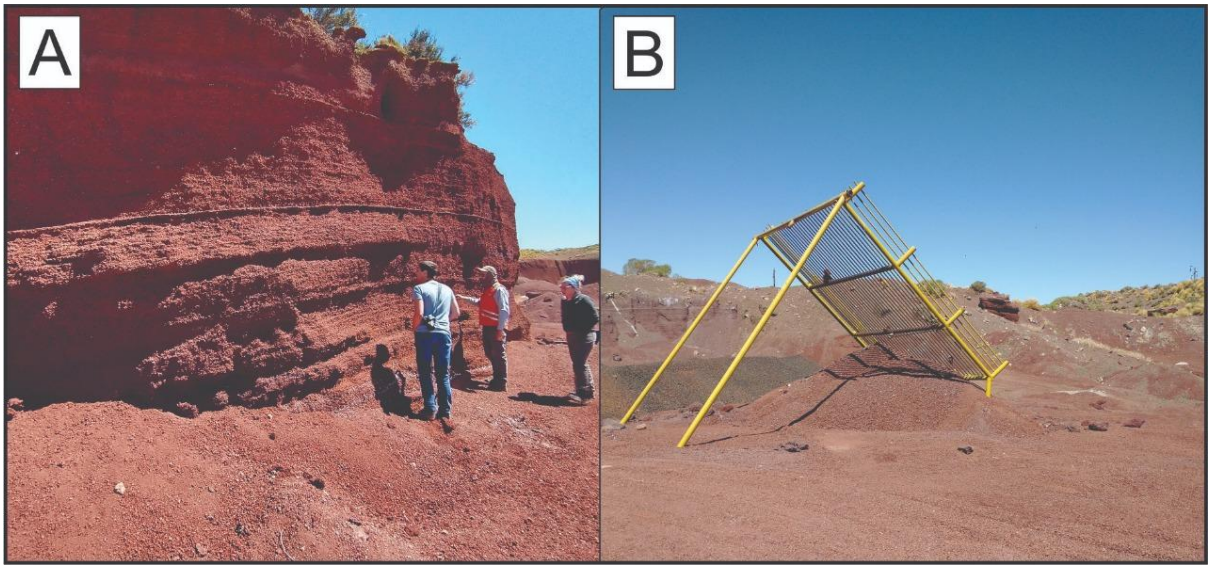

Figure 4. A) Mine wall of the quarry. **B)** Sieve used for the separation of materials.

Cerro Domuyo

The Domuyo geothermal area is located in the northwestern sector of Neuquén Province, Argentina, about 550 km of the city of Neuquén, the provincial capital (Fig. x). It is on the southwestern slopes of Cerro Domuyo, the highest mountain in Patagonia (elevation: 4709 masl). The geothermal area presents many surface manifestations, including fumaroles (Fig. 5B), hot springs and geysers (Fig. 5A).

The western slope of Cerro Domuyo in northern Patagonia is characterized by thermal springs with boiling waters, Quaternary silicic domes, and pyroclastic deposits that suggest the existence of a geothermal reservoir.

Geothermal activity at Domuyo is fault-controlled. The geothermal area of potential commercial interest is located in a graben bounded by the E-W Covunco and Manchana-Covunco normal faults and is subdivided into blocks by other faults.

The source of the thermal waters is precipitation (rain and snow) from high elevations that infiltrate and heat up as they penetrate deep into the system. According to Pesce (1983), most of the fluid recharging the geothermal systems originates from the northwestern flank of the Domuyo Volcano. A geochemical study of the Los Géiseres, Los Tachos, El Humazo, La Olleta, Aguas Calientes, Los Baños, Las Papas and La Bramadora thermal manifestations, indicate that there are three types of thermal waters at Domuyo. The waters of the La Bramadora fumaroles located in this sector are of sulfate-alkaline earth type, the waters of the thermal springs (El Humazo, Los Tachos and Los Geises) of this central sector of the study area are of chloride-alkaline type, the waters of the La Olleta, Aguas Calientes and Los Baños hot springs are of chloride-alkaline type too and the thermal waters of the Las Papas springs are of chloride-bicarbonate-alkaline. The chemical characteristics of the four sectors suggest a transition from the La Bramadora steam-dominated system to the central area of the El Humazo, Los Tachos and Los Géises springs, where steam and waters mix, and to the Los Baños, Aguas Calientes and Las Papas water-dominated thermal springs (Pesce, 1983). There are two distinct zones of surface hydrothermal alteration at Domuyo. One is observed in the La Bramadora area characterized by acid, medium-to-high temperature (alunite-kaolinite) alteration, which is surrounded by an area a low-to-medium medium temperature (kaolinite) alteration. The other type of alteration found in the Los Tachos and Los Géises area is characterized by a silicified area that extends along the Covunco Fault and seems to be evidence of fossil hydrothermal activity. Extensive argillic alteration (including smectite and kaolinite) was observed around the El Humazo area (Mas et al., 2000).

Figure 5. A) Geiser from "Los Tachos" manifestation. **B)** Fumaroles from "Los geysers"manifestation.

Cerro Alquitrán.

Cerro Alquitrán is located in the north of the town of El Sosneado, in the south of the province of Mendoza (Fig. 6). In this hill and to the northeast of it outcrop intrusive bodies of laccolitic character and andesitic composition belonging to the Huincán II Eruptive Cycle or Andesita La Brea.

Figure 6. Location of Alquitrán hill (red star).

In this area, asphaltite manifestations were observed (Fig. 7), which are a form of solid hydrocarbon, as well as liquid hydrocarbon upwellings (Fig. 8).

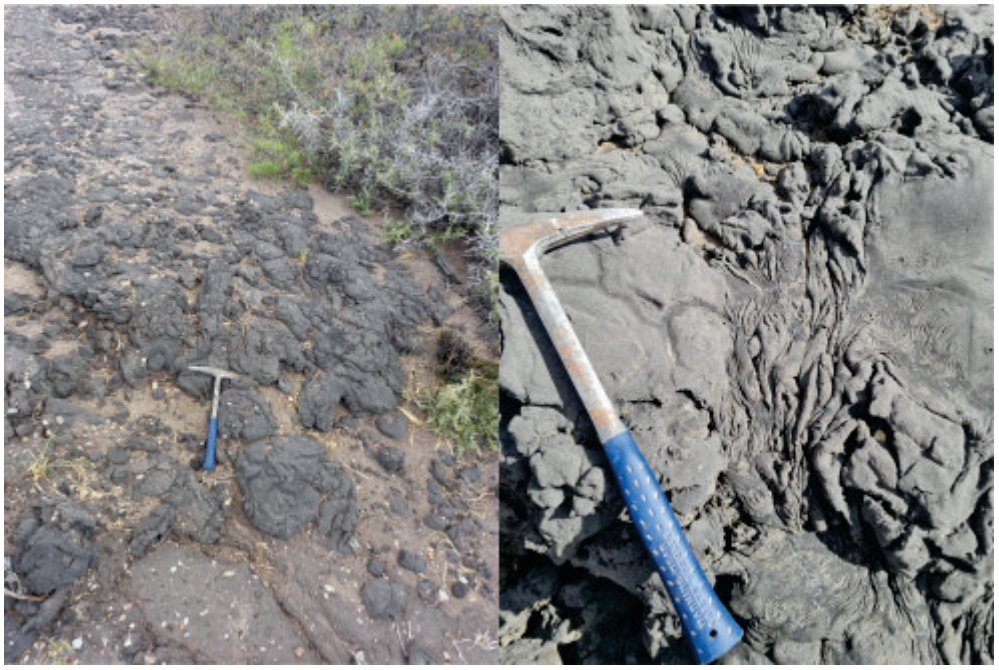

Figure 7. Flow of asphaltites.

Figure 8. Liquid hydrocarbon upwelling.

The first settlers of the provinces of Mendoza and Neuquén stumbled upon this "coal" and used it as fuel for domestic use. Among the pioneer geologists who studied the veins, Groeber (1923) and Rassmuss (1923) stand out. They recognized that asphaltite (or raffaelite), like petroleum, comes from the action of heat on bituminous shales of Mesozoic age. In order to systematically exploit asphaltite, mining companies were organized between 1930 and 1940, which benefited from German capital and technicians. During the Second World War, when imports of charcoal declined, asphaltite was used as fuel for the railroads and the steel industry. In addition, it was valued for the high vanadium content of the ashes (Meyerhoff 1948; Fester & Cruellas 1949). Between 1940 and 1950, the national production of solid fuels reached a peak, under the direction of Yacimientos Carboníferos Fiscales (YCF), and numerous geological-mining studies were carried out. Asphaltite production declined as it was replaced by liquid hydrocarbons and there were several mining accidents due to the explosive nature of the soot. When the workings were abandoned, trenches, wells, galleries, machinery, rubble, embankments, water tanks, houses and access roads survived.

Asphaltites, depending on their origins and types, have a caloric value that ranges between 20921 and 37192 kJ compared to hard coal. The exploitation of asphalt and asphaltites can be done in several ways: 1.Direct use as fuel 2.Distillation, in its natural form up to an initial concentration to obtain gasoline, oil, coke, etc. 3.Pyrolysis and

distillation in the absence of air. 4.Gasification to obtain water gas. 5. Directly used in the manufacture of roofing paper, slabs, asphalt mastics and/or anti-corrosive asphalt paints.

Thanks to everyone who made this field trip possible!

From left to right: Bárbara Lapcak, Morena Pagola, Amanda Galar, Gerardo Paéz, Franco Marelli and Lucas Rolando with Copahue Volcano behind.

Bibliography

-Mas, G.R., Mas, L.C. y Bengochea, L. 1993. Inclusiones fluidas en el pozo exploratorio COP3; Campo Geotérmico Copahue; Provincia de Neuquén, Argentina. 12° Congreso Geológico Argentino, Actas 5: 92-98, Mendoza.

-Mas, G.R., Bengochea, A.L., Mas, L.C. 2005. Thermometric study of Copahue geothermal field; Argentina. World geothermal congress: 24-29, Antalya.

-Mas, L.C, Mas, G.R y Bengochea, L. 2000. Heat flow of Copahue geothermal field, its relation with tectonic scheme. Proceedings of World Geothermal Congress 2000: 1419-1424, Tohoku.

-Mosso, E. H. (1955). Contribución al estudio de la puzolanas mendocinas (Doctoral dissertation, Universidad de Buenos Aires. Facultad de Ciencias Exactas y Naturales).

-Lavandaio, E. O. L. (2008). Elementos de Geología, mineralogía y materias primas minerales.

-Cobbold, P. R., Ruffet, G., Leith, L., Løseth, H., Rodrigues, N., Galland, O., & Leanza, H. A. (2011). Combustibles sólidos (asfaltita). In XVIII Congreso Geológico Argentino, Neuquén, Relatorio, Capítulo (Vol. 58, p. 689e695).

-Alfonso, M. A. A., & Fernández, A. D. ASFALTITA SUS POSIBILIDADES COMO COMBUSTIBLE.

-Pesce, A. H. (2010). The Domuyo Geothermal Area, Neuquén, Argentina. Geothermal Resources Council Transactions, 37, 309-314.

-Silva-Fragoso, A., Ferrari, L., Norini, G., Orozco-Esquivel, T., Corbo-Camargo, F., Bernal, J. P., & Arrubarrena-Moreno, M. (2021). Geology and conceptual model of the Domuyo geothermal area, northern Patagonia, Argentina. Journal of Volcanology and Geothermal Research, 420, 107396.