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HYDROTHERMAL ALTERATION RELATED TO LOS TACHOS GEOTHERMAL MANIFESTATION, DOMUYO VOLCANO, NEUQUÉN PROVINCE, ARGENTINA.

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INTRODUCTION

The Domuyo Geothermal Field is located in the north-western sector of Neuquén province (between 36º30'-36º42'S and 70º27'-70º39'W), and included in Las Minas and Chos Malal Departments. The access is from Chos Malal locality across the National Route 40 and then across the Provincial Route 43 (Figure 1A)

The main manifestations are placed in the west and southwest areas of the Domuyo volcano and are distributed (from east to west) in the following order: La Bramadora, Mallín del Domo, El Humazo, Los Tachos, Rincón de la Papas, Las Olletas and Aguas Calientes (Figure 1B). These, had been grouped depending on the particular characteristics of each manifestation, and from east to west the different types are the following: Type I (*Vapor-Dominated. Sulfate Spring*), Type II (*Water.Vapor-Mixed. Common Salt Springs*), Type III (*Water-Dominated. Common Salt Springs*) and Type IV (*Water-Dominated. Ca-Mg Bicarbonate Springs*) (JICA 1984).

Los Tachos geothermal manifestation is placed in the southern part of the field and is characterized by both, water and vapor expressions. The aim of this work is to determinate the alteration pattern associated to these expressions, including mineralogy and water composition, and try to delimitate different alteration areas.

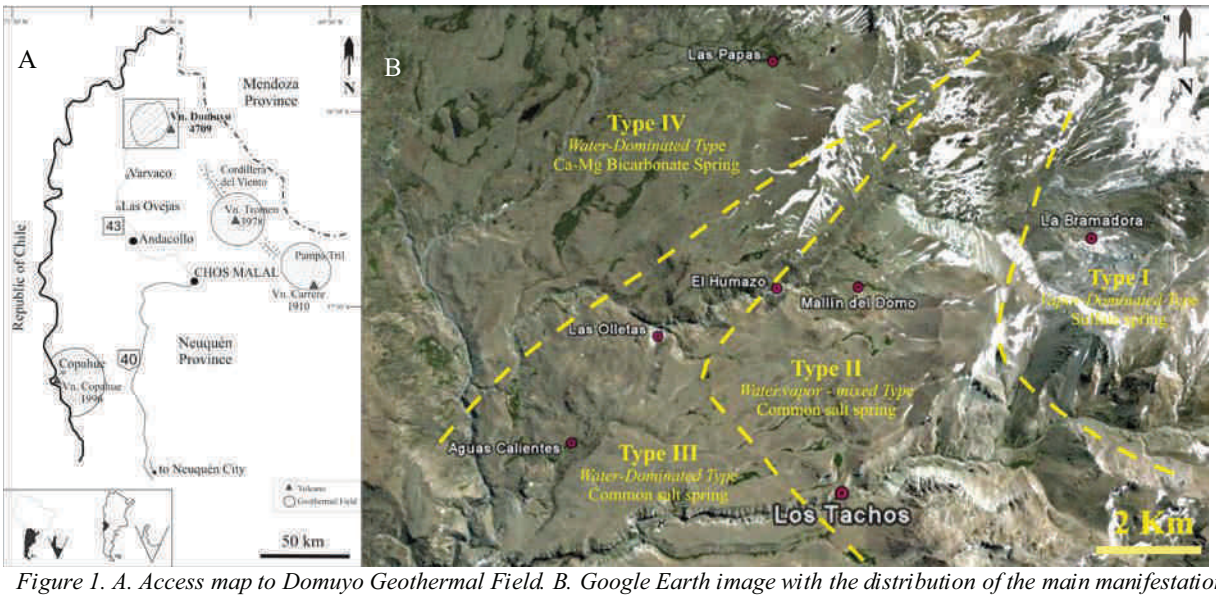

Figure 1. A. Access map to Domuyo Geothermal Field. B. Google Earth image with the distribution of the main manifestations and the different types in which they are grouped (modified from JICA, 1984).

GEOLOGIC SETTING

The studied area is included in one of the most important igneous centers of the northern Neuquén Andes. It has been studied from a regional geologic point of view by Groeber (1947), Llambías *et al.* (1978), Pesce (1981) and others. Muñoz Bravo *et al.* (1989) analysed the structural, geochemical and geocronological characteristics of the Plio-Quaternary volcanism between the 34° - 39° S of Los Andes Ranges, where Vn. Domuyo lies. From a geothermal point of view, Jurio (1978), Panarello *et al.* (1990) and more recently Mas

et al. (2000, 2008a, 2008b, 2009), had worked in this area. A prefeasibility study of the geothermal development in the area has been carried out by JICA-EPEN Project (1983-1984).
Cerro Domuyo (4709 m) consists in a dome unconformably emplaced in an anticline. A K/Ar age of 2.5±0.5 Ma indicates that the Domuyo dome is actually late Pliocene in age (Miranda, 1966).
Cenozoic rocks in the area are mainly volcanic in origin (Llambías *et al.*, 1978). As a whole, this group of volcanic rocks conform a calc-alkaline series.
Late Pliocene to Pleistocene volcanic activity in the Domuyo region is characterized by phreatomagmatic rhyolitic deposits and extrusive dome that occur southwest and on the northeastern flanks of the Domuyo summit.

SURFACE ALTERATION MINERALOGY

The geothermal manifestation of Los Tachos is included in an elongated NE-SW trending zone with a notorious surface alteration. This area can be divided in two sectors (East and West), where active steam and gas emission are intense, and there are numerous steam vents and mud pots. The main differences between these sectors are found in the mineralogy, water composition and water/gas manifestation. Based in the regions proposed by JICA (1984), the East sector is included in Type II (*water.vapor-mixed type*) region and West sector is included in Type III (*water-dominated type*) region. Their sampled points were LT-I1 (West sector) and LT-I2 and LT-I3 (East sector) (Figure 2 A y B). Nowadays the particular mineralogy of these areas has been studied by optical microscopy, X-ray diffraction (XRD) and scanning electron microscopy with elemental detection analysis (SEM and EDAX).

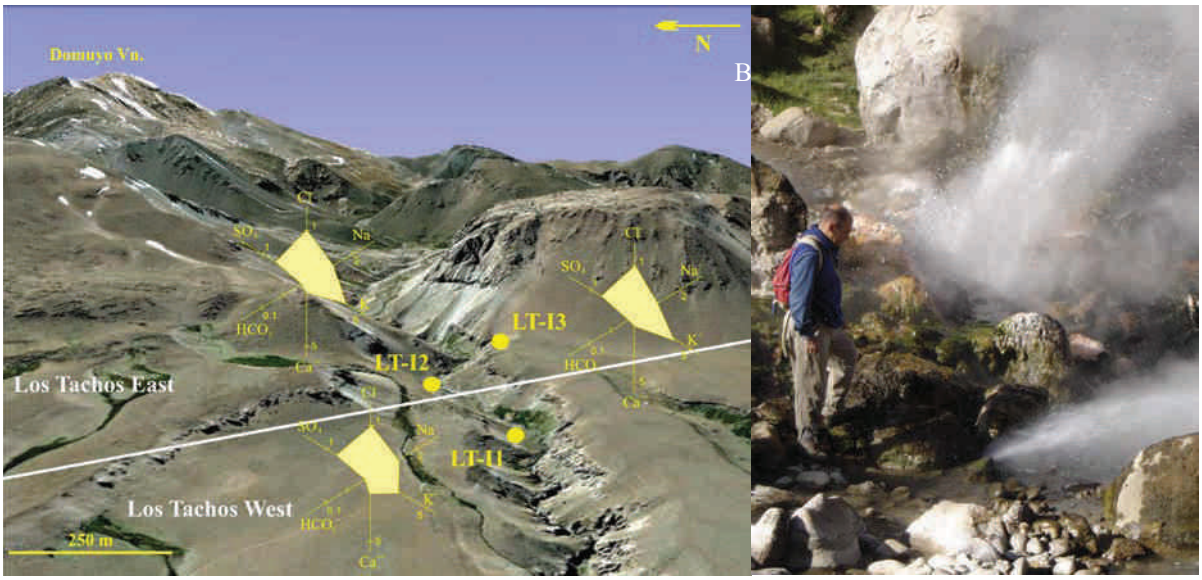

Figure 2. A. Chemical analysis shown in Tickell diagrams. Data from JICA (1983). B. Photograph of active steam and water emission.

WEST SECTOR

Common salt hot springs of western Los Tachos (**LT-I1**) are rich in Na^+ and Cl^- with relatively poor in K^+ and rich in Ca^{++}, and are characterized as *water-dominated* type consisting mainly of a large amount of hot springs with or without very little fumarolic gas. Their geothermo-temperatures range from 160º to 188ºC (JICA 1984).
The alteration mineralogy of the western sector is characterized by SiO_2 polymorphous (cristobalite and quartz), aragonite, zeolites from heulandite-clinoptilolite series and halite. In thin sections the host rock (mainly andesites) is pervasively altered containing chlorites, epidote in small crystals, and calcite as replacement of plagioclase. The groundmass is found replaced by silica. There are narrow veinlets filled by quartz and carbonate, with associated sulfur.

EAST SECTOR

Common salt hot springs of eastern Los Tachos (**LT-I2 and LT-I3**) are also rich in Na^+ and Cl^- with relatively rich in K^+ and poor in Ca^{++}, and are characterized as *vapor.water-mixed* type consisting mainly of hot springs and a large amount of fumarolic gas. This group of hot springs has the highest geothermo-temperatures ranging from 214º to 223ºC.
The eastern sector is characterized by three SiO_2 polimorphous (tridymite, cristobalite, and quartz), abundant manganese patinas and halloysite. There were found also the same zeolites than in western area, from heulandite-clinoptilolite series.
The zeolites are found as open-space fillings in vesicles and along fractures, they were determinated by optic microscopy (Figure 3A), XRD, SEM and EDAX analysis (Figure 3B). This mineral forms in open cavities as fine radiating needles and in length-fast prisms with low birefringence, variable extinction (0º-27º) and moderate relief. In order to distinguish which zeolite from the series is present, it was used the Thermal Stability Method proposed by Mumpton (1960), which involves heating the sample at 450°C overnight and then X-raying. In this condition heulandite is supposedly destroyed (X-ray amorphous), while clinoptilolite remains unchanged.

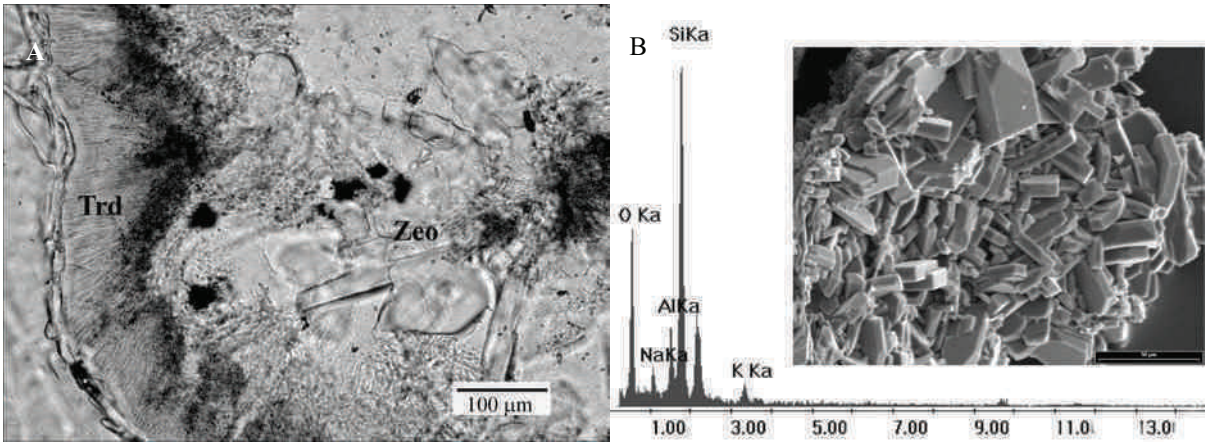

Figure 3. A. Image from optic microscopy. Trd: Tridymite; Zeo: Zeolite. B. EDAX analysis and SEM image of zeolites.

SUMMARY AND CONCLUSIONS

Two major areas of surface alteration were identified in Los Tachos geothermal field. Western area is characterized by silica polymorphous such as quartz and cristobalite near the fumarolas and propilitic alteration in surrounding areas. Epidote and carbonates may be formed by hydrothermal alteration from the interaction of the host rock and Ca^{++} rich water. In Eastern area three silica polymorphous coexist (tridymite, cristobalite and quartz). These, together with halloysite characterize this area as a slight argilic alteration zone. Tridymite is often formed as a desvitrification product of volcanic glasses forming intergrowths with zeolites.
Zeolites present in both areas belong to Heulandite-Clinoptilolite isomorphous series. The structure stability shown by this mineral over 450ºC in addition with EDAX information and optical properties, have demonstrated that clinoptilolite is the most common zeolite in Los Tachos geothermal manifestation.

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