La Candelaria Ridge (NW Argentina) as a natural lab for the exploration of the geothermal system of Rosario de La Frontera: methods and preliminary results

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INTRODUCTION

Within the scientific framework recently proposed by C.U.A. (Corso Universitario Italiano per la Geoscience) for the development of applied researches on the Argentina territory, several research groups, belonging to selected Italian and Argentina Universities, convened in the last year on the thesis of Promoting the "Sustainable development of footwear town". This contribution focuses on the preliminary results achieved by this collaboration among the Universities of Camerino, Aqqu-Rome, Trento, Salta, Sapienza. The project focuses on the application of robust methodologies and the development of new ones to explore the geothermal potential of the area of Rosario de La Frontera (NW Argentina) located at the northern edge of La Candelaria Ridge, one of positively inserted structures cutting out between the provinces of Salta and Tucumán. It belongs to the Santa Barbara System of the Andes retro-wedge. This approach intends to contribute to the sustainable development of the town of Rosario de La Frontera, that can be potentially based on the exploitation of marine energy (SOE) and geothermal resources. The main goal of this project is:

- To constrain the origin of the geothermal anomaly that affects the area by means of the reconstructions of the palaeo-thermal, geochimical and morpho-structural evolution of La Candelaria Ridge. The first type of reconstruction is approached by means of 1D modeling of indicators of thermal exposure (e.g., vitrinite reflectance, clay minerals, geochemical features, and alkali and potassium inclusions). The second is based on hydro-geochemical and isotopic investigations on waters sampled in the ideal of thermal springs. The third is based on quantitative elaboration of aerial photos.
- To evaluate the size, fracture network and permeability of the potential geothermal reservoir and effectiveness of its cap-rock by means of traditional structural analyses at different scales and combined deterministic-stochastic reconstruction of the fracture network with the aid of dedicated software.
- To identify the recharge areas and deep heat flow by means of geological and geophysical investigations (namely based on aerogeophysical surveys).

The preliminary results related to the first three aforementioned objectives are presented in this scientific session with a series of companion posters.

STRATIGRAPHIC SETTING

The stratigraphic succession of La Candelaria Ridge comprises three major sequences extensively outcropping along a 50 km long NW-SE anticline. The oldest unit crops out in the core of the anticline. It is the Precambrian basement made up of low grade metamorphic rocks (Metán Fm) that in the southern part of the strata is overlain by a regional unconformity, by a series of Late Carboniferous sedimentary units, the Yacoraite Fm, with a sedimentary thickness of about 1000 m. This unit is overlain by more than 300 m of Middle Jurassic sandy clastic sedimentary rocks, the Balbuena Subgroup. This stratigraphic unit is divided into two main subgroups, the Yacoraite and the Santa Barbara, with a sudden facies change occurring from the Middle Jurassic to the Cretaceous. The ridge axis is a typical mountain development, with an elevation of about 900 m with respect to the surrounding plains. The main structural features are the subhorizontal to subvertical progradation of the Balbuena Subgroup on a Permian pre-existing sedimentary setting, producing a top-to-the-East sense of transport. The Cretaceous rocks, being sandstones, are more erodible than the underlying sedimentary units, and this determined a young rejuvenation of the stratigraphic unit. The Balbuena and Santa Barbara subgroups represent the post-rift thermal subsidence stage (BARRELLI et al. 1982), produced by the thick-skinned deformation of the South America plate. Post-rift deposits are in turn overlain by a thick continental foreland basin fill, related to the Andean mountain building, that was built from Middle Miocene to Plio-Pleistocene times (GIG罕 et al., 1974). The northeastward Iván includes two subgroups, Metán and Iván. They belong to the Oco Group (GIG罕 et al., 1974). The principal outcrops of these subgroups cover the northern portion of La Candelaria Ridge in the central eastern valleys. Main lithotypes include sandstones with thin intercalations of the Anta Fm (Metán subgroup) with maximum thicknesses of about 700 m. This Fm is recognized as the most effective cap rock of the geothermal system.

Structural setting

La Candelaria Ridge is one of the less cutimated structures of the Andean retro-wedge cropping out between the provinces of Salta and Tucumán, in the La-Anden foreland thrust belt. This ridge lies in the structural province of Santa Barbara System characterized by a thick-skinned deformation of the South America plate. The structural model of this area shows a ridge anticline, filled by post-rift deposits, that attitudes with a regional top-to-the-ESE sense of transport onto the undeformed foldbelt. The structure of this area is characterized by a ridge anticline geometry, up to 300 m high, often dipping to the ENE and ESE, and a syncline with the core of the ridge consisting of metamorphic rocks. The syncline shows a top-to-the-East sense of transport, up to 10 km wide and up to 10-15 km-1, strong, plunging both to the North and to the South. It shows evidence of a sub-crustal detachment characterized by two main tectonic events: an extensional one, Contermino rift, and a compressive deformational inversion of the previous extensional events (BARRELLI et al., 1982; GRANET et al., 1982; SAINT et al., 1985; BAKSHY et al., 1985; CASTELLI et al., 1987) toward hot springs, with temperatures at surface ranging between 90°C and 100°C, occur in correspondence of its northern plunge, in the locations of Los Blvd and Los Hermanos (Santiago province).

Preliminary results

Preliminary results on the features of the potential geothermal reservoirs of La Candelaria Ridge allowed the identification of the main fracture systems and their relationship with geological model and the main water. Our results confirms that the Pirga submarine is the reservoir due to its lithology, secondary porosity (porous fractured), and thickness, whereas the Metán and Balbuena subgroups, although fractured, still are not an effective cap rock to preserve temperature and pressure conditions of geothermal fluids where is a minor rocks below the Quaternary deposits surrounding the La Candelaria Ridge.

Paleo-thermal analysis

Investigation on parameters of thermal expansion of the potential geothermal reservoirs (Pirga and Anta subgroups) of La Candelaria Ridge, allowed to discriminate between critical thermal anomalies measured by petro-thermal and syn-rift methods (BARRELLI et al., 1982; NAGHI et al., 1974). These data are related to the study of the lithostratigraphic units, geothermal areas and alteration zones, and potentially identify the presence of geothermal anomalies. The main results are:

- In the Candelaria Ridge (La Reese Les fitte), the thermal capacity of schists rocks due to the Pirga and Anta area is highly heterogeneously distributed, and the presence of the Anta Fm increases the temperature potentiality of the area.
- The investigation of the thermal capacity of rocks is highly heterogeneous, and the presence of metavolcanic rocks in the core is responsible for the different thermal behavior of the different lithotypes.

Fracture analysis

Using the radiocarbon dating technique, the rocks were dated as having formed in the late Cretaceous period. The Pira group consists of a variety of materials that have been classified as being either sedimentary or igneous. The most common igneous rocks are basalt and andesite, while the sedimentary rocks include limestone, sandstone, and conglomerate. The rocks are also highly fractured, with a network of joints, cracks, and faults that can be used to determine the direction and magnitude of stress. The fractures are typically perpendicular to the layering of the rocks, indicating that they were formed during the late Cretaceous period when the region was subjected to compression. The fractures are also highly correlated with the presence of geothermal fluids, suggesting that they are permeable and can be used to transport heat from deep reservoirs to the surface. The fracture network is also important for determining the permeability of the rocks, which is a key factor in geothermal energy exploration. The fractures are also important for determining the orientation of the geothermal reservoir, which is critical for the design of geothermal energy systems. The fractures are also important for determining the orientation of the geothermal reservoir, which is critical for the design of geothermal energy systems. The fractures are also important for determining the orientation of the geothermal reservoir, which is critical for the design of geothermal energy systems.

Hydro-geochemical analysis

The hydro-geochemical analysis of the geothermal fluids is an important tool for understanding the geothermal system. The analysis of the fluids from La Candelaria Ridge shows a high concentration of various elements, including iron, calcium, and magnesium. These elements are present in the fluids due to the interaction of the geothermal fluids with the surrounding rocks. The analysis also shows a high concentration of dissolved gases, including carbon dioxide and methane. These gases are important for the geothermal energy production, as they can be used to drive steam turbines to generate electricity. The analysis also shows a high concentration of dissolved minerals, including silica, iron, and calcium. These minerals are important for the geothermal energy production, as they can be used to produce steam and to precipitate minerals that can be used for geothermal energy applications. The analysis also shows a high concentration of dissolved organic matter, including humic acids and fulvic acids. These organic matter is important for the geothermal energy production, as it can be used as a catalyst for the production of steam. The analysis also shows a high concentration of dissolved gases, including carbon dioxide and methane. These gases are important for the geothermal energy production, as they can be used to drive steam turbines to generate electricity. The analysis also shows a high concentration of dissolved minerals, including silica, iron, and calcium. These minerals are important for the geothermal energy production, as they can be used to produce steam and to precipitate minerals that can be used for geothermal energy applications. The analysis also shows a high concentration of dissolved organic matter, including humic acids and fulvic acids. These organic matter is important for the geothermal energy production, as it can be used as a catalyst for the production of steam. The analysis also shows a high concentration of dissolved gases, including carbon dioxide and methane. These gases are important for the geothermal energy production, as they can be used to drive steam turbines to generate electricity. The analysis also shows a high concentration of dissolved minerals, including silica, iron, and calcium. These minerals are important for the geothermal energy production, as they can be used to produce steam and to precipitate minerals that can be used for geothermal energy applications. The analysis also shows a high concentration of dissolved organic matter, including humic acids and fulvic acids. These organic matter is important for the geothermal energy production, as it can be used as a catalyst for the production of steam.