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.I.A. (*Consorzio Universitario Italiano per l'Argentina*) for the development of applied researches on the Argentina territory, several research groups, belonging to selected Italian and Argentina Universities, converged in the last year on the research line devoted to the "Sustainable development of future towns".

This contribution focuses on the preliminary results achieved by this collaboration among the Universities of Camerino, Jujuy, Roma Tre, 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 inverted structures cropping out between the provinces of Salta and Tucuman. 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 medium enthalpy (90°<T<150°C) geothermal resources.

The main goals of this project are:

- To constrain the origin of the geothermal anomaly that affects the study area by means of the reconstructions of the paleo-thermal, geochemical 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 geo-thermometers and Th and Tm from fluid inclusions). The second is based on hydro-geochemical and isotopic investigations on waters sampled in the sites 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 fluid flow by means of geological and geophysical investigations (namely based on audiomagnetotelluric survey);
- To model the geothermal system.

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

We present the preliminary analytical and modelling results concerning the paleo-thermal conditions recorded by the sedimentary succession cropping out along *La Candelaria Ridge* that hosts the aforementioned system.

GEOLOGICAL SETTING

Structural setting

La Candelaria Ridge is one of the less culminated structures of the Andean retro-wedge cropping out between the provinces of Salta and Tucuman, in the Sub-andean foreland thrust belt. This ridge lies in the structural province of *Santa Barbara System* characterized by a thick-skinned compressive deformation (ALLMENDINGER *et alii*, 1983; JORDAN *et alii*, 1983; KLEY AND MONALDI, 1998; SEGGIARO AND HONGN, 1999) where structures thrust with a regional top-to-the-ESE sense of transport onto the undeformed foreland. The structure of *La Candelaria Ridge* consists of a broad anticline, uplifted by fault planes dipping to the west with a top-to-the-east sense of transport, ca. 60 km-long and up to 10-15 km-wide, strongly plunging both to the North and to the South. It shows evidences of a complex structural history characterized by two main tectonic events: an extensional one, Cretaceous in age, and a Neogenic tectonic inversion of the previous extensional structures (BIANUCCI *et alii*, 1982; GRIER *et alii*, 1991; SALFITY *et alii*, 1993; KRESS, 1995; CRISTALLINI *et alii*, 1997). Several hot springs, with temperatures at surface

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ranging between 50°C and 99°C, occur in correspondence of its northern plunge, in the localities of *Los Banós* and *Las Termas* (Salta province).

Stratigraphic setting

The stratigraphic succession of *La Candelaria Ridge* comprises three major sequences extensively outcropping along a ca. 60 km long N-S anticline.

The older unit crops out in the core of the anticline. It is the Precambrian basement made up of low grade metasedimentary rocks (Medina Fm) that in the southern part of the anticline is overlain, with a regional unconformity, by a series of Late Cambrian to Ordovician marine siliciclastic sediments (Candelaria and Orcomato Fms).

These strata are disconformably overlain, in the northern portion and in the western limb of the anticline, by a predominantly continental succession of red beds with minor calcareous intercalations (Salta Group) of Cretaceous to Paleogene age. This marks a rift stage (SALFITY AND MARQUILLAS, 1994). The Salta Group is subdivided from bottom to top in the Pirgua, Balbuena and Santa Barbara subgroups (SALFITY AND MARQUILLAS, 1994). The Early to Late Cretaceous Pirgua subgroup consists mainly of red continental conglomerates and sandstones of 1000m average thickness (ESPELTA *et alii*, 1975). This subgroup represents the syn-rift stage and has been interpreted as the reservoir of the active geothermal system (ESPELTA *et alii*, 1975). The Latest Cretaceous to Early Paleocene Balbuena Subgroup is 180m thickness and comprises sandstones and limestones, whereas the Paleocene to Early Eocene Santa Barbara subgroup, with 330m thickness, is dominantly shaly with rare carbonate intercalations. The Balbuena and Santa Barbara subgroups represent the post-rift thermal subsidence stage (BIANUCCI *et alii*, 1981, COMINGUEZ AND RAMOS, 1995).

Post-rift deposits are in turn overlain by a thick continental foreland basin fill, related to the Andean mountain building, that was shed from Middle Miocene to Plio-Pleistocene times (GEBHARD *et alii*, 1974). The retrowedge basin fill includes two subgroups: Metán and Jujuy. They belong to the Oran Group (GEBHARD *et alii*, 1974). The principal outcrops of these subgroups cover the northern portion of *La Candelaria Ridge* at the lowest elevations. Main lithotypes include sandstones, siltstones and mudstones 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.

PRELIMINARY RESULTS

Referring to the constraints on the origin of the geothermal anomaly that affects the study area:

- Present-day heat flow values are dramatically higher (3-4 HFU) than those expected in the peripheral portions of a retrowedge in an orogenic system;
- Paleo-thermal modeling allowed to discriminate between the regional and local causes of thermal anomalies recorded by the Meso-Cenozoic sedimentary succession. They are respectively burial due to sedimentary loading and fluid interaction at shallow crustal levels;
- Hydro-geochemical and isotopic preliminary results indicate a prevalent meteoric signal of the spring waters;
- Elaboration of aerial photos suggests a differential uplift of the structure with more mature landscape characterizing the northern portion of *La Candelaria Ridge* than the southern one where a relic paleo-surface is still partially preserved at the highest elevations;
- Preliminary results on the characteristics of the potential geothermal reservoir and cap-rock allow the identification of the main fracture systems and their relationships with lithology and structures at the macro-scale. Our study confirms that the Pirgua subgroup is the reservoir due to its lithology, secondary permeability (continous fractures) and thickness, while the Metán subgroup, although fractured, can still be a cap rock able to preserve temperature and pressure conditions of geothermal fluids where it is kept and mainly below the Quaternary deposits surrounding *La Candelaria Ridge*.

In detail, fractures orientations show four main different trends: N-S, NE-SW, NNW-SSE and E-W. Furthermore N-S and E-W trending fractures are concentrated in the northern periclinal area of the anticline where several hot springs occur with the E-W system probably exerting a structural control on the distribution of the chemical and physical features of waters. On the other hand NNW-SSE and NE-SW trending fractures are predominant in the reservoir rock cropping out along the eastern and western limbs of the anticline, respectively. Within the reservoir unit, fractures show a typical spacing of approximately 30 cm and aperture values that range from 3 mm up to 1 cm.

As a whole, the detected fracture systems affecting the principal reservoir enhanced its permeability;

- Preliminary modeling of audiomagnetotelluric data provide information pertaining to fractures and geometric properties of the geothermal field at depth.

CONCLUSIONS

Preliminary results concerning the multi-method characterization of the *Rosario de La Frontera* active geothermal system (NW Argentina) by means of geological, geochemical, paleo-geothermal, structural and geomorphological and geophysical investigations are summarized in this contribution.

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