Modelling of organic and inorganic paleo-thermal indicators to constrain the evolution of the geothermal system of Rosario de La Frontera (La Candelaria Ridge, NW Argentina): a new tool for geothermal exploration

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INTRODUCTION

X-ray diffraction of clay grain-size fraction of sediments, organic matter optical analysis and micro-thermometric study of fluid inclusions are widely used in oil exploration for determining the thermal maturity of sedimentary successions and basin evolution (from tens to hundred million years) by means of thermal modelling (ROURE *et alii*, 2010). The quantitative investigation of organic matter physico-chemical variations by optical measurements (e.g., vitrinite reflectance), of clay minerals structural and compositional changes (e.g., mixed layer illite-smectite) by X-ray diffraction and of micro-thermometry recorded by fluid inclusions (e.g., Th and Tm) allows to determine the thermal maturity of sediments, from diagenesis to very low-grade metamorphism, and to constrain the maximum temperatures experienced by rocks (e.g., MAZZOLI *et alii*, 2008).

As a matter of fact this multi-method approach is much less applied to detect paleo-temperatures in fossil and active geothermal systems, despite the validity of the single techniques has been tested in several case histories of geothermal interest to characterise modes of fluid-rock interaction and abnormally high geothermal gradients at shallow crustal levels (ALDEGA *et alii*, 2010).

In the last year, we have been fully developing this integrated methodology to reconstruct the thermal evolution of *Rosario de La Frontera* active geothermal system (ESPELTA *et alii*, 1975), located in the *Santa Barbara* System, in NW Argentina in the foothills of the Cordillera. In this contribution 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

In NW Argentina, the externalmost and less culminated structures of the Andean retro-wedge crop out in the *Santa Barbara* System. These structures thrust with a regional top-to-the-ESE sense of transport onto the undeformed foreland, locally preserving huge thicknesses of syn-orogenic siliciclastics. These structures may host hot springs and thermal manifestations along a regional NNE-SSW alignment currently characterised by strong along-strike variations of heat flux, with values locally exceeding 3-4 HFU.

La Candelaria Ridge is one of these structures cropping out between the provinces of *Salta* and *Tucuman*. It is a ca. 50 km-long and up to ten km-wide asymmetrical macro-anticline cored by neo-Proterozoic phyllite basement and draped by a Cretaceous-Quaternary sedimentary succession, strongly plunging both to the North (below the *Metan* alluvial plain) and to the South. The sedimentary succession, made up of continental syn- and post-rift sequences (Cretaceous to Eocene in age) and syn-orogenic siliciclastics (Oligocene-to present in age) hosts the geothermal system with the main reservoir represented by coarse syn-rift clastics sealed by post-rift and syn-orogenic units at low permeability. In correspondence of the northern plunge, the well-known hot springs and thermal spa of *Las Termas* and *Los Baños* (a few km apart from *Rosario de La Frontera* village) develop with water temperatures up to 99°C and high concentrations of NaCl and $CaSO_4 \cdot 2H_2O$.

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METHODS AND MATERIALS

Samples for XRD and organic matter investigations derive from the main reservoir and seal units collected along the ridge either in undeformed or highly fractured outcrops, whereas samples for fluid inclusions analysis are from calcite syn-tectonic extensional veins developed at various stages during the tectonic evolution since Cretaceous times.

Analytical inorganic and organic thermal indicators concern:

- mean vitrinite reflectance of organic matter dispersed in sediments,
- stacking order and illite content in mixed layers illite-smectite observed in <2μm grain-size fraction of sediments;
- Th and Tm from fluid inclusions.

Furthermore XRD patterns on whole rock samples were also performed to characterize the mineralogical assemblages and alteration facies.

Preliminary thermal models were then performed by means of 1-D Basin-mod software and calibrated against our organic and inorganic thermal indicators, on the basis of published stratigraphic-structural framework, to devise scenarios of temperature distribution and evolution as a function of depth.

PRELIMINARY RESULTS

The thermal signature recorded by unfractured lithostratigraphic units along *La Candelaria* Ridge is sensibly stronger than that expected by performed models that trace the paleo-thermal history of the analysed succession from the Cretaceous rift to the Tertiary foredeep basin disregarding the present-day heat flow anomaly.

The paleo-thermal signature along *La Candelaria* is higher than that recorded at depth by vitrinite reflectance in the productive oil fields, located a few tens of km to the north of *Rosario de La Frontera*, where, at present, heat flux is substantially lower (ca. about 1 HFU) than in the area of *Rosario de La Frontera*.

Moreover, data from samples collected in correspondence of highly fractured outcrops in *Las Termas* and *Los Baños* localities indicate a strong interaction between circulating hot fluids and the host rock and, locally, higher paleo-temperatures of the hosting rock when compared to the rest of *La Candelaria* structure.

CONCLUSIONS

The multi-method approach proposed in this contribution turned out to be particularly useful in discriminating among regional and local causes of thermal evolution of the sub-Andean Meso-Cenozoic sedimentary succession which are the result of simple burial and fluid interaction at shallow crustal levels respectively. Thus this approach turned out to be quite promising as a low-cost tool for investigating the thermal evolutions of geothermal systems hosted in sedimentary contexts.

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