

## Chemical-isotopic analyses and hydrogeologic modeling of the geothermal System of Rosario de la Frontera (Salta, Argentina): preliminary results

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This study is part of the multidisciplinary investigation of the thermal springs emerging in the area of Rosario de La Frontera (*La Candelaria Ridge*, Salta, Argentina); it is carried out in order to produce a preliminary evaluation of geothermal potential of this system. These surface thermal manifestations, whose temperature ranges from 22.7 to 93.3 °C, are located in the northern sector of the *La Candelaria Ridge* anticline in the province of Salta (NW Argentina; SEGEMAR, *Catálogo de Manifestaciones Termales de la República Argentina*; SEGGIARO *et alii*, 1997). The study is based on analytical evidence of the chemical and isotopic composition ( $\delta^{18}\text{O}_2$ ,  $\delta\text{D}$  e  $\delta^{13}\text{C}\text{-CO}_2$ ) of 13 water samples and 5 gas samples taken from hot springs emerging in this restricted area.

Furthermore, more than 20 stations for structural data acquisition have been performed in order to recognize main fracture system network. These data are important to evaluate the reservoir permeability and to determine main fluid flow directions at depth.

Sampled waters show a relatively low salinity (TDS < 1000 mg/L), with the exception of three hot springs (Agua Laxante, Vicky e Salada). These latter are characterized by TDS values in the range of 5500 and 30000 mg/L. All the sampled waters have a prevalent sodium chloride composition, although the presence of sulfate ion is significant (up to 3000 mg/L). Concentration of ammonium (<0.28 mg/L) and boron (<0.51 mg/L) ions, generally used as tracer for hydrothermal origin of water, are negligible. The isotopic ratios of water (-6.7 and -37 ‰ V-SMOW for  $\delta^{18}\text{O}_2$  and  $\delta\text{D}$  respectively), suggest a prevalent meteoric origin of fluids.

Gaseous phases, associated to hot springs as bubbling gases, are mainly  $\text{CO}_2$  (between 550 and 960 mmol/mol), with relevant concentration of  $\text{N}_2$  (>28 mmol/mol). Where concentration of  $\text{CO}_2$  is higher (Sulfurosa de la Vieja Quemada, Sulfurosa e Agua Chica),  $\text{H}_2\text{S}$  (up to 3.6 mmol/mol),  $\text{H}_2$  (up to 0.022 mmol/mol) and  $\text{CH}_4$  (up to 0.087 mmol/mol) are also higher, while atmospheric gases ( $\text{O}_2$ , Ar and Ne) are lower.  $^{13}\text{C}/^{12}\text{C}$  ratio in  $\text{CO}_2$  ( $\delta^{13}\text{C}\text{-CO}_2$  from -5.16 to -3.66 ‰ V-PDB) are consistent with a prevalent mantle origin of this gas.

Preliminary results from structural analyses carried out by scan lines within different lithologies allowed us to define the main characteristics of the potential geothermal reservoir and cap-rock and to identify the main fracture systems and their relationships with the macro-scale structure.

The main structure of the Sierra de La Candelaria is a N-S trending periclinical and asymmetric macro-anticline, strongly plunging either to the North (below the Metan alluvial plain) and to the South, cored by neo-Proterozoic phyllite basement and draped by a Cretaceous-Quaternary sedimentary succession (ESPELTA *et alii*, 1975; SEGGIARO *et alii*, 1997). The sedimentary succession is made up of continental syn- and post-rift sequences (Cretaceous to Eocene in age) and syn-orogenic siliciclastics (Oligocene-to present in age).

The anticline shows an high angle tectonic contact along the eastern limb, which can be interpreted as a reverse fault probably due to the inversion of a previous extensional structure related to the Cretaceous rifting (CRISTALLINI *et alii*, 1997 and references therein). E-W trending extensional faults which realize a general N-S extension offset the stratigraphic succession and the other discontinuities. They are probably related to a younger deformation phase.

In detail, four different fracture sets have been recognised: N-S, NE-SW, NNW-SSE and E-W. N-S and E-W trending fractures are particularly concentrated in the northern plunging area of the anticline where the hot springs occur. This pervasive orthogonal fracture system gives rise to 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 Pigua subgroup cropping out along the eastern and western limbs of the anticline, respectively. This unit represents the main reservoir due to fractures continuity which show a typical spacing of approximately 30 cm and aperture values that range from 3 mm up to 1 cm.

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As a whole, the detected fracture systems affecting the principal reservoir enhanced its permeability, and allows deep circulation of meteoric water.

Comparison between preliminary data from values of spring discharge in the area of *Rosario de La Frontera* and values of average annual rainfalls, which in *La Candelaria Ridge* is about 900 mm/a, allow to estimate recharge time of the reservoir in the order of some years.

Through collected data, it is possible to obtain an hydraulic conductivity value from the formula's application proposed by KIRALY (1969) for the characterization of the rocks heaps. This, even though is a clear simplifications, provides a real parameter that can be compared with that obtained from the Darcy's law.

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