Application of spectral gamma and magnetic susceptibility in a As-bearing loessic aquifer, Argentina.

L. Sierra, S., Dietrich, P.A., Weinzettel, P.A, Bea, L. Cacciabue
Instituto de Hidrología de Llanuras "Dr. Eduardo J. Usunoff" (IHLLA), Azul, Argentina.
M.L. Gómez Samus
Lab. de Entrenamiento Multidisciplinario para la Investigación Tecnológica (LEMIT), La Plata, Argentina
N.N. Sosa
Centro de Investigaciones Geológicas (*CIG*), La Plata, Argentina

ABSTRACT: Application of Natural Gamma Spectroscopy (NGS) borehole logging and magnetic susceptibility (χ) on aquifer samples are compared with the identified mineralogy and trace elemental analyses. Acceptable correlation between ICP analyses (K and Th) and NGS signals has been found. However, some observed discrepancies on them could be related to the different exploratory volumes of each technique. Magnetic Susceptibility measurements present better correlations between the superparamagnetic signal (χdf) and As contents, probably linked to the pedogenetic origin of such particles.

1 INTRODUCTION

Geophysical measurements are easily implemented and non-destructive techniques that allow to obtain key features of aquifers. In fact, Natural Gamma Spectroscopy (NGS) borehole logging is a mineralogical log that improves the results of classical gamma ray log (GR) (Svendsen *et al.*, 2001). This tool estimates the ^{40}K, ^{232}Th and ^{238}U contents based on their radioactive activity (Killeen *et al.*, 2015). Scanlon *et al.* (2009) used GR logging to identify volcanic ash layers and related with As content in water. NGS can be used in cased wells thus expanding the exploratory possibilities. On the other hand, environmental magnetism is useful for studying sedimentary and post-depositional processes of magnetic minerals (Walden *et al*. 1999). Magnetic susceptibility (χ) is related to the presence of magnetic minerals. Frequency dependent susceptibility (χ_{df}) signal may be increased by the relative abundance of superparamagnetic particles (SP) like ultrafine magnetite/maghemite. This pedogenic minerals are very common in soils and paleosols of pampean loessic sediments (Gómez Samus *et al*. 2017). The objective of this work was to assess the NGS and χ logging signals, and relate them with mineralogy and As-bearing phases in the sediments of the aquifer.

2 MATERIALS AND METHODS

The Chaco-Pampean Plain in Argentina is one of the largest flatlands regions ($1x10^6$ km^2) with high As groundwater concentrations (Nicolli *et al.*, 2012). The study site is located in Tres Arroyos city, Buenos Aires province (-38.367°, -60.246°). The hosted aquifer consists locally of 120 m thick reworked aeolian mantle (loess) of Neogene to Quaternary age. It is composed of loessic sandy silts that are intermixed paleosols and calcrete horizons. As content in 1 m-averaged samples is 3.5-6.3 mg/kg. Groundwater is alkaline and dominates the Na-HCO_3 type. Arsenic content ranges between 10 and 234 µg/L. (Sierra *et al.* 2016). The volcanic glass shards are suggested as the main potential As source in this region. Secondary minerals such as clays and Fe-Mn oxyhydroxides may be considered as additional sources of As (Sosa *et al*. 2015).

2.1 *Sediment sampling and analysis*

Thirty samples for X-ray diffraction (XRD) and trace elemental analyses (ICP-MS, aqua-regia acid digestion) on each 1 m-mixed sediments were used.

2.2 *Geophysical measurement*

Magnetic sampling was performed on cores and detritus samples. Bulk samples were air-dried, milled and placed in 10cc plastic boxes. The χ was measured in low (χ_{lf}) and high frequency (χ_{hf}) by a MS Bartington device with MS2B sensor and the frequency dependent susceptibility ($\chi_{df} = \chi_{lf} - \chi_{hf}$), was calculated. NGS logging was performed with a Robertson Geologging equipment using static measurements at 50 cm interval with 1 min counting time.

3 RESULTS AND DISCUSSION

3.1 *Natural Gamma Spectroscopy*

Correlation coefficients between NGS log and ICP trace elements analyses (Figure 1) showed acceptable values for K ($r^2 = 0.65$) and Th ($r^2 = 0.45$). No correlation was observed for U due to a) low concentrations in sediments. Good correlation was also observed between Fe content and K_{NGS} ($r^2 = 0.60$) and Th_{NGS} log (r^2: 0.41). This can be explained by the relative abundance of K-rich micas like illite and I/S interlayer in associations with Fe-oxyhydroxides.

The NGS log can be divided in three sections (Figure 1). The abundance of calcite and quartz minerals lower GR, K_{NGS} and Th_{NGS} signals of the calcareous sands and calcretes between 5 and 17 meters below surface (mbs). High As calcrete at 12 mbs may be to surface or precipitation process that retain As on calcite.

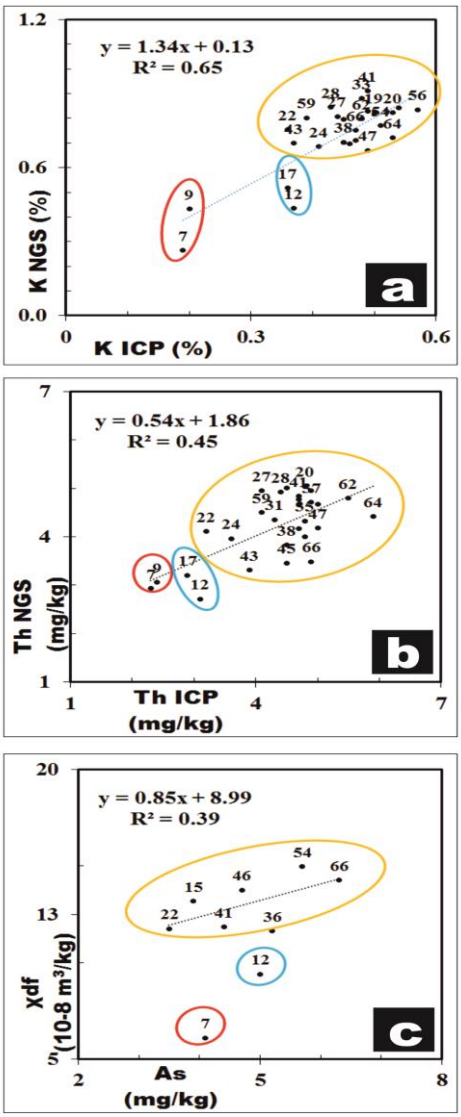

Figure 1. a) and b) Scatter plots NGS vs ICP contentof a) K and Th NGS vs ICP content. b) χ_{df} vs As content. Three sections are marked: Red (low χ_{df} calcareous sands), Blue (variable χ_{df} calcretes) and Orange (high χ_{df} clayey silts).

The lower section is in the range 20-70 mbs. This older sediments (upper Miocene?) are enriched in K and Th. sandy silt loessic sediments palaeosols with intercalations of clayey silt and low As-Fe calcretes.

3.2 *Magnetic Susceptibility*

Magnetic Susceptibility (χ_{lf} and χ_{hf}) correlation with As is low maybe due to multiple mineral sources. However, better correlations were achieved using χ_{df} with Fe (r^2= 0.72) and As (r^2= 0.39). This can be explained by the relative importance of SP magnetic particles, which are typical of paleosols of this region (Gómez Samus et al. 2017). The correlation of χ_{df} with radioelements shows also acceptable values for a) ICP analyses: K_{ICP} (r^2= 0.73) and Th_{ICP} (r^2= 0.75) due to the presence of SP magnetic particles with K-clays. b) NGS logging: K_{NGS} (r^2= 0.64) and Th_{NGS} (R^2= 0.35) lower correlations may be related to sample volumes

4 CONCLUSIONS

Comparison of NGS geophysical log and ICP trace element analysis in sediments showed acceptable correlations that may be useful to characterizes As-bearing mineral in the aquifers. χ measuremts presents better correlations between χ_{df} and As content because of the presence of superparamagnetic particles (SP) because of the pedogenic origin. Disparities are attributable to the different sample volumes

ACKNOWLEDGEMENTS

We thank PICT1805/2014 (ANPCyT) and PID 0075/2011 (COHIFE). for supporting this research. We also acknowledge IHLLA Lab and Institute of Physics Arroyo Seco (IFAS) for analyses. Special thanks to the reviewers.

REFERENCES

Gómez Samus, M., Rico, Y., Bidegain, J. 2017. Magnetostratigraphy and magnetic parameters in Quaternary sequences of Balcarce, Argentina. a contribution to understand the magnetic behaviour in cenozoic sediments of South America. *GeoResJ*, 13, 66-82.

Killeen, P. 2015 Tools and Techniques: Radiometric Methods. In: *Schubert, G. Treatise on geophysics. Elsevier.* (11): 447–524

Nicolli, H.B., Bundschuh, J., Blanco, M., Tujchneider, O., Panarello, H.O., Dapeña, C., Rusansky, J.E. 2012. Arsenic and associated trace-elements in groundwater from the Chaco-Pampeano plain, Argentina: Results from 100 years of research. *Sci. Tot. Environ.* 429: 36-56.

Scanlon, B., Nicot, J., Reedy, R., Kurtzman, D., Mukherjee, A., Nordstrom, D. 2009. Elevated naturally occurring arsenic in a semiarid oxidizing system, Southern High Plains aquifer, Texas, USA. *Appl Geochem*., 24(11): 2061-2071.

Sierra, L., Cacciabue, L., Dietrich, S., Weinzettel, P. Bea, S. 2016. Arsenic in groundwater and sediments in a loessic aquifer, Argentina. In *Arsenic Research and Global Sustainability: Proc. of the Sixth Int. Congress on Arsenic in the Environment (As2016), Stockholm, Sweden* (p. 92).

Sosa, N., Datta, S., Zarate, M. 2015. Arsenic concentrations in soils and sediments of the southern Pampean Plain, within Claromecó River Basin (Argentina). In *AGU Fall Meeting.*

Svendsen, J., Hartley, N.. 2001. Comparison between outcrop-spectral gamma ray logging and whole rock geochemistry: implications for quantitative reservoir characterisation in continental sequences. *Mar. Pet. Geol.*, 18(6): 657-670.

Walden J., F. Oldfield y J.P Smith, 1999. Environmental magnetism: a practical guide. *Technical Guide, No 6. Quaternary Research Association, London*, 214 pp.