Investigation of sedimentary deposits in the Atacama desert-Chile using loop source transient electromagnetics

B. Blanco[1]*, P. Yogeshwar[1], B. Tezkan[1], V. Wennrich[2], S. Buske[3], L. Ninnemann[3], D. Diaz[4]
[1] Institute of Geophysics and Meteorology, University of Cologne. *Contact: bblancoa@smail.uni-koeln.de, www.geomet.uni-koeln.de
[2] Institute of Geology and Mineralogy, University of Cologne.
[3] Institute of Geophysics and Geoinformatics, TU Bergakademie Freiberg.
[4] Departmento de Geofísica, Universidad de Chile, Santiago, Chile.

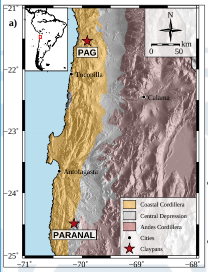
University of Cologne

I. Introduction

The present study was conducted within the collaborative research center CRC 1211 (EARTH - Evolution at the dry limit) which aims to characterize the mutual relationship of Earth processes and biological evolution. In this context, claypans in endorheic basins along the Coastal Cordillera of the Atacama desert (Chile) host unique records of the precipitation history of one of the major hyperarid deserts in the world [4,5].

This study aims to provide detailed information about the sedimentary architecture and bedrock topography of selected claypans (PAG and PAR, see also Fig. 1, 2). Accordingly, we performed a geophysical survey using the Transient Electromagnetic Method (TEM)[1,2] and Seismics. To derive suitable drilling locations for paleoclimatic research, and to better understand the deposition regime.

II. Atacama Desert Fieldwork November 2018



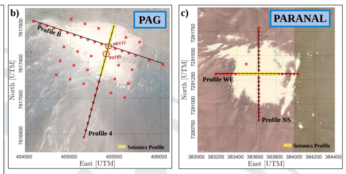


Fig. 1: a) Study areas and location of the selected claypans. b) PAG claypan. c) PARANAL claypan. TEM Soundings in red points. TEM profiles in black and Seismic profiles in yellow.

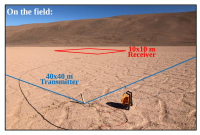


Fig. 2: Field setup (Rx & Tx.)

- Extensive fieldwork was carried out in November 2018 taking measurements in PAG and PARANAL claypans. In both sites, TEM and Active Seismic methods were applied [1,2].
- For each station, TEM central loop array was performed with a transmitter size of 40x40 m and two receivers with effective areas of 5 m² and 200 m².
- In total, more than 50 soundings were measured per claypan distributed along with profiles with a dense site spacing of 40 m. Two seismic transects are highlighted in yellow. (Fig. 1b, 1c).
- Both geophysical methods worked in a perfect coordination at the same time, keeping a rather high survey speed.

III. Data Processing and Validation

- Processing and editing of the raw data were performed. Transients were derived from a robust stacking approach.
- High quality and long transient with strong decay at late times was observed, indicating the resistive basement (Fig. 3a).
- Marquardt and Occam 1D inversion techniques were applied to derive the thickness of the sediment deposits[3]. Induce voltage data above 3×10^{-10} V/Am² and less than 20% error were used in the inversion process (Fig. 3, 4c, 5c).
- The resistive basement is at 90 m depth according to the 1D inversion of the TEM data. The upper part of the model shows a good comparison with the non-conductive resistivity data (Fig. 3b).

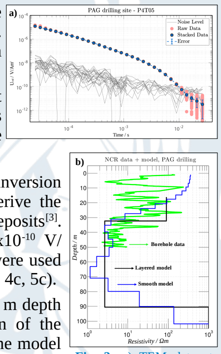


Fig. 3: a) TEM data at P4T05. b) Comparison of 1D model with NCR data.

IV. 1D Inversion Results for PAG & PARANAL Claypans

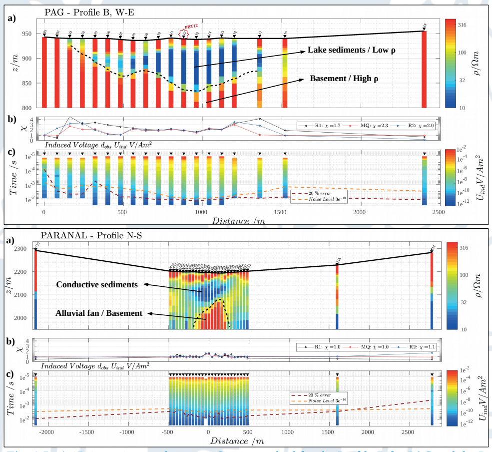


Fig. 4-5: a) 1D inversion results using Occam method for the Profile B for PAG and the Profile NS for PARANAL site, the basement in dash line is highlighted. b) Data fitting (χ) for each sounding along the profile for Occam and Marquardt inversion. c) The induced voltage of observed data with the Noise level and 20% error.

- Data well fitted by all the models referred to Chi (χ) values (Fig. 4b, 5b).
- In all profiles shown information until 350 - 400 m depth (DOI) derived from TEM data.

PAG

- A clear contrast of resistivity between good conducting sediments and resistive bedrock is observed (Fig. 4a, 7).
- Maximum sediment thickness at PAG claypan is roughly 90 m (Fig. 4a, 7).

PARANAL

- The boundaries of the lake sediments are identified in Profile NS. However, it is still under study if the resistive layer corresponds to an alluvial fan or the transition of the basement (Fig. 5a).
- Maximum sediment thickness at PARANAL site is roughly 140 m (Fig. 5a, 8).

V. Existence of basement at PAG?

- A modelling study at PB12-TEM data shows if the base interface is removed. The late time data is not fitted at all with χ ~ 18.41 (Fig. 6, No basement, blue).
- However, the fit is almost same, if the base resistivity is increased from 2×10^3 Ωm to 1×10^6 Ωm (High ρ, green), which means a poor resolution in terms of resistivity (Fig. 6).

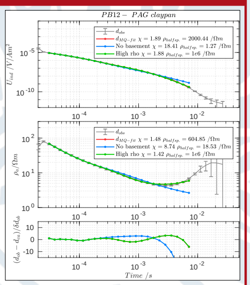


Fig. 6: Data (d_{obs}, gray) and fitting (d_{MQ}, red) for Marquardt inversion at PB12- PAG. Calculated response for different variations of the base layer: base layer removed (No basement, blue); base layer is increased to 1×10^6 Ωm (High ρ, green). The corresponding fit and parameter values are in the legend.

VI. Comparison of TEM Profiles v/s Seismic Profiles

- A P-wave velocity model has been derived from the seismic data by first-arrival traveltime tomography. Only refracted/diving waves are used here so that the depth penetration is limited. A comparison with the TEM results is shown for PAG and PAR in Figures 7 and 8, respectively. A significant velocity increase is observed at 20-40 m depth.

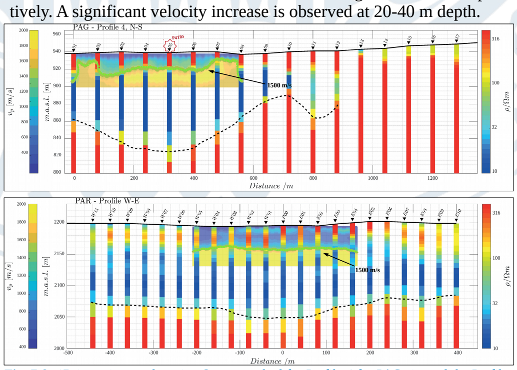


Fig. 7-8: 1D inversion results using Occam method for Profile 4 for PAG site and the Profile WE for PARANAL site. The green line shows the 1500 m/s velocity contour. The dashed black line represents the top of the basement derived from TEM 1D inversion.

- An excellent correlation between the depth of the upper layer of the conductive strata from TEM profiles and the depth in which a high contrast of velocity is observable (Fig. 7, 8).
- Velocity values at lateral boundaries of the model are not well constrained due to limited ray coverage and have to be interpreted with care (Fig. 7, P4T01 and P4T08; Fig. 8, PW05 and PE04).

PAG

- The depth of the upper layer of the sediments at ~20 m is consistent with the velocity model (Fig. 7, between P4T02-P4T06).

PARANAL

- The depth of the upper layer of the sediments at ~40 m is consistent with the velocity model (Fig. 8, between W05-E04).
- The lake deposits are equally distributed from West to the East.

VII. Conclusions & Future Work

- Succesfull TEM measurements were carried out on two claypans in the Atacama desert.
- Thickness of the lake sediments and the depth basement are clearly derived.

Outlook:

- Quasi 2D/ 3D Subsurface model (Bedrock geometry).
- A 2nd fieldwork is being planned to measure TEM on dense 3D grid in PARANAL.
- Multidimensional interpretation of TEM in combination with structural information from seismics.

Acknowledgments

The study was conducted within the collaborative research center CRC 1211 (EARTH - Evolution at the dry limit). We express our appreciation to all those who provided me the support to achieve the objectives purposed. We are very greatful for the Ph.D. funding by Daad/Becas Chile scholarship.

References

[1] Ward, S. H., Hohmann, G. W., & Nabighian, M. N. (1988). Electromagnetic theory for geophysical applications. In Electromagnetic methods in applied geophysics (Vol. 1, No. 3, pp. 131-311).
[2] Nabighian, M. N., & Macnae, J. C. (1991). Time domain electromagnetic prospecting methods. Electromagnetic methods in applied geophysics, 2(part A), 427-509.
[3] **Yogeshwar, P.**, **Tezkan, B.**, & Haroon, A. (2013). Investigation of the Azraq sedimentary basin, Jordan using integrated geoelectrical and electromagnetic techniques. Near Surface Geophysics, 11(4), 381-389.
[4] Ritter, B., Binnie, S. A., Stuart, F. M., **Wennrich, V.**, & Dunai, T. J. (2018). Evidence for multiple Plio-Pleistocene lake episodes in the hyperarid Atacama Desert. Quaternary Geochronology, 44, 1-12.
[5] Dunai, T. J., López, G. A. G., & Juez-Larré, J. (2005). Oligocene–Miocene age of aridity in the Atacama Desert revealed by exposure dating of erosion-sensitive landforms. Geology, 33(4), 321-324.