TEM and MT aquifer study in the Profeta Basin, North Chile

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ABSTRACT

The Atacama Desert represents the driest region on earth and despite the absence of sustainable clean water reserves the demand has increased drastically since 1970 as a result of growing population and expanding mining activities. Few publicly accessible surveys have been conducted and hence an extensive aquifer study was initiated by the Universidad Católica del Norte, Antofagasta. Audiomagnetotelluric (AMT) and Transient Electromagnetic (TEM) measurements were carried out in late 2015 along three profiles in the area of the Profeta Basin, confined by the Cordillera de la Costa in the west and the Precordillera in the east, midway between the cities of Antofagasta and Taltal. This should enable a continuous resistivity image from the surface to at least several hundred meters depth. TEM data was inverted in a 1-D manner, consistently yielding a poor conductive layer near the surface and well conducting structures, suggesting an aquifer, with resistivities between 3 and 10 Ωm and an upper boundary of approximately 30m. At marginal sites of the main profile the resistive basement was found in 150m. These depths are confirmed by interpretation of the AMT soundings. Those were primarily inverted with a 2-D approach. Because clear indications of three-dimensionality exist, we applied the 3-D ModEM inversion code by Egbert, Kelbert and Meqbel. Several modelling runs were performed with different combinations of transfer functions. Generally AMT and TEM results agree reasonably well and an overall image of the resistivity structures in the Profeta Basin could be achieved.

Fig. 1: **The Precordillera in the East of the area under investigation**. Offering an impression of the region and its characteristic features.

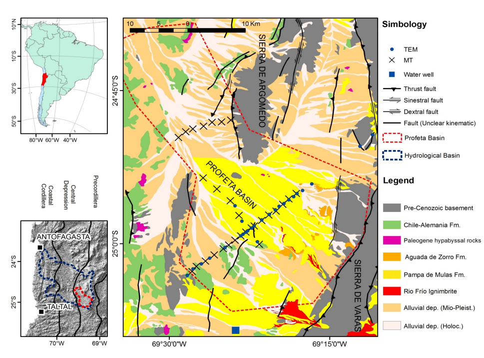

Fig. 2: **Geological map of the Profeta Basin and surroundings in Northern Chile**.

AREA OF STUDY AND GEOLOGICAL SETTING

The Profeta Basin lies within the Central Depression of the Antofagasta region west of the volcanic chain of the High Andes. The uplift of the Andean Orogen accounts for several smaller thrust faults and a mayor strike-slip fault system within the Precordillera area due to extensional forces parallel and shortening perpendicular to the mountain range, and several basins in the forearc region developed within the process. The area is characterized by plutonic and volcanic rocks as well as volcanogenic sediments, continental siliciclastics and marine material. Multiple tectonic deformation processes and reactivations can be assumed, creating an overall highly complex geological structure. The basin is dominated by Quaternary alluvial deposits; volcanic rocks of rhyolithic and dacitic and poorly selected, semi-consolidated gravels and coarse sands of approximately 100 m thickness constitute the remaining share. A detailed map of the area with all major geological formations can be examined in figure 2. The subterranean drainage of water is mainly controlled by the permeability distribution within the boundary layer between basement and topset bed and a structural regulation through faults and tectonic traps can be assumed.

1-D TEM MODELLING

Produced TEM 1-D models all yield reasonably fitting responses and most yield an intermediate, resistive top layer of approximately 100 Ωm associated with a sedimentary topset bed. At depths of 30 m, highly conductive features of 10 Ωm can be found at almost every site. Visualizations in figure 3 only show the late-time apparent resistivity curves as they generate a more easily interpreted graphic image of the data. The displayed 1-D TEM models use light grey colors for conductors and the associated aquifer structures and darker shades for dry sediments and basement. The results quite confidently map the top of the aquifer system under investigation, though only yield a rough image for the lower boundary or the top of the basement, respectively.

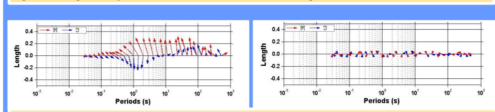

Fig. 5: **Tipper data for exemplary sites.** Some clearly indicate 3-D features. Others are close to zero, have an unnormal appearance and are not to be incorporated.

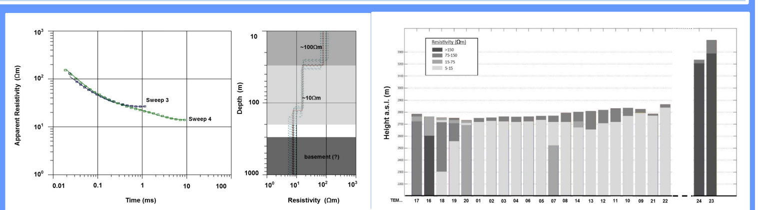

Fig. 3: **Exemplary 1-D result for the TEM data and simplified bar graph model** . Curves represent acquisition runs of different current strengths.

Joint 1-D MT and TEM Examination

Assuming a three-layer case, incorporating an intermediate resistive sedimentary top layer, a highly conductive aquifer and the underlying highly resistive basement, 1-D TEM model parameters were used to calculate the forward response on the basis of the MT data, and vice versa. Model responses agree tolerably well, though 1-D MT results are mapping higher conductivities and therefore response curves are shifted as a result of static distortion.

3-D MT Inversion

As 3-D features are indicated by induction arrows (figure 5), several 3-D inversion runs were performed with different combinations of transfer functions. Ultimately, tipper and main diagonal components were excluded from the inversion. Highly conductive features associated with water-saturated layers can be identified at least until depths of 1.5 km, especially in the supposed center of the basin. The top of the aquifer seems to be imaged already within the first 20 m of depth, which actually agrees with the TEM results.

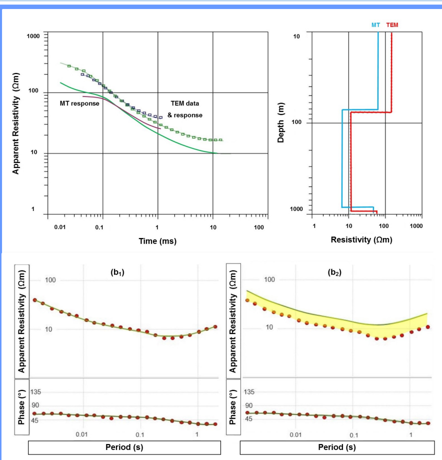

Fig. 6: **Joint examination of 1-D MT and TEM data:** Static shift can be distinctly observed in the MT data.

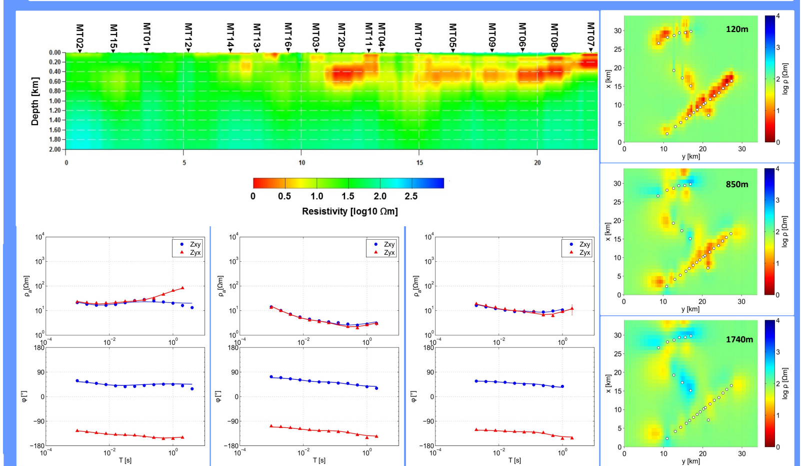

Fig. 1: **Cross-section from the preferred 3-D MT inversion model (employing ModEM), major SW-NE-profile and selected responses**. RMS = 1.497

CONCLUSIONS

Distinct boundaries between topset bed, aquifer and basement can actually not be identified, they ought not to be precisely defined though. As suggested by the geological setting the basement is supposed to consist of sediments which most likely are eroded at the top and are characterized by numerous faults and sediment filled fractures. An unambiguous boundary therefore cannot be expected as the transition from aquifer to surrounding rock is elusive and rather indistinct. To the same degree, a confident top of the aquifer cannot be given. Furthermore the Atacama Desert experienced the heaviest rains for decades in early 2015 which might bias the results as uncertain quantities might have been trapped within shallow layers. Applying Archie's law, resistivities of 1 Ωm can be assumed, indicating highly saline fluids, which can be explained by the multiple salars present in the Andes region.

References

Espinoza, F., Matthews, S., Cornejo, P., Venegas, C., 2011, Carta Catalina, Región de Antofagasta, Servicio de Geología y Minería, Carta Geológica de Chile, Serie Geología Básica No.129: 63p., scale of 1:100.000.

Espinoza, F., Matthews, S., Cornejo, P., 2012, Carta Los Vientos, Región de Antofagasta, Servicio Nacional de Geología y Minería, Carta Geológica de Chile, Serie Geología Básica No. 138: 72 p., scale of 1:100.000.

Fernandez-Mort, A., Riquelme, R., Muñoz, S., Centellas, K., 2015, Cenozoic sedimentary and palaeogeographic evolution of the Quebrada Del Profeta Basin, northern Chile, IX Congreso Geológico de España, Geo-Temas, 16 (2) ISSN 1576-5172.

González, R., Wilke, G.-H., Menzies, A. H., Riquelme, R., Herrera, C., Matthews, S., Espinoza, F., Cornejo, P., 2015, Carta Sierra de Varas, Región de Antofagasta, Servicio Nacional de Geología y Minería, Carta Geológica de Chile, Serie Geología Básica, scale of 1:100.000.

McElderry, S., Chong Diaz, G., Prior, D. J., Flint, S. S., 1996, Structural Styles in the Domeyko Range, Northern Chile, Third International Symposium on Andean Geodynamics (ISAG), St Malo, France, pp. 439-442.

Venegas, C., Cervetto, M., Astudillo, N., Espinoza, F., Cornejo, P., Mpodozis, C., Rivera, O., 2013, Carta Sierra Vaquillas Altas, Regiones de Antofagasta y Atacama, Servicio Nacional de Geología y Minería, Carta Geológica de Chile, Serie Geología Básica 159., scale of 1:100.000.

Acknowledgements

We thank G. Egbert, A. Kelbert, N. Meqbel for their 3-D codes.