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Joint TEM and MT aquifer study in the Atacama Desert, North Chile

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ABSTRACT

The Atacama Desert represents one of the driest regions 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. Magnetotelluric (MT) and Transient Electromagnetic (TEM) measurements were carried out for groundwater exploration in late 2015 in the area of the Profeta Basin at the western margin of the Chilean Precordillera. Both methods complement each other: While MT in general attains larger penetration depths, TEM allows better resolution of near surface layers; furthermore TEM is free from galvanic distortion. Data were collected along three profiles, enabling a continuous resistivity image from the surface to at least several hundred meters depth. TEM data were inverted in a 1-D manner, consistently yielding a poorly conductive near-surface layer with a thickness of approximately 30 m and below a well-conducting layer which we interpret as the aquifer with resistivities around 10 Ωm. At marginal sites of the main SW-NE-profile the resistive basement was found in 150 m. These depths are confirmed by interpretation of the MT soundings. Those were firstly inverted with a 2-D approach and then by 3-D inversion as clear indications of three-dimensionality exist. Several modeling runs were performed with different combinations of transfer functions and smoothing parameters. Generally, MT and TEM results agree reasonably well and an overall image of the resistivity structures in the Profeta Basin could be achieved. The aquifer reaches depths of more than 500 m in parts and, by applying Archie's law, resistivities of 1 Ωm can be assumed, indicating highly saline fluids from the source region of the surrounding high Andes under persisting arid conditions.

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1. Introduction

The Atacama Desert of Chile and Peru represents one of the driest regions on earth and therefore water resource management and exploration represent crucial factors regarding a sustainable economy. According to the UN-Water Country Brief Chile (2013), withdrawal from the industry has tripled since 1975 and to this day governmental expenditures for the development of water supply, sanitation as well as hydroelectric power generation have constantly increased. Especially the area around the city of Antofagasta shows increasing demand as a result of growing population and expanding mining activities. Only few publicly accessible water resource exploration surveys have been conducted and hence an extensive aquifer study was initiated by the Universidad Católica del Norte, Antofagasta in collaboration with the Universidad de Chile, Santiago and the Freie Universität Berlin, funded by the CONICYT Educational Research Center. Various groups involved shall acquire inter alia data from geophysical, hydrogeological and geochemical studies.

MT and TEM measurements were carried out in the context of groundwater exploration in September and October 2015 in the area of the Profeta Basin in the Atacama Desert, North Chile (see Fig. 1). The study area is located midway between the cities of Antofagasta and Taltal at roughly 24.9°S, 69.5°W and at an altitude of about 2400 to 2800 m at the margin of the Chilean Precordillera. In March 2015, the area was affected by untypical heavy rain.

The name "Profeta Basin" (or Profeta-La Ternera Basin) had been used to describe the Late Triassic-Jurassic backarc basin and its marine sedimentary deposits by Chong (1977), Chong and von Hillebrandt (1985) and citations therein; in recent times, authors have used the name "Quebrada del Profeta Basin (Ravine of Profeta Basin)" when discussing the Cenozoic, continental sedimentary, intramontane basin (Fernández-Mort et al., 2015) that is described

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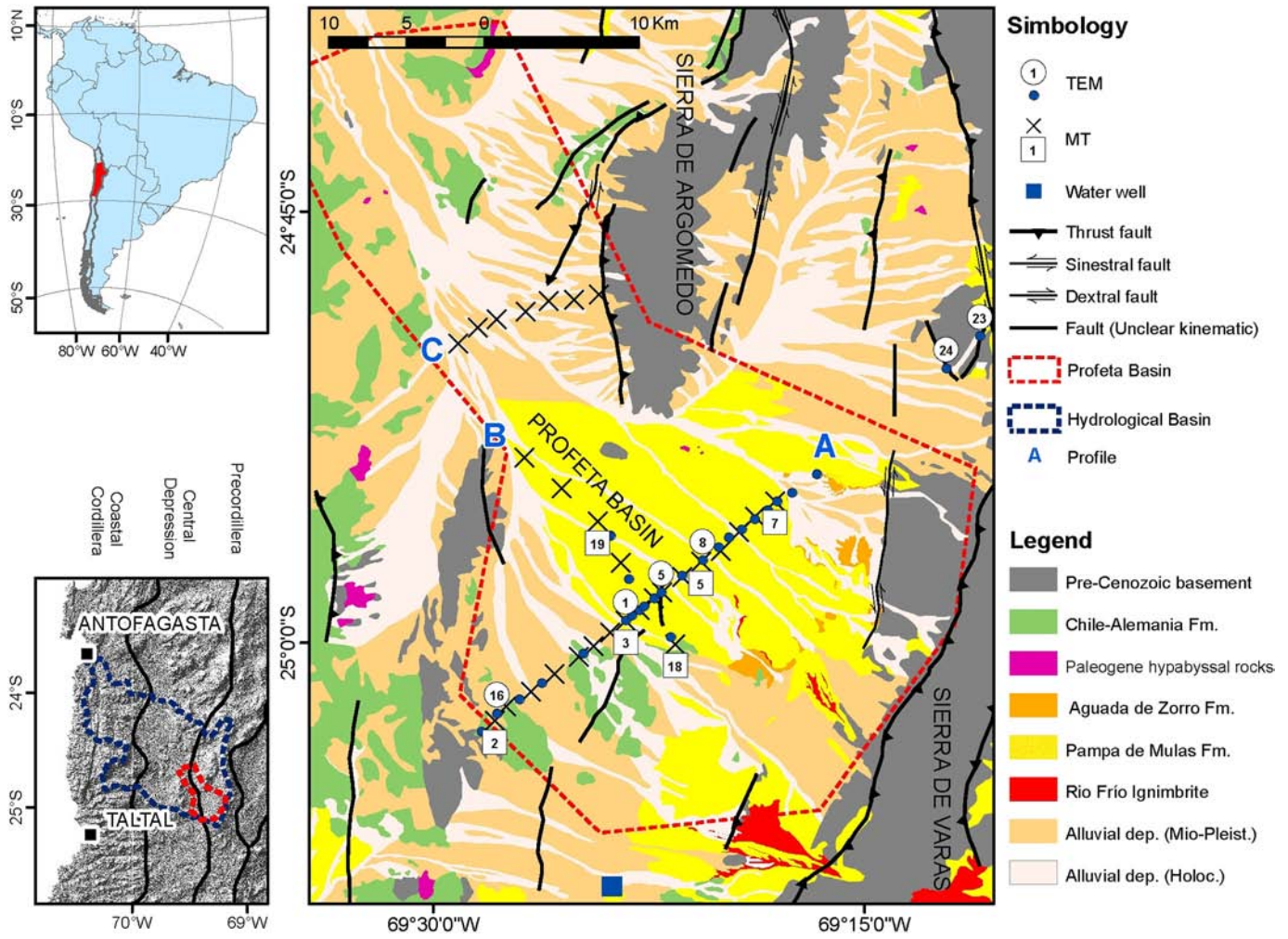

Fig. 1. Location map. Upper left: The study area at the South American margin. Lower left: Major morphostructural elements in the North of Chile with nearby cities. Right: Geological map of the Profeta Basin, including locations of the MT-TEM sites and a water well in the south of the basin (modified from Espinoza et al., 2011; Espinoza et al., 2012; Venegas et al., 2013; González et al., 2015).

in this present work. Because the Triassic-Jurassic strata are beyond the scope of this work, in this context "Profeta Basin" will also refer to the Cenozoic basin.

2. Geological setting

2.1. Tectonic context

In the Andean orogen one may differentiate morphostructural units orientated parallel to the strike of the range. The continuity of these units is interrupted in regions where oceanic ridges intersect the continental margin and corresponds to flat-slab subduction zones, causing segmentation of the orogen and the absence of the Central Depression, a morphological unit that separates the Coastal Cordillera from Main Cordillera. In the regions outside of the flat-slab segments, the Wadati-Benioff zone is steeper, as in the segment between 18° and 27°S (Charrier et al., 2007). The influence of the uplifting of the Andean orogen manifests in the forearc by the existence of major strike-slip fault systems parallel to the orogen in the Precordillera zone, with shortening normal to the orogen (Reutter et al., 1991) and with the development of several sedimentary basins, mostly continental, distributed through the major morphostructural units of the forearc in the north of Chile. The Domeyko Fault System (DFS) is located in the Precordillera and presents structures that evidence a complex history with several deformation events which have influenced the evolution of the Profeta Basin. The major uplifting of the Precordillera occurred during the Incaic Phase of the Andean Cycle, between 50 and 30 Ma (Charrier et al., 2007), when the transpressional geometry for the area was also developed; after this tectonic event at least two reactivations have been recognized (González et al., 2015).

2.2. Stratigraphy

The basement of the basin is formed by rocks of Carboniferous to Eocene age, including pyroclastic, volcanic, siliciclastic and plutonic rocks. The most recent rocks of the basement correspond to the Chile-Alemania Formation, consisting of volcanic and pyroclastic rocks of rhyolitic and dacitic composition (Paleocene to Early Eocene, 65–48 Ma), and small outcrops of hypabyssal rocks of andesitic composition (58 Ma) (González et al., 2015).

The sedimentary filling of the basin corresponds to Aguada de Zorro Formation, Pampa de Mulas Formation, Río Frío Ignimbrite and alluvial deposits. Aguada de Zorro Fm. (Eocene to Oligocene) is composed of partially to totally cemented gravels and conglomerates, and represents a fluvio-lacustrine system, with its source in the west and with more lacustrine facies on the eastern limit of its outcrops (Fernández-Mort et al., 2015). A minimum thickness of

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