CONTRIBUTION OF TIME-DOMAIN ELECTROMAGNETICS (TDEM) TO THE KNOWLEDGE OF LAKE TITICACA AQUIFER SYSTEMS, BOLIVIA

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ABSTRACT
The increasing demand for water in Bolivia implies a better knowledge of the resources. The aim of this study is to provide the first insight of hydrogeological functioning of a major aquifer between La Paz-El Alto cities and Lake Titicaca. A total of 171 TDEM geophysical soundings, hydrogeological and hydro-geochemical measurements were acquired, and correlated with geological, borehole lithology and topographic information. The results allowed identifying two multilayered aquifer systems (Piedmont and Lacustrine) and the geometry of the different geological layers. The TDEM method proved to be an appropriate method since the results showed a consistent picture of the hydrogeological functioning of the Katari and Lago Menor Aquifer systems.

RÉSUMÉ
La demande accrue en eau de surface et souterraine en Bolivie implique une meilleure connaissance des ressources. Le but de cette étude est de donner les premières indications sur le fonctionnement des aquifères entre les villes de La-El Alto et le lac Titicaca. 171 sondages géophysiques TDEM et des mesures hydrogeologiques et hydrochimiques ont été mis en œuvre et corrélés avec des informations géologiques (logs de forage) et topographiques. Les résultats permettent d'identifier deux systèmes aquifères majeurs (de piedmont et lacustre) et les géométries des différents compartiments hydrogéologiques. La méthode TDEM s'est révélée appropriée à contruire une image cohérente du fonctionnement des systèmes aquifères Katari et Lago Menor.

Key words*: Time-Domain Electromagnetism, groundwater resources, Lake Titicaca, Bolivia*

1. INTRODUCTION

The increasing demand for water in Bolivia implies a better knowledge of the resources. Lake Titicaca region faces with rapid growth of the population (El Alto city) and agriculture demand. The Lake itself has experienced severe eutrophication problems in the past ten years mainly from surface water contaminated by urban and industrial discharges (Archundia et al., 2017). However, there is no information about groundwater resources, the functioning of the aquifer systems and the role of groundwater in the nutrient balance of the Lake. This study aims at giving a first insight of the aquifer systems functioning by means of the combination of geophysical, geological, hydrogeological and hydrogeochemical data.

2. MATERIALS AND METHODS

A total of 171 Time Domain Electromagnetic (TDEM) 100x100m coincident loop soundings were performed along 7 profiles with TEMFAST 48 equipment (AEMR technology), in correlation with water levels and hydrogeochemical measurements from 95 wells, as shown in Fig. 1. Results were correlated with geological, hydrogeological, hydrogeochemical and topographic information.

3. RESULTS AND DISCUSSION

Figure 2 illustrates NE-SW profile 1 derived from TDEM soundings, showing quaternary deposits lying above mainly tertiary rocks (Fig.1). The quaternary deposits were related as Piedmont and Lacustrine aquifer systems (Lavenu 1991; Argollo et al., 2008). The Piedmont aquifer system, evidenced by TDEM at the NE of the profile, is as follows: In the upper Piedmont, deposits correspond to, from top to deeper formations: 1) Glacial (Qg) sediments, mostly tills-morains with resistivity values ~100-250Ω·m and thickness of 60-150m, 2) glacial and fluvio-glacial sediments with resistivity values 40-120Ω·m and a thickness of 60-150m. In the lower Piedmont, layer 1 shows an alluvial fan deposit with resistivity values ~200Ω·m and a thickness of 40-75m,made of gravels, sands and clay. Below, layer 2 shows gravel intercalations in a clayey matrix with resistivity values of ~30 Ω·m and a thickness ~130m. The geophysical interpretation of this aquifer system is confirmed by hydrogeochemical data: Groundwater with Ca(Mg)-HCO_3 facies (EC~100 µS/cm) occur in the Alluvial fan deposits while facies of Na(K)-HCO_3 (EC~200-400µS/cm) are found in fluvioglacial outwash sediments. The Lacustrine aquifer system is as follows: at the SW in the flat part of the profile, from top to deeper formations, TDEM evidences 1) terrace deposits (Qt) with resistivity values (40-60Ω·m) and a thickness up to 100m. At the extreme SW clayey and silty layers with resistivity values ~15 Ω·m and a thickness of 2-20m are attributed to the Ulloma formation (Qull), 2) Below, layers may correspond to the ancient Lake deposits of "Cabana and Mataro" units (Qcb-mt) composed of sands and clays with resistivity values ~30 Ω·m and a thickness of 40-100m. In the Lacustrine aquifer System regional groundwater flow direction is towards the NW and groundwater exhibits Na(K)-Cl facies (EC~600-1700 µS/cm) (Fig.2). Both Plio-quaternary Piedmont and Lacustrine aquifers lie above tertiary or Paleozoic rocks considered as the basement of shallow aquifers.

4. CONCLUSIONS

TDEM method proved to be a suitable investigation method in the field area: 1) the existence of two different hydrogeological systems and their limits are evidenced (Lacustrine and Piedmont), 2) the geometry of the different quaternary deposits are delineated and 3) the depth to the top of tertiary substratum representing the bottom of the aquifers is also delineated. Hydrogeological and hydrogeochemical information confirmed the existence of two aquifer systems. Based on this new information, a hydrogeological model will be built to help resources management.

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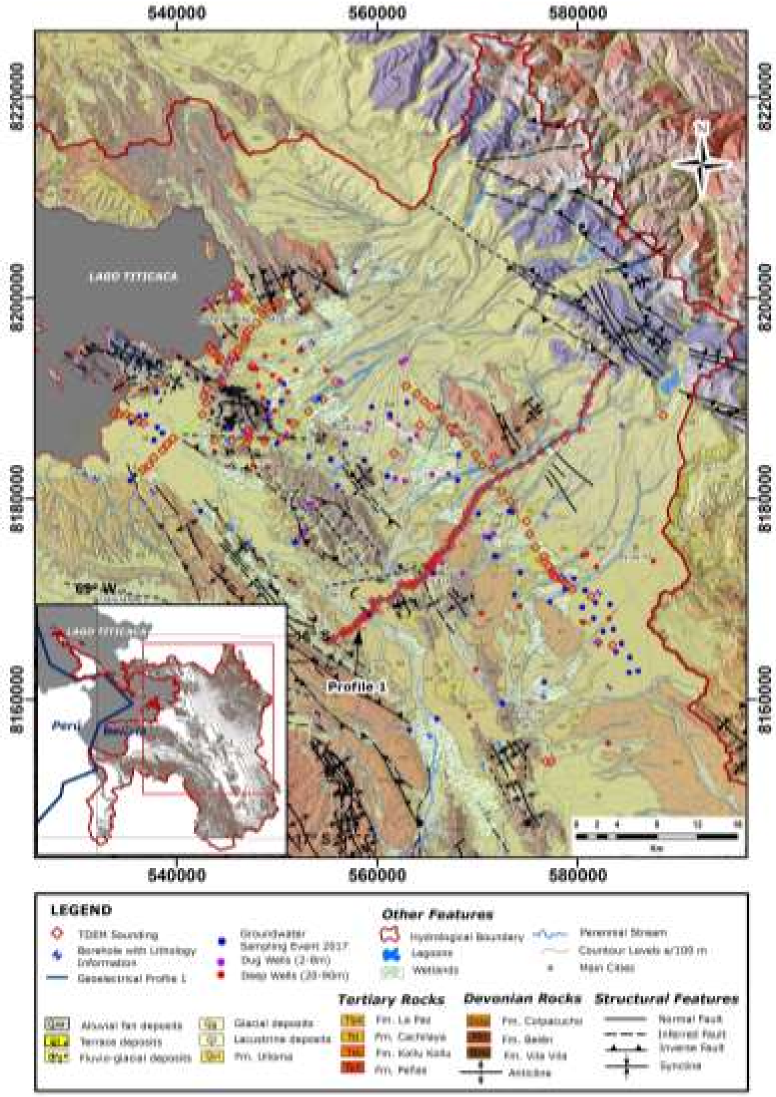

Figure 1. (Bottom) Location of the study area showing the Katari and Lago Menor basin (SE of Lake Titicaca). (Top) Geological and Structural map of the basin, showing TDEM soundings, observation wells for hydrogeological and hydrogeochemical measurements and available information of borehole lithology.

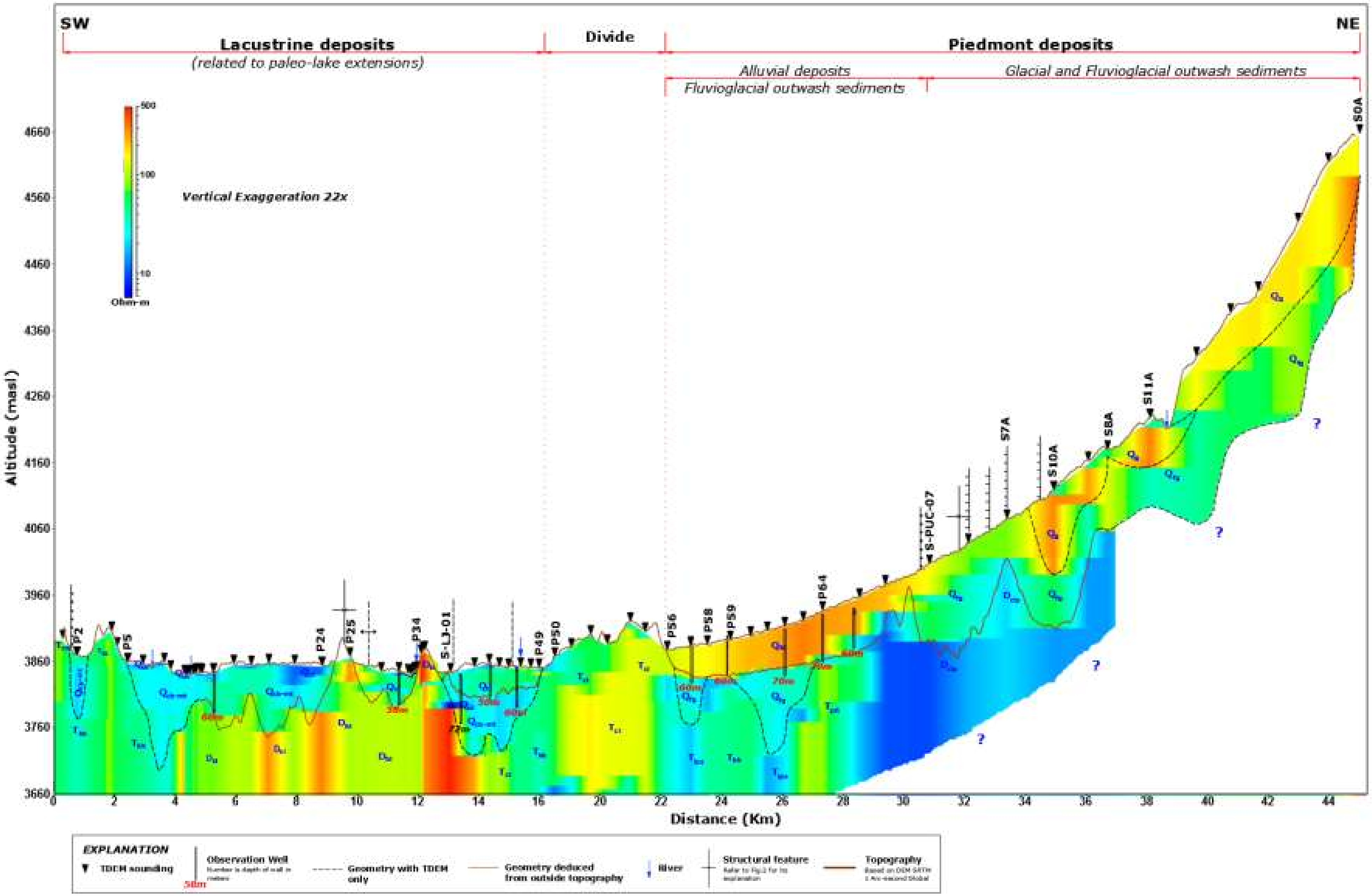

Figure 2. Geoelectrical Profile 1 derived from TDEM soundings and overlaid by the geological formations found in the area (Fig.1). The available boreholes and topography were used for the evaluation and confirmation of the resulted resistivity profiles.