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Resistivity and borehole data interpretation for characterizing the hydrogeology of Western Managua, Nicaragua

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INTRODUCTION

The present study took place in the western part of Managua Graben (Girard et al 2004). Several investigations have described the geological history of this graben with a complex development where different processes were involved (McBirney and Williams, 1965). The result reveals formations of volcanic origin that mainly consists of pyroclastic materials. Freundt et al (2006), Pardo et al. (2008) and Avellán (2009) describe the deposits from the stratrigraphical point of view and at the same time introducing tephra term in Managua geological setting. Tephra and tuff have to be consider as important terms for hydrogeological purposes since tephra is defined as no consolidated pyroclastic deposits (Shane, 2000). On the other hand, tuffs are consolidated pyroclastic or volcanic rocks. Based on the grain size; tuff is also the consolidated equivalent of ash (Fisher et al., 2006).

In such geological studies were also proposed several tephra and tuff successions which are mainly composed by fall and surge deposits. The fall deposits are mainly constituted by pumice and scoria materials and surge deposits by ash and lapilli. In the study area, coarse to medium lapilli and ash sizes are expected for most of the surge and fall deposits (Avellán, 2009). Fall deposits can be used as marked beds for calibrating key lithostratigraphic sections (Németh and Martin, 2007). Therefore, an interpolated stratigraphical section can be established for the borehole data in order to characterise the hydrogeological properties of the study area.

The electrical measurements were performed and analyzed for an area known as Cuajachillo, an area of special interest because it has experienced water supply problems due to a rapid housing development since 2006 (Fig. 1). In order to obtain information about the geological geometry of the area, an analysis of the resistivity values and the lithological information from boreholes was carried out. To achieve the goal, borehole data was interpreted and unified based on the stratigraphical layout of the area and then correlated with electrical profiles.

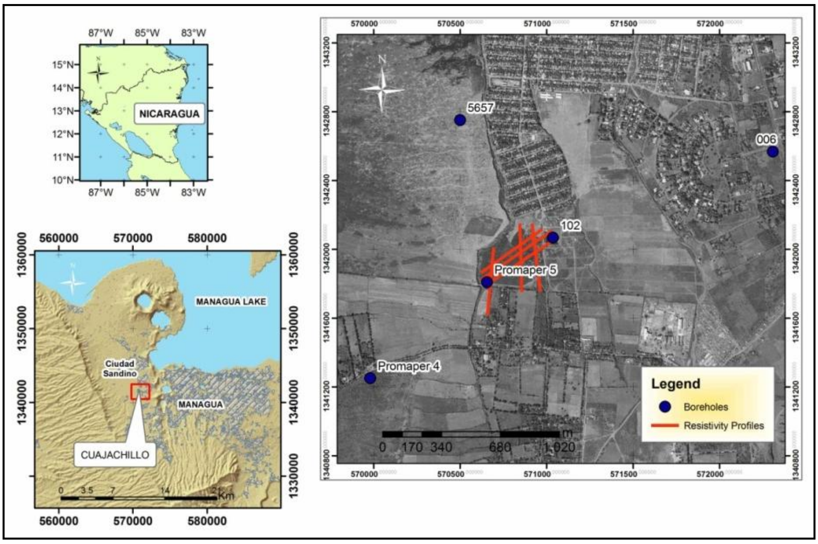

Figure 1. Location Map (1a). Orthophoto map of the Managua area (# 2952-303, right side) showing the electrical profiles and boreholes (1b).

METHODS

Resistivity measurements

A multi-electrode system called ABEM Lund Imaging System was used for resistivity data collection. The system consists of a standard resistivity meter (ABEM Terrameter SAS 4000), an electrode selector switching unit (ES10-64), and five electrode cables, each with 21 take-outs, steel electrodes and various connectors. In the field survey, four electrode cables are laid out and the electrodes are connected directly to them. The electrode cables are linked to the switching unit which is connected to the Terrameter (Dahlin and Zhou 2006). Two-dimensional electrical surveying was carried out along six profiles (CVES 1-6). Profiles CVES 4, 5 and 6 intersected profiles 1, 2 and 3; the space between the profiles was about 30 m. The length of profiles 1, 2, 4, 5 and 6 was 400m and profile 3 was 500 meters long. Three profiles (1, 2, and 3) were measured in the SW-NE direction and the other three in an N-S orientation (Fig 1b.). The field measurements produced apparent resistivities that were converted into true resistivities. The apparent resistivity values were processed and inverted with Res2dinv software using the least-square method (Loke 1997-1999).

Lithological analysis

The lithological interpretation was carried out in order to correlate and integrate the borehole data with the stratigraphic information. The borehole data was provided by ENACAL (Empresa Nicaragüense de Acueductos y Alcantarillados), INETER (Instituto Nicaragüense de Estudios Territoriales) as well as drilling companies: McGregor, and PROMAPER (Proyecto Integrado de Managua Periferia). All the data was interpreted according to the pyroclastic deposits present in the Managua city and its vicinity. To describe and define volcanic deposits, several parameters were also taken into account such as the grain size characteristic of the deposit unit, the grain shape description, borehole location according to volcanic source and lithological composition (Németh and Martin, 2007). The borehole interpretation also provides important data about the aquifer depth, groundwater properties and saturated thickness.

RESULTS

A 3D fence is presented in a diagram (Fig. 2) for the six profiles with the robust inversion (V/H 1.00). In general, the six images illustrate the existence of three different layers with medium to high resistivities. This figure also illustrates a low and a high zone in a good agreement. Overall, three different values of resistivity can be observed in profiles in CVES's 1, 2 and 3. There is low resistivity in the top layer; the bottom layer has medium resistivity. In the second layer of CVES 2, a small discontinuity is observed; in CVES 3 the layer is well defined.

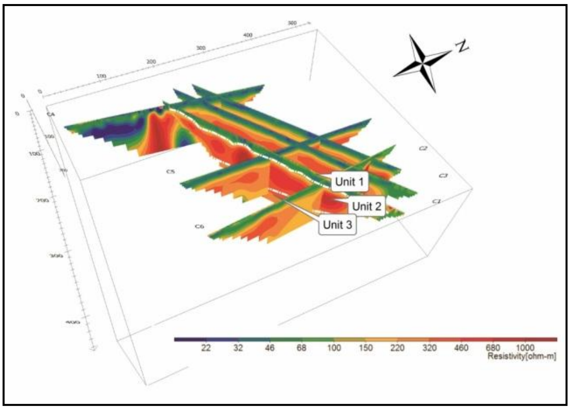

Figure 2. 3D fence diagram. Least squares inversion results (V/H: 1.00) of the electrical profiles.

In this study we emphasize the illustrations corresponding to CVES 3 since the availability of extensive lithology data from boreholes makes possible a highly reliable analysis of the inversion data. According to the Managua stratigraphy, the deposits belong to Chiltepe Tephra (CT), Masaya Tuff (MT), Masaya Triple Layer (MTL) and Satélite Tephra (ST), which are mainly composed of pyroclastic surges and fall deposits) (Fig. 3). The lithological information was added to the CVES 3 inversion results in order to establish the geoelectrical layers. Finally, three distinct resistivity layers were observed in this profile with values from 60 ohm m to 320 ohm m; these layers were correlated with geological units described in the borehole data (Fig. 3).

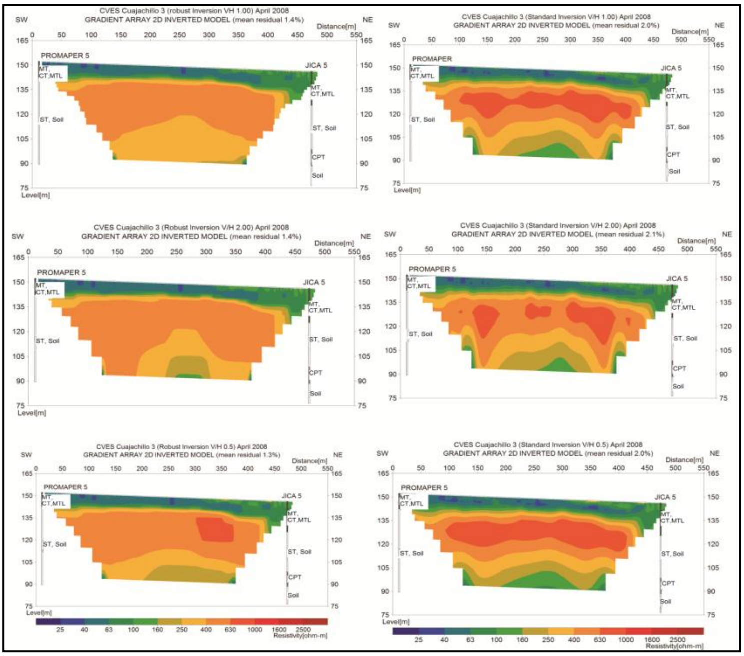

Figure 3. CVES 3 with different inversion results (V/H: 0.5, 1 and 2). Borehole data is also shown in the figure (Promaper 5 and JICA 5).

In the profile 3, the resistivity values of the top and bottom parts of the image indicate a relationship between fine materials and low resistivity values. The values are around 60 ohm m. The values are interpreted as materials with fine to coarse grain size, which in volcanic terminology would be defined as fine ash and lapilli. The medium layer has high resistivity values, from 150 ohm m to 320 ohm m, related to coarse lapilli. Based on the lithological information, the bottom and top layers have fine sediments. In addition, the high resistivity values are related to coarse materials. The lithological interpretation of the borehole data and the outcrops investigated show that the Cuajachillo aquifer was formed by pyroclastic deposits. The materials mainly come from the Cuesta El Plomo Tuff (CPT) and Las Sierras Ignimbrites (BAI) with very high porosity. Groundwater is around 40 m and the water saturated zone is approximately 70 m.

DISCUSSION

The resistivity profiles revealed unique layers in the vadose zone of Cuajachillo aquifer. In addition, a good correlation was obtained between the resistivity values and the lithological borehole information. As a consequence, it was possible to make a detail correlation between the grain size of volcanic deposits and resistivities values. High resistivity in all profiles constantly indicated coarse grain size pointing out good permeable layer and the characterization of the Cuajachillo aquifer as unconfined. Finally, an interpolated stratigraphy section for the borehole data was established showing one main aquifer system (Fig. 4).

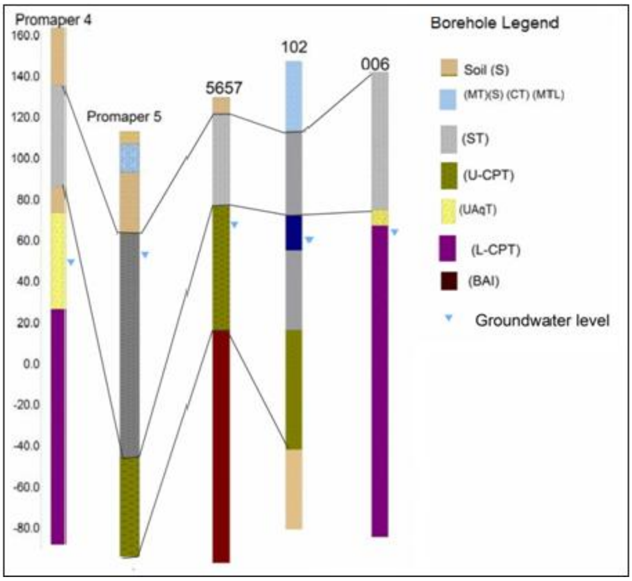

Figure 4. Borehole interpolated stratigraphy section.

In order to improve the information about the aquifer in the area, a detailed lithological borehole interpretation was performed using volcanic deposits classifications. According to these lithological results, the surge pyroclastic deposits called Cuesta El Plomo Tephra were found to have the best aquifer properties. Such volcanic deposits have a high infiltration capacity since most of them are mainly unconsolidated pyroclastic deposits.

The resistivity values obtained in this survey show similar results with previous electrical data. The Japanese International Cooperation Agency (JICA) performed vertical soundings in two boreholes near the study area in 1993. This data can be correlated with the resistivity data produced in this investigation. In addition, resistivity values below 50 meters of depth can be assumed. According to JICA measurements, resistivity values for the materials range from 10 to 700 ohm m. Another correlation is revealed when comparing the JICA measurements and the borehole data. The values from 50 to 130 m depth show low resistivity with 130 ohm m. These values are probably related to Upper Cuesta El Plomo Tephra (U-CPT) with interbedded volcanic soils. The low resistivity can be associated with the fine grain size of these deposits and the existence of a water saturated zone. Below this unit (130 m), a layer with 40m thickness and very low resistivity is also present. The values of this layer are about 24 ohm and could associate with Las Sierras Ignimbrites (BAI) and Lower Cuesta El Plomo Tephra (L-CPT) deposits. These deposits correspond to welded ignimbrites and surge pyroclastic deposits with ash and lapilli grain size (Fig. 5).

Our data			Electrical prospecting (JICA, 1993)					
CVES 3			S-8			S-11		
Layers	Depth (m)	Values (ohm)	Layers	Depth (m)	Values (ohm)	Layers	Depth (m)	Values (ohm)
1	0-15	60	1	0-5	88	1	0-6	82
2	15-35	600	2	5-26	108	2	6-42	410
3	35-50	150-320	3	26-41	700	3	42-130	137
			4	41-130	408	4	130- 450	24
			5	130-170	3	5	450-750	456

Figure 5. Comparison between JICA and electrical profiles.

CONCLUSIONS

The resistivity results, from data obtained in this survey and from the JICA data, indicate the presence of four resistivity layers. The top and bottom layers (1 and 4) have low values and the medium layers (2, 3) have high and medium values, respectively. In the study a well delimited vadose zone has been revealed with three main resistivity layers. JICA data and borehole data was evaluated in order to identify the electrical properties of the aquifer. According to the analysis of the lithological borehole logs and the electrical data, all the layers are interpreted as pyroclastic materials belonging to different tephra deposits of the Managua area. One main aquifer unit has been defined as belonging to Cuesta El Plomo Tephra. The variation in the resistivity can be associated to the differences in volcanic deposits and its properties such as grain size, consolidation and lithological composition.

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