

Hydrogeological investigation in Santiago Island (Cabo Verde) using magnetotellurics and VLF methods

Fernando A. Monteiro Santos^{a,b,*}, Eugénio P. Almeida^{b,c},
Mota Gomes^d, António Pina^d

^a Universidade de Lisboa, Faculdade de Ciências, Campo Grande, Lisboa, Portugal

^b Centro de Geofísica da Universidade de Lisboa and Laboratório Infante Dom Luiz, Campo Grande, Ed. C8, 1749-016 Lisboa, Portugal

^c Instituto Politécnico de Tomar, Tomar, Portugal

^d Instituto Superior de Educação, Praia, Cape Verde

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Abstract

A geoelectromagnetic research was carried out in the Santa Cruz region (Santiago Island, Cabo Verde) during June 2004. The survey comprised MT soundings and VLF profiles. The main purpose of the MT profile, carried out across three important valleys associated with freshwater aquifers, was to study the tectonic structures correlated to seawater infiltration. The VLF method was used inside of the valleys for investigating shallow structures related to the aquifer contamination by seawater.

Numerical modelling shows that the ocean effect is not important for MT data collected at periods shorter than 1 s. The MT data were inverted using a two-dimensional approach, to obtain the sub-superficial electrical conductivity distribution. The VLF data were processed applying the Karous–Hjelt filters to obtain the equivalent current distribution and inverted using 2-D approach. The results obtained in one of the most important valleys show anomalous current concentration/low resistivity ($<20 \Omega \text{ m}$) areas at depths greater than 40 m that may correspond to an increase in seawater content.

The MT data modelling show that the deep zones beneath the valley are strongly fractured representing good pathways for seawater circulation. The depth of the conductive zones increases from south to north, suggesting a northward decreasing of the seawater infiltration effect. This observation correlates very well with in situ geochemical observations.

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1. Introduction

Santiago Island is characterized by scarce hydrologic resources due to the low and irregular precipitation indexes (321 mm/year in the highest mountains and about 169.5 mm/year at low levels). This fact is responsible for

quasi-periodic and sometimes catastrophic dryness. The region is also characterized by high values of potential evapotranspiration. The small amount of superficial water combined with irregular precipitation explains the strong dependence of the population on subterranean water. However, these resources are very limited given the nature of volcanic rocks. The water content of these kind of rocks is strongly dependent of the interconnected fracturation (which is in general discontinuous and restricted to some preferential areas). Moreover, at some places in the islands, fresh water aquifers are in a delicate balance with seawater express by the movement of the fresh–seawater interface. The on land water exploitation should be made together

* Corresponding author. Address: Centro de Geofísica da, Universidade de Lisboa and Laboratório Infante Dom Luiz, Campo Grande, Ed. C8, 1749-016 Lisboa, Portugal. Tel.: +351 217 500 811; fax: +351 217 500 977.

E-mail addresses: fasantos@fc.ul.pt (F.A. Monteiro Santos), epalmeida@ipt.pt (E.P. Almeida).

with a careful monitoring of that interface (the so called sea water intrusion) in order to avoid pumping saltwater. The importance of such knowledge is evident considering that most part of the population lives in coastal areas.

Geophysical measurements in Santiago Island have been carried out using resistivity and VLF-R surveys by Lund University (Dahlin et al., 1986) in the scope of a bilateral project between Lund University of Science and Technology (Sweden) and the Instituto Nacional de Investigação Tecnológica de Cabo Verde. The main objectives of those works were to investigate the applicability of the resistivity and VLF-R methods, as well as, to compare the results from both methods. More recently, the transient electromagnetic method was used by Descloitres et al. (2000) around the Fogo volcano (Fogo Island) to detect low resistivity structures related to groundwater.

This paper presents the results of an electromagnetic hydrogeological oriented research performed in Santa Cruz area (NE Santiago Island), using MT and VLF methods. The main purpose of the MT profile, carried out across three important valleys associated with fresh water aquifers, was to investigate the tectonic structures correlated to seawater infiltration. The VLF method was used inside the valleys in order to investigate shallow structures.

2. Geological and hydrogeological setting

The work conducted by Serralheiro (1974) allowed the establishment of the Vulcano-Stratigraphic Sequence of Santiago Island and it has been used as the basic support for hydrogeological and hydrologic resource research. Important contributions for the understanding of the Vulcano-Stratigraphic sequence in Santiago Island can also be found in Matos Alves et al. (1979). A simplified geological map of the Santa Cruz area is presented in Fig. 1.

The main geological units in Santa Cruz region with hydrogeological interest are the following: (1) the Eruptive Complex of Pico de Antónia (PA), (2) the Monte das Vacas formation (MV) and (3) the recent sedimentary Quaternary formations (a).

The most important reservoir of fresh water is the PA formation, which presents both under terrestrial and submarine facies (pillow-lavas). The storage coefficient of the PA formation is relatively high. Its permeability avoids a rapid emptying of the water supply and it still has a high feeding rate. This geological unit covers a more impermeable formation known as Basic unit composed of the Ancient Internal Eruptive Complex (AIEC). The Flamengo formation and the Conglomeratic-Brechoide formation, two components of the AIEC are characterized by having a levelling alteration practically generalised, a high rate of compactness and low permeability.

The drillings made by the Instituto Nacional de Gestão de Recursos Hídricos (INGRH) in the “pillow-lavas” and its respective pumping tests revealed a relatively high productivity, circa 40 m³/h, having produced hollows of only 0.02–0.5 m and which stabilization has been reached during

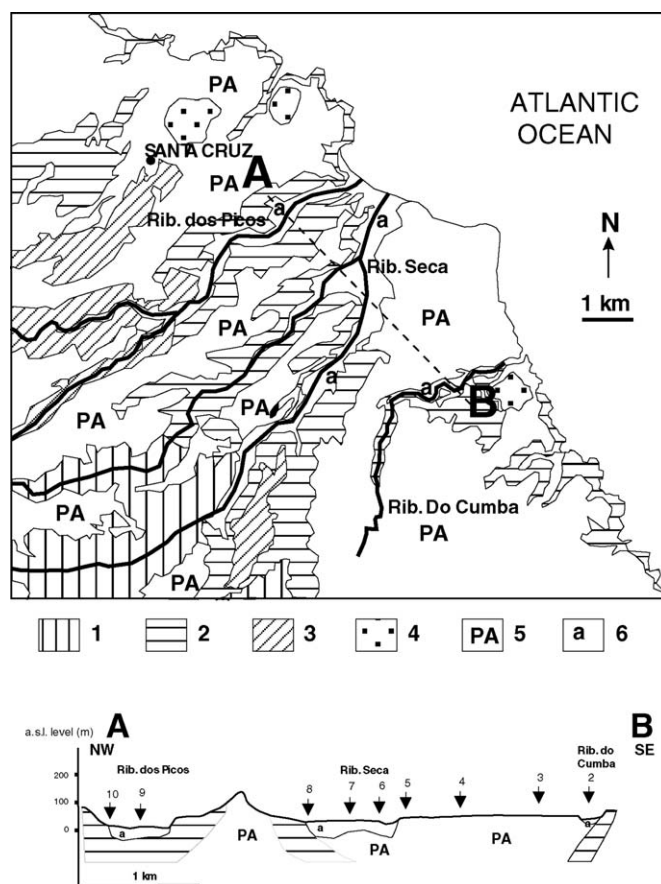


Fig. 1. Geological map of the survey area in the Santiago Island (upper) and geological cross-section along the MT profile (bottom). 1 – Conglomeratic Brechoide; 2 – Pillow-lavas; 3 – Flamengo Formation; 4 – Monte das Vacas Formation (MV); 5 – Pico da Antónia Formation (PA); 6 – Quaternary Formations (a). The solid lines represent the path of the main creeks in the area.

the first minutes. The “pillow-lavas” constitute, with their fissures and hollows, the formation with highest productivity.

The MV formation is composed by pyroclastic material cones and associated leakage with a high degree of permeability and porosity. It is located in the peaks, with high pluviometry rate and due to its permeability, the infiltration is favoured; though because of its characteristics it does not permit the retaining of infiltrated water, and the water is rapidly drained to lower levels, reaching the AIEC.

Concerning the water quality, it can be stated that waters from different geologic formations are characterized by having a more and more accentuated mineralization, depending on the age of these formations. Therefore, the measurement of the electric conductivity and the chemical analyses provide safe indications on the water quality and therefore the indication of the hydrogeological unit (Pina et al., 2005). The water samples collect at high mountains inside of the island are of the type Na–HCO₃ revealing the influence of the marine aerosol in the more recent waters. The water samples collect near the coast line shows a Mg–Cl and Na–Cl composition. The presence of Na–Cl

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