Airborne Hydrogeophysics: how to use data originally surveyed for ore prospection

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Abstract

This work presents the lessons learned about the characterization of geophysical features that plays a role in groundwater occurrence in crystalline rocks at a semi-arid region of Brazil.

Introduction

The history of airborne geophysical exploration began in 1944 when the US Geological Survey used a Magnetic Airborne Detector developed by U.S. Navy to detect submarines and, to fly the first magnetic survey over a petroleum reserve in Alaska (Hildebrand *et al.*, 1997). Subsequent discoveries of massive sulfide deposits in Canada, during 1950´s and 1960´s decades catalyzed airborne surveys for mineral exploration.

The use of airborne geophysical surveys in hydrological applications date from the 1980`s, as found in citations in Becker *et al.* (1987). Such data have been used to map geologic features that identify probable water bearing structures and lithologies in the sedimentary domain (Sattel and Kgotlhand, 2003; Paine and Minty, 2005), and support water quality and salinity management studies, as found in Coppa *et al.* (1998); Meng *et al.* (2006).

Utilizations of such surveys for hydrologic research in crystalline domain are not so common. Studies were done for evaluation of nuclear disposal sites (Rhén *et al*., 2007); mapping of bedrock and fractured zones underneath sedimentary rock (Pedersen *et al.* 2007), dykes networks covered by alluvium facies or regolith mantle (Debeglia *et al.*, 2005), either for evaluating the influence of mineralized and non mineralized structures regarding groundwater flow in volcanic terrane (McCafferty and McDougal, 2008).

Hydrogeophysics has developed in recent years to investigate the potential that geophysical methods hold for providing quantitative information about subsurface hydrogeological parameters and processes (Hubbard and Rubin, 2005). In its turn, this information can be used to build groundwater flow and occurrence models as examples.

In Brazil, airborne magnetic and radiometric surveys have been flown since mid 1950`s under national directives as prospect tools for uranium, oil, gas and metallic ore. Until 2000's, none airborne geophysical surveys have focused on groundwater research. One reason is that the ground electromagnetic induction and direct current resistivity methods have lower costs to survey in isolated small villages; therefore, they have traditionally been the choice during government drilling programs for water supply.

Therefore, few Brazilian authors investigated the advantages of airborne geophysical surveys for hydrogeological application. Silva (2005) processed a time-domain electromagnetic airborne survey, together with magnetic and radiometric data to map groundwater occurrence and salinity distribution in Bahia State. Mandrucci *et al.* (2008) integrated airborne magnetic, remote sensing and geomorphologic data in a multi-variate statistical approach to map favorable areas (in a regional-scale) in São Paulo State.

The investigated Problem

Because the groundwater is slightly saline, the general assumption is that the fractures in crystalline "resistive" rocks are thought to behave as conductors when induced by an electromagnetic field. Another premise is that maps of oriented magnetic gradients may correspond to faults and boundaries that may facilitate or prevent groundwater flow and saline concentrations.

The study-area of 140 km^2 is located at the southwestern part of Irauçuba municipality, in semi-arid of the State of Ceará, Northeast Brazil. The geology is characterized by Neoproterozoic supracrustal units whose ductile deformation are related to the Brasiliano-Pan African Orogeny of same age. There, an ENE-WSW shear zone separates northern migmatites and granites from southern paraderived rocks that include sillimanite-biotite gneisses, calc-silicate gneisses, marbles, deformed granitic sheetings, amphibolites and minor impure quartzites. Mafic dikes (not mapped) are oriented NW-SE and probably related to the opening of the Atlantic Ocean, in Mesozoic Era. Restricted colluvium covers, less than 0.5m thick, occur at the northwest and eastern parts of the area. Along the São Gabriel creek near Juá village, the Quaternary alluvium (composed of conglomerates and sand) reaches 2.5 m in thickness of which the upper most part is characterized by a 0.2 m thick clay layer. The regolith usually is less than 5 m thick or absent, but at some well locations the weathered bedrock continues to depths of 20 m.

The area that is subjected recurrent droughts that last two years or more. Despite the main village, most of about 2,000 inhabitants live in the farms, with the economic resources based on subsistence agriculture (corn and bean) and minor cattle and goat raise. Water supply is provided in the village through a public system consisting of three drilled wells; two wells serves the houses by pipelines for domestic uses and, one is connected to a desalination system where people buy 20 liters of potable water for cooking and drinking for the equivalent of US$ 0.10. Rural inhabitants get their water from drilled wells, dug wells and small reservoirs that they have to carry to their houses. The water provided by the wells and reservoirs is typically insufficient to support both human and animal consumption due to low yields and brackish nature. Besides the climate and the poor quality of the soil, the surface and underground water deficiencies restrain any economic improvements related to agricultural production or cattle ranching.

Metodology/

The methodology combined the employment of processing techniques for magnetic and electromagnetic data, inverse of electromagnetic data with the support of structural and hydrological field information. The results of these processing were used to build preliminary groundwater favorability models based on Bayesian muti-criteria approaches. Whereas in crystalline domains partially covered by sedimentary rocks, the use of both deep and shallow magnetic source data is applicable to delineated boundaries between the different hydrogeologic domains as well as structures that act as hydraulic conductors or barriers.

In general, magnetic anomaly fields are produced by sources spanning a range within the Earth crust, and the separation of these sources helps to understand the structural framework that is important for groundwater flow in a study-area and to eliminate those not important. A matched filtering algorithm can differentiate the depth to the top of magnetic anomalies. The technique uses frequency-domain filters to design wavelength filters based on the segmentation of the power-spectrum of the magnetic data, according simple magnetic source models. The results are groups of anomalies of long-wavelength related to deep-seated sources (hundreds to thousands of meters in depth). Also it is possible to enhance groups of short-wavelength anomalies that comprise shallow magnetic sources (tens to hundred of meters), where generally, groundwater in crystalline domains are found.

The electromagnetic data were also microleveled and interpolated to grids of 25-m cell-size using a minimum curvature method. Similarities regarding the main conductive boundaries are evident among them but due to frequency and coil configurations, each one provides different details information with respect to depth and type of geologic sources.

Results

Two types of magnetic trends were discriminated. The positive gradient anomalies are the traditionally picked and used for interpretation. They occur when rocks of different magnetization intensity are side-by-side, generally due two fault kinematics, mafic dyke or granite intrusion. The positive trends have preferential orientation NNE-SSW to NE-SE, along rock boundaries or mark the northern shear zone. Tthe negative anomaly trends are not considered for metallic ore prospecting but it shall be important for hydrology studies. One cause might be intense weathering favored by water flow along opened fractures. During weathering, oxidation-hydration process partially substitutes magnetite for limonite and it causes de-magnetization of the mineral. However, magnetic minerals as magnetite and illmenite are resistent to alteration so, the mechanical disaggregation of rock is important to erode and transport minerals (including the magnetics) outside of that fracture. The gap produced by the weathering is be replaced by soil, moisture and groundwater generating unusual regolith mantle of about 20 m thick, as seen water-wells drilled in the study-area during PROASNE project (2001).

Negative gradient trends have orientation to NE-SW and NW-SE, forming a shear-pair related to E-W compression of the Brasiliano Orogeny. An important negative magnetic trend is exemplified by the WNE-ESE fault which guides the course of the São Gabriel creek. There, the surface joints and the fault itself favor the water infiltration and posterior chemical weathering producing unusual alluvium cover. Red colluvium venner with considerable magnetite content was found in the upper parts of the alluvium plain attesting the mechanical transportation of magnetic minerals.

Electromagnetic gradient trends were differentiated the same way as the magnetic data. In the Juá area, positive gradients represent electrically conductive joints, faults filled with conductive material such as soil+moisture and water. In some cases, the contact between rocks is a “week zone” susceptible of weathering and downward flow of the surface water. Preferable orientations of positive gradients are to NNW-SSE and WNW-ESE directions. Negative gradients were interpreted as regions associated to fractures or faults without electrical conductive property comparative to the host-rock, probably associated to quartz-filled joints, large neossom layer in migmatites, granite injection in gneisses, or neotectonic structures where weathering did not have enough time to be developed. Most orientations of negative gradients are of NE-SW direction, along with or cross-cuting rock trends.

Discussions and Conclusions

The filtering techniques cited in this study case better enhanced features of hydrogeologic interest. For regional survey data, it is recommended to use a matching filter prior to the high-pass filtering techniques or horizontal derivatives to exclude the anomalies related to deep-seated structures, and therefore, not-related to the level of groundwater occurrence in crystalline domain. The ASA algorithm, although very useful in mineral prospecting, it is not of great advantage because gradient trend information (probable related fractures) and definition is lost.

Comparing vertical derivatives and horizontal gradient amplitude, the latter is more useful to delineate trends related to shallow structures, whereas the former technique is suitable to map boundaries of geomagnetic units but it becomes difficult to extract trends related to fractures of local importance if the survey is of regional character. At last, there is not a definitive procedure, the interpreter must try among the available filtering techniques but having in mind the kind and scale of structures that are present in the study-area.

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