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Audiomagnetotelluric 3D imaging of the Regis kimberlite pipe, Minas Gerais, Brazil

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ABSTRACT

Kimberlite pipes are significant source rocks that form primary diamond deposits. Usually, the low resistivity of kimberlite produces a significant contrast in electrical resistivity, which can be mapped using electromagnetic EM methods. The Regis kimberlite is located in a well-known diamondiferous province in central Brazil. The main tectonic feature of the area is a northwest–southeast major crustal fracture zone that extends for more than 3000 km within the Brazilian territory, where Regis and several other kimberlites have intruded. In this paper, we present an audiomagnetotelluric (AMT) study at the Regis pipe. AMT data were collected in the 10 Hz–100 kHz frequency range at 111 stations on a grid, and three-dimensional (3D) inversions were used to generate a resistivity model of the pipe. Our interpretation was corroborated by available geological information of six drill holes. The final model shows an asymmetric conically shaped body with a conductivity range of 2 to 70 ohm.m and a depth of 0 to 550 m. These conductive sources were associated with crater lake sediments in the upper part and the main kimberlite diatreme at depth.

1. Introduction

In addition to being the world's most famous gemstone, diamond may be the world's most versatile engineering material, as well. Diamond is the hardest known natural substance (10 on the Mohs scale), and it has many unequaled qualities, but it exists in limited environments. Diamonds originate deep within the mantle, ~150 m below the earth's surface and are only brought to the surface by volcanic alkaline magma. Kimberlite and lamproite pipes are the most important primary sources of diamonds, but economic concentrations only occur in approximately one percent of known pipes worldwide, typically as vertical pipes ranging from less than 1 m to almost 1 km across.

Geophysical methods cannot detect diamonds directly, as the physical property of the pipes does not change according to whether diamonds are present (Macnae, 1979). However, the physical property contrasts of magnetic susceptibility, electrical resistivity, density, and seismic velocity between kimberlites and their host rocks can generate anomalies, which, in the case of kimberlite pipes, are most readily detectable using geophysical methods (Hammer et al., 2004; Macnae, 1979; Menezes and Garcia, 2007; Varsanthi and Mallinck, 2005). Therefore, exploration typically focuses on identifying the kimberlites within the host rock, usually following an exploration strategy that involves the application of a staged program of indicator mineral sampling followed by geophysical surveying and subsequent drilling.

Electromagnetic methods have a wide range of applications to several near-surface exploration issues, such as hydrocarbon (Menezes and Moraes, 2003), groundwater (Meju et al., 2001), environmental surveying (Vrbancich, 2011) and mining (Nabighian and Asten, 2002 and references therein). For kimberlite exploration, airborne EM surveys are intensively used as they can directly locate pipes and define optimal targets for ground follow-up surveys that are usually performed with TDEM (time-domain EM) or FDEM (frequency-domain EM), which are fast and cost-effective methods (Nabighian and Asten, 2002). The main disadvantages of these methods are the shallow penetration depths and their interpretation being mostly based on 1-D algorithms (Nabighian and Asten, 2002). However, magnetotelluric (MT) and audiomagnetotelluric (AMT) methods are routinely used for deep investigation in geothermal studies (Arango et al., 2009; Lugão et al., 2002), groundwater exploration (Chandrasekhar et al., 2009; Meju et al., 1999), petroleum exploration (Menezes and Travassos, 2010) and tectonic studies (Menezes and Travassos, 2005). In mining exploration, MT and AMT have a more restricted use, with only a few applications (Farquharson and Craven, 2009). This limitation is mainly due to the suitability of MT and AMT for ground surveys (although airborne systems are currently being tested by a commercial contractor), and the data acquisition using these methods is not fast or easy when compared with TDEM and/or FDEM surveys. The main advantages of the MT and AMT methods are that they allow for an estimation of the earth's dimensionality along with interpretation based on 2D and 3D algorithms, and they allow for deeper investigations.

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In the present work, we present a detailed 3D AMT study of the Regis kimberlite pipe, which is located in a well-known diamondiferous province in the central portion of the Brazilian territory (Fig. 1). Our main objective is to extend a previous 2D AMT study in the area (La Terra et al., 2010), aiming to better define the 3D geometry of the kimberlite pipe. To this end, we applied the 3D inversion methodology of Siripunvaraporn et al. (2005) to unveil the three-dimensional subsurface resistivity distribution associated with the pipe. Our results show that the AMT data can adequately define the geometry of the kimberlite, revealing an asymmetric conical-shape conductive body extending from 10 to 550 m, interpreted as the crater facies and main diatreme facies at the Regis pipe location. Six available drill holes were used to corroborate the inversion results and to build a realistic geological model of the Regis pipe.

2. Geological setting

The Alto Paranaíba Igneous Province (APIP in Fig. 1, Gibson et al., 1995b) is one of the most important Brazilian diamondiferous provinces (Menezes and Garcia, 2007). The APIP is strategically positioned between the NE border of the Paraná Basin and the western margin of the São Francisco Craton (Fig. 1). The region is characterized by a thick upper lithospheric structure extending over 70 km deep (Travassos and Menezes, 1999). The main rock types are carbonatites, kimberlites and ultramafic bodies, represented by intrusive structures such as dikes, sills and diatremes. These rock types usually occur in regions with thick lithosphere plutonic zones and extrusive bodies, such as lavas, and pyroclastic deposits are also observed (Almeida, 1986; Herz, 1977).

The alkaline magmatism of the APIP occurred during the Neocretaceous in a period of intense magmatic episodes. Almeida (1967) associated this magmatic activity with an extensional event named the Wealdenian reactivation, associated with the opening of the South Atlantic Ocean.

These intrusions occurred along important regional NW–SE-trending lineaments. These structures were interpreted from regional airborne magnetic surveys (Bosum and Mollat, 1975; Pereira, 1991) and were associated with dike swarms along deep-seated geological faults by Berbert et al. (1981). These faults are related to South Atlantic transform faults generated during the breakup of Gondwana in the Upper Jurassic (Asmus, 1978).

The Regis kimberlite is located in the central portion of the APIP, and it intruded along the so-called 125-AZ lineament, a major NW–SE crustal zone extending over 3000 km within the Brazilian territory (Menezes and La Terra, 2011). The pipe intruded into plane layers of inter-bedded red quartzites and green schists of the São Francisco Supergroup (Castro and Dardenne, 2000). The igneous structure is separated from the host rock by sharp discordant contacts. The outcrop area presents an oval-shaped structure covering an area of approximately 105 km^2 and showing a sharp discordant contrast to the country rocks. The outcropping area has a relatively flat topography with negligible terrain variations.

Menezes and La Terra (2011), based on an analysis of drill core samples, defined four different geological facies within the main diatreme, from top to bottom: red soil with laterite cover, later crater sediments, later crater sediments mixed with volcanic tuff, and kimberlite breccia.

3. AMT data acquisition and processing

The 111 AMT stations herein interpreted (Fig. 2) were collected in two different field surveys. In the first one, 54 AMT stations were acquired along three main profiles crossing the Regis kimberlite and allowed a 2D interpretation of the pipe (La Terra et al., 2010). In the second campaign, 57 new stations were acquired in the same area with the goal of having a spatial data distribution suitable for the 3D interpretation, the main subject of this study.

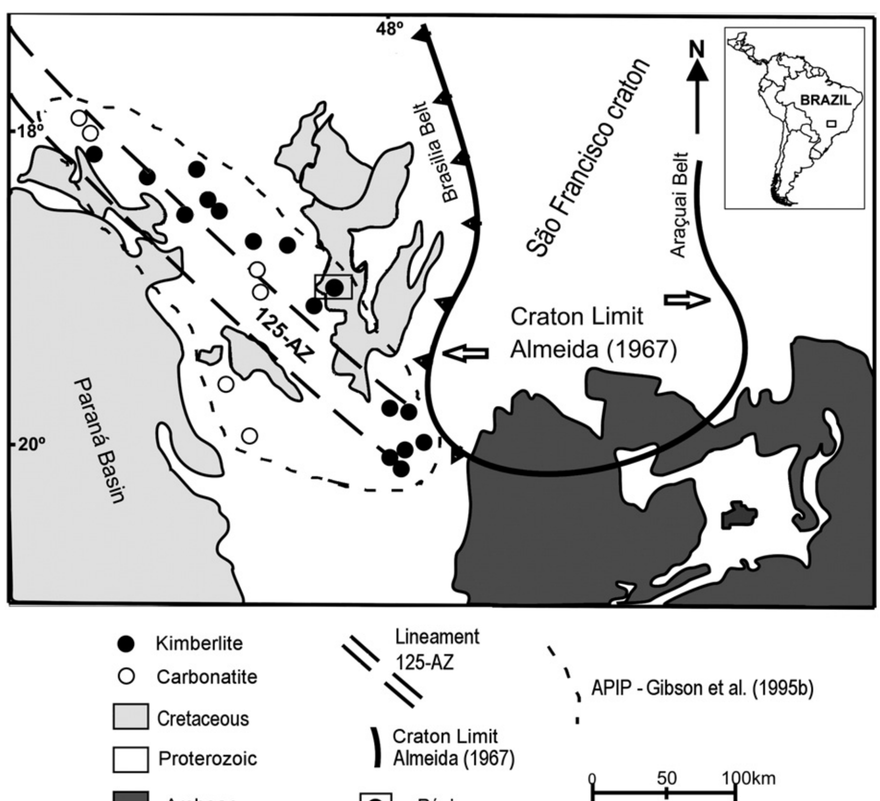

Fig. 1. Simplified geological map of the Alto Paranaíba Igneous Province (APIP). Regis kimberlite indicated in the figure (modified from Schobbenhaus and Campos, 1984).