Geophysical Characteristics of a Few Angolan Kimberlite Examples

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1. Introduction

Airborne geophysical techniques are widely accepted and routinely used in the search for diamondiferous kimberlite intrusions, particularly if large areas need to be explored or if the kimberlites are covered by more recent Tertiary or Kalahari sediments and do not penetrate to the present day surface.

Since its inception about 12 years ago Xcalibur Airborne Geophysics has flown many high-resolution airborne geophysical surveys in a number of African countries for various diamond exploration companies. Among these are a number of recent surveys flown for Sociedade Mineira de Catoca LDA (Catoca) in 2013 in Angola.

Angola is the world's fourth-largest diamond producing country after Botswana, Russia and South Africa. Apart from the well-known Catoca diamond mine in the Lunda Sul province, which is one of the largest kimberlite pipes in the world, Catoca together with partners Endiama and Prescol,hold a number of large very prospective exploration licenses in Angola. In spite of being in 'elephant country' for kimberlites, it remains a challenge to cost-effectively and successfully explore for economically viable prospects. The correct application of both magnetic and electro-magnetic (EM) airborne geophysical surveys forms an integral part of Catoca's exploration strategy for finding kimberlites that contain diamonds.

2.Geophysical techniques employed

The most cost-effective technique for first-pass exploration of large areas, particularly where access on the ground is difficult, is still airborne magnetic surveying. The key is to use state-of-the-art geophysical instruments on a robust, low-noise airborne platform and acquire good quality data along adequately spaced flight lines at the lowest safe flying height. Follow-up with airborne EM helps to differentiate, delineate and confirm targets for direct drilling.

2.1 Aeromagnetic system

The ultra-high resolution fixed-wing Xtract magnetic-radiometric system is installed on demagnetized Air Tractor crop-duster aircraft (figure 1). Their phenomenal agility and power at low speeds produce draping characteristics that mostly negate the necessity for costly helicopter operations, while maintaining the excellent production and safety characteristics.

Data collection at the lowest safe ground clearance, typically between 20 and 40 metres, provides maximum spatial resolution, information detail and signal-to-noise ratios. On-board differential GPS and a laser altimeter ensure accurate navigation and flight tracking while high-sensitivity wingtip-mounted magnetometer sensors, the latest self-calibrating dual crystal pack spectrometers and magnetic compensators produce top quality data.

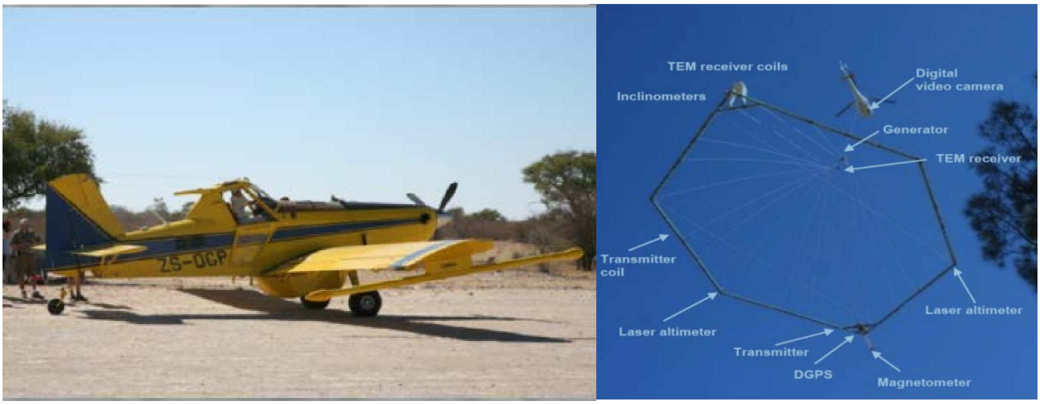

Figure 1: Xcalibur's ultra-high resolution Xtract airborne magnetic system (left) and SkyTEM helicopter-borne EM system with instrument positions shown (right).

2.2 Airborne EM system

Airborne EM data is acquired using the proven world-leader high-resolution helicopter-borne SkyTEM system from SkyTEM Surveys Aps., Denmark. This system is mounted on a large non-metallic hexagonal frame which is slung 35m below a standard Eurocopter B3 helicopter (see figure 1). The unique characteristics of the SkyTEM system are:

- The dual-moment transmitter employing both a low current, high base frequency, fast turn-off signal for better early-time data and high spatial resolution, and a high current, low base frequency signal for simultaneous late time deep imaging data.
- Patented receiver technology that eliminates signal drift and a one-time calibration procedure that minimizes leveling and post-flight corrections.
- Recorded frame attitude measurements, dual laser altimeters and magnetometer, all mounted on the low-flying frame.
- No operator is required on-board the helicopter, thus saving fuel and costs.
- Renowned state-of-the-art data processing and dual moment inversions to yield reliable conductivity-depth image (CDI/LEI) sections along flight lines.

3.Target response characteristicsand geology

The detection of kimberlites using airborne EM and magnetic surveys is a complex task and its success mainly relies on the knowledge of local geological conditions of the area where the survey is flown. The interaction of several factors is important, such as:

- Overburden thickness and conductivity: Post-intrusion overburden can completely mask or subdue the EM and to a lesser degree, the magnetic signals.
- Erosion after kimberlite emplacement: The upper portions of kimberlites (tuffacious rims and crater fills, Figure 2) can be quite conductive and/or have distinctive subtle magnetic ring-like (RVK rim) signatures. If these portions have been eroded away no detectable EM signal may remain. Fortunately, the remaining diatreme facies contains more magnetic minerals and tends to yield detectable magnetic signatures. The reverse can be true if the kimberlite is well preserved in which case an EM signal may be observed but the diatreme facies may be too deep to render clear magnetic anomalies. Anything in between is possible!
- Host rock type:Active EM or magnetic host regions may obscure a subtle geophysical kimberlite response. The laterally more continuous responses of the host rock lithologies might however be disrupted by the younger intrusive body, thus making the relatively weaker response of the kimberlite indirectly detectable.

- Magnetic remanence: Remanently or oppositely magnetized signatures are common and can be used to classify or differentiate kimberlite intrusions of different ages. It does however complicate modeling and determining of parameters (dip, susc.).

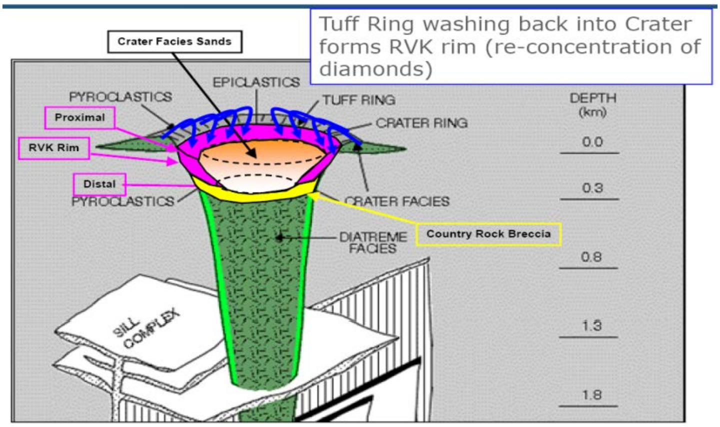

Figure 2 - Typical kimberlite model (after Petra Diamonds internet publication)

3 Airborne geophysical kimberlite responses

Geophysical grids are processed by experienced geophysicists using various standard and specialized filters, overlay and shading techniques to effectively enhance the kimberlite signatures in the different images.

The geophysical signature of a large known kimberlite in one of Catoca's Angolan license areas (shown in figure 4) was used, together with the reasoning in section 2 above, to define criteria for selecting and prioritizing targets using the EM and magnetic data.Some important characteristics, that are assigned scores to rank the targets, are:

- The tuff rim and crater create a thick conductive layer above the fresh kimberlite diatreme. A good example is seen in figure 3 in the conductivity-depth image (CDI), derived from the laterally-constrained layered-earth inversion(LEI) of the EM channel data.
- Circular or semi-circular shapes in plan-view, because kimberlites punch through older rock formations under pressure to produce the typical cone shapes (fig. 4).
- Discrete anomalies disrupting lithological magnetic or EM signatures indicate that the intrusion is younger than the surrounding rocks, even if it is non-magnetic or not conductive. Examples are seen in figures 4 below.
- Small magnetic dipole signatures, either induced (normal polarity) or remanent (reversed or skewed polarity) that are isolated yet distinct from the surrounding host signatures (examples can be seen in figure 4). These should be checked on aerial or satellite images for possible confusion with metallic man-made objects.

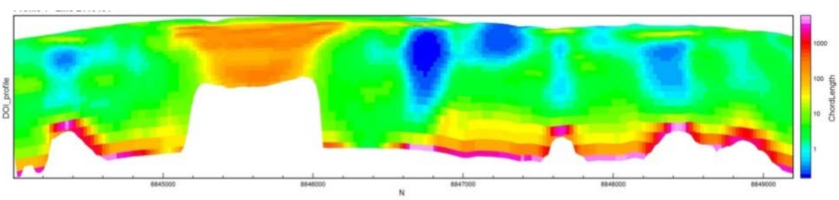

Figure 3: Conductivity-Depth Image (CDI) showing thick conductive crater in-fill.

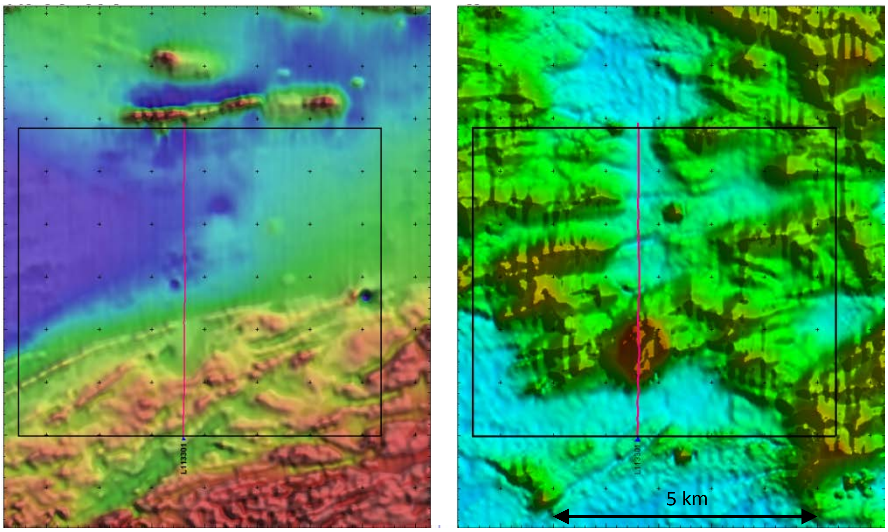

Figure 4. Map view of a number of kimberlite targets with different EM and magnetic signatures. Magnetic RTP grid (left) and EM intermediate channel grid (right).

Although manual target picking may sound somewhat subjective as outcomes certainly depend on the experience and judgment of the interpreter, we believe that it is more effective and reliable than automated computer algorithms. These tend to produce either a multitude of false targets or too few, depending on the parameters chosen by the operator, unless the operator spends a similar amount of time iterating and refining the process.

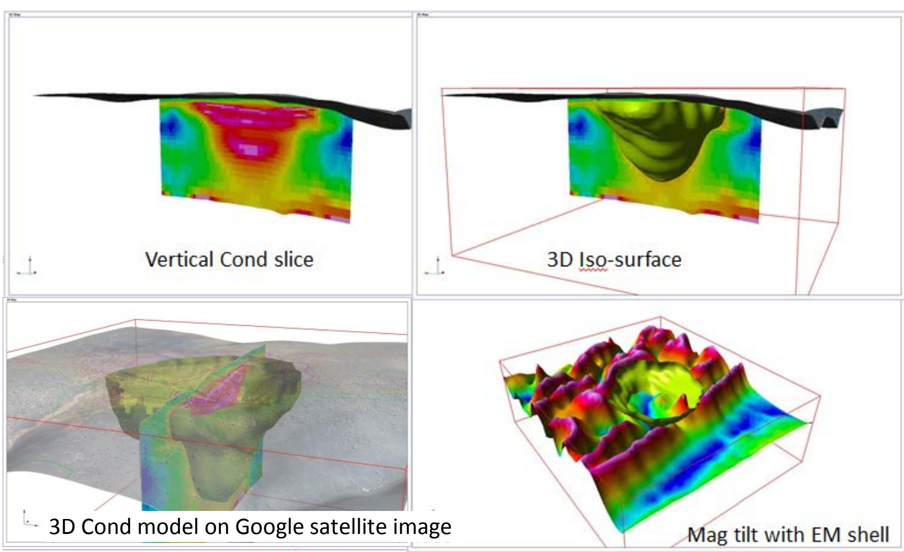

Figure 5: 3D views of conductivity inversion results and data.

Final proof and confidence in the accurate location and depth of the kimberlites are gained from meticulous profile modeling of the magnetics and 3D inversion models, together with the laterally-constrained layered earth inversion (LEI) EM sections and 3D compilation of these results (figures 5 and 6). Unconstrained 3D magnetic inversions produce larger blob-like results, but often highlight zones or facies within the kimberlite of higher magnetic content.

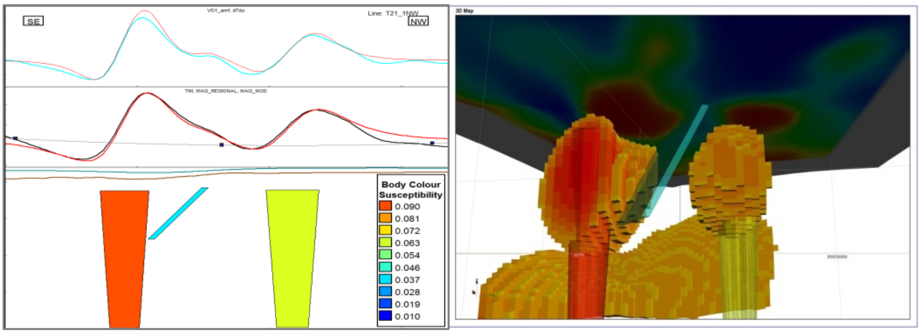

Figure 6: Examples of magnetic parameterized body profile modeling (left) and 3D magnetic susceptibility inversion (John Paine-UBC) results (right).

4 Conclusions

The effectiveness of high-resolution airborne magnetic and electromagnetic (EM) surveys for detecting, delineating and ranking kimberlite intrusions in various environments in Angola has been shown.

Some known and many new targets with very different characteristics have been discovered that now await evaluation and drilling with subsequent feedback and review of the interpretation criteria that were used.

The relatively time-consuming manual interpretation process requires skilled experienced geophysicists for the job, but when combined with good interaction and cooperation with a willing project exploration team providing local knowledge, it is undoubtedly effective.

References / Acknowledgements

As the information presented here comes mostly from proprietary internal company reports and data, it is more appropriate to acknowledge the following contributors:

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