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Special place of airborne electromagnetic survey in detailed exploration of kimberlites in the conditions of the Angolan Shield

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SUMMARY

The advent of complex systems including magnetic channel and TEM airborne survey channel in the first years of 21st century got a huge step forward in kimberlite industry. But up to the present day in many prospective areas only magnetic survey is used for kimberlite exploration on a mass scale. In case of complex surveys with magnetic and transient electromagnetic channels specialists often consider magnetic survey as the main exploration method for data interpretation, pipe anomaly isolation and their rating according to the degree of prospectivity. While electromagnetic survey is considered to be a supplementary method for sorting and classification of magnetic anomalies. In our opinion, this approach is fundamentally wrong and leads to serious negative consequences, decreasing the effectiveness of kimberlite exploration. Let us validate this conclusion by the example of diamond exploration works that have been performed in Angola over the last decade. It is a known fact that through the last years Angola has been the leader both in the number of kimberlite bodies discovered annually and in rough diamond reserves increment, despite of rather meager budget of diamond exploration works.

Key words: inversion, Kalman filter, airborne electromagnetics, frequency domain, time domain.

INTRODUCTION

For many years (from mid-1950s to about 2005) magnetic survey was the only mass geophysical method of kimberlite pipe exploration. Ground and airborne magnetic surveys were used in all diamondiferous regions of the world. Hundreds of kimberlite bodies were discovered using this method, including large diamond deposits (Garanin and Leybov, 2014, Maksimochkin et al., 2013). However, the prospective efficiency of this method has decreased drastically over the last decades, both for new deposits and "empty" kimberlites. For example, in mid-1980s in Yakutia the statistics of kimberlite discovery at the magnetic anomalies was discouraging – one or two pipes at most per 1000 registered anomalies. Nevertheless, long-term single-option prevalence of magnetic survey in kimberlite exploration left a considerable imprint on the industry.

In the conditions of the Angolan Shield, the main criterion for kimberlite discovery is the presence of local low-resistivity anomalies, which is explained by a simple fact – pipe resistivity, including its crater and diatreme, is always lower than resistivity of the host rocks (Fig. 1) (Stognii and Korotkov, 2010). This also refers to the development of low-resistivity weathering crusts along low-resistivity host rocks in the upper part of the section. Pipe crater low resistivity (first Ω·m values) and its diatremes (first hundreds of Ω·m values) in comparison to host rocks are characteristics of kimberlites. Diatremes of non-kimberlite nature and numerous intrusive formations of different composition, similar in shape to kimberlite bodies, usually have higher resistivity values.

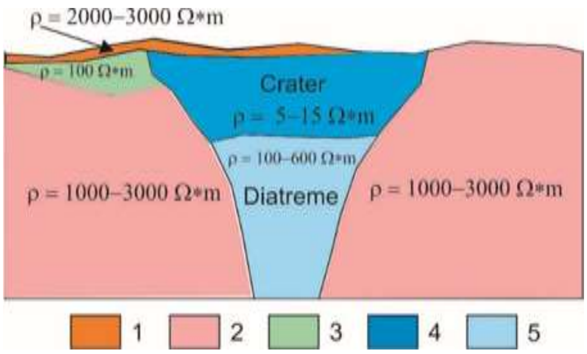


Figure 1. Schematic geoelectric model of a kimberlite pipe for the Angolan shield. 1 – Kalahari Group; 2 – Archean Group; 3 – weathering crusts acc. to Archean Group; 4,5 – Crater and Diatreme Kimberlite Pipe

In the conditions of the Angolan Shield this is the main and fairly reliable identification criterion for pipe anomalies of kimberlite nature.

Let us consider the capabilities of magnetic survey for kimberlite discovery in the same exploration conditions:

1. The presence of non-magnetic or weakly magnetized kimberlite bodies is well known, including diamond deposits, which would certainly be missed in case of magnetic survey.
2. In the conditions of ancient shields, host rocks are often represented by different massifs of intensely magnetized rocks, generating high-gradient alternating sign field. In these conditions, distinguishing of magnetic anomalies from pipes is rather problematic.
3. Large number of local isometric magnetic anomalies (typical kimberlite anomalies) in the Angolan conditions are connected with geological objects of non-kimberlite nature (basic, tufaceous, carbonatite, iron-ore bodies of pipe shape, isometric intrusive bodies of basic rocks, pegmatites, etc.).
4. It should be noted that in favorable conditions (non-magnetic host rocks) modern magnetic survey can reliably register very weak anomalies (fractions of nT), which potentially can be related to weakly-magnetized kimberlite bodies. However, our experience shows that increase in sensitivity and resolution capability of magnetic survey leads

to a considerable increase in the number of anomalies, most of which, according to the results of confirmation, are not connected with kimberlite.

Thus, the class of geological noise, generating typical pipe magnetic anomalies is much larger compared to resistivity anomalies, and disregard of this fact leads to identification of a large number of false magnetic anomalies. This fact is confirmed by the results of exploration activities by Catoca Mining Society. According to the results of airborne magnetic survey at a scale of 1: 5 000 in 2005-2006 in the area of approximately 1000 sq. km, hundreds of magnetic anomalies were identified, while the first kimberlite was intersected at a 4th rank anomaly.

The first complex airborne geophysical study with magnetic and electromagnetic channels was started in Angola by AeroQuest company in 2007. Data interpretation and prospective pipe anomaly identification was performed by Catoca Mining Society specialists, with the participation of diamond search specialists from Russia. An original system was created for primary data processing and assessment of the prospectivity degree of the identified anomalies, based on combined analysis of electrical and magnetic properties of the environment. The effectiveness of this interpretation system was confirmed by results of confirmatory drilling, and the statistics look very convincing: 80% of drilled anomalies were of kimberlite nature, and a new large diamond deposit was discovered at the Luele pipe in one of the isolated anomalies (Luaxe concession).

Let us give some examples. They refer to the survey performed at Quitubia concession in Angola in 2013 on request of Catoca Mining Society (Felix et al., 2014). Together with Norilsk branch of VSEGEI Institute we performed a complex survey with EQUATOR system at a scale of 1:10 000 (with magnetic and transient electromagnetic channels and frequency domain channels) covering the area of approximately 3000 sq. km. This area is also characterized by a large number of local magnetic anomalies of direct and reverse magnetization, while the number of local conductivity anomalies is considerably smaller.

During the works, methods and algorithms for classification and sorting of anomaly objects according to their electrical and magnetic characteristics were improved (fig 2., 3). This allowed for a reliable identification of kimberlite objects, even in unfavorable conditions of low-resistivity lateritic weathering crusts development with a thickness of 30-70 m (Vunda, 2010). That was confirmed by drilling performed in 2015. The total of ten anomaly objects that we recommended were confirmed, and kimberlite was discovered in nine of them.

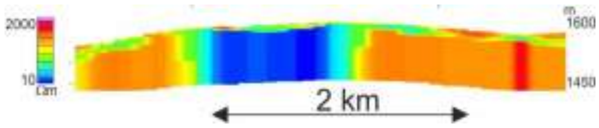


Figure 2. 1D inversion cross section for large (~ 1000 m) non-magnetic diamond kimberlite body in Lunda Norte province (Angola).

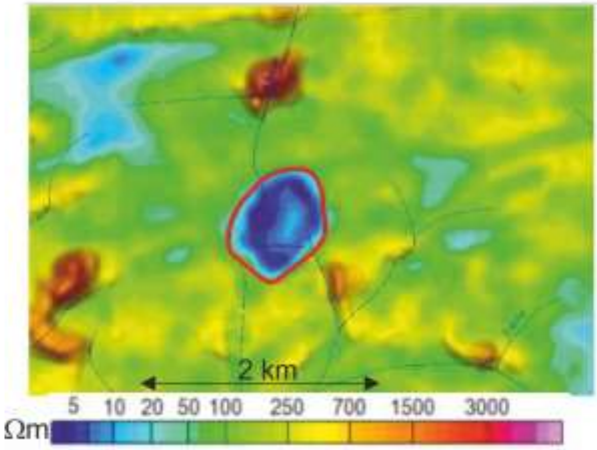


Figure 3. Resistivity map for 3163 Hz frequency channel for large (~ 1000 m) non-magnetic diamond kimberlite body (red circle) in Lunda Norte province (Angola).

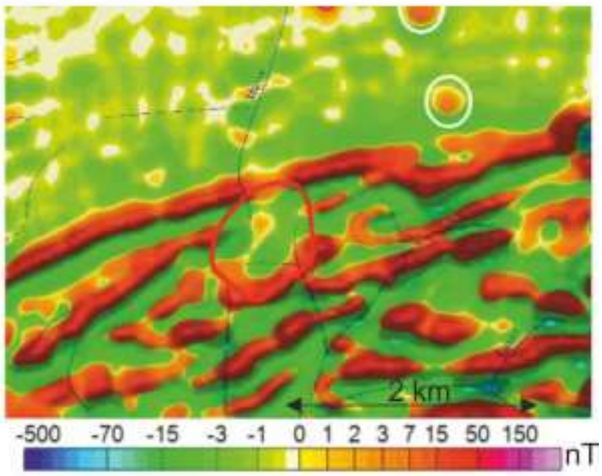
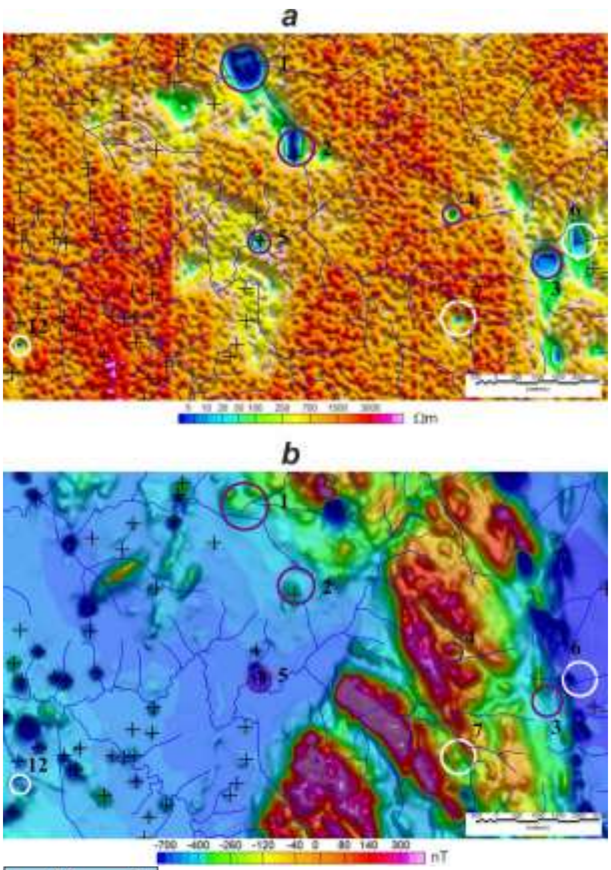
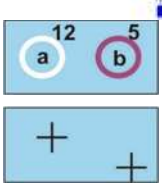


Figure 4. Local part of anomaly magnetic field map for large (~ 1000 m) non-magnetic diamond kimberlite body (red circle) in Lunda Norte province (Angola).

Figure 4 shows that a large diamond body could be missed without using the electrical channel of the complex.





local low-resistivity anomalies:
a - recommended for confirmatory drilling;
b - the same, kimberlite was discovered by drilling.
epicenters of local magnetic typical pipe anomalies

Figure 5. Examples of kimberlite discovery according to the electrical prospecting and magnetometry data.
a – apparent resistivity map for depth interval of 50-80 m;
b – anomaly magnetic field map reduced to the pole.

The above figure shows that local low-resistivity anomalies reliably register kimberlite (five drilled anomalies – five pipes), with only three of seven objects registered by magnetic anomalies, but there are dozens of similar anomalies, which is shown in the picture.

Figure 6 illustrates the ability of transient electromagnetic method to single out objects with a larger depth extension from a number of other conductive objects. In the conditions of the Angolan Shield this is the main feature for kimberlite pipe exploration.

CONCLUSIONS

Survey data interpretation is a very important stage in kimberlite exploration when prospective anomalies are identified. Every electric and magnetic anomaly should be subject to careful non-formal analysis to define its specific characteristics and to further single out such anomaly objects that are most likely to be related to kimberlite. The history of airborne geophysical surveys taken in the conditions of Angolan Shield shows that success of such separation methods have been confirmed by definition drilling. Without doubt, such methods can be efficient for other ancient shields as well.

REFERENCES

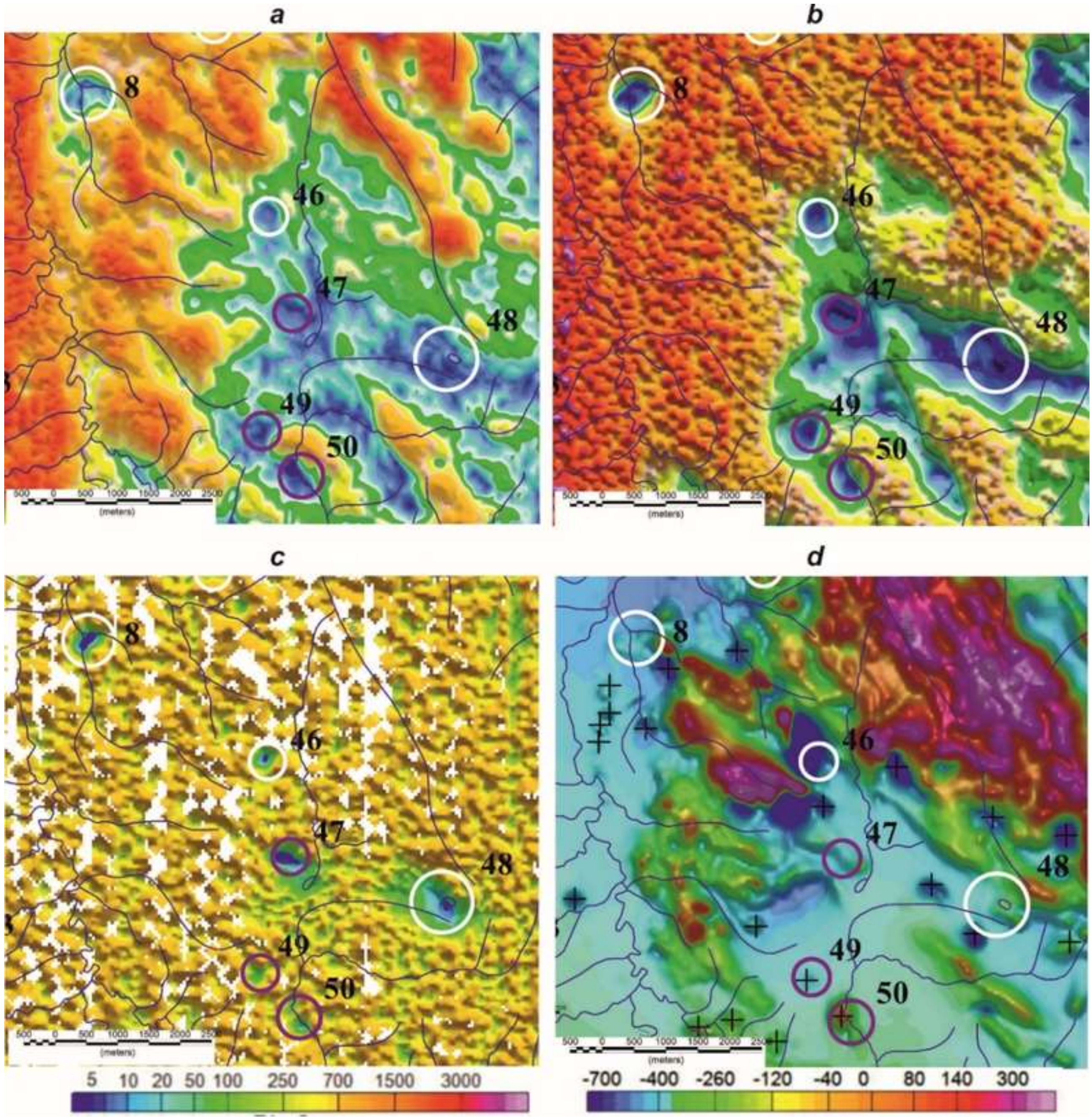
Felix, J.T., Karshakov, E.V., Melnikov, P.V., and Vanchugov, V.A., 2014, Data comparison results for airborne and ground electromagnetic systems used for kimberlites exploration in the Republic of Angola: Geophysika, 4, 17–22 (in Russian).

Garanin, V.K., Leybov, M.B., 2014, Diamonds: a sketch portrait (History of discovery of the Russian deposits and their genesis), Mineralogical Almanac, 19, № 1, 30-47.

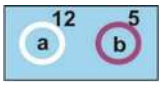
Maksimochkin, V.I., Trukhin, V.I., Minina, Yu A., Garanin, V.K., Bovkun, A.V., Anashkin, S.M., 2013, Magnetomineralogy of Botswana kimberlites, Izvestiya - Physics of the Solid Earth, Maik Nauka/Interperiodica Publishing (Russian Federation), 49, № 2, 289-305

Stognii, V.V., Korotkov, U.V., 2010, Kimberlite Bodies Exploration by Transient Method, Novosibirsk «Short-run Printing 2D», 121 p.

Vunda, T.M., 2010, Geology and Substance Features of Lorelei Kimberlite Pipe Formation (Angola), NSU Scientific Gazette, 3, 56-58.



ρ_a, Ω·m ΔT_a, nT



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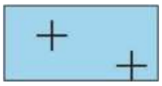

epicenters of local magnetic typical pipe anomalies

Figure 6. Examples of kimberlite discovery in favorable (high-resistivity host rocks) and complicated conditions (low-resistivity host rocks, represented by weathering crusts with a thickness of 30-70 m). Apparent resistivity maps for time windows: a - 10 µs; b - 150 µs; c - 1000 µs; d - anomaly magnetic field map reduced to the pole.