Time Domain Helicopter EM System Equator: Resolution, Sensitivity, Universality.

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ABSTRACT

Time domain helicopter borne electromagnetic system EQUATOR was developed in 2010. For past years it worked well on survey in various conditions. It proved its effectiveness for searching low contrast respectively small targets such as disseminated ore, kimberlites.

EQUATOR's main features are wide towing speed range and wide frequency band of receiver. First is due to construction properties. Speed variations not affect survey results due to high precision transmitter-receiver positioning. Second feature is used for extending system abilities. Due to full time measurements EQUATOR provides also frequency-domain data processing. To get more informative frequency response several additional frequencies are induced. Added signal doesn't affect time-domain response because it is absent in operating impulse spectrum and can be removed in post processing. Due to small footprint EQUATOR is well suited for small sized targets exploration. Its' measurements correspond well with ground EM and drilling data.

Key words: time domain, frequency domain, EQUATOR.

INTRODUCTION

There is a number of excellent airborne electromagnetic systems, perfectly solving their tasks (Fountain, 2008). So, a new one hardly can surprise geophysical society. Especially if it is a time-domain helicopter borne EM. Nevertheless, analyzing current state of AEM technology we came to conclusion that it is possible to develop a new system that will be in demand for sure.

The tasks that we believe should solve the system are following.

- The system should be equally effective in both resistive and conductive environment.
- The system should be well suited for searching low contrast respectively small targets.
- The system should have the performance characteristics for high productivity and low limit for piloting.

Figure 1. Mi-8 picking up EQUATOR

In 2010 the new system called EQUATOR made its first flight (Figure 1). Right after test it performed a series of surveys for low conductive small sized targets in alpine Sayan Mountains with 1200 meters elevations on the routes as short as 4 km.

The paper presents technical description and some survey results confirming achievement of the above characteristics.

TECHNICAL DETAILS

EQUATOR is a time-domain helicopter borne electromagnetic system with towed transmitting loop. Main parameters are presented in Table 1.

Peak dipole moment	100 000 Am^2
Base frequency	77 Hz
Impulse form	Cut half-sine
Impulse duration	1,3 ms
Cable length	70 m
Transmitting loop diameter	7,5 m
Total system weight	250 kg
Off-time measurements	5 μs – 4 ms 14 time gates
Channels	x,y,z B & dB/dt
Vertical receiver offset	≈30 m
Frequency band	77 Hz – 12 kHz
Frequency domain channels	Odd harmonics 77 Hz – 1,7 kHz, 3, 6, 12 kHz
Transmitter-receiver positioning	10 cm
Power supply	120 A (27 V)
Towing speed	0-170 km/h

Table 1. EQUATOR parameters

Perhaps the main features are wide speed range and wide frequency band. First is due to construction properties – the transmitter is attached by center of mass and flies horizontally due to stabilizers on the platform. Speed variations not affect survey results due to high precision transmitter-receiver positioning (Pavlov et al., 2010).

Second feature is used for extending system abilities. Due to full time measurements EQUATOR provides not only time-domain, but also frequency-domain data processing. To get more informative frequency response several addition frequencies are induced: 3, 6 and 12 kHz. Note, added signal doesn't affect time-domain response because it is absent in operating impulse spectrum and can be removed in post processing.

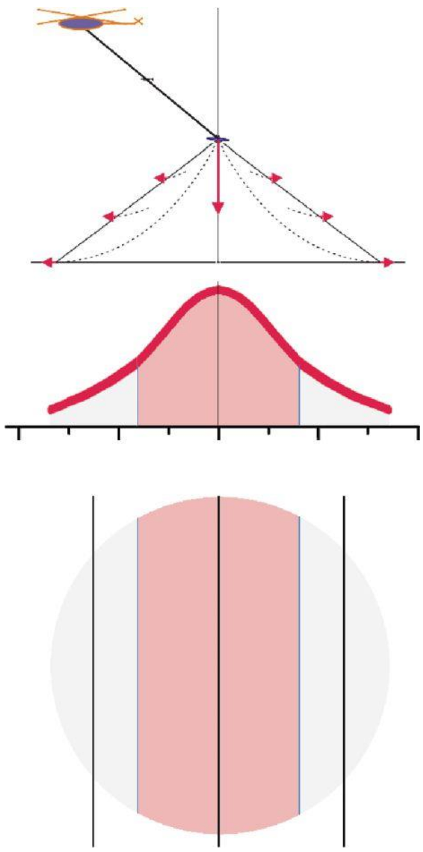

Figure 2. EQUATOR footprint (gray) and zone where 75% energy is concentrated (pink)

Importantly, EQUATOR is airborne geophysical complex providing magnetic measurements of high precision. Cesium vapor sensor is in the same bird with EM receiver.

RESOLUTION

Like many other AEM systems with towed transmitting loop EQUATOR has a small footprint. Figure 2 shows that distance between routes is adequate when it is approximately as big as transmitter clearance. Transmitter’s magnetic field lines that intersect cone surface above ground level won't reach the ground. When transmitter is 50 m above the ground footprint radius will be less than 70 meters. Inside the footprint (grey) highlighted area (pink) is where 75% of field energy is concentrated. Solid lines show the routes at 50 meters distance. It's absolutely clear that increasing route distance and keeping altitude low we lose many details.

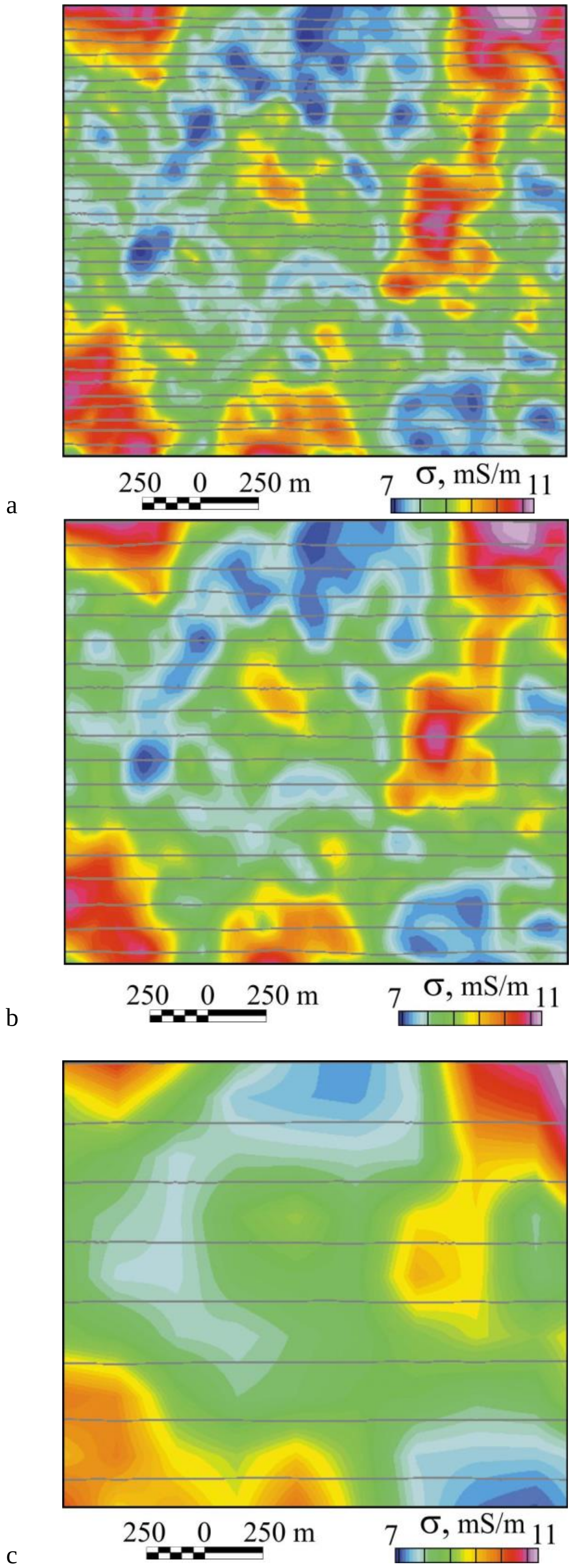

Figure 3. Apparent conductivity after EQUATOR data processing a) 50 m between survey lines b) 100 m between lines (every 2nd line was used) c) 250 m between lines (only each 5th line was used)

If distance is too big, some small objects can be missed. Figure 3 shows conductivity maps of the same survey for 50, 100 and 250 meters between routes. As expected, many conductivity features are lost.

UNIVERSALITY AND SENSITIVITY

Here we are trying to demonstrate system effectiveness for wide range of geological sections. First, in a low conductive area – host rocks are of less than 1 mS/m. Figure 4 demonstrates obtained conductivity map in comparison with results of more detailed ground survey. On the one hand, there is good agreement of conductivity values.

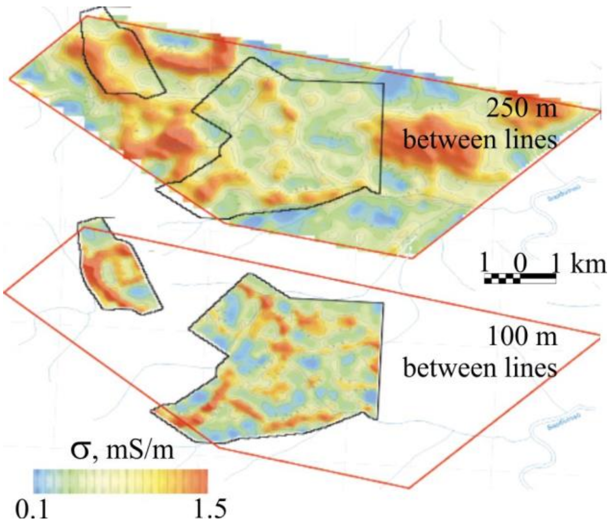

Figure 4. Conductivity map after EQUATOR survey (upper image) and ground survey data (bottom image).

On the other hand, the previous conclusion is confirmed – 250 meters survey line spacing leads to disappearance of some details. On the Figure 5 a conductivity section in the same region is shown and again in comparison with ground survey results.

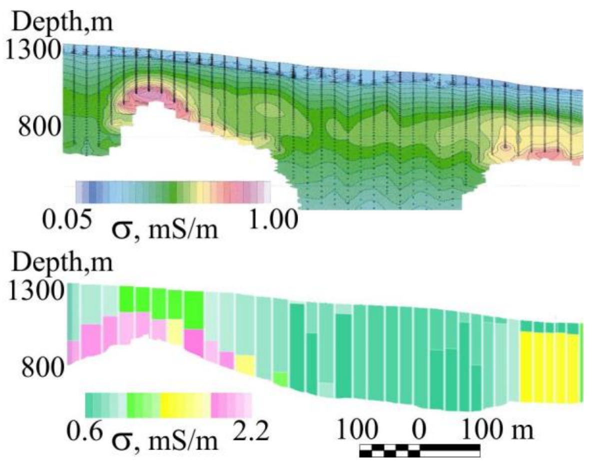

Figure 5. Conductivity-depth image for ground survey data (upper image) and 2 layer inversion results (bottom image) for EQUATOR data over Ergoju deposits (deposits fit perfectly with conductive areas).

There are known ore bodies with Au-Ag-Pb-Zn mineralization of skarn type – Ergoju deposit. It's an ordinary task for time-domain EM to find conductive bodies in resistive host rocks. But note low conductivity of the target – 1,5-2 mS/m only.

The next example is even more interesting. Trying not to display false modesty we call it really hard conditions. Thickness of conductive (about 25 Ωm) overburden – 20-50 meters. Under it there are about 150 meters of respectively resistive neoproterozoic sediments of 100-300 Ωm underlaid by highly conductive thick (200 meters) layer of 15-50 Ωm. The target is an isometric body of 100-300 meters diameter having average resistivity 10-50 Ωm. So, we have to detect a low contrast object between "capacitor" plates.

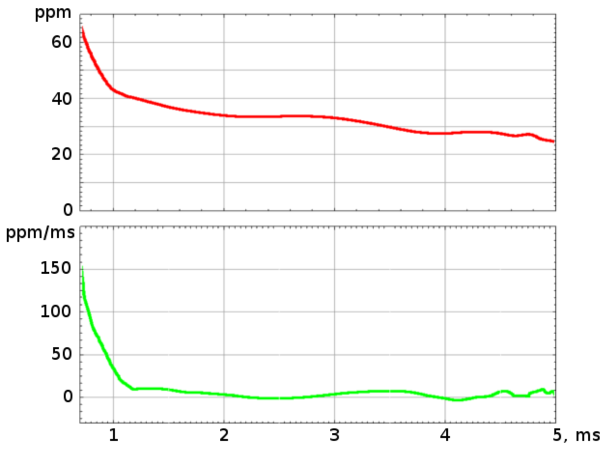

Figure 6. B (red) and dB/dt (green) raw signal in late channels

The problem is that time domain response in all late channels after 1 ms is related to the bottom massive conductor (Figure 6). Note, B-field is non-zero, about 30 ppm while dB/dt signal is of noise level. So, late channels are useless.
But in frequency domain situation is much better. The bottom conductor influence is mostly introduced only in the lowest frequency 77 Hz (Figure 7). Highest frequencies describes overburden well, so we have all odd harmonics from 231 Hz to 1,7 kHz for analyzing contrasts inside the neoproterozoic sediments.

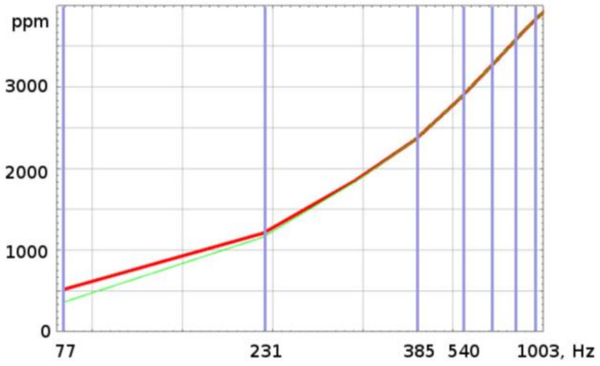

Figure 7. Measured quadrature response (red) for 77 Hz is 150 ppm greater then modeled one over the same medium without deep conductor (green)

As a result, in case of frequency domain data processing even in conductivity depth image the target can be seen as a conductive anomaly in the bottom part of section (Figure 8).

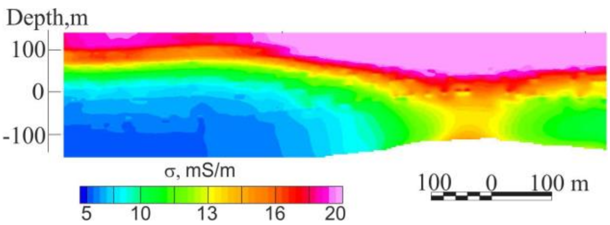

Figure 8. Conductivity-depth image for frequency domain data: the target can be reliably pointed in the right side of section

CONCLUSIONS

Time-domain helicopter borne EM system EQUATOR has features that allow using it most effectively for some special tasks:

- survey in alpine mountains;
- survey for low contrast small sized targets: disseminated ore, kimberlites;
- survey in presence of conductive overburden and even conductive underlying structures.

So, EQUATOR took its own place among the AEM systems.

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