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# Three-dimensional inversion of the frequency domain airborne CSEM data over the kimberlite complex for the conductive and susceptible heterogeneities

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## SUMMARY

The electromagnetic survey data has been used to interpret the susceptibility structure as well as conductivity structure. The frequency domain EM responses related to the conductive anomaly and the susceptible anomaly have different characteristics such as frequency dependance and phase information which make different contribution of each anomalous response the in-phase and out-of-phase components. Based on these characteristics, we set iterative inversion framework that separately uses out-of-phase component for conductivity inversion and low frequency in-phase component for susceptibility inversion. We then applied this inverion framework to the frequency domain EM data set acquired over kimberlite complex. We set two zones of interest that are kimberlite zone and dyke zone and respectively inverted the data sets of two zones. With kimberlite zone data set, conductivity inversion succesfully imaged two isolated conductive anomalies, which are already known as kimberlite pipes, embedded in resistive background. In this kimberlite zone, susceptibility inversion was not possible due to relatively weak susceptibility of anomalies compared to background noise. With dyke zone data set, the same inversion framework was applied and succesfully reconstructed conductivity structure and susceptibility structure of the dyke.

**Keywords**: airborne EM, electrical conductivity, inversion, magnetic susceptibility

## INTRODUCTION

The frequency domain (FD) controlled source electromagnetic (CSEM) data have primarily used to interpret the electrical conductivity structure. However, there also have been efforts to interpret the magnetic susceptibility structure using FD CSEM data. Through the efforts, techniques have been consistently developed from apparent physical properties mapping (Fraser, 1981) to the simultaneous multi-dimensional multi-parameteric generalized inversion (Sasaki et al., 2010).

The interpretation of geophysical data sets over Tli Kwi Cho kimberlite complex has leaded successful exploration of the diamond deposit. Recently, comprehensive interpretation of geophysical data sets for a complete understanding of physical properties has been studying for a three-dimensional (3D) conductivity model using CSEM data (Fournier et al., 2014), a 3D susceptibility model using magnetic data (Devriese et al., 2014), and a 3D chargeability model using time-domain CSEM data (Kang et al., 2015).

In this paper, as a part of efforts to interpret both conductivity and susceptibility structure using FD CSEM data, we focus on the 3D inversion of DIGHEM data set obtained in 1992.

## AIRBORNE FD CSEM DATA SET

In this study, we used the horizontal co-planar (HCP) data set obtained over 900, 7200, and 56000 Hz. Figure 1 shows the data maps of in-phase and out-of-phase components. An intuitive interpretation can be made from these data maps. First of all, out-of-phase data map shows two distinct conductive anomalies embedded in resistive background. After geophysical studies and drilling, it was known that these two anomalies are associated with two distinct kimberlite pipes, named DO-18 and DO-27. The resistive background response is in accord with granite host rock. Secondly, strong negative linear features on the eastern part in the in-phase map indicate the existence of susceptible anomalies. These strong magnetic anomalies are also shown in magnetic data maps (Devriese et al., 2014). Since DIGHEM data set covers large area about 3.5 $\times$ 2.8 km and also includes the region without conductive or susceptible anomalies, we set two regions of interest of kimberlite zone and dyke zone respectively, and these zones are shown as rectangles in figure 1. The 3D inversion was applied to each zone.

## INVERSION

In FD CSEM data sets, it has widely known that out-of-phase component is mainly affected by conductivity structure, not by susceptibility one. If conductivity and source frequency are generally low, the in-phase component can be dominated by the frequency-independent magnetization effect. Taking advantage of these features, we choose iterative inversion framework composed of inverting out-of-phase data to update conductivity structure and inverting low frequency in-phase data to update susceptibility structure.

The 3D inversion algorithm is basically the same that is presented by Noh et al. (2014), but a susceptibility inversion scheme is added. In order to calculate the Jacobian matrix for the Gauss-Newton method for updating susceptibility values, we choose adjoint method in the similar way introduced by Rahmani et al. (2014).

Within our iterative inversion framework, we, firstly, carried out conductivity inversion of out-of-phase data of kimberlite zone. We used 842 source data of three frequencies. Figure 2 shows the reconstructed conductivity structure. Two isolated conductive anomalies embedded in resistive background are well reconstructed. The southern anomaly which indicates DO-27 was images with certain depth from the surface whereas the northern anomaly, DO-18, was imaged beneath the surface. After conducting conductivity inversion with out-of-phase data, we intended to conduct susceptibility inversion with low-frequency in-phase data. However, the estimated susceptibility response in the in-phase data was not strong compared to background noise. For that reason, susceptibility inversion was not carried out with kimberlite zone data.

For the dyke zone data set, we also started with conductivity inversion using out-of-phase data. Figure 3 shows the conductivity structure obtained after the inversion. Within very resistive and layered background, less resistive anomaly, which was clearly shown 56k Hz data, was imaged at the center of the zone. After obtaining conductivity structure, we carried out susceptibility inversion using two low frequency in-phase data sets of 900 and 7200 Hz. Figure 4 shows the susceptibility structure indicating dyke with the strike of north-northwest.

## CONCLUSIONS

We carried out 3D conductivity and susceptibility inversion of FD airborne EM data based on iterative framework. The framework consists of the conductivity inversion scheme which uses out-of-phase data and the susceptibility inversion scheme which uses low-frequency in-phase data. Conductivity structures of kimberlite pipes were successfully reconstructed, but susceptibility was not. With the inversion framework, 3D conductivity and susceptibility structure of dyke zone was well reconstructed. Future work will focus on the suggesting more efficient inversion framework for the conductivity and susceptibility inversion.

## ACKNOWLEDGMENTS

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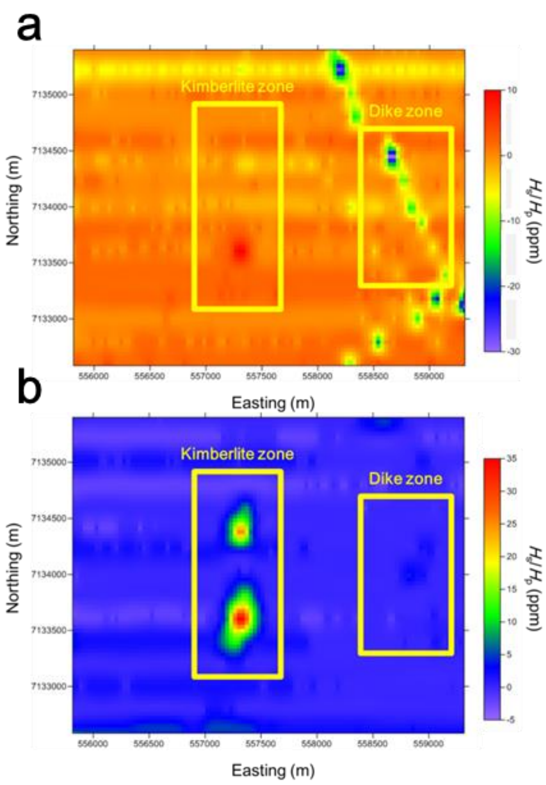


**Figure 1.** The data maps of (a) in-phase and (b) out-of-phase components at 900 Hz. The yellow rectangles indicate the region where the data sets were inverted.

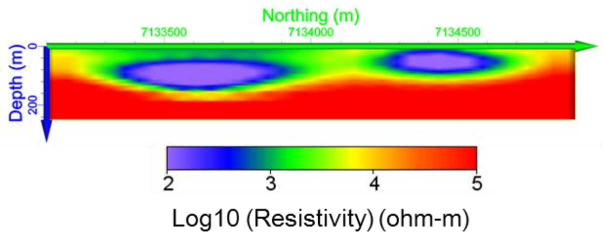


**Figure 2.** The cross-section (at 557250 m easting) of reconstructed conductivity results obtained after inverting out-of-phase data over kimberlite zone.

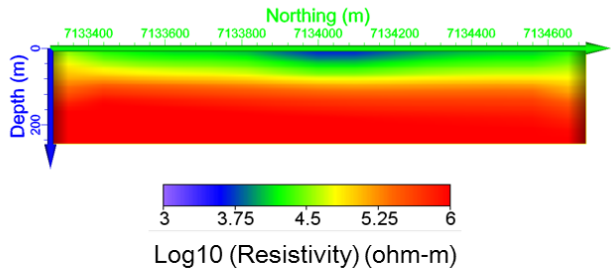


**Figure 3.** The cross-section (at 558800 m easting) of reconstructed conductivity results obtained after inverting out-of-phase data over dike zone.

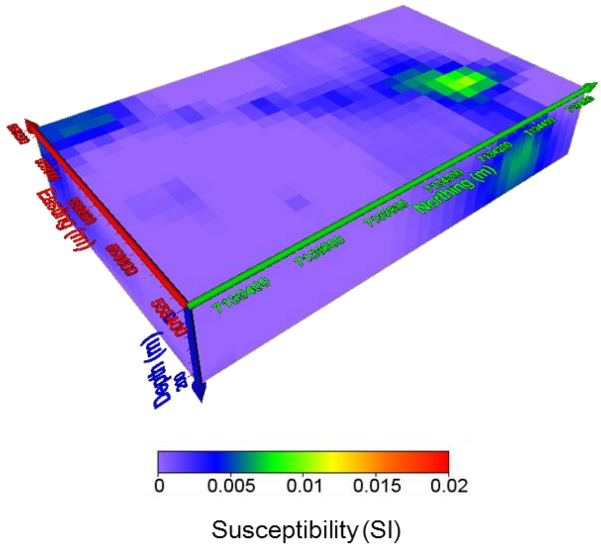


**Figure 4.** The reconstructed susceptibility results obtained after inverting in-phase data over dike zone.