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Seeing between boreholes – a feasibility study

K. Guo[1], B. Milkereit[2]

[1,2] Department of Earth Science, University of Toronto, 22 Russell Street, Toronto, ON, M5S 3B1, Canada

Introduction

Conventional surface mapping and airborne surveys have been extensively used in mineral exploration. However, such methods have a poor constraint on depth of investigation and the results can be obscured by presence of overburden. Borehole logging can provide additional, yet limited, information in the immediate vicinity of boreholes (Fig.1). Cross-hole electrical resistivity tomography (ERT), on the other hand, enables 2D and 3D imaging of electrical properties between boreholes. Compared with other exploration surveys, it has the advantages of having depth-constrained inversion, a sense of target geometry and good repeatability (Fig.1,2).

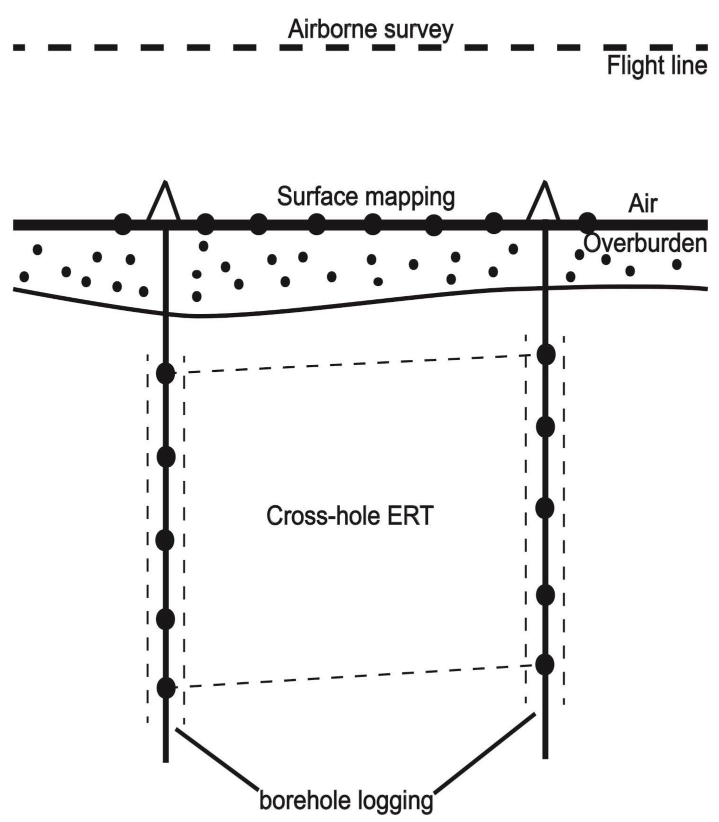

Fig. 1 Schematic plot of various exploration tools.

Motivation

Previous studies on ERT generally assumed that the boreholes are vertical and are in the same plane as what is to be imaged. However exploration boreholes are usually drilled at various dip angles and azimuths in order to maximize geological information to be obtained (Fig.2). As a result, such deviation effects can cause errors well above typical data noise levels and are problematic in accurately imaging target structures. This study investigates how borehole deviations and the half-space to full-space transition affect the apparent resistivity, inversion and interpretation of cross-hole ERT results.

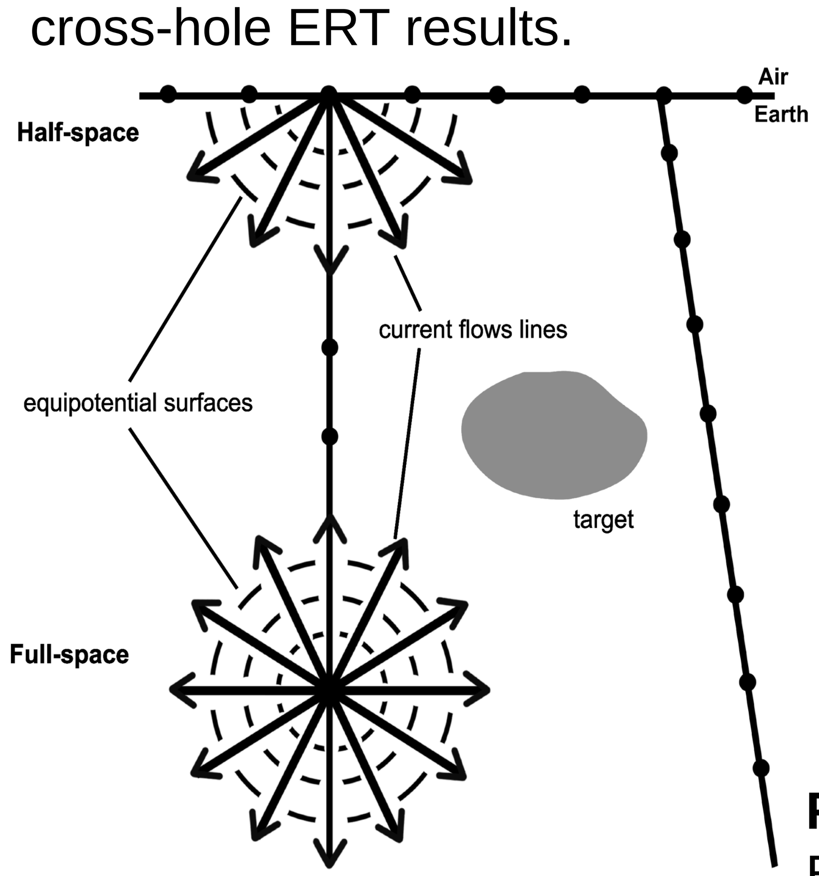

Fig. 2 Schematic plot of electrode layout of surface, borehole and surface-to-borehole DC/IP surveys. Black circles represent electrodes.

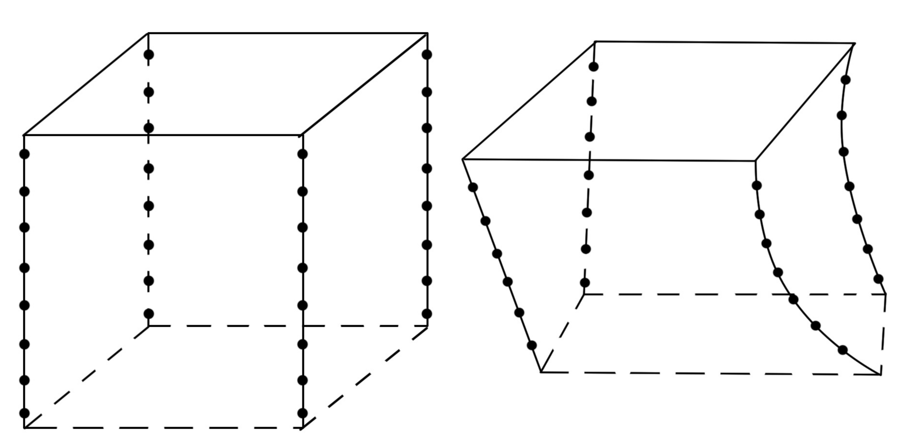

Fig. 3 Schematic plot of idealized ERT survey geometry (top) and that of exploration boreholes in reality (bottom).

Methodology

In measuring bulk resistivity, a pair of current electrodes (A, B) is used to inject current I into the Earth. The resulting potential difference ΔV at another pair of electrodes (M, N) is measured (Fig. 4)

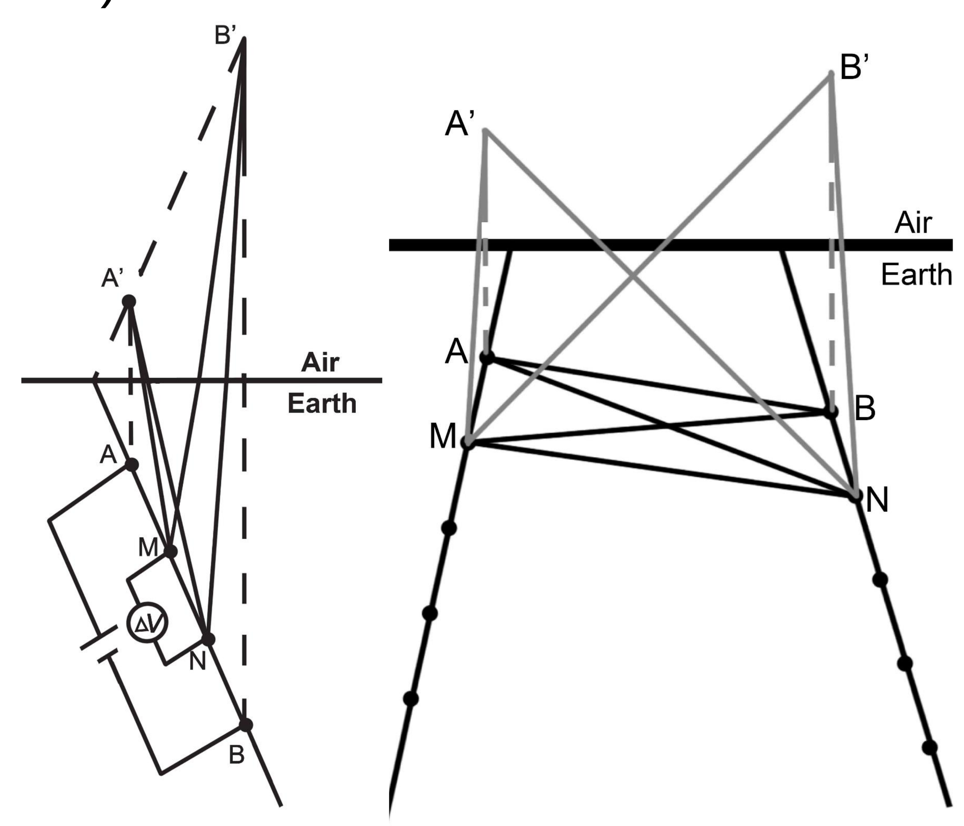

Fig. 4 Electrode array AB-MN and induced images for a single hole profiling (left) and cross-hole ERT (right) survey. Current is injected at A (positive) and sinks at B (negative). A', B' are the induced images. Overall potential difference between M and N is measured.

For an electrode array AB-MN in a near surface borehole, electrical images A' and B' are induced with equal current strength at equal distances to the air-Earth interface above the Earth (Van and Cook, 1966). Both electrical images will also generate potentials at M and N. Then the total potential difference between M, N and its apparent resistivity ρ_a can be calculated via

$$\Delta V = \frac{\rho_a I}{4\pi}\left(\frac{1}{AM}+\frac{1}{A'M}-\frac{1}{BM}-\frac{1}{B'M}-\frac{1}{AN}-\frac{1}{A'N}+\frac{1}{BN}+\frac{1}{B'N}\right)$$

$$\rho_a = \frac{\Delta V}{I}k,$$

$$k = 4\pi/\left(\frac{1}{AM}+\frac{1}{A'M}-\frac{1}{BM}-\frac{1}{B'M}-\frac{1}{AN}-\frac{1}{A'N}+\frac{1}{BN}+\frac{1}{B'N}\right)$$

where k is the geometry factor which accounts for electrode array geometry and deviation effect.

Results

Geometry factors are calculated by fixing A, M at the top of the borehole and moving B,N from the top to the bottom. We define normalized geometry factor $\hat{n}_k$ by dividing geometry factor (k) along near surface boreholes at various dip angles by that of along vertical boreholes (k_v) or that of the full-space case (k_f).

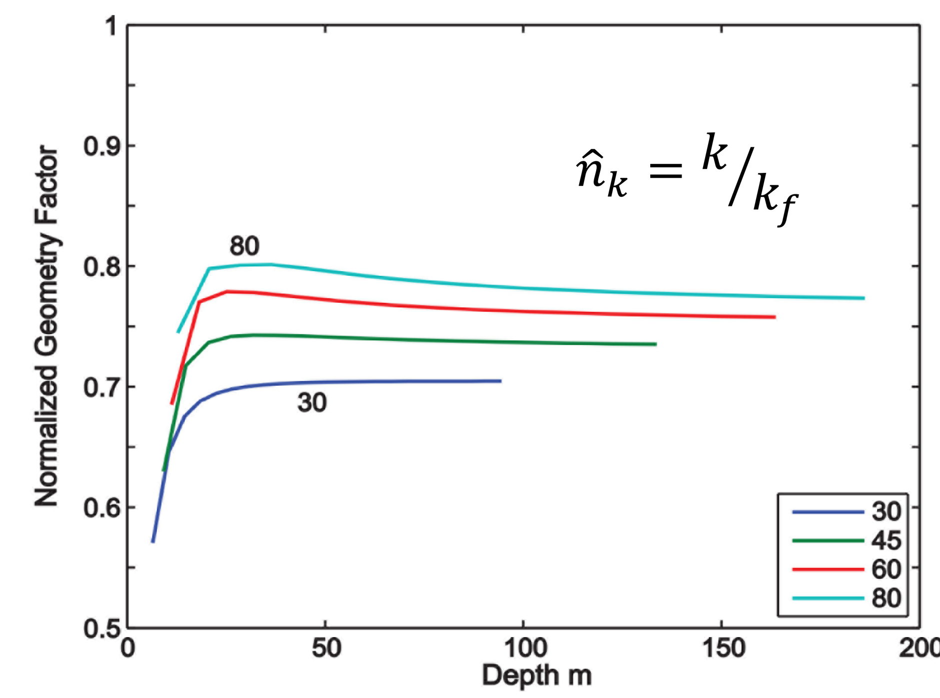

Fig. 5 Geometry factors along boreholes dipping at various angles (in degrees) normalized by the full-space case. 0.5 corresponds to half-space case and 1.0 correspond to full-space case. k transits into full-space case with depth.

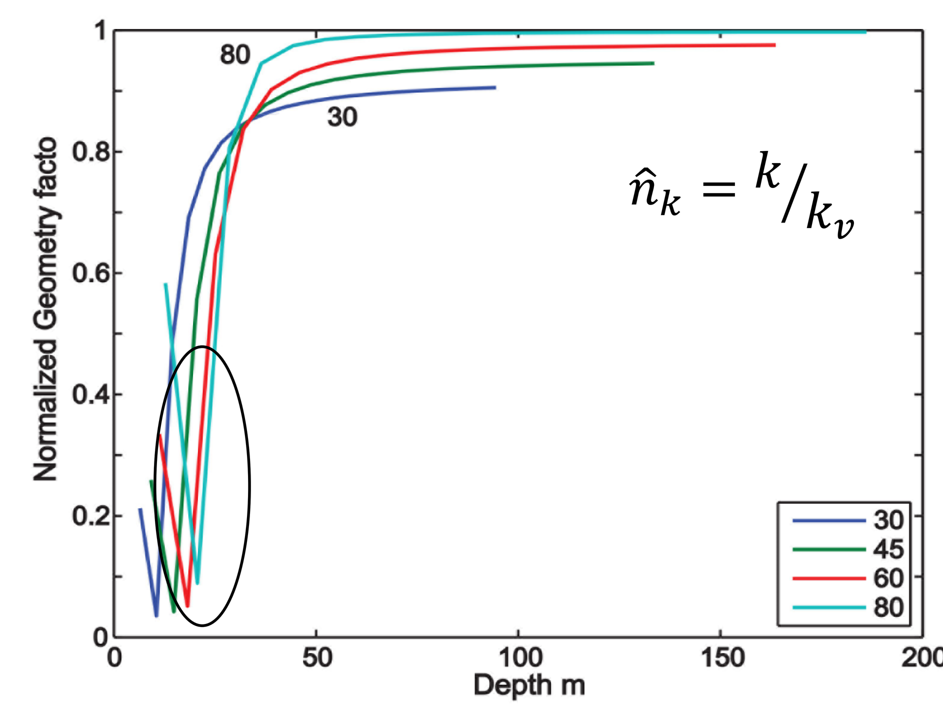

Fig. 6 Geometry factor normalized by vertical case. k transits into vertical case with depth. Circled area is the ERT shadow zone when the bottom of k tends to 0 and signal-to-noise ratio tends to be small.

Conclusion

We find that the deviation and transition effects are both depth and electrode separation dependent, and are especially important at shallow depths. In order to accurately image target structures, we propose that accurate array locations need to be obtained so that correct geometry factors can be applied to correct for such effects.

Acknowledgement

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References

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