Paper

# The Channelling of Natural Electric Currents by Orebodies

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## Introduction

Natural fluctuations of the magnetic field of the earth induce large scale electric currents to flow in the crust and upper mantle. The currents are commonly known as telluric currents, and where an inhomogeneity of high electrical conductivity exists these currents will preferentially tend to flow through it. On the regional scale of continent-wide induction such channelled currents are sometimes strong enough to be detected by the surface observation of their associated magnetic fields. This paper investigates the extent to which a measurable effect might occur on the physically smaller scale when the inhomogeneity is an orebody.

## Theory

The complete solution of electromagnetic induction in general three-dimensional structures is well-known to be very complex. In exploration geophysics, a traditional and rewarding approximation has been to ignore the electrical conductivity of a host-rock where it is much less than that of an orebody, and to estimate the response of a model orebody to a locally applied electromagnetic field as if the orebody were situated in free space.

The approximation at the basis of this paper is fundamentally different. The frequencies of the time-varying fields considered are very much lower, so low in fact that induction in the orebody itself is taken to be negligible. The presence of the host rocks is important because regional electric currents are induced in them by large-scale natural electromagnetic fields, and these regional electric currents are taken to be locally channelled by the high electrical conductivity of the orebody, essentially according to Ohm's law.

The "current channelling" approximation thus considerably simplifies the general induction problem, but still results in mathematics of some complexity: firstly, in calculating for a given model what the flow pattern of the electric currents will be; and secondly, in calculating what the magnetic fields of such electric current flow patterns will be.

In this paper some approximate calculations will be made for a representative orebody, to obtain some idea of the strength of the effect involved.

## Calculations

A. The regional currents.

Consider natural electromagnetic induction in a uniform half-space of electrical conductivity $\sigma_0$ S m$^{-1}$. Basic magneto-telluric theory indicates that at the surface of such a half-space orthogonal electric ($E_0$) and magnetic ($B_0$) signals will occur with amplitudes in the ratio

$$|E_0/B_0| = (0.2\ P\ \sigma_0)^{-1/2}$$

where P is the period of the sinusoidal disturbance in seconds, and the units of E and B are the practical ones of mV km$^{-1}$ and nT respectively.

If one takes a half-space of conductivity $10^{-2}$ S m$^{-1}$, and a representative magnetic substorm of sinusoidal period 1 hr and surface magnetic field amplitude 20nT, then the accompanying oscillating electric field in the ground (both at the surface and for the purposes of this paper down to several hundred metres depth) will be of amplitude

$$|E_0| = 7.5 \text{ mV km}^{-1}$$

Such surface electric fields are indeed commonly recorded in magneto-telluric studies. For this particular half-space the electric field will be accompanied by an oscillating current density, at and near the surface, of amplitude $I_0$ where

$$I_0 = \sigma_0 E_0 = 7.5 \times 10^{-8} \text{ amp m}^{-2} \qquad (1)$$

B. The magnetic field above a current channel.

The magnetic field above a simple buried line current of infinite length and strength I amp has components (in m.k.s. units) as shown in Fig. 1 of

$$By(y) = \frac{\mu_0}{2\Pi} \frac{I\ z_0}{(y^2+z_0^2)} \qquad (2)$$

$$Bz(y) = \frac{\mu_0}{2\Pi} \frac{I\ y}{(y^2+z_0^2)} \qquad (3)$$

where $\mu_0$ is the permeability of free space (= $4\Pi \times 10^{-7}$ henry m$^{-1}$). If the current is oscillating (relatively slowly) these values of By and Bz will be amplitude values for observed oscillating fields.

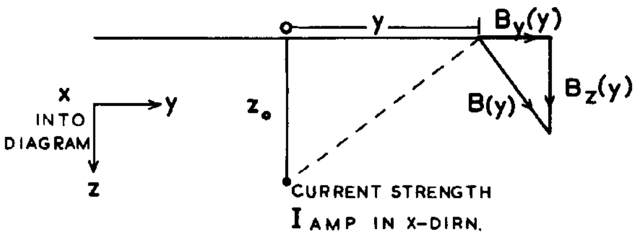


**FIGURE 1**
**Magnetic field components of a buried line current.**

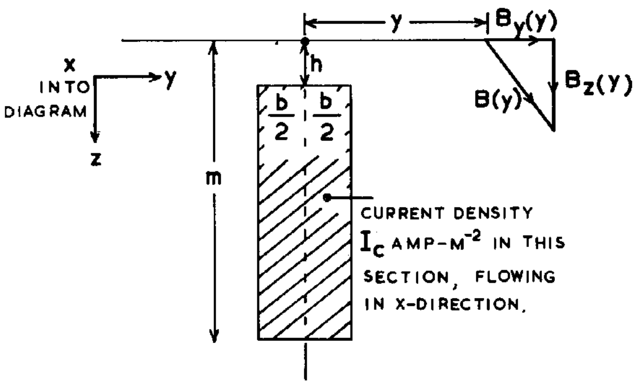


**FIGURE 2**
**Magnetic field components above a uniform current density in a buried rectangular channel.**

To obtain the equivalent expressions for the field components above a flow of uniform current density (now $I_c$ amp $m^{-2}$) in a rectangular channel as shown in Fig. 2, equations (2) and (3) are integrated over the cross-section of the channel. An elegant expression of the result is given by Wilhjelm and Friis-Christensen (1974) as

$$By(y) = \frac{\mu_0 I_c}{2\Pi} \left[ F(y+b/2,m) - F(y+b/2,h) - F(y-b/2,m) + F(y-b/2,h) \right] \quad (4)$$

and

$$Bz(y) = \frac{\mu_0 I_c}{2\Pi} \left[ F(m,y+b/2) - F(m,y-b/2) - F(h,y+b/2) + F(h,y-b/2) \right] \quad (5)$$

where the auxiliary function F(s,t) is defined

$$F(s,t) = \frac{1}{2} s \ln(s^2+t^2) - s + t \arctan(s/t) \quad (6)$$

If a cross section is taken of width 40m, upper surface at depth 10m, and lower surface at depth 110m, then evaluating expressions (4) and (6) for these parameters and y=0 indicates that at the surface above the centre line of the channel an anomalous horizontal magnetic field will be present of strength

$$By(0) = 1.6 \times 10^4 I_c \text{ nT} \quad (7)$$

C. The channelling effect.

Assume now that the effect of embedding a long body with the cross-section just described into the half-space of conductivity $\sigma_0$ is to concentrate into the body a uniform current of strength $I_c$. Let the concentration of the current in the channel be c times the undisturbed regional current density $I_0$, so that

$$I_c = c\, I_0 \quad (8)$$

Then, using (7) and (8), and making the approximation that the field above the long body is approximately that above one of infinite length carrying the same current density, one obtains

$$By(0) = 1.6 \times 10^4 c\, I_0 \text{ nT} \quad (9)$$

Using now (1) for a particular value of $I_0$ in (9) gives

$By(0) = 1.2 \times 10^{-3} c$ nT.

Thus, for the particular case considered, a current concentration of 1000 in the orebody will give an anomalous field of strength approximately 1 nT at the surface, and a concentration of 10 in the orebody will give an anomalous field of strength approximately $10^{-2}$nT.

## Discussion

Approximate though the calculations have been, and restricted to one particular case, it is nevertheless evident that the magnetic effects of current channelling in orebodies may be expected to be slight. It may, however, be premature to dismiss them as negligible. Modern magnetometers now measure to a milligamma ($10^{-3}$nT), and for an anomalous signal of ten milligamma a current concentration of 10 is needed in the particular case considered, which is possibly not unrealistic for an orebody with an electrical conductivity perhaps $10^3$ times that of the host rock.

The next steps in this investigation would be (i) the theoretical analysis of what current concentrations are actually likely to occur for particular model orebodies, starting perhaps with the results by Lee (1977) for channelling in a buried ellipsoid; and (ii) the practical measurement of the variability of geomagnetic fluctuations over a scale length of tens or hundreds of metres, to give an indication of the background variation against which the orebody signal would be occurring.

## Acknowledgements

One of us (D.V.W.) is the recipient of an Australian National University research scholarship.

## References

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