Newmont chargeabilities, apparent time constants and finite bandwidths

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There has been significant research into spectral methods in IP as applied to mineral exploration. However, most published IP field data examples from mineral exploration have IP amplitude estimated from phase differences between two frequencies or time domain systems use the Newmont chargeability as the IP parameter. For a Newmont measurement, an injected current is used with an alternating waveform: 2 second on, 2 second off (50 % duty cycle). The Newmont chargeability is the integral of the measured voltage response between 0.45 and 1.1 s after the turn-off, normalised to the peak voltage. The units of Newmont chargeability are typically ms. Most modelling for mineral exploration code however implements a Cole-Cole description of intrinsic IP parameters. This is a frequency domain model with parameters m, c and T (I am using T or capital τ for IP time constants)

Fundamental IP

My favourite description of sulphide mineral IP comes from Wong (1979). The Cole-Cole model has the form:

$$Z(\omega) = R_0\left[1 - m\left(1 - 1/\left(1 + (j\omega T)^c\right)\right)\right]$$

where Z is impedance, R_0 DC resistivity and ω angular frequency.

If $c = 1$, (sometimes called a "Debye" model); in time domain (off-time) the intrinsic decays are exactly exponential $\exp(-t/T)$ with time constant T. Basically $c = 1$ characterises EM and not sulphide IP decays, but can model clay (membrane) polarization decays.

If $c = 0.5$, (sometimes called a "Warburg" model); in time domain the intrinsic decays follow a simple mathematical expression $\mathrm{erfc}((t/T)^{1/2}) \exp(t/T)$. This is the fundamental IP decay for a distribution of uniformly sized polarisable spheres (electronic conductors in an ionic medium). Such decays are illustrated in Fig. 1 with a Newmont system waveform.

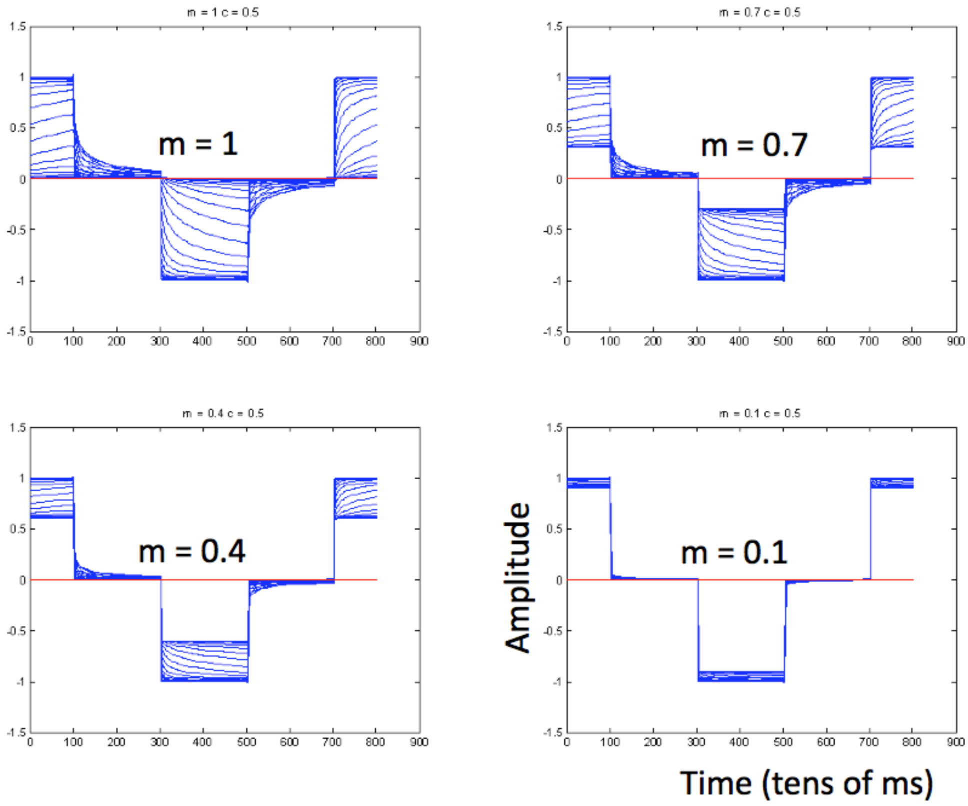

Fig. 1: IP decays with c = 0.5, with varying time constant T in four plots, each with a specific m value.

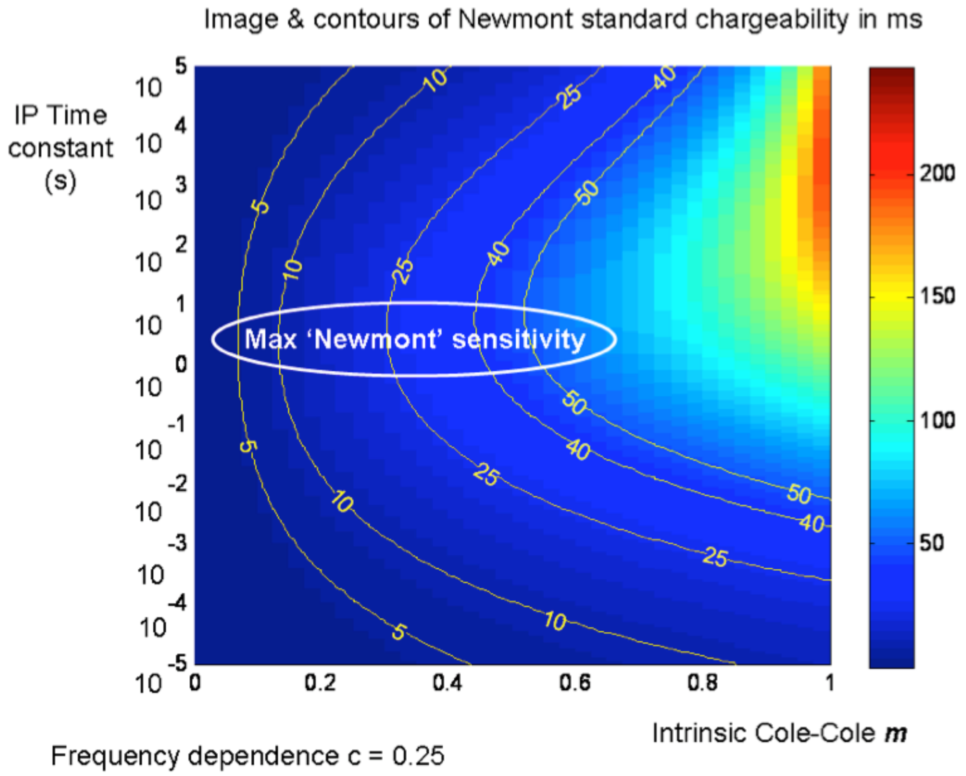

Fig. 2: Contours of Newmont chargeability in ms showing ambiguity with Cole-Cole parameters of a half-space.

If the Newmont chargeability of a half-space is estimated from decays such as those in Fig. 1, for a wide range of *T* and *m*, then it is clear that maximum sensitivity occurs for intrinsic *T* values around 1 to 10 seconds. Newmont chargeabilities over shallow, extensive economic sulphide deposits often exceed 25 ms. In this case, the minimum *m* value would be about 0.3, indicating a significant fraction of polarisable material.

Just as real EM decays can be synthesized from a spread of exponential decays (Stolz and Macnae 1998), real sulphide (electrochemical) IP decays can be synthesized from a spread of Warburg decays. The Cole-Cole model uses parameter $c < 0.5$ to simulate this spread, corresponding to varying grain sizes, each of which has an intrinsic Warburg *T*.

Further complications arise from target geometry and burial. The observed Newmont chargeabilities from a finite target are reduced in amplitude (called "dilution" in some historic literature). These can be modelled, but only with assumed Cole-Cole parameters. In this case, apparent time constants can be changed by orders of magnitude if observed responses are fitted with a basic Cole-Cole model.

Conclusions

Apparent chargeabilities estimated from field data are less than true chargeabilities (whether expressed as Newmont or *m* value).

Apparent time constants can be changed by orders of magnitude if observed responses from a buried target are fitted with a basic Cole-Cole model. Cole-Cole models apply to conductivity rather to decay shape (except to decays measured on lab samples or directly on uniform materials).

Apparent *c* value is always greater than intrinsic *c* value if observed data from a buried target are fitted with a Cole-Cole model without accounting for "dilution".

It is tricky to use published field data (Newmont ms chargeability) to drive modelling. However, maximum *m* values and "typical" *c* values can be fairly safely assumed for modelling.

References

Wong, J., 1979. An electrochemical model of the induced-polarization phenomenon in disseminated sulfide ores. *Geophysics*, 44, 1245-1265.

Stolz, E.M. and Macnae, J., 1998. Evaluating EM waveforms by singular-value decomposition of exponential basis functions. *Geophysics*, 63, 1908-1913.