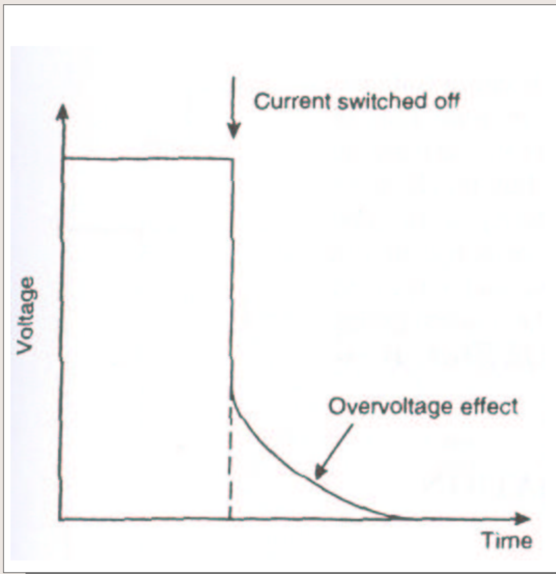
Induced Polarization Method

- Principles;
- Areas of application;
- Measurement;
- Equipment and layout;
- Interpretation;
- Case histories.

- Reading:
  - Reynolds, Chapter 9.
  - Telford et al., Chapter 9.

Induced Potentials

- After current is switched off (or turned on), the voltage between potential electrodes takes 1s - 1 min to decay (or build up)
  - The ground acts somewhat like a capacitor.
- Overvoltage decay times and rise times are measured and are diagnostic of the nature of the subsurface.
- Applications:
  - Metallic deposits with low EM anomalies and high resistivity;
  - *Disseminated* Cu, Pb-Zn ores, Au;
  - Pyrite, chalcopyrite, magnetite, clay, graphite.



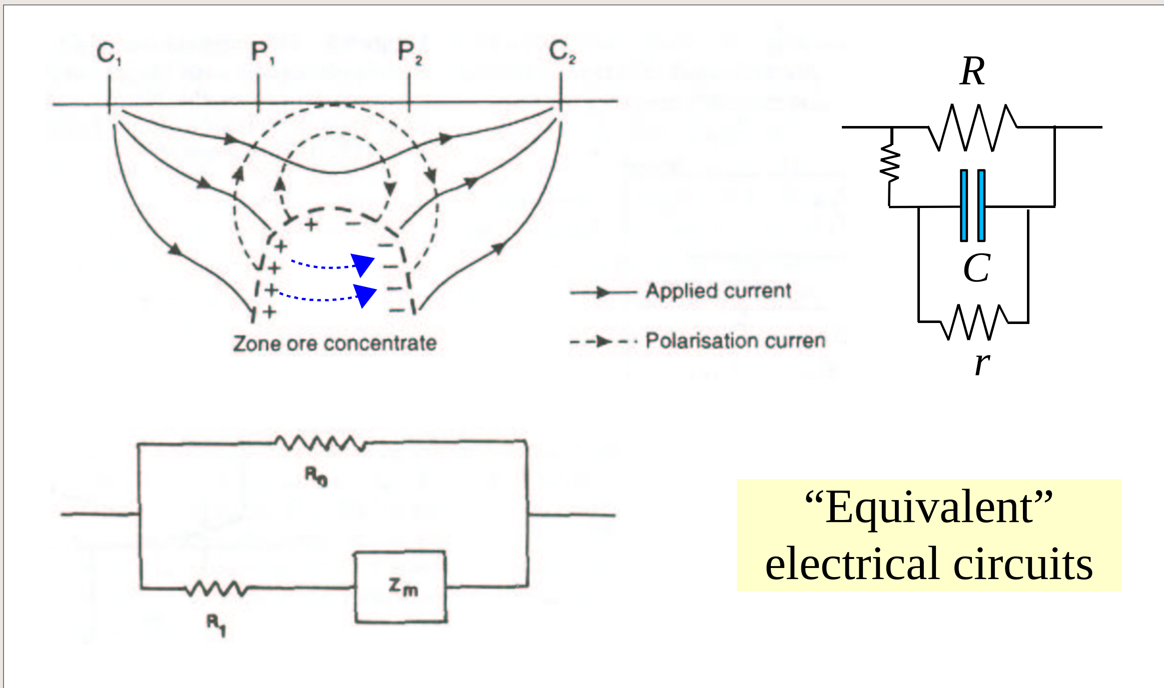
IP Techniques

- *Time domain* (pulse transient);
- *Frequency domain* (using harmonic signals):
  - *Traditional* variable-frequency IP (using two or more frequencies of < 10 Hz);
  - *Phase domain* (measure phase delays between current and voltage);
  - *Spectral IP* (measure phases and amplitudes at frequencies 10^{-3} to $4{\cdot}10^{3}$ Hz).
- Using conventional resistivity arrays
  - Most commonly *double-dipole* configuration;
  - Schlumberger arrays for broad reconnaissance surveys.

Origin of IP

Macroscopic

- IP s sensitive to *dielectric* rater than conductivity characteristics.
- Disseminated (poorly conductive) ore body is polarized (develops *surface charges*) by the imposed current;
- When the current is switched off, the charges cause transient current through the conductive overburden.
  - These currents flow *in the same direction* and cause the overvoltage effect.

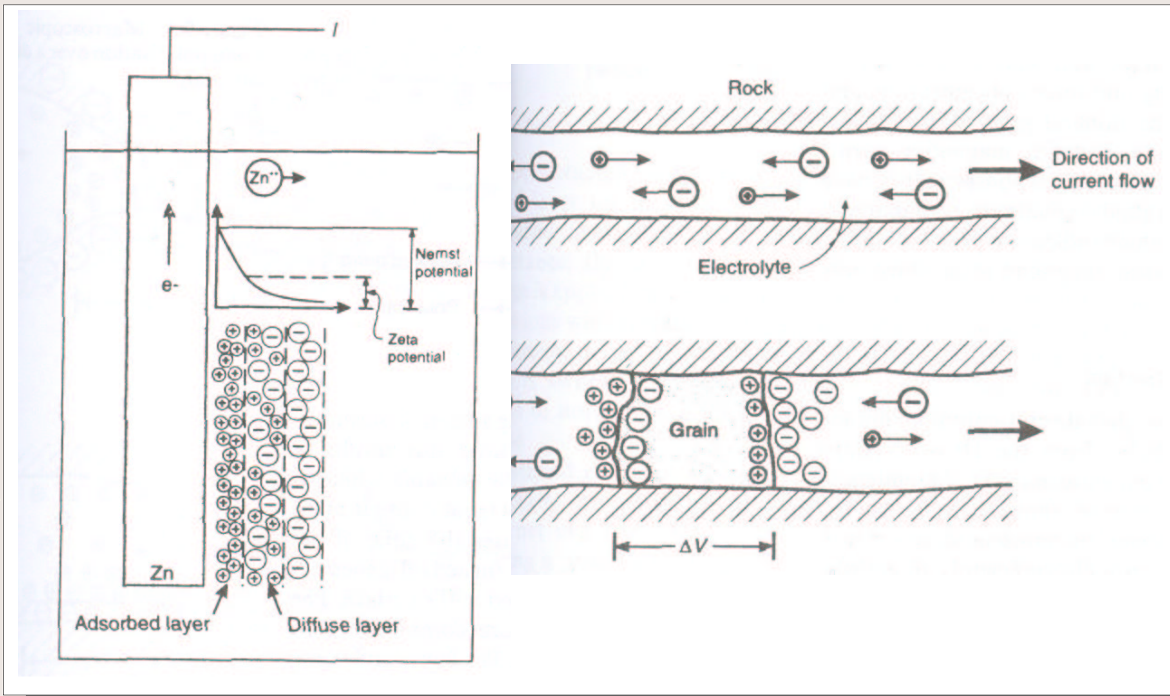


"Equivalent" electrical circuits

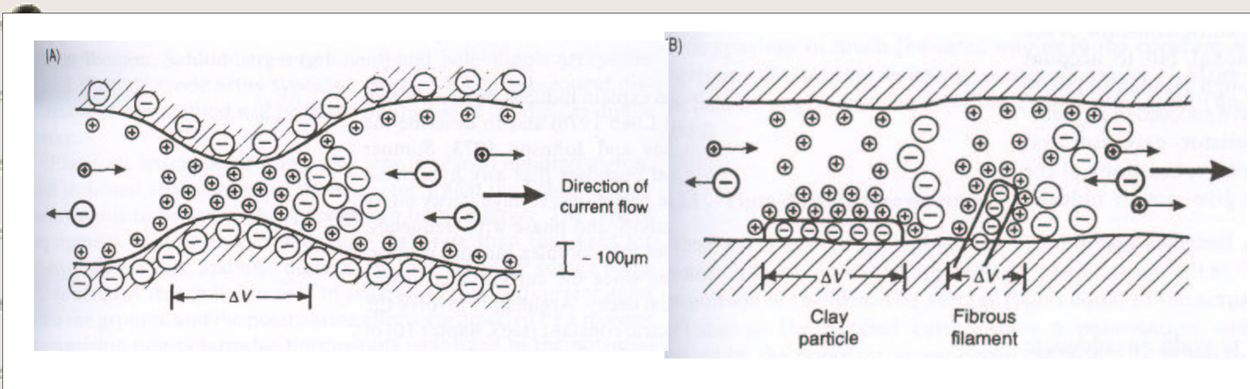
Origin of IP

Microscopic

- Grain (and electrode) polarization:



- Electrolytic (membrane) polarization:

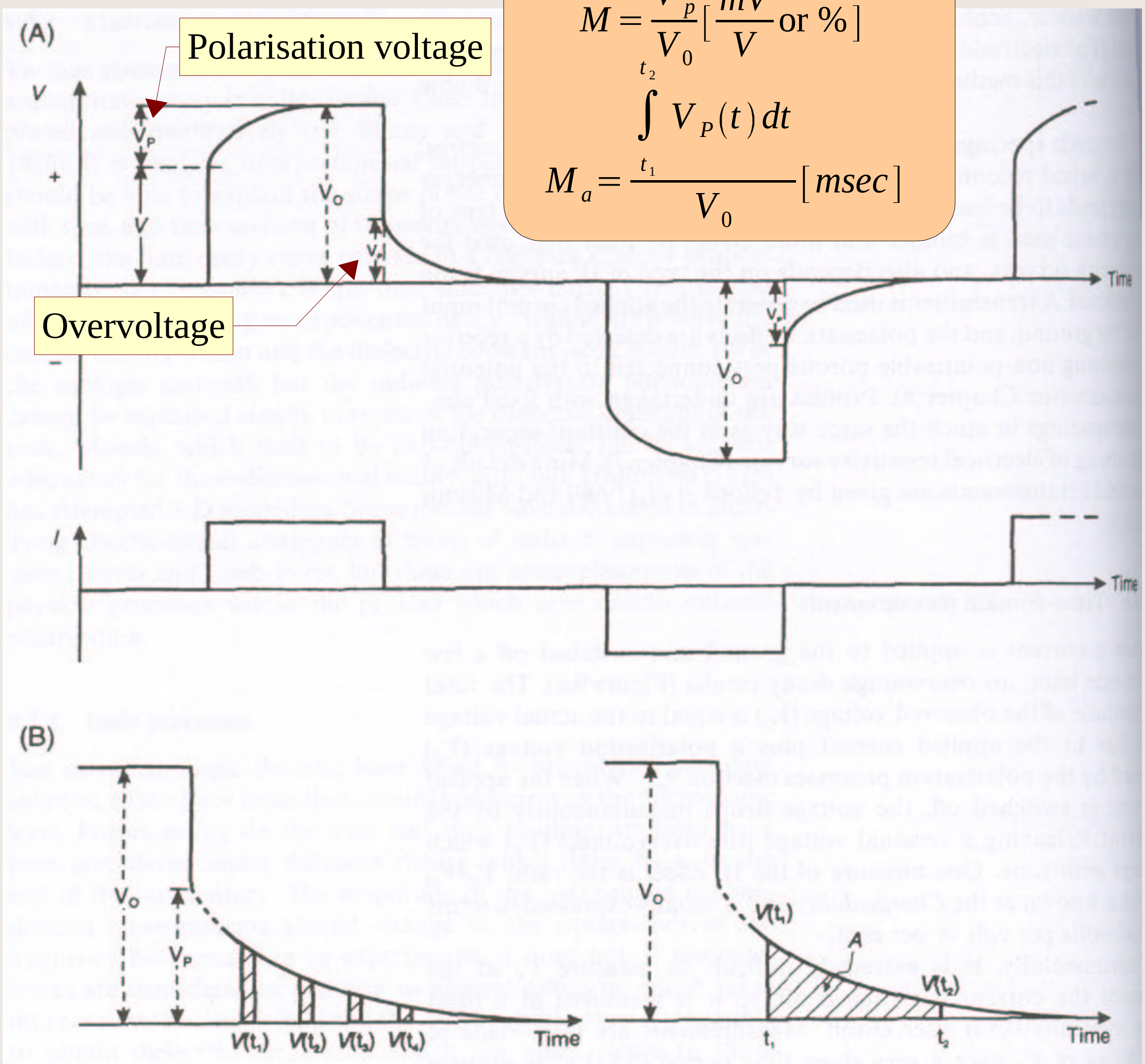


Time-domain IP

- Measuring *apparent chargeability (M)*
  - Apparent chargeability (M_a) increases with increasing duration of the pulses (~ 3-5 s);
  - Graphite has M_a.=11.2 ms, magnetite - 2.2 ms at 1 s integration.

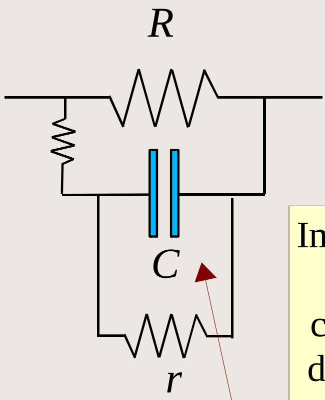
$$M = \frac{V_p}{V_0}\left[\frac{mV}{V} \text{ or } \%\right]$$

$$M_a = \frac{\int_{t_1}^{t_2} V_P(t)\,dt}{V_0}\left[msec\right]$$



Variable-frequency IP

- Using the same array as in DC resistivity measurements but driving AC current at several frequencies.
- Measuring ρ_a(*frequency*):
  - ρ_a *decreases* with frequency;
  - This decrease is measured as the *Frequency Effect* (FE):



Impedance of the capacitor decreases with frequency: $Z=1/i\omega C$; hence the total resistance *decreases.*

$$Frequency\,Effect = \frac{\rho_a(f_0)-\rho_a(f_1)}{\rho_a(f_1)} \quad [\text{unitless or } \%].$$

- FE can also be expressed as the *Metal Factor* (variation of apparent *conductivity*):

$$Metal\,Factor = 2\times10^5\pi\,\frac{\rho_a(f_0)-\rho_a(f_1)}{\rho_a(f_0)\rho_a(f_1)} = 2\times10^5\pi\,(\sigma_a(f_1)-\sigma_a(f_0))$$

$[\text{siemens/m}]$.

Spectral (complex resistivity) IP

- Using AC current at *a range* of frequencies from 30 to 4000 Hz.
- Measuring complex *impedance*:

$$Z(\omega) = \frac{U(\omega)}{I(\omega)} K.$$

Geometric factor of the array

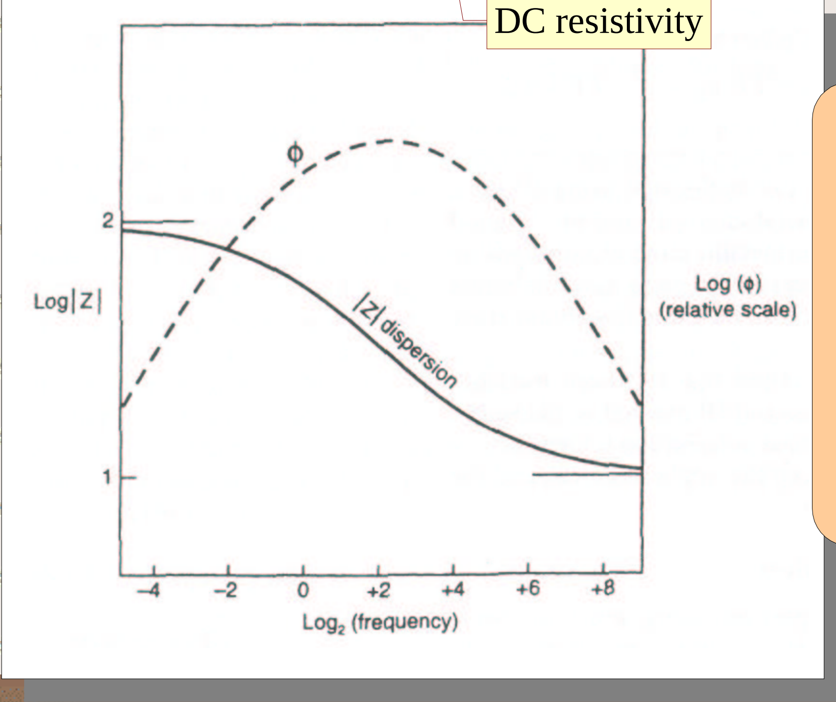
- The *Cole-Cole* model for complex resistivity:

$$Z(\omega) = \rho_0 [1 - M(1 - \frac{1}{(1 + i\omega\tau)^c})] = |Z| e^{i\phi}$$

Chargeability

Relaxation time

DC resistivity

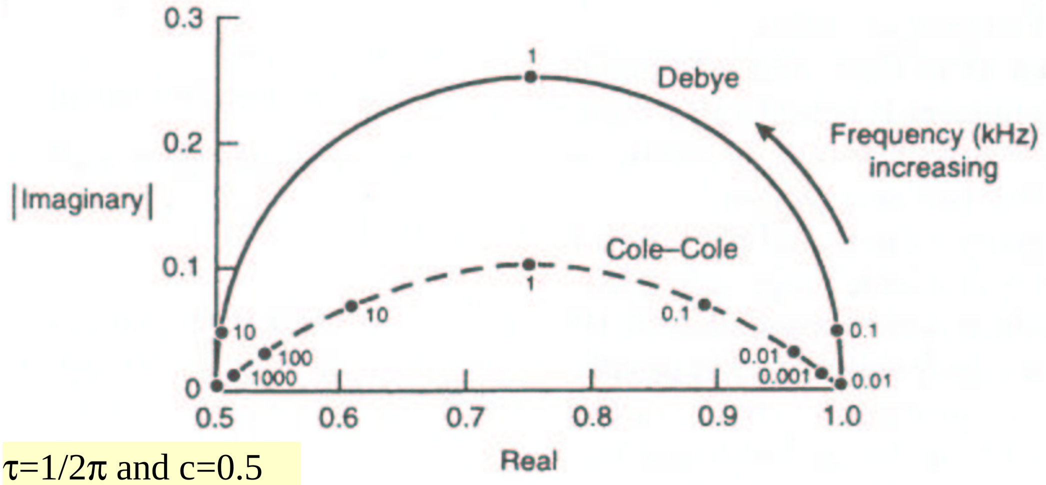


Typical values:
M: 0-1 (depending on mineral content);
τ: 10^{-4} - 10^{4} (depending on grain size);
c: 0.2 - 0.6 (depending on grain size distribution)

Cole-Cole relaxation spectra

- For varying frequencies, complex resistivity describes a semicircle in (Re*Z*, Im*Z*) plane:

$$Z(\omega)=\rho_0[1-M(1-\frac{1}{(1+i\omega\tau)^c})]=\Re(Z)+i\Im(Z)$$



$\tau=1/2\pi$ and $c=0.5$

- The *critical frequency* at which the maximum phase shift is measured is indicative of τ:

$$F_c=\frac{1}{2\pi(1-M)^{1/2c}}$$

Independent of resistivity

Chargeability of various materials

Table 9.3. *Chargeability of various materials.*

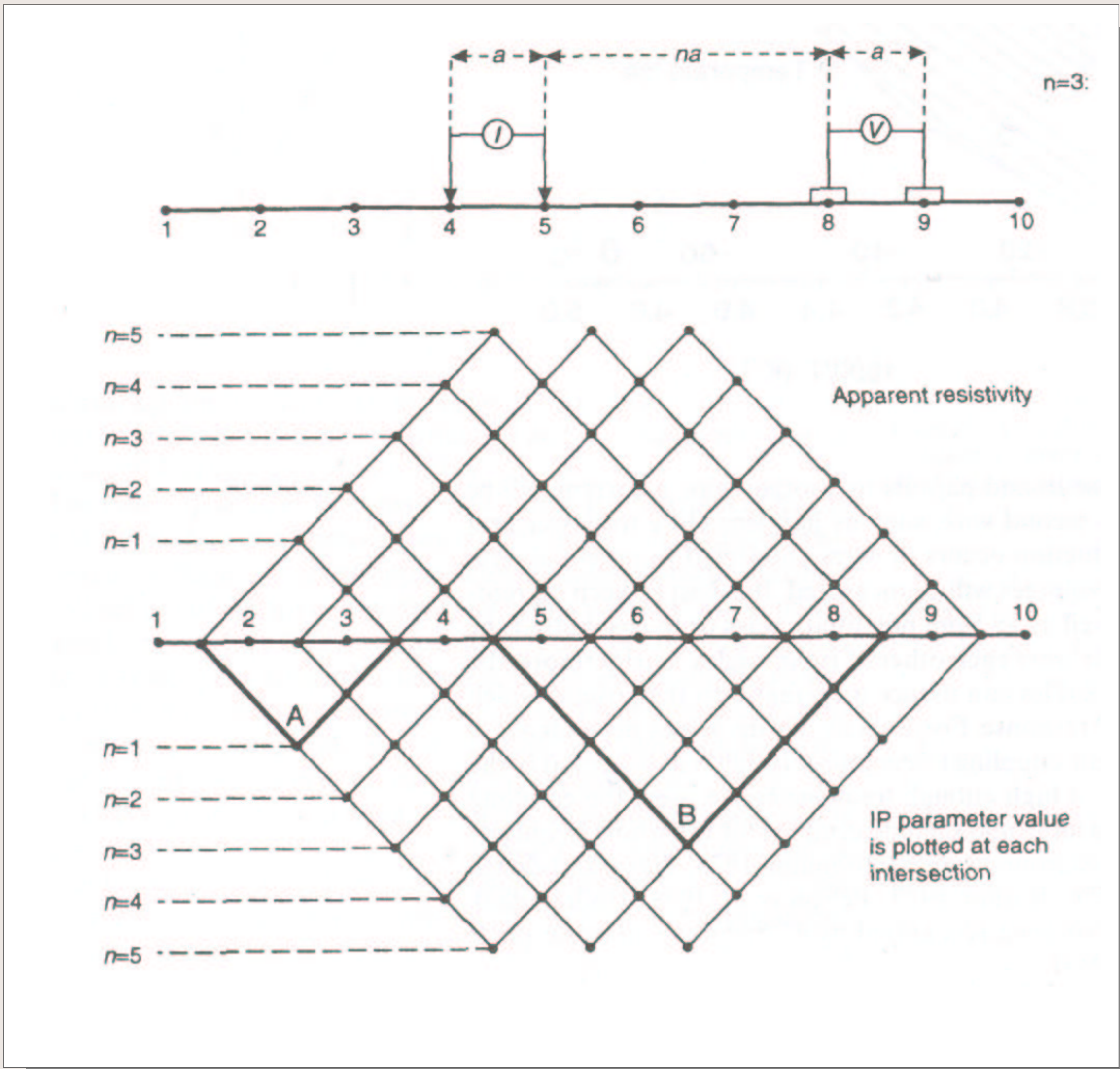
Material	Chargeability (ms)
Ground water	0
Alluvium	1 – 4
Gravels	3 – 9
Precambrian volcanics	8 – 20
Precambrian gneisses	6 – 30
Schists	5 – 20
Sandstones	3 – 12
Argillites	3 – 10
Quartzites	5 – 12

Table 9.4. *Metal factor of various rocks and minerals.*

Material	Metal factor (mhos/cm)
Massive sulfides	10,000
Fracture-filling sulfides	1,000 – 10,000
Massive magnetite	3 – 3,000
Porphyry copper	30 – 1,500
Dissem. sulfides	100 – 1,000
Shale-sulfides	3 – 300
Clays	1 – 300
Sandstone – 1 – 2% sulfides	2 – 200
Finely dissem. sulfides	10 – 100
Tuffs	1 – 100
Graphitic sandstone and limestone	4 – 60
Gravels	0 – 200
Alluvium	0 – 200
Precambrian gneisses	10 – 100
Granites, monzonites, diorites	0 – 60
Various volcanics	0 – 80
Schists	10 – 60
Basic rocks (barren)	1 – 10
Granites (barren)	1
Groundwater	0

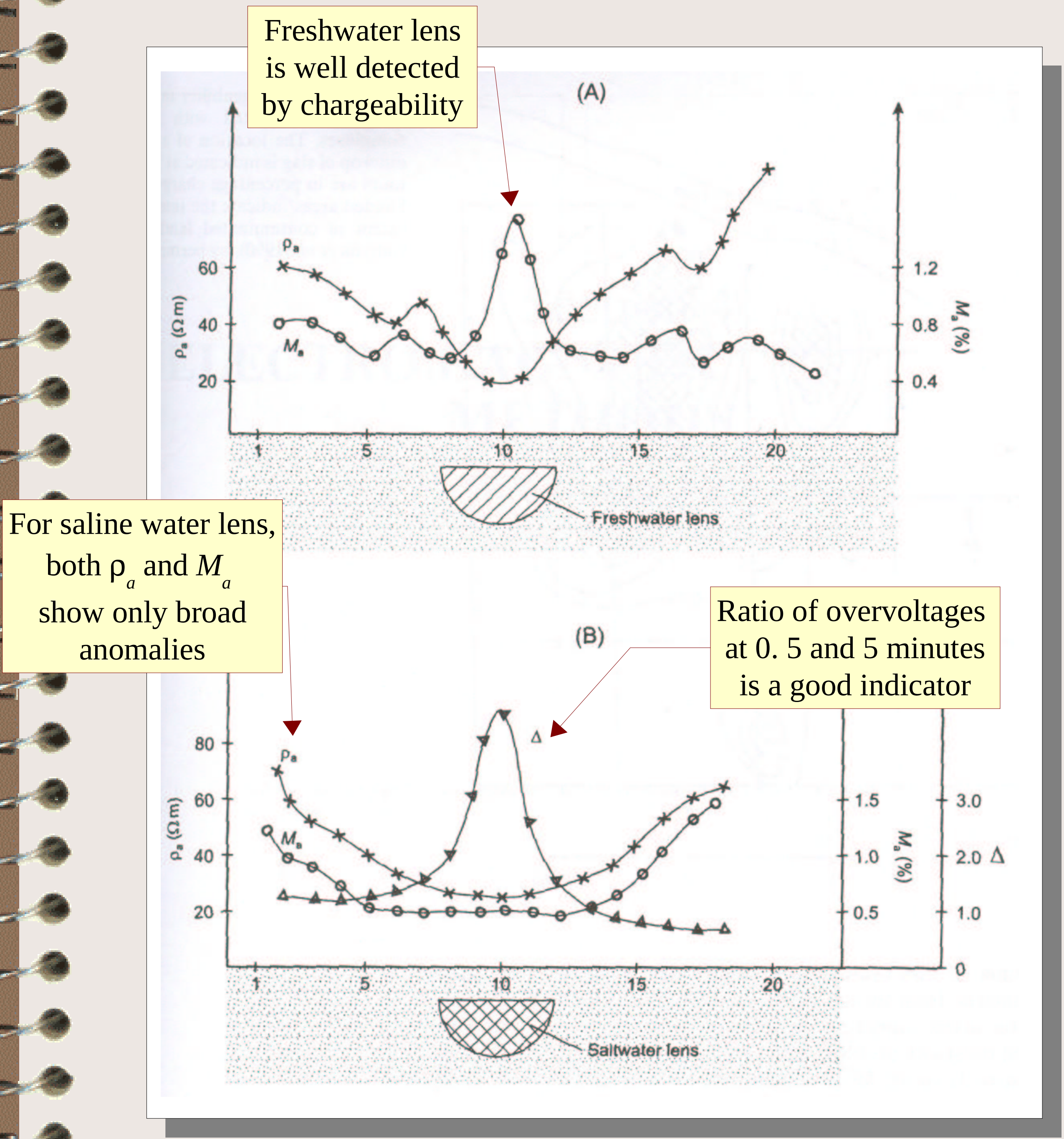
Displays of IP data

- Profiles and maps of apparent chargeability (time-domain IP);
- Pseudo-sections (combined with ρ_a)



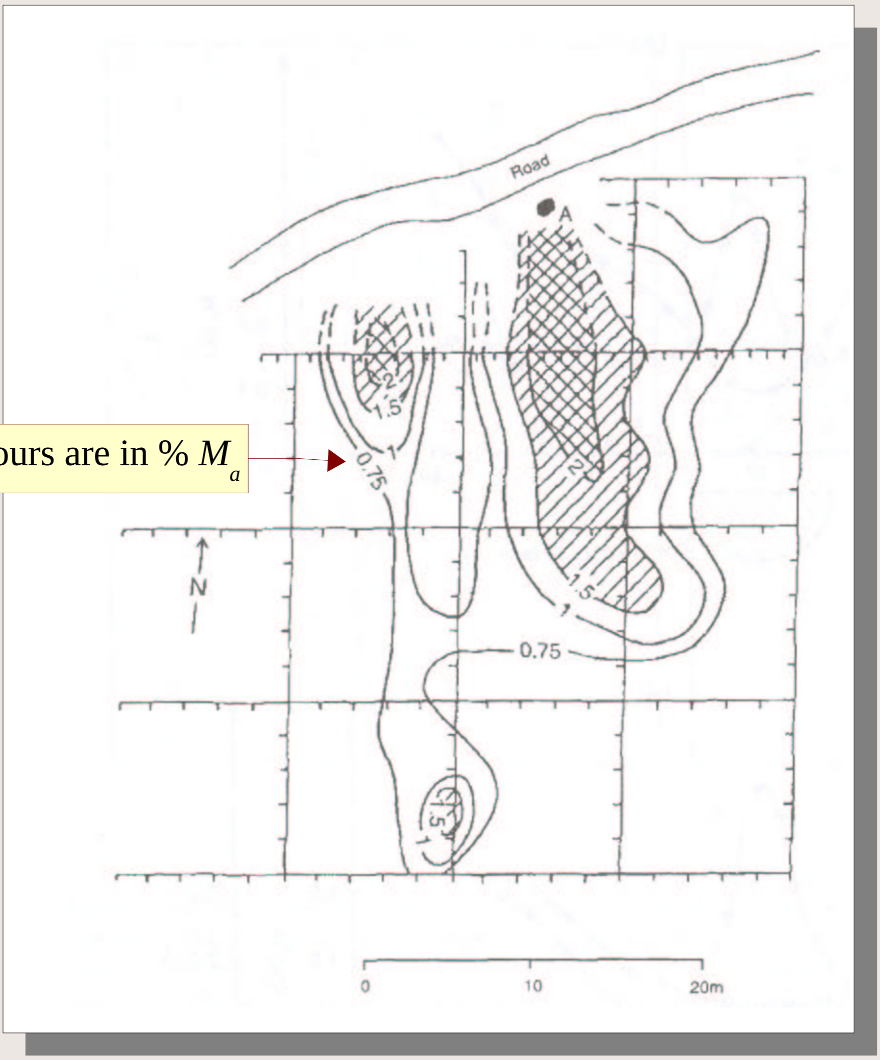
Lab Case History

(Ogilvy and Kuzmina, 1972)



IP Case History

- Identification of a contamination with cyanide complexes (slags from plating works; Cahyna et al., 1990);
  - Resistivity survey failed to detect th contamination;
  - IP chargeability identified both the known and unknown slag deposits.



Contours are in % M_a