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Electrical Surveying
Part II: Induced polarization method

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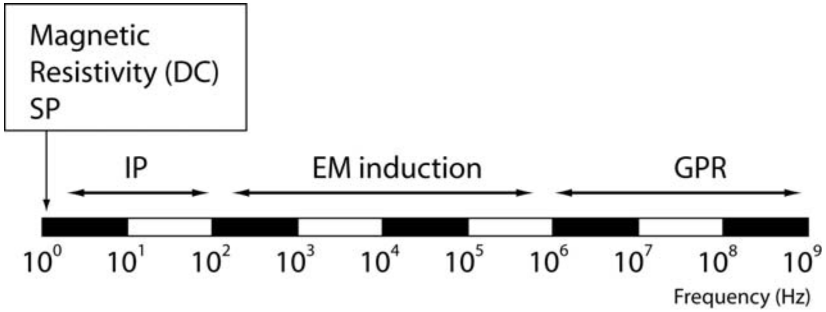
Introduction

Electrical surveying…



- Resistivity method
- Induced polarization method (IP)
- Self-potential (SP) method

Higher frequency methods (electromagnetic surveys):

- Electromagnetic induction methods
- Ground penetrating radar (GPR)

Induced polarization method

The induced polarization method makes use of the capacitive action of the subsurface to locate zones where clay and conductive minerals are disseminated within their host rocks

Application

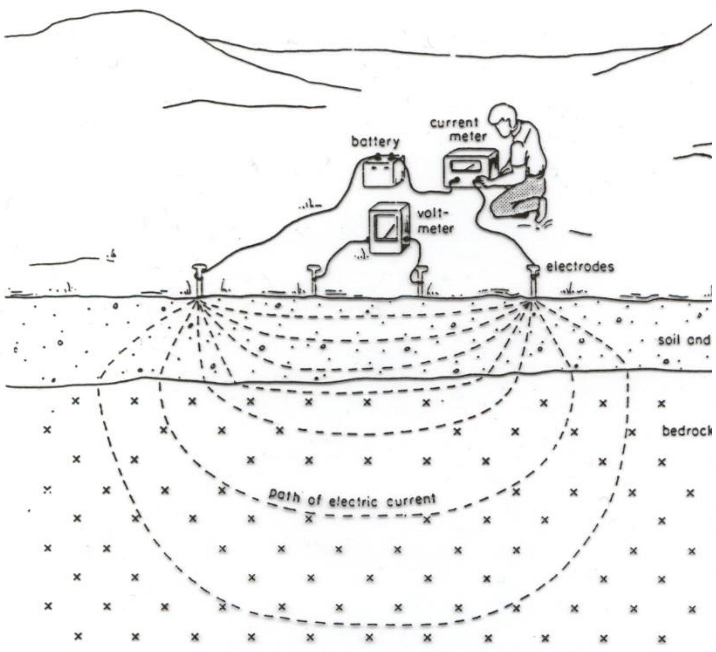
- Exploration of metalliferous mineral deposits
- Clay location for hydrogeological surveys
- Mapping electrochemical reactions for pollutants in the ground

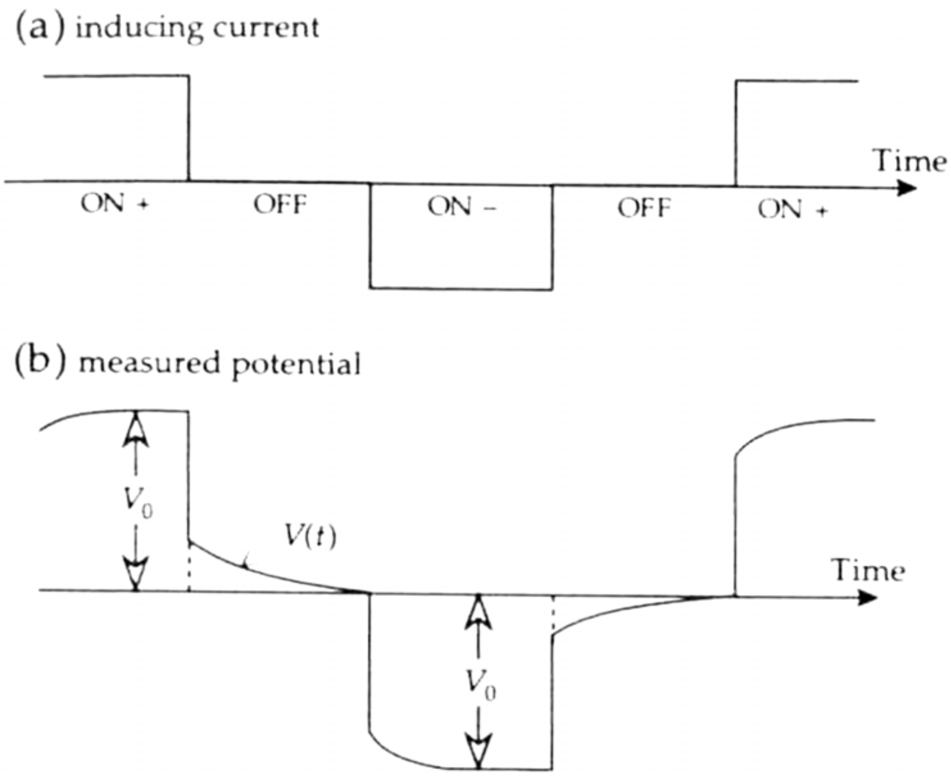
Structure of the lecture

1. Basic IP theory and units
2. IP properties of rocks
3. Survey strategies and interpretation
4. Conclusions

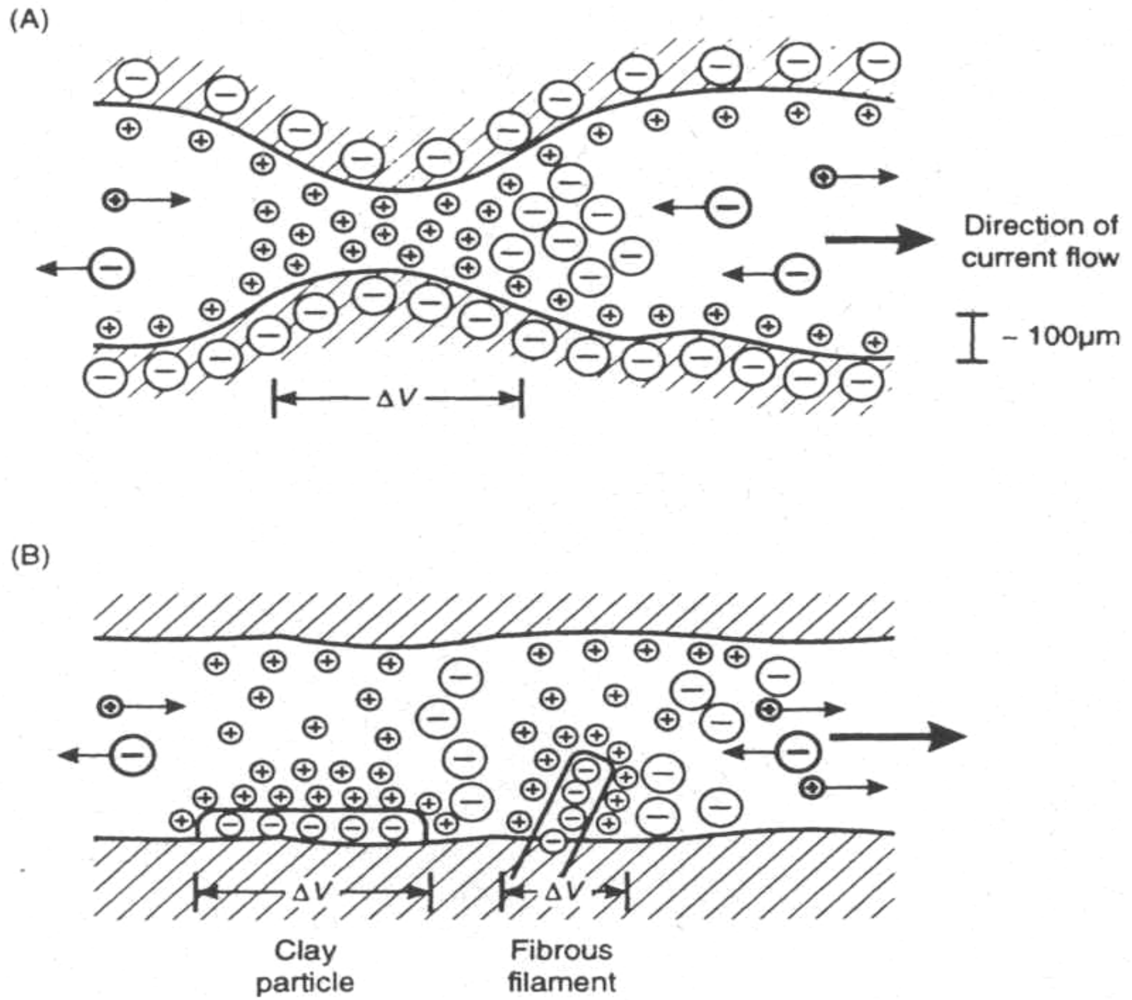
1. Basic IP theory and units

Basic theory

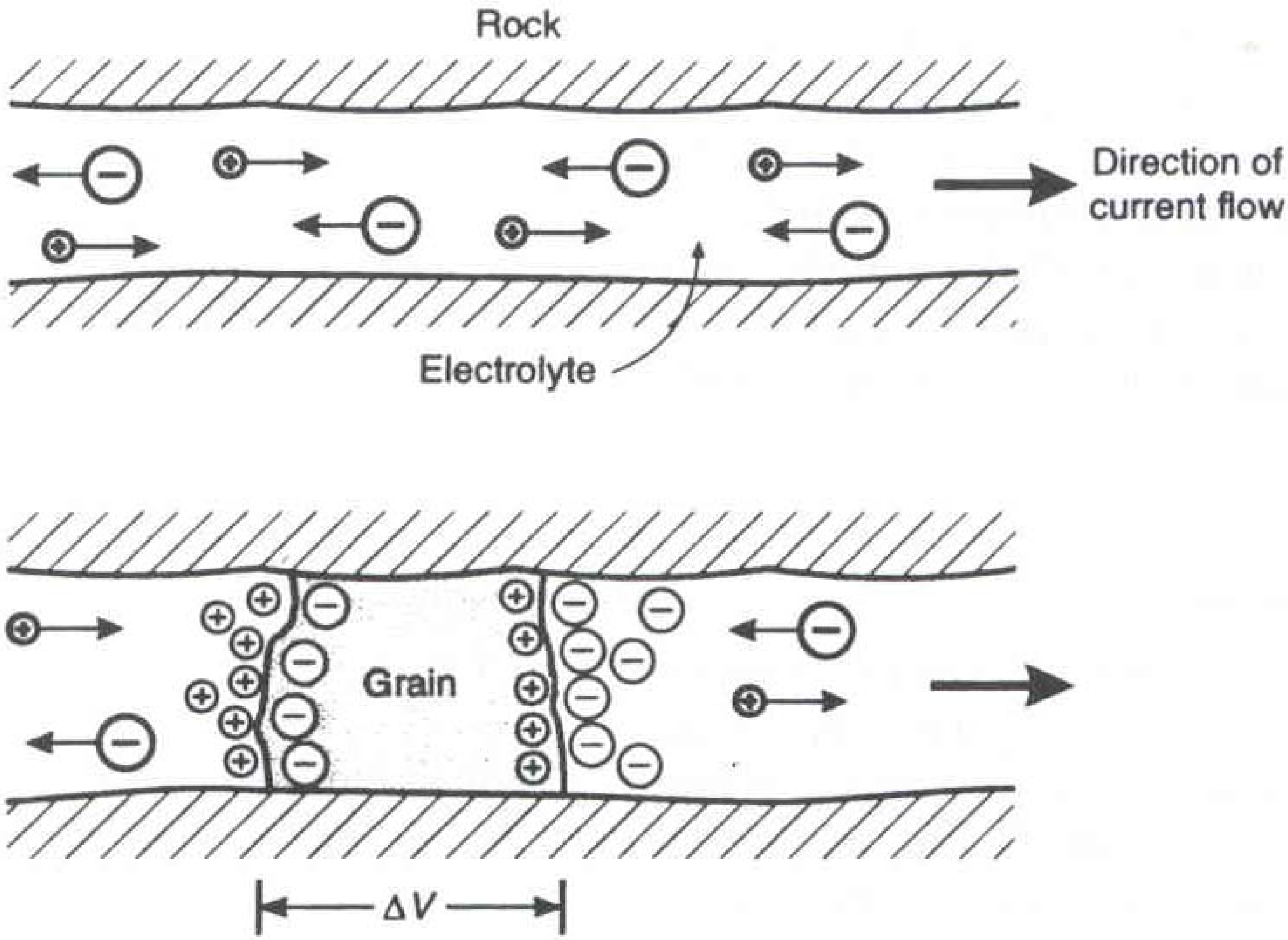


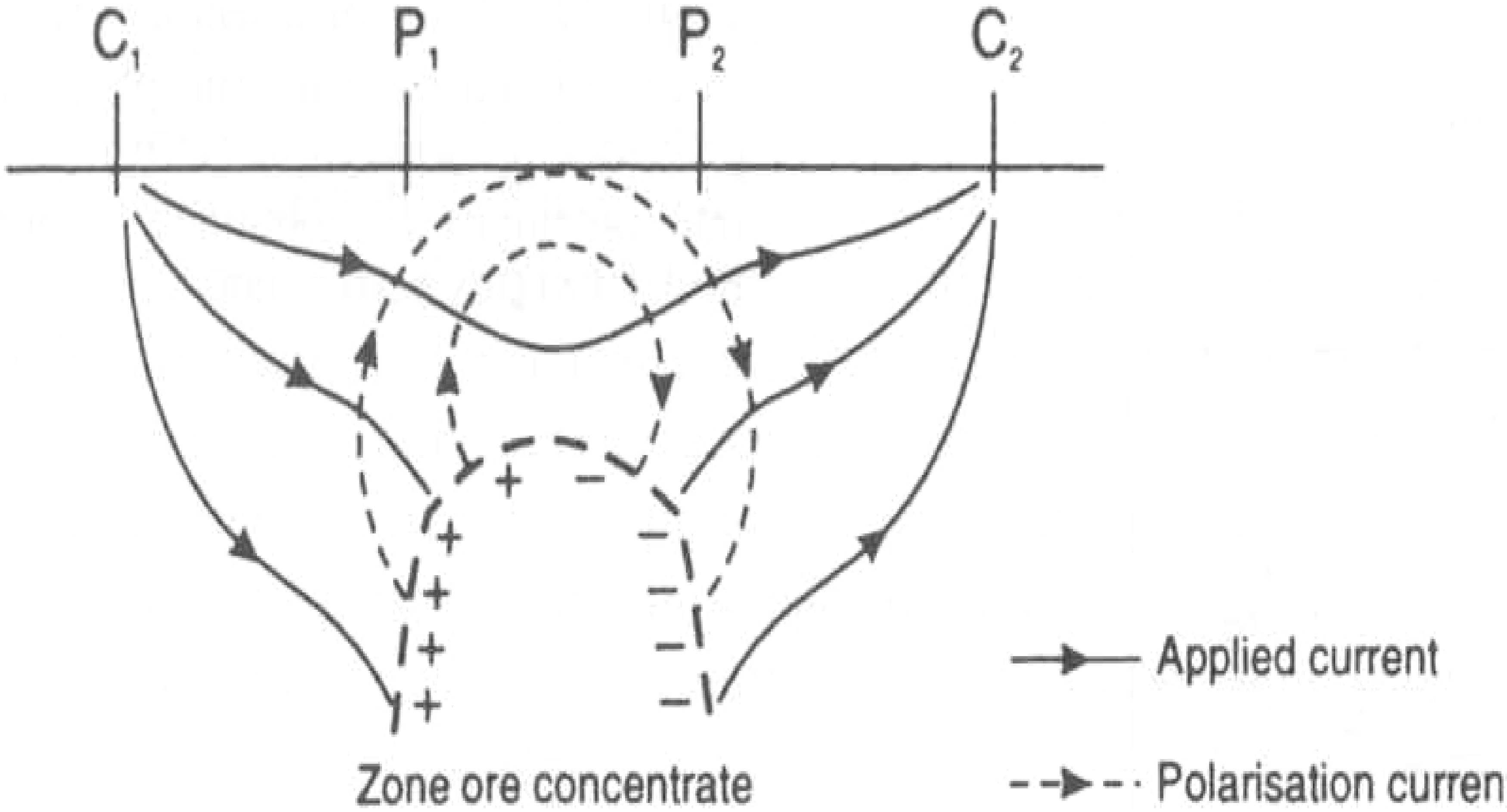


Membrane polarization



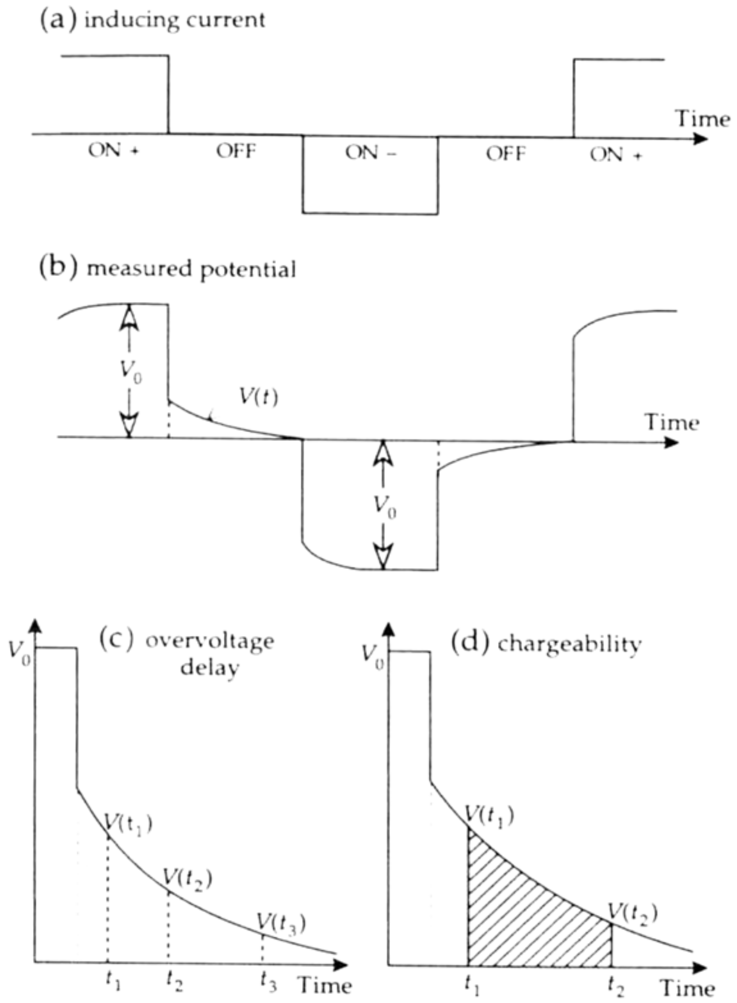
Electrode polarization





Note that membrane and electrode polarizations cannot be separately identified!

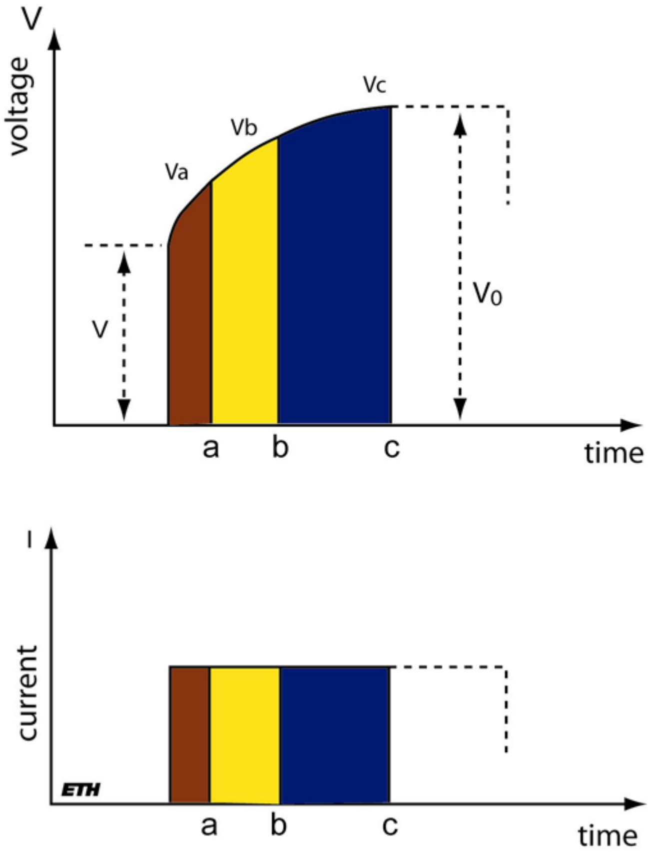
Time-domain IP



$$M_a = \frac{1}{V_0}\int_{t_1}^{t_2} V(t)\,dt$$

M_a is the apparent chargeability in milliseconds (ms)

Frequency-domain IP



$$FE = 100\,\frac{\rho_{a\,DC} - \rho_{aAC}}{\rho_{aAC}}$$

FE is the percent frequency effect (in %)

ρ_{aDC} is the apparent resistivity mesured at low frequency (0.05-0.5 Hz)

ρ_{aAC} is the apparent resistivity mesured at higher frequency (1-10 Hz)

Frequency-domain IP

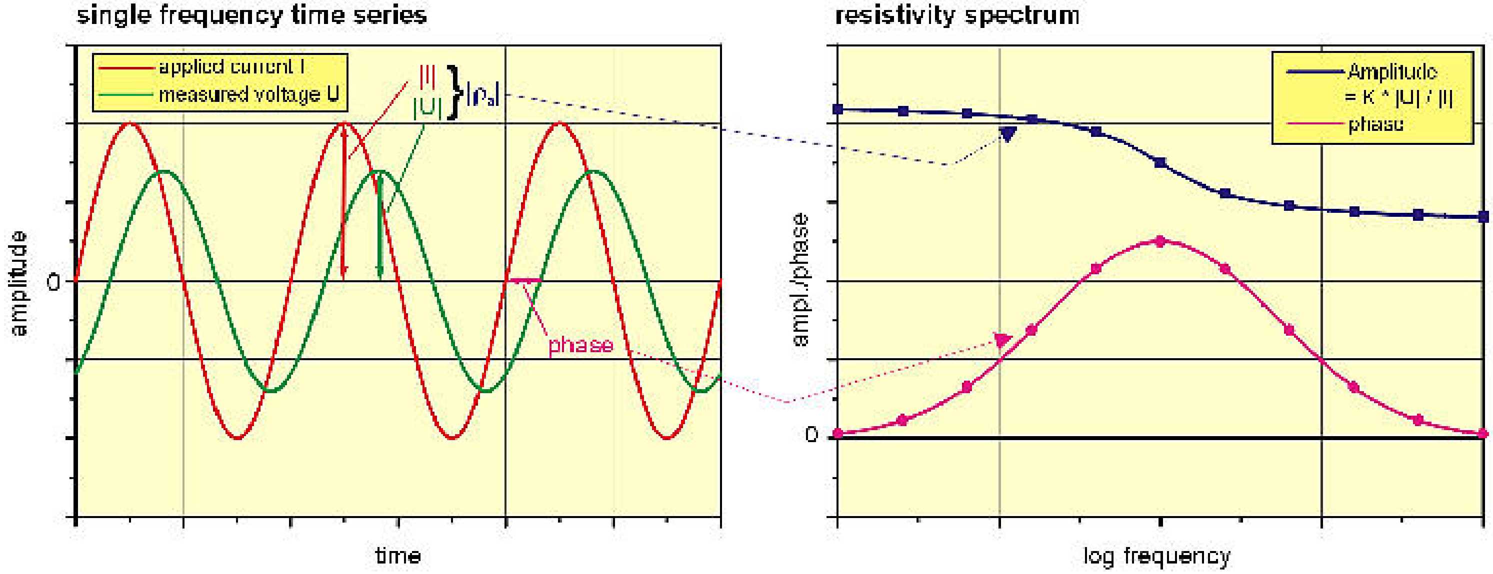
$$MF = 2\pi \cdot 10^5 \frac{(\rho_{aDC} - \rho_{aAC})}{\rho_{aDC}\rho_{aAC}} = 2\pi \cdot 10^5 \frac{FE}{\rho_{aDC}}$$

MF is the metal factor in Siemens per meters (S/m)

This normalization removes to a certain effect the variation of IP effect with the effective resistivity of the host rock (ρ_{aDC})

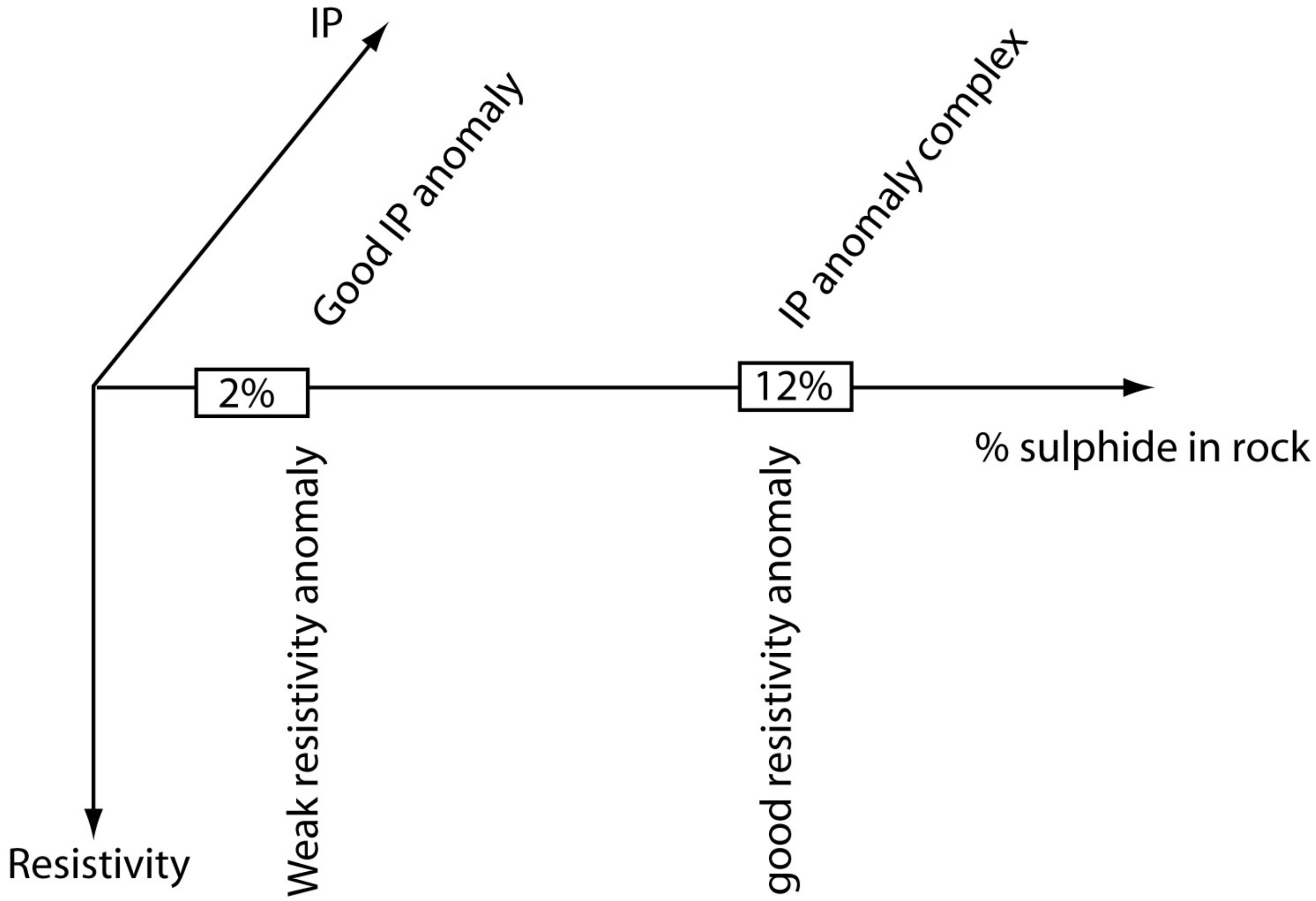
Spectral induced polarization (SIP)

- For a complete description of the IP phenomenon, two frequencies are not enough. The SIP technique measures a frequency spectrum ranging from 10^{-2} to 10^{4} Hz.
- The shift between the current and the potential is used to discriminate between various metallic ores or substances



2. IP properties of rocks

IP versus resistivity



Chargeability of minerals

Mineral	Chargeability (ms)	Mineral	Chargeability (ms)
Pyrite	13.4	Erubescite	6.3
Chalcocite	13.2	Galena	3.7
Copper	12.3	Magnetite	2.2
Graphite	11.2	Malachite	0.2
Chalcopyrite	9.2	Hematite	0.2

Concentration 1 %, current injection time 3 s, integration time 1 s

Chargeability of rocks

Rock	Chargeability (ms)	Rock	Chargeability (ms)
Aquifer	0	Schist	5 to 20
Alluvion	1 to 4	Sandstone	3 to 12
Gravel	3 to 9	Argilite	3 to 10
Volcanic	8 to 20	Quartzite	5 to 12
Gneiss	6 to 30		

Current injection time 3 s, integration time 0.02 s to 1s

IP effect…

- … is higher for disseminated than massive clay and metallic particles
- … depends on the concentration of clay and metallic particles
- …increases if water in the ground has a low conductivity
- … increases with decreasing porosity
- …varies with the amount of water in the ground
- …depends on the current intensity and the current frequency

3. Survey strategies and interpretation

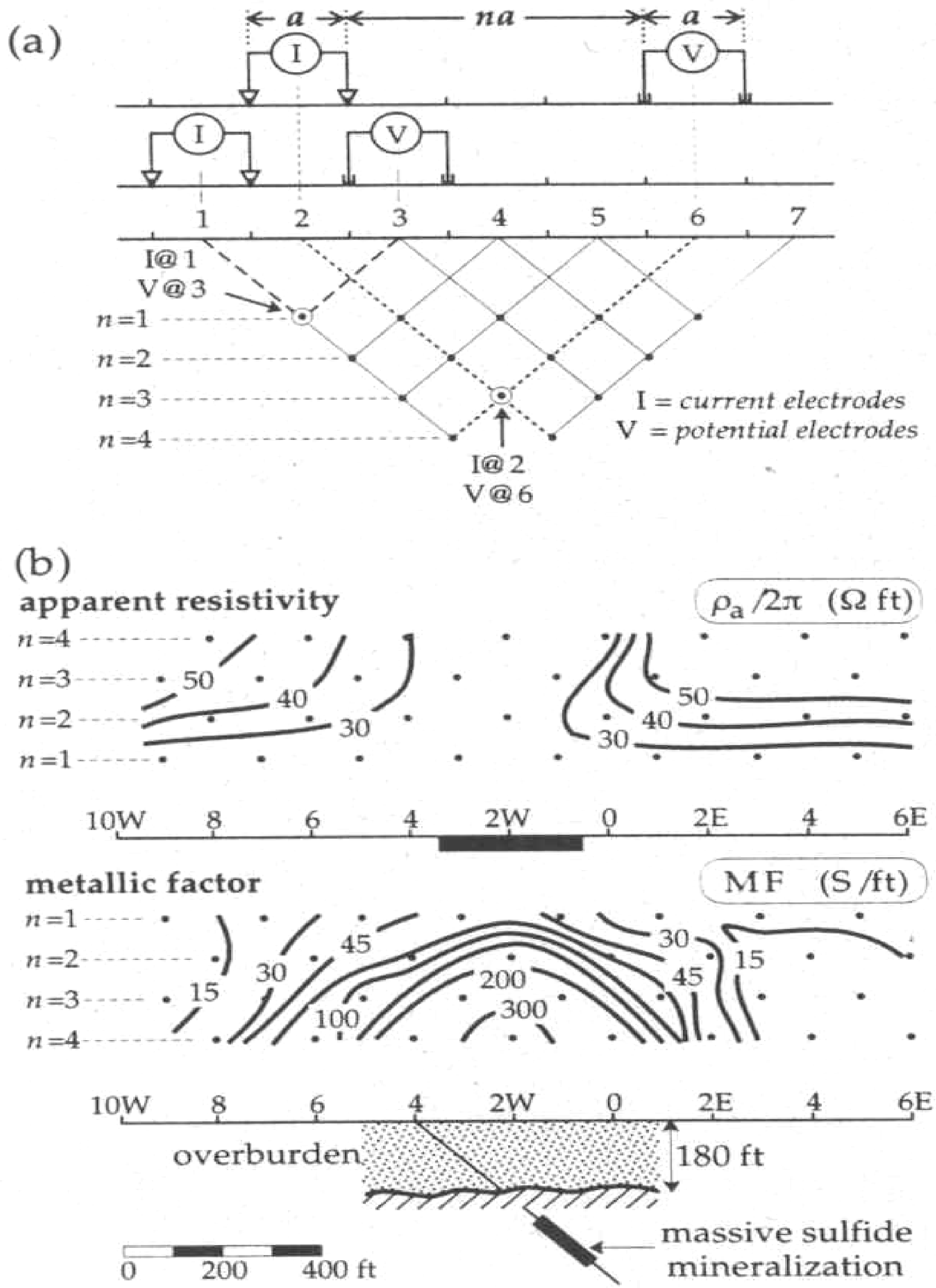
IP measurement

- Different measurement devices for Time-domain IP and Frequency-domain IP
- Same electrode arrays (for mapping and sounding) than in conventional resistivity
- Sensitive to telluric noise
- Sensitive to noise resulting from electromagnetic coupling between adjacent wires (dipole-dipole array very useful)
- Stability of potential measurements can be a problem (use non polarizable electrodes, see lecture on SP surveying)

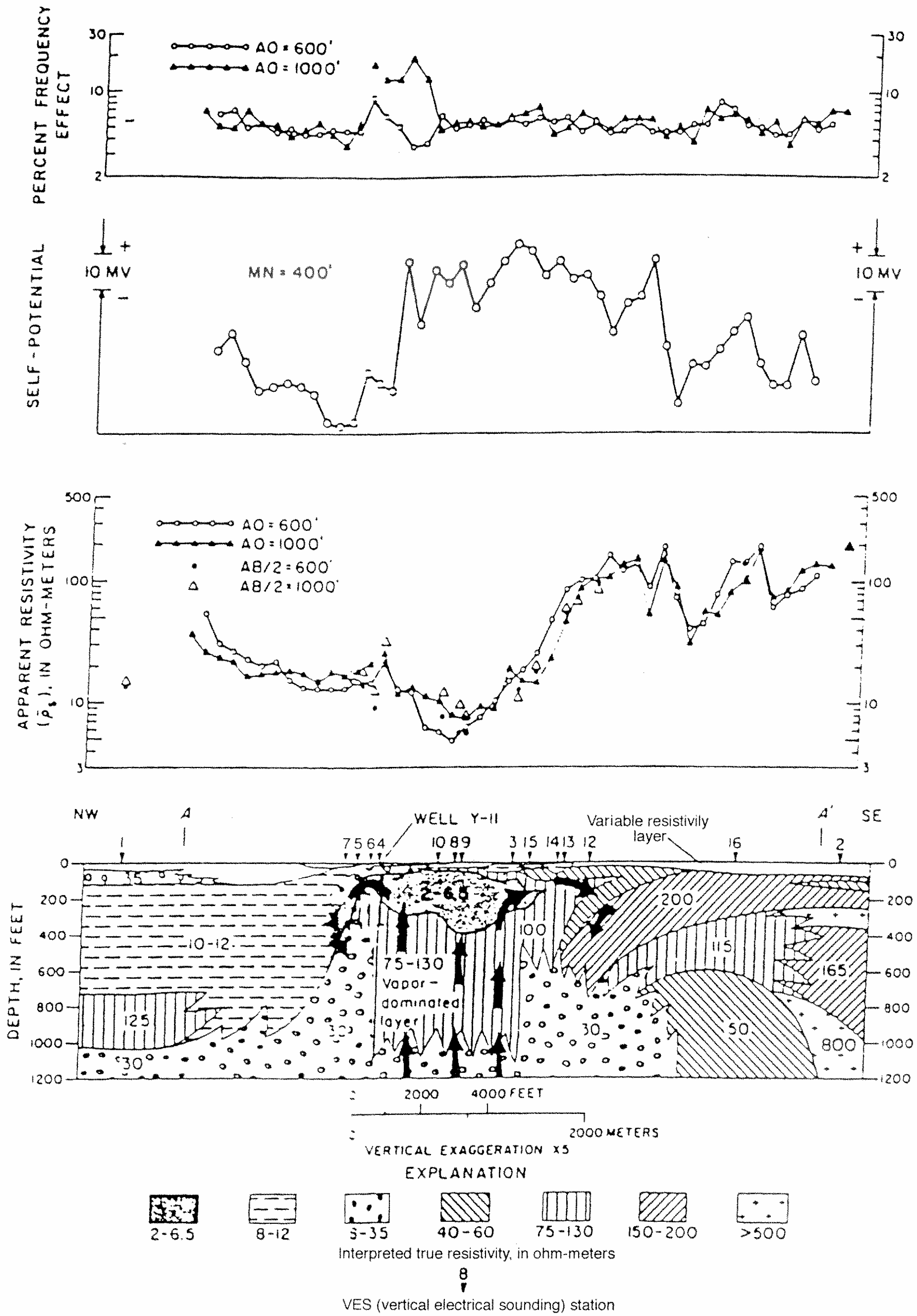
Interpretation

- Mainly qualitative, more complex than for resistivity
- Inversion using iterative algorithms (similar to resistivity)
- For SIP, getting information on material structures (e.g. size of pores) using the Cole-Cole model

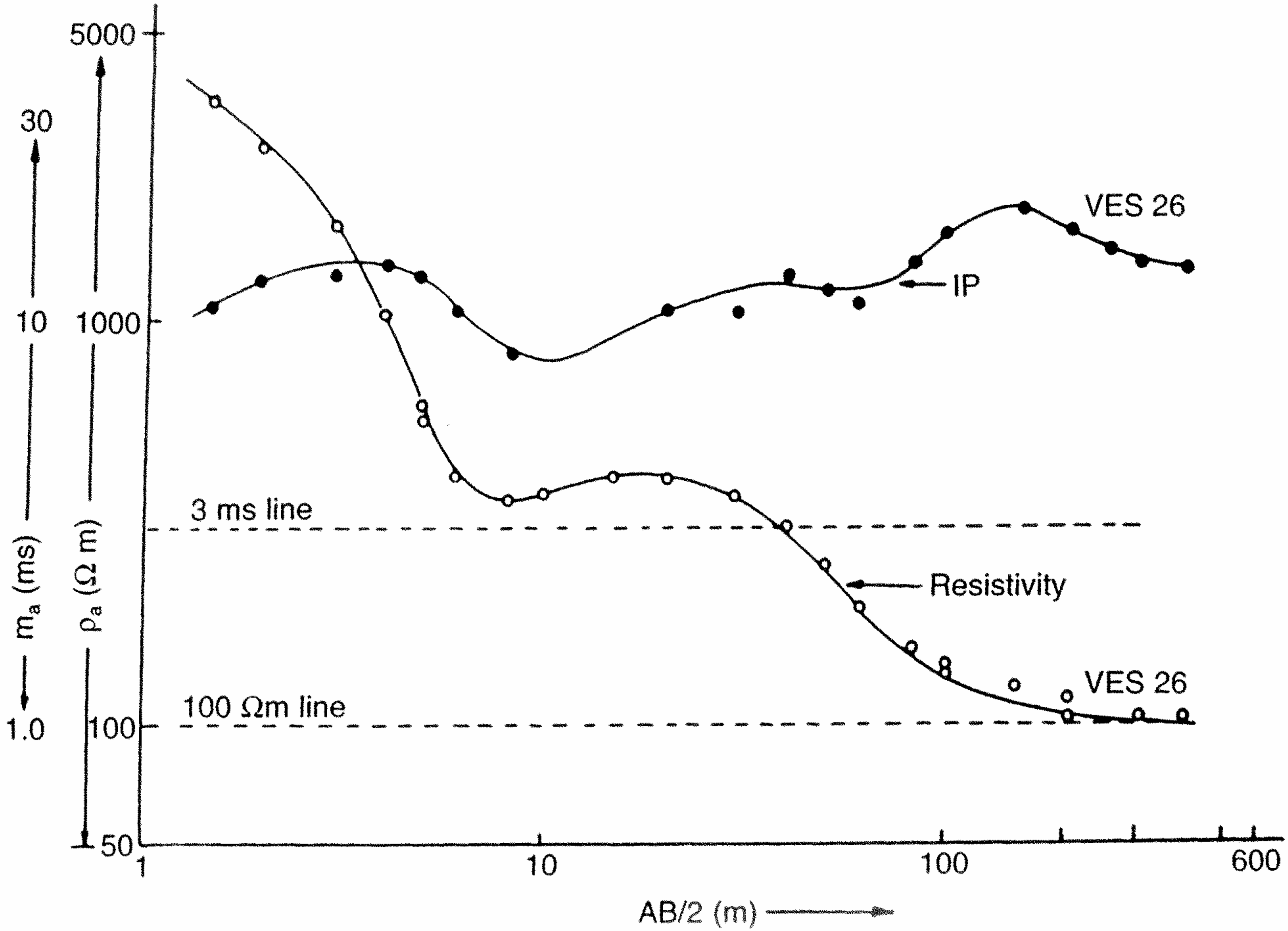
Mining geophysics



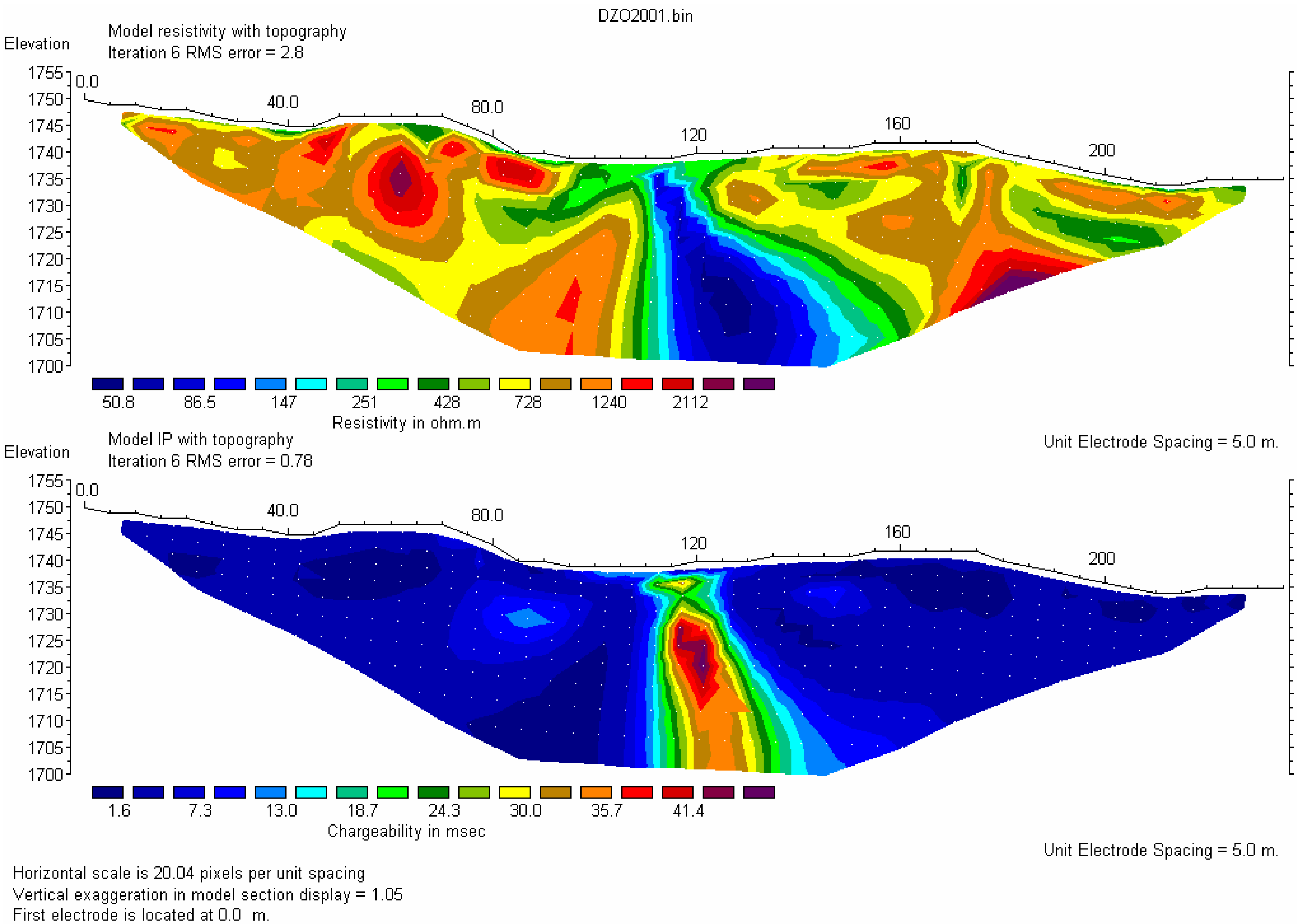
Geothermy



PERCENT FREQUENCY EFFECT
AO = 600'
AO = 1000'
SELF-POTENTIAL
10 MV
MN = 400'
APPARENT RESISTIVITY ($\bar{\rho}_a$), IN OHM-METERS
AO = 600'
AO = 1000'
AB/2 = 600'
AB/2 = 1000'
NW
SE
WELL Y-11
Variable resistivity layer
DEPTH, IN FEET
10-12
75-130
Vapor-dominated layer
2-6.5
100
200
115
165
125
30
50
800
2000
4000 FEET
2000 METERS
VERTICAL EXAGGERATION X5
EXPLANATION
2-6.5
8-12
3-35
40-60
75-130
150-200
>500
Interpreted true resistivity, in ohm-meters
VES (vertical electrical sounding) station


5000
30
10
1000
1.0
100
50
m_a (ms)
ρ_a (Ω m)
VES 26
IP
3 ms line
Resistivity
VES 26
100 Ωm line
1
10
100
600
AB/2 (m)

Geology


DZO2001.bin
Elevation
Model resistivity with topography
Iteration 6 RMS error = 2.8
1755
1750
1745
1740
1735
1730
1725
1720
1715
1710
1705
1700
0.0
40.0
80.0
120
160
200
50.8
86.5
147
251
428
728
1240
2112
Resistivity in ohm.m
Unit Electrode Spacing = 5.0 m.
Elevation
Model IP with topography
Iteration 6 RMS error = 0.78
1755
1750
1745
1740
1735
1730
1725
1720
1715
1710
1705
1700
0.0
40.0
80.0
120
160
200
1.6
7.3
13.0
18.7
24.3
30.0
35.7
41.4
Chargeability in msec
Unit Electrode Spacing = 5.0 m.
Horizontal scale is 20.04 pixels per unit spacing
Vertical exaggeration in model section display = 1.05
First electrode is located at 0.0 m.

4. Conclusions

Advantages

- Detection of disseminated mineral (difficult with resistivity)
- Method sensitive to clay in aquifers

Drawbacks

- Same disadvantages than resistivity method
- Electrochemical phenomena are still not well understood
- IP surveys is slow and more expensive than resistivity surveys