2. GEOELECTRIC METHODS

- ☐ D.C. METHODS
  - ☐ PROFILING
  - ☐ SOUNDING
- ☐ ELECTROMAGNETIC (GPR)

HORIZONTAL RESISTIVITY MAPPING AND VERTICAL ELECTRICAL SOUNDING (VES) GEOPHYSICAL SYSTEMS

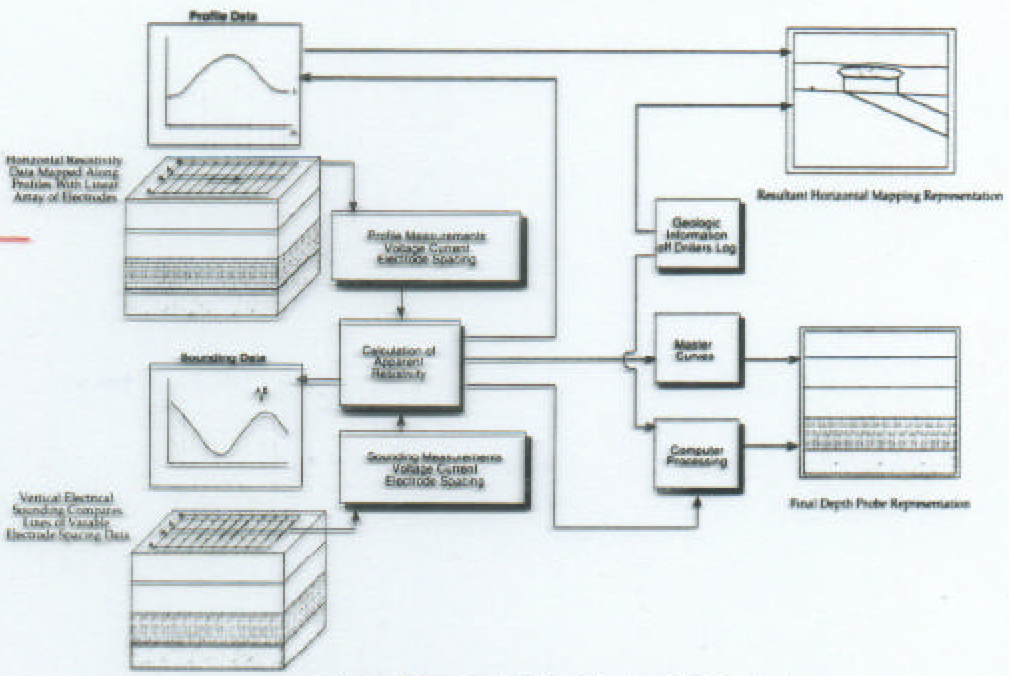


Figure 3-27 Resistivity Geophysical Method

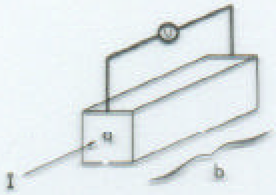
D.C. METHODS

- ☐ Uses electrical conductivity/resistivity contrasts.
- ☐ Apply D.C. field.
- ☐ Measure modified field

Ohm's Law

$U = I \cdot R$

R = resistance $[\Omega]$



I = Current (A)
U = Potential (V)
q = Cross section of rectangular parallelepiped
b = Length of parallelepiped

Fig. 2.3. Current flow through a limited conductor

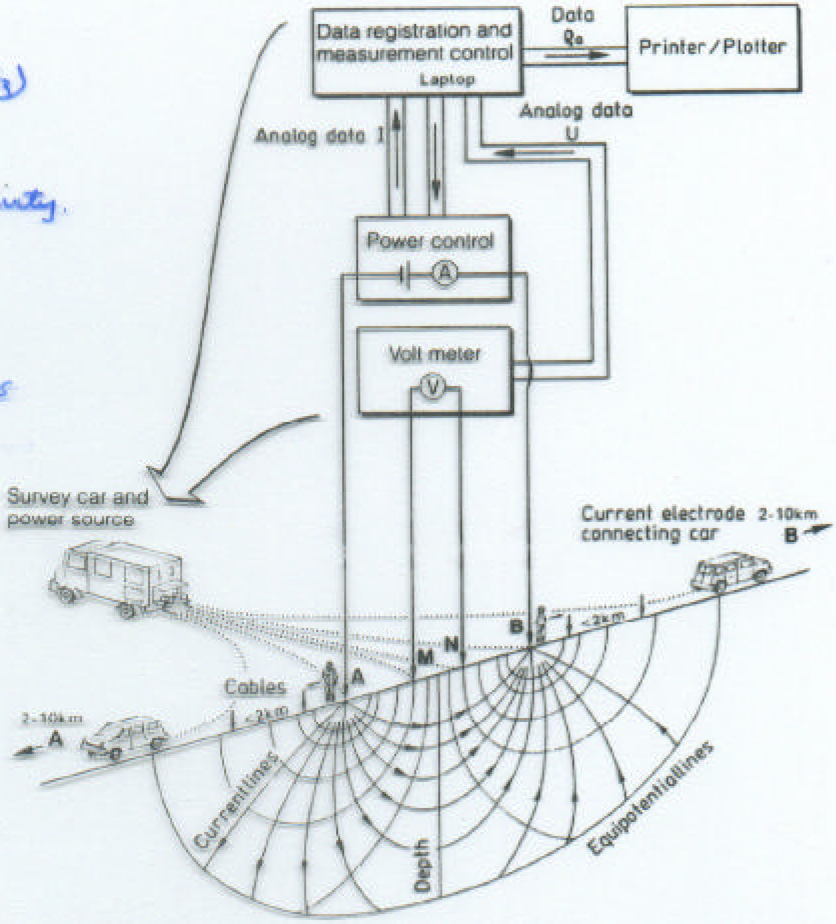
$$R = \frac{b}{q} \rho$$

ρ = Specific resistivity $[\Omega m]$

Method

Apply 1. DC
2. AC @ low frequency (< 100Hz)

- Two stakes with high conductivity.
- Causes potential field
- Measure field by increasing spacing of input electrodes to ↑ depth penetration.
- Infer distribution of conducting layers.



I = Current (A)
U = Potential (V)
A, B = Current electrodes
M, N = Potential electrodes: non-polarizable

Fig. 2.4. Principle of measurement and potential field for geoelectric DC surveys

Data Reduction

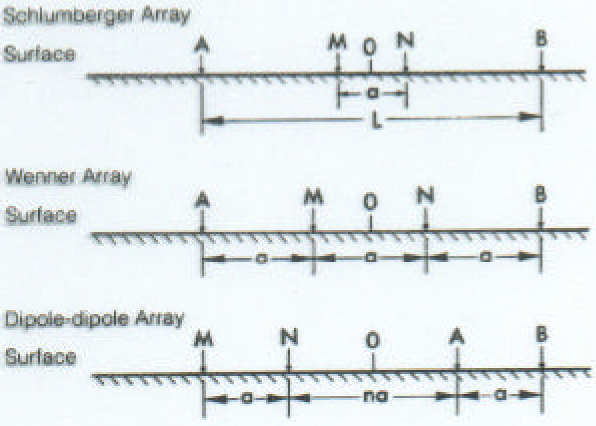
Plot $\frac{U}{I}$ at variable separation.

$\frac{U}{I} \approx R$ but are really specific resistivities, ρ_a, since measured at top of half-space.

Correct to specific resistivities as:

$$\rho_s = K\left(\frac{U}{I}\right)$$

	K
Schlumberger	$\frac{\pi}{a}\left[\left(\frac{1}{2}L\right)^2 - \left(\frac{1}{2}a\right)^2\right]$
Wenner	$2\pi a$
Dipole-dipole	$\pi a \cdot n(n+1)(n+2)a$

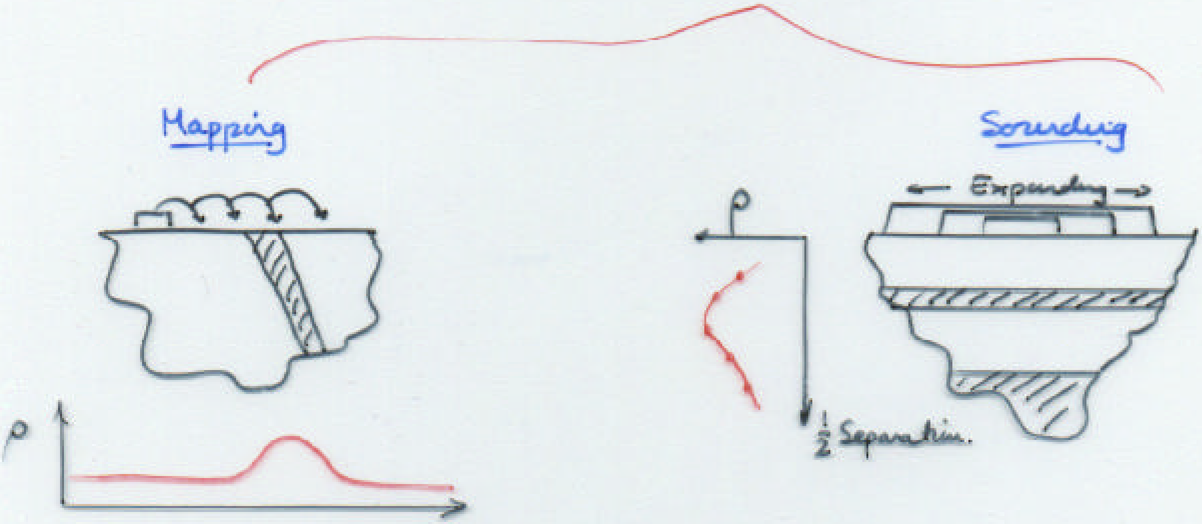


L = AB = Separation current electrodes
a = MN = Separation potential electrodes
O = Point of measurement

Fig. 2.5. Arrays for geoelectric mapping and sounding

Connect the magnitudes to ρ_s:

Method depends on resistivity contrast between layers



Mapping

- □ Locate rim of disposal sites / or drums / or plumes

- □ Fixed array separation ∴ locate changes in ρ_s or absolute magnitude of ρ_s
- □ Separation between electrodes chosen for sampling depth.
  Wenner array commonly used.
- □ Require contrasts in ρ_s

Garbage	< 20 Ωm	
Gravel/sandstone	1000 Ωm	Contrast ok
Clays	3–30 Ωm	No contrast.

SOUNDING

Determine:

1. Apparent resistivities of strata
2. Thickness and depth of interfaces

Mainly Schlumberger array

1. Increase separation logarithmically
2. Plot $\rho_a = \frac{U}{I}$ with half spacing L/2
3. Match with model type curves, or invert numerically.

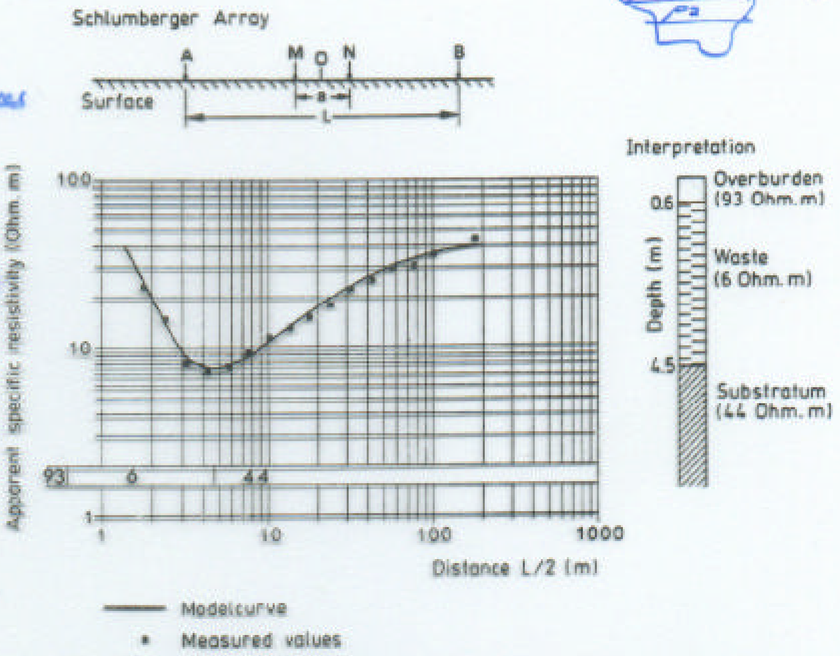


Fig. 2.6. Geoelectric sounding curve (VES) of a Schlumberger array with digital interpretation and computed model curve of the minimum type "H"

Problems

1. Omitted beds

Thin layers or layers masked by very conductive beds

2. Equivalence

Non-unique curves since equivalence of behavior

Table 2.1. Specific resistivities

Rock type/Material	Specific resistivity [Ωm]
Rock type	
clay, marl, rich	3 – 30
clay, marl, meagre	10 – 40
clay, sandy, silt	25 – 150
sand, with clay	50 – 300
sand, gravel in ground water	200 – 400
sand, gravel, dry	800 – 5000
rubble, dry	1000 – 3000
limestone, gypsum	500 – 3500
sandstone	300 – 3000
salt beds and salt domes	> 10000
granite	2000 – 10000
gneis	400 – 6000
Deposited refuse	
domestic garbage	12 – 30
debris and dumped soil	200 – 350
industrial mud	40 – 200
scrap metal	1 – 12
pieces of broken glass and porcelain	100 – 550
casting sand	400 – 1600
wastepaper (wet)	70 – 180
contaminated plume of domestic-garbage dump	1 – 10
used oil	150 – 700
tar	300 – 1200
cleaning clothes and materials	30 – 200
used lacquer and paint	200 – 1000
barrels (empty)	5 – 20

Equivalence

- Non-unique solution
- Match with borehole data
- Effect of saturant may influence results.

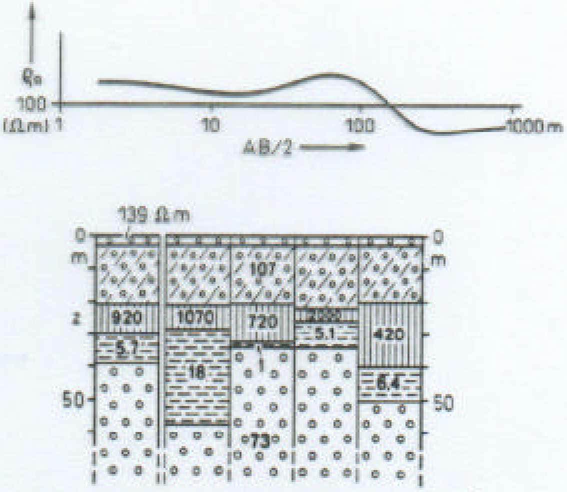
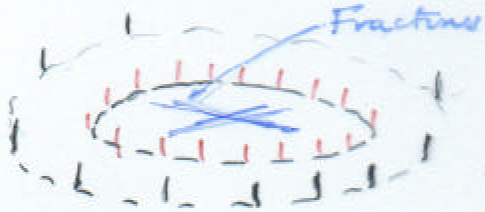


Fig. 2.7. Equivalent digital interpretations of a Schlumberger sounding curve. Left column = mathematically best model. The selection of the most suitable model has to consider neighboring curves and the known geology

Fracture detection methods



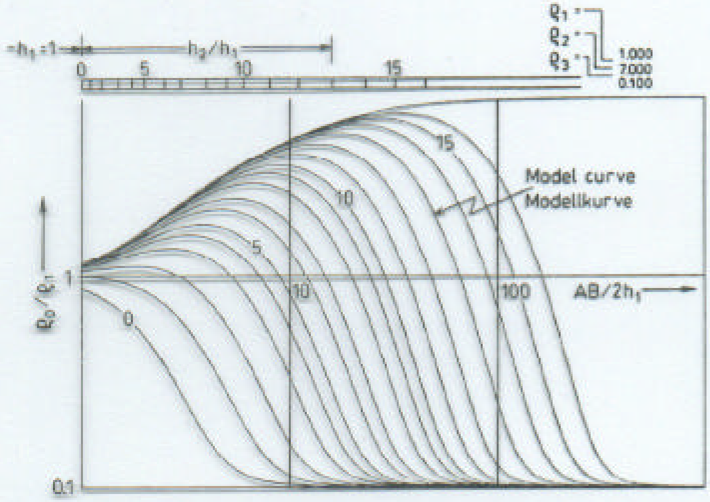
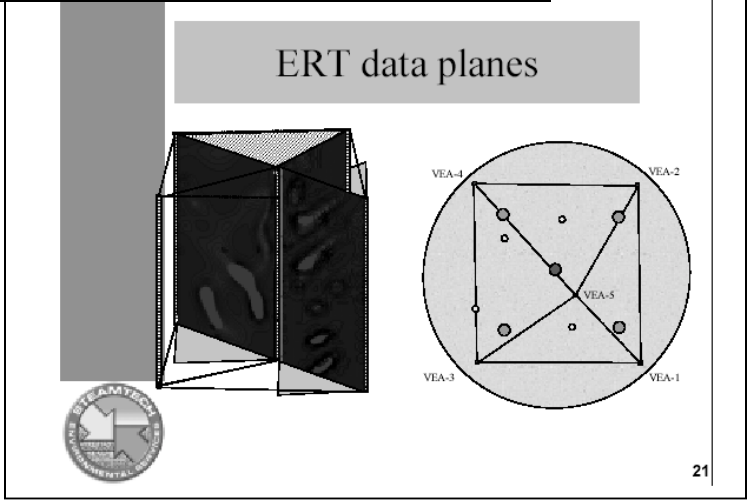


Fig. 2.8. Three-layer master curves in a log-log graph of the INGESO atlas. The resistivities of the three beds are in the ratios 1 : 7 : 0.1; first layer : second layer : third layer. The sounding curve, which has been drawn on log-log graph paper in the field, is laid on top of the master curve and moved around until one of the master curves tallies with the field curve. The thickness of the second layer, which has here seven times the ρa-value of the first layer (see the resistivity values at the top right) can be found by the number of the curve no.13. On the thickness beam at the top left, which is divided from 0 to 16, the thickness h_2 can be directly determined

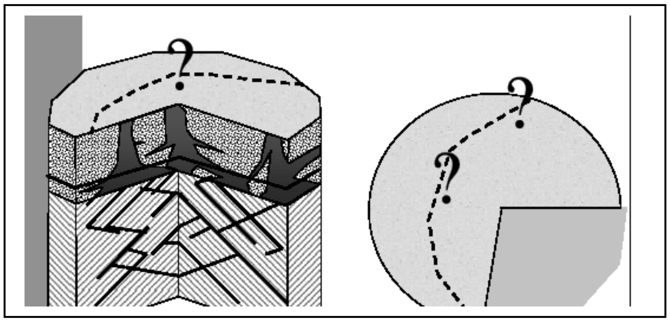
Edwards AFB, CA – Thermal Remediation Monitoring with ERT

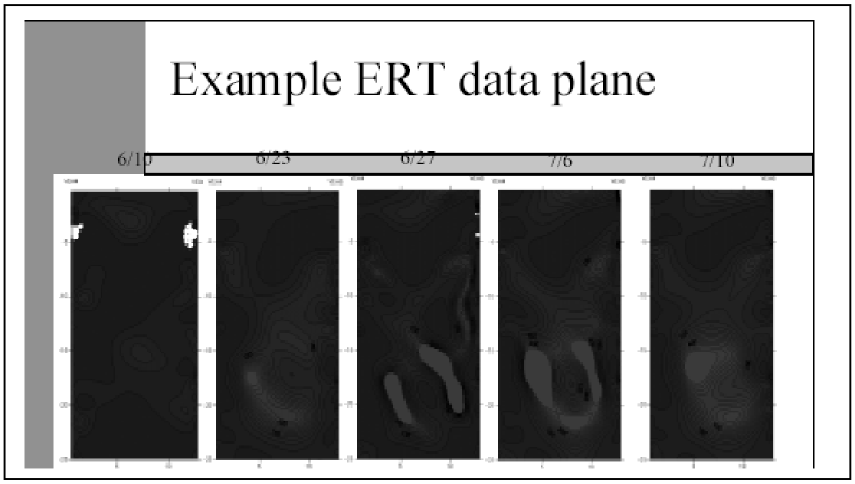
Edwards Air Force Base, Edwards, CA

Contaminants Treated:	TCE
Hydrology:	Groundwater at 30 feet bgs
Geology:	Fractured granite
Starting Contaminant Levels:	DNAPL expected
Cleanup Levels Achieved:	Project Awarded in 2000
Remediation Time Period:	May-June 2002
Client Reference:	Scott Palmer, Earth Tech, San Jose CA, (408)-232-2826
Remediation Design Engineers:	Dr. Gorm Heron, Dr. Steve Carroll, Mr. Hank Sowers

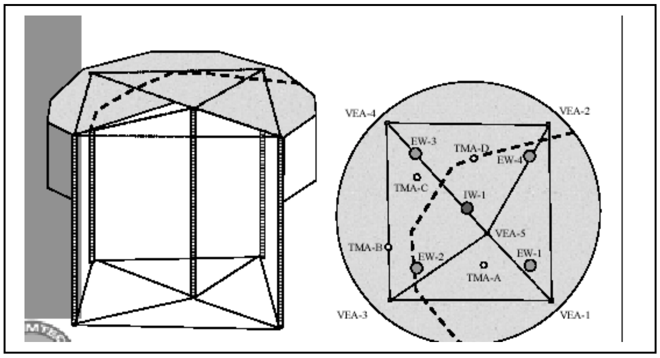


ERT data planes





Example ERT data plane



INDUCED POLARIZATION (INDUCED POTENTIAL)

- Apply DC current as Wenner or Schlumberger.
- Cut current and measure voltage decay with time 1s – 8s
- Reverse current to erase remnant charge

Effective depth penetration, D

$$D \sim a(n+1)\frac{1}{2}$$

Dipole lengths n = 1 to 6

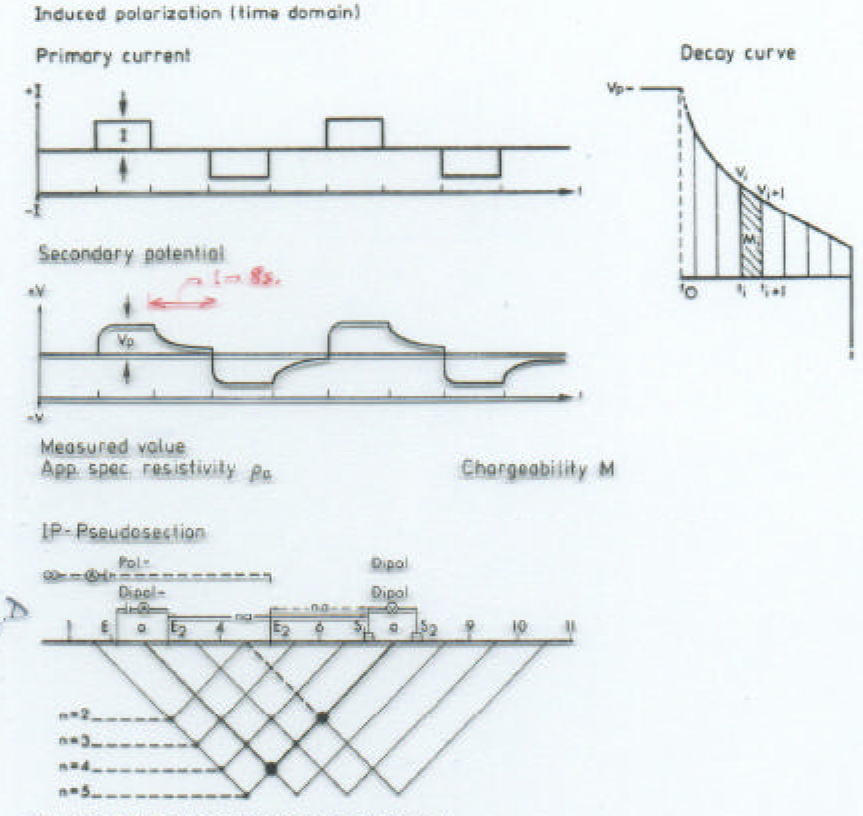


Fig. 2.9. Principle of induced polarization (IP)

SELF POLARIZATION

- Measures natural geo-electric field
- Results from chemical reactions (natural battery) eg Redox.

30mV – 200 mV

– sometimes results from rapid fluid flow < 10mV.

2.2 ELECTROMAGNETIC METHODS

NOTE: $v = f\lambda$

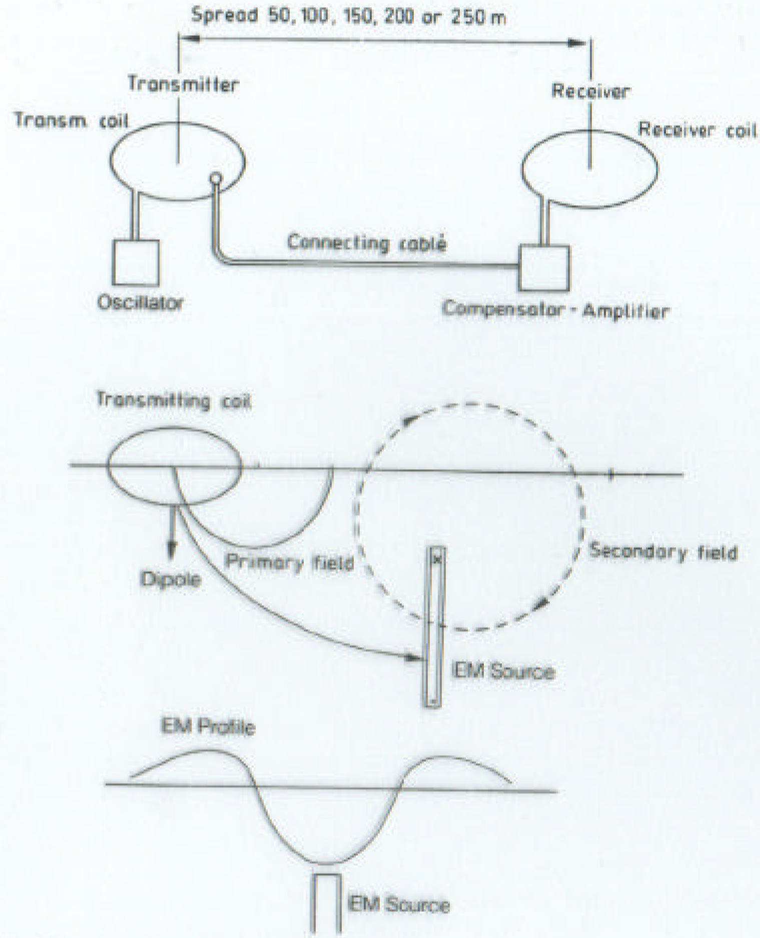
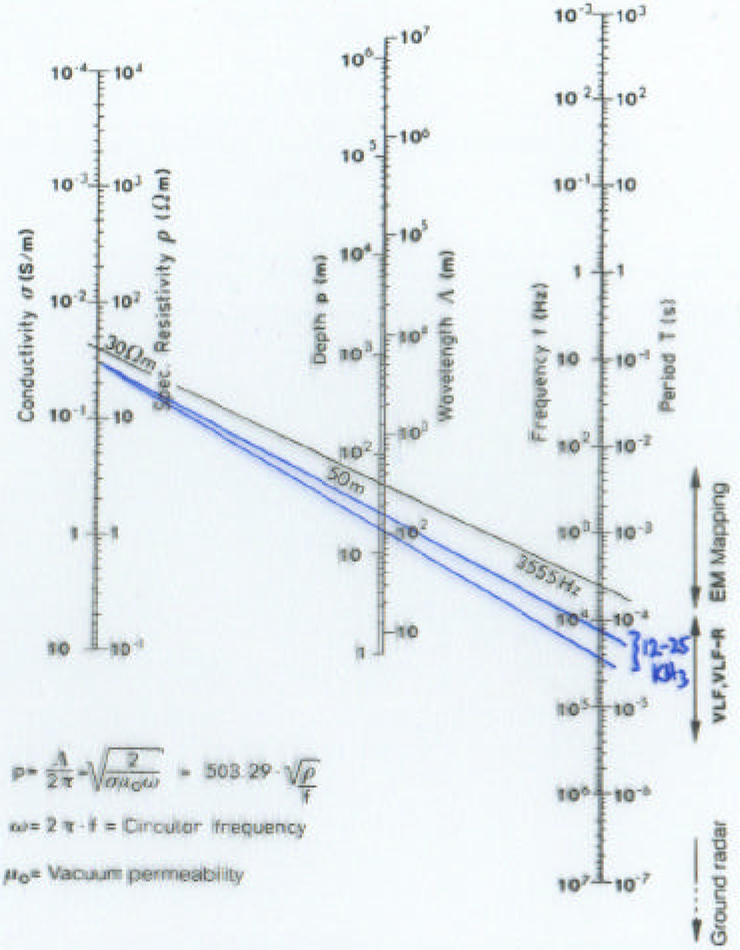


Fig. 2.11. Principle of electromagnetic mapping



$$p = \frac{\Lambda}{2\pi} = \sqrt{\frac{2}{\sigma\mu_0\omega}} = 503.29\cdot\sqrt{\frac{\rho}{f}}$$

$\omega = 2\pi\cdot f$ = Circular frequency

μ_0 = Vacuum permeability

Fi. 2.12. Nomogram showing the relations of specific resistivity (left column), depth of penetration (middle column) and frequency (right column) of a homogenous plane wave

EM Mapping (Longitudinal profile)

- ☐ Primary EM field by primary coil
- ☐ Induces secondary EM field in body of different specific resistivity ρ_s
- ☐ Resolve interpretive ambiguities using multiple frequencies. (perhaps 12)

EM by Distant Transmitter (VLF)

- ☐ Permanent transmitters around globe (12 - 2.5kHz)
  (Submarine navigation)
- ☐ Measure induced secondary fields & interpret.
- ☐ Set frequency ∴ depth of penetration ~15m for $\rho_a < 30\ \Omega m$.

TIME - DOMAIN ELECTROMAGNETICS (TDM)

- Similar to IP but decay of EM signal is measured. with time.

- Transmitter loop of 5m to 100m diameter but achieve large depth penetration 50 - 1000m.

Applied to determine brine pools and salt water intrusion.

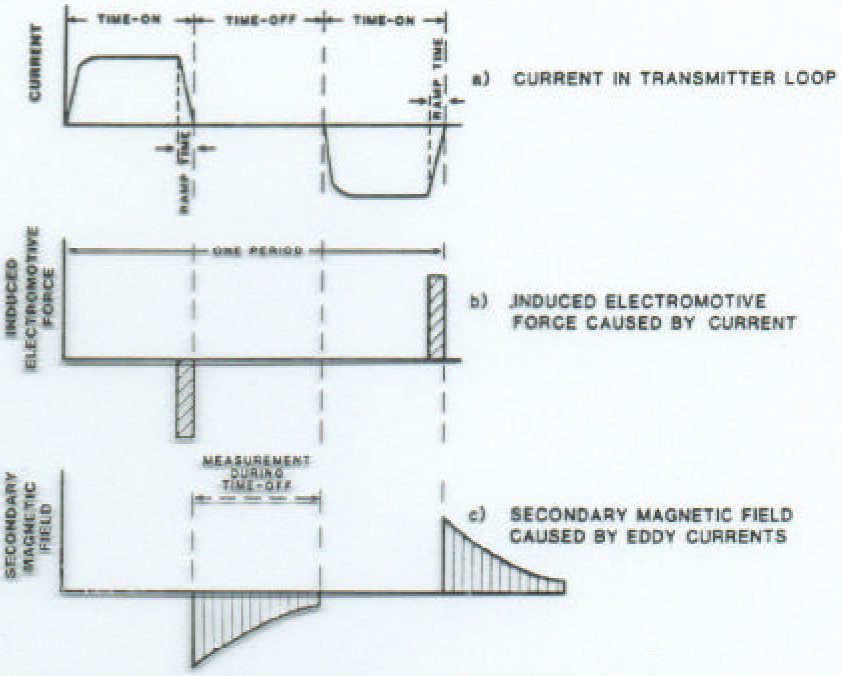
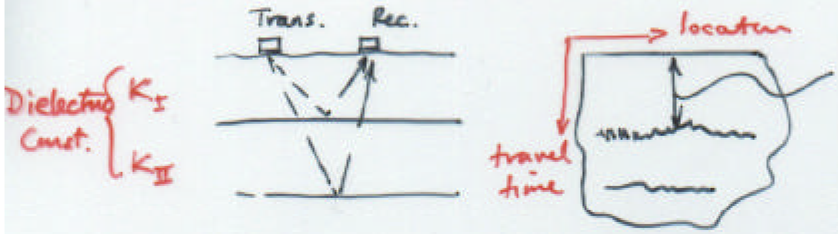


Fig. 2.15. System wave forms employed by the TDEM method

GROUND-PENETRATING RADAR (GPR)



Records travel time
that must be scaled to
a velocity → depth.

- Shallow depth penetration for EM waves 8 MHz – 4 GHz
  Reflection from interfaces with dielectric constant contrast, K

- Dielectric constant, $K = \frac{\text{Capacitance of material}}{\text{Capacitance of vacuum}} = \varepsilon$ (non-dimensional)

- Depth penetration – Limited in low conductivity (high resistivity)
  Clays 0.2 m
  Salt, ice, dry granite > 300 m
  Typically 3–10 m.

- High dielectric contrast of water (80) greatly influences response
  - Changing saturation (record infiltration in real time)
  - Type of saturant (LNAPL or DNAPL)

- Depth penetration controlled by frequency
  ↑ frequency → reduce penetration and increase resolution
  (see nomogram)

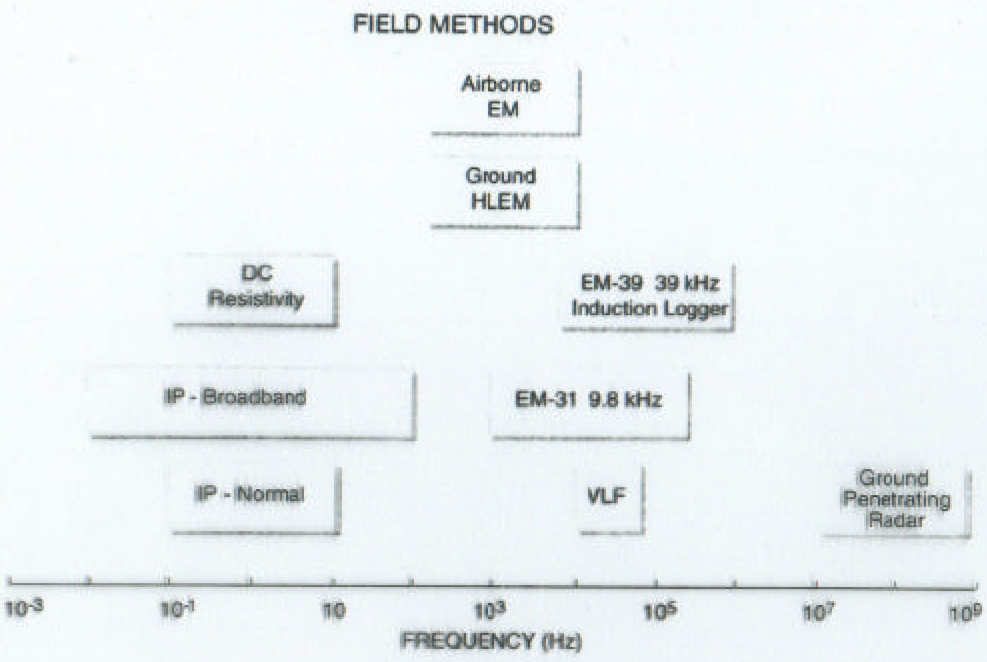


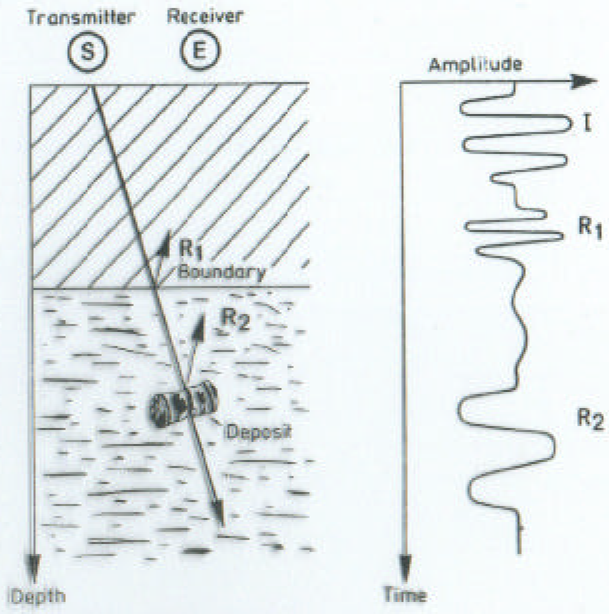
Figure 3-22 Frequencies Used By Electrical Geophysical Methods

Table 2.3. Dielectric constants (K), electric conductivity (σ), electric velocity and attenuation (a) at a frequency of 100 MHz. Davis and Anan (1989)

Material	K	σ(mS/m)	v (m/ns)	a(dB/m)
Air	1	0	0,3	0
Freshwater	80	0,01	0,33	$2 \cdot 10^{-1}$
Seawater	80	$3.0 \cdot 10^{4}$	0,01	0,1
Dry sand	4	0,01	0,15	0,01
Wet sand, Aquifer	25	$0{,}1^{-1}$	0,06	0,03
Limestone	6	$0{,}5^{-2}$	0,12	0,04
Fat clay	5–35	0,05	0,06	1,0–300
Granite	5	0,1–1	0,13	0,01
Rock salt	6	0,1–1	0,13	0,01
Slate	5–15	0,03	0,09	1,0–100

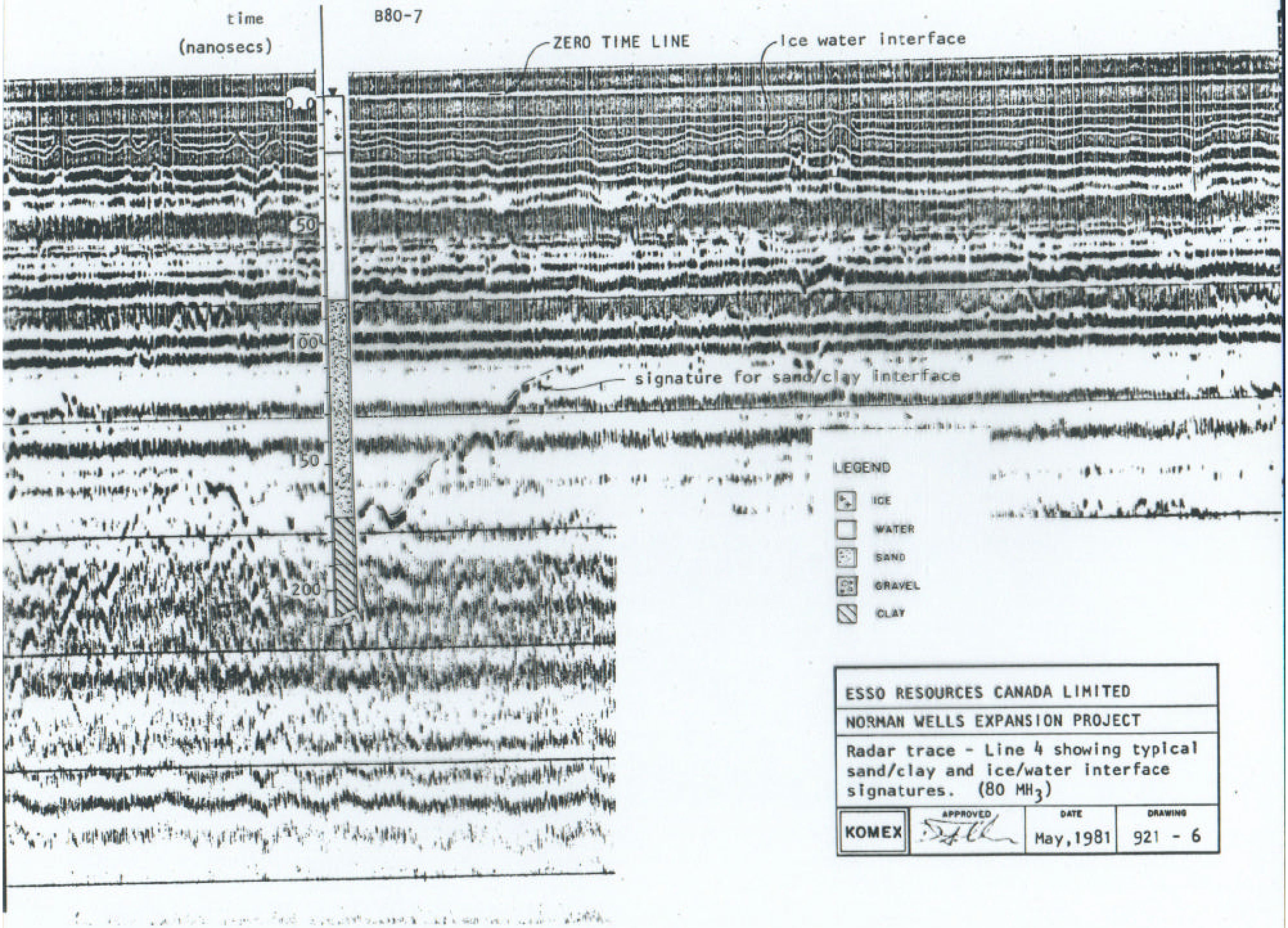
↑ Velocity of EM wave enables calculation of reflector depth

↑ Dielectric const defines the potential for attenuation



I = Transmitted radar-pulse
R_1, R_2 = Reflected pulses

Fig. 2.17. Principle of ground radar measurements



ESSO RESOURCES CANADA LIMITED			
NORMAN WELLS EXPANSION PROJECT			
Radar trace - Line 4 showing typical sand/clay and ice/water interface signatures. (80 MH_3)			
KOMEX	APPROVED	DATE May, 1981	DRAWING 921 - 6