Self-potential (SP) Method

•or *spontaneous polarization* method is based on the surface measurement of natural potentials resulting from electrochemical reactions in the subsurface.

•does not require electric currents to be injected into the ground as in the RESISTIVITY & IP methods.

•has been used in base metal exploration, to detect the presence of *massive* ore bodies, in contrast to the *IP method* which is used to predominantly to investigate *disseminated* ore bodies.

•has been increasingly used in groundwater & geothermal investigations, environmental and engineering applications---> mapping seepage flow associated with dams, geological mapping, delineate shear zones and near-surface faults.

•ranks as the cheapest of surface geophysical methods in terms of equipment necessary and amongst the simplest to operate in the field.

Occurrence of Self-potentials

- SP method is passive, i.e. differences in natural ground potentials are measured between any two points on the ground surface.

- The potentials measured can range from < a millivolt (mV) to > 1 Volt.

- + or – sigh of the potential is an important diagnostic factor in the interpretation of SP anomalies.

- Self-potentials are generated by a number of natural sources (exact physical processes still unclear).

Occurrence of Self-potentials

- Natural ground potentials consist of 2 components

1. *Background Potentials*---fluctuate with time caused by different processes ranging from AC currents induced by thunderstorms, variations in Earth’s magnetic fields, effects of heavy rainfalls

2. *Mineral Potentials*---constant due to electrochemical processes

Table 8.1 Types of SP anomalies and their geological sources

Source	Type of anomaly
Mineral potentials	
Sulphide ore bodies (pyrite, chalcopyrite, pyrrhotite, sphalerite, galena)	Negative ≈ hundreds of mV
Graphite ore bodies	
Magnetite + other electronically conducting minerals	
Coal	
Manganese	
Quartz veins	Positive ≈ tens of mV
Pegmatites	
Background potentials	
Fluid streaming, geochemical reactions, etc.	Positive +/− negative $\leqslant 100$ mV
Bioelectric (plants, trees)	Negative, $\leqslant 300$ mV or so
Groundwater movement	Positive or negative, up to hundreds of mV
Topography	Negative, up to 2 V

Mechanism of Self-potentials

- Some physical processes caused sources of SP are still unclear.
- *Groundwater* is thought to be common factor responsible for SP.
- Potentials are generated by the flow of water, by water reacting as an electrolyte and as a solvent of different minerals.

- Electrical conductivity to produce potentials of porous rocks depends on porosity and on mobility of water to pass through the pore spaces ---depend on ionic mobilities, solution concentrations, viscosity, temperature & pressure.

- There are a few types of SP :
  1. *Electrokinetic potential*
  2. *Thermoelectric potential*
  3. *Electrochemical potential*
  4. *Mineral/mineralization potential*

Electrokinetic potential

- Flowing of fluid (electrolyte) through a capillary or porous medium generates potentials along the flow path.
- The potentials are alternatively called as *electrofiltration, electromechanical or streaming potentials.*
- The effect is believed to be due to electrokinetic coupling between the fluid ions and the walls of the capillary.
- *The electrokinetic potential (E_k)* generated between the ends of the capillary passage is given by

$$E_k = \frac{\varepsilon \rho C_E \Delta P}{4\pi\eta}$$

ε = Dielectric permittivity of pore fluid

ρ = Electrical resistivity of pore fluid

C_E = Electrofiltration coupling coefficient

ΔP = Pressure difference

η = Dynamic viscosity of pore fluid

Electrokinetic potential

- E_k gradient is in the same direction as the pressure gradient, i.e. opposite to the direction of the electrolyte flow.
- E_k normally providse amplitudes of some mV to several hundreds of mV.
- E_k can be found associated with flow of subsurface water and thermal fluids
- E_k *effects* have been observed over zones of water leakage through fissures in the rock floor of reservoirs, over terrains with large elevation changes, and in geothermal areas.

Thermoelectric potential

- Potential gradient will appear across a rock sample if a temperature gradient is maintained across the rock sample.
- Thermoelectric coupling coefficient (TEC) is defined as the ratio of the voltage to the temperature difference---> **TEC=ΔV/ΔT**
- **TEC** values of rocks vary from -0.09 to + 1.36 mV/°C

  average ~ 0.27 mV/°C
- SP generated from TE potentials are of smaller amplitudes than usually seen in geothermal areas.
- More concentrated areas of high temperature at shallow depth, such as thermal fluids in a fault zone, could give rise to anomalies of greater amplitude.
- Boundaries of SP anomalies measured in several geothermal areas appear to correlate with zones of known anomalous high heat flow---->portion of anomalies is generated by TE mechanism.

Electrochemical potential

- If the concentration of the electrolytes in the ground varies locally, potential differences are set up due to the difference in mobilities of anions and cations in solutions of different concentrations---called ***liquid-junction*** **or** ***diffusion potentials***.
- For this mechanism to explain the continued occurrence of such potentials, a source capable of maintaining imbalances in the electrolytic concentration is needed, otherwise the concentrations differences will disappear with time by diffusion.
- Electrical potential is also generated when 2 identical metal electrodes are immersed in solutions of different concentrations---called ***Nernst potential***.
- **Diffusion + Nernst potentials = Electrochemical, or static, self-potential.**

Electrochemical potential

- One of the most common natural electrolytes is NaCl.
- For NaCl solutions of different concentration (C_1,C_2) but at the same temperature, T (°C), the amplitude of the electrochemical potential (E_c) is given by

$$E_c = -70.7 \frac{(T + 273)}{273} \ln \left(\frac{C_1}{C_2}\right)$$

- For example, if C_1:C_2 = 5:1 -----> $E_c \approx 50$ mV

Mineral potential

- is the most important in mineral exploration of SP associated with massive sulphide ore bodies.
- Large negative (-) SP anomalies (100-1000mV)can be observed particularly over deposits of pyrite, chalcopyrite, pyrrhotite, magnetite, and graphite.
- The potentials are almost invariably negative over the top of the deposit and are quite stable in time.
- Sato and Mooney (1960) have provided the most complete explanation of the electrochemical processes caused the observed SP anomalies.
- However this hypothesis does not explain all the occurrences of the SP indicates that the actual physical processes are more complicated and no yet truly understood.

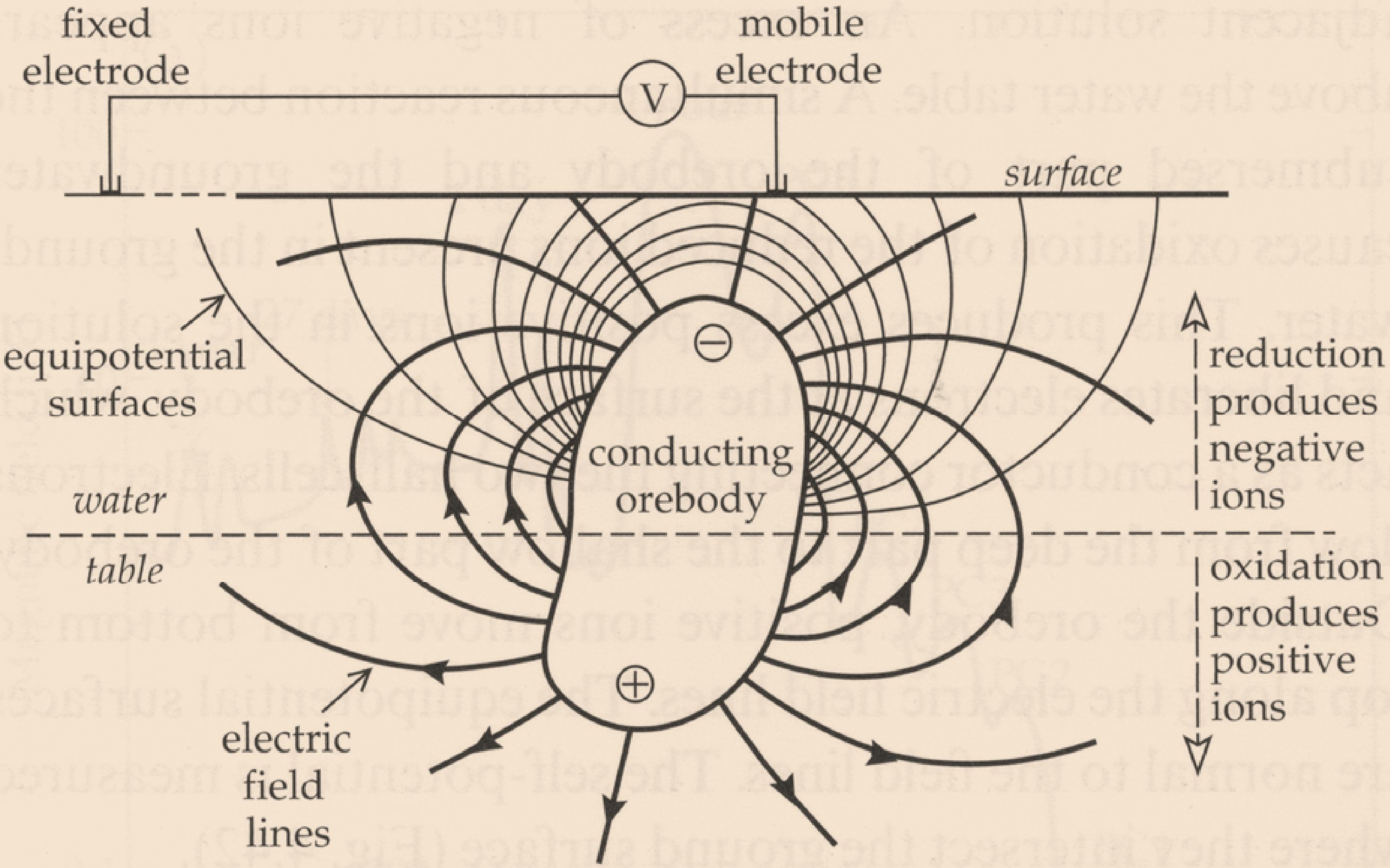
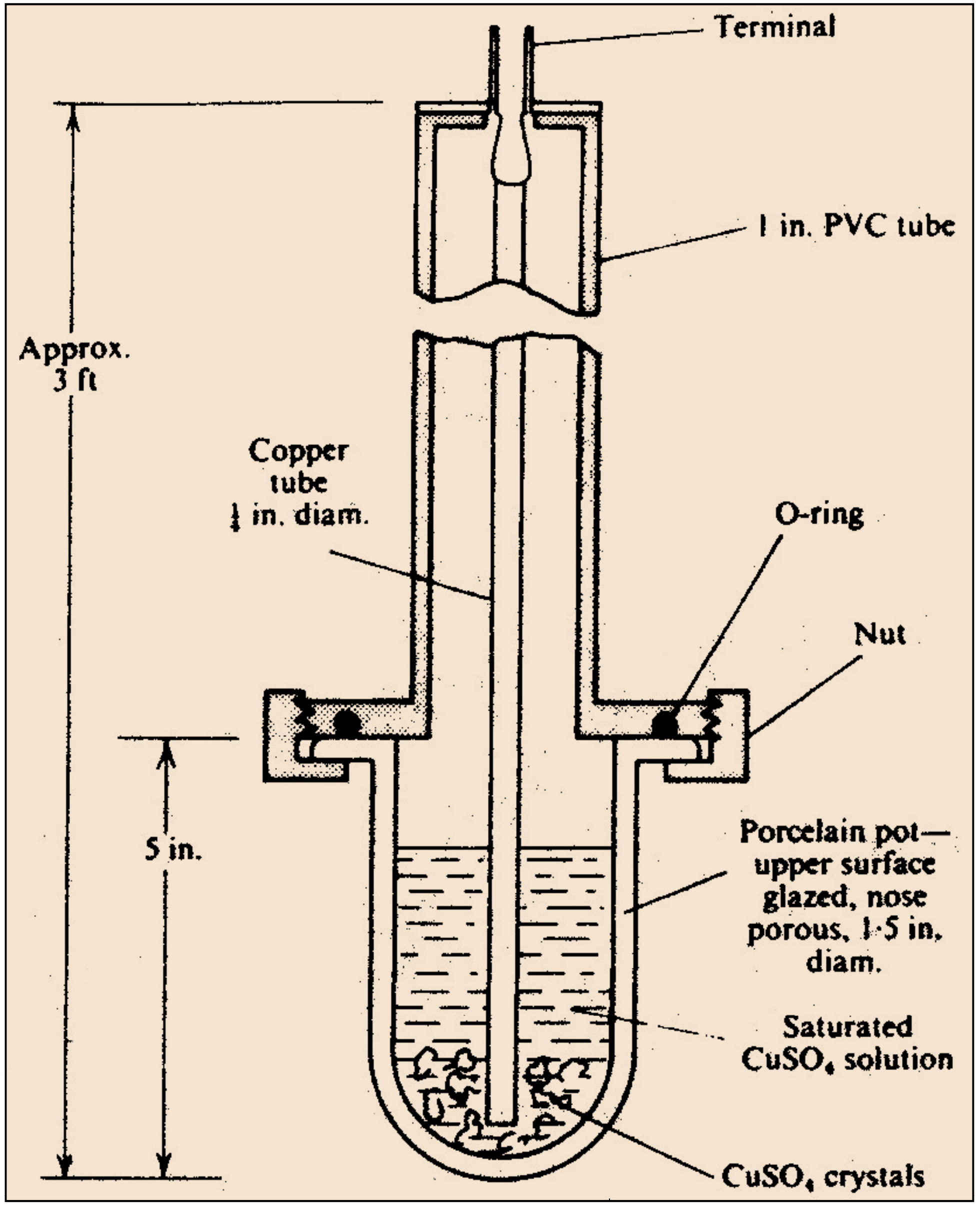


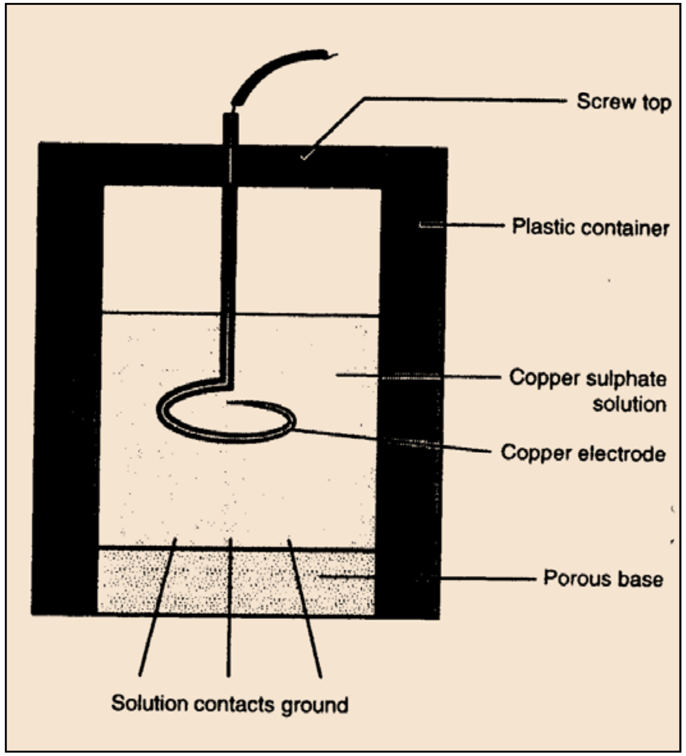
Fig. 4.42 A schematic model of the origin of the self-potential anomaly of an orebody. The mechanism depends on differences in oxidation potential above and below the water table.

Measurement of Self-potentials

- simple and inexpensive.
- 2 non-polarizable porous-pot electrodes connected to a precision voltmeters capable of measuring to at least 1 mV
- Each electrode is made up of a copper electrode dipped in a saturated solution of copper sulphate which can percolate through the porous base to the pot.
- An alternate zinc electrode in saturated zinc sulphate solution or silver in silver chloride can be used.

Maximum depth of sensitivity of SP method = ~60-100m depending on ore body and nature of overburden.





Porous pot electrodes

Measurement of Self-potentials

2 field techniques or 2 electrode configurations

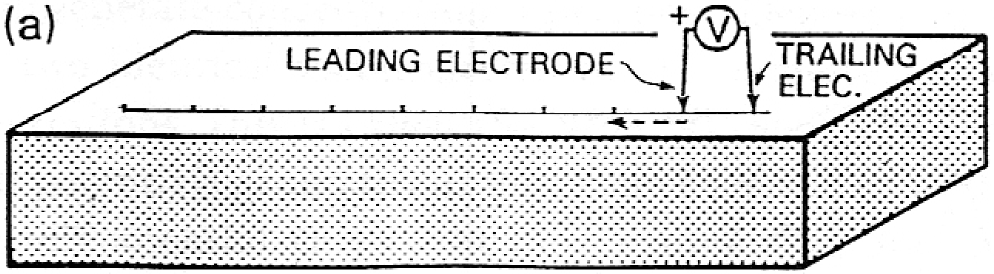
1.Potential gradient method (dipole/leap frog/gradient configuration)

-fix separation of 2 electrodes (5 or 10 m)

-measure potential difference between 2 electrodes = potential gradient [mV/V]

-2 porous are leap-frogged along traverse with care of correct polarity of potential recorded

-observation points = midpoint between 2 electrodes



Measurement of Self-potentials

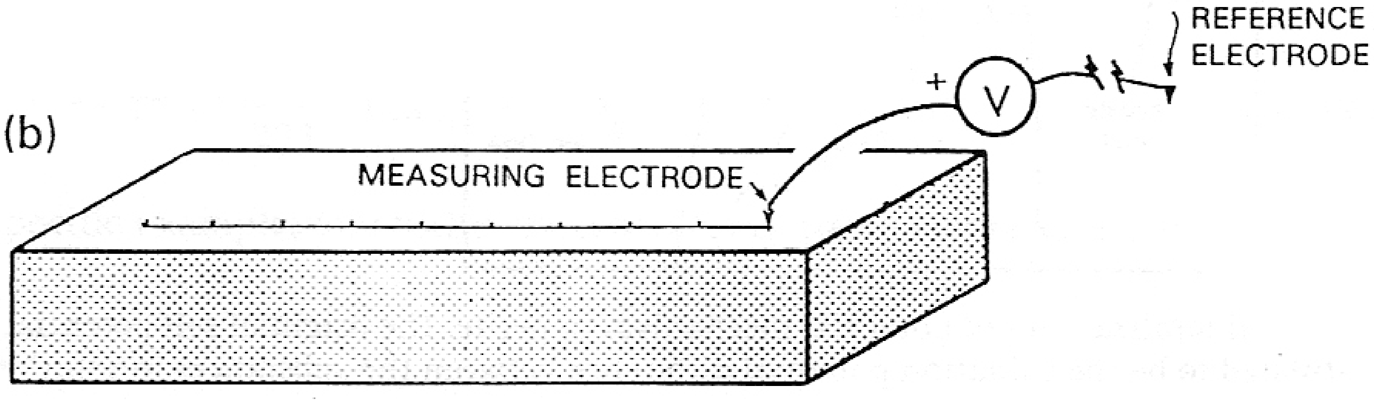
2.Potential amplitude, or total field method (fixed-base) configuration

-keep one electrode fixed at a base station

-measure potential difference [mV] between base & 2nd electrodes moving along traverse

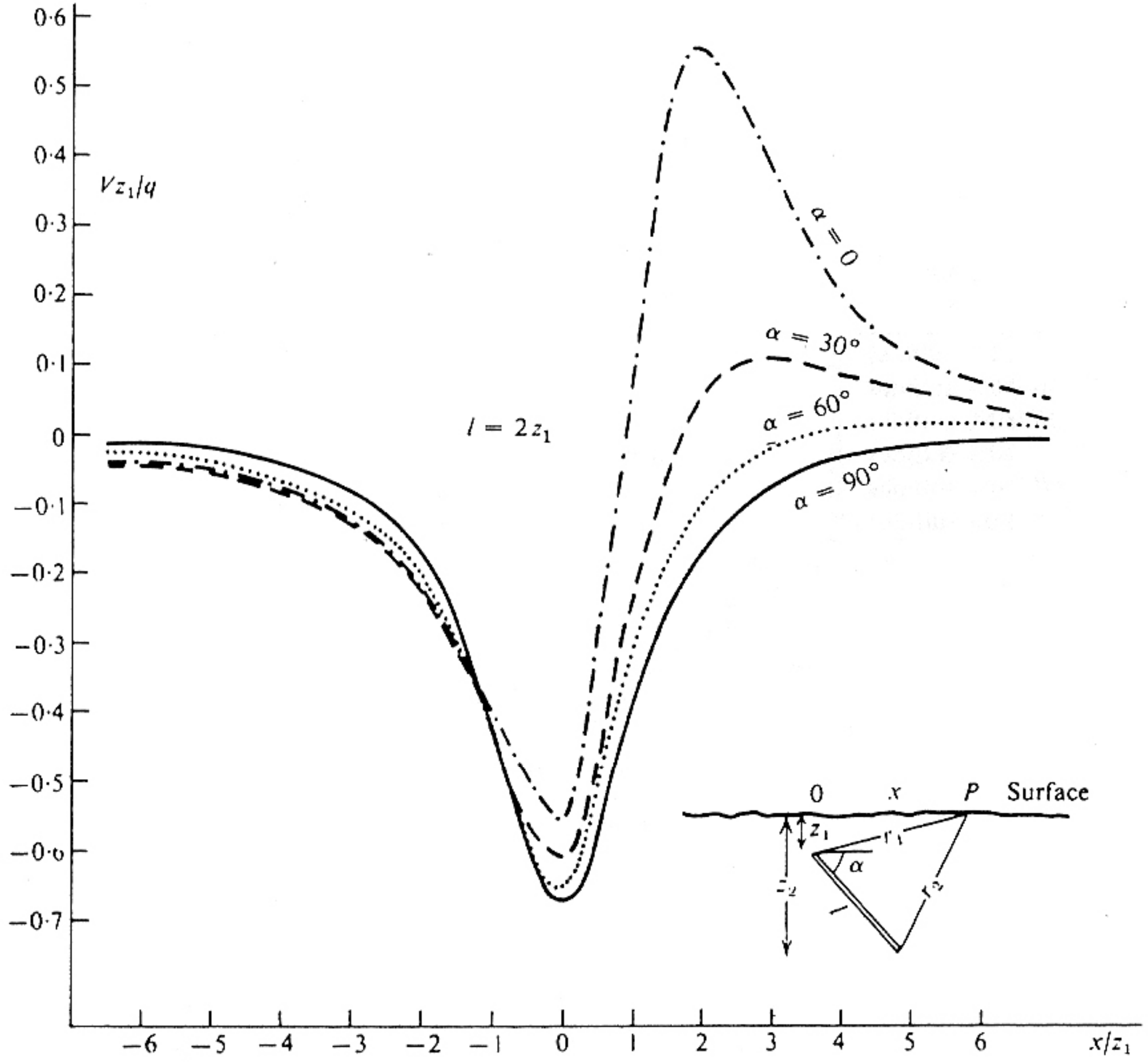
-lower level of cumulative errors & confusing polarity

-disadvantages of transporting long wire

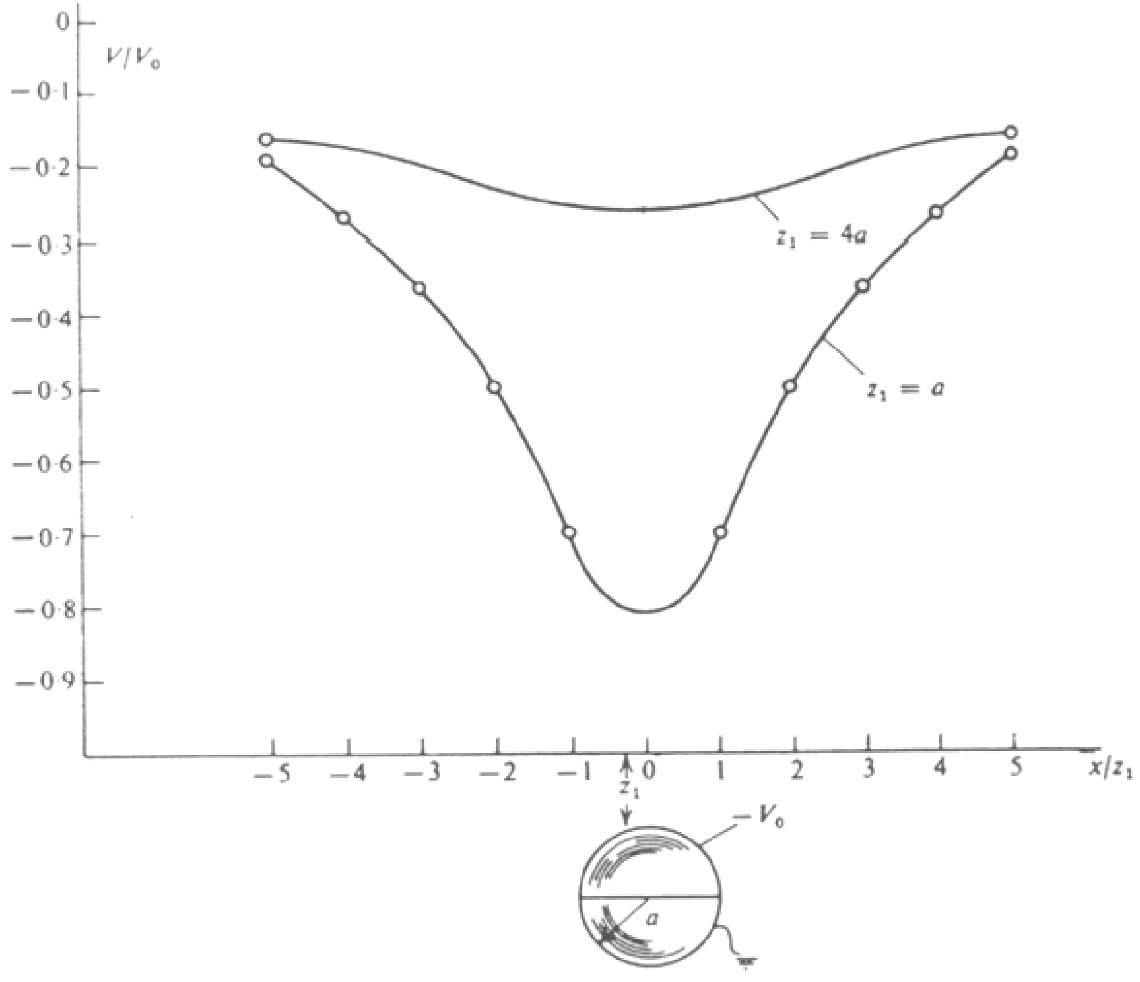


Interpretation of Self-Potential Data

- SP anomalies are often interpreted qualitatively by
  - Profile shape
  - Amplitude
  - Polarity (+ or -)
  - Contour pattern
- Top of ore body is assumed to lie directly beneath position of minimum potential.
- For quantitative interpretation, it is possible to calculate the potential distributions around polarized bodies of simple shape, such as sphere, ellipsoid, and dipole, by making some simplifications and assumptions concerning the potential on the surface of the sources.



SP profiles over buried polarized rod



SP profiles over buried polarized sphere

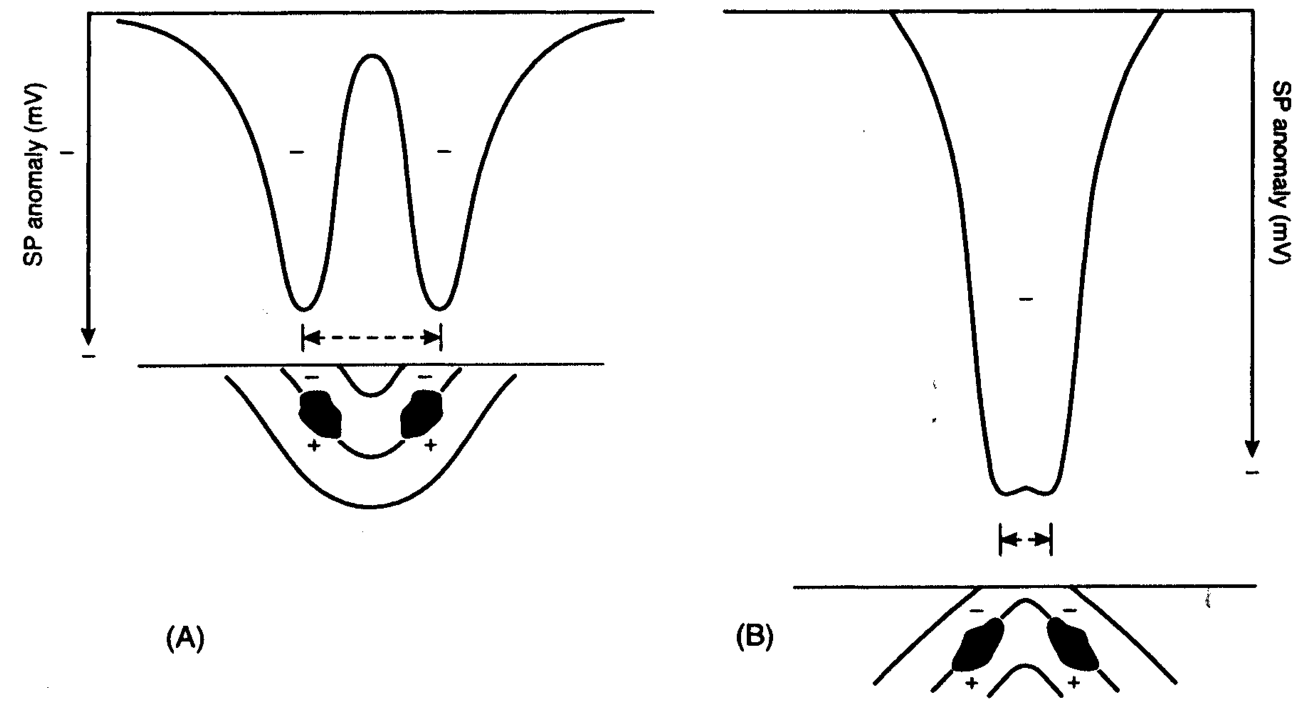


Figure 8.7 SP anomalies due to (A) two graphite bodies with axes of polarisation inclined away from each other (in syncline), and (B) inclined towards each other (in anticline). After Meiser (1962), by permission

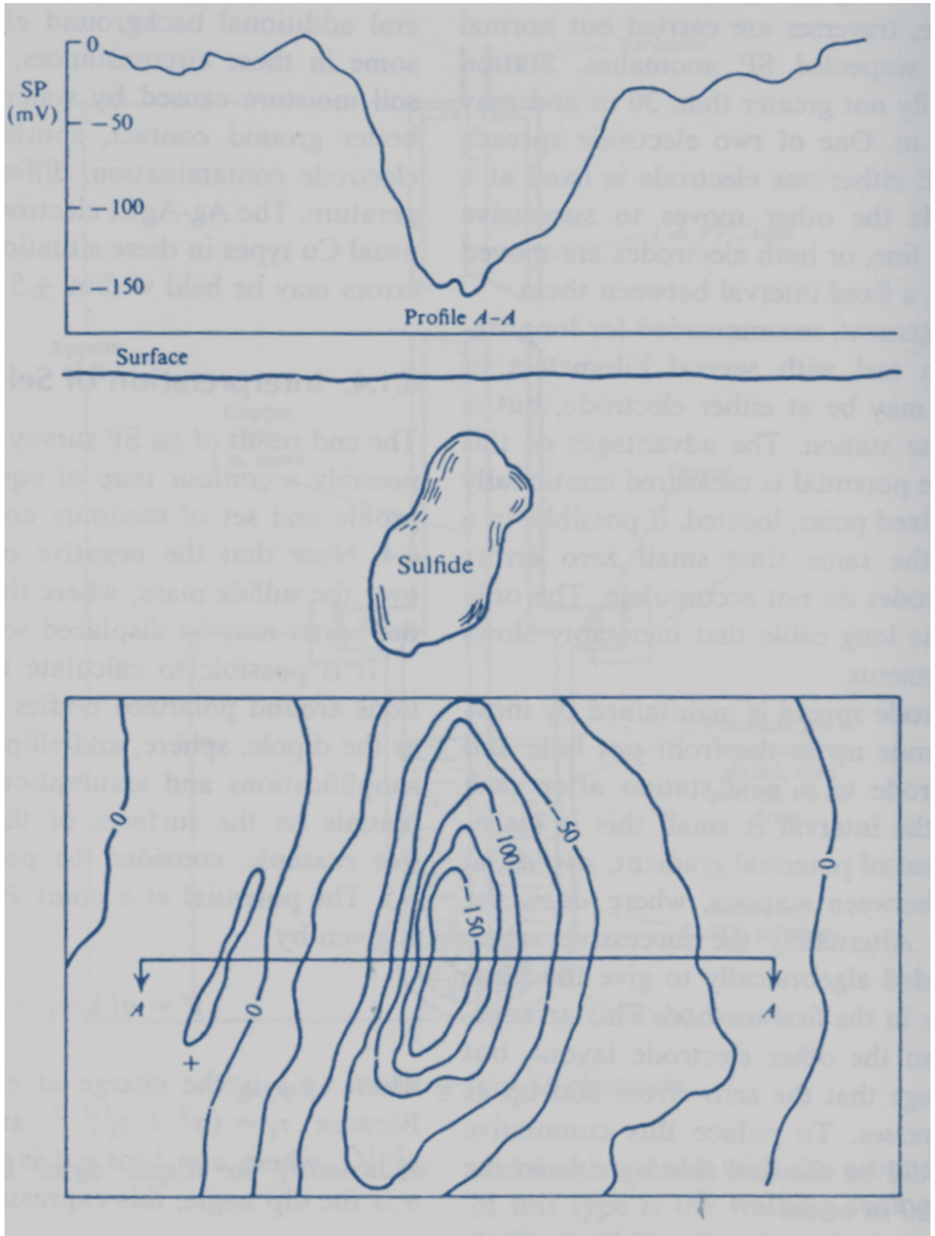


Figure 6.4. Typical SP profile and contours over sulfide body.

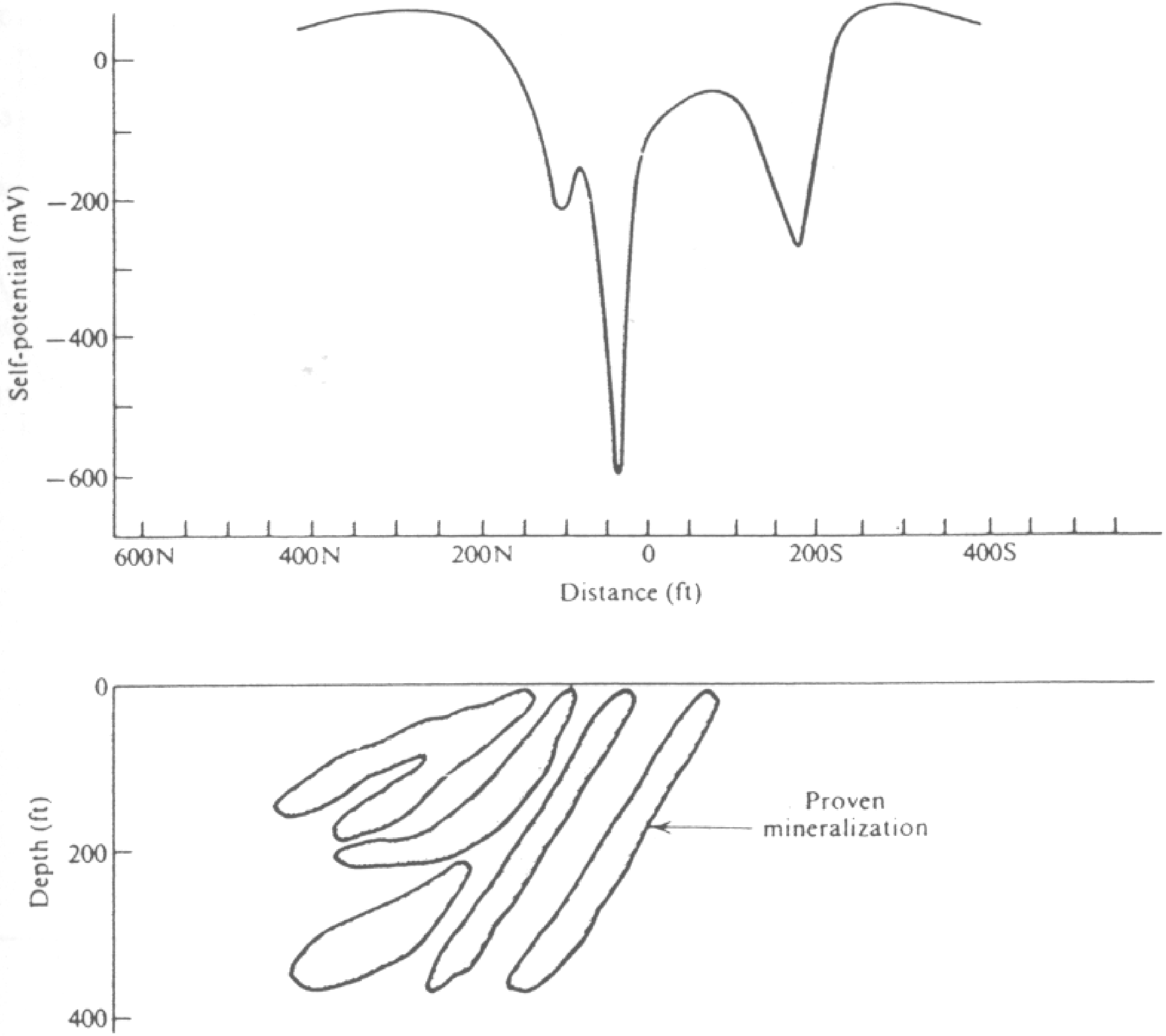


Figure 6.25. SP profile across massive sulfides, Senneterre Area, Quebec.

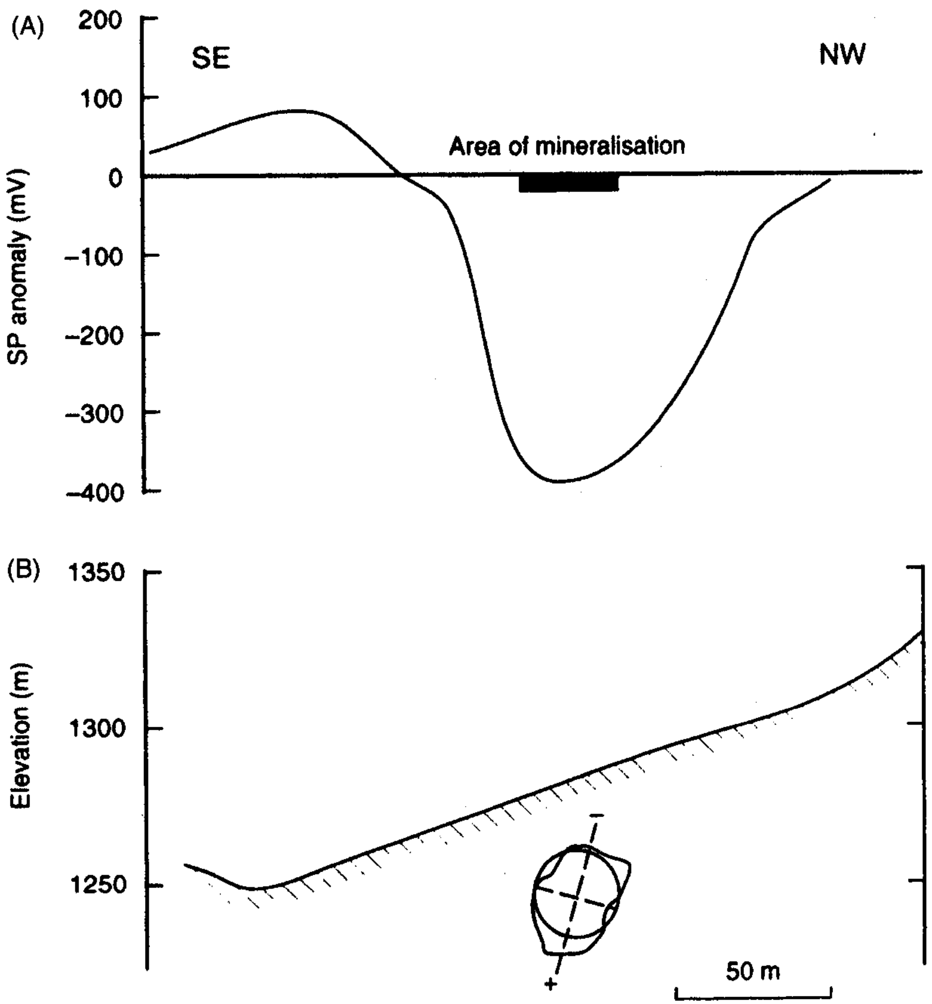


Figure 8.5 (A) Weiss SP anomaly in Ergani, Turkey, with the causative orebody shown schematically in (B). Note that the axis of polarization is inclined uphill. After Yüngül (1950), by permission

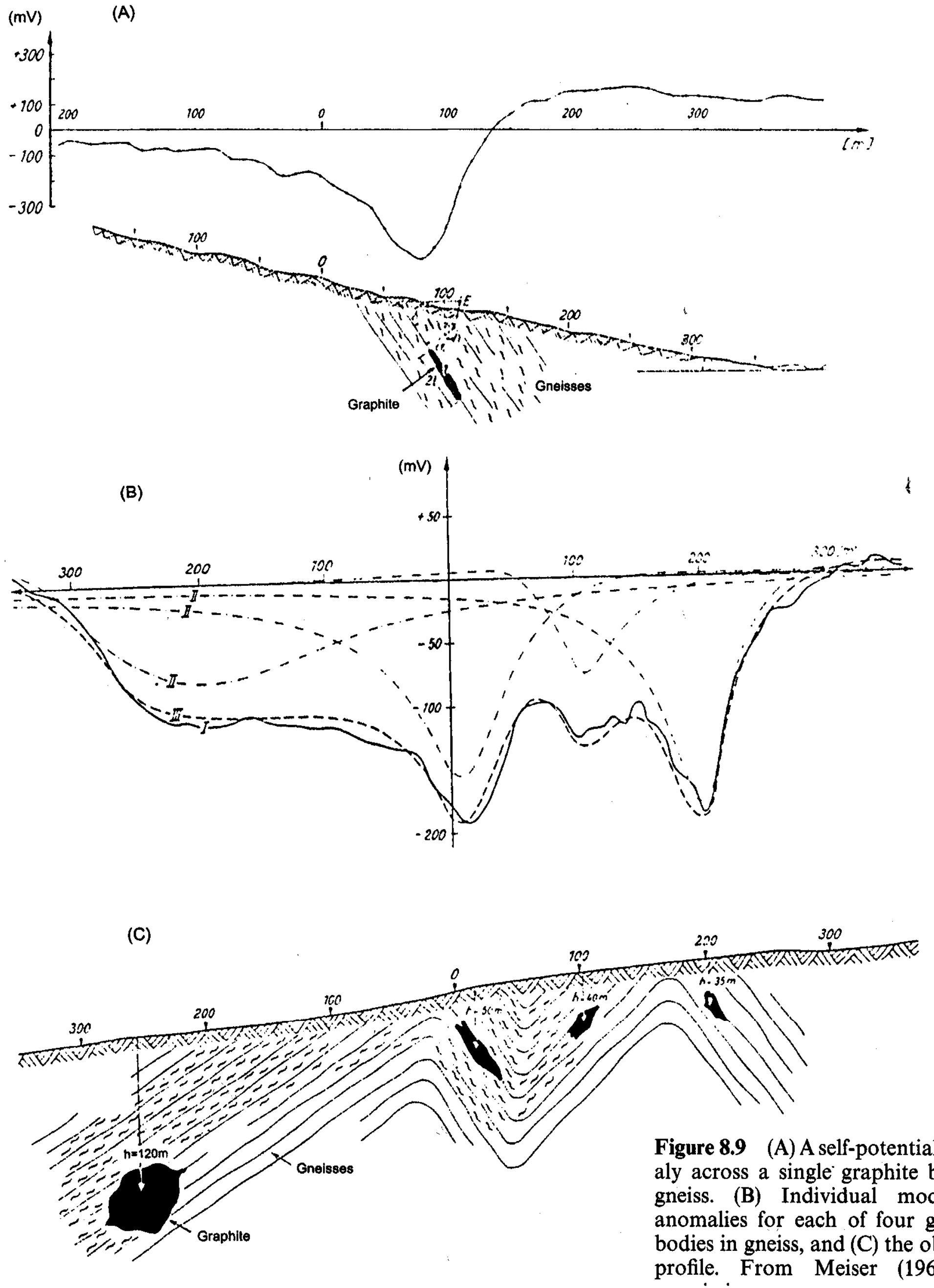
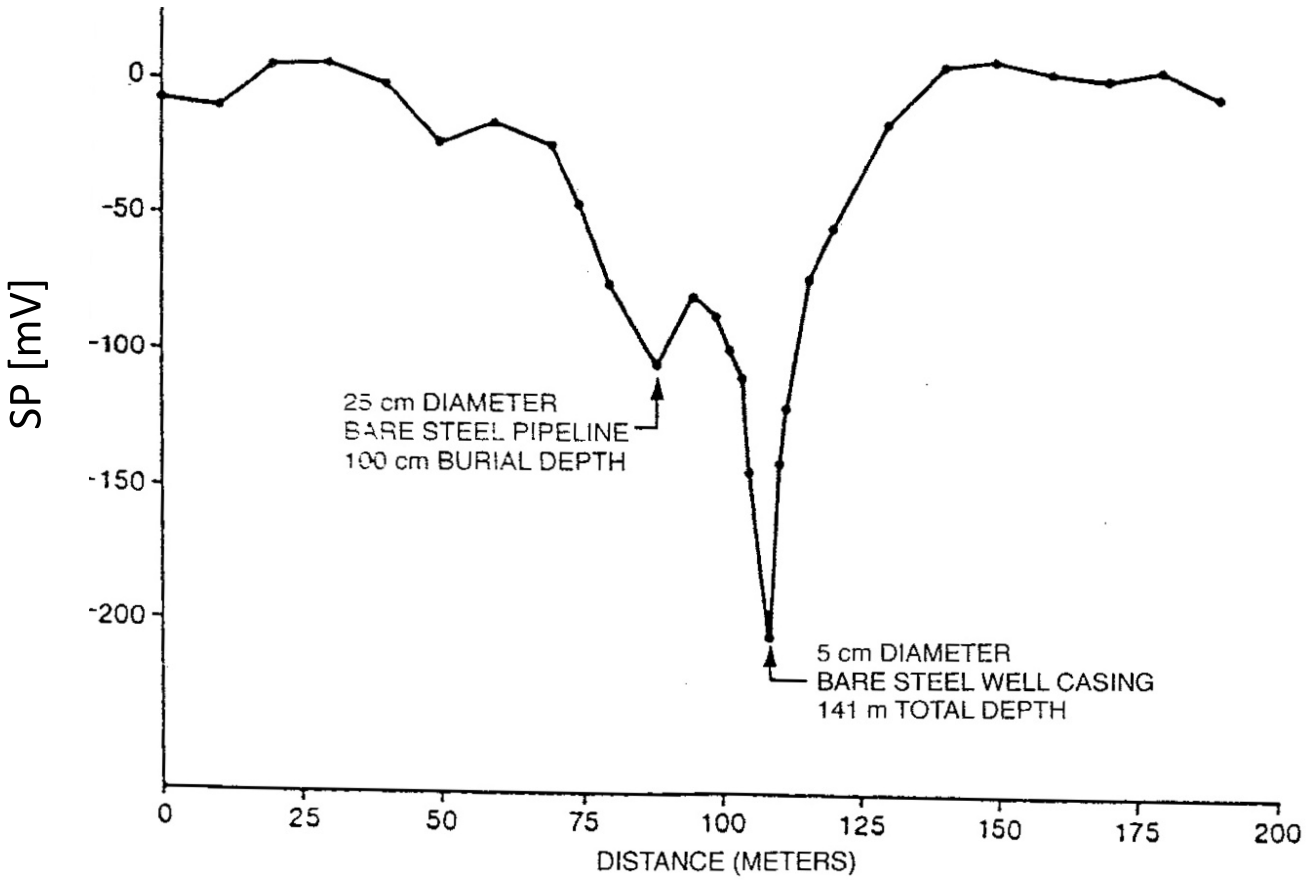


Figure 8.9 (A) A self-potential anomaly across a single graphite body in gneiss. (B) Individual model SP anomalies for each of four graphite bodies in gneiss, and (C) the observed profile. From Meiser (1962), by permission



SP anomalies generated by buried metal pipelines and well casings at Meso, California, USA

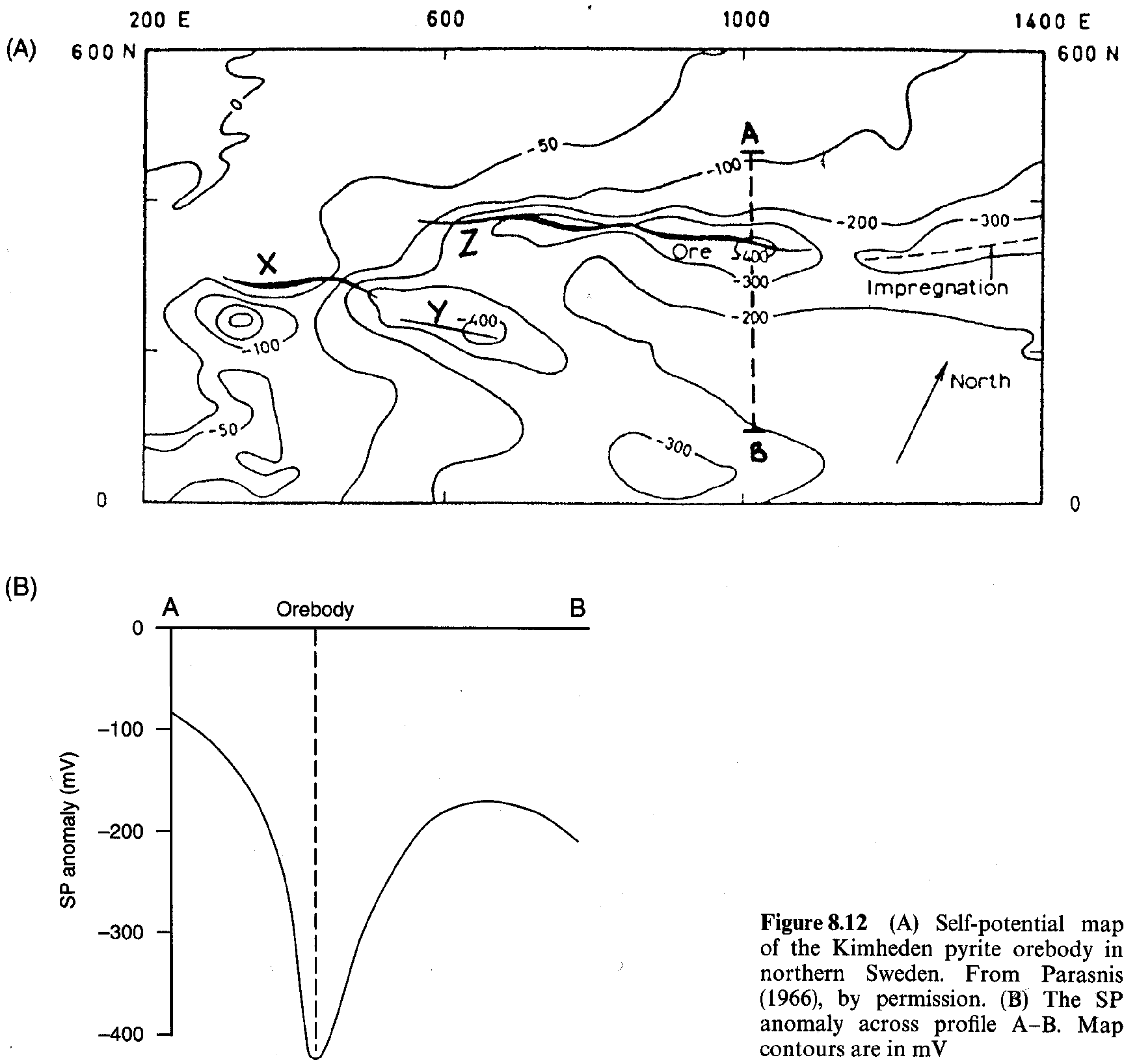
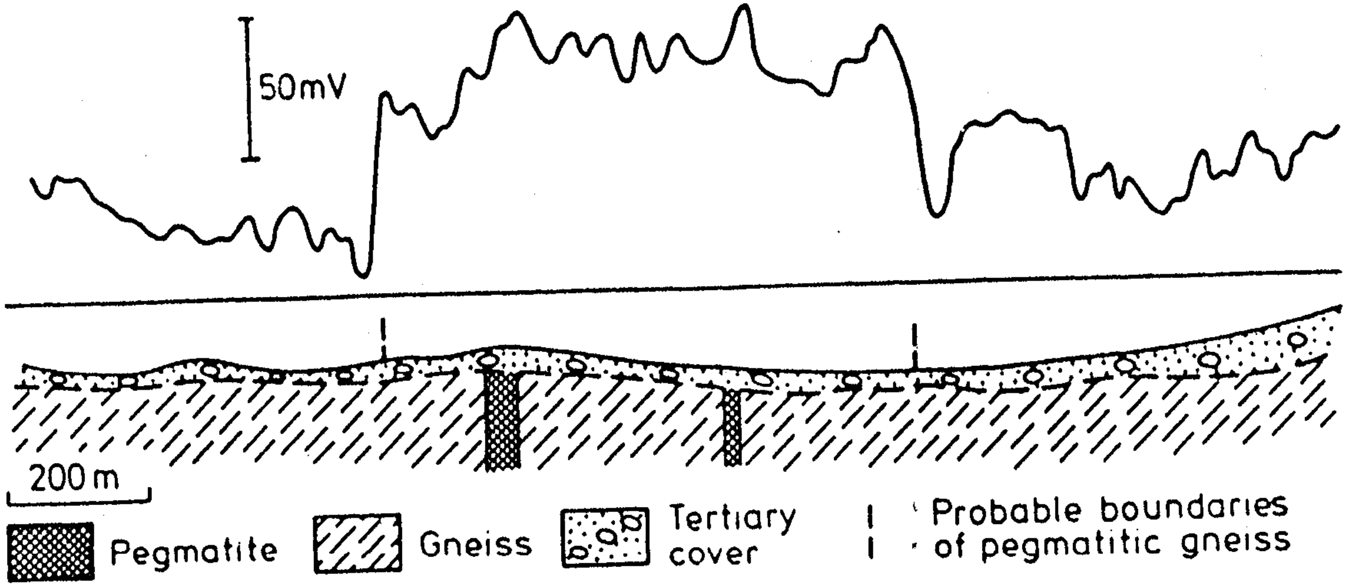


Figure 8.12 (A) Self-potential map of the Kimheden pyrite orebody in northern Sweden. From Parasnis (1966), by permission. (B) The SP anomaly across profile A–B. Map contours are in mV



An SP profile across pegmatite dikes in gneiss

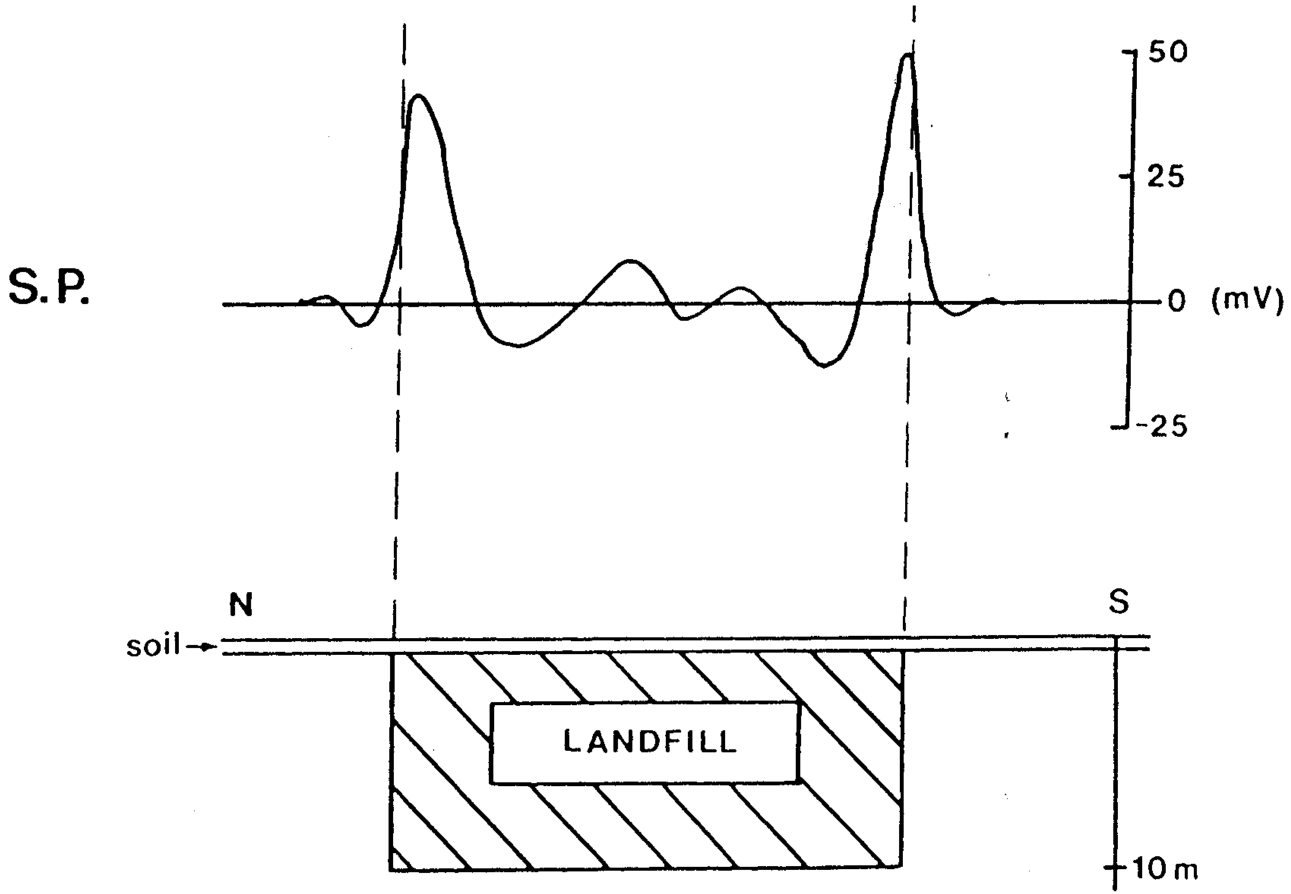


Figure 8.17 SP anomaly over a closed landfill, showing the typically larger anomalies associated with the landfill boundaries compared with those observed in the interior. From Coleman (1991), by permission

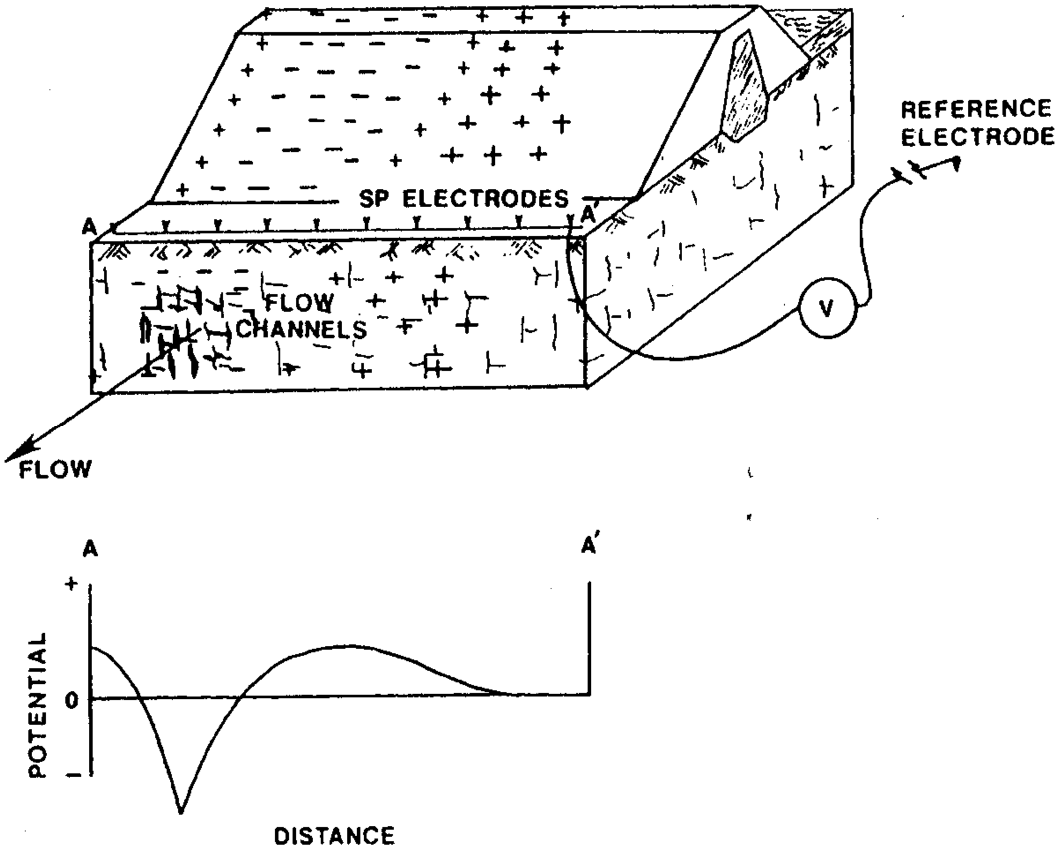


Figure 8.18 Schematic of the concept of SP anomalies generated by features associated with seepages through earth dams. From Butler and Llopis (1990), by permission

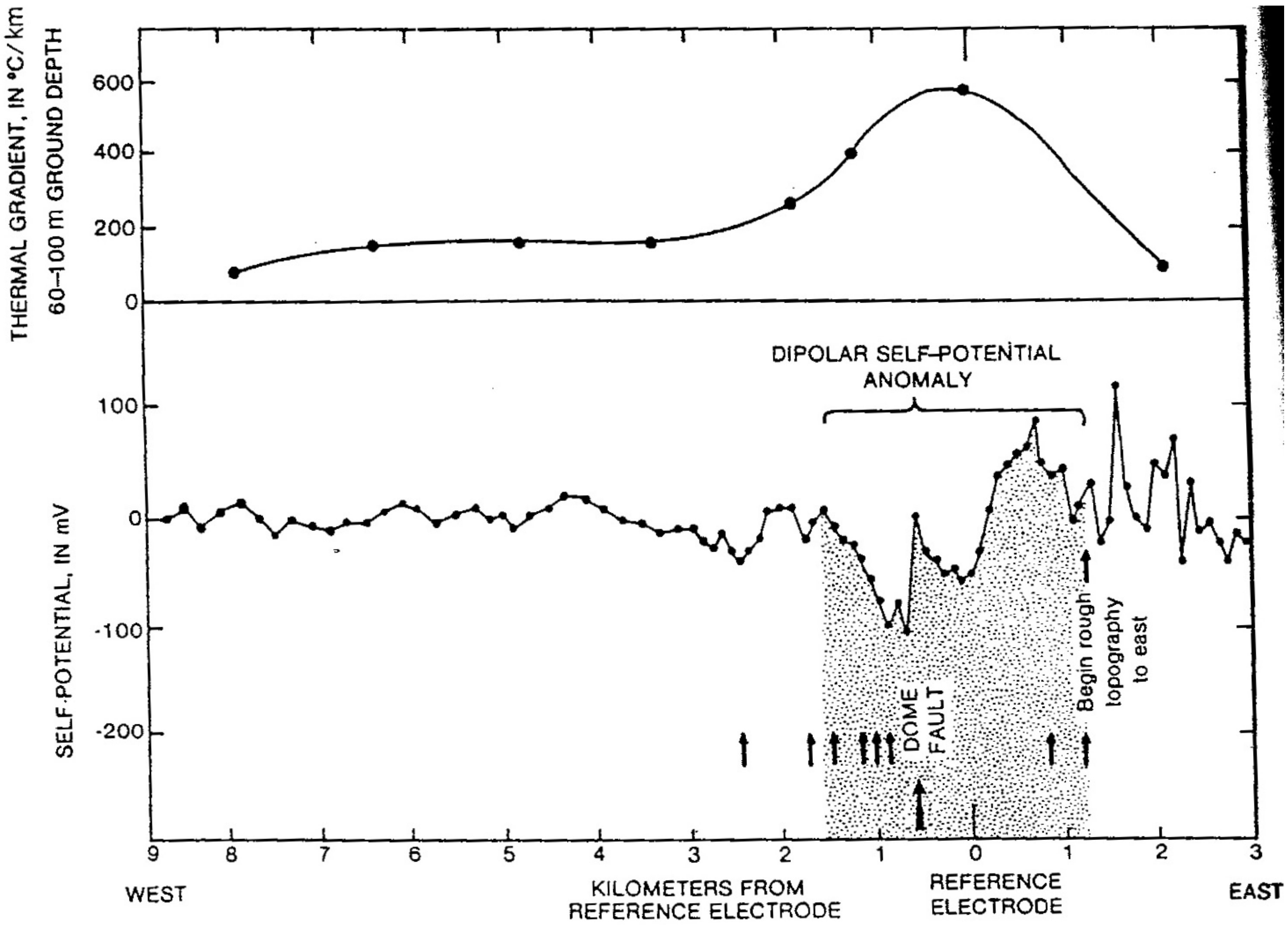


Fig. 5.11 Thermal gradient and self-potential profile across the Dome fault, Roosevelt Hot Springs, Utah, U.S.A. Thermal gradient data from Sill and Bodell (1977). Arrows denote points at which faults mapped by a geological survey cross the self-potential survey line. (After Corwin and Hoover, 1979.)