Well Logging and Interpretation

Lecture 8 – Self Potential (SP) Log

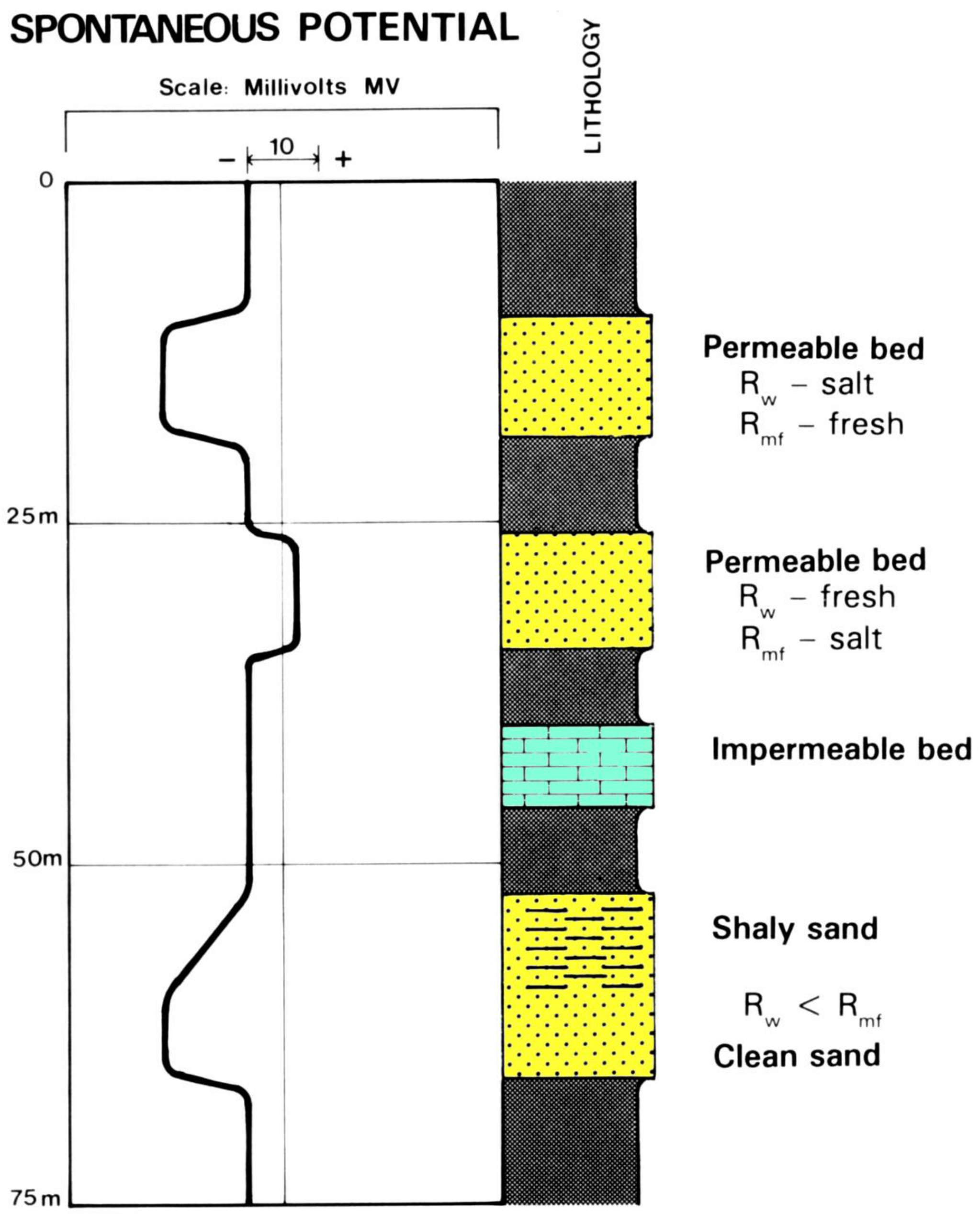
SP Log – General Overview

- Self or Spontaneous Potential is one of the earliest logs used and still in use.
- It is one of the electrical log types.
- Measured in millivolts (mV).
- Primarily used for:
    - Determining gross lithology, $i.e.$ Reservoir versus non-reservoir (permeable vs non-permeable).
    - Correlation.

The Use of SP Log

Nowadays SP log is used to:

- Detect permeable beds
- Detect boundaries of permeable beds
- Determine formation-water resistivity (***Rw***)
- Determine the volume of shale in permeable beds
- Detection of hydrocarbons



SP Requirement

- There are three requirements for the existence of an SP current:

1. A conductive borehole fluid (i.e., a salt-water based mud).
2. A sandwich of a porous and permeable bed between low porosity and impermeable formations.
3. A difference in salinity between the borehole fluid and the formation fluid, which are the mud filtrate and the formation fluid in most cases.

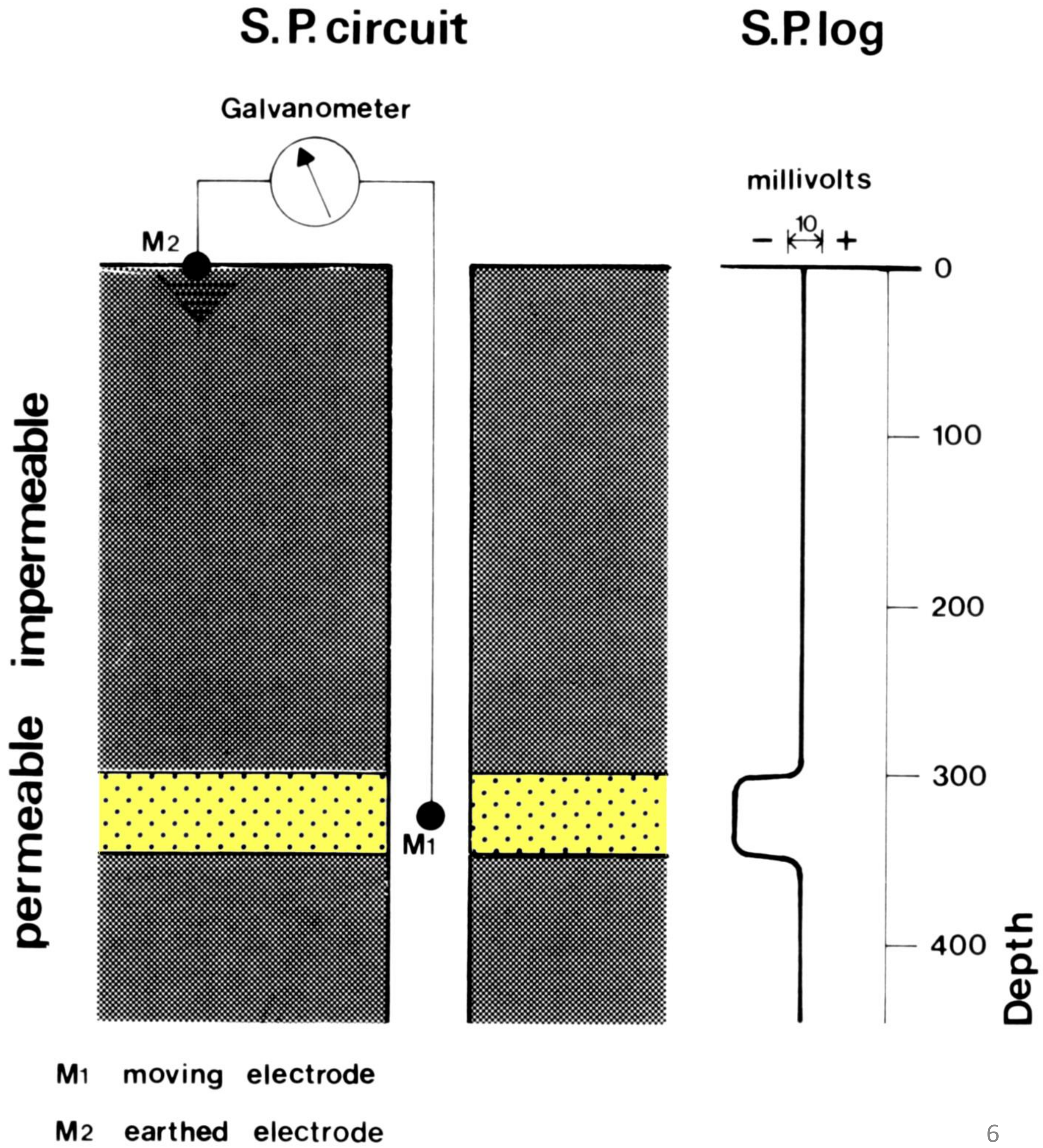
SP Log Operation

- An electrode (usually lead) is sent down to the well and an electrical potential is registered at different points in the hole with respect to surface electrode.

- Therefore SP is a recording of the difference in potential (Voltage difference or direct current - DC) of a moveable electrode in a borehole and a fixed electrode on the surface.

- In order to record a potential the hole must contain conductive mud, as it cannot be recorded in air or oil-base mud, because, SP readings are caused by differences in salinities between mud filtrate and formation waters in permeable beds.

Principle of the SP Log



Source of SP Log

- SP results from electric currents result in the interface between drilling mud and formation fluid (water).

- There are three sources of the currents, two $Electrochemical\ E_c$ and one $Electrokinetic\ E_k$.

- Deflection of SP is caused by the Electrochemical E_c and Electrokinetic E_k actions.

Electrochemical Component (E_c)

- Two potential effects are the main structure of this component which are caused as a result of difference in salinities of the mud filtrate and the formation water and between shale bed and virgin zone.

Where;

$$E_c = E_{lj} + E_m$$

- Elj is the "Liquid Junction Potential“
- Em is "Membrane Potential"

- The ions Na^+ and Cl^- have different mobility at the junction of the invaded and virgin zones. The movement of the ions across this boundary generates a current flow and hence a potential. This is known as the Liquid Junction Potential (Elj).

- Shale beds are permeable to Sodium ions but not to Chloride ions. Hence there is a movement of charged particles through the shale creating a current and thus a potential. This is known as the membrane potential (Em).

Liquid Junction Potential E_{lj}

- E_{lj} occurs when two solutions have different salinities are in direct contact. As it is known that ions move from the more concentrated solution to the more diluted one. This situation occurs at the interfaces of the mud filtrate and the undisturbed formation water.

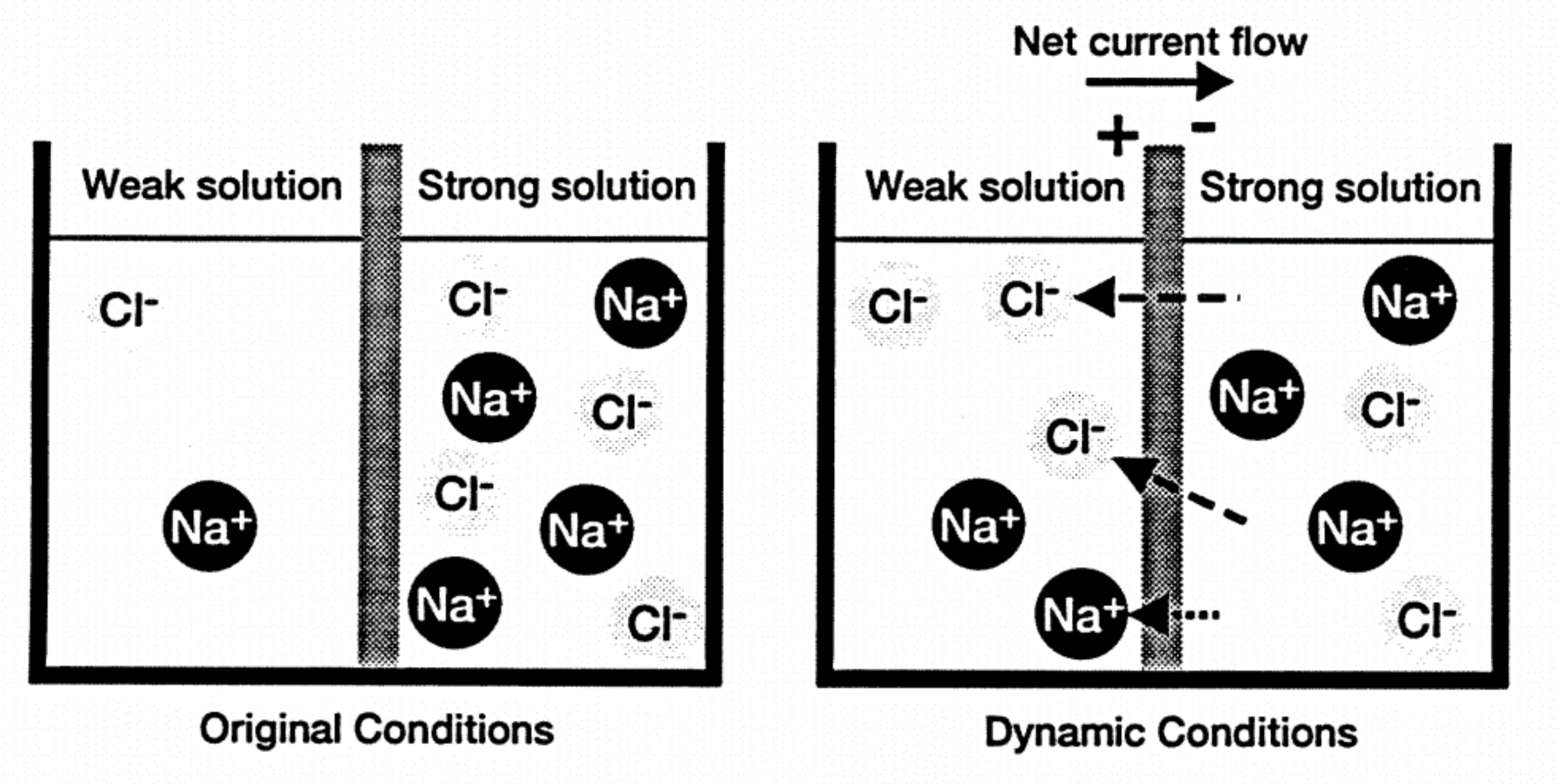
- In the case of solution saturated with sodium chloride ($NaCl$) the negative chlorine ions Cl^{-} move at a faster rate than the positive sodium ions Na^{+} due to their size difference.

- The ionic imbalance causes a current flow to develop; hence the potential is from the mud filtrate to the more saline formation water, but this situation could be reversed if the formation water is less saline than mud filtrate.

E_{lj} (Contd.)

- This potential exists at the junction between the invaded and the non-invaded zone, and is the direct result of the difference in salinity between the mud filtrate and the formation fluid.
- In permeable sand, if the formation water is more saline than the mud filtrate, then the salt ions Na^+ and Cl^- will diffuse toward the mud filtrate.
- The Cl^- ions are more mobile than Na^+ ions.
- The more saline side will become positive with respect to the less saline side.
- The liquid junction potential will always be present as long as there is a difference in salinity between the formation and the mud filtrate.

Liquid Junction Effects



Developing of liquid junction effect

Membrane Potential (E_m)

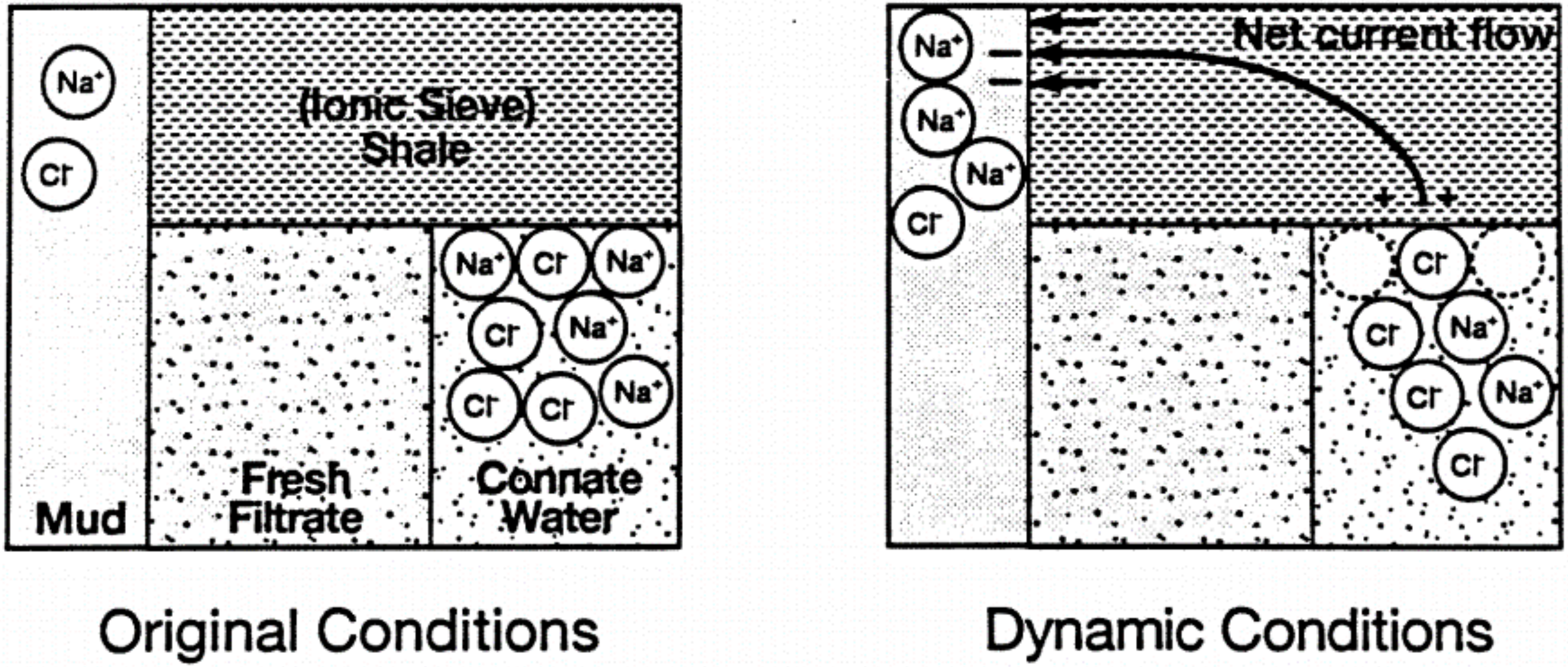
- E_m occurs at the shale interface.

- This potential exists at the junction between the non-invaded zone and the shale (or other impermeable rock) sandwiching the permeable bed.

- The crystal structure of the clay minerals within the shale act as an ion selective membrane within which negative chlorine ions Cl^- are selectively filtrate, while, positive sodium ions move freely through the clays. This will result in a positive current flow towards the borehole in contact with shale.

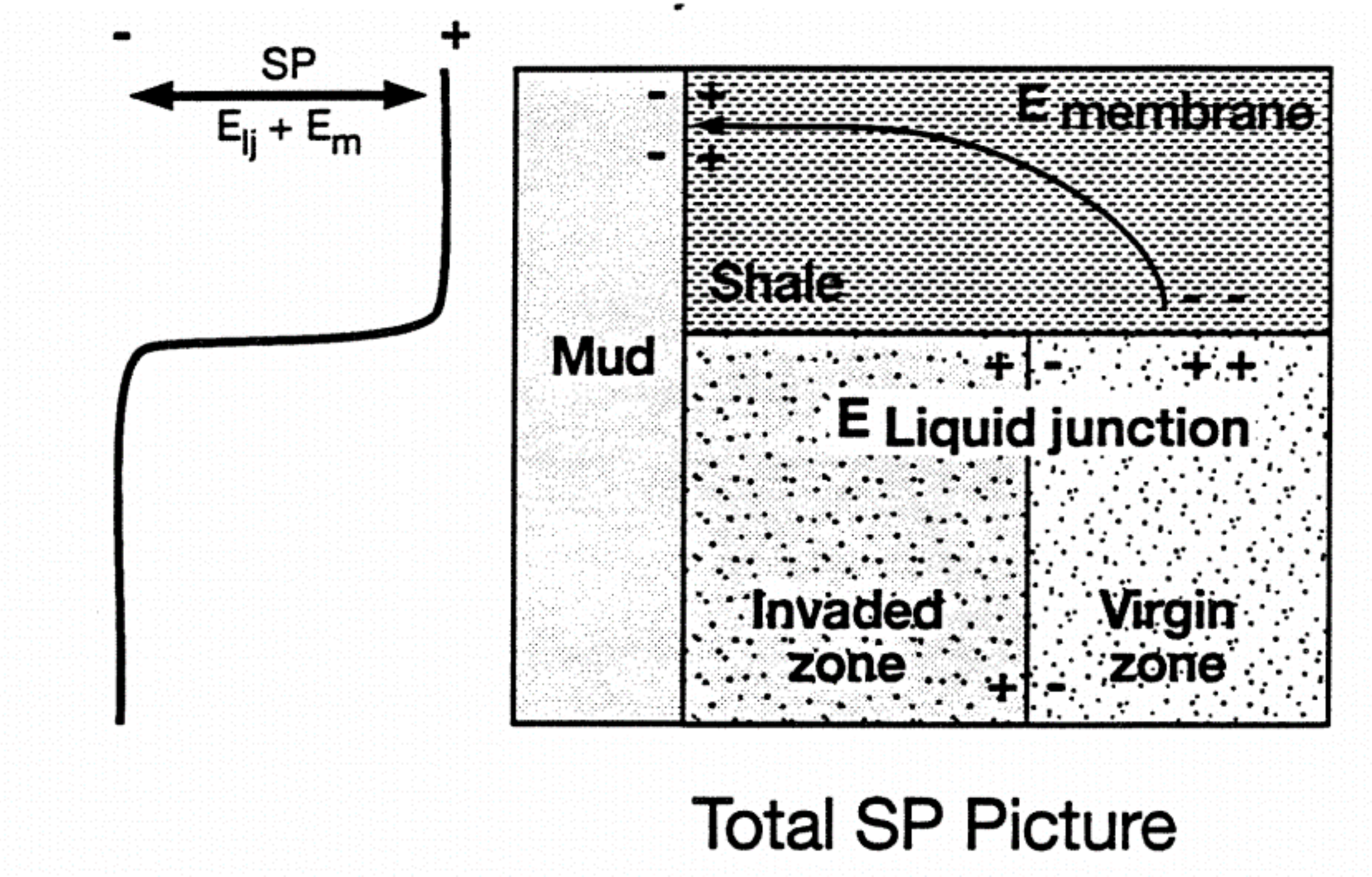
- The shale allows only the Na^+ ions to move from the formation into the mud by diffusion so that the mud becomes more positive than the formation.

Membrane Potential SP



Membrane potential developing process

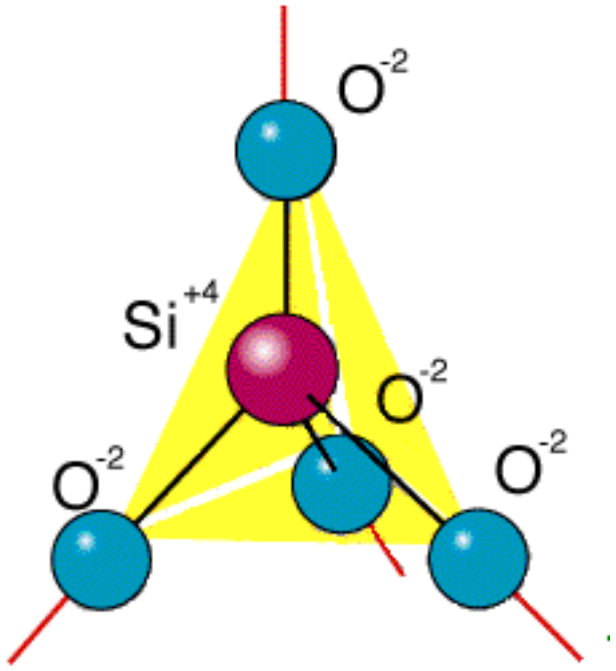
Total SP



Total SP Recording Diagram

The Nature of Shale

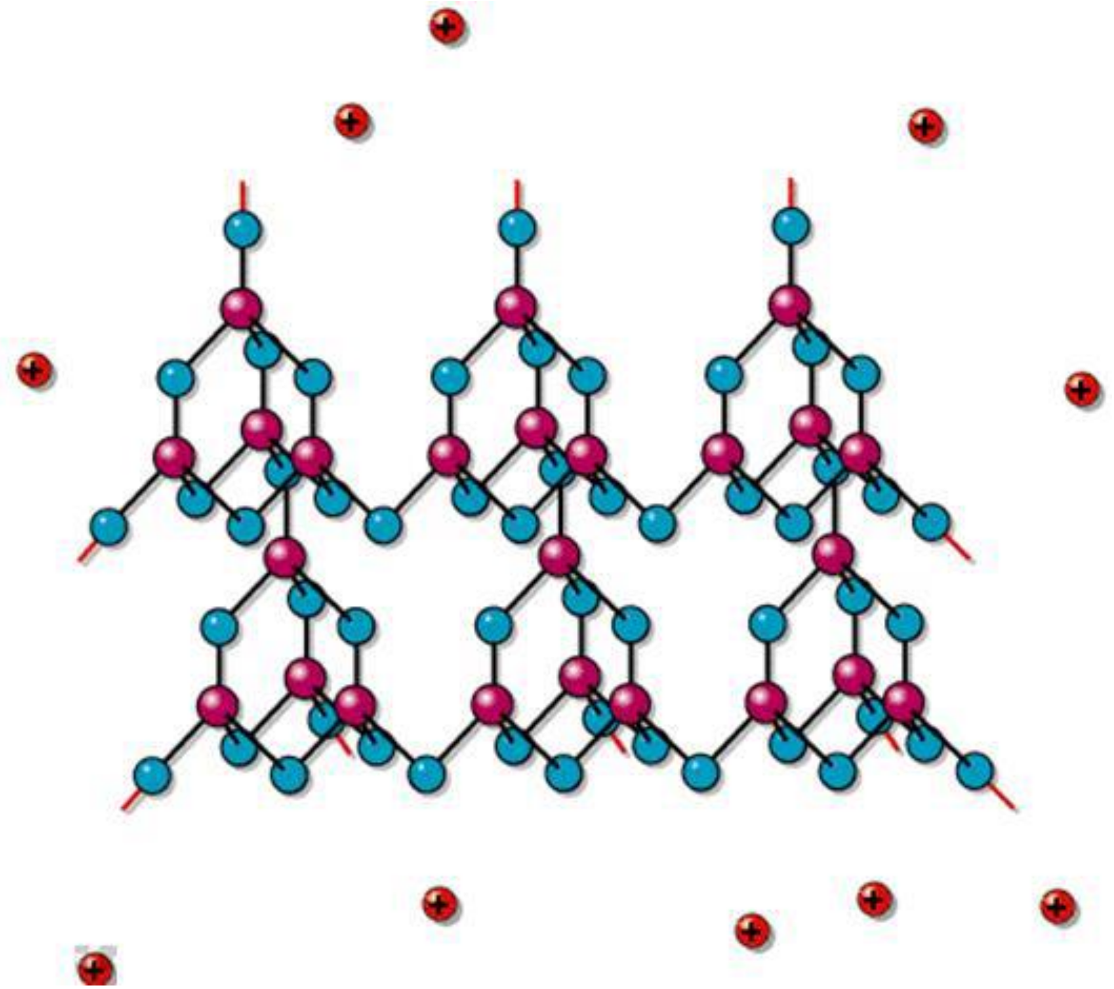
- Shales are mostly mixtures of various clay minerals which are generally composed of:
  - $Silicon\ (SI^{+4})$
  - $Aluminium\ (AL^{+3})$
  - $Oxygen\ (O^{-2})$



Chemical composition of shale

The Nature of Shale (Contd.)

- As shown in the figure, Silicon forms a strong bond with Oxygen, leaving Oxygen atoms on the edge of the SiO_4 sheets.
- These sheets have a negative charge which attracts positive ions (cations) such as K+, Na^{+}, Ca^{++}, Sr^{++} and Ba^{++}.



Shale bond structure

Electrokinetic Component (E_k)

- An Ek is generated by the flow of mud filtrate through a porous and permeable bed. It depends upon the resistivity of the mud filtrate and will only become important if there are high differential pressures across the formation.

- This process is not well understood and the effects are normally negligible in permeable formations because the mudcake builds quickly and stops any further invasion. In low porosity, low permeability formations, the mudcake builds slowly and the Electrokinetic potential becomes predominate.

- This is the potential that makes the SP appear to float randomly in very tight formations such as low porosity carbonates. In these conditions, the SP cannot be used to determine Rw.

Shape of the SP curve

- Shape of the SP deflection opposite a permeable bed depends on:
  - Thickness h and true resistivity R_t of the permeable bed.
  - Resistivity R_{xo} and diameter d_i of the zone contaminated by mud filtrate invasion.
  - Resistivity R_s of the adjacent shale formation.
  - Resistivity of the mud R_m and the diameter d_h of the borehole.

The SSP term

difference btw SSP / PSP

- SSP: Static Spontaneous Potential
- Maximum SP that a thick, shale free, porous and permeable formation can have for a given ratio between R_{mf} and R_w.
- Determined by formula or by chart (more details during tutorials).
- Necessary for determining accurate values of R_w and volume of shale.

The PSP term

- PSP: Pseudo-static spontaneous potential
- PSP is the SP record that results in the deflection of the signals from the permeable beds but with the presence of shale.
- The deflection value will be less than both normal SP and SSP.
- i.e. $PSP < SP$ and SSP

Factors influence SP

- Bed Thickness

  In thin formations (< 3m), the measured SP is less than the SSP.

  Narrow, pointed SP curve; correction for bed thickness required.

- Bed Resistivity

  Higher resistivities reduce the reflection of the SP curve.

- Borehole and Invasion

  Usually very small and in general can be ignored. This effect is noticeable in depleted reservoirs. There is no way to handle it quantitatively. (This phenomenon is called the electrokinetic SP).

- Shale Content

  Presence of shale in a permeable formation, reduces the SP deflection.

- Hydrocarbon Content

  In hydrocarbon bearing zones, the SP curves deflection is reduced. Hydrocarbon saturation will reduce SP measurements. Thus, only water-bearing sands should be selected for Rw determination from the SP.

Schematic summary of SP curve behaviour under a variety of different logging circumstances

Figure A

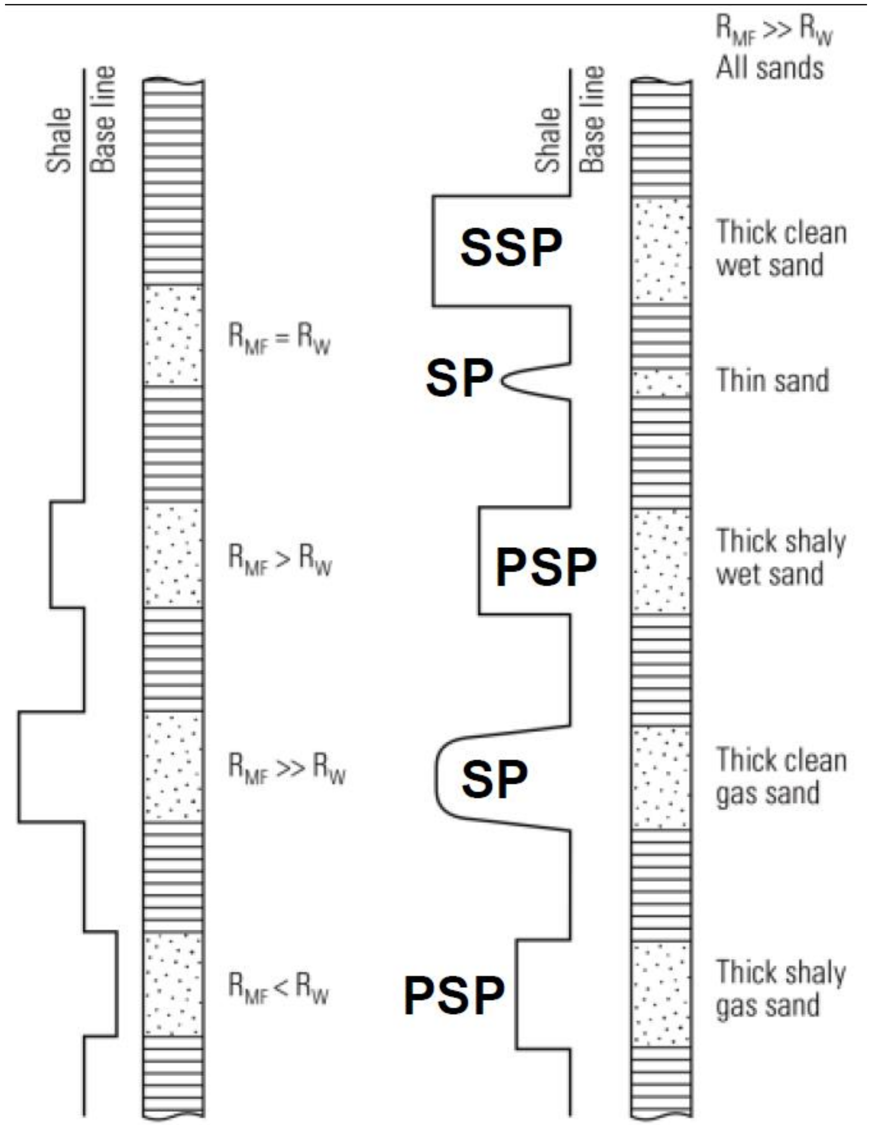


Figure B

Figure A

- In the left panel of figure A, a sequence of shale and clean sand beds is represented, along with the idealized response.
- The shale baseline is indicated, and deflections to the left correspond to increasingly negative values.
- In the first sand zone, there is no SP deflection since this case represents equal salinity in the formation water and in the mud filtrate.
- The next two zones show a development of the SP which is largest for the largest contrast in mud filtrate and formation water resistivity.
- In the last zone, the deflection is seen to be to the right of the shale baseline and corresponds to the case of a mud filtrate which is saltier than the original formation fluid.

Figure B

- The second panel of Figure B illustrates several cases, for a given contrast in mud filtrate salinity and formation water salinity.

- The first point is that the deflection will be reduced if the sand bed is not thick enough because not enough of the potential drop occurs in the borehole. The transition at the bed boundary is much slower for the same reason.

- SSP (Static spontaneous potential) at the top of the diagram, is the maximum deflection possible in a thick, shale-free, and water-bearing (wet) sandstone for a given ratio of Rmf/Rw.