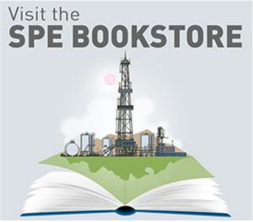

Lecture(4)

Spontaneous (SP) log

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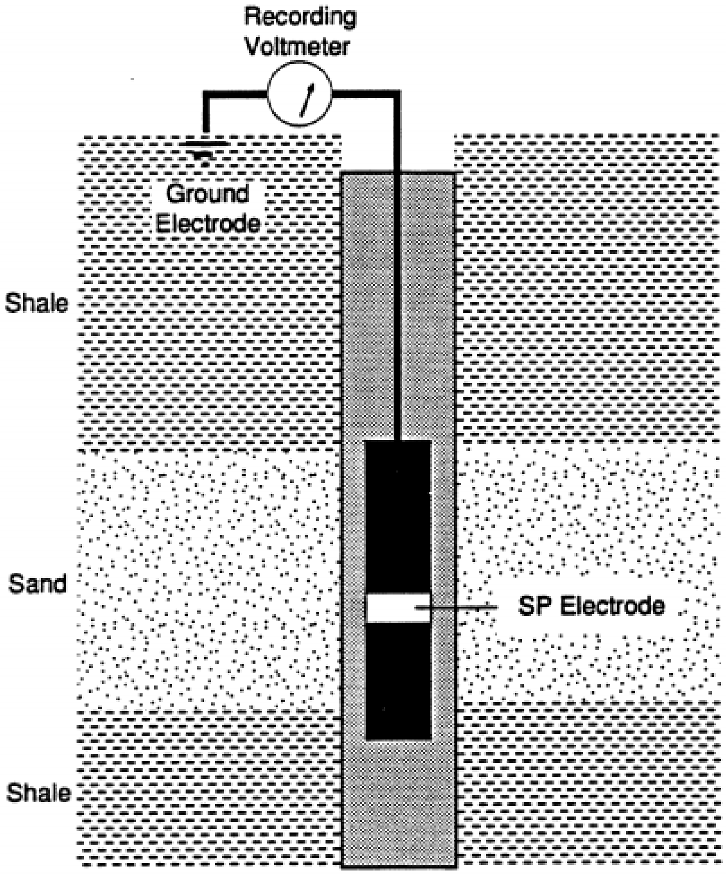
The SP curve is a continuous recording vs. depth of the electrical potential difference between a movable electrode in the borehole and a surface electrode,Fig(1).



Fig(1) Sp logging

Adjacent to shales, SP readings usually define a straight line known as the shale baseline. Next to permeable formations, the curve departs from the shale baseline; in thick permeable beds, these excursions reach a constant departure from the shale baseline, defining the "sand line." The deflection may be either to the left (negative) or to the right (positive), depending on the relative salinities of the formation water and the mud filtrate. If the formation-water salinity is greater than the mud-filtrate salinity (the more common case), the deflection is to the left.

The relevant features of the SP curve are its shape and the size of its departure from the shale baseline. Because the absolute reading and position of the shale baseline on the log are irrelevant, the SP sensitivity scale and shale-baseline position are selected by the logging engineer for convenience. The SP log is typically scaled at 100 mV per log track. If the resistivities of the mud filtrate and formation water are similar, the SP deflections are small and the curve is rather featureless. An SP curve cannot be recorded in holes filled with nonconductive muds, such as oil-based muds (OBMs).

Origin of the SP

deflections of the SP curve are the result of electrochemical and electrokinetic potentials in the formations that cause electric currents to flow in the mud in the borehole.

A-Electrochemical component:

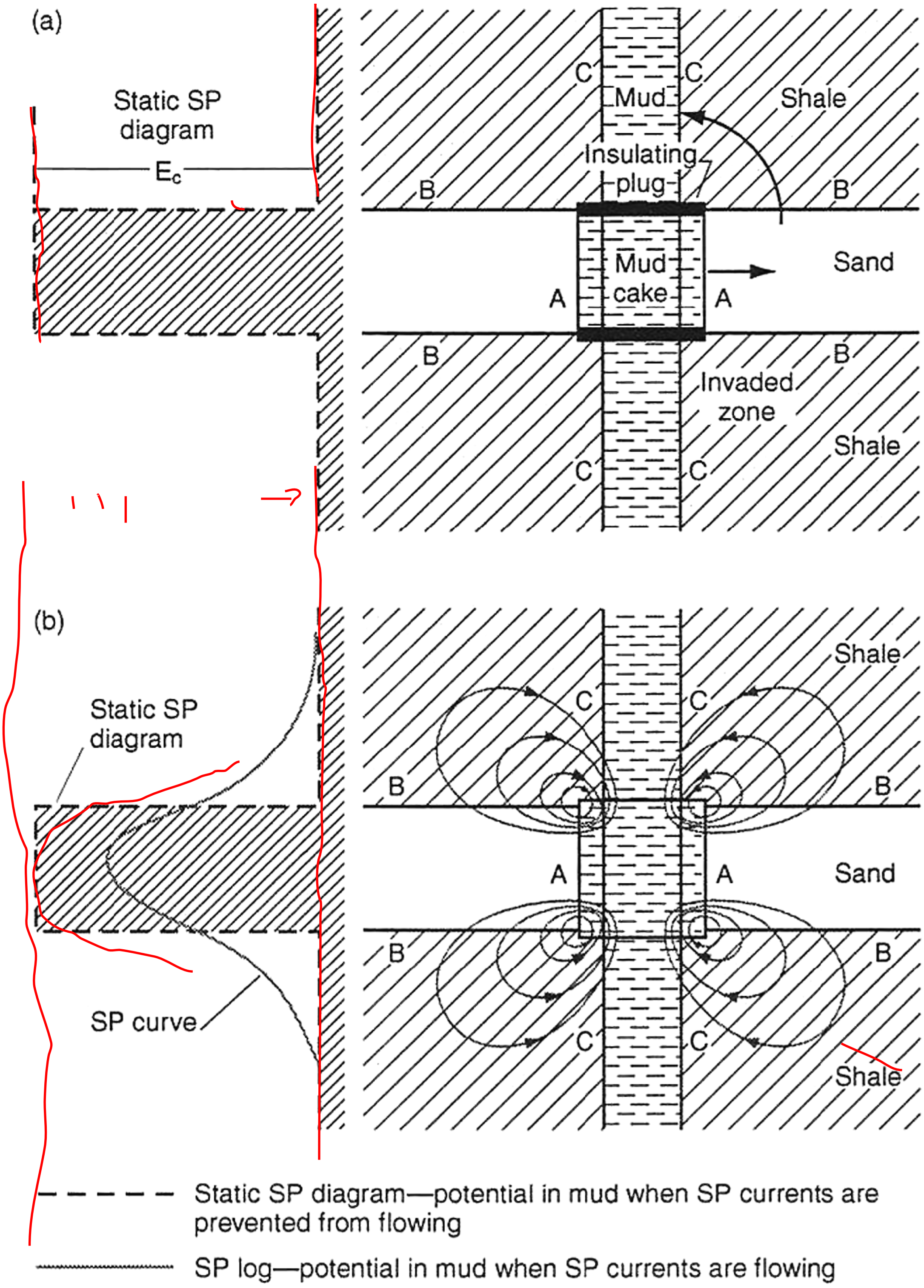
-==================------

1-Membrane potential

The structure of clay minerals in shales and the concentration of negative electric charges on the clay particle surfaces give shales a selective permeability to electrically charged ions. Most shales act as "cationic membranes" that are permeable to positively charged ions (cations) and impermeable to negative ions (anions).

The upper part of **Fig. 2** shows saline formation water in a sandstone formation and mud in the borehole separated by a shale. Sodium chloride, which is usually present in both the formation water and the drilling mud, separates into charged ions (Na^+ and $Cl^–$) in solution in water. The Na^+ and $Cl^–$ ions tend to migrate from a more-concentrated to a less-concentrated solution, but because the intervening shale is a cationic membrane, impervious to $Cl^–$ ions, only the Na^+ ions can migrate. If, as usual, the formation water is a more concentrated NaCl solution than the mud, there is a net flow of positive ions through the shale from the sandstone to the borehole. This corresponds to a positive electric current in the same direction (indicated by the curved arrow) driven by an electric potential, or electromotive force (EMF), across the shale. Because the shale acts as an ion-selective membrane, the electric potential is known as the membrane potential.

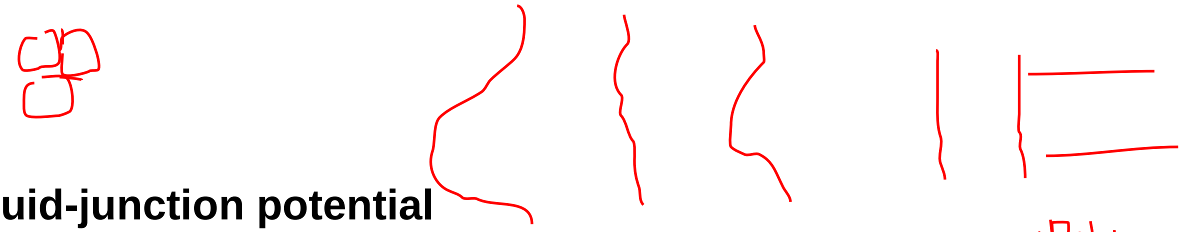
SSI SSP



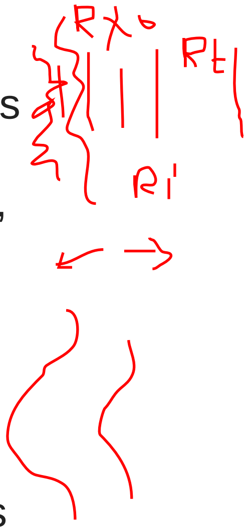
- - - - Static SP diagram—potential in mud when SP currents are prevented from flowing

—— SP log—potential in mud when SP currents are flowing

Fig. 2 – Schematic representation of potential and current distribution in and around a permeable bed.



2-Liquid-junction potential



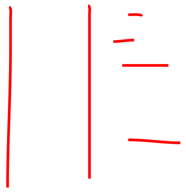
At the edge of the invaded zone, where the mud filtrate and formation water are in direct contact, Na^+ and Cl^- ions can move freely from one solution to the other. But Cl^- ions are smaller and have greater mobility than Na^+ ions, so the net diffusion of ions from the more-concentrated formation water to the less-concentrated mud filtrate includes a greater number of Cl^- ions than Na^+ ions. This is equivalent to a positive current flow in the opposite direction (indicated by the straight arrow at A in **Fig. 1**.)

The current flowing across the junction between solutions of different salinity is driven by an EMF called the liquid-junction potential. The magnitude of the liquid-junction potential is only approximately one-fifth of the membrane potential.

If the solutions contain substantial amounts of salts other than NaCl, the value of K at 77°F may not be 71. If the permeable formation contains some shale or dispersed clay, the total electrochemical potential, and therefore the SP deflections, is reduced.

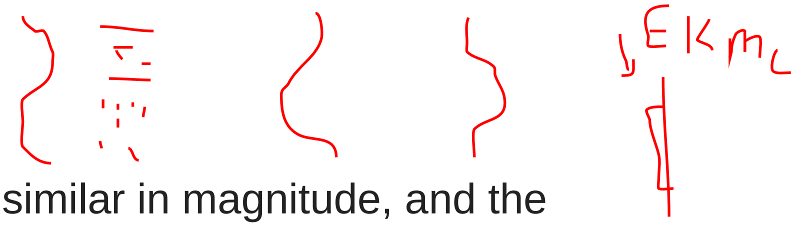
B-Electrokinetic Component

An electrokinetic potential (E_k, also called the streaming potential or electrofiltration potential) is produced when an electrolyte flows through a permeable medium. The size of the electrokinetic potential is determined mainly by the differential pressure producing the flow and the resistivity of the electrolyte.



In the borehole, the electrokinetic potential E_{kmc} is produced by the flow of mud filtrate through the mudcake deposited on the borehole wall opposite permeable formations. Little or no electrokinetic potential is generated across the permeable formation itself because the differential pressure is usually low. The electrokinetic potential E_{ksh} may, however, be produced across a shale if it has any permeability.

hP = 0.052 x M.Wt
T.V.D



Typically, E_{kmc} and E_{ksh} are similar in magnitude, and the net electrokinetic contribution to the SP deflection is negligible. If the formation water is fairly saline (resistivity less than 0.1 ohm•m) and the differential pressure is in the normal range of only a few hundred psi, the contribution of the electrokinetic potential can usually be ignored.

Electrokinetic effects may be significant in highly depleted formations or when heavy drilling muds are used because of unusually large differential pressures. Significant electrokinetic effects may also occur in very-low-permeability formations, where an appreciable part of the pressure differential occurs in the formation itself, especially if little or no mudcake is formed. If the formation water is brackish, the mud is resistive, and the low-permeability formation is clean and has some porosity, the electrokinetic effect could be as large as –200 mV.

SP and permeability

The movement of ions, essential to develop an SP, is possible only in formations with some permeability, however small—a small fraction of a millidarcy is sufficient. There is no direct relationship between the magnitude of the SP deflection and the value of either the formation's permeability or its porosity.

Static SP

The lower part of **Fig. 2** shows SP currents in the borehole and formations. The current directions indicated correspond to the more usual case of formation-water salinity greater than mud-filtrate salinity, producing a potential by the permeable bed lower than the potential by the shale. This corresponds to a deflection to the left on the SP log by the permeable bed.

If the mud-filtrate salinity is greater than the formation-water salinity, the currents flow in the opposite direction, producing positive SP deflections. If the salinities of the mud filtrate and formation water are similar, no SP is generated.

The SP currents flow through four different media:

- Borehole fluid
- The invaded zone
- The uninvaded part of the permeable formation
- Surrounding shales

The SP log measures only the potential drop from the SP currents in the borehole fluid, which may not represent the total SP because there are also potential drops in the formation. If the currents could be interrupted by hypothetical insulating plugs (see the upper part of **Fig. 2**), the potential observed in the mud would be the total spontaneous potential. This idealized SP deflection is called the static SP (or SSP). The SP deflection practically reaches the SSP in a thick, clean formation.

The borehole presents a much smaller cross-sectional area to current flow than the formations around it, so the resistance of the borehole part of the SP current loop is much higher than the formation part. Nearly all the SP potential drop, therefore, occurs in the borehole if formation resistivities are low-to-moderate and formation beds are thick, so, in practice, the recorded SP deflection approaches the static SP value in thick, permeable beds.

Determination of SSP

To determine the SSP, a sand line is drawn through the maximum (usually negative) excursions of the SP curve adjacent to the thickest permeable beds. A shale baseline is drawn through the SP through the intervening shale beds. The separation of the sand line from the shale baseline, measured in mV, is the SSP. Any SP anomalies are discounted.

If there are no thick, clean, permeable invaded beds in the zone under study, the SP reading can be corrected for the effects of bed thickness and invasion to estimate the SSP by using charts available from service companies.

Shape of the SP curve

The slope of the SP curve is proportional to the intensity of the SP currents in the borehole at that depth. Because the current intensity is highest at the boundaries of the permeable formation, the slope of the SP curve is at a maximum, and an inflection point occurs at these bed boundaries.

The shape of the SP curve and the amplitude of its deflection in permeable beds depend on the following factors: thickness and true formation resistivity of the permeable bed, resistivity of the flushed zone (R_{xo}) and diameter d_i, resistivity of the adjacent shale bed (R_s), and resistivity of the mud and the diameter of the borehole (d_h).

Fig 3. shows examples of SP curves computed for $R_t = R_s = R_m$ (on the left) and $R_t = R_s = 21R_m$ (in the center). In the first case ($R_t = R_s = R_m$), the SP curve gives a much sharper definition of the boundaries of the permeable beds, and the SP deflections approach the SSP value more closely than in the case where the formation-to-mud resistivity ratio is 21.

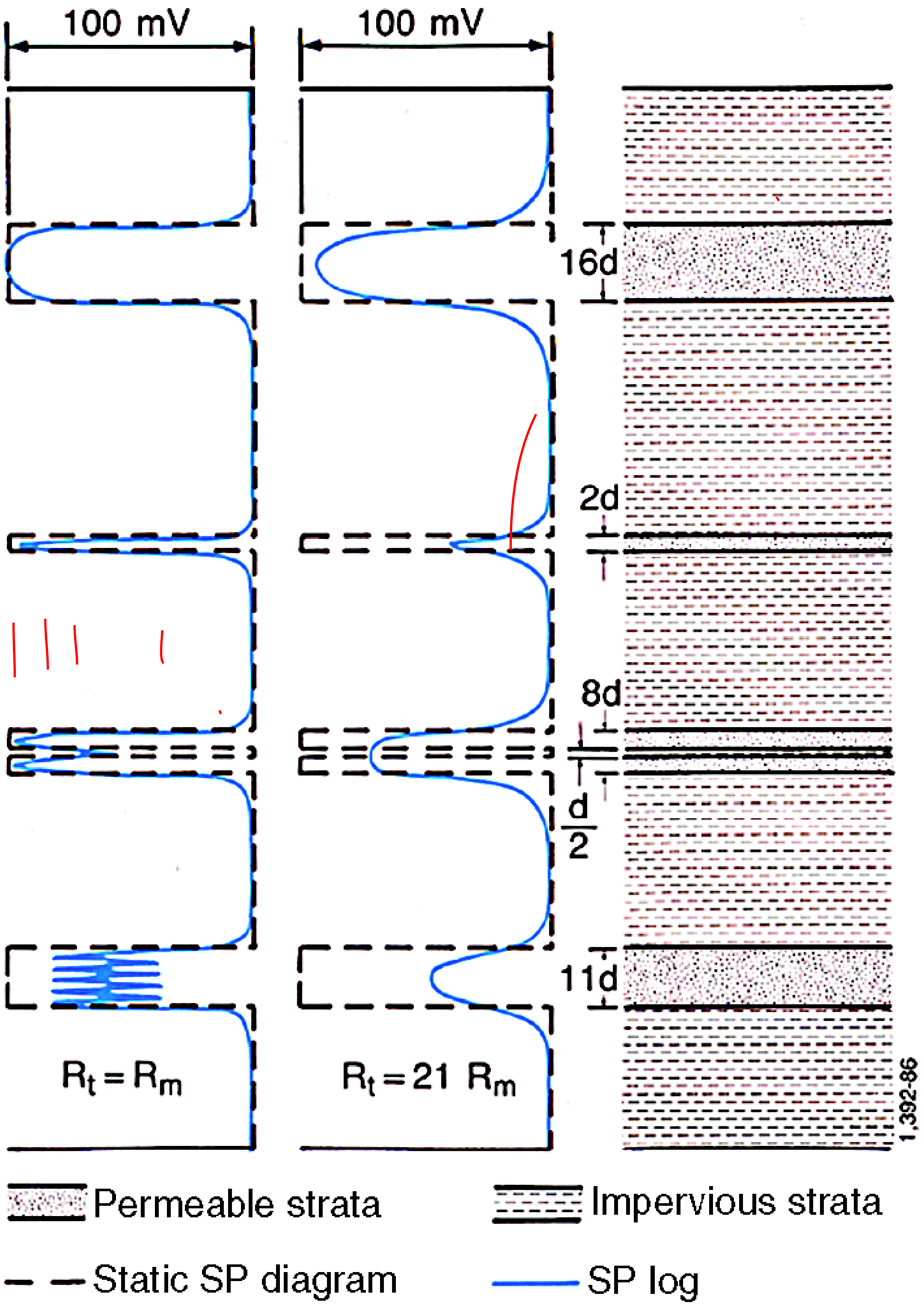


Fig3. shows examples of SP curves computed for $R_t = R_s = R_m$ (on the left) and $R_t = R_s = 21R_m$ (in the center).

SP anomalies

The SP curve may be difficult to interpret and use for R_w determination because it does not always behave ideally. The following are a few cases of apparently anomalous SP responses.

1) Highly resistive formations

Highly resistive formations between some shales and permeable beds can significantly alter the distribution of the SP currents and change the expected shape of the SP curve. The currents shown flowing from shale bed Sh 1 toward permeable bed P_2 in **Fig. 4** are largely confined to the borehole by the high resistivity of the formation separating Sh_1 and P_2. The current in the borehole over this interval is constant, so for a constant borehole diameter, the SP curve is a straight line inclined to the shale baseline.

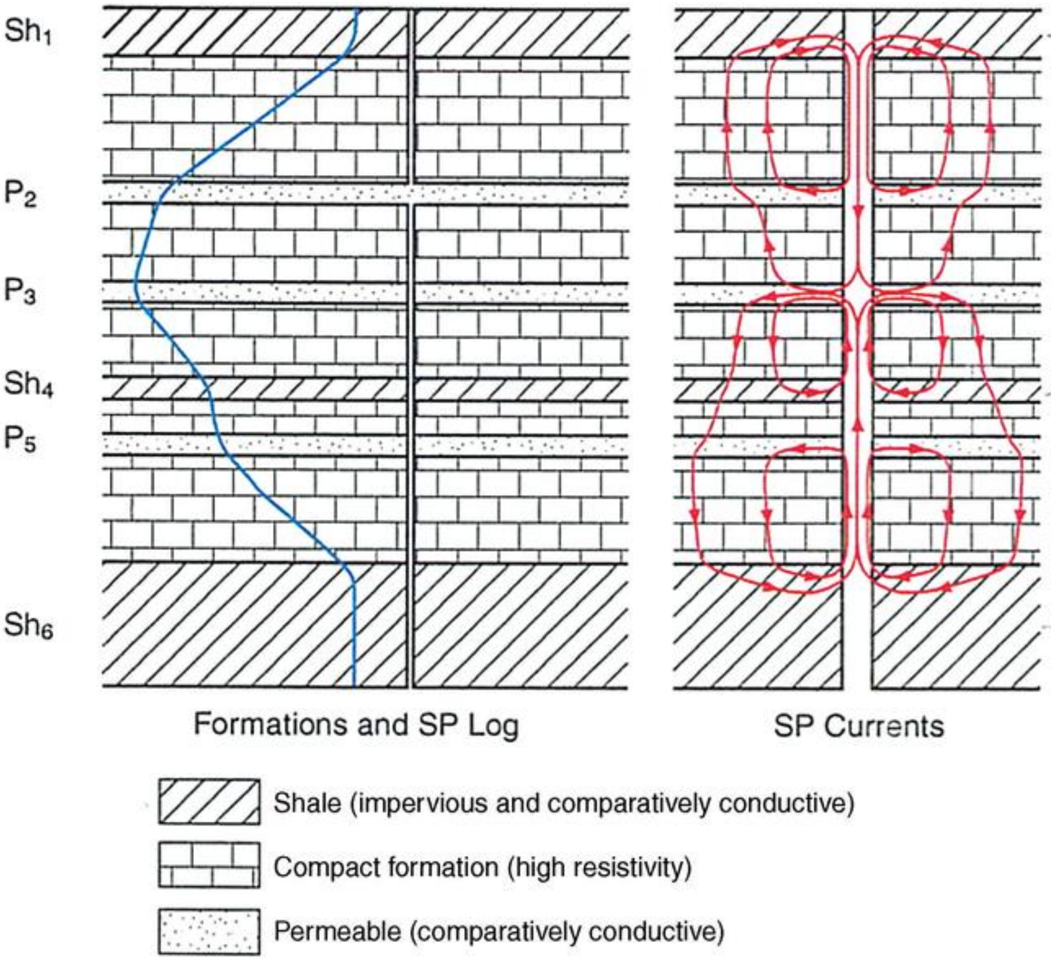


Fig. 4.
Schematic representations of SP phenomena in highly resistive formations.

The SP curve consists of straight portions adjacent to the high-resistivity zones with a change of slope at each more conductive permeable interval (the SP curve is concave toward the shale line) and opposite every shale bed (the SP curve is convex toward the shale line). Defining permeable bed boundaries from the SP log is difficult in the vicinity of highly resistive formations.

2) Shale-baseline shifts

A shift of the shale baseline can occur when formation waters of different salinities are separated by a shale bed that is not a perfect cationic membrane. **Fig. 5** shows an SP log recorded in a series of sandstones (B, D, F, and H) separated by thin shales or shaly sandstones (C, E, and G). The SSP of Sandstone B is –42 mV. Shale C is not a perfect cationic membrane, and the SP curve does not return to the shale baseline defined by Shale A. A new shale baseline defined by Shale E gives SP deflections of +44 mV in Sandstone D and –23 mV in Sandstone F.

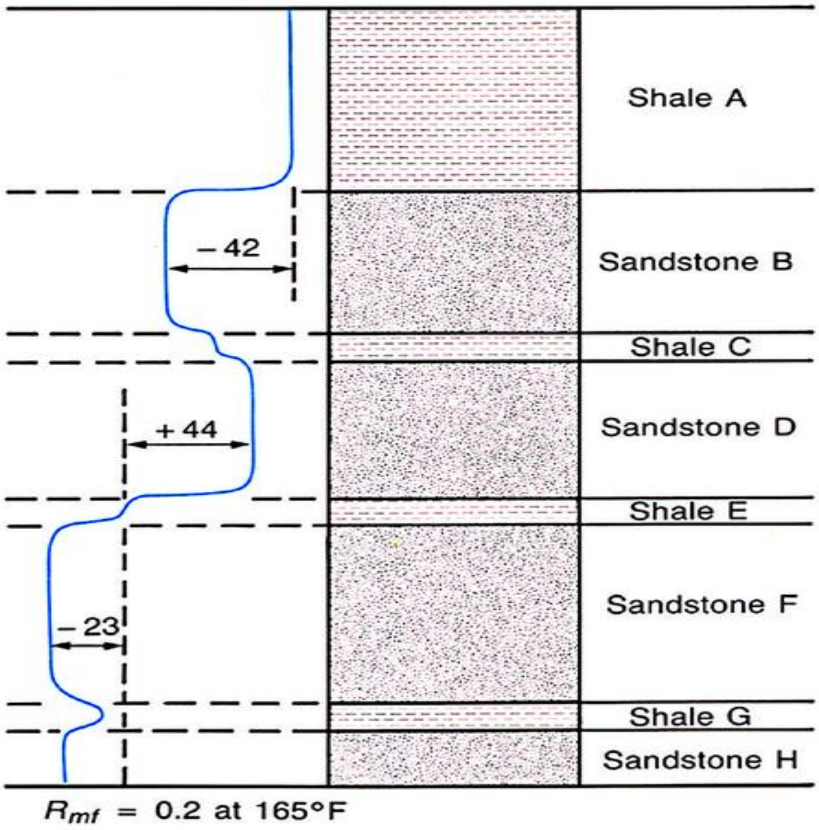


Fig-5.Sp base line Shift

Baseline shifts also occur when formation waters of different salinities are separated by an impermeable layer that is not a shale. In this case, the SP curve shows little or no variation at the level of the change in salinity, but the deflections at the upper and lower shale boundaries are different and may even have different polarities.

3) Invasion-related anomalies

If the mud filtrate and the formation water have significantly different salinities, and therefore different densities, gravity-induced fluid migration can cause SP anomalies in highly permeable formations, as shown in **Fig. 5**. Invasion is very shallow near the lower boundary of each permeable interval and deeper near the upper boundary.

The SP curve is rounded at the upper boundary because of the deep invasion, and it may have a sawtooth profile at thin, impervious shale streaks in which the SP deflection exceeds the SSP above the shale streak. A reading greater than the SSP is caused by the accumulation of filtrate below the shale streak. Encircling the hole is a horizontal disk of shale sandwiched between salt water and fresher mud filtrate that acts like a battery cell. The EMF of this cell is superimposed on the normal SSP, producing the sawtooth profile.

4) Noisy SP logs

SP measuring circuits are sensitive and therefore prone to recording spurious electrical noise superimposed on the SP curve. Occasionally, the source of noise cannot be eliminated during logging, and a noisy log is recorded. However, this does not always render the log A regular sine-wave signal may be superimposed on the SP curve when some part of the logging winch is magnetized. An intermittent contact between the casing and cable armor may also cause spurious spikes on the SP curve. In these situations, the SP curve can usually be read so that the sine-wave amplitude or noise spikes are not added to or subtracted from the authentic SP deflection.

Direct currents flowing through formations near the SP electrode can cause erroneous SP readings, particularly where formation resistivities are high. These currents may be caused by "bimetallism," when the logging tool has exposed metal housings. The currents are small and have a significant effect on the SP only in highly resistive formations. If an SP curve looks questionable in highly resistive formations, it should be relied on only in lower-resistivity intervals.

The offshore logging environment is notorious for its ample supply of sources of electrical noise, such as:

- Wave motion
- Cathodic protection systems
- Rig welding
- Onboard generators
- Leaky power sources

On land, proximity to power lines and pumping wells may have a similar effect on the SP curve, but the effects can usually be minimized by carefully choosing the ground-electrode location.