5
SELF-POTENTIAL OR SP LOGS

5.1 Generalities

The log

The SP log is a measurement of the natural potential differences or self-potentials between an electrode in the borehole and a reference electrode at the surface: no artificial currents are applied (Figure 5.2). (The currents were actually called *'potentiels spontanés'*, or 'spontaneous potentials', by Conrad Schlumberger and H.G. Doll who discovered them.) They originate from the electrical disequilibrium created by connecting formations vertically (in the electrical sense) when in nature they are isolated.

Principal uses

The principal uses of the SP log are to calculate formation-water resistivity and to indicate permeability. It can also be used to estimate shale volume, to indicate facies and, in some cases, for correlation (Table 5.1, Figure 5.1).

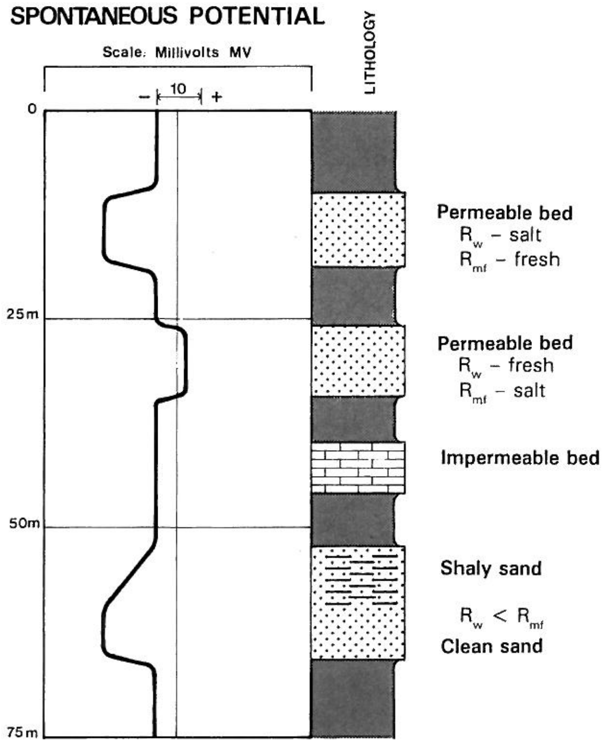

Figure 5.1 The SP log: some typical responses. The SP log shows variations in natural potentials. R_w = formation-water resistivity; R_{mf} = mud filtrate resistivity.

5.2 Principles of measurement

Three factors are necessary to provoke an SP current: a conductive fluid in the borehole; a porous and permeable bed surrounded by an impermeable formation; and a difference in salinity (or pressure) between the borehole fluid and the formation fluid. In oilfield wells, the two fluids concerned are the mud filtrate and (usually), formation water.

SP currents are created, when two solutions of different salinity concentrations are in contact, by two principal electrochemical effects; *diffusion or liquid junction potential and shale potential* (Figure 5.3). The diffusion potential (or liquid junction potential) arises when solutions of differing salinity are in contact through a porous medium. Sodium chloride, NaCl, is the most common cause of oilfield salinity, so that it is effectively two solutions of sodium chloride of different salinities that come into contact. Through the porous medium,

Table 5.1 The principal uses of the SP log.

	Discipline	Used for	Knowing
Quantitative	Petrophysics	Formation-water resistivity	Mud filtrate resistivity and formation temperature
		Shale volume	SSP and shale line
Qualitative	Petrophysics	To indicate permeability	Shale line
	Geology	Facies (shaliness)	Clay/Grain size relationships
		Correlation	

mixing of the two solutions takes place by ionic diffusion. The Cl^- ion is both smaller and more mobile than the larger, slower Na^+ ion. The ions mix (diffuse), therefore, at unequal rates, creating a charge separation. The Cl^- ion mixes the quickest, thus increasing its saturation in the more dilute solution. A potential is created between the negatively charged dilute solution with excess Cl^- and the positively charged, concentrated solution with excess Na^+ (Figure 5.3,*1*).

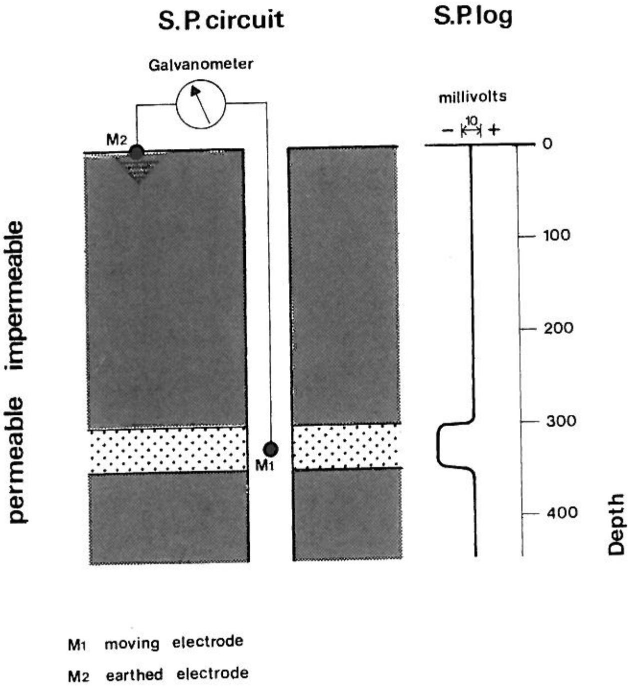

Figure 5.2 Illustration of the principle of the SP log. A natural potential is measured between an electrode in the well and an earth at the surface.

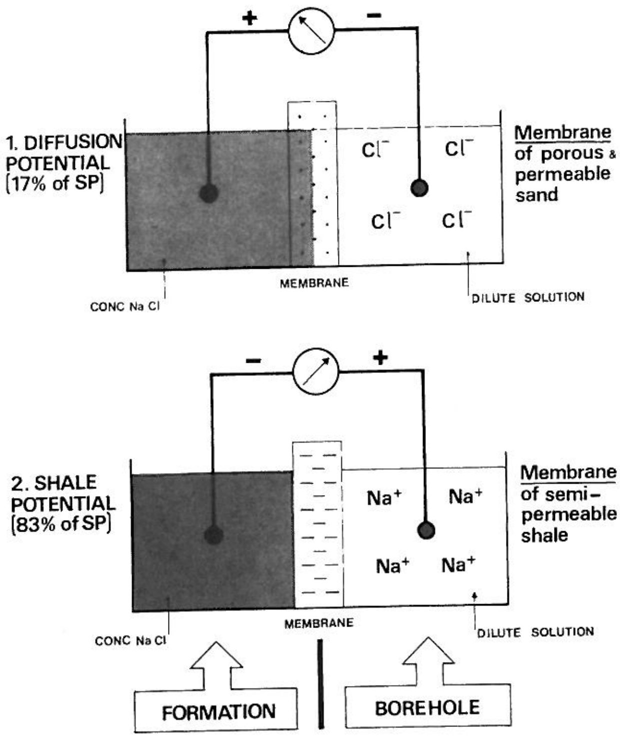

Figure 5.3 Schematic illustration of the main electrochemical SP effects. (1) Diffusion potential across a porous and permeable membrane; (2) shale potential across a membrane of semi-permeable shale. (Modified from Desbrandes, 1968).

The shale potential arises when the same two solutions are in contact across a semi-permeable membrane. In the borehole, this, as the name suggests, is shale (Figure 5.3,*2*). Clay minerals which form shales, consist of layers with large negative surface charge. Because of charge similarity, the negative chloride ions effectively cannot pass through the negatively charged shale layers, while the positive sodium ions pass easily. The shale acts as a selective barrier. As Na^+ ions therefore diffuse preferentially across a shale membrane, an overbalance of Na^+ ions is created in the dilute solution, and hence a positive charge. A corresponding negative charge is produced in the concentrated solution (Figure 5.3,*2*). The shale potential is the larger of the two electrochemical effects.

The actual spontaneous potential currents which are measured in the borehole are, for the most part, a result of the combination of the two electrochemical effects described above. Consider a porous and permeable sandstone penetrated by a borehole; the mud filtrate (for the example) is less saline than the formation waters (Figure 5.4). Opposite the sandstone bed (permeable membrane) the less saline solution, the mud filtrate, will become negatively charged as a result of the diffusion potential (cf. Figure 5.3,*1*). But above the sand, opposite the shale (semi-permeable membrane), because of the shale potential the less saline solution, the mud filtrate, will become positively charged (cf. Figure 5.3,*2*). The excess charge is therefore negative opposite the sand and positive opposite the shale.

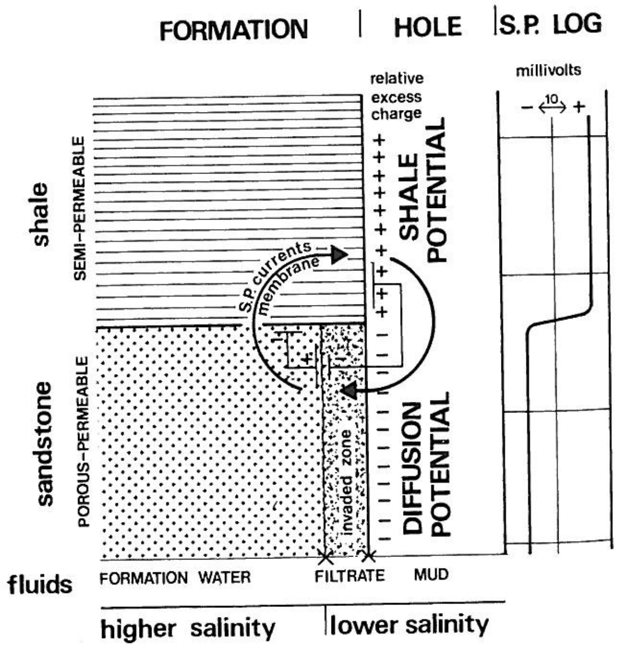

Figure 5.4 SP currents in the borehole. The effects of the shale potential and the diffusion potential act together at bed boundaries causing an SP log deflection.

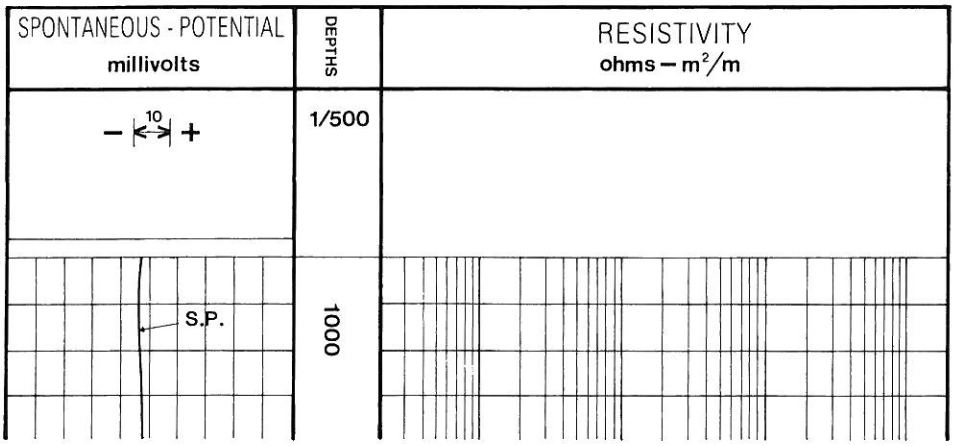

Figure 5.5 SP log presentation. The SP is in track 1. There is no absolute scale, only relative deflection – negative or positive. 1 division equals 10 millivolts.

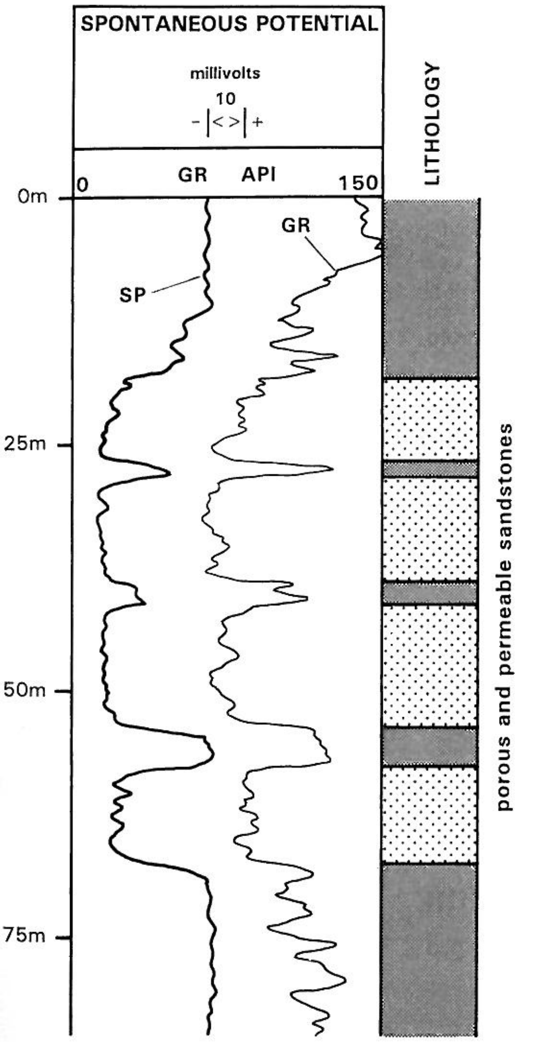

Figure 5.6 The bed definition and 'character' of the SP log compared to the gamma ray log. In most cases the gamma ray log gives much more formation information and better bed boundary definition than the SP.

This couple works in a complementary sense and creates a spontaneous current flowing between the borehole (mud filtrate), the porous formation and the

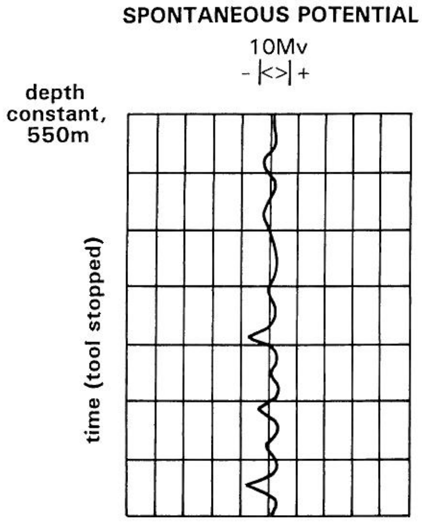

Figure 5.7 The SP log indicating sea state! For this test, offshore Louisiana, the SP tool was grounded to the rig and stopped at 550m. The changes in SP potential occur with the passing waves, which were 2.5m – 3.0m (8' – 10') crest to trough. The hole was cased (from Wallace, 1968).

contiguous shale (Figure 5.4). The flow of current is focused at the bed junction. It is only here that there is a change in potential. This is important since SP measurements are made not of absolute values, but of changes in values. It is only at the bed junctions, then, that changes take place and will be recorded.

If a bed is not permeable, ions will not be able to move, there will be no current flow and thus no potential change: that means no SP. However, even the slightest permeability will permit current flow and an SP change will be recorded.

The SP tool

The SP tool approaches the simplicity of the circuit described (Figure 5.2) and consists simply of an electrode (lead) mounted on an electrically isolated bridle on the downhole tool. A 1.5 volt battery is included in the circuit to give a bucking current to bring the SP to the required scale. The tool's galvanometer records only