SPWLA SYMPOSIUM
STATIC SP MEASUREMENT TOOL AND ITS FIELD APPLICATIONS

Guozhu Nie and Hui Xu, Jiuyun Energy Technology Company, Beijing, China

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ABSTRACT

Conventional Spontaneous Potential (SP) measurements are usually affected by many factors such as formation thickness, formation resistivity, mud resistivity, and borehole diameter. Because of these factors, the measured SP values could be much less than the Static SP (SSP) values and thus rendering the formation water resistivity determined from the SP inaccurate. This paper presents a new tool called Static SP Tool (SSPT) that can directly measure the SSP.

SSP is the electrochemical potential consisting of the diffusion potential and membrane potential. Conventional SP measures the potential difference of the SSP on the mud column in the well. When the formation is very thick, the measured SP is close to the SSP because the mud column resistance is high enough to represent all the resistances in the SSP electric current loop. To directly measure the SSP, the conditions of large mud column resistances should be created in the real well situations.

In order to simulate the condition of a large mud column resistance, a new sonde with an electrode array was designed. The electrodes consist of M0, M1, M2, A1, and A2, in which M0 is in the center and all others are symmetric pairs above and below the M0 electrode. The SSP current flowing through the mud inside the borehole creates a potential difference called Vm1m2 between M1 and M2. Based on the value of Vm1m2, the electronics inside the SSP tool supplies a current to the A1 and A2 electrode array. This current creates a potential between M1 and M2 having the same value and opposite polarity as Vm1m2 reducing the potential difference at M1 and M2 to zero. There is now no current flow between M1 and M2. In the other words, the virtually infinite large mud column resistance is simulated and the SP measured on M0 is very close to the SSP.

The SSPT was tested in several oilfields in China. In one of the test wells that has complete coring data, the formation water salinities computed from the SSP curves are very close to the lab analysis data from the cores. The vertical resolution of the SSP curves is as thin as 30 cm. With the help of the Rw computed from the SSP curves, several bypassed thin oil-bearing zones were found from log interpretations.

INTRODUCTION

The SP measurements are affected by some other factors like true resistivity of the permeable formation, resistivity and invasion diameter of the mud filtration invaded zone, resistivity of the adjacent shale formation, resistivity of the mud; and borehole diameter (Schlumberger, Log Principles/Applications). When computing formation water resistivity (Rw) from conventional SP logging curves, we need to do some environmental corrections like borehole, formation thickness, and invasion (Schlumberger, Log Charts, Bissiouni, Zaki and Mathews, Diane M.). Therefore, the desired SP logging tool is to measure the equivalent SSP curves directly without the effects by these factors.

Based on the SP measurement method (Schlumberger, Log Principles/Applications), the SP value is the electrical voltage drop on the mud column due to the SP current flow inside the borehole. To measure SP that is very close to the SSP, the mud resistivity is often required to be relatively large. However, this requirement is often not realistic. When the mud resistivity is low, the SP curve is relatively flat and the SP curve is not useful for its applications.

To minimize the effect of the mud resistivity, we borrow the concept of the dual laterolog tool (DLL). By applying the similar electrods of DLL, we can reach the effect of high mud resistivity. The SP values measured by this type of tool are very close to the SSP values.

ORIGIN OF SP

The theory of SP measurement was discussed by many references (Ellis, Darwin V. and Singer, Julian M., Schlumberger). The SP curve represents the electrochemical potential inside the borehole. There are two major components for the electrochemical potential: the diffusion potential and the membrane potential. The diffusion potential is produced by the ion diffusion between two solutions (formation water and mud filtrate) of different salinity. The membrane potential is caused by the ion-selective property of shales above and below a permeable formation. The diffusion potential is about one fifth of the membrane potential.

If the permeable formation is not shaly, the total electrochemical potential in the permeable formation is equal to (Schlumberger, Log Principles/Applications)

$$SSP = Ej + Em = K \times \lg \frac{Rmf}{Rw} \quad (1)$$

Where, SSP is the Static Spontaneous Potential in a permeable formation
Ej is the diffusion potential
Em is the membrane potential
K is the coefficient of Spontaneous Potential
Rmf is the mud filter resistivity
Rw is the formation water resistivity

The SP measurement is affected by the following major factors: thickness, H, and true resistivity, Rt, of the permeable formation; resistivity, Rxo, and invasion diameter, Di, of the mud filtration invaded zone; resistivity, Rsh, of the adjacent shale formation; resistivity, Rm, of the mud; and diameter, Dw of the borehole. Figure 1 illustrates how the SP measurement is affected by these factors.

Based on Figure 1, the SP measurement can simplified as an electric circuit with an electrical current Isp. The SP amplitude can be represented by the following equation (Schlumberger, Log Principles/Applications):

$$\mathrm{SP} = \mathrm{Rm} \times \mathrm{Isp} = \mathrm{SSP} \times \frac{\mathrm{Rm}}{\mathrm{Rm} + \mathrm{Rsh} + \mathrm{Rxo} + \mathrm{Rt}} \quad (2)$$

SSPT PRINCIPLE

Conventional SP measurement is affected by several factors as illustrated in Figure 1. The formation thickness contributes the most for the effects when the permeable formation is thin. In the other word, the SP values will be much smaller than the Static SP values in the thin layers.

The SSPT was designed to greatly reduce these effects. The designing principle of SSPT came from the assumption of Rm＞＞Rsh+Rxo+Rt. In this case, we have:

$$\frac{Rm}{Rm + Rsh + Rxo + Rt} \approx 1 \quad (3)$$

Based on the equation (2), we will have: SP≈SSP. That is, the measured SP values are very close to the SSP.

It is not practical to increase mud resistivity to satisfy the above assumption. We designed a new electrode array to accomplish this task. Figure 2 illustrates the design of the SSPT electrode array (Nie, Guozhu). M0 is the measure electrode, M1 and M2 are the monitor electrodes, and A1 and A2 are the guard electrodes. The SP current Isp flows through the mud and causes a electrical potential difference (Vm) between M1 and M2. By supplying a current from A1 and returning to A2 for producing a focusing current, which work like the laterolog, the focusing current will reduce the Vm to minimum. The ideal value of Vm is zero, which means that the potentials of M1 and M2 are equal. In this case, no current flows through the mud column between M1 and M2, the Rm between M1 and M2 is close to infinite, and the assumption of Rm＞＞Rsh+Rxo+Rt is reached.

FIELD APPLICATIONS

SSPT tools were tested in several oilfields in China. Figures 3 and 4 show some sections of the SSPT logs. As shown on the top remarks of Figure 3, the SSPT curve clearly indicates the boundaries of the permeable zones and shows better vertical resolutions than the conventional SP curve. The bottom remarks of Figure 4 show that the laminated shales inside a thick-permeable layer are clearly identified. Figure 4 also shows that some of the thin permeable layers clearly identified by the SSPT curve are invisible for the conventional SP curve. The resolutions of the SSPT curve matches with the Microlog curves and other high resolution tools like the DLL.

Figures 5, 6, and 7 show the formation water salinities calculated from the SSPT curve. The second column of Figures 5, 6, and 7 shows the calculated formation water salinities and the measured values from the core lab analysis data. In the large clean sands, the calculated values are very close to the measured lab data. The comparisons supported the claim of the static SP measurements from the SSPT log. In the shaly sands, the comparisons show some differences between the calculated and measured values because the shaly effect was not corrected in the calculations.

The formation water salinities will be changed when the oil zones are flooded by the injection water. The SSPT log is very sensitive to the salinity changes and, therefore, can be used to estimate the water flooding effects. The blue curve in the third column of Figures 5, 6, and 7 shows the water flooding index curve calculated from the SSPT curve. In the index curve, value of 1 means that the oil zone is completely flooded by injection water and value of 0 means that the oil zone is untouched by the injection water. As shown in the water flooding index curve, most of the oil zones are heavily flooded by injection water. A few thin layers (1132.1 ~ 1133.1 m, 1149.5 ~ 1150 m, 1167.6 ~ 1168.4 m, and 1183.0 ~ 1183.3 m) and the top parts of some thick layers are lightly flooded. The estimations of the water flooding effects match well with the coring data.

Figures 5, 6, and 7 also show the comparisons of Sw curves computed from the SSPT and conventional SP. The Sw values from both logs in a large oil zone (1175.8 ~1180.2 m) are close. In medium size oil zones, our SSP Sw curve shows bigger Sw values in four layers (1135.4 ~ 1139.8 m, 1154.4 ~ 1157.4 m, 1162.8 ~ 1164.1 m, and 1183.7 ~ 1184.5 m). In thin-bed oil layers, our SSPL Sw curve finds eight thin-bed oil layers (1121.6 ~ 1123.5 m, 1124.6 ~ 1126.6 m, 1132.1 ~ 1133.1 m, 1149.5 ~ 1150 m, 1167.6 ~ 1168.4 m, 1172.1 ~ 1172.6 m and 1183.0 ~ 1183.3 m) that are completely missed by the conventional SP Sw curve.

SUMMARY

Conventional SP measurements are affected by many factors and the measured SP values could be much smaller than the SSP values. By applying the focusing current similar to the DLL, a new logging tool called SSPT was designed and implemented to essentially eliminate the effect of those factors.

The SSPT was tested in several oilfields in China. The SSPT logs demonstrated better measurements in thin layers. The vertical resolutions of SSPT are close to the Microlog and the SSPT logs are much better than the conventional SP log when used to calculate the Rw values especially in the thin layers.

In summary, the SSPT provides a new solution for better Rw calculation and vertical resolution.

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ABOUT THE AUTHORS

Guozhu Nie graduated from the Petroleum University of China with BS degree in well logging in 1982. After his graduation, Guozhu started to work for Daqing Well Logging Company (Daqing oilfield is the largest oilfield in China). During the almost twenty years in Daqing, he worked as field and research engineer and was promoted to the company's chief engineer and vice president. In 2001, he was hired by Huanding as the chief engineer. In 2003, he founded Jiuyun Energy Technology Company and is very active in developing new technologies to renovate the logging tools since then.

Hui Xu graduated from the Petroleum University of China with BS degree in well logging in 1982. He earned his MS degree in well logging from the Research Institute of Petroleum Exploration and Development (Beijing) in 1985 and his PhD degree in petroleum engineering from Louisiana State University in 1990. He received his MS degree in computer science from Oklahoma State University in 1999. His working experience includes numerical simulations of logging measurements, data modeling for upstream oil industry, database related software system design and implementation, etc. He worked for several energy companies, Schlumberger, and the Bureau of Geophysical Prospecting (BGP) of China National Petroleum Company (CNPC). He is responsible for the numerical simulations of the tools and software development at Jiuyun. He can be contacted by email at huixu@hqtek.com.

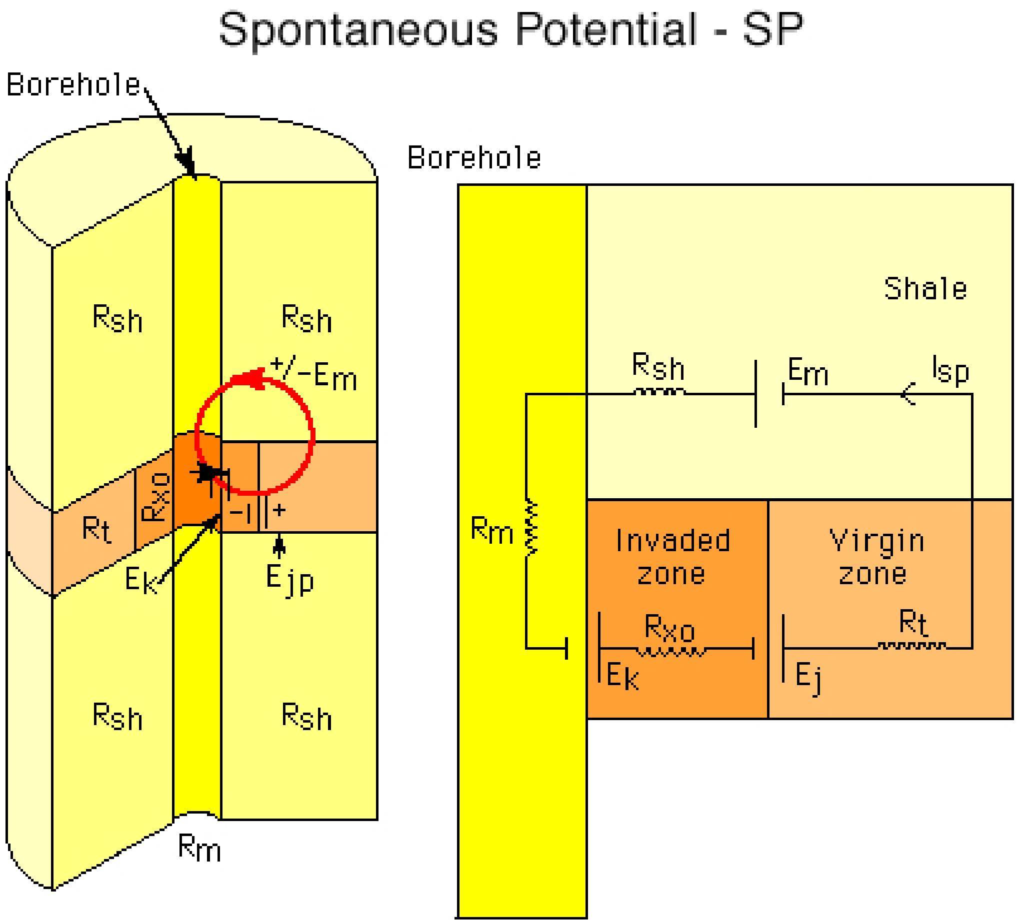

Fig. 1 *Main factors affecting the SP curve*

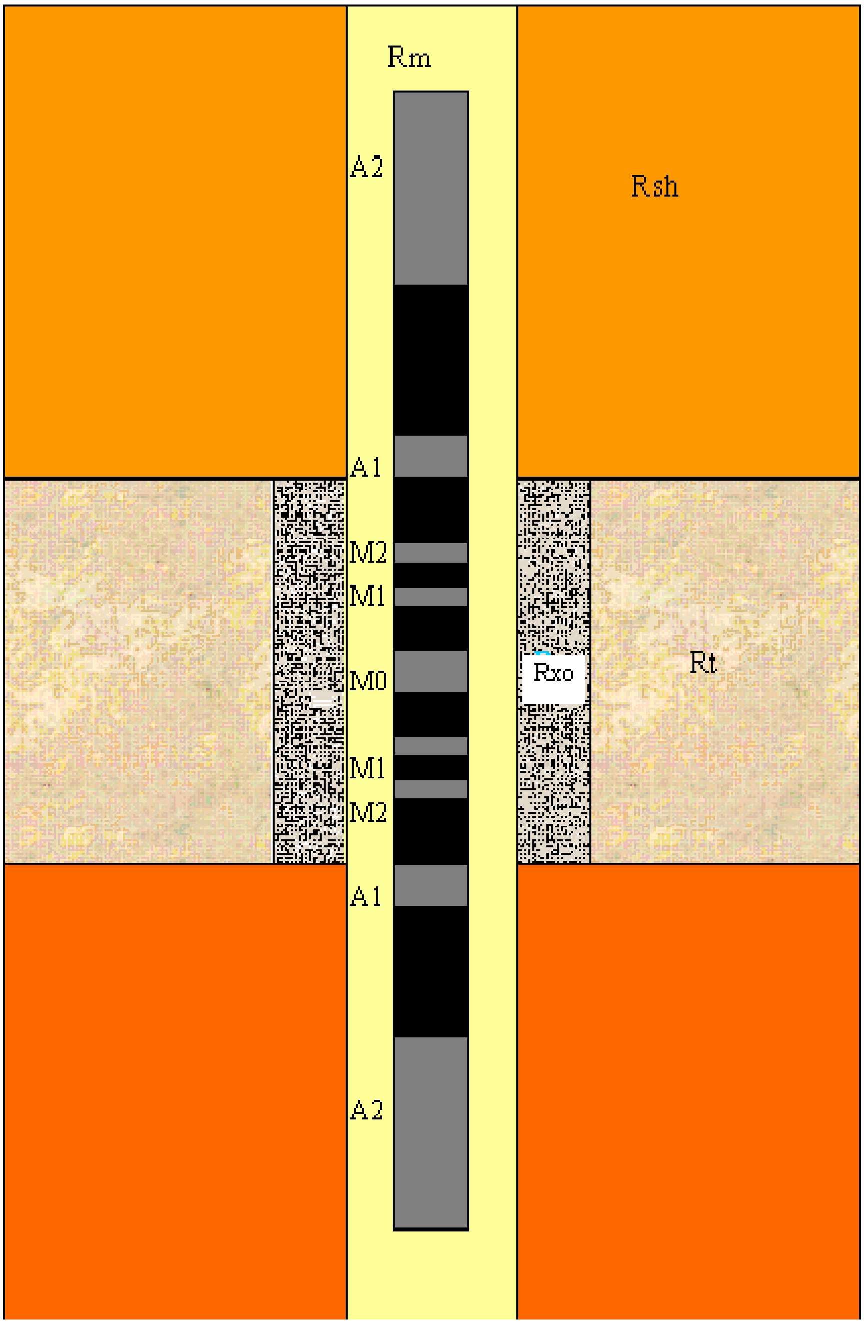

Fig. 2 *Illustration of the SSPT electrode design*

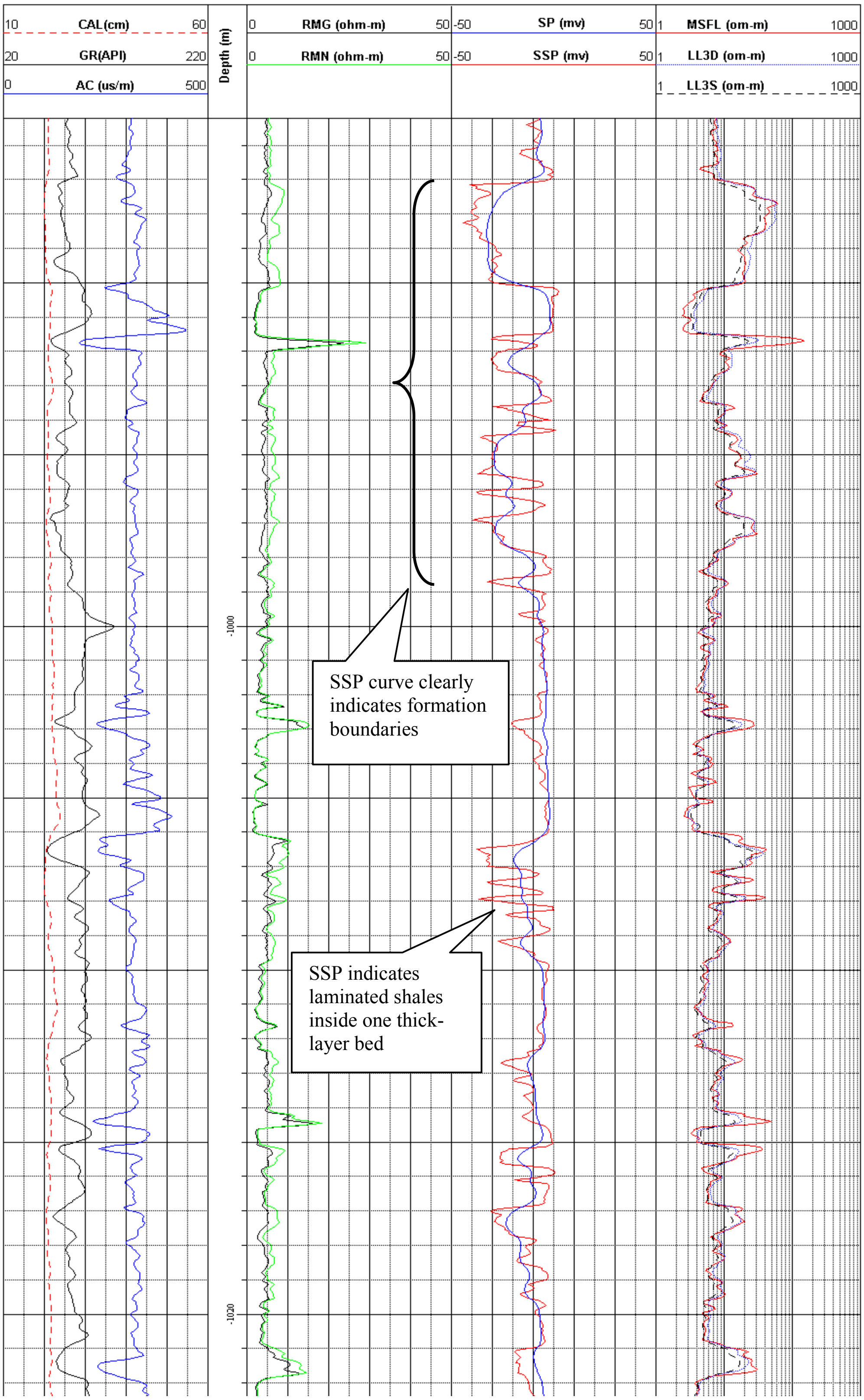

Fig. 3 *SSPT log, North East China*

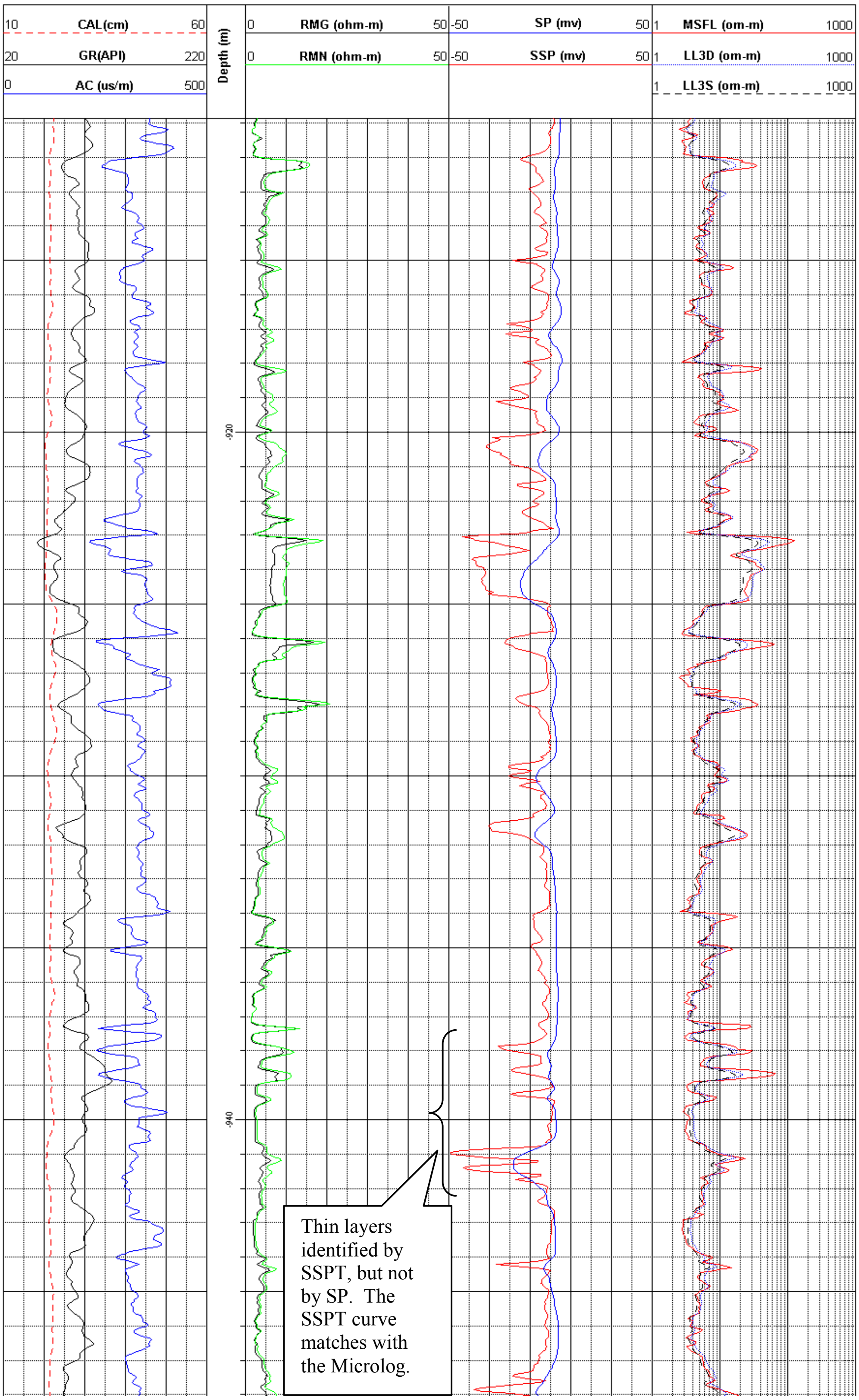

Fig. 4 *SSPT log, North East China*

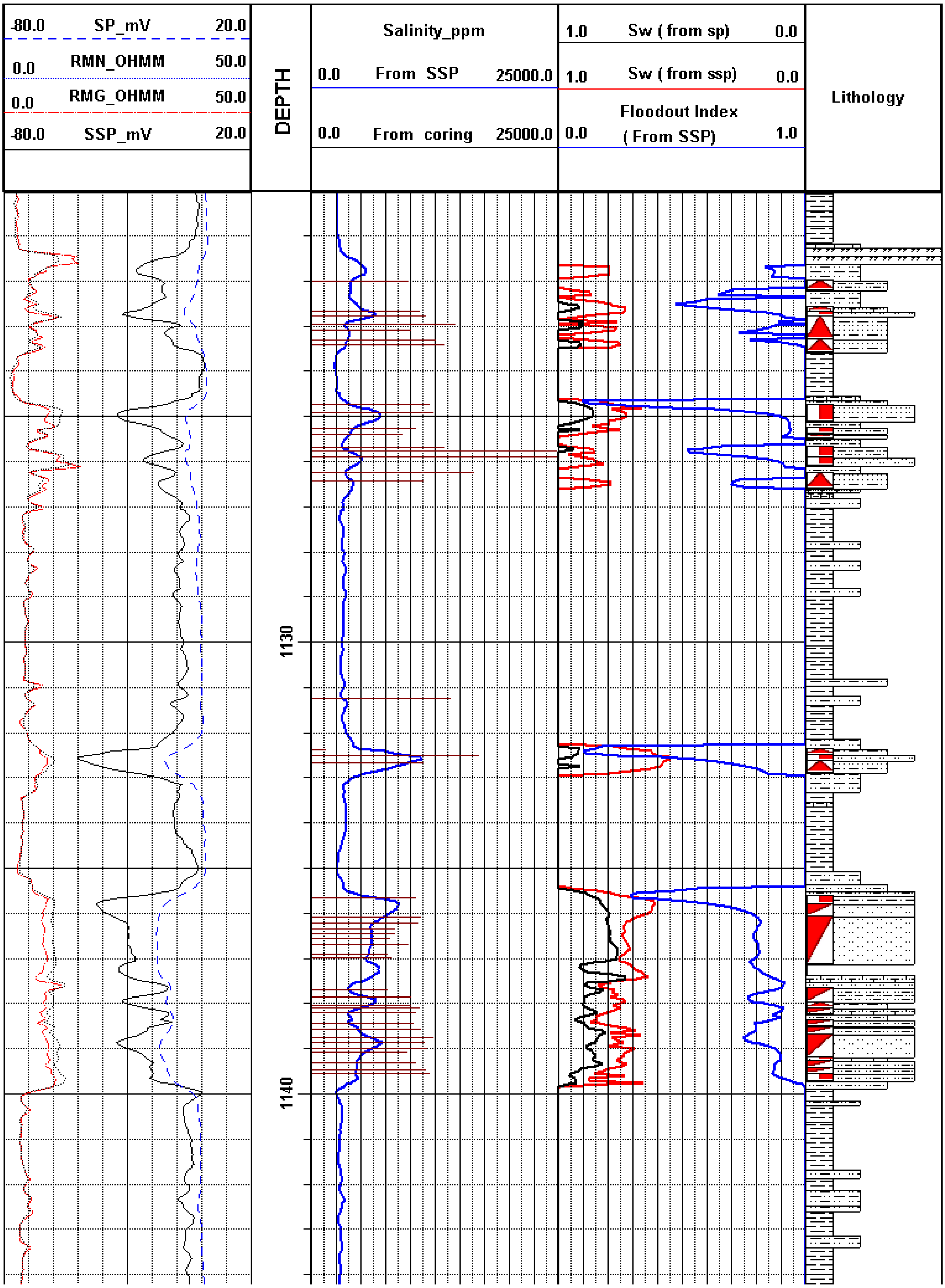

Fig. 5 *Salinity and Sw calculations in a well with complete coring data*

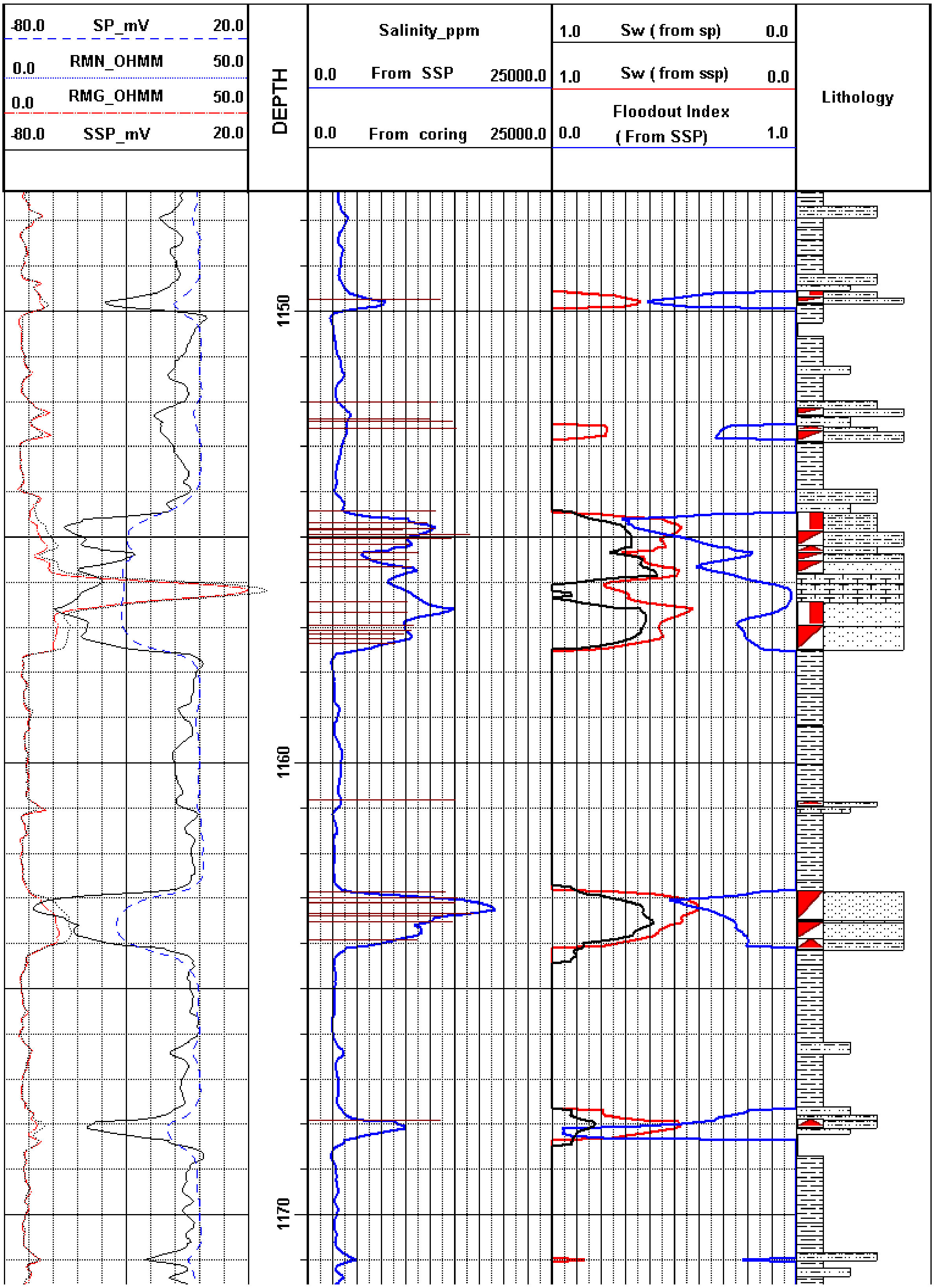

Fig. 6 *Salinity and Sw calculations in a well with complete coring data*

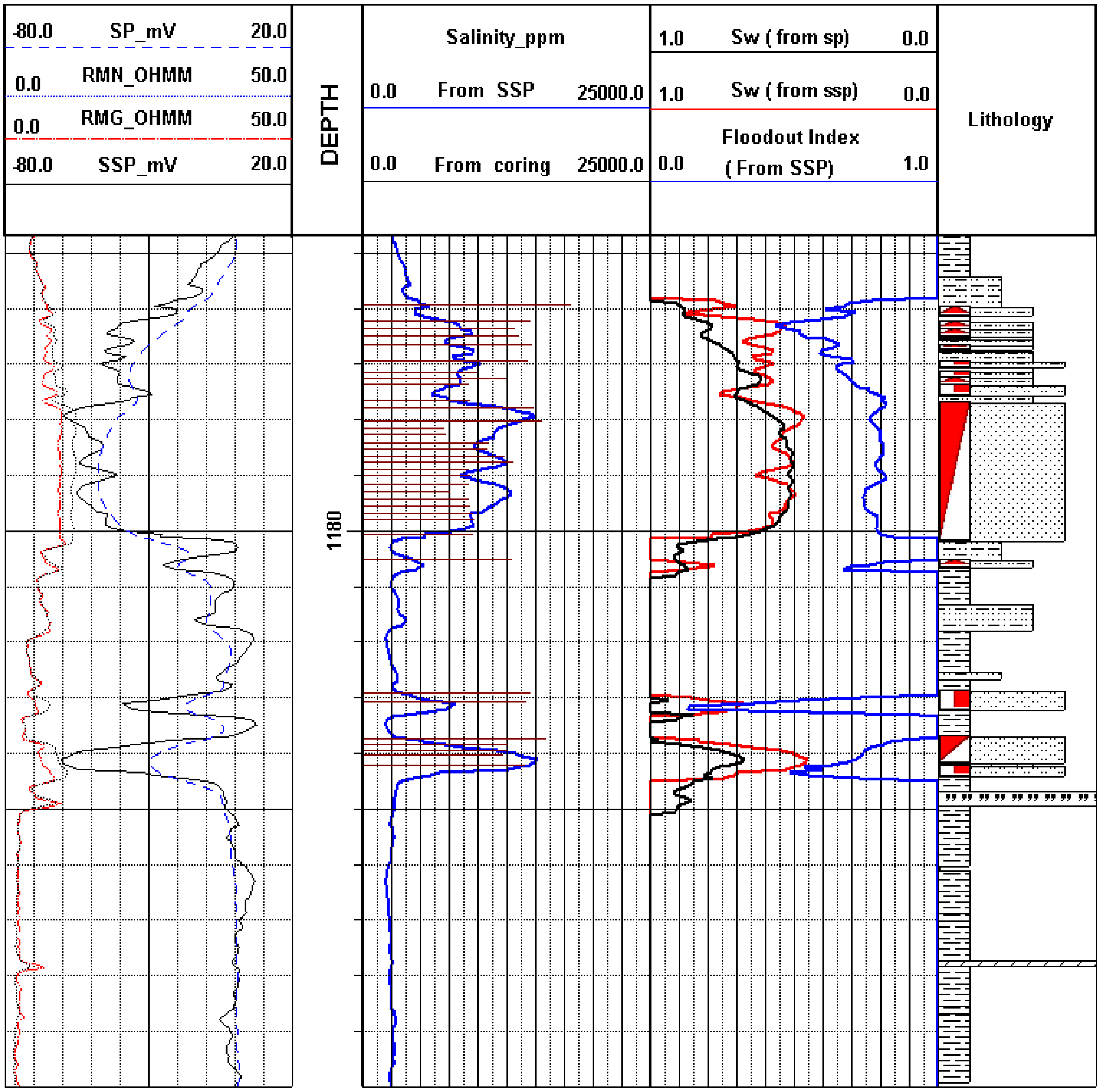

Fig. 7 *Salinity and Sw calculations in a well with complete coring data*