METHOD OF THE CONTROLLED CURRENT REGULATION – THE STATIC AND SELECTIVE SP-POTENTIALS

METODA KONTROLOVANÉ REGULACE PROUDU – STATICKÉ A SELEKTIVNÍ SP-POTENCIÁLY

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Abstract

The focused electric field may be successfully used for registration of the static and selective SP-potentials. These are registered with the help of two different conditions: for the static potentials it is that $U_N = U_M$ and for the selective potentials is $U_N = 0$. We register also the non-stabilized current evoked by SP-potentials. This equals the feeding current, because the electrode A is identical to electrode M and the mentioned electric current flows between electrodes M and N_0 being simultaneously electrode B. This well-logging method is old, however, at the beginning of 60-s it was believed perspective. Thanks to new electric and acoustic methods its using had decreased. In the recent time that method begins to return. The method of the controlled current regulation offers too its return, because location of thin permeable beds saturated with hydrocarbons or fresh water remains permanently attractive.

Abstrakt

Usměrněné elektrické pole lze úspěšně použít pro registraci statických a selektivních potenciálů SP. Potenciály se registrují za pomoci dvou rozdílných podmínek; pro statické potenciály platí podmínka, že $U_N = U_M$, pro selektivní potenciály je podmínka $U_N = 0$. Zároveň registrujeme i nestabilizovaný elektrický proud vyvolaný potenciály SP. Jedná se o proud procházející centrální elektrodou, neboť elektroda A je identická s elektrodou M a zmíněný proud protéká mezi elektrodami M a N_0, která je současně elektrodou B. Tahle karotážní metoda je stará, ale ještě začátkem šedesátých let byla považována za perspektivní. Zásluhou nových elektrických a akustických metod se její používání zmenšovalo. V dnešní době se pozornost k této metodě opět začíná obracet. Metoda kontrolované regulace proudu také nabízí její návrat, protože lokalizace tenkých propustných vrstev nasycených uhlovodíky nebo sladkou vodou je stále atraktivní.

Keywords

constant of tool, static SP-potentials, selective SP-potentials, well-logging

Klíčová slova

konstanta sondy, statické SP-potenciály, selektivní SP-potenciály, karotáž

1 Introduction

This paper reassumes on those works published by MARUŠIAK, I. (1968) and (1969) who applied theory of controlled current regulation just for the static and selective SP-potentials. In this case there is registered voltage on M-electrode which is simultaneously the current electrode A. Through this electrode there flows the non-stabilized current formed with SP-potentials and denoted as I_{SP}. Maybe, just this was why registering of static and selective SP-potentials has finished. The electric current I_{SP} is variable, is not stabilized. It is the current flowing between electrodes A and B which are electrodes M and N_0 depicted in fig.1. The regulative current I_E is variable too, because the feeding current I_{SP} is changing. In the 50-s of the past century it was technically difficult to manufacture an apparatus permanently registering and regulating all system.

MARUŠIAK, I. dealt with static and selective SP-potentials only marginally. He did some records, but he preferred implication of the method of the controlled current regulation for Laterolog. After all activity he had abandoned this method, because he took incorrect procedure of evaluation. I decided the method of the controlled current regulation again to investigate, because new procedure through partial constants, which can be exactly counted, offers new evaluation and an exact calibration. For static and selective SP-potentials it presents to locate very thin permeable beds which usually remain hidden within standard registering of SP-potentials.

As the first it was DOLL, H.G. (1950) who offered theory of the static and selective SP-potentials. He considered very thin permeable beds hidden in the rocks having very high resistivity. In the recent time such beds are ever attractive, even if for their location are used modern electric and acoustic methods, Nevertheless, the before methods have too their restriction, because thanks to big diversity of the nature it is not possible to locate all very thin permeable beds by the only method. Therefore each of next well-logging methods means higher probability to find new thin beds.

Authors GUOZHU, N. and HUI, X. (2009) make renovation of this method. It is a new tool with 9-electrode array. The equipment is fully functioning, the authors received a lot of records from boreholes with very good results, so they could compare records of U_{SP} and U_{SSP} one another. They have confirmed their comparison by tests from laboratory. Values of the static SP-potentials are almost identical with those from laboratory. The equipment is commercially produced; there are registered boreholes in China. The results are in fig.3.

Mathematical operations with formulas in this paper, their analyses and deduction are works of author. He picked up the threads of papers MARUŠIAK, I. (1968) and (1969)**,** DOLL, H.G. (1950) and GUOZHU, N. and HUI, X. (2009), however, implied the universal principle on the basis of the method of the controlled current regulation for theory and interpretation of the static and selective SP-potentials.

The well-logging method can be used generally, but mainly there where salt mud is and rocks have high resistivity. In the geological sense there exist three big domains for using registering of the static and selective SP-potentials:

- In the sand-shale borehole section where are formations classified like “ sandwich”;
- In carbonates having very high resistivity where are thin beds of sand/sandstone and shale;
- In volcanic and metamorphic rocks with thin crashed permeable zones.

These domains present for prospecting of fresh water and for hydrocarbons too potentially new sources and this paper can help to return the mentioned method again on the stage.

2 Principles of method and registration of SP-potentials

Through the central electrode remarked as $M/M_0 \equiv A$ flows an electric current evoked by electrochemical potentials that is remarked as I_{SP}. The current I_{SP} flows in the loop where are resistivities like the resistivity of adjacent beds R_{sh}, the resistivity of invasion zone R_{x_0}, the resistivity of non-invaded zone R_t and finally the resistivity of mud R_m.

The voltage U_{SP} being registered is defined as:

$$U_{SP} = R_m \times I_{SP} = U_{SSP} \times \frac{R_m}{R_m + R_{sh} + R_{x_0} + R_t}, \qquad (1)$$

where U_{SP} = pseudo-static SP-potentials [mV],
U_{SSP} = static SP-potentials [mV],
I_{SP} = electric current evoked by SP-potentials [mA].
R_x = electric resistance [Ω], x = m, sh, x_0 and t.

Formula (1) is presented in SCHLUMBERGER (1989) and authors GUOZHU, N. and HUI, X. (2009) refer to that. If you want to register only U_{SSP} you need to have filled following condition:

$$R_m \gg \left(R_{sh} + R_{x_0} + R_t\right). \qquad (2)$$

Just this condition implies that $\left(R_{sh} + R_{x_0} + R_t\right) \to 0$; the dominating influence must have only mud resistivity, it eliminates all next factors. If the influence of mud is very strong, equation (1) receives such form:

$$U_{SP} = U_{SSP} \times \frac{R_m}{R_m} = U_{SSP}. \qquad (3)$$

Relation (3) exists when you register SP-potentials against thick and clean beds. There is possible to suppose that $U_{SP} \approx U_{SSP}$. In such

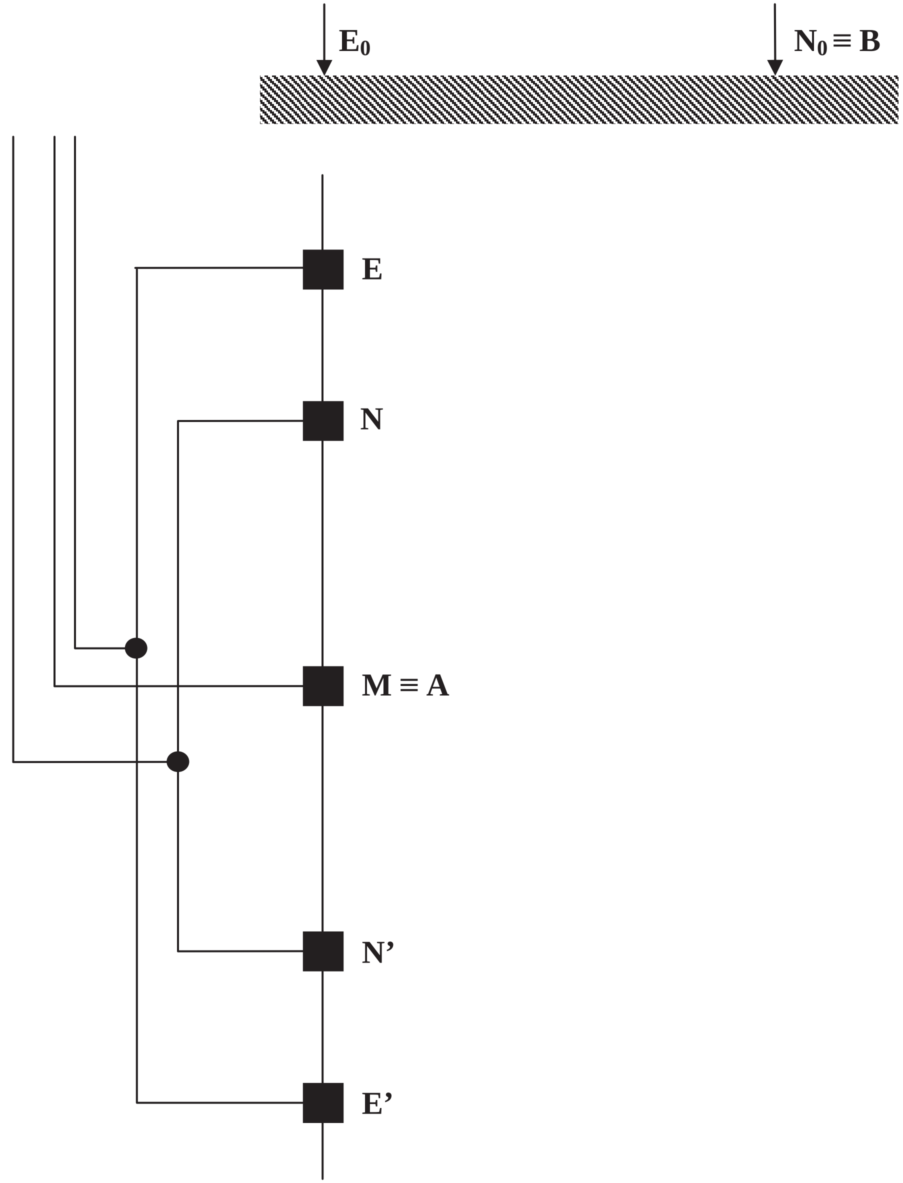

***Fig.1** The array of the electrode tool for the method of static and selective SP-potentials using the principle of the focused electric field; after I. Marušiak (1968), (1969)*

formations where thin and very thin beds occur the curve of SP is smoothened, little distinctive and some thin beds even are out. We need to have the same conditions like it is when registering SP-potentials are against thick beds.

As they are thin beds we cannot manipulate with thickness of bed, but it is possible to manipulate with the resistivity of mud. It must be much higher. To change the mud in the borehole with the chemical adjustment is very expensive and non-economic. However, luckily here is the way using principles of focused electric field like it is for Laterolog.

If you use the electrode array which is in fig.1 you will be able to form virtually column of mud which has infinite resistivity and satisfies formula (3).And what is more. The mentioned the mud influence acts permanently within registration SP-potentials. Principles are following. The electric current evoked by SP-potentials I_{SP} creates on the central electrode remarked as $M \equiv A$ certain negative potential. Thanks to the regulative current I_E that flows electrodes E, E´ on the electrodes N, N´ there is formed exactly the same potential but positive. As both potentials are equal but have inverse orientation it holds that between central electrode $M \equiv A$ and electrodes N, N´ cannot flow any electric current through mud, because there is $U_M - U_N = 0$. It is well-known situation when electric current does not flow by mud but enters perpendicularly in the bed. This holds during all registering. If you register voltage being between central electrode and electrode N_0 on the surface of earth you have filled relation (3) and $U_{SP} = U_{SSP}$.

The scheme of tool having cylindrical electrodes is in fig.1. The electrode array is similar to the tool of 7-electrode Laterolog, however, here are 5 electrodes only, because electrodes A and M are identical in this case and both present the common electrode only. On the surface there are electrodes E_0 for the regulative current and electrode N_0 that presents simultaneously the current electrode B for the feeding current.

From what has been said before it is clear that the feeding current is one created with SP-potentials and streaming through the common electrodes $M \equiv A$ and $N_0 \equiv B$. The feeding current is not stabilized, is variable. Registration can be made either for the static SP-potentials and then you must regulate with the help of the regulative current I_E to keep condition that $U_N = U_M$, or for the selective SP-potentials and in such case you regulate again with the current I_E to hold condition that $U_N = 0$. The regulative current I_E is too variable like it is for the feeding current I_{SP} which flows between guard electrodes E and E´ being on the tool and the surface electrode E_0.

For the static SP-potentials you will register the voltage between M-electrode and N_0-electrode being on the earth surface. If you register the selective SP-potentials, you shall register the voltage being between M and N electrodes of tool which both are inside of the borehole. It presents registration of the SP-lateral being on zero level, whereas, registration of the static SP-potentials responds to the SP-normal.

The main registered factors are voltage of M-electrode, further, the non-stabilized feeding current flowing through M-electrode which is remarked as I_{SP}, the regulative current remarked as I_E and too the coefficient of focusing η. Character of electric field is interesting. Basic electric field is formed by current contours closing themselves among shale, sand and mud. If you connect electrodes M and N_0, there begins the feeding current I_{SP} to flow, because these electrodes are simultaneously feeding electrodes A and B. The field of regulative current I_E is different. Its current contours go from electrodes E and E´ through mud towards electrode $A \equiv M$. The just electrode, because has the same charge as E and E´, will curve them up to such degree that they go perpendicularly into the borehole wall. Section of electric contours in the space looks like a thin straight disc which is embattled on short axis where both ends of axis are the guard electrodes E and E´. It is well explained in DACHNOV, V.N. (1967).

I have to say that in now time there exist various electrode arrays similar to situation for different tools of Laterolog. It seems that the method registering static and selective SP-potentials began again to be up-to date one in the world. Now, we shall try to suppose that equation (1) has not values for electric resistance in [Ω]; they are values of electric resistivity in [Ωm]. In such case holds:

$$U_{SP} = \frac{R_m \times I_{SP}}{k} = U_{SSP} \times \frac{R_m}{R_m + R_{sh} + R_{x_0} + R_t} = U_{SSP} \times \frac{1}{1 + \left(\frac{R_{sh} + R_{x_0} + R_t}{R_m} \right)} . \tag{4}$$

where R_x = resistivity [Ωm], x = m, sh, x_0 and t.

k = constant determined by distance between electrodes[m].

Formula (4) is fundamental for next derivation and logically more correct than relation (1). However, let's go back to it. If we are able to simulate virtually the mud column having infinite resistivity, i.e., $R_m \rightarrow \infty$, and it is with the help of the electrode array and focusing electric field always possible, equation (4) will gain the following form.

$$U_{SP} = \frac{R_m \times I_{SP}}{k} = \lim_{R_m \rightarrow \infty} U_{SSP} \times \frac{1}{1 + \left(\frac{R_{sh} + R_{x_0} + R_t}{R_m} \right)} = U_{SSP} , \quad \text{for } U_N = U_M . \tag{5}$$

This formula is very important for derivation of formulas in the next chapters. It tends to influence of partial constants and, of course, to definition of the main constant. The inverse case when $R_m \rightarrow 0$ is not suitable for measurement.

3 Theory of the static SP-potentials U_{SSP}

In this case the condition of regulation is following:

$$U_N = U_M . \tag{6}$$

That means that:

$$U_M - U_N = 0 . \tag{7}$$

Voltages being on electrodes M and N are expressed as follows:

$$U_M = R_m \times \frac{I_{SP}}{k_{AM}} + R_m \times \frac{I_E}{k_{EM}} \text{, and} \tag{8}$$

$$U_N = R_m \times \frac{I_{SP}}{k_{AN}} + R_m \times \frac{I_E}{k_{EN}} . \tag{9}$$

Both equations can be adjusted into form:

$$U_M = R_m \times I_{SP} \times \left(k_{AM}^{-1} + k_{EM}^{-1} \times \eta \right), \text{ and} \tag{10}$$

$$U_N = R_m \times I_{SP} \times \left(k_{AN}^{-1} + k_{EN}^{-1} \times \eta \right). \tag{11}$$

where R_m = resistivity of mud [Ωm].

The coefficient of focusing η is defined like this:

$$\eta = \frac{I_E}{I_{SP}}, \tag{12}$$

where I_{SP} = the feeding non-stabilized current evoked with SP-potentials [mV], and

I_E = the regulative current streaming through guard electrodes, which is variable like the feeding current [mV].

This coefficient can be enumerated from condition that $U_N = U_M$. From formulas (10) and (11) you receive the following identity:

$$k_{AM}^{-1} + k_{EM}^{-1} \times \eta = k_{AN}^{-1} + k_{EN}^{-1} \times \eta . \tag{13}$$

Solution of this identity for η is following:

$$\eta = \frac{k_{AN}^{-1} - k_{AM}^{-1}}{k_{EM}^{-1} - k_{EN}^{-1}} = \frac{k_{AM}^{-1} - k_{AN}^{-1}}{k_{EN}^{-1} - k_{EM}^{-1}} . \tag{14}$$

Now, we can express the regulative current:

$$I_E = \eta \times I_{SP} = \left(\frac{k_{AM}^{-1} - k_{AN}^{-1}}{k_{EN}^{-1} - k_{EM}^{-1}} \right) \times I_{SP} \ldots \text{for } \eta > 0 . \tag{15}$$

For U_M you receive the following formula:

$$U_{SSP} = U_M = \frac{R_m \times I_{SP}}{K_{SSP}} = R_m \times I_{SP} \times \left\{ k_{AM}^{-1} + k_{EM}^{-1} \times \frac{\left(k_{AM}^{-1} - k_{AN}^{-1} \right)}{\left(k_{EN}^{-1} - k_{EM}^{-1} \right)} \right\}, \tag{16}$$

If the regulative current I_E is adjusted after formula (15) then there is automatically secured condition $U_N = U_M$ and on electrode M is voltage defined by formula (16).

$$K_{SSP} = \left\{ k_{AM}^{-1} + k_{EM}^{-1} \times \frac{\left(k_{AM}^{-1} - k_{AN}^{-1} \right)}{\left(k_{EN}^{-1} - k_{EM}^{-1} \right)} \right\}^{-1} ; \text{ note, please that } K_{SSP} \text{ is in [m].} \tag{17}$$

By that we know all what is needed for registration of the static SP-potentials. We register voltage being between electrodes M and N_0 and the feeding non-stabilized current remarked as I_{SP}. The regulative current I_E is multiple of the feeding current I_{SP}. It flows through electrodes E, E' and electrode E_0. It has positive orientation and changes immediately with each change of the current I_{SP}.

4 Theory of the selective SP-potentials U_{SLSP}

Here holds condition that:

$$U_N = 0 . \tag{18}$$

Voltages being on electrodes M and N are directed again with equations (10) and (11) and formula (12) for the coefficient of focusing is valid too. However, because the condition of regulation is different, you will attain different expression of formula (13). Condition (18) applied on equation (11) presents the following relation:

$$k_{AN}^{-1} + k_{EN}^{-1} \times \eta = 0 . \tag{19}$$

This is basic equation for calculation of factor η. This factor has form like this:

$$\eta = -\frac{k_{AN}^{-1}}{k_{EN}^{-1}} = -\frac{k_{EN}}{k_{AN}} . \tag{20}$$

As the coefficient of focusing is negative there will hold it that the regulative current I_E will have been contradictory to the feeding current *i*. You will get this formula:

$$I_E = \eta \times I_{SP} = -\left(\frac{k_{AN}^{-1}}{k_{EN}^{-1}}\right) \times I_{SP} \ldots \text{for } \eta < 0 . \tag{21}$$

For voltage on the electrode U_M holds that

$$U_{SLSP} = U_M = \frac{R_m \times I_{SP}}{K_{SLSP}} = R_m \times I_{SP} \times \left\{ k_{AM}^{-1} - k_{EM}^{-1} \times \frac{k_{AN}^{-1}}{k_{EN}^{-1}} \right\} , \tag{22}$$

If the regulative current I_E is adjusted after formula (21) then there is automatically secured condition $U_N = 0$ and on electrode M is voltage defined by formula (22).

$$K_{SLSP} = \left\{ k_{AM}^{-1} - k_{EM}^{-1} \times \frac{k_{AN}^{-1}}{k_{EN}^{-1}} \right\}^{-1} \text{; also } K_{SLSP} \text{ is expressed in [m].} \tag{23}$$

For $(k_{EM}/ k_{EN}) \to 1$ it holds that $\overline{MN} \to 0$. Under this condition simultaneously must hold that $\overline{EN} \to \overline{EM} \to \infty$ what present that guarding electrodes are enough far from the potential electrodes. Formulas (22) and (23) will be adjusted in the form:

$$U_{SLSP} = U_M = \frac{R_m \times I_{SP}}{K_{SLSP}} \approx R_m \times I_{SP} \times \left\{ k_{AM}^{-1} - k_{AN}^{-1} \right\}, \tag{24}$$

$$K_{SLSP} \approx \left\{ k_{AM}^{-1} - k_{AN}^{-1} \right\}^{-1}. \tag{25}$$

The regulative current will flow in the opposite direction as it was in the case of the static SP-potentials. We register voltage being between electrodes M and N, both are in the borehole, on condition that $U_N = 0$. Note, please, that when holds condition $\overline{MN} \rightarrow 0$, it is about registering of SP- lateral being on zero level. Further, we have to record the feeding non-stabilized current evoked by SP-potentials; this current flows through electrode M and is remarked as I_{SP}. The regulative current streaming through guard electrodes E and E' is the multiple of the feeding current and is variable too.

Deflections of U_{SLSP} ought to be very distinctive, namely, for thin beds. They are positive and negative ones. The negative ones present thin permeable beds having low and lower resistivity. The positive deflections belong to thin beds with high resistivity. They can be carbonate beds, however too, the beds being saturated by hydrocarbons.

As both potential electrodes are close one another, it holds that $\overline{MN} \rightarrow 0$, it is very probable that they are the curves of SP-lateral registering being on zero level.

5 The selective potentials after DOLL, H.G. (1950) denoted $U_{SLSP}^{(sh)}$, $U_{SLSP}^{(sd)}$ and U_{SLSP}

DOLL, H.G. supposed that investigators will be able to determine reliably the shale level and possibly the sand level too. It is not always simple mainly in those cases when you cannot shales identify. And to find any clean sands in the borehole section – it is rather an exception than the rule, if you register pseudo-static SP-potentials.

We will suppose this condition:

$$U_N = U_{SSP}^{(sh)}. \tag{26}$$

It presents that you know the shale level in a numeric form. The continuous curve of the shale line you will receive when you insert continuous trend curve through intervals of shales. From (26) when you use formula (11), you will obtain then condition:

$$R_m \times I_{SP} \times \left(k_{AN}^{-1} + k_{EN}^{-1} \times \eta \right) = U_{SSP}^{(sh)}. \tag{27}$$

The coefficient of focusing η is like this:

$$\eta = k_{EN} \times \left\{ \frac{U_{SSP}^{(sh)}}{R_m \times I_{SP}} - k_{AN}^{-1} \right\} = -k_{EN} \times \left\{ k_{AN}^{-1} - \frac{U_{SSP}^{(sh)}}{R_m \times I_{SP}} \right\}. \tag{28}$$

$$I_E = \eta \times I_{SP} = \left(\frac{k_{EN}}{R_m}\right) \times U_{SSP}^{(sh)} - \left(\frac{k_{EN}}{k_{AN}}\right) \times I_{SP} = -\left\{ \left(\frac{k_{EN}}{k_{AN}}\right) \times I_{SP} - \left(\frac{k_{EN}}{R_m}\right) \times U_{SSP}^{(sh)} \right\} \ldots \quad \text{in [mA]}. \tag{29}$$

In first view you see it is necessary to register not one factor, but three. Beside factor I_{SP} you need to know factor R_m and $U_{SSP}^{(sh)}$, as well. Regulation is getting more complicated. Now, we register the voltage difference being between electrode M and N under condition (26). Into formula (10) imply equation (26) and the final formula is following:

$$U_{SLSP}^{(sh)} = U_M = \left\{ k_{AM}^{-1} - \left(\frac{k_{EN}}{k_{EM}}\right) \times k_{AN}^{-1} \right\} \times R_m \times I_{SP} - \left(\frac{k_{EN}}{k_{EM}}\right) \times U_{SSP}^{(sh)} \quad \text{for } U_N = U_{SSP}^{(sh)}, \tag{30}$$

$$K_{SLSP} = \left\{ k_{AM}^{-1} - \left(\frac{k_{EN}}{k_{EM}}\right) \times k_{AN}^{-1} \right\}^{-1}. \tag{31}$$

If it holds that $(k_{EM}/ k_{EN}) \to 1$, what presents that $\overline{MN} \to 0$, formulas (28) and (29) will get simpler:

$$U_{SLSP}^{(sh)} = U_M \approx \left\{ k_{AM}^{-1} - k_{AN}^{-1} \right\} \times R_m \times I_{SP} - U_{SSP}^{(sh)}, \tag{32}$$

$$K_{SLSP} \approx \left\{ k_{AM}^{-1} - k_{AN}^{-1} \right\}^{-1}. \tag{33}$$

Let's return to equation (30) and imply the following substitutions:

$$\nu = \left(\frac{k_{EN}}{k_{EM}}\right) \tag{34}$$

$$\frac{1}{K_{SLSP}} = \left\{ k_{AM}^{-1} - \nu \times k_{AN}^{-1} \right\} \text{ and} \tag{35}$$

$$U_{SLSP} = \frac{R_m \times I_{SP}}{K_{SLSP}}. \tag{36}$$

Thanks to substitutions you get formula (30) in the form:

$$U_{SLSP}^{(sh)} = \frac{R_m \times I_{SP}}{K_{SLSP}} - \nu \times U_{SSP}^{(sh)} = U_{SLSP} - \nu \times U_{SSP}^{(sh)} \quad \text{for } U_N = U_{SSP}^{(sh)}. \tag{37}$$

Now you can suppose condition for the line of clean sands:

$$U_N = U_{SSP}^{(sd)}. \tag{38}$$

You obtain very similar relation like formula (37).

$$U_{SLSP}^{(sd)} = \frac{R_m \times I_{SP}}{K_{SLSP}} - \nu \times U_{SSP}^{(sd)} = U_{SLSP} - \nu \times U_{SSP}^{(sd)} \text{ for } U_N = U_{SSP}^{(sd)} . \qquad (39)$$

From equation (37) you express coefficient ν like this:

$$\nu = \frac{U_{SLSP} - U_{SLSP}^{(sh)}}{U_{SSP}^{(sh)}} .$$

That expression you have to insert into equation (39). Then you can separate U_{SLSP}.

$$U_{SLSP} = \frac{U_{SLSP}^{(sd)} - \left(\frac{U_{SSP}^{(sd)}}{U_{SSP}^{(sh)}} \right) \times U_{SLSP}^{(sh)}}{1 - \left(\frac{U_{SSP}^{(sd)}}{U_{SSP}^{(sh)}} \right)} . \qquad (40)$$

This is final formula for the selective SP-potentials after proceeding H.G. Doll. For registering pseudo-static SP-potentials is not easy to find the line of clean sands and too can be that the shale line is varying and little visible. However, owing to focused electric field situation is much more favourable. If you register the curve of the static SP-potentials you will able to monitor both the shale line and the sand line. Such curve of SSP is very little influenced by geological and technical factors of borehole. It is well visible in fig.3.

Through maximal values in shales you insert the trend curve with the borehole depth presenting the shale line in all registered interval. The same you will do for minimal values in sands and obtain the sand line. Both curves for $U_{SSP}^{(sh)}$ and $U_{SSP}^{(sd)}$ are saved into the computer memory. Then you can begin to register curves $U_{SLSP}^{(sh)}$, $U_{SLSP}^{(sd)}$ like ones of the focused electric field being under conditions $U_N = U_{SSP}^{(sh)}$ and $U_N = U_{SSP}^{(sd)}$. Note please if holds that $U_{SSP}^{(sh)} >> U_{SSP}^{(sd)}$ in formula (40) and it is for negative values SP always, you will have the following identity: $U_{SLSP} \approx U_{SLSP}^{(sd)}$. It is close to separation of thin sandy beds if that is formation of the sandwich type.

After Doll's process you have to receive at first two continuous curves $U_{SLSP}^{(sd)}$ and $U_{SLSP}^{(sh)}$ after formulas (30) and (39); the next two are the trend curves from the computer memory $U_{SSP}^{(sh)}$ and $U_{SSP}^{(sd)}$. From them you will determine ex post after formula (40) a value of the selective SP-potentials remarked as U_{SLSP}. However, it seems me a bit complicated, because if you use condition $U_N = 0$, you will get the selective SP-potentials too and it is easier.

6 The static and selective SP-potentials in the recent time

In today's time the method of the static and selective SP-potentials go through new blooming. It is not only in US and Europe, but in China, in particular. They are constructed and manufactured electrode systems on the basis of knowledge with focusing of electric field. Producers use similar electric systems like it is at Laterolog. So you can meet 9-electrode, 7- electrode, 5- electrode and 3-electrode systems. I found on websites very interesting paper of authors GUOZHU, N. and HUI, X. (2009) presented their paper on Annual Logging Symposium, The Woodlands, Texas, June 21 – 24. It is about all a new tool with 9-electrode array. This equipment was functioning, the authors received a lot of records from boreholes with very good results, so they could compare records of U_{SP} and U_{SSP} one another. The results fully support registering with new electrode system based on focusing electric field for static SP-potentials. Moreover, they have confirmed their comparison by tests from laboratory. Values of the static SP-potentials are almost identical with those from laboratory.

In fig.2 there is depicted schema of the tool of both authors. It is 9- electrode system on basis Dual Laterolog. The highest dimension is for electrodes E_0, E_0'; electrodes E and E' are shorter. As it is visible the both types of guard electrodes are directly on tool not on the earth surface. The central feeding electrode $A \equiv M_0$ is short. The current electrode $B \equiv N_0$ is on the surface of earth. The potential electrodes M, M' and N, N' are short and have very short base. It holds that $\overline{MN} \rightarrow 0$. I should like to apply principles of the method of the controlled current regulation for the electrode array depicted in fig.2.

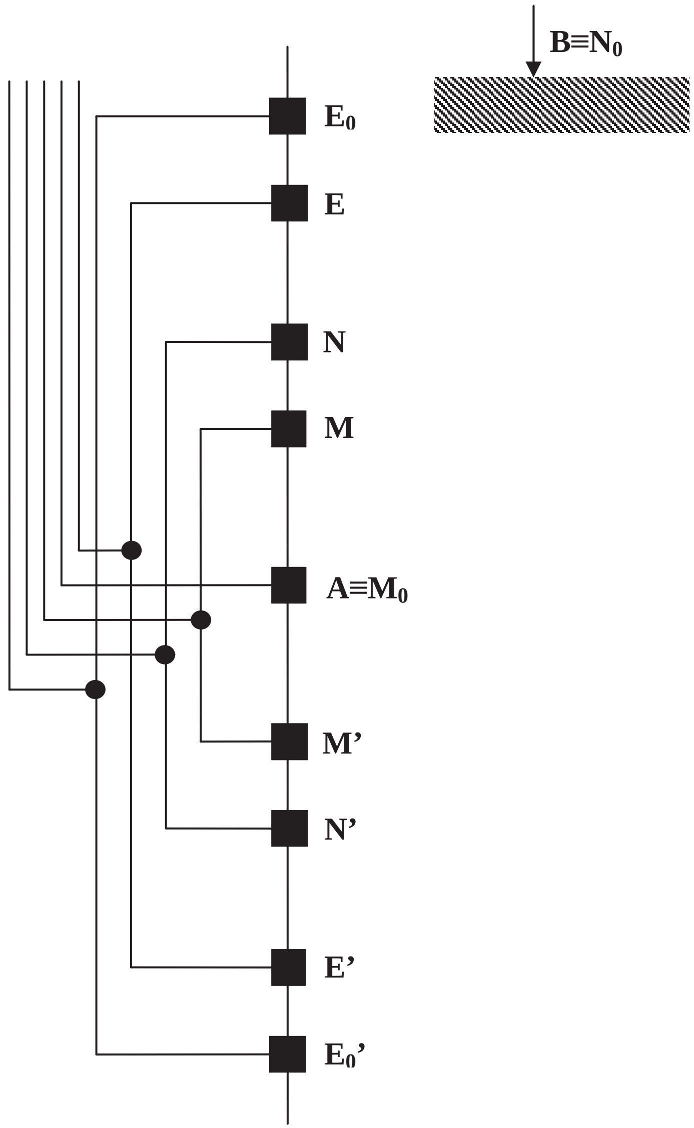

Fig.2 The 9-electrode array for registering of selective and static SP – potentials after Guozhu, N. and Hui, X. (2009)

6.1 The static SP-potentials U_{SSP}

The voltages on electrodes M, N and M_0 are defined:

$$U_{M_0} = R_m \times \frac{I_{SP}}{k_{AM_0}} + R_m \times \frac{I_E}{k_{EM_0}} - R_m \times \frac{I_{SP}}{k_{E_0 M_0}}, \qquad (41)$$

$$U_M = R_m \times \frac{I_{SP}}{k_{AM}} + R_m \times \frac{I_E}{k_{EM}} - R_m \times \frac{I_{SP}}{k_{E_0 M}}, \text{ and} \qquad (42)$$

$$U_N = R_m \times \frac{I_{SP}}{k_{AN}} + R_m \times \frac{I_E}{k_{EN}} - R_m \times \frac{I_{SP}}{k_{E_0 N}}. \qquad (43)$$

Equations (41), (42), (43) will change their form as follows:

$$U_{M_0} = R_m \times I_{SP} \times \left\{ \left(k_{AM_0}^{-1} - k_{E_0M_0}^{-1} \right) + k_{EM_0}^{-1} \times \eta \right\}, \qquad (44)$$

$$U_M = R_m \times I_{SP} \times \left\{ \left(k_{AM}^{-1} - k_{E_0M}^{-1} \right) + k_{EM}^{-1} \times \eta \right\}, \text{ and} \qquad (45)$$

$$U_N = R_m \times I_{SP} \times \left\{ \left(k_{AN}^{-1} - k_{E_0N}^{-1} \right) + k_{EN}^{-1} \times \eta \right\}. \qquad (46)$$

The coefficient of focusing η and the regulative current I_E are defined like that:

$$\eta = \frac{I_E}{I_{SP}},$$

$$I_E = \eta \times I_{SP}.$$

Now, you have to apply condition that $U_N = U_M$. This condition is for electrodes M, N and too for M', N', but not for central electrode $M_0 \equiv A$. Thanks to it you are able to calculate coefficient of focusing.

$$\eta = \left(\frac{k_{AN}^{-1} - k_{AM}^{-1}}{k_{EM}^{-1} - k_{EN}^{-1}} \right) + \left(\frac{k_{E_0M}^{-1} - k_{E_0N}^{-1}}{k_{EM}^{-1} - k_{EN}^{-1}} \right). \qquad (47)$$

You can enumerate too the regulative current.

$$I_E = \eta \times I_{SP} = \left(\frac{k_{AN}^{-1} - k_{AM}^{-1}}{k_{EM}^{-1} - k_{EN}^{-1}} \right) \times I_{SP} + \left(\frac{k_{E_0M}^{-1} - k_{E_0N}^{-1}}{k_{EM}^{-1} - k_{EN}^{-1}} \right) \times I_{SP}. \qquad (48)$$

The voltage measured is between electrodes M_0 and $N_0 \equiv B$; for U_{M0} you receive the following formula:

$$U_{SSP} = U_{M_0} = \frac{R_m \times I_{SP}}{K_{SSP}} = R_m \times I_{SP} \times \left\{ \left(k_{AM_0}^{-1} - k_{E_0M_0}^{-1} \right) + k_{EM_0}^{-1} \times \left(\frac{k_{AN}^{-1} - k_{AM}^{-1}}{k_{EM}^{-1} - k_{EN}^{-1}} \right) + k_{EM_0}^{-1} \times \left(\frac{k_{E_0M}^{-1} - k_{E_0N}^{-1}}{k_{EM}^{-1} - k_{EN}^{-1}} \right) \right\}, \qquad (49)$$

$$K_{SSP} = \left\{ \left(k_{AM_0}^{-1} - k_{E_0M_0}^{-1} \right) + k_{EM_0}^{-1} \times \left(\frac{k_{AN}^{-1} - k_{AM}^{-1}}{k_{EM}^{-1} - k_{EN}^{-1}} \right) + k_{EM_0}^{-1} \times \left(\frac{k_{E_0M}^{-1} - k_{E_0N}^{-1}}{k_{EM}^{-1} - k_{EN}^{-1}} \right) \right\}^{-1} \qquad (50)$$

; K_{SSP} is again in [m].

Registering the static SP-potentials present measurement of the SP-normal that is much more intended than it is when you register the pseudo-static SP-potentials.

6.2 The selective potentials U_{SLSP}

Here holds condition that $U_N = 0$. This condition is again for electrodes M, N and too for M', N'. Then coefficient of focusing will be negative and its form derived is as follows:

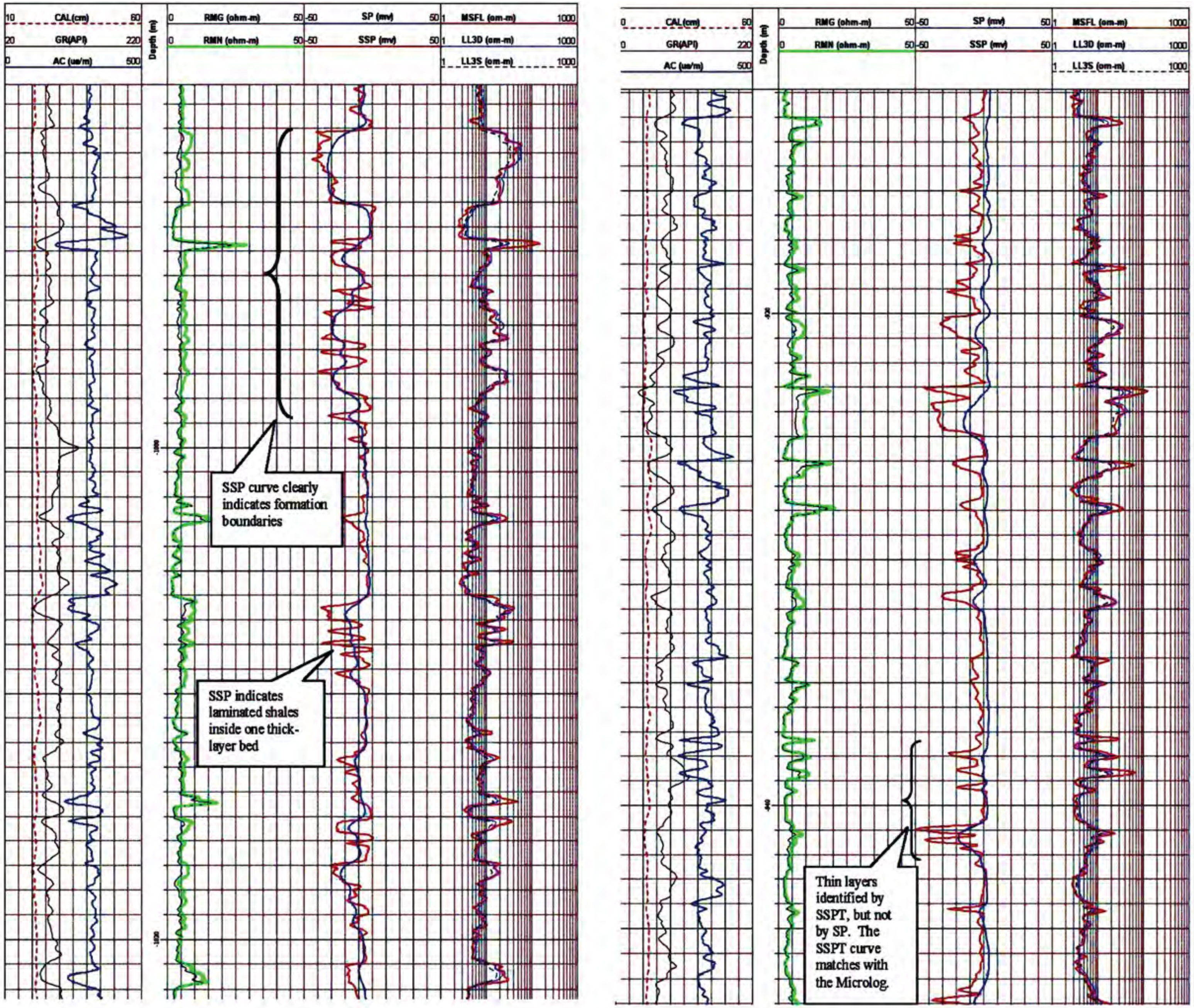

Fig.3 SSP Log, North East China – authors: Guozhu Nie and Hui Xu, SPWLA 50 th Annual Logging Symposium, June 21 – 24, 2009

$$\eta = -k_{EN} \times \left(k_{AN}^{-1} - k_{E_0N}^{-1} \right). \qquad (51)$$

The regulative current I_E will be like this:

$$I_E = \eta \times I_{SP} = -k_{EN} \times \left(k_{AN}^{-1} - k_{E_0N}^{-1} \right) \times I_{SP}. \qquad (52)$$

The regulative current has contradictory polarity to I_{SP}. Simply speaking, the current I_E flows in the contradictory direction than is direction for the current I_{SP}. Now, we can express U_{SLSP}; registering holds for electrode M.

$$U_{SLSP} = U_M = \frac{R_m \times I_{SP}}{K_{SLSP}} = R_m \times I_{SP} \times \left\{ \left(k_{AM}^{-1} - k_{E_0M}^{-1} \right) - \left(\frac{k_{EN}}{k_{EM}} \right) \times \left(k_{AN}^{-1} - k_{E_0N}^{-1} \right) \right\}, \qquad (53)$$

$$K_{SLSP} = \left\{ \left(k_{AM}^{-1} - k_{E_0M}^{-1} \right) - \left(\frac{k_{EN}}{k_{EM}} \right) \times \left(k_{AN}^{-1} - k_{E_0N}^{-1} \right) \right\}^{-1}$$; also in this case K_{SLSP} is in [m].

(54)

As you see in case of the selective SP-potentials we register on electrode M, not on M_0, and it is difference of potentials being between electrodes M and N. Because the electrodes are very close one another, $\overline{MN} \to 0$, it convinced me that the selective SP-potentials present registering SP-lateral on zero level.

Here exists too the case to have condition $U_N = 0$, however, not to register on electrode M but on electrode M_0. The voltage measured is again between electrodes M_0 and $N_0 \equiv B$ like it was for the static SP-potentials; for U_{M_0} holds:

$$U_{SSP} = U_{M_0} = \frac{R_m \times I_{SP}}{K_{SSP}} = R_m \times I_{SP} \times \left\{ \left(k_{AM_0}^{-1} - k_{E_0M_0}^{-1} \right) - \left(\frac{k_{EN}}{k_{EM_0}} \right) \times \left(k_{AN}^{-1} - k_{E_0N}^{-1} \right) \right\}, \qquad (55)$$

$$K_{SLSP} = \left\{ \left(k_{AM_0}^{-1} - k_{E_0M_0}^{-1} \right) - \left(\frac{k_{EN}}{k_{EM_0}} \right) \times \left(k_{AN}^{-1} - k_{E_0N}^{-1} \right) \right\}^{-1} \qquad (56)$$

As you see formulas (55) and (56) are very similar to formulas remarked as (53) and (54); the main constants will be however different. Nevertheless I think that comparison between both ways of registration can be very interesting and like supplement information important.In both cases the main level is zero; positive and negative deflections correspond to boundaries of bed. And, because the electric field is focused, one can expect that the selective SP will well supplement basic information after the static SP. For location of thin beds it is sure needed.

7 Discussion over variants

I am sure, you noticed that the voltages U_{SSP}, U_{SLSP}, $U_{SLSP}^{(sd)}$ and $U_{SLSP}^{(sh)}$ differ one another by their constants determining amplitude of voltage. Each of the mentioned constants is in other way defined with the help of partial constants and it makes that they are different and influence then relevant voltage. Next important factors I_{SP} and R_m are common for all three cases, so it looks like that you receive the only curve depicted in three different scales. However, it plays a role too the form and depth of focusing, lower but not all negligible contribution components of resistivity like mud R_m, invasion zone R_i and non-invaded rock R_t are. In vertical direction it is resistivity of adjacent rocks R_{sh} which for method has crucial significance, because it is about separation of thin permeable beds laying in carbonates with high resistivity. And do not forget factors like both thickness of bed H and too ratio D_i/d is. This all can have influence.

On the other side focusing of electric field influence of many factors eliminated so recorded SP-curves are depurated. GUOZHU, N. and HUI, X. (2009) in their paper present the borehole records having been registered. They are curves U_{SP} and U_{SSP} . Curves U_{SP} are smoothened, little distinctive and very often thin beds are out, whereas, curves U_{SSP} are intended and thin beds are well visible. Very good those thin beds correspond to the resistivity curve of Proximity Log having 5 electrodes remarked as Micro-spherically Focused Log – MSFL and authors GUOZHU, N. and HUI, X. (2009) pasted commentaries directly to records. Both authors present too that data having been registered for U_{SSP} very good corresponds to data received from laboratory. It does not hold for data U_{SP}. See, further fig.3.

For selective SP-potentials U_{SLSP} I suppose that it is registering of SP-lateral on zero level. The original proposal of H.G. Doll how to evaluate the selective SP-potentials seems to be enough complicated in comparison to one using of zero level. Now, I should like to open one very interesting theme. I am sure you had noted that static and selective SP-potentials are thanks to used method of the controlled current regulation exactly defined; you see the following expressions:

$$U_{SSP} = \frac{R_m \times I_{SP}}{K_{SSP}}, \; U_{SLSP} = \frac{R_m \times I_{SP}}{K_{SLSP}}.$$

Here offers such question; the curves of the mud resistivity R_m and the electric current evoked by SP-potentials I_{SP} are permanently registrable, you can use two continuous records with the borehole depth. And constants K_{SSP}, K_{SLSP} are exactly defined for the given electrode array. It would be very easy to have created continuous curves of voltages U_{SSP} and U_{SLSP} ex post by simulation on the computer. It is, of course, very tempting offer but a shifty one. You have to realize it is simulation that has not any focused electric field; here just lacks conditions that $U_M = U_N$, $U_N = 0$, what presents real existence of the focused electric field. It would be the same blind way which I. MARUŠIAK has gone on. Therefore this tempting offer I cannot recommend.

As the last what here further should sound is the focusing efficiency is quantified, because you can enumerate the coefficient of focusing for each of the electrode arrays. It offers to model in advance several different electrode arrays and to count their coefficients of focusing. Then it is very easy to select the best of all them.

8 Partial constants k_{AM}, k_{AN}, k_{EM} and k_{EN}

What is quite clear is that the above constants are positive only. They are dependent on the electrode geometry. Surface of such electrode presents a mantle of cylinder. The main geometrical factors are height and diameter of cylinder. And next important factor is the distance between centres of the current and potential electrodes. Derivation of formulas expressing calculation of partial constants was made in other paper. However, I present the final derived formulas in this paper, because I regard this as important. The above formulas are valid not only for the static and selective SP-potentials, but too, for Laterolog and induced polarization. They are formulas published in RYŠAVÝ, F. (2013).

For partial constants remarked as k_{AN}, k_{EM} and k_{EN} we use these formulas:

$$\left(\frac{k}{a_L}\right) = \frac{1}{F_1 + F_2}, \tag{57}$$

$$F_1 = \frac{1}{8} \times \left(\frac{n}{a_n}\right)^{-1} \times \left\{ \ln\left[\left(\frac{\sqrt{2}}{2}\right) \times \sqrt{\left(\frac{2L}{a_L} + \frac{m}{a_m}\right)^2 + 1} + \frac{n}{a_n}\right] - \ln\left[\left(\frac{\sqrt{2}}{2}\right) \times \sqrt{\left(\frac{2L}{a_L} + \frac{m}{a_m}\right)^2 + 1} - \frac{n}{a_n}\right]\right\}, \tag{58}$$

$$F_2 = \frac{1}{16} \times \left(\frac{n}{a_n}\right)^{-1} \times \left\{ \operatorname{Argsinh}\left[\left(\frac{\sqrt{2}}{2}\right) \times \sqrt{\left(\frac{2L}{a_L} + \frac{m}{a_m}\right)^2 + 1} + \frac{n}{a_n}\right] - \operatorname{Argsinh}\left[\left(\frac{\sqrt{2}}{2}\right) \times \sqrt{\left(\frac{2L}{a_L} + \frac{m}{a_m}\right)^2 + 1} - \frac{n}{a_n}\right]\right\} \tag{59}$$

where L = distance being between both centres of the current and potential electrodes [m],
m = length of the current electrode [m],
n = length of the potential electrode [m],
a_L = diameter of the tool body [m],
a_m = diameter of the current electrode [m], and
a_n = diameter of the potential electrode [m].

Those six variables can be reduced only on three ones. They are these: (L / a_L) is slenderness ratio of the electrode tool, (m / a_m) is slenderness ratio of the current electrode and (n / a_n) is slenderness ratio of the potential electrode. All new variables are dimensionless.

For calculation of $k_{AM,}$ because it is the common electrode, A ≡ M, there holds simplification characterized with relations: L = 0 and (m / a_m) = (n / a_n). In such case there hold the following formulas:

$$\left(\frac{k}{a_n}\right) = \frac{1}{F_1 + F_2}, \tag{60}$$

$$F_1 = \frac{1}{8} \times \left(\frac{n}{a_n}\right)^{-1} \times \left\{ \ln\left[\left(\frac{\sqrt{2}}{2}\right) \times \sqrt{\left(\frac{n}{a_n}\right)^2 + 1} + \frac{n}{a_n}\right] - \ln\left[\left(\frac{\sqrt{2}}{2}\right) \times \sqrt{\left(\frac{n}{a_n}\right)^2 + 1} - \frac{n}{a_n}\right]\right\}, \tag{61}$$

$$F_2 = \frac{1}{16} \times \left(\frac{n}{a_n}\right)^{-1} \times \left\{ \mathrm{Argsinh}\left[\left(\frac{\sqrt{2}}{2}\right) \times \sqrt{\left(\frac{n}{a_n}\right)^2 + 1} + \frac{n}{a_n}\right] - \mathrm{Argsinh}\left[\left(\frac{\sqrt{2}}{2}\right) \times \sqrt{\left(\frac{n}{a_n}\right)^2 + 1} - \frac{n}{a_n}\right]\right\}. \tag{62}$$

As you see in such case the partial constant k_{AM} is determined only and only with the electrode diameter and the length of electrode. The published formulas make possible enumeration of all partial constants. It should be noticed yet the segmented electrodes eliminating an influence of the electrode potentials are for registration of SP-potentials more than desirable. More about segmented electrodes is in RYŠAVÝ, F. (2006).

9 Relations between SP-potentials and the diffusively-adsorptive electrochemical activity of rocks

Registering of SP-potentials is done simultaneously with the registering of the diffusively-adsorptive electrochemical activity of rocks. Both the above characteristics have the same dimension, milivolts [mV]. However, priority of them has the electrochemical activity. You can see when you will see over the formula:

$$A_{da}^{(sh)} = A_{da} + U_{SP}, \tag{63}$$

where A_{da} = the diffusively-adsorptive electrochemical activity of rocks [mV],

$A_{da}^{(sh)}$ = the adsorptive electrochemical activity of shales [mV], and

U_{SP} = pseudo-static SP-potential taken away of the line of shale [mV].

It is clean that the basic is calibration of the electrochemical activity that is the main characteristic, not SP-potentials. The line of shale is simultaneously the continuous line of characteristic $A_{da}^{(sh)}$. So, when you express SP-potentials, it holds that:

$$U_{SP} = A_{da} - A_{da}^{(sh)}; \text{ as } A_{da} < A_{da}^{(sh)} \text{ then } U_{SP} < 0. \tag{64}$$

Thanks to that characteristic U_{SP} presents registering being differential, because registers differences of the shale line. Left of the shale line are negative values, right are positive values. This characteristic is further defined as follows:

$$U_{SP} = -k_{SP} \times \alpha_{SP} \times \log \frac{R_{mf}}{R_w}, \tag{65}$$

where k_{SP} = the constant depending on temperature and ion mobility of salts dissolved in the water [mV],
α_{SP} = the coefficient of the volume sandiness; it is dimensionless,
R_{mf} = resistivity of the mud filtrate [Ωm], and
R_w = resistivity of the formation water [Ωm].

For characteristics from formula (65) holds:

$$k_{SP} = 69.6 \times \frac{t + 273}{293}, \text{ and} \tag{66}$$

$$\alpha_{SP} = \frac{p_f}{p_f + v_{sh}} = 1 - \frac{v_{sh}}{p_f + v_{sh}} = 1 - \eta_{sh}, \tag{67}$$

where η_{sh} = the coefficient of the volume shaliness,
p_f = the effective porosity; it is characteristic for interstitial water having relation to diffusive electro-chemical activity,
v_{sh} = shaliness after Gamma Ray Log; it is characteristic for connate water having relation to adsorptive electrochemical activity,
t = temperature in the borehole [°C].

Formula (66) supposes that there prevails salt water; the constant 69.6 mV is for temperature 20°C. Formula (67) supposes again between characteristics α_{SP} and η_{sh} linear relation. It is case enough frequent, however, there are known also non-linear relations. It depends on activity of the shaly particles and too on mineralisation of the formation water. Linear relation is used when relation α_{SP} = f (η_{sh}) is unknown.

Formula (67) is used in the literature but instead characteristic p_f has characteristic of the total porosity p. I think it is not right. The total porosity summarize both interstitial and connate waters together, however, in the formula (67) are two different parameters where characteristic v_{sh} has unambiguously relation only and only to the connate water. The second parameter must have logically the similar type of relation only to the interstitial water; that is why I implied characteristic of the effective porosity instead of the total porosity into formula (67).

Characteristic v_{sh} is shaliness after Gamma Ray Log. Particles of shale well retain water and radioactive elements. It is highly dispersive material. However, in the nature there exist next rocks being highly dispersive. They are aleurits, volcanic ash, rocks having ferruginous cement (limonite) and next ones. If they adsorb except water too radioactive elements like shales then can be classified like shales as well. It is favourable for determination characteristic v_{sh} and, of course, for characteristics α_{SP} and η_{sh}. And it is not an error.

10 Interpretation of resistivity of the formation water

You can start from formula (65). If you express ratio (R_{mf} / R_w) you will get relation:

$$\frac{R_{mf}}{R_w} = \exp\left\{-\frac{U_{SP}}{k_{SP} \times \alpha_{SP}}\right\} \qquad (68)$$

Now, it is possible to separate characteristic R_w. You will get formula:

$$R_w = R_{mf} \times \exp\left\{\frac{U_{SP}}{k_{SP} \times \alpha_{SP}}\right\}. \qquad (69)$$

The characteristics being in braces are strictly defined by formulas (64), (66) and (67).It needs to be now to explain how to use characteristic R_{mf}. Here holds the following algorithm. If resistivity of mud is higher than 0.1 Ωm, i.e., $R_m > 0.1$ Ωm for temperature 75 °F (approximately 24°C) then is valid this relation:

$$R_{mf} = 0.85 \times R_m. \qquad (70)$$

11 Shortly to focusing

Salty muds present too problem for recording SP-potentials. If the mud is salt more than formation water along with all borehole section then you will get not negative but only and only positive deflections. However, the more salt the mud is, the lower deflections are. For certain mineralization holds that deflection is zero, i. e, $U_{SP} \rightarrow 0$. On the record there is continuous shale line. To overcome such unpleasant situation you have to supplant mud by one having high resistivity. It can be fresh water or the mud made on the basis of the transformer oil. Such exchange is very expensive, does not take long time and the transformer oil is not convenient for registering of SP-potentials.

Therefore it was a miracle when focusing of electric field on condition that $U_N = U_M$ did the same and very effectively. The current contours starting from the electrode M ≡ A are sharp incurvated that they come perpendicularly into the rocks. An influence of mud is in this way suppressed. It is evident in formula (5) which is again presented here.

$$U_{SP} = \frac{R_m \times I_{SP}}{k} = \lim_{R_m \to \infty} U_{SSP} \times \frac{1}{1 + \left(\frac{R_{sh} + R_{x_0} + R_t}{R_m}\right)} = U_{SSP}, \quad \text{for } U_N = U_M.$$

This is case of effective focusing. Let's suppose the situation we have a record of SP-potentials having very low positive deflections and decide to use focusing with condition $U_N = 0$. It is all different focusing reflecting condition $R_m \rightarrow 0$. Such focusing would evoke worsening of the record quality. It would be like you added salt into mud. The low positive deflections would be away, it would be the only line for all borehole section. It is done the current contours are incurvated not perpendicularly to the borehole wall but parallelly to the borehole wall. Only near to the guard electrodes E and E´ they income into rocks. It is evident that this way of focusing is not convenient for registering SP-potentials. It can be seen in the following relations.

$$U_{SP} = \frac{R_m \times I_{SP}}{k} = \lim_{R_m \to 0} U_{SSP} \times \frac{1}{1 + \left(\frac{R_{sh} + R_{x_0} + R_t}{R_m} \right)} \approx \begin{cases} U_{SSP} \times \left(\frac{R_m}{R_t} \right) \rightarrow 0 \text{ for } U_N = 0 \text{ and } \left(R_{sh} + R_{x_0} \right) \rightarrow 0. \\ U_{SSP} \times \left(\frac{R_m}{R_{sh} + R_{x_0}} \right) \rightarrow 0 \text{ for } U_N = 0 \text{ and } R_t \rightarrow 0. \end{cases}$$

I like shortly to return to fig.2 yet. You must have noted that the second guard electrode remarked as E_0 is on the tool. Such electrode array belongs to terminology the SFL (Spherically Focused Log). The electric field of current contours is more compact, closer and has oval almost spherical character. You record the part being closer to the borehole wall. For measurement of SP-potentials just this can be the main and the fact that between SSP-records and MSFL-records for resistivity very good comparison exists can be well explained.

12 Calibration of the diffusively-adsorptive electrochemical activity A_{da} and SP-potentials

For calibration of the diffusively-adsorptive electrochemical activity A_{da} and SP-potentials in [mV] you need to have a calibrator presenting a voltage source with accurately calibrated values. These present primary etalons for calibration. They have certain accuracy determined with an error. For linear scale one etalon is enough, whereas, for non-linear scale you have to use all set of primary etalons. Voltage of etalon remarked as U_0 is reflected on a linear scale like deflection l_0.

$$l_0 = \frac{U_0}{n} = \frac{A_{da}}{n} \quad , \tag{71}$$

where $U_0 = A_{da}$ = the voltage like primary etalon of SP-potentials or the simulated diffusively-adsorptive electrochemical activity A_{da}; both factors are in [mV],

n = the step of linear scale [mV/ 1cm], and

l_0 = deflection presenting U_0 [cm].

Metrological control is made like the control of all voltage values U_0 with the help of testing instrument having, at least, two-times higher precision than the above voltage source. For each of values you make ten observations that are averaged. If so counted value lays in the confidence interval given for the value of voltage source, it is acceptable for next calibration.

It offers to take in account formulas (16) and (22) and to write down them as follows:

$$U_{SSP} = U_M = \frac{R_m \times I_{SP}}{K_{SSP}} = \left(A_{da}^{SSP} - A_{da}^{(sh)} \right), \text{ and}$$

$$U_{SLSP} = U_M = \frac{R_m \times I_{SP}}{K_{SLSP}} = \left(A_{da}^{SLSP} - A_{da}^{(sh)} \right).$$

From the all that results that calibration can be relative and absolute. If you calibrate relatively, you will register directly static/selective SP-potentials U_{SSP}/ U_{SLSP} when the shale line is shifted on the zero level when its numeric value is unknown. In case you calibrate absolutely, then you will register directly the diffusively-adsorptive electrochemical activity A_{da}. In such case the value of the shale line remarked as $A_{da}^{(sh)}$ is well known.

If it holds that $A_{da} = A_{da}^{SSP} = A_{da}^{(sh)}$ or $A_{da} = A_{da}^{SLSP} = A_{da}^{(sh)}$, the voltage remains zero, because $U_{SSP} = U_{SLSP} = 0$. I think it is easy to draw a line between these ways of calibration. To make picture complete I offer yet one next way of calibration. It will start from these formulas:

$$W_{SSP} = U_{SSP} \times K_{SSP} = U_M \times K_{SSP} = R_m \times I_{SP} = \left(A_{da}^{SSP} - A_{da}^{(sh)} \right) \times K_{SSP}, \text{ and} \quad (72)$$

$$W_{SLSP} = U_{SLSP} \times K_{SLSP} = U_M \times K_{SLSP} = R_m \times I_{SP} = \left(A_{da}^{SSP} - A_{da}^{(sh)} \right) \times K_{SLSP}, \quad (73)$$

where W_{SSP} = the electric power flux of static SP-potentials [mV×m], and
W_{SLSP} = the electric power flux of selective SP-potentials [mV×m].

As an etalon you can use again the voltage source with calibrated values, however, if you have multiplied the values by the main constant remarked as K having been exactly presented in the before chapters, you will receive values of the electric power flux as follows:

$$W = U_0 \times K, \; K = K_{SSP} \cup K_{SLSP}; \quad (74)$$

for the tool of authors GUOZHU, N. and HUI, X. (2009) holds that the static SP-potentials it is the main constant remarked as formula (50), whereas for the selective SP-potentials it can be formulas (54) and (56), the tool of MARUŠIAK, I. has formulas (17) and (23),where
U_0 = the calibrated value of voltage [mV],
K = the main constant of the electrode tool [m], and
W = the simulated electric power flux of rocks for static/selective SP-potentials [mV×m].

I am sure you noted that both created standards after formula (74) are not same, $W_{SSP} \neq W_{SLSP}$, because both main constants are various too, $K_{SSP} \neq K_{SLSP}$, even if the first and second variants have common voltage U_0. Setting of the simulated electric power flux on the linear scale as deflection l_0 is directed with formula:

$$l_0 = \frac{W}{n} \quad , \tag{75}$$

where n = the step of linear scale [mV/ 1cm].

So you attain the continuous calibrated records with data of the electric power flux for SP-potentials. For static SP-potentials the output curve is relation $W_{SSP} = A_{da}^{SSP} \times K_{SSP}$ whereas for selective SP-potentials holds that $W_{SLSP} = A_{da}^{SLSP} \times K_{SLSP}$. As numeric data of the main constant are exactly known it is very easy to have the continuous records of A_{da}^{SSP} and A_{da}^{SLSP}.

$$A_{da}^{SSP} = \frac{W_{SSP}}{K_{SSP}} \quad \text{and} \quad A_{da}^{SLSP} = \frac{W_{SLSP}}{K_{SLSP}}. \tag{76}$$

Even if for the shale line can probably hold that $A_{da}^{SSP} = A_{da}^{SLSP}$, for sands and sandstones it will must be $A_{da}^{SSP} \neq A_{da}^{SLSP}$, because likewise holds $U_{SSP} \neq U_{SLSP}$. And the continuous curve of SP- potentials you can have too thanks to formula (62). However, before you must have the trend curve of $A_{da}^{(sh)}$.

$$U_{SSP} = \left(A_{da}^{SSP} - A_{da}^{(sh)} \right), \text{and } U_{SLSP} = \left(A_{da}^{SLSP} - A_{da}^{(sh)} \right).$$

Just this way of calibration allows you to imply in the calibration process an influence of the electrode array whereas the both previous did not. It is why I believe that the last way of calibration is the best and universal.

13 Conclusions

This well-logging method was in 60th years of the last century accounted like hopeful and more informative but within 70th years of the same century sneaked away. I think that it was done by rapid starting of new geophysical methods using altering current which presented wider and faster information about thin permeable beds. And too technical produce such equipment permanently registering the feeding current to adjust the regulative current could be in that time too expensive. Nevertheless, I am sure that in the recent time on basis method of the controlled current regulation just this old method can be again in the interest of geophysicists, because such manufactured equipment now will not be financially expensive. It confirms the last papers, mainly from China, where manufacturers offers tools constructed on basis of focused electric fields. The results of such records are demonstrably better than those before.

Thanks to analysis made here are the following conclusions:

- The static and selective SP-potentials can be registered with the help of the focused electric field.
- The static SP-potentials register voltage being between electrodes M and N_0 on condition that $U_N = U_M$. It presents registration of SP-normal.
- The selective SP-potentials register voltage being between electrodes M and N on condition that $U_N = 0$. It presents registration of SP-lateral being on zero level.

- Within registration in both cases we record also the feeding non-stabilized current evoked with SP-potentials which is streaming through electrode M. This electrode is simultaneously by electrode A.
- The regulative current flowing through guarding electrodes E, E' and E_0 is product of the feeding current and the coefficient of focusing.
- The coefficient of focusing is different for the static potentials and for the selective potentials. Its calculation is given with partial constants. Thanks to the coefficient of focusing you can also quantify various electrode arrays and to compare among themselves.
- Partial constants are four and they are positive. It is possible to enumerate them if you know geometry of the electrode tool.
- The records of SP-potentials should be indicated like records of the simulated diffusively-adsorptive electrochemical activity A_{da}.

References

DACHNOV, V.N. *Elektritscheskie i magnitnye metody issledovania skvazhin*, Textbook, Nedra, Moskwa, 1967

DACHNOV, V.N. *Geophyzitscheskie metody opredelenya kollektorskych svoystv i neftegazonasystchenya gornych porod*, Textbook, Nedra, Moskwa, 1985

DOLL, H.G. *Selective SP-logging*, Journal of Petroleum Technology, No.5, 1950

GUOZHU, N. and HUI, X. *Static SP measurement tool and its field applications*, Jiuyun Energy Technology Company, Beijing , China, presented on Annual Logging Symposium, The Woodlands, Texas, June 21 – 24, 2009

MARUŠIAK, I. *Princip kontrolirovannoj reguljacii toka mnogoelektrodnych karotažnych zondov*, 1. část, Užitá geofyzika, 7, 1968

MARUŠIAK, I., TĚŽKÝ, A., JONÁŠOVÁ, V. *Princip kontrolirovannoj reguljacii toka mnogoelektrodnych karotažnych zondav*, 2. část, Užitá geofyzika, 8, 1969

RYŠAVÝ, F. *Method of the controlled current regulation – Laterolog*, EGRSE Journal, vol.XX, no. 2, 2013, p.67 - 85

RYŠAVÝ, F. *Elimination of the Electrode Potentials for Well-logging electric Micro-systems*, Transactions of the VŠB – Technical University of Ostrava, Civil Engineering Series, No.2, Vol. VI, 2006, p.237 – 242

RYŠAVÝ, F. *Method of the controlled current regulation – calculation of partial constants for cylindrical electrodes*, EGRSE Journal, vol.XX, no. 2, 2013, p.86 - 103

SCHLUMBERGER, *Log Interpretation Principles /Applications*, Schlumberger Well Wireline & Testing, Sugar Land, 1989

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