A METHOD FOR CORRECTING BIAS IN SPONTANEOUS POTENTIAL (SP) LOG READING DUE TO HEAVY PRESENCE OF METALLIC MINERALS

by
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I. INTRODUCTION

In reservoir characterization and modeling, information derived from well log surveys (Figure 1) plays an important role. Petrophysical properties such as porosity and water saturation are important factors in the determination of hydrocarbon accumulation. (The same is true for the determination of reservoir geometrical dimensions.) Inaccurate Spontaneous Potential (SP) log-derived shale contents (V_{sh}) results in inaccurate porosity and water saturation.

SP log is catagorized as lithology log, which primary role is to differentiate between permeable zones and non-permeable zones (i.e. shale). SP log also has secondary purposes such as determination of shale contents and formation water resistivity, as well as its use in many reservoir geological analyses.

Some problems that are often asscociated with geological complexity in Indonesia is that many subsurface formations contains significant amount of minerals that have the potential to bias log survey reading including SP log's. Considering SP log's wide span of presence, misleading SP log reading may also have adverse consequence at wider scale. Therefore, a measure is required to minimize the SP log's potential bias due to presence of metallic minerals. The method presented in this paper is suggested to be used for the purpose.

A. *Disturbing minerals*

Minerals that have the potential to disturb SP log reading are mineral characterized as heavy/metallic and electrically conductive. The classification of a mineral to belong to heavy mineral cathagory is usually based on its contents of metallic elements especially iron (Fe) in its molecular chain, which is then reflected in its high density and electrical conductivity. However, mineral cathagorization as 'heavy' and 'not-heavy' also has elements of relativity, which originates from comparisons with 'standard' rock forming minerals such as quartz and calcite. For practical purpose, therefore, a heavy mineral is defined as a mineral that has 'sufficiently high' metallic elements (such as Fe) in its molecular chain.

Serra (1986) presented a useful table containing log characteristics and reading for minerals commonly found in sedimentary rocks. From the compilation, it can be seen that in general metallic elements (Fe especially) can be present in many forms and various molecular chains. This fact strengthens further the assumption saying that SP log reading that are potentially affected by presence of metallic minerals (especially in large quantity) must undergo correction before being used in log interpretation.

B. *The effect of metallic/conductive minerals on SP log reading*

In the history of well logging in the petroleum industry, SP log is one amongst the earliest generation of well logging equipment and is still being used today. From

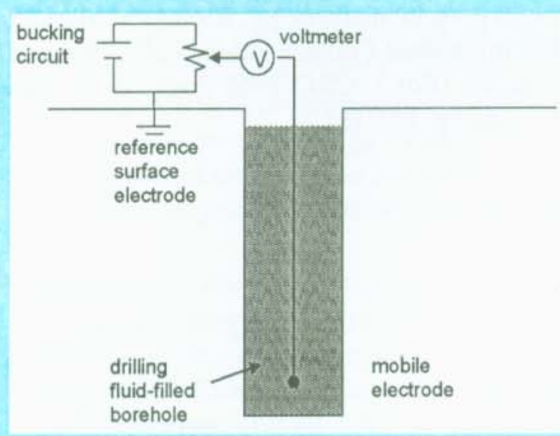

Figure 1
Schematic diagram of spontaneous potential logging survey

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time to time the logging equipment underwent improvements even though the principles used in the measutement remain the same. In principle, SP log measures natural electric potential generated by formation rocks in milivolt (mV) unit. Natural electric potential is essentially generated by several causes, two of the most predominant are electrochemical and electrokinetics processes (e.g. Helander, 1983).

In brief, electrochemical potential is generated as a result electric current activities in two fluids (mud and formation brine with different salinity values), which are separated by a shale/clay membrane (membrane potential, see Figure 2). SP deflection caused by this potential is generated and recorded at sand (permeable) – shale boundary. The deflection polarization (negative or positive) is governed by relative difference in mud and formation brine salinities. Explanation over the process can be found in many references (e.g. Helander, 1983). The other potential, the electrokinetics potential (Figure 3), is generated as results of ionization on the rock's surface. This takes place as mud filtrate invades the formation. The polarization of this potential is the reverse of the polarization of the membrane potential. Of the two potentials membrane potential is nevertheless far more predominant in magnitude (Bassiouni, 1994) underlining the main use of SP log as sand – shale boundary identification tool.

Various factors influence magnitude and shape of SP log deflection. Among others are ratio between mud filtrate resistivity and formation water resistivity (R_{mf}/R_w), permeable layer thickness and resistivity, wellbore diameter, size of invasion zone, and shale contents of the permeable layer. Due to the predominant role played by R_{mf}/R_w in general SP log curve follows

$$SP = -K_c \log \frac{R_{mf}}{R_w} \qquad (1)$$

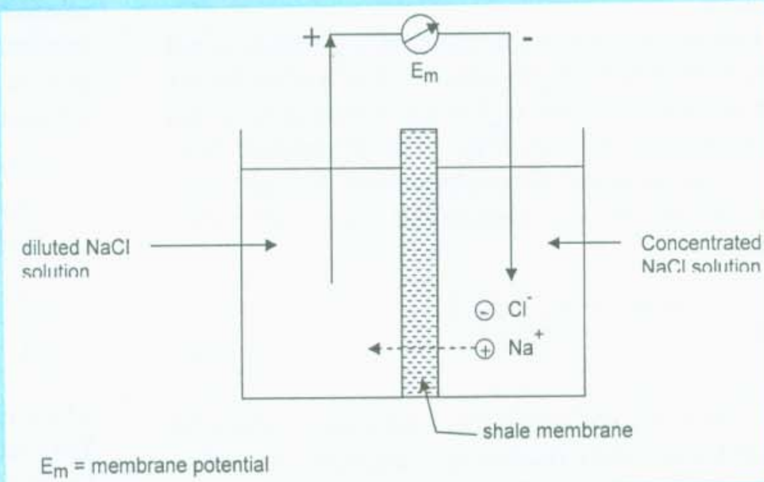

Figure 2
Membrane potential. The negatively charged shale membrane encourages Na^+ to move through it while preventing Cl^- from leaving the concentrated NaCl solution, generating current from dilute solution to concentrated solution. This phenomenon occurrs at sand-shale boundary with the two NaCl solutions representing reservoir brine and drilling mud

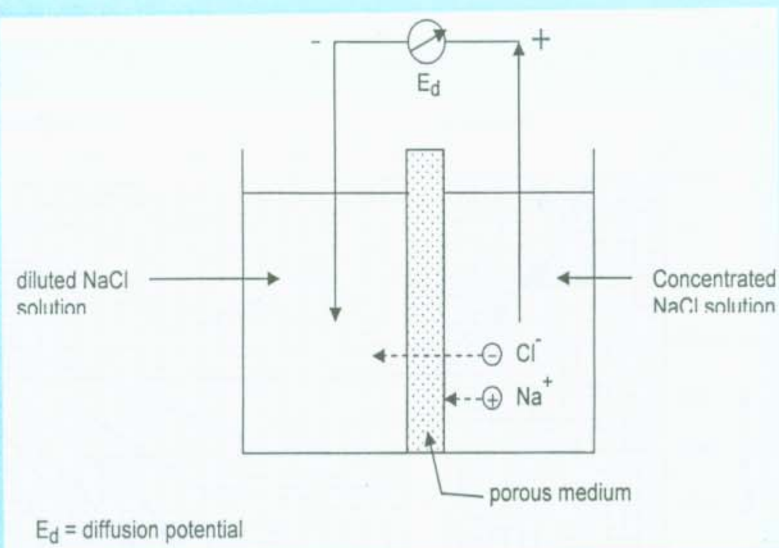

Figure 3
Diffusion potential. The porous medium let the two solutions to be in contact. The lighter Cl^- travels faster than the Na^+ generating current from concentrated solution To dilute solution. This phenomenon occurrs at invaded zone around wellbore with the two NaCl solutions representing reservoir brine and mud filtrate

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where K_c is a constant representing surrounding condition.

Depite the utmost importance, SP log reading is not solely controlled by R_{mf}/R_w only but also by other factors such as mud resistance (r_m), shale resistance (r_{sh}), and permeable layer resistance (r_{sd}). The influence of those factors can also quantitatively visualized through a relation between SP log reading and 'static SP' (SSP) through

$$SSP = \frac{SP\left(r_m + r_{sh} + r_{sd}\right)}{r_m} \tag{2}$$

In brief, the SSP represents a situation in which SP log deflection curve reaches its maximum. This ideal situation can be reached for a permeable layer that is sufficiently thick, clay/shale-free, and contains only formation brine. Shale or clay presence (represented by r_{sh}), and other factors that can increase r_{sd} will depress SP log deflection relative to the constant imaginary SSP value. Several examples are hydrocarbon presence, inter-layerred permeable and non-permeable thin layers, and presence of metallic minerals in sufficiently high proportion. If the presence of hydrocarbon, shale, and laminated clays tends to depress the SP log deflection through increasing r_{sd} in Equation (2), the reverse is true for the presence of metallic minerals. Theoretically, signifiicant amount of metallic may decrease r_{sd} to an unreastically low value. Correction over this influence of r_{sd} is needed in order to get the theoretically true SP log reading.

C. *Correction method*

The resistance of various substance in the Equation (2) is linked to resistivity through

$$R = \frac{1}{C} = \frac{rA}{l}, Ohm - m \tag{3}$$

where r, A, and l are electrical resistance (Ohm or Wð), medium's cross sectional area (m²), and medium length (m).

Considering the presence of 'false' r_{sd} in Equation (2) due to metallic mineral presence has to be corrected, the r_{sd} then should be replaced by a theoretically correct r_{sd} that is not influenced by the metallic minerals (may be taken as r_{sd} '). Starting from this point of view, and by observing Equation (3) one knows that the resistance in Equation (2) can be substituted with resistivity (R). This, theoretically, allows correction to be done in form of resistivity correction in a manner described in an earlier work reported by Widarsono (2000). In other words,

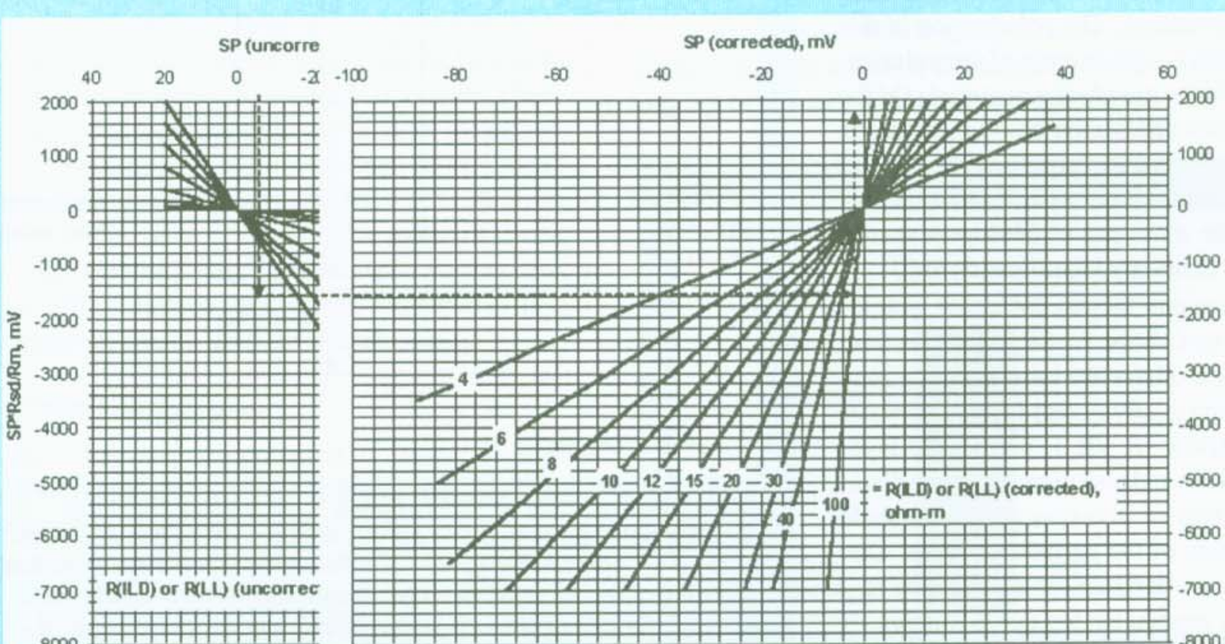

Figure 4
Nomograph for correction on SP log reading (mud resistivity, R_m = 0.1 Ω-m). R(ILD) and R(LL) are deep resistivity from induction log and laterolog, respectively

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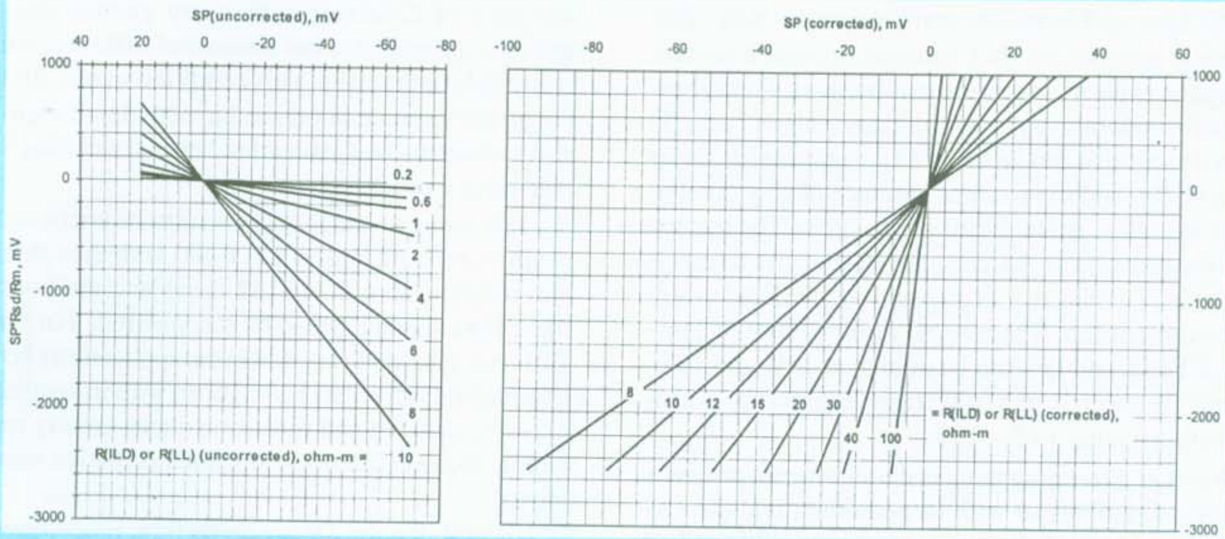

Figure 5
Nomograph for correction on SP log reading (mud resistivity, R_m = 0.3 Ω-m). R(ILD) and R(LL) are deep resistivity from induction log and laterolog, respectively

the correction on SP log reading is to be carried out through correction on true resistivity (R_t) reading. See Widarsono (2000) for full information regarding the resistivity correction method. It is worth nothing here that r_{sd} can be directly substituted by R_{sd}, considering the difference between resistance and resistivity is just in the process of normalization on medium's length.

Based on Equations (2) and (3) a correction method was developped in the form of nomographs, and two of them are presented in Figures (4) and (5). Procedure for using the nomographs is as follows (see Figure 4):

1. Determine an SP reading value from log curves,
2. Draw vertical line downward onto a curve that represents formation resistivity (uncorrected) at the same depth point,
3. Draw horizontal line to the right (right graph) onto a curve that represents resistivity (corrected), at the same depth point, obtained from the method presented in Widarsono (2000) (Figure 6),
4. Draw a line upward to x axis, and
5. A corrected SP value is obtained.

This procedure is repeated until all SP log values that are affected by the presence of metallic mineral have undergone correction.

With the establishment of a correction method, a question may have been raised of whether more representative and accurate shale content (V_{sh}) values can be obtained after correction. Conceptually, as evident from Equation (2), this is not the case considering the existence of other factors such as r_{sh} and implicitly $r_{hydrokarbon}$ (in r_{sd}) which also influence SP log reading. In other words, correction on r_{sd} from the influence of metallic mineral presence will not neccessarily yield the most accurate V_{sh} without the effect of hydrocarbon presence (for hydrocarbon-bearing interval) also removed. Nevertheless, any correction made using the suggested method remains to be considered as relevant theoretically.

It is also worth noting that the nomographs presented in Figures (4) and (5) can also be used for other purposes such as to support correction on SP log leading to determination of formation water resistivity (R_w) from water bearing zones that are free from hydrocarbon influence. With the correction made, it is hoped that more representative R_w values can be obtained.

II. APPLICATION

As a case of trial for the suggested, reservoirs with known cases of metallic minerals were taken into selection. Several cases in our data inventory were found to have shown such prominent presence, and Jatibarang field with its vulcanic reservoir was chosen and its JTB-1xx (identity undisclosed) well was taken for the trial. Jatibarang vulcanic rocks in general are made of tuff,

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tuff lapili, aglomerate, vulcanic breccia, andesitic lava, basaltic lava, and sandstone and limestone lenses. Petrographic analyses on rock samples provide a general illustration of the rocks mineral composition, which show quartzose minerals (up to 30 %), fragments of basic igneous andesitic rocks (up to 50 %) , plagioclase/feldspar (up to 40 %), and some minor presence of clay (kaolinite, up to 10%). An interesting fact that can be learned from the analyses is the presence of metallic minerals such as iron oxides (e.g Fe_2O_3) and pyrite (FeS) in significant proportion. The analysis results show that presence of Fe_2O_3 and FeS can be as high as 22% and 10%, repectively, even though in average the presence is usually within a range of 5 – 10%.

Another interesting thing is the significant presence of plagioclase/feldspar with its potassium feldspar (K-feldspar). Although its presence cannot be described easily through direct visual description, but the mineral's presence in vulcanic rocks is common. Haack (1982) presented compositions of potassium contents as sources of redioactivity in various geotechnical positions. Certainly, not all of the potassium present are of radioactive isotope. However, as pointed by Helander (1983), since roughly 2% of all potassium in the world is represented by the radioactive isotope (K_{40}) it is likely that the presence of such large potassium presence has contributed significantly to the total radioactivity emitted by the vulcanic rocks. The direct consequence of the heavy presence of K-felspar is that any gamma ray (total gamma) log available has become of little use, which is really indeed the case. This condition makes SP log as the primary source of permeable bed identification and shale contents (V_{sh}) estimation hence correcting SP log reading is a neccesity.

Jatibarang vulcanic rocks start to be encountered at depth of 1830 meter (well JTB-88) with their thickness that reaches more than 1132 meter and the bottom of the rocks column is yet to be encountered. For the well JTB-1xx, interval to be used in the application of correction method is from 2130 – 2160 m with its temperature of 94 °C (200 °F) and formation water salinity ranging within 23,000 – 38,000 ppm NaCl (separate measurement).

In applying the SP log correction, nomograph presented in Figure (4) (with metallic mineral resistivity, R_m = 0.1 Wðm) was chosen based on suitability consideration. Data of corrected R(ILD) or R(LL) (*deep resistivity*) needed by the right-hand chart in Figure (4) is the result of correction on deep resistivity using a procedure presented in Widarsono (2000). Figure (6) presents a correction nomograph for deep resistivity correction for R_m = 0.5 Wðm and cementation factor, m = 1,8. (Note: in using the nomograph, the main input is porosity, presumably from acoustic log, and metallic mineral contents

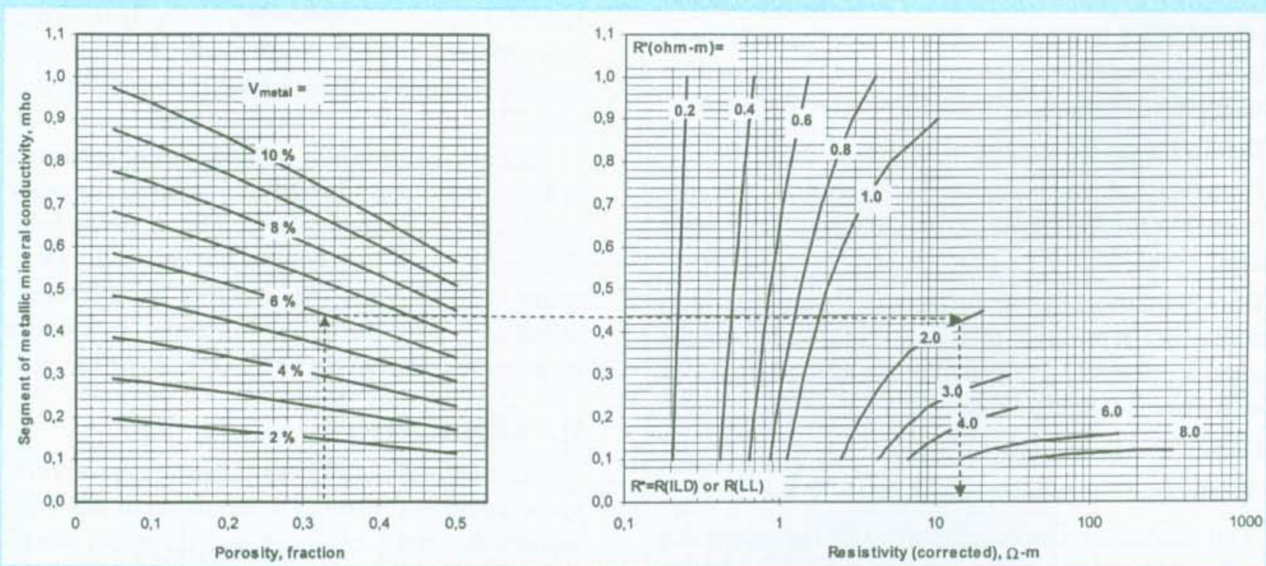

Figure 6
Nomograph for correction on resistivity log reading (metal resistivity, R_{metal} = 0.1 Ωm, mcementation factor, m=1.8) (from Widarsono, 2000). Note that R(ILD) or R(LL) are uncorrected deep resistivity obtained directly from induction log or laterolog, respectively

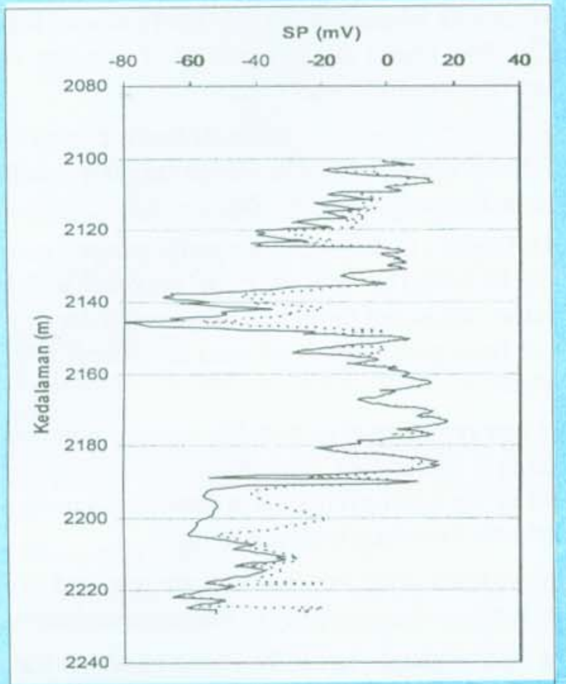

Figure 7
Result of correction on SP log reading (dashed curve)
Well JTB – 1xx (interval: 2100 – 2225 m)

which information is primarily obtained from petrographic analysis. R* is uncorrected deep resistivity either read directly from resistivity log curves or after environmental corrections.)

With using the nomograph presented in Figure (4), with R(ILD) values read directly from resistivity log (in the case of JTB - 1xx, induction log) and metallic mineral contents (V_{metal}) of within 5 – 10%, correction on SP log reading from interval of 2100 – 2220 m was conducted. Figure (7) shows comparison between the uncorrected (solid curve) and corrected (dashed curve), which shows reduction in the SP reading deflection. This deflection reduction is in accordance with expectation, which suggests that with the removal of metallic mineral's influence the r_{sd} in Equation (2) increases, with r_m and r_{sh} remain the same, leading to reduction in SP deflection. This reduction may encourage one to think that the SP reading has become worsened, but since this correction is based on theoretical point of view, the 'worsened' SP reading should be taken as a more realistic fact and undoubtedly will serve as a better input for better analysis results.

For testing the validity of the corrected SP log reading three kinds of tests, related to SP log's functions, can be made: 1) as a permeable bed indicator, 2) as a means to give shale contents estimates, and 3) as a means to provide formation water resistivity (R_w) estimates.

From the corrected curve, separations between permeable intervals (e.g interval 2135 – 2150 m) and non-permeable/shale intervals (e.g. interval 2151 – 2185 m) are indeed less clear. However, separations between the two intervals can still be made without sacrificing much of its vertical resolution and accuracy. Estimation of shale contents was not carried out since there was no other source for comparison (gamma ray log, total gamma, is biased and core analysis derived shale contents is non-exist). Therefore, the third test, estimation of R_w using the corrected SP reading will be taken as proof of effectiveness of the correction method.

For R_w estimation (interval 2135 – 2150 m), additional data required is:

Mud filtrate resistivity, R_{mf}	= 0.91 W-m @ 93 °C ($T_{reservoar}$)
Well diameter	= 8 inches (20 cm)
Bed thickness	= 12 m

Using the conventional method for R_w estimation using SP log data (see Helander, 1983 for instance) the followings are obtained:

SSP (uncorrected SP)	= - 112.5 mV
SSP (corrected SP)	= - 87.5 mV

with 'equivalent R_w', R_{weq}, values of

R_{weq} (uncorrected SP)	= 0.044 Wm
R_{weq} (corrected SP)	= 0.09 Wm

resulting in

R_w (uncorrected SP) =	0.11 Wðm @ 25 °C or salinity of ± 55,000 ppm eq. NaCl
R_w (corrected SP) =	0.28 Wðm @ 25 °C or salinity of ± 25,000 ppm eq. NaCl

From the results, it can be concluded that the corrected SP reading has provided a better result. Direct laboratory measurements on formation brine samples have provided us with various R_w values ranging within a range of 23,000 – 38,000 ppm eq. NaCl. In comparison with the direct measurements, it is obvious that the salinity estimate provided by the corrected SP of ± 25,000 ppm eq. NaCl proves better than the salinity estimate provided by uncorrected SP (± 55,000 ppm eq. NaCl). Based on this salinity estimates, it can be concluded that the suggested correction method for SP log is valid and can be used practically for log analysis activities when required.

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III. FURTHER DISCUSSION

There are some questions left over the practicality of using the correction nomographs: 1) what is the most representative value of V_{metal}?, 2) is the assumed representatif V_{metal} value distributed evenly throughout the rocks under evaluation?, and 3) how do we get V_m value if there is no petrographic analysis at all?". To answer the questions, a comprehensive petrographic evaluation should be conducted. However, it is also understandable that such a study is not easy to implement due to economics consideration and the desired representative V_{metal} will be left to everybody to guess when required.

One alternative to a comprehensive direct petrographic study is to take a 'trial and error' approach. This approach could be done sequentially in an iterative manner through: 1) assume V_{metal}, 2) perform correction on deep resistivity log using the procedure presented in Widarsono (2000), 3) perform correction on SP data, 4) determine salinity and/or R_w using uncorrcted SP data, 5) compare the estimated salinity or R_w to salinity or R_w obtained from direct laboratory measurement (if any) on formation brine, and 6) assume new V_{metal}. This procedure is repeated until an R_w value that shows a good agreement with laboratory data is obtained. Another result of this approach is that in the end the most representative value of V_{metal} is obtained. In the case of absence of direct laboratory R_w measurement, validation can still be performed through further estimating water saturation using the most suitable water saturation model. The water saturation estimates are then compared with water cut data from production or production tests, and new V_{metal} is assumed if the comparison is not yet satisfactory.

Further problem can raise in the case of absence of water cut data from well/ production tests. The 'trial and error' procedure can still be utilized but definitely with larger chance of yielding erroneous outcome due to absence of source for validation. Further considerations are needed in order to solve this problem.

IV. CONCLUSIONS AND RECOMMENDATIONS

From this study, a set of conclusions has been drawn and a set of recommendations has been suggested

1. A method for reducing uncertainty in the interpretation of SP log has been established and ready for field practical uses.
2. Validation of the suggested correction method has shown a good result hence confirming its usefulness.
3. SP log can play a significant role in vulcanic reservoir rocks where gamma ray (total gamma) log suffers from biases due to presençe of non-clay radioactive minerals in reservoir.
4. Resistivity of metallic minerals that is present in the Jatibarang vulcanic rocks used in the study is unlikely to be lower than 0.1 Wð-ðm.
5. Difficulties in determining metallic mineral contents can be solved by 'trial and error' approach with laboratory-measured formation brine resistivity or water cut from production/well tests as sources of reference.
6. When representative metallic mineral contents are more or less known, application of correction method on SP log reading is helpful in determination of a more reliable formation brine resistivity.
7. More trials using various cases are required in order to increase the reliability of the suggested method.
8. A field example has to be found in which the data availability enables us to compare between shale content estimates derived from corrected SP reading and shale contents from other reliable sources such as spectral gamma ray log, core gamma, and core/petrographic description.

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