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LOGGING THE PRAIRIE EVAPORATE FORMATION IN SASKATCHEWAN

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ABSTRACT

The use of well log data for the solution of sylvite, carnalite, halite and clay content has been made on many exploration and development potash projects. A new neutron device, the Sidewall Epithermal Neutron (SNP), recently introduced, will aid the basic program. The effect of well bore variables and chlorine presence is diminished with this device. The effect of these variables on the SNP system is discussed as well as their effect upon older well logs. A guide to the use of older logs is included.

INTRODUCTION

Earlier authors, (1) (2) (3), have outlined the application of geophysical logs to the evaluation of the prairie evaporite.

This evaluation can be provided at the drill site by use of nomographs and hand calculation. Subsequent detailed description of constituent minerals; sylvite, carnalite, insolubles and halite is produced by electronic computer.

Application of geophysical logs and techniques (4) common to the oil industry has provided the data for this. A recent development in neutron logging 'The Sidewall Epithermal Neutron Device (SNP) (5) has been compared with the 'long spacing' neutron/gamma system previously used for this analysis.

This paper will review the theoretical basis for log evaluation and compare results obtained using the SNP neutron with the Neutron/gamma system.

The basin is dotted with old exploratory drill holes. The older logs run in these wells can provide some approximation of potash content and grade. The general theory presented plus a section devoted to old logs, provides a guide to the use of these surveys.

THEORY

Previous papers (1) (2), have shown that potash minerals can be effectively identified and assayed through the use of geophysical logs. The Gamma Ray log provides the prime description of K_2O content and is augmented by neutron and sonic logs to give carnalite and clay content respectively. This analysis is based on these premises:

1. It is assumed that the minerals present are halite (w), sylvite (x), carnalite (y), and clay (z).

$$W + X + Y + Z = 100 \qquad \text{...equation 1}$$

2. The gamma ray emission in the evaporate section is related to the concentration of the isotope K^{40} of Potassium (3) (a fixed proportion, 12% of the total Potassium concentration), plus the emission eminating from the Potassium, Thorium, and Uranium constituents of the clay content.

$$0.63X + 0.17Y + 0.05Z = K_2O_{app} \qquad \text{...equation 2}$$

3. The Neutron Log determined hydrogen indix is that contributed by the water of crystalization of carnalite plus the water in the clay.

$$0.65Y - 0.30Z = \emptyset_N \qquad \text{...equation 3}$$

4. The recorded sonic interval travel time (Δt log) in microseconds/ft is the algebraic sum of the Δt of the constituant minerals in proportion of their presence. (4)

$$67W + 74X + 78Y + 120Z = 100\,\Delta t_{log} \qquad \text{...equation 4}$$

Reducing these equations accounts for the individual effect of the minerals W, X, Y, Z on the logs GR, N, and S and provides a solution in terms of W, X, Y, and Z.

INSOLUBLE $\quad Z = 2.07\Delta t_{log} - 0.23\,K_2O_{app} - 0.29\,\emptyset_N - 138.91 \qquad$ ...equation 5

CARNALITE $\quad Y = 1.54\,\emptyset_N - 0.46Z \qquad$ ...equation 6

SYLVITE $\quad X = 1.59\,K_2O_{app} - 0.41\,\emptyset_N + 0.04Z \qquad$ ...equation 7

HALITE $\quad W = 100 - X - Y - Z \qquad$ ...equation 8

To convert from a proportion to K_2O equivalent the final analysis follows:

$K_2O_{total} = K_2O_{app} - 0.05Z \qquad$ ...equation 9

$K_2O_{sylvite} = 0.63X \qquad$ ...equation 10

$K_2O_{carnalite} = 0.17Y \qquad$ ...equation 11

This evaluation, aided by nomographs can be performed for key intervals in the field. Subsequent detailed electronic computor analysis gives both tabular and graphic plots of the constituent mineral.

This program has been successfully run in both exploratory and development holes. Where discrepancies with core analysis have been apparent the authors believe the error to lie in borehole variables not in the basic premises. The SNP by system and design removes the effect of many of these variables.

VARIABLES

Hole Size

A drill hole filled with either oil or salt mud constitutes a large hydrogen rich volume. As the formation porosity decreases, as in the evaporite sequence, the variation in hole size becomes of greater significance. Caliper data can be used to reduce measured neutron count levels to the standard charts used in this analysis, however, oval shaped holes and the effect of sonde position increases the limit of possible error.

The SNP (5) device is a skid mounted sidewall neutron that is pressed to the ore face by a caliper recording arm. (fig. 1) Any residual hole size effect is further diminishe by a caliper controlled computer. This effectively removes the effect of borehole environment over its limits--6" to 16".

Matrix Effect

The neutron/gamma systems which were used to provide the information in earlier papers had a strong matrix component in their response. In this type tool fast neutrons (100,000 ev) are emitted from the source, and degrade by collision with formation atoms. They go through the spithermal (.5 ev) to the thermal (0.25 ev) level where they are captured by hydrogen or chlorine with the consequent production of a gamma ray of capture, that is monitored by the counter.

The SNP system is a epithermal device i.e. fast neutrons are emitted and are detected as they pass through the epithermal energy level. Hence, the chlorine effected capture stage is eliminated. This system is largely hydrogen sensitive, the role of chlorine is minimized.

Temperature/Pressure

Conventional neutron systems are affected by borehole temperature and pressure and require after logging chart corrections before normalized data is provided. The SNP incorporates an environmental computer to provide output data that is ready for immediate computation.

Presentation

The neutron/gamma system (linear count rate) generates a scale that is logarithmic in response to porosity. This causes difficulty in assignment of zero porosity plus a decrease in resolution in zones of high carnalite concentrations.

The SNP system produces a linear porosity scale with a preset absolute zero porosity indicated. (fig. 2) Also, direct use of log data without logarithmic table look up speeds field analysis and simplifies computer use. Much more meaningful visual analysis is provided.

Potash Evaluation with SNP Neutron

The SNP porosity recorded in the salt is a reflection of the included water. This can be used to modify the existing equations to refine the analysis.

1. If V is the SNP reading in the salt section then equation 1 is expanded to become:

$$V + W + X + Y + \zeta = 100 \quad t \qquad \qquad \text{... equation 1a}$$

Where V is the included water as indicated by the SNP in the upper and lower salt sections, generally 3-4%.

2. The included water has zero gamma ray emission so equation 2 remains unchaged:

$$0.63X + 0.17Y + 0.05Z = K_2O_{app} \qquad \text{...equation 2a}$$

3. The porosity is read directly by the SNP hence, equation 3 becomes:

$$1.00V + 0.65Y + 0.30Z = \emptyset_{snp} \qquad \text{...equation 3a}$$

4. The effect on Δt of varying amounts of included water is under current study. For the present, a refined evaluation is possible by applying a moderator (m) to the log values. Using normalized sonic data, equation 4 remains the same.

$$67W + 74X + 78Y + 120Z + m = 100\,\Delta t_{log} \qquad \text{...equation 4a}$$

Where $m = \Delta t_{log\ salt} - 67$

Reduction of these equations results in:

$$Z = 2.07\,(\Delta t_{log} - m) - 0.23\,K_2O_{app} - 0.29\,(\emptyset_{SNP} - V) - 138.91 \qquad \text{...equation 5a}$$

$$Y = 1.54\,(\emptyset_N - V) - 0.46Z \qquad \text{...equation 6a}$$

$$X = 1.59\,K_2O_{app} - 0.41\,(\emptyset_N - V) - 0.04Z \qquad \text{...equation 7a}$$

$$W = 100 - X - Y - Z \qquad \text{...equation 8a}$$

(when V is considered part of W)

Conversion to K_2O equivalent remains the same

$$K_2O_{total} = K_2O_{app} - 0.05Z \qquad \text{...equation 9}$$

$$K_2O_{sylvite} = 0.63X \qquad \text{...equation 10}$$

$$K_2O_{carnalite} = 0.17Y \qquad \text{...equation 11}$$

Application

The recording of Induction Resistivity, Gamma Ray, BHC Sonic, Neutron gamma type, Neutron and SNP Neutron, plus core data allows the following comparison. (fig. 3)

1. The suite of geophysical logs clearly indicates the top of the prairie evaporite at 3055'. The contrast with the covering red bed shale is seen as:

    1. A dramatic increase in resistivity

    2. A decrease in gamma ray level

    3. An increase in GNT neutron counts

    4. A decrease in SNP $\emptyset$

    5. A decrease in Sonic Δt

The gamma ray gives the indication of K_2O presence. The maximum deflection (depth) 3152') represents a K_2O content of 48.4%, as determined either by nomograph, or machine program.

The sonic log, adds some basic lithology information by dramatically separating the anhydrite (50 u sec) at 3290 - 3326' from the salts (67 - 78 us sec).

The neutron/gamma type neutron displays the chlorine effect. The count rates in the halite that are greater than in anhydrite are due to the high energy gamma rays of capture by chlorine atoms. This masks the ability of the neutron gamma system to assess carnalite.

The SNP neutron correctly assess 0 - 1% Ø in the anhydrite section and 3% Ø in the halite. Assuming the included water to be uniform throughout the section, any greater apparent Ø in the section would be due to carnalite and/or shale.

A comparison of computer printout (fig. 4) of the neutron/gamma with the SNP shows a much higher halite fraction in the upper salt - average 98% using SNP vs 95% with neutron gamma. The comparison of the cored interval (fig. 5) shows the Gamma Ray BHC SNP system to equal the Gamma Ray BHC neutron/gamma in sylvite assessment. The Gamma Ray BHC SNP system shows improved insoluble response throughout the cored interval

As expected, the Gamma Ray BHC SNP system gives a marked improvement in carnalite assessment. Particularly at the bottom of the cored section.

Potash Exploration Using Older Logs

While it is not possible to measure K_2O content with the same accuracy using older logs, they can be used qualitatively for potash exploration. The logs available were made on wells drilled as petroleum prospects. The evaporite section is usually badly caved. Under these conditions all factors act to reduce the apparent K_2O.

Differential Solution

When a salt section is drilled, solution of the salt continues until the mud becomes saturated. Further drilling with the salt saturated mud will cause little enlargement. Should a potash bed be encountered however, potash will go into solution. This results in caves and if the potash bed is thin the logging tool is held away from the ore by the adjacent salt shoulder beds. The recorded radioactivity and, hence, the apparent K_2O content are reduced. A neutron log over the interval will show increased porosity in the caved zone. If a caliper log is not available the analyst would tend to interpret the caved sylvite bed as a carnalite bed.

Tool Response

Early gamma logs were run with geiger type counters. While the count rate increases linearly with increasing gamma ray emission in most zones, this is not true in zones of high radioactivity where the response tends to fall off. Practically this means that high grade ores will appear poorer than they actually are.

Unscaled Logs

Some of the logs available in the basin are unscaled. An approximate scaling can be done using the reading in salt and in the Second Red beds as calibration points. A study of 25 logs shows that the average radioactivity level in the Second Red beds is 4 micrograms. The difference in radioactive levels between the salt and the Red beds is 3.3 micrograms. This scaling when applied to the potash section is a drastic extrapolation, hence, this evaluation must be taken only as a guide to the zones richness.

CONCLUSION

The system of evaluating potash zones using common geophysical logs has been improved by the introduction of the SNP neutron system.

The assessment of sylvite, carnalite, clay and halite can be obtained at the wellsite by nomograph and hand calculation using the data provided by Gamma Ray, SNP Neutron and BHC Sonic logs. Subsequent machine computation gives detailed printout and graphic plots of these constituent minerals.

The old logs from the basin can, to a lesser degree, provide a guide to the presence and richness of potash.

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