Role of Borehole Geophysics In Deep Water Exploration And Production In Cuu Long River Delta, South Vietnam

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ABSTRACT: Currently, in Cuu Long river delta, South Vietnam the deep groundwater is more interested in exploration and abstraction due to saline and contaminated surface water and shallow groundwater is excessive exploited resulting water level decrease and subsidence. Complication in distribution of fresh and saline ground water by depth in the area and hazards in deep production well construction require enhanced accuracy in exploration and hydrogeological data processing. One solution used for solving problems is an application of advanced hydrogeologic logging probe that allows logging of 4 normal resistivity measurements (8, 16, 32 and 64 inch), as well as single point resistance, spontaneous potential, natural gamma, fluid temperature and fluid resistivity. Geophysical parameters and hydrogeologic properties can be calculated using processing software. Clay content is estimated using corrected gamma signals and gamma ray index (GRI). Water resistivity is calculated using shallow and deep resistivity measurements along with the resistivity of the mud filtrate or formation factor. Then total dissolved solids (TDS) can be found from the water resistivity. Lithostratigraphic models are generated from data sets obtained with the multi-spaced normal resistivity probe that provides better vertical resolution due to the 8 inch normal resistivity measurement. The results of borehole geophysical data interpretation, as illustrated example, are effective contribution in design and construction of production well.

INTRODUCTION

Cuu Long river delta located in South Vietnam (Fig. 1) is important economic area of the country. However, almost surface water in the area is brackish, saline or contaminated. So demand of groundwater for living and production in the area is very pressing.

Previous studies on groundwater in Cuu Long river delta have shown that distribution of fresh and saline water is complicatedly changed by areas as well as by depth. Lithology of sediment layers is frequently altered in narrow scale.

Groundwater abstraction from shallow aquifers is developed in large scale over the whole of the delta. This situation will result water level decrease and subsidence. Hence, exploitation of deep water (300 - 400 m and deeper) is more interested. Exploration and production of deep fresh water specially thin permeable layer are big challenges due to hazard and costly spending.

Recent years borehole geophysics play important role in discovery of deep fresh water layer and well design. Application of multi-spaced normal resistivity data and PC based processing software allows estimate accurately hydrogeologic parameters in low clay aquifers and perform lithostratigraphic delineation. According to these results production well can be constructed.

Figure 1: Location of Cuu Long River Delta and Cross-section Line
HYDROGEOLOGY AND CHALLENGES IN DEEP WATER EXPLORATION AND PRODUCTION

Hydrogeology

Results of previous hydrogeological studies allow hydrogeologists to divide six aquifers in Kanozoic unconsolodated sediments of Cuu Long river delta (Figs.1, 2) as follow:

- Holocene porous aquifer of multi-origin sediments (QIV)
- Upper-Middle Pleistocene porous aquifer (QII-III)
- Lower Pleistocene porous aquifer (QI)
- Upper Pliocene porous aquifer ($N_2^2$)
- Lower Pliocene porous aquifer ($N_2^1$)
- Upper Miocene porous aquifer ($N_1^3$)

Hydrochemical characteristics of the above aquifers complicatedly changed and established into 5 vertical sections as below:

- Saline water section from surface to bottom
- Upper saline – lower fresh water section
- Fresh water section from surface to bottom
- Upper fresh – lower saline water section
- Alternative saline – fresh water section

Thus, there are existing zones with entire fresh or saline water, however alternative saline – fresh water section is predominant in Cuu Long river delta.

Challenges in deep water exploration and production

The most problems in deep water exploration and production in Cuu Long river delta are:

a. To predict existing of fresh water layers in some depth before drilling
b. To face difficulties in deep drilling and seepage
c. More importance to be certain of success is:

- To evaluate proper aquifer properties like water quality, degree of water storage, layer thickness
- And to install production well, casing, isolation of productive layer from upper and lower saline water

To solve all above questions efficiency and accuracy of a reconnaissance, exploration need to be enhanced specially borehole geophysics and drilling technology.

BOREHOLE GEOPHYSICAL LOGGING AND DATA PROCESSING

Borehole geophysical logging

New logging probe allows logging of 4 normal resistivity measurements (8, 16, 32 and 64 inch), as well as single point resistance, spontaneous potential, natural gamma, fluid temperature and fluid resistivity. These measurements

Figure 2 : Typical Hydrogeological Cross-section of Cuu Long River Delta
can be added by a caliper log, a gamma-gamma density or neutron porosity log. The data can be processed to provide derived parameters and properties. With a knowledge of the local geology, intervals with clean sand or clay/shale easily be identified and a lithostratigraphic model can be established.

**Data processing**

- **Borehole corrections**

  The first at all and most important step in processing of well logging data is borehole corrections. For the gamma trace, the borehole diameter, the diameter of the probe and the mud density are known to influence the gamma ray value. The application Excelog can carry out corrections of the measured gamma ray value for these effects. The software contains a user-defined function as follows:

  \[
  GRC = f(\text{mud}, \text{bit}, \text{cal}, \text{GR})
  \]

  Where
  - mud = mud density in lb/ugallons
  - bit = diameter of gamma probe in inches
  - cal = diameter of borehole in inches
  - GR = uncorrected gamma trace
  - GRC = corrected gamma trace

  For the borehole resistivity, using of equations (Scott, 1978) for the Schlumberger Resistivity Departure Curves can specify the corrected resistivity in terms of the measured resistivity, the borehole diameter, and the resistivity of the fluid in the borehole. In our case of the mud rotary drilled boreholes, the resistivity of the mud must be measured at known temperature. If the mud resistivity is measured on the surface then it must be corrected for the borehole temperature.

- **Estimation of clay content from the gamma logs**

  The clay content at a certain depth can be estimated from the so-called gamma ray index (GRI). The GRI is determined using the following formula:

  \[
  \text{GRI} = \frac{I_x - I_{\text{min}}}{I_{\text{max}} - I_{\text{min}}}
  \]

  where:
  - \(I_x\) = the observed gamma signal at certain depth
  - \(I_{\text{min}}\) = minimum gamma value in the log
  - \(I_{\text{max}}\) = maximum gamma value in the log

  This formula is applied to the gamma signals at certain depths where a sample for sieve analysis has been taken and a relationship between measured clay content (fraction in % of sample smaller than 0.005 mm) and the GRI is established for the study area.

- **Water quality**

  Water quality is indicated by the resistivity of the formation water \(R_w\). There are two approaches generally used for estimation of the formation water \(R_w\).

  **Calculating \(R_w\) using ratio method:** The method using the resistivities of the flushed zone is based on the following equation:

  \[
  R_w = \frac{R_o \times R_{mf}}{R_x}
  \]

  where \(R_o\) is true resistivity of the formation, \(R_{mf}\) is the resistivity of the mud filtrate, and \(R_x\) is the resistivity of the invaded zone. The deep (R64) and shallow (R8) resistivity measurements are usually used for \(R_o\) and \(R_x\) respectively. If \(R_{mf}\) is measured at the surface then it must be corrected for borehole temperatures.

  **Estimating \(R_w\) from formation factor**

  The formation resistivity factor \(F\) depends on the lithology of the aquifer and usually consistent for a given sedimentary unit within a depositional basin.

  \[
  F = \frac{R_o}{R_w} \quad \text{or} \quad R_w = \frac{R_o}{F}
  \]

  Using relationship established between the lithological descriptions and the formation factor determined by laboratory analysis of samples, the formation factor can be estimated according to lithology at certain depth. Then the water resistivity \(R_w\) is obtained by dividing the corrected resistivity signal of R64 by this formation factor.

  The calculated resistivity \(R_w\) can be used for estimating the total dissolved solids (TDS) in ppm of the formation water that is given by:

  \[
  \text{TDS} = 0.64 \times \text{EC} = 0.64 \times \frac{10,000}{R_w}
  \]

  Where:
  - EC = electrical conductivity of the formation water in micromhos/cm

- **Porosity**

  Porosity can be estimated using Archie’s Law in case of \(R_w\) and \(R_o\) accurate calculation. Hydraulic conductivity can be found from porosity and \(R_w\). Not quantitatively hydraulic conductivity can be estimated using the depth of mud filtrate invasion.

- **Lithostratigraphic model**

  Lithostratigraphic model is constructed by synthesizing all logs and bed boundaries must be selected using bed boundary indicators or using the electrode spacing and the behavior of normal resistivity logs for determination of layer thickness.
ILLUSTRATION EXAMPLE

The data set of production well SP3 in Figure 3 is owned, DHES. The well is located about 50 km south-west of Ho Chi Minh city. This well penetrates Kainozoic sand and clay/silt sequences of all aquifers mentioned in 2.1. The sands vary from fine grained to coarse and may contain some amount of clays. The blue shade shows sand interval of the Lower Pliocene where water was abstracted by nearby old production well stopped due to excessive exploitation therefore deeper water is solution of new production well SP3. The producing sands in the new well are from the Lower Pliocene (upper yellow shade) and the Upper Miocene (lower yellow shade) formations. Upper parts of the well section belong to the Pleistocenes and the Upper Pliocene formations where waters are saline or brackish.

Borehole corrections were performed to the natural gamma and the resistivity data. The gamma signals and GRI used to estimate the clay content. The ratio method was used to calculate Rw. The corrected 8 inch and 64 inch resistivity traces were used for Rxo and Ro respectively. TDS of waters

Figure 3 : Borehole Geophysical Data and Construction of ProductionWell SP3
Role of Borehole Geophysics In Deep Water Exploration

was calculated using Rw. Calculated clay contents in sand intervals of blue, upper yellow and lower yellow shades range in 4-8%, 5-10% and 7-12% respectively. Analysis of rock samples taking from the same intervals in nearby wells gave the values lay in this range. Water from blue shade aquifer in the old well had resistivity of 25.43 ohm.meters and analyzed TDS is 278 ppm. The calculated Rw value from this high resistivity sand interval is 25.34 ohm.meters and TDS of 252.56 ppm. Waters in upper and lower yellow shaded high resistivity producing sands have calculated Rw values of 26.2 and 21.5 ohm.m and TDS value of 243.9 and 298 ppm. Water sample from the two yellow shaded sand intervals in new production well SP3 gave chloride content of 30-40 mg/l.

The Figure 3 shows the separation in resistivity logs in the shaded high resistivity sand intervals. This separation is result of invaded lower resistivity mud filtrate and indicates higher hydraulic conductivity than the surrounding low resistivity clays. Note in the upper parts of the logs the resistivity values of short normals (8 and 16 inch) are higher than that of deep normals (32 and 64 inch). This is due to the saline native formation waters the resistivity of which is lower than the resistivity of the mud filtrate. The Figure 3 also illustrates bed boundary selection using resistivity logs. The short normals best exhibit separation because they are less susceptible to the thin bed effects.

The construction of the production well SP3 is presented in Figure 3. The depth location of water abstraction is selected according to borehole geophysical results. Gravel pack and cement grouting were performed. The production capacity of formerly nearby old well and nowadays SP3 is 60 m³ per hour and 40 m³ per hour respectively.

CONCLUSION

The application of advanced hydrogeologic multi-spaced probe is good solution for useful estimates of hydrogeologic parameters and accurate construction of lithostratigraphic model in Cuu Long river delta where is need to exploit deep ground water.

A data set obtained by logging of 4 normal resistivity measurements (8, 16, 32 and 64 inch), single point resistance, spontaneous potential, natural gamma, fluid temperature and fluid resistivity is a minimum required for processing and determination of clay content, water resistivity, TDS of native formation water and bed boundary selection.

To calculate the porosity and hydraulic conductivity based on depth of invasion, Rw and Ro must be accurately
determined and additional parameters may need to be considered. The normal resistivity measurements shorter than 16 inches allow a more accurate estimation of Rw and best separation of thin beds. A knowledge of the local geology must be known to validate results and to determine which intervals the calculated parameters are reliable.

Borehole corrections are paramount step since the relationships between the various geophysical readings are
to derive rock properties. Correcting normal resistivity logs for thin bed effects could also be added before processing.

Illustration example of the production well SP3 can tell the role of borehole geophysics in the success of deep water exploration and production in Cuu Long river delta.

REFERENCES


Dankhnov V. N., 1982, Interpretation of Borehole Geophysical Data, Nedra, Moscow.

Log Interpretation Charts, Atlas Wireline Services, Western Atlas International.


Nguyen Hong Bang, Bui The Dinh, 1992, Evaluation of Geophysical Parameters for Hydrogeology study in Nam Bo Plain, Special Subject, Division for Hydrogeology and Engineering Geology for the South of Viet Nam (DHES), Ho Chi Minh City.


