



Petrophysical Approach for Unconventional Shale Gas Resources Evaluation

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Abstract. Shale reservoirs comprise the source rock, which seal the reservoir and production is stimulated through hydraulic fracturing treatments. The economic productivity prediction and optimal fracture stimulation design is based on integrated petrophysical evaluation.

Integrated petrophysical evaluation shale gas integrates different types of data, including standard full-set logs, geochemical logs and advanced acoustic logs. These data, when combined together provides better answers about quality of the shale gas reservoirs.

The reservoir quality is established from conventional formation evaluation log (full-set logs) and geochemical logs, which include TOC, NMR porosity and mineralogy of gas in place. In this new integrated petrophysical evaluation method, elemental capture spectrometry log (ECS) and advanced acoustic measurements (DSI) are the keys for estimating reservoir dynamic properties.

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1 Integrated Shale Gas Reservoir Interpretation Method

The unconventional gas reservoir formation evaluation is different than conventional reservoir. In conventional gas reservoir the petrophysicist is dealing with the gas trapped in the pores, but in unconventional gas reservoir presence in both inorganic pores and organic materials called kerogen. The Kerogen is a solid inorganic matter. The hydrocarbon potential in shale gas depends on volume of total organic content (TOC).

The below flowchart (Fig. 1) shows an integrated method for a shale gas reservoir formation evaluation.

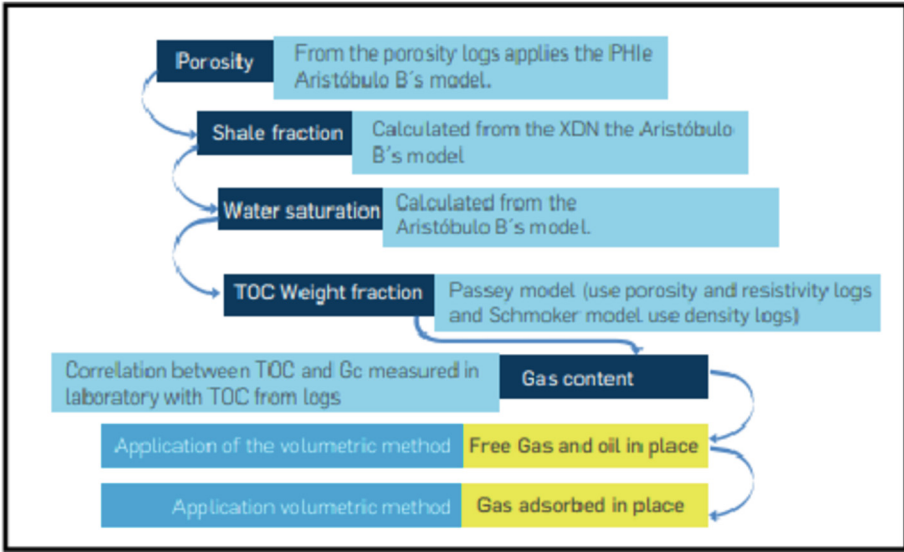


Fig. 1. Flowchart of shale gas reservoir formation evaluation flowchart

1.1 TOC Determination

Characterization of organic materials need to evaluate Total carbon content in organic materials which has direct relation with amount of TOC (high TOC better hydrocarbon volume). The amount of the measured carbon which is associated with the organic material (CTOC) is calculated by subtracting the amount of carbon required as a component of the inorganic minerals determined by the expert system.

$$CTOC = C \text{ total measured} - C \text{ calcite} - C \text{ dolomite} - C \text{ other minerals computed.}$$

Recommended a new TOC calculation we made using nuclear magnetic resonance log (NMR) porosity and bulk density from litho density log.

The calculation is as follows:

$$RHO \text{ (total)} = ((RHO_b - (RHO_f * Phi)) / (1 - Phi))$$

$$VTOC = RHO_m - RHO \text{ (total)} / RHO_m - RHO \text{ (TOC)}$$

$$m \text{ (TOC)} = (RHO \text{ TOC} / RHO \text{ total}) * RHO_m - RHO \text{ total} / RHO_m - RHO \text{ TOC}$$

where,

RHO_b: bulk density from log

RHO_{total}: total grain density of organic mater and inorganic matrix density

Phi: calculated porosity from NMR log

RHO_f: fluid density presence in the pores

VTOC: volume fraction of organic components

mTOC: mass fraction of organic components

RHOM: organic density of the components determined using mineralogy of geochemical logs.

1.2 Porosity Determination

Shale gas reservoirs porosities are low, often maximum 5%. The conventional Porosity calculation from neutron and density logs may have significant uncertainties due to the variable mineralogy and the variable amount of organic material present in the reservoirs. In an integrated petrophysical approach porosity is preferably derived from NMR log, is independent lithology. Comparison of NMR total porosity to core porosity in several shale gas plays has shown good agreement.

nmrPhit: $\Phi (CBF) + \Phi (CBW) + \Phi (\text{free fluid})$

nmrPhit: NMR total porosity

$\Phi (\text{free fluid})$: NMR porous media porosity which is the movable fluids

$\Phi (CBW)$: clay bound water porosity

$\Phi (CBF)$: capillary bound fluid porosity.

1.2.1 Gas-in-Place Determination

Shale gas reservoirs has two components, free gas and adsorbed gas calculations. The free gas calculation is made by a conventional petrophysical method; calculating water saturation from measured resistivity log and calculated porosity from NMR log.

True resistivity log (R_t) should use in water saturation model which is invasion corrected.

The Simandoux model is the best formula to use in clastic formations (shaly sand).

The Archie base Simandoux equation is:

$$S_{w\text{sim}} = a * R_w/R_t * n_{\text{mr}\Phi}^m * \text{Sqrt} (V_{\text{sh}}/R_{\text{sh}})^2 + 4 n_{\text{mr}\Phi}^{m/a} * R_w * R_t - V_{\text{sh}}/R_{\text{sh}}$$

where,

$S_{w\text{sim}}$: Simandoux water saturation

a : tortusity factor

R_w : formation water resistivity, ohm.m

$n_{\text{mr}\Phi}$: porosity calculated from NMR log

m : cementation factor

R_t : true resistivity

V_{sh} : calculated shale volume from corrected GR log (CGR)

CGR: corrected GR from NGs tool

R_{sh} : shale resistivity from deep resistivity log (minimum deep resistivity value in pure shale layer)

The Indonesian model is the best formula to use in carbonate formations (tight carbonate). The Poupon-Laveraux equation (Indonesian) and has shown in the below:

$$\text{Swindo} = ((\text{Sqrt}(1/\text{Rt})/(\text{Vsh}^{(1-0.5\text{Vsh})/\text{sqrt Rt}})) + \text{sqrt}(\text{nmrPhi}^{m/a} * \text{Rw}))$$

where,

Swindo: Indonesian water saturation

a: tortusity factor

Rw: formation water resistivity, ohm.m

nmrPhi: porosity calculated from NMR log

m: cementation factor

Rt: true resistivity

Vsh: calculated shale volume from corrected GR log (CGR)

CGR: corrected GR from NGs tool

Rsh: shale resistivity from deep resistivity log (minimum deep resistivity value in pure shale layer)

1.2.2 Geochemical Analysis

Standard dynamic mechanical rock properties including Young's Modulus and Poisson's ratio are computed from dipole sonic log (DSI) and density log inputs. Overburden and pore pressure gradients and maximum and minimum horizontal stress are computed. The orientations of the horizontal stresses are derived from examination of the borehole stress environment from image log and acoustic anisotropy interpretation.

Young's Modulus Equation:

$$\lambda = \text{strees/strain}$$

Poisson's Ratio Equation:

$$\nu = \frac{0.5R_v^2 - 1}{R_v^2 - 1}$$

$$R_v = \text{DTs}/\text{DTc}$$

DTs: shear wave transit time from DSI tool

DTc: compressional wave transit time from DSI tool.

2 Gas Inplace Determinations

The total gas inplace in a shale gas reservoir is included adsorbed gas and free gas volumes.

$$\text{GIPtotal} = \text{GIPfree} + \text{GIPadsorb}$$

GIPtotal: shale gas total gas in place volume

GIPadsorb: adsorbed gas in place volume in the organic materials

GIPfree: free gas in place volume in the pores.

2.1 Adsorbed Gas Inplace Determination

$$\text{GIP adsorb} = \text{KG6} * \text{GC} * \text{D} * \text{H} * \text{A/Bg}$$

where,

GIP adsorb = adsorbed gas in place, Mcf

A = Area,

D = Layer density from log or lab measurement ρ_b (g/cm^3)

GC = Gas content, scf/ton

H = Thickness, ft

Bg = Gas formation volumetric factor, cf/scf

KG6 = units conversion factor; 1.3597×10^{-3}

The typical shale densities are in the range of 2.20 to 2.60 g/cm^3 .

2.2 Free Gas Inplace Determination

$$\text{GIPfree} = \text{K1} * \text{PHIt} * (1 - \text{Swt}) * \text{H} * \text{A/Bg}$$

where,

GIPtotal = Total gas in-place, MCF H = Thickness, ft

A = Area, acres

Bg = Gas formation volumetric factor, cf/scf

K1 = Unit conversion factor; $43560 * 10^{-6}$.

GIPfree = l free gas in place, Mcf

PHIt = Total porosity, fraction

PHIe = Effective porosity, fraction

Swt = Total water saturation, fraction

Swe = Effective water saturation, fraction

Figure 2 shows an interpretation plot of a shale reservoir.

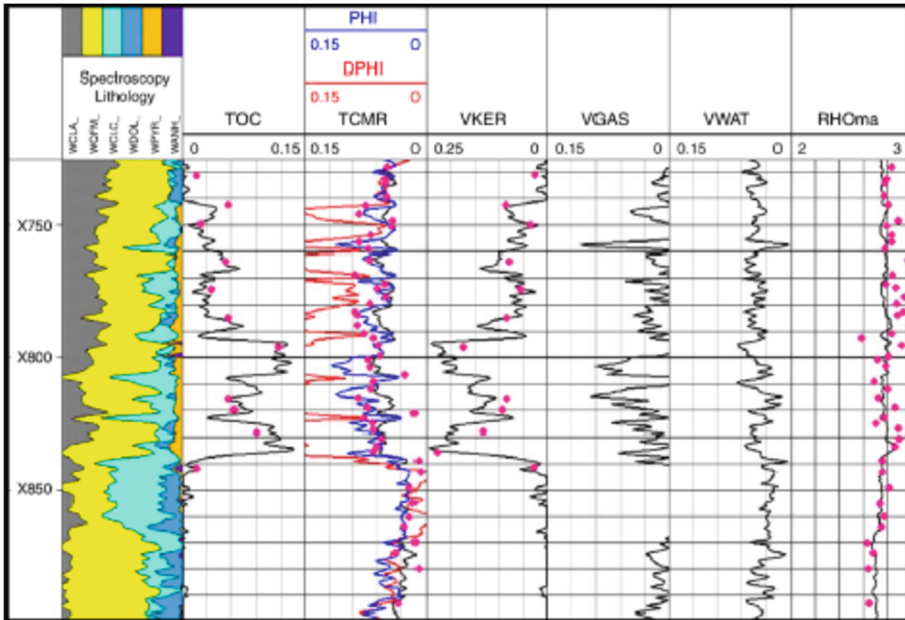


Fig. 2. Shale gas formation evaluation log plot

3 Conclusions

- Formation evaluation of shale gas need NMR, DSI and ECS and core for integrated formation evaluation.
- Shale gas total gas volume includes free gas and adsorbed gas volumes.
- Shale gas porosity includes inorganic free gas porosity and organic matter porosity.
- Geomechanical parameters measurements need for evaluation of multi stage hydraulic fracturing.
- Shale gas plays are in the form of tight carbonates and shale as source rock.
- Basically, shale gas porosity in the range of 1–5%.
- The shale gas plays have ultra-low permeability.
- TOC characterization is the main part of shale gas formation evaluation.
- The China sits on giant shale gas reservoirs.

4 Nomenclature

- Rt: true resistivity
- Rd: deep resistivity
- Phi: porosity
- Sw: water saturation
- GIPadsorb: adsorbed gas initial gas inplace
- GIPfree: free gas gas initial gas inplace
- Landa: Young's modulus

- DTs: shear wave transit time
- DTc: compressional wave transit time
- TOC: total carbon content
- a: tortuosity factor
- m: cementation exponent
- Rw: formation water resistivity
- Swt: total porosity
- Swe: effective porosity
- Bg: reservoir volumetric factor
- H: formation thickness
- A: reservoir area
- Gc: adsorbed gas content
- Vsh: shale volume
- Rsh: shale resistivity
- λ : Yangou's modulus
- ν : Poisson's ratio

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