A Simplified Shaly-Sand Model
To Provide Qualitative If Not Quantitative Insight into Observations*

Donald G. Hill¹ and D. O. Seevers²

Search and Discovery Article #42377 (2019)**
Posted June 17, 2019

*Adapted from oral presentation given at 2018 Pacific Section AAPG Convention, Bakersfield, California, April 22-25, 2018
**Datapages © 2019 Serial rights given by author. For all other rights contact author directly. DOI:10.1306/42377Hill2019

¹Consulting Petrophysicist; Adjunct Professor of Petrophysics, The University of Southern California, Los Angeles, CA (dgh@hillpetro.com)
²Deceased

Abstract

Clay minerals affect essentially every measured petrophysical property. They destroy effective porosity and permeability, as well as contaminate essentially all wireline measurements.

A simplified mixing model consisting of coarse and fine grains of about two orders of magnitude difference offers qualitative, if not quantitative insight on these effects. The qualitative results predicted from this simplified model are remarkably similar to those observed from a Canadian Arctic shaly-sand well and published by Alan Heslop, in the mid-1970s.

Selected References


A Simplified Shaly-Sand Model

To Provide *Qualitative*
If not *Quantitative* Insight
into Observations

D. G. Hill & D. O. Seevers

dgh@hillpetro.com
Clay Minerals

_Bane of Petrophysicists Since 1950’s_

- Destroy Effective Porosity & Permeability.
- Increase _Apparent_ Neutron Porosity.
- Decrease/Increase _Apparent_ Density Porosity.
- Increase _Apparent_ Water Salinity.
- Increase apparent $S_w$.
- Increase _Apparent_ Sonic $\Delta t$.
- Decrease _Apparent_ NMR $T_2$. (Surface Relaxation).

Shaly-Sand Petrophysics

- Not Needed in 1940’s:
  - Only Clean Pays competed.
- Then Some Crazy Idiot Completed a Shaly-Sand:
  - There was a *lot* of oil in those rocks.
- The Birth of Shaly-Sand FE:
  - $V_{sh}$ Algorithms.
  - Electro-Chemical Algorithms.
- Now Hundreds of Shaly-Sand Algorithms Abound:
  - Each one seemingly more complex than the last.

Need a Simple Model to Explain:

Consider A Rock Consisting of

- A Coarse-Grained Framework:
  - Porosity, \( \varphi_c \).
  - Matrix volume, \( V_{mac} \).

- With Coarse-Grained Framework Pores Filled with Fine-Grained Material:
  - Porosity, \( \varphi_f \).
  - Matrix volume, \( V_{maf} \).
Conceptual Model

Bi-Modal Grain Size Model

Two Orders of Magnitude

Sedimentary Particle Size

Two Orders of Magnitude

dgh@hillpetro.com
Recent Gulf Coast Sediment Sieve Analysis

Two orders of Magnitude Difference

dgh@hillpetro.com
Gulf Coast Compaction Models
(Both Indicate Deposition Porosities of ~ 42.5%)

Sand Compaction Model  Shale Compaction Model

dgh@hillpetro.com
Coarse & Fine-Grained Porosities

Coarse-Grained Framework

“Porosity”

\[ X_c = \frac{V_{mac}}{\left( V_{mac} + V_{maf} \right)} \]

and:

\[ V_{pc} = V_R - V_{mac} \]

and:

\[ J_c = \frac{V_{pc}}{V_R} = \frac{V_{pc}}{\left( V_{pc} + V_{mac} \right)} \]

Fine-Grained Intergranular

“Porosity”

\[ X_f = \frac{V_{maf}}{\left( V_{mac} + V_{maf} \right)} \]

and:

\[ V_{fn} = V_{pf} + V_{maf} \]

and:

\[ J_{fn} = \frac{V_{pf}}{V_{fn}} = \frac{V_{pf}}{\left( V_{pf} + V_{maf} \right)} \]
$X_c \ & \ X_{fn}$ Mixing Relationships

For $1.00 > X_c > X'_c$

$$\phi_T = \frac{V_p}{V_R} = \frac{(v_{pc} - v_{maf})}{(v_{pc} + v_{mac})} = \frac{(v_{pc} + v_{pf} - v_{mf})}{(v_{pc} + v_{mac})}$$

or:

$$\phi_T = 1 - \frac{(1 - \phi_c)}{X_c} = \frac{(\phi_c - X_{fn})}{(1 - X_{fn})}$$

at:

$$X_c = X'_c = \frac{(1 - j_c)}{(1 - f_j j_{fn})}$$

and:

$$j_T = j_{Tmn} = \frac{V_p}{V_R} = j_j j_{fn}$$

For $X'_c > X_c > 0.00$

$$j_T = \frac{(1 - X_c)j_{fn}}{(1 - X_f j_{fn})}$$

or:

$$j_T = \frac{X_{fn}j_{fn}}{(1 - j_{fn} + X_f j_{fn})}$$

dgh@hillpetro.com
Through the Magic of Algebra

\[ \phi_t \& \phi_e \text{ for } 100:1 \text{ grain size and } \phi_c = \phi_{fn} = 40\% \]

Variation of $X'_c$ and $\varphi_m$
with Changes in $\varphi_c$ and $\varphi_f$

$\varphi_m$ Variations

$X'_c$ Variations

dgh@hillpetro.com
Bi-Modal Model $\varphi_N - \varphi_D$ X-Plot

$\varphi_c = \varphi_{fn} = 35\%$

Heslop Canadian Arctic Well

GR log with Sand, & Shale Lines


dgh@hillpetro.com
Heslop Canadian Arctic Well

W/L GR vs. Core Clay Content  V\textsubscript{cl} vs. GR Trend

dgh@hillpetro.com
Density vs. GR

Heslop Canadian Arctic Well

Bi-Modal Model

dgh@hillpetro.com
PhiN vs. GR

Heslop Canadian Arctic Well

Bimodal Model

dgh@hillpetro.com
Heslop Canadian Arctic Well

$\Delta T$ vs GR

$R_t$ vs GR

dgh@hillpetro.com
Heslop’s Canadian Arctic Well
GR Log Picks
Why this is Important

References

Heslop, A., 1974a, “Gamma Ray Response of Shaly Sandstones”,
15th Annual Logging Symposium, SPWLA, Paper M.

Heslop, A., 1974b, “Gamma Ray Response of Shaly Sandstones”, The Log Analyst,
v. 15, No. 5 (September-October, pp. 16 – 21).

Technical Memorandum, TM78000300, Chevron Oil Field Research Company.

Formation Evaluation Committee Meeting Minutes - Supplement, Standard Oil
Company, of California.

Research Committee, Standard Oil Company, of California (Transcribed by W.
J. Plumley).
