Clay Mineralogy, Shale Types, and Petrophysical Corrections in Shaley Reservoir Formations

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By

Mohammad Kamal Ghassem-Alaskari

Edited by Mohammad Zaman Kassaee

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ABOUT THE AUTHOR AND EDITOR

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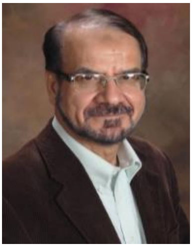
Dr. M. K. Ghassem-Alaskari holds B.Sc., M.Sc., and Ph.D. degrees in Geosciences. He has served as a senior geophysicist and professor at the Petroleum University of Technology (PUT) in Ahwaz, Iran, for over 30 years. He earned both his M.Sc. and Ph.D. in Applied Geophysics and Reservoir Geophysics from Southern Methodist University (SMU) in Dallas, Texas, USA. Approximately 15 years ago, Dr. Ghassem-Alaskari founded the PGPZ-International Laboratory, which has since become a hub for advanced research in geophysics. He has authored numerous papers and books in both English and Persian, focusing on applied geophysics and related fields. His primary research interests include unconventional reservoir characterization and associated technological challenges. In this book, he applies his interdisciplinary expertise to the characterization of clay minerals, shale types, and petrophysical corrections in shaley formations.

Editor: Dr. Mohammad Zaman Kassaee



Dr. M.Z. Kassaee is a chemist with extensive experience in nanochemistry, molecular modeling, and green synthesis. He has published over 230 scientific papers and supervised numerous graduate students. In this book, he applies his interdisciplinary expertise to the characterization of clay minerals, shale types, and petrophysical corrections in shaley formations.

PREFACE

Shale is a fine-grained sedimentary rock formed through the compaction of silt (50%), clay (35%) and other autogenic-sized mineral particles, commonly referred to as "mudrock". This composition classifies shale within the broader category of sedimentary rocks known as mudstones. However, shale is specifically distinguished from other mudstones by its fissility and lamination. Lamination refers to the presence of numerous thin, parallel layers within the rock, while fissility indicates its tendency to split readily along these layers.

Shale originates from autogenic rocks that are broken down through weathering and interaction with moving water, ice or wind. Extremely fine particles of minerals such as feldspar, quartz, mica, pyrite, and others gradually settle in still bodies of water-such as swamps, deep ocean basins, and lakes-where they mix with decaying fine organic matter to form clay and mud. Since weathering is a continuous process, new layers accumulate over time and the overlying pressure from these layers compact the material below. Eventually, the accumulated pressure initiates lithification-a process by which sediments are transformed into solid rock. Lithification results in the formation of the fine lamination characteristic of shale types.

Shale is a relatively soft sedimentary rock that fractures easily along its bedding planes. Its color varies depending on its mineral composition and environment, commonly appearing in shades of red, grey, green, or black. Geologists classify shale as a mud rock or mudstone due to the extremely fine grain size of its constituent particles (Silt=0.0625-0.0039 mm and Clay minerals less than 1/256 mm in diameter). It is one of the most abundant rock types in the Earth's crust.

Clay minerals possess the unique ability to absorb specific ions and retain them in an exchangeable state (see Chapter 2). This property, which is also shared to some extent by certain non-clay minerals, is referred to as the cation exchange capacity (CEC).

Geologically, shale is notable for its role in slope instability. It is the most common rock associated with landslides. When saturated with water, shale becomes slick and muddy, making slopes prone to failure. Excavation in shale-rich areas often serves as a trigger for such landslides. In the context of oil and gas drilling, shale can present technical challenges by contributing to borehole instability. Additionally, certain types of shale reduce reservoir quality by filling pore spaces and decreasing both porosity and permeability in carbonate rocks. Nevertheless, shale remains an important source rock for petroleum and natural gas

This book focuses on the characterization of shaley rocks, particularly in terms of their *Cation Exchange Capacity (CEC), shale types, shale volume, and various clay mineral properties. CEC is a critical property of clay minerals and plays a vital role in several geological and petroleum engineering applications. It is used in the characterization and quantification of sorbents in clays and sedimentary rocks, Enhanced Oil Recovery (EOR), log interpretation corrections, acidizing treatments, and the formulation of drilling fluids.

In our laboratory, CEC was measured using the methylene blue method on samples obtained from drilling cores and cuttings. Measurements were conducted at varying pH levels. Based on the CEC values and cross-plots, the types of clay minerals and shale types were inferred. Additionally, complementary techniques such as X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM), log analysis and petrophysical corrections were employed to qualitatively and quantitatively investigate clay mineralogy, shale classification and shale types. The results from CEC measurements showed good agreement with those obtained from XRD, SEM, and log analysis.

In the final chapter, we present a comprehensive overview of the terminology, classification, and historical development related to the unconventional production of oil and gas from shale formations.

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- Mr. Mohsen Minaei (RockLog2005, SeisPlot2006, etc.)
- Mr. Naser Tamimi (AIV2005, GeoMancy Image Processing Package, 2007)
- Mr. Seyed Kourosh Mahjour (Statistical Package, GeoLog, etc.)
- Mr. Mohammad Moeini (Data Processing, Shale-Type Programs, etc.)
- Mr. Ali Roozmeh (Data Evaluation and Shale-Type Determination)
- Mr. Meysam Bayazidi (Reservoir Geophysical Logs, etc.)

Their continued technical contributions and research efforts were essential to the success of this book.

The manuscript was expertly typed and edited by Dr. Maliheh-Sadat Kazemi and Ms. Azam Pourentazari, whose dedicated work on the final chapters significantly contributed to the completion of this book.

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Ghassem-Alaskari, M.K.

NOMENCLATURES

Formulae:
Chaper-3

$$Sw^{n} = \frac{F.Rw}{Rt} \tag{3.1}$$

$$F = \frac{Ro}{Rw} \tag{3.2}$$

$$F = \frac{1}{\varphi^{m}} \tag{3.3}$$

$$Co = \frac{Cw}{F} + Vsh^{2}.Csh \tag{3.4}$$

$$Co = \frac{Cw}{F} + Vsh.Csh \tag{3.5}$$

$$\sqrt{Co} = \sqrt{\frac{Co}{F}} + Vsh^{1-\frac{Vsh}{2}}.\sqrt{Csh} \tag{3.6}$$

$$\sqrt{Co} = \sqrt{\frac{Cw}{F}} + \frac{Vsh.Csh}{0.324\ Cw} \tag{3.7}$$

$$Sw = \sqrt{\frac{F.Rw}{Rt}} - \left(\frac{Vsh.Rw}{0.4\ \varphi\ .Rsh}\right) \tag{3.8}$$

$$F = \frac{0.81}{\varphi^2} \quad (3.9)$$

$$\frac{Ro}{Rw} = Fa = F_{0.01}\left(100\ Rw^{b\ log\,(100\ Rw)}\right) \quad (3.10)$$

$$b = \left(-0.135\frac{CEC}{PV}\right) - 0.0055 \quad (3.11)$$

$$Co = \frac{1}{F^*}(B.Qv + Cw) \quad (3.12)$$

$$F^* = \frac{1}{\varphi^m} \quad (3.13)$$

$$B = 0.046\left[1 - 0.6\ e^{\frac{-Cw}{0.013}}\right] \quad (3.14)$$

$$C_o = \frac{C_{we}}{F_o} \quad (3.15)$$

$$C_{we} = Cw.\left(1 - V_Q.Q_V\right) + V_Q.Q_V.C_{CW} \quad (3.16)$$

$$C_o = \frac{1}{F_o}\left[C_W.\left(1 - V_Q.Q_V\right) + V_Q.Q_V.C_{CW}\right] \quad (3.17)$$

$$C_o = \varphi_t^2\left[S_{WB}.C_{WB} + (1 - S_{WB})C_{WF}\right] \quad (3.18)$$

$$\varphi_t = \varphi_{WB} + \varphi_{WF} \quad (3.19)$$

$$S_{WB} = \frac{\varphi_{WB}}{\varphi_t} \quad (3.20)$$

$$C_{WB} = \frac{(\varphi_t)_{sh}^{\ 2}}{C_{sh}^{*}} \tag{3.21}$$

$$C_{WF} = \frac{(\varphi_t)_{ss}^{\ 2}}{C_{o}^{*}} \tag{3.22}$$

$$Q_{Vn} = \frac{Q_V}{Q_{Vsh}} = \frac{V_{sh}(\varphi_t)_{sh}}{\varphi_t} \tag{3.23}$$

$$C_{we} = V_{fdl}.C_{cl} + (1 - V_{fdl})C_w \tag{3.24}$$

$$V_{fdl} = \left(\frac{0.084}{C_w} + 0.22\right)Q_V \tag{3.25}$$

$$C_{cl} = c_{eq}.n_{eq}^{+} \tag{3.26}$$

$$n_{eq}^{+} = \frac{3.571}{\left(\sqrt{f_{dl}} - 0.188\right)^2} \tag{3.27}$$

$$f_{dl} = (X_h^2 . B_o^2 . n)^{-\frac{1}{2}} \tag{3.28}$$

$$B_o = 0.3248 + 1.5108 * 10^{-4}.T + 8.935 * 10^{-7}.T^2 \tag{3.29}$$

$$n_{eq}^{+} = \frac{Q_v}{V_{fdl}} \tag{3.30}$$

$$c_{eq} = \frac{c'_{eq}}{[f_g.F(ne)]} \tag{3.31}$$

$$c'_{eq} = \frac{12.645 + 7.6725\sqrt{n_{eq}}}{1 + 1.3164\sqrt{n_{eq}}} \quad (3.32)$$

$$f_g = f_{dl}^{\frac{1}{n_c}} \quad (3.33)$$

$$n_c = 0.6696 + 1.1796 f_{dl} - 0.14426 f_{dl}^2 \quad (3.34)$$

$$F(ne) = 1 + 3.83 * 10^{-2}(n_{eq} - 0.5) + 1.761 * 10^{-2}(n_{eq} - 0.5)^2;\ n_{eq} > 0.5\frac{mol}{liter} \quad (3.35)$$

$$F(ne) = 1\ ;\ n_{eq} \leq 0.5\frac{mol}{liter} \quad (3.36)$$

$$C_o = \frac{C_{we}}{F_e} = \frac{\left[c_{eq}.n_{eq}^{+}.V_{fdl} + (1 - V_{fdl})C_w\right]}{F_e} \quad (3.37)$$

$$F_e = \varphi^{m_c} \quad (3.38)$$

$$E_m = \frac{-2RT}{F}\int_{m2}^{m1} \tau.Tna^{+}.d\ ln(m\gamma \pm) \quad (3.39)$$

$$\tau = 1 - 0.28Q_V\frac{(C_w - C_{wn})}{C_w}\ ;\ C_w > C_{wn}\ ;\ \tau = 1\ ;\ C_w \leq C_{wn} \quad (3.40)$$

$$Tna^{+} = \frac{c_{eq}.Q_V + Tna^{h}.(1 - V_{fdl})C_w}{c_{eq}.Q_V + (1 - V_{fdl})C_w} \quad (3.41)$$

$$Tna^{h} = \frac{50.1 + 55.402.\sqrt{n}}{126.45 + 155.726.\sqrt{n}} \quad (3.42)$$

$$log(\gamma \pm) = \frac{-0.5115.\sqrt{n}}{1 + 1.3065.\sqrt{n}} - 1.75\, log(a_A) - log(1 - 0.027m) \quad (3.43)$$

$$a_A = 0.99948 - 0.03959m - 0.0015075m^2 \quad (3.44)$$

$$V_{fdl} = \left[0.28 - 0.0344\, ln\left(\frac{T}{25}\right)\right]\left[\frac{\left(\sqrt{\frac{T_a}{298}}\right)}{\left(\sqrt{X_h^2.B_o^2.n}\right)}\right]Q_V \quad (3.45)$$

$$ln(n) = 68.1 - 13.58\, ln(T_a) + 0.0229T_a + 1.1851\, ln(C_w) + 0.00467C_w \quad (3.46)$$

$$n_{eq} = n_{eq}^{+}\left(\frac{T_a}{298}\right) = \left(\frac{Q_V}{V_{fdl}}\right)\left(\frac{T_a}{298}\right) \quad (3.47)$$

$$ln(c_{eq}) = -58.84 - 0.1026n_{eq} - 0.07871\, ln(n_{eq}) - 0.0216T_a + 11.85\, ln(T_a) \quad (3.48)$$

$$C_o = \frac{\left[c_{eq}.n_{eq}.V_{fdl} + (1 - V_{fdl})C_w\right]}{F_e} \quad (3.49)$$

$$Q'_V = \frac{Q_V}{S_W} \quad (3.50)$$

$$SP = Em_{sh} - Em_{ss} \quad (3.51)$$

$$SP = \frac{-2RT}{F}\int_{m2}^{m1}(Tna^{sh} - Tna^{ss}).d\, ln(m\gamma \pm) \quad (3.52)$$

$$SP = \frac{-2RT}{F}\int_{m2}^{m1} m_{eff}.d\, ln(m\gamma \pm) + \frac{2RT}{F}\int_{m2}^{m1}\frac{c_{eq}.n_{eq}.V_{fdl} + Tna^{+}(1 - V_{fdl})C_w}{c_{eq}.n_{eq}.V_{fdl} + (1 - V_{fdl})C_w}\, d\, ln(m\gamma \pm)$$

(3.53)

$$Tna^{+} = Tna^{h} + t_w$$ (3.54)

$$ln(Tna^{h}) = -2.50893 - 0.01803769\, ln(m) + 0.264709\, ln(T_a) - 1.41764 * 10^{-5} T_a . m$$ (3.55)

$$t_w = 0.053m - 0.043 + [0.1961\, ln(m) + 0.1244 Q_V];$$
m≤ 1.0 (3.56)

$$t_w = 0.036m^{1.1} - 0.04377 + 0.04Q_V, \; m \leq 1.0$$ (3.57)

$$log(\gamma \pm) = log\,(\gamma \pm)^{298} + 0.5Y.L_{298} - 0.5Z.J_{298}$$ (3.58)

$$log\,(\gamma \pm)^{298} = \frac{-0.5115\sqrt{n}}{1 + 0.3065\sqrt{n}} - 1.75\, log(a_A) - log(1 - 0.027m)$$ (3.59)

$$a_A = 0.99948 - 3.0959 * 10^{-2}.m - 0.0015m^2$$ (3.60)

$$Y = \frac{298.15 - T_a}{8.3147(298.15)2.3026T_a}$$ (3.61)

$$Z = 298.15Y + \frac{1}{8.3147} log\left(\frac{T_a}{298.15}\right)$$ (3.62)

$$L_{298} = \frac{2878.6\sqrt{m}}{1 + \sqrt{m}} - 3182.8m + 986.5\sqrt{m^3}$$ (3.63)

$$J_{298} = \frac{43.5\sqrt{m}}{1 + \sqrt{m}} - 72m - 20.36\sqrt{m^3}$$ (3.64)

$$C_o = \frac{C_w}{F_{fw}} + \frac{C_{cl}}{F_{bw}}$$ (3.65)

$$F_{fw} = \frac{1}{\varphi_e^{m_f}} \tag{3.66}$$

$$F_{bw} = \frac{1}{\varphi_{bw}^{m_c}} \tag{3.67}$$

$$\varphi_e = \varphi_t (1 - V_{fdl}) \tag{3.68}$$

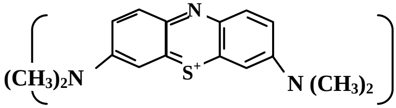
$$\varphi_{bw} = \varphi_t - \varphi_e = \varphi_t . V_{fdl} \tag{3.69}$$

$$C_o = \left[C_w (1 - V_{fdl})^{m_f} . \varphi^{m_f} + c_{eq} . n_{eq} . V_{fdl}{}^{m_c} . \varphi^{m_c} \right] \tag{3.70}$$

$$\mathrm{Tna}^+ = \frac{c_{eq} . n_{eq} . V_{fdl}{}^{m_c} + \mathrm{Tna}^+ (1 - V_{fdl})^{m_f} C_w}{c_{eq} . n_{eq} . V_{fdl}{}^{m_c} + (1 - V_{fdl})^{m_f} C_w} \tag{3.71}$$

$$\mathrm{SP} = \frac{-2RT}{F} \int_{m2}^{m1} m_{eff} . d \ln(m\gamma \pm) + \frac{2RT}{F} \int_{m2}^{m1} \frac{c_{eq} . n_{eq} . V_{fdl}{}^{m_c} + \mathrm{Tna}^+ (1 - V_{fdl})^{m_f} C_w}{c_{eq} . n_{eq} . V_{fdl}{}^{m_c} + (1 - V_{fdl})^{m_f} C_w} d \ln(m\gamma \pm) \tag{3.72}$$

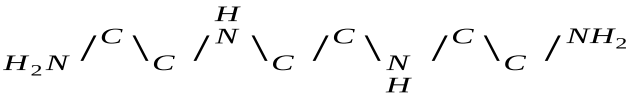
Chapter-4



or

$$(C_{16}H_{18}N_3SCl)_2 ZnCl_2 . H_2O \tag{4.1}$$

or $NH_2(H_2H_4NH)_2C_2H_4NH_2$ (4.2)



$$n\lambda = 2d\sin\theta\ , \quad \sin\theta = \frac{\lambda/2}{d} = \frac{\lambda}{2d}$$ (4.3)

Chapter-5

IGR = (GR_log – GR_min) / (GR_max – GR_min) (5.1)

(for older rocks) Vsh = 0.33 × [2^(2 × IGR) – 1.0] (5.2)

(for Tertiary rocks) Vsh = 0.083 × [2^(3.7 × IGR) – 1.0] (5.3)

(Stieber, 1970) Vsh = IGR / [3 – 2 × IGR] (5.4)

For Potassium Log),

Vsh_K = (K_log – K_min) / (K_max – K_min) (5.5)

For Thorium Log,

Vsh_Th = (Th_log – Th_min) / (Th_max – Th_min) (5.6)

For Uranium Log,

Vsh_U = (U_log – U_min) / (U_max – U_min) (5.7)

GRS = A × K + C × Th (5.8)

Vsh_GRS = (GRS_log – GRS_min) / (GRS_max – GRS_min)(5-9)

:

φN_corr = φN – ΔφN (5.10)

$$\Delta\varphi_N = \varphi S_{hr}\,\frac{\rho_h - 0.7 + 0.4P}{1 - 0.4P}$$ for oil (5.11)

$\Delta\varphi_N = \varphi S_{hr} \frac{2.2\rho_h - 1.0 + 0.4P}{1 - 0.4P}$ for gas

(5.12)

(for oil) $\Delta\varphi N = \varphi Shr \times (\rho h - 0.7)$ (5.13)

(for gas) $\Delta\varphi N = \varphi Shr \times (2.2 \times \rho h - 1.0)$ (5.14)

$\varphi d\_corr = \varphi d - \Delta\varphi d$ (5.15)

$\Delta\varphi_d =$

$1.07\varphi S_{hr} \frac{(1.11(1-\rho_h) + 0.65P - 0.03)}{\rho_{ma} - 1.0 - 0.7P}$ for gas (5.16)

$\Delta\varphi_d =$

$1.07\varphi S_{hr} \frac{1.11 - 0.65P - 1.24\rho_h}{\rho_{ma} - 1.0 - 0.7P}$ oil for (5.17)

$\frac{0.7 \times \left(1 + \frac{\varphi_N}{\varphi_d}\right) S_{hr} - (1 - \frac{\varphi_N}{\varphi_d})}{(1 + 0.72\frac{\varphi_N}{\varphi_d}) S_{hr}}$ $= \rho_h$ for oil (5.18)

$\frac{\left(1 + 0.72\frac{\varphi_N}{\varphi_d}\right) S_{hr} - (1 - \frac{\varphi_N}{\varphi_d})}{(2.2 + 0.8\frac{\varphi_N}{\varphi_d}) S_{hr}}$ $= \rho_g$ for gas (5.19)

$S_{xo} = \sqrt{\left(\frac{a}{\varphi^m} \times \frac{R_{mf}}{R_{xo}}\right)} = \sqrt{\frac{F R_{mf}}{R_{xo}}}$ (Archie, 1942) (5.20)

Or $Sxo = [(a \times Rmf) / (\varphi^m \times Rxo)]^{(1/n)}$

$S_{hr} = 1 - S_{xo}$ (5.21)

$\varphi e = \varphi N - (\varphi NSh \times Vsh)$, $\varphi e = \varphi d - (\varphi dSh \times Vsh)$ (5.22)

$\varphi d = \varphi e + Vsh \times \varphi DSh$, and $\varphi N = \varphi e + Vsh \times \varphi NSh$ (5.23) φd = φd × 0.7 and φN = φN × 0.7 (5.24)

$$k = \left(\frac{1}{K_T s_{Vgr}^2}\right)\left(\frac{\phi_e^3}{(1-\phi_e)^2}\right) \quad (5.25)$$

$$\sqrt{\frac{k}{\phi}} = \frac{1}{Sv_{gr}\sqrt{K_T}}\left(\frac{\phi_e}{1-\phi_e}\right) \quad (5.26)$$

$$RQI = 0.0314\sqrt{\frac{k}{\phi_e}} \quad (5.27)$$

$$FZI = \frac{1}{Sv_{gr}\sqrt{K_T}} \quad (5.28)$$

$$RQI = FZI(\phi_Z) \quad (5.29)$$

$$\phi_Z = \frac{\phi_e}{1-\phi_e} \quad (5.30)$$

$$\log(RQI) = \log(\phi_Z) + \log(FZI) \quad (5.31)$$

$$\log(RQI) = H_{sh}\log\phi + \log(FZI_{sh}) \quad (5.32)$$

$$H_{sh} = 0.5m + 2.5 \quad (5.33)$$

$$FZI_{sh} = 78.5\sqrt{\frac{R_t}{aR_w}} \quad (5.34)$$

$$\mathrm{BVM} = \phi \mathrm{S_W} \quad (5.35)$$

$$BVI = \phi S_{wir} \tag{5-36}$$

$$FFI = \phi(1 - S_{wir}) \tag{5.37}$$

$$k = (10\phi)^4 \left(\frac{FFI}{\phi - FFI} \right)^2 \tag{5.38}$$

$$RQI = 3.14 \left(\frac{FFI}{\phi - FFI} \right) \sqrt{\phi^3} \tag{5.39}$$

$$Log\ RQI = Log\left(\sqrt{\phi^3}\right) + Log\left(3.14 \frac{FFI}{\phi - FFI}\right) \tag{5.40}$$

$$H_T = \frac{1}{FZI^2} \tag{5.41}$$

$$\frac{1}{L-1} \left[\sum_{i=1}^{L} m_i \left(\bar{k}_{i.} - \bar{k}_{..}\right)^2\right] = B \tag{5.42}$$

$$\frac{1}{N-L} \left[\sum_{i=1}^{L} \sum_{j=1}^{m_i} \left(k_{ij} - \bar{k}_{i.}\right)^2\right] = V \tag{5.43}$$

$$R = \frac{B-V}{V} \quad , \quad 0<R<1, \tag{5.44}$$

$$\left(\bar{k}_{h.} - \bar{k}_{i.}\right) > \sqrt{\frac{1}{2}\left(\frac{1}{n_h} + \frac{1}{n_i}\right)}\ S z_{(v,p)} \tag{5.45}$$

$$V_K = \frac{k_{50} - k_{84.1}}{k_{50}} \tag{5.46}$$

text:

A

Å (angstrom): a unit of length equal to 10^10 meters or 0.1 nm
a: is the tortuosity factor or rock texture (Archie constant=L/l)
AAS: Atomic Adsorption Spectrometry
AI: artificial intelligence
Acres: a unit of land area equal to 4840 yards or 0.405 hectare
ASTM: American Standard of Testing Material

B

bar: is a unit of pressure equal to 100 kPa or 14.5038 PSI
BCF: billion cubic feet
BS: Bit Size
BVI: bulk water volume irreducible
BNAA: British North America Act
BNA: British North America Act

C

CAL: small CALiper
CAGR: compound annual growth rate
CCS: carbon capture and storage
Ccl: Clay Conductivity, mho/m
Ccw: Conductivity of Clay Bound Water
CEC: Cation Exchange Capacity
Ceq: Equivalent Conductivity of Clay Counter Ions at 25°C
CAGR: compound annual growth rate
CO2: carbon dioxide
CO: carbon monoxide
Co*: Conductivity of Clean Sand, mho/m
C0: Conductivity of Water-Saturated Reservoir Rock, mho/m
CS_2: Carbon disulfide
Csh*: Conductivity of Pure Shale, mho/m
Csh: Conductivity of Shale, mho/m
Co: conductivities of formation water-saturated rock
Cw: water conductivity
CGR: corrected gamma ray
C_{excess}: excess conductivity
Cwb: Conductivity of the Bound Water
Csh×: pure shale conductivity
co: clean sand conductivity
Cwe: Equivalent Conductivity of Mixture Water

Cwf: Conductivity of Free Water

C_{eq}: estimate the counter ions conductivity

C'_{eq}: Equivalent Conductivity of the Equivalent Sodium Chloride Solution

C_{wn} : water electrical conductivity mho/m at 25 °C

cmole/kg: centimoles of positive charge per kilogram of rock

C_w: formation water conductivity (mho/m).

C_{cl}: clay conductivity (mho/m).

D

d-value: Density Value

E

EOR: Enhanced Oil Recovery

Em: membrane potential model

Em_{sh}: the electrochemical potential of shales

Em_{ss}: the electrochemical potential adjacent sands

EIA: Energy Information Administration

EROI: energy return on investment

EIAs: environmental impact assessments

EPA: Environmental Protection Agency

EIA: Environmental Impact Assessment

F

F: Faraday Constant

FFl: Free Fluid Index

f: geometric factor or formation resistivity factor

Fa : apparent formation resistivity factor

fdl: the double-layer expansion factor at 25°C

F0.01 : formation resistivity factor extrapolated to a saturating solution of 0.01 ohm-m at 77°F

Fbw: Formation Resistivity Factor for Clay Bound Water

Fo: Formation Resistivity Factor Associated with Total Porosity

F_{fw} the formation resistivity factors for free water

F_{bw} clay-bound water

FZI: Flow Zone Indicator

FRF: Formation Resistivity Factor

Ffw: Formation Resistivity Factor for Free Water
F^* : Shaley Sand Formation Factor
FDIR: Fourier-Diffracted Infrared

G
GR gamma ray log
GC: gas chromatography
GHGs: Emissions of greenhouse gases
GWP: global warming potential
GRS: gamma ray spectroscopy
GHG: greenhouse gas

H
HFU: Hydraulic Flow Unit
h: rock type thickness
Hectare: equal to 10000 square meters
H_T:Tiab characterization factor

I
I-B: Ipek-Bassiouni models
IGR is the Gamma Ray Index
Iso-map: map of the same thickness
IEA: International Energy Agency
IOOC: Iranian Offshore Oil Company
Int: Intensity

K
K: permeability, μm^2
K_T : Tiab factor
$K_{ps}\tau$: effective zoning factor
k: Potassium Log
$\bar{k}_h$: is average permeability data in a well (mD).
$\bar{k}_i$: average permeability data for ith zone in adjacent well (mD).
kWh: kilowatt-hour
K·h: flow capacity

L
L-B: Lau-Bassiouni models
LPG: liquefied propane gas or liquid petroleum gas
LNG: liquid natural gas

LSU: Louisiana factor

M

m : mole concentration (mol/kg).
Meq/100g: milliequivalents per 100 grams
Meq/Kg : milliequivalents per 1000 grams
M: Mole Concentration (mol/kg)
MB: Methylene Blue
m_c: Cementation Exponent of Bound Water
m_f: Cementation Exponent of Free Water
m : cementation exponent
mc: is the cementation exponent
m_{eff}: membrane efficiency
m_f: cementation exponent for free water
m_c: cementation exponent for bound water
mL: milliliter
mg: milligram
MLP: Modified Lorenz Plot
MMT: million metric tons
MIT: Massachusetts Institute of Technology
MWh: megawatt-hour
MBtu: million British thermal units
MWh: megawatt-hour

N

n: molar concentration (mol/l).
NMR: Nuclear Magnetic Resonance
n: saturation exponent.
n_{eq}: the equivalent clay counter-ion concentration
NIOC: National Iranian Oil Company
NO_x: nitrogen oxides
NGCC: natural gas combined-cycle
NN: Neural Network
NRDC: Natural Resources Defense Council
NGLs: natural gas liquids

O

OM: Organic Matter
OH: hydroxyl

P

P: is the salinity of the mud in PPM × 10
Pcf: Pound Per Cubic Feet
PHIT: total porosity
PHIE: effective porosity
Pef: Photoelectric Factor
PwC: Price water house Coopers
PUT: petroleum University of Technology
pH: is a logarithmic scale used to specify the acidity (1-6: or basicity (8-14: of aqueous solutions
ppm: Part Per Million
PV = Pore Volume, Fraction
phi: porosity

Q

Qv: Cation Exchange Capacity Per Total Pore Volume

R

R: Universal Gas Constant
RCS: Reduced Charge Smectite
Rel. int.: Relative Intensity
Rsh: Resistivity of Shale, ohm.m
Rw: Resistivity of Formation Water or connate water, ohm/m
Rt: resistivity of formation rock (ohm·m).
Rsh: shale resistivity (ohm.m).
Rmf: is the resistivity of mud filtrate
Rxo: is the resistivity of the flushed zone (micro resistivity tools response).
Ro: fully water-saturated sample
RI: Resistivity Index
ROP: Rate of Penetration
RQI: Reservoir Quality Index
RCS: reduced charge smectites
R^{2+}: divalent cations
R^{3+}: trivalent cations

S

S-B: Silva and Bassiouni Model
SEM: Scanning Electron Microscopy
SEM: Scan Electronic Microscope

Signif.: Significance
SP: Spontaneous Potential
Ssa: Specific surface area
Sw: Formation Water Saturation, Fraction
Swb: Bound water saturation
SPL: Spontaneous Potential Log
SIOC: South Iranian Oil Company
S_{wir} : irreducible water saturation
SO2: sulfur dioxide
S: standard deviation
SHU: Storage Hydraulic Units
Shr: residual hydrocarbon saturation
S_{Vgr}: specific surface area per unit grain volume
SwB: bound water saturation
S_{xo}: Residual Oil saturation in flushed zone using Archie's equation

T

T : temperature, °C
Ta: Absolute Temperature in Kelvin, K=Celsius+273.15
T0: ZeroTemperature in K= -273.15 Celsius.
TOC: total organic content
TFU: Tiab Flow Unit
TDS: total dissolved solids
Tna+: Sodium Transport Number
T_a : absolute temperature, °K
Tna^+ : sodium chloride transport number
Tna^h :the Hittorf transport number
t_w :the water transport number
TETRA: Triethylenetetramine
Th: Thorium Log
TOC: High total organic content
TWh: terawatt-hour
THU: Transmissibility of Hydraulic Units
TCF: trillion cubic feet
TWh: terawatt-hour

U

U: Uranium Log
UGC map: underground counter map

USGS: United States Geological Survey

V

Vsh: Volume of Shale, Fraction

Vfdl: Fractional Volume of Double Layer

V_q: Amount of Clays Associated with 1 Unit (meq) of Clays Counter Ions

V_{fdl} : fractional volume of the double layer

VOCs: volatile organic compounds

X

XRD: X-Ray Diffraction

Y

γ±: the mean activity coefficient of sodium chloride at 25°C.

Z

φ: porosity

φt: Total porosity

(φt)sh: total porosity in pure shale

(φt)ss: total porosity in clean sand

φ_{bw}:bound water porosity

φN-corr: neutron porosity correction:

Δφd: correction term

φN: neutron porosity correction term

φShr: is the residual hydrocarbon saturation

φd: is the density porosity

φd-corr: is the corrected density porosity

ρh: is the hydrocarbon density

φShr: is the residual hydrocarbon saturation

φe: effective porosity, fraction

Φ: Porosity of Reservoir Rock, Fraction

Φt: Total Porosity, Fraction

φ_{WF} : Porosity Occupied by Free Water

$(\varphi_t)_{sh}$: Total Porosity in Pure Shale, Fraction

$(\varphi_t)_{ss}$: Total Porosity in Clean Sand, Fraction

φ_{WB} : Porosity Occupied by Bound Water

φdSh : density porosity in shale zones

φNSh : neutron porosity in shale zones

$\boldsymbol{\phi_z}$ **:** is the ratio of pore volume to grain volume (normalized porosity).

$\varphi \cdot h$: storage capacity
μm: micrometer
Γ: Mean Activity Coefficient
$\gamma_{\pm}^{298}$**:** is the activity coefficient at 25°C
T: tortuosity of the flow path=L/l