Petrophysics Skill Set Guidelines

(PSSG)

Version 2.0 | Dec 2022

Society of Petrophysicists and Well Log Analysts

(SPWLA)

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Introduction

The Petrophysics Skill Set Guidelines (**PSSG**) are produced as a set of general rules and principles related to petrophysics for the hydrocarbon industry with adaptations for the geothermal, mining, water resource and gas storage industries - including CO_2 sequestration fields. As custodians of these documents, the SPWLA Education Special Interest Group (SIG) maintains, reviews, revises and periodically updates this document with emerging and evolving technologies.

The PSSG was launched in 2019 and published in January 2021 as version 1.0. Numerous comments, revisions, suggestions and feedback have been incorporated into version 1.1; and, to date as version 2.0. Please continue to submit observations to: PSSG@spwla.org.

This document was envisioned in response to the evolving role of a petrophysicist, the lack of a formal petrophysics degree program in most universities, intertwined with lessons learned from historical industry downturns - a genuine concern for the industry commonly known as, "*The Great Crew Change*." This refers to the oncoming waves of senior professionals reaching retirement age – a time when the next generation of professionals are expected to be there and ready to be able to step into their shoes and start their own long-lasting petrophysical careers. The advance in information technology and the disruptive COVID-19 pandemic created a seismic shift in how we learn, creating an emergence of a new hybrid model of education that just may be here to stay.

Key benefits of PSSG:

- students and young professionals interested in investing career time as a petrophysicist
- subsurface energy companies interested in developing a training program for petrophysicists
- impact to recruitment of petrophysicists
- development of competency skill assessment for petrophysicists

By definition, petrophysics is the study of the physical and chemical properties of rocks and their contained fluids. **Petrophysics is multidisciplinary** – you may even say it has blurred lines. In order for the petrophysicist to provide critical interpretations, the boundaries of discipline are blurred, or integrated, between physics, chemistry, math, geology and geophysics (G&G), and reservoir and well engineering.

Sequentially, a generic petrophysics workflow may be divided into the below four sections:

1. Data acquisition
2. Data processing
3. Data interpretation
4. Data integration

Functionally, petrophysics may include the following five subjects:

1. Laboratory studies of reservoir cores and fluids
2. Resources exploration
3. Resources development
4. Reservoir surveillance
5. Integrated petrophysical studies

Competent petrophysicists are in demand, some say they are worth their weight in gold and must stay current in this constantly evolving industry. Seminars, commercial courses, formal training and the most powerful on-the-job training, the petrophysicist performs an extremely complex task using numerous and variable forms of data which are "welded" into one interpretable dataset while simultaneously working across virtually every discipline, from drillers to G&G, from reservoir engineers to production groups.

Topics & Tasks Outline

This document is divided into eleven (11) sections. The sections reflect a topic / discipline / task, and are not listed in any particular order. Each section reflects required tasks that a pedigreed petrophysicist must have a working knowledge, or a basic understanding – a starting point from which something can develop not necessarily expert knowledge.

Some of the listed skills are a must and require a higher level of competency beyond "basic understanding." For instance, a skilled petrophysicist must have an in-depth grasp of Archie's equation but not necessarily be prepared to present a lecture on the depositional origin of rocks and their subsequent alteration by diagenetic processes during burial. The items colored in **green text herein** are more basic and are commonly used by a petrophysicist, it is also realized that it may be subjective and depend on where the operation occurs. For example, when developing shaly clastics reservoirs, technologies required skills may be different from that in developing carbonate reservoirs that are clean but complex in pore geometries.

Whatever your core discipline, if you have practical knowledge of reservoir architecture, reservoir properties, property modeling, reservoir simulation, reservoir management and an ability to effectively communicate across disciplines and departments, incorporating these guidelines will strengthen your contributions as a petrophysicist.

To maintain brand neutral, related services and technologies are referred to using its generic names rather than commercial names in this document. Petrophysicists are encouraged to become familiar with the commercial names in practice.

Section 1: General Geoscience and Engineering Operations

Section 2: Fundamental Petrophysical Data Acquisition and Interpretations

Section 3: Integrated Formation Evaluation

Section 4: LWD Petrophysics in Formation Evaluation and Geosteering

Section 5: Reservoir Dynamic Surveillance

Section 6: Integrated Petrophysical Modeling

Section 7: Resource / Reserves Assessment or Evaluation

Section 8: Gas Storage Petrophysics

Section 9: Geothermal Petrophysics

Section 10: Mining Petrophysics

Section 11: Petrophysics Data Analytics

	Section
# General Geoscience and Engineering Operations	1

Petrophysics is a multi-discipline science involving geoscience and engineering. A good understanding of geology and engineering is critical in applying petrophysics.

1) **Ethics**
   a) Understanding the ethics expectation as a petrophysicist in conducting petrophysics analysis and related business activities. See Article V of the **SPWLA Code of Ethics:** General Principles:
      i) petrophysics is a profession, the privilege of professional practice requires integrity and professionalism.
      ii) honesty, integrity, loyalty, fairness, impartiality, candor, fidelity to trust, and inviolability of confidence are incumbent upon every member as professional obligation.
      iii) each member shall be guided by high standards of business ethics, personal honor, and professional conduct.

2) **Geology**
   a) Basic geology concepts related to oil and gas reservoirs, especially those related to petrophysics in resources exploration, field development, and production.
   b) Basic geology concept related to mining, gas storage, and geothermal.

3) **Geophysics**
   a) Geophysics operation and interpretation, especially those related to petrophysics and rock physics.
   b) Wellbore check-shots and well seismic data acquisition and operations.
   c) Basics of time-to-depth conversion and generation of well synthetics.
   d) Quantitative petrophysics/seismic integration including generation on impedance / reflectivity curves / traces, fluid substitution analysis, AVO, inversion etc.

4) **Petrography and Mineralogy**
   a) Petrography and mineralogy concepts and measurements, especially those concepts related to well logs and core analysis.

5) **Drilling and Completion Operations**
   a) Drilling and completion operations, effects of drilling / drilling fluids and completion quality on formation evaluation.
   b) Well deviation – data acquisition methods, analysis, and limitations.
   c) Preparing well proposal and data, especially petrophysical data, acquisition plans.
   d) Value of information analysis to support data acquisition
   e) Commercial / basic economics of a simple oil and gas project.

6) **Petroleum Engineering**
   a) Petroleum engineering concepts, principles, and interfacing between petrophysics and drilling, reservoir, and production engineering.
   b) Petrophysical applications in each stage of field life cycle.

7) **Wireline and MWD/LWD Operations**
   a) Operation basics of slickline, wireline, coil tubing, tractor, and LWD/MWD.
   b) Similarities and differences between LWD and Wireline technologies. Safety related to logging operation: radioactive sources, well control, and explosives, etc.

	Section
# Fundamental Petrophysical Data Acquisition & Interpretations	2

A critical part of a petrophysicists' role is to quality control (QC) acquired data. Logs and cores are acquired and analyzed in various environments utilizing a variety of instruments. Understanding data acquisition processes, physical principles, and limitations are important to avoid misinterpreting the acquired data and misusing the interpreted data.

8) Coring and Core Analysis

a) Objective-driven coring program design, core handling and preparation.
b) Detailed understanding of routine core analysis for measurement of porosity, grain density, permeability, and saturation.
c) Formation evaluation static special core analysis.
d) Reservoir engineering dynamic special core analysis.
e) Digital rock physics; its applications and limitations.

9) Reservoir Fluid Analysis and Geochemistry

a) Understanding basic hydrocarbon PVT (pressure, volume, and temperature relationships), compositional analysis of reservoir fluid concepts especially those related to well log, core analysis, and integrated petrophysical studies.
b) Geochemical analysis of water and hydrocarbon in support of petrophysical analysis to characterize conventional and unconventional resources in place.
c) Concept of fluid and mineral interaction which affects petrophysics, e.g., clay swelling, dolomitization, diagenesis, wettability, etc.

10) Petrophysical Aspects of Rock Geomechanics

a) Laboratory measurements of rock mechanical properties and their applications.
b) Deriving geomechanics properties from petrophysics logs, such as sonic and formation testing.
c) Geomechanics regarding in-situ stress, borehole stability and breakout, sanding, nature fracturing.

11) Auxiliary Logging

a) Depth: basic principles of depth measurements in wireline and LWD.
b) Tension: tension measurement and its use in log quality control.
c) GR/SGR logging principles and applications.
d) SP logging principles and applications.
e) Caliper logging principles and applications.
f) CCL: casing collar locator logging principles and applications.
g) Temperature logging principles and applications.

12) Electromagnetic (EM) Petrophysics- Resistivity

a) Laterolog: lateral resistivity logging principles and applications.
b) Induction resistivity logging principles and applications.
c) Invasion effects.
d) Propagation resistivity logging principles and applications.
e) Triaxial measurements, effects of anisotropy.
f) Shoulder-bed effects.
g) EM measurements behind casing.

13) Nuclear Petrophysics

a) Density logging principles and applications.
b) Neutron logging principles and applications.
c) Lithology effect on neutron and density logs.

14) Acoustic Petrophysics

a) Basic compressional and shear sonic logs and its application.
b) Stoneley permeability.
c) Sonic anisotropy.
d) Synthetic seismic.
e) Time to Depth conversion.

15) NMR Petrophysics

a) T1 and T2 logging principle and applications.
b) T1 and T2 cutoffs for capillary bound water determination
c) 2D NMR and other advanced applications, such as fluid typing.

16) Borehole Imaging

a) Wireline resistivity, dielectric, and ultra-sonic borehole imaging principles and applications in water-based mud and oil-based mud.
b) LWD borehole imaging of GR, density, and resistivity for geosteering and reservoir characterization.
c) Use of borehole imaging for reservoir characterization such as fracture identification.

17) Formation Testing and Sampling

a) Formation tester and sampler measurement principles and applications.
   i) Reservoir pressure and its gradient for fluid typing.
   ii) Mobility.
   iii) Sampling and sensors for evaluating sample contaminations.

18) Surface Data Logging

a) Analysis of drill cuttings for geological and petrophysical applications.
b) Fluid analysis from cuttings, such as mud gas (gas ratio, pixler, etc.).

19) Electromagnetic Petrophysics- Dielectric

a) Dielectric logging principles and applications.
b) Water filled porosity

20) Elemental Mineralogy Petrophysics

a) Elemental spectroscopy mineralogy logging principles applications.
b) Clastic reservoirs
c) Carbonate reservoirs

21) Cement Bond Evaluation

a) Acoustic logging for cement bond evaluation.
   i) Schlumberger's services are cement bond log (CBL), variable density log (VDL), with similar technologies from other service providers such as Baker Hughes (SBT), HAL (Radial cement bond log), and WFT (SBT).
b) Ultrasonic logging for cement bond evaluation.
   i) Schlumberger's services are USIT, with similar technologies from other service providers such as Baker Hughes (SBT), HAL (CAST), and WFT (URS).

22) Casing Inspection

a) Physics and principle of different types of casing inspection logs:
   i) Cased-hole multi-arm calipers.
   ii) Flux-leakage tools.
   iii) Electromagnetic phase-shift tools.
   iv) Ultrasonic tools.

23) Data Quality Control

a) Common petrophysics data quality issue and how to identify and mitigate them.

24) Data Uncertainty Quantification and Management

a) Data uncertainties, methods for data uncertainty quantification and management.

25) Value of Information

a) Understanding the value of information of acquired petrophysical data.
b) Optimize data acquisition programs with maximize value of information with consideration of all disciplines and for potential future applications.

	Section
# Integrated Formation Evaluation	3

Formation evaluation, a major part of petrophysics, is the application of integrating all available data (i.e., geological, geophysical, drilling, production, petrophysical and reservoir engineering) to determine various formation properties, including lithology, storage, saturation, flowing capacity, as well as geomechanics parameters.

26) Evaluation of Clean Formations

a) In-depth understanding of Archie equation and its applications and limitations.

27) Evaluation of Carbonate Formations

a) Techniques for rock pore structure characterization.
b) The effect of pore structure on fluid distributions and its effect on log responses and formation evaluation.

28) Evaluation of Shaly Sand Formations

a) Volume of shale / clay determinations.
b) Cation exchange capacity and its measurements.
c) Familiarity with commonly used shaly sand petrophysical models.
   i) Dual water.
   ii) Waxman-Smits.
   iii) Simandoux (+ Modified Simandoux).
   iv) Indonesian.
   v) Normalized Qv (Juhaz).
   vi) Application and limitations of the above shaly sand models.

29) Evaluation of Source Rocks

a) Laboratory source rock analysis.
b) Integrated source rock petrophysical evaluation.

30) Deterministic vs Probabilistic Petrophysics

a) Probabilistic petrophysics analysis and its uncertainties.
b) Similarity and differences between deterministic vs probabilistic petrophysics analysis.

	Section
# LWD Petrophysics in Formation Evaluation and Geosteering	4

To maximize reservoir contacts, the majority of development wells are drilled horizontally, especially onshore wells. First, LWD logs and other advanced geosteering measurements are required to place those horizontal wells on target; and, second, for evaluating the potential of the reservoir sections penetrated by the well. Consequently, understanding LWD logging and log analysis is essential for successful geosteering and proper formation evaluation.

31) LWD Log Data Acquisition

a) Bottom hole assembly (BHA).
b) Type of LWD measurements.
c) Placement of LWD sensors.

32) Bottom-hole Assembly Operations

a) Operation modes of sliding and rotating.

33) Data Transmission and Storage

a) Real-time data vs memory.

34) High-angle/horizontal (HAHZ) wells

a) Differences between vertical, low-deviated wells, highly deviated and horizontal (HAHZ) wells.
b) Importance and the necessity of obtaining true formation properties in HAHZ wells.

35) Resistivity Modeling for Evaluation of HAHZ Wells

a) Resistivity forward modeling and inversion, e.g., anisotropy effect, thin bed effect, invasion effect.
b) Uncertainties in HAHZ well formation evaluation.
   i) High resistivity hydrocarbon producers.
   ii) Low resistivity water injectors.

36) Borehole Imaging for Geosteering

a) Imaging with LWD and its applications in geosteering.
   i) GR imaging.
   ii) Density imaging.
   iii) Resistivity imaging.
b) Concept of landing, geo-stopping, reservoir steering, and reservoir mapping

37) Extra Deep Azimuthal Measurement for Geosteering

a) Principles and applications of **inversion** of extra deep azimuthal measurements.
b) Awareness of look-ahead/look-around measurements.

	Section
# Reservoir Dynamic Surveillance	5

Petrophysicists play a critical role in monitoring the health of a reservoir from development to abandonment, by logging for flow profiles, fluid contact movement, and saturation changes with production. In addition to the knowledge and skills covered in the previous sections, special requirements are related to reservoir engineering and management.

38) Fluid Contact Movement Monitoring

a) Reservoir dynamic and techniques commonly used to monitor reservoir fluid contacts movements, such as pulsed neutron sigma.

39) By-Passed Hydrocarbon and Sweep Efficiency Evaluation

a) Reservoir dynamic and techniques commonly used to identify and quantify by-passed hydrocarbon: such as resistivity and pulsed neutron sigma and C/O (carbon/oxygen).
b) Reservoir dynamic and techniques commonly used to quantify sweep efficiency: such as pulsed neutron C/O (carbon/oxygen).
c) Data uncertainty of reservoir saturation monitoring.

40) Production Profiling

a) Reservoir dynamic and techniques commonly used to quantify production profiling of multiphase flow in the borehole.
b) Array measurements of production logging in horizontal wells.
c) Horizontal and multilateral well logging conveyance techniques.

41) Well Integrity Evaluation

a) Corrosion logging for pipe and casing inspection.
b) Cement evaluation and cement quality deterioration over time.

42) Integrated Reservoir Dynamic Evaluation

a) Integrate all available data to diagnose reservoir performance.

	Section
# Integrated Petrophysical Modeling	6

Petrophysical modeling is an essential step for reservoir geological modeling and dynamic simulation by providing critical inputs for lithology, porosity, permeability, and initial distribution of saturation. Critical skills and knowledge are required to conduct petrophysical modeling.

43) Porosity Evaluation

a) In-depth knowledge of porosity estimation from multiple measurements.
b) Understanding the relationship, application, and limitation of these measurements and techniques.
c) Effective vs total porosity concepts, and its limitations.

44) Permeability Modeling

a) Rock permeability and its relations to fluids and stress.
b) Permeability modeling using machine learning techniques.

45) Petrophysical Rock Typing

a) Commonly used methods for petrophysical rock typing.
b) Petrophysical rock types and their relations with geological facies and reservoir engineering rock types.

46) Capillary Pressure Modeling

a) Understand capillary pressure measurements and data quality control.
b) Building capillary model for reservoir saturation modeling.

47) Reservoir Modeling

a) 3D geological modeling of petrophysical properties
b) Reservoir simulation in relating to petrophysical properties

Section

Resource / Reserves Assessment and Evaluation

7

Petrophysicists play an important role in resource /reserves assessment and evaluation. Petrophysics provides key parameters (e.g., net pay thickness, porosity and saturation) used in the volumetric estimation of Petroleum Initially in Place (PIIP) volumes, helps determine reservoir fluid type, and the ability of the fluid to flow (permeability) that are critical in assessing the potential and development of any petroleum resource or reserves.

The fluid type can be characterized with properties such as density, hydrogen index and viscosity, among others. All these properties are the subject of wireline electrical logs, formation testing/fluid sampling devices, and core sampling. In addition, several petrophysical parameters are used to establish analogs to a field and commerciality of resources (volumes and flow capacity).

Early in the life of a project, volumetrics and/or analogy are the foremost methods by which PIIP and resources are assessed. As a project matures, performance and/or material balance methods, including reservoir simulation, may supplant volumetric and/or analog methods. However, the in-place volumes derived from these methods should remain consistent with PIIP volumes from petrophysical evaluations.

48) Reservoir / Pay Thickness Assessment

a) Understanding the basis for assessment of pay and support for discovery criteria.
b) Gross / net reservoir or pay thickness analysis and limitations.
c) Use of cut off criteria: definition of cut offs, applications, and limitations of cut offs.
d) Impact of cut off or lack of cut offs on assessment on net reservoir or pay thickness.

49) In Place Volumetric Assessment

a) Relevant input, especially petrophysical input properties, source of estimates and calibrations and equations used to estimate in place volume.
b) Estimating petrophysical input to projects in exploration, appraisals, and development phases.
c) Fluid typing, and assessment of fluid limits/contacts.
d) Sensitivity of in-situ volumes to petrophysical properties.
e) Basis for rock properties modeling away from wellbore.
f) Uncertainty in petrophysical properties based on their source, amount, and quality of information available.

50) Recoverable Volume Assessment

a) Recoverable volume assessment and impact of petrophysical properties.
b) Understanding the necessary petrophysical support in resources and reserves assessment.
c) Well test information, production logging information, borehole/casing/formation integrity in assessment potential recoveries from mature fields.
d) Use of analog information for recoverable volume assessment.

	Section
# Gas Storage Petrophysics	8

Petrophysics has a large role to play in the green economy. The petrophysicist plays a critical role in characterizing storage sites for natural gas storage and CO_2 sequestration. In addition to estimating the volumetrics and flow properties of reservoir, the petrophysicist is tasked with evaluating the safe containment and conformance of storage site including the well, reservoir, cap rock, and the seal. The petrophysicist also plays an important role in the MMV (measurement, monitoring, and verification) program of CO_2 sequestration sites.

51) Natural Gas and Hydrogen Storage

a) Rock mechanics and geomechanics.
b) Cap rock sealing capacity evaluation, specific to the targeted gas for hydrogen molecular size is smaller than natural gases.
c) Evaluation of storage (porosity) and injectivity (permeability).
d) Evaluation of well integrity of cement quality and metal pipe corrosion status.

52) CO_2 Sequestration

a) Rock mechanics and geomechanics.
b) Cap rock sealing capacity evaluation.
c) Characterization of reservoir boundaries.
d) Evaluation of storage (porosity) and injectivity (permeability).
e) Evaluation of well integrity of cement quality and metal pipe corrosion status.
f) Basic understanding of microseismic.
g) Interactions between carbonated water and rock minerals, especially carbonates.

	Section
# Geothermal Petrophysics	9

In geothermal resource development, petrophysicists play a critical role in characterizing the flow capacity of the geothermal source which usually involves igneous rock. Borehole image logs are critical in identifying open fractures which may greatly enhance the geothermal productivity. Formation evaluation is often conducted with limited data due to challenges of acquiring petrophysical data at high temperature conditions.

53) Log interpretation in igneous rock

54) Fracture interpretation from borehole images

55) Rock mechanics and geomechanics

56) Evaluation of porosity and permeability

Mining Petrophysics	Section 10

Core based petrophysics and downhole logging are used across the minerals value chain from exploration to closure - both to find and exploit the mines themselves and for the evaluation of hydrogeology and waste and tailings deposits. In contrast to petroleum, drilled holes in mining are often cored from surface to total depth (TD) and will ultimately be drilled down to spacings on the order of tens of meters. Informing the analysis of other geophysical surveys to provide 3D information around and between drilled holes as well as the ability to measure in-situ properties, improve quantification and replace manual core logging and sampling are key use cases. A good understanding of tool physics and operational constraints (such as knowledge of water table impacts, the need for slim hole tools, deployment constraints etc.) are essential to adapting existing and developing new approaches to suit the minerals industry.

57) Petrophysics in Exploration:

a) Understanding of petrophysical responses to mineralogy, alteration, texture, pressure (P), temperature (T) with an emphasis on hard rock environments (relatively understudied)
b) Link observations to mineral systems elements and exploration targets.
c) Collect and analyze petrophysical parameters to inform forward modeling and calibration of other geophysical surveys (e.g., gravity, magnetics, electromagnetic (EM), induced polarization (IP), seismic and other methods)
d) Plan and safely execute petrophysical operations in remote environments.

58) Petrophysics in Mine Development & Extraction

a) Petrophysics as proxy for resource assay (e.g., pulsed neutron spectroscopy)
b) Petrophysics in geotechnical evaluation of geomechanical properties and structure (e.g., structural image logs; OTV (optical televiewer), ATV (acoustic televiewer), proxies for rock strength etc.).
c) Understanding of differences between petrophysical evaluation of in situ and core properties and executing and analyzing downhole seismic / DAS (distributed acoustic sensing) surveys for rock mass characterization.
d) Petrophysical proxies for geometallurgical and processing parameters.
e) Petrophysical analysis for properties, handling and processing of waste rock.
f) Plan and safely execute petrophysical operations in challenging surface and underground environments.
g) Leverage data analytics and machine learning across potentially thousands of drilled holes.
h) Link petrophysical analysis to inform and analyze geophysical evaluations of rocks between and away from drilled holes (potential fields, seismic, radiometric etc.).

59) Petrophysics for hydrogeology and tailings

a) Petrophysical analysis of geotechnical parameters.
b) Petrophysical analysis of porosity, permeability and fluid flow.
c) Linkage between petrophysical and other geophysical methodologies to model and monitor geotechnical changes and fluid movement over time.

	Section
# Petrophysics Data Analytics	11

Data analytical techniques have been developed to estimate and predict properties without an analytical solution. Uncertainty can be reduced when the petrophysicist understands the application, uncertainty and limitation of these techniques. Large quantities of well-related measurements are associated with petrophysical projects. Project tasks include considerable amounts of tedious time devoted to data gathering, data quality control, data corrections, data transformation, and data interpretation for a complete formation evaluation.

60) Regression of Petrophysics Data

- a) Recognize errors and have solutions in both independent and dependent variables.
- b) Understanding uncertainty linked to properties or results obtained from these methods and how to properly calibrate results as additional data are acquired during the life of the field

61) Advanced Curve Fitting Techniques

- a) Using polynomial, exponential, logarithmic, power law and other regression functions.

62) Multilinear Regression (MLR)

- a) Understanding of how to use MLR to produce predictive relationships and its limitations.

63) Machine Learning Techniques

- a) Basic concepts of statistics and probability.
- b) General awareness of big data, machine learning and the potential applications and limitations to petrophysics.
- c) Supervised techniques – Regression.
- d) Unsupervised techniques – Clustering.
- e) Model QC.

	PSSG
# Acknowledgement & Contributions	

Acknowledgement
Authors, Zach Liu and S. Mark Ma, wish to acknowledge contributions of SPWLA distinguished members for their time, knowledge, petrophysical perspective and technical insight in the creation, and continuation, of the PSSG.

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