Unconventional Petrophysics: Shale Source Rock Plays - Fundamentals

Presentation for LPS Petrophysics 101 Seminar
March 17\textsuperscript{th} 2016

Andrew Foulds
Director/Geoscientist/Petrophysicist
Petrafiz Ltd
Email: petrafiz@yahoo.com; or andrew.foulds@petrafiz.com
Web Address: www.petrafiz.com
Mobile: +447956309657
Office Tel: +44156686844

From Loucks & Reed et al 2009
What are unconventional resources?

Conventional gas
Gas that is produced by conventional techniques from reservoirs that generally support flow with little intervention

Unconventional gas
Unconventional gas is produced from a reservoir that cannot support economic flow rates or recover economic volumes of natural gas without intervention because of low reservoir permeability
What is shale?

- Shale is the most abundant sedimentary rock (50% – 80%) quite variable
- Naturally heterogeneous and extremely variable
- Historically, poorly studied – lots of studies now
- Poorly defined grain size, composition, texture
- Can be clay rich, organic rich, siliceous, calcareous, marly

Not all shales are alike – they can be very different
Shale Source Rock properties

Basic physics/First Principals

- Shales and mudrocks are solid matrix (clay sized particulates) and pore water
- Organic-rich mudrocks additionally contain solid organic matter
- When mature, organic-rich mudrocks will generate HC’s which enter porosity expelling water and where generation is sufficient, hydrocarbons are expelled which migrate to form conventional accumulations

After Passey AAPG 1990

Hydrocarbons
Three main messages

• Not all shales are alike – they can be very different

• Shale does not equal shale gas/oil or a shale source rock

• Not all source rock make good shale source rock play
Shale gas/oil properties:

Kerogen type is important

Product type varies with organofacies maturity and hydrogen index. Pragmatic scheme used in areas of geological uncertainty. Widely used in the industry.

After Pepper and Corvi 1995; modified by Mark Osborne BP pers com
Shale Source Rock Properties

Fundamentals of maturity

- As organic material is matured at depth via temperature and pressure, organic materials are “cooked” and organic material “cracked” to oil in the “oil window.”
- Further heating to higher temperature and pressure will yield gas generation. Generation of gas involves a large volume expansion; as gas is generated pores are “bubbled” within the organic material.
- As organics are matured, TOC (wt. and vol. %) is reduced.
- Upon uplift out of gas window and assuming temperature and pressures do not continue to increase, the low permeability of the shale allows gas to be retained in organic pore spaces.
- After uplift, the HCPV of the shale is therefore directly proportional to the amount of hydrocarbon generating TOC in the shale. Crossplots of TOC and porosity measured from core yield very clear dependency of porosity upon organic content.
Shale Source Rock fundamentals – Porosity Types

Various porosity types can exist in these mudrock systems, interparticle, intraparticle and in the organic matter depending on organic type, as well as fractures both natural and induced.
Shale Source Rock – Permeability mD vs nD

Due to the very low permeability the core measurement technique is different to plugs perms relying on a pressure or pulse decay method on crushed samples and the subsequent simulation of this decay to derive a permeability; and there are some differences between laboratories that need to be addressed.
Shale Source Rock fundamentals – KPIs

Successful play

- Brittle-ness
- Inorg. comp.
- Struct. comp.
- TOC Vol
- Resource density
- Resource density
- Kero type
- Perm/PHI/SW
- Pore pressure
- HC comp.
- IP & EUR
- Mech props
- Stress field
- Fracture system
- Ro
- Seal
- Basin Model

Prepared by Andrew Foulds
Shale Source Rock - Integrated Petrophysical Analysis

Petrophysical/Formation Evaluation Objectives

• To deliver parameters critical to assess any Shale Source potential
  
  • Recovery Potential = mechanical properties, fraccability etc.

Achieved by delivering the following products

• Organic richness (TOC) and maturity (log and lab)  
• Porosity: total, gas filled, effective, organic (log and lab also volume and nature)  
• Hydrocarbon/ fluid content (SG, SO, BVG, BVO- volumes and lab)  
• Mineralogy, XRD, elemental analysis (core and log)  
• Fracture occurrence and characterization (core and image log)  
• Geomechanical properties/Formation Damage (core and log)  
• Describe the criteria for “net reservoir” determination in shale gas reservoirs: (core and log)  
• Describe vertical distribution of “net reservoir” (log and core)  
• Describe how petrophysical properties relate to geomechanical properties  
• Relate petrophysical response to seismic response to allow extension away from the borehole.
Core Analysis for Shale Source Rock Plays

Significant Core Analysis measurements

Desorption and Adsorption – gas content and ultimate storage potential. Some operators are not acquiring desorption data, data quality issues (Lost Gas etc.) and costs (esp. outside USA)

GRI-SRP or TT-TRA measurements - bulk and grain density data, along with porosity, permeability (pressure decay measurement) and water, oil and gas saturations.

Organic Geochemistry -TOC, VR, RockEval Pyrolysis, gas composition and isotopes – organic content and maturity

Inorganic Geochemistry - TS, XRD, SEM analysis – including ion milled SEM – inorganic composition, pore typing, grain framework.

Geomechanical Analysis, PR, YM, fluid compatibility, capillary suction tests, etc.

Lithological/sedimentological description – facies analysis – help workout the stratigraphic framework across the basin. Do not underestimate the value from this exercise. Shales can be very complex from a geoscience perspective. Lots of university research on this subject at the moment

Core fracture analysis, frequency, direction type, description etc.
**Core Analysis for Shale Source Plays**

**Sampling Strategy – maximising core material**

- Carcass is saved for future use.
- Vertical plugs are used for Geomechanics (drill with oil).
- If Geomechanical vertical plug fails (< ¾ inch): Cut 4 inch segment adjacent to sampling site.
- Slab remains in core interval for future description, photography and viewing.
-NOTE: After sampling, the remainder of the core is slabbed, photographed and described as required.

- Thin Section
- XRD/Ion Milled SEM
- Organic Geochemistry
- Plugs cut with N2 as a bit and saw lubricant
- Non plug based geomechanics testing on carcass
- Carcass is used for GRI K/PHI/SW/GD (250 grams)

**Core Analysis for Shale Source Plays**

**Sampling Strategy – maximising core material**

- Carcass is saved for future use.
- Vertical plugs are used for Geomechanics (drill with oil).
- If Geomechanical vertical plug fails (< ¾ inch): Cut 4 inch segment adjacent to sampling site.
- Slab remains in core interval for future description, photography and viewing.
-NOTE: After sampling, the remainder of the core is slabbed, photographed and described as required.
Core Analysis for Shale Source Rock Plays

Development of Laboratory and Petrophysical Techniques for Evaluating Shale Reservoir

Final Report (GRI-95/0496)
Gas Research Institute, April 1996

SELECTED SAMPLE
(Fresh Core Material)
(~ 300 grams)

BULK DENSITY
(Representative Sample)
(Multiple Measurements)
(Vb by Hg Immersion)

PRESSURE-DECAY
MATRIX PERMEABILITY
(Effective Perm, Crushed sample)

CRUSH SAMPLE
(20/35 Mesh Size)
(~ 200 grams)

UNUSABLE SIZE FRACTION
(~ 50 grams)

DEAN-STARK ANALYSIS
(Toluene, 1 week)
(~115 °C)

HIGH-TEMPERATURE DRYING
(110° C, 1 week minimum)

GRAIN VOLUME MEASUREMENT
(Total & Gas-Filled Porosity)
(Sg & Grain Density)
(Total So & Sw)

DATA INTEGRATION

S_w computed using a default brine concentration of 30,000 ppm

S_o computed using a default ambient oil density of 0.8 g/cc

Total Porosity & Saturations include all interconnected pore space

Gas Research Institute, April 1996

Prepared by Andrew Foulds
Core Analysis for Shale Source Rock Plays

Some Core Analysis Issues

Plots to the left show differences between two labs – the main issue is the Pressure Decay Permeability measurement (see SPE131350, 131771 & 152257 as well as Spears et al 2011 Petrophysics for further discussion).

Comparison of TOC’s between Lab and Method vs Depth

Not much difference between lab and method

Big difference between lab and method

Sample preparation thought to be an issue especially with carbonate rich samples
Core Analysis for Shale Source Rock Plays

X-ray Diffraction

Mineralogy

Clay volume (Vcl)

Grain density ($\rho_{ma}$)

Log calibration – ECS/Flex/Gem calibration

Input to Geomechanical models

Some issues with data – XRD traces need to checked

Triangle of Death or Opportunity

Most of the prolific shales lay the lower clay content below 50%. It is an unwritten rule, but water sensitivity fraccing issues etc make clay rich rocks more difficult to produce.

Need to be consistent with the representation of the data. Prefer the pure QTZ/CLAY/CARB triangular plot rather than some derivative
Shale Source Rock - Integrated Workflow Analysis
Shale Source Rock - Integrated Petrophysical Analysis

Suggested Petrophysical Workflow

1. Data Gathering
   • petrophysical logs, core samples, mud log
   • gather analytical results, core data, desorption, adsorption, TOC, XRD, gas etc.
   • initial understanding of resource, shale gas/oil, tight gas potential etc.

2. Data QC
   • petrophysical logs QC, depth match, log quality, splicing, repeatability, corrections etc.
   • review core data, quality issues, types of data, amount of data, variability etc.

3. Qualitative interpretation – internal relationships., data mining
   • WL Data – raw data, radioactivity, caliper, resistivity, SP, ND relationships
   • WL Data – semi quantitative analysis – phi/res DLR relationships, N-D differences etc.
   • Core Data – inter-relationship of core data, GD/Phi, TOC/Gas, TOC/BD, TOC/SCT etc.

4. Quantitative interpretation – Phi, Sw/Sg, Perm, Lithology etc.
   • Integration of core/log data to create a robust HPV model
   • Geomechanical analysis coupled with lithology analysis – fracture zones etc.
   • Core Data – inter-relationship of core data, GD/Phi, TOC/Gas, TOC/BD, TOC/SCT etc.

5. Report and Visualize Reservoir Parameters
   • assessment parameters, Phi, Sag, HPV values per unit, resource density mapping
   • fraccable rock thickness – potential fraccing zones
   • uncertainty analysis, min/max/ml, multiple scenarios etc

If it doesn’t look right most probably isn’t right – reiterate through cycle
Shale Source Rock fundamentals

Environmental issues

- FUD policy (fear, uncertainty and doubt)
- Fracking – dirty word – emotive subject – massive amount in the press, some positive, but mostly negative.
- Methane issues – fracking in to aquifers, casing leaks, etc.
- Water Issues: Frack fluid compositions etc.; water source/chemicals etc.; usage and water disposal – water monitoring and treatment
- Well pad footprint and heavy traffic issues
- Earthquakes – a frack job wouldn’t be successful if fractures (earthquakes) were not created – size, type and causation need to be monitored (DECC recommendations). Use of microseismic going to be widespread if not a pre-requisite
Shale gas/oil key properties

- Rock is both the source and the reservoir, previously regarded only as source rocks and seals
- Type of organic matter is key – Type II marine best but can Type I work?
- Limited horizontal perm nD range – very limited vertical perm
- Porosity is generally low, circa generally <10%, average ~ 6%
- Localized fracture network – which can be enhanced
- Good shales generally have high Young’s Modulus, low Possion’s Ratio – but that is not all the story
- Siltstone/sandstone/limestone lamina and stringers – help hybrid shale gas/oil reservoirs
- Hydrocarbon storage in micropores, fractures, pores in kerogen and adsorbed on kerogen – can be up to 50% adsorbed – but will this be produced – possible near wellbore and late in field life
- Structural Inversion and formation overpressure is generally good

Shale does not equal shale gas/oil
Conclusions

• These so called shale source rock plays are very special rock/fluid systems that need some special techniques – not many of them are true shales – but what’s in a name?

• Shale source rock plays can be very different – the ones found in North America seem very special from a pressure and fracking perspective than the ones I have seen outside North America. Analogues are important but they are not the panacea for everything.

• There is no silver bullet – some of the methods outlined today will work in some shale plays, but not in others – work out the key points of your specific shale – both positive and negative by due diligence.

• To a certain extent – it is not what is in the rock that counts, it is what comes out – and at present the only way to do this is to test and frack, and then test and frack again, ad infinitum – until you work out the play.

• You have to get involved in the big picture – doing this in geoscience isolation will not work – work closely with other disciplines; geomechanics, completion, drilling, economics and finally, but most importantly, management – to get a total understanding of your shale.

• Enjoy it, think outside the box and keep learning! Bury your heads in the shale from a geological rather than a metaphorical perspective.

• As we have recently witnessed economics are key

And we have not even started to discuss geomechanics, microseismic, DFIT’s and hydraulic fracturing.
More final opinions
The End