Unconventional Petrophysics:
Shale Source Rock Plays and CBM Fundamentals

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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.
**Shale Source Rock fundamentals**

**What is shale?**

- Shale is the most abundant sedimentary rock (50% – 80%) quite variable
- Naturally heterogeneous and extremely variable
- Historically, poorly studied – lots of recent studies and papers; see OnePetro and the explosion of SPE Papers since the ‘00’s; university research projects; commercial databases e.g. Core Labs
- Poorly defined grain size, composition, texture
- Can be clay rich, organic rich, siliceous, calcareous, marly, some grade towards siltstones and become hybrid plays (Bakken Play and parts of the Permian Basin Plays)

**Not all shales are alike – they can be very different**
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
Four key messages

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

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

• Not all source rocks make good shale source rock play

• Economics are key
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 and oil 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. Quite often, Crossplots of TOC and porosity measured from core yield very clear dependency of porosity upon organic content.
Kerogen type is so important

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

After Pepper and Corvi 1995; modified by Mark Osborne BP pers com
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 fundamentals – Porosity Types

- Apendular om
- pyr
- spongy om
- om
- om pores
- cal
- hd

Eagleford

1 μm

Vertical Direction
Shale Source Rock – Permeability mD vs nD

Due to the very low permeability the core measurement technique is different to plug permeabilities; 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. Permeability is so important for oil shale source rocks.
Shale Source Rock fundamentals – KPIs

Successful SSR play

- Brittle-ness
- Pore pressure
- Perm/PHI/SW
- HC comp.
- IP & EUR
- Mech props
- Stress field
- Fracture system
- Basin Model
- Seal
- Ro
- Kero type
- Resource density
- TOC Vol
- Struct. comp.
- Inorg. comp.
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)
• Permeability determination – carrier beds, e.g. Bakken Play and hybrid plays (cores primarily)
• Mineralogy, XRD, elemental analysis (core and log)
• Fracture occurrence and characterization (core and image log)
• Geomechanical properties/Formation Damage (core and log)
• Define criteria for net reservoir/“sweetspot” determination in SSR reservoirs: (core and log)
• Describe vertical distribution of net reservoir/“sweetspot” (log and core)
• Describe how petrophysical properties relate to geomechanical properties
• Relate petrophysical response to seismic response to allow extension away from the borehole.
Significant Core Analysis measurements – early evaluation stage

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). No really valid of liquid shale source rocks.

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


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., combined with stress history.
Core Analysis for Shale Source Plays

Sampling Strategy – maximising core material

- Slab remains in core interval for future description, photography and viewing
- If Geomechanical vertical plug fails (< ¾ inch): Cut 4 inch segment adjacent to sampling site
- Carcass is saved for future use.
- Vertical plugs are used for Geomechanics (drill with oil)
- Non plug based geomechanics testing on carcass
- Carcass is used for GRI K/PHI/SW/GD (250 grams)
- Thin Section
  - XRD/Ion Milled SEM
  - Organic Geochemistry
- Plugs cut with N2 as a bit and saw lubricant
- 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

NOTE: Sampling Strategy – maximising core material

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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)
- CRUSH SAMPLE (20/35 Mesh Size) (~250 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)

Total Porosity & Satuations include all interconnected pore space

- Data Integration

*So* computed using a default brine concentration of 30,000 ppm
*Sg* computed using a default ambient oil density of 0.8 g/cc

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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)

Sample preparation thought to be an issues especially with carbonate rich samples – lower sample set predominantly carbonate
Core Analysis for Shale Source Rock Plays

X-ray Diffraction

Mineralogy
Clay volume (Vcl)
Grain density (ρma)
Log calibration – ECS/Flex/Gem calibration
Input to Geomechanical models

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.

Some issues with data – raw XRD traces need to checked

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 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.
   - AI and or ML techniques can work in these data rich plays

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
   - fracable 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 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. e.g. some of the Permian Basin Shales
- 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, analogies to CBM production.
- Structural Inversion and formation overpressure is generally good

Shale does not equal shale gas/oil
Business purposes of Formation Evaluation in CBM Reservoirs:

1. Evaluate well for hydrocarbon presence and content
2. Estimate ‘gas in place’ using both log and core data.
3. Identify potential completion intervals through permeability testing IFOT.

Main aspects of FE important to CBM Reservoirs:

1. Coal rank/maturity and inorganic and organic composition
2. Gas saturation and saturation state; desorption/adsorption isotherms
3. Coal thickness and Cleat system development and orientation
4. Permeability estimation through IFOT testing
5. Water Analysis – disposal etc.

Main techniques for evaluating CBM Reservoirs:

1. Deterministic/probabilistic core-log approach: use core data directly to calibrate logs directly to various parameters such as ash content, gas in place (scf/ton).
2. Coal thickness and distribution, coal description and cleat orientation utilising core, FMI and other log techniques e.g. dipole sonic etc., orientating core from FMI
3. Economics are key for CBM plays and lower technology is often employed – it can take years before any economic gas production is achieved

Just the first stage can take a number of years depending coal type, gas content, pressure regime and depressurising methodology.
Conclusions

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

• SSR Plays can be very different; the plays 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 and coal plays, but not in others – work out the key points of your specific target horizon, both its positive as well as its negative aspects, by a focused and detailed core and log (WL & or LWD) based acquisition programmes and subsequent analysis

• To a certain extent – it is not what is in the rock that counts, it is what comes out – and 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. e.g. Barnet Shale.

• You have to get involved in the big picture; evaluating shales and coals from a geoscience/petrophysics isolation perspective 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 SSR and or CBM play

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

• Economic understanding is critical; one company’s economic model can be so different to another.

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

NORTHERN ENGLAND: A SHALE GAS GUIDE

BY MIKE BARFIELD

- Judderburgh
- Asunderland
- Shockermouth
- Cleaveland
- Drillington
- Unsettle
- Slipton
- Faulton
- Kingston-Upon-Howell
- "Yet-More-Carbon-To-Burn"-Ley
- Pontefract
- Crackburn
- Shuddersfield
- Outlook: Grimsby...
The End