

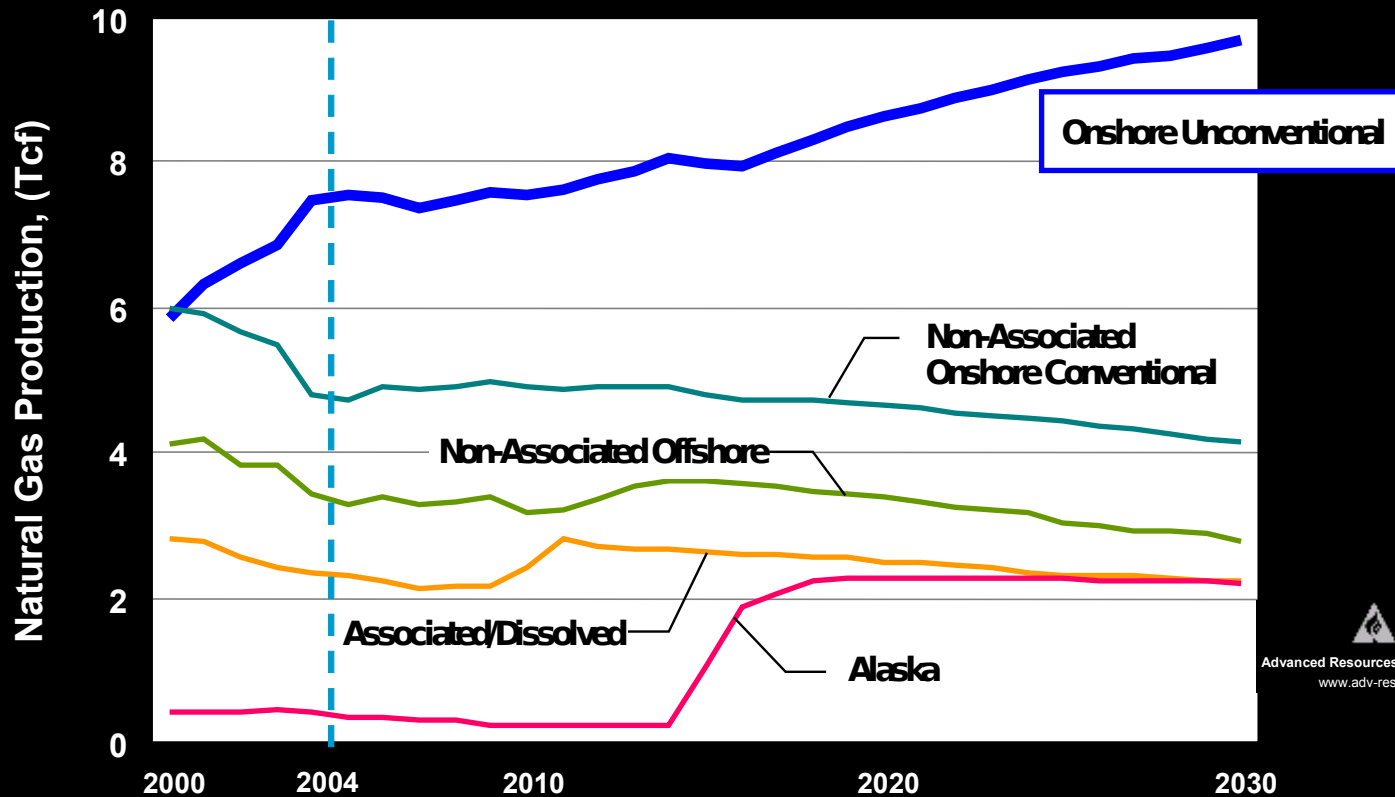
Shale gas in Europe's energy mix: research directions, tools and developments (at least some of them...)

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Outlook for U.S. Natural Gas Supplies (AEO 2006)

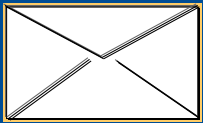
Currently, unconventional gas, the single largest source of U.S. natural gas production, provides 21 Bcfd (7.5 Tcf per year); its role is expected to grow.



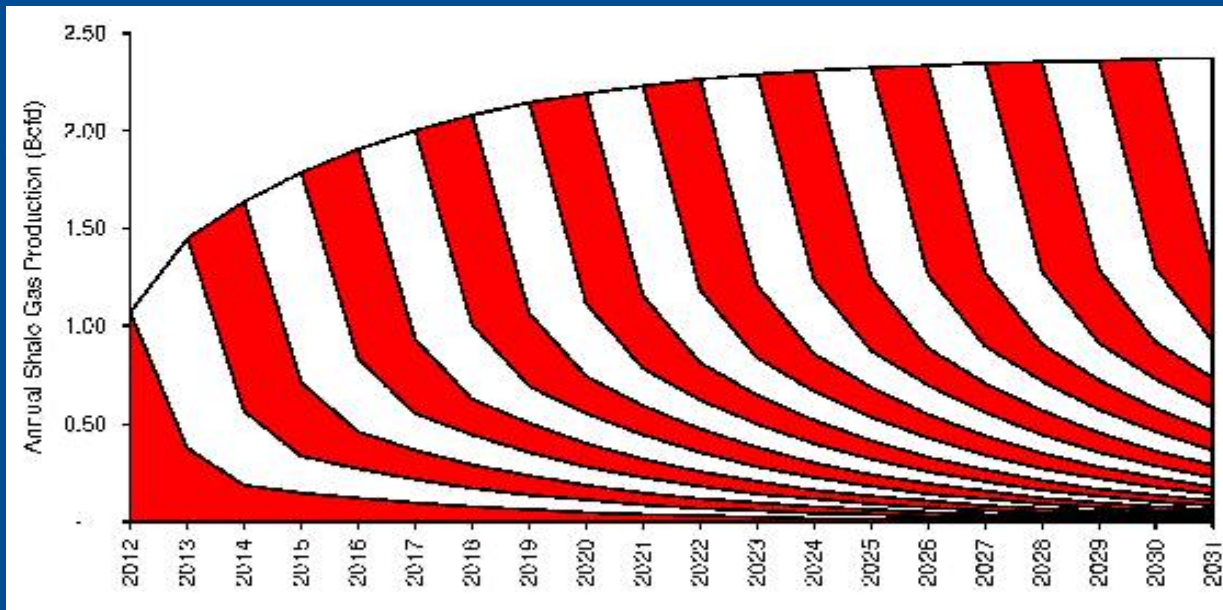
Source: DOE/EIA AEO 2006

Advanced Resources International
www.adv-res.com

What if....



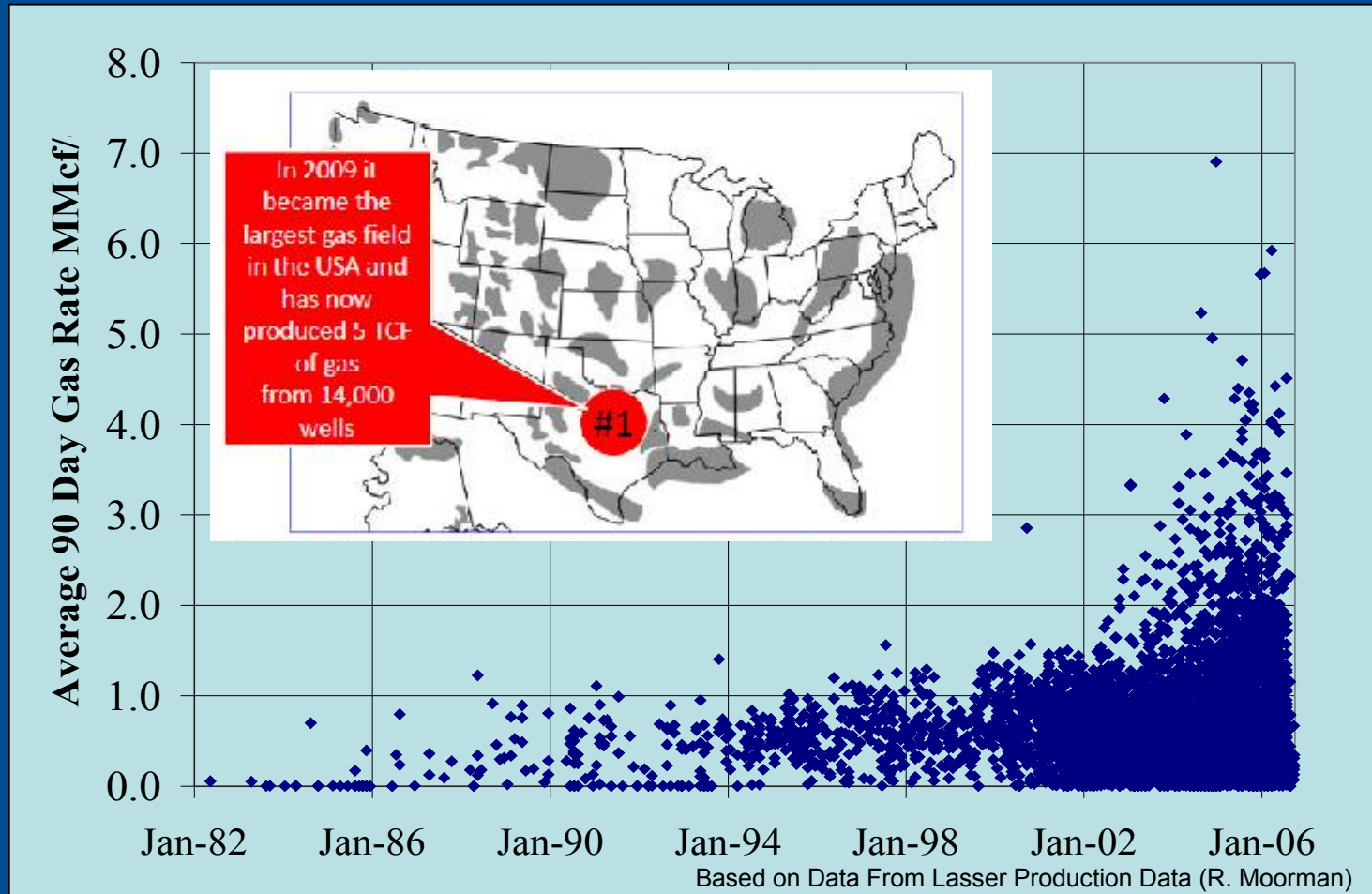
- All of Europe's 67 land rigs move to Poland
- Drill 10-11 wells per year
- Average first year 3mmscfd



2.2 Bcfd
by 2020

4.5%
current annual
European
consumption

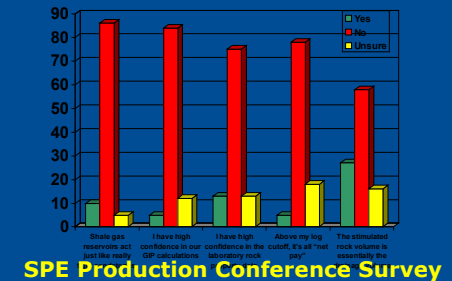
Barnett Shale Learning Curve



Developing European Shale Gas

Why do R&D?

- Poor confidence in GIP calculations
- Recovery factors poorly constrained
- Many wells fail: move from trial & error and empiricism to process understanding
- Drilling costs in Europe likely to be higher so failure is more costly
- Basic process understanding seems to be lacking from current state-of-the-art:
 - Rock description allowing definition of flow/mechanical/physical properties, chemical and biological rates of change
- The environmental perspective/media



Industry R&D Perspective

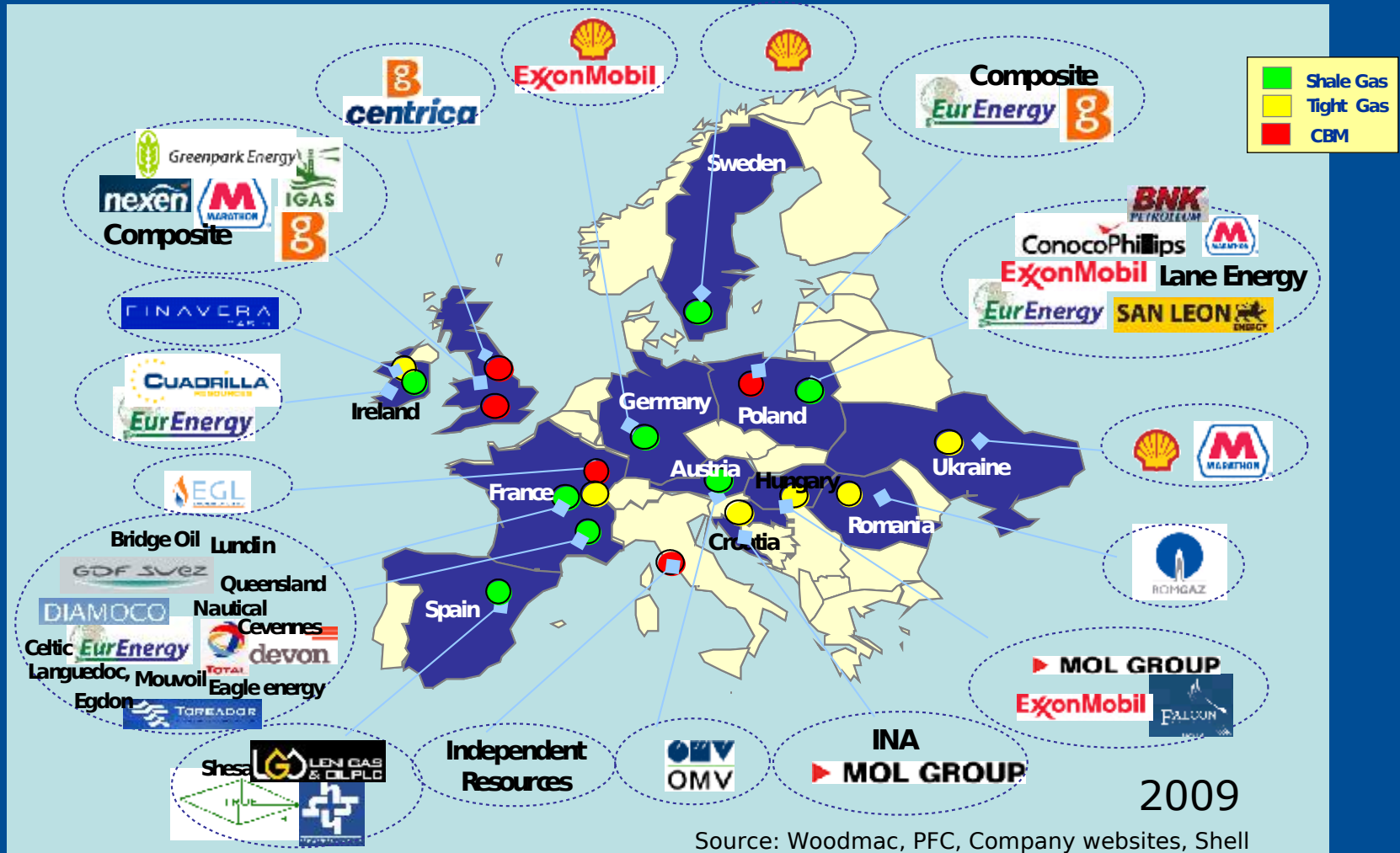
- Acquire - land grab
- Explore - sweet spots
- Produce - optimise
- Supply - infrastructure

Research Focii

- Safeguard - environment
- Inform - general public

Unconventional Gas, Europe 2009

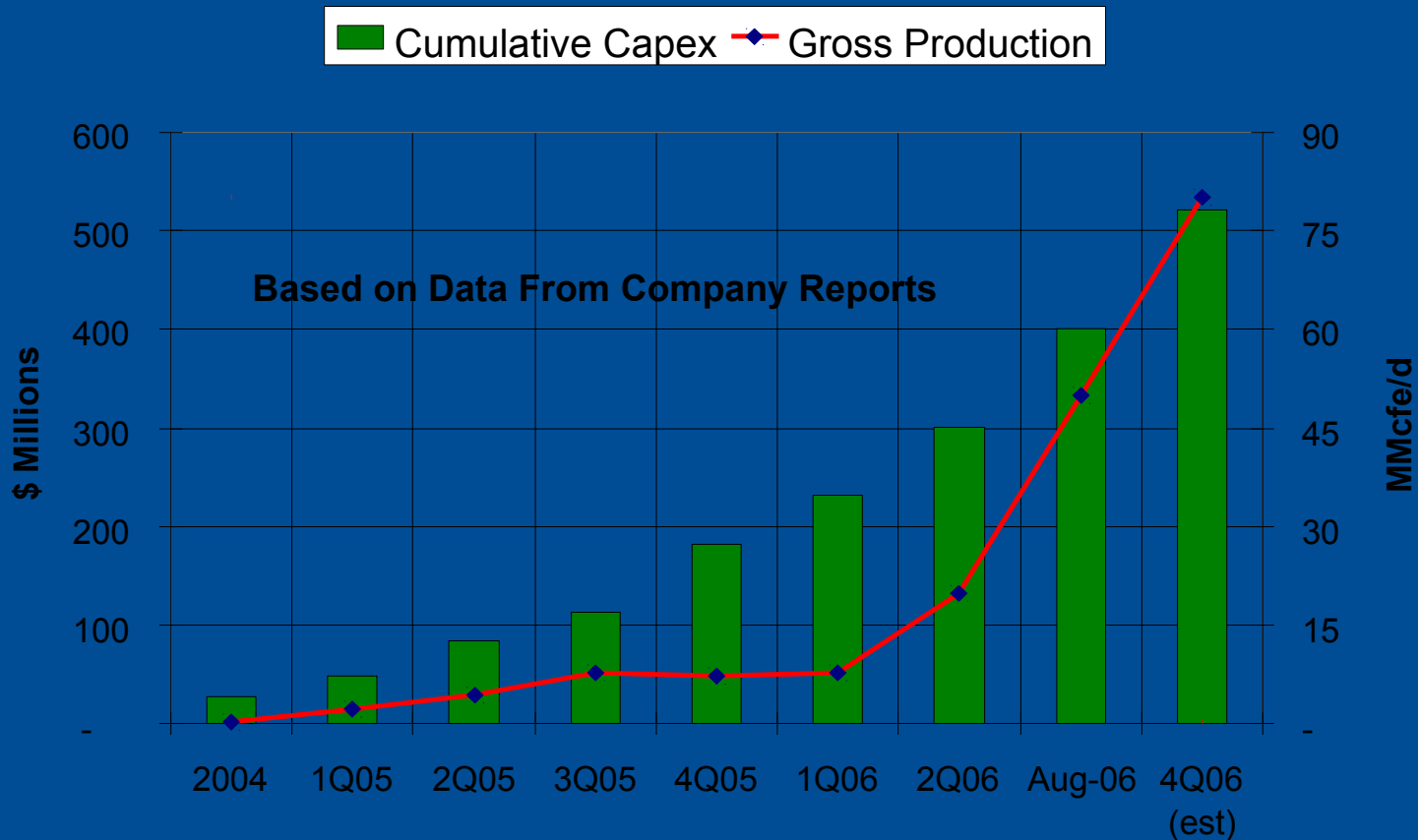
(courtesy of Dave Rimmer, Shell International E&P)



Source: Woodmac, PFC, Company websites, Shell analysis

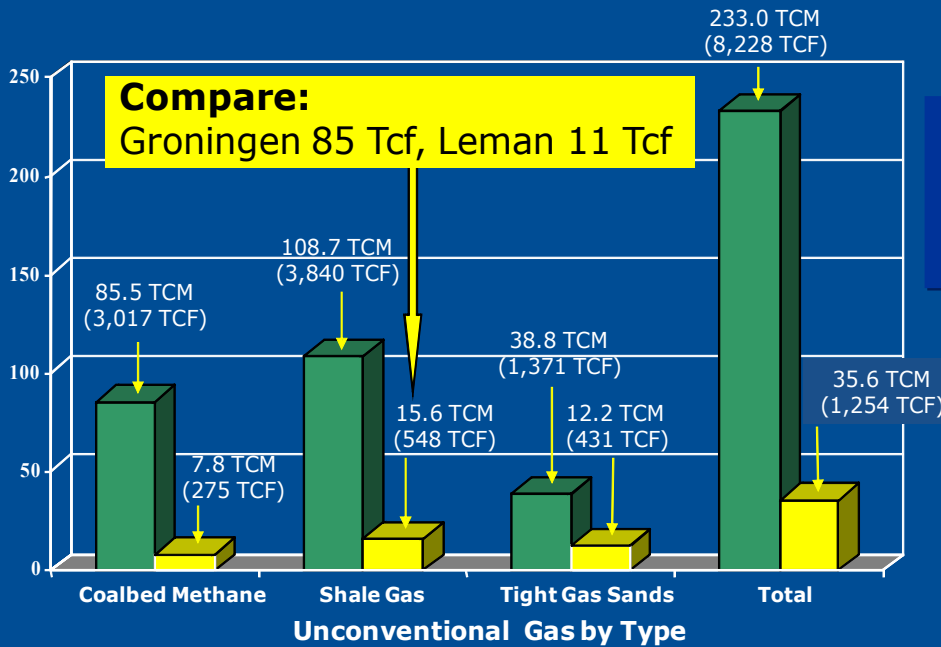
Access to Capital Is Critical

Fayetteville Shale (R. Moorman)

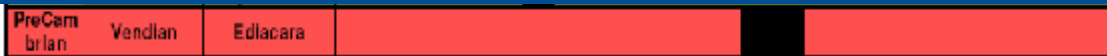
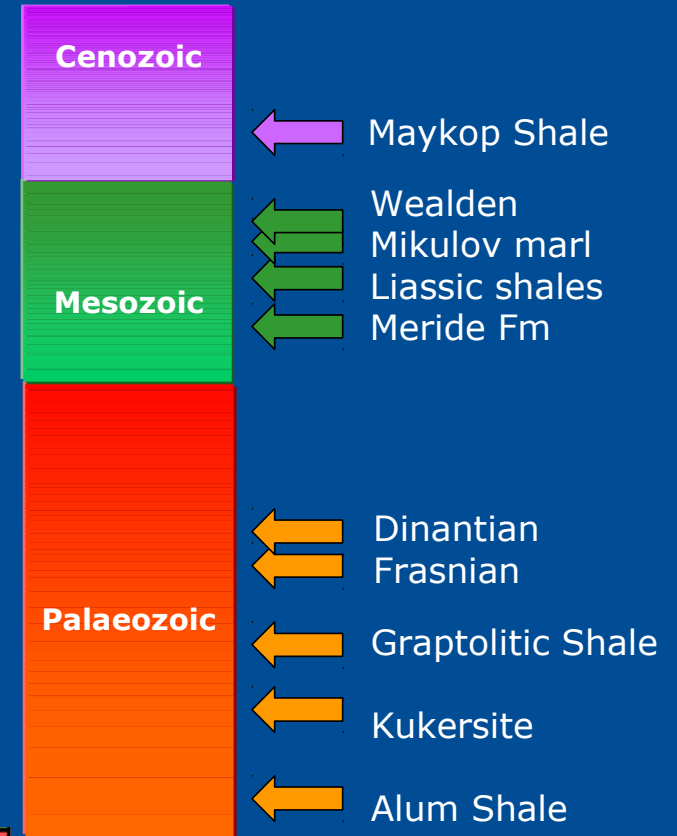


European Black Shale Database

Geological Surveys – it's what they do best



Examples include



Exploration and Production

- Where do we stand?
- Concept carryover from USA?
- Literature dominated by routine stuff
- Dictated by company profiles in USA
- Does high tech need adding?
- New R&D required?

Exploration and Production

- Where do we stand? **Unclear**
- Concept carryover from USA? **Yes**
- Literature dominated by routine stuff
- Dictated by company profiles in USA
- Does high tech need adding? **Yes**
- New R&D required? **Yes**

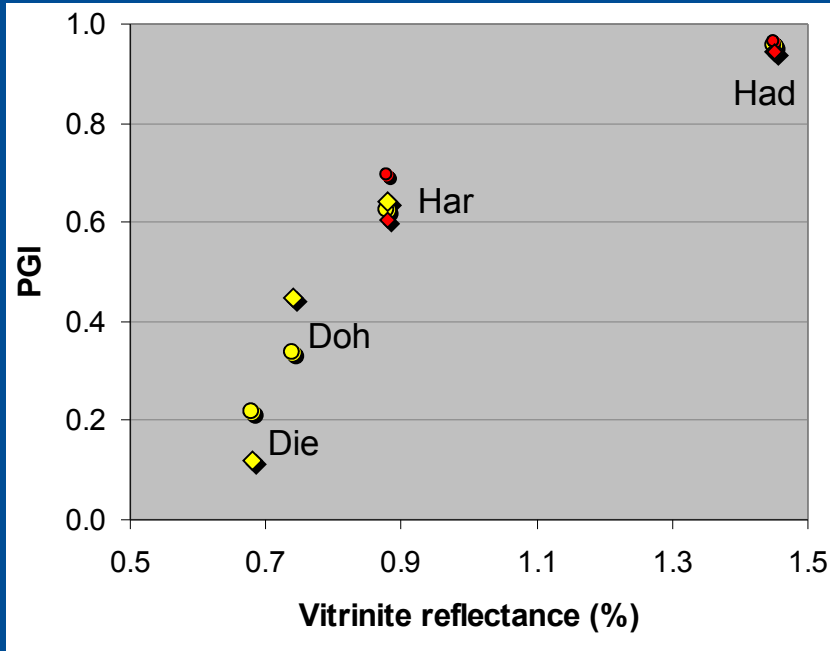
Gas in Place: Issues

- Controls on location and quantity of gas
 - Organofacies and maturity
 - Pore network, sorbed, fractures
- Fluid saturation
 - Organic
 - Aqueous
- These vary according to geological setting on many spatial scales: shale reservoirs are very heterogeneous

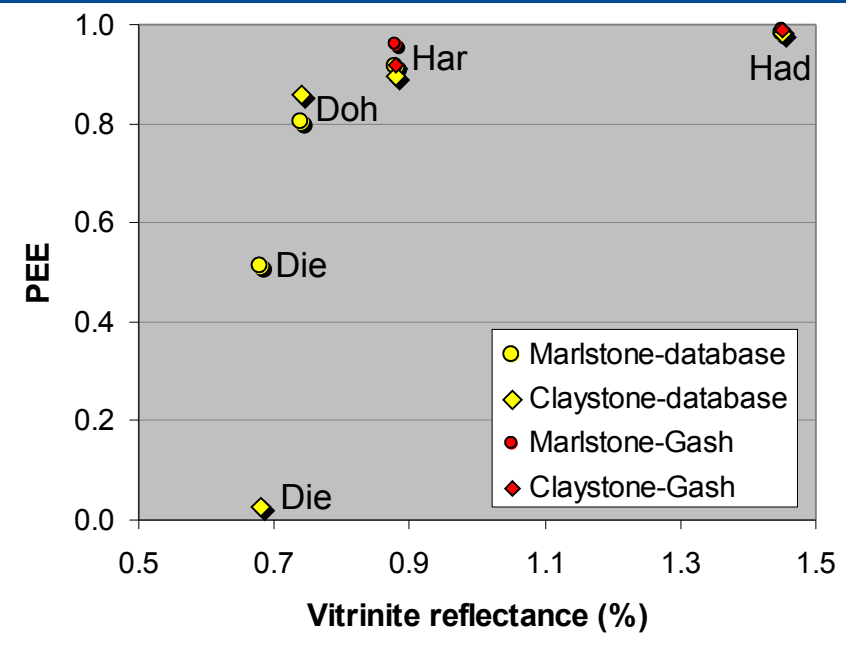
Gas in Place: R&D Solutions

- 3D architecture of shale gas reservoirs: predictive understanding of critical mm-km scale heterogeneities of storage, flow and mechanical properties
- Bridging scales: core – log – seismic
- Characterisation of pore systems and prediction of key controls
- Provide high quality laboratory data (pore systems, geomechanics; rock physics): solid ground on which to underpin calibrations between rock and remote data (seismic, downhole)

Posidonia Shale (Jurassic) of Germany



High conversion

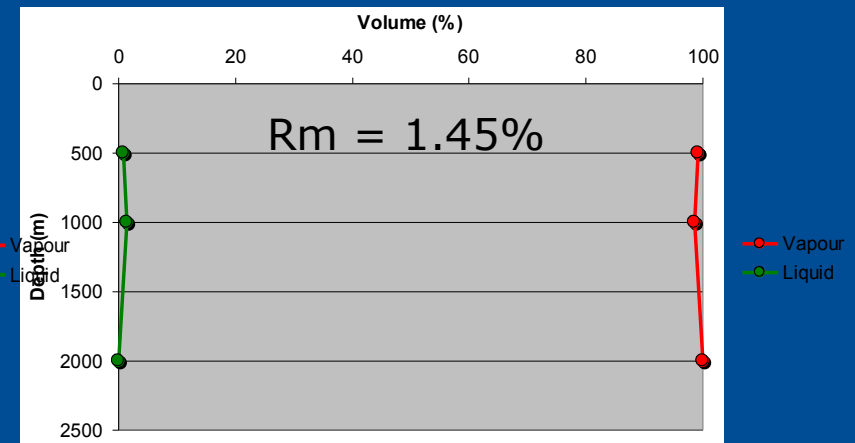
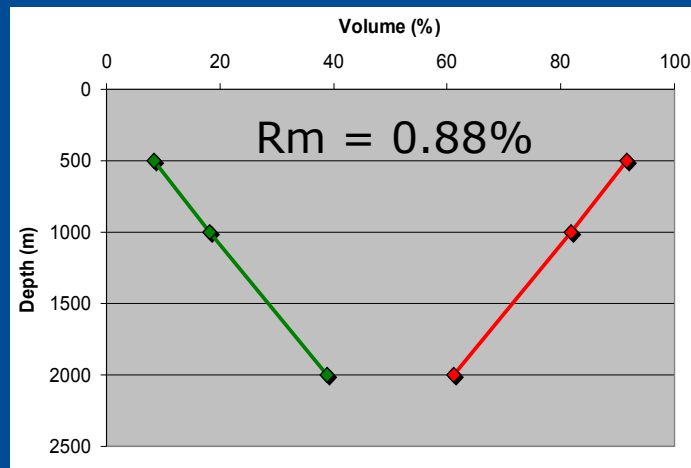
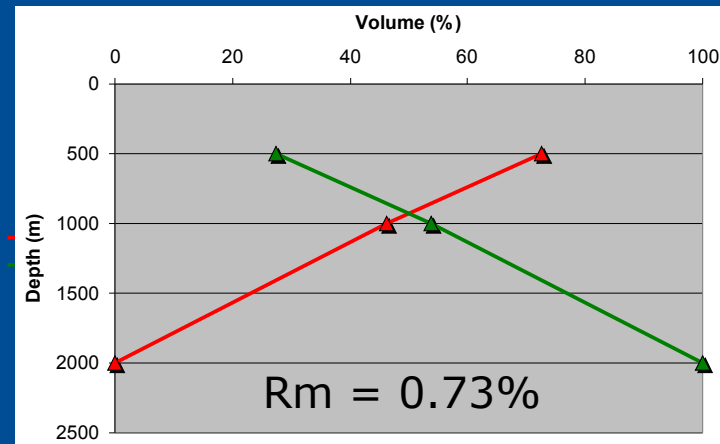
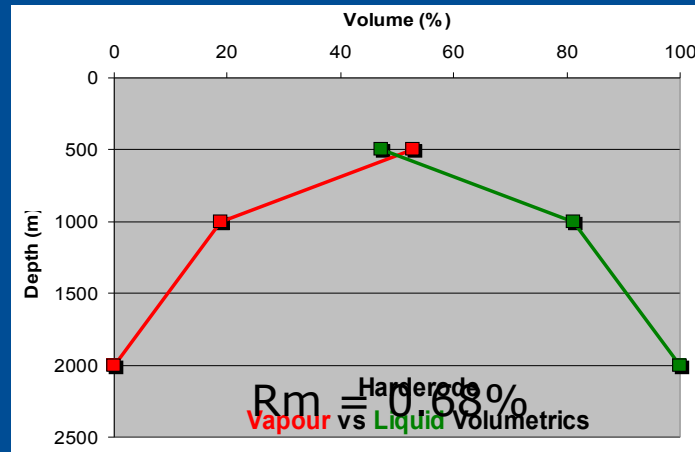


Efficient expulsion

Mass balance model
Evaluate the whole petroleum system!
Available data: 476 samples

Pre-drilling prediction of phase behaviour Inversion and GOR

Dohnsen
Vapour vs Liquid Volumetrics



High Temperature Methane Generation (HiTMe)



Not all shales have this extra potential

In excess of 200°C, $R_o = 2.5\%$

primary gas
(open system)

C6+

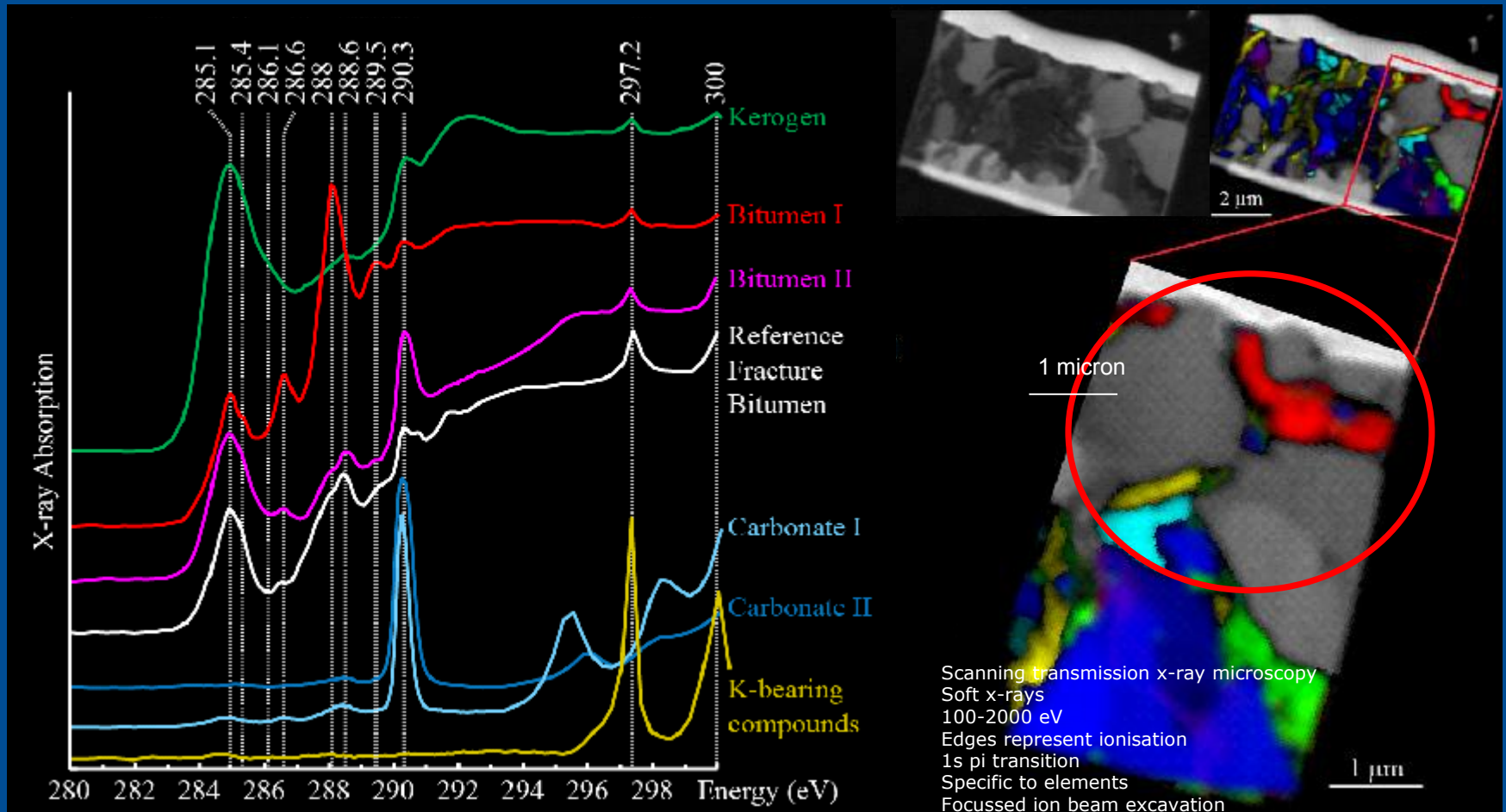
remaining gas

secondary gas (MSSV)

Compositional Mapping sub-micron level

Bernard et al., 2010

Haddessen Well : STXM characterisation at the C K-edge



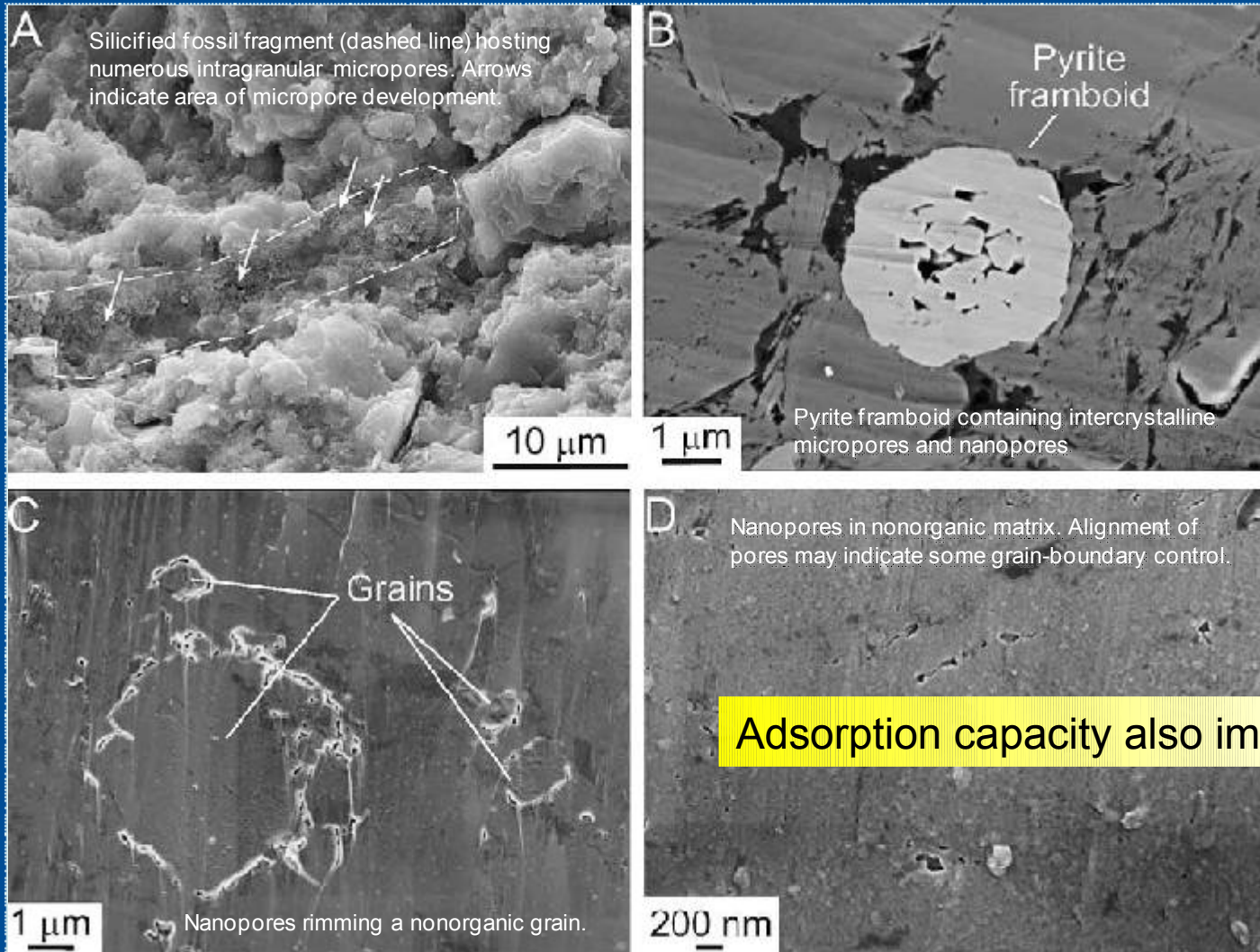
Delivery to Well: Issues

- Water/gas saturation
- Permeability structure
- Two phase flow in heterogeneous, very low permeability media
- Nature (extent, connectivity) of natural and hydraulic fracture networks
- Definition and prediction of drainage volume
- Well completion and fracturing strategies honed to geological setting

Delivery to Well: R&D Needs

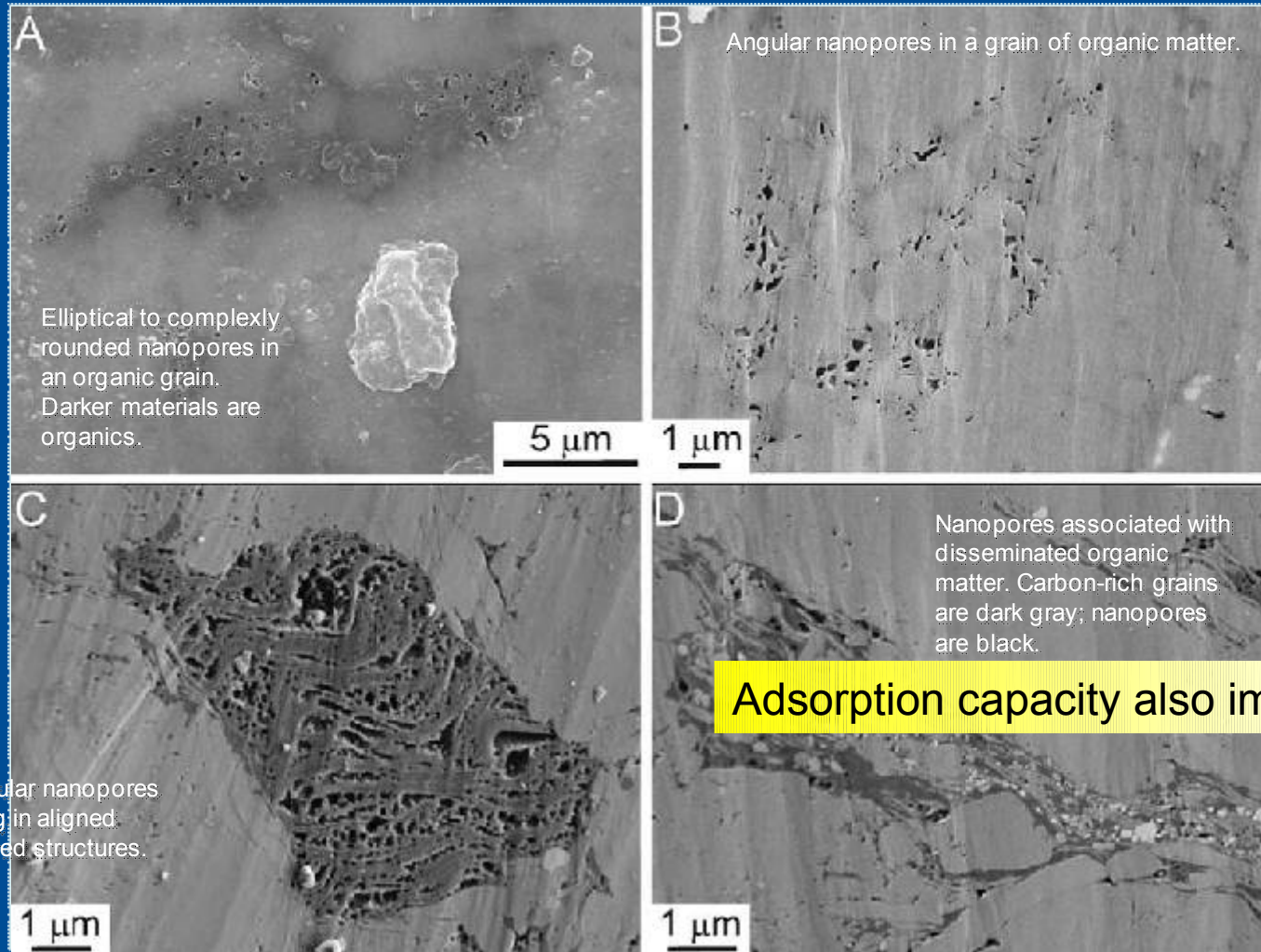
- Sample acquisition and carefully chosen analytical programme:
 - Porosity and pore structure
 - Special core analysis: capillary properties, relative permeability, imbibition
 - Location of gas, water and petroleum liquid predicted in context of porous and solid medium
- Predictive models for fractures: intrinsic mechanical properties and stratigraphy
- Calibrated geology and geophysics (seismic and microseismic) will guide well placement, design and deliverability

Secondary electron (SE) images of pores in nonorganic matter



Loucks et al. (2009)

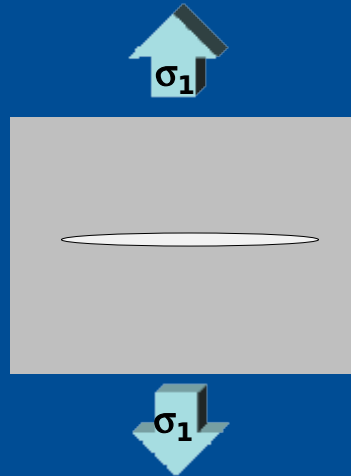
Secondary electron (SE) images of pores associated with organic matter



Adsorption capacity also important

Shale Characterization - Advanced Fraccability, Fracture Closure/Healing/Sealing

Fracture Mechanics

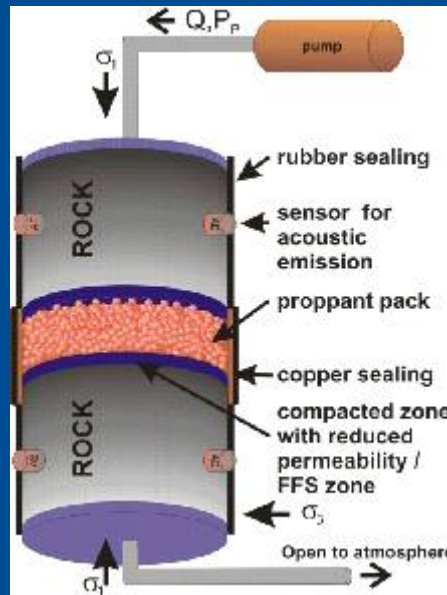


Fracture toughness

Tensile Strength

Subcritical crack growth

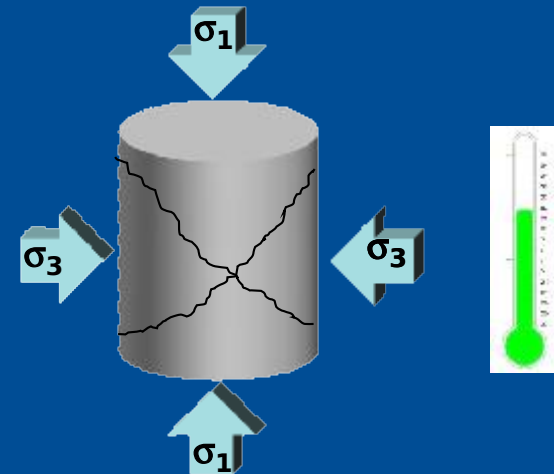
Proppant Embedment



Closure

Permeability reduction

High Temperature High Pressure Tests



Crack healing

Semi brittle behaviour

High-temp creep

Environment and Acceptance

- Induced seismicity
- Radon (Alum?)
- Benzene (as per Barnett?)
- Catastrophic leakage
- Water contamination
- Water availability

Regulations
Company policy

Earth science

Social science

*Like war and prisons –
absolutely necessary but not in my backyard*

2.8 on the Richter scale were reported on June 2, 2009 in Cleburne, Texas