Fluid Flow Mechanisms in Mudrocks as a Function of Fracture and Grain Scale

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Background

- There are 3 main processes affecting fluid flow in mudrocks:
  - Slow diffusion processes through rock matrix
  - Very low permeability deformation features acting as seals to fluid flow
  - High fluid transmissivity open fracture systems
- Intimate coupling between them
- Also dependent upon porosity, permeability, composition & microstructure
- Also upon the history and local mechanisms of:
  (i) fracturing, (ii) dissolution, (iii) precipitation, (iv) elastic and plastic deformation, and (v) wettability

Scaling Problems: Introduction

- Deformation features in mudrocks occur over a restricted range of scales - affecting the ability of mudrocks to transmit fluids
- There are three areas of uncertainty:
  - Scale - What controls the scale of deformation features in mudrocks?
  - Degree – Compaction is accommodated by fracturing at all scales. What controls the degree of fracturing (grain size)?
  - Mechanisms – Fluid overpressure, permeability, porosity and grain size all control the brittle/ductile transition in mudrocks. What are the mechanisms, relationships and scaling behaviour?

Scaling Problems I: Scale

- **Deformation features in mudrocks occur at 3 different scales**
  - **What is the displacement/thickness/length scaling relationship (DTLSR) like?**
  - **What controls the DTLSR (grain size, overpressuring etc.) ?**
  - **Are the same fluids entrapped at all 3 scales? OR**
  - **Are earlier or later fluids restricted to particular scale?**
    - **(i.e. does scale of deformation feature change with T?)**
  - **Does the salinity of fluids in mudrocks vary with scale?**
  - **Are multiple populations of inclusions (repeated events) more prevalent in larger veins?**

Scaling Problems II: Degree

- Many (most?) sandstones exhibit grain fracturing, even at shallow levels (often visible only in CL)
- Stress and fracturing is focussed at grain point contacts
- In mudrocks, grain contacts more likely tangential, and content of ductile grains is higher
  - PREDICT grain fracturing less likely
- Prove by CL studies of mixed sandstone-mudrock sequences
- Is there a critical scale of fracturing related to a critical grain size that controls the degree of fracturing?

Scaling Problems III: Mechanisms

- **Porosity and Permeability - low and strongly anisotropic in mudrocks**
- **Overpressuring - (due to uplift, injection of diagenetic fluids and controlled by permeability) may lead to deformation by shearing and/or fracturing**
- **Grain size – has strongest control over the physical properties of mudrocks**
- **Interplay - between porosity, permeability, pressure and grain size controls all aspects of deformation**

Scaling Problems IV: Mechanisms

Porosity

Permeability

Grain Size

Fluid Flow

Pressures, Fluid, Overburden and Effective

Precipitation

Compaction

Dissolution

Cementation

Industrial Drivers

- **Hydrocarbon Industry**
  - **Analysis of cap-rock sealing potential**
  - **Reservoir compartmentalisation and fault propagation from DTLSR**
  - **Influence of sub-seismic clay-rich deformation bands upon net pay**
- **Water industry**
  - **Aquifer management**
- **Radioactive Waste Repositories and Domestic Land-fill**
  - **Use of clay-rich materials in the near-field**
  - **Role of fluid flow and adsorption in clay-rich rocks**
- **Geothermal Resources**
  - **Role and management of precipitates in the geothermal reservoir**

Aims & Objectives

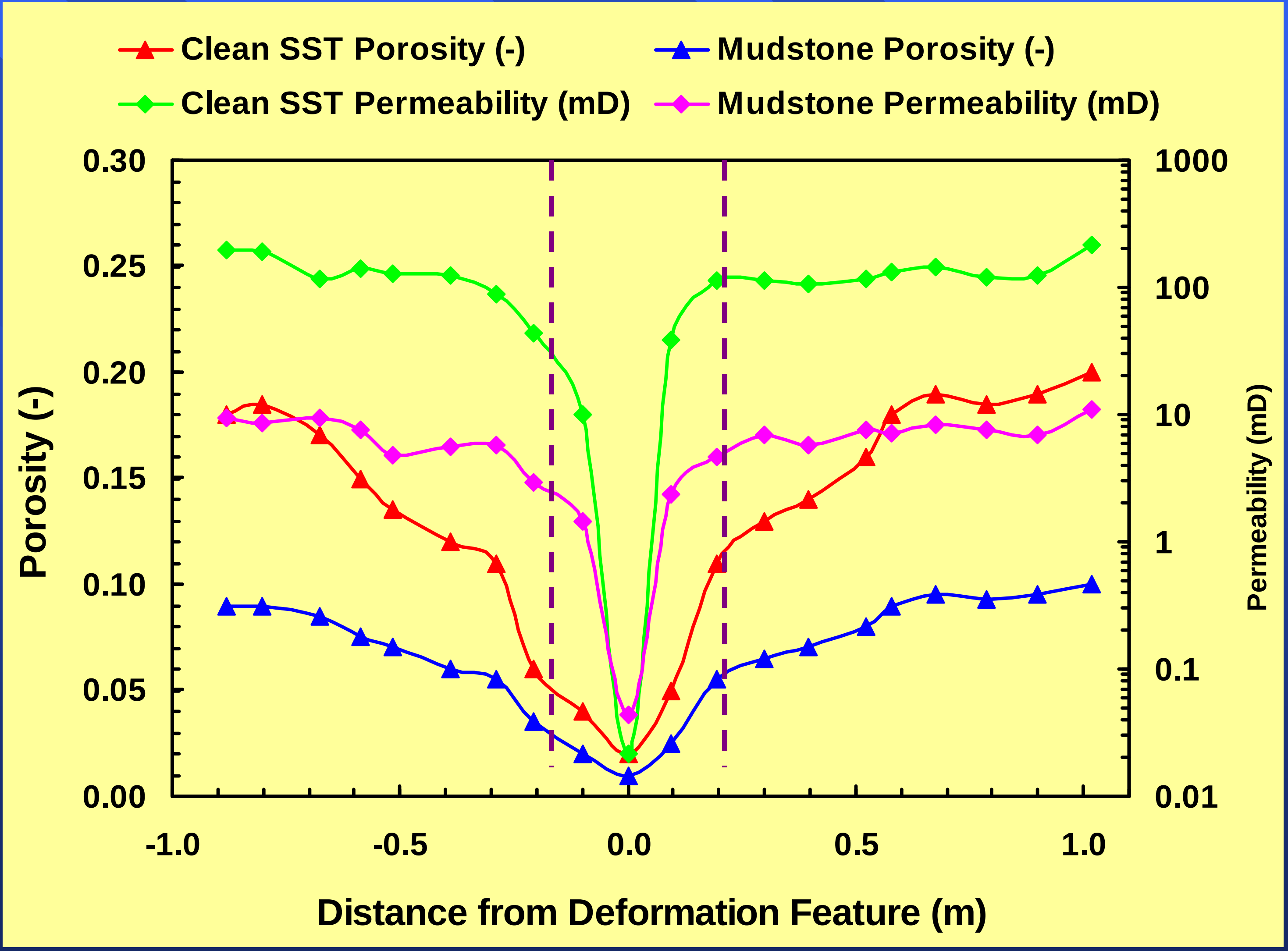
Aim To gather and integrate data describing the characteristics and mechanisms of fluid transport in mudrocks as a function of scale

Objectives

1. To examine the microstructural, hydraulic, mechanical and diagenetic characteristics of closed and open fractures in mudrocks at a wide variety of scales
2. To assess the relative importance and coupling between mechanisms involved in fluid flow as a function of scale in mudrocks
3. Ultimately, to integrate all data in a numerical model capable of modelling parameters affecting fluid flow in mudrocks at a range of scales

Pilot Study I: What is Known

Clay-rich deformation features show lower magnitude changes in porosity and permeability than clean rocks



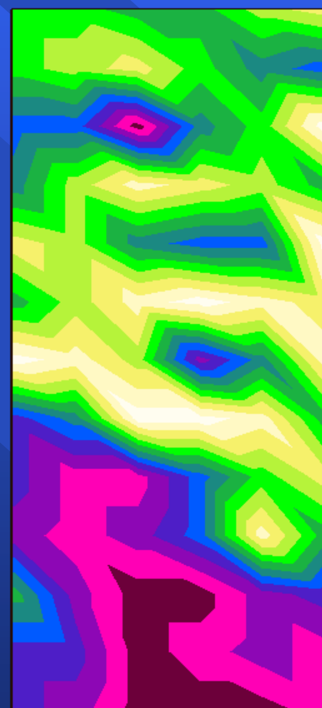
Pilot Study II: What is Known

- These permeabilities can be mapped in slabbed core and surface analogues

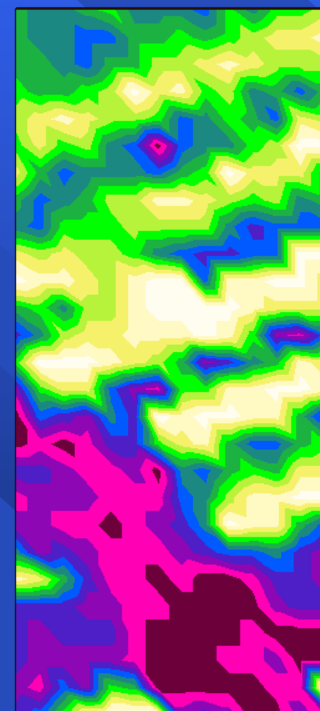
Legend

	0.00026	to	1.22
	1.22	to	2.52
	2.52	to	4.46
	4.46	to	6.87
	6.87	to	11.5
	11.5	to	13.6
	13.6	to	16.5
	16.5	to	20.7
	20.7	to	25.1
	25.1	to	30.7
	30.7	to	39
	39	to	1070

Clay-rich faults in immature sandstone



1cm grid resolution



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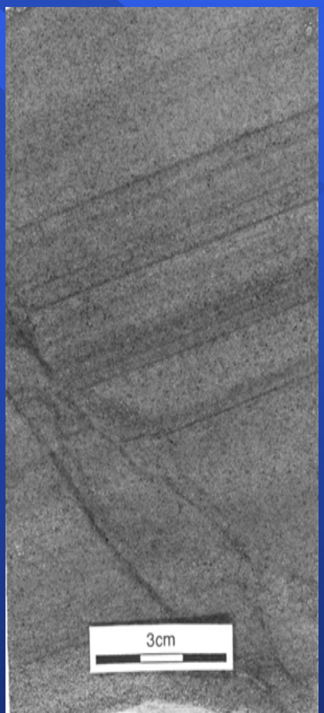
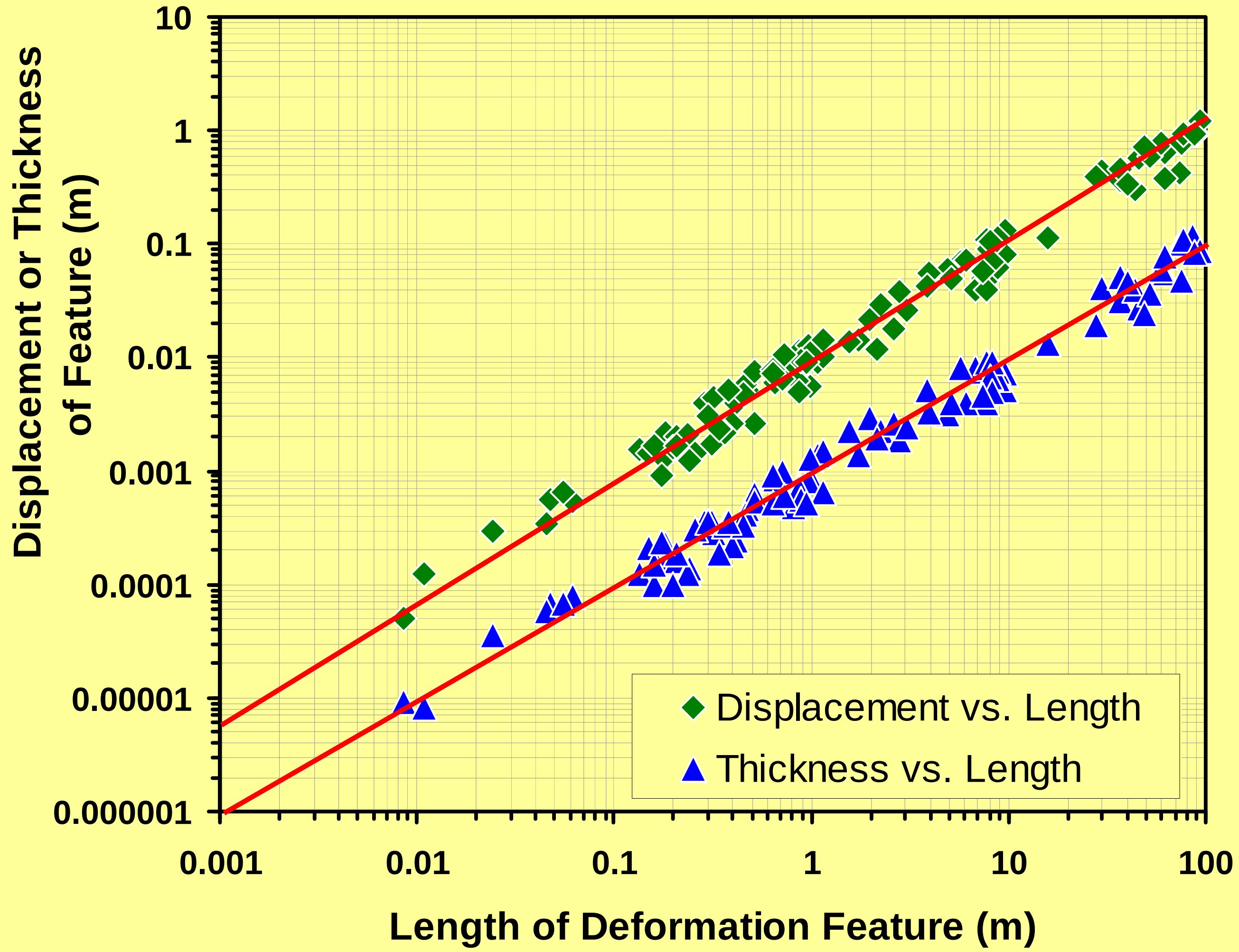


Clay-rich sandstone

Pilot Study III: What is Known

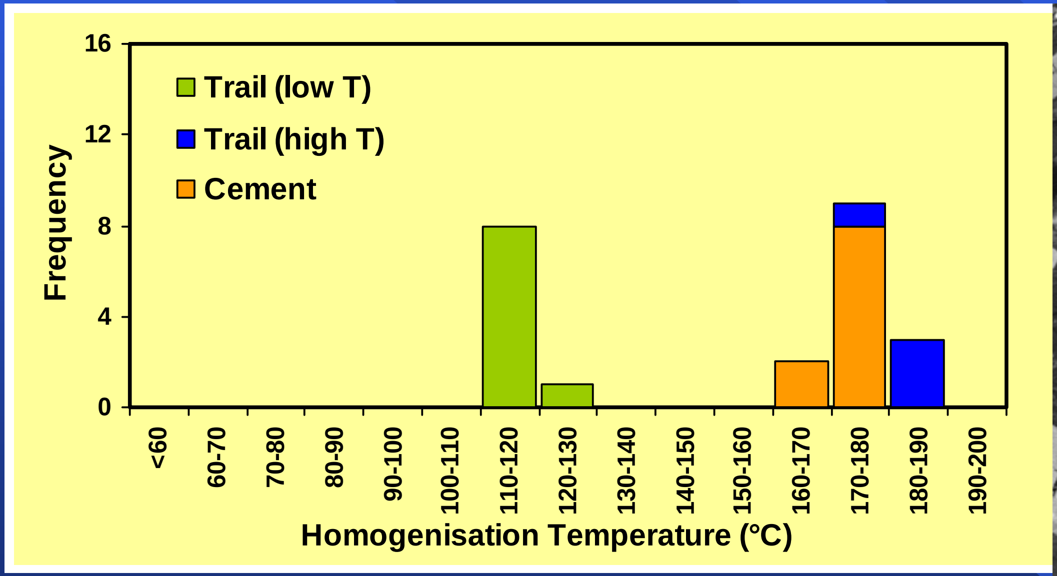
The displacement/ thickness/ length scaling relationship (DTLSR) can be found and used to predict flow features

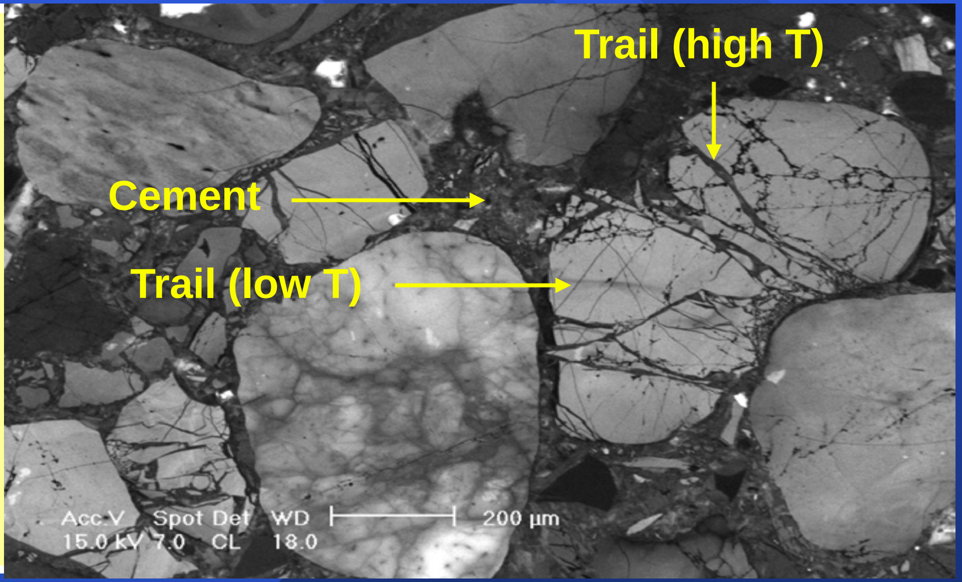


Deformation bands in clean sandstones

Pilot Study IV: What is Known

- **The history of cementation can be determined from fluid inclusion data**

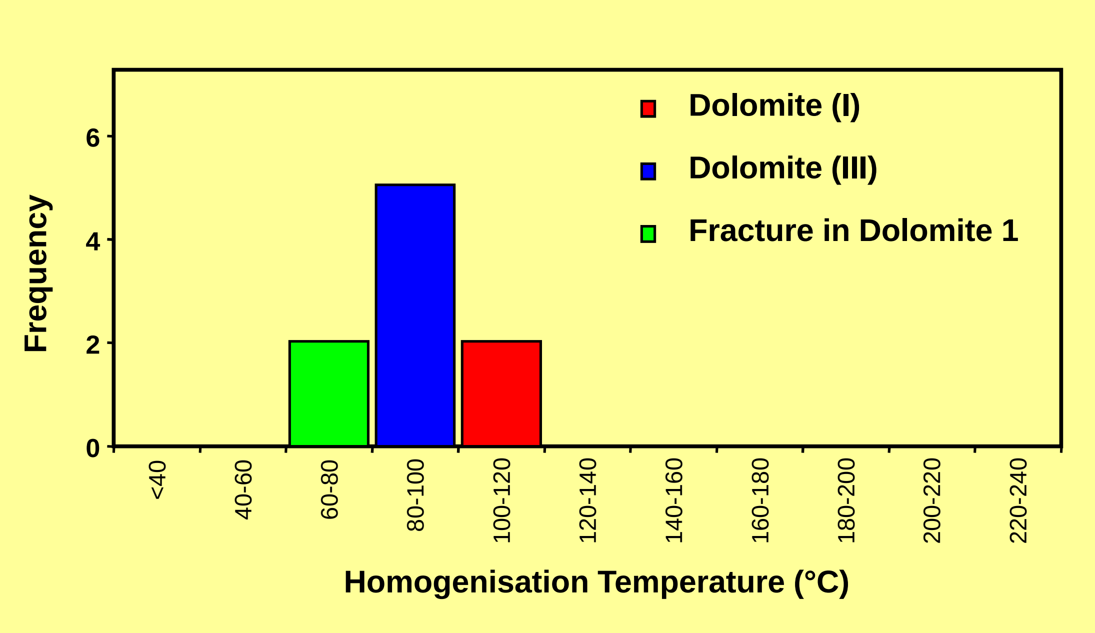


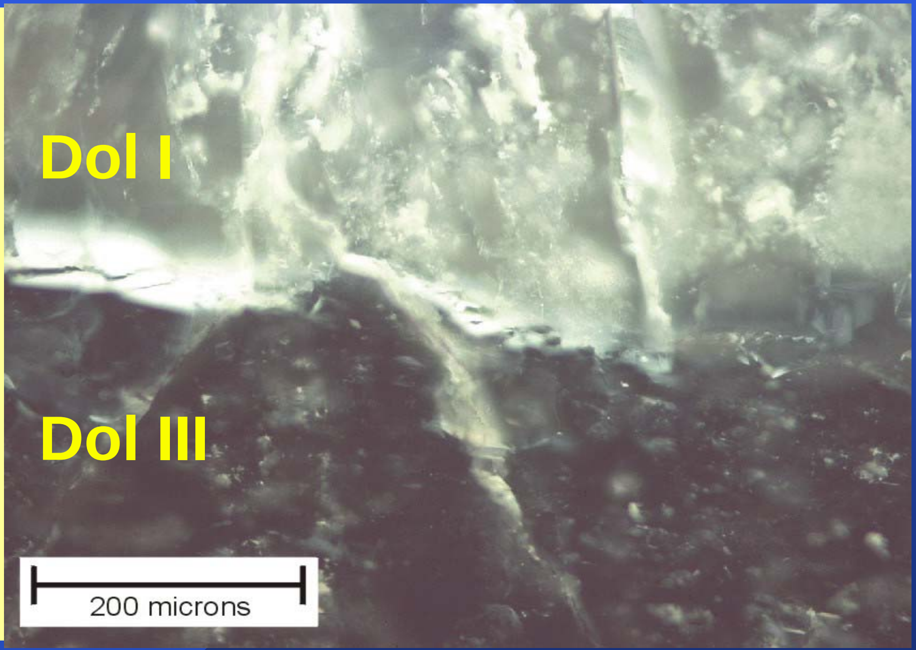


Fluid temperature reconstructions in sandstone using integrated SEM-CL and fluid inclusion studies

Pilot Study V: What is Known

- **The history of cementation can be determined from fluid inclusion data**





Fluid temperature reconstruction from veins in mudstone using integrated UV fluorescence imaging and fluid inclusions

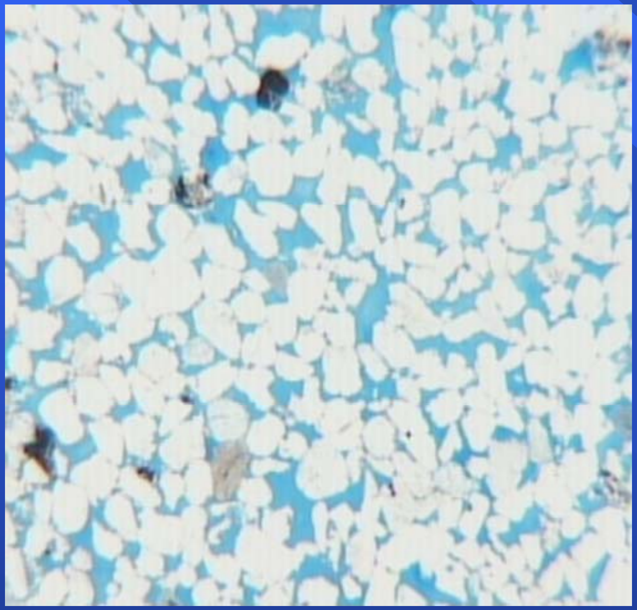
Methodology I: Sample and Field

- Samples - Obtained from
  - (i) The Kimmeridgian (offshore, Conoco Ltd., onshore, Yorkshire)
  - (ii) Outcrop analogues (Lothbeg, Moray Firth)
- Kimmeridgian samples – exhibiting different degrees of compaction and deformation
- Lothbeg samples – exhibiting ranges of grain scales and sequence from sand → silt → mud
- Sampling carried out with regard to scale from small scale (septaria) to outcrop scale
- Systematic field measurements of deformation features during sampling

Methodology I: Petrophysics

- **Samples subjected to the following:**
  - **Fluid saturation, He gas, and 2D image analysis porosity**
  - **Hg porisimetry (porosity, grain size, pore size, capillary pressure)**
  - **Klinkenberg, gas and liquid permeability determinations**
  - **PDPK permeability determinations**
  - **Amott wettability determinations**
  - **SEM analysis**
  - **XRD/XRF analysis of clay content**
- **Full multivariate analysis of results**

Methodology II: Examples



Thin section micrograph

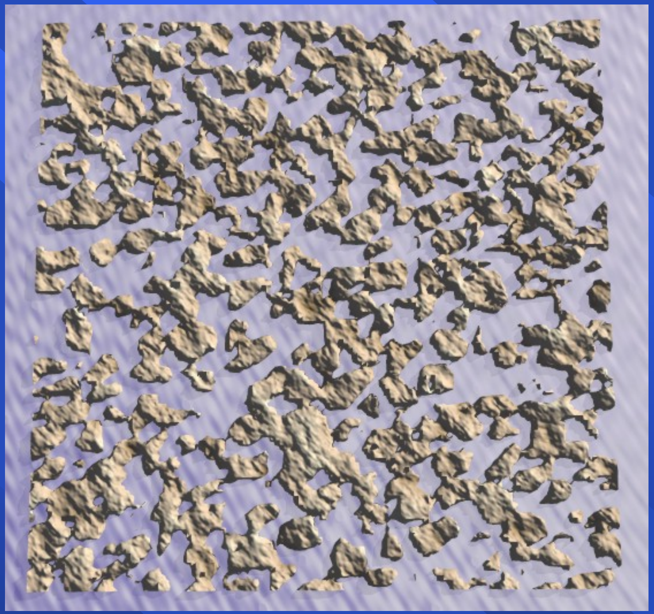
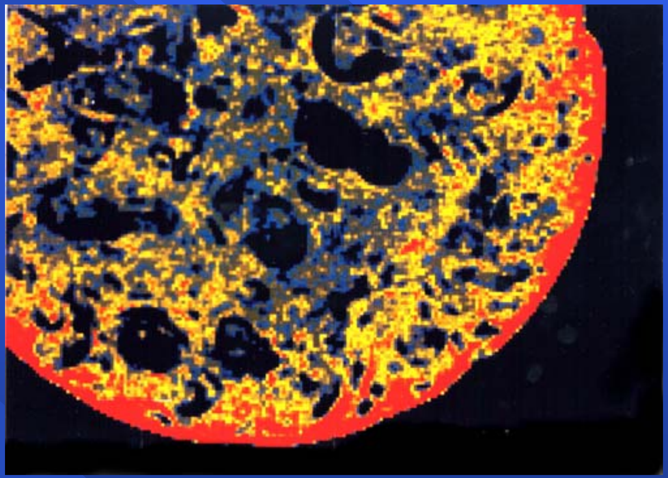


Image analysed micrograph
Porosity = 0.34



CT scan of clay-rich rock

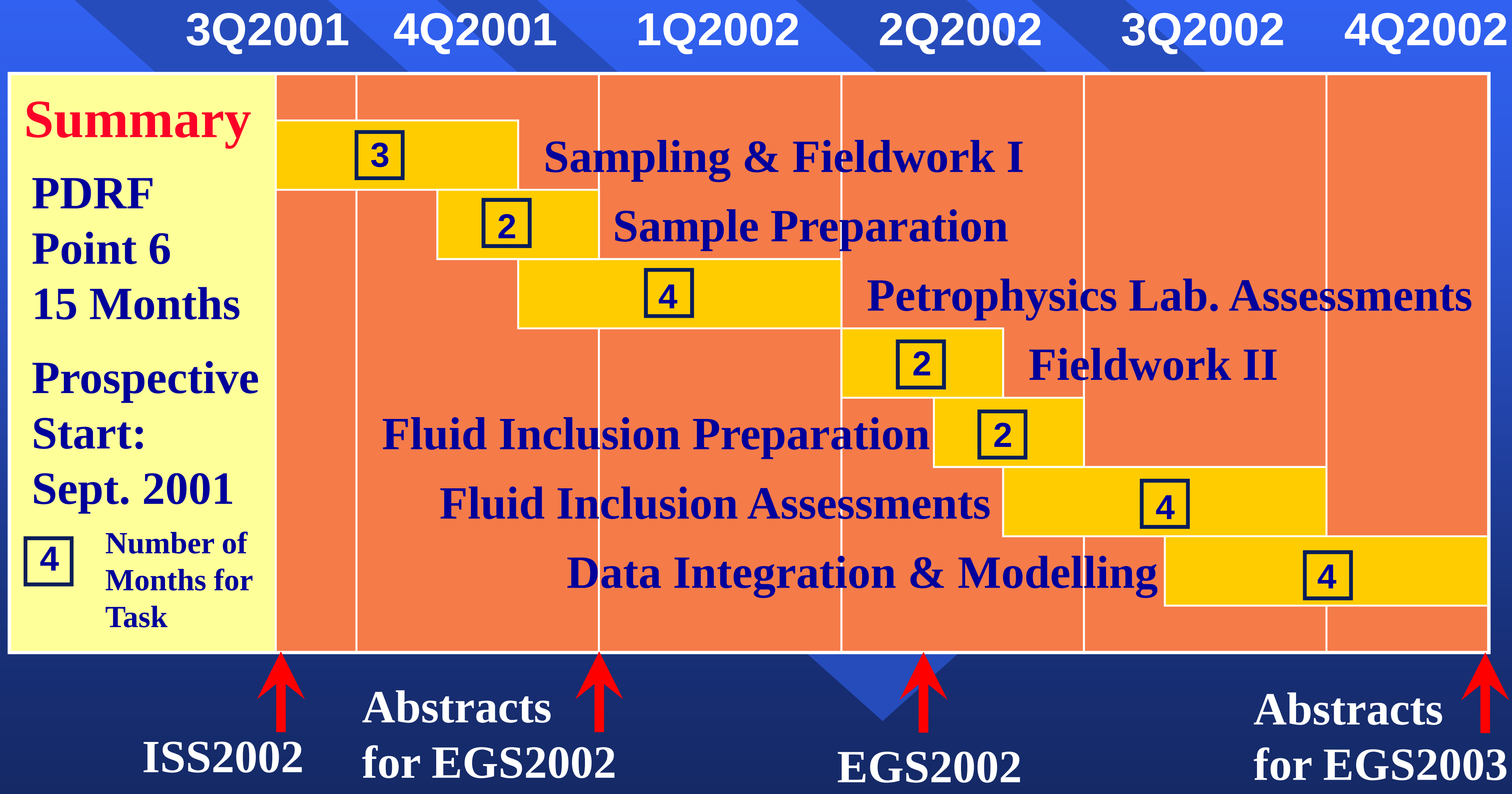
Methodology III: Geofluids

- **Fluid Inclusion Measurements**
  - **Temperature of fluid entrapment**
  - **Relative time of fluid entrapment**
  - **Salinity of fluids**
- **Related Measurements**
  - **SEM and CL analysis combined, SEM-CCD-CL**
  - **Petrography, UV Fluorescence**
- **Populations of inclusions tied into different mineral phases**
- **Full integration with petrophysics data**

Methodology IV: Integrated Modelling

- Analysis of textural and microstructural properties of deformation features at different scales of fracture and grain size
- Detailed petrography and microstructural analysis
- Analysis of mechanical deformation history (from petrophysical and fluid inclusion analysis) as a function of sample type, scale and grain size
- Field relationships

Methodology V: Timescales



Scientific Capability

- Combined Effort - Aberdeen University Petrophysics Group & Geofluids Research Group
- Two fully equipped laboratories supported by dedicated technicians
- 30 years experience in relevant research for the PIs
- 4 PDRFs with relevant experience already in-post
- Existing productive collaborations with industry (e.g., UK NIREX Ltd., Conoco UK Ltd.) and academia (Montpellier, Stony Brook, Tohoku Universities)

Research Management

- Bi-weekly progress meetings of the entire team
- Clearly defined and practical objectives
- SMART (Specific, Measurable, Achievable, Realistic, Timed)
- Open-door policy of PIs towards contract researchers
- Regular internal seminars
- Commitment to training of post-docs
- Publication saturation policy (e.g., EGS 2001 in Nice)
- Commitment to integrated scientific achievement through collaboration within the μ2M community

Data Management

- Open data policy
- All data held in a clearly defined internal structure
- Robust procedures for back-up of data
- All data available for dissemination
- Data available in real-time through web-based reporting
- Integration of all data with the NERC μ2M database
- Data available also by (i) CD-ROM, (ii) Posters, (iii) NERC Reports, (iv) Publications

Summary I

- **Need – Fluid flow in mudrocks occurs through deformation features. The scale, degree and mechanisms of fluid flow in such features are currently unknown.**
- **Approach – Integrated**
  - **(i) Field studies**
  - **(ii) Petrophysics**
  - **(iii) Fluid inclusion studies**
  - **(iv) Technical petrography**
  - **(v) Numerical modelling**
- **Capability – Well equipped labs., experienced PIs and PDRFs**

Summary II

- **Deliverables –**
  - (i) Comprehensive petrophysical and fluid inclusion data set for mudrocks
  - (ii) Information on the scale and degree of development of fluid flow features in mudrocks
  - (iii) Information regarding the mechanisms controlling the development of fluid flow features in mudrocks
  - (iv) Information on the history of flow features in mudrocks
  - (v) A numerical model for predicting the occurrence of deformation features in mudrocks and their likely ability to transport fluids