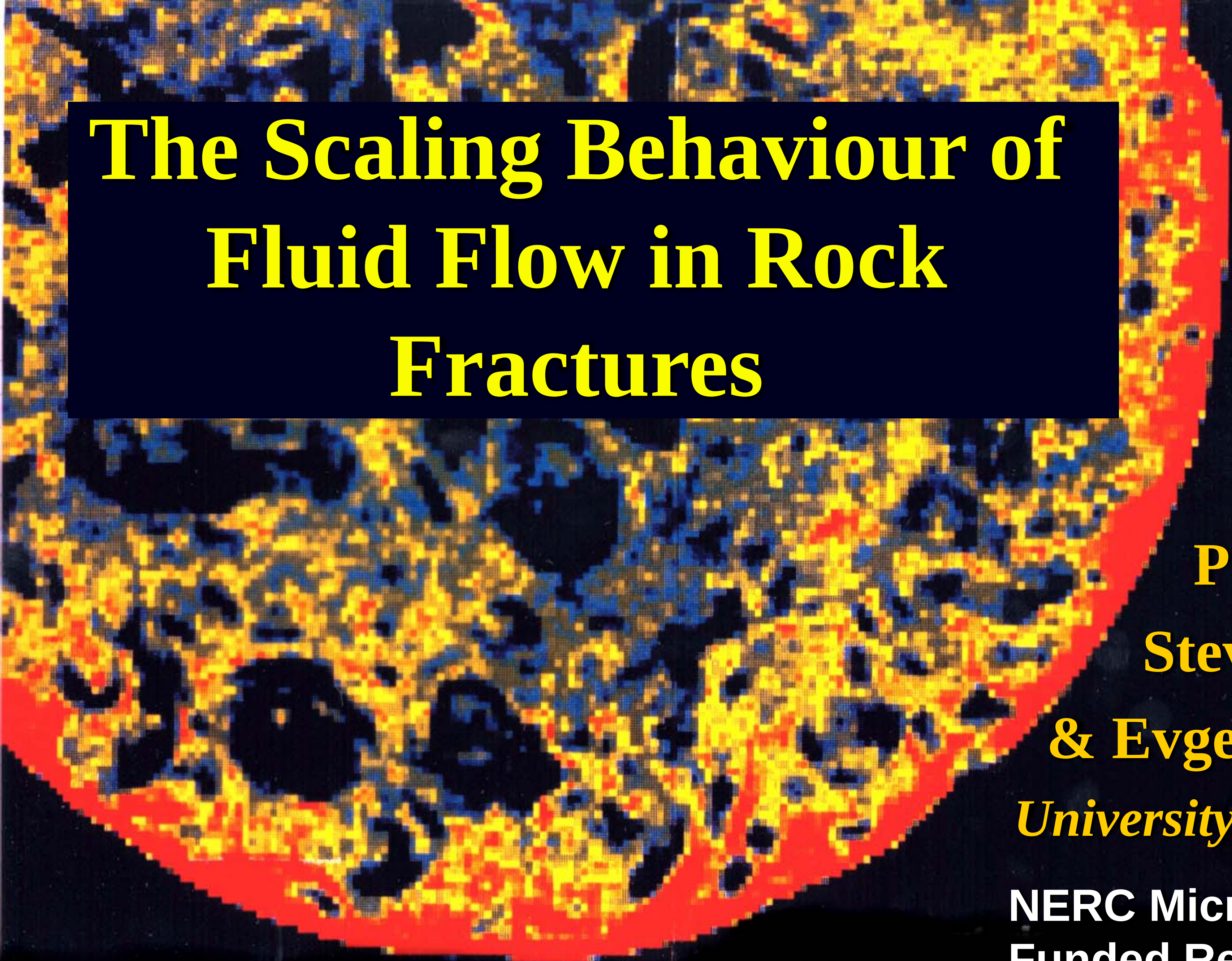

The Scaling Behaviour of Fluid Flow in Rock Fractures

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NERC Micro-to-Macro Funded Research

Structure

- Introduction
- Novel Experimental Methods
- Fluid Flow Modelling
- Summary

Introduction

Fluid flow in rough rock fractures is central to many problems in Earth Sciences, e.g.:

- **Flow channelling and compartmentalization in hydrocarbon reservoirs**
- **Management of water resources**
- **Control of contamination by domestic and chemically toxic industrial waste, and remediation**
- **Design of safe repositories for nuclear waste**

Rough Surfaces and Scaling Behaviour

- **Rough fracture surfaces have the potential for affecting fluid flow in thin fractures**
- **The effect depends upon scale because:**
  - **The surfaces are fractal**
  - **There is fracture matching at long wavelengths but not at short wavelengths**
- **Many other parameters affect fluid flow, such as the stress regime, mean aperture, fluid properties and flow rate…..**

Novel Experimental Methods

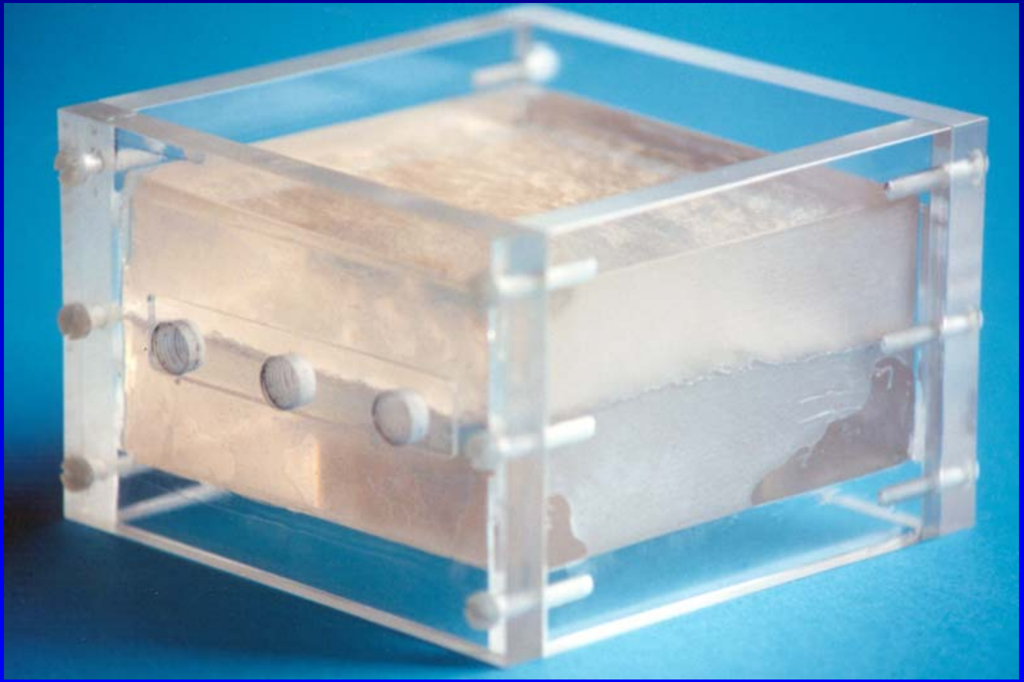
- CT Scanning
- NMR Measurements
- DOI Imaging
- PDPK Imaging
- PET Imaging
- Image Analysis

Digital Optical Imaging (DOI)

- **Being developed at Aberdeen University**
  - **Measurement of fluid flow in rough rock fractures**
  - **Miscible/immiscible fluids, flow rates, viscosities and densities**
  - **Sample may contain an analogue gouge material**

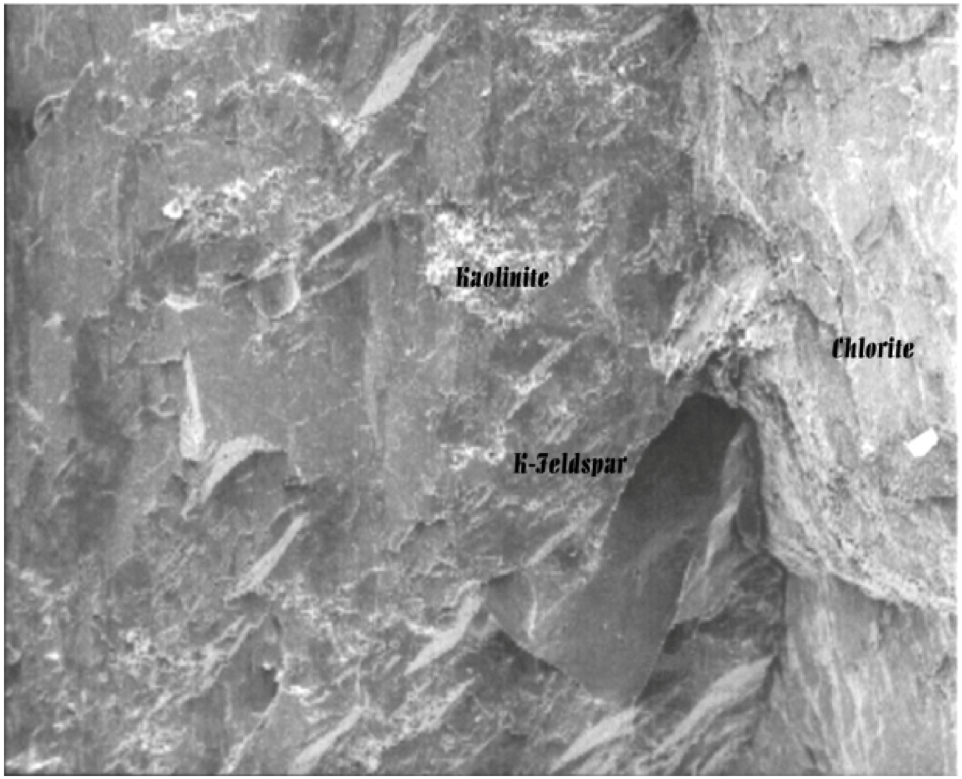
- **High fidelity polymer models (HFPMs) are produced by casting from moulds produced from rock fractures**
- **To a precision better than 1 micron**
- **HFPMs inserted into holder for fluid flow**
- **High resolution camera/image analysis captures flow data**

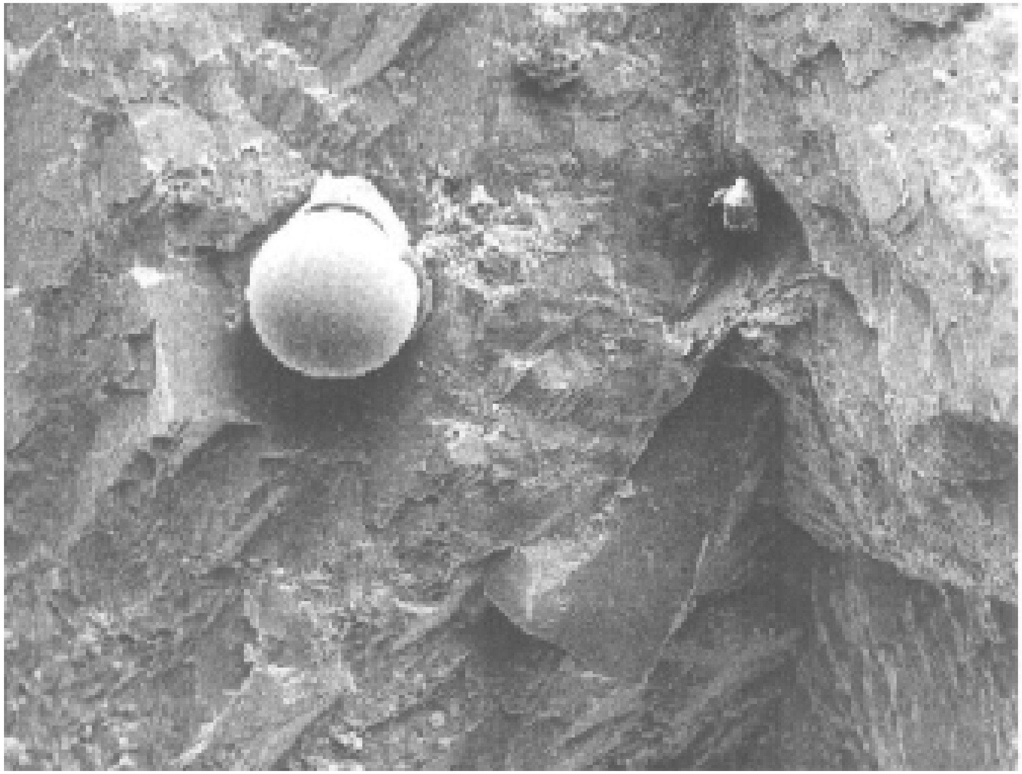
HFPM Construction



HFPM Construction

HFPM Resolution





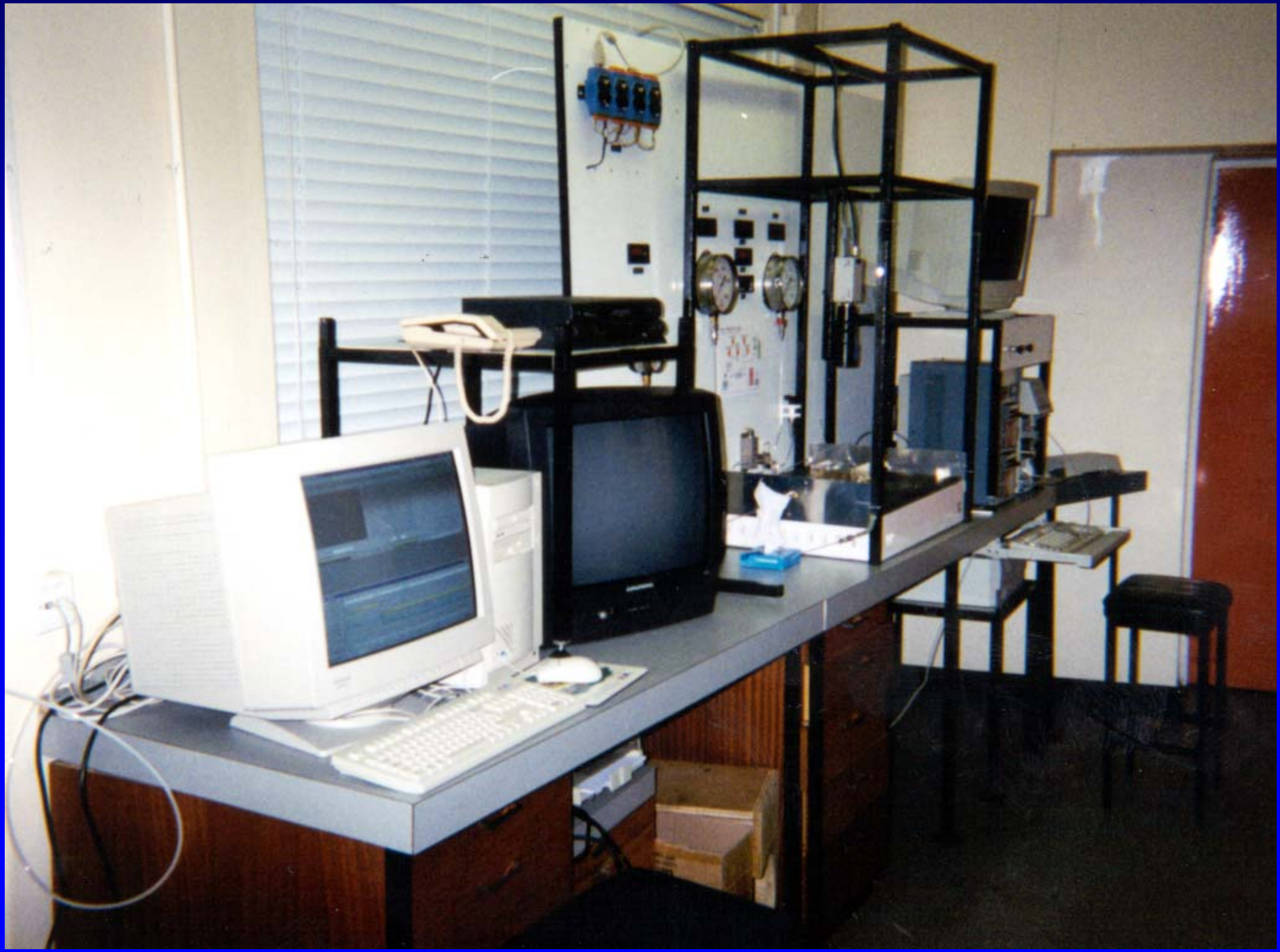
- Original Fracture

150 μm

- HFPM

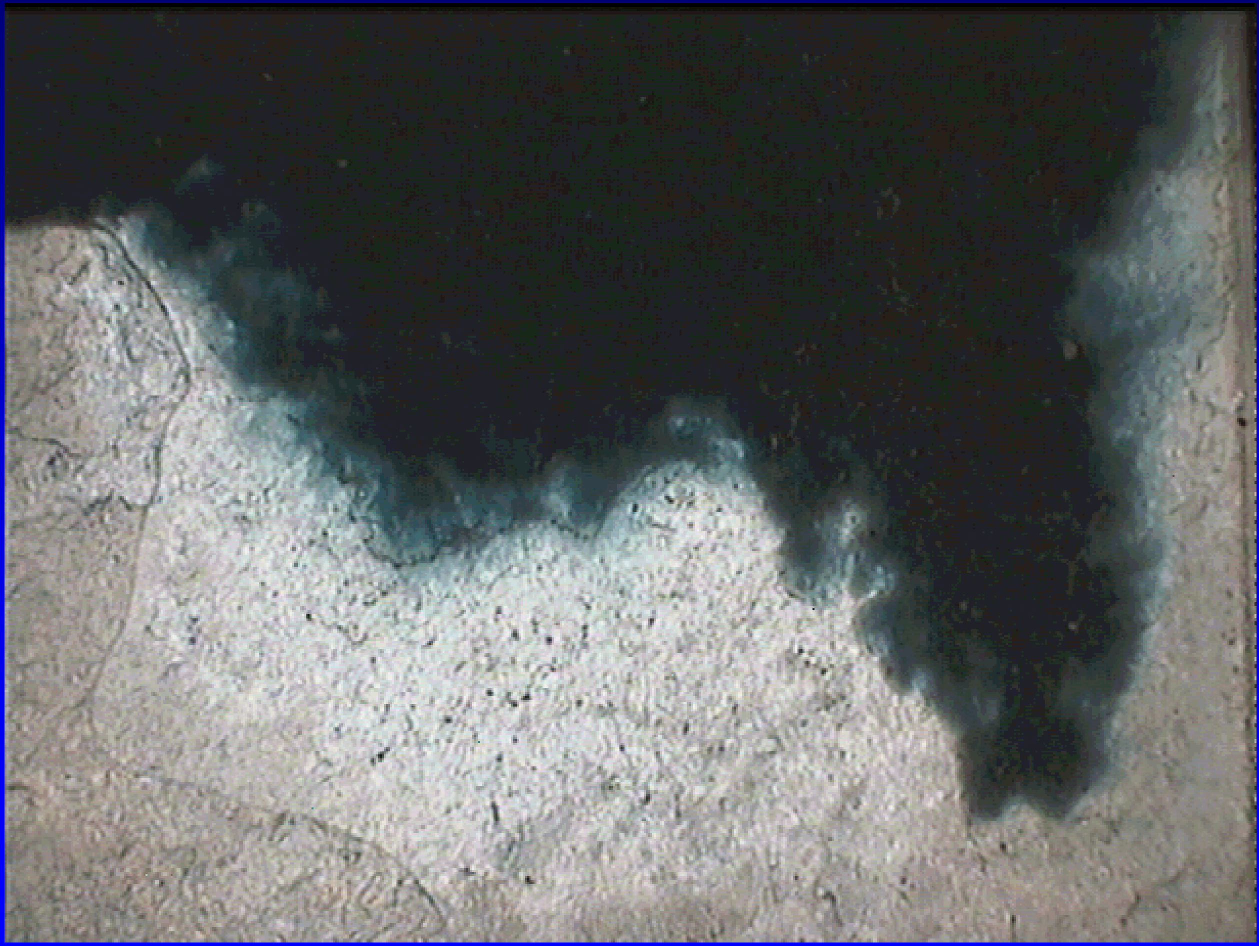
Digital Optical Imaging (DOI)

- **The DOI setup**



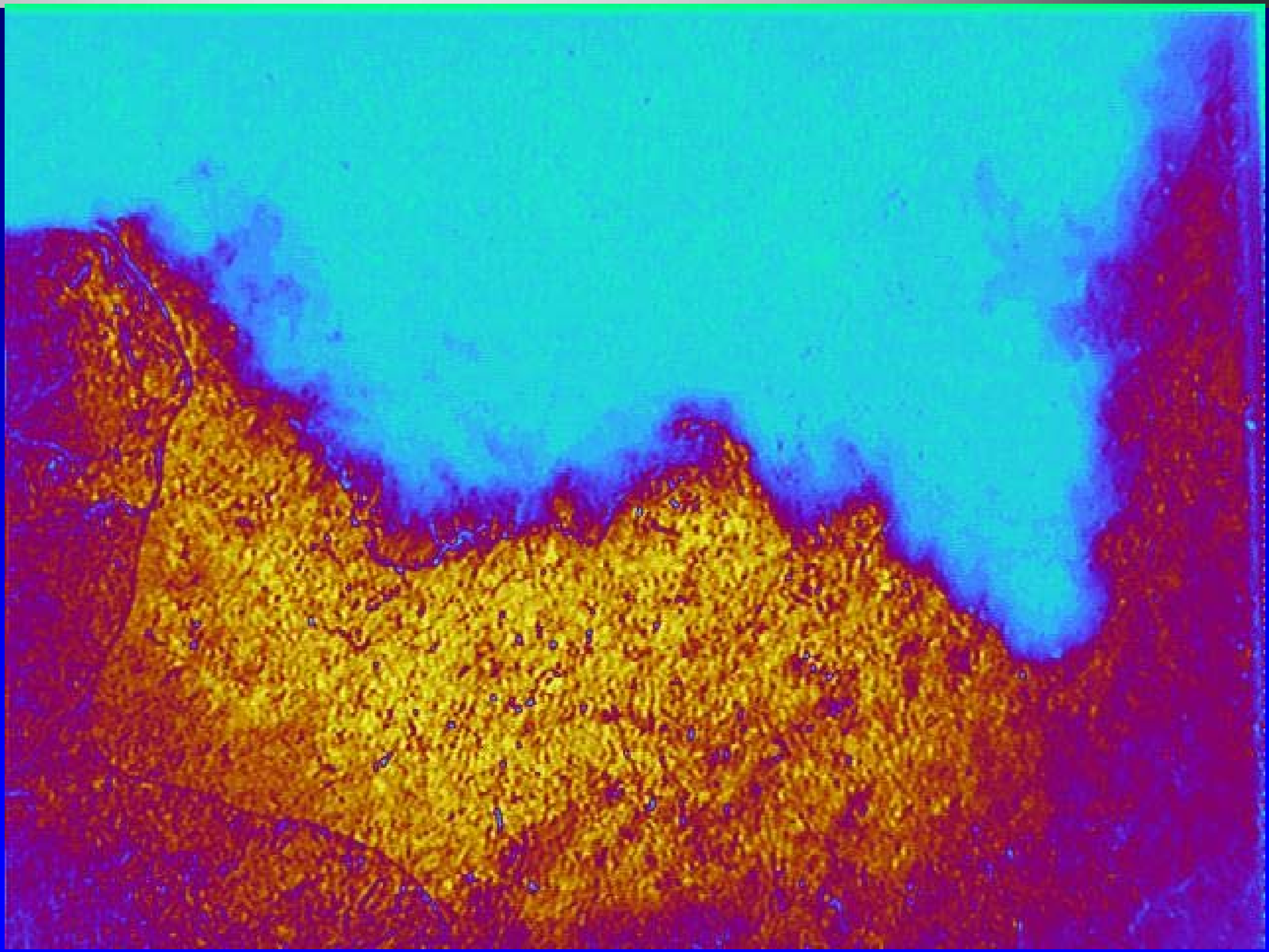
Digital Optical Imaging (DOI)

- An example flood



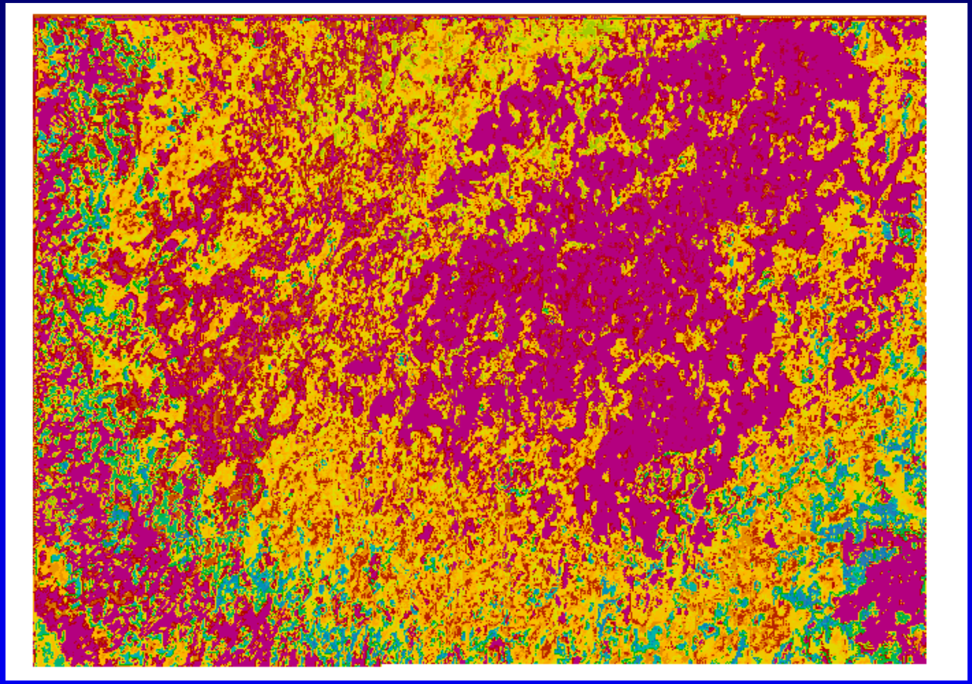
Digital Optical Imaging (DOI)

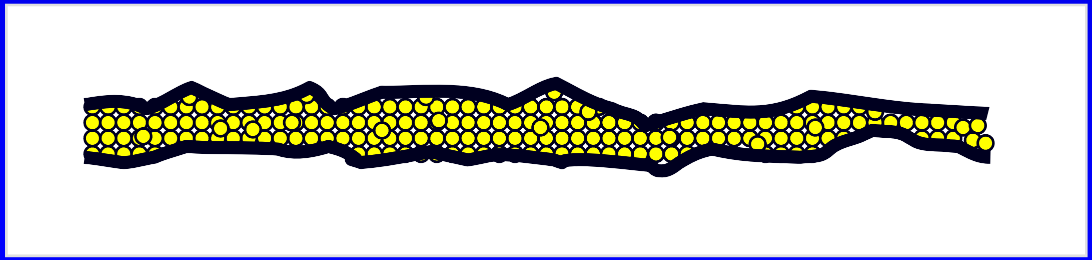
- An example flood



Digital Optical Imaging (DOI)

- Current developments
  - Digital video and image analysis
  - Fracture aperture modelling
  - Adding gouge to HFPMs





PET Imaging

- **Positron Emission Tomography**
  - **Measures position of radioactive doped tracer in a rock**
  - **Dopant emits positrons**
  - **Positrons decay in very short distance to 2 photons**
  - **Photons travel in opposite directions and are contemporaneously measured by a ring of detectors**
  - **Original position of the emission calculated by computer**

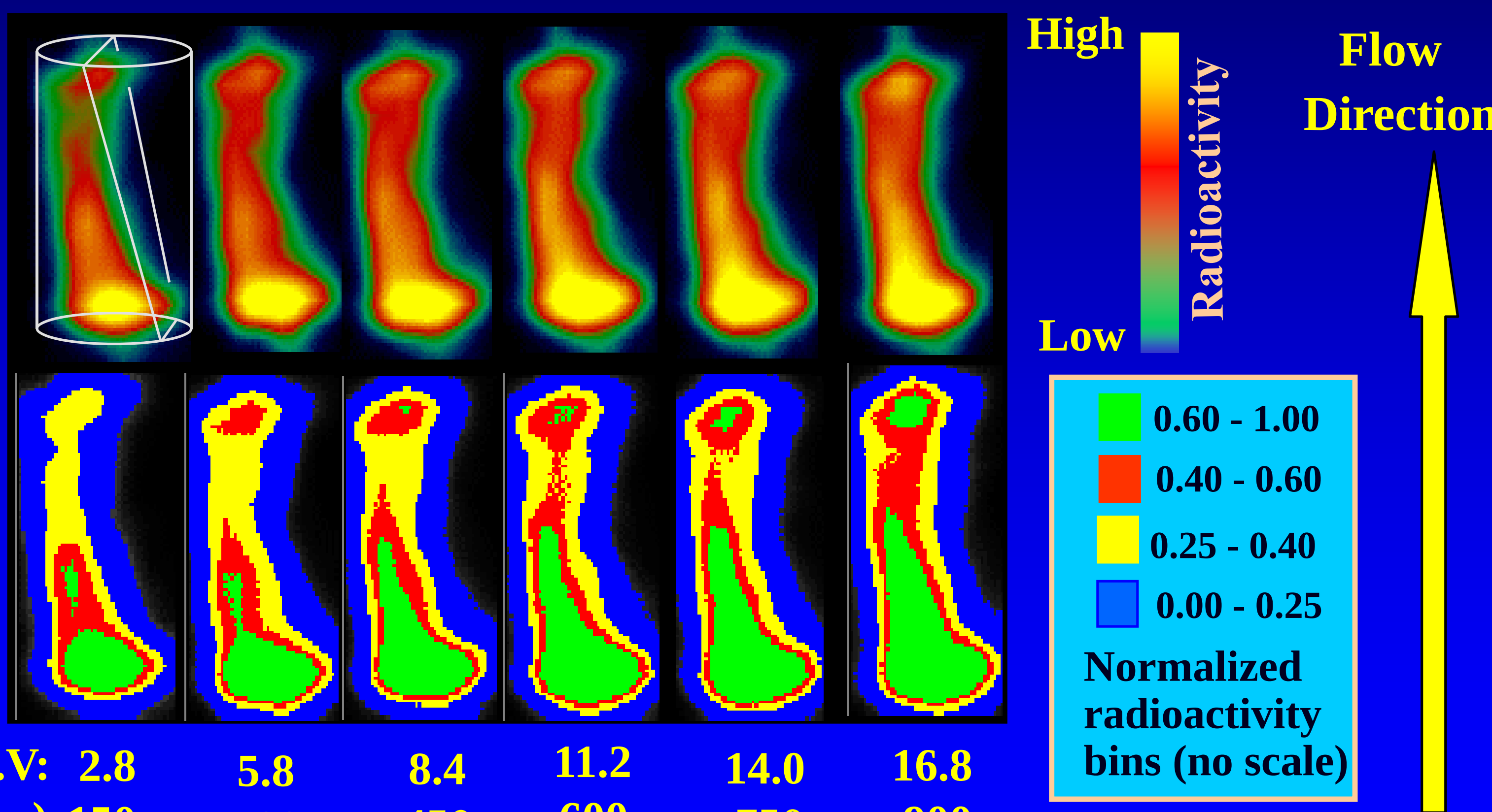
PET Imaging

- Uses
  - To trace any mobile chemical in a rock
  - Water and oil dynamic flow
  - Water and oil diffusion
  - Adsorbance of fluids to mineral surfaces
  - Transport of toxic and radioactive contaminants
  - Remediation of contaminants

PET Imaging

- **Example**

  Flow of water through a core containing deformation bands

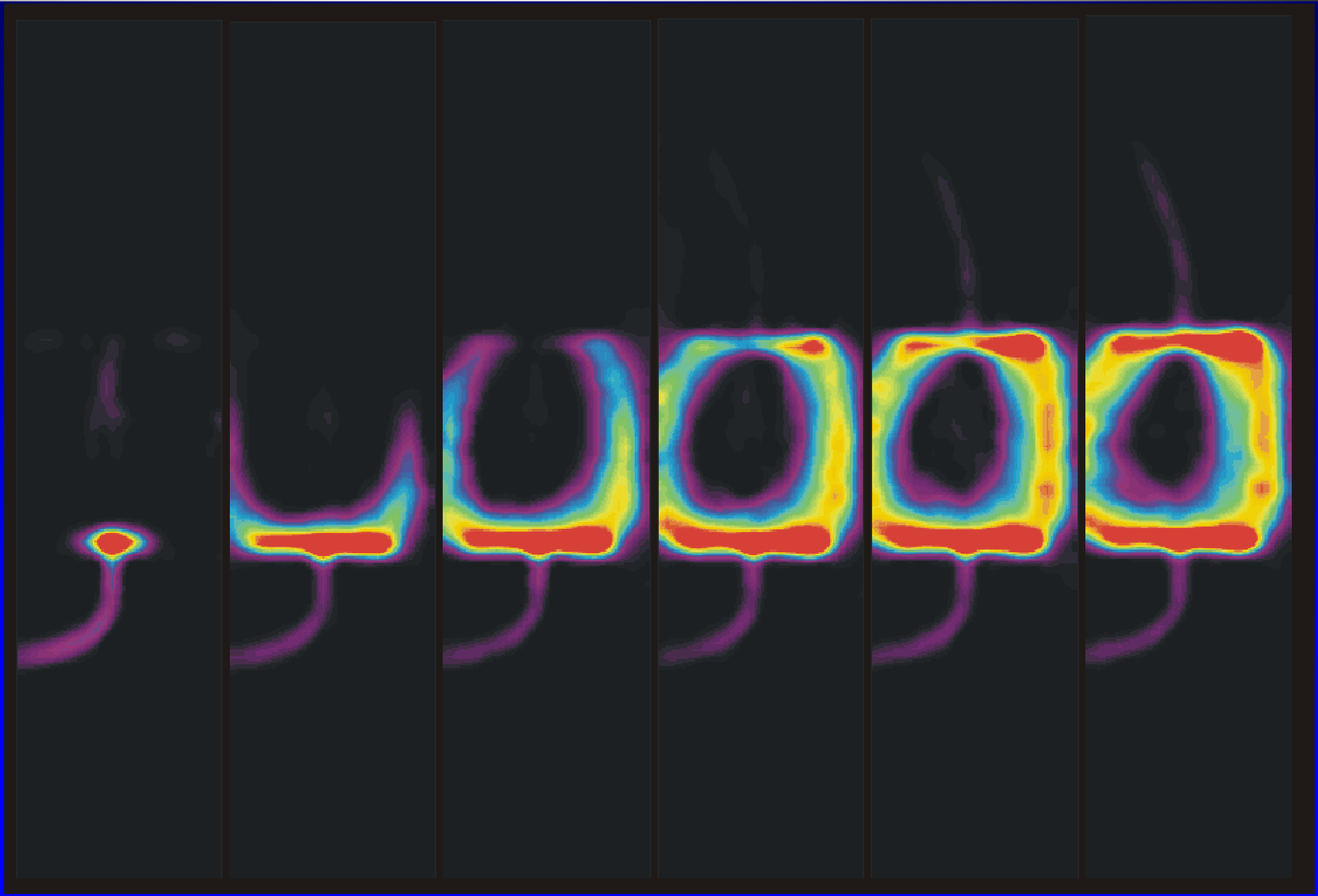


P.V:	2.8	5.8	8.4	11.2	14.0	16.8
T (sec):	150	300	450	600	750	900

PET Imaging

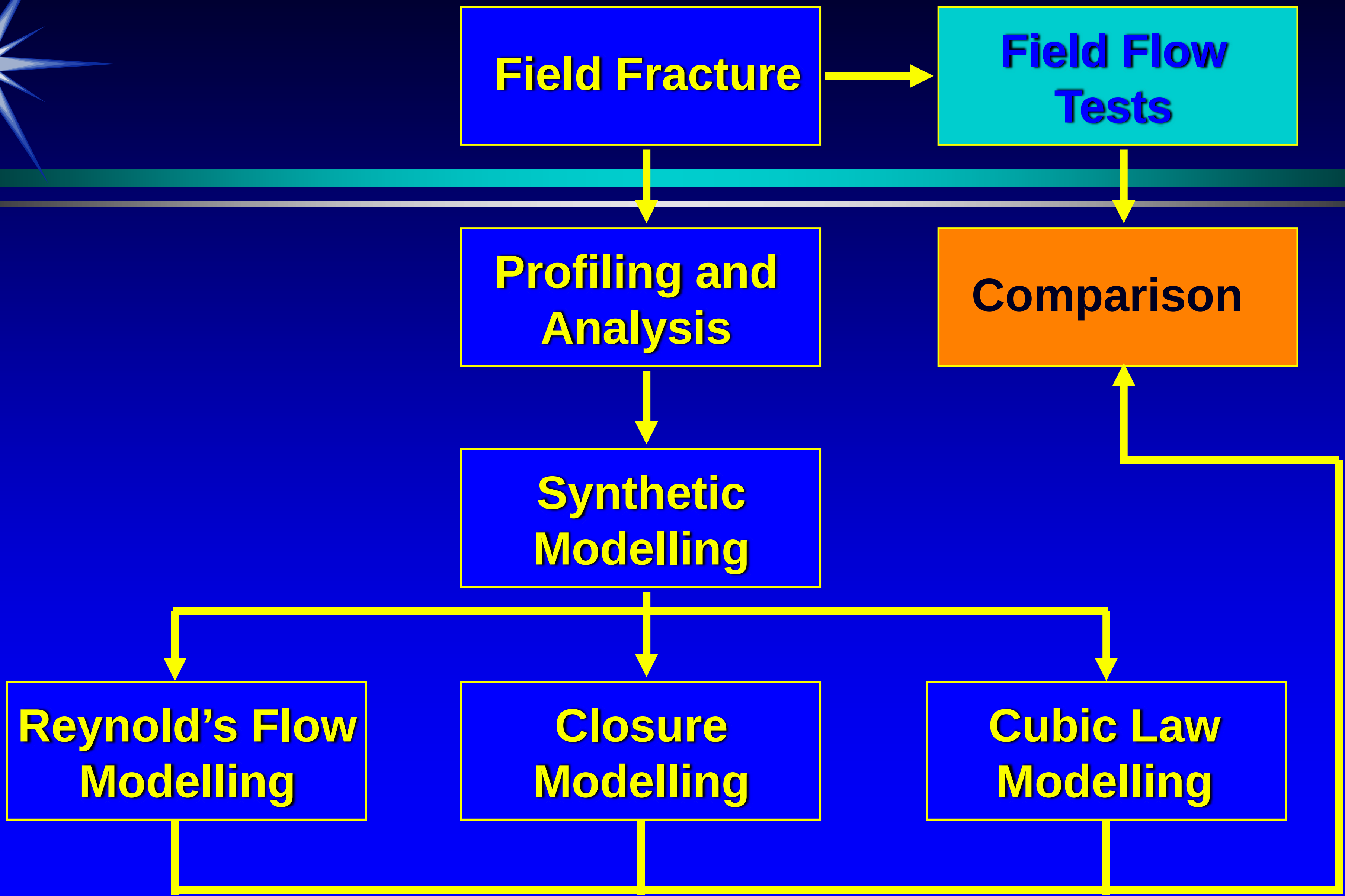
- **Example**

  Flow of water through a HFPM



Fluid Flow Modelling

- Mathematical Description
- Fracture Profiling & Analysis
- Synthetic Fracture Modelling
- Flow Modelling in the SynFrac
- Comparison with Field Flow


Field Fracture
Field Flow Tests
Profiling and Analysis
Comparison
Synthetic Modelling
Reynold's Flow Modelling
Closure Modelling
Cubic Law Modelling

Mathematical Description

- **Fracture surface needs 3 functions:**
  - **<u>Probability Density Function</u> of surface heights irrespective of spatial position**
  - **<u>Power Density Spectrum</u> for spatial correlation or texture of the surface**
  - **<u>Mismatch Wavelength Function</u> to separate matched & unmatched behaviour at long and short wavelengths**

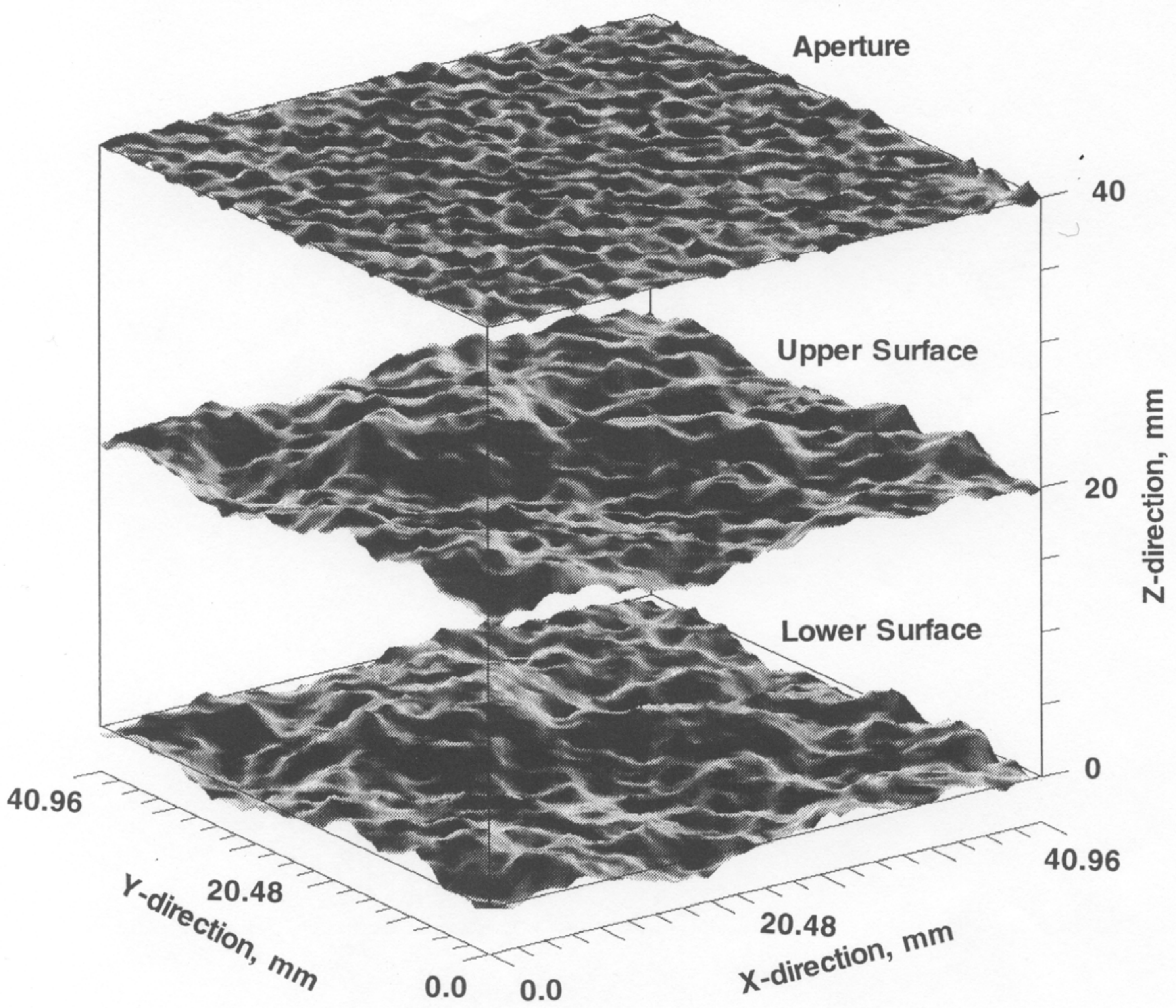
Synthetic Fracture Modelling

Spectral Synthesis Method Inputs

- Fractal Dimension
- Standard deviation of surface heights
- Anisotropy
- Lateral scaling parameters
- Mismatch wavelength control parameters

All obtained from profiling an original fracture

Synthetic Fracture Surfaces



Flow Modelling in SynFracs

Hagen-Poiseuille Cubic Modelling

- **Input:** **Mean geometric apertures**
  Fluid viscosities (T,P)
- **Output:** **Fluid transmissivity vs. normal closure**
  Fluid transmissivity vs. normal pressure
- **Results only valid for smooth parallel fractures!**

Flow Modelling in SynFracs

Reynolds Flow Modelling

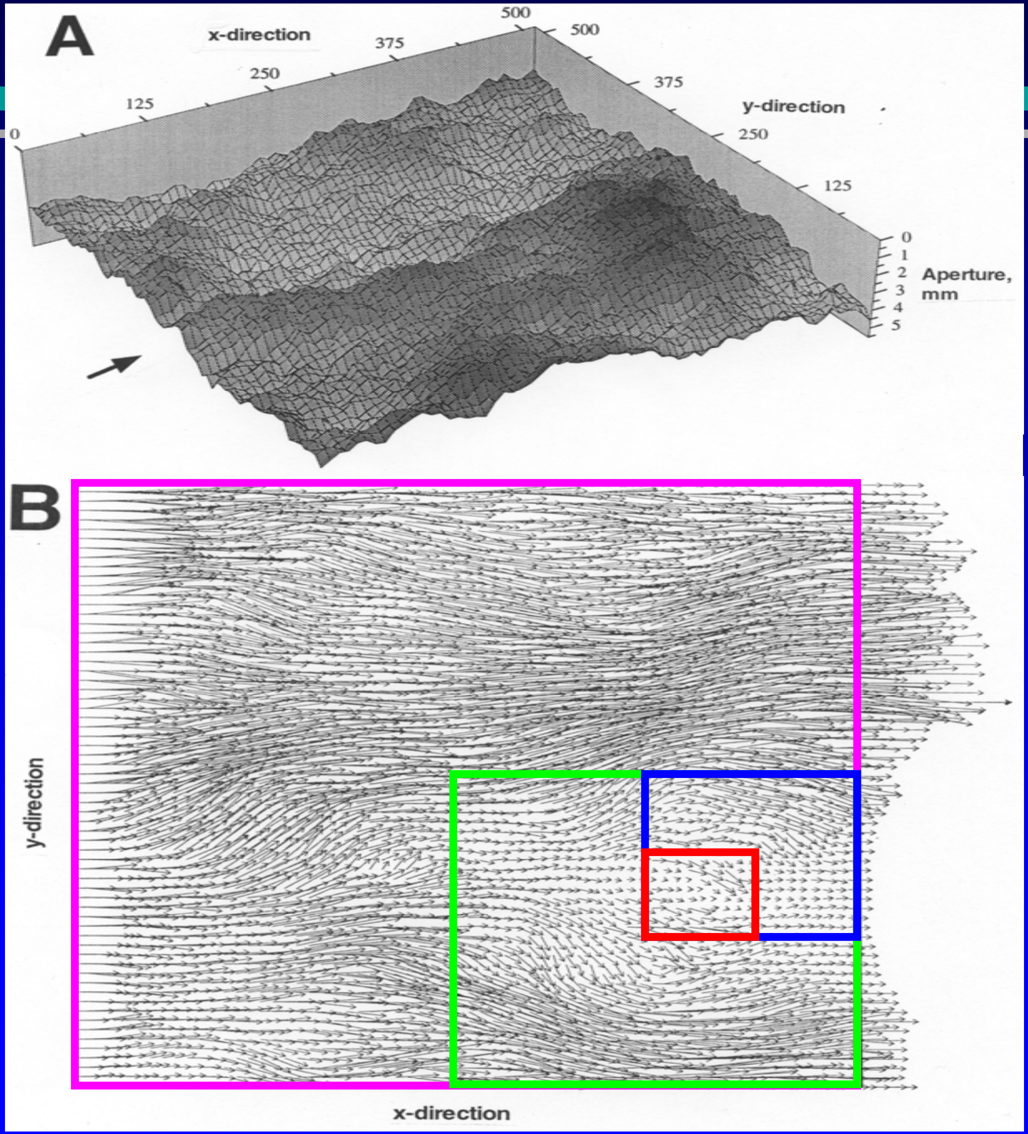
Reasons: Accounts for rough fracture surfaces

Application: Finite difference, full multi-grid with Gauss-Seidel pressure equations

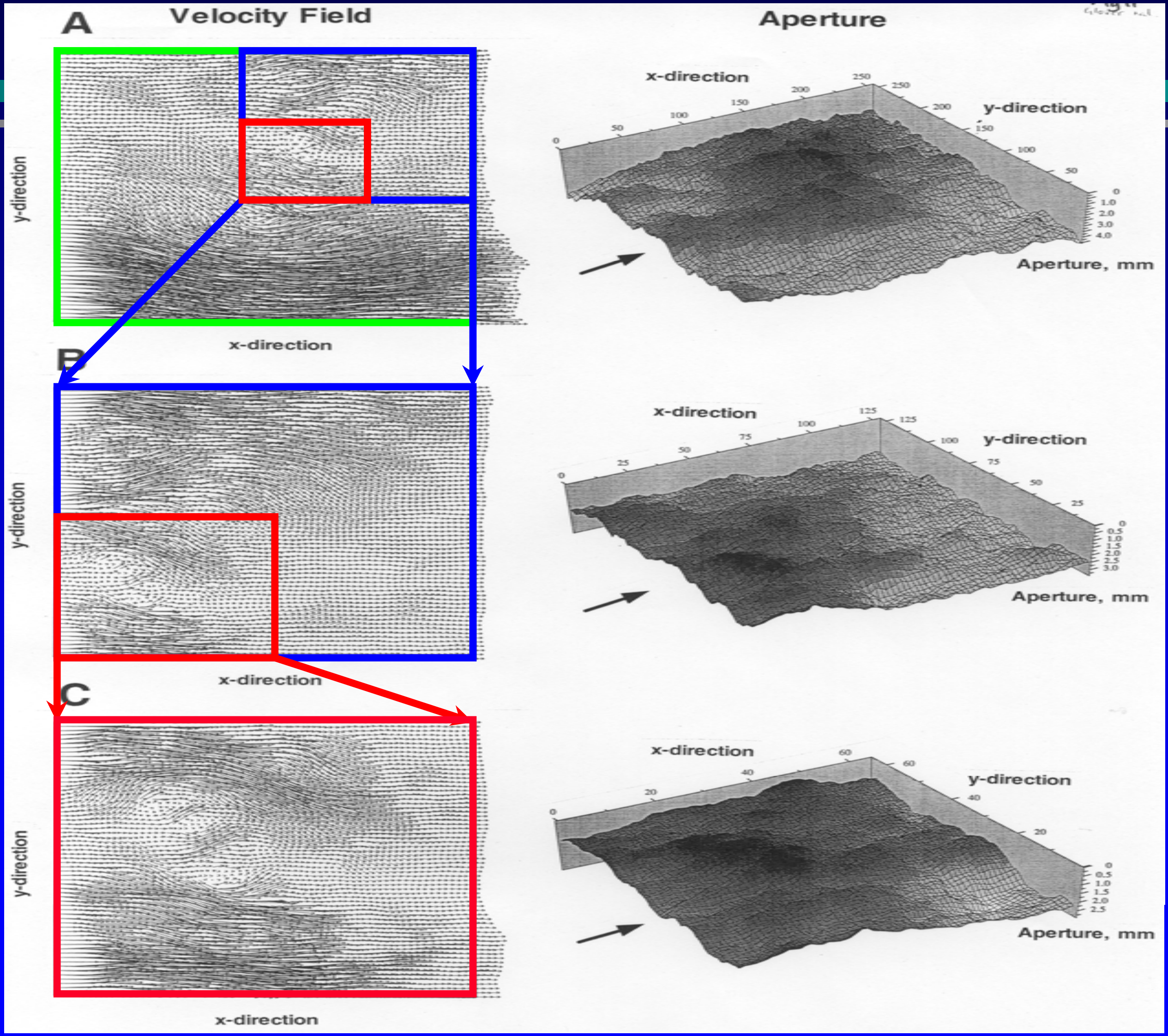
Machine: NEC SX3 & Cray-916 Computers

Output: Local fluid velocities
Mean hydraulic apertures

Flow Modelling in Synthetic Fractures



Flow Modelling in Synthetic Fractures



Comparison with Field Flows

Field Flow Tests

- Field transmissivity measured between 2 boreholes for different fracture fluid pressures

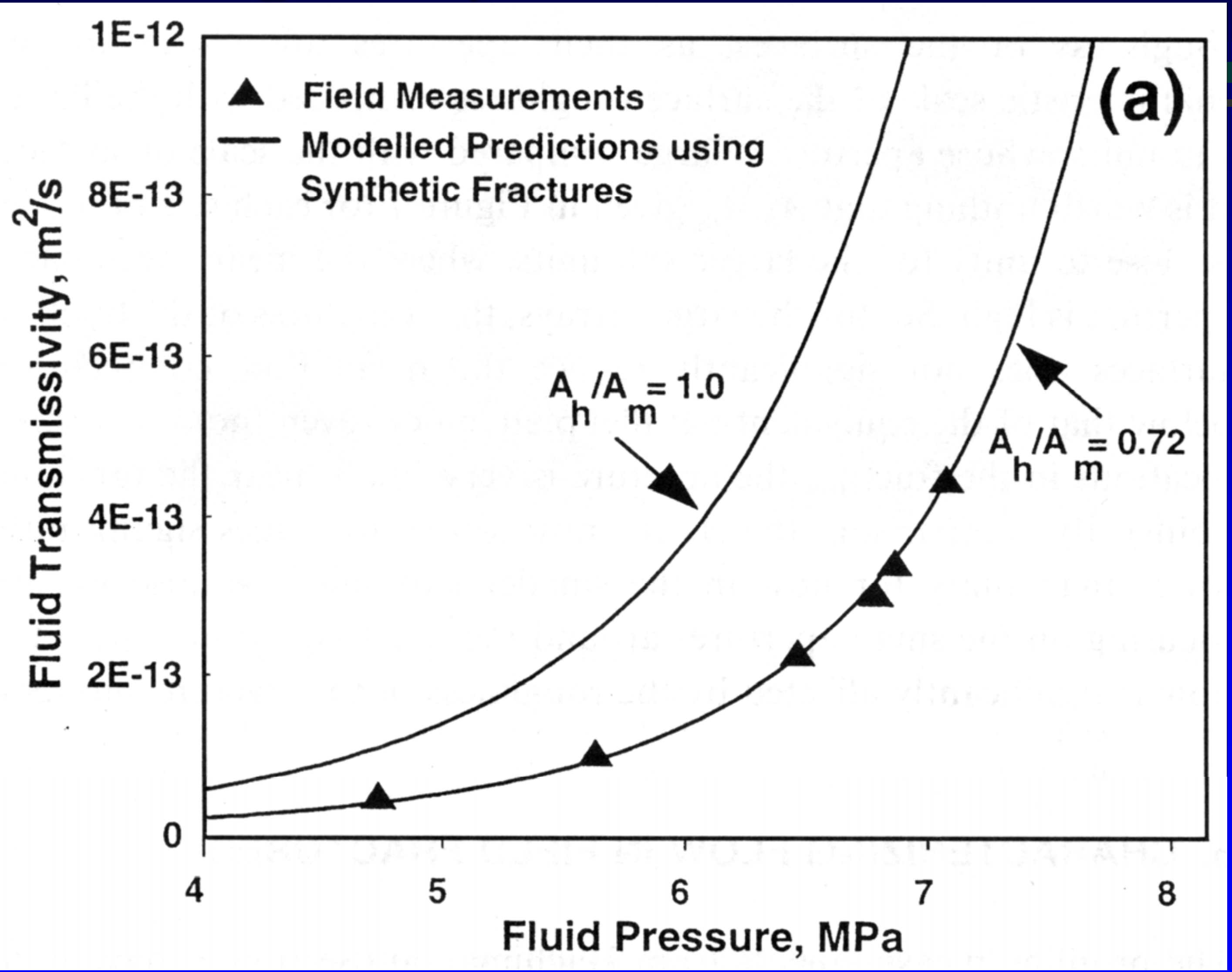
Modelling

- Fluid transmissivity vs. Fluid pressure
  - Hagen-Poiseuille with SynFrac closure apertures
  - Reynolds modelling, aperture touching once
  - Reynolds modelling for modelled SynFrac closure

Flow Modelling in Synthetic Fractures

Comparison with Field Data:

- Field Measurements from Hachimantai, Japan
- Hagen-Poisseuille Modelling, smooth parallel plates
- Reynolds Modelling with rough surfaces



Summary

- A number of new experimental techniques can be used to monitor fluid flow through rough fractures
- Rough fractures can be profiled, and numerical synthetic fractures can be produced to high precision
- These fractures mimic all characteristics of real fractures including their implicit matching scales
- Fluid flow modelling in synthetic fractures allow a comparison with field flow tests

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