High Resolution Aperture Determinations of Rough Fractures

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μ2M Natural Environmental Research Council

petrophysics.webhop.net

Background: Fractures

- The impact of fractures upon fluid flow has many practical applications:
  - Flow channelling and compartmentalisation in hydrocarbon & water reservoirs
  - Control of contamination by domestic & chemically toxic industrial waste, & remediation
  - Design of safe repositories for nuclear waste
  - Hot dry rock/Geothermal energy projects

Macro-Properties of Fault damage zone:-

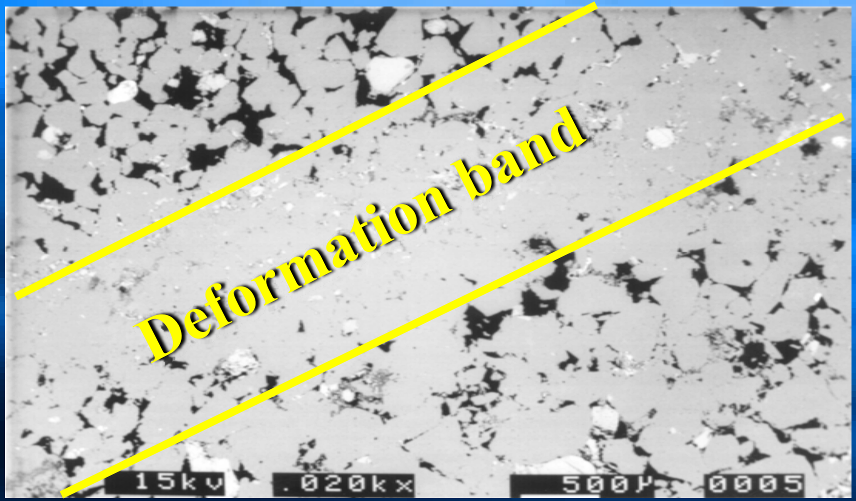
Type
Open
Vs
Closed
Fractures

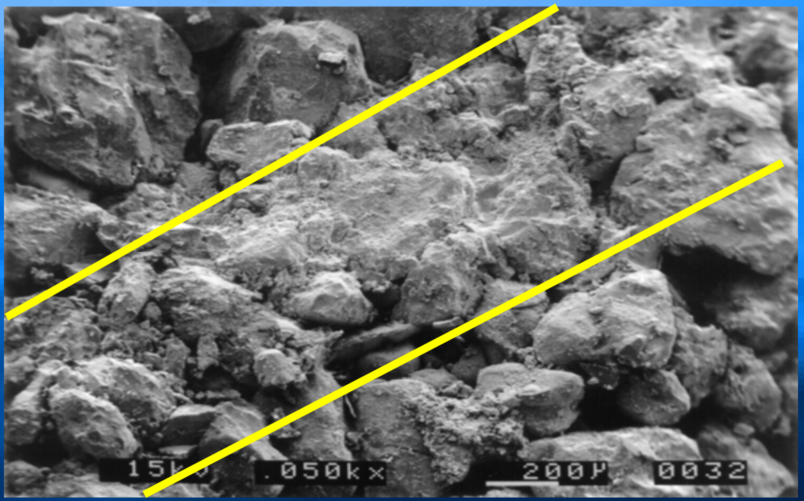
Cements

Fracture cements: Large "geohistory" component to fault-seal analysis:-

- Timing
- Lateral continuity
- Volumes & distribution
- Types & Origin

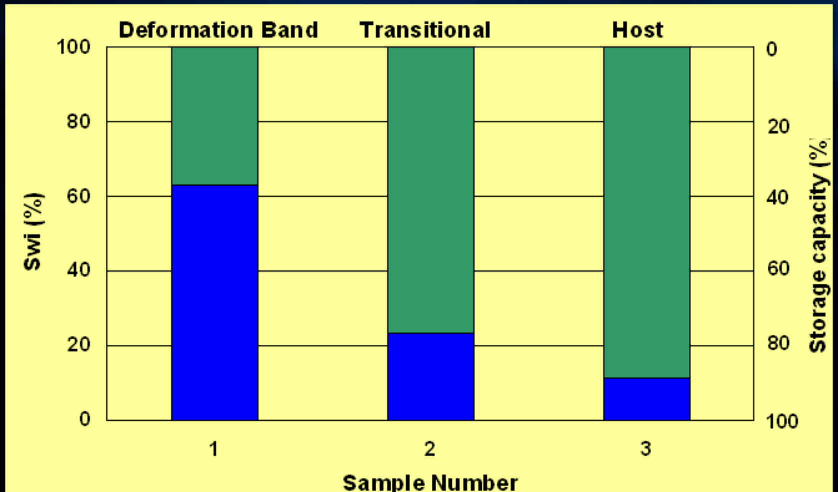
Micro-Scale Analysis



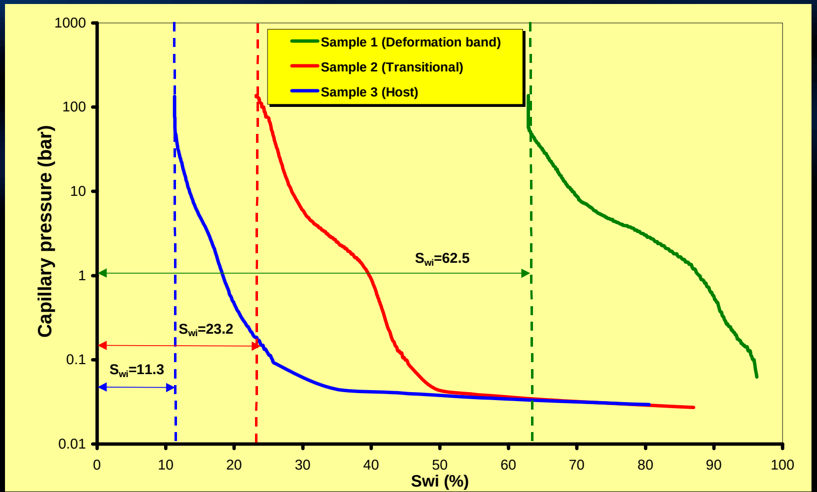


Sample number	Sample Location	Swi (%)	Porosity (%)			Klinkenberg Permeability (mD)	
		MICP	Helium	MICP	Image analysis	Kn	PDPK
1	Deformation band	62.5	13.3	9.01	4 - 10	555	0.0034 - 397
2	Transitional	23.2	20.5	18.35	10 - 15	677	29.6 - 899
3	Host rock	11.3	25	19.95	15 - 21	1750	397 - 3080

Storage Capacity



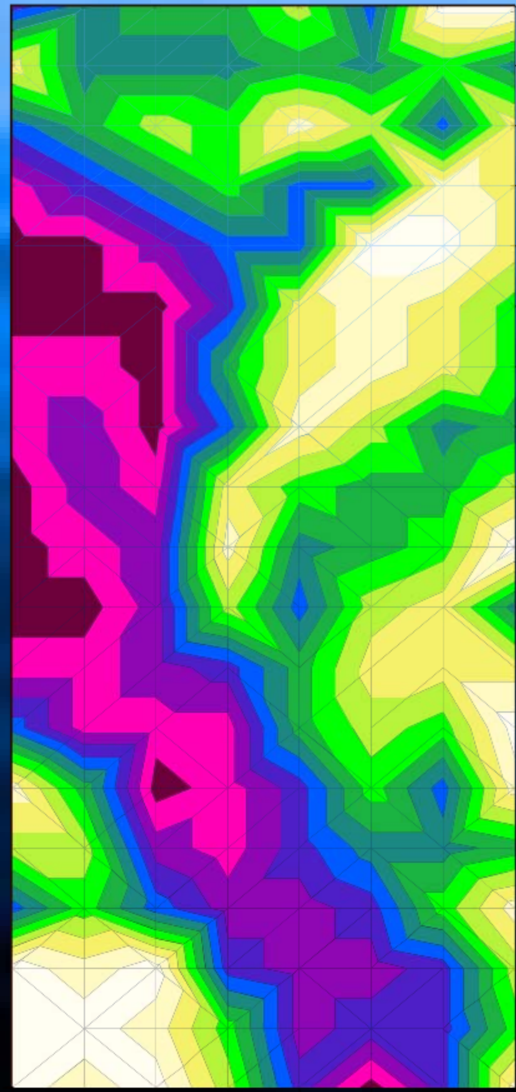
Swi and Capillary Pressure



Permeability Profiles

Legend

0.0034	to	2.35
2.35	to	29.6
29.6	to	192
192	to	397
397	to	682
682	to	785
785	to	899
899	to	1090
1090	to	1220
1220	to	1420
1420	to	1850
1850	to	3080



1 cm grid resolution

Highly porous sandstone

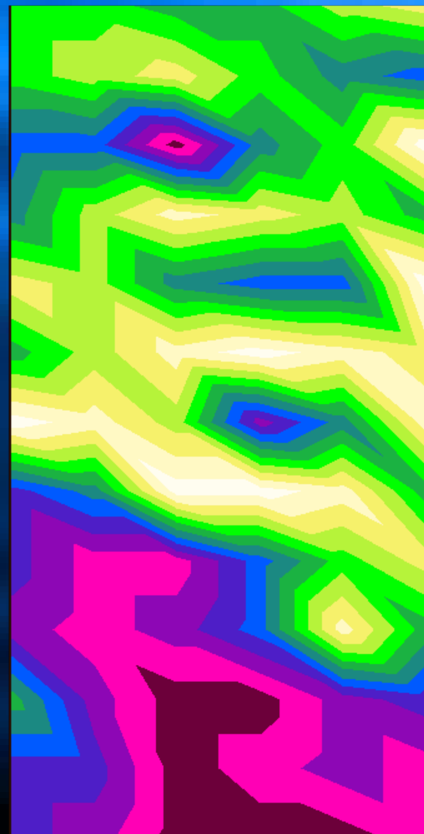
Zone of cataclastic faults in porous sandstone

Permeability Profiles

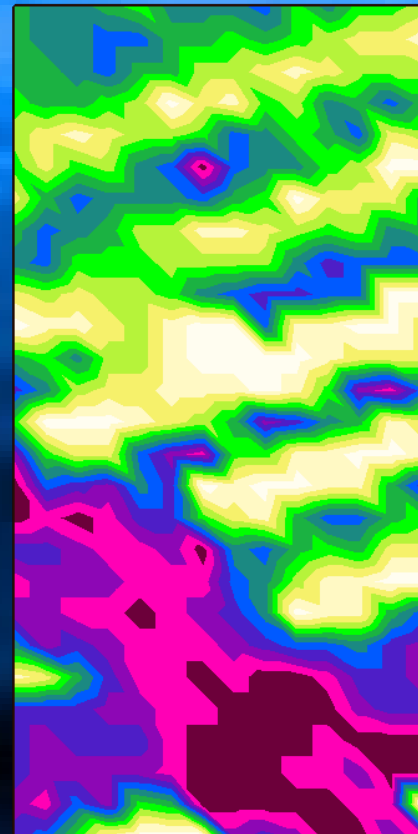
Legend

	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

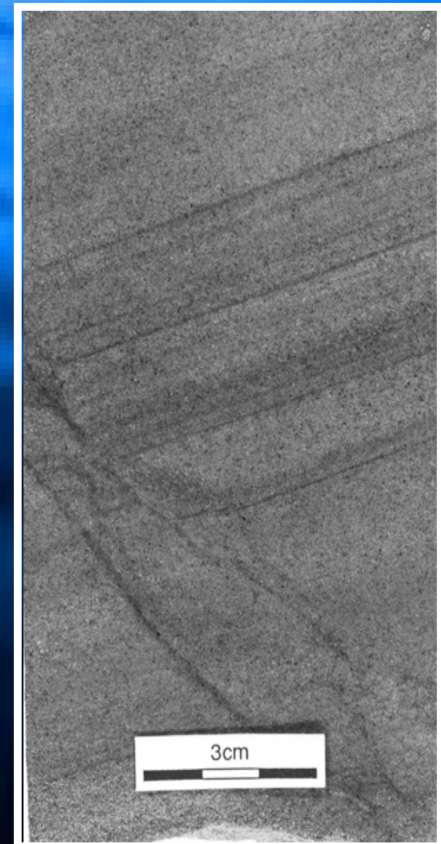
Clay-rich faults in immature sandstone



1cm grid resolution



5 mm grid resolution



Clay-rich sandstone

Surface Roughness Profiling

- In absence of filling materials, flow of fluids controlled by roughness of fracture walls & physical separation
- Stress regime, mean aperture, fluid properties and flow rate etc. also affect fluid flow
- Fracture roughness profiles measured using mechanical profilometers and optical methods:-
  1. Time consuming
  2. Expensive
  3. Low resolution

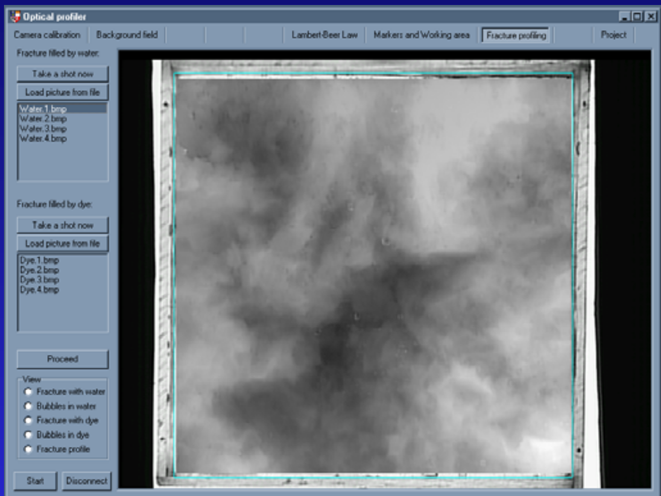
Rocks

1 sandstone, 1 limestone, 1 granite, 1 grano-diorite, 2 syenites

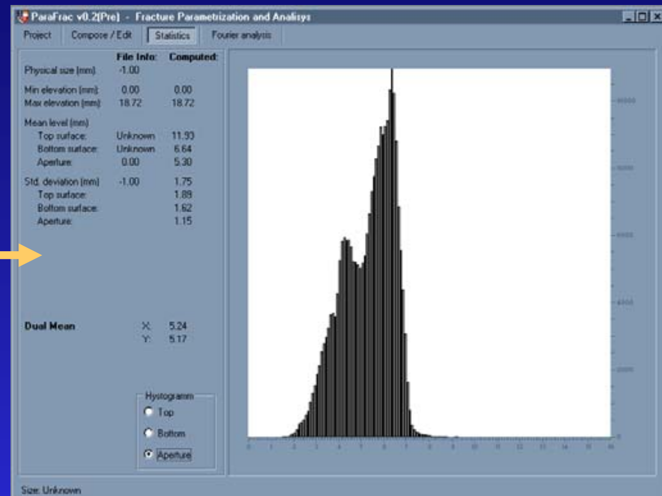
Petrophysical data:

1. Porosity (effective & non-effective)
2. Permeability (K_L)
3. Grain density
4. Water saturation
5. Capillary pressure
6. Composition

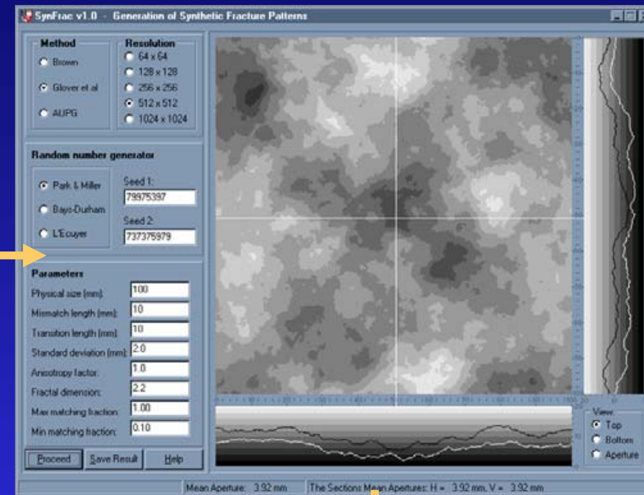
The Framework



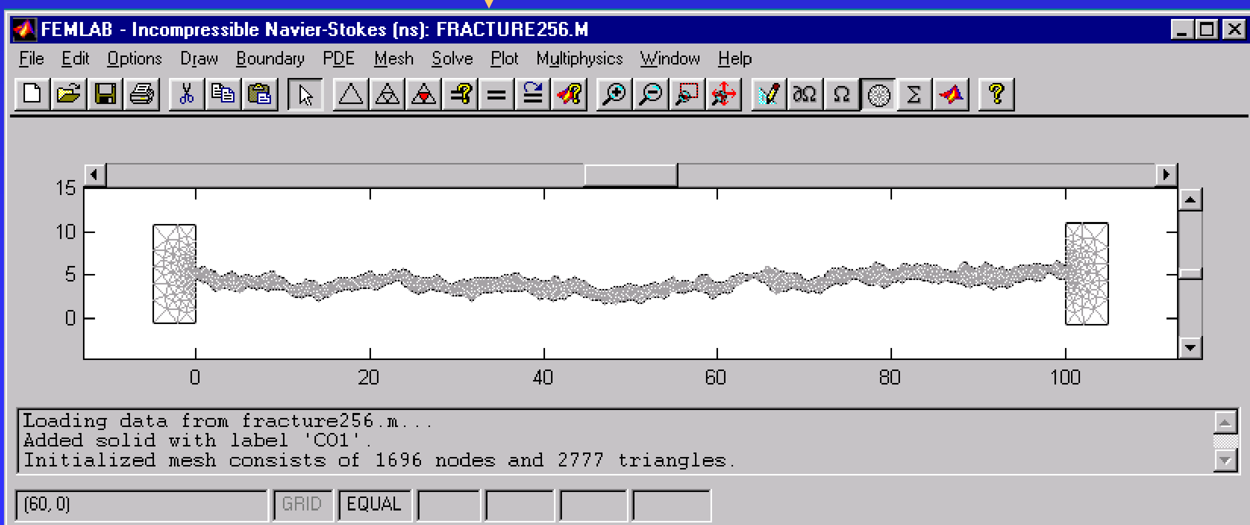
OptiProf (v.0.8)



ParaFrac (v.0.5)

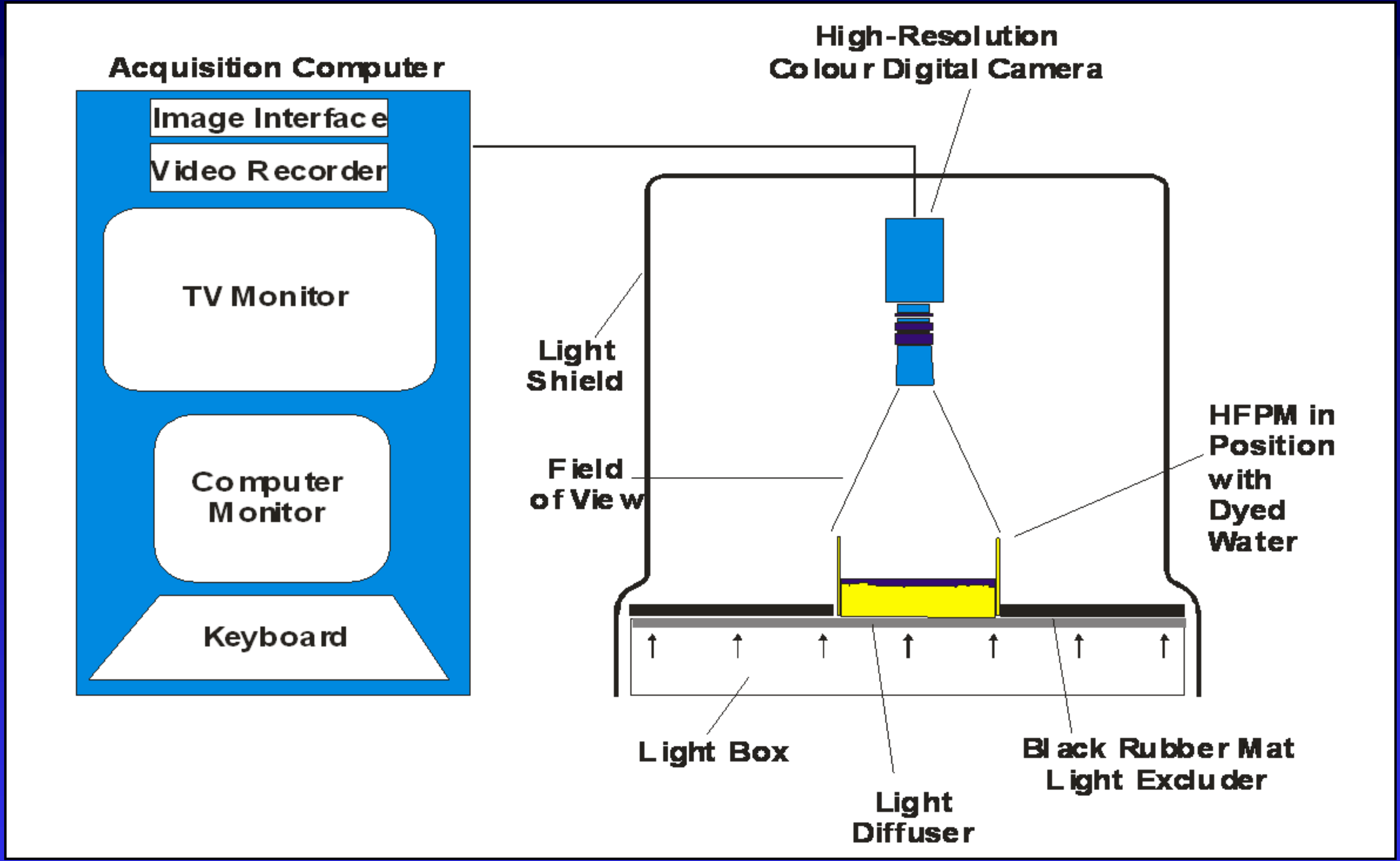


SynFrac (v.1.0)



Comsol FEMLAB software for physical processes modelling

Digital Optical Imaging

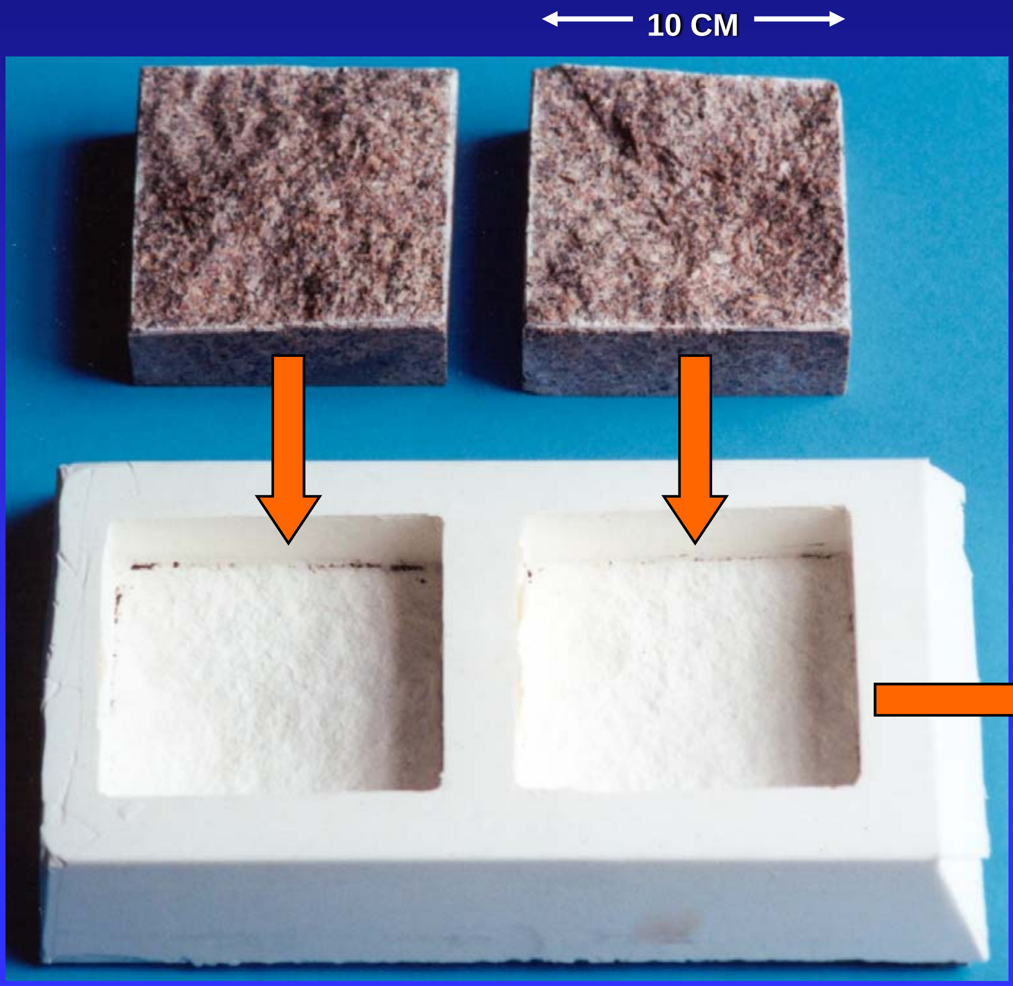


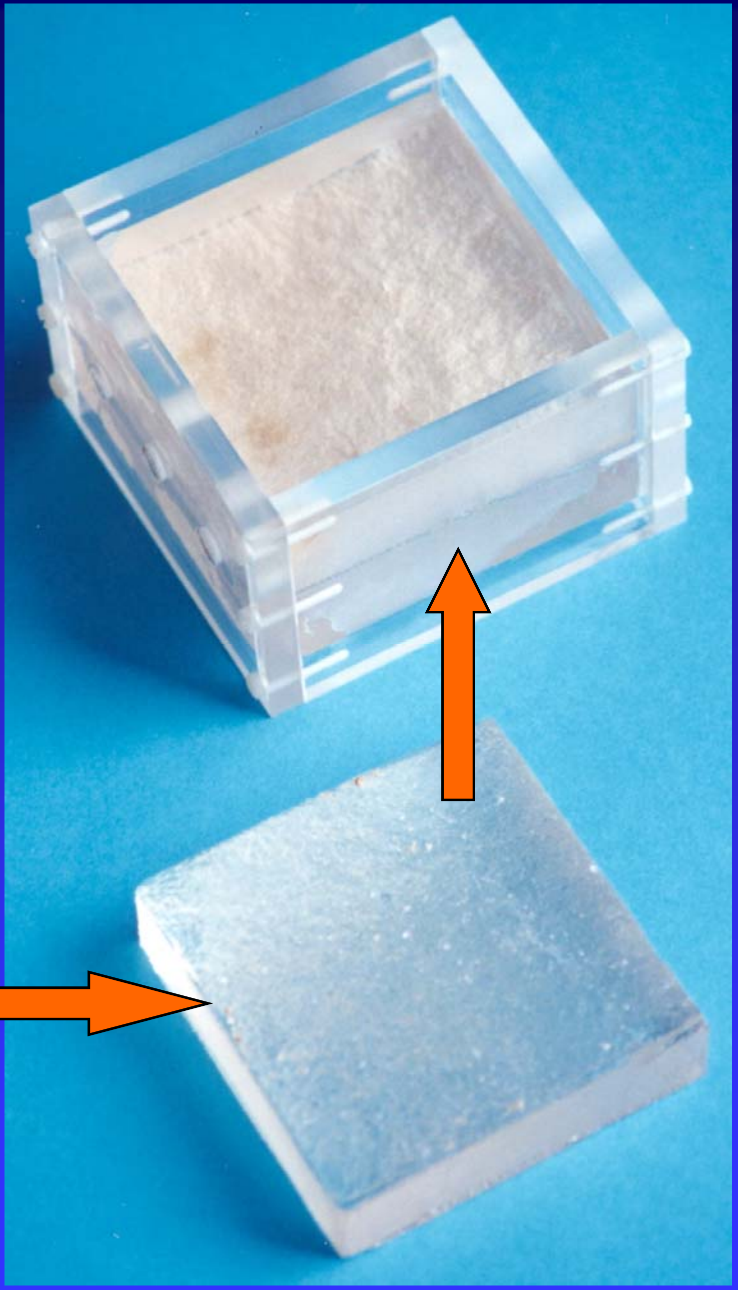
Resolution of method:

Camera pixel array: 640 x 480 (307200 pixels).
Widest zoom: 100 x 100 mm of fracture surface imaged with resolution of 200 μm. Highest Zoom mode, 10 x 7.5 mm of surface imaged with resolution of 15.6 μm.
Vertical resolution same as above at 8-bit grey-scale depth.

HFPM Construction

HFPMs produced by casting from moulds of rock fractures

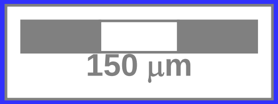




HFPM Resolution

SEM used to see how well and to what scale the original rock has been reproduced in the epoxy resin replica. Resolution = 1 micron

◆Original Fracture

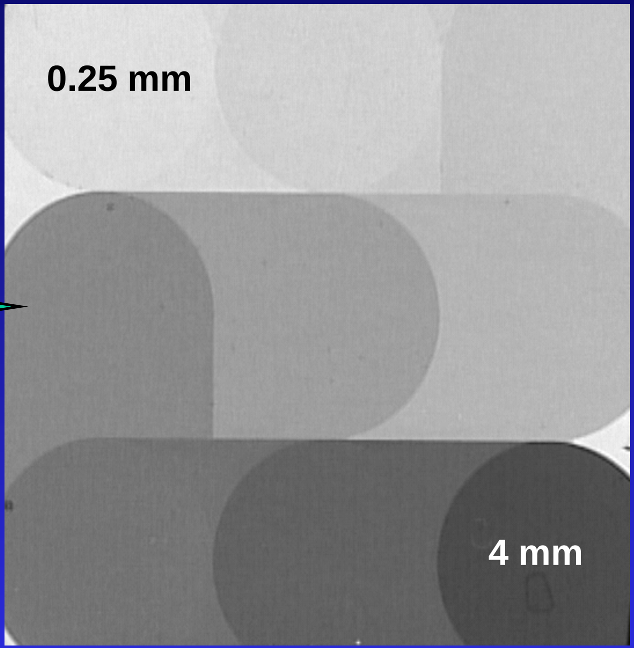


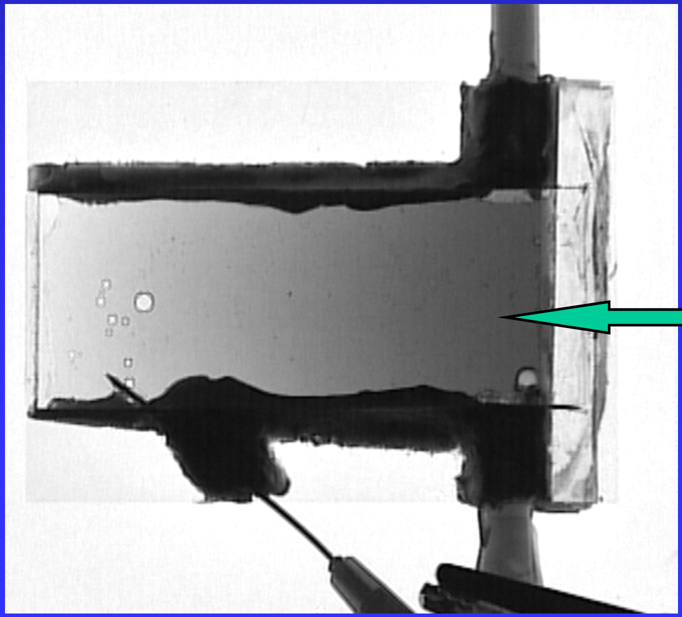
◆HFPM

Optical Profiling

Calibration Devices

Tile with pocket areas of known thickness filled with dye (1g/l). Greyscale image obtained

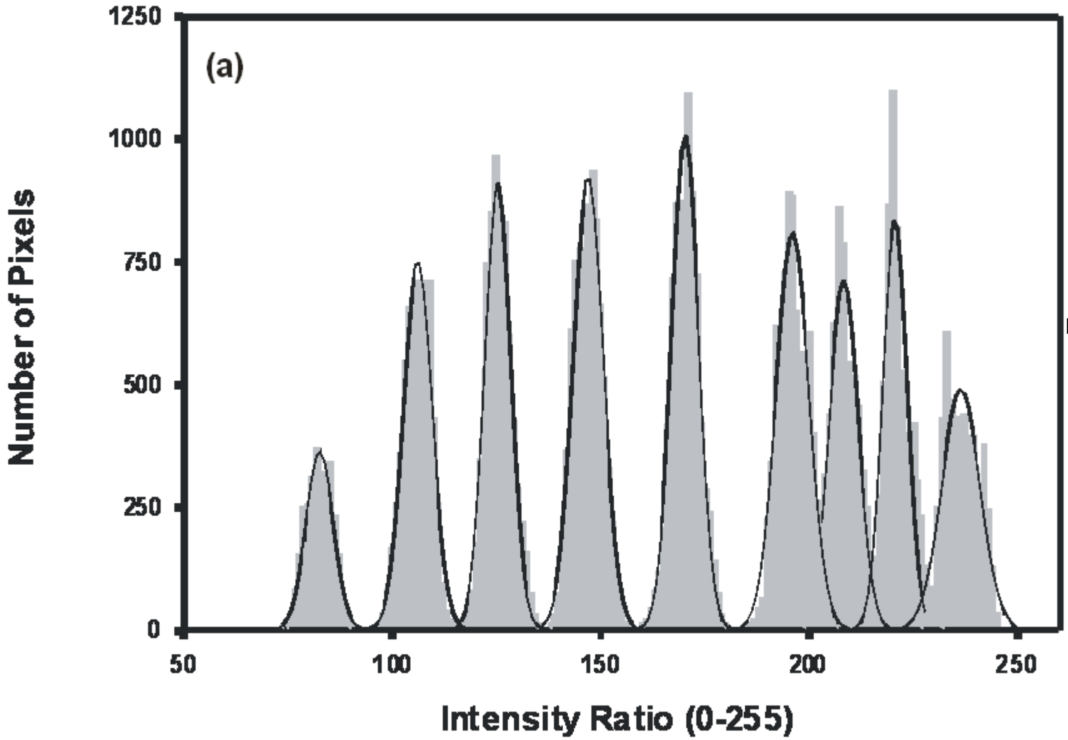


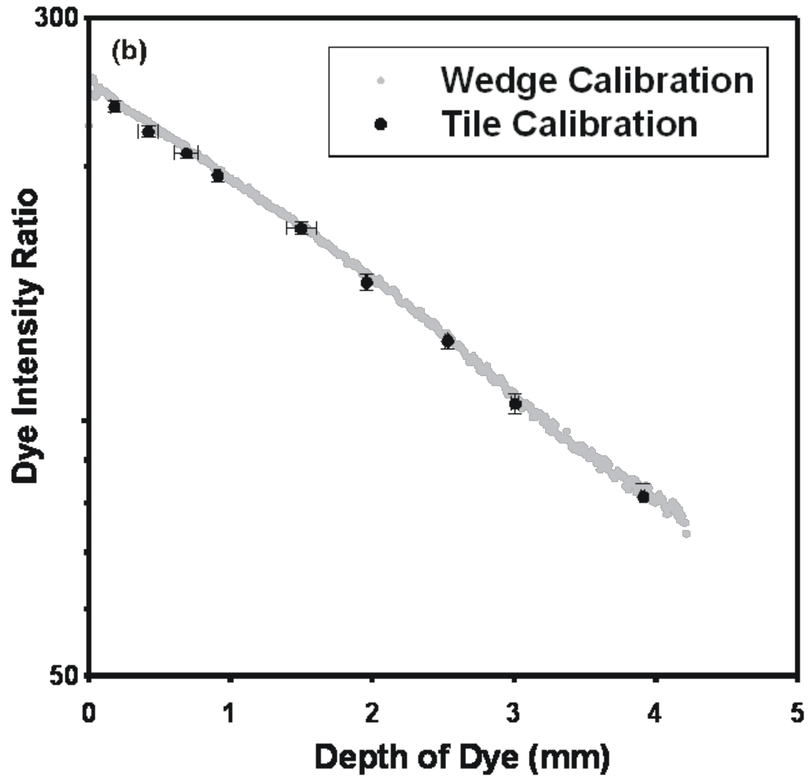


Supporting data from wedge with max thickness of 4.3 mm

Calibrating the Dye

Individual tile pocket intensities





Optical Profiling of Fractures

Computational Flow Models require the geometry of flow channel to be prescribed. An optical method was chosen to explore the fracture surface profiles.

Features of the choice:

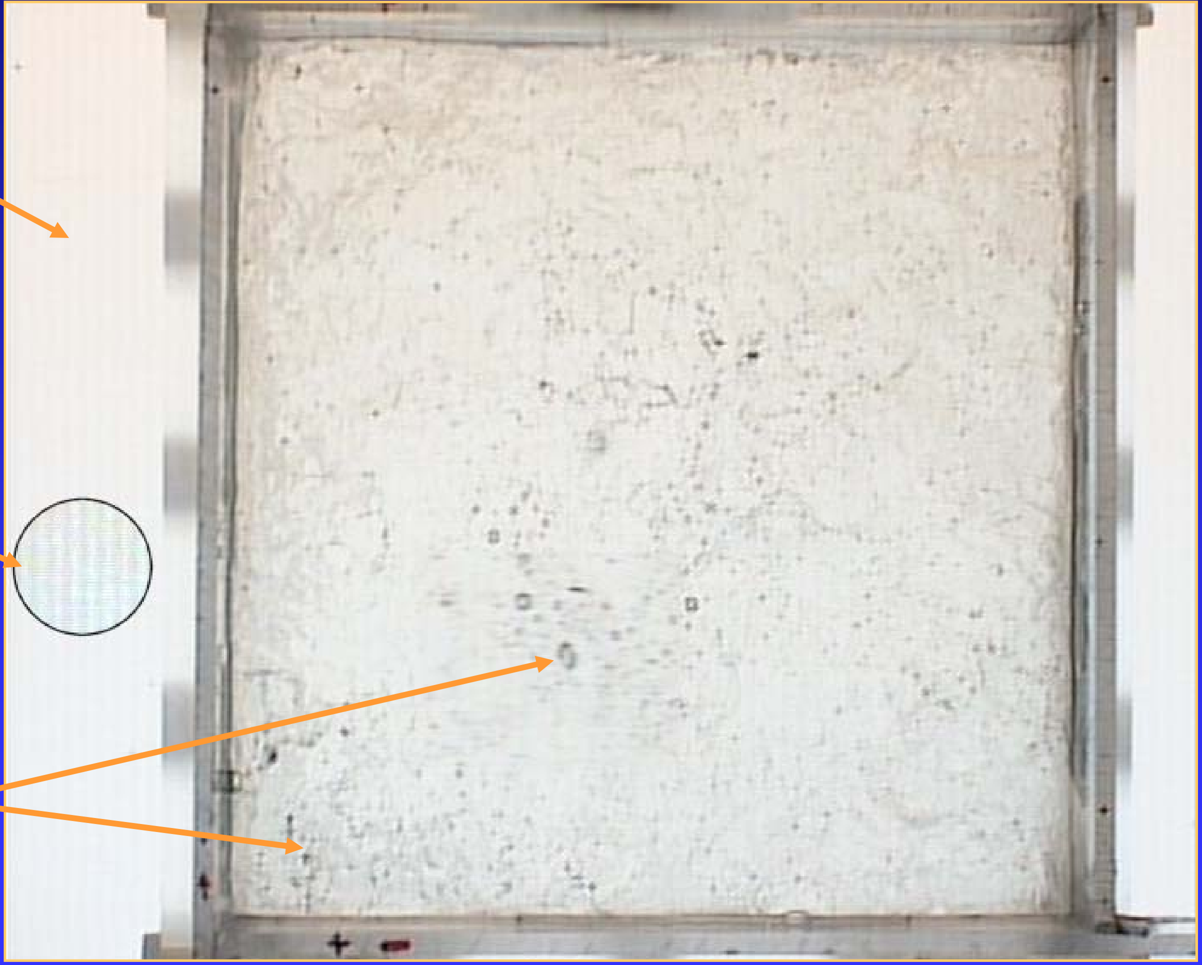
- **Cheap, does not require an expensive equipment.**
- **Fast (relatively), whole fracture surface to be scanned simultaneously.**
- **Accuracy of the method is subject of particular technique to be used.**

Technical Reality

Non-uniform backlight

Video channel distortions:
Coarse structures
CCD noise

Bubbles and particles in the liquid (water or dye)

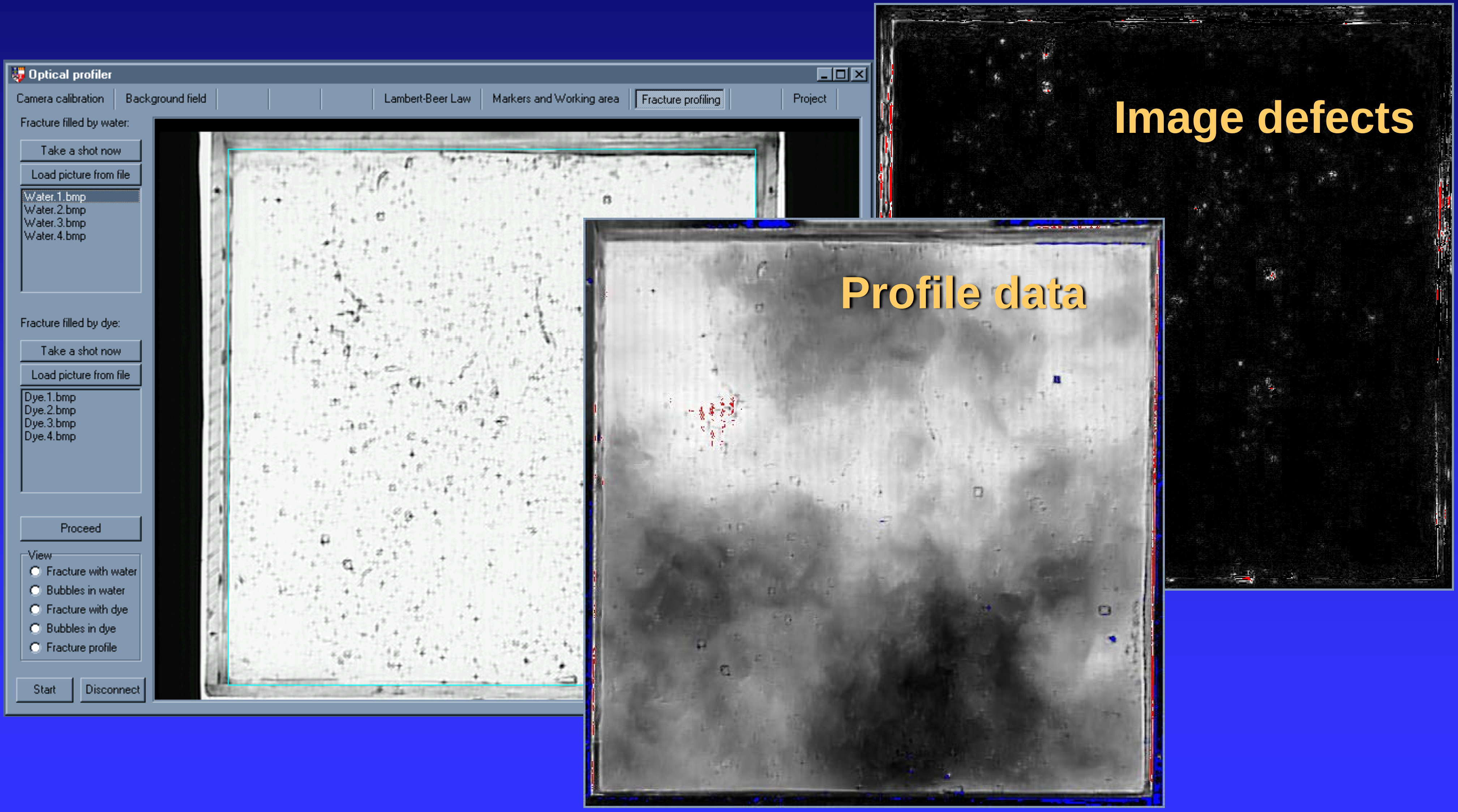


Profiling Methodology

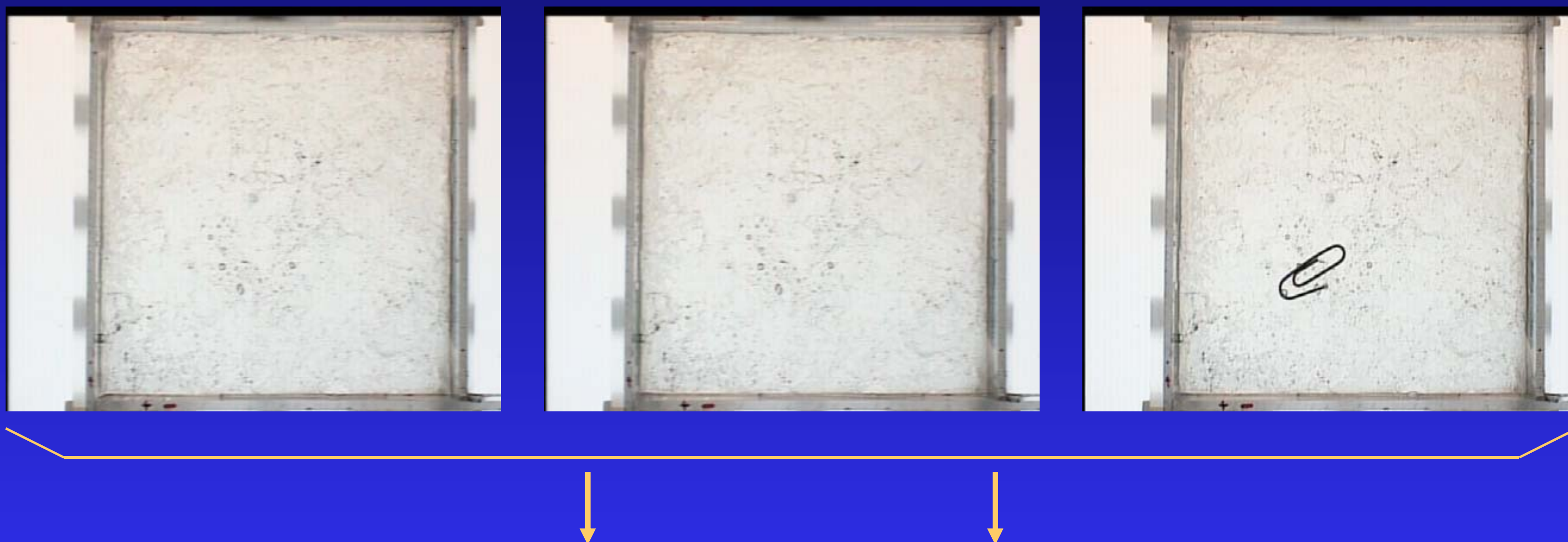
- Individual calibration of the pixels of CCD matrix.
- Stacked images to be taken with further averaging to neglect the camera noise.
- Clearfield equalization.
- Comparison of several images allow to recognize effectively bubbles and particles in liquid.

The methodology is implemented as a software algorithm.

Profiling Software



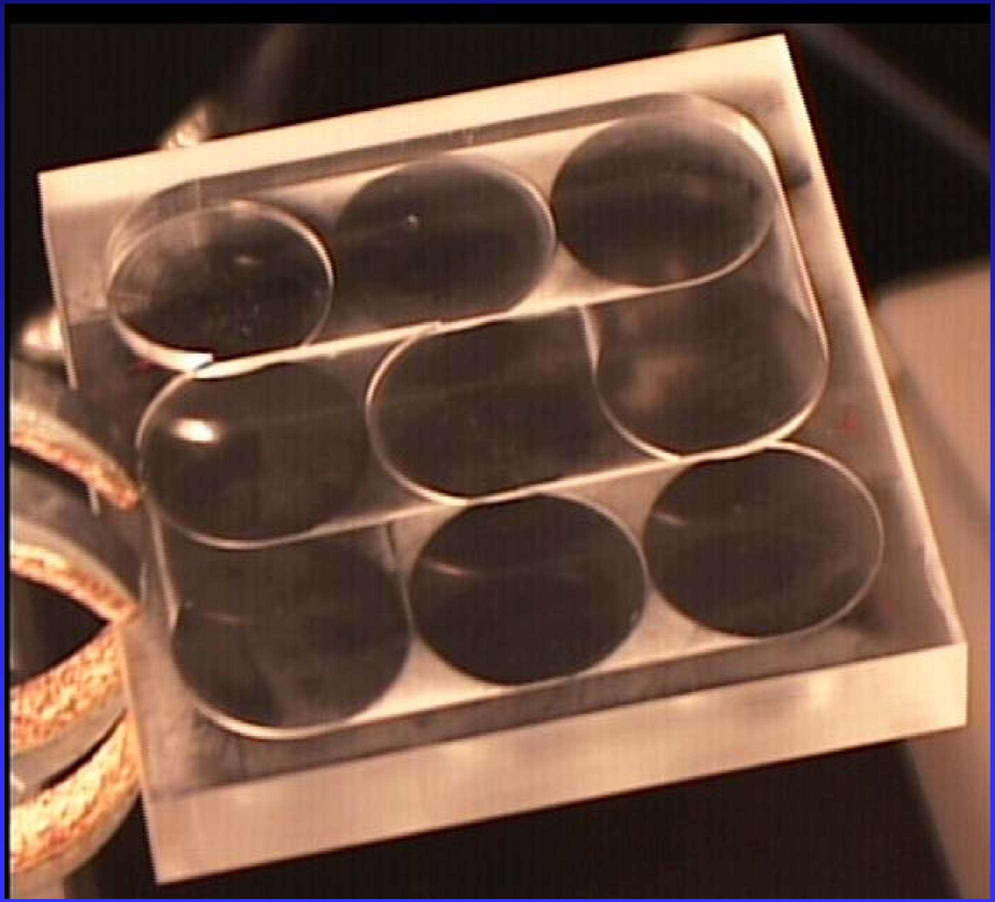
Automatic Defect Recognition

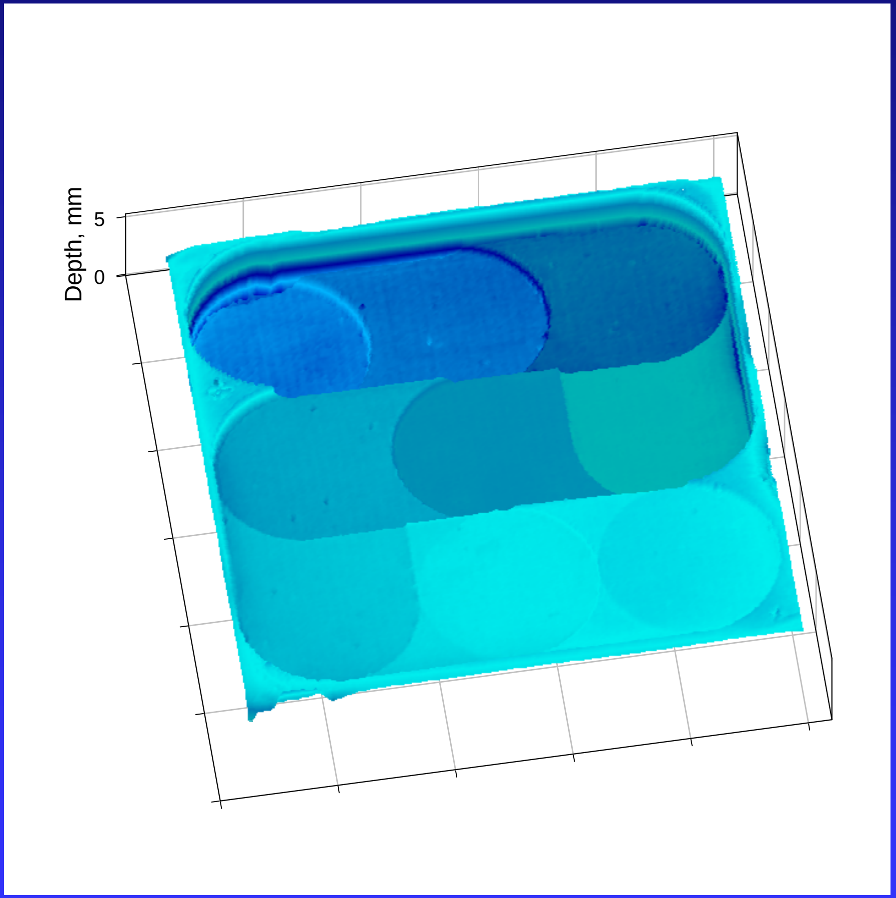


Resulting image

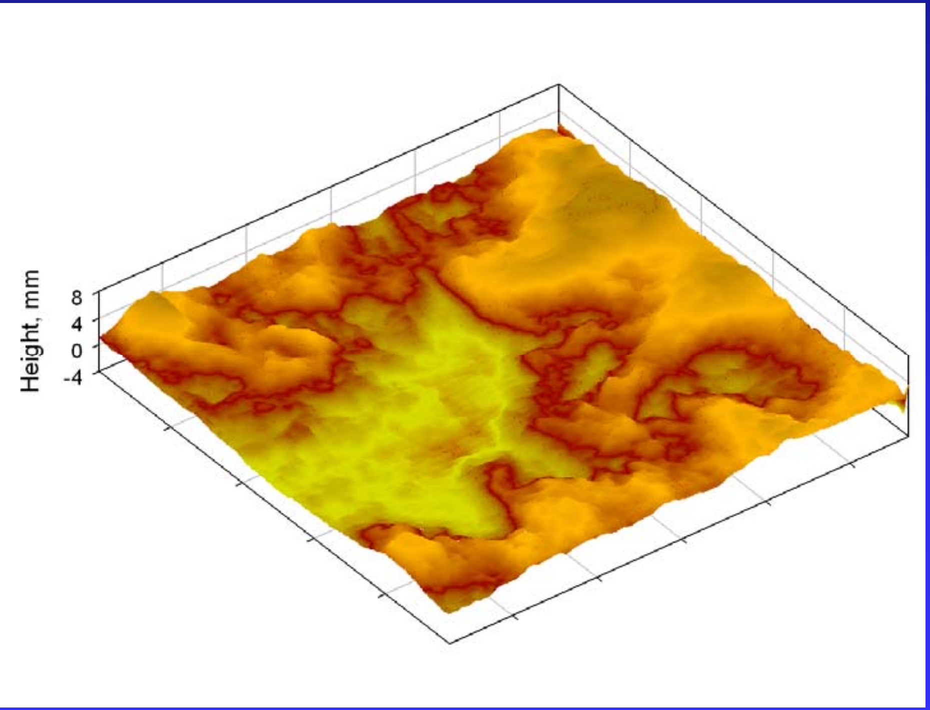
Defects map

Sample of Profiling Result

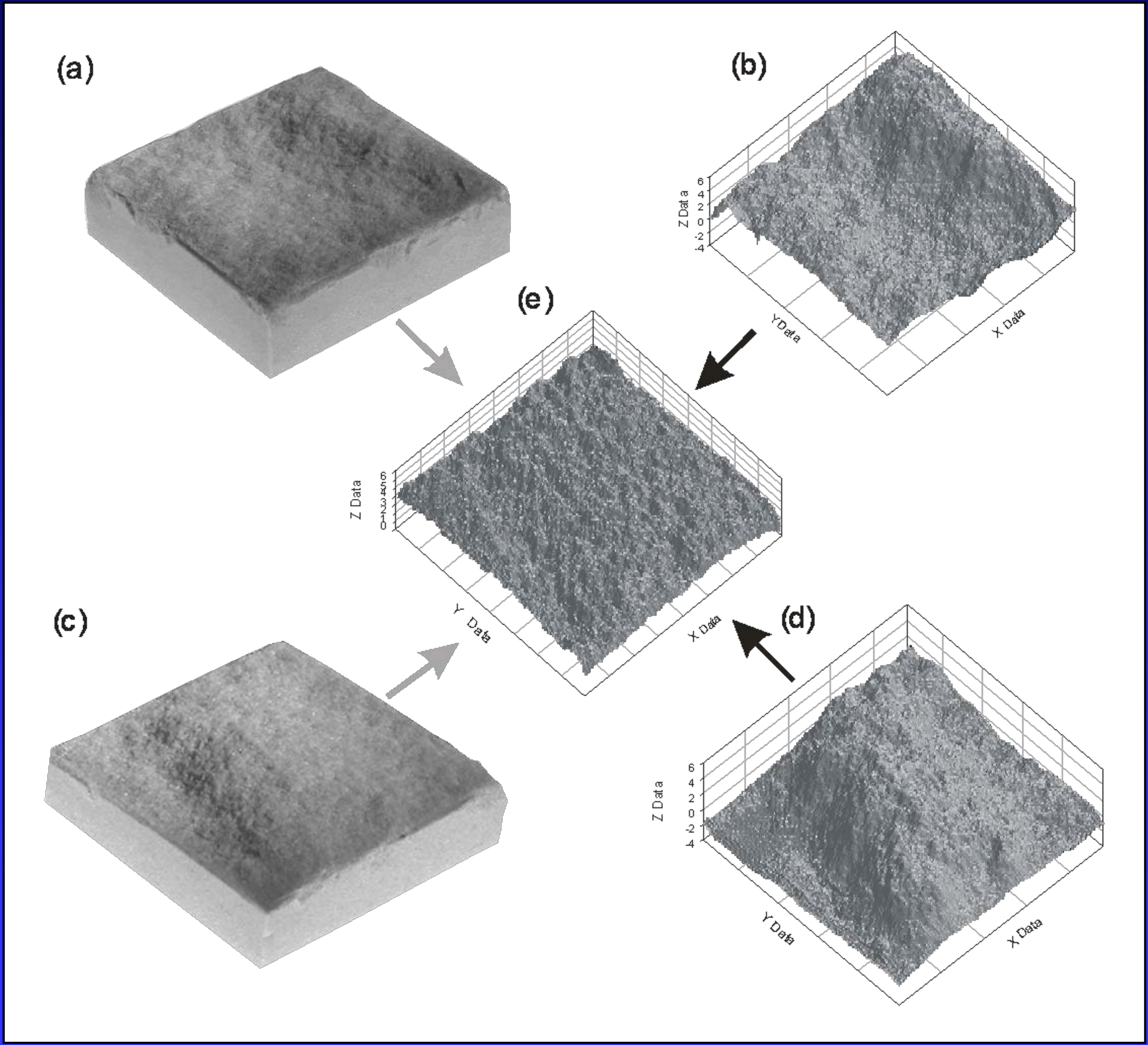




Profiling Sample: Red Granite

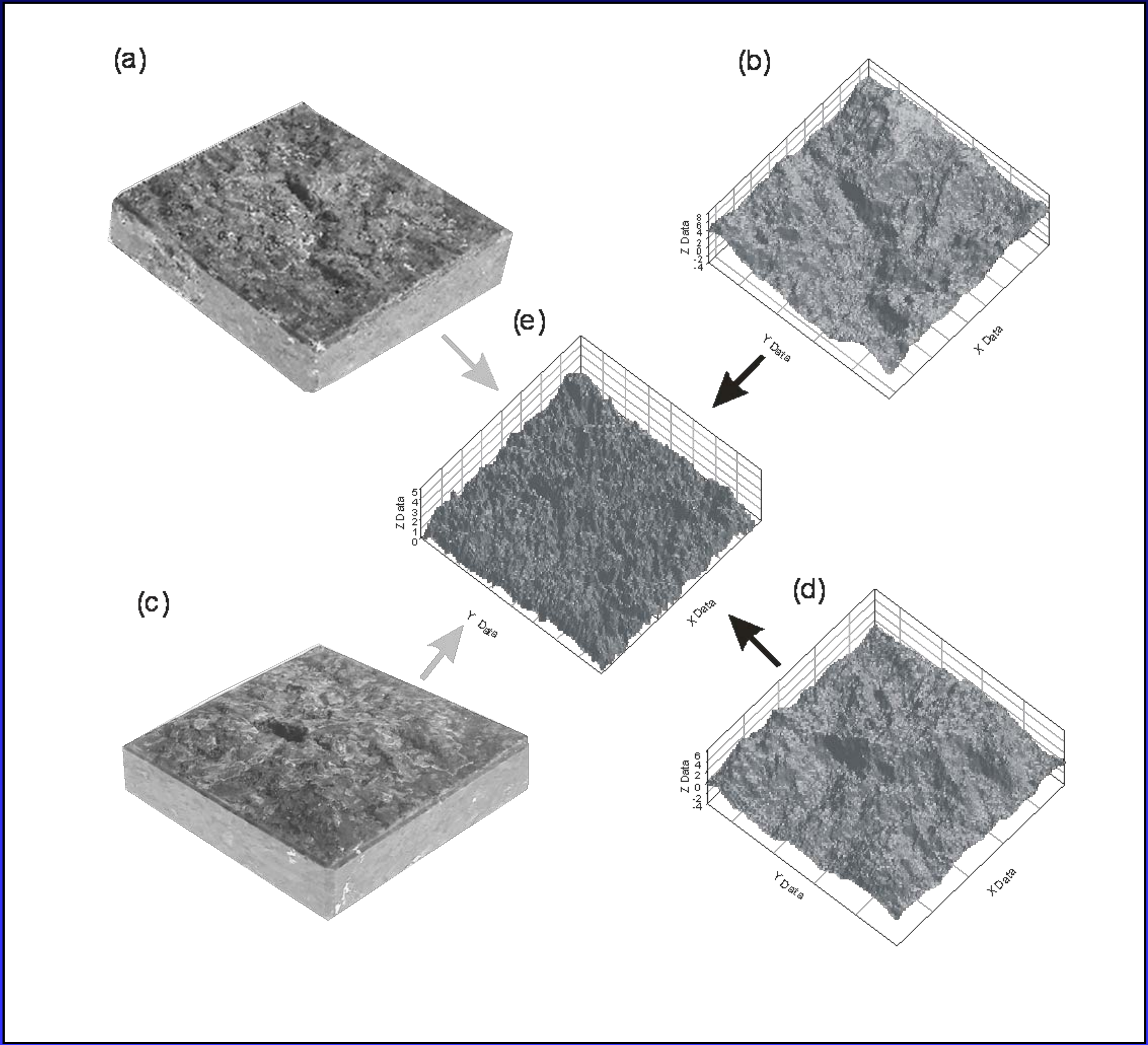


Fracture Profiles & Aperture Maps



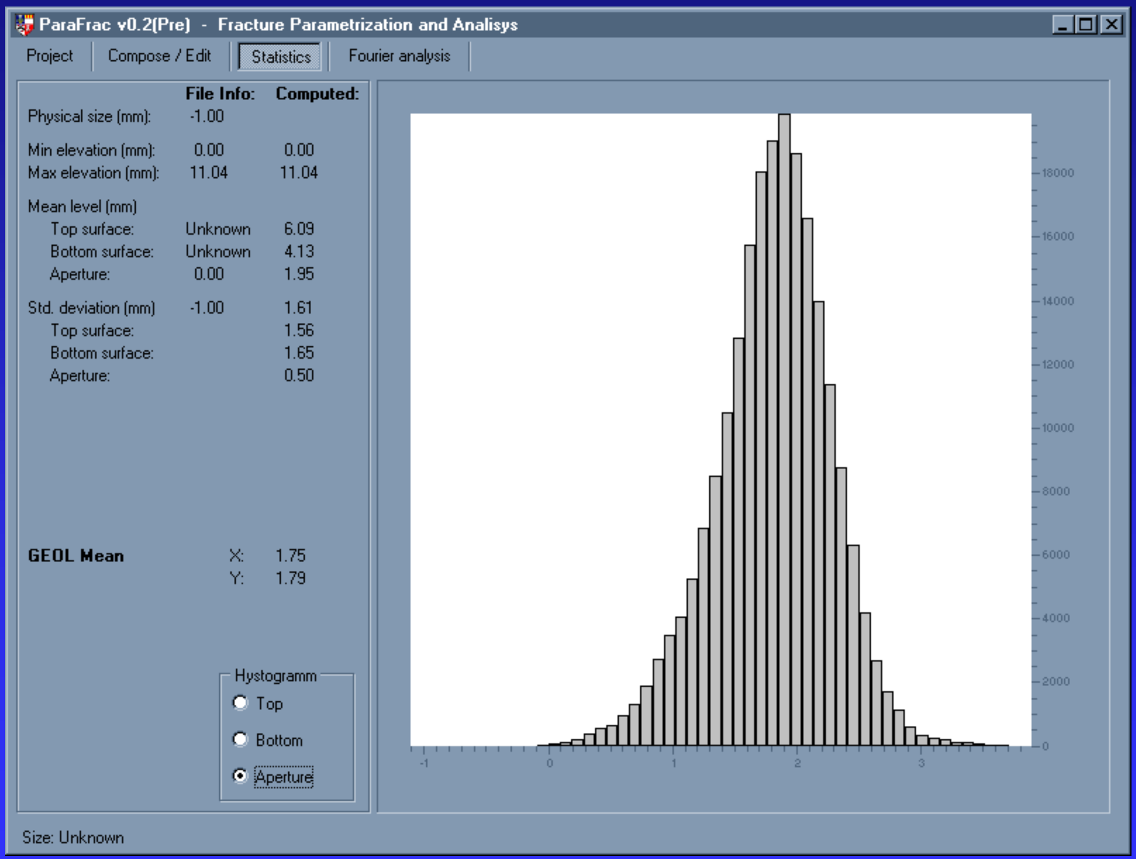
Sandstone

Granite



Fracture parameterisation & synthetic models

Fracture Parameterisation



- Statistical Analysis
- Spectral Analysis
- Fractal Analysis
- Correlative Analysis

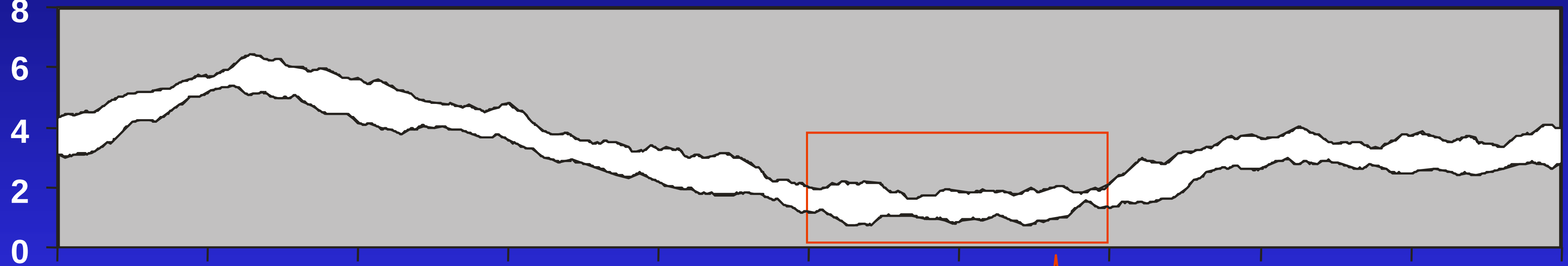
↓

Set of Fracture Parameters

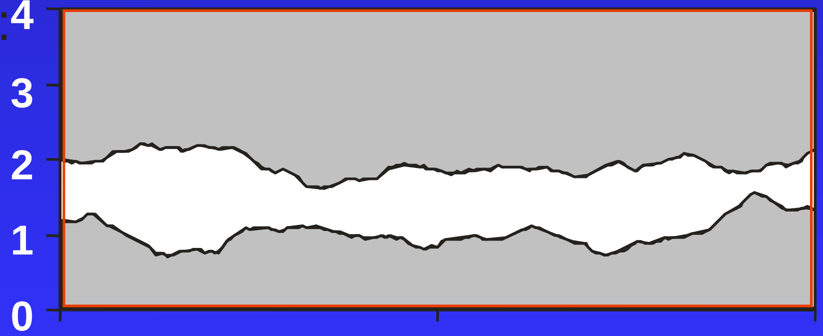
Numerical Synthesis of Fractures

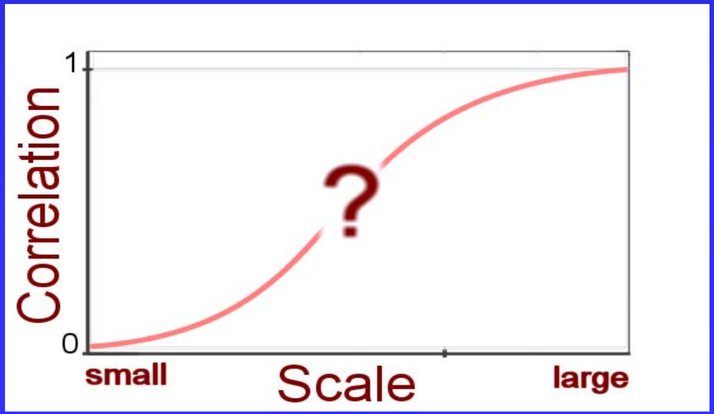
- Fractal synthesis is used to generate fracture surfaces.

Fracture surfaces match at macroscale:

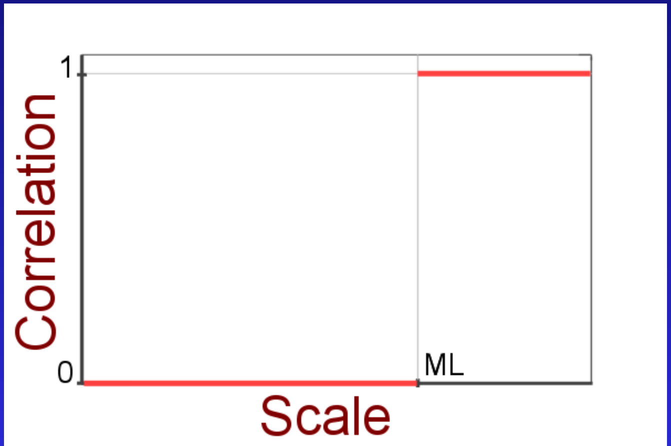


…And relatively independent at microscale:

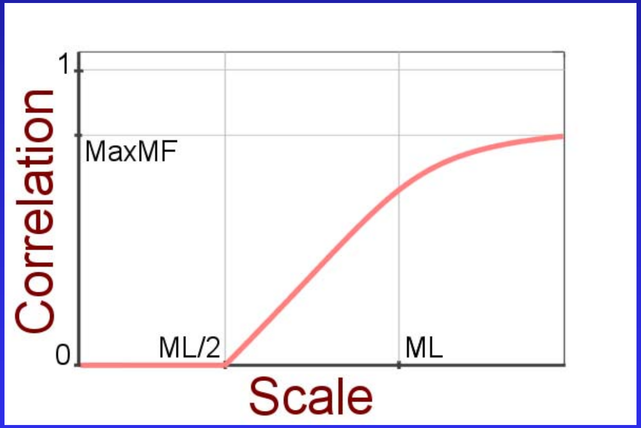




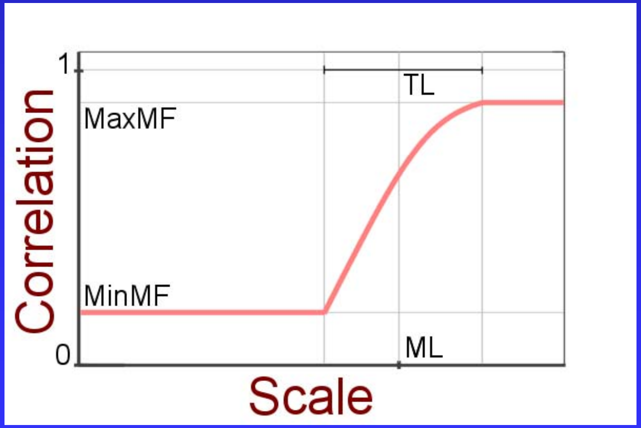
Synthesis methods



Brown (1995)

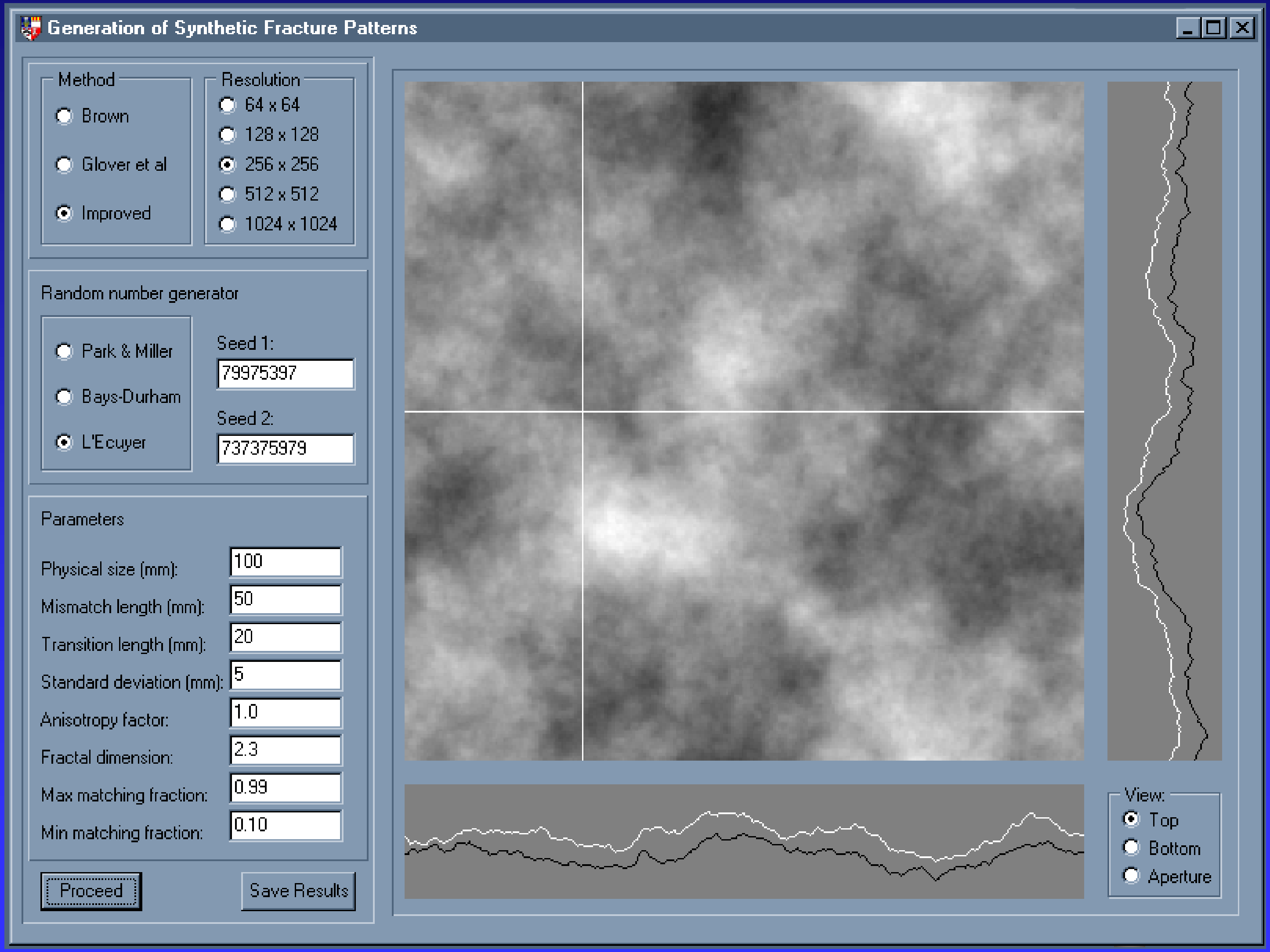


Glover et al. (1998)

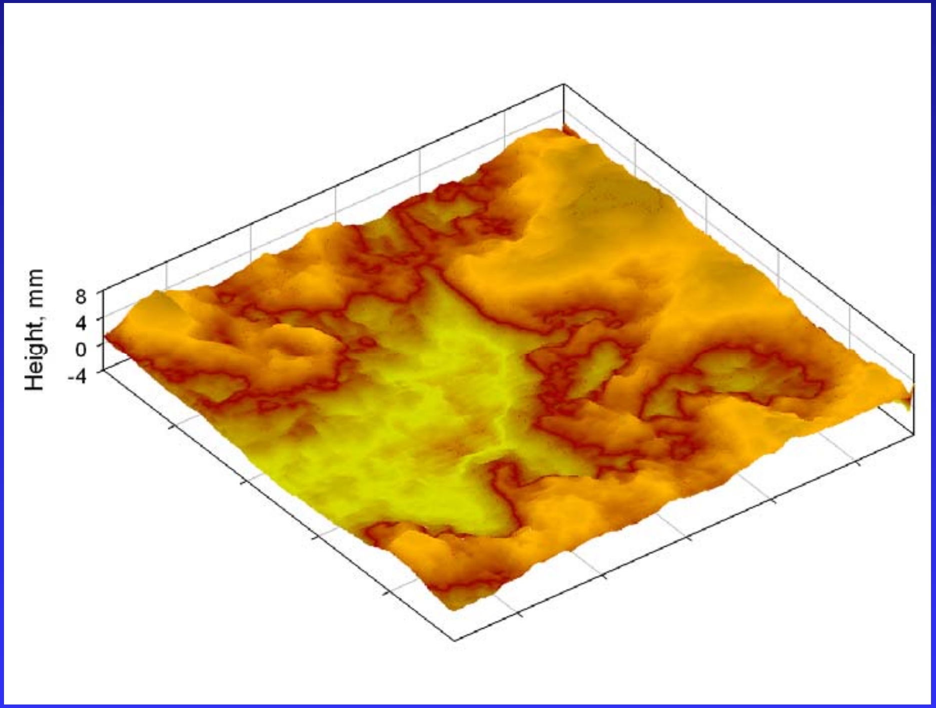


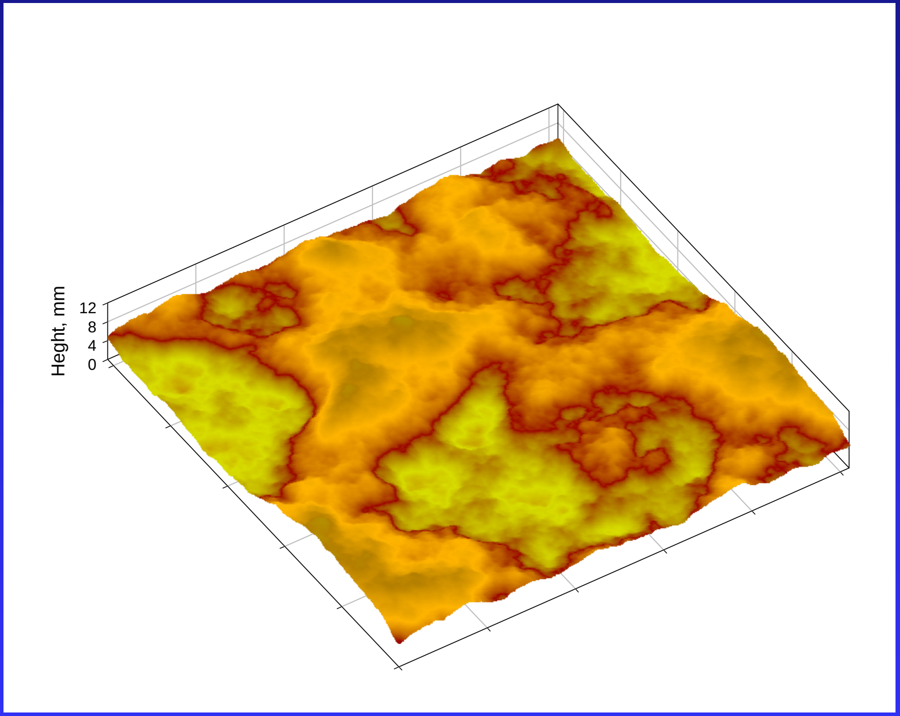
Present method

Software for Numerical Synthesis



Result of Numerical Synthesis





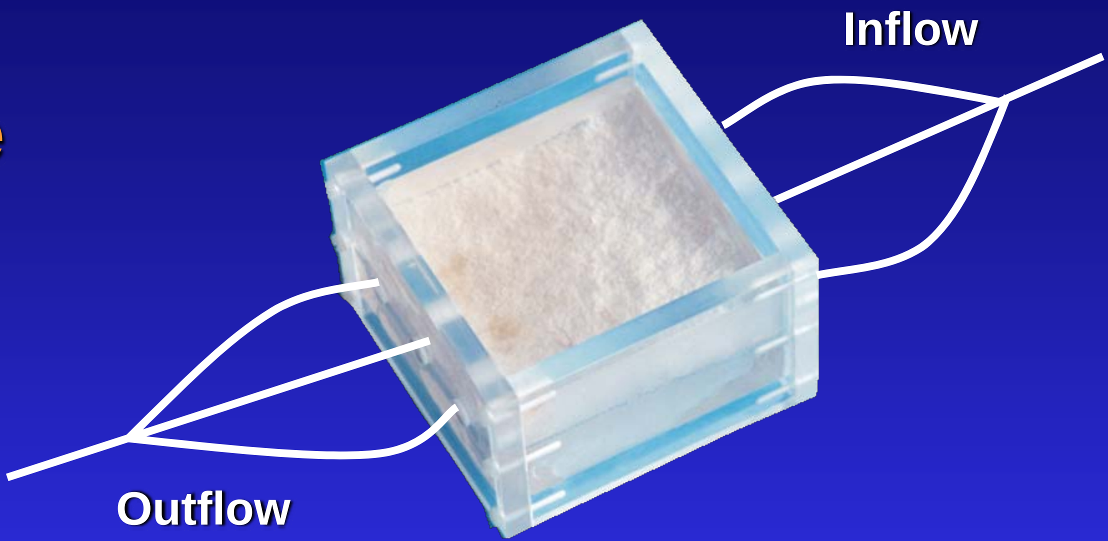
Pearly granite fracture surface

Synthesized fracture surface

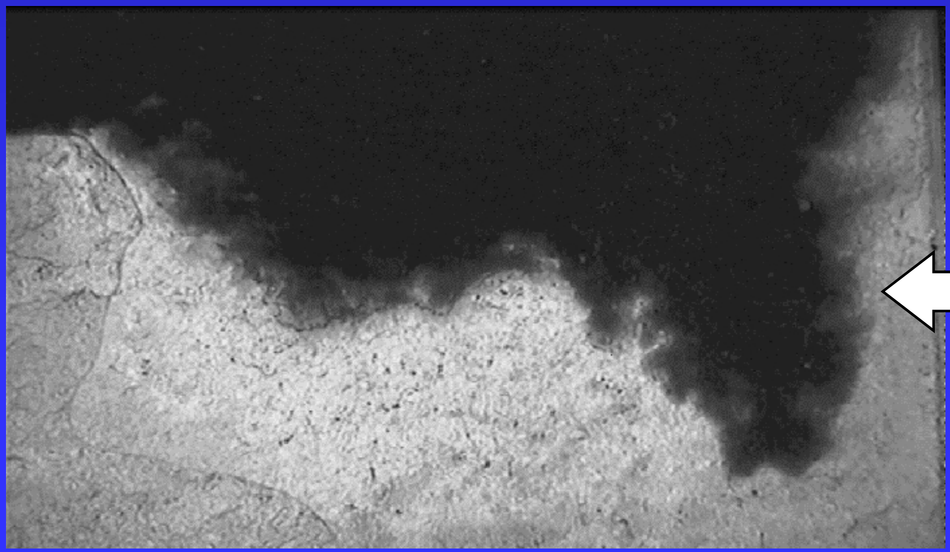
Flow Experiments

Fluid Flow through Rough Fracture

Fracture surface halves are mated and secured in a fluid - flow rig.



Flow manifolds at input & output ports

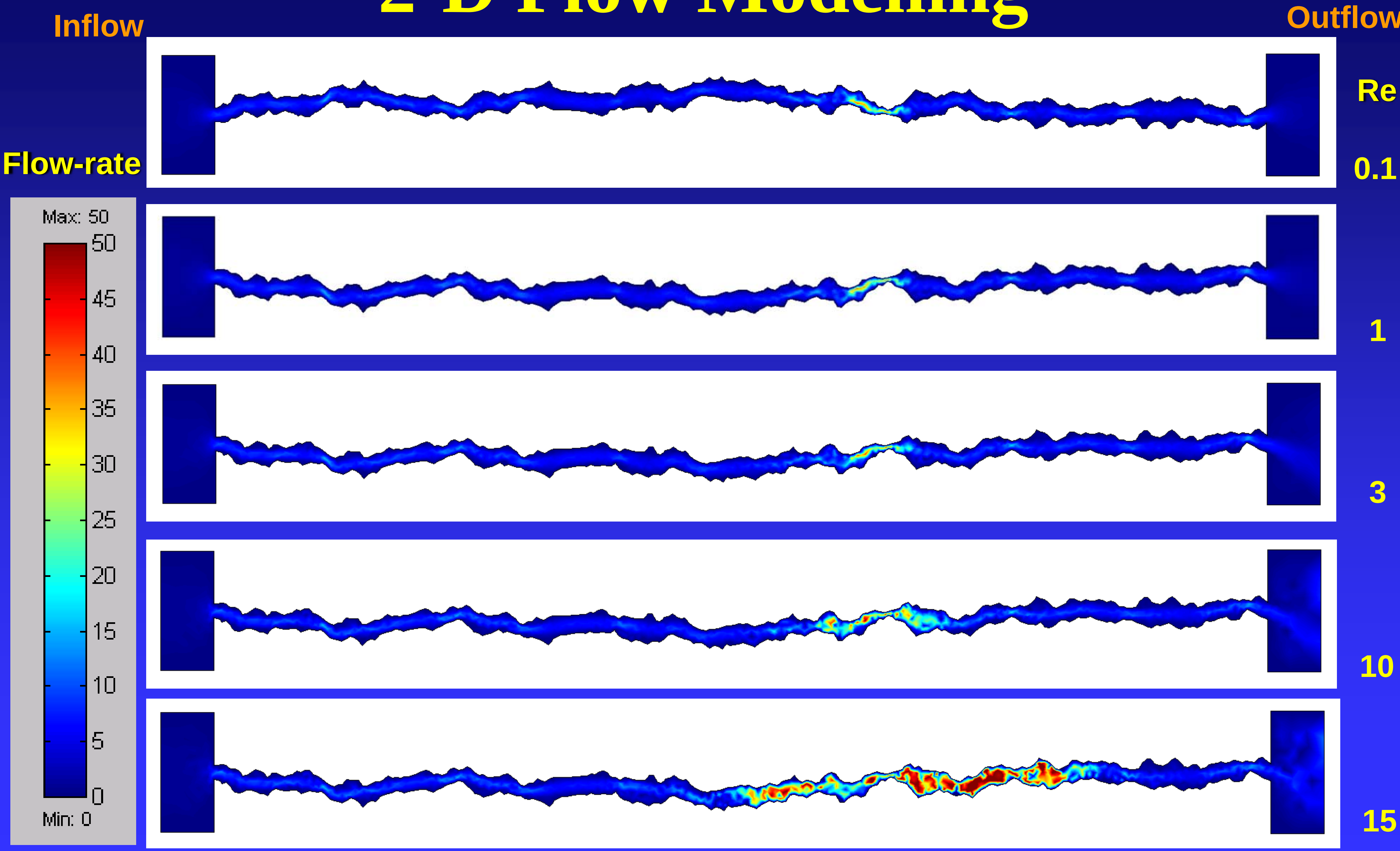


Clear water is replaced by dyed water in the flow through a rough fracture.

Flow Conditions

- HFPM cleaned with detergent & dried using compressed air
- Black dye (5g/l) pumped through HFPM using peristaltic pump
- Also performed at 90º to original HFPM
- Variable flow rates, fluid viscosities & densities.
- Pressure gradient set-up across HFPM

2-D Flow Modelling



Summary

- An optical technique developed in this study has provided high-resolution aperture determinations of rough fractures.
- Quicker & cheaper than PET/NMR techniques & also used to observe and monitor fluid flow through fractures
- Rough fractures be profiled, and numerical synthetic fractures can be produced to high precision

Summary

- A new methodology was developed to generate a synthetic numerical models of rough fractures in rocks.
- The technique allows to parameterise surfaces of a real fractures in rocks.
- After tuning parameters of the numerical model, the synthetic numerical fracture surfaces have properties, which are quite close to real ones.
- Both numerical and real fracture surfaces can be used in computational flow modelling.

This work is funded by NERC as part of Micro to Macro thematic programme ongoing in the U.K.

Digital Optical Imaging Method

The absorption of light passing through the fracture filled with dye can be used to derive the 2D aperture distribution using Lambert-Beer Law.

Camera records images directly onto TV monitor connected to a PC-based workstation.