Imaging Porous Media

**Imaging Techniques & Examples**

Optical - Fracture Geometry / Sandstone Pores

Scanning Electron Microscopy - Sandstone Pores

Acoustic Microscopy - Portland Cement

Laser Confocal Microscopy - Micro-Cracks/Pores

X-ray Tomography - Sandstone/Carbonates

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**Optical Imaging**

Low-Tech: 35 mm photography, hand digitization, computer drawing program, slice sawing. Can be combined with a microscope or camera lenses. Resolution controlled by grain size of film.

High-Tech: Digital Camera, digital image processing, surface grinding. Sample size & Megapixels of digital system control resolution.

*Gertsch, 1995*
Optical Imaging

Three-dimensional reconstruction of fractures in a gneiss core.

Gertsch, 1995

Scanning Electron Microscopy

Sandstone with pores filled with Wood’s metal.

(Chen et al., 2003)
Scanning Electron Microscopy

Sample 5a
Layer 1:

2.7 mm
Backscattered electron mode

Resolution
67x ~ 3.9 microns/pixel

(Chen et al., 2003)

Acoustic Scanning Microscopy

Lateral resolution: 1 micron

(Prasad et al., 1997)
Acoustic Scanning Microscopy

Figure 1. Acoustic (a) and SEM (b) images of concrete sample made with granitic aggregate grains and Portland cement paste. The acoustic image was made at 400 MHz, z=0.

Laser Confocal Microscopy

(Fredrich & Wong, 1995; Fredrich, 1999)
Laser Confocal Microscopy

Table 1. Lateral resolution $R$ (Eq. 1) and optical section thickness at $\lambda=514 \text{ nm}$ for various settings of the confocal aperture

<table>
<thead>
<tr>
<th>Objective</th>
<th>$M$</th>
<th>NA</th>
<th>$R$ ($\mu$m)</th>
<th>Section thickness ($\mu$m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Open</td>
<td>1/2</td>
</tr>
<tr>
<td>$\times 10$</td>
<td>0.45</td>
<td>0.71</td>
<td>38</td>
<td>25</td>
</tr>
<tr>
<td>$\times 20$</td>
<td>0.75</td>
<td>0.42</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>$\times 40$</td>
<td>1.0</td>
<td>0.31</td>
<td>6.1</td>
<td>4.2</td>
</tr>
<tr>
<td>$\times 60$</td>
<td>1.4</td>
<td>0.22</td>
<td>3.7</td>
<td>2.0</td>
</tr>
</tbody>
</table>

(Fredrich & Wong, 1995; Fredrich, 1999)

Laser Confocal Microscopy

3D reconstruction of the pore space in sandstone

(768 x 512 x 101 voxels at 1 micron resolution)

(Fredrich & Wong, 1995; Fredrich, 1999)
X-ray Tomography

**a)**

LCAT Industrial System with a linear diode array for detection.

**b)**

Commercial Medical Scanner with a ring of diode detectors.

(From Wildenschild et al, 2003)

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X-ray Tomography

**c)**

GSECARS synchrotron-based microtomography with an charged-coupled device (CCD) providing areal detection.

(Wildenschild et al, 2003)

Laboratory-based microtomography (μCT) system with an charged-coupled device (CCD) providing areal detection.

(Sakellariou et al, 2003)
## X-ray Tomography

<table>
<thead>
<tr>
<th>System</th>
<th>Resolution</th>
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</thead>
<tbody>
<tr>
<td>Industrial</td>
<td>50-100 microns</td>
</tr>
<tr>
<td>Medical</td>
<td>200-500 microns</td>
</tr>
<tr>
<td>Synchrotron</td>
<td>1 - 50 microns</td>
</tr>
<tr>
<td>μCT</td>
<td>2-5 microns</td>
</tr>
</tbody>
</table>

*Note: Resolution is effected by sample size, size of the detectors, and on collimation of the beam.*

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### Two Sandstone Plugs

Porosity as a function of Depth in Sample

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(Sakellariou et al, 2003)

(Wildenschild et al, 2003)
**X-ray Tomography**

*Carbonate Sample*

_Sakellariou et al, 2003_

Fig. 6: Slices of the carbonate image. Left, the original 4 cm disk at 40 micron resolution showing the vugs (dark) and the dense dolomite phase (lighter shade). The circle in the lower left indicates the region where the plug was extracted. Right, the 5 mm plug cored from the disc at 5 micron resolution exhibiting pores across a range of scales.

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**X-ray Tomography**

*Carbonate Rock*

_Helium-based Measurement of Porosity for this sample 21.7%*_

_Sakellariou et al, 2003_

Fig. 9: Comparison of pore resolution at (left) 5 μm resolution versus (right) 2.5 μm resolution on the subset of the 5 mm plug. The magnified view comes from the region at 10 o’clock on the right hand image of Fig. 6.

<table>
<thead>
<tr>
<th>Resolution</th>
<th>5μm</th>
<th>10μm</th>
<th>20μm</th>
<th>40μm</th>
</tr>
</thead>
<tbody>
<tr>
<td>ϕ</td>
<td>9.76%</td>
<td>6.73%</td>
<td>3.21%</td>
<td>3.55%</td>
</tr>
<tr>
<td>Largest vug (mm³)</td>
<td>.198</td>
<td>.144</td>
<td>.133</td>
<td>–</td>
</tr>
</tbody>
</table>