# Imaging Porous Media

***Imaging Techniques & Examples***

Optical - Fracture Geometry / Sandstone Pores

Scanning Electron Microscopy - Sandstone Pores

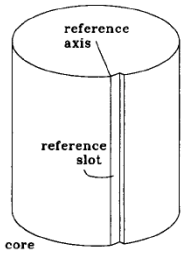
Acosutic Microscopy - Portland Cement

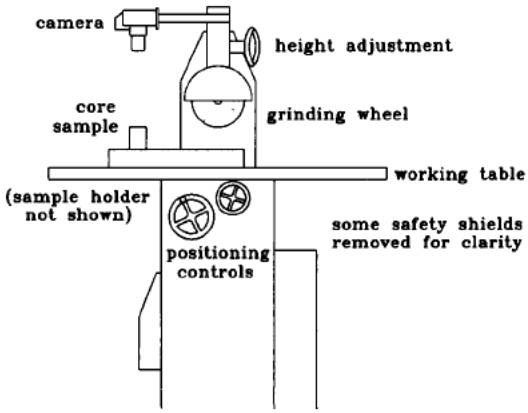
Laser Confocal Microscopy - Micro-Cracks/Pores

X-ray Tomography - Sandstone/Carbonates



# Optical Imaging



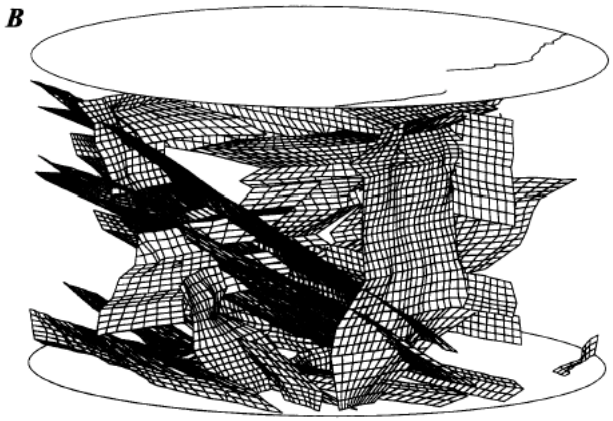




*Gertsch, 1995*

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.

## Optical Imaging



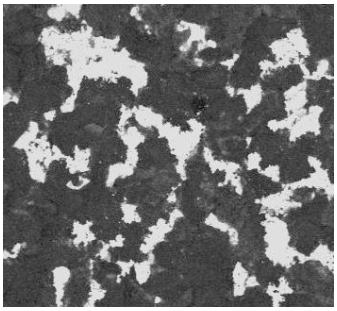

Three-dimensional reconstruction of fractures in a gneiss core.

*Gertsch, 1995*



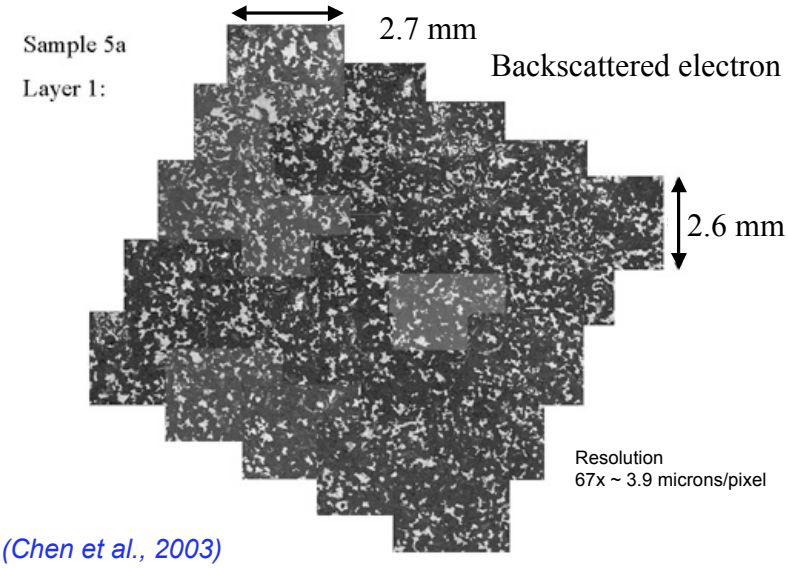
## Scanning Electron Microscopy

Sandstone with pores filled with Wood's metal.



*(Chen et al., 2003)*

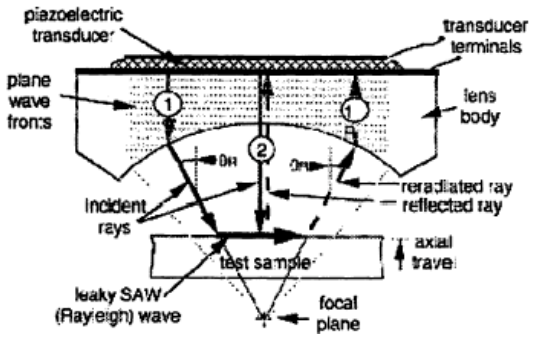
# Scanning Electron Microscopy




*(Chen et al., 2003)*



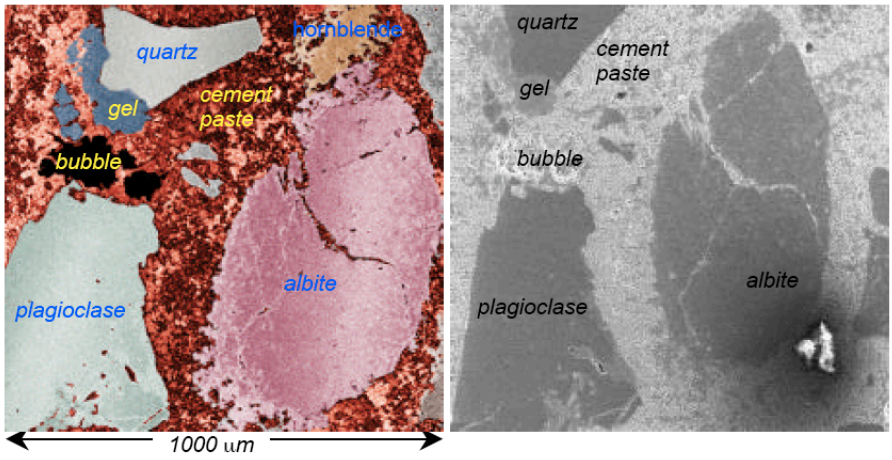
# Acoustic Scanning Microscopy




Lateral resolution: 1 micron

*(Prasad et al., 1997)*

# Acoustic Scanning Microscopy

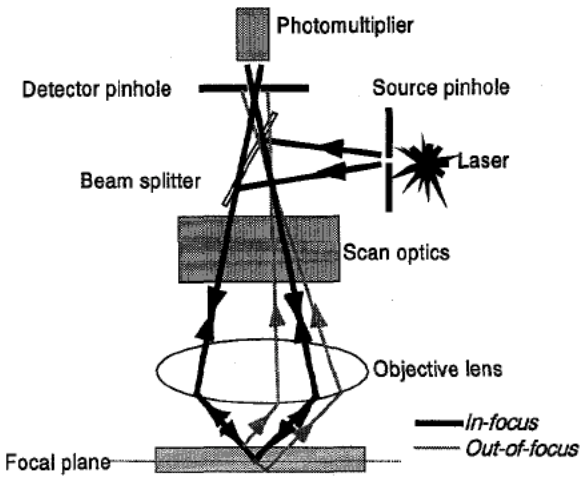



(a) (b)

*(Prasad et al., 1999)*

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

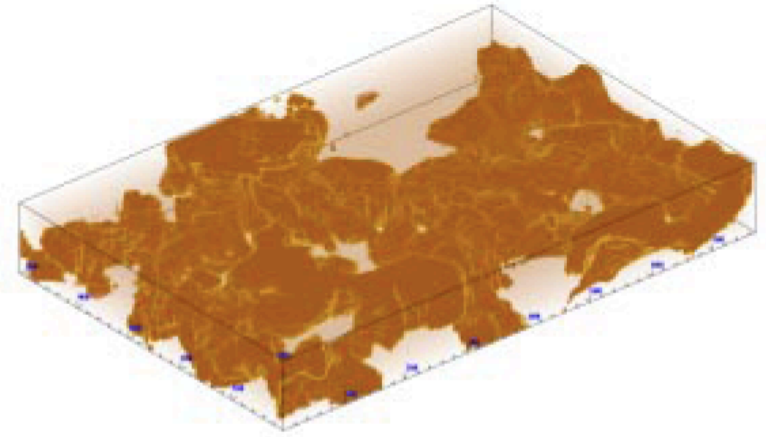
**Table 1. Lateral resolution $R$ (Eq. 1) and optical section thickness at λ=514 nm for various settings of the confocal aperture**

| Objective | | $R$ (μm) | Section thickness (μm) | | | |
|---|---|---|---|---|---|---|
| $M$ | $NA$ | | Open | 1/3 | 2/3 | Closed |
| ×10 | 0.45 | 0.71 | 38 | 25 | 13 | 7.0 |
| ×20 | 0.75 | 0.42 | 14 | 10 | 6.7 | 5.0 |
| ×40 | 1.0 | 0.31 | 6.1 | 4.2 | 2.6 | 1.4 |
| ×60 | 1.4 | 0.22 | 3.7 | 2.0 | 1.0 | 0.7 |

*(Fredrich & Wong, 1995; Fredrich, 1999)*



# Laser Confocal Microscopy

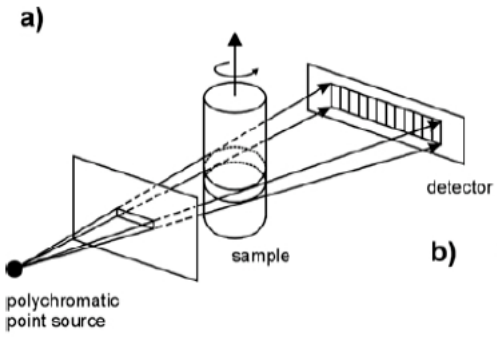


*3D reconstruction of the pore space in sandstone (768 x 512 x 101 voxels at 1 micron resolution)*

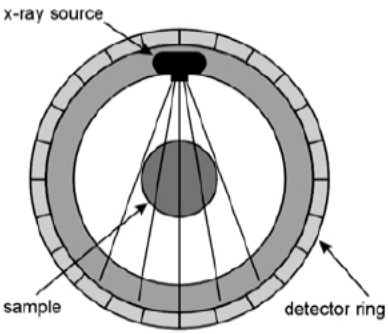
*(Fredrich & Wong, 1995; Fredrich, 1999)*

# X-ray Tomography

*(From Wildenschild et al,2003)*



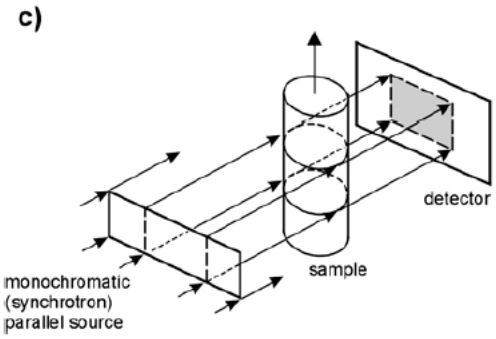

LCAT Industrial System with a linear diode array for detection.




Commercial Medical Scanner with a ring of diode detectors.



# X-ray Tomography




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

| System | Resolution | |
|---|---|---|
| Industrial | 50-100 microns | *(Wildenschild et al, 2003)* |
| Medical | 200-500 microns | |
| Synchrotron | 1 - 50 microns | |
| µCT | 2-5 microns | *(Sakellariou et al, 2003)* |

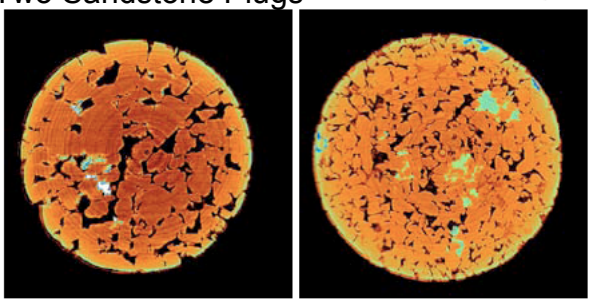
*Note: Resolution is effected by sample size, size of the detectors, and on collimation of the beam.



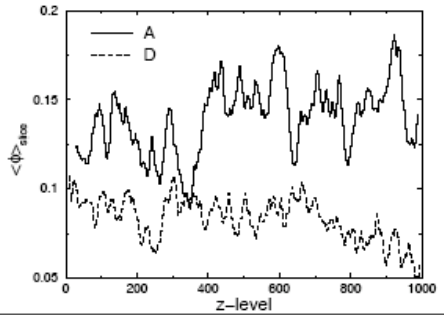
# X-ray Tomography

Two Sandstone Plugs

*Sakellariou et al, 2003*



Porosity as a function of Depth in Sample



# X-ray Tomography

*Sakellariou et al, 2003*

Carbonate Sample

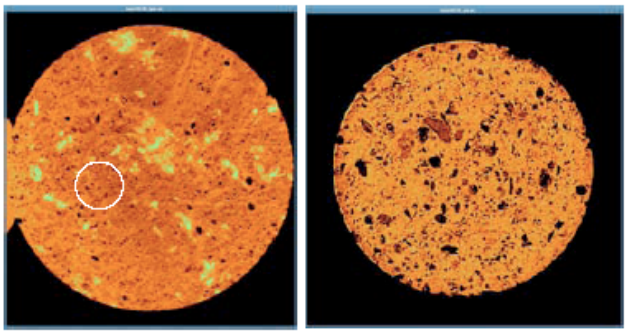


Fig. 6: *Slices of the carbonate image: Left, the original 4 cm disk at 40 micron resolution showing the vugs (dark) and the dense dolomite phase (lighter shade). The circle in the lower left indicates the region where the plug was extracted. Right, the 5 mm plug cored from the disc at 5 micron resolution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



# X-ray Tomography

Carbonate Rock

*Sakellariou et al, 2003*

**Helium-based Measurement of Porosity for this sample 21.7%**

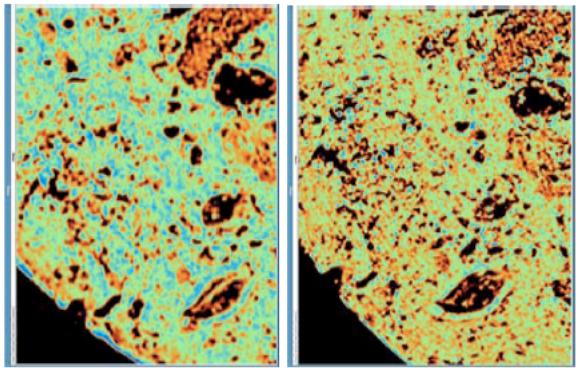


Fig. 9: *Comparison of pore resolution at (left) 5 μm resolution versus (right) 2.5 μm resolution on the subset of the 5 mm plug. The magnified view comes from the region at 10 o'clock on the right hand image of Fig. 6.*

| Resolution | $5\mu m$ | $10\mu m$ | $20\mu m$ | $42\mu m$ |
|---|---|---|---|---|
| $\phi$ | 9.76% | 6.73% | 3.21% | 3.55% |
| Largest vug $(mm^3)$ | .198 | .144 | .133 | – |