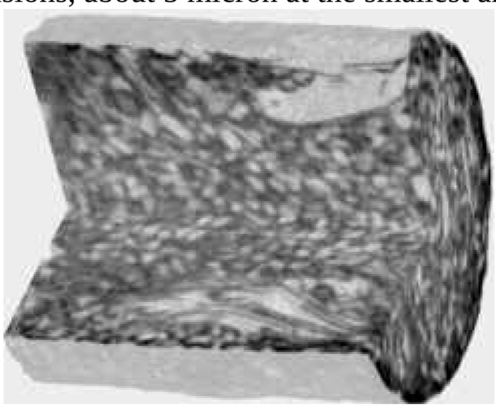
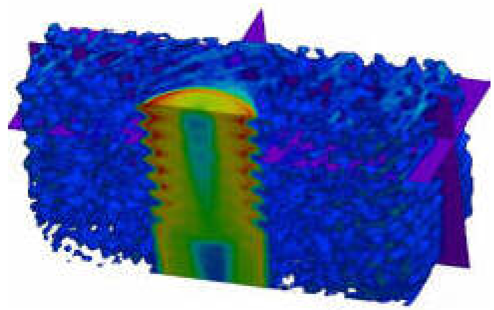
041001 Quiz 1 XRD

X-ray tomography is a technique for analysis of structure on the micron scale. The figure below, left, is a computer derived x-ray tomograph of limestone showing the internal pore distribution from a solid piece. The image (left) is reconstructed from hundreds of thousands of transmission measurements using micron size focused x-rays from a synchrotron in Europe (*http://www.ndt.net/article/wcndt00/papers/idn399/idn399.htm*). The image on the right is a titanium implant in trabecular bond. Both samples were measured as whole pieces and the slice shown is done on a computer. Limitation in size resolution (about 5 micron) in these images is due to the limits of the x-ray beam dimensions, about 5 micron at the smallest and scattering of the beam in the sample.





a) Explain why refractive lenses are not used in x-ray tomography to provide magnification of the images.

b) The image represents a 3D plot of x-ray absorption coefficient. If you measured the transmitted beam intensity, I/I_0, for a sample of thickness x, how would you obtain the linear absorption coefficient, μ? Can you guess how these images are produced from hundreds of thousands of bulk transmission measurements?

c) Does x-ray tomography measure phase information? (You will need to define phase information in the context of these images).

d) Does x-ray diffraction measure phase information? (You will need to define phase information in the context of Bragg's law).

e) If you were interested in high-energy x-rays (hard x-rays) in order to increase the penetration depth what wavelength would you need? (Write a relationship between energy and wavelength for electromagnetic radiation).

ANSWERS: **041001 Quiz 1 XRD**

a) Lenses generally use refraction to change the path of electro-magnetic waves. Refraction relies on an index of refraction difference between two materials such as air and silica glass and follows Snell's law,

$$n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$$

(see for instance http://www.physics.nwu.edu/ugrad/vpl/optics/snell.html), where $n_1 = c/v_1$ and v_1 is the velocity of the electromagnetic wave in medium 1. High energy electromagnetic waves such as x-rays are not largely effected in terms of speed by the medium in which they travel. The index of refraction is extremely close to 1 for all materials and the refraction angle is a fraction of a degree making refractive lenses impossible. Fresnel lenses use interference rather than refraction and there has been some attempts at producing x-ray microscopes (http://www-cxro.lbl.gov/microscopy/).

b) $\mathbf{I/I_0 = exp(-\mu\ x)}$ Beer-Lambert linear absorption law.
The sample is rotated in a microfocus synchrotron beam stepwise with a transmission detector. The location of phases (phase information) can be determined by interpolation of hundreds of thousands of such transmission measurements. For instance if a dense phase is located at one face of a cube a transmission measurement through that face would be low while transmission through the two other independent faces would be high. Transmission measurements at 45° angles could resolve which surface contained the high density phase.

c) The images shown display the relative location of all phases at the micron scale. This is phase information for the structure.

d) XRD yields a diffraction pattern that must be modeled using, usually, crystallographic structures. If the calculated diffraction pattern from the proposed structure agrees with the diffraction pattern we can say that the structure is consistent with the measurement. Other structures could potentially explain the measurement. Information concerning the relative arrangement of phases is not available from this analysis. For instance the diffraction pattern from Swiss cheese would be identical (in most respects) to the diffraction pattern from disks of cheese where the holes had been (Babinet principle see for instance: *http://www.silcom.com/~aludwig/Physics/Gensol/Babinet.htm*).

e) $E = \eta|\chi|/\lambda$
You would need low-wavelength x-rays, the best would probably be less than 0.5 Å.