Vickery. "This is a plausibility argument. Until there is a lot more information about the surface of Mars, this is about as well as we can do." Most helpful might be a reevaluation of crater ages.

Another alternative would be the evaluation of a different ejection mechanism in the same scenarios. The only other serious contender at the moment is the mechanism of vapor jetting. Recently, John D. O'Keefe and Thomas Ahrens of the California Institute of Technology have shown in a computer model supported by laboratory experiments that a martian impactor hitting the surface at an angle of anywhere from 25° to 60°, the most common sort, can blow rocks right off the planet. The force of the impact vaporizes parts of the impactor and planet. The resulting gases jet across the surface at upwards of 20 kilometers per second, scour the surface down to depths of at least 10 meters, and accelerate boulders as large as 1 to 10 meters to martian escape velocity, according to their model.

The jetting mechanism has the advantage of requiring a crater only about 50 kilometers in diameter, which might ease the problem of the lack of large craters on young martian terrain. On the other hand, O'Keefe and Ahrens have not estimated the amount of rock of the required size that jetting could launch or the probability of such a crater being created, so they have not tested the plausibility of the mechanism the way Vickery and Melosh have. Also, it is not obvious how the jetting mechanism would explain the Mars-moon conundrum—there are eight SNCs supposedly from the distant, more massive Mars but only four from the moon. Vickery and Melosh's large impact would be "a singular event in recent martian history," that is still sending a surge of rocks to Earth that is temporarily overshadowing the usual trickle of lunar meteorites.

The problem of transporting intact rocks from one planet to another is now being approached with a positive outlook, but its solution could take time. How far researchers are willing to go on the assumption that the SNCs are from Mars will depend on their attitude toward the sufficiency of the physical evidence. If recent trends are any indication, the temptation to work with exciting new data will more than balance second thoughts. ■ RICHARD A. KERR

ADDITIONAL READING

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Imaging Unaltered Cell Structures with X-rays

With the bright radiation from a synchrotron light source researchers are using a scanning x-ray microscope to make high-resolution images in a wet environment

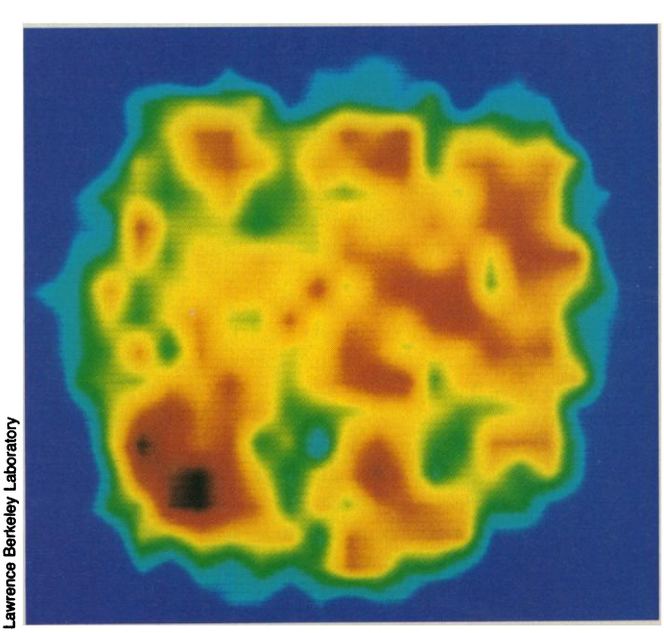
THERE has been no satisfactory method for high-resolution imaging of biological materials in their natural state. The resolution of optical microscopy is limited by the wavelength of light, whereas electron microscopy generally requires dehydrated, stained specimens. But a multiinstitutional group working at the National Synchrotron Light Source (NSLS) has now shown that scanning x-ray microscopy can bridge the gap between the two older techniques. The investigators have made x-ray micrographs of zymogen granules extracted from the cells of the rat pancreas. The granules were in an aqueous environment. The microscope has a demonstrated resolution of 750 angstroms. With further development, including a hoped-for boost in the resolution to about 100 angstroms, the scanning x-ray microscope will eventually be made available to the general community on a routine basis.

X-ray microscopy is not a new idea. For several years, Ralph Feder and David Sayre of the IBM Yorktown Heights Laboratory and others have been doing so-called contact x-ray microscopy in which shadowgraphs of samples illuminated by an x-ray beam are recorded in a photosensitive polymer of the type used in the microelectronics industry. With a transmission electron microscope to magnify the image, a resolution of about 100 angstroms could be obtained. And there has been some work on the x-ray analog of an optical microscope. A group headed by Günter Schmahl of the University of Göttingen in West Germany has achieved a resolution of 500 angstroms with such an instrument.

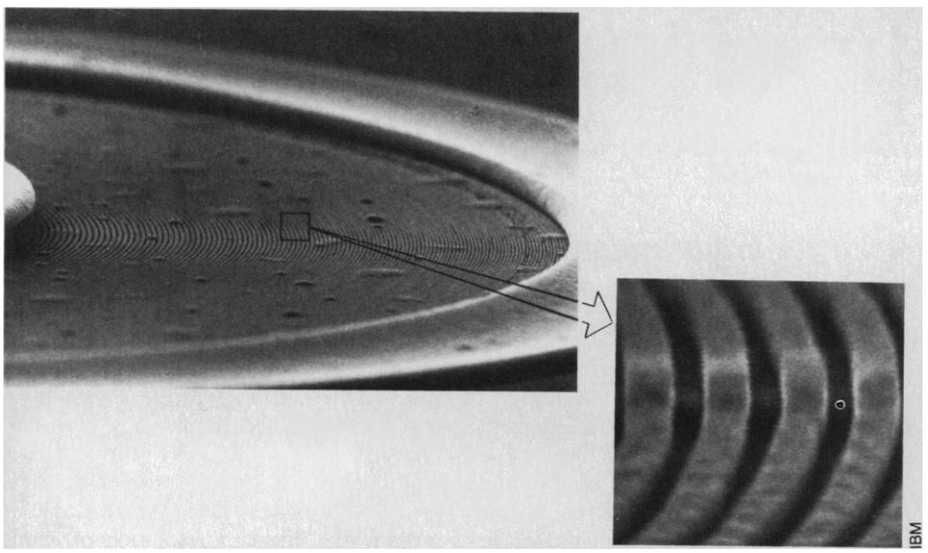
In both cases, the use of an intense beam of "soft" or long wavelength x-rays from a synchrotron light source is the key. For example, x-rays in this wavelength range pass relatively unattenuated through water but are absorbed by carbon-containing substances, thereby allowing the imaging of organic material in a wet environment. The use of a scanning instrument opens additional possibilities, partly because the radiation dose is lower, which causes less damage to specimens and potentially allows researchers to follow changes within living cells as they occur. The disadvantage of scanning is that a very bright x-ray source is

Zymogen granule.

The digital image reconstructed by computer from the intensity of x-rays penetrating the specimen shows the nonuniform distribution of enzymes in a granule. Red represents opaque and blue transparent regions.



Lawrence Berkeley Laboratory



Fresnel zone plate. *(Left) View of a zone plate that is 62 micrometers in diameter showing concentric rings of x-ray absorbing gold on a transparent silicon nitride substrate. (Right) Close-up of the zone-plate rings, which are 700 angstroms wide, 1200 angstroms thick, and 300 angstroms apart.*

needed for the image to be made rapidly enough for studies of dynamic processes because the image is recorded serially, picture element by picture element.

Scanning x-ray microscopes at the NSLS have, in fact, been operating for almost 5 years under the direction of Janos Kirz of the State University of New York at Stony Brook and Harvey Rarbak of the NSLS. The earliest instrument served as a proof of principle, but suffered from a poor resolution (3000 angstroms) and a long imaging time (about 1 hour per image) even with the bright light from an NSLS beam line.

Both problems have since been solved. The main factor determining the resolution is an x-ray optical element known as a Fresnel zone plate, which consists of a series of concentric rings of an x-ray–absorbing material, such as gold, of ever smaller radial thickness. By diffraction, the zone plate focuses the x-rays to a point whose diameter is approximately the thickness of the outermost ring. To make an image, the sample is mechanically scanned past the point. Using the microelectronics technique of electron-beam lithography, Yuli Vladimirsky of the Lawrence Berkeley Laboratory and Dieter Kern of IBM have gradually learned how to make zone planes with outer ring thicknesses of 500 angstroms. To do much better than this, a new patterning technique may be necessary.

Last year, the NSLS put into operation an x-ray beam line (X-17T) that received its synchrotron light from an undulator, a periodic array of magnets that generates an x-ray flux better than that available on the old beam line (U-15) by a factor of 100, and an improved scanning x-ray microscope was built on this beam line. By the time the x-rays moved through the optical system, the recording time for an image decreased by a smaller factor to about 1 minute. At the moment, the NSLS x-ray source is shut down for a major upgrade project (although the ultraviolet source is running), but when it reopens next year a still brighter undulator beam line (X-1) will be available for a scanning x-ray microscope that may finally bring imaging of dynamic processes into the realm of possibility.

The zymogen granule experiment originated with Stephen Rothman of the University of California at San Francisco, who has had a long-time interest in the mechanism by which these bodies release digestive enzymes from the cells of the pancreas in which they are manufactured. According to the most widely accepted model, a granule is an essentially structureless container that carries its load of enzymes to the cell membrane. There it fuses with the membrane to form a hole that opens to the outside of the cell, so that the enzymes can escape.

Rothman and his co-workers have evidence for an alternative mechanism in which a granule with internal structure releases its cargo while still in the cell, and the enzymes then pass individually through the cell membrane. Electron microscopy has not been helpful in settling the issue, in great part because the proposed events cannot be observed in living cells. Rothman hopes that dynamic imaging with the scanning x-ray microscope can settle the issue.

A 12-person team comprising members from San Francisco, Berkeley, Stony Brook, IBM, and the NSLS collaborated on the first step of the investigation, imaging isolated zymogen granules. For this purpose, a special wet cell thin enough to transmit the x-rays while maintaining the 1-micrometer-diameter granules in a sugar solution was designed by Nasif Iskander of Berkeley. Because of demand for the beam line and the impending shutdown of the NSLS, however, data-taking was limited.

According to Rothman, the images obtained establish several points. First, it is possible to image unaltered biological materials in water with a resolution of 750 angstroms. Second, x-ray contrast can be obtained from very small amounts of material, a few attomoles of the carbon-containing protein for the 32-angstrom x-rays used in this experiment. Third, the enzymes are not uniformly distributed throughout the interior of the granules as the conventional electron microscopy–based model holds. Instead, concentrated clumps are embedded in relatively transparent regions of the cells. Moreover, concentrated material is seen toward the granule edge, while the center is transparent, which suggests a nonrandom arrangement. However, noise in the not yet perfected microscope system and the small sample size available precluded an unambiguous discrimination between an ordered and a random arrangement.

In addition to instrumental improvements, such as reduction of noise in the images, on the agenda for future experiments is the use of a more sophisticated wet cell that will allow recording of dynamic processes, such as changes in the location and quantity of enzymes in the granules with time. It is yet to be demonstrated, however, that cell structures will always survive the x-ray dose. It is also desirable to obtain three-dimensional information. Consideration is being given to taking data from two or more angles, so that images can be reconstructed as in computerized medical scanners. A distinctly different way to get three-dimensional information is holography. Although no existing synchrotron source is bright enough to make imaging of dynamic processes feasible, experiments by others at the NSLS are trying to show that it is possible to make high-resolution holograms of dried but unstained specimens.

Together with other scanning x-ray microscope projects that are under way at synchrotron light sources in West Germany, the United Kingdom, and Japan, the next round of experiments should go a long way toward determining just how useful scanning x-ray microscopy will be to biologists. In the meantime, the International Symposium on X-ray Microscopy beginning 31 August at Brookhaven National Laboratory should provide an overview of the current state of the art. ■ **ARTHUR L. ROBINSON**