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Presentation of the Mineralogical Society of America Award for 2012 to Karim Benzerara

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Fellow mineralogists, I am honored to introduce Karim Benzerara of the IMPMC (Institut de Minéralogie et de Physique des Milieux Condensés), University of Paris 6-7, as the 2012 MSA Award winner. Karim is receiving this award for his exceptional contributions to our understanding of mineral-microbe interactions and biomineralization. He has accomplished this using a combination of transmission electron microscopy, synchrotron-based scanning transmission X-ray microscopy (STXM), the application of which Karim has pioneered in the Earth Sciences, and an uncanny knack for choosing important geobiology problems that require nanoscale solutions.

Karim completed his Ph.D. degree at the University of Paris 7 working with Francois Guyot, a mineral physicist at Paris 7 who transformed himself into a geomicrobiologist, Thierry Heulin, a molecular microbial ecologist at the French Atomic Energy Commission, and Philippe Gillet, a geochemist who was then at the University of Lyon.

A fragment of a martian achondrite meteorite fell in the Tatahouine Desert in southern Tunisia in 1931. If you don't remember the Tatahouine Desert, it played a prominent role in *Star Wars* II. Fragments from this same fall were collected again in 1994, which allowed a comparison of changes that occurred on the surfaces of these achondrite fragments during their almost 64 years in a controlled natural environment. In 2001, Karim embarked on a remarkable study of these fragments, which were initially thought to harbor martian nanobacteria. However, Karim subsequently showed that these "nanobacteria" were in reality small calcite crystals of unusual rod-shaped morphology that likely formed in a protein matrix on Earth. During the course of his study, Karim characterized a new filamentous bacterium—*Ramlibacter tatahouinensis*—that had populated the surfaces of orthopyroxenes in this achrondite after its fall to Earth, and he subsequently found a diversity of other microbial organisms that populated the surface of the Tatahouine meteorite in this hot, dry desert environment. To study how *R. tatahouinensis* interacted with the orthopyroxene substrates, Karim used a then new ultramicrotomy method known as focused ion beam SEM to prepare 100 nm thick cross-sections through the bacterium-orthopyroxene interface and carried out transmission electron microscopy studies of the bioweathering products as part of his Ph.D. work.

Karim joined my research group in 2003 as a post-doc, just when we were beginning to utilize a new X-ray microscopy beamline at the Advanced Light Source at Lawrence Berkeley National Laboratory. This new scanning transmission X-ray microscopy or STXM beamline is capable of imaging thin geological and environmental samples at a 25–30 nm spatial resolution scale over the energy range 130 to 2200 eV, which includes the *K* absorption edges of the so-called life elements (N, C, O) and *L*-edges of P and the first-row transition elements, among others. Thus, in addition to nanoscale imaging, we could also simultaneously measure chemical state information on these elements at the same high spatial resolution in the form of near-edge X-ray absorption spectra. Karim used this new capability to examine nanoenvironments in the vicinity of an *R. tatahouinensis* bacterium and showed through direct measurements that the nanoenvironments differed substantially from the macroenvironments around the bacterium, including redox potentials, resulting in weathering products that were not predicted by equilibrium thermodynamics. Karim quickly followed this study by a STXM study of bacterial calcification using Ca *L*-edges to show that the bacteria precipitated carbonate hydroxyapatite in the presence of excess Ca rather than a Ca-carbonate polymorph. During the course of this study, Karim also found that the C *K*-edge XANES spectrum of a bacterium provided a spectroscopic signature that could be used to identify the presence and location of bacteria in complex heterogeneous samples, which is a difficult problem for transmission electron microscopy and laser confocal microscopy. The resulting publication was seen by a group of cardiac surgeons at the famous Mayo Clinic in Minnesota who had found some evidence that the hydroxyapatite plaque that builds up in human heart valves and arteries is stimulated by nanobacteria. Karim carried out a STXM study of plaque samples from human heart valves and arteries provided by the Mayo Clinic team and found no evidence for nanobacteria associated with the hydroxyapatite plaque at the nanoscale. These interesting results were published in the *Journal of Investigative Medicine*.

Over the past eight years, Karim has worked on many important biogeochemical and geomicrobiological problems at the nanoscale using electron and X-ray microscopy methods. His 57 publications to date present the results of exciting new studies ranging from microbial diversity and microbialite formation in modern alkali lakes, the search for nanoscale microbial signatures in ancient stromatolites, and microbial alteration of submarine basalts, to the preservation of plant spores in high-grade metamorphic rocks, ultrastructural studies of model and fossil sporoderms, arsenic biomineralization in acid mine drainage environments, and iron biomineralization by neutrophilic iron-oxidizing bacteria. One of Karim's most recent publications in collaboration with Purificacion Lopez-Garcia, Estelle Couradeau, me, and others appeared in *Science* and presents evidence for an early-branching cyanobacterium from an alkali lake in Mexico that produces nanocrystals of intracellular carbonates that reveals for the first time a new pathway for bacterial calcification. Each of Karim's studies is characterized by careful attention to detail, great efficiency, and exceptional expertise in microscopic methods. His work is breaking new ground and producing exciting new results in geomicrobiology—a rapidly emerging interdisciplinary area that has a strong overlap with geochemistry. He is an exceptional geomicrobiologist/geochemist/mineralogist who has a knack for choosing important problems and achieving a successful outcome. I have had the privilege of working with Karim and watching this brilliant young scientist develop into a rising star. Mr. President and fellow mineralogists, I am very pleased to present Karim Benzerara to you.

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