Selecting life: Scientists find new way to search for origin of life

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Over the last half century, researchers have found that mineral surfaces may have played critical roles organizing, or activating, molecules that would become essential ingredients to all life--such as amino acids (the building blocks of proteins) and nucleic acids (the essence of DNA). But which of the countless possible combinations of biomolecules and mineral surfaces were key to this evolution?

This vexing question has stumped scientists for years because of the sheer volume of possibilities. Now an interdisciplinary team of researchers led by Robert Hazen, of the Carnegie Institution's Geophysical Laboratory and former president of the Mineralogical Society of America, has developed new protocols and procedures for adapting DNA microarray technology to rapidly identify promising molecule/mineral pairs.

Hazen's Presidential Address in the November/December issue of *American Mineralogist* describes this work. It sets out a first-of-its-kind comprehensive survey into research that has identified processes by which minerals may have prompted the transition from a geochemical world to a biological one almost four billion years ago.

Scientists understand several probable steps in the origin of life, notably how the first organic molecules could have formed. In fact, prebiotic synthesis processes are now thought to have been so productive that the ancient Earth must have had far more different kinds of molecules than could have been used by early life. One of the biggest questions in origins research, therefore, is how just the right blend of critical biomolecules was selected, concentrated, and organized from the diverse primordial "soup." Previous research by the Carnegie team and others has shown that many molecules, including amino acids, can adhere to mineral surfaces, prompting further organic reactions. These findings have made surface/molecule interactions the subject of intense study.

Scientists suspect that organic material was likely introduced to Earth from many complementary sources. Abundant biomolecules form in molecular clouds in deep space, and these extraterrestrial compounds must have rained down on the early Earth. Other molecular synthesis was driven by lightning and ultraviolet radiation in the atmosphere or volcanic heat and chemical reactions in the deep oceans. Some of these building blocks of life were attracted to specific mineral surfaces, where they collected, concentrated, and underwent further reactions.

"Some 20 different amino acids form life-essential proteins," Hazen explained. "In a quirk of nature, amino acids come in two mirror-image forms, dubbed left and right-handed, or chiral molecules. Life, it turns out, uses the left-handed varieties almost exclusively. Non-biological processes, however, do not usually distinguish between left and right variants. For a transition to occur between the chemical and biological eras, some process had to separate and concentrate the left- and right-handed amino acids. This step, called chiral selection, is crucial to forming the molecules of life."

Like amino acids, some minerals have pairs of crystal surfaces that have a mirror relationship to each other, called left and right faces. Calcite, one such mineral, is common today and was prevalent during the Archean Era when life first emerged. In 2001 Hazen and colleagues performed the first experiments showing that the left-handed amino acid, aspartic acid, preferentially adhere to left-faced calcite. That study confirmed previous theoretical suggestions of a plausible process by which the mixed right- and left-handed -amino acids in the primordial soup could be concentrated and selected on a readily available mineral surface. The challenge since has been to determine which of the countless biomolecules/surface interactions are the most likely candidates to the first steps to life.

"Crystal surfaces are complicated," Hazen continued. "They have crevices and craters, and are seldom flat. We need to find which surface types are the best 'docking stations' for different biomolecules. However, there are hundreds of mineral surface types and thousands of plausible prebiotic molecules, making literally millions of possible biomolecule/mineral pairs. It's an overwhelmingly large number of possibilities."

DNA microarrays provide a means to address this problem. Microarrays are produced robotically to spot tens of thousands of microscopic droplets of DNA from as many genes onto a slide, enabling scientists to measure which genes are turned on. This rapidly developing technology can be used to identify, for example, the genes involved in disease. The high-throughput has revolutionized biotechnology research.

Hazen, working with Carnegie staff scientist Andrew Steele and his team, has developed modifications of this tool to study molecule/mineral interactions. The scientists have devised protocols for cleaning mineral surfaces, spotting the surfaces with up to 96 different organic species, washing the surfaces to remove molecules that don't adhere to a mineral surface, and locating the remaining adsorbed molecules.

To discover "which molecules stick and which don't," as Hazen says, the Carnegie scientists are also collaborating with a team at the Smithsonian Institution led by Edward Vicenzi to employ a workhorse of chemistry called Time-of-Flight Secondary Ion Mass Spectrometry (ToF-SIMS). The instrument effectively blasts a sample with ionized particles and fragments the surface-bound molecules and topmost mineral layer. The mass spectrometer allows the researchers to determine what's there. "ToF-SIMS will also allow us to detect the organic molecules that bind most strongly to mineral surfaces," commented Hazen.

"In many ways, Hazen's approach cuts to the chase of addressing this problem," said Patricia Dove, professor of geochemistry at Virginia Tech. "By adapting the microarray approach from molecular biology, his research group can identify up to one million types of biomolecules very quickly to learn which have the strongest interactions with mineral surfaces. It doesn't stop there though--another real advance lies in analyzing their experiments by the ToF-SIMS. This eliminates the need for chemical tags whose own properties could influence the results."

David Deamer, professor of chemistry and biochemistry at U.C. Santa Cruz, commented that "Bob Hazen is boldly asking a fundamental question related to the origin of life. We know that organic compounds were present in the early Earth environment, but as dilute solutions of thousands of different species in the global seas. How were specific kinds of organics selected to assemble into the first forms of life, and by what process were they sufficiently concentrated to initiate a primitive version of metabolism? We now know that minerals select specific organic compounds out of solution, and can even distinguish between subtle properties such as chirality, binding a left-handed amino acid in preference to one that is right handed. These are very significant results that are guiding my own research as well as many other investigators in the field."

Once Hazen and coworkers have identified molecule/surface pairs of interest with the DNA microarray and ToF-SIMS, an arsenal of other techniques can be used to look at the details of the interactions.

"What's particularly rewarding about this research is that it's an interdisciplinary effort from different areas of science--biology, chemistry and geology," reflected Hazen. "It marries them to search for an answer to a question that has intrigued humanity since the birth of consciousness: How did we get here?"

Source: Carnegie Institution