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Life in the Multiverse

Could the strange physics of other worlds breed life?

How Asteroids Built Continents

PLUS:
The Truth about Nanobacteria

THE RISE AND FALL of nanobacteria

Once believed to be the smallest pathogens known, nanobacteria have now proved to be something almost as strange. They do play a role in health—just not the one originally thought

By John D. Young and Jan Martel

KEY CONCEPTS

- Discoveries of purported nanoscale bacteria caused shock and excitement because the organisms seemed too small to live.
- Claims for the tiniest of pathogens outpaced scientific validation until the authors and other scientists showed that although the particles appeared alive, in fact they were merely aberrant crystallizations of minerals and organic molecules.
- The mineral-protein interactions that produce the nanoparticles nonetheless reveal details of processes that can protect or undermine human health.

—The Editors

Evidence of life on Mars, even if only in the distant past, would finally answer the age-old question of whether living beings on Earth are alone in the universe. The magnitude of such a discovery is illustrated by President Bill Clinton's appearance at a 1996 press conference to announce that proof had been found at last. A meteorite chipped from the surface of the Red Planet some 15 million years ago appeared to contain the fossil remains of tiny life-forms that indicated life had once existed on Mars.

Geologic research showing that similar creatures, smaller than any beings previously encountered or even imagined, could have shaped Earth's early terrain suggested these specimens might be relics from the very dawn of life. The only news that could top such findings would come next: evidence that those ancient entities, which would come to be known as nanobacteria, were still among us—indeed, dwelling in our own bodies and potentially causing a range of illnesses.

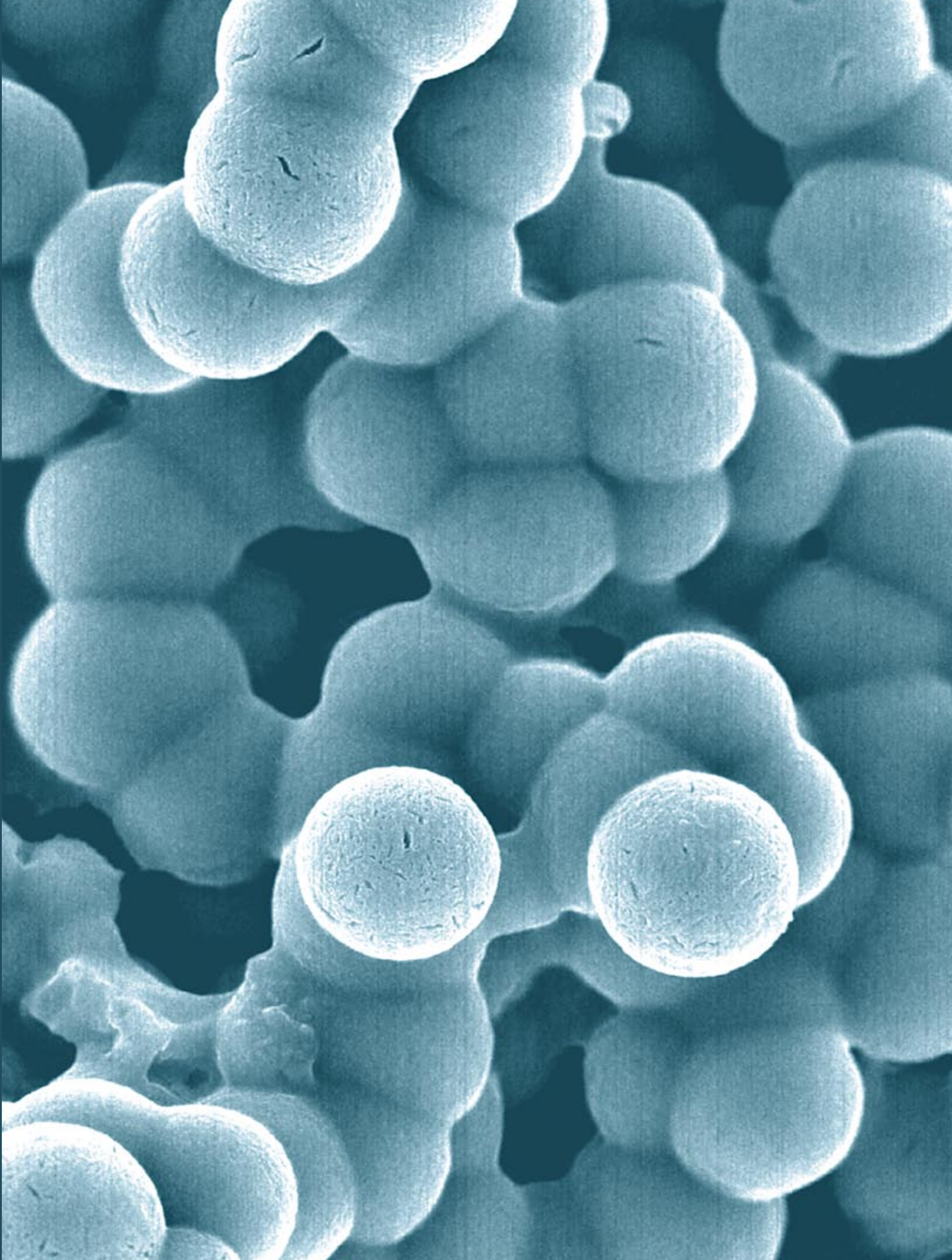
When these collective findings first appeared, plenty of scientists were skeptical, and many signs pointed to the possibility that the discoverers' excitement was outpacing scientific validation of the data. Questions remained about what nanobacteria actually were and what they were not. After more than a decade, understanding of these infinitesimally small particles and their bizarre lifelike behavior has advanced considerably. As it turns out, nanobacteria are not exotic new pathogens—in fact, they are not alive at all. They are no less important to human health, though, and could have played a role in the early evolution of life—just not the one previously assumed.

The evolution of the nanobacteria saga thus offers lessons about how science works and how it can go awry. And like any good story, its real-life ending is even more interesting than the fictional one. Now investigators can move forward to use our knowledge about these nanoentities in advancing human health and nanomaterials research.

Too Tiny for Life?

In 1993 Robert L. Folk, a geologist at the University of Texas at Austin, had been working with rock specimens collected in the Italian hot springs of Viterbo when he first reported what he called "nannobacteria." While examining his samples with an electron microscope, Folk found small spheres that resembled the

NANOPARTICLES FORMED by the binding of proteins to crystallizing mineral ions resemble budding bacterial cells under an electron microscope.



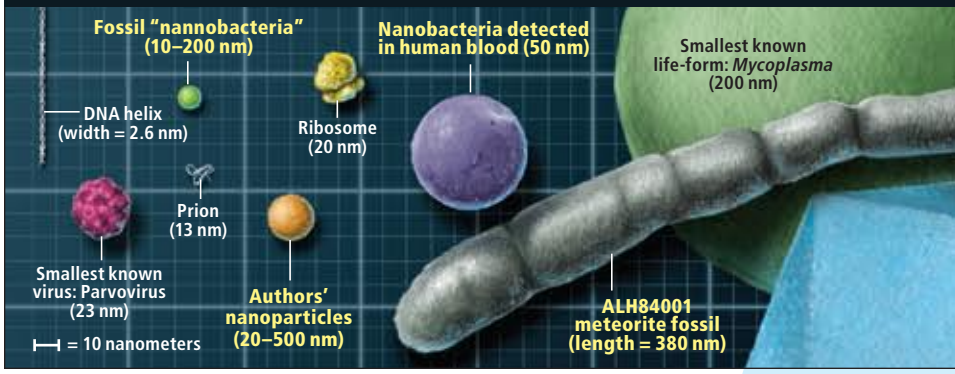
fossilized remains of bacteria. Like bacteria, these little blobs appeared to have cell walls and filamentous surface projections. Folk's spheres were quite small, however, significantly smaller than any known bacteria.

Bacteria themselves normally measure in microns—one micron is a millionth of a meter, which is roughly 100th of a typical hair's width. The fossils observed by Folk were some five to 100 times as small as common bacteria, ranging between 10 to 200 nanometers (one nanometer equals 1,000th of a micron). Folk obtained these nanoentities from the remains of ancient geologic beds, including those from the Paleozoic and Mesozoic periods, considered to have preceded the era of life on Earth. As a result, he proposed that the creatures' cycling of both organic and inorganic matter could have formed the very geologic strata in which they were found.

Folk's findings went largely unnoticed until 1996, when David S. McKay of the NASA Lyndon B. Johnson Space Center in Houston published evidence that a Martian meteorite discovered in Antarctica, ALH84001, carried similar nanofossils. Believed to have been formed from molten material some 4.5 billion years ago, the rock is one of the oldest in the solar system. In addition to finding tiny carbonate spheres resembling Folk's nannobacteria in the meteorite specimen, McKay and his colleagues also detected magnetite and iron sulfide particles, along with polycyclic aromatic hydrocarbons—all raw materials involved in biological processes. These findings were heralded as groundbreaking evidence pointing to the possibility of previous life on Mars and elsewhere in the solar system.

[THE CLAIM]

THE SMALLEST LIFE-FORM



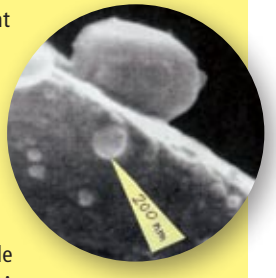
Critics noted that all the claims for these tiniest of creatures had so far been based only on their appearance.

The McKay report, and consequently the earlier Folk studies, were met with great media fanfare but also with great doubt and controversy in scientific circles. Critics noted that all the claims for these tiniest of creatures had so far been based only on their appearance, with no evidence of their ever having been alive. Moreover, the nanoentities unleashed debates on the minimal size required to support life in a unicellular organism. Given that a double strand of DNA is more than two nanometers in diameter, and the protein-manufacturing ribosomes of a

ALLAN HILLS 84001 (*above*), a meteorite discovered in Antarctica, contains nanoscale spheres and elongated formations (*left*) made of carbonate, as well as elements that serve as raw material for life processes.

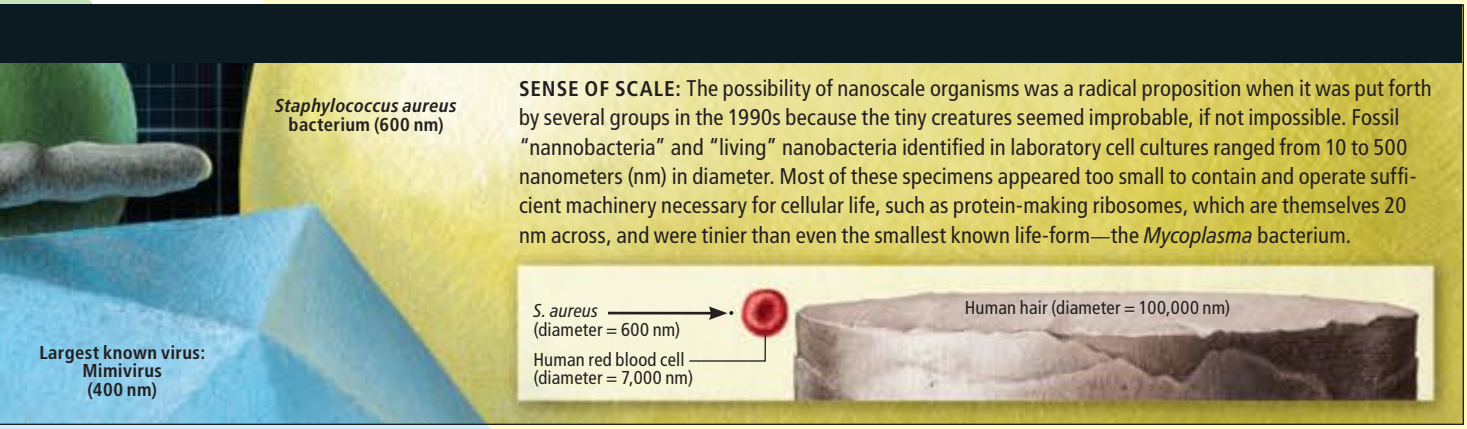
[THE IMPLICATIONS]

Early Excitement



Carbonate structures thought to be the fossil remains of nanoscale bacteria were first reported in 1993. The spheres identified by geologist Robert L. Folk in rock specimens from Italy (*right*) were 10 to 200 nanometers across. But their discovery received little attention until 1996, when NASA scientists announced finding similar fossils in a meteorite that had originated on Mars (*left*). The prospect of a rock more than four billion years old containing evidence of extraterrestrial life garnered worldwide attention. The potential import of the find prompted President Bill Clinton to comment: "Today rock 84001 speaks to us across all those billions of years and millions of miles. It speaks of the possibility of life. If this discovery is confirmed, it will surely be one of the most stunning insights into our universe that science has ever uncovered."

COURTESY OF JOHN D. YOUNG AND JAN MARTEL (*preceding page*); TRAVIS HEYING *AFP/Newscom* (*meteorite*); COURTESY OF NASA (*SEM*); COURTESY OF ROBERT L. FOLK (*University of Texas at Austin*) (*calcite crystal*)



SENSE OF SCALE: The possibility of nanoscale organisms was a radical proposition when it was put forth by several groups in the 1990s because the tiny creatures seemed improbable, if not impossible. Fossil "nannobacteria" and "living" nanobacteria identified in laboratory cell cultures ranged from 10 to 500 nanometers (nm) in diameter. Most of these specimens appeared too small to contain and operate sufficient machinery necessary for cellular life, such as protein-making ribosomes, which are themselves 20 nm across, and were tinier than even the smallest known life-form—the *Mycoplasma* bacterium.

cell are some 20 nanometers across, critics questioned whether a nanoscale "cell" could possibly contain the equipment needed to live.

At the height of this controversy, two scientists at the University of Kuopio in Finland, E. Olavi Kajander and Neva Çiftçioğlu, would ignite an even greater debate. In 1998 the Finnish team provided the first evidence for nanobacteria as living entities. The researchers had been examining small "contaminants" in their cell cultures that proved resistant to all efforts at elimination. Not only were these particles making the cultured cells sick, they appeared to resist the usual sterilizing techniques of heat, detergent and antibiotic treatments. Observing the tiny spherical bodies under an electron microscope, Kajander and Çiftçioğlu found that they ranged in size between 50 and 500 nanometers and were so strikingly similar to Folk's nannobacteria, they must be one and the same.

The Smallest Pathogens

On closer examination, the Finnish researchers found nucleic acids and proteins in the small particles—signs of life. Based on the specific sequences of DNA in the specimens, the scientists assigned their discovery, which they named *Nanobacterium sanguineum,* to a subgroup of bacteria that includes *Brucella* and *Bartonella,* both of which have been shown to cause disease. The Finnish group also noted unusual features of the nanobacteria, including their ability to change shapes in culture, a property known as pleomorphism, which is a rare trait in living organisms. The nanobacteria were seen to change from small spherical bodies to films and clumps of mineralized material. The mineral in question turned out to be hydroxyapatite (apatite), a crystalline complex of calcium and phosphate found everywhere in nature, including mammalian bones as well as the shells of some invertebrates.

[THE AUTHORS]


John D. Young is chair of Chang Gung University (CGU) and Mingchi University of Technology in Taiwan and head of the CGU Laboratory of Nanomaterials. He is mainly interested in understanding the interactions of organic with inorganic materials and how they affect health. Young was head of the Laboratory of Molecular Immunology and Cell Biology at the Rockefeller University, where he remains an adjunct professor. Jan Martel is a doctoral candidate at the Graduate Institute of Biomedical Sciences at Chang Gung University. Originally from Sherbrooke, Quebec, he joined Young's group in Taiwan to investigate blood-borne pathogens and the potential bases for alternative therapies.

The small, round nanobacteria were not only covered by apatite walls but were often found hiding within large "igloo-shaped castles" or "dwelling places," the researchers wrote.

Attempting to identify the source of nanobacteria, the Finnish team was surprised to find the creatures in most animal and human body fluids they examined—blood, saliva and urine, among others—and concluded that the tiny bugs posed a risk for diseases involving abnormal mineral agglomerations, such as kidney stones. Eventually conditions linked by various researchers with nanobacteria would expand to include many types of cancer, atherosclerosis, degenerative diseases such as arthritis, scleroderma, multiple sclerosis, peripheral neuropathy, Alzheimer's disease, and even viral infections such as HIV. Initial studies by the Finnish team had shown that 14 percent of healthy Scandinavian adults tested positive for antibodies against nanobacteria. Other scientists, such as Andrei P. Sommer of the University of Ulm in Germany, would later promote the idea that nanobacteria behave as transmissible pathogens, incriminating nanobacteria as a global health hazard.

Despite all these frightening implications, in many ways nanobacteria fulfilled the wildest dream of every scientist. Their very primitive nature, unusual characteristics and ubiquitous distribution suggested that nanobacteria might help explain the origins of life—not only on Earth but elsewhere in the cosmos. Moreover, they could represent a new unifying disease principle by virtue of being associated with practically every disease process imaginable, an unprecedented scenario. For all the extraordinary characteristics attributed to nanobacteria, however, many critics remained unconvinced. One who still deemed nanobacteria too small to be true, Jack Maniloff of the University of Rochester Medical Center, labeled them "the cold fusion of microbiology."

COURTESY OF LIN SHOU-SHENG *Taiwan Tatler (Young)*; COURTESY OF JAN MARTEL *(Martel)*; JEN CHRISTIANSEN *(Illustration)*

By 2000 research led by John O. Cisar of the National Institutes of Health provided the first alternative view of nanobacteria. Cisar found that phospholipids—common components of cell membranes—would bind to both calcium and phosphate, fostering the formation of calcium-phosphate (apatite) crystals. The small crystalline clumps seeded this way bore an uncanny resemblance to the nanobacteria described by the Finnish group. Remarkably these same crystalline blobs were seen to grow and replicate in the test tube as if they were alive. As for the presence of unique nucleic acid sequences that had been previously identified as hallmarks of nanobacteria, the Cisar study demonstrated that these same sequences could occur in the genomes of common bacteria that often contaminate laboratory reagents and glassware.

The nanobacteria fervor started to lose momentum. Then suddenly in 2004, a Mayo clinic team led by Virginia Miller and John C. Lieske claimed to have found nanoparticles in specimens of calcified blood vessels that not only harbored DNA and proteins but also seemed to synthesize RNA, the intermediate molecules that all living things use to convert DNA instructions into cellular proteins. Overnight, the nanobacteria debate, along with all the familiar controversies and media attention, was reignited.

Heralded as prototypes of a new mechanism of disease, perhaps resembling prions—the proteinaceous particles responsible for such conditions as mad cow disease—nanobacteria were now a threat to public health, which opened avenues for commercial interests to begin selling methods to detect and treat the tiny pathogens. Nanobac OY, a company founded by the Finnish scientists who had first discovered "living" nanobacteria, became a major supplier of diagnostic reagents, including antibodies, designed to detect nanobacteria in human tissues. Later, Nanobac Pharmaceuticals, a Florida company that absorbed Nanobac OY in 2003, became a provider of medicines for nanobacteria "infections."

Building Nanobacteria

Intrigued by the extraordinary claims and counterclaims about the behavior of nanobacteria, our research group embarked in 2007 on a series of experiments to dissect the particles' chemical and biological nature. Before discussing the possible roles of these nanoparticles in disease, we thought, scientists must first establish what the particles are and what they are not, including whether they are really alive. Toward that end, we set out to see if nanobacteria could be replicated with nonliving materials.

We worked with simple calcium compounds such as calcium carbonate (limestone) and calcium phosphate, knowing that they have a natural tendency to aggregate in a precise molecular pattern to form crystals. Crystals are highly ordered, self-nucleating structures similar to geometric prisms, with flat surfaces and sharp edges. If their growth is disturbed or interrupted, however, they can take on dramatically different properties. We hypothesized that doping the minerals with proteins and other nonmineral compounds would disrupt the precise order of lattices needed for crystal seeding, leaving the mineral aggregates amorphous—organized in a random or disorderly manner at the molecular level.

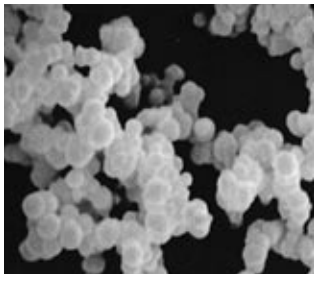
We also thought this disruption would simply abort the mineral aggregates' growth as crystals. Surprisingly, these mineral agglomerations continued to grow and to propagate as particles, or more precisely, as nanoparticles. We certainly did not expect that such simple compounds would readily assume shapes and geometries that make them look virtually identical to nanobacteria, acquiring cell-like walls and appearing to divide just like living bacteria. Using these simple nanoparticle constructs as a springboard, we then proceeded to attempt to reconstruct the entire nanobacteria biology. That is, we tried to see whether all the exotic properties of nanobacteria already described by other scientists could actually be reproduced through the interaction of simple organic molecules and minerals.

It soon became clear that the nanoparticles made of calcium carbonate–phosphate mixtures are rather sticky. They bind avidly to any charged molecules, whether ions, small organic compounds (such as carbohydrates), lipids, or even DNA and other nucleic acids. Binding to charged groups stabilizes the growing particles, giving them structural integrity and impelling the calcium particles to continue to grow and assume complex shapes. Eventually, however, one of two scenarios prevails. If excess minerals are available, the particles will finally crystallize into apatite. But if the organic compounds available exceed the local amount of minerals, crystallization may cease altogether or will continue slowly, with the particles continuing to evolve into more complex forms.

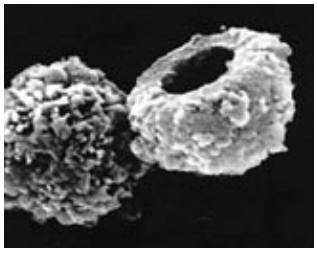
Among the charged groups we studied, the most interesting and complex effects were produced when proteins were the binding agents. Proteins roam freely in the body. Some proteins,

LOOKING ALIVE

Finnish scientists Olavi Kajander and Neva Çiftçioğlu claimed in 1998 to have discovered nanoscale bacteria whose calcium phosphate coatings created mineral structures thought to reflect the changing shapes and activities of the proliferating organisms.



In the Finnish group's experiments, mineralized particles slowly multiplied and grew to sizes ranging in diameter from 20 to 500 nanometers in cell culture dishes.



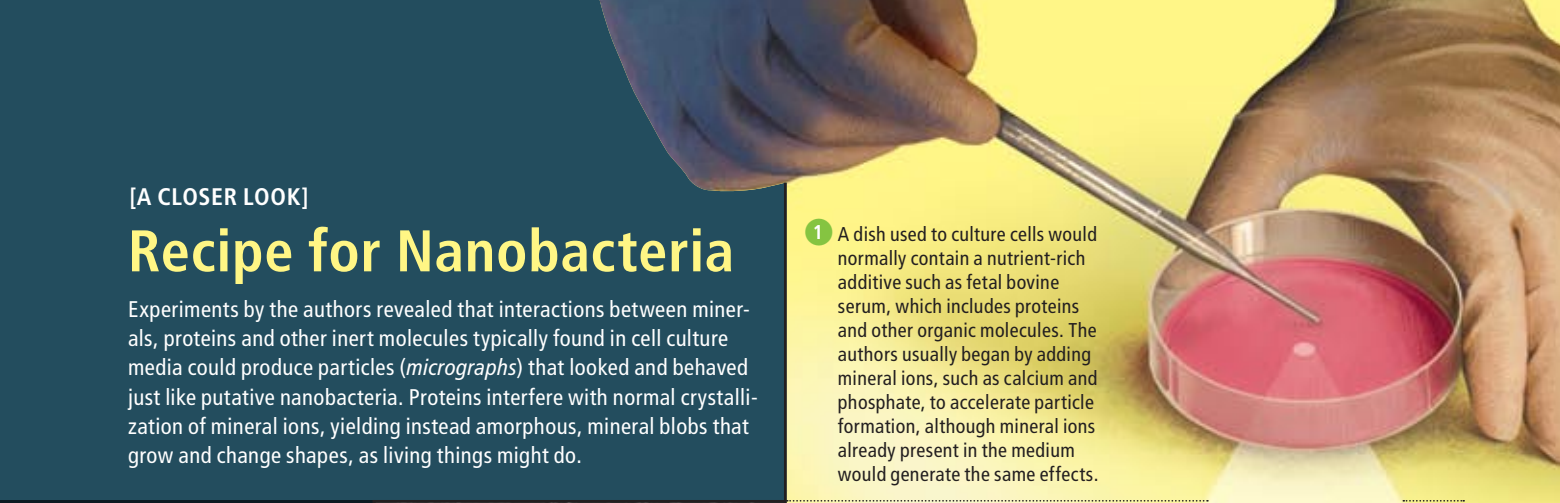
Empty hydroxyapatite structures seen in the cultures were characterized as "dwellings" made by the nanobacteria from accumulated minerals.

THIS PAGE: "NANOBACTERIA: AN ALTERNATIVE MECHANISM FOR PATHOGENIC INTRA- AND EXTRACELLULAR CALCIFICATION AND STONE FORMATION," BY E. OLAVI KAJANDER AND NEVA ÇIFTÇIOĞLU, *IN PMAS*, VOL. 95, NO. 14; JULY 7, 1998 *(mineral structures)*; OPPOSITE PAGE: COURTESY OF JOHN D. YOUNG AND JAN MARTEL *(top three micrographs)*; "PUTATIVE NANOBACTERIA REPRESENT PHYSIOLOGICAL REMNANTS AND CULTURE BY-PRODUCTS OF NORMAL CALCIUM HOMEOSTASIS," BY JOHN D. YOUNG ET AL., *IN PLOS ONE*, VOL. 4, NO. 2, FEBRUARY 9, 2009 *(bottom two micrographs)*; JEN CHRISTIANSEN *(illustration)*

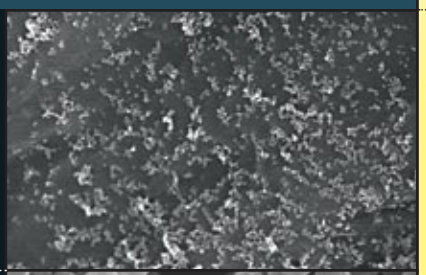
[A CLOSER LOOK]

Recipe for Nanobacteria

Experiments by the authors revealed that interactions between minerals, proteins and other inert molecules typically found in cell culture media could produce particles (*micrographs*) that looked and behaved just like putative nanobacteria. Proteins interfere with normal crystallization of mineral ions, yielding instead amorphous, mineral blobs that grow and change shapes, as living things might do.

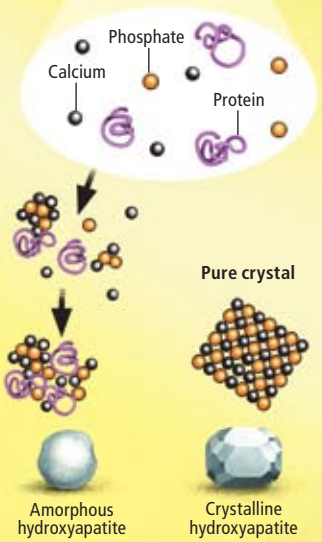


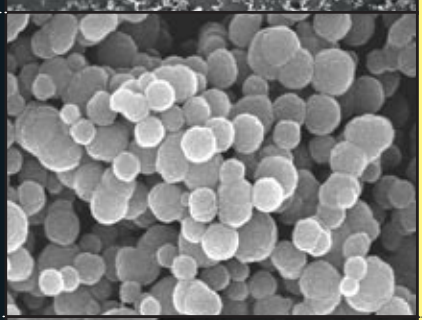
1 A dish used to culture cells would normally contain a nutrient-rich additive such as fetal bovine serum, which includes proteins and other organic molecules. The authors usually began by adding mineral ions, such as calcium and phosphate, to accelerate particle formation, although mineral ions already present in the medium would generate the same effects.



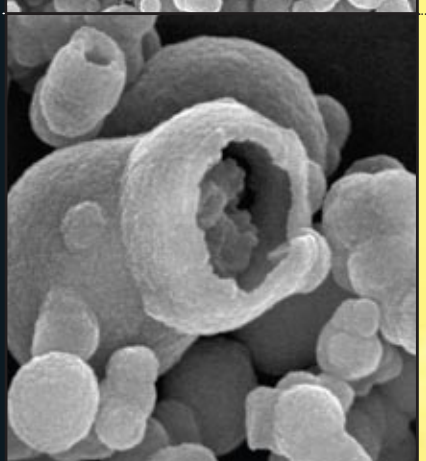
Within hours after ions are added to cell culture medium, nanoparticles 20 to 50 nanometers in diameter are visible by electron scanning microscope.

2 Calcium and phosphate ions naturally bind together to form larger mineral particles of calcium phosphate (hydroxyapatite); however, certain proteins also avidly bind calcium and interfere with this crystallization process. Instead of an orderly lattice structure typical of pure hydroxyapatite crystals (*far right*), the resulting mineral-protein particles have an amorphous molecular structure and visible shape.



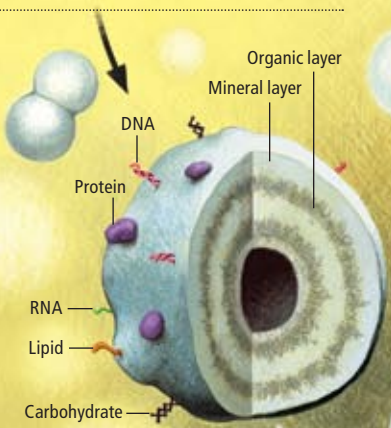


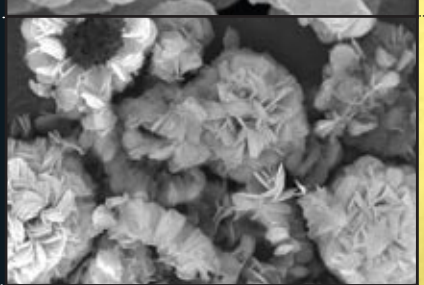
These particles, each 100 to 500 nanometers, could resemble living cells because of their uniform shapes and sizes. They do resemble purported nanobacteria.



By the time particles reach several hundred nanometers in diameter, their continued fusion creates odd shapes and sometimes the appearance of dividing cells.

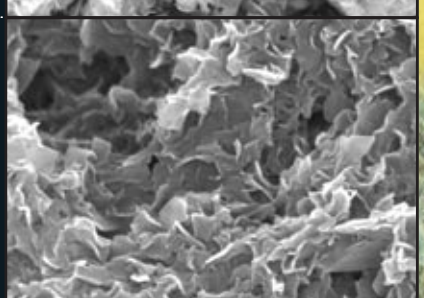
3 As the particles continue to grow by the accretion of layers of mineral-protein material, they may also fuse into larger particles and adopt diverse shapes. In addition to minerals and serum proteins, the particles incorporate any other readily available molecules in the culture medium. This organic material provides structural support for the particles' continued growth.





Crystallization is prevailing in these particles, each 600 nanometers wide, producing sharp-edged mineral petals.

4 Eventually proteins in the medium get used up and crystallization prevails, producing needlelike whiskers on the particles' surface. These crystalline structures then collapse together to form larger spindles or fanlike leaves. As crystallization progresses, particles become less distinct and finally fuse into jagged mineral sheets.



Finally, the mineralized particles collapse into solid mats that will eventually cover the entire bottom of the culture dish.

such as albumin or fetuin-A, are present in large amounts in the blood and are also avid binders of calcium. Albumin alone accounts for half of the calcium-binding capacity of blood serum. Fetuin-A is even more unusual in that it binds not only to calcium but also strongly to calcium phosphate in the form of nascent apatite.

The ability of these proteins to bind nascent apatite crystals is well known to abort further crystallization and thereby protect against unwanted mineralization of body tissues. Considering the fact that all body fluids, including blood, contain supersaturated concentrations of calcium and phosphate yet do not undergo spontaneous calcification, the protection offered by these proteins is clearly important. Without it, blood vessels would become hardened, and bony formations would crop up everywhere.

The growing nanoparticles simply hijack any readily available proteins in their surrounding environment.

As we were pursuing this line of inquiry, an independent study led by Didier Raoult of the Medical School of Marseille in France gathered important evidence indicating that the main protein detected in nanobacteria turned out to be fetuin-A. Our own experiments later showed that fetuin-A is only one of several proteins found embedded in the calcium nanoparticles. Others include albumin, lipid-binding proteins known as apolipoproteins, complement proteins, and many common proteins that are normally abundant in the blood and that are all well known to avidly bind calcium and apatite. In essence, our tests indicated that the growing nanoparticles simply hijack any readily available proteins in their surrounding environment that are capable of binding to calcium and apatite.

We were also able to show that the antibodies sold as diagnostic tools for nanobacteria by the Nanobac group of companies are in fact detecting fetuin-A and albumin. Thus, the earlier studies using the Nanobac antibodies to find nanobacteria in human tissue cultures were actually detecting common blood proteins. More alarmingly, the antibodies purported to detect exotic nanobacterial proteins in human blood were actually specific to the versions of those proteins in the cow. As bizarre as this discovery may sound, it can be easily explained by the fact that laboratories generally include fetal bovine serum, an excellent source of nutrients, in cell culture media. In the case of nanobacteria cultures, however, this serum is also a main source of the proteins integrated into the particles, leaving a final bovine imprint on the nanoparticles. In retrospect, the numerous studies claiming to have detected nanobacterial proteins with these antibodies can now be seen as fundamentally flawed.

What's Really Going On

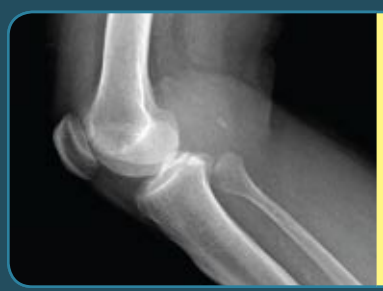
Although nanobacteria have now been conclusively shown to be nonliving nanoparticles crystallized from common minerals and other materials in their surroundings, these nanoentities may still play an important role in human health. We believe that nanobacterialike particles are generated through a natural process that normally protects the body against unwanted crystallization but that can also promote nanoparticle formation under certain conditions.

Many minerals aggregate spontaneously in nature and may even display a tendency to crystallize. Calcium, for example, avidly binds car-

[MECHANISM]

MINERAL MANAGEMENT

Aggregates of nanobacterialike particles may resemble the calcified deposits seen in human tissues because both arise from natural mineralo-protein interactions responsible for mineralizing teeth and bone and for inhibiting unwanted calcification. Abnormal tissue calcifications are often a symptom, rather than a cause, of disease; however, when abnormal calcification becomes advanced, it can produce illnesses such as kidney stones.

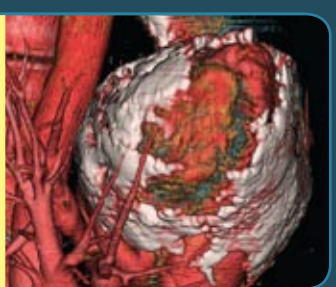


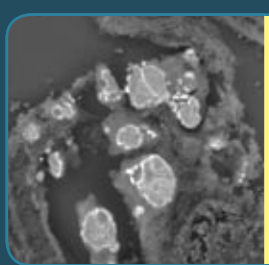
NORMAL MINERALIZATION

Bone formation requires 10-nanometer hydroxyapatite spheres to fuse into strings of mineral beads interwoven among collagen fibers. These apatite building blocks gradually coalesce into fibers, then into mineralized mats that envelop the collagen scaffold, giving bone its tensile strength.

HARDENED HEARTS

Calcified deposits (*white*) in the heart and arteries form by the same mineralization mechanisms as bone and are a sign of cardiovascular disease. The calcifications are believed to be a response to tissue injury and may halt or recede if the underlying disease is treated.





CAUSE OR EFFECT?

Tiny calcifications are seen in other parts of the body, such as this sample of nonmalignant tissue from a human thyroid affected by cancer. The calcium-phosphate structures may reflect a failure of normal mineral clearance processes in the diseased tissue. Another possibility is that the mineralizations are seeded by foreign particles, such as pollutants, a theory that remains to be tested.

MEDICAL BODY SCANS *Photo Researchers, Inc. (bone)*; OLIVIER VOISIN *Photo Researchers, Inc. (heart)*; COURTESY OF ANTONIETTA M. GATTI *University of Modena and Reggio Emilia* AND STEFANO MONTANARI *Nanodiagnostics Srl*

bonate and phosphate to form crystals of calcite and apatite. Any molecule with a high affinity for calcium or nascent apatite crystals, whether a protein, a lipid or some other charged moiety, can therefore be seen as a calcification inhibitor in the sense that it will directly interfere with the process of crystallization by binding to the minerals. Inside the body, the binding of calcium and nascent crystals by proteins would also target the complexes for either storage or elimination.

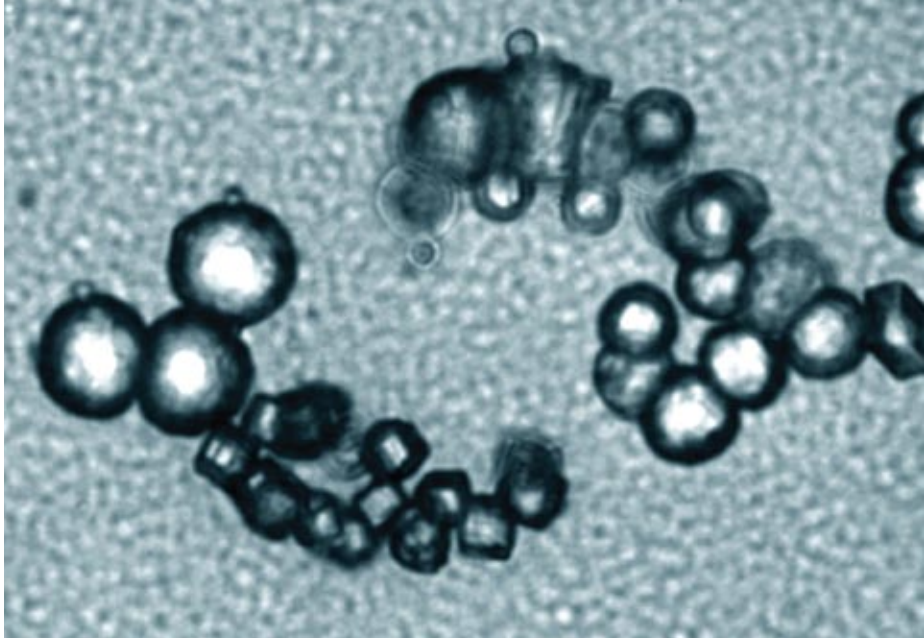
This constant clearance of the minerals serves to prevent abnormal calcium deposits that could cause disease. More proteins are continually needed to bind the minerals, however, and if the minerals come to outnumber the inhibitory proteins, the inhibitory mechanism is eventually overwhelmed. When the minerals saturate the binding sites of proteins, the protein-bound minerals can instead become seeds for further crystallization, creating a runaway process that may produce not only the phenomenon of nanobacteria but also anomalous calcification, such as stone formation and calcification of arteries. As potential agents of disease, these nanoparticles must first be viewed as parts of a larger cycle of normal calcium regulation. The mechanisms of mineral-protein complex formation described here are certainly involved in normal bone formation as well. Rather than being the cause of ailments involving abnormal calcification, therefore, the calcified deposits may be the end result of other metabolic anomalies that affect mineral inhibition and clearance.

It is too early to know how these insights may be translated into therapeutic approaches. This inhibition/seeding concept can probably explain the entire body of prior observations about nanobacteria, however. By growing in size through fusion, for instance, these mineral-protein spheres evolve and coalesce into spindles and, eventually, films. Those shape changes can now be documented and explained by the simple interaction of proteins and minerals, with mineralization finally winning out. According to our hypothesis, nanobacterialike particles arise in culture dishes because the dynamic clearance mechanisms operating in the body are absent. The nanobacteria described in cell cultures may now be seen as simple by-products of normal calcium metabolism under static conditions.

All the nanobacteria particles that we were able to assemble from blood and other body fluids have demonstrated a simple and predictable chemical composition, one that mirrors the nature of the building blocks available in the surrounding medium. By changing the medium composition, we can easily alter the constitution of the nanoparticles, and today we are able to engineer nanobacterialike particles to any prescribed composition. Exploiting this process, we have been able to produce an entire family of biologically related and structurally similar ion complexes that we have termed bions. Bions come in all sizes and shapes and they can mimic biological forms that appear alive. Beyond demonstrating the nonliving nature of nanoparticles, they promise to further elucidate how building materials consisting of tiny nanoblocks are fabricated and assembled in nature.

Understanding how such small particles composed of minerals complexed with organic molecules are generated naturally may shed light on the emergence of life on Earth billions of years ago. It is conceivable that by a process of self-replication similar to nanoparticle growth, minerals complexed with small organic molecules formed the first building blocks of life and found a way of perpetuating themselves. Such mineral-organic complexes could have served to shelter and compartmentalize the earliest life-related processes and perhaps could have become the very catalytic centers needed to initiate the life processes themselves. This remains an exciting possibility, which we are currently exploring.

That such a wide array of calcifications seen in nature and in so many chronic diseases can now be at last understood in the context of molecular interactions between proteins, lipids, minerals and other discrete factors is an exciting prospect. Unlike the nanobacteria hypotheses advocated in the past, current understanding of well-defined naturally occurring mineral-organic particles will allow scientists to move forward in exploring how these tiny entities can benefit life, even if they are not themselves alive. ■



COURTESY OF JOHN D. YOUNG AND JAN MARTEL

PURE CRYSTALS of calcium carbonate can take varying shapes. Understanding how nanoparticles form naturally and how they might affect human health will help scientists to control the properties of man-made nanoparticles.

MORE TO EXPLORE

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