BUCKY

EXPLORATIONS
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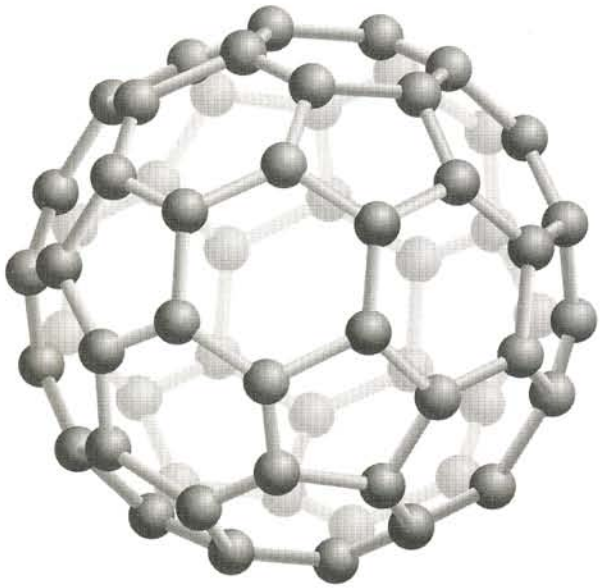
STRIKING THE MOTHER LODE

BY JANET HOWARD



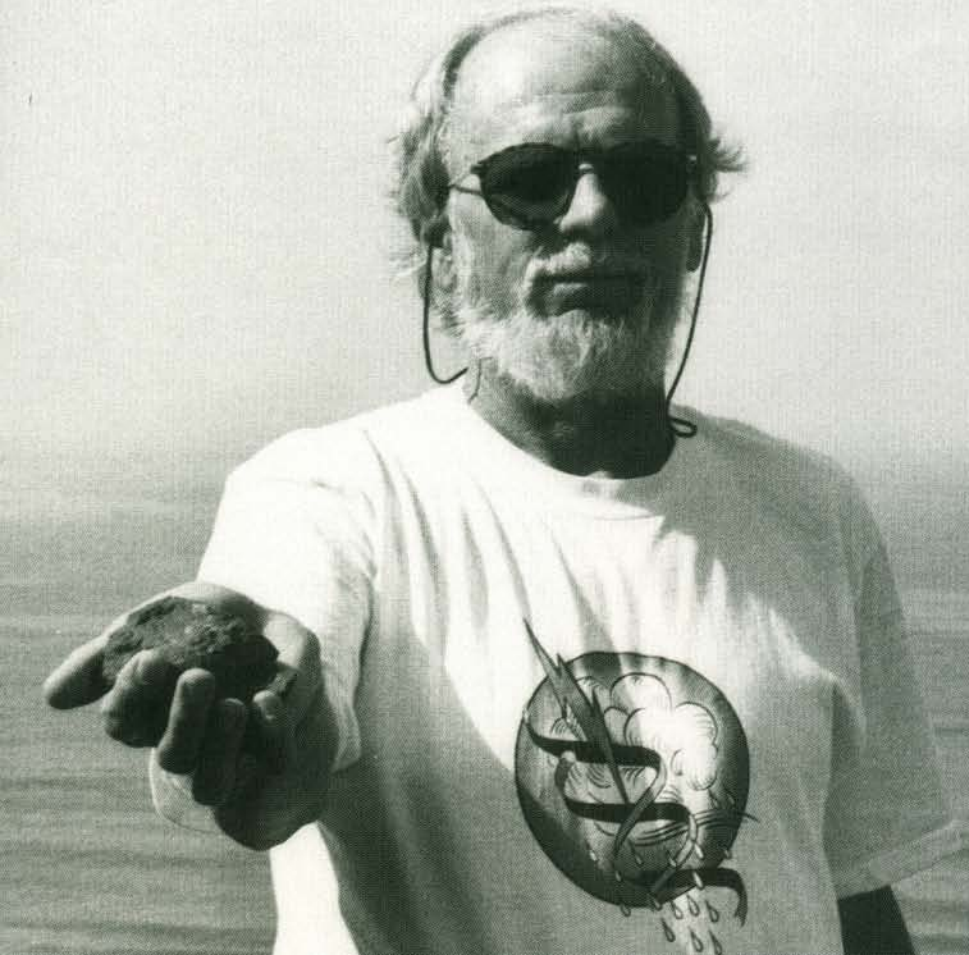
Talking to Jeff Bada is like listening to a man who tucked away a lottery ticket in his dresser drawer only to pull it out years later and discover it was a winning number.

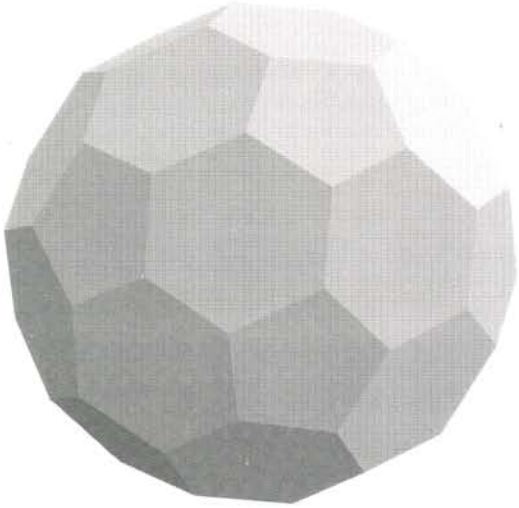
In Bada's case the winning ticket was a couple of samples taken from a crater in Sudbury, Ontario, and given to him by a NASA scientist. The massive crater is believed to have formed almost two billion years ago when a large meteorite slammed into the earth.

Undecided about what to do with the samples, Bada simply put

BALLS

Buckyballs were the furthest thing from Jeff Bada's mind when a NASA scientist gave him a couple of rock samples from a two-billion year old crater. Ten years later the samples yielded the largest discovery of the soccer-ball-shaped form of carbon found on earth to date.





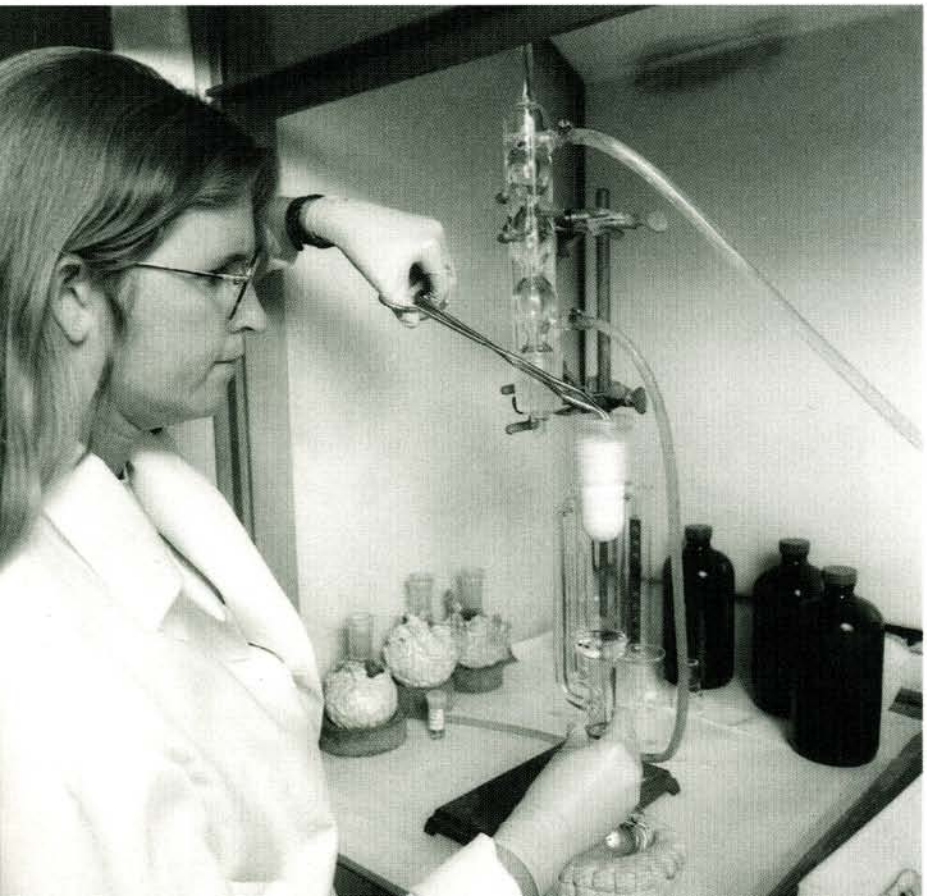
them on his desk–and left them there for 10 years.

When Scripps graduate student Luann Becker was about to set off for a stint at the Argonne National Laboratory in Illinois, the two researchers decided to take advantage of the lab's sophisticated spectrometers and analyze the Sudbury samples for an exotic form of carbon called fullerene.

"Luann was really the driving force behind it," said Bada, a professor of marine chemistry at Scripps. "I said, 'Sure, what the heck. It's a long shot–I doubt if you'll see anything–but let's do it'."

As luck will have it, the samples yielded the largest discovery of natural fullerenes found on the earth to date. The researchers published their results in a recent issue of the journal *Science*.

Luann Becker



Because fullerenes only form under certain chemical conditions, including a low-oxygen atmosphere, their presence in the Sudbury site could give scientists clues about the earth's environment two billion years ago when the carbon molecules were created.

"The fact that you are able to find fullerenes this old suggests that two billion years ago there wasn't much oxygen around," said Becker. "One of the things researchers are trying to determine is when did the atmosphere have oxygen levels near present day values."

Nicknamed buckyballs because their structure resembles the geodesic domes designed by R. Buckminster Fuller, fullerenes were found by accident in 1985 when two researchers were heating carbon vapor to temperatures exceeding 14,000° Fahrenheit.

Scientists had previously assumed there were only two forms of pure carbon present on the earth: graphite and diamond.

"All this time, we thought we understood the chemistry of carbon and all of a sudden there is this whole new player in the ball game that has completely changed even our understanding of matter," said Bada.

The first fullerene to be synthesized in the lab was C60, which is comprised of 60 carbon atoms linked in such a manner that they form a pattern of interlocking hexagons and pentagons, similar to the pattern on a soccer ball.

It is this molecular structure that is responsible for buckyballs' unusual properties, including their extreme chemical stability. Indeed, the structure of buckyballs is so unique that researchers are optimistic it could engender a new class of materials that could be used to develop everything from extremely strong plastics to tiny ball bearings.

Scientists are particularly intrigued by buckyballs' cage-like structure. By filling the center of

the carbon balls with drugs, they may be able to use fullerenes as a new form of drug delivery system. By encapsulating certain metal ions, on the other hand, buckyballs could be converted into high-temperature superconductors.

Buckyballs are thought to form naturally on the earth as the result of extremely energetic events, such as lightning strikes. Scientists also believe the soccer-ball-shaped molecules are created in the fiery interiors of stars.

The first naturally occurring fullerenes were discovered in July 1992, when a team of researchers discovered them in a coal-like type of rock–shungite–found in Russia. The same team later reported finding buckyballs in lightning-seared rocks called fulgurites in southern Colorado.

But the amount of fullerenes detected at both sites was much smaller than that discovered at the Sudbury site. Analysis of samples taken from three different locations in the 37 mile by 19 mile crater revealed that fullerenes were present in concentrations between 1 and 10 parts per million–a virtual mother lode in the world of buckyballs.

"I think we have certainly uncovered the possibility that at some time upon the earth fullerenes were a very important form of carbon," Becker said. "They probably began to be destroyed, however, with the onset of oxygen in the atmosphere and when other forms of carbon, such as graphite, began to play a more important role."

Becker believes that the Sudbury fullerenes probably were formed in the gaseous plume created when the carbon-rich meteorite collided with the earth.

"The earth at those times looked dramatically different in terms of the sources of carbon available," she said. "That is why we feel comfortable with the idea that the fullerenes must have been either synthesized during the impact event–or must have come from the meteorite itself."

The first evidence that buckyballs may form in space was reported in May by two research groups who discovered fullerenes in carbon residue from a tiny impact crater on NASA's Long Duration Exposure Facility (LDEF) satellite. This satellite was retrieved after orbiting the earth for about five years to test the performance of various materials in the harsh environment of space.

The scientists theorized that the fullerenes must have formed when a chondritic micrometeoroid struck the craft at high speed.

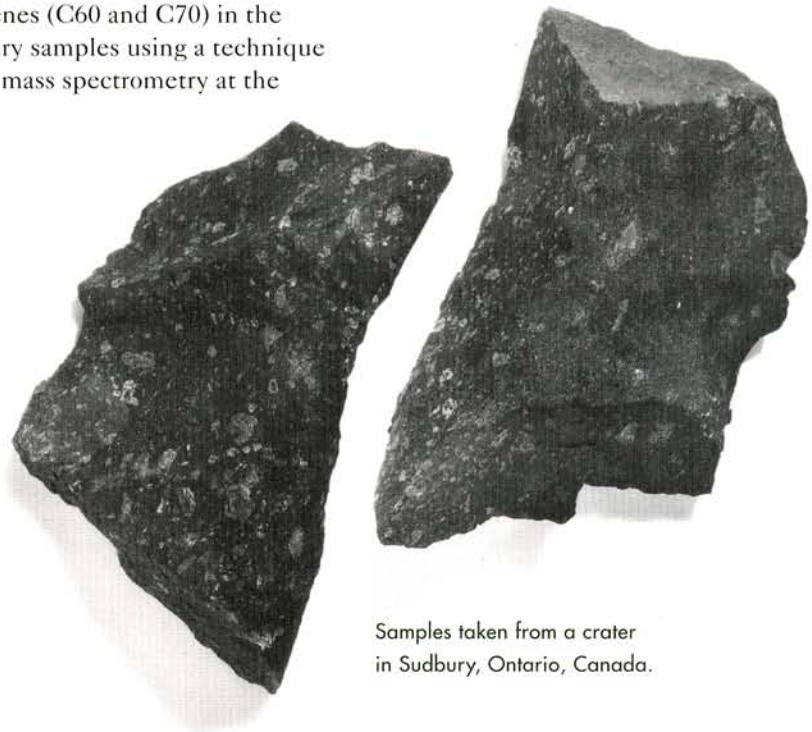
"LDEF is significant in that it suggests that fullerenes form on impact," said Becker. "The thing that everybody is waiting to find out is whether fullerenes exist in the interstellar medium. Then we might be able to identify where they came from based on what we know about the chemistry of space."

Becker and colleagues detected fullerenes (C60 and C70) in the Sudbury samples using a technique called mass spectrometry at the Argonne National Laboratory. "We took the bulk rock and did some chemical extractions and analyzed the carbonaceous residue that was left over to determine if fullerenes were present," she said. "And, in fact, it looks as though fullerenes are the predominant form of carbon in the Sudbury impact structure."

The buckyballs probably only survived the last two billion years because they were embedded in ore and sulfur deposits, which protected them from exposure to oxygen and sunlight.

Impressed by the huge quantity of fullerenes preserved, Becker and Bada are optimistic that there are more buckyballs out there waiting to be discovered. And they're not confining their prospects to the earth.

The next place the scientists would like to search: the Moon. Then, on to Mars!



Samples taken from a crater in Sudbury, Ontario, Canada.

Maverick Architect Designed for Future World

Anyone who has sat under the Astrodome in Houston, seen the giant golf-ball like dome at the entrance to Disney's EPCOT Center, or watched children climb across sphere-shaped monkey bars at the local playground, has come under the influence of R. Buckminster Fuller.

The structures are all based on Fuller's renowned invention: the geodesic dome.

An outgrowth of Fuller's quest to discover a coordinate system based on nature's principles, and thus of optimum efficiency, the geodesic dome requires significantly less building materials to enclose a given space than conventional architecture.

Such efficiency was in perfect harmony with Fuller's central quest: to translate the energy relationships of the universe so as to allow society to reap the maximum benefits from the planet's natural and industrial resources.

"I did not set out to design a house that hung from a pole," Fuller once said, "or to manufacture a new type of automobile, invent a new system of map projection, develop geodesic domes, or Energetic Geometry. I started with the Universe–as an organization of regenerative principles frequently manifest as energy systems of which all our experiences, and possible experiences, are only local instances. I could have ended up with a pair of flying slippers."

Fuller, often called Bucky, built his first geodesic dome in 1948 at Black Mountain College, near Asheville, North Carolina. The dome, 50 feet in diameter, was constructed out of lightweight aluminum. Unfortunately, the fragile structure immediately collapsed.

Undeterred, Fuller fashioned his second dome at Black Mountain College the following summer. This time he built a 14-foot-diameter hemisphere out of strong aluminum aircraft tubing and the project was a success.

Fuller did not achieve international recognition for his work, however, until 1953 when he erected a giant dome over the circular corporate headquarters of the Ford Motor Company. The dome, weighing more than eight tons, was made of almost 12,000 aluminum struts.

The geodesic dome was only one of a multitude of interests that captured Fuller's imagination. Fuller also experimented with new forms of transport, including various models of the 'Dymaxion car,' which featured a streamlined body and such things as air intake 'nostrils' and a cooling system that relied on dry ice. One model of the vehicle could carry a dozen passengers at speeds up to 120 miles per hour and traverse rough terrain.

A philosopher and poet,as well as an architect and engineer, Fuller was considered one the most original thinkers of his time. He died in 1983 shortly before his 88th birthday. Recently scientists discovered C60, a symmetric form of pure carbon whose structure resembles that of a soccer ball. They named their discovery buckminsterfullerene after the man who gave the world the geodesic dome. The exotic form of carbon soon became known as buckyballs.

R. Buckminster Fuller with his Fly's-eye dome and Dymaxion car.