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HEADLINE: Too Rich a Soil: Scientists Find the Flaw That Undid the Biosphere

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BODY:

THE major flaw in the \$150 million Biosphere 2 project has been discovered by a leading geochemist and his student, raising questions of whether the venture in the Arizona desert will be corrected in the interest of serious science or will be doomed to repeated cycles of failure in the years ahead. In theory, the experiment is to last 100 years.

A mysterious decline in oxygen during the two-year trial run of the project endangered the lives of crew members and forced its leaders to inject huge amounts of oxygen, spoiling the idea of a self-contained ecosystem that was supposedly a way to learn about living in space. The cause of the life-threatening deficit, scientists now say, was a glut of organic material like peat and compost in the structure's soils. The organic matter set off an explosive growth of oxygen-eating bacteria, which in turn produced a rush of carbon dioxide in the course of bacterial respiration.

The main mystery was where this carbon dioxide was going, since so little of its calculated mass was found in the dome air.

The scientists who solved the riddle were Dr. Wallace S. Broecker, a geochemist at the Lamont-Doherty Earth Observatory of Columbia University in Palisades, N.Y., and one of his graduate students, Jeff Severinghaus. Late this summer the two found that the missing carbon dioxide had been absorbed by the concrete that forms and lines the structure's interior. The 110,000 square feet of exposed concrete has a surface area greater than two football fields.

"The oxygen is disappearing because they were arrogant and put five to 10 times more organic matter in the soil than you'd get outside," Dr. Broecker said in an interview. "They made a fundamental day one mistake.

"Our assessment is that this decline will continue for decades," he said, unless major steps are taken to correct the mistake, like replacing all or most of the soils in the domes. All told, the soil weighs 30,000 tons.

Dr. Broecker advises the Arizona group but gets no fee, he said, in order to avoid the perception that his opinion is shaded in any way.

Search for Solutions

Dr. John Corliss, the recently appointed scientific director of Biosphere 2, which is outside Tucson, said in an interview that the group was still considering options for dealing with the soil trouble, ranging from replacing the overly rich loam to doing nothing but continuing to pump tons of oxygen into the domes. Most of the possible actions would involve minor changes, he said, at least for the immediate future.

"My assumption is that we'll go ahead with the second mission the way it is," he said. "We're searching for ideas that might be alternatives to taking the soil out."

The next experiment in human habitation is scheduled to begin Feb. 26 and to last one year. The shorter period of occupation -- one year versus two -- in itself will lessen the severity of the problem since the decline in oxygen becomes more severe and dangerous over time. The crew of men and women for the new mission has yet to be selected, although a group of candidates is now training at the Arizona site.

During the two-year trial run, which ended Sept. 26 amid celebratory fanfare, four men and four women gasped increasingly thin air inside the 3.15 acres of glass domes. Beginning in January, then again in August and September, project officials injected 23 tons of pure oxygen into the sprawling glass bubble to avoid a medical emergency, raising levels from a low of 14 percent oxygen to the normal 21 percent.

Work on Biosphere 2 (project officials refer to Earth as Biosphere 1) began in earnest around 1984, financed by Edward P. Bass, the Texas billionaire and oil heir. The plan was that human inhabitants would thrive in a miniature world whose environmental cycles were powered by an ocean, rain forest, marshland, desert and farm. Everything would be recycled. Most importantly, the project sought to show that humans could for the first time create a life-support system that was totally self-sufficient and esthetically pleasing -- sort of a new Eden.

Despite its New Age overtones, the project was promoted as highly scientific. Its officials were quick to note the prestigious talent hired to get things under way, including the Smithsonian Institution's Marine Systems Laboratory, the New York Botanical Garden's Institute of Economic Botany and the University of Arizona's Environmental Research Laboratory.

Delicate Atmospheric Balance

The university laboratory used powerful computers to predict how various combinations of plants, animals and soils would affect the structure's atmosphere. Dr. Robert J. Frye, a senior researcher there, said in an interview that all his mathematical models assumed that the agricultural soils would contain 4 or 5 percent organic matter -- what he called "representative figures" for standard enrichment.

Dr. Frye said that some project officials "wanted to use much higher amounts" and that an important issue in discussions was whether bacterial respiration would upset the atmospheric balance. Those questions, he said, "came up frequently in meetings." Limited to giving advice, the university laboratory apparently had little idea that the enrichment of some soils would turn out to be quite high.

As Dr. Frye remarked: "I don't think anybody here ever said, 'This is going to explode on you,' in a formal way, simply because our involvement was very small."

But other experts say the red flags were plentiful. "A lot of people warned them," said Dr. Mary W. Olsen, a plant pathologist at the laboratory who advised the project.

John Allen, the leader of the ecology project, has previously noted the importance of rich compost and soil microbes to decomposition. In a 1991 book, "Biosphere 2: The Human Experiment," published by Penguin, he wrote: "Bacteria help recycle nutrients. Without them, dead animals and plants would simply pile up until Biosphere 2 became a large heap."

High Level of Organic Matter

The actual soil of the newly built structure, Mr. Allen wrote, was "rich in microbes." The all-important agricultural soil, he noted, was 70 percent dirt, 15 percent peat and 15 percent compost -- that is, about 30 percent organic matter, far higher than the university laboratory assumed in its calculations.

The first crew was sealed inside the structure in September 1991, along with 3,800 species of plants and animals. Things went downhill fast. Most distressing was the declining oxygen, which, after the repair of a faulty sensor, was measured as steadily going down throughout 1992.

Abigail Alling and Mark Nelson, two crew members, wrote in "Life Under Glass: The Inside Story of Biosphere 2," published last month by the Biosphere Press: "This drop in oxygen was particularly startling because during all the Test Module experiments we had never experienced a fall in oxygen levels. Nor had it been reported by other life-support facilities, so it had not been an area anyone in the field considered critical."

The outside experts were put on the problem in May 1992. The rich soils were immediately suspect. Dr. Broecker of Lamont-Doherty gave the riddle to his graduate student, Mr. Severinghaus, who for months struggled to find the missing oxygen or its metabolic byproduct, carbon dioxide. One suspect was urine. The original dirt, from a nearby pond, contained dung and urine from cattle, and the experts thought that perhaps urea in the urine was somehow responsible for the drop. It was not.

Many other theories were later tested and rejected, including one that the carbon dioxide was reacting directly throughout the soil to form calcium carbonate, the material found in limestone and caves.

Finally, Mr. Severinghaus's father, Dr. John W. Severinghaus, a high-altitude physiologist at the

University of California at San Francisco, suggested in a telephone call to his son that the structure's concrete might be soaking up carbon dioxide from bacterial respiration. And so it was.

Tests Support Theory

Careful tests of the hypothesis were done by the son this spring and summer. Concrete samples from inside and outside the structure showed strikingly different levels of calcium carbonate, which was rapidly being formed inside the domes as huge amounts of carbon dioxide reacted with calcium hydroxide in the concrete.

"Their concrete is dripping with it," Mr. Severinghaus said of the calcium carbonate. "It's 10 times more than outside."

Dr. Broecker and Mr. Severinghaus say the reaction increases the concrete's acidity, weakening it and creating a danger that reinforcing bars will eventually start to erode as the carbon dioxide works its way deeper.

The obvious cures, the scientific team says, are to paint the interior concrete with a nonporous coating and replace the offending soils, steps that would bring the project to a halt for months or perhaps years as fauna and flora are removed and then painstakingly reintroduced.

"Biosphere 2 management should take a very deep breath, start over, clean out all the topsoils, replace them with soils that are more representative of natural soils, and make a serious attempt to balance the carbon budget," Mr. Severinghaus wrote the group Sept. 22. "Although starting over seems like a lot of work now," he added, "in the long run, 10 years from now, it will more than pay for itself in a system that truly works instead of a lame one we are dealing with now."

Dr. Corliss, the project's scientific director, who joined the group this year, said many possible solutions were being considered, including painting the concrete and replacing some soils, although perhaps just those in the farming area.

Other possible solutions are to find new plant species that might soak up carbon dioxide faster, or perhaps to add a layer of dense soil that would block the flow of gases in and out of soil. "The question is whether we can slow down the rate," Dr. Corliss said.

The decision of the moment, he added, is simply to keep pumping in more oxygen and to do detailed studies of the concrete to see how fast it is being transformed.

Dr. Broecker said the original error occurred because the group was led by environmental zealots who chose the intuitive wisdom of organic gardening over scientific advice. Even so, he said, he still felt sympathy for the members of the project. He said they had done fairly well, considering the challenging goals they had set.

"It's not easy to think of all the possible things that could go wrong," he said. "Anybody else would have made equally bad blunders, but different ones. Over all, I'd give them an A-minus."

GRAPHIC: Diagram: "An Environment Out of Balance"

Researchers found that the Biosphere's oxygen shortage was connected with the microbe-rich soil under the dome. Oxygen-dependent bacteria produce carbon dioxide, which reacts with the calcium hydroxide in concrete to produce calcium carbonate. Abnormal levels of calcium carbonate were found in the dome's extensive concrete structures, confirming the diagnosis. (Sources: Dr. Wallace S. Broecker and Jeff Severinghaus/Lamont-Doherty Earth Observatory) (pg. C10)

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