Mercury: More Surprises in the Second Assessment

The Mariner 10 mission to Mercury produced dazzlingly clear pictures of what seemed from the earth only a fuzzy sphere. The early assessments—that Mercury is moon-like in appearance but has a trace atmosphere and evidence of an intrinsic magnetic field—have been substantiated. Now, after more study, the Mariner 10 investigators are able to quantify their characterizations of the innermost planet. They are finding that the magnetic field does not seem centered on the planet, that high energy electrons and protons are accelerated in some cyclic fashion that is still mysterious, and that Mercury underwent a period of global compression very early in its history.

Because Mercury rotates slowly (once in 58.6 days) and emits no radio emissions that can be detected from the earth, the early evidence for a magnetic field was surprising. The data still do not force one to conclude that there is an intrinsic magnetic field, but the case is strong. Mariner 10 found that the solar wind passing Mercury formed a detached bow shock. If it is not the result of a complicated process that induces a magnetic field around the planet, then Mercury has a significant intrinsic field. That field is apparently not tilted more than 10° away from the pole, but it seems to be offset by 47 percent of the radius of the planet (see page 151). Perhaps it is the remnant of an extinct dynamo.

Since no magnetic field was expected at Mercury, particles were not expected to be accelerated to high energies by the interaction of the solar wind with the planet. But electrons and protons with energies above 100 kev were found. Furthermore, the large fluxes of electrons showed 6-second fluctuations that were at times accompanied by similar fluctuations of protons (page 160). Such well-defined structure was certainly not expected in the streams of high energy particles, and it will probably be quite difficult to find a physical mechanism that will accelerate particles with opposite charges simultaneously.

The morphology of the surface of Mercury is extremely similar to that of the moon, but one set of features seems to be unique to Mercury. Long cliffs or scarps, at least 3 km high and frequently over 500 km long, are widely distributed over the old and heavily cratered regions of the planet. They may be the result of compressional forces in the crust and have no lunar counterpart (see page 169). On the other hand, the tensional features of the moon, such as the graben which are valleys formed where the crust pulls apart, are not found on Mercury.

The scarps can be explained in a direct fashion if Mercury is chemically differentiated into a light silicate crust and a dense iron-rich core, as in the earth. Earth-based measurements of the albedo (the fraction of reflected light) of Mercury indicated a surface similar to the silicate crust of the moon, which has a density of about 3 g/cm^3. Mariner 10 showed that this analogy holds true for specific regions of Mercury as well as the whole disk. Along with other evidence, this indicates that Mercury is not a homogeneous aggregate of solid debris left over from the condensation of the solar nebula, but was chemically differentiated at some point early in its history. The high density of the planet, 5.4 g/cm^3, indicates that an iron-rich core with terrestrial composition would extend outward 75 to 80 percent of the radius of the planet. A very plausible explanation of the scarps is that they were formed by compressive stresses set up in the crust as the core cooled and shrank. Such a large core would also allow an intrinsic magnetic field frozen into Mercury to be offset as greatly as measured by Mariner 10.

Alongside the surprising details of the close assessment of Mercury, the impact of the early assessments should not be forgotten. Lava-flooding of large basins by some sort of volcanism appears to be a stage in the evolution of planets, for Caloris (left half of the cover photo) is similar to Hellas on Mars and Mare Imbrium on the moon. Even more striking, Mercury, like the moon and Mars, appears to have evolved asymmetrically. Rough and heavily cratered crust, thought to be the primordial surface, seems to cover half the planet, while smoother plains seem to cover the rest. Why three of the five bodies studied among the inner planets have such modal asymmetry is perhaps the greatest puzzle of all.

The first pass by Mercury gave pictures of about 25 percent of the planet under good viewing conditions. After orbiting the sun, Mariner 10 will return on 21 September. The second pass, by the south pole, should increase the picture coverage to about half the planet. If the spacecraft continues to function well, a third pass could give still more information next March.

—WILLIAM D. METZ

Nitrogen Fixation: Research Efforts Intensify

Under the pressures of increasing populations and shortages of energy and fertilizer, food reserves have dwindled, and abundance is being supplanted by scarcity. Because of the tightening global situation with regard to both food and energy, techniques that can increase food production without expending large quantities of energy are assuming new importance. Many scientists think that biological nitrogen fixation—the reduction of atmospheric nitrogen to ammonia by bacteria and blue-green algae—is one key to attaining this goal.

Ammonia availability is critical to agriculture because the supply of such fixed nitrogen frequently limits field crop productivity. If not produced naturally by soil microorganisms or by release from soil minerals, it must be applied in the form of commercial fertilizers; but the Haber-Bosch process, the current industrial process for ammonia synthesis, consumes large quantities of fossil fuel energy (see box).

Participants in a recent symposium* considered all aspects of the nitrogen fixation problem—everything from its economic and agricultural ramifications, to the genetics of the organisms that fix nitrogen, to the biochemistry and

* International Symposium on Nitrogen Fixation, sponsored by the Charles F. Kettering Research Laboratory and the National Science Foundation, 3 to 7 June 1974, Pullman, Washington.

inorganic chemistry of the reaction. These investigators have a number of objectives. They would like to find ways to induce nitrogen-fixing bacteria to form associations with important cereal crops, including corn and wheat, not now favored by such associations; to increase the yields of crops that do have the associations; and to develop chemical systems for ammonia synthesis that are more conserving of energy than the Haber-Bosch process.

Among the promising developments described at the symposium are discoveries of new associations between nitrogen-fixing bacteria and plants. Johanna Döbereiner of the Instituto de Pesquisas Agropecuárias do Centro-Sul in Rio de Janeiro, Brazil, found that nitrogen fixation takes place at the roots of a number of tropical grasses.

Some bacteria can fix nitrogen only when they have formed a symbiotic relationship (one that benefits both organisms) with plants. Others are completely free-living. Still others are free-living bacteria that can form loose associations with plants, live around the roots, and supply the plants with fixed nitrogen.

According to Döbereiner, the association between the microorganism, which she identified as *Spirillum lipoferum* Beijerinck, and the grass *Digitaria decubens* appears to be truly symbiotic. The bacteria are located within the inner cells of the root cortex (the layer of cells immediately under the root epidermis). Here they are in close proximity to the vascular tissue of the plant and thus have easy access to the photosynthetic products that are needed to support nitrogen fixation. In return, fixed nitrogen is supplied directly to the plant.

The efficiency of fixation by *S. lipoferum* is high—almost as high as that of bacteria of the genus *Rhizobium* which fix nitrogen in symbiosis with legumes such as peas, soybeans, alfalfa, clover, and vetch. Döbereiner said that *S. lipoferum* differs in important ways from the rhizobia, however. The latter form nodules on the legume roots and only fix nitrogen in nodules and not when grown in laboratory cultures. (Bacteroids, the membrane-encapsulated form of rhizobia in nodules, can fix nitrogen if they are properly isolated.) *Spirillum lipoferum* does not form nodules and can fix nitrogen if cultured with the appropriate nutrients.

Because of the unusual properties of *S. lipoferum* and its association with

Nitrogen Fertilizer

The success of the "Green Revolution" has depended on the availability of cheap, abundant energy, and on the use of pesticides and fertilizers. Now, energy is no longer cheap or abundant, and neither is fertilizer, especially nitrogen fertilizer. There are limited shortages of these fertilizers in the United States, and developing countries like India are being frozen out of the market by sky-rocketing prices. The wholesale cost of ammonia used in producing nitrogen fertilizers has increased from about $30 per metric ton in 1972 to the current price of $140 per metric ton.

Part of these increased prices can be attributed to the soaring costs of the natural gas and petroleum products required for commercial ammonia production. Ammonia has been synthesized by the Haber-Bosch process since 1913. In this process, 1 mole of nitrogen gas (N_2) reacts with 3 moles of hydrogen gas (H_2) under conditions of high temperatures (approximately 400°C), and pressures (approximately 200 atmospheres). Ammonia synthesis requires large quantities of energy. According to David Pimentel and his colleagues at Cornell University in Ithaca, New York, almost one-third of the energy expended for corn production in the United States is due to the nitrogen fertilizer used.

George Sweeney of Arthur D. Little, Inc., Cambridge, Massachusetts, estimated that the energy consumed by commercial ammonia synthesis in 1972—about 43 million metric tons—was equivalent to that of 300 million barrels of oil. Most of the energy input is in the form of natural gas and petroleum products used to generate up to 90 percent of the hydrogen, and which, at today's prices may represent as much as 80 percent of the total cost of ammonia manufacture. But Sweeney said that increased fuel costs represent only a part of the increased price of ammonia.

Because demands for fertilizer are soaring as a result of agriculture's all-out efforts to increase food production, a shortage of ammonia production capacity is giving the industry an opportunity to increase profits. Since higher prices are stimulating the building of new ammonia plants, Sweeney predicts that by 1980 there will again be excess capacity.

Edwin A. Harre of the National Fertilizer Development Center of the Tennessee Valley Authority, Muscle Shoals, Alabama, concurs that the ammonia fertilizer shortage will be eliminated by the end of this decade. His projections require, however, that plants in the developing countries, now operating at about 50 to 60 percent of capacity, attain the operating efficiencies of those in the industrial countries which operate at 80 to 90 percent of capacity, and that all ammonia-synthesizing facilities, both under construction and planned, are operating by then.

Not everyone agrees that the current situation is temporary. Raymond Ewell, a fertilizer expert and retired vice president for research at the State University of New York in Buffalo, thinks that the fertilizer shortage may continue indefinitely.

According to these observers, adequate ammonia production will require sufficient supplies of three essential commodities: natural gas or a substitute; capital (approximately $9 billion per year) for building new plants; and personnel with the technical expertise to design and run the plants. Estimates of natural gas reserves vary according to the source and the adequacy of supplies over a long period is uncertain. There may also be a shortage of capital and trained personnel since the ammonia industry must compete for them with other industries, including the nuclear power and oil industries.

Thus, uncertainties about the supplies of fertilizer and food, coupled with projected population increases, are providing an impetus for research into biological nitrogen fixation. The research could contribute significantly to the human welfare, but many investigators warn that practical results—increased nitrogen fixation and improved crop yields or a more efficient chemical process for synthesizing ammonia—will not be seen for at least 10 years.—J.L.M.

D. decubens, Döbereiner thinks that it may be an intermediate form between the completely independent nitrogen-fixing bacteria and nodule-forming symbionts like the rhizobia. She has suggested that this kind of symbiosis may be a good model for the development of symbioses between nitrogen-fixing bacteria and grasses or grain crops.

Legumes, especially soybeans, are excellent sources of vegetable proteins, which is why soybeans are in such demand in world markets. Cereals, which lack symbiotic nitrogen-fixing bacteria, have proteins of poorer quality and quantity. According to Döbereiner, tropical grasses, supplied by their symbiotic bacteria with ammonia for amino acid and protein synthesis, may one day compete with legumes as protein synthesizers because these grasses are much more efficient photosynthesizers than are legumes.

Evidence acquired by Ralph Hardy and U. D. Havelka of E. I. duPont de Nemours and Company, Wilmington, Delaware, indicates that the amount of nitrogen fixation on legumes grown in the field is determined by their capacity to photosynthesize. Photosynthesis is the ultimate source of the energy needed for nitrogen fixation, both in the form of adenosine triphosphate (ATP) and of the reducing power needed to convert molecular nitrogen to ammonia. In addition, it provides carbon compounds that combine with the ammonia and form amino acids.

Havelka and Hardy found that stimulating photosynthesis in legumes by increasing the concentration of carbon dioxide available to the plant also stimulated nitrogen fixation by their rhizobia. In fact, the bacteria fixed more nitrogen in 1 week than they normally do during the 100-day growing cycle of soybeans. Hardy concedes that atmospheric carbon dioxide enrichment is not practical for large-scale application, but says that these experiments indicate the magnitude of the effects that might accrue from increasing photosynthetic efficiency. Other strategies such as the use of chemicals to inhibit the reactions that decrease photosynthetic efficiency or the selection and breeding of plant strains that have lower levels of these reactions may be more feasible.

Until recently there were no examples of symbiotic associations between rhizobia and plants other than legumes. That situation changed when M. J. Trinick of the CSIRO in Wembley, Australia, found a *Rhizobium* in nodules on the roots of a tree, *Trema cannabina*, in New Guinea. It may not be possible to induce bacteria such as this one and those studied by Döbereiner to form associations with cereal crops. But these discoveries mean that the genetic variability and potentials of nitrogen-fixing bacteria are greater than

Speaking of Science

Human Biogeography: Similarities between Man and Beast

How similar are the patterns of distributions of human populations to those of other animal species? In some cases, quite similar, according to a small group of anthropologists and biogeographers. Their common interest concerns some qualitative mathematical models that were developed to describe the patterns of distributions of species of plants and animals. The utilization of these models to describe human populations appears to be an example of how techniques and ideas from one field may be applied to another.

The excitement which this interdisciplinary transfer can provoke was in evidence at a recent meeting* of biogeographers, population geneticists, and anthropologists. Discussions focused on attempts to use specific biogeographical models to analyze the distributional behavior of certain primitive peoples who live in arctic, desert, rain-forest, and island environments. For example, W. Fitzhugh of the Smithsonian Institution in Washington, D.C., is applying one such model to descriptions of Arctic Eskimos. He finds that a model that provides an estimate of the probability that a population will go extinct as a function of population size and environmental fluctuations is appropriate to describe patterns of colonizations by small groups of Eskimos and their subsequent extinctions in the harsh and fluctuating arctic environment.

* The meeting, entitled The Smithsonian Conference on the Application of Models in Theoretical Biology and Biogeography to Anthropology was held on 30 April to 2 May 1974 in Washington, D.C., under the auspices of the Wenner-Gren Foundation for Anthropological Research, Inc., and the Smithsonian Institution.

Another biogeographical model that may provide insight into human behavior is a model of bird distributions proposed by J. Diamond of the University of California at Los Angeles Medical School. Diamond suggests that this model may be used to describe the distributions of Polynesians and Melanesians at the time of the European discovery—a suggestion of great interest to the meeting participants. Diamond's theory can be used to classify bird species into two sets: supertramps and overexploiters. The supertramps are good colonizers but not good competitors and thus are found only on small or remote islands. The overexploiters are good competitors but poor colonizers and are found on large islands close to land masses.

Diamond notes that the past distributions of the Polynesians, who are known for their ability to disperse over water, were like those of the supertramps, whereas the Melanesians were distributed like overexploiters. He proposes that it would be interesting to ask whether Polynesians shared other traits with supertramps—such as rapid population growth and a lack of self-regulation of population size—and whether the Melanesians shared the corresponding opposite traits with overexploiters.

R. Levins of the University of Chicago points out that implicit in the analysis of distributions of Polynesians and Melanesians is the assumption that the two groups can be distinguished from each other. This assumption leads to the question of what characterizations of human populations should serve as the units of analysis when biogeographical models are applied to anthropology.

once thought, so that plant scientists and agronomists have new tools with which to work.

The geneticists are exploring and developing techniques with which to exploit these potentials in addition to gathering fundamental information about the genes required for nitrogen fixation and their control. A better understanding of the control of the expression of nitrogen fixation or *nif* genes could result in development of methods to increase nitrogen fixation and thus increase legume crop yields. It has long been known that ammonia, the product of nitrogen fixation, shuts off or represses the genes that direct the synthesis of nitrogenase, the enzyme that catalyzes nitrogen reduction.

This repression of nitrogenase synthesis has frustrated agronomists interested in increasing the yields of legumes, especially soybeans. Adding ammonia fertilizer to these crops does not increase ammonia assimilation by the plants because their nitrogen-fixing symbionts simply stop working. This is one of the reasons why soybean yields per acre have increased only slightly during the past 30 years while corn yields have more than doubled, partly as a result of a 15-fold increase in the amount of nitrogen fertilizer applied per acre.

A number of investigators have now implicated glutamine synthetase, an important enzyme for ammonia utilization, as a direct participant in *nif* gene control. Among the investigators studying this problem are Raymond Valentine, of the University of California at San Diego; Stanley Streicher, of the Massachusetts Institute of Technology (MIT), Cambridge; and John Postgate and R. A. Dixon, of the University of Sussex, England. These workers have found that mutants of such free-living bacteria as *Klebsiella pneumoniae* or *Azotobacter vinelandii* that lack glutamine synthetase are incapable of synthesizing nitrogenase. When the mutants acquire the glutamine synthetase genes as a result of conjugation with *Escherichia coli*, they can again make nitrogenase. (Conjugation is a bacterial mating process in which DNA is transferred from one organism to another.)

Bacterial strains in which glutamine synthetase is constitutive continue to synthesize glutamine synthetase under conditions in which they would normally turn it off. In the presence of ammonia, one of these strains (derived by Streicher and his colleagues) continued to synthesize nitrogenase, at levels up to 30 percent of those produced when ammonia was absent. These results indicate that nitrogenase is synthesized only when glutamine synthetase is present, although other factors may also be involved in *nif* gene control.

Winston Brill of the University of Wisconsin, Madison, has found that certain methionine derivatives that in-

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Biogeographical units of analysis are individual animal species that cannot interbreed. But all human populations can interbreed.

J. Terrell of the Field Museum of Natural History in Chicago believes that there is no universally appropriate solution to this problem of distinguishing human populations. Defining the most appropriate human population unit depends on the problem to be studied and may be defined by language, genetic composition, or culture. Terrell has used languages as a basis of differentiating among peoples of the Solomon Islands. He finds that the number of languages spoken on an island is a function of island size, just as the number of animal species on an island is a function of its size.

Some of the anthropologists at the meeting noted that their attempts to apply biogeographical models to human populations have led them to rephrase the questions that they wish to answer and to subsequently gain new insights into interpretations of their data. For example, J. Yellen of the Smithsonian Institution has recently formulated questions about the behavior patterns of peoples that live in relatively stable environments, such as rain-forest and desert, as compared to patterns of those living in more fluctuating environments, such as savannah. Biogeographers find that species living in constant environments have lower birth rates than similar species living in fluctuating environments. Yellen proposes that this pattern may extend to human populations. He points to a study of the desert dwelling !Kung Bushmen in which N. Howell of the University of Toronto found that time between pregnancies of !Kung women was greater than one would expect on the basis of comparisons with other primitive peoples in more fluctuating environments.

The transfer of information across disciplines was not just one way. According to Diamond, anthropological studies of the history of human populations may also prove useful to biogeographers. In general, biogeographers only have information about the numbers of species in an area at the present time or at a few scattered times during the past. It is difficult to reconstruct the detailed history of distributional patterns from such data. Anthropologists, on the other hand, often have a continuum of data. For example, Fitzhugh has analyzed the past 4000 years of Arctic history. He is thus able to describe patterns of expansions and extinctions of populations that could never have been extrapolated from a few scattered samples of population distributions.

Although the application of specific biogeographical models to anthropology was the subject of most discussions at the meeting, the conference participants agreed that there is one other aspect of biogeographical theory that is immediately applicable to anthropology. That aspect is the existence of certain techniques of analysis. For instance, mathematical indices devised by biogeographers for comparing the diversities or similarities of colonies of species may be directly applied to comparisons of samples of artifacts from different archeological levels or sites.

Many of the participants expressed the hope that the development of a new interdisciplinary field of human biogeography will result in new ways of organizing data and formulating hypotheses in anthropology. They noted that certain fundamental concepts—such as immigration, extinction, competition, and population growth and regulation—are implicit or explicit in descriptions of human populations. Moreover, it is these concepts that are central to the most detailed biogeographical models. It is too early to say whether these models and the ideas that underlie them will ultimately have much effect on anthropology. But the attempt is worth noting and may lead to intriguing insights into human behavior.

—GINA BARI KOLATA

hibit glutamine synthetase activity allow nitrogenase synthesis by *A. vinelandii* and *K. pneumoniae* in media containing ammonium ions. Thus, chemicals may abrogate the repression of *nif* genes—an approach now being explored with strains of rhizobia.

If investigators are to realize their goal of inducing nitrogen-fixing bacteria to associate with cereal crops, it may be necessary to transfer the ability to fix nitrogen to bacterial strains that do not normally possess it. There are a number of ways that genetic information can be transferred between bacteria, and all have been applied to the transfer of *nif* genes to organisms lacking them. Many of these transfers have been from donors to recipients of the same strain where the recipients are mutants deficient in nitrogen fixation. In some cases, however, *nif* genes have been transferred to other species of bacteria that do not naturally fix nitrogen. For example, Postgate and Dixon transferred *nif* genes from *K. pneumoniae* to *E. coli* by conjugation.

The *nif* genes were expressed in *E. coli*, conferring on these bacteria the capacity to fix nitrogen. Moreover, addition of ammonium ions to the culture medium repressed expression of the genes in *E. coli*. According to Dixon and Postgate, this meant that control genes, in addition to structural genes for the enzyme proteins, were transferred to *E. coli*.

Genetic information may also be transferred in the form of plasmids—circular DNA molecules that are much smaller than bacterial chromosomes and replicate independently of them. Dixon and Postgate and, also, L. K. Dunican of University College, Galway, Ireland, have prepared plasmids carrying *nif* genes. Dunican found that *nif* genes could be transferred on a plasmid from *R. trifolii* to *K. aerogenes*. As a result, the *K. aerogenes* gained the capacity to fix nitrogen.

Valentine speculates that plasmids might even be incorporated into plant cell protoplasts (plant cells whose outer cellulose wall has been digested away). If the protoplasts develop into whole plants, they would then carry *nif* genes and—possibly—the plants could fix their own nitrogen. Since nitrogen fixation consumes large quantities of energy, however, the *nif* gene might be detrimental to wheat, for example, unless photosynthesis could be increased. Needless to say, the prospect of increasing nitrogen fixation by such genetic manipulation is not imminent.

Although the genetics of nitrogen-fixing bacteria received the greatest attention at the symposium, T. A. G. LaRue of the Prairie Regional Laboratory, Saskatoon, Saskachewan, pointed out that the most practical approach to increasing yields of legume crops lies with the plant—not the bacteria. Introduction of new strains of rhizobia, however superior their nitrogen-fixing characteristics, into fields already populated by other strains of rhizobia usually fails because the new strain cannot successfully compete with established strains. Establishment of a symbiotic relationship is a complex process, and its success is as much determined by the characteristics of the plant as of the microorganism. LaRue and his colleagues have thus far identified three plant genes (in pea plants) affecting symbiosis. He anticipates that genetic dissection of the plant will permit selection of strains that can establish more effective symbioses with rhizobia.

It should also be possible to identify plant strains with other traits that favor nitrogen fixation or high crop yields. These include higher photosynthetic efficiency and protein content, or the capacity to support fixation throughout the growing season instead of just until seed formation begins. Although this type of research is more tedious than glamorous—the Canadian group has screened some 2000 variants of peas—it has the greatest potential for paying off quickly in increased yields.

Biochemistry of Nitrogen Fixation

Biological nitrogen fixation occurs under very mild conditions compared to those of the Haber-Bosch process. Biological ammonia synthesis is accomplished enzymatically by nitrogenase. Among the contributors to an understanding of nitrogenase biochemistry are Hardy and Richard Burns of DuPont; Postgate and R. R. Eady of the University of Sussex; Robert Burris and William Orme-Johnson of the University of Wisconsin, Madison; Leonard Mortenson of Purdue University, Lafayette, Indiana; Harold Evans, of Oregon State University, Corvallis; and William Bulen of the Charles F. Kettering Research Laboratory, Yellow Springs, Ohio.

Although there are variations in the nitrogenases isolated from different sources, all described thus far consist of two proteins, neither of which has any enzymatic activity by itself. The smaller protein has a molecular weight of about 60,000 and consists of two identical subunits; it contains iron and acid-labile sulfur. (This is sulfur other than that in the amino acids cysteine and methionine, which is stable to acid.) The other protein has a molecular weight of 200,000 to 220,000, depending on its source, and consists of four subunits, two each of different proteins; it contains molybdenum in addition to iron and acid-labile sulfur.

The investigators believe that the iron, molybdenum, and sulfur participate in the catalytic activity of the enzyme. Nitrogenase requires ATP and a strong reducing agent to reduce molecular nitrogen. In vivo, reduced ferredoxin, which is itself an iron- and sulfur-containing protein, may serve as the reducing agent.

Because molecular nitrogen is so inert, inorganic chemists who are trying to reduce it chemically under conditions similar to those in nature have achieved only limited success. When complexes of nitrogen with metals were first synthesized 10 years ago, chemists thought the problem was virtually solved because they expected that the nitrogen would be more reactive in the complexes. Although this has not been the case, investigators think that recent research both clarifies the mechanism of biological nitrogen fixation and points the way to new methods of ammonia synthesis.

For example, Eugene van Tamelen of Stanford University in Palo Alto, California, described a new reaction system that produces ammonia although the yield is very low. The reaction requires three reactants: a reducing agent like sodium anthracene, a molybdenum-nitrogen complex that may be a model of the active site of the large nitrogenase protein, and an iron-sulfur complex. Richard Holm of MIT synthesized the latter complex, which has a structure closely resembling that of the active center of ferredoxin. Another system, described by Gerhart Schrauzer of the University of California at San Diego, can reduce the same substrates as nitrogenase, but again the yields are extremely low.

The widely disparate lines of investigation into the nitrogen fixation problem appear to be converging. The work of the geneticists and agronomists, for example, has been facilitated by the availability of a simple, reliable assay for nitrogen fixation and by progress made toward elucidation of the structure and function of nitrogenase. Such convergence of ideas always bodes well for progress in science.—JEAN L. MARX