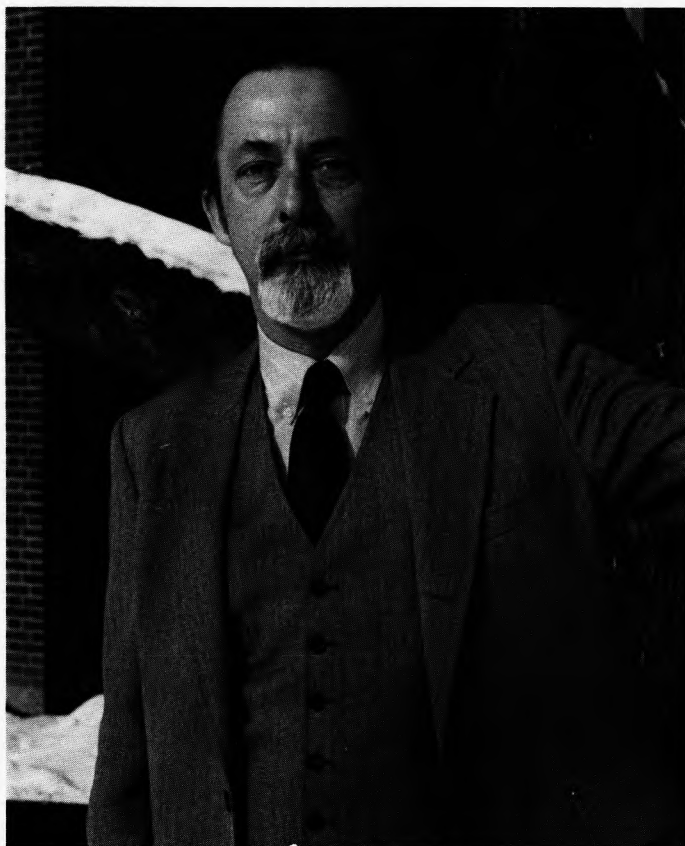


EARTH AND MINERAL SCIENCES

THE PENNSYLVANIA STATE UNIVERSITY, COLLEGE OF EARTH AND MINERAL SCIENCES, UNIVERSITY PARK, PENNSYLVANIA



John A. Dutton

NEW EMS DEAN NAMED

Dr. John A. Dutton has been named Dean of the College of Earth and Mineral Sciences and assumed leadership of the College on February 1, 1986. Dr. Dutton, a professor of meteorology, has been a member of the College faculty for 20 years and head of the Department of Meteorology since 1981.

At the January meeting of the Board of Trustees, University President Bryce Jordan cited Dr. Dutton's impeccable academic credentials, his leadership qualities and managerial skills as instrumental in the administration's decision.

As head of Meteorology, he supervised an ever-expanding program of instruction, research and public service in a department with an international reputation as one of the finest in the nation. Under his leadership, graduate enrollment increased by 37 percent, sponsored research rose almost 140 percent to \$1,567,331 in 1985, and four new faculty positions were created.

Dr. Dutton is an elected Fellow of the American Meteorological Society. His research has focused on atmospheric dynamics and energetics, global thermodynamics, and nonlinear hydrodynamics. He has published widely and is author of two books: *The Ceaseless Wind: An Introduction to the Theory of Atmospheric Motion*, which was selected as an "outstanding academic book" of 1976 by the American Library Association; and in collaboration with Hans A. Panofsky, *Atmospheric Turbulence: Models and Methods for Engineering Applications*. He has taught at both undergraduate and graduate levels.

Dr. Dutton has also been closely involved in professional and advisory efforts at a national level. He has served as trustee,

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This is an exciting time to become Dean of the College, to recognize anew its accomplishments and strengths, to contemplate its potential for continued improvement, and to accept the challenge of finding new pathways to excellence and distinction.

There are two essential components to the past and future success of this College. The first is its people—the amazing collection of creative and dedicated faculty members, talented students, loyal staff, and accomplished alumni and friends that together form the College family.

The second is our focus on the planet Earth—its processes that produce both structure and change, and its energy, materials and environments that sustain human societies. We are concerned with how this planet evolved, how it functions, what its future will be, and how to use its resources wisely and effectively. Nearly everything we see is part of the Earth and everything we have comes from it; thus we are concerned with how we extract, process, and synthesize the forms of energy and matter that support our existence and activities.

Our common interest in the phenomena, processes, and materials of the Earth creates strong intellectual ties among us all. Our increasing recognition of the interactions that govern the evolution of the planet, of the unity of the Earth System, of the increasing importance of the engineering and technological developments that guide our own interactions with the Earth will strengthen the collegial spirit that binds the College family together.

We are engaged, as part of the University's comprehensive strategic planning initiative, in developing specific plans for strengthening all aspects of the College's activities. We are renewing our commitment to the principles that led to our success, to a continued emphasis on scholarship, research, and teaching. Fostering creativity and maintaining freedom of inquiry are our foremost concerns. We will strengthen graduate research and education, particularly our doctoral programs, making it an even more important part of our total effort. We are planning greater integration of our general education offerings and new emphasis on communication skills in

our undergraduate majors. We are developing specific plans to increase the stature of each of our departments.

We anticipate strong support from the University administration for our initiatives. The President and Provost recognize the unique nature and the exceptional accomplishment of the College; they know full well that investments in this College return handsome dividends.

Some of our new efforts to achieve eminence will be made possible by our alumni and friends whose gifts have been such an important asset to the College in providing flexibility and stimulus. We are confident that our contributors will recognize that their generosity provides an element of financial independence that, in the years ahead, could become the third essential component of the greatness of this College.

Our associations with the College have enriched us all, and the brightness of its future is now our responsibility. It will reflect our dedication, vigor and resolve.

John A. Dutton

The Oxygen Content of Our Atmosphere

The oxygen content of our atmosphere is controlled by a fairly complex feedback system; some human activities are decreasing its quantity, others are increasing it.

HEINRICH D. HOLLAND (Harvard University),
Visiting Professor of Geochemistry

The Earth is the only planet in our solar system which has an oxygen-rich atmosphere. We owe most of this unusual gas to photosynthesis by green plants. These primary producers combine carbon dioxide, water, and energy from sunlight to produce organic matter and molecular oxygen. The rest of the world lives off this organic matter: vegetarians do so directly, carnivores indirectly, omnivores such as humans and pigs do so both directly and indirectly.

A small amount of molecular oxygen is converted to ozone (O_3) in the atmosphere; this gas serves as an efficient shield against solar ultraviolet radiation. The maintenance of a sufficient oxygen supply and the continued presence of an ozone shield are obviously matters of great concern to the human race. We need to know how humanity will affect the oxygen and ozone content of the atmosphere. To do this, we need to know what controls the present concentration of these gases in the atmosphere.

Molecular oxygen accounts for just under 21 percent of the volume of the atmosphere. This amounts to a mass of some 230 gm/cm^2 of Earth surface, and a total mass of $1.2 \times 10^{21} \text{ gm}$; i.e., about 1/1000 the mass of the oceans and less than a millionth of the mass of the Earth as a whole, but about a thousand times the total mass of all living things today. Most of the Earth's biomass lives on dry land; the marine biomass is a very small part of the total biosphere. The large difference between the mass of the terrestrial and the marine biosphere is largely due to trees. There is no marine equivalent of trees; microorganisms are the dominant primary producers in the oceans.

The biosphere is enormously active—witness the large ratio of the mass of atmospheric oxygen to the mass of the biosphere. Just how small the biosphere is, can be illustrated by a simple calculation. If the entire biosphere were homogenized in a giant blender, and then applied evenly to the continents with a suitably large spatula, the layer of biosphere would be roughly that of a reasonably satisfying peanut butter and jelly sandwich.

It seems intuitively reasonable that the Earth's blanket of oxygen has been built up by this thin biosphere over geologic time. But, as happens so often, intuition is

not a reliable guide. Measurements of the rate of photosynthesis on land and at sea (for a recent summary see Sundquist, 1985) have shown that the entire inventory of atmospheric oxygen could be generated by green plant photosynthesis in some 5,000 years, provided none of the organic matter were lost during this period of time. The proviso is, however, unreasonable. Not enough carbon dioxide is available in all of the atmosphere and oceans to serve as the starting material for the generation of $1.2 \times 10^{21} \text{ gm } O_2$, and it is the fate of organic matter on Earth to be reoxidized to carbon dioxide and water on a time scale much shorter than 5,000 years. Oxygen is continually being produced and consumed by the biosphere in a rapid and very efficient cycle.

The Oxygen Cycle

Figure 1 represents the oxygen cycle in a schematic way. If this cycle were truly closed, there would—of course—be no net oxygen gain or loss by the operation of the cycle. It turns out, however, that the cycle is not entirely closed; there is a small leak in the system. A very small fraction of the organic matter produced each year is buried with sediments, largely with marine sediments. Marine organic matter is produced almost entirely in the upper

100 meters of the oceans, where sunlight is available. Most of this organic matter is consumed locally. A small fraction sinks; much of this is consumed in the deeper parts of the oceans. A still smaller fraction reaches the ocean floor and is largely consumed there. The very small residue, on the order of a few tenths of one percent of the biomass generated in the surface layers, is buried with sediments and is preserved for geologically significant lengths of time.

Although the fraction of organic matter that is preserved in this way is very small, its significance is very great. Our reserves of fossil fuel are all derived from this store, and potentially important resources of uranium, vanadium, molybdenum and several other metals are contained in accumulations of this organic matter. It is also important for the oxygen balance of the atmosphere.

Controls on Atmospheric Oxygen

Each year, some $(3 \pm 1) \times 10^{14} \text{ gm}$ of organic matter are buried with sediments, and the molecular oxygen which was produced during the generation of this quantity of organic matter remains in the atmosphere. If it were to accumulate there indefinitely, the oxygen content of the atmosphere would double in a few million years, and it is clear that in a matter of a few hundred million years there would be a very dense oxygen atmosphere indeed. This has not happened. There must, therefore, be one or more sinks for atmospheric oxygen which use up O_2 at a rate that is essentially equal to the rate of oxygen production by the burial of organic matter.

Two important sinks have indeed been identified; these have been described at some length (Holland, 1978) and are illustrated in Figure 2. One involves the loss of atmospheric oxygen during weathering,

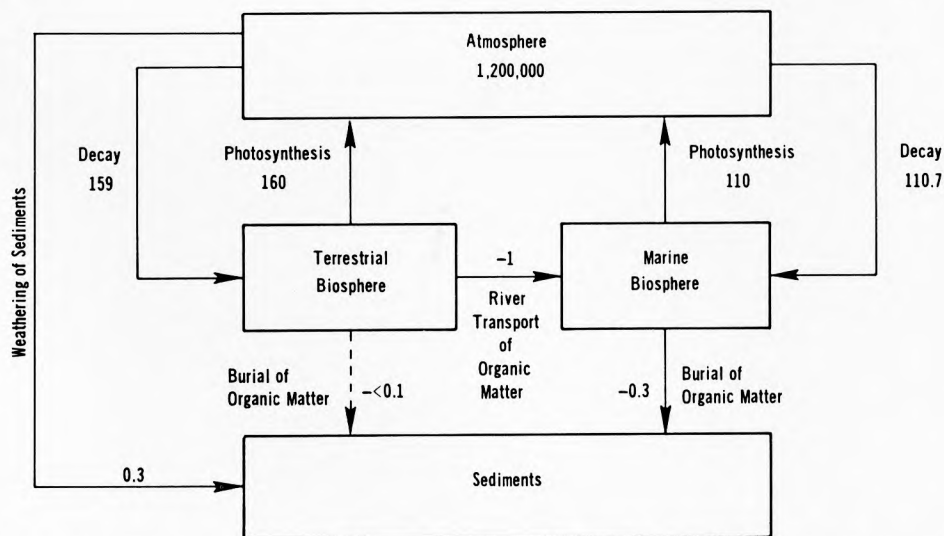


Figure 1. Atmospheric oxygen and the oxygen production and oxygen use of the biosphere. The mass of oxygen in the atmosphere is in units of 10^{15} gm ; rates of oxygen transfer are in units of 10^{15} gm/yr . Negative rates of transfer designate the quantity of oxygen required to oxidize a particular flux of organic matter; data from Sundquist (1985) and Holland (1978).

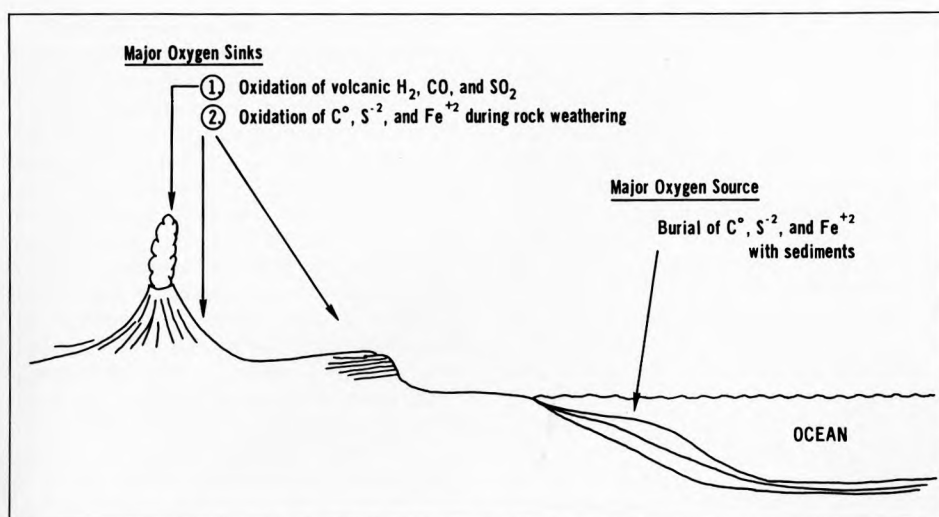


Figure 2. The major source and nonanthropogenic sinks of atmospheric oxygen.

the other during the oxidation of volcanic gases.

Weathering involves dissolution, hydration, carbonation, and oxidation reactions. A large number of elements change valence state during weathering. Most of these are only trace elements in rocks, and their oxidation consumes an insignificant quantity of oxygen. Only the oxidation of elemental carbon (C^0), sulfide sulfur (S^{-2}), and ferrous iron (Fe^{+2}) turn out to be quantitatively important.

The main source of elemental carbon is the residue of organic matter buried with the sediments which were subsequently converted into the rocks that are currently being weathered. The main source of sulfide sulfur is pyrite (FeS_2) in these same rocks. Ferrous iron is a constituent of nearly all rock types. In a sense, the oxidation of elemental carbon in sedimentary rocks closes the oxygen cycle. Organic carbon that was saved from reoxidation by burial with sediments, perhaps hundreds of millions of years earlier, is finally oxidized and returned to the atmosphere as carbon dioxide during the exposure of the enclosing sediments to the atmosphere.

A fascinating and pertinent observation was made some time ago by Gehman (1962): the content of elemental carbon in old shales is nearly the same as the elemental carbon content of modern sediments. This suggests that the system as a whole has been well balanced for a long time; elemental carbon in shales appears to be oxidized during exposure to the atmosphere, and a similar quantity of carbon is reburied in new sediments as a constituent of organic matter.

This cannot be the whole story, however. About 75 percent of modern sediments consist of recycled old sediments; the remaining 25 percent consist of weathered igneous and high grade metamorphic rocks. Igneous and high grade metamorphic rocks contain very little carbon. If no carbon were added to their weathering products prior to burial, the

concentration of elemental carbon in modern sediments would be only about 75 percent of the elemental carbon content of old sediments. The difference is made up by the carbon contained in volcanic gases. These gases consist largely of water, carbon dioxide, sulfur dioxide, carbon monoxide and hydrogen. The oxidation of hydrogen to water, and of carbon monoxide to carbon dioxide consumes a significant amount of oxygen; the supply of volcanic carbon monoxide and carbon dioxide supplies carbon for photosynthesis and for the burial of organic matter with modern sediments.

An oxygen balance is thus established: the rate of oxygen generation by the burial

of elemental carbon, sulfide sulfur, and ferrous iron with modern sediments is balanced by the rate of oxygen loss during the oxidation of C^0 , S^{-2} , Fe^{+2} in rocks exposed to weathering, and by the oxidation of reduced volcanic gases.

Operation of the System

The oxygen content of the atmosphere now appears in a new light. Atmospheric oxygen is not the result of a gradual build-up of this gas during Earth history; rather, the gas acts as a governor, which keeps the oxidation state of the whole system in balance. The oxygen pressure continually adjusts itself, so that the rate of oxygen use in weathering and in the oxidation of volcanic gases is equal to the rate of oxygen burial of C^0 , S^{-2} , Fe^{+2} .

Figure 3 illustrates the operation of this control system. The rate of oxygen production and the rate of oxygen use are plotted, rather schematically to be sure, against the oxygen content of the atmosphere. It has been shown (Holland, 1978, Ch.6) that most of the elemental carbon, sulfide sulfur, and ferrous iron in rocks exposed to weathering today are oxidized during contact with the atmosphere. Volcanic gases are oxidized completely on contact with air. It is likely, therefore, that the oxygen use curve is nearly flat down to oxygen pressure values much lower than 0.2 atm. If so, the oxygen use rate today is nearly independent of the oxygen pressure in the atmosphere, and cannot act as a control on it.

The shape of the oxygen production curve is poorly known. The slope of the curve must, however, be negative—and

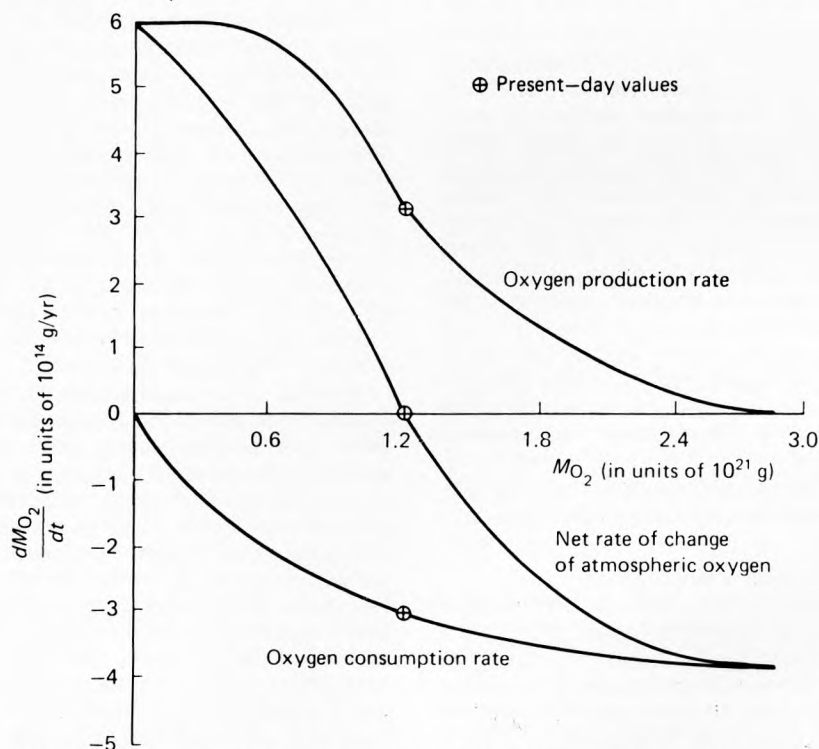


Figure 3. Semischematic diagram illustrating the relationship between the oxygen content of the atmosphere, the rate of oxygen production, the rate of oxygen consumption, and the net rate of change of atmospheric oxygen (Holland, 1984).

significantly so in the region of 0.2 atm. O_2 . The rate of oxygen generation depends in large part on the rate of burial of organic matter in the oceans. This is equal to the product of the organic productivity of the oceans and the fraction of organic matter that is preserved in marine sediments. The fraction thus preserved depends on a number of factors; these include the oxygen content of the water column, particularly the oxygen content of bottom waters. The fraction of organic matter preserved in sediments overlain by well-oxygenated bottom waters is usually a few tenths of one percent, whereas the fraction of organic matter preserved in sediments overlain by anoxic bottom waters is usually several percent.

The oxygen content of surface seawater is determined by equilibrium with atmospheric oxygen, and varies between about 250 and 300 $\mu\text{mol/liter}$. After surface seawater sinks, as it does in parts of the North Atlantic, it begins to lose oxygen by the oxidation of particulate organic matter that has sunk into deeper parts of the ocean. The effect is quite sizeable. North Atlantic deep water travels southwards and flows into the Indian and Pacific Oceans. When deep seawater reappears at the surface in the North Pacific, its oxygen content has been reduced to about half its initial value. In some fairly isolated parts of the oceans, the oxygen content of bottom water is either zero or very close to zero. The oxygen supply there is barely able, or unable to keep up with the biologic oxygen demand created by sinking organic matter.

If the oxygen content of the atmosphere were reduced by a factor of two, the oxygen concentration of surface seawater would be reduced to half its present value. If the rain of organic matter were kept constant, the oxygen content of deep waters in large parts of the North Pacific would be zero, and the quantity of organic carbon buried in this part of the oceans would be dramatically greater than today. This, in turn, would increase the net rate of oxygen generation. On the other hand, an increase in atmospheric oxygen would decrease the area covered by anoxic and nearly anoxic bottom waters; the rate of burial of organic matter would then decrease, and the rate of oxygen production would drop. The relative magnitude of these effects is not known, and is the subject of current research at several institutions, including Penn State.

The Role of Phosphorus

Prediction of the behavior of the system at different atmospheric oxygen pressures is complicated by the linking of the marine carbon cycle with the marine phosphorus cycle. Today, rivers transport phosphate to the oceans in solution as inorganic phosphate, as a constituent of dissolved organic matter, and as a constituent of particulate organic and inorganic matter.

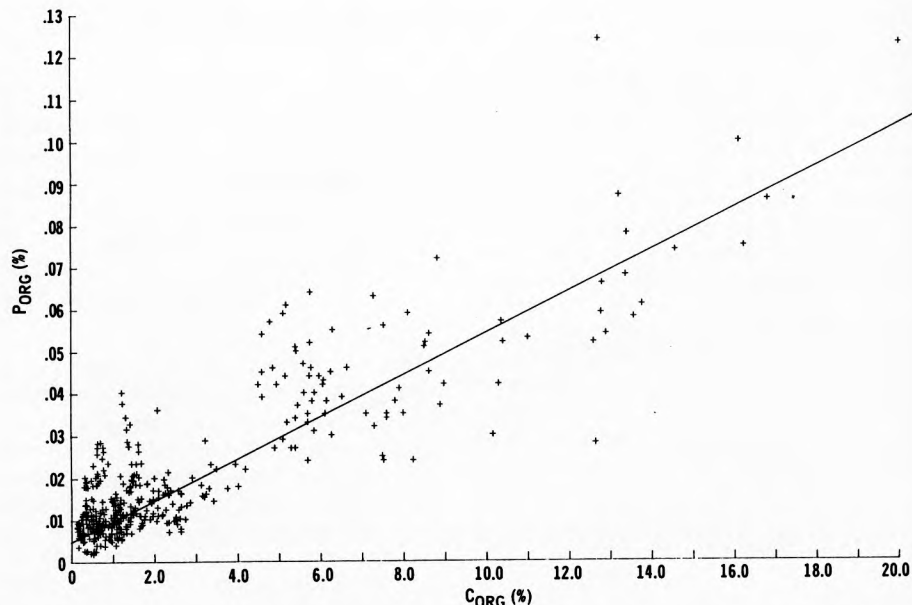


Figure 4. The correlation between the content of organic phosphorus and organic carbon in modern sediments (Mach, Ramirez, and Holland, in preparation).

All but the particulate inorganic phosphorus participate as nutrients in the marine life cycle, and a significant fraction of this phosphorus flux is removed from the oceans as a constituent of organic matter buried in sediments.

The correlation of the organic phosphorus and the organic carbon content of marine sediments is shown in Figure 4. The ratio of the concentration of organic carbon to organic phosphorus is approximately 200. Since organic carbon is being buried at a rate of some $(1.2 \pm 0.3) \times 10^{14}$ gm/yr, the rate of burial of phosphorus with organic matter is some $(0.6 \pm 0.2) \times 10^{12}$ gm/yr. The total river input of phosphorus that is available for incorporation in organic matter is probably $(1.5 \pm 0.5) \times 10^{12}$ gm/yr. The fraction of river phosphorus that is removed with organic matter is therefore between 20 and 80 percent. If the oxygen content of the atmosphere is lowered and the burial rate of organic matter is increased, the system soon becomes limited by the availability of phosphorus. The maximum rate of burial of organic matter seems to be between two and five times the present rate.

Whether even such increases would ever occur depends on the response of the other marine phosphorus sinks to the general draw-down of phosphorus in the oceans. Today, several tens of percent of phosphorus input from rivers are removed as a constituent of sediments that are rich in calcium carbonate. Recent work has shown that most of the phosphorus in these sediments is present not as a constituent of CaCO_3 shells, but in iron and manganese coatings on these shells. Figure 5 shows the correlation of the concentration of P with that of Fe and Mn in coatings on recent foraminifera from the North Atlantic. The coatings probably consist of an amorphous or extremely

fine-grained mixture of oxides and phosphates of iron, manganese, and perhaps aluminum.

Much of the remainder of the river flux of phosphorus may be removed from ocean water as calcium phosphates in areas where deep ocean water upwells. The nutrient supply is large in these areas, the productivity of surface waters is high, and the rain of organic carbon to the ocean floor is rapid. Phosphorus that is now removed from seawater as a constituent of iron-manganese coatings and as calcium phosphates is presumably available for removal as a constituent of organic matter, but the extent of the potential transfer of phosphorus among these sinks is not known. We also know little about the effects of changes in other parameters, such as climate, the circulation of the oceans, the distribution of the continents, tectonic regimes, and the hydrologic cycle on the proposed control mechanisms.

Oxygen Content over Geologic Time

We do know that changes in the oxygen content of the atmosphere during the past 250 million years have been sufficiently small that animal life has not been extinguished by excessively high or low levels of oxygen. James Lovelock has suggested that the oxygen content of the atmosphere has been no lower than 0.15 atm and no greater than 0.25 atm during this period. Such tight limits are indicated by the presence of charcoal in sediments deposited during the last 250 million years. Lovelock argues that charcoal is the product of forest fires, and that forest fires are hard to sustain when the oxygen pressure is below 0.15 atm. Above 0.25 atm oxygen, forest fires could become so common that forests, and hence charcoal, would be very rare. This line of thought surely deserves careful study.

There is a considerable body of evidence indicating that the oxygen content of the atmosphere during much of the Precambrian Eon, i.e., more than 600 million years ago, was considerably less than today. The reasons for this are almost certainly related to biological evolution. It seems likely that the productivity of oceans dominated by prokaryotes was lower than the productivity of the oceans today, but at present we can only speculate about the reasons why this might have been so. Before the development of green plant photosynthesis, oxygen was probably present in no more than trace quantities. The date of the development of green plant photosynthesis is not known; it could have occurred as much as 3,500 million years ago.

The Impact of Man

Although the chemistry of the atmosphere in the distant past is still shrouded in mystery, we can be a good deal more certain about the effect that man's activities could have on atmospheric oxygen in the near future. Some years ago, a writer raised the spectre of the complete loss of atmospheric oxygen due to fossil fuel burning. The last family on Earth breathing the last bit of oxygen was described in suitably tragic terms. Fortunately, this is one catastrophe that is extremely unlikely.

If all of our known and projected reserves of fossil fuels were burned instantaneously, the carbon dioxide content of the atmosphere would increase by a

factor of about ten—from 0.035 percent to 0.35 percent. This is a very significant increase; one that would most certainly have important climatic consequences. The increase of about 0.3 percent in the carbon dioxide content of the atmosphere would be matched by an approximately equal decrease in oxygen. But this would only decrease the oxygen content of the atmosphere from 20.9 percent to 20.6 percent; the effect of such a small decrease in oxygen would probably be negligible.

It has also been proposed that the extensive clearing of tropical rain forests would decrease the rate of oxygen production by the biosphere, and hence lead to a major decrease in the oxygen content of the atmosphere. The rate of photosynthesis might indeed be decreased significantly, but so would the rate of oxygen consumption due to the decay of rain forest vegetation. The decrease of the net rate of oxygen production as a result of replacing jungle with edible crops would probably be minor, as would its long-term effects on atmospheric oxygen. Many reasons can be advanced for preserving tropical rain forests, but the retention of atmospheric oxygen is not one of them.

While fossil fuel burning and forest clearance tend to reduce the oxygen pressure slightly, the mining of phosphate ores for use as fertilizers has the opposite effect. Phosphate levels in many rivers are much higher now than during the early part of this century. The flux of phosphate to the oceans has increased significantly; we are therefore increasing the fertility of

the oceans. Increases in the rate of marine photosynthesis will be followed by an increase in the rate of burial of organic carbon, and hence in the net rate of oxygen production in the oceans. The overall effect will, however, be small. The oceans today contain a supply of phosphate equivalent to about 50,000 years of river input; even if we increase the phosphate content of all the world's rivers by a factor of ten, it will be hundreds of years before this change will have a significant effect on the net oxygen production of the oceans.

Are we able to perturb the atmosphere in any serious way? The answer to this question is emphatically "Yes." Although the oxygen content of the atmosphere is so large that this gas is virtually immune to change on a time scale of hundreds of years, the concentrations of minor and trace gases are and will continue to be altered significantly by man. The concentration of ozone, the rare triatomic oxygen molecule, is vulnerable to many human contaminants, and the rise in the carbon dioxide content due to fossil fuel burning is well documented.

During the past 30 years, we have learned some important lessons regarding man's impact on the global environment. We have learned that the consequences of our actions reach far beyond our immediate environment and our own lifetimes, and that difficult, detailed, and expensive research is needed to assess these consequences. We have learned that the results of partial and preliminary studies can be misleading, and we have learned that seemingly innocuous changes can have serious consequences. We must understand the effects of these changes, and we must let this understanding guide our future.

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HEINRICH D. HOLLAND is well known for his contributions to the emerging science of the Earth system; his broad scholarship in the application of geochemistry to global cycles involving the Earth's crust, the oceans and the atmosphere have brought him international scientific recognition. Dr. Holland, professor of geology at Harvard University, is an elected member of the National Academy of Sciences and of the American Academy of Arts and Sciences. He has provided valuable assistance in the development of our new Earth System Science Center.

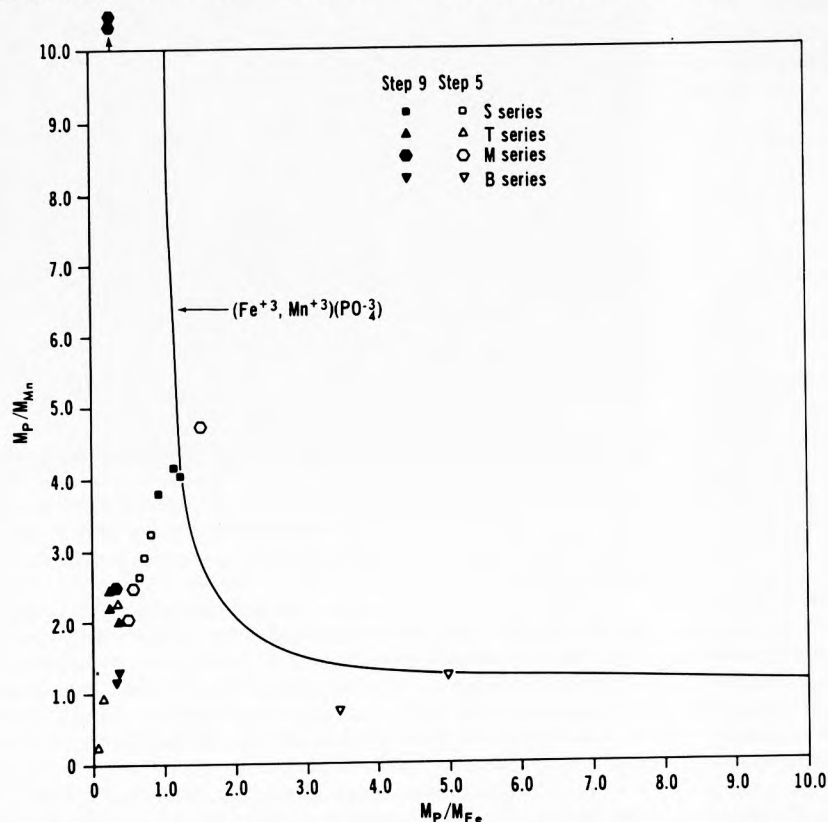


Figure 5. The ratio of phosphorus to manganese, plotted against the ratio of phosphorus to iron in oxide-phosphate coatings on foraminiferal shells (Sherwood, Sager, and Holland, in preparation).

Lightweight Ceramics — A New Materials Opportunity

DAVID J. GREEN, Associate Professor of Ceramic Science and Engineering

There has recently been a renaissance in the use of ceramic materials in a wide variety of technological applications. In the area of structural materials, for example, ceramics are being considered as various high temperature engine components, as heat exchangers, and as cutting tools. These advances are a direct result of research and development efforts in understanding the relationships among processing, microstructure, and properties.

For the most part, however, the emphasis of these scientific studies has been on ceramics that are close to theoretical density; that is, the primary goal has been to produce materials with a minimum of pores or voids. Indeed, in the structural application of materials, with the exception of wood, man tends to utilize dense materials. Conversely, Nature invariably uses porous, fibrous or cellular materials in such applications, and this presumably represents a careful evolutionary optimization. It has been pointed out that cellular materials such as bone, wood and cork permit the simultaneous optimization of stiffness, strength and weight in a material. To give an idea of the scale of the engineering in these natural structures, it is worth noting that a large 100 m high redwood tree would weigh around 2,500 tonnes. Figure 1 shows an example of Nature's handiwork with the cellular microstructure of cuttlefish bone.

Although the majority of man-made materials are dense, there are some examples of highly porous materials, with polymeric foams being the most familiar. Within the field of ceramics, there are several examples, including fibrous or foam materials that are used for thermal insulation, and open cell materials used for filtering molten metals. Indeed, lightweight ceramics possess a very attractive set of properties, including high surface area, low weight, low thermal conductivity, high temperature stability, corrosion resistance, and good thermal shock resistance.

Currently, these materials are not used in structural applications because of their low strength, but it is reasonable to suspect that if some of the scientific advances made for dense ceramics were applied to these highly porous materials, a new generation of lightweight ceramics would become available and that these could fulfill a wide range of new applications. Even for the nonstructural application of such materials, it is still important to maximize strength for an optimum design. The ceramic tiles used on the heat shield of the space shuttle, for example, were chosen primarily for their high temperature stability, low thermal conductivity, and low weight; yet prior to the first flight, their mechanical behavior and its understanding was a critical issue.

In this article, I will discuss our current understanding of the mechanical behavior of lightweight ceramics to demonstrate that there is the opportunity to substantially improve these properties, and that this is a prime area for research and development—lightweight ceramics indeed represent a new materials opportunity.

Microstructures of Lightweight Ceramics

Rigid lightweight ceramics have been produced with densities as low as 3 percent of the theoretical density. The microstructures of these materials are classified into two broad groups as fibrous or cellular. The fibrous materials generally consist of a bonded tangled network of ceramic or glass fibers, as can be seen in Figure 2, a micrograph of a space shuttle tile. In this case the fibers are a high purity silica glass and can withstand temperatures as high as 1250°C (2300°F).

The fibrous materials often possess anisotropic properties, as a result of the fibers being oriented along specific directions. The preferred orientation generally arises during the fabrication pro-

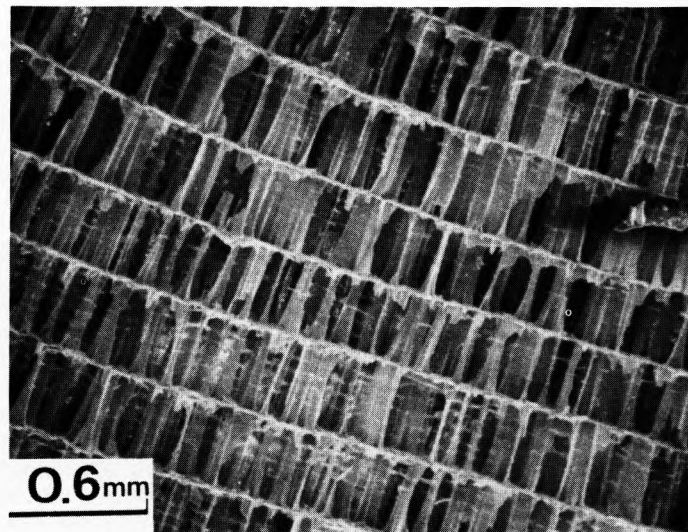


Figure 1. Scanning electron micrograph of cuttlefish bone, an example of a natural lightweight material (Courtesy of Jill Glass, Penn State).

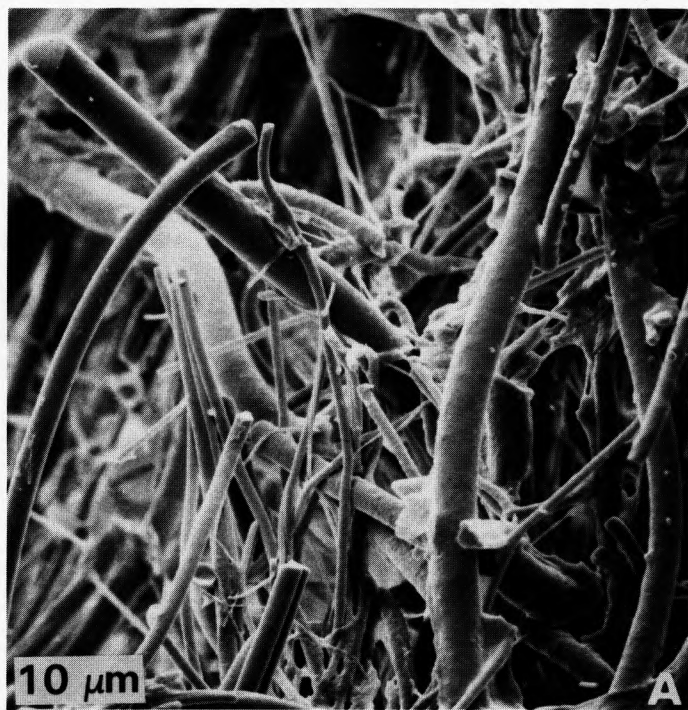


Figure 2. Microstructure of a space shuttle tile, showing the tangled network of bonded silica fibers.

cess when the fiber slurries are pressed and filtered, since the fibers prefer to lie perpendicular to the pressing direction and/or gravity. The space shuttle tiles were found to be transversely isotropic; that is, their properties were isotropic in one principal plane but possessed a different set of properties perpendicular to this plane.

Cellular materials consist of a relatively regular array of hollow cells. These materials are classified into two further groups: open cell (like a sponge) and closed cell (like a soap foam), with the difference being whether the cell faces are present or not. Figure 3 shows an example of an open cell silicon carbide material. Closed cell ceramics are generally produced by foaming techniques, and foamed glass has been available for many years as a low cost thermal-insulating building material. Figure 4 shows the microstructure of a closed cell glass made not by foaming but by sintering together hollow glass spheres. The properties of cellular materials tend to be relatively isotropic, although it would be

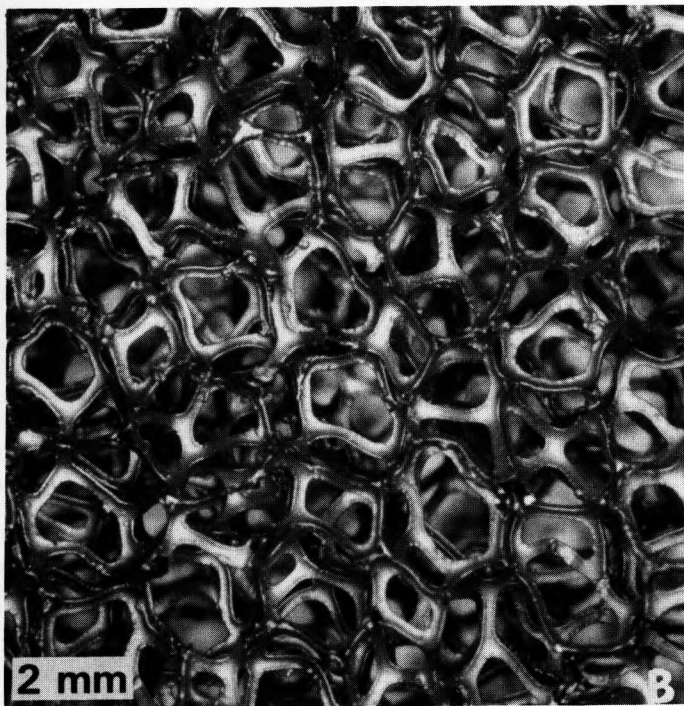


Figure 3. Microstructure of an open silicon carbide showing the arrangement of hollow cells with the cell faces absent.

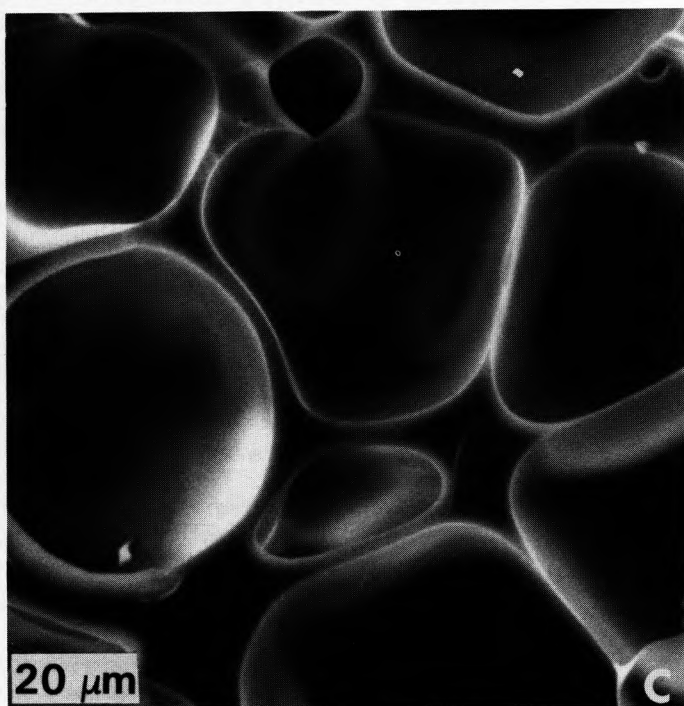


Figure 4. Microstructure of a closed-cell sodium borosilicate glass; the structure is analogous to a soap foam but on a finer scale.

feasible to produce materials with long thin cells in which significant anisotropy could arise.

An essential feature of ceramic science is to develop relationships between the microstructure and the properties of a material, which allows microstructures to be designed to produce a specific set of engineering properties. Thus, in order to understand the mechanical behavior of lightweight ceramics, it is crucial to obtain theoretical relationships between the microstructural parameters, such as cell size, fiber diameter, and cell wall thickness, and the macroscopic properties, e.g., strength, elastic constants, toughness, and fractional density. A powerful scientific approach to accomplish this task has been to model the

microstructure using an idealized arrangement of micro-mechanical unit cells. The unit cell is analyzed using the approaches developed for macroscopic engineering structures, which consider the effect on various forces on the framework.

The microstructure of cellular materials has been modeled using a variety of unit cells, including open and closed cell cubic, and a variety of dodecahedrons chosen to reflect the morphology of foamed materials. During foaming, the pressure difference between adjacent cells is expected to be small, due to the rapid diffusion in liquids, which implies that the reduction of surface area should be an overriding factor in establishing the final geometry. This behavior is equivalent to soap bubbles, in which surfaces can be met in only two ways; that is, either three surfaces meet along a curve at angles of 120° or six surfaces (four edges) meet at a vertex with angles of 109.50° . There is no regular polyhedron that can fulfill these requirements, as well as being able to fill space. Lord Kelvin showed that if the edges of a truncated octahedron were curved, both the required angles and the compatibility conditions could be satisfied: this polyhedron is called the minimum area tetrakaidecahedron. Such curvature is not usually observed in cellular materials, so it has been suggested that plane-faced figures, such as dodecahedrons, represent a reasonable choice for a unit cell, even though they do not fill space. Recently, Ashby has suggested that a cubic unit cell consisting only of struts can be used to analyze the essential mechanics of the deformation process, provided that bending of the cell struts is the predominant form of deformation. Figure 5 shows the type of cell he has used in this work. He also argues that as the cell faces in closed cell materials are often extremely thin, the model shown in Figure 5 can be used for both open and closed cell materials.

The unit cells analyzed for fibrous ceramics are very similar to that shown in Figure 5, though there has been some debate about the amount of fiber-bending that occurs in these materials. Moreover, for these materials, it is necessary to account for anisotropy of the microstructure. This has been accomplished by making the spacing between fibers different in the different principal directions. It is clear that the unit cell for the fibrous materials is much more of an abstraction of the real microstructure than that for the cellular materials, but even so it was found particularly useful in understanding the mechanical behavior of the space shuttle tiles.

The Mechanical Behavior of Lightweight Ceramics

The stress-strain behavior of fibrous and cellular materials in compression, shown in Figure 6, is surprisingly enough, qualitatively independent of the choice of material. Initially, the materials deform elastically, but then further deformation occurs at an almost constant stress. Actually, the detailed deformation mechanisms that occur in this plateau region vary from material to material; for example, the fibers or cells may collapse, plastically deform, or fracture. In the case of lightweight ceramics, the predominant mechanism, is brittle crushing. Whatever the deformation mechanism, the process allows the cell walls or fibers to approach each other. Finally, there is a densification stage that occurs when the cell walls or fibers contact each other. It is important to note that large strains are possible, even in lightweight ceramics, and the large amount of energy that can be absorbed in these materials can be a very useful attribute. The behavior of lightweight ceramics in tension is also initially elastic, but this is followed by brittle failure.

Can the Mechanical Properties of Lightweight Ceramics be Improved?

The analysis of micromechanical cells, such as that shown in Figure 5, allows us to develop two types of theoretical relationships. Firstly, we can relate the microstructural geometry to the fractional density; for example, finding that the fractional density depends on the ratio of cell size to cell wall thickness in the cellular materials. Secondly, when we analyze the deformation of the unit cell, we obtain relationships among the various

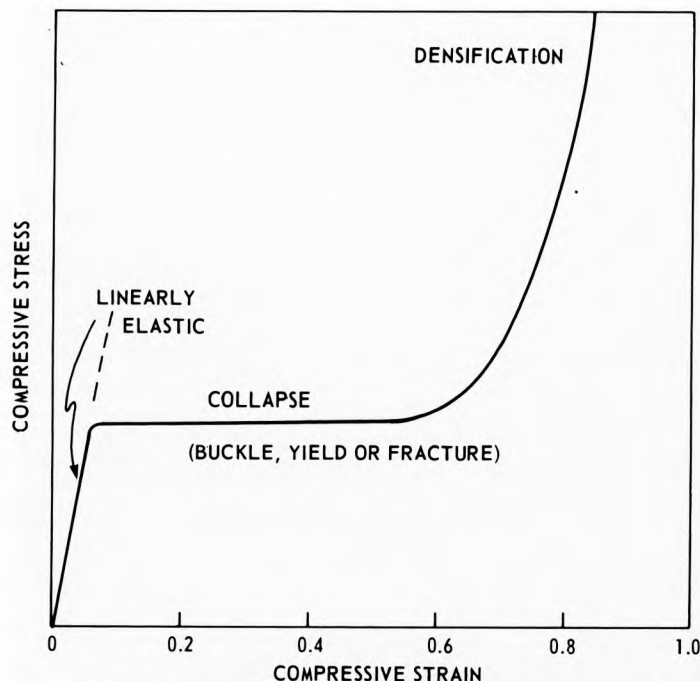
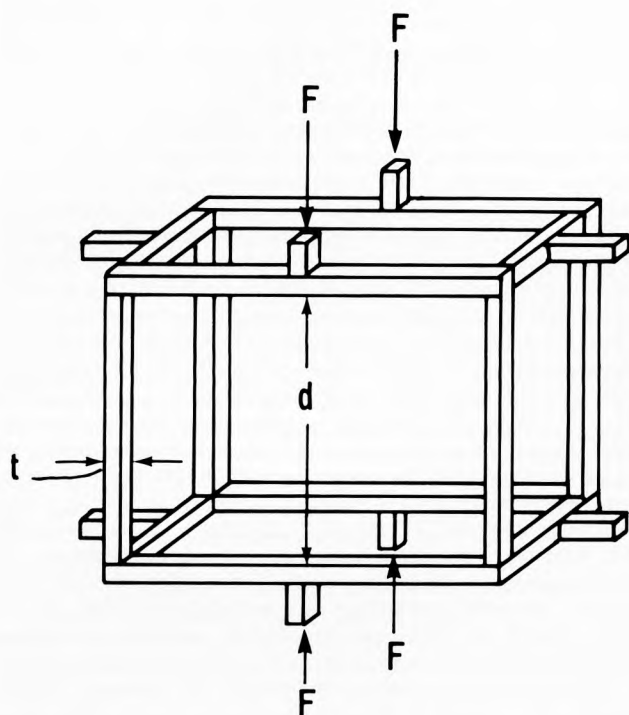


Figure 6. The stress behavior of a cellular material in compression, showing the three distinct phases of deformation: elasticity, collapse, and densification. The behavior in tension is generally elastic and brittle.

Figure 5. An example of a micromechanical cell that is used to model the behavior of cellular materials (after Ashby, *Metall. Trans.* 14A: 1755, 1983).

mechanical properties of the fibrous or cellular material and the microstructural geometry.

Using this procedure, equations have been developed for the various elastic constants, the compressive and tensile strengths, the hardness, and the fracture toughness of lightweight materials. As expected, all these properties depend on the fractional densities. In addition, however, the properties depend directly on the properties of the cell wall; for example, the tensile strength is found to depend on the fractional density, the cell size, and the strength of the cell walls. In order to maximize strength, we need to make sure that the flaws in the material are less than the cell size, and that the strength of the cell edges is as high as possible. Thus, we have to also consider carefully the microstructure of the cell edge material; in other words, start considering a microstructure within a microstructure. This is a very important conclusion, as it means that if new approaches to strengthening, such as fiber reinforcement, are applied to the cell edge material, and processing routes that carefully control flaw size and cell size are introduced, major improvements can be made in the mechanical behavior of lightweight materials. Indeed, calculations indicate that the strength and toughness of lightweight ceramics, when normalized to their weight, could approach the values of dense ceramics. For this reason, major advances could be made in the use of lightweight ceramics. For example, a new generation of space shuttle tiles was developed in which a second type of fiber was incorporated into the microstructure. The additional fibers were stronger and allowed more bonding to occur between fibers. This latter effect was equivalent to decreasing the cell size, and allowed more fibers to carry the loads. This approach allowed the tensile strengths of the tiles to be increased by a factor of three, and can be readily understood in terms of the micromechanical models.

Future Challenges

Another engineering application for these lightweight ceramics also has considerable potential—to sandwich a lightweight ceramic material between dense ceramic plates. This approach has been used in the aerospace industry using other materials. The availability of a lightweight sandwich panel that could withstand high temperatures would be very useful in many structural

applications. The attractive feature of such panels is that the strength and stiffness of the outside is combined with the low weight and thermal protection of the inside; in a sense, it is an equivalent concept to that of the I-beams used in so many engineering structures. Again, improvements in the mechanical properties of the lightweight core would be an essential part of this development.

In response to the opportunities that lightweight ceramics represent, there is an active research program currently under way in the Department of Materials Science and Engineering at Penn State. There are two aspects to this program. Firstly, the mechanical behavior of commercially available lightweight ceramics are being studied under my direction. The aim here is to test the theoretical equations that have been developed and to identify the defects that are currently limiting the strength of these materials. The work will involve various aspects of mechanical behavior, such as strength, fracture toughness, thermal shock resistance, and impact resistance.

In the second phase, the emphasis will turn to developing new methods for fabricating lightweight ceramics. This work will be a joint effort with Dr. Gary L. Messing. In addition, work is also planned to assess some of the applications of these materials, such as ceramic fiber burners and burner blocks, and to determine which aspects of the materials are currently limiting their performance.

Thus, the development of lightweight ceramics has considerable potential and offers exciting opportunities in science and technology. In order to capitalize on this potential, several challenges have to be met: challenges to the processing scientist to improve fabrication techniques; to the physical materials scientist to understand the intricate relationships between the microstructure and the properties; and to the engineer to design with these unusual materials. Only then will these opportunities be realized.

DAVID J. GREEN came to Penn State in 1984 from Rockwell International Science Center, California, where he was a member of the technical staff. He was previously a research scientist at the Canadian Center for Mineral and Energy Technology in Ottawa. He holds B.S. degrees in chemistry and materials science from the University of Liverpool, U.K., and M.S. and Ph.D. in materials science from McMaster University, Canada. He is a specialist in the mechanical behavior of lightweight and structural ceramics.

Great Events, Grand Experiments: Man's Study of the Variable Climate

Part II — Prospects of a Warming Earth

PETER J. WEBSTER, Professor of Meteorology

In Part I, we discussed the variations of climate taking place on relatively short time scales and man's attempts to monitor and forecast these changes. Such climate variability may be thought of as rather low-frequency oscillations of the atmosphere and ocean system. The oscillations occur because the state of both of these components of the climate system are mutually dependent; that is, the atmosphere, and hence the weather, is driven largely by the heat stored in the ocean. On the other hand, the ocean currents are forced, to a large degree, by the wind stress on the ocean's surface. The final result is a modulated climate driven by a slowly varying ocean-atmosphere system.

Beyond the periods of anomalous climate that result from the interaction of the components of the Earth system, many scientists feel that there lurks in the background a much more dangerous and insidious climate effect which may be steadily growing and increasing its influence. This is a warming of the troposphere that may accompany a rapidly growing concentration of carbon dioxide and methane in the atmosphere. These gases, together with water vapor, are the major so-called greenhouse gases of the atmosphere which partially absorb the heat of the Earth being lost to space. They are, in effect, the Earth's insulators and are responsible for the Earth's benign climate and for its habitability. Without them, the climate of the Earth would be far colder and certainly too harsh to develop a biosphere. The warming Earth hypothesis considers the changes induced in the Earth system by a larger concentration of greenhouse gases.

If the warming Earth hypothesis is real, we will have identified another major perturber of climate which appears to have a sufficiently short time scale that it will have to be reckoned with during our lifetime. The first, the intermittent interannual variability of climate discussed in Part I, will re-occur every few years and will require serious but relatively short-term social and economic adjustment. The second, to be discussed here in Part II, the possible warming trend of the globe, will require changes in society that we have yet to approach or even comprehend.

The Entwining Nature of Carbon Dioxide

One of the most interesting aspects of CO₂ is its ubiquity in the Earth system. Carbon dioxide should not be thought of as a passive constituent of the Earth system, but as an integral part of an evolving carbon cycle that involves the ocean and the atmosphere, as well as the biosphere. Man and his activities are key players in the evolution of the concentration of CO₂.

Carbon dioxide is contained within a number of very large reservoirs between which two-way exchanges exist. Figure 1 (from Tucker, 1981) summarizes, in gigatons (Gt), the flux between each reservoir (Gt/yr) and the content of the four main pools of carbon dioxide (Gt). These pools are within the ancient biosphere where CO₂ is stored in fossil fuels and shale, within the oceans, and in the atmosphere. The largest pool, though, is within the oceans, where it is estimated there resides almost 50 times the total atmospheric loading, i.e., 40,000 Gt compared to 700 Gt. Most of this carbon dioxide is dissolved in the deep cold ocean.

The arrows in Figure 1 indicate the exchanges between the pools, and represent such processes as ocean out-gassing and

in-gassing as the ocean changes temperature through the year, and biospheric respiration of both green autotrophic plants and heterotrophic plants that feed on the green plants or on the dead parts of plants. Averaged over a period of time, all of the exchanges nearly balance out, so that the content of each pool remains constant. This is true for all pools but one. We note that the arrow from the fossil fuel pool is in one direction only. This represents man's contribution to the carbon cycle by the burning of fossil fuels. Thus emerges a very basic question. We feel that there may be some impact on climate caused by the increases in the atmospheric carbon dioxide, but will these changes interfere with the content of the great pools of CO₂?

The message here is very clear. To understand changes in the concentration of carbon dioxide in the atmosphere, we require an intimate knowledge of processes in the ocean as well as in the atmosphere, and at the ocean floor as well as at the land surface.

The multiplicity of the components of the carbon cycle and the ability of carbon to entwine through the complete Earth system is on the one hand bewildering, but on the other hand fascinating. We are unsure if the complicated nature of the carbon cycle attests to its robustness or to its fragility. What we are aware of is that there is within a changing carbon cycle the potential for gross effects on the Earth's climate and habitability. That potential alone is sufficient cause for concern and for the development of remedial strategies.

Both the scientific questions and the gravity of the social implications are beginning to be appreciated and grappled with by the national and international scientific community. Scientific discussion and debate have been encouraged throughout academe, and the national academies of science throughout the

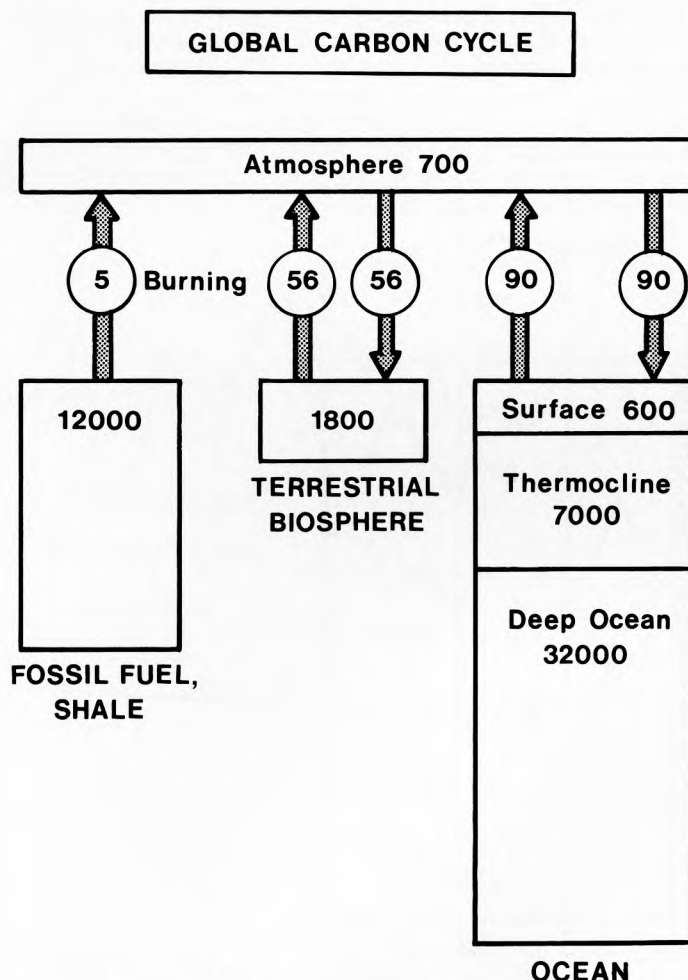


Figure 1. The main carbon reservoirs in the global carbon cycle and the fluxes between them. The content of the pool is in gigatons (Gt) and the fluxes between them in Gt/year. (after Tucker, 1981)

world have created appropriate mechanisms for the scientific communities to interact with government. Many governments have responded by creating legislation that provides funds for basic research into both scientific and social aspects of the changing climate. For example, the National Climate Act of the United States allocates funds on a long-term basis for fundamental research for the government agencies and universities.

If a full appreciation of the social adjustments are as yet beyond us, we can at least attempt to understand the physical nature of the changes, and thus establish the probable impact on the climate system. To this end, we will describe a nest of experiments, planned and funded by the international community, that are aimed at providing data to elucidate the underlying physics of the variability and to stimulate basic research, especially in the modeling of the interactive ocean-atmosphere system. The hope, of course, is to gain sufficient information from the experiments to understand the phenomena, and then predict their future state.

The Changing Chemical Composition of the Atmosphere

So large is the emission of carbon dioxide from anthropogenic effects that the concentration may have achieved a doubling time of less than 50 years. The two longest observational records are in Antarctica and Mona Loa, Hawaii, and have been made since 1958, showing an increase in CO₂ concentration of over 10 percent during the period. Attempts have been made to extrapolate backwards to the beginning of the Industrial Revolution, and forwards to the middle of the next century. Making such estimates has required assumptions of the production rates of carbon dioxide due to fossil fuel consumption and of the take-up rates of the biosphere and the ocean.

Figure 2 shows a plot of CO₂ concentration over the two centuries, 1850-2050. Prior to the Industrial Revolution, the carbon dioxide concentration was about 270-290 ppm, while the

present level is over 340 ppm. A rise to nearly 600 ppm is expected by the middle of the 21st century. In the upper left part of the diagram is a longer term estimate of the CO₂ concentration. In order to estimate backwards some 1800 years, the changes in carbon-13 concentration in tree rings was painstakingly determined. Throughout the period, very large changes in CO₂ have been inferred, but it is important to note that the largest concentrations are certainly occurring at the present time.

Impact of Changes in Chemical Composition on the Climate of the Earth

It would be less than candid to say that there is universal agreement on the magnitude of the global temperature increase that may be induced by the expected changes in carbon dioxide. Indeed, there is even some debate regarding the very sign of the temperature change (Idso, 1982). However, using the best available technology and methodology, the consensus is that the doubling of carbon dioxide concentration will increase the globally averaged temperature by about 2-4°C (National Academy of Sciences, 1982). Such estimates **must** be accompanied by caveats expressing wariness regarding the results obtained from imperfect models and techniques. For example, most estimates are made using models that do not contain either an interactive ocean or an interactive cloud structure. These may be dangerous omissions given the important role the ocean plays in the carbon dioxide saga, and the changes in insolation caused by cloud variation (Webster and Stephens, 1984).

However, the fallibilities of the techniques aside, it is likely that if the Earth does go through a warming phase, the local changes in temperature and weather may be much larger than the global average. Computer simulations of the climate suggest that near the poles, the rises in temperature may approach an average of 6-8°C over the year, enough to make the summer Arctic Ocean ice-free and to cause a significant reduction in the

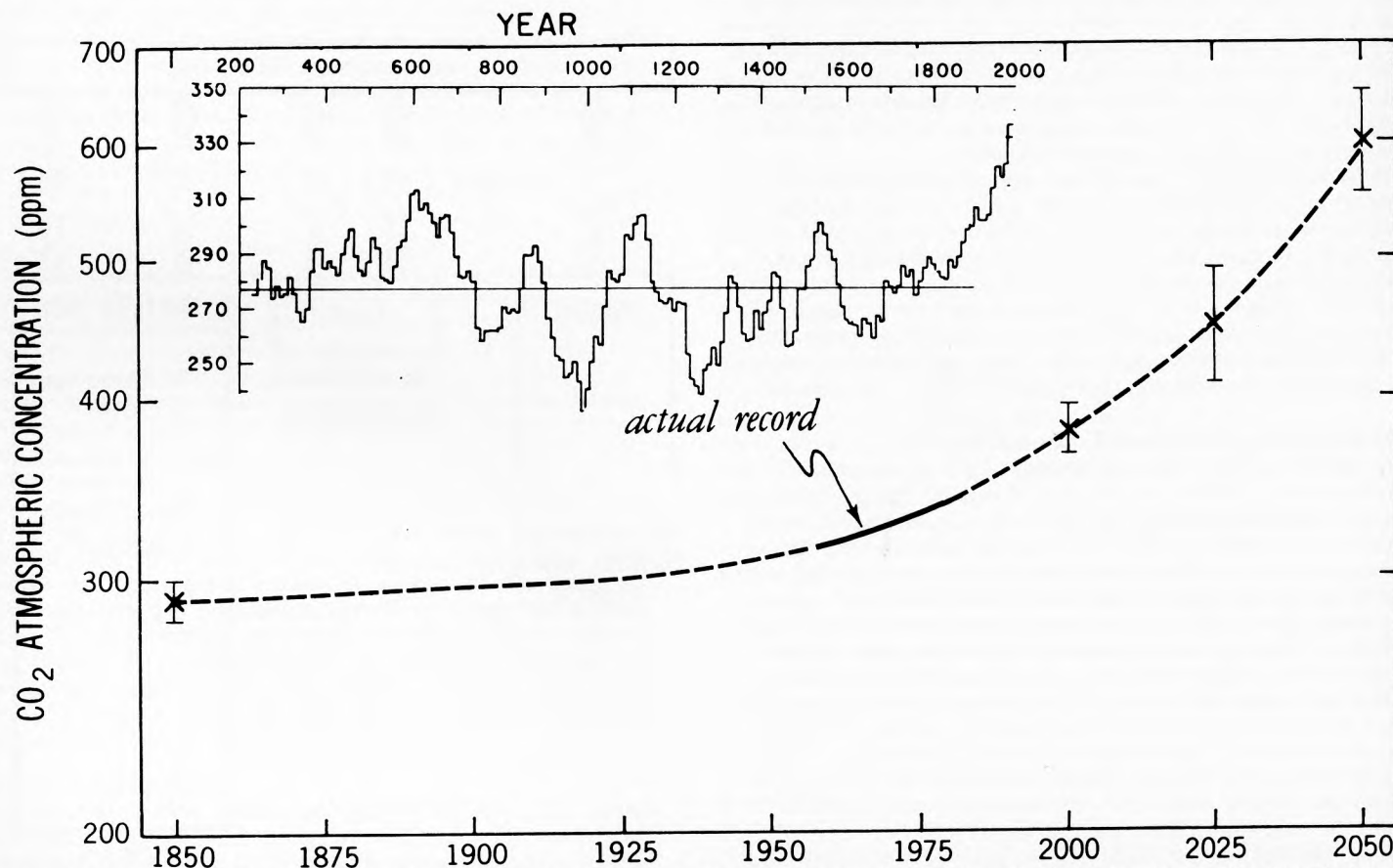


Figure 2. The variation of the concentration of atmospheric carbon dioxide between 1850 and 2050. Actual observations constitute the record between 1958 and the present. The remainder of the curve is estimated. The variation in carbon dioxide concentration between 200 B.C. and the present, as determined from the carbon-13 content of tree rings, is shown in the upper left.

ice held in the Antarctic and Greenland. It is thought that sufficient water would be released (if the temperature rise were to materialize) to raise the mean global sea level by a few meters; sufficient to flood many coastal plains and major cities.

But attached to the changing temperature of the globe may be another factor of even greater significance. There are suggestions, again from computer simulations, that accompanying the warming of the Earth, the major precipitation patterns may alter their location significantly and permanently. Of the gravest concern is that the wheat belt areas of North America and Eurasia may become dryer, and thus less useful for cereal production. Thus, not only may the globe reorient itself climatically, but significant economic and social adjustments would have to accompany the changes.

Mechanisms of Climate Change

It is important to realize that the major factor that may cause the temperature to rise is not the carbon dioxide itself, but the increase in water vapor in the atmosphere accompanying the temperature rise associated with the initial carbon dioxide increase. Carbon dioxide is an absorber of the infrared radiation from the Earth and as such is a greenhouse gas. However, it absorbs in a relatively narrow spectral range, so that its ability to insulate the Earth is limited. But the initial warming caused by the CO₂ increase may be sufficient to increase the water vapor content of the atmosphere. Water vapor is an excellent absorber of infrared, absorbing over a much broader spectral range than carbon dioxide. Thus, in the CO₂-climate problem, the actual increase in CO₂ plays the role of a climate change catalyst that produces other stronger effects.

As the major source of water vapor, the ocean is a critical component of the CO₂-climate connection. Of particular importance is the temperature of the surface of the ocean, as this will determine to a large degree the atmospheric water vapor pressure distribution, and therefore the amount of infrared absorption in the Earth's atmosphere. Furthermore, the ocean contains an enormous reservoir of dissolved carbon dioxide. The holding capacity of a dissolved gas of a fluid is inversely proportional to its temperature (Henry's Law) and some scientists feel that as the surface temperature of the globe increases, vast amounts of the dissolved gas will be released to the atmosphere.

There is another implication of a warming climate that is rarely discussed. This is related to the stability of the marine biosphere. The oceanic carbon cycle is critical to marine biology. If the ocean were to warm and lose large amounts of dissolved carbon dioxide, it is thought that the carbonate balance could alter significantly. Unfortunately, we have little understanding of the implications to the global ecology of upsetting delicate balances in the chemistry of the oceans.

There is one positive role that the ocean may play. The ocean, with its much greater thermal mass and heat storage capacity, may at the same time slow down the rise of the global surface temperature. That is, the ocean may invoke a rather complicated signature on the slow decadal timescale variations of climate.

Observing Interdecadal Climate Change

To establish a climatology for the oceans, to determine its interannual variability, and to assess the role played by the ocean in the carbon dioxide-climate question, much more oceanographic data is required than we possess at this time. Information is required regarding the ocean circulation and composition throughout its depth, especially the features of the very deep ocean. To this end, another international experiment WOCE (the World Ocean Circulation Experiment) has been organized; again under the auspices of the World Climate Programme, formed jointly by the International Council of Scientific Unions (ICSU) and the World Meteorological Organization (WMO).

The scientific objectives of WOCE are very different from those of TOGA, the Tropical Ocean-Globe Atmosphere Experiment described in Part I of this article. These differences dictate the adoption of a different observational strategy. Whereas TOGA

concentrated on the rapidly evolving upper ocean circulation, WOCE emphasizes the structure and evolution of the middle and deep ocean. There, changes are so slow that measurements may not have to be made simultaneously over the entire oceans to determine the chemical composition and motion fields. During WOCE, numerous ocean traverses will be made by research ships that measure the hydrographic and chemical structure of the ocean, from surface to sea-bed.

Despite considerable dependence on well-tested ship-borne techniques, a major part of WOCE will be clearly space age. Unfortunately, there is no recognized method for viewing the internal structure of the ocean from space. In fact, WOCE will depend greatly on the success of the altimeter mission aboard the TOPEX satellite. The altimeter will measure variations in the height of the ocean surface with great accuracy. The slope of the ocean surface is analogous to the slopes of pressure surfaces in the atmosphere, and will allow scientists to determine the direction and the strength of the ocean currents. It is through careful monitoring of the ocean transports, together with variations of the composition of the ocean as measured from ships and spacecraft, that WOCE hopes to be able to assess changes in the ocean circulation system and in geochemical cycles such as the carbon cycle.

Some Ponderables

A very reasonable question to ask at this stage is whether or not there is any evidence that the Earth has already started to warm? After all, Figure 2 has indicated that the change in the CO₂ concentration is already substantial. However, after a number of exhaustive studies, there appears to be no temperature trend which withstands rigorous statistical scrutiny that supports the contention of a warming Earth! Indeed, the temperature record is something of an enigma.

Figure 3 shows the mean surface air temperatures for the last hundred years for three latitude bands: 30°-50°N (top curve); 10°N-10°S (middle), and 30°-50°S (bottom), adapted from Idso (1982). Obviously, the record is confusing. Only the southern hemisphere data shows a continual temperature rise. The tropical and northern hemisphere data show a distinct cooling after a

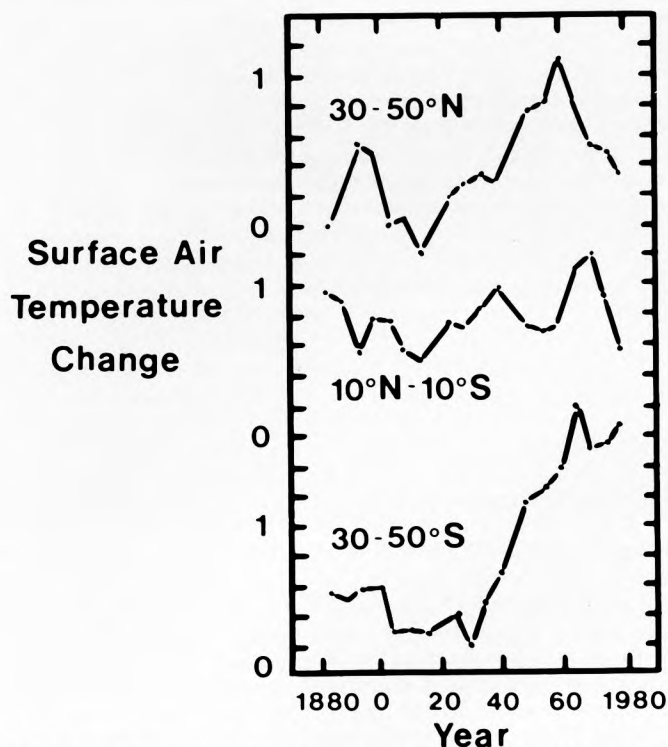


Figure 3. The time evolution of the average air temperature of the latitude bands 30°-50°N (upper curve), 10°N-10°S (middle curve), and 30°-50°S. The interval is 0.2°C. (after Idso, 1982)

small upward trend. This cooling is, unfortunately, occurring at the time of the maximum increase in carbon dioxide.

Quite naturally, critics of the carbon dioxide-warming-Earth hypothesis see these curves as very convincing evidence that confounds the warming Earth hypothesis. But whether or not one supports the hypothesis, one is morally bound to explain the apparent lack of connection between the rapid increase in the concentration of the greenhouse gases and the temperature traces. Theories fall into one of two camps:

- (1) The increase in the concentrations of greenhouse gases are as yet insufficient to produce a warming that stands above the natural variations of temperature—the type of variation associated with such climate events as El Niño.
- (2) The climate of the Earth is sufficiently robust that any number of internal feedbacks may compensate for the increase in CO₂.

Of course, with (1) there is no answer except to wait and see, making sure that during the interim we have sufficient observations to make a better assessment at some point in the future. But with (2), one can conjure up many processes that could buffer the climate system and so minimize the impact on the concentration of greenhouse gases. Unfortunately, with almost all of these contenders, we have only a small appreciation of how they work. This is certainly the case with cloudiness.

One of the simplest ways the Earth system could neutralize the impact of a change in carbon dioxide or any greenhouse gas would be to increase cloudiness. While the greenhouse gases would increase the temperature, an increase of cloudiness would decrease the amount of solar radiation reaching the ground, and thus cool the Earth. Webster and Stephens (1984) estimate that an increase of only 10 percent in the cloudiness of the low troposphere would compensate for a doubling of CO₂. Unfortunately, our understanding of the relationship between cloudiness and surface temperature is sufficiently vague that we are unsure whether clouds would increase or decrease with an increase in the temperature of the Earth.

A very beautiful theory that is consistent with (2) is the Gaia Hypothesis—Gaia was the ancient Greek goddess of the Earth. Here, Earth is seen as an interactive organism in which the biosphere adjusts in order to keep the climate within the rather narrow bounds in which it has rested for millions of years. The adjustments may be seen as a change in chemical composition, such as CO₂, or as a change in vegetation, which may alter the albedo of the Earth. The followers of Gaia point to the Earth hundreds of millions of years ago when the energy received by the Earth was much less, the Sun then being a much younger star. However, the climate was not too different from what it is today. The Gaia theory suggests that the biosphere compensated by possessing excessive concentrations of carbon dioxide. Indeed, there is evidence that at this time the CO₂ concentration was closer to 30 percent in the atmosphere; in other words, over 1000 times the present concentration.

Critics of the Gaia hypothesis worry at the suggestions of an almost conscious governing of the climate by a “knowing” biosphere. They argue that a natural evolution of systems could account for a similar governing and buffering of climate.

But a more basic response to the dilemma posed in (1) and (2), above, is that we really do not have an answer. Our knowledge of the physical basis of the climate system is still sufficiently primitive that we are not sure at what rate the Earth system will warm, or if it will warm at all. What we do understand fully is that the consequences of a warming, if it were to occur, could be catastrophic to life as we know it, and that is sufficient information for action. In the stockmarket, when a stock has a large downside potential, a good investor will hedge against loss by diversification of this investment. Our hedge in the carbon dioxide-climate relationship is in continued research, experimentation, and data collection.

Benefits, Hopes and Aspirations

Meteorology and oceanography have a rich history of international research programs. We have just concluded the Global

Weather Experiment (1976-79) that included both summer and winter Monsoon Experiments (MONEX). Only now after years of compilation and reanalysis are the final data sets becoming available. These experiments must be considered as major successes and the data sets they produced will serve as standards for years to come. But perhaps the most important influence of the experiments is the mental stimulus and scientific focus they have provided for the scientific community. Even before MONEX or GWE were completed, a surge of research activity into monsoon dynamics and global weather was initiated.

Perhaps it is not surprising that the same pattern is being followed with the World Climate Programme experiments, TOGA and WOCE. Modifications have already been made to some of the hypotheses that were instrumental in instigating these experiments in the first place, and even a new variability, a 40-60 day variation that appears to be strongly linked to the El Niño phenomenon, has been discovered and examined. Yet the TOGA experiment has only been under way for one year, and a data set has yet to be compiled, let alone analyzed.

Perhaps when the worth of an experiment is finally evaluated, it is the accompanying surge of interest that is just as important as the data which is collected and analyzed. That, of course, is difficult to decide. But what we are sure of is much simpler. Great events are occurring within the climate of the Earth system, and the international community has rallied with grand plans. Only in the years to come will we be sure that the stimulus provided by planning and the data provided by observations are grand enough to answer the questions that are vital to society and the habitability of the planet.

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PETER J. WEBSTER is a member of the Joint Scientific Committee that oversees the international World Climate Research Program, and a member of both the national and international TOGA committees. He joined the Penn State faculty in 1983, having previously held research and teaching positions in Australia, California, and Washington. Dr. Webster received his undergraduate training in Australia and graduate education at MIT. His research interests are focused on the fluid dynamics of atmospheric and oceanic systems, particularly monsoons and tropical phenomena.

Dean — continued from front page

secretary, treasurer and vice chairman of the University Corporation for Atmospheric Research, a consortium of 53 universities responsible for establishing and overseeing the operation of the National Center for Atmospheric Research in Boulder, Colorado. He is currently the chairman of UCAR's Unidata Steering Committee which is developing a nationwide weather data and communications network for atmospheric research and education. He is a longstanding member of the NASA Space and Earth Sciences Advisory Committee which advises NASA on its \$1.4 billion research program. Dr. Dutton has been active in affairs of the American Meteorological Society as former publications commissioner and elected councillor. He previously served on National Academy of Sciences committees concerned with atmospheric science.

He received his B.S., M.S. and Ph.D. in meteorology from the University of Wisconsin. From 1962-65, he served on active duty as a commissioned officer with the U.S. Air Force Air Weather Service. In 1963 he was awarded the Air Force Commendation Medal and the Zimmerman Award of the Air Weather Service. He joined the Penn State faculty in 1965.

(Dr. Dutton's photograph by Steven Krepps, La Vie).

COLLEGE NEWS NOTES

Koss Heads Metallurgy

Dr. Donald A. Koss has been appointed professor of metallurgy and chairman of the Metallurgy Program in the Department of Materials Science and Engineering.

He comes to Penn State from Michigan Technological University, where he was a member of the metallurgical engineering faculty from 1970-85. In 1978, he received a National Science Foundation Fellowship to carry out research at the Los Alamos National Laboratory.

Dr. Koss has considerable teaching experience and holds the distinguished teaching award of MTU. His research has focused on the microstructure and stress mechanisms in alloys and he has published extensively in national and international professional journals. He has been active in professional organizations, particularly as a member of the Titanium Committee of TMS-AIME, and on the Board of Review Committee for Metallurgical Transactions of AIME.

He is a member of AIME, the American Society for Metals, the American Powder Metallurgy Institute, and Alpha Sigma Mu, an honorary metallurgical society.

Dr. Koss obtained his B.S. in metallurgy at the University of Minnesota, and M.S. and Ph.D. from Yale. From 1965-1970 he carried out research in the Advanced Materials Research and Development Laboratory of Pratt and Whitney Aircraft Company.

New EMS Faculty

Dr. Donna J. Peuquet has joined the faculty as associate professor of geography. She is a specialist in the development and management of large data base information systems, geographical data sensing and processing, and computer cartographic and graphics techniques.

Dr. Peuquet comes to Penn State from the University of California at Santa Barbara, where she was research assistant professor. From 1979 to 1982 she was with the U.S. Geological Survey, Earth Resources Observation Systems Office and conducted research on high technology automated systems and worked with multidisciplinary teams in developing general methodologies for their application to land and natural resource problems. She has also been on the faculty of the Department of Geography at the State University of New York at Buffalo. Dr. Peuquet holds B.A. and Ph.D. degrees in geography from the State University of New York at Buffalo, and an M.A. from the University of Cincinnati.

Dr. Wayne Huebner has been named assistant professor of ceramic science and engineering in the Department of Materials Science and Engineering. He obtained B.S. (summa cum laude) and Ph.D. degrees from the University of Missouri-Rolla, specializing in degradation phenomena in ceramics and thermally stimulated current processes in dielectrics.

Dr. Michael L. Machesky has been appointed assistant professor of geochemistry in the Department of Geosciences. He recently obtained his Ph.D. in water chemistry from the University of Wisconsin. His research is concerned with low temperature aqueous geochemistry.

Dr. Eric K. Albert has been named assistant professor of mining engineering in the De-

partment of Mineral Engineering. He obtained his B.S. in computer science and M.S. and Ph.D. in mining engineering, all at Penn State. Dr. Albert is a specialist in computer systems, simulation techniques, and hardware and software development.

Recent Faculty Appointments

Richard E. Tressler, professor and program chairman of ceramic science and engineering in the Department of Materials Science and Engineering, has been appointed a member of the National Research Council's National Materials Advisory Board Committee on Ceramic Technology for Advanced Heat Engines.

Z. T. Bieniawski, professor of mining engineering and director of the Pennsylvania Mining and Mineral Resources Research Institute at Penn State, has been appointed to the National Research Council's Task Group on Advances in Technology for Construction of Deep-Underground Facilities. The Group will assess the current state-of-the-art for the purpose of deep defense installations. Professor Bieniawski has also been named to the editorial advisory board of *World Mining Equipment*, a monthly technical trade journal with worldwide circulation.

Shelton S. Alexander, head of the Department of Geosciences, has been elected to a three-year term on the Board of Directors of the Seismological Society of America.

Gary L. Messing, associate professor of ceramic science and engineering, has been appointed editorial co-chairman for the *Journal* and *Bulletin* of the American Ceramic Society.

Vladimir S. Stubican, professor of ceramic

science and engineering, was recently elected to the editorial board of a new international journal, *Reactivity of Solids*, which will be published by Elsevier, Amsterdam, Netherlands, and to the Organizing Committee of the XIth International Conference on Reactivity of Solids to be held in Princeton, N.J. in 1988. In fall, Dr. Stubican delivered the opening address at the XXth Meeting of the Yugoslav Crystallographic Center in Sarajevo, Yugoslavia, speaking on "Crystallography and Applications of Zirconia and Zirconia Solid Solutions."

College Obtains New Computer Facility

The College has recently acquired a new advanced computing facility, the Earth Science Engineering Center, established under the Engineering Center Network Program of Control Data Corporation. Penn State was one of 12 universities nationwide selected by CDC to receive a CYBER 180 computer system and membership in the CDC Engineering Network. The Center is being sponsored by the Department of Mineral Engineering and the Department of Geosciences to support their expanding needs for versatile computing equipment that can be used equally for instruction and research. The system meets these needs with 500 megabytes of on-line disk storage, a dual-state central processor, a 6250 bpi tape drive, and a 300-line-per-minute printer. Some of the packages already installed are: a full-screen text editor, FORTRAN 4 (ANSI 66) and FORTRAN 77, an ICEM 2D and 3D drafting facility supported on color terminals with color hardcopy,



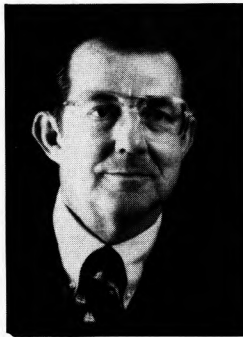
Representatives of Standard Oil were on campus recently to review research progress in the College's Standard Oil Center of Scientific Excellence in Mining Technology, and present University President Bryce Jordan with the funds that will support the Center's activities for the coming year. Shown above, left to right, are: Dr. R.V. Ramani, professor of mining engineering and co-director of the Center; Jennifer Frutchy, Standard Oil program associate, corporate contributions; Y.E. Young, senior counsel, Standard Oil Patent & License Division; University President Bryce Jordan; William Hake, vice president of engineering, Old Ben Coal Company; Dr. Arnulf Muan, acting dean of the College of Earth and Mineral Sciences; G.E. DiClaudio, senior planning engineer, Old Ben Coal Company; and Professor R.L. Frantz, head of the Department of Mineral Engineering and co-director of the Center. The Center was established in 1983 under a five-year \$2 million grant from Standard Oil to seek scientific, engineering and technological solutions to problems in longwall mining and carry out research into the capabilities of longwall mining systems.



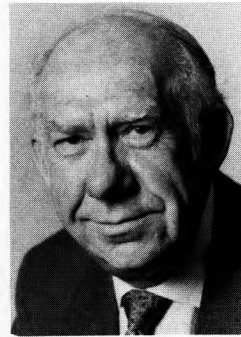
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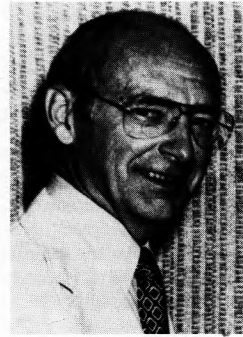
Fletcher L. Byrom



John W. Hanley



John M. Ruffner



Quentin E. Wood

Campaign for Penn State

The University is soon to embark on the most ambitious fund raising effort it has ever undertaken—a capital campaign that will strengthen Penn State's position as one of the nation's leading public teaching and research universities.

The Campaign for Penn State will be a major five-year effort to raise some \$200 million for academic program support. The Campaign will seek major gifts that will benefit all segments of the University through endowed faculty positions, increased student aid, new and innovative academic programs, and improved facilities.

G. David Gearhart, vice president for development and University relations, has emphasized that if Penn State is to sustain its position in the increasingly competitive academic world, support is needed from the private sector to supplement funds from the state and from tuition.

Although Penn State is a state-related university, less than 25 percent of the University's total budget is funded by the Commonwealth of Pennsylvania, and this percentage is decreasing annually. Penn State tuition is already high compared with other state universities.

Consequently, the University must turn to corporate, foundation, and individual donors to provide support for the constant upgrading of academic programs essential for maintaining and enhancing our reputation.

University Provost William Richardson has pointed out, for example, that academia is now no less competitive than the business world, and that to attract and support scholars and scientists of world class status and to maintain faculty at the forefront of their disciplines, we must increase the number of University-endowed chairs, named professorships, and faculty fellowships.

Two-thirds of the money raised by the Campaign for Penn State will create endowed faculty positions, provide student scholarships and support other academic programs. Other campaign plans call for improving instruction, research and public service programs; expanding the University Libraries' collections; funding construction and renovation; purchasing equipment; and increasing annual support to sustain future growth.

Within the College, Campaign funding would be apportioned among new endowed faculty positions, scholarships to attract top students, and equipment. The highly successful fund drives already under way, the Stahl Fund to establish an Enhanced Oil Recovery Laboratory in Petroleum and Natural Gas Engineering and the H.M. Davis Equipment Fund in Metallurgy, are a part of our Campaign effort.

Campaign's Executive Committee

In January, University President Bryce Jordan announced the formation of the Campaign's Executive Committee, an impressive array of 27 corporate executives and distinguished business and civic leaders who will be instrumental in the success of the fund raising effort.

The National Campaign Chairman and head of the Executive Committee will be William A. Schreyer '48 Liberal Arts, chairman and chief

executive officer of the worldwide financial services firm Merrill Lynch & Company Inc., New York. Other committee members are top executives drawn from corporations, industry, banking and insurance.

The College is well represented on the Campaign Committee, since five distinguished alumni have agreed to give their time, talent and energy to further the cause of the University:

Victor G. Beghini, senior vice president for exploration and production, U.S. Marathon Oil Co., is a 1956 graduate of Petroleum and Natural Gas Engineering, a member of the Mount Nittany Society and a Distinguished Alumnus of the University. He is already serving as chairman for the College's Stahl Fund.

Fletcher L. Byrom, retired chairman of the board of Koppers Company, Inc., is a 1940 graduate of the Metallurgy Program, a Distinguished Alumnus of the University and an Alumni Fellow. He is a former trustee, past president of the Alumni Association, and a Mount Nittany Society member.

John W. Hanley, retired chairman and chief executive officer of Monsanto Co., is a 1942 Metallurgy graduate. He is a Distinguished Alumnus of the University, an Alumni Fellow, and member of the Mount Nittany Society.

John M. Ruffner, president, Delbridge Computing Systems, Inc., is a 1953 graduate of Mineral Processing. He is a member of the Mount Nittany Society, the Penn State Development Council, and the Alumni Association.

Quentin E. Wood, chairman and chief executive officer of Quaker State Oil. Mr. Wood, a 1948 graduate of Petroleum and Natural Gas Engineering, is a member and past president of the University's Board of Trustees and a member of the Mount Nittany Society.

Current plans call for the official launching of the Campaign for Penn State to take place in September.

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