Geology and Culture: A Call for Action

***Eldridge M. Moores,** GSA President, 1996*

There is a tide in the affairs of men [and women],
Which, taken at the flood, leads on to fortune.
Omitted, all the voyage of their life
Is bound in shallows and in miseries.

—W. Shakespeare, Julius Caesar, IV, iii, 217

INTRODUCTION

The delivery date of this address, October 28, 1996, was the 5999th anniversary, or thereabouts, of the alleged creation of the Earth. So think roughly half of U.S. citizens. I mention this not to criticize these people or Bishop Ussher, who first published the estimate, but to indicate the gulf in perception separating us as geoscientists from many other people as we approach the milennium.

The last half century has been a golden age for geology, a time of major scientific revolutions (e.g., plate tectonics, Earth in space, organic evolution, imaging). And there are still many exciting questions left to be answered. Many of us came of age scientifically in the post-Sputnik era when jobs and funding for research were abundant, and geology was caught up in the excitement of these revolutions.

Times have changed, however. Many younger members of our society were attracted to the field by the excitement of the revolutionary developments and the perceived career opportunities, but now they face a declining job and research funds pool. Many geologists from government organizations, academia, and industry have faced disruption of careers or underemployment as downsizing has hit and the projected shortage of advanced degree holders did not materialize.

It had been my intention to present a talk on pure science as my presidential address. However, events have conspired against such a presentation. The last year has seen the continuation of an ongoing crisis in geology of sufficient severity to make any preoccupation with pure science akin to fiddling while Rome burns.

Manifestations of this crisis include:

1. There is very little knowledge of the geosciences among the public as a whole (as indicated above), although there seems to be a great hunger for knowledge on the part of many nonscientists.

2. There seems to be little knowledge or appreciation of geoscience in Washington in general and Congress in particular.

3. Society in general is moving (or has moved) toward two separate groups, one science literate, of which we are a part, and the other science illiterate and increasingly in the thrall of religious fundamentalism, of whatever stripe. This latter group is growing in numbers and political influence and views much of what we do as anathema (geological time, environmental considerations, renewable vs. nonrenewable resources, etc.)

4. Many other sciences speak much more consistently with a single voice or at least a coordinated public stance; geosciences by contrast are like a covey of quail—going in all directions.

The problem, however, is larger than just geosciences. The "social contract" between science and the public, which has been in effect since the end of World War II, is ending (Byerlee and Pilke, 1995). In the future the scientific community will have to make it more clear how its research benefits society (e.g., Moores, 1996). Funding for research and development in the United States may be cut some 30%, regardless of which party is in control in Washington. Similar situations in Australia, Canada, the UK, and France indicate the international scope of the problem.

Furthermore, as funds become more scarce, many universities and colleges are seeking to downsize. One of the most vulnerable departments seems to be, paradoxically, the local geoscience department, which is viewed by many administrations, apparently, as "irrelevant" in an era of tight money. This past year, I have written, as GSA President, two letters to college administrators (one unsuccessful) in support of departments theatened with abolition, and there have been others (e.g., Feiss, 1996).

How can the geosciences possibly be seen as irrelevant in view of their centrality to resolution of problems of the environment, resource limitation, and global carrying capacity that face society as a whole? Our collective perception is that geosciences are not only exciting, but also essential. How much money could have been saved, for example, if the builders of dams or highways or flood-control systems had factored geology into their plans? How can our own perception be so different from that of the rest of society? What can we do to remedy this situation?

My own journey into several of these issues began a couple of years ago with a question from writer John McPhee: "Why is there so little knowledge of geology on the part of the public as a whole, and why is so little taught in schools when the subject is so interesting?" What follows is a progress report of what I have learned on this journey. It includes brief overviews of the history of science education, relations between earth science and culture, between geological thought and society, and the present-day situation and what we might do about it.

HISTORY OF SCIENCE EDUCATION IN THE UNITED STATES

The present U.S. organization of science education stems from the effort a century ago (National Education Association, 1894) to institute a systematic set of expectations for secondary school education. This committee was the brainchild of Charles Fielding Eliot, long-time president of Harvard and one of the giant figures in U.S. education in the late 19th and early 20th centuries. Eliot's efforts led to the establishment of a Committee of Ten to oversee the development of lists of subject matter that should be taught in classes in grades 9 through 12. The committee's recommendations are the foundation of the curriculum still taught in high school. In science, the recommendations were "geography" in the 9th grade, botany or zoology in the 10th grade, chemistry in the 11th, and physics in the 12th. "Geography" was a mixture of physical geography, geology, and meteorology. The subcommittee that formulated the recommendations on "geography" included one current and two future GSA presidents—T. C. Chamberlain (1894), I. C. Russell (1906), and W. M. Davis (1911).

As teaching developed in the early 20th century, "geography" was replaced by general science, including not only physical geography, geology, and meteorology, but also astronomy, biology, chemistry, physics, and health (Frank Eierton, written communication, 1995). Biology replaced botany and zoology.

In 1894, geology was at the peak of its 19th century development (Baker, 1996). After all, this time followed publication of Darwin's *Origin of Species* (1859), and the exploration of the western United States and Canada in the previous several decades. Yet geology was marginalized in science education. Why? I speculate that

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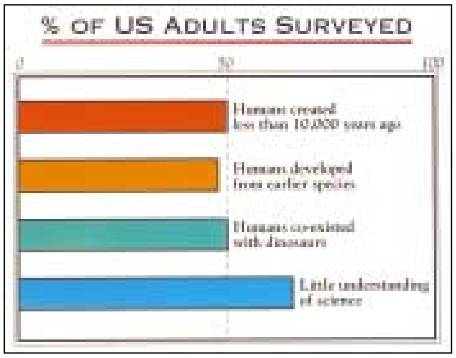

Figure 1. Attitudes of U.S. adults about science (after National Science Board, 1996).

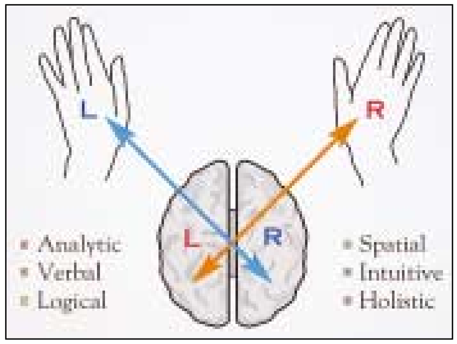

Figure 2. Diagram of brain, showing possible relationship between hands and thought processes (after Edwards, 1979).

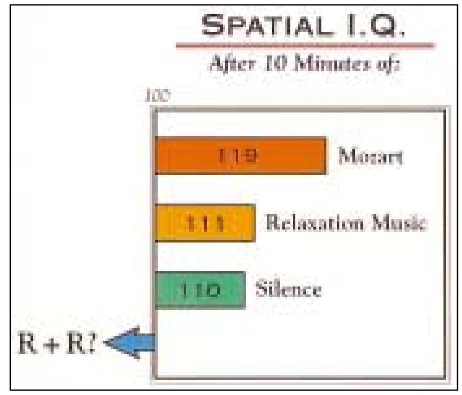

Figure 3. Spatial IQ and music (after Rauscher et al., 1993).

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geology may have been suffering from some sort of "Kelvin effect." At the time of deliberations of the Committee of Ten, geologists were locked in a controversy with Lord Kelvin and his followers about the age of Earth. Assuming all the heat from Earth was left over from its accretion, Kelvin calculated that Earth was about 100 million years old and possibly not more than 10 m.y. Many geologists—e.g., T. H. Huxley—argued that it was much older. The debate received wide attention in both the scientific community and the public press. Kelvin greatly disparaged the opinion of geoscientists, who could not quantify their intuitive notion for a much older Earth. Kelvin also argued that only knowledge expressible in numbers was science, a restatement of Descartes' dictum that knowledge must be "certain," and preferably expressed quantitatively (Frodeman, 1996). One of his cohorts, Peter Guthrie Tait, said that Kelvin had "removed the blinders from the eyes of the geologists and (set) them back on the path to truth" (Albritten, 1980, p. 190). The subsequent discovery of radioactivity, of course, meant that Kelvin's calculations were off by a factor of about 50 to 500, and that the intuitive, semiquantitative geologic estimates were more accurate than his mathematical "proof."

The Committee of Ten did its work at a time when geology was under a cloud, in both the science community and the public. Its recommendations and the Kelvin debate have resonated throughout the 20th century in the development of a reductionist (science separated into component parts with no overarching view of the whole), hierarchical (one field more "worthy" than another; "pure" better than "applied"; Alvarez, 1991; Baker, 1996) system of science education and science establishment, a "pecking order" in science, with mathematics and physics at the top, geology somewhere on the slope, and social sciences on the bottom. This situation was enhanced by the Manhattan project, which spawned the Faustian bargain among scientists, government, and the military leading to the era of "big science," and the now-defunct social contract between science and society.

As a result, an entire century's worth of students have grown up with no comprehensive view of science and with little or no knowledge of Earth. Despite efforts by the American Geological Institute and others beginning in 1959, geology has never received the attention in primary and secondary school education that it deserves. GSA's own SAGE (Science Awareness through Geoscience Education) program is making great strides and has many programs for increasing geoscience awareness. The problem is huge, however, and SAGE can't do it all. We all need to get involved.

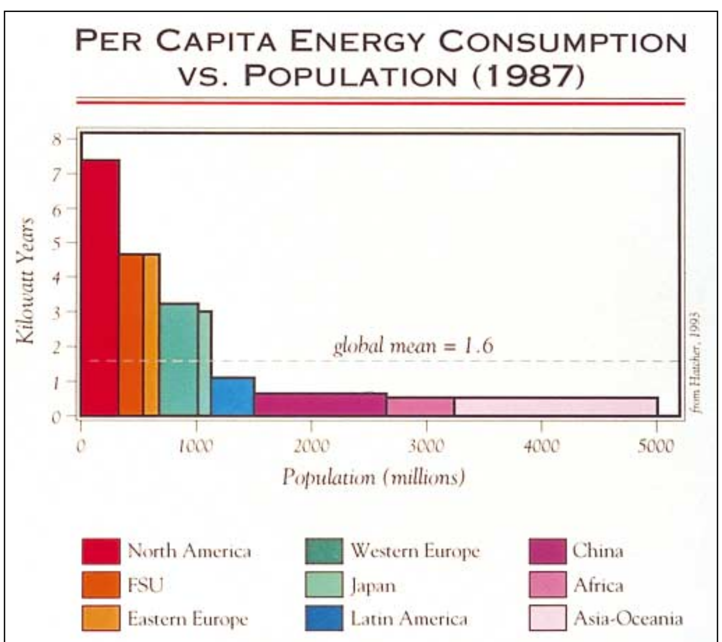

Figure 4. Per capita energy consumption vs. population (after Hatcher, 1994).

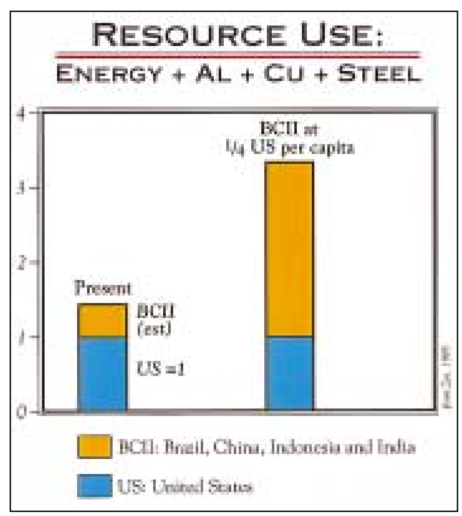

Figure 5. Comparison of total resource consumption at present for United States (normalized to 1) and Brazil, China, India, and Indonesia (BCII) (left column), and projected consumption assuming BCII consumption of 1/4 U.S. consumption and constant population (after Zen, 1995)

EARTH AND CULTURE

This separation of human thought from the earth is a relatively new phenomenon, historically. Earth plays a prominent role in many indigenous cultures. For example, Semken and Morgan (1996) and Murray (1996) outlined the relation between Diné (Navajo) and Cree traditions and geology. Legends of a Mother Earth Goddess are abundant in Europe and Asia. Greek mythology includes a battle between Hercules and Antaeus, the son of Gaia, the earth goddess. As long as Antaeus could maintain contact with the earth, he was unbeatable. Only when Hercules held him above his head was that contact broken, so that Hercules was able to vanquish his opponent. The moral for modern humans is that we should "keep our feet on the ground," and maintain our kinship with the earth (Mather, 1986).

The relation between indigenous cultural traditions and myths and the earth implies an almost subconscious need for a connection with the earth on the part of humans everywhere. This is in accord with my own experience. As a result of John McPhee's best seller, *Assembling California* (McPhee, 1993), I have heard many comments about geology from nonscientists, and I have developed something of a second (mostly volunteer) career taking nonscientists on field trips. This experience has shown me that there is a great deal of interest, even hunger, for geologic knowledge on the part of the average person. Many regret not having had geology in school. Furthermore, if you ask the average 3rd grader what (s)he is interested in, the answer typically includes dirt, rocks, volcanoes, earthquakes, dinosaurs. People are naturally attracted to the earth and are very interested in their surroundings—they need a sense of place.

Yet most of us live in urban areas surrounded by our own edifices and out of contact with nature. Traditionally, teachers have been ill-prepared to teach science; what little is taught is esoteric, not earth-based, and hard to apply to daily life. Certainly, there is no overarching view of the natural world. What is the result? Though people generally express faith in the ability of science to solve societal problems, ignorance of science is widespread—only 6% of U.S. adults are "science literate" (Sarewitz, 1996) and some 64% are science illiterate (Fig. 1).

Most people's knowledge of science is spotty and idiosyncratic, which probably accounts for the growing frustration of the public with the claims of scientists. Furthermore, popular conceptions about Earth history are shocking—approximately 50% believe that Earth is less than 10,000 years old; only 48% recognize that the earliest humans and dinosaurs did not live at the same time; and only 44% recognize that humans developed from earlier species of animals (National Science Board, 1996; Fig. 1). Most people, when asked, remember their science education as "fear and loathing and dead frogs," as one wag put it. I believe that this lack of knowledge of and aversion to science is a direct result of the reductionist-hierarchical system of education. This system has failed us.

The reductionist-hierarchical practice of science has given us much new knowledge of interest and societal importance, and there are many new results to be anticipated. It has produced, however, an increasingly specialized science culture, characterized by a series of disciplines that are "fragmented into little islands of near conformity surrounded by interdisciplinary oceans of ignorance" (Ziman, 1996). With regard to critical science-policy issues, it has outlived its usefulness. One result has been that "willful ignorance of the increasingly convoluted nexus between science, technology, and society seems to be a theme of modern culture" (Sarewitz, 1996, p. 175).

I believe that these misunderstandings and attitudes are dangerous for an increasingly global society needing science-based solutions to its problems. Also, I suspect that this state of affairs exists approximately in proportion to the lack of geoscience in the educational system.

The gulf between our understanding of Earth history and processes and that of our fellow citizens, many of whom are deeply religious, is also of concern. This is analogous to the problem of "two cultures," first enumerated by Snow (1959). Kirtley Fletcher Mather provided some insight into this issue. Mather was an early 20th century geologist, a Harvard professor, a lifelong evolutionist, Baptist, advisor to Scopes in his famous trial, and social activist (Bork, 1994). Mather clearly saw no conflict between his devout Christian beliefs and his acceptance of evolution. His philosophy (Mather, 1986) gives guidance in how to bridge the gulf between the two cultures.

Mather argued that there are two kinds of knowledge: (1) measurable in space and time, or "scientific," and (2) qualitative, or "spiritual," which is subject to evaluation but inherently unmeasurable in space and time. Spiritual knowledge includes aspects of knowledge such as beauty, awe, reverence, ethics, righteousness, loyalty, creativity, and integrity. Mather states that both kinds of knowledge are necessary for wisdom. He further posits that there is a fundamental need for grounding of culture in the earth, a grounding that is generally lacking today.

GEOLOGY, SCIENTIFIC INQUIRY, AND SOCIETY

I believe that it is precisely this point where the gulf between the scientific and nonscientific community originates. Mather's point is generally ignored by many scientists who argue that science is detached from other fields and basically amoral or "premoral" (Sarewitz, 1996, p. 102). One can argue, however, that scientific inquiry makes a moral judgment simply in its choice of topics to investigate. Also, such items of ethics are important—in fact, GSA is sponsoring a conference on the subject in summer 1997.

We are all familiar with the standard scientific method: i.e., statement of problem, hypothesis, experiment, and analysis, the so-called "analytic philosophy" of philosophers of science (Frodeman, 1995). Application to societal problems of knowledge thus gained is widely thought to be linear, specifically by generation of new knowledge, search for applications, development of specific products, and introduction of products into society. This widespread view is not, however, the way that things happen. Science and technology are inextricably intertwined, as are basic and applied research. We geoscientists have lots of experience with such interconnections, which seem foreign to some other scientists. Furthermore, science and technology are "entirely symbiotic … with economics, politics, and culture" (Sarewitz, 1996, p. 97). Widespread disregard of this point by practitioners of science leads to trouble, such as the failure of ambitious basic research proposals, the disparity between claims for societal benefits of basic scientific research and the actual results, and the dwindling political support for science.

Any scientific inquiry includes the processes of deduction, induction, or, as in geology, a combination of both. Arguments that science is strictly rational, and nonintuitive do not specify, however, how the deduction or induction is to take place. Both processes depend upon the nonrational, nonlogical creativity, imagination, and intuition of the scientist. The "Eureka!" of a scientific leap of insight is key to the progress of science, but it is a fundamentally nonlogical, intuitive process. This process of insight unites the work of scientists and artists. Mather (1986) likened it to religious revelation.

Some geology deals with the study of active processes on and within Earth and other planetary bodies. One can perform, say, geochemical experiments in the laboratory or seismic experiments in the field and arrive at quantitative explanatory models of the process in question. This part of geology thus resembles the analytic method of science as practiced by, say,

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chemists and physicists. Of course, any geoscientist knows that Earth is much more complex than any model, and includes many nonlinear, time-dependent, and overlapping processes (e.g., Zen, 1993), and that the criterion of a good model is that it is testable, not that it is right.

Geology is also historical. We are interested not only in ongoing processes, but the history of those processes through time. For this information, we are dependent on the incomplete, mute, geologic record. Because much of this record is missing, much of the historical aspect of geologic inquiry is intrinsically not quantifiable. That doesn't make it less worthy or less interesting, despite Kelvin's comments to the contrary. However, in such situations, insight depends upon the intuition of the geologist. Piecing together geologic history relies upon consideration of many aspects of the problem in a holistic, all-encompassing manner.

In these ways, geologic inquiry differs from the purely analytic method of inquiry. Geologists look at an entire complex system, Earth, in a way that is partly quantitative, but also partly intuitive and involving value judgments. Frodeman (1995) argued that the philosophy thus developed is not a derivative of the more conventional (analytic) philosophy of physical science, but is a unique method of inquiry in its own right, more suited to application to societal problems than "mainstream" analytic philosophy. The geologic philosophy certainly is well suited to analysis of the complex interconnected system that constitutes the environment. Furthermore, complex science-policy issues such as nuclear waste isolation, toxic waste disposal, global climate change, or resource extraction require balancing of scientific information with nonscientific issues values such as ethics, aesthetics, equity, and ideology. In other words, these issues involve integration of scientific knowledge with Mather's "spiritual knowledge." (Harry Hess, 1963 GSA president, and John Maxwell, 1973 GSA president, observed from their World War II experiences that geologists were well suited to intelligence activities because they were accustomed to looking at a whole situation and were comfortable making decisions on incomplete or otherwise faulty information.)

Geologic instruction also shares ingredients with some instruction in the arts. Two key ingredients common in both artistic and geological education are thinking in three dimensions and teaching students to see things that were always there but that they had not seen before. They are probably right-brain activities (see Fig. 2) . Rauscher et al. (1993) have shown that a short exposure to Mozart can increase students' spatial acuity (Fig. 3). I salute the many geoscientists who are active or frustrated artists and musicians. Playing classical music in laboratory sessions might well improve the efficiency of the students' learning processes.

THE SITUATION TODAY

Vannevar Bush's[1] (1945) concept of the "endless frontier" was an extension of the Baconian dictum "nature to be commanded must be obeyed," which itself was an outgrowth of the Biblical admonishment that humanity must seek to dominate nature (Sarewitz, 1996). We may indeed be in a true crisis in the sense of Kuhn (1970) if the old paradigm that describes the interaction of policy and science is no longer valid, and a new one must be found. The new paradigm may be "sustainable development" or "sustainability," defined as "meeting the development needs of the present without compromising the ability of future generations to meet their own needs" (Sarewitz, 1996, p. 193). In other words, we must live within our means, with an eye toward future generations. If this paradigm takes hold, society will have come full circle in our Biblically mandated journey away from our close connection with the earth, and will have returned to a position resembling that of traditional Native American and other indigenous cultures, as mentioned above.

Geoscience today falls perhaps into three distinct areas, all of which depend on the same data, but which interest three quite different communities. All these areas fundamentally deal with the instantaneous rates of processes integrated over varying intervals of the geologic time scale. All of these are global in their reach and bear on the issue of sustainability and carrying capacity:

1. Active surface, near surface, and internal processes. These include hazard assessment and prediction, sustainable interaction with the environment, geohydrology, soil formation and erosion, climate change, volcanism, and any other active process that enables us to interpret history.
2. Natural resource exploration and exploitation. Here the basic *modus operandi* has not changed very much over the past century or so except for the application of increasingly sensitive and efficient imaging, exploration, and extractive technologies to compensate for the declining richness of deposits, the regulatory framework of exploitation, the increasingly international (exo–North America) nature of activity, and the increasing environmental awareness of the extractive industries.
3. Earth history, from astronomy–solar system origin to present day. The plate tectonic, imaging, and planetary exploration revolutions fit most readily within this category. Ironically, all modern revolutions are stepchildren of the Cold War.

All of these parts of geology are active, exciting fields of inquiry. All are integral to issues of global science–policy relations. The public finds these all very interesting when they are informed about them.

WHAT TO DO?

If we agree that we need a scientifically literate population and that geoscience is central to culture, to the outstanding policy dilemmas facing the world community today, and to the development of science literacy, then we need to act. When Mao Tse-tung took over in Beijing in 1949, he allegedly said, "China has stood up." Regardless of how one views events of the past 48 years, China is no longer "sleeping," as Napoleon allegedly described it. As with China, it is time for the geosciences to stand up and assert ourselves. We need to:

1. Get our message across to the rest of the science and policy communities. We have a lot to offer: a perspective on the whole Earth, a sense of ongoing processes, and a distinctive philosophy of inquiry uniquely suited to application to societal problems.
2. Get geoscience education in the schools, starting right down at the kindergarten level. Here, SAGE has made a good start. Predictions are for a need for more than 100,000 K–12 teachers in the next decade. It would be great if many of these new teachers had geoscience backgrounds. The recently published proposed national standards for K–12 education (National Research Council, 1996), including earth sciences, are a promising development in national recognition of a role for earth science in K–12 education. These new standards are going to need close attention and advocacy at the local level if they are to be adopted. *It is time for all of us in the geoscience community to get involved.*
3. Develop adult education classes in general geology and the relationship between geology and the problems facing society.
4. Offer field trips to local sites, wherever they might be. Explain to your audience that the landscape is there for a reason and tell them how it got there. Talk about geologic time.[2]
5. Develop the ability to explain how basic research might have societal benefit. This is not easy. It requires being able to con-

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[1]Science advisor to Presidents Roosevelt and Truman.

[2]I like to use a 1 mm equals one year analogy. Work out the distances for a human lifetime (1 dm = 4 inches), 1000 yrs (one meter), all of recorded human history (10,000 years max = 10 m), the K/T boundary (65 km = 35 mi), etc. (The age of Earth is about the number of millimeters from New York to San Francisco, Vancouver to Montreal, or Prince Rupert to Mexico City).

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dense a comprehensive scientific description into jargon-free but representative one-liners (see Moores, 1996, for one recent attempt). It will also mean removing one's pure-research blinders from time to time, even attempting to formulate one's proposed new research with an eye toward possible societal benefit. Another useful technique may be a narrative-logic approach, communicating in a series of scenarios (Frodeman, 1996).

6. We could take a page from the astronomers. They are united in their stance toward the public, in contrast to the geoscientists, and they work at popularizing their science. For example, a recent NASA publication on proposed future exploration (Dressler, 1996), begins with a section entitled "Astronomy: Its Rewards for Science and Society." In this section, Dressler stated (p. 2), "Astronomy is inspirational. Of all the sciences it remains the most accessible and approachable." I would dispute this statement. Geoscience is also inspirational and arguably more accessible and approachable. After all, we stand on Earth. *It is up to us to make this point.*

7. Those of us who have the aptitude and necessary fortitude can get involved in the public and political arena. Here, GSA's Institute for Environmental Education (IEE) can help. It has provided media workshops and is developing a Geology and Environment Public Outreach Program (GEPOP) of individuals who are capable of effective interaction with policy makers.

8. Institute college curricula that emphasize global geoscience as a general science major for people intending to go on into such fields as law, teaching, or business. Such a course of study ideally would involve development of a different set of courses from those required of geology majors. It could be quite popular and beneficial. It would help to build the science-literate populace that we need. In addition, in view of the need for additional K–12 teachers in the next decade, it's potentially a good way to increase student enrollments in geology courses, and to reduce the pressure on geoscience departments for downsizing or elimination.

9. Develop a Society-wide program to internationalize and to increase our diversity. Geology is increasingly global in scope, and this should be reflected in Society activities. In addition, geoscience is one of the least diverse professions. Increasing diversity is not only a question of simple equity, but also a way to develop a more accurate world-view of outstanding problems than we currently possess. This is a difficult task and will require a carefully constructed, multifaceted approach, working with primary and secondary educators, especially in areas of rural or urban poverty.

10. Work for more effective integration of basic and applied research perspectives. Because GSA includes individuals active in both the extractive and environmental fields and industries, we can provide society a perspective on bringing together these disparate points of view to focus on the problem of sustainable development.

Accomplishing this task of getting our place in the sun will not be easy. It may meet resistance from individuals from fields higher in the "science pecking order" attached to the more conventional scientific point of view. But the potential rewards for our field in terms of public awareness, acceptance, and support, as well as for society as a whole, are profound.

FINAL THOUGHTS

In the global society to which we all are rushing, sustainability and Earth's carrying capacity are critical issues. North American per capita resource use and waste generation are much greater than for any other region (Fig. 4). Zen (1993, 1995) pointed out the implications of this when he examined the prospect of developing nations coming up to the North American comsumptive levels. Bringing only four countries—Brazil, China, India, and Indonesia, which together aggregate about 40% of Earth's 5.5 billion people—up to *one-quarter* of the U.S. per capita level of consumption would *double or triple* the environmental load on Earth. It doesn't seem possible. Yet, who are we to persuade these countries not to strive for what we have? Society somehow needs to work out a way for these and other countries to prosper without environmental ruination and to find a way ourselves to prosper with less draw on Earth's resources. We geoscientists can help in this quest. *Geoscience should become the central science of the 21st century! Let's get going!*

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