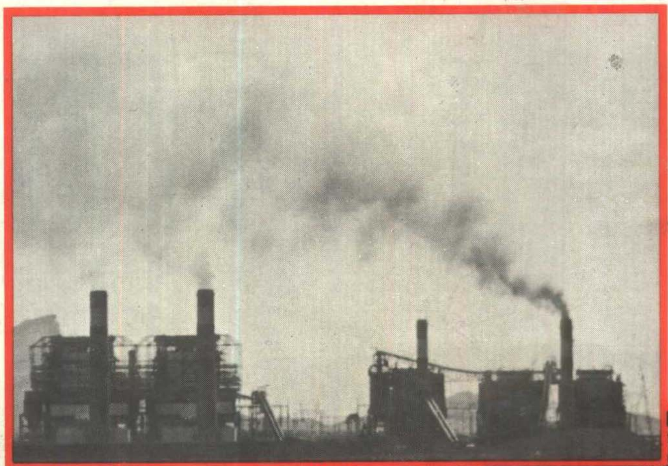
Environmental Geoscience:

Interaction between Natural Systems and Man



Arthur N. Strahler
Alan H. Strahler

Interaction between Natural Systems and Man

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Preface

The unprecedented explosion of public and academic interest in environmental problems within the last three years has stimulated the birth of a new discipline: environmental science. The components of this discipline are not new, for they are drawn from existing areas of science within biology, chemistry, physics, and the geosciences. What is really new about environmental science, however, is its viewpoint—its orientation to global problems, its conception of the earth as a set of interlocking, interacting systems, and its interest in Man as a part of these systems.

In the words of the National Science Board of the National Science Foundation, in its report to the president entitled *Environmental Science—Challenge for the Seventies,** environmental science is "the study of all systems of air, land, water, energy, and life that surround Man. It includes all science directed to the system-level of understanding of the environment, drawing especially upon such disciplines as meteorology, geophysics, oceanography, and ecology, and utilizing to the fullest knowledge and techniques developed in such fields as physics, chemistry, biology, mathematics and engineering. . . . Environmental systems contain the complex processes that must be mastered in the solution of such human problems as the maintenance of renewable resources (water, timber, fish), the conservation of non-renewable resources (fuels, metals, species), reducing the effects of natural disasters (earthquakes, tornadoes, floods), alleviating chronic damage (erosion, drought, subsidence), abating pollution by Man (smoke, pesticides, sewage), and coping with natural pollution (allergens, volcanic dust, electromagnetic noise)."

*Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 1971, pp. vii-viii.

Given such a broad definition of environmental science, no single textbook can offer even adequate introductory treatment to the whole field. As authors we must also be editors, and in this book we choose to stress the understanding of the *natural systems and processes* of the earth and their implications for and impact on Man. Thus, we omit such related subjects as noise pollution and nuclear warfare (as impacts of Man on Man); we also neglect the technologies of materials processing and pollution control (as man-made, rather than natural, processes); we do not treat consumerism, a subject sometimes confused with environmental science.

Even within these bounds we must limit ourselves still further. The interactions of Man with natural systems occur in two areas—those within the realm of physical phenomena, denoted here as *geoscience,* and those within the realm of biological phenomena, referred to here as *ecoscience.* Whereas geoscience and ecoscience are interdependent through system interactions, we choose to concentrate here on geosciences and to introduce only briefly such ecoscience as is required to understand the flows of energy and biogeochemical cycling of matter at the earth's surface. It is our plan to produce in the near future a larger volume that will include a general coverage of ecoscience and bring into balance the two branches of natural environmental science.

Like a coin, environmental science has two sides: one side displays the impact of natural environmental forces upon Man (for example, floods, hurricanes, earthquakes, and landslides); the other side displays the impact of Man upon the environment (for example, air and water pollution). Our book would not be complete without treating both sides of this environmental coin, for the interaction of Man and environment is our central theme.

The consumption of nonrenewable natural resources—especially minerals and the fossil fuels—is an integral part of the subject matter of environmental science. Extraction, processing, and consumption of these resources bring about a large share of our problems of environmental pollution and degradation. Consequently, we give special attention to natural resources, their origin and occurrence, and the impact of their use.

We offer here an introductory text that interweaves the basic principles of geoscience with environmental and resource problems. Topics in basic science are selected solely on criteria of relevance. We focus on the essential points of interactions between organisms and their physical environments in the atmosphere, hydrosphere, and lithosphere. Throughout, we use an *energy systems approach*, examining and analyzing flows of energy and matter within and between open energy systems. The foundation for this approach is laid in our introduction and in our preliminary chapter on energy systems. Students with limited background in basic science will have some remedial work to do. To this end we include basic information on topics in elementary physics, chemistry, and biology, not only in the introductory chapter, but also at many points throughout the book. For example, elementary principles of electromagnetic radiation are explained in developing the radiation balance; principles of calorimetry are reviewed in developing the heat balance, and so forth. It is our hope that this treatment will accommodate a wide range of student preparation levels.

Environmental science expresses itself through the medium of the environmental problem. Each problem is real; it is actually experienced at a place and time in the biosphere. Therefore, our book includes numerous descriptions of real problems. Space has permitted only the briefest thumb-box sketch of each case, but we hope that each testifies to the reality of an environmental science.

When the student reaches the end of this book, he is introduced to new perspectives of broader scope in our epilogue, which concerns the relationships between society and environment. The future of mankind as embodied in the triad—*population, resources, technology*—is briefly discussed to show where the vital issues lie. Hopefully, our book will lead the student to inquire more deeply into problems of environmental planning and management. Hopefully, his curriculum will provide an organized program for this further study. Hopefully too, he will become involved in environmental issues and develop for himself the educational base needed to participate in the decision-making processes, helping to plan and manage our future environment wisely.

The bibliography placed at the end of the book has been the object of special attention. The rapid evolution in environmental science publications poses many problems in selection. We have, therefore, designed a working bibliography leading the student and instructor as quickly and directly as possible to literature in available works. Items are arranged as they occur in the text—chapter by chapter and topic by topic. Only recent works in print are included, and only a few widely distributed periodicals are used. In addition to supplementing the text, we intend this bibliography to serve as the starting point for a basic reference library of environmental science. The purpose of such a library is to allow students to broaden their knowledge on selected topics, to find the material needed to prepare term reports on selected topics, and to allow the instructor to round out his background in areas other than his specialty. The selections range in level from elementary, descriptive treatments to rather technical discussions, but we have stopped short of listing papers requiring advanced knowledge of mathematics, physics, and chemistry.

We wish to express our thanks and appreciation to several individuals who reviewed portions of the manuscript. We are particularly indebted to Professor F. Kenneth Hare,* presently serving as Director-General, Research Co-ordination Directorate, Environment: Policy, Planning and Research, Government of Canada. Professor Hare critically read the entire manuscript and made many valuable suggestions for correcting and improving the text, not only in the atmospheric sciences—his field of special authority—but also over the whole range of subjects covered. Others who reviewed single chapters or groups of chapters are the following: Professor Helmut E. Landsberg, University of Maryland, Chapter 10 (Man's impact on the atmosphere); Dr. Martin Prinz, Institute of Meteoritics, University of New Mexico, Chapters 7, 8, and 10 (petrology and mineral resources); Professor Charles L. Drake, Dartmouth College, Chapter 9 (tectonic processes and continental evolution); Professor Donald F. Palmer, University of Southern California, Chapter 10 (Man's consumption of planetary resources); Pro-

*On leave, Department of Geography, University of Toronto.

fessor S. Fred Singer, University of Virginia, Chapter 10 and "Energy Systems"; Professor Joseph H. Butler, State University of New York at Binghamton, Chapters 12, 13, and 14 (hydrologic systems and water resources); Professor Nicolay P. Timofeeff, State University of New York at Binghamton, Chapter 12 (soil moisture balance); Professor Michael Barbour, University of California at Davis, Chapters 18 and 19 (pathways of energy and matter in the biosphere); and Professor Preston Cloud, University of California at Santa Barbara, "Epilogue" (environmental perspectives).

ARTHUR N. STRAHLER
ALAN H. STRAHLER

About the Authors

Arthur N. Strahler (b. 1918) received his B.A. degree in 1938 from the College of Wooster, Ohio, and his Ph.D. degree in geology from Columbia University in 1944. He is a fellow of the Geological Society of America and the Association of American Geographers. He was appointed to the Columbia University faculty in 1941, serving as Professor of Geomorphology from 1958 to 1967 and as Chairman of the Department of Geology from 1959 to 1962. His published research has dealt largely with quantitative and regional geomorphology. Dr. Strahler pioneered in the development of environmental education by introducing an interdepartmental course in environmental science into the Columbia College curriculum in 1965. He is the author of several widely used textbooks on physical geography and the earth sciences.

Alan H. Strahler (b. 1943) received his B.A. degree in 1964 and his Ph.D. degree in 1969 from The Johns Hopkins University, Department of Geography and Environmental Engineering. His published research lies in the fields of plant geography and forest ecology. Dr. Strahler is presently Assistant Professor in the Department of Environmental Sciences of the University of Virginia, Charlottesville, where for the past four years he has directed development of the introductory college course in environmental science. In 1973–1974 he will hold appointment as Bullard Forest Research Fellow at Harvard University.

Contents

Introduction to Environmental Science

For Londoners, December 8, 1952, was the fifth day in a row of heavy smog, better described as poison fog. Hospitals were crowded with seriously ill persons unable to breathe effectively. Many who had chronic respiratory diseases succumbed to an environmental stress from which they could not escape. This incident is not news; most of you have heard it before. The recurrent crisis of air pollution over urbanized areas is never very far from the minds of city dwellers. It is obvious that Man has played a leading role in degrading atmospheric quality over his cities. Understanding the smog problem requires a knowledge of basic principles of atmospheric science. These principles are explained in early chapters of this book and will help you to be more effective in formulating action programs that must be instituted to improve the quality of air over cities.

In May, 1971, the Food and Drug Administration announced that swordfish should not be eaten because an extensive sampling of canned swordfish in markets revealed the presence of mercury in amounts too great to be considered safe for human consumption. To what extent, if any, are Man's industrial processes responsible for the concentration of mercury in the tissues of swordfish? Is it possible that the mercury level in these fishes is no higher now than it has been for centuries in the past? To get the answers to these and other problems of mercury contamination requires that a number of sciences be tapped. First, of course, is biological science. The food chain must be traced back to its source. But one must also look to geology for the prime sources of mercury compounds and to hydrology (water science) for an understanding of the transport processes by which it enters the sea water.

As far back as 1947 the pumping of water from wells in Kings County, on Long Island, New York, (the Borough of Brooklyn) was finally discontinued because the fresh water beneath the surface had become contaminated by salt water drawn in from beneath the adjacent ocean. Since then, this large urban community has had to be supplied with fresh water brought from reservoirs in the Catskill Mountains, far upstate. Will the same fate overtake Long Island communities farther to the east? Planning for Long Island's future urban development depends very heavily upon the question of availability of adequate supplies of fresh water. Already serious problems of contamination by salt water and detergents have arisen. To understand what is happening on Long Island requires a knowledge of the basic principles of water beneath the ground surface. We shall explain these principles, so that you can recommend effective action to head off the disaster of a failing water supply.

In November, 1970, a great surge of sea water, generated by a powerful tropical cyclone in the Bay of Bengal, swept over a densely populated low-lying coastal area in East Pakistan. The sudden, 20-foot rise of water level drowned many tens of thousands of persons and destroyed over 200,000 houses along with all rice crops in the area. Comparable disasters of the same origin are known to have occurred in this region in the past. Here is an area where the physical environment has dealt harshly with Man, and through little fault on his part. So we must recognize that Man, along with all other life forms, has always been subjected to environmental stresses over which he has no control. The list of severe environmental hazards and disasters is well known to all of us: volcanic eruptions, earthquakes, landslides, tornadoes, hurricanes and typhoons, "tidal waves" (misnomer for storm surges and seismic sea waves), river floods, blizzards, forest fires. But protective and evasive action is possible where advance knowledge permits. We shall be foolish if we don't take the opportunity to arm ourselves with information about these forms of environmental hazards. Where do such things occur? When can they be expected? Can warning systems be made effective? What should we do when disaster threatens? Broadly speaking, such information comes under the heading of *environmental protection*. Although we shall not give a full account of protection procedures, we will explain how and where these dangerous natural phenomena operate.

Less lethal in terms of human life toll, but nevertheless of severe economic importance, are environmental stresses whose effects are persistent in certain geographical regions—for example, drought, dust storms, and hail in the Great Plains region of the interior United States. To some degree, as yet not fully exploited, Man can act to alleviate these stresses. Rainmaking shows potentiality for success in favorable situations; hail formation may yet be reduced in intensity by artificial means; and treatment methods applied to the ground surface can to some extent reduce the blowing of dust and sand. Evidently, Man has at his disposal various means of exerting at least some limited controls over the environmental processes. We might wish to group these activities under the heading of *planned environmental modification*. Success in programs of this type requires knowledge of the fundamental processes of the atmosphere and of water on and beneath the lands.

It seems clear enough from the foregoing examples that there is a field of scientific investigation, actually an applied discipline, that can be labeled *environmental science*. Perhaps this label is just another term for applied science generally. In any case it is a field of such enormous scope that even a general overview would require many textbooks and many semesters of courses. The word "environment" is so common in the everyday vocabulary that we shall have to qualify its meaning very carefully to fit the sense of this book.

Environment, defined most broadly as "that which surrounds," requires a receiving object. What is surrounded? Surrounded by what? Primarily, our concern is with the environment of Man. But Man cannot exist or be understood in isolation from the other forms of animal life and from plant life. Therefore, we must deal with the environment of all life forms within the life-bearing layer, or *biosphere* of planet earth. This shallow *life layer* lies at or close to vital *interfaces* between the basic earth realms: the *atmosphere* (gaseous realm), the *hydrosphere* (liquid water realm), and *lithosphere* (solid mineral realm). Interfaces are found between the atmosphere and the land surfaces, between the atmosphere and free water surfaces of oceans, streams, and lakes, and between water bodies and the solid earth surface below. Interfaces of the biosphere are vital because of the exchanges of matter and energy that take place between the superimposed realms.

Organisms, whether of one species or many, whether belonging to the plant kingdom or to the animal kingdom, interact not only with the physical environments which they occupy, but with each other as well. Study of these interactions—in the form of exchanges of matter, energy, and stimuli of various sorts—between life forms and the environment is the science of *ecology,* very broadly defined. The total assemblage of components entering into the interactions of a group of organisms is known as an *ecological system,* or more simply, an *ecosystem.* The root eco comes from a Greek word connoting a house in the sense of household, which implies that a family lives together and interacts within a functional physical structure. Ecosystems have inputs of matter and energy, used to build biological structures (the *biomass*), to reproduce, and to maintain necessary internal energy levels. Matter and energy are also exported from an ecosystem. An ecosystem tends to achieve a balance of the various processes and activities within it. For the most part these balances are quite sensitive and can easily be upset or destroyed.

While study of the environment of life forms is concentrated on the life layer itself, understanding of the fluxes of matter and energy that operate in that layer requires that we probe rather deeply into the overlying and underlying layers. To understand the exchanges of heat and water at the earth's surface requires understanding of processes operating in the entire lower atmospheric layer, and also of the action of upper atmospheric layers upon the sun's radiant energy as it travels earthward. To understand the properties of mineral matter exposed at the earth's surface requires study of the geologic processes of change that operate in a deep crustal layer of the solid earth.

For practical reasons, we must limit our study of Man's environment to a manageable area of concern, excluding other considerations that would make up a complete survey. For example, in its broadest sense the environment consists of all matter and energy capable of influencing life forms. A knowledge of the structure and activity of matter at the level of molecules, atoms, and subatomic particles and the behavior of that matter in the field of the earth's gravity (e.g., sciences of physics and chemistry) is the fundamental basis of all environmental study. While it's absolutely essential to apply principles of physics and chemistry to an understanding of the environmental processes, we can't undertake to supply that knowledge in this book. Hopefully, you have already acquired a good general science background.

Environmental influences include in the broadest sense forces and restraints that arise from Man's accumulated cultural resources contained in his elaborately developed social structures. These structures of society are industrial, political, religious, or esthetic in nature. No problem of the physical environment can be approached and solved without taking into account value judgments that are weighed against the consequences to our total culture. Cleaning up the air over cities and the water of lakes and streams requires an enormous output of human energy and tangible resources. Resources so expended must be drawn against other alternative resource uses. To what extent are we willing to change our life styles to restore quality of environment? Are we willing to relinquish the automobile in favor of mass rapid transit systems? Are we willing to put a larger share of our incomes into pollution abatement programs from which we will derive no pleasure or entertainment? Are we willing as a society to submit to rigid population control? The relationships between society and environment are beyond the scope of this book, since we plan to deal primarily with the physical and biological processes involved in interactions between Man and his environment of energy and matter.

To understand these processes you will need to take up a systematic study of each of the global realms: atmosphere, hydrosphere, lithosphere, and biosphere. This systematic study provides the understanding of natural processes, without which environmental problems can be neither understood nor solved. When you are planning programs of environmental action, there is no substitute for a real understanding of the workings of the earth's natural physical and biological systems. Perhaps it is accurate to say that most of the environmental problems facing the human race today have developed in the absence of the sustained application of principles of science and technology that have been at our disposal. Had society chosen to put this knowledge to use we might have headed off most of the troubles in which we now find ourselves. But now society is awakening and responding; it is calling upon research scientists to divert energy from pure science research and technological development to the alleviation of environmental problems. National priorities are changing in response to the demands of a troubled society. We see this change today in appeals to reconsider the necessity for indefinite rapid growth in the population and in the gross national product.

This last statement brings us to the subject of Man's resources of materials and energy and the prospects of their adequacy in the future. The raw materials of industry, in the form of mineral concentrations, have accumulated through exceedingly slow geologic processes acting over millions of years of time. Yet we are using these resources at an alarming rate and inevitably the world supplies of certain key minerals will run low or give out entirely. Use of industrial mineral resources, particularly the metals, has an important impact upon the environment. After use these materials are largely disposed of as wastes, with attendant problems of pollution of air, water, and soil. Extraction of the minerals in many cases leaves gaping pits and scars upon the land. The fossil fuels (petroleum, natural gas, and coal) now supply most of our energy for industrial processes, transportation, and heating. Here, again, we are rapidly consuming energy resources that required vast spans of geologic time to create. World supplies of fossil fuels will eventually run out and we must turn to other sources, such as solar energy and nuclear fuels. The combustion of fossil fuels has had an important impact upon the environment. One area of impact is upon the atmosphere; another is upon the face of the solid earth as huge strip mines scarify the lands and pipe lines cut across wilderness areas. Because of their environmental implications, we shall want to make a study of mineral and energy resources and their use.

Industrialization has added a new dimension to the environment, namely the introduction of new substances into the air, water, and ground—substances that were never present in the preindustrial era. One striking example is the radioactive substances (radioisotopes) disseminated into the atmosphere by nuclear explosions and eventually returning as fallout into soil and surface waters of the lands and into the oceans. Another example is the production and dissemination of synthetic compounds, such as insecticides and herbicides, which enter the natural cycles of water transport and the food chains of life forms. A third example is the dissemination of lead into the atmosphere through combustion of gasoline to which a lead compound has been added. So, we can recognize technological environmental science as a major field of study. Besides industrial pollutants, this science would deal with many phases of urban environmental problems that are in a large sense synthetic, such as disposal and purification of industrial wastes, the production of noise and heat, and the physical and psychological stresses of city life upon humans. Our concern with technological environmental problems will have to be limited to the effects of technology upon natural physical and biological systems, excluding the direct effects of technology upon Man.

Throughout this book you will find numerous case studies and examples of Man's impact upon environmental systems. These examples cover many facets of the environment and bring into play many areas of knowledge of processes of the atmosphere, hydrosphere, lithosphere, and biosphere. Typically, interactions occur in such a way that more than one field of science must be drawn upon for an understanding of the problem and its solution. Evaluating the problems presented by the case studies will test the strength of the systematic knowledge you acquire in mastering the principles of environmental science.

Energy Systems

Imagine yourself newly arrived on Moon Base Alpha. Sitting inside your life support compartment, you gaze through the spaceport at a majestic earthrise, your planet a patchwork of royal blues, verdant greens, and rich browns, superimposed with vast white cloud swirls, surrounded by the velvet blackness of space. From your lunar viewpoint the planet's environmental realms are easily identified by their colors. You note that the blue of the world oceans—the hydrosphere—dominates the area of the disc. Rich browns characterize the lithosphere—the solid portion of the planet, where it rises above the seas. Vast white cloud expanses dominate the gaseous portion of the planet—the atmosphere. The lush greens of plants are the visible portion of the biosphere, the realm of life on earth, which is confined to the life layer—the interface between land, sea, and air.

The dramatic contrast between the day and night portions of the globe strikes you immediately. The land and water masses of the illuminated side bask in the sunlight, absorbing its warmth and reflecting its light. You can anticipate the energy transformations occurring there: solar light energy is striking the earth and is being absorbed and converted to heat, increasing the temperature of the life layer. On the shadowed side of the globe, however, the reverse process is dominant: the heat energy stored by the oceans and continents is continuously being lost—radiated into outer space. Consequently, when sunlight is cut off the earth's surface cools.

As you watch the earth during the next few hours, its slow rotation becomes evident. The continent of South America glides from the center of the disc to its edge, then disappears. Australia emerges from behind the curtain of night and makes its way out onto the illuminated portion of the disc. Under your eye, each land and water mass takes its turn in the sun, absorbing and reflecting its quota of solar energy. Clearly, Africa and South America receive the lion's share, for they lie near the midline of the earth, where they meet the perpendicular rays of the sun. North America and Europe, on the other hand, are near the edges of the disc, and are short-changed because they intercept the sun's rays at a low angle. Not only are you witnessing great transformations of energy, but you are also seeing that while the sun's energy input to the whole earth is constant, there is a great variation, both through time and with position on the globe, in the quantity received by any given small area of surface.

Energy Systems

As the days go by (for you are still keeping earth time), you gaze often at your planet, noting the changes. Swirls of clouds form, dissolve, and reform in the atmosphere, making their way eastward across the disc, first obscuring one portion of a continent, then another. It seems reasonable that this atmospheric turmoil is related to unequal solar heating of the globe, and that it is part of a transport mechanism serving to carry excess heat of the equatorial belt to polar regions of heat deficit. Somehow these great swirls are tied in with the earth's rotation as it carries the turbulent atmosphere with it. Once again, you are witnessing a set of energy transformations: a portion of the radiant energy of the sun after being transformed into heat, is now being converted to kinetic energy of motion. Energy of matter in motion meets with resistance—friction of various sorts—again generating heat, and increasing the radiation of energy back into space.

In fact, from your point of view on Moon Base Alpha, you might visualize the earth as a single great *energy system* which receives solar energy as an input while it reflects light energy and radiates heat energy as an output. Within this system, many transformations of energy occur, and each transformation is associated with matter in one form or another. Thus, an energy system has (1) a body of matter, (2) an *energy input,* (3) an *energy output,* and (4) a set of *energy transports* and *transformations* which are produced where energy interacts with matter. In a system as complex as our earth, there are many energy transports and transformations associated with many different types of matter. Each of these is an *energy pathway* within the system. An example of an energy pathway is the absorption of light energy by matter at the earth's surface. This energy is converted to internal heat within the matter, and then radiated out to space. Thus, energy enters the pathway as light, interacts with matter, and then leaves the pathway as radiant heat.

Another basic principle of energy systems can also be observed from Moon Base Alpha, provided we use the proper instruments—the fact that *rate of energy input must equal rate of energy output,* unless energy is being stored somewhere in the system or is being removed from storage. The physical law behind this statement is that energy can neither be created nor destroyed: a fundamental law of the real world. (A seeming exception to this rule lies in the production of atomic energy, in which matter changes to energy—an environmentally significant process we will discuss later.) In other words, if we were to list in one column all the energy inputs to the system, including energy withdrawn from storage, and in another column all the energy outputs, including energy going into storage, we would find that both columns total alike. Since our list would resemble a household budget with its incomes, expenditures, and savings, we might call such a list an *energy budget* for our system. Analyzing the budget of an energy system will be an important tool in our future studies of planetary systems.

If you watched the earth for a longer time, you would also see matter entering and leaving the planetary surface. A meteoroid, no larger than a grain of sand, is deviated by our planet's gravitational field and plunges into the atmosphere, glowing as the heat of friction with the atmosphere vaporizes its components, providing new atoms for the atmosphere. Or, if the meteoroid is a very large one, it may impact the solid earth, increasing the planetary mass and providing a small additional chunk of rock for the action of erosive processes on the land or perhaps a contribution to the ocean's floor. Matter leaving the earth is not so conspicuous: a few atoms near the edge of the atmosphere diffuse into the emptiness of space; or perhaps a space probe blasts off for Mars, never to return.