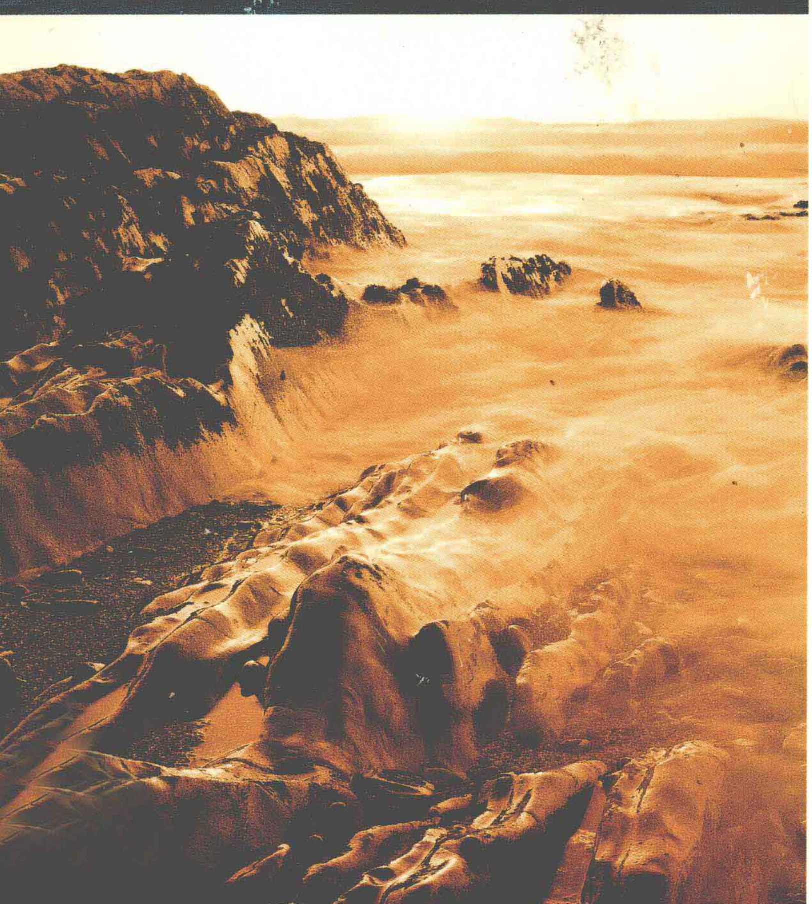

Eighth Edition

OCEANUS

The Marine Environment

Study Guide

Tom Garrison / Ruth Lebow

This study guide is keyed to two textbooks, *Oceanography: An Invitation to Marine Science,* by Tom Garrison, and *Oceanography: An Introduction,* by Dale Ingmanson and William Wallace, either of which may be used with the television course Oceanus.

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Wadsworth Publishing Company

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Preface

And I have loved thee, Ocean! and my joy
Of youthful sports was on thy breast to be
Borne like thy bubbles, onward: from a boy
I wanton'd with thy breakers – they to me
Were a delight; and if the freshening sea
Made them a terror – 'twas a pleasing far,
For I was as it were a child of thee,
And trusted to thy billows for and near,
And laid my hand upon thy mane – as I do here.

George Gordon,
Lord Byron

Few courses of study are more intriguing to life-long learners or undergraduates attempting to fulfill their general education science requirement than introductory oceanography. The visual and intellectual richness of the marine sciences makes a deep impression on students and contributes significantly to their awareness and appreciation of the natural environment. Few of us can remain impassive while viewing film of a tidal wave striking the Hawaiian Islands, reading an account of the U.S. Navy's encounter with the largest wave ever measured at sea, considering the origin of the molecules that make up our bodies, reading about the amazing adventures of polar explorers such as Ernest Shackleton, or hearing the lovely sound of dolphins and whales communicating.

Whether you live in a coastal city or an inland town, the ocean affects you. It affects you because of its influence on the earth's weather, its stunning physical size and diversity of life forms, its contributions to the physical and historical development of humans, its impact on geopolitical and economic matters, and its importance in literature and the graphic arts.

The goals of this course focus on the uniqueness of the earth and on areas of intense scientific and public concern: plate tectonics and earthquake prediction, the impact of oceanic pollutants, climatic fluctuations, and the potential exploitation of marine resources. If, as microbiologist Barry Commoner predicts, we have "perhaps a generation in which to save the environment from the final effects of the violence we have done it," what better use could we make of our time than learning about the water environment that covers 70.8% of the earth on which we live?

Introduction

This is your study guide. Treasure it; struggle with it; use it as your personal road map to the world of *Oceanus*. Following the instructions in this guide will enable you to devote your time to absorbing course content rather than puzzling over what it is you are supposed to be learning.

Whether you are a newcomer to television courses, or an old hand, it is important that you become familiar with the components of *Oceanus*, how they function with each other, and how they relate to you. Each of the elements in a telecourse contributes to the whole, effectively using the style of communication peculiar to that particular medium.

The Television Lesson

The video component of *Oceanus* calls your attention to key concepts and abstract ideas through a variety of formats, from documentary to demonstration. The camera has the ability to travel and observe many activities not normally available to the classroom student. It brings noted authorities into your home on a moment's notice. You become an eyewitness to natural phenomena rarely seen in a lifetime.

Using television for learning is not like watching a comedy series or sporting event. At first you will have to concentrate on *active* watching. It is very easy to slip into the passive, half-viewing stance used for entertainment television. In most instances, you will have a chance to review the lesson in an alternate time period, or watch video cassettes of the lesson at the learning center on campus.

If you have an audio recorder available, tape the audio portion of the program as you view it. After you have watched the program and can visualize it, the audio portion is an excellent source for review. If you have any questions about content or wish additional information, contact the faculty advisor at the campus where you are enrolled. He or she is eager to help.

The Text

Oceanus is keyed to two textbooks, either of which may be used with the television lessons: *Oceanography, An Invitation to Marine Science*, third edition, by Tom Garrison, published by Wadsworth in 1998; or *Oceanography: An Introduction*, Fifth Edition, by Dale Ingmanson and William Wallace, published by Wadsworth in 1995. A text is an essential part of the course, providing information most appropriate to the print medium. It establishes a foundation of knowledge and elaborates on concepts introduced in the television segments through charts, studies, research, and additional photographs. The assignment section of the study guide coordinates reading and review assignments with the television segment.

You should leaf through each assignment before you begin to read. Some text assignments are fairly short, some rather long. In this way you can gauge the length and detail of the reading, and pace yourself.

Your campus instructor will tell you which of the texts to use. Assignments will be given for both books (you need not read both).

The Study Guide

As the title indicates, the study guide helps you to synthesize and integrate the materials presented in the text and television segments. Each lesson of the study guide contains the following:

- ☐ The *Overview* is a summary of the highlights of that particular lesson – major facts, concepts, and opinions placed in the total perspective of the course.
- ☐ The *Learning Objectives* are the goals you are expected to accomplish as a result of completing the required activities for that particular lesson.

- The *Key Terms and Phrases* segment provides a vocabulary list of important words and expressions that will be encountered in the lesson. This segment complements but does not substitute for the Glossary in the textbook.
- *Before Viewing* informs you of the required reading for that particular lesson and may direct you to perform some type of required activity in preparation for viewing the television program.
- The *After Viewing* section includes a variety of opportunities to apply and practice what you have learned from the text and video lessons. These activities are required. Sometimes answers are provided; in other instances you will be given the chance to plot your solution and test your knowledge without help. Any questions, discoveries, or difficulties may be shared with your campus instructor.
- The *Optional Activities* section suggests activities to expand your understanding of the subject matter.
- The *Self-Test* is a series of multiple-choice questions designed to serve two purposes: to test your understanding of the objectives of each lesson and to prepare you to take the course examinations.
- The *Supplemental Readings* is a list of suggested books and articles for additional information on the various concepts and issues discussed in the lesson.

Occasionally, other special sections and notes that are specific to a particular lesson will be added for clarification or to identify supplementary resources.

As we indicated earlier, each component in a telecourse contributes to the whole. The course is not any one of the elements by itself. It is a blending of all three: the television lesson, the text, and the study guide.

How to Use This Study Guide

These few suggestions may assist you in using this study guide and in understanding the rationale for its design.

First, read the Overview, study the Learning Objectives and Key Terms and Phrases, and do all the Before Viewing assignments for each lesson before you watch the corresponding television program. Each 30-minute television episode will go by too quickly for you to take comprehensive notes. Moreover, if you try to take notes on everything, you will soon discover that you have missed a great deal of the visual impact of the program because you are looking at a pad of paper. By completing all the pre-viewing requirements before watching the program, you are preparing yourself to select and retain those major concepts and facts not fully covered in the text. You will already have acquired the specialized vocabulary needed to understand the content of the television program, thereby eliminating one more obstacle in the learning process, and you will gain the ability to distinguish between that which is truly important and that which is interesting, but incidental. Test items may cover material presented in the video program only, so be sure to pay attention and review the programs, if possible, on audio or videocassette.

Second, it is a good idea to reread the assigned passages in the text as soon as possible after viewing the television lesson to reinforce what you have just seen. The activities in the After Viewing section are designed to further your understanding of the objectives for each lesson, so they should be taken seriously. Incidentally, inasmuch as the After Viewing portion of the study sequence is required, you may be tested on the content.

Third, take the Self-Test honestly. Make a genuine attempt to answer each question without glancing first at the Answer Key. The Self-Test is your opportunity to practice what you have just learned, without penalty, and with almost instantaneous feedback. Make the most of this opportunity. Remember, the Self-Tests are a dry run for the examinations to come. Whenever you miss a question on the Self-Test, take the time to find out why. Use your errors to find out what fact or concept you missed or misunderstood along the way. You can learn as much from a wrong answer as from a right one and can avoid making the same mistake again.

Fourth, if you should experience difficulty, seek help from the campus instructor. All of us who were involved in designing and producing this course hope not only that you will learn a great deal about the ocean environment, but also that the whole process of learning will be an exciting and enjoyable one.

Contents

Lesson One The Water Planet

Overview

The Greeks were experienced voyagers and knew their Mediterranean well. Occasionally they would venture past the protecting arms of the Straits of Gibraltar and encounter the "ocean-river," a great breathing and moving entity they named Oceanus. This vast, boundless river was believed to flow endlessly around the earth. Homer, with remarkable prescience, named Oceanus as the origin of all things, including the gods. In Hesiod's *Theogony*, Oceanus is a Titan, son of Uranus and Gaea (Heaven and Earth). Oceanus and his wife Tethys, according to mythology, bore 3,000 sons (the rivers) and 3,000 daughters (the water nymphs, Oceanides).

A Greek view of the ocean-river is an altogether appropriate way to begin our work. During the childhood of the world thoughtful Greeks were as awed by the ocean and its creatures as we are today. Through their mythology comes a sense of the beauty, power, majesty, and potential of the seas. The astronauts have spoken lovingly of the sight of this ocean and the world it dominates. Surely it is as lovely a sight from space as it was, and is, from the temples of Poseidon.

Earth is unique. Seventy and eight-tenths percent of the planet is covered by water. The oceans affect and moderate temperature, dramatically influence weather, provide at least two percent of the world's direct human intake of protein, support about one-third of the world's petroleum demand, border most of the world's largest cities, and supply primary shipping and communication routes and major recreational resources. We will someday look to the seas for additional food, raw materials, energy and energy resources, living space, and special products.

The ocean also lives within us. Whether terrestrial, aquatic, or marine, all life evolved in the ocean, developing and flourishing there for a few billion years before venturing onto the unwelcoming land. All life on earth depends on an internal seawater mix to provide a suitable environment for life processes. The life forms of the land carry an ocean within themselves. Their blood, their eggs, even the fluids that bathe their cells are oceanic. Humans are at least 71 percent water – water that contains nearly the same concentration and proportion of major elements as the oceans themselves. The first nine months of human life are spent in a water world – a warm, supportive ocean that cradles from shock and provides a stable and weightless environment for the complex processes of growth and development. After birth, our entire personal view of the universe is seen through an ocean: The fluid behind the cornea in our eyes is a very close analog to seawater. Without water, life as we know it would be impossible. Cells require water as surely as they require oxygen and food.

There is also a diversity and potential for intelligence among oceanic life that is likewise unmatched by most terrestrial counterparts. This seems plausible when one understands that modern scientific theory supports the premise that life evolved in the ocean. Though the seas were much different 3.5 to 4 billion years ago, all of the elements necessary for organic molecules were present in those ancient waters. Scientific investigation has demonstrated that amino acids will form in a solution containing dissolved materials similar to those found in primordial seawater when stimulated by light or electricity. These amino acids are not alive, but they are the building blocks of life. To support this hypothesis, we can point to fossils of simple bacteria-like organisms in rocks over 3 billion years old, which are some of the most ancient sedimentary rocks on earth. It is interesting to contemplate that it probably took less than 1 billion years for those simple forms to develop, but it took about 2 billion years to make the step to many-celled organisms.

Life slowly grew ever more complex, branched onto land and continued developing to its present apex on land and in the sea. Some of the resulting ocean creatures defy description: whales over 30 m (100 ft) long, squid of great size and bizarre shape living at almost unimaginable depths, glowing fishes, tiny planktonic creatures on which life on earth ultimately depends for much of its daily oxygen, intelligent porpoises and dolphins, tremendous fisheries that provide food for millions of humans, graceful sea stars that enliven our trips to tidal pools, seaweeds swaying and floating near divers. There are birds with migration routes 40,225 km (25,000 mi) long, turtles that navigate unerringly to a spot near where they were born, and sea lions by the thousands on desolate beaches. There are penguins and pelicans, corals and conchs. There seems to be a little bit of anything alive in the seas.

In the terrestrial sense, the oceans contain and cover all the shapes familiar to us on dry land. There are hidden mountain ranges, submerged peaks higher than any above the waters, hot springs of immense dimension, volcanoes spewing lava in huge underwater eruptions, earthquakes, avalanches, mineral treasures, and more.

The ocean itself is incomparably vast – it contains 361,000,000 cubic kilometers (139,000,000 cubic miles) of water, a mass weighing a staggering 155 billion billion tons! The ocean's volume is eleven times the volume of land above sea level. We tend to divide the ocean into artificial compartments called "oceans" or "seas," but in fact there are no dependable natural divisions, only one great mass of water termed the World Ocean.

In spite of the size dominance of the ocean, the history of the ocean is the history of exploration. Since the beginnings of human development the barriers of ocean have not impeded the movement of humans over the earth's surface. This was aptly illustrated when the European explorers set out to "discover" the world only to meet native populations at nearly every landfall! The tales of adventure and discovery are grand to hear, though the era of exploration is by no means at an end. True, the great land masses have been plotted and traversed, but exploration on and under the seas continues. Perhaps the best is yet to come!

Of course, ocean people today are not always explorers in the traditional geographical sense. Of the nearly 2,500 professional oceanographers working in the United States, about 48 percent are biological oceanographers and 31 percent are physical oceanographers and meteorologists. Many more people work in support of these scientists as marine technicians and technologists and ships' captains and data reducers and computer specialists, but the number of key ocean scientists is not large.

Certainly, the areas to explore and the scientific disciplines involved are many: biology, geology, chemistry, and physics, among others. The text reading assignment for this lesson gives a good overview of the historical development of these disciplines in the study of the oceans. Applying these many fields of study, professionals in oceanography spend their working lives looking for answers to questions that have fascinated humanity since those first days when the Greeks looked past the western reaches of the Mediterranean and said, "Beautiful!" and asked, "Why so?"

Learning Objectives

After completing the reading assignment and viewing the program, the student will be able to:

- ☐ Recognize the fascination the sea has held for generations of people.
- ☐ Appreciate the variety of organisms residing in the ocean environment.
- ☐ Describe some of the features one would see in the underwater world.
- ☐ Distinguish between the nature of the terms *Atlantic Ocean*, *Pacific Ocean*, or *Indian Ocean*; and the term *World Ocean.*

Key Terms and Phrases

Oceanus The legendary Greek ocean-river.

Ocean The word *ocean* is properly reserved to describe the single great body of water that covers 71 percent of the surface of the badly named Earth. In common use, however, we know of the Pacific Ocean, the Atlantic Ocean, and so on.

Sea One of the larger bodies of salt water. Smaller in size than the ocean. The word *sea* is frequently used interchangeably with ocean.

Technically, and from mythology, there can be many seas but only one ocean.

Evolution The maintenance of life under changing conditions. As conditions change, organisms experience stress. Certain natural variations between organisms permit some organisms to withstand this stress better than others. The organisms that withstand the stress survive and reproduce; those that cannot will die. Some characteristics that allow survival are transmitted to offspring, which then are also capable of survival. By this natural selection the shapes and characteristics of organisms change through time. These changes in shapes and characteristics, when combined with environmental isolation, eventually lead to the appearance of new species.

Species A group of actually (or potentially) interbreeding natural populations reproductively isolated from all other organisms.

Oceanographer An ocean scientist. Oceanographers are by necessity acquainted with the relation of a large number of scientific subdisciplines to the sea. They generally possess graduate degrees in one or more marine science specialty areas such as marine geology, chemistry, marine biology, cartography, or sedimentology. They also usually have broad backgrounds in the fundamentals of science (mathematics, physics, and chemistry), as well as basic skills such as writing. Oceanographers plan experiments and courses of investigation.

Marine technician An ocean paraprofessional, trained in the manipulation of oceanographic equipment and in the analysis and reduction of data. Marine technicians do the work that oceanographers plan.

Before Viewing

- ☐ Become familiar with the textbook your instructor has selected to accompany the telecourse. This book is an important resource for the course, and it will be most useful if you get a feel for the overall content of the text before you embark on the reading of the individual chapters. Read the preface to the book and look through the table of contents. Thumb through the book and stop at interesting photographs. Read any sections that interest you now. Locate the various Appendixes and note the presence of the helpful Glossary in which you can identify unfamiliar terms. Now you are ready to begin your reading in earnest.
- ☐ Note the units of measure to be used throughout the book and in this study guide. These are described in the Appendixes in the text.
- ☐ Read Chapter 1, pages 1–7, and Appendix I in Garrison; or Chapter 1, pages 2–22, and Appendix IV in Ingmanson & Wallace.
- ☐ Watch Program 1: "The Water Planet."

After Viewing

Reread the text sections, being sure you understand the key terms and phrases, and complete the following exercises:

1. What do you suppose gave the Greeks the impression that the ocean was a flowing river?
2. If this planet is dominated by water, how did it get the name *earth*?
3. Why do biologists largely agree that life arose in the ocean?
4. If oceanography and marine science are so important, why are so few professional oceanographers at work in this country?

Answer Key for Exercises

1. The Canaries Current passes close to the Straits of Gibraltar at the mouth of the Mediterranean Sea. When the Greek navigators ventured past the mouth and into the ocean, they drifted to the south because of this current. Without an understanding of the global nature of the oceans, it would have been a logical assumption that this body of water was really a huge river, impossible to see across, that was flowing to the south. They could not know that the Canaries Current is only one of four huge currents that move water clockwise around the periphery of the North Atlantic Ocean.

2. The word *earth* is derived from the old Anglo Saxon word *eorthe*, which itself is descended from the ancient German word for earth, *Erde*. The Germanic tribes, in their forest fastness, could be forgiven for their lack of understanding of the true nature of the World Ocean. A better name for the earth would surely be *Oceanus*, but so far the authors of this study guide have not had much luck in getting the name changed!

3. The main evidence that life evolved initially in the seas is the presence, within every living thing, of water containing most of the same basic components as seawater. All of cell physiology on this planet seems based on a solution of materials within water. The water provides a fluid matrix within which the processes of life can take place. Because all of the organisms here share this matrix, whether the organisms live on the driest deserts or in the ocean, it is logical to assume evolution from a common origin in the sea.

4. The numbers are deceptive. There may be only around 2,500 professional oceanographers in the United States, but there are many, many more paraprofessionals and business people in association with them. In coastal areas a large number of people derive their income from recreationally related marine industries, from fisheries, from mineral and petroleum companies, and other sources. A Ph.D. and an academic position are not immutable requirements for work within the ocean area. Many universities and community colleges in the coastal areas of the United States have marine science and technology curricula and would be pleased to offer you more information.

Optional Activities

1. Schedule a visit to a research or educational institute and talk to a marine science professional about his or her work. Why did these people decide on this vocation?

2. When you visit the ocean, keep your eyes and ears open. Be a good observer. Look at things and question why they occur. Try to relate what you see in the "real world" to the things you learn through this telecourse.

3. The ocean is an inspiring object and has stimulated a great deal of literature, music, and art. Read some of the poetry of California poet Robinson Jeffers, listen to Ralph Vaughan-Williams's "Sea Symphony," or look at the wonderful abstract seascapes of J. M. W. Turner for a representative sample.

Self-Test

1. Which of the following are generally considered to be within the province of modern marine science?
   a. the deep-diving adaptations of marine mammals
   b. how ocean basins are formed
   c. why earthquakes occur
   d. prospecting for oil
   e. all of the above

2. The ocean covers about ______ percent of the surface of the earth.
   a. 50
   b. 71
   c. 80
   d. 61
   e. 90

3. The concentration of salts and other minerals in the cell fluids of organisms is ____________ the concentration of these same materials in the ocean.
   a. very close to
   b. much greater than
   c. much less than
   d. in no way related to
   e. identical to

4. In the scientific method, scientific theories
   a. must be tested and verified by observations
   b. must be verified by the leading authorities in the field
   c. must be consistent with previous, universally accepted scientific concepts
   d. must be consistent with the fact that the ocean is of great age
   e. are accepted as absolute fact until proven otherwise

5. The world ocean
   a. plays a minor role in the weather and shape of landmasses of the earth
   b. does not influence the way organisms live on land
   c. is the dominant feature of the earth and its biological systems
   d. is a common occurrence in the known universe
   e. is a temporary phenomenon on Earth
6. Life on Earth appears to have evolved
   a. in the ocean
   b. on land
   c. in space

Supplemental Reading

Borgese, E. M., *The Drama of the Oceans*. New York: Abrams, 1974.

Broecker, W. S., "The Ocean." *Scientific American*, vol. 249, no. 3 (1983). (This is an excellent overview of the current state of oceanographic understanding.)

Carson, R., *The Sea Around Us*. New York: Houghton Mifflin, 1951.

Dickerson, R. E., "Chemical Evolution and the Origin of Life." *Scientific American*, vol. 239, no. 3 (1978), 70–86.

Hamilton, E., *The Greek Way*. New York: Norton, 1958. (This book is a classic well worth reading.)

Miller, S. L., "Production of Some Organic Compounds Under Possible Primitive Earth Conditions." *Journal of the American Chemical Society*, vol. 77, no. 2351 (1955).

Revelle, R., "The Ocean." *Scientific American*, vol. 221, no. 3 (1969), 54–65.

Slocum, J., *Sailing Alone Around the World* (1899). Reprinted: Sheridan House, 1972. (Astonishing account of the first single-handed circumnavigation.)

Lesson Two   Cosmic Origins

Overview

Earth seems badly misnamed. The very feature that makes the earth unique in our solar system, that makes life possible, that controls the weather and gives the planet its startling blue color from space, is ignored in that name. The ocean is clearly the dominant feature of this lovely and graceful sphere, and, curious though it may seem, these waters were formed through unimaginable violence within a star.

The connection between stars and oceans may seem unlikely, but stars are great nuclear furnaces that achieve the alchemists' goal of transmuting elements – that is, of changing one substance into another. The predominant form of matter in the universe is hydrogen, and stars convert hydrogen to heavier substances, releasing huge quantities of energy in the process. Our earth and its oceans are plainly made of more than just hydrogen gas, so the alchemical machinery of a star is needed to construct the heavy elements from which we are made.

Stars are born when a quantity of hydrogen, dust, gas, and debris coalesces into a tenuous cloud-like sphere, which gradually shrinks under the influence of its own weak gravity. The shrinking continues until compression causes temperatures within the cloud to reach approximately 20,000,000°F, at which point nuclear fusion reactions begin to produce heavy elements at the core.

Such a star may live for billions of years, constructing tremendous quantities of oxygen, carbon, lithium, and other heavier elements from the hydrogen that forms its bulk. When it has converted a certain percentage of its nuclear fuel, the star may become unstable and explode, forcing its shattered mass into space at tremendous speeds. Such an exploding star is called a *nova*. The sighting in February, 1987, of a nova bright enough to be visible to the unaided eye from the Southern Hemisphere has given astronomers an opportunity to observe such an event with sophisticated detectors and telescopes. Data gathered by these devices have confirmed most theories about a star's collapse and the subsequent formation of heavy elements. The earth and its oceans are the indirect result of such an explosion.

Our star, the sun, is believed to be a second-generation star. The condensing cloud that was forming into our sun many billions of years ago was probably struck by the remnant of an earlier exploded star. Our young sun was dramatically influenced in at least two ways by this confrontation. First, spin was imparted to the sun; and second, a fraction of the heavy atom content of the expanding remnant was absorbed into our sun. As a result of these occurrences, planetary material was spun away from the sun as it continued to shrink toward its present size. Some of the resulting planets are gas and vapor bodies. Others, such as Earth and Mars, are rocky spheres that lost their thick early atmosphere when the sun first "turned on." Earth was at the proper place within the scheme of things to retain a large dose of hydrogen hydroxide in its recipe . . . water!

The earliest years of the earth were years of violent change. The earth probably began as a cool, homogeneous body that had collected mass from the material in the vicinity of its orbit around the sun. As time and gravity acted on this sphere, the heat of compression and radioactive elements heated the planet and caused a heavy molten core to form. Lighter substances were forced to the exterior, becoming crust and atmosphere.

The earth's age is generally given as about 4.6 billion (4,600,000,000) years. The point at which the earth clock begins is the time of solidification of the crust – brittle rock that floats, then as now, on a more dense but viscous mantle. When the radiation of heat away from the earth allowed the crustal surface to cool toward the boiling point of water, the stage was set for the greatest rain in the history of our solar system.

The original waters were probably contained in the rocks of the mantle and were released to the surface primarily through volcanic activity. The hot vapors rose and condensed in the cool layers of the upper atmosphere. The rains fell on the young planet only to boil back again into the clouds. This cycle, which lasted for millions of years, accelerated the cooling of the crust and eventually the oceans stabilized in their basins, having taken along an assortment of dissolved minerals leached from the hot solid surface. An alternate hypothesis suggests that a part of the earth's surface water may have come from frozen water-rich comets striking the upper atmosphere.

The physical expanse and distribution of the early oceans is a matter of some controversy. Some researchers have held that huge emergent masses of granite rock (called *sial*) have always protruded through the ocean surface to form continents. However, more recent evidence suggests that the waters of the earth covered the entire surface for some 200 million years before the continents emerged.

Today a large volume, but relatively insignificant percentage, of water remains in the atmosphere as vapor, and some water is within the freshwater lakes and rivers, ice caps, and groundwater mechanisms of the world. However, the vast majority of Earth's water is oceanic; this oceanic water distinguishes the planet Earth from all the other known planets.

Not only does water exist in liquid form on Earth, but ocean water is intimately intertwined with life on this planet: Virtually all forms of life on Earth reflect the composition of the oceans in their body fluids. Though the scientific community cannot agree upon exactly how life evolved, scientists generally agree that:

- all forms of life on Earth share the same basic mechanisms for transferring information from one generation to the next (genetic code);
- the biochemical machinery for energy conversion and storage is shared by virtually all life forms; and
- all life exists, internally, in a fluid matrix very closely resembling seawater. In a sense, all life on Earth is marine.

These ideas have some interesting portents for the origin of life on Earth. For example, it is a fairly safe assumption that life arose in the sea and that the forms of life we see today on the earth probably had a common ancestor in the dim distance of time. The commonality of systems and the presence of oceanlike water in virtually all organisms make this a reasonable conclusion.

Exactly where in the ocean the first forms of life arose is also a matter of debate. In the past it was theorized that the origin occurred on the surface. The rich "earth soup" of the surface (which resulted from the dissolution and concentration of the crustal minerals), the ready availability of all sorts of energizing radiation, and the surface film, which traps small bubbles of air in which active compounds combine and recombine, make the surface a good candidate.

Convincing arguments have been made for life's first glimmer as an abyssal event that occurred in the deep seabed rifts that girdle the earth like seams on a softball. Within these deep, hot spring areas are chemicals leached from superheated rocks and protected from the intense ultraviolet radiation now present at the ocean's surface. It is theorized that these concentrated compounds provided the conditions for cell division and, thus, life on Earth.

Finally, when our star, the sun, becomes unstable and dies or explodes and envelops the earth, this blue jewel world will cease to exist. Its atoms will be distributed into space, perhaps to be incorporated within another planet with another ocean. It is thought that only a small handful of planets in the galaxy have an ocean. There may be lots of rocky planets, and lots of gaseous planets, but a water planet is very, very special. And we named it Earth!

In October 1984 astronomers announced the discovery of what may be a solar system forming around the nearby star Beta Pictoris in the Southern Hemisphere constellation Pictor. This system, discovered by IRAS (infra-red astronomy satellite), was confirmed by photographs taken by the largest optical telescope in the Southern Hemisphere located in Chile. Beta Pictoris is 50 light-years distant (about 300 trillion mi) and may represent an embryo system in a configuration similar to our own about 4.5 billion years ago.

Astronomers have long felt that solar systems are not unusual, and these new pictures are the first direct evidence of planets condensing around another star. Scientists using the Hubble Space Telescope, an optical instrument powerful enough to resolve such systems in our local neighborhood of the Milky Way galaxy, have reported new candidates.

Learning Objectives

After completing the reading assignment and viewing the program, the student will be able to:

- ☐ Appreciate the uniqueness of a water planet.
- ☐ Understand, in general terms, the events leading to the formation of the earth and its oceans.
- ☐ Know the age of the earth.
- ☐ Compare the major scientific hypotheses for the origin of life on Earth.

Key Terms and Phrases

Transmutation The conversion of one element into another. This may be accomplished naturally in stars or artificially in the nuclear laboratory. It may occur spontaneously during the decay of radioactive elements. Alchemists spent much of their time trying to transmute base metals into gold, but they did not have the nuclear physics to do this successfully.

Star A self-luminous, gaseous, celestial body usually of great size. Generally, stars obtain their energy from the conversion of hydrogen into helium and other heavier elements. The nearest star to us is the sun, some 93,000,000 miles away.

Supernova Popular term used for the period at the end of a massive star's life when it becomes unstable and explodes. The supernova stage is the most dramatic event in a star's life and results in the fabric of the star being flung into space at tremendous speeds.

Planet A subordinate body associated with a star. Our sun has two basic kinds of planets in orbit around it: gas planets (such as Jupiter) and rocky planets (such as Mars or Earth). Planets and stars form from similar processes, but the mass of the star is sufficiently greater to permit nuclear fusion to begin during the compression stage.

Accretion Increase of mass by external accumulation or addition of particles.

Life A system that can capture, store, and transmit energy and that is capable of self-replication (reproduction).

Before Viewing

- ☐ Read Chapter 1, pages 7–19 in Garrison; or Chapter 2, pages 23–29 in Ingmanson & Wallace.
- ☐ Watch Program 2: "Cosmic Origins."

After Viewing

Reread the text sections, being sure you understand the key terms and phrases, and complete the following exercises:

1. Why is the earth so special? What conditions would be required to give rise to a planet such as ours with liquid water at the surface?
2. How do scientists know how old the earth is?
3. Would life on other planets, assuming it exists, be like life on Earth?

Answer Key for Exercises

1. For starters, let's look at stars. Most stars visible to us are members of multiple-star systems. If the earth were in orbit around a typical multiple-star system, we would be close to one of the host stars at certain places in our orbit and too far away at others. Some systems have up to nine stars in orbit around each other, and no one knows how many planets are associated with them. Also, not all stars are as stable and steady in energy output as our sun. If we were in orbit around a star that grew hotter and cooler at intervals, our situation would be radically different than it is at the moment. And if we were in a multiple-star system with unstable stars, the whole situation would be even

worse. But our sun is a single star and is relatively stable in heat and light output.

Next, let's look at orbital characteristics. Our earth is in a nearly circular orbit at just the right distance from the sun to allow liquid water to exist over most of the surface through most of the year. That's luck!

Next, consider our "load" of elements. We picked these up during the accretion phase. At our area of orbit there was an unusually large amount of water (or chemical materials that would later lead to the formation of water) and we were again lucky.

So, with a stable star, a pleasant circular orbit that is well placed, and the right raw materials, we are a water planet. This marvelous combination probably is not found in many places in the galaxy.

2. Going to the moon helped. Samples obtained from the surface of the moon have helped to verify information obtained from rock samples, radioactive dating, astronomical evidence such as the age of meteorites, and so on. All of these evidence lines are in agreement that the earth is between 4.5 and 5 billion years old, and 4.6 billion seems like the best estimate we can currently make.

3. Life on other planets would presumably be much different from life here on Earth. Remember, the common denominator for life on this planet is the ocean itself. Life probably arose within it, and all living forms carry an ocean of sorts around within their bodies. If the ocean is removed as a factor from the equation of life, the resulting organisms would, of course, be different.

   For example, consider a hypothetical planet without an ocean but with large amounts of liquid ammonia on its surface. If life were to evolve on that planet, the biochemistry of the organisms would almost certainly not include fats or oils because of a chemical incompatibility between ammonia and lipids. Without these fats and oils, membranes are impossible. Without membranes, cells, as we know them, are not possible either. No cells, no earth-type life.

   Notwithstanding this argument, life may not be confined to planets with water. Other life forms may exist based upon other "brews." Certainly, though there is a lot of evidence to indicate that the earth is unique to known planets, the universe is a gigantic place. There are more stars in our local group of galaxies alone than there are grains of sand on an average beach. The thought that we are alone as a planet harboring life within the universe is untenable to many scientists.

Optional Activity

Planetarium shows occasionally have as their theme the origin and nature of the universe. If you are fortunate enough to be near a large planetarium when such a show is scheduled, see it!

Self-Test

(More than one answer may be correct.)

1. Which of these is arranged in correct order, smallest-to-largest?
   a. atom, star, planet, universe, galaxy
   b. atom, planet, star, universe, galaxy
   c. atom, planet, star, galaxy, universe
   d. atom, galaxy, planet, star, universe
   e. atom, universe, galaxy, planet, star

2. Given almost limitless time, the operation of gravity, and large quantities of hydrogen gas, what is a likely first outcome?
   a. A planet will form.
   b. An ocean will form.
   c. A star will form.
   d. All of these will happen simultaneously.
   e. None of the above.

3. Researchers now possess the tools that may help reveal whether Earth is the only planet in the galaxy possessing significant quantities of liquid water on its surface.
   a. true
   b. false

4. The earth is about
   a. 4.6 million years old
   b. 4,600,000 years old
   c. 4,600,000,000 years old
   d. 4.6 billion years old
   e. 460 billion years old

5. The most likely explanation for the origin of the universe involves
   a. a steady state with no beginning and no end
   b. a cataclysmic "bang" and consequent expansion of material
   c. a cataclysmic "bang" and consequent contraction of material
   d. a slow growth through accretion
   e. none of these
6. Our position within the galaxy is
   a. near the center
   b. in a spiral arm, surrounded by dust and gas
   c. above the polar axis
   d. in a special place on the galactic axis, but greatly removed from the main structure
   e. none of these
7. There is now good evidence for planets surrounding other nearby stars. What would you estimate for the probability that at least one of these nearby planets, away from our own solar system, resembles the earth?
   a. The probability is pretty high.
   b. The probability is about 50 percent.
   c. The probability is rather low.
   d. The probability is extremely low.
   e. It is not possible for these planets to resemble the earth.
8. Which of these statements is true for life on Earth?
   a. Life on Earth appears to have arisen in the oceans between 4 and 5 billion years ago.
   b. Living systems on this planet share similar genetic and energy conversion mechanisms.
   c. Life on Earth seems to require an inner environment of seawater-like fluid.
   d. Life can be defined as a system that can capture, store, and transmit energy, and that is capable of reproduction.
   e. All of the above
9. It is inconceivable that other planets could harbor intelligent life.
   a. true
   b. false

Supplemental Reading

Badash, L., "The Age-of-the-Earth Debate." *Scientific American*, Aug. 1989, 90–96. (An excellent summary of the history of the question.)

Hawkings, S., *A Brief History of Time*. New York: Bantam Books, 1988. (A wonderful introduction to a challenging topic.)

Horgan, J., "In the Beginning . . ." *Scientific American*, Feb. 1991, 116–125. (Thoughts on the origin of life by a number of researchers.)

Jastrow, R., *God and the Astronomers*. New York: Norton, 1978.

Jastrow, R., *Red Giants and White Dwarfs*. New York: Harper & Row, 1967. (Although a bit dated, this is perhaps the best and most readable book covering the evolution of stars, planets, and life.)

Maran, S. P., "In Our Backyard, a Star Explodes." *Smithsonian* VR 19 #1; April 1988, 46–57.

Sagan, C., *Cosmos*. New York: Random House, 1980.

Stahler, S. W., "The Early Life of Stars." *Scientific American*, July, 1991, 48–55. (Discusses the turbulent youth of stars.)