OCEAN WORLD ENCYCLOPEDIA

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PREFACE

There is no credible evidence that modern human beings are, in any fundamental sense, intellectually superior to their counterparts at the dawn of recorded history. And yet, we have left far behind the period when transportation and construction relied solely on puny human muscles and those of domesticated animals; when disease—such as the Great Plague that laid waste to 33 million Europeans in 1348—repeatedly rode the land and when ignorance and superstition combined to shackle the questing mind. Instead, we have tapped and are learning to use the fabulous energy of the atom; we have brought to heel the ancient diseases and tripled life expectancy; and we have walked the boulder-strewn surface of the moon and explored the deepest, darkest depths of the ocean. For those who would seek the answer to this disparity in intellectual achievement, it can be found in a single word: accumulation. Each generation has the decisive advantage of being able to draw on the accumulated knowledge of all previous generations.

Beginning with Denis Diderot's great 35-volume *Encyclopédie* of 1772, it is the traditional objective of an encyclopedia to translate and summarize the accumulated knowledge of a given field for the benefit of those not specialized in that field. In keeping with established tradition, McGraw-Hill's *Ocean World Encyclopedia* is the first encyclopedia of oceanography to be written specifically for the nonspecialist and the first to address, in a single volume, all the major divisions of oceanography along with several categories of related subjects. Included are articles on

- Physical Oceanography
- Geological Oceanography
- Chemical Oceanography
- Biological Oceanography
- Oceanographic Instrumentation
- Hurricane

- International Marine Sciences Organizations
- Individual Famous Oceanographers

By their writing style (largely nontechnical) and by the selection of articles, the authors have attempted to produce an encyclopedia both useful and interesting to high school and college students as well as to interested nonspecialists from many walks of life. For easy accessibility, considerable care has been taken in selecting the more obvious titles for articles, and the articles themselves have been arranged in alphabetical order. Liberal use has been made of *See* and *See also* to indicate either additional articles which expand on a given subject or related articles of possible interest to the reader. Words and phrases in small capital letters have also been used to indicate a separate article under that title. And, wherever appropriate, broad survey articles have been provided for those interested in a quick overview, followed (alphabetically) by specialized articles for those interested in a more detailed discussion of some aspect of the general subject.

The plant and animal life of the ocean, or that related to it (e.g., MARINE BIRDS), has been covered quite extensively by both general and specific articles. For the benefit of those with more than a casual interest in the subject, taxonomy has been emphasized so that members of common groups may be more easily related.

For those interested in the geography of the coeans, there is a separate article on each of the five oceans and the 60-odd seas describing the physical and political boundaries, water characteristics, bottom configuration and, in most cases, early exploration in the area. In like manner, all the major ocean currents are discussed under individual headings.

In discussing the physics, geology, geophysics, chemistry, and meteorology of the oceans the authors have concentrated on those subjects thought to be of greatest interest and use to the intended audience. Broad articles are often used to explain specific phenomena and processes: e.g., CORIOLIS EFFECT to discuss the mechanics of ocean and atmospheric circulation; SUBMARINE CANYON to discuss the processes of sediment transport and erosion in the ocean; and the anatomy of a HURRICANE to discuss the interaction between ocean and atmosphere. In all cases the authors have attempted to use an uncomplicated approach to the discussion and have avoided the use of formulas wherever possible.

Ocean engineering and oceanographic instrumentation, both vital to the study and utilization of the ocean, have not been addressed by way of numerous specialized articles. Rather, both have been treated extensively under a single, broad article. Acoustics, or underwater sound, has been similarly treated.

Perhaps the most difficult task faced by the authors was the selection of those scientists whose biographies were to be included in the encyclopedia. Space limitations dictated that only 25 could be chosen. Final selection was made on the basis of a questionnaire completed by many members of the oceanographic community. The authors take full responsibility for the final selection, but are indebted to those who responded with their recommendations.

In completing a task that has spanned three years the authors are, first and foremost, indebted to that long line of explorers, adventurers, scientists, engineers, technicians, and sailors whose inquisitive minds, exhaustive labors and lonely voyages produced the knowledge summarized in this volume.

Special acknowledgement and appreciation is also due the many institutions (credited in the text) that were so helpful in providing photographs. And finally, we are deeply indebted to those friends, colleagues and family members who provided support, encouragement and inspiration throughout the effort.

Donald G. Groves
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SI UNITS

SI UNITS are values used in the International System for measurements (Système International). SI represents a streamlined version of the metric system in which units of length, time, and mass are the meter, second, and kilogram, respectively, or decimal multiples and submultiples thereof. The United States is a signatory to the General Conference on Weights and Measures which gave official status to the metric SI units in 1960.

Metric System The metric system has been used by oceanographers and other scientists for many years in varying degrees. Now it is used almost exclusively worldwide in all scientific work. However, the United States is the last industrialized nation of the world to adopt the system in any widespread way. United States engineers, including ocean engineers, and the American public have traditionally used a system of measurement that consists of the inch, foot, pound, pounds per square inch, and so forth.

This customary system of measurement traces its ancestry back to Anglo-Saxon days and is probably based on the ancient Egyptian practice of measuring things by using parts of the human body as gauges. For instance, in Egypt the standard of length for the construction of pyramids, the cubit, was the distance from the elbow to the end of the middle finger [about 18 in (46 cm)]. The hands and arms were used to measure short lengths, while a man's stride served as a measure for longer distances. The Anglo-Saxons adopted this scheme based on physical standards. They used the cubit as well as the inch (the distance from the knuckle to the end of the thumb), the foot (the length of four palms or sixteen fingers), and the yard (the distance from King Edgar's nose to the end of the middle finger of his extended arm). A fathom was the length of a Viking's embrace.

When, some 1000 years ago, the Anglo-Saxons realized that not everyone's thumb, nose, or embrace was quite the same, more meaningful standards began to evolve. These were eventually sophisticated by basing various measurement units on standardized bars, metal weights, and all the types of measures that have existed, especially in the American-used system.

In the late eighteenth century, the French initiated the metric system and based its measurement units on various natural constants. For instance, the meter was defined first as that length equal to one ten-millionths of the quadrant of the earth measured on the meridian passing through Dunkirk and Barcelona. The liter was the volume occupied by a unit mass of one cubic decimeter of water at the TEMPERATURE of its maximum DENSITY. While there are some built-in inaccuracies in these particular definitions, the metric system, based on natural standards, is excellent in almost every respect and perhaps much sounder than the customary one that has been used in the United States.

While there is considerable resistance to metric use in the United States, its usage is rather substantial. Since international activity in oceanographic research and engineering promises to increase at a rapid rate as do other international efforts, it is logical and practical to utilize some compatible internationally agreed-upon standard of measurements in these efforts. The SI units are a step in this direction. Some conversion factors for measurements are listed in the following tables.

SI UNITS

When You Know	You Can Find	If You Multiply By
Length		
inches	millimeters	25
feet	centimeters	30
yards	meters	0.9
miles (statute)	kilometers	1.6
miles (nautical)	kilometers	1.85
millimeters	inches	0.04
centimeters	inches	0.4
meters	yards	1.1
kilometers	miles (statute)	0.6
Area		
square inches	square centimeters	6.5
square feet	square meters	0.09
square yards	square meters	0.8
square miles	square kilometers	2.6
acres	square hectometers (hectares)	0.4
square centimeters	square inches	0.16
square meters	square yards	1.2
square kilometers	square miles	0.4
square hectometers (hectares)	acres	2.5
Mass		
ounces	grams	28
pounds	kilograms	0.45
short tons	megagrams (metric tons)	0.9
grams	ounces	0.035
kilograms	pounds	2.2
megagrams (metric tons)	short tons	1.1
Liquid Volume		
ounces	milliliters	30
pints	liters	0.47
quarts	liters	0.95
gallons	liters	3.8
milliliters	ounces	0.034
liters	pints	2.1
liters	quarts	1.06
liters	gallons	0.26
Temperature		
degrees Fahrenheit	degrees Celsius	$\frac{5}{9}$ (after subtracting 32)
degrees Celsius	degrees Fahrenheit	$\frac{9}{5}$ (then add 32)
degrees Celsius	kelvins (SI temperature unit, K)	by adding 273
Pressure Stress		
pounds per square inch	newtons per square meter	6895 (= 1 pascal)
pounds per square foot	newtons per square meter	47.88 pascal

Equivalents

The following is a partial list of equivalents:

10 millimeters = 1 centimeter
10 centimeters = 1 decimeter
10 decimeters = 1 meter
10 meters = 1 dekameter
10 dekameters = 1 hectometer
10 hectometers = 1 kilometer

1 centimeter = 0.3937 inch
1 inch = 2.54 centimeters
1 decimeter = 3.937 inches
1 foot = 3.048 decimeters
1 meter = 39.37 inches
1 yard = 0.9144 meter
1 dekameter = 1.9884 rods
1 rod = 0.5029 dekameter
1 kilometer = 0.62137 mile (statute)
1 mile (statute) = 1.6093 kilometers
1 fathom = 1.828 meters (6 feet)

1 square centimeter = 0.1550 square inch
1 square inch = 6.452 square centimeters
1 square decimeter = 0.1076 square foot
1 square foot = 9.2903 square decimeters
1 square meter = 1.196 square yards
1 square yard = 0.8361 square meter
1 acre = 3.954 square rods
1 square rod = 0.2529 acre
1 hectare = 2.47 acres
1 acre = 0.4047 hectare
1 square kilometer = 0.386 square mile
1 square mile = 2.59 square kilometers

1 cubic centimeter = 0.061 cubic inch
1 cubic inch = 16.39 cubic centimeters
1 cubic decimeter = 0.0353 cubic foot
1 cubic foot = 28.347 cubic decimeters
1 cubic meter = 1.308 cubic yards
1 cubic yard = 0.7646 cubic meter

1 gram = 0.03527 ounce
1 ounce = 28.35 grams
1 kilogram = 2.2046 pounds
1 pound = 0.4536 kilogram
1 metric ton = 1.1023 USCS tons
1 USCS ton = 0.9027 metric ton

1 liter = 0.908 quart dry
1 liter ≐ 1.0567 quarts liquid
1 quart dry = 1.101 liters
1 quart liquid = 0.9436 liter
1 dekaliter = 2.6417 gallons
1 gallon = 0.3785 dekaliter

10 milliliters = 1 centiliter
10 centiliters = 1 deciliter
10 deciliters = 1 liter
10 liters = 1 dekaliter
10 dekaliters = 1 hectoliter
10 hectoliters = 1 kiloliter

Thermal Conductivity, κ

1 cal (thermochemical)/cm · s · °C = 418.40* watt/meter · kelvin

Specific Heat, C

1 cal (thermochemical)/g · °C = 4184.00* joule/kilogram · kelvin

SI UNITS

The following table makes it easy to do conversions from the old system to the new one. The letter f as in lbf stands for "force."

Conversion of U.S. Customary Units to Equivalent Values in SI Units

1 ft = 0.3048 m
1 in = 25.4 mm = 2.54 cm
1 milli-inch = 25.4 μm
1 ft^2 = 0.0929030 m^2 = 920.030 cm^2
1 in^2 = 645.16 mm^2 = 6.4516 cm^2
1 yd^3 = 0.764555 m^3
1 ft^3 = 28.3168 dm^3
1 in^3 = 16.3871 cm^3
1 Imp. gal = 4.54609 dm^3 = 4.546 L
1 U.S. gal = 3.78541 dm^3 = 3.785 L
1 qt = 1.13652 dm^3 = 1.137 L
1 pt = 0.568261 dm^3 = 0.568 L
1 ft/s^2 = 0.3048 m s^{-2}
1 ton = 1016.05 kg = 1.01605 metric ton
1 cwt = 50.8023 kg
1 lb = 0.45359237 kg
1 oz = 28.3495 g
1 lb/ft^3 = 16.0185 kg m^{-3}
1 lb/in^3 = 27.6799 g cm^{-3} = 27.6799 Mg m^{-3}
1 lb/gal = 0.0997763 kg dm^{-3} = 0.09978 kg l^{-1}
°F $= \frac{°C \times 9}{5} + 32$
°C = K − 273
1 tonf (loosely 1 ton) = 9.96402 kN
1 lbf (loosely 1 lb) = 4.44822 N
1 $tonf/in^2$ = 15.4443 MN m^{-2}
1 lbf/in^2 = 6894.76 N m^{-2} = 68.9476 mbar
1 ft H_2O = 2989.07 N m^{-2}
1 in H_2O = 249.089 N m^{-2}
1 in Hg = 3386.39 N m^{-2} = 33.8639 mbar
(1 torr = 1 mm Hg)
1 therm = 105.506 MJ
1 hph = 2.68452 MJ
1 kWh = 3.6 MJ
1 Btu = 1.05506 kJ
1 ft·lbf (loosely 1 ft·lb) = 1.35582 J
1 hp = 745.700 W (J s^{-1}) = 0.745700 kW
1 ft lbf/s = 1.35582 W
1 Btu/h = 0.293071 W (J s^{-1})
1 Btu/ft^2 h = 3.15459 W m^{-2} (J m^{-2} s^{-1})

Decimal multiples and submultiples of the SI units are formed by means of the prefixes given below:

Factor by Which the Unit Is Multiplied	Prefix	Symbol*
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

* The symbol of a prefix is considered to be combined with the symbol to which it is directly attached, forming with it a new unit symbol which can be raised to a positive or negative power and which can be combined with other unit symbols to form symbols for compound units.

ABBREVIATIONS USED IN THIS BOOK

~	approximately
Btu	British thermal unit
°C	degrees Celsius
cm	centimeter
eH	redox potential
°F	degrees Fahrenheit
ft	feet
g	gram
h	hour
in	inches
K	kelvin
kg	kilogram
kHz	kilohertz
km	kilometer
kn	knot (kts in some places)
L	liter
lb	pound
m	meter
mg	milligram
mL	milliliter
mm	millimeter
mph	miles per hour
%	percent
pH	hydrogen ion concentration
ppm	parts per million
ppt	parts per thousand
‰	parts per thousand (salinity)
psi	pounds per square inch

CONTENTS

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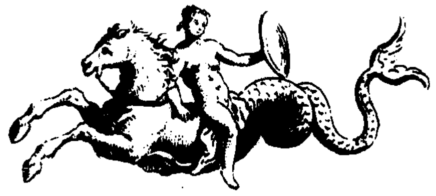

ABALONE is a gastropod mollusk composing the single genus *Haliotis* of the family Haliotidae. (See GASTROPODS, MOLLUSK.) Also known as ear shell, ormer, or paua, the abalones (over a hundred species are known) are found in temperate and tropical oceans and are fished on the Pacific Coast of North America, as well as in southern Peru, China, Japan, Korea, and the Republic of South Africa. These animals tightly adhere to a solid substrate such as rocks, especially in waters from the low-tide mark to depths of about 120 ft (36.6 m). The attachment to a substrate is made by a large and muscular foot or disk, which is edible and highly esteemed as a food by many peoples. Abalones are vegetarians and feed primarily on ALGAE, which they take from the substrate by means of the radula, a ribbon-shaped organ, studded with chitinous teeth, that is found in the mouth of these mollusks.

The shell of the abalone resembles a valve of a large clam except for the spiral whorl (see CLAMS). Typically, this flattened shell is perforated by a series of small pores or natural holes. SEAWATER is drawn in under the edges of the shell, passes over the gills, and exits from the mantle cavity through the pores. The nacreous lining of the shell, composed mostly of calcium carbonate and held together by a tenuous network of organic conchiolin, is used commercially as mother-of-pearl.

Reproduction takes place by separate abalone sexes, and fertilization is external. The single gonad empties into the kidney, thus permitting transport of the gametes to the outside. The larvae are pelagic and swim among the PLANKTON in coastal waters for about 2 days. They then settle and develop to the adult stage.

ABYSSAL PLAIN is an unusually flat area of the deep ocean basin in which the slope of the bottom is no more than 1 : 1000, and may be as little as 1 : 10 000. This smoothness is due to an evenly distributed sediment cover which has masked the original irregularities of the bottom. These sediments appear to be derived from the CONTINENTAL SHELF and transported downslope by turbidity currents. A TURBIDITY CURRENT tends to seek the lowest elevation on the bottom across which it flows to deposit the greater part of its sediment load. Therefore, depressions on the ocean floor tend to be erased early.

The existence of abyssal plains was not determined until the Mid-Atlantic Ridge Expedition of 1947 in which extensive use was made of the newly developed continuous depth recorder. (See UNDERWATER SOUND.) In 1948, the Swedish Deep-Sea Expedition, using the same technique, discovered abyssal plains in the INDIAN OCEAN. Since then such features have been discovered and mapped in all oceans.

Since abyssal plains owe their existence to an ample supply of eroding sediment and a slope sufficient to spawn and nourish turbidity currents, they are most commonly found just seaward of the CONTINENTAL RISE that borders the continents. Further seaward the smooth abyssal plain terminates in hilly terrain composed of abyssal hills. Such hills lie outside the reach of the turbidity currents with their masking sediment loads and represent the true nature of the original seafloor. These hills range from small mounds to hills of a few hundred feet in height and a few miles in width. Little or no sediment overlies the surface of these hills, whereas the sediment cover overlying abyssal plains averages about 0.6 mi (1 km).

Where continental margins terminate in deep-sea TRENCHES, as off the west coast of Central and South America, trench abyssal plains often occupy the floor. In other words, the trench serves to trap the turbidity current flowing down the slope and its floor is smoothed by the resulting sediment deposition. Where trenches exist, no abyssal plain will be found beyond their seaward rims. In some cases an abyssal plain will be interrupted by a rough area called an abyssal gap. This is thought to be the long-used path of turbidity currents which lies short of the point at which sediment deposition begins to take place. An abyssal plain which lies off an oceanic island or group of such islands is called an *archipelagic plain.*

ACOUSTICS See INSTRUMENTATION; SEA NOISE; SONAR; UNDERWATER SOUND.

ADSORPTION is the property of a substance to retain or concentrate at its surface one or more components from another substance in contact with the surface. Adsorption is a fundamental physiochemical property of solids and liquids. The greatest importance of adsorption is in colloidal systems (see COLLOID). In such systems the particle sizes are small, but the very large surface area of all PARTICULATE MATTER results in many binding sites for adsorption. Many ocean-life processes depend upon adsorption.

ADVECTION FOG See FOG.

AGASSIZ, LOUIS (1807–1873), a Swiss naturalist, made many fundamental contributions to geology and marine biology.

Like his fellow countryman and friend Arnold Guyot (see GUYOT, ARNOLD), Agassiz spent his boyhood in an impressive geographical area that doubtless first stimulated his interest in a study of the mysteries of nature.

At the age of 17, Agassiz entered the Medical School of Zurich. Two years later he enrolled at the University of Heidelberg to study physiology, anatomy, zoology, and botany. He finished his academic training with a degree of Doctor of Philosophy at the University of Erlangen in 1829 and a Doctor of Medicine at Munich in 1830.

Concurrent to his university studies. Agassiz was chosen by von Martius; the Brazilian explorer, to describe the fishes collected during the latter's expedition. Agassiz' outstanding work in this regard ranked him among the best naturalists of the time. Following this accomplishment, and while continuing his preparations in 1830 for the publication of a natural history of the freshwater fishes of Europe and a dissertation on fossil fishes of Europe, Agassiz visited Paris and Vienna to study the museum collections there.

In 1832, Agassiz accepted the position of professor of natural history in the College of Neuchâtel where he served for 14 years. In this capacity, he published his research works in a most accurate and scholarly manner. For example, his *Recherches sur les Poissons Fossiles,* plus other books related to echinoderms and studies of fossil mollusks, (see ECHINODERM; MOLLUSK) greatly enhanced his reputation as an outstanding scientist of the time.

Agassiz, in this period, conducted several investigations relative to glaciers and made important contributions by his lectures and publications (e.g., *Système Glaciaire*) on the subject. However, important as these particular research areas were, his friend Humboldt (see HUMBOLDT, ALEXANDER VON) thought Agassiz should not be diverted from other natural history investigations. Accordingly, Humboldt convinced the King of Prussia to send Agassiz on a scientific mission for the comparison of the fauna of temperate Europe and the United States. At the same time Agassiz received an invitation to lecture before the Lowell Institute in Boston, Massachusetts. He accepted the invitation and made an extraordinary impression both in scientific circles and on the United States public in general.

Because of this, Alexander Bache, Superintendent of the U.S. Coast Survey, funded Agassiz in his investigations of marine life on the U.S. Atlantic coast and among the Florida reefs. Also, an expedition to Brazil and the Amazon was arranged, as well as the means provided for Agassiz' publication *Contributions to the Natural History of the United States,* for the establishment of a biological laboratory, and for the organization of a scientific school and museum of comparative zoology at Harvard University which largely embodied and displayed Agassiz' ideas. Such ideas were reinforced by Louis Agassiz' son, Alexander Agassiz (1835–1910), who made many outstanding contributions to physical and biological oceanography.

AGE OF OCEAN WATER is the time that has elapsed since a given WATER mass was last at the surface of the sea. In many areas of the world's oceans the surface water increases in density—due to decreasing temperature or increasing salinity, or both—and sinks to great depths. Water movement at these depths is very slow, and conditions tend to be rather stable. Therefore, it becomes of interest to know how long a mass of water has been away from the surface. Such knowledge is useful in determining the rate at which overturn occurs and deep nutrient-rich water is brought to the surface. It is also useful in reaching decisions regarding the disposal of toxic chemicals and radioactive waste in the deep sea.

The most effective technique thus far for determining the age of seawater is to measure the depletion that has taken place through radioactive decay in carbon 14. The technique assumes that the only source of carbon 14 available to the ocean is the atmosphere. It further assumes that, once away from the surface, the water receives no further carbon 14. The technique indicates the following ages for different water masses, with a reported accuracy of ± 100 years: North Atlantic Central water, 600 years; North Atlantic Bottom water, 900 years; North Atlantic Deep water, 700 years; Antarctic Intermediate and Bottom water in the South Atlantic, less than 350 years. Measurements of South Pacific Deep water have given ages ranging from 650 to 900 years.

AGE OF THE OCEAN is, for the present, unknown. As yet no evidence has been uncovered in the geologic record which would indicate that the ocean did not exist prior to the event responsible for creating that evidence. The best that we can do is bracket the probable age with two statements: If we assume that WATER is essential to the creation of life on this planet, then the ocean is at least as old as the earliest fossils. Obviously, the ocean cannot be older than the Earth itself.

Based largely on the study and dating of meteorites, the Earth is now taken to be about 4.5 billion (4.5×10^9) years old. The oldest fossils are those of algae of the blue-green variety, fungus colonies, and worm burrows found in some pre-Cambrian rocks. The pre-Cambrian era ended about 600 million (600×10^6) years ago. Therefore, we may consider the ocean to be between 600 million and 4.5 billion years old, but we must realize that these numbers are likely to increase as new evidence is uncovered and more sophisticated analytical tools are brought to bear.

Attempts have been made, of course, to measure the age of the ocean. In 1715, Edmund Halley, the English astronomer after whom Halley's comet is named, suggested that the age of the ocean might be determined by dividing the total salt content of the world's ocean by the annual amount of salts added to the ocean by all the rivers emptying into it. But reliable data upon which to estimate the salt content of the ocean did not exist then, and would not until the *Challenger* expedition of 1872–1876—the first attempt to systematically examine the world's oceans from the chemical, physical, and biological points of view. Subsequently a number of calculations, beginning with those of John Joly in 1899, were made as a result of Halley's suggestion. These calculations yielded an "age" for the ocean which ranged from about 80 million to around 150 million years. (See CHALLENGER EXPEDITION.)

Clearly, as indicated by the fossil evidence noted earlier, the salt calculations yielded an age far too small. In part, this was due to factors now considered obvious. For instance, account was not taken of the large volumes of salts extracted by evaporation from arms of the sea cut off from normal circulation for long periods of time. And, it has only recently been known that tiny salt crystals are continually being transferred from the ocean to the atmosphere by the evaporation of water droplets ejected by spray and bursting bubbles. These salt crystals, swept upward by wind currents, serve the important function of acting as a nucleus about which raindrops form. By this mechanism, known as the "salt cycle," enough salts are transferred to the land by rain to quantitatively account for the salt found in rivers. And finally, the calculations were biased in the opposite direction by failing to account for the salts added to the ocean by volcanic activity on the seafloor.

AGUAJE See EL NIÑO

AGULHAS CURRENT, one of the swiftest of ocean currents, flows southward along the east coast of Africa. As the South Equatorial Current (see EQUATORIAL CURRENT SYSTEM), flowing from east to west in the vicinity of the equator, approaches the African coast, it is deflected to the left by the CORIOLIS EFFECT and flows south. Part of this current flows between Madagascar and the coast to form the Mozambique Current, while the remainder passes to the east of Madagascar to feed the Agulhas Current. South of 30° south LATITUDE the Agulhas becomes a narrow, well-defined current that extends less than 62 mi (100 km) from the coast. Reaching the tip of Africa, part of the current apparently enters the ATLANTIC OCEAN to join the northward-flowing BENGUELA CURRENT. However, most of the WATER turns sharply south and then eastward to join the WEST WIND DRIFT CURRENT as it flows west to east across the southern INDIAN OCEAN.

Being fed by water warmed by a slow drift across the Indian Ocean in the vicinity of the equator, the Agulhas water is warm, although the temperature drops gradually as it flows southward toward Antarctica. A narrow tongue of water—called Warm Agulhas Water—extends to a depth of about 492 ft (150 m) and has a temperature of about 68° F (20° C). Below and to either side of the tongue of Warm Agulhas Water, and extending down to a depth of about 1300 ft (400 m), is another identifiable envelope of water with a temperature of around 62.6° F (17° C). The temperature of the water to either side and below this second envelope drops rather sharply. The boundary between the warm and cool Agulhas water is marked by a salinity of around 35.6 ppt.

The velocity at which the Agulhas Current flows varies with location, depth, and season. A velocity range of 7.8–24 in/s (20–60 cm/s) is representative of the main southerly current.

ALBACORE See TUNA.

ALBATROSS See MARINE BIRDS.

ALEUTIAN CURRENT is an eastward-flowing current in the north PACIFIC OCEAN. Also called the Subarctic Current, it flows between the North Pacific Current to the south and the Aleutian Island chain to the north. An early branch of the current turns northward to flow into the BERING SEA. Further along, as the current nears the North Pacific coast of North America, one branch turns north to flow into the Gulf of Alaska while another turns south to become the CALIFORNIA CURRENT which flows south along the coast of California.

The Aleutian Current originates as a mixture of water from the KUROSHIO CURRENT and the OYASHIO CURRENT. Where it is best developed, the current flows at the rate of 530 million (530 × 10^6) ft^3/s (15 million m^3/s) above a depth of 2000 ft (610 m).

ALGAE is a general term for autotrophic organisms which includes both prokaryotes and eukaryotes; that is, which includes those organisms with a primitive type of nucleus lacking a clearly defined membrane (prokaryotes) and those with a well-defined nuclear membrane, chromosomes, and mitotic cell division (eukaryotes); approximately 8000 of the known 18 000 species are marine forms. Algae are the predominant "plant" forms in the world's oceans and the producer organisms in the marine ecosystem.

Some algae belong to the subkingdom Thallobionta (Thallophyta) of the kingdom Metaphyta; others are members of the kingdom Protista (see TAXONOMY). These organisms vary in size from microscopic acellular species to massive seaweeds, (see KELP), which may attain a length of 200–300 ft (60–91 m). They dominate in the oceans not only in their number of species (about 8000), but also in their number of individual organisms.

Like land plants, they possess chlorophyll by which they utilize sunlight in the process of PHOTOSYNTHESIS to manufacture their own food. Organisms with this ability are called autotrophic. Unlike most terrestrial plants, algae never form true roots, stems, or leaves. Because of their lack of structural complexity, algae are characterized as primitive or "low" forms of plant life, or thallus plants.

However, some thallus plants display more complex developmental patterns than flowering plants. For example, in the algae, the plant body varies greatly in both size and shape, and the methods of reproduction are quite diverse. Three general types of reproduction are used: vegetative, which includes cell division and fragmentation of the thallus; asexual, by motile (zoospores) or nonmotile spores; and sexual, by gametes which may be isogamous (undifferentiated in respect to maleness and femaleness), anisogamous (with a degree of differentiation), heterogamous (differentiated as egg and sperm), or oogamous (differentiated, with small male gametes and large female gametes).

Vegetative reproduction is accomplished primarily by fragmentation of the plant. This occurs when the mature nonfilamentous parts are split up into two or more segments, or when filaments (or fragments) of the plant are broken apart. In the larger brown and red algae, relatively small portions of the plant bodies often become detached to form entire new plants. The extent to which such dispersion and propagation occurs is largely unknown. However, it is known that the plant resulting from a fragment contains the same chromosomal composition as the fragment. Thus, each new plant is not a different generation but an identical twin.

Reproduction may also take place in some species by simple cell division. By this division, two daughter cells are formed, each becoming a new individual. These cells also may separate immediately after formation, or they may stay together for a time so as to resemble an algal colony.

Asexual reproduction by zoospores is common. These zoospores, or animallike unicellular reproductive units, possess a cell membrane rather than a true cell wall. They are free-swimming and move by means of whiplike threads, or flagella, which sometimes grow laterally on the zoospores or (more frequently) on the ends of them. Since these zoospores yield spores, plants of this generation are called sporophytes. Sporophytes are diploid (that is, their genetic complement of chromosomes is duplicated) with pairs of each kind of chromosome in every cell. The spores, however, are monoploid (that is, they contain only one of each kind of chromosome), and the settled spores give rise to male and female plants (gametophytes). The sexual gametophyte plants, as in the higher plants, produce reproductive cells, or gametes. (A gamete is a cell that grows into a new individual only after fusion with another gamete.) The gametes are male (sperm, antherozoids, or spermatia) and female (eggs, or ova). Union of the sperm and egg produces a diploid single-cell zygote which then develops into the sporophytic generation (green, brown, and some red algae) or the carposporophytic generation (most red algae).

Most "sexual" algae deposit all or a portion of the reproductive cells (spores and gametes) into the water. The cells are mesoplanktonic (floating) for varying periods, and chance usually determines whether spores settle on a suitable substrate. However, chemical attractants may assist sperm of some species in locating mature ova. The spermatia of red algae lack flagellar swimming mechanisms so that fertilization apparently depends on random contacts.

Algae do not have, nor do they require, true roots, stems, or leaves. The stem of a typical plant is designed to transport water and food and provide structural support, but because most algae have the ability to absorb food and materials for sustenance without such stems, there is no need for these types of root systems or stem appendages. However, some algae, notably brown and red algae, have what is termed a *holdfast,* a structure that holds the plant in place. Such a structure is, by definition, not a root since it does not absorb water or nutrients from the soil. On the other hand, some algae have blades resembling leaves, which are extensions of the plant body. These blades act to increase the surface area of the plant body itself and make absorption and photosynthesis more efficient.

In all, there are some 18 000 varieties of algae which exist on land, in fresh water, and in SEAWATER. Many of these are microscopic one-celled organisms; others are land forms as large as bushes and still others, the massive sea KELPS (brown seaweed), are really huge. They grow in the tropics and in the Arctic regions—on ice-locked mountains, in hot geysers, and as floating plants in oceans, lakes, ponds, rivers, and creeks.

Most authorities agree that the algae comprise seven different divisions. These phyla, which vary according to body structure, reproductive organs, the types of pigments produced, and the kinds of stored food in each, are as follows:

- *Green Algae* (*Chlorophyta*). Some 10 percent are marine, and many are small, with the largest being the *Ulva* or sea lettuce.
- *Blue-Green Algae* (*Schizophyta—prokaryotes*). Common both in salt and fresh water; reproduce asexually.
- *Yellow-Green Algae* (*Chrysophyta*). Mostly found in fresh water, although marine DIATOMS (class Bacillariophyceae) are included in this group (Chrysophyta) as well as the golden-brown algae (class Crysophyceae) which are mostly found in fresh water but also occur as marine forms.
- DINOFLAGELLATES (*Pyrrhophyta*). More common in marine forms than freshwater forms.
- *Euglenoids* (*Euglenophyta*). Mostly freshwater forms. Most species are autotrophic; others such as *Astasia* have no chlorophyll.
- *Brown Algae* (*Phaeophyta*). Primarily marine.
- *Red Algae* (*Rhodophyta*). Primarily marine.

Some green or blue-green algae may become commensal with, or parasitized by, different species of fungi (see FUNGUS) to produce different species of LICHENS. Many marine algae, especially Rhodophyta, are epiphytic or parasitic on other larger algal forms which sometimes are close relatives. A few species occur as endozoophytes within the cells of small animals (PROTOZOA, SPONGES, and Hydra) or in the digestive tract of mammals; some are epizoic (externally attached) on skin, hair, or scales.

Some red algae, such as the coralline algae of the family Corallinaceae, have the ability to secrete lime within and between the cell walls so that the fossils commonly show the cellular structure of the tissue. These algae make important contributions to the building of limestones and coral reefs. (See CORAL REEF.) In a number of the atolls of the PACIFIC OCEAN, coralline algae have contributed significantly to CORAL in the formation of the reefs. (See ATOLL.)

Marine algae show distinct zonations along coasts and in the marginal waters of continental shelves. (See CONTINENTAL SHELF.) Littoral algae (*Fucus, Ulva,* and *Chondrus*) occupy the intertidal zone. In the supralittoral zone are forms especially adapted for existing during intermittent moist and long dry periods (the splash zone), whereas the infralittoral is characterized by those genera which must live submersed, occuring below the lowest low-tide (see TIDES) level and on out into deeper waters.

In this regard, the particular algae that are found in the oceans are usually further divided into two main ecological classifications or groups: (1) the small drifting phytoplankton; and (2) the larger holdfast, or attached, plants called macrophytes. However, some of the latter marine plants grow while drifting, and attachment to a solid base or substrate is not necessarily a requirement among the macrophytes.

The tiny phytoplanktonic life forms of the ocean world are represented chiefly by the diatoms (the Chrysophyta division of algae) and dinoflagellates (the Pyrrhophyta division). Both have high surface-to-volume ratios, which make them quite efficient in feeding upon the dissolved nutrients in ocean waters. They live in the sunlight (photic) and epipelagic HABITABLE ZONES of the oceans and are incalculably abundant, prodigally self-renewing, and beautifully structured. When examined under a microscope, diatoms and dinoflagellates exhibit fabulous designs resembling strings of jewelry of great beauty. In addition to such beauty, together with their approximate total of some 6000 varied and diverse species (5000 diatoms and 1000 dinoflagellates), these algae provide the basis of aquatic food chains. In that sense, they are really the giants and wealth of the ocean (planktonic) flora. It has been estimated that in 1 ft^3 (0.028 m^3, or 28.3 L) of coastal seawater off the British Isles, there are on an average more than 20 000 of these minute plants, plus millions of even smaller plant forms. In a corresponding volume of water, there are probably some 120 minute animal forms, primarily COPEPODS or tiny (1–10 mm long) CRUSTACEANS, medusae, and larvae which later develop into decapods, echinoderms, cirripedes, and GASTROPODS (see LARVA; ECHINODERM). These copepods are the chief link in the food chain between the phytoplankton and higher forms of animal life of the ocean.

Some other kinds of more complex attached marine algae are commonly called seaweeds. This group of plants, contrary to the connotation of their namesake—weeds—yields a number of products having many important uses. These larger (macrophytic) plants are members of three of the groups of algae:

1. Brown (Phaeophyta)
2. Red (Rhodophyta)
3. Green (Chlorophyta)

Although most species of seaweeds grow in the ocean's intertidal zone where they are partially or totally exposed at low tide, a considerable number also grow below the surface [approximately 50–100 ft (15 to 30 m)] in abundant beds. It is in deep water that the large weeds are found. Agarum, a species of KELP, commonly known as the sea colander, is an abundant seaweed on the ATLANTIC OCEAN coast of Nova Scotia that grows in these depths.

In southern California many seaweed species are found at deeper levels along the offshore islands, as compared with their maximum depths on the mainland shelves. The difference probably results from clearer waters offshore, permitting higher light intensities at a given depth. In some coastal areas, the large kelps, including *Macrocystis*, become sparse at 50–60 ft (15–18 m). Their range may extend to 90–100 ft (28–31 m) in clearest coastal situations. At San Clemente Island, the lower limits can be as great as 200 ft (61 m) for some brown algae and as deep as 130 ft (40 m) for *Macrocystis*.

Another species of seaweed is the sargassum weed which floats in the surface layers of the SARGASSO SEA. It is a gold and olive-colored alga that was once land-based but became pelagic in the oceans millions of years ago when parts drifted out into the ocean surface from coastal areas. The plant reproduces asexually by breaking off fragments that then thrive separately. The sargasso weed comprises two species of brown algae, *Sargassum natans* and *S. fluitans*. These plants normally live in the shallow tropical waters of the Atlantic coasts of North and South America. When they are detached by the action of WAVES, they float because of their gas-filled pea- and grape-sized bladders and follow the current to the Sargasso Sea in the North Atlantic Ocean. (See CURRENTS.) Here, the weed is trapped and joins other patches of accumulated sargassum that make up a huge egg-shaped area two-thirds as large as the contiguous United States.

A wide variety of animal life lives on and among this ponderous, widespread mass of floating weeds that itself is a mystery to science and has long been a subject of legend and folklore. (See MYTHS AND LEGENDS.) Most species of fauna are similar to species found in coastal waters, and it is said that when Columbus saw a sargassum CRAB (*Planes minutus*) there, many hundreds of miles from North America, he believed himself to be near land.

One of the most interesting forms of Sargasso life is the sargassum fish (e.g., *Histrio histrio*) that can devour prey almost as large as itself and whose mottled coloration blends perfectly with the new and old plant life. The small toad fish (*Antennarius marmoratus*) with its gold and brown marbled body melts into its surroundings and is hardly distinguishable from the seaweeds.

Perhaps the most fantastic of all the inhabitants are the American and European eels, temporary visitors to the area. (See EEL.) These eels come annually from the rivers of Europe and the United States to spawn. The larvae they produce develop into young eels called elvers, and they make their way back somehow to the very same rivers that their parents came from. (See LARVA.)

Although thousands of different kinds of seaweeds have been identified, only about a dozen are used commercially. However, their many potential applications are yet to be found. These highly useful plants are capable of yielding a number of products having many important uses, since the major con-