2.2 Origin of the Oceans

The oldest sedimentary rocks found on Earth, rocks that formed by processes requiring liquid water at the surface, are about 3.9 billion years old. This indicates that there have been oceans on Earth for approximately 4 billion years. Where did the water in the oceans come from? There are two possible sources for this water, the interior of Earth and outer space.

Traditionally, scientists have suggested that the water in the oceans and atmosphere originated in the interior of Earth in a region called the mantle (discussed in more detail in chapter 3, section 3.1) and was brought to the surface by volcanism, a process that continues to this day (fig. 2.2). The rock that makes up the mantle is thought to be similar in composition to meteorites, which contain from 0.1%–0.5% water by weight. The total mass of rock in the mantle is roughly 4.5×10^{27} g; thus, the original mass of water in the mantle would have been approximately 4.5×10^{24} to 2.25×10^{25} grams. This is from three to sixteen times the amount of water currently in the oceans, so it is clear that the mantle is an adequate source for the water in the oceans; but is enough water brought to the surface through volcanism to actually fill the oceans? Magmas erupted by volcanoes contain dissolved gases that are held in the molten rock by pressure. Most magmas consists of 1%–5% dissolved gas by weight, most of which is water vapor. The gas that escapes from Hawaiian magmas is about 70% water vapor, 15% carbon dioxide, 5% nitrogen, and 5% sulfur dioxide, with the remainder consisting mostly of chlorine, hydrogen, and argon. It is estimated that thousands of tons of gas are ejected in volcanic eruptions each day. Undoubtedly, the rate of volcanic eruptions on Earth has varied with time, probably being much greater earlier in Earth's history when the planet was still very hot. However, if we conservatively assume that the present rate of ejection of water vapor by volcanism has been roughly constant over the last 4 billion years, then the volume of water expelled by volcanoes would have produced roughly 100 times the volume of water in the oceans.

The traditional view of the interior of Earth serving as the source of ocean water has recently been challenged by a bold new suggestion that large volumes of water are continually being added from outer space. Evidence for this idea comes from data collected by a polar-orbiting satellite called the *Dynamics Explorer 1 (DE-1)* (fig. 2.3). The *DE-1* carried an ultraviolet photometer capable of taking pictures of Earth's **dayglow.** Dayglow is ultraviolet light, invisible to the naked eye, emitted by atomic oxygen in the upper atmosphere when it absorbs and reradiates electromagnetic energy from the Sun. In many of the

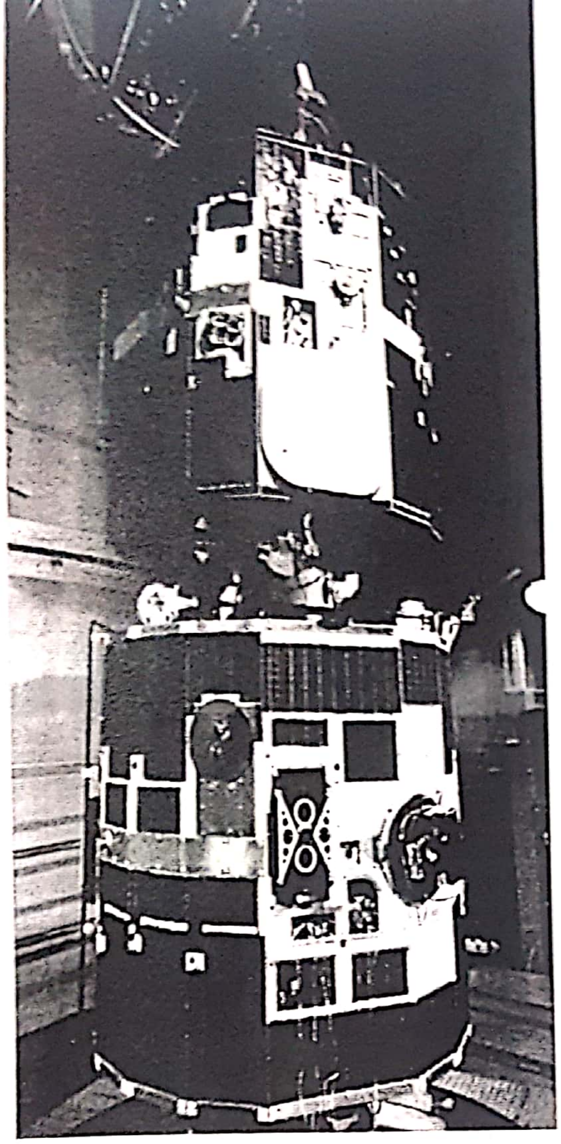
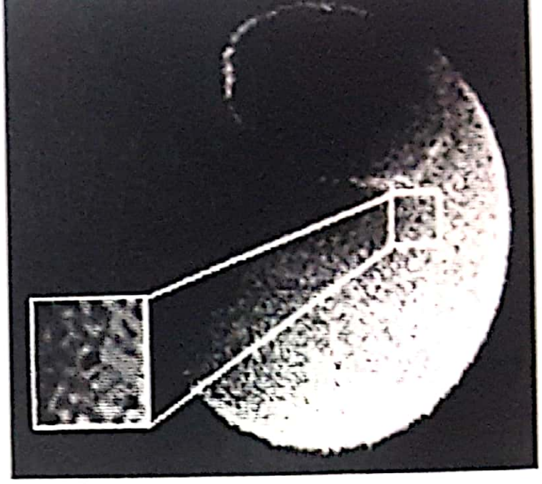


Figure 2.3 A prelaunch photo of the *Dynamics Explorer 1* and 2 (*DE-1/DE-2*) spacecraft stack before being covered by their fairings and mated with the Delta Launch vehicle. *DE-1* is on the bottom. *DE-1* was launched into a high-altitude elliptical orbit, while *DE-2* was launched into a lower orbit.

dayglow images of Earth obtained by the satellite, there are distinct dark spots, roughly 48 km (30 mi) in diameter, that appear to move across the face of Earth, suggesting that they were caused by moving objects (fig. 2.4). The direction of motion of the dark spots matches the direction of motion of meteoritic material as it approaches Earth. Atmospheric physicist Louis Frank has suggested that these dark spots are created when small icy comets vaporize in the outer atmosphere, creating clouds of water vapor that absorb the ultraviolet radiation of Earth's dayglow over a small area, thus creating a dark spot in the bright ultraviolet background. The size of the spots implies that the average mass of the comets is about 10 kg (22 lb). He estimates that an average of twenty of these comets enter the atmosphere each minute, or a staggering 10 million each year. If all of the water in these comets condensed to form a layer on the surface of Earth, it would be roughly 0.0025 mm (0.0001 in) deep. While this doesn't seem like a significant amount of water, over 4 billion years this rate of accumulation would fill the oceans two to three times.



web link Figure 2.4 Image of Earth's dayglow at ultr wavelengths taken from an altitude of 18,500 km (11,500 mi dayglow is due to the excitation of atomic oxygen by solar rad Inset shows a magnified view of a dark spot, or "hole," in the da thought to be caused by the vaporization of small cometlike balls

Some debate continues about the role of comet impa the formation of the oceans. Additional study may give u ther insight to the relative importance of volcanism and th pact of extraterrestrial objects in creating the oceans. It i likely that both processes have contributed to their formati

It is also believed that during the process of differenti gases released from Earth's interior formed the first atmos which was primarily made up of water vapor, hydrogen ga drogen chloride, carbon monoxide, carbon dioxide, and gen. Any free oxygen present would have quickly com with the metals of the crust. Oxygen gas could not accur in the atmosphere until it was produced in amounts enough to exceed its loss by chemical reactions with the This did not occur until life evolved to a level of comple which green plants could convert carbon dioxide and wate the energy of sunlight into organic matter and free oxygen process and its significance to life are discussed in chapter

What was the source of the early Earth's water and atmosphere?

2.3 Extraterrestrial Oceans

Data obtained by NASA's Voyager and Galileo spacecraf cate that two of Jupiter's moons, Europa and Callisto, ma oceans beneath their ice-covered surfaces (fig. 2.5). Despi tremely cold surface temperatures, −162°C (−260°F), oceans are believed to be possible on Europa because o generated by friction as the moons are continually deform Jupiter's strong tide-producing gravitational force.

Some of the most compelling evidence for the prese oceans has come from magnetic measurements made b Galileo spacecraft. Neither moon has a strong internal ma field of its own, but Galileo detected induced magnetic around both moons indicating that they both consist pa strongly conducting material.

It is unlikely that the ice covering the moons can account for the induced magnetic fields because ice is a poor electrical conductor. Fresh water is also a relatively poor conductor, but water with a high concentration of dissolved ions, such as sea water, is a very good conductor. The most plausible explanation for the observed magnetic effect is that Europa and Callisto have liquid oceans beneath their surfaces containing electrolytic salts. It is believed that magnesium sulfate might be a major component of Europa's water rather than sodium chloride as in the case of Earth's oceans.

One proposed model for Europa includes a surface ice layer 15 km (10 mi) thick covering a 100 km (62 mi) deep ocean. If this is the case, the European ocean would contain twice as much water as Earth's oceans and it would be roughly ten times deeper than the greatest depths below sea level on Earth. In contrast, one model proposed for Callisto is a surface ice layer 100 km (62 mi) thick covering a shallow 10 km (6.2 mi) deep ocean. If such oceans exist, they may provide the most likely environments for life outside of Earth.

There is also some indication that Mars once had an ocean covering portions of its northern hemisphere. The martian northern lowlands may have been covered by either a single, continuous body of water or partially covered by a series of smaller seas. This idea is still controversial and will require more study before there is general agreement among planetary scientists. High resolution photographs taken by the *Mars Global Surveyor* show what appear to be relatively recent geologic features similar to features on Earth created by flowing water. These recent features include fan-shaped deposits of sediment at the ends of channels, or gullies, along crater walls.

Diagram Earth's orbit of the Sun, and explain why the seasons change during the orbit.

What is the latitude of the Tropic of Cancer, Tropic of Capricorn, Arctic Circle, and Antarctic Circle?

Why are the Arctic and Antarctic Circles displaced from the poles by 23$^1/_2$°?

How will the seasons change over a calendar year at each of these latitudes?

2.10 The Hydrologic Cycle

Earth's water is found as a liquid in the oceans, rivers, lakes, and below the ground surface; it occurs as a solid in glaciers, snow packs, and sea ice; it takes the form of droplets and gaseous water vapor in the atmosphere. The places in which water resides are called **reservoirs,** and each type of reservoir, when averaged over the entire Earth, contains a certain amount of water at any one instant. But water is constantly moving into and out of reservoirs. This movement of water through the reservoirs, diagrammed in figure 2.17, is called the **hydrologic cycle.**

Water is taken out of the oceans and enters the atmosphere by evaporation where it may condense to form clouds. Most of this water returns directly to the sea by precipitation, but air currents carry some water vapor over the continents. Precipitation in the form of rain and snow transfers this water from the atmosphere to the land surface, where it percolates into the soil, is taken up by plants, fills rivers, streams, and lakes, or remains for longer periods as snow and ice in some areas. Some of this water will return to the atmosphere by evaporation of surface water, **transpiration,** the release of water by plants, and **sublimation,** the conversion of ice directly to water vapor. Melting snow and ice, rivers, groundwater, and land runoff move water from the continents back to the oceans. For a comparison of the water volume stored in different reservoirs, see table 2.2 and figure 2.18.

The properties of climate zones are principally determined by their surface temperature (mean Earth surface temperature is 16°C) and their evaporation-precipitation patterns: the moist, hot equatorial regions; the dry, hot subtropic deserts; the cool, moist temperate areas; and the cold, dry polar zones. Differences in these properties, coupled with the movement of air between the climate zones, moves water through the hydrologic cycle from one reservoir to another at different rates. The transfer of water between the atmosphere and the oceans alters the salt content of the oceans' surface water and, with the seasonal latitude changes in surface temperature, determines many of the characteristics of the world's oceans, which will be explored in chapters 6 and 7.

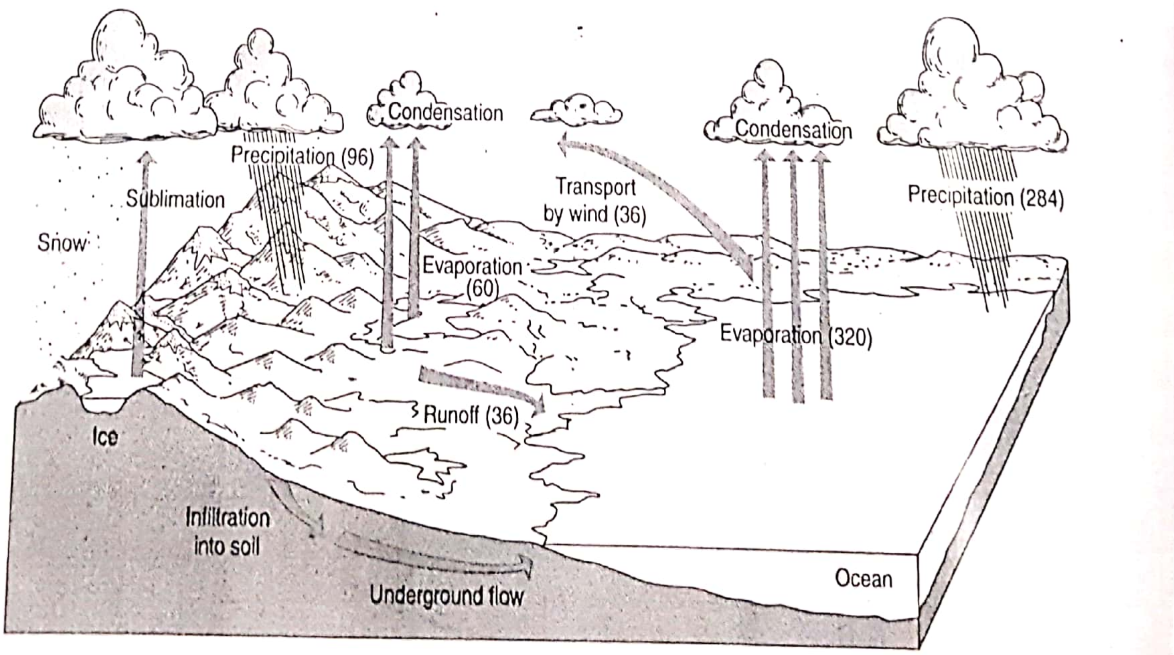
Use the annual transfer amounts in figure 2.17 to show that ocean volume does not change during the year.

Why does the whole Earth cycle shown in figure 2.17 not apply to a specific region of Earth?

What is the relationship between the hydrologic cycle and climate zones?

2.11 Distribution of Land and Water

The oceans cover 362 million square kilometers (362×10^6 km^2 or 139.8×10^6 mi^2) of Earth's surface. (If you are unfamiliar with scientific notation to express very large numbers, see Appendix C.) Because these numbers are so large, they do not convey a clear idea of size; therefore, an easier concept to remember is that 71% of Earth's surface is covered by the oceans, and only 29% is land above sea level.

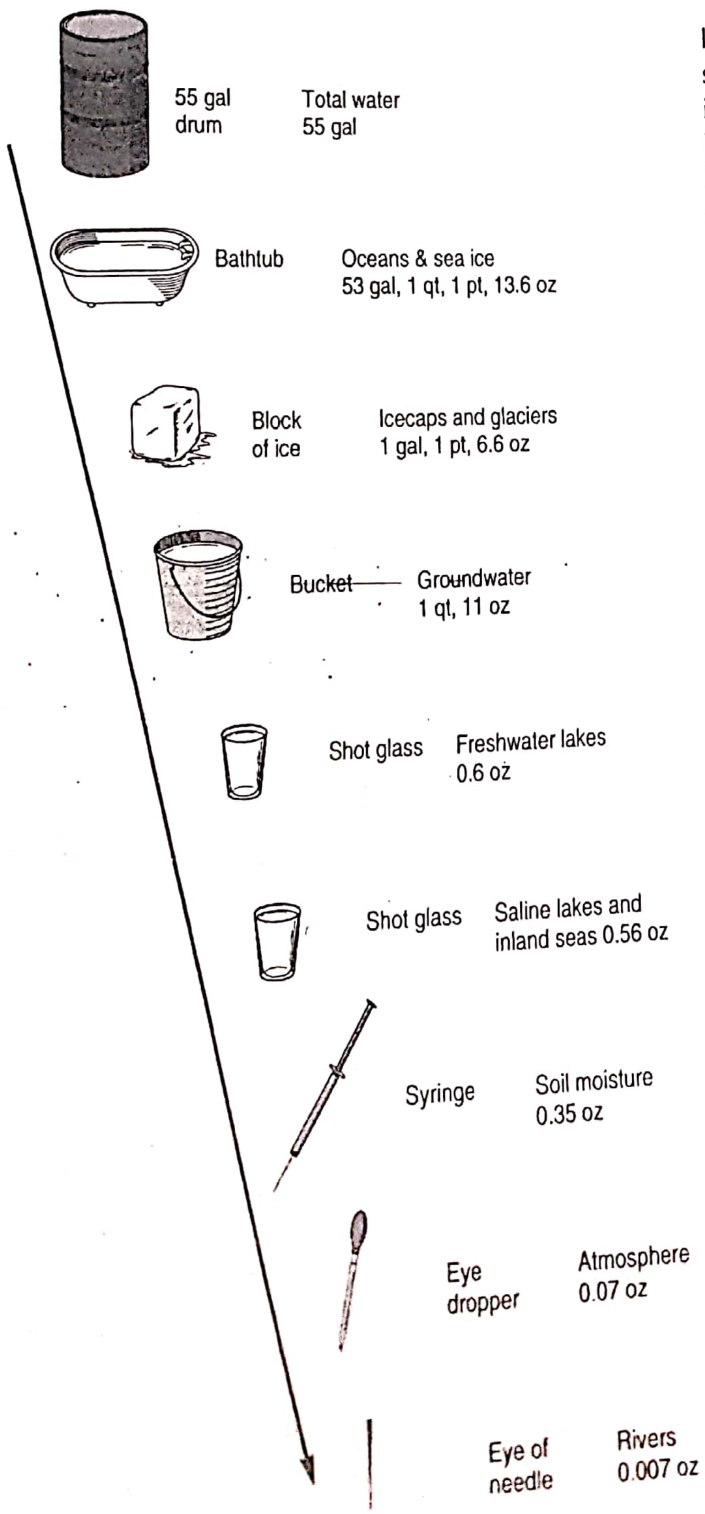


web link **Figure 2.17** The hydrologic cycle and annual transfer rates for Earth as a whole. Precipitation transfer rate includes both snow and rain. Evaporation transfer rate from the continents includes evaporation of surface water, transpiration (the release of water to the atmosphere by plants), and sublimation (the direct change in state from ice to water vapor). Runoff from the continents includes both surface flow and underground flow. Annual transfer rates in thousands of cubic kilometers (10^3 km^3).

Table 2.2 Earth's Water Supply

Approximate Water Volume

Reservoir	(km³)	(mi³)	Approximate Perce of Total Water
Oceans & sea ice	1,349,929,000	323,866,000	97.26
Ice caps and glaciers	29,289,000	7,000,000	2.11
Groundwater	8,368,000	2,000,000	0.60
Freshwater lakes	125,500	30,000	0.009
Saline lakes and inland seas	105,000	25,000	0.008
Soil moisture	67,000	16,000	0.005
Atmosphere	13,000	3,100	0.0009
Rivers	1,250	300	0.0001
Total water volume	1,387,897,750	332,940,400	100



web link **Figure 2.18** Comparison of the amount of the water supply held in each of the major water reservoirs. For purp illustration Earth's total water supply has been scaled down to the of a 55-gallon drum.

The volume of water in the oceans is enormous: 1.35 lion cubic kilometers (1.35×10^9 km³). A cubic kilomet seawater is very large indeed. Consider this: the largest bui in the world in cubic capacity is the main assembly plant c Boeing Company in Everett, Washington. This building is for the manufacture of Boeing airplanes and has a cubic ca ity of 0.0847 km³; in other words, 11.8 of these buildings w fit into one cubic kilometer. Another way to express the oc volume is to think of a smooth sphere with exactly the surface area as Earth uniformly covered with the water fro oceans. Such a sphere would be covered by a layer of 2645 m (8680 ft) deep. If the water from all other sources i world were added, the depth would rise to 2720 m (8924 ft

To understand the distribution of land and water over consider Earth when it is viewed from the north (fig. 2.19a from the south (fig. 2.19b). About 70% of Earth's landm are in the Northern Hemisphere, and most of the land lies middle latitudes. The Southern Hemisphere is the water sphere, with its land located mostly in the tropic latitudes a the polar region.

Another method used by oceanographers to depict water relationships is shown in figure 2.20. This graph of or elevation versus area is called a **hypsographic curve.** volume is the product of height and area, the hypsogr curve can also be used to show both the volume of land sea level and the volume of the oceans below sea level.

How much of Earth's surface is land, and how much i covered by the oceans?

How do the land-water distributions of the Northern Southern Hemispheres differ?

What does the hydrographic curve show us about the relationship of Earth's land and water?