Why Do We Have an Ocean?

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Abstract - The question at first seems rather straightforward - we've got lots of water, and 97% is in the marine realm. Most oceanography texts tell us "the earth's surface is 71% water - we are "the blue planet." But little more attention is paid to <u>why</u> we have an ocean, as we know it. There is water ice on 19 moons of the giant planets, with a distinct possibility that the Jovian moon Europa may have a liquid ocean beneath an icy crust. Evidence from Mars suggests large volume of liquid water (lakes, small oceans) may have been present in the past, and large in channels and gullies on the Martian surface show evidence of liquid (water) erosion. Yet nothing in our solar system compares with earth's marine dominance.

To make an ocean like Earth's several elements are required:

1) A large volume of liquid
2) This requires elements forming the liquid be plentiful
3 The compound must have a prominent broad liquid phase
4) Gravity to retain the fluid
5) Depressions to contain the fluid if land and ocean are to be separate
6) An atmosphere
7) Luck - the proper narrow distance from a solar source.

This paper will assess these requirements and demonstrate why the earth is unique in our solar system, and that life as we know it is dependant on these variables.

Introduction

In a wonderful book published 120 years ago, J. W. Van Dervoort (The Water World) introduces his text as follows:

"We never tire of the sea; it is a laboratory in which delightful processes are continually being wrought out for our admiration and use. Its flora and its fauna, its waves and its tides, its salts and its currents, all afford grand and profitable themes of study and thought." (Van Dervoort, 1883). In the current frenzy of publishing, a glance back at more tranquil times when quiet reflection of ocean processes captured general perceptions which naturalists extolled can provide us with broader insights into fundamental aspects of oceanography. These brief notes were excerpted from introductory materials collected for teaching a graduate course in Oceanography at The Johns Hopkins University. It was surprising when the same topics were presented at a Woods Hole workshop - Why Do We Have An Ocean?- and participants asked if the author had ever published these observations.

I had not considered such material profound, but in a collective sense it seemed no one had put such factors all together. Considering the aspects of why (?), it seemed interesting to assemble the factors in a context for others to consider and perhaps use as introductory material for an oceanography class.

A Large Volume of Liquid

The volume of oceanic waters is about 1.4 billion cubic kilometers, representing 97% of the total liquid water on the planet. Only 3% is fresh water, and about 2% of this amount is in the form of ice. The remainder is found is lakes, rivers, ground water and organisms (you readers should know you are about 71% water). The allotment of water is shown in Figure 1, with the fresh water volume somewhat enlarged for labeling. Thus the first requirement for an ocean - a large volume of liquid - is met by this quantity. It is believed that most of the water was derived in the early formative periods of the earth when liquids were released from hot springs, volcanoes and crystallization of magma which expel water and gasses. These processes go on today, although perhaps not at the rates and scales of earlier times.

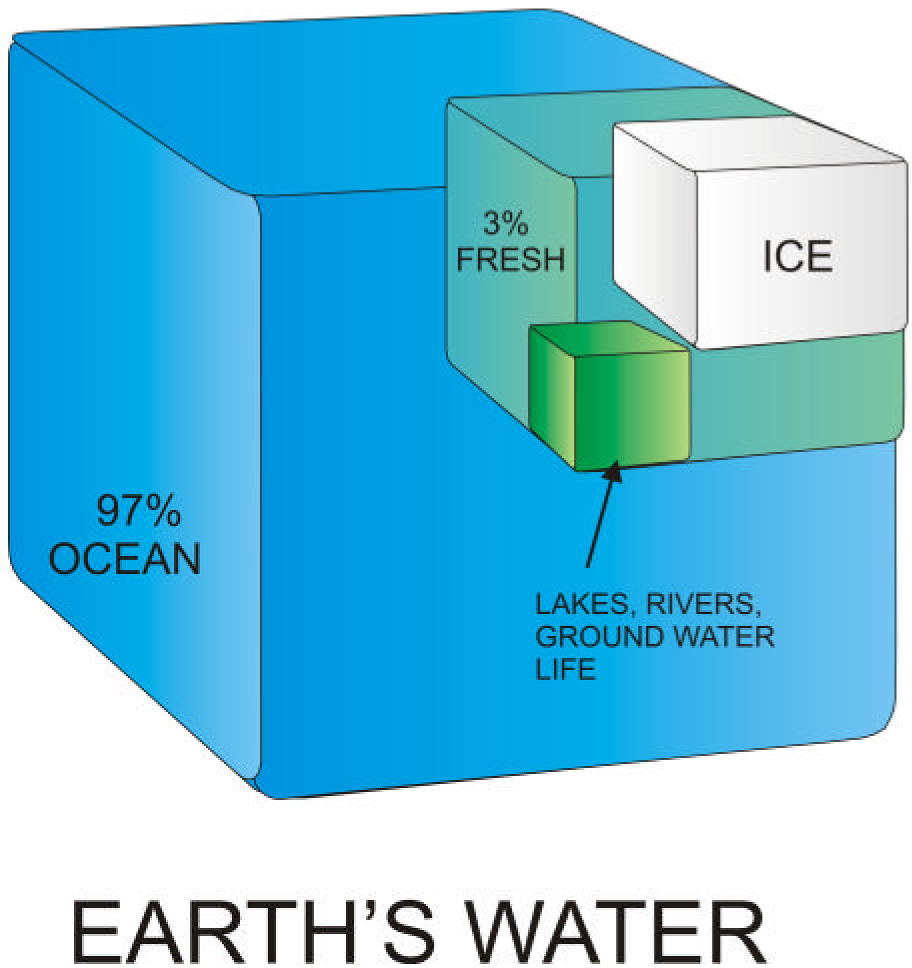

Figure 1: Distribution of water on Earth.
(Not to scale)

Plentiful Elements

Figure 2 provides a snapshot of the 6 most plentiful elements in out solar system. They are, in decreasing abundance, Hydrogen (H), Helium (He), Oxygen (O), Neon (Ne), Nitrogen (N), and Carbon (C). While Neon and Helium may be found in the atmosphere, they do not combine with other elements and are thus not "ocean makers" in our quest for building a liquid. We need to merge the remaining 4 into compounds that can provide our liquid requirements.

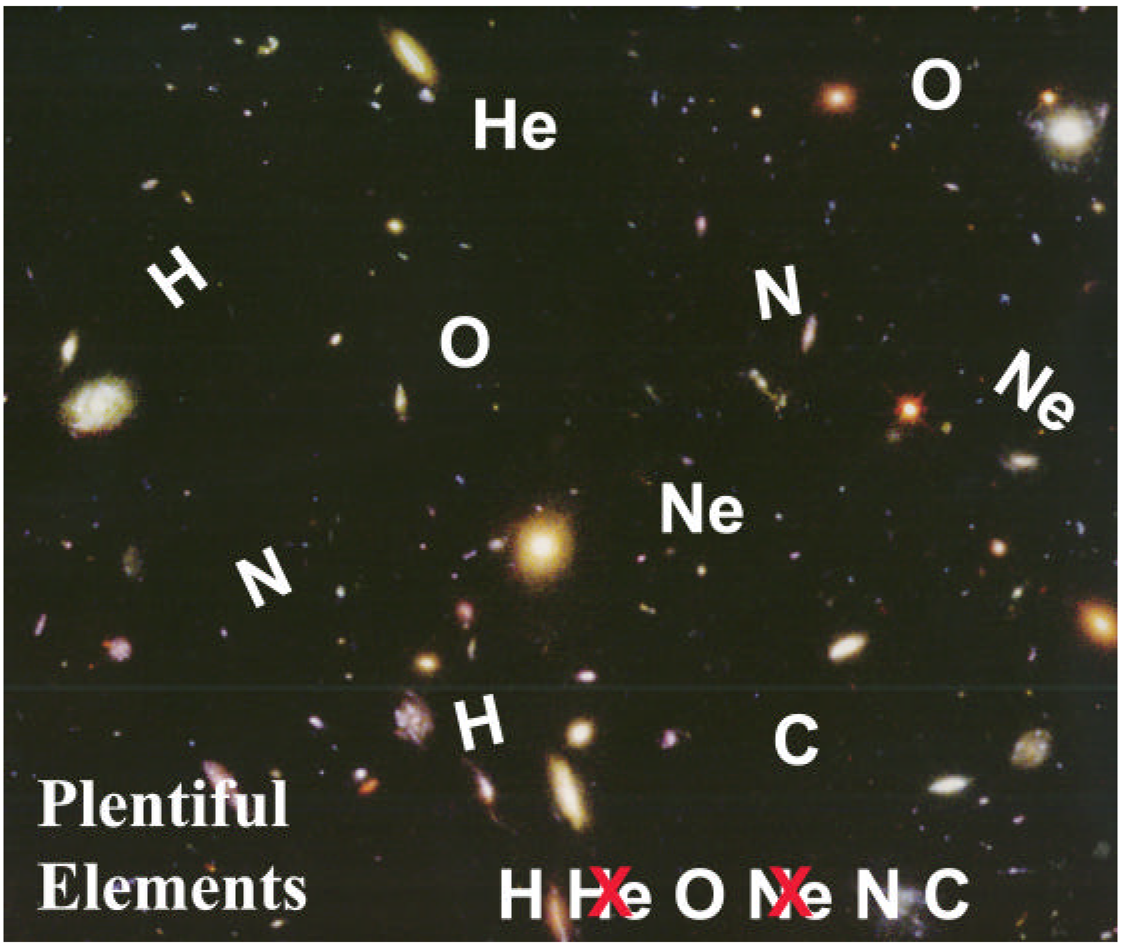

Figure 2: The six most common elements in the universe. He and Ne cannot combine to form compounds and are excluded from "ocean makers."

Prominent Liquid Phase

Now we have to select the remaining 4 common elements into "ocean makers." Constrained by a one-atmosphere condition (about 1013 millibar at the surface) we can consider hydrogen combining with the other three common elements (O, N and C). Looking at Figure 3, we see that 2 candidates (N and C) can make a liquid ocean but only under unusual (or on earth impossible) conditions. Within the bounds of earth temperatures (say -40ºC to +49ºC) a methane ocean (CH4) cannot exist. An ammonia ocean (NH3) might be possible in, say, Antarctica, but it would seem an ephemeral body that would not survive in winter (northern hemisphere) months. So we are left, thankfully, with an H2O ocean stable over much of the terrestrial temperature range as either a liquid or solid form. The range is so broad that this ocean can remain "stable" at our conditions.

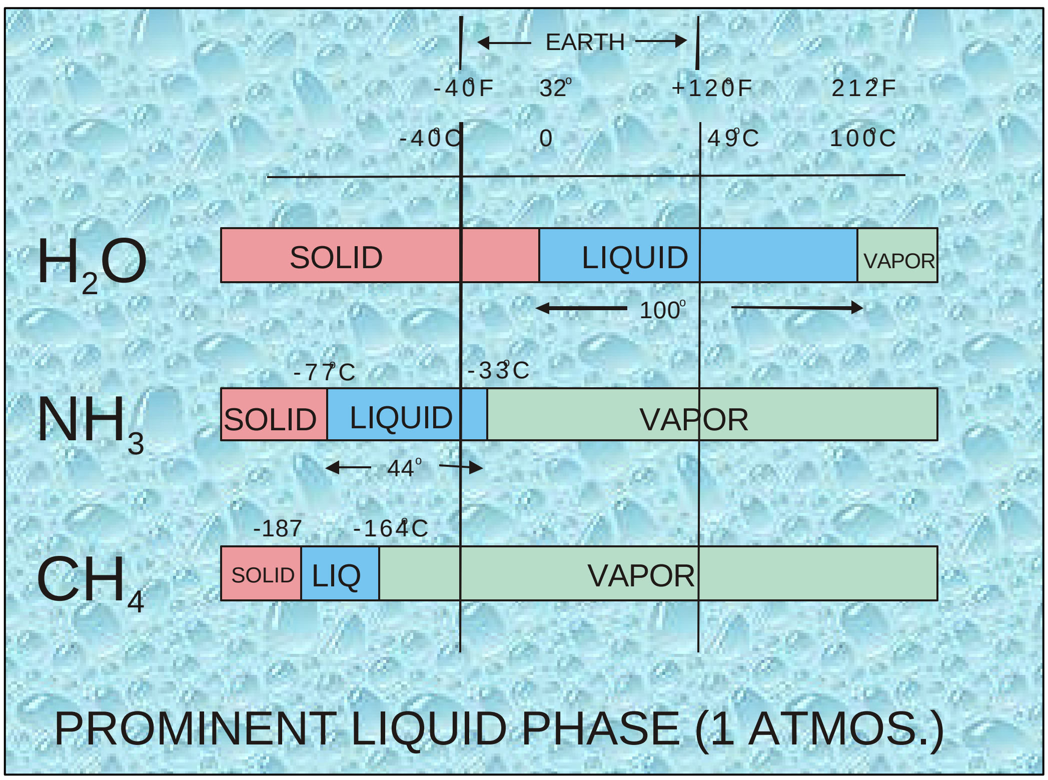

Figure 3: Three possible ocean compounds from plentiful elements. Constraints of Earth's temperature (at 1 atmosphere) permit only one combination for a liquid ocean.

Recently, various sensors on spacecraft provided imagery and spectral data on planets and their moons that reveal the presence of H20 as ice, or perhaps liquid water, which at one time (Mars) may have formed extraterrestrial oceans. While we are anticipating findings from probes to these sites, our unique "blue marble" planet remains the only domain where an ocean is dominant.

Europa, a Jovian moon, appears to have an icy crust whose fractures may reflect liquid turbulence at some depth. The intriguing prospect of an ocean beneath this icy rind kept in a liquid state by volcanic (core) heat has excited scientists who consider possible extraterrestrial life as a real possibility in a remote corner of our solar system. Even more remote is a possible ocean of ethane on Saturn's moon Titan Spacecraft now en route to Saturn will investigate the possibility of an exotic ocean on a moon about one-third of the size of earth

Gravity to Retain the Fluid

The size and density of the earth is sufficient to provide a gravitational field that will hold our liquid ocean (and atmosphere) intact and bound to the surface. While this may seem a superfluous factor, the fluid and atmospheric elements are captured and retained by earth's gravity. Without this force, a fluid and elements can escape a planetary body.

Depressions to Contain an Ocean

Considering the volume of ocean waters, if the earth were a smooth sphere without depressions the liquid envelope would be about 270 meters deep (Figure 4). Since we (homo sapiens) exist on a dry surface, this is an important distinction. The good news is that plate tectonics theory has developed to the point that we can now understand how ocean basins evolved, and continental masses became separated and oceans filled the voids (Figure 5). While these continental masses shifted about, the ocean volume did not change significantly.

Figure 4: If there were no depressions on the Earth's surface, the ocean would be a liquid envelope 270 meters deep.

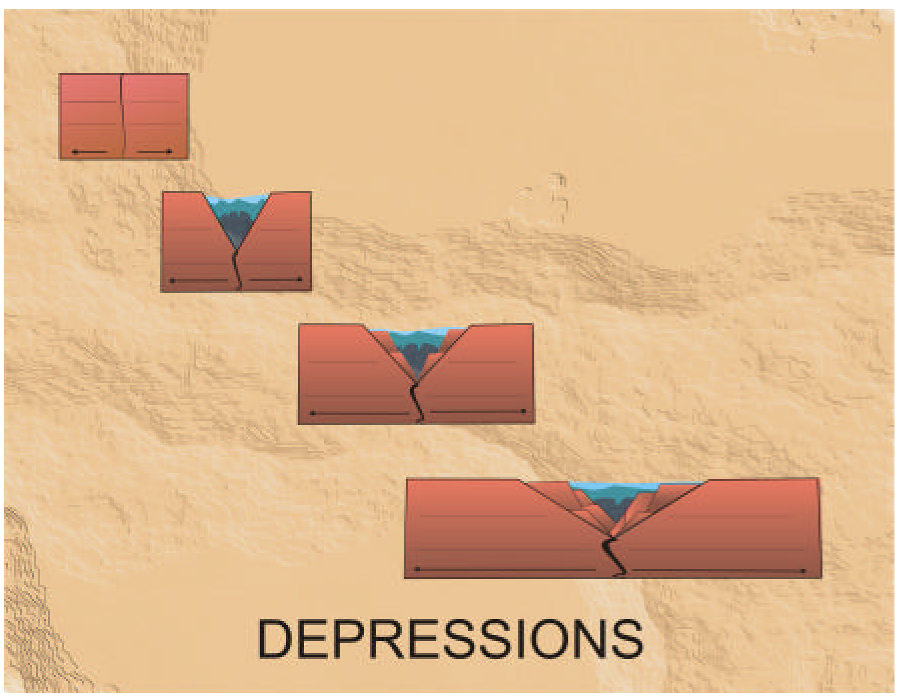

Figure 5: Global processes create depressions through rifting of the crust.

Atmosphere

An atmosphere was essential in the development of an ocean. It evolved as the earth "degassed," its fluids and gasses being expelled to create the liquid ocean and atmosphere. It provides protection from harmful radiation, a "cap" for the water cycle (Figure 6) and an envelope of life supporting gasses. It is held in place by gravity.

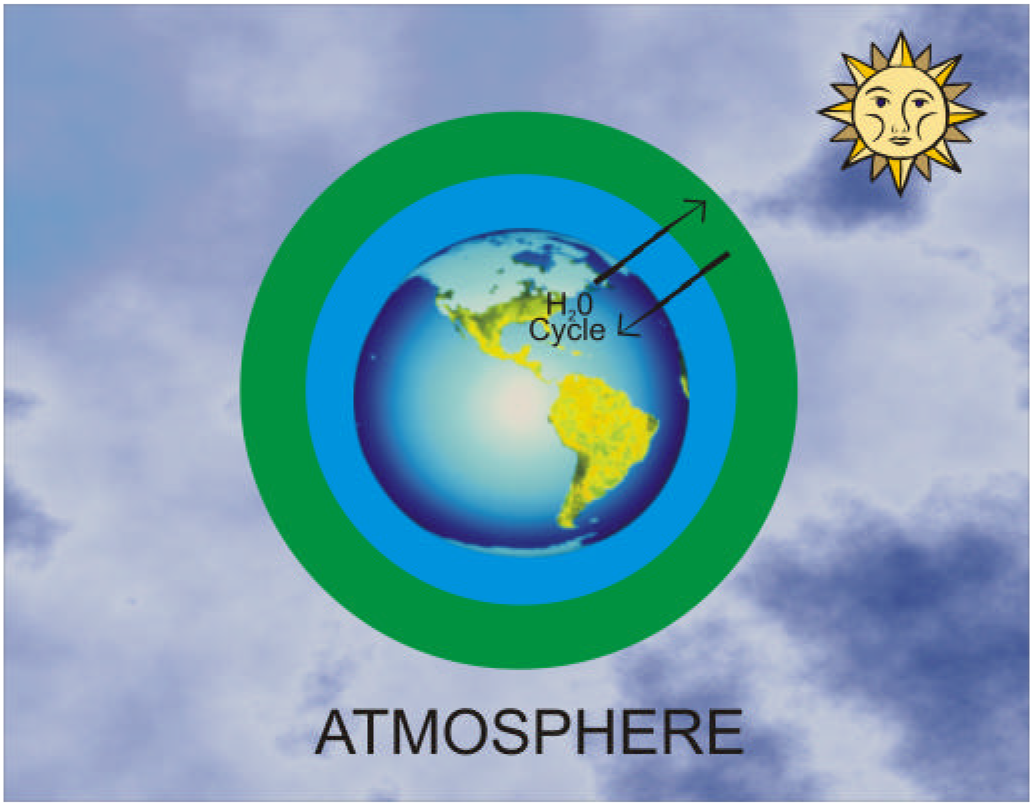

Figure 6: The atmosphere provides protection from solar radiation and a cap for the water cycle

Luck - the right place

This is the most subjective of the elements. Looking at our inner solar system it is clear our location is fortuitous. Hot planets are closer to the sun, cooler ones farther out. The narrow band (10 million kilometers) of hospitable temperatures enclose our planet. This tiny window (Figure 7) has determined our success and survival in the earth's biosphere – too close and we cook, too far and we freeze.

Figure 7: Solar system lotto! Earth is in the narrow band that allows for a liquid H_2O ocean.

Coda

Consider the 7 elements we have looked at above. Think about the consequences if only **one** was lacking. Life and oceans certainly exist elsewhere – it's exciting to think about what we may find in the next few decades as probes and explorations investigate our solar system and perhaps other worlds. But we must acknowledge the incredible combination of factors that have, all together, permitted this planet to have a liquid ocean in which life began and which " … is essential to the existence of man and of all vegetation (van Dervoort,1883)."

References

Van Dervoort, J.W. (1883) "The Water World." Acme Publishing House, Chicago. 480 p.