The Water Planet and Life

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Let us suppose we wanted to compare the Earth to other planets. What would be its distinguishing features? If we had to limit them to just one, it would be difficult to choose. For instance we might try to find a feature which is not found on any other planet than Earth. Even then there are quite a few things to choose from: life, the sea, the land, plate tectonics, an oxygen-based atmosphere, civilization and a whole range of others come to mind. The answer will therefore depend on where we choose to look.

But if we were to narrow it down to one of these, the answer would most likely be that the Earth is what we will call a water planet. The significance of the phrase water planet is in fact very deep, and that is what I would like to explain in the present article. In doing so, we will find that each of the other distinctive features which we mentioned above can be organically linked into a continuous story, which also connects with the story of Water and Life which I will tell here.

When we hear the phrase a water planet, we think first of all of a planet which is rich in the substance called water. However, that planet is not the Earth. As to the total volume of water on Earth, since the amount contained in the mantle, which makes up the majority of the planet, is unknown, we do not actually know. But even allowing for this uncertainty, it cannot account for more than a few percent. There are indeed planets in the solar system which consist to several tenths of substances based on water. These are Uranus and Neptune. In these planets, the part corresponding to what in the Earth is called the mantle consists of water, so that they are literally made up mostly of water. However, the form in which the substance is present is not liquid but probably ice. These planets are therefore sometimes called the icy planets.

So what makes a planet a water planet? To put it in specialist terms, we need to ask how the element ratio of hydrogen to carbon in the Earth's surface region compares with that on other planets and meteorites, but for present purposes, we use the term water planet to mean a planet the surface of which is covered in liquid water, that is the sea. When we investigate the conditions under which this water planet came into being, in other words the conditions under which a stable ocean can form, we will see that a number of the distinctive features of the Earth which we mentioned above are interrelated.

First of all, I will speak about the process of formation of the seas. Planets, as we shall see in detail later, are formed through the collision of small heavenly bodies of 10 kilometers or less in diameter known as planetesimals. The speed of the collisions, however, is 10 km a second or more, so that what I called a collision is in fact more like an explosion. When this happened, the volatile substances contained in the planetesimals evaporated and formed a cloud of gas around the primitive Earth. The greenhouse effect of this gas sealed the heat of the explosions into the Earth's surface, causing temperature to rise at the surface, which melted and became a magma ocean. The primitive atmosphere and the magma ocean engaged in physical and chemical interaction until a state of equilibrium was reached. As a result, the primitive atmosphere consisted mainly of steam and had a pressure of around 100 atmospheres. As the Earth approached its present size, the number of colliding planetesimals decreased and the surface began to cool; the primitive steam atmosphere became unstable, condensed, and fell to the surface as rain. This was how the sea was formed.

The question was whether this sea could continue to exist in a stable manner. Related to this question is the paradox of the faint young sun. The brightness of the sun is not constant. It is thought to have once been dark and to have gradually become brighter to reach its present brilliance. If the brightness of the sun changes, the temperature on the planet surface also changes. For instance, if, with the atmosphere as it is at present, the brightness of the sun gradually decreased, the surface temperature would also decrease. If we calculate the past surface temperature of the Earth based on current estimates of the change in the sun's brightness over time, we would find that around 2 billion years ago, the average temperature was 0°C. Before then it would have been below freezing, which would mean that the sea would have been frozen. However, geological records prove that the Earth gets warmer the further back we go and that even 3.8 billion years ago the seas were in existence. This contradictory state is known as the paradox of the faint young sun.

However, when we think about the process of formation of the sea mentioned above, the paradox of the faint young sun resolves itself. The primitive atmosphere of the time immediately after the formation of the sea consisted chiefly of carbon dioxide. If we allow for the related greenhouse effect, even if the sun was faint, the surface temperature would have been kept at the relatively high level of several tens of degrees Celsius. Now, the problem becomes the opposite: if the surface temperature began at around the same level as now or higher, as the sun's brightness increased from the past toward the present, the surface temperature would have increased and the sea would have evaporated. This time we are faced with the bright sun paradox.

These contradictions arise when we take the premise that the atmosphere was the same as now, or that the original atmosphere did not change. In actual fact, the Earth is a system of which the atmosphere, the sea, the continents, and so on are constituent elements. If an external condition such as the brightness of the sun changes, the Earth responds to it as a system. The abovementioned premise is therefore inaccurate. Specifically, the carbon cycle in the surface region depends on the surface temperature and this interrelationship regulates the amount of carbon dioxide in the atmosphere, so that whether the sun was faint or bright in the past, a constant surface temperature was maintained. To balance this, the volume of carbon dioxide in the atmosphere varied greatly.

I will now give a simple explanation of this so-called carbon cycle. When it rains, the carbon dioxide in the atmosphere dissolves into the rain, falls with it, and is removed thus from the atmosphere. The rain erodes the rocks of the continent and carries a variety of chemical elements into the sea. For instance, carbon dioxide in the form of heavy carbonate ions flows into the seas together with positive ions of calcium and magnesium, where they are used by shellfish and other creatures to make shells (calcium carbonate). When the shellfish die, their shells sink to the seabed, and when the seabed shifts under the influence of plate tectonics, they are carried to the edge of the continents, where they are submerged with the oceanic crust into the Earth's mantle. When a certain temperature is reached, the submerged seashells (calcium carbonate) react with the surrounding quartz (silicic acid) to form silicate minerals. The now redundant carbon dioxide is then released into the atmosphere in volcanic gases through the island-arc volcanism, whereby the cycle is completed.

The removal of carbon dioxide from the atmosphere depends on the amount of rainfall, which in turn depends on the surface temperature of the Earth. The supply of carbon dioxide through volcanic activity, however, does not depend on the surface temperature. Therefore, when the surface temperature falls, the amount of carbon dioxide removed from the atmosphere decreases, and carbon dioxide begins to accumulate in the atmosphere. This reinforces the greenhouse effect and the surface temperature rises. In the opposite set of circumstances, the amount of carbon dioxide in the atmosphere falls, the greenhouse effect is weakened, and the surface temperature falls. In this way, the carbon cycle has a negative feedback effect on changes in the surface temperature of the Earth.

Additionally, carbon dioxide in the atmosphere is exchanged with living things through photosynthesis, so that when they die and decompose it is returned to the atmosphere. However, the amount of carbon dioxide involved in this cycle is negligible compared to that in the cycle described above, accounting for only one-fifth of all the carbon dioxide in the atmosphere. I will therefore from now on take into account only the first-mentioned carbon cycle. What is important is that this cycle depends on the existence of the continental crust and on the process known as plate tectonics which involves the interaction between the Earth's crust and the mantle. If there were no continental crust and no plate tectonics on Earth, the sea would not have been able to remain stable.

Meanwhile, the origin of the continents is profoundly connected with the existence of the sea. The continental crust is made up of a type of rock known as granite, while the Earth's crust below the sea is made up of a kind of rock known as basalt.

Apart from its presence on Earth, basalt is also a main constituent of the crust of earthlike planets, the moon, and other bodies, and is thus a kind of universal element in the rock forms of the solar system. Granite, however, is a very special type of rock which has so far not been found on any heavenly body apart from the Earth. Granite is thought to have been formed by partial melting of basalt which was part of the oceanic crust and contained water. It is thus a kind of rock which could only come into being if there were a sea. It is also lighter than basalt. This means that it can float like icebergs on the mantle so that its surface is exposed above the sea surface. This is also a very significant factor in the creation of the carbon cycle mentioned earlier.

The origin of life is still somewhat unclear. At the moment, one factor which is known to have determined its origin is the close agreement between the elements from which life is made and the elements dissolved in the sea. In this sense, the existence of the sea is a precondition for the birth of life. The point to note here is that when we refer to the elemental composition of the sea, what we mean is its composition after the creation of the continents. In other words, it was when the sea and the continents had come into being and the conditions for the long-term stable existence of the sea had been fulfilled that life was born. The fact that the sea and the continents are found only on the Earth, like life too, suggests that the origin and evolution of these three were closely intertwined.

Subsequently, the birth of photosynthetic life led to the profusion of life on Earth and the biosphere within the Earth system came into being. Living beings have since been an influence on the behavior of the Earth system. For instance, the free oxygen which is present in large quantities in the atmosphere is produced by photosynthetic life and is therefore closely related to biological activity. So close is the relation that if we wanted to undertake remote sensing of planets containing life, we would do well to try to detect free radicals in the atmosphere.

From the above, it should be clear that the distinctive feature of the Earth is in the story of the water planet that links together the sea, the continents, and life. Lastly I want to consider what degree of universality the story of the water planet could have in the universe. This is to ask whether biology, like physics and chemistry, is a universal science valid in the universe as well as on Earth. Specifically, the questions are for instance whether Earth is a universal model for a planet that can produce and nurture life; whether life on Earth is a universal model for life on a universal scale; and similarly with regard to us as an intelligent life form and our civilization.

First, let us give an outline of how a water planet like Earth or the solar system is formed. A star is formed on the condensation of a highly dense cloud of gas and dust known as a molecular cloud core. When a star has been formed at its core, there is left around the periphery a disk-shaped cloud called a protoplanetary accretion disk. When this cools and condenses, a wide range of mineral particles is formed. From these disks of mineral particles, small heavenly bodies of up to 10 km in diameter are formed, known as planetesimals, which through a series of collisions finally grow into planets. If large volumes of gas are left over in the protoplanetary accretion disk, the planets draw these in and become giant gaseous planets.

Our solar system shows a distribution from inside to outside in the order of Earth-type planets, giant gaseous planets, and icy planets. When a protoplanetary accretion disk of a certain size is present around the star, a planetary system of this kind is formed. However, if the volume of the gaseous material is different, a planetary system of a kind different to the solar system is formed. For instance, if the volume is great there is formed a planetary system in which two or three giant gaseous planets are found in the region where, in the solar system, earthlike planets are present. The planetary systems of which a whole series has been discovered recently are systems of this kind which are predicted by numerical calculation. Unfortunately, no planetary system like the solar system has yet been discovered. This suggests that the solar system is not a generally and universally valid planetary system. But this does not mean that a planetary system like the solar system does not exist. It simply means that the currently available measuring technology has not reached a sufficient level of development.

In the case of these planetary systems of other kinds, a water planet of the Earth's kind is not formed. However, around the giant gaseous planets found close to the Earth's orbit, there is a strong likelihood of there being water satellites. In the present solar system, we would not be surprised to find that a satellite such as Jupiter's moon Europa was a water satellite. If the existence of the sea is a precondition for the birth of life, it is possible that life could emerge on one of these water satellites. However, in the life that emerged there, even if its main constituents were the same carbon, hydrogen, nitrogen, and oxygen, the other elements involved might be completely different. This is an issue which would need to be considered if in future an exploratory vessel were to be sent to the Jupiter moons Galileo and Europa to search for life.

The above suggests that even in the absence of the factors Earth and solar system, a whole range of possibilities for the emergence and evolution of life can be imagined. In other words, if we try to extend our conception of the Earth and life on Earth to the timespace scale of the universe, we will find that they do not constitute universal models for a heavenly body that gives birth to and nurtures life or for a form of life.

What about intelligent life forms and civilization? The structure of an intelligent life form may change as the constituent elements of life themselves change. However, the actual content of that intelligence should have potential universality. This is to say that, in the end, the essence of intelligence is nothing other than the result of understanding what nature is, which is common to the whole universe. Nature is a thing created in the process of the formation and evolution of this universe and can be likened to an ancient text recording the history of the universe. Since the ancient text we must decipher is the same, the structure of the intellect must also be similar.

Civilization, if we categorize it from the viewpoint of the present paper, can be defined as a way of living created within the Earth system by one of its constituent elements, the human sphere. In this sense, civilization could also have universality.

Unless this kind of way of living is used, an intelligent life form able to create advanced science and technology cannot develop. From this viewpoint, to try rethinking the meaning of universality is perhaps one of the most important things for us to do now. By which I mean that many of the problems now being discussed in society have a profound connection with this question of universality.