S39-90
118676
11 P.

N89-26363

CHEMICAL EVOLUTION: A SOLAR SYSTEM PERSPECTIVE

J. Oró
Department of Biochemical and Biophysical Sciences
University of Houston H2086788
Houston, TX 77004

During the last three decades major advances have been made in our understanding of the formation of carbon compounds in the universe and of the occurrence of processes of chemical evolution in the solar system and beyond. This has been made possible by the development of new astronomical techniques and by the exploration of the solar system by means of properly instrumented spacecraft. We summarize here some of the major findings made as a result of these observations.

1. Interstellar molecules. By means of radioastronomy and microwave spectroscopy it has been found that the interstellar medium contains a diversity of molecules made of biogenic elements (H, C, N, O, S, P, etc.). About 75% of the molecules contain the element carbon, that is to say, they are organic. Formaldehyde was the first organic molecule discovered in interstellar space. The other molecules vary in complexity from diatomic species, such as CO, to molecules with thirteen atoms, such as cyanopentaacetylene. Using other methods of astronomical observation and chemical analysis, much more complex molecules have been found in interstellar space, namely polycyclic aromatic hydrocarbons and other probable precursors of different forms of carbon (amorphous, graphitic, and with diamond-like structures). It appears obvious that the immediate sources of most of the carbon-rich molecules are the carbon-rich stars. There, upon combination of carbon with itself and with other biogenic elements (in the atmospheres of stars, or in their circumstellar shells), the newly formed molecules are ejected into the cold interstellar space. It is only in this way that one can explain the formation of cyanoacetylene and all the higher homologues up to cyanopentaacetylene found in the circumstellar shells of some of these carbon-rich stars. It should be pointed out that one of the more recent discoveries is that of PN, which is the first molecule with the element phosphorus detected in interstellar space. Some of the interstellar molecules are considered be the primeval precursors of the biochemical compounds present in living matter. Indeed, in experiments carried out in terrestrial laboratories, twelve of these molecules (H_2, H_2O, NH_3, CO, CH_2O, CH_2S, CH_3CHO, RCHO, HCN, HC_2CN, H_2NCN, PN, or H_3PO_4) have been demonstrated to yield the basic building blocks of proteins, nucleic acids and membrane lipids. It should also be said that most of the above interstellar molecules are also present in comets.

2. Comets. Comets are without doubt the most interesting bodies in the solar system from the point of view of chemical evolution and the origin of life. They contain large quantities of organic molecules and related chemical species which have been detected in the past by optical and microwave spectroscopy and more recently by mass spectrometry. The spacecrafts sent by the Soviet Union and the European Space Agency to Halley's comet have provided a wealth of information concerning the chemical organic composition of this comet. Aside from the finding of water, ammonia, carbon monoxide, carbon dioxide, hydrogen cyanide, formaldehyde, and presumably a number of heterocyclic (e.g., adenine) and other interesting organic compounds, one of the most surprising observations was the finding of what appears to be the first homologous polymeric molecule present in comets: Polyoxymethylene, or POM, which is a homopolymer of formaldehyde. This supports the concept that comets are aggregates of interstellar molecules condensed prior to the formation of the solar nebula, out of which the solar system was formed. The observation of the pristine nature

of the matter in comets has been held since the beginning of the study of these interesting objects of the solar system. Another observation supporting the pristine nature of comets is the low density determined for Halley's comet, which is indicative of the absence of any significant differentiation of metamorphic processes occurring in such objects.

3. The Jovian planets and Titan. The molecular composition of the atmospheres of the giant planets shows the presence of simple organic compounds in their most hydrogenated forms, such as methane and other hydrocarbons. One could expect this because the large mass of these planets is capable of retaining the hydrogen which is lost in the smaller bodies. However, a close examination of their atmospheres, as well as that of Titan, shows the presence of a number of the same organic molecules which we have encountered first in interstellar space and then in comets. In the case of Jupiter and Saturn, due to the highly dynamic nature of the convection processes occurring in their atmospheres, where large masses of gases and other matter go through regions of different thermal history, one may expect to find concentrations of different organic molecules in conditions of steady state since organic compounds must continuously be formed and destroyed. The thermal processes occurring in the lower layers of the atmosphere of Jupiter would rule out the possibility of chemical evolutionary processes leading to the formation of labile biochemical compounds. Thus it may not be useful to search in these planets for biochemical compounds such as amino acids, or any other important building blocks of biochemical molecules. On the other hand, adenine and other polymers of hydrogen cyanide may be found in the oceans of Titan as a result of the photocondensation of hydrogen cyanide present in its atmosphere. Indeed Titan may turn out to be a storehouse of organic and biochemical compounds preserved in its ocean at very low temperatures.

4. Asteroids and parent bodies of meteorites. Recent observations have indicated that about three-fourths of the asteroids are characterized by having a reflectance spectra somewhat similar to that produced by carbonaceous chondrites. The presumption is made that the composition of the dark asteroids is somewhat similar to that of carbonaceous chondrites. This observation is in line with the widely held hypothesis that the asteroidal belt is probably the major source of the carbonaceous chondrites which have fallen on Earth. As it is known, since 1806 when the first of the carbonaceous chondrites, the Alais meteorite, was analyzed, this group of meteorites contains substantial amounts of water and organic compounds. Among the organic compounds, amino acids and other biochemical molecules have been found. Some of the recent analyses have established the presence of more than 70 amino acids. Among them there are eight amino acids that are usual components of proteins. Some of the others are only found occasionally in biological systems as metabolic products but the remaining amino acids are completely alien to life. It should be clear that in all the cases examined so far (excluding the few cases of possible terrestrial contamination) the amino acids have been found to be racemic mixtures, that is to say, there is an equal amount of the enantiomeric forms D and L for each amino acid. This is the best demonstration that these compounds are indigenous to the meteorite and that they were synthesized by chemical processes, prior to or at about the time of the formation of the solar system. It should also be said that no significant amount of polymers of amino acids, or of other biochemical building blocks, have been isolated from meteorites and unequivocally characterized. This observation is important because it provides an insight into the limitations of the processes of chemical evolution in dark asteroids or the parent bodies of carbonaceous chondrites. Since the Soviet Union is sending probes to Phobos and Mars, 1988-1998, it is appropriate to point out that the characteristic features of Phobos are somewhat comparable to that of the dark asteroids. Therefore it will be interesting to find out if the analyses performed on Phobos demonstrate the presence of amino acids or related biochemical molecules.

5. Terrestrial planets, Earth. The current theory of the origin of the Earth-Moon system suggests that a body the size of Mars collided with the proto-Earth, injected most of the iron into the core of Earth, melted the proto-Earth, and as a result of the impact a significant portion of Earth mantle was ejected into an orbit around Earth, which eventually aggregated and coalesced to form what is the Moon. It is obvious such a catastrophic process would have thrown out of the proto-Earth most of the water and other volatile components. If such was the case one has to ask the source of the secondary primitive atmosphere and hydrosphere after such an event took place. There are two probable sources; additional outgassing from Earth's interior, and capture of planetesimals, comets and other solar system bodies containing these volatiles. We have argued elsewhere that comets could have contributed to primitive Earth as much as 10^{23} grams of matter. Since water and organic compounds are major components of comets this means that primitive Earth captured substantial amounts of simple organic compounds which were probably used as precursors of biochemical molecules. In fact if only 10% of the captured cometary material was involved in this process, this is equivalent to about 10,000 times the total amount of the matter in Earth's biosphere. In an anoxic Earth, whether the compounds are pyrolyzed, or not, upon impact, is irrelevant, because the new molecules formed, e.g., hydrogen cyanide, can recombine with water and ammonia to generate again amino acids, purines and other biochemical molecules.

6. Terrestrial planets, Mars. One could argue that similar collisional processes occurred during the formation of Mars. This was probably the case, but there are several major differences between Mars and Earth. The most significant difference is the fact that the mass of Mars is roughly about one-tenth of that of Earth. This immediately limits the capacity of internal heat generation by Mars and at the same time the ability to retain the volatiles in its atmosphere. A second major difference is that Mars is closer to the asteroidal belt and therefore it could, in principle, receive many more impacts from asteroidal bodies than Earth. A third difference is that Mars is more distant from the Sun than Earth, and that the amount of solar radiation falling on the surface is proportionately less. Thus, it is more difficult for Mars to keep the water liquid although it was probably possible on early Mars, by means of an appropriate greenhouse effect. Indeed, the observations made by the Mariner and Viking spacecrafts point out the presence of extensive "fossil" fluvial features indicating the existence of large bodies of liquid water in the past. The question arises, "Where is the water that was present during the first 800 million years of Mars history?" One of the theories suggests that a substantial portion of this liquid water and atmosphere was lost from the planet by one or several catastrophic collisions with the planet a long time ago. Small impacting cometary bodies will add volatiles, but large asteroidal bodies would deplete the atmosphere of a small planet. This depletion, together with the limited internal heat production was such that it became impossible for the planet to recapture or to generate the water and other volatiles to replenish the ancient Mars hydrosphere and atmosphere. So this leaves us with the question about the possibility of formation of biochemical compounds on the primitive Mars environment during the first 800 million years. An answer to this question can only be obtained if appropriate missions are planned for Mars. From the point of view of exobiology the primary objective should be to examine ancient sediments (subsurface layers of channels, river basins, lakes, and "mud-flower" impact craters) for the presence of organic compounds. The criteria for selecting the different sites to be examined should be studied carefully and follow a systematic approach. Thus, the Mars Observer Mission should be followed within a short time by a Mars Network Mission capable of using appropriately instrumented surface penetrators. This mission, as suggested by several exobiologists, should be planned in accordance with the best judgements and conclusions arrived at from the observations made by the Mariner, Viking and Mars Observer Missions. At a later appropriate time and in light of the findings made by these past four missions, especially the Network Mission, plans should be made for a Mars-Rover

Sample Return Mission. The latter mission should include deep drilling devices and sophisticated analytical instruments, such as combined laser beam-mass spectrometry, for the identification of organic compounds buried in the rocks or deep layer sediments.

7. Europa. Europa is different from the other three major Galilean satellites in that it has a uniformly rounded surface made of a thick layer of solid water ice. The uniqueness of its surface is that it does not show any significant impact craters but on the other hand it shows extensive linear markings several thousand km long and about km wide. These are considered to be massive cracks on the ice crust caused by the tides in its subsurface oceans which result from the gravitational interaction of this satellite with Jupiter. The presence of substantial amounts of water ($\sim$ 6%) and its density of about 3 is taken as evidence of a composition somewhat similar to that of C2 carbonaceous chondrites. These chondritic meteorites have a density of about 2.7, contain $\sim$ 2.5% carbon and $\sim$ 13% water, the rest being primarily silicates. Therefore it would not be surprising if this satellite would contain, in addition to water, substantial amounts of organic compounds similar to those present in C2 carbonaceous chondrites. But, perhaps what is more important is that the mutual interaction of the different organic compounds in the presence of fluid water under favorable primordial conditions may have pushed the organic evolutionary processes to a more advanced degree of organization than that observed in meteorites. If this were the case an appropriate landing mission to this satellite may provide a key to the understanding of the intermediate steps in the processes of chemical evolution of carbon compounds in the solar system, which on Earth led to the origin of life. The possibility of survival of terrestrial microorganisms in the subsurface oceans of Europa has been discussed in the recent literature. Indeed, a good terrestrial analog is offered by the microbial ecological community inhabiting the cold subsurface waters of the perennially frozen lakes of Antarctica.

REFERENCES

Oró, J., 1983, Chemical evolution and the origin of life, *Adv. Space Res.* **3**, 77-94.

Oró, J. (editor), 1979, The Viking mission and the question of life on Mars, Special Issue, *J. Mol. Evol.* **14**, pp. 1-233.

Snyder, C. W., 1979, The planet Mars as seen at the end of the Viking mission, *J. Geophys. Res.* **84**, 8487-8519.

McKay, Christopher P., 1986, Exobiology and future Mars missions: The search for Mars' earliest biosphere, *Adv. Space Res.* **6**, 269-285.

Reynolds, Ray T., Squyres, Steven W., Colburn, David S., McKay, Christopher P., 1983, On the habitability of Europa, *Icarus* **56**, 246-254.

Parker, Bruce C., Simmons, Jr., George M., Love, F. Gordon, Wharton, Jr., Robert A., Seaburg, Kenneth G., 1981, Modern stromatolites in Antarctic Dry Valley Lakes, *Bioscience* **31**, 656-661.