Introduction

Questions relating to the origin of life on Earth, and its possible presence elsewhere in the Universe, have fascinated Man since antiquity, whether as a man of science, a philosopher, or quite simply as a man-in-the-street. Understanding how life appeared on Earth would be the culmination of a form of a very ancient quest for our origins. Such a culmination would also be a decisive advance in our knowledge of an extremely complex natural process, the sequence of which raises numerous questions. It is these questions, which are fascinating in themselves, and frequently still without any reply, that are at the heart of the current work.

To this day, we know of one single example of life: that of life on Earth. Defining life and its essential properties is not a simple task either for a biologist, who studies life, or for an epistemologist, as someone who seeks to understand the way in which Mankind forms a concept of the world around it. We are able, however, to recognize life as a state of complex matter that is evolving in a dynamical context. And as such, life does not, therefore, escape the laws of physics and chemistry. Far from it. It is based on physical and chemical mechanisms that take place in a specific geological and atmospheric environment: that of our planet. So, life is the result of a *natural* process, and that implies that it is possible that other life forms have appeared elsewhere in the universe, based on analogous physical and chemical foundations, yet must always be constrained by the universal laws of nature.

Exploring When and How Life Emerged

Is it really possible that the life that we know today on Earth resulted from a unique combination of circumstances in the universe? What was the relative significance of determinism (predictable events obeying natural laws), chance, and contingency (not predictable, historical sequences of events) in the emergence of living beings? Is life the result of a gradual and continual increase in complexity, or was there, at one specific moment, a sudden jump in complexity leading to the emergence of new properties – for example, through a combination of several elements that interacted? All these questions currently remain open, but it is very probable that examination of the scenarios capable of explaining the emergence of life on Earth could progressively provide us with some of the factors in the answer. But for all that, both the spirit and the approach of scientists who are interested in this problem are extremely varied, depending on the disciplines involved.

So, for example, astrophysicists seek to know if other objects in the Solar System could shelter life, or even if there exist, beyond the Solar System, "other Earths" or, at least, other "habitable" planets. They expect that the study of terrestrial life and its origins will reveal the conditions that were necessary for its development, and they focus their research on extraterrestrial objects where similar conditions are likely to be combined – such objects then being considered as potentially inhabitable. Chemists, however, try to understand the process of self-organization and the establishment of sequences of reactions leading to systems capable of evolving in the same way as living beings. They thus try to determine, how, on Earth, the passage from abiotic organic chemistry to biochemistry could have taken place. Geologists are interested in the history of the planet and the impact of life on its evolution, but, above all, they try to define as precisely as possible the environmental conditions that prevailed when life emerged and that favored its development. Finally, biologists seek to know how biological evolution started, such that it gave birth to an extraordinary diversity of organisms, with very different forms, sizes, and abilities, but which all possess common properties. Exploring *how* and *when* – two crucial questions – life emerged in this small corner of the universe that is the planet Earth, concerns any one of these just as much as any other, but the scientists are only able to answer within the limits of the field in which they are involved.

As regards the question "When?", we shall see that the first difficulty is linked with the question of time, that fourth dimension which is difficult to grasp, and where scientists of the different disciplines need to establish common conventions if they wish to speak of the same thing. In fact, time is measured differently by astrophysicists, for whom time advances in an absolute manner from an initial instant of reference (t_0) – which corresponds in this book to the start of the formation of the Sun, 4.57 billion years ago (4.57 Ga) – and by geologists and biologists, who measure time backwards, relative to the present. This characteristic is very real in this book where, for a given event, we progress from an absolute time scale expressed in billions of years running *towards the present day* from the reference point, t_0 (as will be the case in the early chapters, relating to the formation of the Solar System), to a relative scale expressed in billions of years, *towards the past* (or "before present", BP, and thus, by convention, before the year 1950) when, in our story, geology and then biology take over from astrophysics. Chemists are disoriented and worried by these notions of long timescales, whether relative or absolute. In fact, for them, rather than the chronological moment when they occur, the important factor is the kinetics and thus the relative duration of chemical reactions which, to add to the difficulty, cannot be understood except in statistical terms (that is to say, over populations of molecules, in contrast to the individual random fate of a single molecule). Be that as it may, all these disciplines need to know to which common time scale they are referring when they attempt to reply to the question of "when did life appear?". We shall see in this book that, although this question remains without any precise answer, it is still possible to define a range of time during which the transition from inert to living matter occurred.

Replying to the question "How?" is more difficult and controversial. We shall never be able to obtain a definitive answer, because life is a historical (contingent) process, in other words it has evolved in an irreversible fashion over the course of time. At best we may hope to reconstruct a plausible scenario, compatible with the laws of physics as well as with the experimental data, and present-day and future observations. To this day there is no consensus about this problem – far from it! – and we sorely lack reliable, realistic data on the physical and chemical conditions that prevailed on the primitive Earth where life emerged. Consequently, numerous hypotheses, often mutually exclusive, have been suggested by researchers. Some of these, even if they do allow an explanation of the observations, could never be tested. Others, in contrast, are susceptible to being refuted one day if they do not agree with the constantly increasing body of observable data. Apart from these "structural" difficulties, there is a human factor, as shown by the fact that there exist opposing schools of thought, which sometimes rather dogmatically refuse to consider and analyze in detail any arguments that are not their own. However, it is essential to remain optimistic: such a situation tends to disappear as and when new, more reliable, data are acquired, and research into alternative pathways, often intermediate ones, enables more concrete scenarios to be proposed. We have chosen to give a broad and as neutral as possible view of these different models, preferring to put the emphasis on the existing data rather than to interpret them in a partisan manner.

A Novel Challenge: Getting Several Disciplines to Talk to One Another

The aim of this book is to present, in a chronological manner – or, at least, logically as a relative succession of events – the history of the origins of life on Earth and the conditions that allowed it to appear on our planet. The novel challenge is that for each of the time periods that form this chronology, we, as different specialists, will speak *together* to lift a corner of the veil; with the approach and questions appropriate for each original discipline. The image of the questions that it presents is therefore firmly multi-disciplinary. Astrophysics and geology will thus allow us to reconstruct the history of the formation of the Sun, of the Solar System, and of the Earth. Geology and chemistry, subject to certain constraints derived from observation that biology will impose, will deal with the occurrence of conditions required for complex chemistry and life to appear. Finally, biology will enable us to sketch the main features of evolution, and in particular to discuss the emergence of eukaryotic cells and their diversification, until the appearance of animals and terrestrial plants, which form the greatest part of the world visible to the human eye.

We have decided to stop this great tale at the Cambrian explosion, 540 million years ago, when the ancestors of the major animal lines that we see today made their appearance. At that time, biological evolution had been in progress for over 2 or even 3 billion years, and the multiplicity of directions that it was to follow subsequently – including the appearance of humans within a small phylogenetic line of descent among hundreds of others – is of lesser importance for our understanding of the origins and evolution of primordial life on Earth.

Lessons for Astrobiology?

The present book is based on a translation of the French original “Le Soleil, la Terre... la Vie” (the Sun, the Earth... Life), published in 2009 by Editions Belin (Paris). At the request of Springer, we have completed the original version by a new chapter on “Extrasolar planets”, i.e., the hundreds of planets and planetary systems discovered since 1995 around normal stars other than the Sun. To stick to the original spirit of the book, we have put emphasis on the fascinating question of a particular sub-class called “habitable planets”.

As the reader will see, the state-of-the-art in this field is still entirely astronomical, with no indication whatsoever of any “biological” evidence. In this context, is it really justified to use the terms “exobiology”, or “astrobiology”, which *stricto sensu* should etymologically mean “extraterrestrial biology” and “biology applied to astronomy”, respectively? In his Preface to the Springer “Encyclopedia of Astrobiology” (2011), C. De Duve (awarded the Nobel-Prize for Physiology and Medicine in 1974), speaks of “the new discipline of exobiology-cum-bioastronomy-cum-astrobiology”, implying that these three commonly found denominations are equivalent. In the context of the present book, however, we conclude that so far no evidence for life has been found elsewhere than on the Earth: neither in the Solar System, nor on planets around other stars – even if we suspect, and hope, that this evidence will come in the future. At this stage, astronomers, for their part, tend to support the term “bioastronomy”* (meaning, *astronomy applied to the search for life in the universe*, as “biophysics” or “biochemistry” etymologically are the fields of physics or chemistry applied to biological phenomena) as appropriate term to use for now.

But of course life is all about biology (the science of life!), so it is fair to say that all the disciplines combined in this book, to describe how we think life emerged on Earth, indeed can be considered as providing “Lessons for astrobiology” (the subtitle of this book), in the sense that the authors hope it can contribute to laying ground for the future – if, and when, a “biology” will be discovered in another world than the Earth.

* Indeed, a commission of the International Astronomical Union is called by this name (http://www.iau.org/science/scientific_bodies/commissions/51/).

http://www.springer.com/978-3-642-22551-2

Young Sun, Early Earth and the Origins of Life
Lessons for Astrobiology
Gargaud, M.; Martin, H.; López-García, P.; Montmerle, T.;
Pascal, R.
2012, XII, 301 p. 303 illus., 250 illus. in color., Softcover
ISBN: 978-3-642-22551-2