Chapter 1
What Is Astrobiology?

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Abstract Astrobiology is a multidisciplinary scientific field encompassing biology, chemistry, physics, geology, planetary science and astronomy. Scientists participating in this field are interested in trying to answer fundamental questions of life. These questions may include the search for extraterrestrial life through the discovery of primitive life forms such as bacteria or by detecting other intelligent beings in the universe. The basic premise of this research is to deepen knowledge of ourselves as human beings.

Astrobiologists are required to apply a scientific approach to assessing the potential for extraterrestrial life forms and developing methods for their discovery. There are possible locations for extraterrestrial life to thrive on Mars and icy satellites. Another target in the search for life is extrasolar planets. However, we require a method to search for life outside of Earth, but based on our current knowledge of life on Earth.

Keywords Origin · Evolution · Distribution · Exploration · Life

1.1 Introduction

Astrobiology is a multidisciplinary scientific field encompassing biology, chemistry, physics, geology, planetary science and astronomy. Scientists participating in this field are interested in trying to answer fundamental questions of life such as "Where did we come from? Are we alone? Where are we going?" (Bertka 2009), or "What is life? What is the course of life? Who are we?" (Sullivan and Barross 2007). These questions may be more specific: "How did life originate and diversify? How does life co-evolve with a planet? Does life exist beyond the Earth? What is the future of life on the Earth?" (Cockell 2015). These are the questions that motivate

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the search for extraterrestrial life through detection of very primitive forms of life, such as bacteria, or the presence of other intelligent beings.

These questions are motivated by a fundamental need to know ourselves as human beings and terrestrial life but are challenging to answer because there are no other life forms or intelligent beings known to us for comparison. To answer these fundamental questions, we need to find another form of life. However, our search for other life forms needs to be guided by the answers to these fundamental questions. This poses one of the challenges that must be addressed in astrobiology.

There are other textbooks focused on astrobiology, including an introductory guidebook (Catling 2013) and a textbook for an undergraduate course with an accompanying web site (Cockell 2015). There are good overviews covering planets, life and intelligence (Ulmschneider 2006), a multi-authored review book encompassing the search for extraterrestrial intelligence and alien biochemistries (Sullivan and Baross 2007) and one with even more emphasis on philosophical and ethical perspectives (Bertka 2009; Vakoch 2013). As opposed to these textbooks, this book was intended to be a concise but comprehensive handbook, not a textbook describing basic concepts in detail but sufficient for a scientist outside of his profession to comprehend a current overview of the field.

In this book, each chapter will summarize the current state of the continuously developing field of astrobiology. In this broad field, students and senior scientists must learn a different way of thinking as well as be able to understand different terminology from the divergent sciences that make up astrobiology. Each chapter will summarize the relevant discoveries in each field to provide readers with an overview of current research with sufficient references for more in-depth understanding.

1.2 Why Astrobiology Now?

The term astrobiology was introduced in 1995 by Wes Huntress, based at NASA's headquarters in Washington, D.C. (Catling 2013). NASA was trying to develop Mars missions to locate water and then search for signatures of life. Since then, explorations of the solar planets have revealed the novel appearance of solar system bodies. Mars was considered a dead planet that lost geological activity and most of its atmosphere, but the explorations of Mars revealed aspects of the planet indicating it is still at least partially active (Chaps. 21, 22 and 23). Other active environments such as hydrothermal fields have been found under the frozen oceans of icy satellites of Jupiter and Saturn (Chaps. 24 and 25). These are all possible locations for extraterrestrial life to thrive.

Another target in the search for life is extrasolar planets. As reviewed in Chap. 28, more than 3500 extrasolar planets have been found, and the number is increasing every year. The extrasolar planets include those of a similar size as Earth and those within the habitable zone, which is the estimated distance from the central star allowing for an expected temperature permitting the presence of liquid water and oceans. A possible habitable planet was found in the closest star to our solar system, which is only at about 4 light-year distance from Earth.

These extrasolar planets are current targets in the search for life and prompt us to consider what life is, so that we can develop methods to search for it. We experience a dilemma when we consider the form that extraterrestrial life is expected to take. If we tend towards fact-based predictions, extraterrestrial life should resemble terrestrial life. On the contrary, imagination lets us imagine extraterrestrial life forms highly divergent from terrestrial life forms. These contradictions facilitate development of new avenues of life science, where scientists have started the scientific reevaluation of knowledge on life, planets and the universe.

1.3 Why Astrobiology Is Needed

There are several aspects of astrobiology that must be addressed. One is the science versus fantasy of extraterrestrial life. We know of many fiction movies involving extraterrestrial intelligent species attacking and invading the Earth, either via infectious disease or by supernatural beings. Of course, scientists are aware of the differences between science and fantasy but also realize that knowledge on extraterrestrial life is lacking. Astrobiologists must reinforce a scientific approach to predicting possible extraterrestrial life forms and styles.

There is also a need for further development of scientific approaches to the search for life. We must develop techniques for searching for life beyond Earth that are based on our current knowledge of life on Earth.

1.4 Textbook Overview

Astrobiology is a scientific field that studies life from a universal point of view, not only related to life alone nor limited to terrestrial life alone. The vast field of astrobiology is divided into four sections in this book. In Part II, we will follow the synthesis and accumulation of organic compounds before the origin of life on the Earth. Terrestrial life consists of 70% water with the remainder mostly organic compounds (Table 1.1). Organic compounds were found in a molecular cloud in the Galaxy, and they must have been transported to primitive Earth before the origin of

Table 1.1 Molecular composition of *Escherichia coli* cell (Watson 1976)

	Composition (%)
Water	70
Protein	15
Nucleic acid DNA	1
RNA	6
Lipid	3
Carbohydrate	4
Mineral	1

life. Understanding the processes of synthesis, modification and transport of organic compounds is the target of research in astrobiology. RNA, one of the most important organic compounds, may have been produced on Earth.

In Part III of this book, we will follow the origin and evolution of terrestrial life and intelligence. We will summarize major evolutionary time points including RNA as the origin of life, the common ancestor, origin of eukaryotes, origins of photosynthesis, language and intelligence. We will follow the co-evolution of life and the planet Earth from a biological perspective.

The formation and evolution of planets are also the target of research in astrobiology and will be reviewed in Part IV. We know the Earth is a rocky planet with approximately 70% of its surface covered by ocean. We know that the presence of an ocean seems to be necessary for life to emerge. However, we do not know how and from where adequate amounts of water came to primitive Earth. The current knowledge on how planet systems and early atmosphere emerged will be reviewed. Geological records, including biological fossils, are important information that allows us to reconstruct the history of Earth. The fossil record of carbon and cellular fossils will also be explained. Major impacts on the biological history on Earth, including the great oxidation event and mass extinction events, will be addressed.

In the Part V, the current status and future direction of exploration of life will be addressed. The limits of life on Earth will provide a tentative guideline where to search for other forms of life. The main targets in the solar system are Mars and icy planets around Jupiter and Saturn. The possible transfer of life between planets may alter scientists' approach to searching for life; this hypothesis is called Panspermia. The search for extrasolar planetary system, life and intelligence will be addressed in the final chapters, including a discussion on the possible implications once they are found.

1.5 Conclusion

Astrobiology is a multidisciplinary field of research addressing fundamental questions of life such as how and where life emerged. How has the Earth emerged and co-evolved with life? Less often asked, but of equal importance, is "Why has life emerged and evolved in the universe?". These questions all try to understand the emergence of life and consequently further understanding of ourselves. By knowing our universe, planet and ourselves, it will be possible to predict and prepare for the future of our world.

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