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Introduction

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LIFE FLOATS in the clouds and is carried on the winds to all corners of the globe. This life includes fungi, protists, bacteria, archaea, viruses, pollen grains, and other biotic particulates that originate from the oceans, lakes, deserts, tropics, temperate regions, cities, forests, agricultural fields, and other habitats all over the world. Eventually these particles fall from the sky affixed to raindrops or snowflakes. Some die during their airborne journey, but many survive. If they fall to the earth in the polar regions they may become immured within the vast Arctic and Antarctic ice sheets for tens, hundreds, or thousands of years, and possibly longer. But is this the end of the story? No, it is not. Many of these life forms die, some become dormant, and still others thrive under such harsh but stable conditions. Eventually, the ice in which they are entombed melts, and these organisms, including the dead, dormant, and living ones, are released into the contemporary biosphere. This book is a compilation of the research that describes the environs and organisms that have been found in ice and permafrost.

What happens after the organisms reenter the contemporary environment? We do not know the answer to this question, but research to address this question must be conducted because some of the effects could be profound. Do these organisms reproduce and spread throughout the biosphere once again, or do they die because they cannot adjust to a different environment? If they survive, do they reintroduce ancient genes back into the contemporary gene pools? If so, what are the consequences of this gene flow on evolutionary rates, adaptability, fitness, and so on.? What are the consequences if some of these organisms are pathogens? Could they possibly start epidemics or a pandemic? These are just a few of the many questions that can be raised. The answers to them and others are unknown at this time, although the authors of the chapters in this book are addressing many of these questions.

This scenario may sound like science fiction, but it is not. Within this book is the evidence to support the entire story. It is a fascinating story. It is a new story because research into this field of science is new. Serious investigation began only thirty years ago in Russia with the work of Sabit Abyzov. It also is a very old story because it is likely to have been repeated annually since the vast ice sheets formed millions of years ago. As you will see, some problems

were solved, but others are yet to be solved. There were successes and failures; some questions were answered, but many more were raised.

This book had its origins in a workshop sponsored by the National Science Foundation and organized by the editors that was held at the Westin Salishan Lodge, Gleneden Beach, Oregon, from 30 June to 3 July 2001. The intensity and excitement were evident, indicating that additional collaborations and enhanced research activity should occur. The purpose of the workshop was to bring together experts studying ice, permafrost, ancient life, biological preservation, evolution, and astrobiology to assess current and future research that would extend our knowledge of life in ancient frozen matrices. Thirty-five internationally renowned scientists from Australia, Canada, Denmark, Germany, Israel, Russia, and the United States attended the workshop, and their presentations are the basis for the book. Many additional coauthors contributed to the chapters. The interactions among the participants were stimulating, and we hope that the workshop will lead to future meetings, collaborations, and research.

There were several objectives of the workshop, among which were

- providing the evidence for the presence of life in glacial ice and permafrost
- evaluating the reliability of that evidence
- discussing the significance and implications of the results to date
- identifying the more important and immediate research needs, and our recommendations for future research

The workshop and the book were organized according to scientific discipline. Chapter 2 introduces the many protocols that have been used when studying organisms and biological molecules entrapped in ice. It discusses some of the central problems, issues, and challenges in this research. One of the major challenges is to exclude, or somehow separate, external contaminants from the analyses of the internal ancient organisms and biological molecules. It recommends a set of goals to assure that only authentic entrapped organisms are identified as such. Chapters 3 through 6 outline the potential sources of microbes in polar environments, as well as describing microbes that each research group has found in ice, water, and the atmosphere. They state the quantities and types of microbes found in polar oceans, lakes, and the atmosphere, and describe some of the ways in which microbes can be transported to and deposited in glacial ice. In particular, waterborne and windborne (aeolian) transport is discussed in detail.

In chapter 7, Rivkina et al describe their evidence for microbial metabolic activity at temperatures below freezing. The authors state that the microbes do this by surrounding themselves with supercooled liquid water. This introduces the possibility that the microbes are not in states of suspended animation but, rather, may be metabolically active, although at low levels. This is an important

point, because if the organisms are able to survive for millennia or longer in the ice, they would probably need to continue to repair their DNA, since some damage to their chromosomes would be expected over such long spans of time.

The next several chapters (chapters 8 through 16) detail the microbes that have been found in permafrost (chapters 8 through 10) and glacial ice (chapters 11 through 16). Several describe fungi (chapters 8, 9, 11, and 12), many of which are common in cold climates; however, many others appear to have blown in from temperate and tropical zones. Similarly, many of the bacteria described (chapters 10, 15, and 16) appear to have been transported by wind from warmer climates. This is the case whether the glacier is near temperate zones (chapter 15) or very far from any temperate zone (chapter 16). Chapter 10 describes cyanobacteria that are able to survive and metabolize in cold and dark permafrost, which emphasizes that most of the viable microbes in permafrost and ice are able to survive in a range of environments, some of which are extreme.

Viruses are discussed in two of the chapters. In chapter 13, bacteriophage are described that were isolated from bacteria that had been isolated from polar ice cores. In a previous paper, the same authors described plant viruses isolated from ancient glacial ice. Together, these findings indicate two possible modes of preservation of viruses in glacial ice, the first being as intact virus particles (or fragments of particles), and the second is through integration into bacterial chromosomes (becoming prophage). In chapter 14, the significance of the disappearance and reappearance of viruses through time is discussed. The importance of glacial ice as a reservoir for these viruses also is discussed. In the future, this topic will probably be the focus of many research studies. The diversity of organisms described in these chapters, the extreme environments where they are found, the modes of movement, and the implications of their reentry into a more recent environment cause us to reexamine our views of where and how microbes can survive.

The final chapters describe several areas of research that have been developed over the past few years. The first of these chapters (chapter 17) presents details about Lake Vostok, a subglacial lake about the same size as Lake Ontario. The lake is buried by more than 3500 m of glacial ice and has been covered with ice for millions of years. Although Lake Vostok is the largest such lake found to date, there are hundreds of other subglacial lakes. No one knows whether life exists in Lake Vostok. It has been the subject of a great deal of speculation and will be the focus of research for many years to come. In the next chapter (chapter 18) a unique robot is described. This robot can be lowered into ice core boreholes to detect the presence of microbes. It can log data and send it to computers on the surface. It is possible that robots can be used more extensively to study other boreholes, as well as to examine subglacial lakes such as Lake Vostok. The following chapter (chapter 19) discusses the use of icy environments on Earth as model systems for the study of similar

environments on planets and moons. Ice has been found on our moon, Mars, and Europa (one of Jupiter's moons). Ice, permafrost, and ice-covered bodies of water on Earth are being used to test methods for detecting life on other bodies in the solar system. This chapter indicates one of the very practical aspects of the study of life in ancient ice. The final chapter (chapter 20) summarizes the most significant and important points in the book. It details some of the most key discoveries and outlines the areas that will be of importance in the future.

This book presents many of the facets of the study of organisms entrapped in ice. One can consider this a summary of the current state of research in the study of life, both contemporary and ancient, in ice. We anticipate that this will change rapidly in the near future. From the pioneering work of Sabit Abyzov and co-workers to the most recent publications, it is clear that ice and permafrost represent unique ecosystems and preservation matrices that can yield valuable information on microbial longevity, biological molecule preservation, past climates, recent climate change, evolutionary processes, epidemics, origins of life, life on other planets/moons, and other fields of study. It is true that with the scores of ice and permafrost cores that have been collected over the past several decades, we have gained a deep understanding of the potential benefits for the study of the ancient cryosphere. However, it also is clear that we have only begun to scratch the surface. At the time of printing, this is the only book of its kind, but we are hopeful that many more books on this subject will follow.