Preface

This book tells a strange and fascinating story—the entangled histories of life and this planet. Our central idea is that a very few profound revolutions have made the Earth as we know it. Each revolution can be traced back to unlikely innovations in the evolution of life, and each involved radical changes in the non-living environment. For the most part, these revolutions are buried in the dark ages of Earth history, known traditionally as the Precambrian, but there is one exception: what we humans are doing now to transform the planet could be the start of a new revolution.

It is hard not to feel a rather urgent concern about how we are altering the Earth. Are the heralds of the climate change apocalypse right to argue that we are dooming ourselves and much of the rest of the biosphere? Rather than dwell on the present to try and answer this, our approach is to look at the past—and examine the course of previous revolutions of the Earth. Life, in every case, was the instigator. Often the revolutions led to near-catastrophe. Ultimately stability was always restored, but these happy conclusions were not inevitable; if it hadn't been that way, we wouldn't be here to remark upon them. Our contention is that the past offers some valuable lessons that can help us navigate the troubled waters that lie ahead. It also reminds us what an utterly remarkable planet we live on.

The revolutions we trace are best viewed as fundamental transformations of the whole system of life coupled to its planetary environment, which we call the 'Earth system'. What exactly is that? Well, we mean the many processes that interact together to set the living conditions at the surface of the planet—atmospheric and ocean composition, temperature and climate, and the life on the land and in the ocean. All-encompassing as this definition is, it nevertheless describes a very coherent system whose properties can only be fully understood by considering it as a whole.

If this sounds very much like James Lovelock's 'Gaia' to you, you're absolutely right. 'Gaia' and the 'Earth system' are for us, close to being synonymous. However, many scientists still react negatively against the idea, or even just the name, of Gaia. Based on a too-literal reading of Lovelock's earlier books and articles, or perhaps instinctively distrustful of such a grandiose theory, they associate it with a teleological viewpoint, an assumption that the biology of the planet somehow knows what's good for it. We disagree with this criticism, but we fear that the name 'Gaia' is so closely tied to Lovelock that it is in a sense defined by his views. 'Earth system science' may be less poetic and resonant, but it is also less personalized and polarized.

Why 'revolutions' that made the Earth? Well, the changes we describe were fundamental ones for life and the planet. They were triggered by new evolutionary innovations, resulting in great and often violent shifts in the environment, which in turn killed off many existing species. Out of this chaos emerged a new system and new life forms. So, in some sense there was a forcible overthrow of incumbents by a new regime. However, unlike human political revolutions there was no foresight or planning on the part of those driving the revolution—at least until now. 'Revolution' also suggests cyclic change, and as we will show, there are theoretical reasons why revolutions have recurred, at long intervals through the planet's history.

We've written for a reader with a science education and a keen interest in how we came to be here, but we have assumed little specialist knowledge. Inevitably we have to cross some complex scientific terrain, and we have put some more technical or non-essential material in boxes alongside the main text, so as not to interrupt the narrative. At the same time we think we have something interesting to say to our colleagues, and we use extensive references to show the links to existing work. The content ranges over the biological and geological sciences, but it is in the synthesis of the two that we think a truly 'Earth system' science emerges. We have attempted such a synthesis, but our belief is that it should still be readable and, we hope, entertaining to the uninitiated.

The idea for this book crystallized in 2003 out of a very special kind of scientific meeting, a Dahlem Conference on 'Earth system analysis for sustainability'. In this week-long retreat in the beautiful outskirts of Berlin, we first began to flesh out the connection between major transitions in evolution and revolutions of the Earth system. Many of those present had an input at the start, especially Eörs Szathmáry, John Schellnhuber, and Wolfgang Lucht.

The prehistory of this book, owes a great deal to Jim Lovelock. Andrew was one of Jim's very few PhD students, and Tim in turn was one of Andrew's PhD students, part supervised by Jim. Lynn Margulis has also been an inspiration to both of us, with her adventurous intellect, undying enthusiasm, and passion for teaching. If there is a family of Gaia-inspired researchers out there then we represent two of its generations. As in all families there have been some disagreements (and what we have written may spark more), but we want to make it clear that whatever you think of Gaia, a book like this could not have been written without Lovelock and Margulis' founding contributions to Earth system science.

At the same time, there are several others who have played key roles in shaping the subject and our thinking. Mike Whitfield has been a great support to both of us, especially in our time in Plymouth where Andrew worked for many years, and Tim started his PhD. Jim Kasting and Lee Kump, both at Penn State University, have been championing Earth system science as a subject for decades. The late Bill Hamilton and the late John Maynard Smith both helped Tim sharpen his thinking about Gaia and natural selection. We'd also like to thank Dick Holland, Peter Liss, John Raven, and David Wilkinson. There are many others we haven't named but you will find their work referenced within.

A number of our students and postdoctoral researchers, past and present, have helped develop the ideas, especially Noam Bergman, Richard Boyle, James Clark, Colin Goldblatt, Ben Mills, and Hywel Williams. Andy Ridgwell (who studied with Andrew alongside Tim) deserves a special mention.

Our attempt to write 'scholarly popular science' has proved a difficult trick to pull off, at least for a couple of first time authors. So, we thank the friends and family who have helped by commenting on earlier drafts, especially Peter Horton, Oliver Morton, John Lenton, Tee Rogers-Hayden, Jackie, Adam and James Watson.

A Reader's Guide

The book covers terrain that ranges in difficulty from easy to strenuous, in the fields that would traditionally be classified as astronomy, geophysics, geochemistry, and biology. Some readers may find the mix of material hard to navigate smoothly, so here we give a quick overview of what to expect.

We have opted for a hierarchical structure of six parts, each containing three or four chapters. Part I is Introductory. We preview the main ideas and material we will be covering, in non-technical mode.

Part II is Theory. We explore two theoretical models, which we subsequently use frequently as 'lenses', through which to view Earth history. In the first of these we reason backwards from our own existence, and identify key rare events in Earth history. In the second we switch to reasoning forwards, exploring the properties of an Earth system dominated by feedbacks. These chapters have some technical content, but they should not be too taxing to those with some general scientific knowledge. Both Parts I and II range over the whole of Earth history.

The remaining four parts proceed chronologically. The technical heart of the book starts in Part III, which focuses on the first great transformation of the Earth system. This hinged on the creators of oxygen gas and its abrupt accumulation in the atmosphere, halfway through the planet's history. We call it the oxygen revolution. Part IV we call the complexity revolution and it tackles the transformation which started with the evolution of a new type of cell, and culminated in the appearance of complex creatures from out of the turmoil of extreme ice ages and rising oxygen, at the 'Cambrian explosion'. Each of these parts begins with a chapter on the biological innovation involved, before moving to chapters on the Earth system response.

Part V covers the interlude between the Cambrian and the present, the part of Earth history that many studies of evolution and geology spend nearly all their time examining. The Earth system transformations during this period are less revolutionary, but we know much more about them and they serve to illustrate important properties of the system.

Finally, Part VI addresses whether we are entering a new revolution. We examine the instability of the recent Earth climate, before summarizing the rise of our own species to prominence as an Earth system phenomenon. Then comes perhaps the most ambitious part of the book, where we attempt to apply what we have learned about the Earth system to the future. The penultimate chapter summarizes the common features of Earth system revolutions. In the last chapter, we examine possible routes ahead.

We believe that if we use our deepening understanding of the Earth system wisely, we can avoid the most painful consequences of past revolutions. It is possible to find a path to a new and dynamically stable state which is secure, both for ourselves and for the majority of our fellow-traveller species on Earth, in an indefinitely sustainable world.

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