PREFACE

Could life have originated from scratch on planet Earth or did it begin elsewhere? Life as we know it today is obviously complex, yet its earliest traces on Earth had numerous features that even now seem highly advanced. Although the Earth is very ancient its beginnings can be dated quite accurately. Life is also very ancient, but how ancient is much less certain. And that's the problem. If life turns out to be considerably older than the Earth, then there's a lot of explaining to do.

The exploration of this problem begins nevertheless with a certainty: life has existed for billions of years. That's not seriously in dispute, but whether it means 3 or 4 billion years (less than the age of the Earth) or perhaps 6 or even 12 billion years (considerably longer than the Earth has existed, approaching the age of the universe) – well, that's the question. Life just might be sufficiently young to have started here after the Earth came into existence 4.6 billion years ago. But if life is older, it must have started at an unknown place at an unknown time, or places and times, elsewhere in the universe.

Where and when, exactly? Nowhere; everywhere, all the time. No particular place or time needs to be pinned down. As soon as the new universe was cool enough for molecules to be built from atoms, the path towards life was inevitable. The components were forming everywhere and the laws of thermodynamics stirred the mix to ensure that they eventually came together.

As little as 150 years ago the vast majority of people believed that life, complete with all the species, had been created just the way it is, and created quite recently. Before evolution was discovered, an origin for life was not even a question. The belief

that the world and all its flora and fauna were created especially for humans was very comforting, but was not the result of rational enquiry.

This is not a book on evolution, yet to some extent it concerns evolution, because that reality had to be accepted before people were prepared to go further and think about an origin of life. Much of the evidence for evolution was easily observed and quite well known hundreds of years ago, but the universal mindset was to push the evidence out of sight and out of mind. Extinct fossils were dismissed with every contrived explanation except one: that they were extinct fossils. Few people accepted the sweepingly logical deduction that complex life developed from simple life over a very long period of time. But how much further forward are we today, a century and a half after Darwin's *Origin of Species*? Not a lot: surveys indicate that a surprisingly large proportion of people, perhaps around half, are not ready to accept the ideas that life created itself spontaneously and evolved naturally over time.

Over the past century or so, two important dates have been pushed steadily further into the remote past. One is the date of the Earth's formation. An increasingly ancient Earth has been comforting in providing more time for evolutionary events to have occurred – up to a point. But one problem has been exchanged for another, because the other date to have been revised progressively earlier is the first appearance of life on Earth. Innovations in science and technology have opened up a startlingly clear view of ancient life that now converges in time on the formation of the Earth itself. As the origin of life has slipped progressively earlier, the interval between the formation of a hospitable surface on the Earth and the appearance of primitive life has effectively disappeared. There just wasn't enough time for life to come into existence.

Something has to give. Is the Earth older than we think? Did life on Earth originate incredibly rapidly? Did life or its components originate somewhere else before finding their way to our planet?

The trail has been well obscured. The earliest species have disappeared altogether and been replaced many times over. Hardly any living organisms are a century old, yet life has existed on our planet for about 40 million centuries. Regardless of how 'primitive' some modern life forms appear to be, they are not in fact primitive at all, having been refining themselves, through their antecedents and the process of selection, for billions of years. All life on Earth today is the same age – antiquity might be a better word – having descended from the first enduring germination of life.

Most of the vestiges left by primordial life were wiped out long ago – but not all. The clues left behind are often microscopic and many are as small as atoms, but they live on, and by asking the correct questions and applying a little inescapable logic we can edge just a little closer to the facts. For example, why do the carbon atoms found in some extremely ancient sediments appear to have been sorted by mass in a way that only life sorts them – are they first-hand witnesses of primordial life? Why do unquestionably ancient oils have biochemical signatures uncannily similar to modern life? Where did the atmosphere obtain the oxygen on which animal life so depends for respiration? If the answer is from plants, that throws up a new problem because plants both photosynthesise (harness the Sun's rays for synthesis) and respire (burn fuel and oxygen for energy) whereas animals do only the latter. Since this makes plants more complex than animals, not more simple, how come plants appeared first? The familiar red haemoglobin of blood carries oxygen around the body, but molecular clues show that haemoglobin existed long before multicellular bodies did, and it existed in plants. Whatever for?

These clues, coupled with the powerful scientific principle that the general case (life could have originated anywhere, anytime) is always a sounder proposition than special pleading (Earth is unique in having life), lead to serious questions as to whether life evolved from scratch on this Earth.

Good scientific thinking is never to assume more than the minimum necessary to explain the observations. The sure sign of a good scientific theory is a sweeping simplicity without the need for special conditions to explain away any awkward bits. $E = mc^2$; what can anyone add? The simplest view of life is that at one time there wasn't any, and now there is. Some time in between, it appeared. Logic demands that life progressed from simple to complex and not the other way about. The conundrum, that the earliest primitive life seems actually to have been highly complex, can lead to the trap of so-called irreducible complexity, the easy assumption that a certain level of life (in effect, a cell) is the minimum below which life could not exist, because taking away any of its component parts would be fatal. 'Irreducible complexity' is an entirely artificial paradox that doesn't really exist and can readily be resolved, a figment of an arbitrary definition of life. The complexity of early life is not at all irreducible – but it is irrefutable.

In the past 30 years new technologies have yielded a rich harvest of molecular data providing fresh evidence of life's origins. The DNA of genes contains the information to duplicate life (but, interestingly, not to make life). Most of this information is expressed as the structure of proteins. Closely related species have closely related proteins. Distantly related species have more distantly related proteins, but they are nonetheless still related. Modern molecular technology makes it possible to measure protein relationships, to put numbers and ages to them. This is where the fun starts, because it soon becomes obvious that modern, complex proteins have exceedingly ancient histories. It follows that primordial life on Earth was capable of mass-producing highly complex proteins, a process demanding extremely intricate biochemistry.

It is easy to be misled by the superficial complexity of supposedly advanced life such as humans and flying insects, porpoises and fly-catching plants, but beneath the surface their

cells and their biochemistry are remarkably similar. Their complexity lies not in their antics but right inside their cells. As powerful microscopical techniques have been teamed with ways of visualising molecules atom by atom, as the internal workings of membranes have been teased out and reconstructed with computer models, as the language of the genes has been translated, it has become clear that the structural complexity of each individual cell is almost beyond comprehension. Nano-sized molecular motors spin inside cells like invisibly tiny turbines. In one respect complexity is irreducible – these features are likely to have been similarly complex billions of years ago when primitive life consisted only of single cells but, as we shall see, functioned like modern cells. However, if biochemistry has changed little in the past three or four billion years, then, inescapably, early life was virtually as complex as it is now. If life did not achieve such stunning complexity quickly, the process must have begun before the timeframe of Earth's existence. Our overall task is to assess the likelihood of this being the case and look for clues to the ways and means.

As the story unfolds, it becomes clear that any attempt to predict life as it will be in 10 or 100 million years' time is futile, beyond the conclusion that at the cellular level it may never become very different. Nevertheless at the macroscopic level, the whole body, the opposite is true: the lesson of life's history is that nothing about bacteria or any other single-celled life could have prompted an observer of primitive Earth to predict the evolution of trees or bees, feathers or onions. Whatever life turns out to be like in the far distant future, the one certainty is that nobody alive today has any chance of predicting it correctly.

Of course, many people for varied reasons will tell me that I am wrong about life's origins. Nothing would give me greater pleasure than to be *proved* wrong, because that is precisely how science makes progress. Science does not recognise proof of being right, only disproof. There is all the difference between disproof and

disbelief, however, and I have no wish to change anyone's beliefs. It is a sad fact of life that the less a subject is understood the more vehemently people defend their own ideas, but in this debate we should all be on the same side: the search for rational explanation. As Spanish philosopher Miguel de Unamuno (1864–1936) commented, 'True science teaches, above all, to doubt and to be ignorant.'

It would be impossible to satisfy every reader in a book of this kind. I have chosen a readership with a broad interest in science, but not an academic readership. It simply is not possible to incorporate in one work complete textbooks of animal and plant biology, chemistry, nuclear physics, geology, genetics, molecular biology, palaeontology and statistics! For readers who demand chapter and verse on sweeping statements and calculations, some background information and references are provided in the Appendix. Most of the references can be found in a reasonable public library (or the library can easily borrow them), and these lead to more specialised references that the enthusiast can pursue if desired.

Many people have kindly explained to me things outside my field so that I can attempt to explain them to you. The advent of the Internet has made it possible to contact expert sources of information (and disinformation) all over the world. What is remarkable is that complete strangers who have never met, and probably never will, are happy to devote time and energy to the exchange of scientific ideas and information over the Internet. I thank all the helpful people I have met in this way.

The recurring nightmare when planning a research lecture is to project the customary slide acknowledging all the people to be credited, then to realise with horror that a person has been left off – predictably the most crucial and easily wounded. After much agonising I decided to delete the list drawn up for this book, not only fearing the risk of omission but also not wanting to imply that anyone's help meant that they agreed with my conclusions. Most

were highly qualified professionals and I will not enhance my own credibility through other people's credentials. Similarly, acknowledgements to people named in the text or listed in the references do not in any way imply that they would agree with my interpretations. To everyone who has helped me, often through spirited argument, I offer my personal and sincere thanks.

There are two exceptions who must be singled out, however. They are (chronologically) my extremely hard-working and assiduous literary agent, Lavinia Trevor of London, who never misses a thing on behalf of her clients. And Sally M. Smith, publisher, of Wiley, for her breathtaking ability to place herself in the shoes of precisely the readership I had in mind, always asking the most penetrating questions and never failing to spot the points, large or small, that I had so often fudged. All errors, of course, remain my own responsibility.