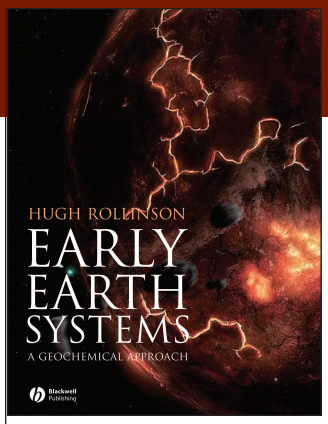
EARLY EARTH SYSTEMS – A GEOCHEMICAL APPROACH[1]



At the world's start, according to the medieval Norse, there was "no sea nor land, nor salty waves, neither earth was there, or upper heaven, but a gaping nothing, and green things nowhere." Origin myths commonly echo the ideas of void or darkness, heat or cold, water and rock, at Earth's inception. It is an ancient art for people to fill the "gaping nothing" in our knowledge of the beginning of it all. For Earth's first two billion years, this quest is especially enticing.

Nowadays, minding the gap is accomplished by (1) sifting through scraps of the oldest rocks and minerals; (2) constructing physical models for the earliest systems, with or without observational constraints (proof positive that output is only as good as the input); (3) comparing evolutionary paths of the planets to provide bearings on the different turns Earth took compared to other worlds; and (4) creating new mythologies through speculation. In an early attempt, G.W. Leibnitz (1680) considered that the "incandescent" young Earth drove out gases that condensed to form the oceans and immediately interacted with the crust to initiate the geochemical cycles. This view was kindled well before W. Thompson's (Lord Kelvin) physical models, which sought to thwart evolutionist geologists such as T. Huxley ("Darwin's Bulldog"), and the haunting words of C. Lyell who proclaimed that for the geologic record there exists "no vestige of a beginning, no prospect of an end." Chemists ended up saving the day (once again) from the physicists, but ever since Lyell's infamous dirge, the quest for "vestiges" has dogged those who gamble life, limb, and professional reputation on the oldest rocks. These lunatics must believe that the rewards justify the risks. What is there to vindicate them?

Enter the latest book to show that the discovery opportunities awaiting Precambrian daredevils are like low-hanging fruit: Hugh Rollinson's *Early Earth Systems – A Geochemical Approach*. Why pay $85 for a 296-page paperback about really old rocks? The last decade has seen an amazing burst of activity in the decipherment of the oldest geologic record. Analytical advances have made it possible to measure what was previously toilsome or quite impossible to accomplish, and new isotopic tools have revolutionized our understanding of the Earth. This book provides a breakdown of these new discoveries and is up to date to about mid-2006. Rollinson is a well-qualified guide, and his expertise is revealed in a comprehensive handling of the vast panoply of topics written in a readable style. This book will sit in good company with others, like *The Evolving Continents* by B. Windley and *Archean Crustal Evolution* by K. Condie, to name but two. These are essential sources for any serious student of the early Earth.

Because so much material is covered, I will only touch on a few of the topics that comprise each chapter. Actually, the conceptual pedigree of "Earth System Science" is traced to J. Lovelock's Gaia hypothesis, which promoted the notion that the various geospheres are part of a synergistic system of geologic–biologic–atmospheric processes operating at the global scale. Whatever you think of the Gaia hypothesis, Earth System Science is here to stay, and the approach has informed us in new ways about how the Phanerozoic world works. Thankfully, chapter 1 defines early Earth System Science and explains what the sources of information are (e.g. greenstone/supracrustal belts, highly deformed granitoid gneiss terranes, and detrital zircon grains). The classical Huttonian perspective suffers a serious breakdown when it comes to Earth's first eons; here was a world where *basic* physical parameters were different from those of the past billion years. The solar "constant" has been anything but, terrestrial heat flow was greater, life was microbial, free oxygen was generally absent, and bolide impacts were frequent and occasionally devastating. Later chapters treat these devils-in-the-details in a stepwise way. Chapter 2 reviews the origin of the universe, matter, stars, galaxies, and planets. After we come up for air, chapter 3 plunges us into the origin and evolution of the largest geochemical reservoir, the mantle. How and when did it form and thereafter reach its present physical and chemical state? How was the mantle different in the distant past? Was there a magma ocean? When did plate tectonics begin? This theme segues nicely into chapter 4 on the origin of continental crust. The old idea that the continents likely experienced significant growth in the early Hadean has been resurrected. Most workers, Rollinson included, would agree that continental crust existed at 4 Ga but was volumetrically much less than now. Chapter 5 follows nicely with the origin of the hydrosphere and atmosphere, and their co-evolution with the crust and mantle. We have seen much new research into the evolution of the atmosphere–ocean system, in particular with paleoredox estimates. The breakthrough achieved from mass-independent sulfur isotope studies is second only to the historical studies of redox-sensitive elements and minerals. This new tool has revolutionized our understanding of the rise of atmospheric oxygen and the nature and extent of photochemistry in the Archean atmosphere. Who would have thought, just a few years ago, that the ephemeral record of the atmosphere from so long ago would be within our grasp? Chapter 6 touches upon the greatest unsolved problem in science: the origin of life. Rollinson does us a big favor and begins with a chemical (rather than biological) approach to the problem, while folding in the role of geology in life's emergence. Afterwards, he shows how molecular phylogenetic analyses of existing genomes is both a guide to follow in understanding the nature of the earliest biomes (but does *not* provide the place of life's origin) and a tool for understanding when certain early microbial metabolic styles could have emerged. Molecular phylogenetic studies are performed on extant organisms, nothing alive today is primitive, and all life is far from the origin after about four billion years of biological evolution. Could the biologists' discovery of microbes with very old pedigrees (hyperthermophiles and their ilk) tell us something of the physical character of the early Earth, such as the effects of bombardments? Unlike fancy wines, the quality of the rock record only gets worse with time. Controversy over what constitutes "interpretable evidence" for past life diminishes only by the time one gets to things that are less than half the age of the planet.

A book review is useful to somebody only if it mixes positive with negative. I liked how the chapters start with the Big Picture that prepares us for what is to come. The writing style is clear to the point of masterful in its explanation of crucial and oftentimes complex concepts. The list of recent references is solid. Things I did not like include the low-resolution greyscale copies of original color figures, the choppy quality of the maps, and the difficulty in reading some of the cartoon depictions of processes. These are, however, minor quibbles and should not detract from an excellent book.

The last section, called "In the Beginning," contains an unambiguous challenge. One well-regarded senior colleague once confided to me over beer at a poster session that "geochemists make excellent servants, but poor masters!" A dangerous quote to share in *Elements*! Yet, here is another chance for geochemists to find redemption. Recent strides into the hitherto impenetrable early Archean and Hadean were made by risk-takers. For those who sweat over the record of the first two billion years, Rollinson dares us to "*quantify* interactions between the early Earth reservoirs." Get to it.

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[1] Rollinson HR (2007) Early Earth Systems – A Geochemical Approach. Blackwell Publishing, Oxford, UK, 296 pp, ISBN 9781405122559, US$84.95