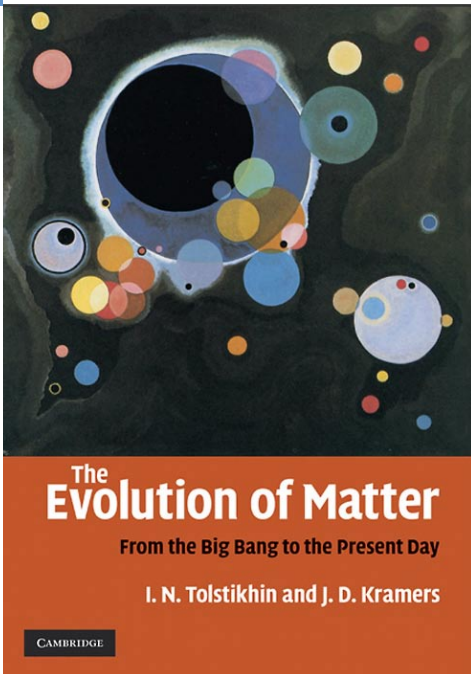
The Evolution of Matter: From the Big Bang to the Present Day[2]

Earth scientists have long embraced the deep dimension of time and the powerful unifying concept that small physical changes integrated over billions of years can transform a planet. From the movement of continents to the weathering of mountain ranges, Earth history must be understood in the context of deep time. Now a second, equally profound aspect of time and history is emerging to inform our understanding of Earth and the cosmos. A number of recent articles and books explore how natural systems spontaneously, irreversibly evolve from relatively simple states to those of increasing complexity (i.e. with a greater diversity of species, a wider range of patterning, and a richer repertoire of behaviors). To date, most of the emphasis on complex evolving systems has focused on biology and the transformative effects of Darwinian natural selection. But recently the rhetoric of evolution has been applied systematically to nonliving systems as well, including isotopes, organic molecules, minerals, and rocks. *The Evolution of Matter: From the Big Bang to the Present Day*, by geochemists Igor Tolstikhin (Russian Academy of Sciences) and Jan Kramers (University of Berne, Switzerland), is among the latest and most comprehensive contributions to this important and growing genre.

Tolstikhin and Kramers describe their ambitious objective as "an attempt to link depth and breadth in cosmo- and geochemistry" by summarizing the 14-billion-year evolution of elements and isotopes from the Big Bang, through the stellar nebula and formation of the solar system, to the history of Earth. Such a grand evolutionary story is only possible because, while the historical details are vast beyond telling, the physical and chemical principles that led irreversibly from the cosmic simplicity of hydrogen to the modern living world are relatively few and straightforward.

The text is divided into four broad chronological sections. Part I is a familiar retelling of cosmological nucleosynthesis, starting with the production of copious H and He shortly after the Big Bang and tracing the expanding richness of elements and isotopes produced in stars of varying mass. The concise text is supplemented with many useful tables and figures of relative element and isotope abundances, as well as illustrations of various mechanisms of nucleosynthesis. This section serves as a valuable reference for those already familiar with the subject, but I wonder whether this swift 100-page condensation of a large and complex subject makes it less effective as a textbook. For example, "s-process" and "r-process" are mentioned in chapters 2 and 3, but are not



explained until chapters 5 and 6, respectively. Thus, while Part I is comprehensive in its content, in some respects it lacks a unified narrative flow.

Part II of *The Evolution of Matter* employs diverse isotopic data to focus on the first historical stage in the evolution of the solar nebula, i.e. dust accretion into planetesimals. Separate chapters of Part II address the characteristics and origins of calcium–aluminum-rich inclusions (CAIs), chondritic meteorites (which incorporate presolar grains, CAIs, chondrules, and matrix), and "highly processed meteorites" (including various objects that represent planetesimal differentiation and magmatic processing). Collectively, these topics underscore the deterministic nature of nebular evolution and the power of various isotopic markers to reveal physical and chemical mechanisms, as well as absolute and relative timings, of those sequential events.

Part III summarizes geochemical and seismological data that document Earth's initial accretion from millions of planetesimals, its differentiation into mantle and core, the formation of the atmosphere and hydrosphere, and the formation of the Moon through a late-stage impact. The broad sweep of this important section is somewhat interrupted by chapter 19, a rather more detailed examination of the enigmatic core–mantle D´´ boundary and whole-mantle convection. Here the authors present their speculative hypothesis regarding early formation of this layer through subduction of relatively dense and dry mafic crust—an hypothesis that plays a central role in the book's concluding chapters.

Part IV, "Global Evolution of the Earth," is the book's longest and most ambitious section. Citing diverse elemental, isotopic, and seismological data, the authors attempt to document the principal present-day geochemical reservoirs and the key processes by which matter has been exchanged among these reservoirs over Earth history. Plate tectonics provides a framework for this largely successful, if complex, presentation. Ocean-ridge and ocean-island magmatism (chapter 24) and subduction and island-arc magmatism (chapter 25) are shown to account for the principal modern fluxes, while various igneous, metamorphic, and sedimentary processes explain the ongoing formation and reworking of the heterogeneous continental crust (chapter 26).

The Evolution of Matter could have ended there, but the authors devote two additional (and rather more detailed) chapters to developing a whole-Earth geochemical-transport model in which the D´´ layer, consisting of sunken Hadean oceanic crust with a significant chondritic component, plays a central role. In this model the D´´ layer holds 20% of Earth's incompatible elements, including significant radioactive U, Th, and K. Gradual release of radiogenic noble gases from D´´ into the lower mantle, coupled with assumed whole-mantle convection, is used to explain observed anomalies in isotopic distributions, particularly for Xe.

Whether or not the geochemical model of Tolstikhin and Kramers gains significant traction, *The Evolution of Matter* will provide advanced undergraduates and Earth science professionals with an unusually broad and integrated view of isotope cosmo- and geochemistry, from the ancient origin of atoms to the modern living Earth. The separate parts of this story have been told many times before in both the primary and secondary literature, but seldom have the parts been woven into such an engaging historical narrative.

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2 Tolstikhin IN, Kramers JD (2008) The Evolution of Matter: From the Big Bang to the Present Day. Cambridge University Press, Cambridge, UK, 521 pp, ISBN 978-0-521-86647-7, hardcover, US$140