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Essay Book Review

The Historical Reconstruction of Geohistorical Reconstruction

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WORLDS BEFORE ADAM: The Reconstruction of Geohistory in the Age of Reform *by Martin J. S. Rudwick. Chicago: University of Chicago Press, 2008. xxii + 614 pages, sources, index. Hardcover; $49.00. ISBN: 0226731286.*

If you never read more than one volume on the history of geology, then this is the one you should read.

To initiate a stimulating discussion, ask a gathering of scientists to speculate about the most significant discovery that has been made within their particular discipline. A chemist might point to the periodicity of the elements. A physicist might mention the pivotal role of mathematics. A biologist might call attention to DNA. The ensuing discussion will surely generate many plausible alternatives.

In geology, a strong case can be made that "deep time" is the discovery with the most profound consequences for the study of planet Earth, not so much for the bare fact that Earth is far older than was believed for millennia, but because the discovery of deep time opened up the realization that Earth has a long, dynamic, complex, fascinating *history* all its own that *preceded* human history, not to mention making Darwin's theory of natural selection possible. Until the mid- to late-eighteenth century, a very brief, relatively uneventful Earth history was inextricably linked in the Western world to the human drama that unfolded within the biblical framework of creation, fall, deluge, redemption, and consummation.

The result of the realization, roughly two centuries ago, that Earth has its own dynamic history is that geologists now almost automatically place the geological phenomena they investigate into a historical context. For example, a buried lava flow provides evidence of a former episode of volcanic eruption, a distinct geological *event* that may be located within a long sequence of events. A fault provides evidence of localized former episodes of earthquake activity, distinct geological *events* that may be located within a long sequence of events. Or a body of stratified sedimentary rock within a larger succession of sedimentary rock layers may provide evidence of the deposition of sediment on a former lakebed, beach, or ocean floor, distinct geological *events* that may be located within a long sequence of events. In every geological mapping project, whether on Earth, Mars, or the moon (the latter two obviously by remote sensing at present), a field investigator seeks not only to establish the relative temporal relationships of the various rock bodies encountered but also to place the geological events that produced those bodies within the larger historical framework of geological time.

Just as US history might be subdivided into discrete, well-defined units such as the Washington presidency,

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the Adams presidency, the Jefferson presidency, and so on up to the Obama presidency or alternatively into calendar years such as 1787, 1788, and so on up to 2009, so, too, geologists have subdivided geologic time into various units called epochs, periods, eras, or eons. Thus we have *period* names such as Cambrian, Devonian, Permian, Triassic, Cretaceous, and the like or *era* names such as Paleozoic, Mesozoic, and Cenozoic. Every movie buff on the face of Earth knows at least one geologic time period whether or not he or she has taken a course in geology: the Jurassic Period.[1] Thus, geologists may refer to a specific lava flow in northern New Jersey as a *Triassic* basalt or to a lacustrine (lake) sediment in Utah as an *Eocene* mudstone. All geologists understand that a Triassic basalt is a much older rock than an Eocene mudstone. Moreover, geologists will immediately realize that Triassic basalts are on the order of 210 to 240 million years old and that an Eocene mudstone is roughly 40 to 55 million years old.

Geologists, of course, are very much interested in developing general theoretical explanations of various geological processes. They seek to develop general principles of volcanism, tectonics, and sedimentation. Thus, for example, geologists have a theory of partial melting to account for many bodies of magma; a theory of plate tectonics to account for large-scale patterns of volcanism, seismicity, and mountain building; and a theory of marine transgression and regression to explain many sedimentary rock successions. In the end geologists want to apply general principles and theories to specific situations. How, for example, can we apply what we know generally about volcanism to *this* particular group of Triassic basalts in northern New Jersey or knowledge of lacustrine sedimentation to *that* accumulation of Eocene mudstones in Utah?

Most geologists know, in very general terms, the story of the discovery of deep time and of the gradual deciphering of the broad contours of Earth history. Students in the early stages of geology programs are typically introduced to some of the leading players in the story, generally in a course on historical geology. In such a course, fledgling geology majors normally learn the names of such geological luminaries as Georges Cuvier, William Buckland, Adam Sedgwick, Roderick Murchison, Charles Lyell, and Louis Agassiz. Here, too, they encounter the methodological principle that the present is the key to the past, and they also face the daunting prospect of learning the major divisions of the geological timescale. Terms like Paleozoic, Precambrian, Silurian, and Jurassic then become part of their vocabulary.

Introducing Martin Rudwick

A sizeable Anglophone literature has explored the achievements of several key figures in the development of the geological timescale and fundamental concepts of geohistory.[2] But absolutely no one has delved deeper into the historical development of the concept of deep time and what he calls "geohistory" than Martin J. S. Rudwick. Winner of the 2007 Sarton Medal awarded by the History of Science Society, Rudwick is widely regarded as the premier historian of geology. After graduation from Cambridge, Rudwick embarked on a professional career at Cambridge in the Department of Geology and at the Sedgwick Museum as a paleontologist specializing in the morphology and feeding mechanisms of brachiopods. During this work, resulting in his first book, Rudwick's interest in the historical foundations of the Earth sciences began to blossom.[3] He evolved into a historian of geology and migrated to the Department of History and Philosophy of Science at Cambridge where he served as Lecturer. In subsequent years he held appointments as Professor of History and Social Aspects of Science at the Free University of Amsterdam, in the Program in the History of Science at Princeton University, and as Professor of History in the Science Studies Program of the University of California at San Diego. Now in "retirement," Rudwick has returned to Cambridge as Affiliated Research Scholar in the Department of History and Philosophy of Science.

As a historian of geology, Rudwick has not concerned himself with the history of such major geological sub-disciplines as mineralogy, igneous petrology, metamorphism, geochemistry, geophysics, structural geology, tectonics, or economic geology. Virtually all of Rudwick's historical work has concerned the central questions of the discovery of deep time, the development of principles of geohistorical reconstruction, and the construction of the geological timescale. In his own words, Rudwick stated that

> the historical problem at the centre of my research, ever since I turned myself in mid-

> career from a geologist into a historian, has been to try to understand how this new kind of science, with a sense of nature's own history at its core, was first constructed: initially in a quite tentative way, but eventually on such firm foundations that earth scientists now take it completely for granted.[4]

Rudwick's writings are invariably characterized by lucidity, elegance, and thorough research into the original sources. In one of his most significant articles, Rudwick carefully teased apart four distinct senses in which Charles Lyell had incorporated the concept of uniformity in his classic *Principles of Geology*.[5] It was Rudwick who first untangled the strands of the fabric of Lyell's thought so thoroughly.

It is in Rudwick's books, however, where we come to appreciate the remarkable breadth of his knowledge. His major books address several facets of the beginnings of the deciphering of geohistory. These works include the role and significance of a profoundly important group of geological artifacts, namely fossils, that are employed routinely in geohistorical reconstruction *(The Meaning of Fossils*[6]*)*; the establishment of one of the major units of the geological timescale, namely, the Devonian System and Period, named after Devonshire on the south coast of England *(The Great Devonian Controversy*[7]*)*; a critical component in communicating the results of geohistorical reconstruction, namely, the use of illustrations of life forms from the ancient past *(Scenes from Deep Time*[8]*)*; and studies of some of the significant geological texts produced by one of the major participants in the emergence of geohistorical thinking, namely, the great French vertebrate anatomist Georges Cuvier.[9]

Throughout this period of great productivity, Rudwick was blending the great diversity of his research into one vast synthesis of the origins of geohistory. To set the stage for his crowning achievements, under review here, Rudwick published a pair of anthologies of his articles.[10] The first massive volume (708 pages) of his grand synthesis was *Bursting the Limits of Time*, a monumental work that concerned the gradual realization that geohistorical reconstruction is, in principle, a possibility.[11] This volume, noteworthy for its liberal use of original French sources like Horace-Bénédict de Saussure and Jean-André de Luc, examined the period from 1787 (Rudwick's "golden spike"), the year in which French geologist Saussure conquered the summit of Mont Blanc, to 1822, the year in which William Buckland presented a landmark paper before the Royal Society of London describing the discovery of fossil hyena bones in Kirkdale Cave, discovered the previous year. During the period under review, "geology" became a new science, the first *historical* science, and savants who studied Earth processes, phenomena, and history were transformed into "geologists."

Worlds Before Adam

Worlds before Adam, the volume now under review, is a self-contained sequel to *Bursting the Limits of Time*. Rudwick set out to write a narrative that would make his topic familiar even for those who know little about geology or about the England of the first half of the nineteenth century. Rudwick has admirably succeeded in his goal. The reader should come away with an understanding of the evidence that led geologists to their various conclusions. If *Bursting the Limits of Time* concerns the discovery that geological history can be worked out in principle, the narrative of *Worlds* picks up at the point when geologists are beginning to busy themselves with undertaking the grand project of figuring out not only what happened during terrestrial history, but also what were the causes that produced the events.

Rudwick laments the unbalanced Anglophone leaning of much historiography of the era that he investigates, but he has rectified that deficiency by providing a narrative that does justice to the truly international character of the developments described. The reader does meet a plethora of British geologists—after all, they were very much in the thick of the early days of geohistorical reconstruction—but there are also plenty of French, Swiss, Norwegian, Italian, and German geologists in the mix.

Rudwick also admits unabashedly to giving us an elitist account that focuses squarely on the concerns and contributions of leading scientific researchers. Little heed is paid to the popular reception of geological advances or even to the question of the relation of geology to Genesis, a question which, then as now, often exercises lay people much more than professional geologists.

Rudwick stresses that *all* geologists of the time he reviews (and this includes a host of Christians such as Adam Sedgwick, William Buckland, John Fleming, William Conybeare, and Jean-Baptiste Croizet) believed in an earth with a past of "inconceivable magnitude."

Rudwick's masterful narrative highlights several important themes. These include the growing body of information about the details of geohistory, methods of reconstructing geohistory, the relationship between human and geological history, the interlacing of life history with geological history, and the question of transformism and the place of humanity in the history of life. Arguably the dominant issues of the age were the relative importance of actual causes and catastrophic revolutions in reconstructing geohistory, and the directionality or stasis of geohistory. These issues are developed in four parts distributed over thirty-six chapters. Each part surveys several roughly simultaneous but partially overlapping developments. Each chapter is approximately twelve to fourteen pages long and contains an excellent one- or two-page conclusion. A chapter a day is an excellent way to digest this intellectual feast.

Fleshing out Geohistory

In Part I, Rudwick surveys developments in the period between 1817 and 1827 in eight chapters. He begins the narrative with Georges Cuvier, the great French anatomist who founded the science of vertebrate paleontology. In contrast to William Smith, an English surveyor who successfully employed fossil remains as markers of particular rock strata, Cuvier was not content simply to engage in what Rudwick (following Earth specialists of that time) calls *geognosy*, that is, that side of geology concerned with description of the structure and relationships of rock masses.[12] Going beyond simply working out the geometric relations of the relatively youthful Tertiary strata of the Paris basin,[13] Cuvier and Alexandre Brongniart regarded these strata and their fossil content as materials for reconstructing the events of a deep past of "worlds before Adam," a deep past that preceded the advent of the human race. Cuvier saw the potential for doing what Rudwick calls *geohistory*. Moreover, he understood that a significant dimension of geohistory concerned the history of life. From his fieldwork, Cuvier concluded that the geohistory of the deep past preceded human history and was separated from it by a profound revolution that left evidence in the form of extensive gravel deposits and erratic boulders that had been moved far from their source areas.

Similarly, Cuvier's recognition of alternating marine and terrestrial strata in the Paris basin, as indicated by their fossil remains, led him to conclude that previous violent incursions of the sea had also occurred from time to time during the deep past. In essence, his conviction was that the geologic deep past could not be explained entirely in terms of *actual causes*, that is, causes that are observable at present.[14] Knowledge of the fossil record indicated that ancient life forms differed from modern forms, suggesting change in organisms through time, hence implying some directional character to geohistory. But Cuvier, a vigorous champion of the fixity of species, had no use for transformism (what we would today call evolution) such as proposed by Lamarck. And so it was for most of Cuvier's geological contemporaries around the year 1817.

During the years immediately following 1817, many details of the stratigraphic record were filled in. Spectacular discoveries by "fossilists," such as Mary Anning, of ancient marine reptilian creatures, in particular, ichthyosaurs and plesiosaurs in English strata, stimulated research into precise assignment of their stratigraphic position. Building upon William Smith's use of fossils as markers in stratigraphic procedure, several geologists set about to determine local stratigraphic successions and began to correlate English strata with those in continental Europe. Geologic maps continued to improve, and a widely influential compendium of regional British stratigraphy was published by William Conybeare and William Phillips in 1822.[15] These stratigraphic labors laid the foundations for serious geohistorical work.

Alexandre Brongniart and his son Adolphe, Anselm-Gaëtan Desmarest, John Samuel Miller, and Henri Marie Ducrotay de Blainville worked out the precise stratigraphic ranges of individual fossil groups such as trilobites, crustaceans, crinoids, belemnites, and land plants. Increasingly, fossils were regarded as indicators of the history of life, and the strangeness of the life forms of the deep past in relation to modern forms became more striking. That strangeness was emphasized by remains of giant terrestrial vertebrate reptiles found in

Secondary rocks, like *Megalosaur* and *Iguanodon*, along with sparse remnants of small mammalian forms. Growing knowledge of fossils confirmed the realization that life forms extracted from Secondary strata were even less like modern forms than those obtained from the younger Tertiary deposits. Thus the Tertiary age came to be viewed as a means for bridging the gap from the present to the ancient deep past. And yet the widespread unconsolidated superficial deposits (so-called "diluvium") that rested on top of the older Tertiary and still older Secondary strata indicated that an important conceptual gap still remained between the present and Tertiary time.

During these years, work on superficial deposits commonly attributed to a catastrophic geological deluge associated with mass extinction, especially by Cuvier and Buckland (who even linked this event to the Genesis deluge), was supplemented by several studies of cave deposits containing fossil bones of extinct mammals. No *human* remains had been discovered in these superficial and cave deposits. Fleming challenged Buckland's view of the superficial deposits as products of a gigantic deluge, claiming that modern causes, such as several small floods, were sufficient to account for the so-called diluvium.

Geologists intensely debated the adequacy of actual causes to explain the allegedly diluvial deposits and some other rocks from the deep past. The actualistic method was taken for granted by those concerned with geology as a historical science. They agreed that actual causes should be invoked wherever possible. In other words, they wished to explain the past in terms of present observed geological processes wherever that made sense, but most geologists acknowledged that causes no longer operating might also have occurred. From an inventory of historically recorded geological changes, Karl Von Hoff concluded that the cumulative effects of actual causes could have been substantial over long time periods, a view that was reinforced by studies of Mount Etna and volcanoes in the Andes that appeared to have eruption histories clearly preceding the presence of humans or human records. As a result, Cuvier's claim of numerous "revolutions" was no longer considered self-evident. Nonetheless, geologists were still baffled over what present causes could possibly explain the alleged deluge deposits.

Rudwick concludes Part I by describing studies of crustal movements during human history whose effects were visible along the Chilean coastline and at the remains of the Roman Temple of Serapis near Mount Vesuvius. The temple displayed compelling evidence of both up and down local fluctuations of sea level, and a great earthquake that struck Chile in 1822 produced considerable elevation of long stretches of the coast. Geologists pondered whether the Andes could have been uplifted solely as a result of numerous small-scale events or by means of such events punctuated by a handful of enormous cataclysmic uplifts. The adequacy of actual causes to explain the deep past became a hot topic.

Actual Causes under Scrutiny

In Part II, Rudwick examines the years between 1824 and 1831 in nine chapters. During the 1820s, application of Smith's methods of stratigraphy continued to strengthen the framework for geohistorical interpretation, at least for Secondary and Tertiary strata. Paleontological work indicated that life history was directional and progressive. Human history was still regarded as a brief moment topping off a vast span of geological time. Studies of causal Earth physics began to yield important implications for geohistory. The directional character of geohistory was confirmed by Joseph Fourier's application of the mathematics of heat conduction to the cooling of an initially hot earth and by Pierre Cordier's empirical demonstration of Earth's internal heat.

Leopold von Buch and Léonce Élie de Beaumont both deciphered evidence for multiple episodes of folding of strata and crustal disturbance in Europe. Élie de Beaumont worked out the precise timing of these episodes, linked them to drastic revolutions, and envisaged those violent upheavals producing mega-tsunami that resulted in mass extinctions and faunal/floral changes. He attributed the episodes of buckling to crustal shrinking caused by global cooling. For these geologists, actual causes were insufficient to account for mountain-forming events.

Geologists recognized that Tertiary deposits and life forms, being most similar to modern ones, were a good place to start in evaluating the adequacy of actual causes to explain the past. Tertiary strata then might serve as a cognitive gateway to the Secondary. In one significant study, Constant Prévost undercut the reality of Cuvier's alleged alternating marine and terrestrial strata in the Tertiary Paris basin by demonstrating that the different marine and terrestrial deposits interfingered, indicating that both marine and terrestrial environments and faunas had been juxtaposed simultaneously. Studies of other European Tertiary basins further disclosed variations in fossil forms from one basin to another, indicating differences in their precise ages within the Tertiary Period.

On the paleontological front, Prévost showed that mollusk assemblages in Tertiary deposits must have changed through time, while Paul Deshayes identified three successive Tertiary faunas containing an increasing proportion of modern species from older to younger fossil assemblages. Heinrich Bronn developed similar statistics for other fossil groups. These findings gave greater force to the impression of directionality in the fossil record. Geologists proposed that climatic conditions might have changed in response to global cooling, a hypothesis supported by the discovery of fossil corals and tropical plant remains in strata in Arctic regions.

The nature of the "diluvium" persisted as a great puzzle. Geologists continued to accept the reality of a sharp break between the present and the former worlds of the deep past caused by some natural physical event of great intensity. The *diluvium* resulting from such an event was distinguished from *alluvium* along river courses, obviously the product of actual causes. Among the major phenomena marking the putative diluvial revolution were broad U-shaped valleys whose rivers many geologists regarded as incapable of eroding such large valleys, and also erratic blocks scattered across the face of Europe tens to hundreds of miles from their source areas. Henry de La Beche noted the presence of enormous erratics on both sides of the Alps and linked them to sudden uplifts of that range. More puzzling were erratics scattered across northern Europe and in the vicinity of Lake Huron in North America. Fieldwork indicated that these great boulders had been transported from north to south, arguably by an aqueous event of huge magnitude. Jens Esmark suggested glacial origin for erratics, but his idea gained little support. The idea of more extensive glaciation prior to the human era ran counter to widely accepted belief in a gradually cooling earth.

Buckland toured several European caves that had been interpreted as pre-diluvial hyena and bear dens. Meanwhile Fleming suggested the possibility that human hunting led to the extinction of mammals such as the "Irish elk." The youthful Charles Lyell expressed confidence in the directionalism of geohistory thanks to a cooling globe as well as strong advocacy of the explanatory power of actual causes, but he did not rule out violent episodes of sudden change.

George Poulett Scrope as well as the team of Croizet and A. C. G. Jobert closely studied the extinct volcanoes of the Central Massif of the Auvergne in south-central France. Both recognized that the area preserved evidence of an extensive series of phases of fluvial erosion and volcanic eruption, and neither saw any signs that those episodes could be related to a great deluge. Scrope emphasized the importance of vast drafts of time to carry out the uninterrupted sequence of events, whereas Croizet and Jobert argued that extinction in the area must have been gradual, piecemeal, and prior to human presence. To them, actual causes had obviously been adequate in sculpting the terrain.

Questions began to arise about both the antiquity of humans and the transmutation of earlier species (transformism) to form new species. The boundary between the modern and former worlds began to crumble just a bit when Jules de Christol and Paul Tournal both believed that they had found evidence of human remains with ante-diluvial species, but Buckland and Cuvier continued to hold out for exclusively post-diluvian human remains. Although the idea of transmutation of organisms was in the air, the origin of species remained a mystery. Belief in divine design, suggested by the close adaptation of organisms to their environments, was widespread. Cuvier's belief in the extinction of species was also accepted. Étienne Geoffroy Saint-Hilaire suggested that some species might be changed in response to environmental changes during sudden geological revolutions while other species simply went extinct. His view, however, gained little traction because geologists were generally more interested in using various fossil species for precise dating of specific points in geohistory. They wanted to know when a given organism first appeared and when it disappeared. Interest in the history of life overshadowed interest in causation of the origin of species.

Nevertheless, there was enough talk about transformism that Lyell became concerned about its implications for human nature. Wishing to safeguard human dignity, Lyell realized that if the directional character of geohistory proved to be an illusion, then there would be no room for transformism. Within this context Lyell set out to formulate a steady state conception of Earth history.

Lyell's Principles of Geology

In Part III, Rudwick reviews the years from 1827 to 1833 in nine chapters. The focus is entirely on Charles Lyell's famed theory of geohistory and its reception. Lyell planned to write a book that would emphasize the adequacy of actual causes, always acting at the same intensity as at present. In preparation for the ambitious project, he undertook a grand tour of Europe akin to Charles Darwin's voyage on the HMS *Beagle* just a few years later.

Lyell visited the volcanic terranes of the Auvergne, Velay, and Vivarais in France and found the same kind of volcanic evidence in each area. Along the Mediterranean coast of Provence, he was struck by the considerable thickness and substantial amount of elevation of the Tertiary strata. He assessed the proportions of fossil mollusk species in Tertiary sequences for use as time markers. In northern Italy, Lyell examined younger Tertiary rocks of the Apennine region before moving south to visit the Temple of Serapis, Vesuvius, Pompeii, and Sicily. He closely studied Mount Etna and recognized that numerous cinder cones, apparently predating human records, had been constructed on the flanks of an enormously thick pile of lava flows, which in turn had accumulated atop a thick stack of Tertiary strata, all of which contained many fossils of extant species. He concluded that Mount Etna must be unimaginably ancient by human standards, and he came to envision the Tertiary world as continuous with our present world in one unbroken chain of geohistory.

From his observations, Lyell appreciated the adequacy of modern causes for explaining the former world. He also concluded that the operation of actual causes was never more intense than at present. Even as geologists continued to debate the nature of the causes that produced the diluvium, Lyell issued volume 1 of *Principles of Geology* in 1830.[16] He presented an elaborate new "system" of geohistory, a new theory of the earth, à la James Hutton, in an era when most geologists were skeptical of such grandiose theorizing. They were concentrating on establishing and absorbing a wealth of factual geological data rather than indulging in unwarranted speculation. To lay the foundation for his case, Lyell led off with a rather biased and self-serving historical essay followed by an inventory of actual causes that, in his judgment, contributed to both sides of a dynamic equilibrium in a steady-state world. Lyell emphasized the power and violence of modern causes (provided they had been witnessed) to render their successful and exclusive application to the record of the past more convincing and palatable.

Although Lyell's book received much praise for its treatment of actual causes and its firm repudiation of "Scriptural geology,"[17] Scrope, De La Beche, Conybeare, William Whewell, Sedgwick, and others criticized Lyell's rejection of directionalism in favor of a somewhat static model of geohistory. They charged Lyell with confusing highly complex geological processes with the basic physico-chemical laws of nature. His critics all agreed with Lyell on the uniformity of the latter but insisted that the power and intensity of the former had to be established empirically rather than assumed a priori.

Lyell planned to devote a concluding second volume of *Principles of Geology* to his reconstruction of the Tertiary period, which he calibrated on the basis of changing mollusk faunas. However, by continuing his inventory of actual causes and including a discussion of the history of organisms, the projected second volume became so bulky that he and his publisher decided to postpone consideration of the Tertiary reconstruction to a third volume.

In volume 2, Lyell rejected Jean-Baptiste de Lamarck's transformism and adopted the stability of organic species.[18] He expressed skepticism about the reality of mass extinctions (unobserved at present and too drastic for his blood) and argued instead for piecemeal birth and extinction of organisms. To discount the apparent directional character of the history of life, Lyell argued that the fossil record was extremely incomplete, that it was an artifact of systematic biases in preservation, and that higher life forms, preserved only in younger strata, did exist during earlier eras of geohistory but that their remains had either eroded away or had not been preserved, perhaps due to alteration.

Reviewers of volume 2, as did Lyell, also rejected transformism. Whewell thought that species might have a transcendent origin. On the adequacy of actual causes, Whewell postulated the existence of two opposing camps among geologists, those of the "catastrophists" and those of the "uniformitarianists." Implicit in Whewell's discussion was that Lyell was the only member of the latter!

The third volume of *Principles of Geology* contained Lyell's analysis of the Tertiary strata as a test case for his steady-state conception of uniformity with its notion that the identity, power, and intensity of causes of the present remained much the same throughout all of geohistory.[19] Lyell introduced a subdivision of Tertiary strata into Eocene, Miocene, Older Pliocene, and Newer Pliocene groups, from older to younger. He explained the diluvium in terms of modern processes, such as the melting of icebergs at a time of higher sea level or the breaking of ice dams in the Alpine region, rather than a gigantic deluge. He interpreted the old Primary rocks as resulting mostly from plutonic injection and metamorphism, making it impossible to do geohistorical reconstruction because of lack of fossils. The beginning of Earth's history, he said, was a matter of inadequate knowledge. The successive periods of Lyell's geohistory were distinctive, knowable, and datable. Lyell transformed the practice of geohistorical reconstruction by provoking other geologists to articulate their own attitudes to geological method and to geohistory more clearly than they had.

The Aftermath of Lyell's *Principles of Geology*

In Part IV, Rudwick reviews the years from 1830 to 1845 in ten chapters and deals with the aftermath of the publication of Lyell's masterwork. Geologists welcomed Lyell's repertoire of actual causes, acknowledging that he had demonstrated that actual causes successfully explained more aspects of the deep past than they had previously realized, but they never warmed to Lyell's rejection of directionalism or his insistence on the uniformity of intensity of actual causes.

In a cave at Languedoc, France, Tournal found associations of human remains and the bones of extinct mammalian megafauna, leading him to advocate the contemporaneity of humans and extinct animals. Philippe Schmerling found similar associations in a cave at Liège, Belgium. In some cases, stone and possibly bone tools accompanied the remains. On the basis of these findings, Tournal proposed the existence of an ante-historical period preceding the era of recorded human history. However, he was met with skepticism. But then, fossil primate bones were found by Édouard Lartet in France and by others in India and Brazil, finds that reinforced belief in the progressive nature of the fossil record and also raised the troubling question of transformism in relation to human origins.

The directionality of the fossil record was further reinforced by Louis Agassiz's detailed research on fossil fishes. He showed that fish diversity increased through time and suggested that an Age of Fishes in the Carboniferous period preceded an Age of Reptiles which, in turn, preceded a period characterized by mammals. John Phillips did a detailed study of Carboniferous (the lowest part of the Secondary strata) invertebrates, and Roderick Murchison worked downward from the base of the Secondary into the Transition rocks (which he named Silurian). He found abundant fossils of invertebrates but no land plants. Sedgwick investigated even older parts of the Transition rocks, which he termed Cambrian, but found fewer fossils. He proposed the term Paleozoic for the life forms in the Cambrian and Silurian strata.

De La Beche found fossil plants in coal layers beneath the Carboniferous strata in Devonshire. Further study disclosed the existence of flora and fauna that were intermediate between those of Murchison's Silurian rocks and Carboniferous rocks. These deposits of intermediate character were assigned the name Devonian. This finding reinforced Lyell's claim that life forms changed piecemeal without breaks in continuity.

The topic of crustal elevation remained controversial. Élie de Beaumont favored the uplift of the Andes in one sudden violent event, but an 1835 earthquake that produced small elevations all along the coast of Chile was witnessed by Darwin and Captain Robert Fitzroy during their famed voyage on HMS *Beagle*. Darwin returned to England a convinced Lyellian and postulated that elevation and subsidence of landmasses occurred by means of repeated slow vertical movements of large crustal plates, evidence for which he saw in raised beaches, coral reefs, and atolls.

Widespread broad valleys, erratics, poorly sorted gravels, and scratches and grooves on polished bedrock surfaces needed explanation: diluvial currents of water or mud, icebergs melting and dropping embedded rocks, and extended glaciation were all invoked. From field study of modern depositional and erosion features associated with active glaciers, Ignaz Venetz and Jean de Charpentier demonstrated that Alpine glaciers had been much larger in the past. To account for the phenomena, Agassiz proposed the former existence of an ice age during which most of the northern hemisphere as far south as northern Africa had been covered by vast ice sheets. Other geologists began to recognize local examples of former glacial activity. Buckland was convinced of the glacial hypothesis by Agassiz as they toured northern Scotland together. Even Lyell was partly convinced. A major problem for the concept of an ice age, however, was that it ran counter to evidence for a continuously cooling globe, thus conflicting with the directional view of geohistory. On the other hand, an ice age was also akin to a gigantic catastrophe, hence not fitting neatly into Lyell's steady-state view. Debate over the reality of an ice age continued for years, and, of course, Agassiz's theory ultimately triumphed.

The cause of the obviously directional and even progressive sequence of organic remains in the fossil record remained obscure and mysterious. Ironically, even as Lyell continued his attempt to shore up his beleaguered steady-state, uniform model of geohistory, Darwin, his closet ally, was busy working out a causal theory of species origin, thinking that it might help fill a major gap in Lyell's inventory of actual causes. Little did Lyell realize that his major supporter regarding the advocacy of the complete adequacy of actual causes would one day thoroughly annihilate any thought of a steady-state geohistory or history of life.

Final Observations

In *Worlds before Adam*, Martin Rudwick has brilliantly shown how geology became the first of the historical sciences, how early geologists went about deciphering geohistory, and how they came to take the historical nature of geology for granted. While granting due recognition to the importance of social activities and social influences on the development of geology as a historical science, Rudwick parts company from those who would argue that science is simply a social construct. After all, conceptual developments in geology were consistently grounded in solid empirical research, particularly geological fieldwork. Moreover, Rudwick emphasized, the details of Earth history could not and cannot be deduced from a set of first principles, but had to be, and still must be, worked out empirically from what we see in the field. Geohistory could have been different from what it actually is. The lesson, according to Rudwick, is that geology is not the same kind of science as physics. As a result, we ought not hold up any one science as the standard by which others must be judged. The differences among the sciences are real. They must be recognized and then celebrated, not regretted.

The University of Chicago Press has produced a handsome and weighty volume that is worthy of the excellence of this magnificent text. The book is printed on very heavy glossy paper and weighs an intimidating 4.2 pounds (although less than the 5.0 pounds of *Bursting*). The print is clear and very readable. The text is supported by copious, very detailed footnotes. It is also enhanced by 165 original illustrations from early nineteenth-century geological publications, each of which is accompanied by the most comprehensive captions I have ever encountered. Typographical errors are negligible. The headers for chapter 27 were unfortunately continued as the headers for chapter 28. Other than that I noticed only one minor misprint.

Worlds before Adam is a must read for all geologists who desire a better grasp of the roots of the science they love so much. Advocates of flood geology and young-earth creationism would do well to read both this work and its predecessor, *Bursting the Limits of Time*, very carefully. Ideally, such reading would serve as a healthy corrective to the historical errors that abound in the writings of many adherents of that persuasion. And to historians of science who specialize in a science other than geology, I simply say that, if you never read more than one volume on the history of geology, then this is the one you should read. Profuse thanks to Martin Rudwick for providing lovers of planet Earth with such pure intellectual pleasure.

Notes

[1]We should note that *Tyrannosaurus rex*, the villainous dinosaur that wreaked havoc in *Jurassic Park*, never lived during the Jurassic Period, but only during the succeeding Cretaceous Period. *Cretaceous Park*, anyone?

[2]See, for example, Dorinda Outram, *Georges Cuvier: Vocation, Science and Authority in Post-Revolutionary France* (Manchester: Manchester University Press, 1984); Nicolaas Rupke, *The Great Chain of History: William Buckland and the English School of Geology* (Oxford: Clarendon Press, 1983); Leonard G. Wilson, *Charles Lyell, The Years to 1844: The Revolution in Geology* (New Haven: Yale University Press, 1972); James A. Secord, *Controversy in Victorian Geology: The Cambrian-Silurian Dispute* (Princeton: Princeton University Press, 1986); Robert A. Stafford, *Scientist of Empire: Sir Roderick Murchison, Scientific Exploration and Victorian Imperialism* (Cambridge: Cambridge University Press, 1989); and Jack B. Morrell, *John Phillips and the Business of Victorian Science* (Aldershot: Ashgate, 2005).

[3]Martin J. S. Rudwick, *Living and Fossil Brachiopods* (London: Hutchinson, 1970).

[4]Martin J. S. Rudwick, *Lyell and Darwin: Studies in the Earth Sciences in the Age of Reform* (Aldershot: Ashgate, 2005), vii.

[5]Martin J. S. Rudwick, "Uniformity and Progression: Reflections on the Structure of Geological Theory in the Age of Lyell," in D. H. D. Roller, ed., *Perspectives in the History of Science and Technology* (Norman, OK: University of Oklahoma Press, 1971), 209–27.

[6]Martin J. S. Rudwick, *The Meaning of Fossils: Episodes in the History of Palaeontology* (London: Macdonald, 1972).

[7]Martin J. S. Rudwick, *The Great Devonian Controversy: The Shaping of Scientific Knowledge among Gentlemanly Specialists* (Chicago: University of Chicago Press, 1985).

[8]Martin J. S. Rudwick, *Scenes from Deep Time: Early Pictorial Representations of the Prehistoric World* (Chicago: University of Chicago Press, 1992).

[9]Martin J. S. Rudwick, *Georges Cuvier, Fossil Bones, and Geological Catastrophes* (Chicago: University of Chicago Press, 1997).

[10]Martin J. S. Rudwick, *Lyell and Darwin* and Martin J. S. Rudwick, *The New Science of Geology: Studies in the Earth Sciences in the Age of Revolution* (Aldershot: Ashgate, 2004).

[11]Martin J. S. Rudwick, *Bursting the Limits of Time: The Reconstruction of Geohistory in the Age of Revolution* (Chicago: University of Chicago Press, 2005).

[12]Rudwick discussed the contributions of Smith in *Bursting the Limits of Time*.

[13]In the early nineteenth century, investigators of geological phenomena categorized rocks by use of such terms as Primary, Transition, Secondary, Tertiary, and Diluvium. These terms provided a crude geological timescale in that the "diluvium" lay atop Tertiary or older rocks; Tertiary strata lay atop Secondary or older rocks; Secondary strata lay atop Transition rocks or older; and Transition rocks lay atop Primary rocks. In this scheme, then, Tertiary rocks are relatively young.

[14]"Actual" causes were so named on the basis of the French words "actuel, actuelle" meaning "current" or "present."

[15]William Daniel Conybeare and William Phillips, *Outlines of the Geology of England and Wales with an Introductory Compendium of the General Principles of that Science, and Comparative Views of the Structure of Foreign Countries* (London: William Phillips, 1822).

[16]Charles Lyell, *Principles of Geology*, vol. 1 (London: John Murray, 1830).

[17]So-called "Scriptural geology" was the term applied to theories of geology and Earth history that were based primarily on a literal interpretation of the creation and flood narratives. "Scriptural geologists" characteristically rejected the concept of deep time and emphasized the geological capabilities of the Genesis deluge.

[18]Lyell, *Principles of Geology*, vol. 2 (London: John Murray, 1832).

[19]Lyell, *Principles of Geology*, vol. 3 (London: John Murray, 1833).