Earth cycles: A historical perspective

By David Oldroyd

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For at least two centuries, most geologists have been convinced that Earth has experienced a "linear," directional history. There is no doubt that our planet is very different from what it was a few billion years ago. No one expects Earth's internal differentiation into a core, mantle, and crust to be reversed, and future evolution of life is unlikely to revert to one-celled organisms and then repeat itself. In spite of such mega-examples of non-cyclic processes, every introductory geology student is confronted almost immediately with the "rock cycle" and eventually with the "hydrological cycle" and even the cyclic nature of plate tectonics. Geology majors learn about cyclothems, the carbon cycle, and cyclic crystallization in layered intrusions. Geologists have no doubt that the one-way Earth history has included a multitude of cyclic processes, many of them interlinked. They also recognize that cyclic processes are like musical "themes" that are repeated with considerable "variations" in extent, duration, intensity, and nature of their components. So important in geology are known cyclic phenomena and processes that contemporary geologists have a tendency to seek for cycles, even where they may not exist.

In light of the enormous importance of known cyclic geologic processes and cyclic interpretation in geology, David Oldroyd, Honorary Visiting Professor in History and Philosophy of Science at the University of New South Wales and a former Secretary General of INHIGEO, has produced this stimulating study of the historical aspects of cyclic thinking in geology. *Earth Cycles: A Historical Perspective* is the first book devoted to geology in a series of *Guides to Great Ideas in Science* published by Greenwood Press. Among earlier titles in the series are volumes on Evolution, The Chemical Element, The Gene, The Cosmos, and Quantum Mechanics. These guides are "devoted to concepts that are fundamental to different branches of the natural sciences" (p. vii), and the series editor has aimed for writing that will successfully combine the effort to reach a wide audience of non-scientists while still being technically accurate (see p. viii). Oldroyd has, as usual, written with accuracy and lucidity, although some lay readers will probably find discussions of astronomical and geochemical cycles a bit daunting. In *Earth Cycles*, Oldroyd, who is well known for his exceptional work *The Highlands Controversy*, and for *Thinking about the Earth*, has given us a fascinating

synopsis of the historical development of numerous fundamental geologic ideas that is impressive for its grasp of key literature and concepts from a wide range of geologic subdisciplines.

Oldroyd starts with investigations leading up to the general acceptance of the "geostrophic cycle" of erosion, sedimentation, and uplift espoused by Hutton and Lyell. From there he moves to more detailed investigations of geomorphic, sedimentologic, stratigraphic, and tectonic components of the geostrophic cycle, some of which disclosed further cyclic processes. Finally, he introduces the application of astronomic cycles to glaciology and stratigraphy; points out efforts to produce global stratigraphic correlations on the basis of inter-related sedimentary and tectonic cycles; discusses more recently recognized cyclic phenomena in geophysics and geochemistry; and elucidates attempts to demonstrate the interplay of geologic cycles and their possible dependence on astronomical cycles.

The first six chapters contain material that will be fresh for the general reader but is very familiar to fans of the history of geology: the Greeks and Romans, Buridan, Leonardo, Descartes, Steno, Burnet, Leibniz, Hooke, Hutton, Lamarck, and Lyell. Despite leading us one more time over such well trodden terrain, Oldroyd still manages to give us a fresh look at these well-known "landmarks" by pointing out the cyclic or linear character of their thinking about geologic processes and phenomena. After a brief introductory chapter on the nature of cyclicality, Oldroyd reminds us in Chapter 2 of the familiarity of the Greeks and Romans, such as Anaximander, Aristotle, and Ovid, with the concepts of a hydrologic cycle and cyclic interchanges of land and sea. He describes Jean Buridan's medieval attempt to build on Aristotle's *Meteorologica* by postulating that the Earth's center of gravity remained in balance at the center of the universe thanks to perpetual cycles of sedimentation and elevation. As sedimentation occurred in the oceans, the ocean floor would be depressed

toward the Earth's center, resulting in a corresponding outward movement toward the surface on the opposite side of the Earth that produced land elevation. In turn newly elevated land would erode, with deposited sediment again depressing the sea floor toward the Earth's center, thus leading to another episode of elevation, and so on.

In Chapter 3, Oldroyd examines some seventeenth-century efforts to develop rationalistic accounts of Earth history, formulated in terms of a Bible-based "straightforward," one-way, linear history proceeding in a few thousand years from Creation through Adam's Fall and Noah's Flood to the final Consummation. After referring to Descartes' explanation of the development of an internally stratified globe in terms of mechanical interactions of particles at various discrete "vortices," Oldroyd elaborates on Steno's exposition of fundamental principles of stratigraphy and reconstruction of the history of Tuscany. Oldroyd writes that Steno could easily have placed his reconstruction into the linear biblical scenario of his contemporaries had he chosen to do so. Steno's famous six-step stratigraphic cross sections of Tuscan geology are said to envision two similar yet not identical cycles of sedimentation, undercutting, and collapse. Next we are directed to Burnet and Leibniz, both of whom constructed directional Earth histories on Cartesian principles. Although Burnet's theory of globe formation, subsequent crustal collapse with release of the subterranean abyss to produce Noah's flood, and ultimate destiny of the Earth as a star was decidedly linear, Oldroyd notes that Burnet's theory treated Earth history as one grand cycle that proceeded from the initial Creation to a renovated New Creation. Leibniz, far more influenced by Steno than Burnet was, still came up with an essentially linear theory of the Earth while bringing into focus the important roles of both fire and water as geologic agents.

A brief Chapter 4 is devoted to Robert Hooke who wanted to test his theory of the Earth with field evidence and experiment. Oldroyd reviews Hooke's acceptance of the organic origin of fossils and of interchanges in relative levels of sea and land likely brought about by earthquakes. We learn that Hooke, like Buridan, envisioned repeated cycles of erosion, deposition, and uplift, proposing that land regions moving to higher latitudes thanks to pole wandering would be elevated and eroded, whereas regions moving to lower latitudes, again thanks to pole wandering, would become depressed and receive sediment. Hooke's theory was criticized for allegedly being incompatible with a biblical timescale.

Cyclic theory of the Earth came into its own with James Hutton, whose geologic contribution is summarized in Chapter 5. Hutton, we learn, adumbrated his cyclical approach to geology in his 1749 doctoral thesis on blood circulation where he spoke of "the glorious cycle of life" and the body as a

"very beautiful instance of a perpetual motion machine." As a deist, Hutton believed that the deity was a cosmic designer who prepared the Earth with water, air, and soil for the welfare of humanity. The constant loss of soil to the sea by erosion, however, set Hutton to thinking about how to replenish soil in a scheme that invoked divine design. Obviously an unending cyclic process of soil generation was in order. The steam engine of Hutton's friend, James Watt, set him to thinking about the globe as a giant heat engine driving his putative cycles. Without explaining the source of the Earth's internal heat, Hutton constantly sought and discovered, so he believed, geologic field evidence for his heat-driven cycles. Among these, as Oldroyd recounts, were the discovery at Glen Tilt and Arran of intrusive granite veins penetrating into secondary strata as evidence of heating and melting of rock at depth. Nodules and layers of chert provided presumed evidence of heat as the source of solidification of sediment. And the discovery of angular unconformities on Arran, at Jedburgh, and at Siccar Point reinforced the idea of land elevation, subsequent erosion, marine subsidence, and renewed sedimentation. Hutton's "geostrophic" cycle, Oldroyd maintains, was the first consistently thought through and geologic field-tested cyclic theory of Earth history. The chapter finishes with a nod toward Lamarck's *Hydrogéologie*, which contains a cyclic theory that Oldroyd characterizes as likely the most "fanciful theory in the history of geology."

The arch-uniformitarian Charles Lyell comes into view in Chapter 6. Lyell was a Huttonian who placed great emphasis on the role of fossils. As he saw it, life history, like Earth history, followed a steady-state uniformitarian, non-directional course. In Lyell's conception, the endless cycles of erosion, sedimentation, burial, and uplift showed great variety because climatic and tectonic conditions continuously varied from place to place and time to time, even while the Earth maintained a more or less constant overall energy balance throughout its history. Lyell also thought that the basic types of life remained constant, although within those stable types, animals and plants came and went depending on variation in environmental conditions. He suspected that there might even be cyclic reversals of life forms should environmental conditions reverse. For Lyell, there was a "gradual turnover of species through time" (p. 62). Lyell's cyclic turnover of organisms eventually gave way to Darwin's directionalist, progressionist arrow thanks to failure to find remains of higher organisms in lower strata coupled with Darwin's success in persuading the reluctant Lyell of the likelihood of evolution by natural selection. As Oldroyd put it, "after Darwin, the old Lyellian cycle was no more" (p. 67).

In the nineteenth century, enormous strides were taken in understanding the various components of the geostrophic cycle,

and it is to these that Oldroyd turns next, beginning in Chapter 7 with the explosion in geomorphic knowledge brought about by the nineteenth-century explorations in the western United States. Here Oldroyd alludes to the labors of Powell, Gilbert, and others in introducing such fundamental geomorphic concepts as base level, downcutting, grade, and antecedent and consequent streams, and of Dutton in developing the notion of isostasy. William Morris Davis, the focal point of the chapter, combined these basic geomorphic concepts in his cyclic theory of landscape evolution, which he cast in Darwinian biological language. Thus, he considered landscapes to pass through youthful, mature, and old age stages. The cycle of landscape evolution might begin all over again by rejuvenation of the landscape thanks to renewed elevation of an old age peneplain, followed by more erosion and leveling. Davis's cycle of landscape evolution with its stage of erosion following a stage of uplift was challenged by Walther Penck as being too simplistic. Penck insisted that erosion accompanied uplift and that the course of landscape development would be affected not just by vertical elevation and wearing down but also by crustal folding and arching. Moreover, changes in rates of tectonic processes and significant changes in climate had to play a role in landscape formation. Davis's concept of simple geomorphic cycles did not withstand the test of time. As Oldroyd saw it, "the wheels fell off Davis's cycle!" (p. 77).

Geologists also pondered the causes of mountain uplift that allowed erosion to do its work. And they worried about how a sedimentary basin could accumulate all the erosion products from mountain ranges. Enter the "tectonicists." In Chapter 8, by far the longest, Oldroyd reviews the labors of several geologic giants of the nineteenth and early twentieth centuries who endeavored to make sense of mountain building: Élie de Beaumont, Prévost, Hall, Dana, Suess, and Chamberlin, all of whom, except Chamberlin, thought that mountain systems resulted from repeated episodes (cycles) of contraction of a cooling Earth. Oldroyd gives us synopses of Élie de Beaumont's idea of mountain ranges as pentagonal networks forming on an increasingly wrinkled globe, James Hall's notion that the thick piles of sedimentary rocks in mountain systems developed by sedimentation in continuously subsiding shallow-water basins, and James Dwight Dana's concept of geosynclinal basins of sedimentation and geanticlinal highs produced by lateral compression as well as successive episodes of continental growth. The contributions of Eduard Suess are highlighted. Working in the Alps, Suess also invoked large-scale lateral stresses directed toward the stable interior of Europe and generated by global cooling and contraction. He developed the idea of eustasy in linking global marine regressions and transgressions with episodes of mountain building and subsequent erosion and sedimentation. He con-

sidered the successive Caledonian, Variscan, and Alpine orogenies to involve mountain building, metamorphism, seismicity, and volcanism succeeded by sedimentation and new life forms. "There was," according to Oldroyd, "a grand cyclicality in Suess's theory" (p. 89). Thomas Chamberlin broke new ground in recognizing the inadequacy of global contraction and attributing a role to Dutton's concept of isostasy in mountain building theory. He proposed that "diastrophism" provided the ultimate basis for global stratigraphic correlation.

Oldroyd turns next to the march toward plate tectonics. Alfred Wegener questioned why oceans and continents would have such different compositions if they were formed by global contraction with attendant rising and foundering of large domains of the same crustal material. Paleontology and geographic similarity of continental coastlines led him to the idea that continents drift by plowing through oceanic crust. Holmes invoked radioactive heating to drive convection currents in the mantle as a way to move continents and account for cycles of mountain building. Continental drift, however, did not attract a large following until the discovery of ridge systems, trenches, and seamounts on the ocean floors; of changes in magnetic pole positions; and of steeply inclined planar zones of deep-focus earthquakes beneath the trenches by Wadati and Benioff. These discoveries led to the sea-floor spreading hypothesis, proposed independently by Harry Hess and Robert Dietz, which envisions formation of new ocean floor material at ridge systems and consumption of such material at trenches by way of large-scale upper mantle convection. Sea-floor spreading was confirmed when Matthews and Vine recognized symmetrical magnetization patterns associated with sea-floor basalts on opposite sides of ridge systems. The plate tectonic theory, in which both oceanic and continental lithosphere plates collide at subduction zones to produce mountain belts and diverge at oceanic ridge systems, entails all manner of interconnected cyclic processes. The terrestrial magnetism that generated the symmetrical magnetization patterns in sea-floor basalts cycles between alternating periods of normal and reversed magnetic polarity. The upper mantle convection cells that carry lithosphere plates continuously cycle material and heat. And J. Tuzo Wilson postulated that plate movement has resulted in repeated episodes of opening and closure of ocean basins in what came to be known as Wilson cycles.

In Chapter 9, Oldroyd introduces astronomical cycles as a potential cause of geologic phenomena, in this case, former ice ages. He notes that Louis Agassiz explained the former extent of Alpine glaciers and his postulated Ice Age by episodic stepwise heating and succeeding excessive cooling events during the overall cooling trend of the Earth. Throughout the eighteenth and nineteenth centuries, several individuals began to

assess the effects that changes in the Earth's orbit have on solar insolation. Oldroyd discusses both James Croll's linkage of ice ages to the combined effects of the precession of the equinoxes and rotation of Earth's elliptical orbit, as well as the detailed study of moraines and terraces by Penck and Brückner that led to the now abandoned hypothesis of four major ice advances during the European Pleistocene. The chapter then looks at Milutin Milankovic whose sophisticated mathematical analysis of the cycles of eccentricity (98,000 years) and obliquity (41,000 years) of the ecliptic and precession of equinoxes (23,000 years) led to calculation of the effects of these cycles, modified by processes and phenomena such as reflection of ice and snow, sea level changes, vegetation, and fog, on solar insolation at specific latitudes. Subsequent calculations of sea temperature fluctuations based on studies of oxygen isotopes and radiolarians from marine sediments of the past 450,000 years suggested a reasonable match with the three main Milankovic cycles around 100, 42, and 23 thousand years.

Oldroyd considers cyclic themes in sedimentology and stratigraphy in the next two chapters, the first of which focuses on cyclothems. The chapter begins in the early twentieth-century with Joseph Barrell's stress on the rhythmic character of sedimentation as evidenced by alternation between periods of deposition in subsiding basins and temporal breaks in sedimentation accompanied by erosion, all brought about by changes in base level due to sea level fluctuations. The heart of the chapter deals with the recognition of widespread cyclic sedimentation in stable cratonic, non-orogenic environments as a result of detailed mapping of Upper Paleozoic strata in mid-continent North America by stratigraphers like Udden, Moore, Wanless, and Weller. Wanless and Weller designated these rhythmic sediment packages as cyclothems. They and other stratigraphers debated the components of the ideal cyclothem and sought causes in large-scale vertical tectonic movements or in eustatic sea level changes. Philip Heckel and others related the eustatic sea level changes that presumably produced individual cyclothem cycles to episodes of glaciation and Milankovic's astronomical cycles. Heckel also envisioned the possibility of world-wide stratigraphic correlation due to cyclic rises and falls in global sea level.

The stratigraphic theme continues in Chapter 11 on sequence stratigraphy. After a brief pass at the efforts of early twentieth-century geologists like Ulrich, Stille, Grabau, and Umbgrove to identify large-scale, regional unconformities that might form the boundaries of the major systems of the geologic timescale, Oldroyd homes in on the work of Laurence Sloss, with whose name sequence stratigraphy is so closely associated. In mid-twentieth century, Sloss identified several very large, regional unconformity-bound packages of related sedimentary

rocks that he linked to major marine transgressions and regressions. He proposed his now famous succession of North American sequences: Sauk, Tippecanoe, Kaskaskia, Absaroka, Zuni, and Tejas. In Sloss's view, synchronous deposition of different facies of sediment in a transgressing sea produced sand-limestone-shale sequences both horizontally and vertically. Repeated cycles of transgression and regression generated cycles of sedimentary rocks and unconformities. In the final part of the chapter, Oldroyd details the controversial studies of Peter Vail and his co-workers at Exxon Corporation. Combining data, much of it proprietary, from seismic profiles, well-log data, and surface stratigraphy, and assuming that seismically identified unconformities represent isochronous surfaces, Vail produced elaborate sets of sea level curves for the Phanerozoic. These curves show a characteristic sawtooth pattern that he believed indicated numerous cycles, presumably global, of gradual marine transgression followed by rapid regression. Vail also identified several orders of cycles, e.g., very long term and short term, from the curves. Eventually the cycles were linked to astronomical causes. Oldroyd points out that, although the Vail curves were supported by a huge database, they have not been universally accepted on the grounds that tectonic factors have been downplayed, the cycles are more precise than warranted, the assumption of isochronous unconformities is questionable, and the curves have been used to date sediments rather than vice versa.

Oldroyd examines the geomagnetic timescale in Chapter 12. He mentions the discovery of opposed magnetization of rocks by Brunhes, the postulation of global geomagnetic field reversals by Matuyama, and the application of K-Ar dating to sequences of interbedded lava and sedimentary rocks in which magnetic reversals are recorded, thus leading to establishment of a global magnetic reversal timescale. The paleomagnetic timescale has been linked to paleontologically defined horizons, climate changes through time, and sea temperature changes as measured by oxygen isotopes through the work of Emiliani and others. Oldroyd also notes that astronomical cycles have been used to calibrate the timing of the sedimentologic and paleontologic record, geomagnetic cycles, and, in some cases, radiometric data.

Oldroyd concludes the historical studies of the book by examining geochemical cycles. He reviews Halley's initial geochemical investigation of the accumulation of sodium in seawater as a potential geochronometer and subsequent refinements of Halley's calculations by Reade and Joly. He notes that Clarke and Nieuwenkamp called attention to the cyclic nature of the geochemical behavior of sodium by pointing out the role of sinks and sources such as evaporite deposition and salt spray. After passing references to the idea of geochemical cycling in Schonbein, Bischoff, and Goldschmidt, we are introduced to Vernadsky, who stressed

the role of organisms in geologic processes such as sedimentation as well as the importance of quantitative assessment of sources and sinks of elements. The bulk of the chapter concentrates on the labors of Garrels, Mackenzie, and their colleagues, who have spent careers in making Vernadskyan assessments, investigating chemical reactions involved in element cycling, and producing elaborate flow charts for various elements. The chapter draws to a close with examination of the contribution of isotopes to our understanding of geochemical cycling and of recent attempts to link geochemical cycles with Vail curves and plate tectonic cycles of plate convergence and divergence, with the stabilizing assistance of life.

Oldroyd wraps up *Earth Cycles* (Chapter 14) with the observation that cyclic thinking permeates modern geology in striking contrast to the time of Hutton when he had to push his case hard to gain a hearing for the idea of the existence of grand cycles. Despite the host of major cyclic processes that have occurred throughout Earth history and the ease with which contemporary geologists look for cyclic phenomena, Oldroyd reminds us that cyclism appears to have little relevance in some geologically important processes such as evolution, volcanism, and earthquake activity, or in the world of minerals and crystals. He also emphasizes the theme and variation nature of cyclic processes in Earth history.

Although very few typographic errors mar the main text of *Earth Cycles*, an exceptionally egregious typographic offense occurs in the International Stratigraphic Chart (p. 192) where the terms Precambrian, Pal(a)ozoic, and Phanerozoic are misspelled as Precanbrian, Paslaezic, and Phanevozoic respectively. Ouch! It's difficult enough for beginners to learn the correct names of the timescale! On p. 93, the rock type, peridotite, is referred to as a mineral. Despite these minor annoyances, Oldroyd is to be congratulated for producing a stimulating volume that, because it touches on so many important developments in such a wide range of fields, might easily take its place as one of the required texts in a survey course on the history of geology.

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