James Hutton

A Theory of the Earth

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James Hutton was a chemist, geologist, agriculturist, and prominent member of the Edinburgh intelligentsia during the height of the Scottish Enlightenment. His contemporaries and friends included Robert Adam, David Hume, Adam Smith, Dugald Stewart, and James Watt. Hutton's major work, *Theory of the Earth*, published first in 1788 and expanded in 1794, describes his geological observations and resulting theory for the cycling of the earth.[1] His conclusion was startling: "We find no vestige of a beginning, no prospect of an end."[2] It was a unique perspective among seventeenth- and eighteenth-century scientific efforts, expressed freely and without regard for any scriptural constraints. Hutton's ideas are easily recognizable in today's understanding of deep time and the geodynamic cycling of the earth by plate tectonics. Like a Lazarus taxon, which disappears from the fossil record and resurfaces later, his notion of a recycling earth was born from scientific endeavor in the Age of Enlightenment and resurrected in the nuclear age.

The major sources for what is known of Hutton's life and work come courtesy of his friend and biographer James Playfair, as well as seventeen preserved items of personal correspondence.[3] Hutton was born in 1726 in Edinburgh of prosperous merchant stock. His father and elder brother died when he was young, and he and his sisters were raised by their mother. At the University of Edinburgh, he followed the mathematics lectures of Isaac Newton's protégé Colin Maclaurin and studied humanities and medicine. Hutton never practiced the latter, but its study was the best route to pursue his interest in chemistry. From 1747, he continued his studies at the Universities of Paris and Leiden, and graduated from Leiden with a medical degree in 1749. Returning to Edinburgh, he set up with a friend in the profitable manufacture of sal ammoniac, a salt used for dyeing and metalworking, using chimney soot as raw material. He then made a radical change in life direction. In the early 1750s, he took a two-year stint on a Norfolk farm where he learned advanced agricultural practices. He took charge of two family farms in Berwickshire in the Scottish Borders and there became a hands-on landlord who developed the land by applying the latest techniques in agriculture and landscaping.

From the mid-1760s, Hutton lived with his sisters in central Edinburgh and threw himself into the city's scientific and philosophical life. Over the next twenty years, he gained enough field experience to have a detailed understanding of the basic geology of Scotland, England, and Wales, and so established himself as the premier Scottish geological philosopher. His practice of geology gained breadth and substance through his love of chemistry, extensive surveys of the French scientific literature, and a close friendship with the prolific chemist Joseph Black. It was Black who discovered the latent heat of steam, invented the eighteenth century's most precise analytical balance, and discovered carbon dioxide, a product of animal respiration and organic fermentation. He also produced aqueous precipitates of calcium carbonate and investigated silica precipitation from Icelandic geyser waters.

An initial version of *Theory of the Earth* was read to the Royal Society of Edinburgh on two occasions in 1785, the first by Black when Hutton was ill, and the second by Hutton himself. Organized in four parts, the work was published three years later in the debut volume of the *Transactions of the Royal Society of Edinburgh*.

The intellectual method in Hutton's magnum opus was influenced by his fieldwork, agricultural experience, and deism. He worked from a deductive hypothesis that the planet's machinelike workings had been envisaged by a benevolent and canny creator who parried destructive mountain denudation by constructive processes of renewal involving sedimentation, consolidation, and uplift. Hutton made detailed observations on the nature of rocks, minerals, and fossils and their arrangement in the geological record. But his observations on fossils were nugatory beyond their being indicative of former marine conditions during stratal deposition; nonetheless he became known as "the famous fossil philosopher," as Watt referred to him in a letter of 1774.[4]

In his view of the planet as machinelike—a word used five times in his first nine paragraphs—Hutton established links with contemporary industrial steam-powered machines and particularly the role of heat to drive them. He posited that, like any machine, the planet must have had a designer who knew how best to attain a certain purpose: in this case, the creation of a habitable and renewable surface world.

Regarding the deeper earth, he claimed a general ignorance: "We know little of the earth's internal parts, or of the materials which compose it at any considerable depth below the surface."[5] During Hutton's time, a good deal more was known about the earth's subsurface than he acknowledged; Georges-Louis Leclerc, the comte de Buffon, devoted a whole appendix in his *Les Époques de la Nature* to measurements of ambient temperature in deep mines.[6]

Hutton focused instead upon the earth's surface, where "the more inert matter [i.e., rock] is replenished with plants, and with animals and intellectual beings."[7] This replenishment came courtesy of soil formed from the breakdown of solid rock. But there was a problem, since "this soil is necessarily washed away, by the continual circulation of the water, running from the summits of the mountains towards the [ocean]."[8] Hutton realized that the end result would be the gradual elimination of global relief and the transfer of all land into the oceans. These observations on soil erosion were not new; they had been made as far back as Homer and Plato.[9] Hutton invited readers

> to examine the globe; to see if there be, in the constitution of the world, a reproductive operation, by which a ruined constitution may be again repaired, and a duration or stability thus procured to the machine.[10]

He found evidence that the earth maintained a form of stability. "In examining things present," he wrote,

> we have data from which to reason with regard to what has been; and, from what has actually been, we have data for concluding with regard to that which is to happen hereafter … upon the supposition that the operations of nature are equable and steady.[11]

Hutton believed that the traces of the past bear witness to times "extremely remote" compared to the ancestry of humanity recorded in the scriptures. His examination of fossils indicated that the expanse of historical time was vast:

> It is thus that, in finding the relics of sea-animals of every kind in the solid body of our earth, a natural history of those animals is formed, which includes a certain portion of time.[12]

For estimating this portion of time, Hutton recommended making "recourse to the regular operations of the world" and by calculations based on those.[13]

His theory depended upon a number of assumptions: creation without scripture and myth; a benevolent and forward-looking creator; and linked, steady processes of destruction, consolidation, and replenishment.[14] Of course, some Christians rejected his theory out of hand on the basis of its first assumption.

Hutton proposed that eroded land is replenished by a "consolidating operation" that involves the hardening of loose sediment and fossil remains on and below the ocean floor:

> The loose materials that had subsided [deposited] from water, should be formed into masses of the most perfect solidity, having neither water nor vacuity between their various constituent parts, nor in the pores of those constituent parts themselves.[15]

He considered two possible chemical reasons as to why strata may become consolidated: "either by aqueous solution and crystallization, or by the effect of heat and fusion."[16] He regarded the former as impossible:

> There must be made to pass through those porous masses, water impregnated with some other substances in a dissolved state; and the aqueous menstruum must be made to separate from the dissolved substances, and to deposit the same in those cavities through which the solution moves.[17]

But he found no reason to object to the efficacy of heat and fusion in consolidation. Soft sediment will compact by compression and

> by the fusion of their substance; and foreign matter may be introduced into the open structure of strata, in form of steam or exhalation, as well as in the fluid state of fusion [i.e., as melt].[18]

He ascribed various features to melting, notably siliceous and clay ironstone concretions, the arrangement of crystals in metallic ore veins, and concentrically arranged stratification of rock salt.

Inductive logic was required to arrive at these conclusions, and while it served him well on some occasions, his overzealous eliminative induction severely constrained him at others and left him with only a few possible mechanisms by which to explain matters.[19] In this way, he ruled out the real *causa* for aqueous precipitation: sediment pore waters were static and unmovable at and under the ocean floor. He also rejected the ability of water to either dissolve or precipitate natural crystalline substances that might consolidate loose sediment by cementation, like calcareous, siliceous, bituminous, sulfidic, and ferruginous minerals. Likewise, he ignored the consequences of mechanical compaction and Buffon's observations that the earth's ambient temperature increases with depth.[20] The huge influxes of water into many mines seem not to have persuaded him of the efficacy of deep, warm, aqueous flow through rock masses. He also ignored the ready evidence for calcareous precipitation in caves and springs and for siliceous precipitation from Icelandic geysers.[21]

All of the detailed cases that Hutton enlisted to explain fusion and melting came from observations on a limited number of equivocal specimens. He deduced that a single unlocated sample of fossil wood had been intruded by molten silica, but considered no examples from the Cretaceous chalks where nodular flint is overwhelmingly abundant and fossil wood rare. Other cases included the structure of septarian concretions, and the order of crystallization of certain mineral aggregates.

For the uplift of consolidated sediment to make new mountains, Hutton found the effects of expansive subterranean heat to be the only possible cause. He saw metalliferous mineral veins, lava flows, "subterraneous lavas" (intrusions), and extreme stratal dislocation as thermal accompaniments to violent uplift. Volcanic edifices in mountain ranges pointed both to the existence of great subterranean heat and to the tapping of this heat to relieve pressure:

> A volcano is not made on purpose to frighten superstitious people into fits of piety and devotion, nor to overwhelm devoted cities with destruction: a volcano should be considered as a spiracle to the subterranean furnace, in order to prevent the unnecessary elevation of land, and fatal effects of earthquakes.[22]

Hutton argued that the only possible alternative to the hypothesis of heat-induced uplift was that the uplift was relative, that is, that the level of the ocean had fallen. He reasonably argued that this was impossible without some sink to hold the displaced ocean volume, as well as for other reasons.

The origin, source, and extent of subterranean heat and the reasons for the permanence of violent uplift were unknown and probably unknowable, according to Hutton. Nevertheless, his scheme allowed two kinds of deep heat: a relatively benign form during consolidation, and a violent, expansive form that caused rock uplift and deformation. He never explored the origin of these heat sources or why the two kinds of heat should occur sequentially.

In his finale, Hutton set out "to reason with regard to the duration of this globe."[23] He began by contrasting his own theory with those that involved a once perfectly created Earth violently destroyed by subsequent natural or supernatural events. He mentions no names, but the works of Buffon, Thomas Burnet, Nicolaus Steno, and John Whitehurst are clearly implicated. Hutton stressed that his theory did not deal with the beginning and end of mountain formation but with the linked cyclical processes of destruction, deposition, consolidation, and uplift. These processes worked so "that the destruction of one continent is not brought about without the renovation of the earth in the production of another."[24]

Turning to the likely rates of such processes, especially those calculated based on historical observations of landmass erosion, he found the rates to be so extremely slow as to "require a time indefinite for their destruction."[25] Going back in time:

> if the former continents were of the same nature as the present, it must have required another space of time, which also is indefinite, before they had come to their perfection as a vegetable world.[26]

The earth system he had discovered determined that earth history involved a succession of eroded former worlds. But he added an important caveat:

> It is not necessary that the present land should be worn away and wasted, exactly in proportion as new land shall appear … It is only required, that at all times, there should be a just proportion of land and water upon the surface of the globe, for the purpose of a habitable world.
>
> Neither is it required in the actual system of this earth, that every part of the land should be dissolved in its structure, and worn away by attrition … Parts of the land may often sink … and parts again may be restored, without waiting for the general circulation of land and water … Many of such apparent irregularities may appear without the least infringement on the general system.[27]

In an emphatic finale, he offers his well-known conclusion:

> it is in vain to look for any thing higher in the origin of the earth. The result, therefore, of this present enquiry is, that we find no vestige of a beginning, no prospect of an end.[28]

From this statement, some have claimed that Hutton believed in an eternal world.[29] This is a mistaken view since Hutton made perfectly clear that his conclusion was conditional: he left open the option that others might continue his quest and find otherwise. The abstract for Hutton's 1785 presentation is clearer on this point, though according to one biographer, it may not have been written by Hutton himself.[30]

> But, as there is not in human observation proper means for measuring the waste of land upon the globe, it is hence inferred, that we cannot estimate the duration of what we see at present, nor calculate the period at which it had begun; so that, *with respect to human observation* [emphasis added], this world has neither a beginning nor an end.[31]

I have claimed elsewhere that the well-known conclusion in Hutton's book is a paraphrase of Thomas Browne, who in his *Religio Medici* (1643) gave the following ruminations on time and eternity:

> Time we may comprehend … but to retire so far back as to apprehend a beginning, to give such an infinite start forward, as to conceive an end [emphasis added] in an essence that wee affirme hath neither the one nor the other.[32]

Hutton's remorseless logic delivered a mighty challenge to geological theories that attempted to assimilate field observations with scriptural notions of time, including creation in a few days soon followed by a global flood. But his deism offered additional difficulties for atheists.

Hutton has been criticized for having made little attempt to develop a historical framework for the primary and secondary strata familiar to him over the length and breadth of the British Isles.[33] Such criticism reveals the particular interests of paleontologists, not those of Hutton himself, who had no interest in, and saw no possibility of, such an exercise. In fact, major progress in stratigraphy and the use of fossils had been made, but these efforts were ignored, both by him and by others.[34]

Between 1785 and 1794, Hutton prepared an expanded, amplified, and illustrated version of his theory, which he published in book form "with Proofs and Illustrations."[35] Although he was entering his early sixties, Hutton remained constantly active. Fieldwork campaigns on horseback through the Grampian Mountains and Scottish Borders and by boat to the Isle of Man and the Inner Hebrides yielded evidence for the molten origin of granite and of stratal discordances later to become known as unconformities.[36] He wrote long and antagonistic responses to criticism of his 1785 work, mostly concerning the thermal origin of consolidation, from the Irish chemist and mineralogist, Richard Kirwan, president of the Royal Irish Academy. Hutton also made commentaries on the geological opinions of his contemporaries, principally those of Jan Filip Carosi, Déodat Gratet de Dolomieu, Jean-André de Luc, Antoine-Grimoald Monnet, Peter Simon Pallas, Eugène Patrin, and Horace Bénédict de Saussure. All this was incorporated into the first three volumes of the book, added onto the original 1785 opus which was reproduced more-or-less verbatim. A fourth and final volume was never completed and is lost.

The discovery of unconformity was one of the significant contributions in the expanded edition of *Theory of the Earth*. Hutton never intended to imply that former mountain ranges were completely destroyed by erosion after their consolidation and uplift from the oceans: if this had occurred, there would be no prima facie evidence for his theory! At some point after 1785, he seems to have realized that uplifted, consolidated, and eroded remnants of what he termed primary mountains might be succeeded by subsequent deposition and consolidation of secondary mountains, and the two preserved together by further uplift. Examples could be distinguished in central and southern Scotland. In the Southern Uplands, the primaries were thoroughly consolidated, steeply inclined, fractured, faulted, and folded. The secondaries were less consolidated and deformed. Hutton discovered two exquisite exposures of the discordant junction between such overlying strata, separated by layers of eroded detritus derived from underlying primary, Lower Paleozoic, strata. One was along the Jed Water river near Jedburgh, the other along the east coast at Siccar Point.[37] These discoveries were to prove key in the eventual acceptance of Hutton's general theory, if not its particulars.

Playfair described Hutton as a man of straightforward character and manners with no outward trace of self-importance: vivacious, animated, and forcible in conversation, with wit and a sense of the absurd mixed in. The surviving letters written while away on fieldwork, during which he was usually alone, likewise reveal Hutton's vigorous and decisive mind, together with a more worldly side to his gregarious character.[38]

Playfair notes that though Hutton would rise late,

> he began immediately to study, and generally continued busy till dinner [lunch]. He dined early, almost always at home, and passed very little time at table; for he ate sparingly, and drank no wine. After dinner he resumed his studies, or, if the weather was fine, walked for two or three hours … The evening he always spent in the society of his friends. No professional, and rarely any domestic arrangements interrupted this uniform course of life, so that his time was wholly divided between the pursuits of science and the conversation of his friends, unless when he travelled from home on some excursion, from which he never failed to return furnished with new materials for geological investigation.[39]

Henry Raeburn's portrait of Hutton from ca. 1776 in the Scottish National Portrait Gallery shows him in his intellectual prime, aged around fifty, two years on from his long 1774 field excursion to England and Wales, in which he was accompanied on the southward journey from Edinburgh to Birmingham by Watt. Hutton is plainly dressed in breeches, a long waistcoat, and tailed jacket, all in rustic dun cloth. He sits in an informal and relaxed pose, left arm hooked around the chair back, waistcoat partly unbuttoned at the bottom as if after a generous lunch. Playfair viewed the portrait as

> calculated to heighten the effect that his conversation produced. His figure was slender, but indicated activity; while

> a thin countenance, a high forehead, and a nose somewhat aquiline, bespoke extraordinary acuteness and vigour of mind. His eye was penetrating and keen, but full of gentleness and benignity.[40]

Manuscripts and a quill, together with rock, mineral, and fossil specimens are on an adjacent table. Some of these he used to illustrate his *Theory*: they include a partly excavated fossil in a piece of chalk, and reticulate calcitic veining of a cut and polished specimen of a septarian nodule.

HUTTON'S GRAND THEORY of earth recycling was of little consequence to the practitioners of empiricism in the early British geological community. Its makeover by Playfair,[41] and his eventual fêting by Charles Lyell in *Principles of Geology*, published between 1830 and 1833, firmly established Hutton's empirical scheme and made his intellectual authority impregnable. Much later, in the early decades of the twentieth century, his central theme of crustal recycling became relevant following the advent of radiogenic isotope chemistry and the establishment of the first geological timescales based on radiometric dating. Emerging concepts of a mobilistic outer earth came via Alfred Wegener's 1915 theory of continental drift and gave new momentum to the theory. The true source of the powerful earth movements required to produce mountains and granitic masses was realized in the 1960s when plate tectonics quickly emerged from the continental drift controversy via the evidence for seafloor spreading, plate motion, plate subduction, and continental collision. Hutton's appeal to Earth's inner heat for providing the power necessary for mountain formation was correct. The late Gordon Craig, Huttonian Professor of Geology at the University of Edinburgh, wrote an amusing pastiche in which Hutton writes from hell in a scorch-marked "Letter to the Earth," directed to the editor of a fictitious journal, *Séance de la Terre*:

> We all look forward to meeting some of your young colleagues who have made such spectacular advances in plate tectonics, and I am especially glad to hear that they are using *my* [emphasis added] heat to *drive* [emphasis added] their plates.[42]

Results from dilute aqueous geochemistry and stable isotopes have led to a deeper explanation for Hutton's old problem with stratal consolidation by aqueous processes and of the concept of global geochemical cycling. Interlinkage of the workings of the solid, liquid, and gaseous parts of the planet, notably in the success of strontium isotope tracers in determining tectonic control of ocean water composition,[43] led to the culmination of Huttonian theory in the 1990s. Consolidation and denudation could thereafter be seen as processes driven by both tectonics and geochemistry.

One must imagine Hutton in hell as a happy man!

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1. James Hutton, "Theory of the Earth; or an Investigation of the Laws Observable in the Composition, Dissolution, and Restoration of Land upon the Globe," *Transactions of the Royal Society of Edinburgh* 1 (1788): 209–304, doi:10.1017/s0080456800029227. James Hutton, *Theory of the Earth with Proofs and Illustrations* (Edinburgh: Cadell, Davies, and Creech, 1795).
2. Hutton, "Theory of the Earth" (1788), 304.
3. John Playfair, *Illustrations of the Huttonian Theory of the Earth* (Edinburgh: Cadell, Davies, and Creech, 1802; Urbana: University of Illinois Press, 1956). John Playfair, "Biographical Account of the Late Dr James Hutton," *Transactions of the Royal Society of Edinburgh* 5 (1805): 94–95, doi:10.1017/s0080456800020937. Victor Eyles and Joan Eyles, "Some Geological Correspondence of James Hutton," *Annals of Science* 7 (1951): 316–39, doi:10.1080/00033795100202451. Jean Jones, Hugh Torrens, and Eric Robinson, "The Correspondence between James Hutton (1726–1797) and James Watt (1736–1819) with Two Letters from Hutton to George Clerk-Maxwell (1715–1784): Part I," Annals of Science 51 (1994): 637–53, doi:10.1080/00033799400200471; and "Part II," *Annals of Science* 52 (1995): 357–82, doi:10.1080/00033799500200291.
4. Jones, Torrens, and Robinson, "The Correspondence between James Hutton … Part I" (1994), 639.
5. Hutton, "Theory of the Earth" (1788), 209.
6. George-Louis Leclerc, comte de Buffon, *Les Époques de la Nature*, ed. Jacques Roger (Paris: Éditions du Muséum National d'Histoire Naturelle, 1962 [1778]); or in English, *The Epochs of Nature*, trans. and ed. Jan Zalasiewicz, Anne-Sophie Milon, and Mateusz Zalasiewicz (Chicago: University of Chicago Press, 2018).
7. Hutton, "Theory of the Earth" (1788), 209.
8. Hutton, "Theory of the Earth" (1788), 214.
9. Homer: "As when a man channels water from a dark-welling spring and directs its flow … it clears all the pebbles from its path, then gathers speed and runs gurgling down over the sloping ground…" *The Iliad*, Book 21, lines 257–63; translation from Martin Hammond (Harmondsworth: Penguin Classics, 1987). Plato in his *Critias*:

   > the soil which has kept breaking away from the high lands during these ages and these disasters, forms no pile of sediment worth mentioning, as in other regions,

but keeps sliding away ceaselessly and disappearing in the deep.

Robert Gregg Bury, ed., *Plato, in Twelve Volumes: Vol. 9: Timaeus, Critias, Cleitophon, Menexenus, Epistles* (Harvard University Press, 1975).

10. Hutton, "Theory of the Earth" (1788), 216.
11. Hutton, "Theory of the Earth" (1788), 217.
12. Hutton, "Theory of the Earth" (1788), 217.
13. Hutton, "Theory of the Earth" (1788), 218.
14. Hutton has often been criticized for having no interest in the historical development of the planet outside of the main tenets of his theory, yet he noted more than once the desirability of such a scheme.
15. Hutton, "Theory of the Earth" (1788), 223.
16. Hutton, "Theory of the Earth" (1788), 225.
17. Hutton, "Theory of the Earth" (1788), 227.
18. Hutton, "Theory of the Earth" (1788), 230.
19. Here and elsewhere I follow the definitions of scientific logic for *vera causa*, eliminative induction, etc., in Rachel Laudan's *From Mineralogy to Geology: The Foundation of a Science, 1650–1830* (Chicago: University of Chicago Press, 1987).
20. Leclerc, *Les Époques de la Nature*.
21. Silicified plant petrifications from two Icelandic geysers were discovered in 1772 by Sir Joseph Banks. Black obtained samples and doubtless informed Hutton of this first discovery of silicification by natural waters, even though Hutton dismisses it as irrelevant to his theory of consolidation. Black subsequently obtained water samples from the geysers and reports on their dissolved siliceous content in his "An Analysis of the Waters of Some Hot Springs in Iceland," *Transactions of the Royal Society of Edinburgh* 3, no. 2 (1794): 95–126, doi:10.1017/s0080456800020329.
22. Hutton, "Theory of the Earth" (1788), 275.
23. Hutton, "Theory of the Earth" (1788), 285.
24. Hutton, "Theory of the Earth" (1788), 294.
25. Hutton, "Theory of the Earth" (1788), 301.
26. Hutton, "Theory of the Earth" (1788), 301.
27. Hutton, "Theory of the Earth" (1788), 302.
28. Hutton, "Theory of the Earth" (1788), 304.
29. Martin Rudwick, *Bursting the Limits of Time* (Chicago: University of Chicago Press, 2005), 170: "It is not surprising … that one of the two points on which Hutton was criticized most vigorously by his contemporaries was his eternalism." Martin Rudwick, "Hutton Owes No Debt to Browne," *Geoscientist* 27, no. 9 (2017): 23: "The very words of Hutton's famous 'vestige… prospect…' quote show what he himself was open about: that he was an 'eternalist.'"
30. Dennis Dean, *James Hutton and the History of Geology* (Ithaca: Cornell University Press, 1992), 275–76. This is by far the best modern biography of Hutton in his historical context.
31. James Hutton, *The 1785 Abstract of James Hutton's Theory of the Earth*, facsimile reprint (Edinburgh: Scottish Academic Press, 1987), 28.
32. Mike Leeder, "Hutton's Debt to Browne?" *Geoscientist* 27, no. 7 (2017): 9.
33. Notably in modern times by Stephen Jay Gould, *Time's Arrow, Time's Cycle* (Cambridge, MA: Harvard University Press, 1987).
34. John Strachey, "A Curious Description of the Strata Observ'd in the Coal-Mines of Mendip in Somersetshire," *Philosophical Transactions of the Royal Society of London* 30 (1719): 968–73, doi:10.1098/rstl.1717.0054. For a thorough account of Strachey's achievements, see John Fuller, "Smith's Other Debt: John Strachey, William Smith and the Strata of England 1719–1801," *Geoscientist* 17, no. 7 (2007): 5–12.
35. James Hutton, *Theory of the Earth with Proofs and Illustrations* (Edinburgh: Cadell, Davies, and Creech, 1795).
36. James Hutton, "Observations on Granite," *Transactions of the Royal Society of Edinburgh* 3, no. 2 (1794): 77–85, doi:10.1017/s0080456800020305. Ironically, Robert Jameson was an avid Wernerian Neptunist and for many years a fierce opponent of Hutton, though he eventually capitulated. Yet he had the good sense to write of the importance during fieldwork of determining whether strata were conformable or unconformable. Robert Jameson, *A Mineralogical Description of the County of Dumfries* (Edinburgh: Bell & Bradfute, 1805), 37–38.
37. Playfair, *Illustrations*. Playfair, "Biographical Account."
38. Eyles and Eyles, "Some Geological Correspondence." Jones, Torrens, and Robinson, "The Correspondence between James Hutton … Part I" and "Part II."
39. Playfair, "Biographical Account," 93–94.
40. Playfair, "Biographical Account," 94–95.
41. Playfair, *Illustrations*. Playfair, "Biographical Account."
42. Gordon Craig and E. J. Jones, eds., *A Geological Miscellany* (Princeton: Princeton University Press, 1985), 115.
43. Maureen Raymo and William Ruddiman, "Tectonic Forcing of Late Cenozoic Climate," *Nature* 359 (1992): 117–22, doi:10.1038/359117a0.

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