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Abstract: During Charles Lyell's lifetime the concept of geological time was gradually rendered meaningful through the construction of a heuristic geological timescale, the development of quantitative methods to calculate the duration of that scale, and the acceptance of a quantitatively determinable limit to the age of the Earth. This paper describes a few episodes in the process of 'inventing' the concept of geological time, episodes chosen primarily for their relevance to the work of Lyell.

Reflecting on the panoramic record of the Earth's past exposed to view as he travelled across the North American continent on US interstate highway 80, John McPhee observed, 'The human mind may not have evolved enough to be able to comprehend deep time. It may only be able to measure it' (McPhee 1980, p. 127). Travelling from east to west in a horizontal plane, McPhee passed through the assemblies of rock that contained the record of the Earth's past in no apparent chronological order. Rocks of different geological ages were exposed seemingly at random. From time to time, in cuts and tunnels, a more orderly but limited chronological sequence of rocks was exposed in a vertical plane. To produce McPhee's sense of 'deep time', the record of the rocks had to be assembled and interpreted. In this paper I suggest that the 'invention' (or perhaps more accurately, the 'construction') of geological time was the historical process by which the concept that McPhee calls 'deep time' was first recognized and then rendered conceptually meaningful, if not truly comprehensible. For a working definition of 'conceptually meaningful', I will adopt Lord Kelvin's variation on McPhee's cogent distinction, namely his famous dictum that 'when you can measure what you are speaking about and express it in numbers you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind: it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of science' (Thomson 1891, pp. 80–81).

Time has always presented unique conceptual difficulties for scientists and philosophers alike (see Kitts 1966, 1989). We experience time only in the present. Our sense of the duration of time is subjective, an inference based on our transitory perceptions of experienced events and our memory of the past. We create a concept of external, non-personal time by analogy, by imposing an order, a constructed memory, on the evidence of external events. We make our concept of 'duration' more or less objective by reference to some repetitive quantifiable standard such as a day or a year, but our ability to comprehend duration remains subjective, both shaped and limited by the conditions of individual experience. Since geological time, like historical time, lies forever outside the scope of our direct experience, our concept of geological time is an artefact. It had to be created or 'invented'.

The invention of geological time

In this paper, I will argue that the invention of geological time involved at least five essential steps: the recognition of the evidence of a succession of past events in the static record of the rocks, the acceptance of a terrestrial age significantly greater than the historical record of human-kind (the notion, however vague, of 'deep time'); the development of a historical sense of the Earth's past through the construction of a heuristic geological timescale; the creation of quantitative methods to calculate the duration of that scale; and the acceptance of a quantitatively determinable limit to the age of the Earth. Also important was the creation of a new concept of 'historical time' embracing what Stephen Toulmin has called 'the twin ideas of "periods" and "development"' (Toulmin 1962–1963, p. 105). In the sense of step one, the process of inventing geological time began in the seventeenth century with the work of Nicolaus Steno and Robert Hooke: in the sense of steps three and four, it is still going on and has been particularly vigorous during the past two or three decades (see Berggren et al. 1995). By limiting this paper largely to British geologists in the age of Lyell, I can deal with only a few episodes in the
early stages of invention, a few of the steps in sketching the preliminary design.

By the time of Charles Lyell’s birth in 1797, the first hints of a notion of geological time had been appearing for several decades. The pioneering local stratigraphies published by Johann Gottlob Lehmann, Christian Fichsel and Giovanni Arduino between 1756 and 1761, for example, all pointed to an Earth formed by a succession of events rather than a single act of creation (Albritton 1980, pp. 117–119; Berry 1968, pp. 29–34). None of the three suggested that the duration of these events would require a terrestrial age significantly greater than that implied by the Mosaic narrative. Nonetheless, the notion of ‘deep time’ had already been suggested a decade earlier by the Cartesian speculations of Benoît de Maillet and the Newtonian cosmology of Georges Buffon, and by 1774 it had been quantified by Buffon’s experimental extrapolation from Leibniz’s hypothesis of a primordial molten Earth (Haber 1959, pp. 115–136). Despite the controversies aroused by de Maillet’s countless ages for the diminution of the seas and Buffon’s more modest 75,000 years for the cooling of the Earth, by the final quarter of the eighteenth century, a growing body of field evidence had begun to create an intellectual climate where some notion of deep time was, at least in principle, acceptable (Porter 1977, pp. 157–160). No single event, even the Noachian deluge, could account for the complexity of the strata, nor could the succession of life revealed by the fossils be accommodated in six literal days of creation. By 1785, this new intellectual climate was sufficiently widespread to inspire William Cowper’s acerbic lines:

...Some drill and bore
The solid Earth, and from the strata there
Extract a register, by which we learn
That he who made it, and reveal’d its date
To Moses, was mistaken in its age (Cowper 1785, pp. 166–167).

Although a long span of time before the advent of humans seemed necessary to account both for the record of ancient life preserved in the fossils and for the thickness and complexity of strata exposed by the new field studies, there was no agreement about the magnitude of the time spans involved. Buffon’s quantitative chronology was hardly less controversial than de Maillet’s eternalism, and, though speculations on the nature of geological causes were sometimes hotly debated, scant attention was paid to their rates of action. Thus, when James Hutton, an Enlightenment rationalist, published the Abstract of his now famous 1785 address, the opening lines read: ‘The purpose of this dissertation is to form some estimate with regard to the time the globe of this Earth has existed, as a world maintaining plants and animals’ (Hutton 1785, p. 3). But, after systematically reviewing the natural causes that he believed had shaped and continued to shape the Earth’s crust, he was faced with the conclusion that... 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, this world has neither a beginning nor an end. (Hutton 1785, p. 28)

Hutton had perhaps clarified the problem, but the concept of geological time remained formless. Much has been written about the ‘birth of geology’ in the years that coincide closely with Charles Lyell’s youth. I will not attempt to rehash the many ways in which time was invoked in the conflicts over ‘Genesis and geology’ and the disputes between the neptunists and pluto-nists. I will suggest only the obvious: that no meaningful conception of geological time had yet been formulated. Nonetheless, the foundations for such a conception were being laid (see Rudwick 1996). The palaeontological researches of Georges Cuvier, J. B. Lamarck, William Buckland and others made the strange inhabitants of the remote past vividly visual and thus sensibly real. They pointed unmistakably to a temporal succession of living forms. Fossils also provided William Smith with one of the three principles by which he solved the puzzle of the strata and showed how to correlate its widely scattered parts. The way had been opened for the record of the rocks to be organized into a single chronological column.

By the second decade of the nineteenth century, the identification and systematic classification of the fossiliferous strata were underway in earnest. In the two decades between J. B. J. d’Omalius d’Halloy’s grouping of the Chalk and underlying sandstones and marl into a single Terrain Cré-tacé in 1822 and Roderick Murchison’s identification of the Permian in 1841, most of the subdivisions now designated as systems were identified and arranged chronologically according to the principle of superposition. Also by 1840, Adam Sedgwick and John Phillips had suggested new names reflecting the temporal progression of life revealed by the fossil record – Paleozoic, Mesozoic and Cenozoic – for larger chronological groups of systems (Albritton 1980, pp. 123–130; Berry 1968, pp. 64–95). Agreement over the new systems was far from general. There was little consensus about the relative importance of lithology and fossils as the basis for the classification of strata, and heated controversies over disputed system boundaries.
sometimes dragged on for years (see Rudwick 1985; Secord 1986a). One conclusion, however, was inescapable. Placed in ordered sequence, the strata revealed unmistakable evidence of the temporal succession of past geological events. The Earth had been given a history. The rocks themselves gave no indication of the duration of the events they recorded, but the sheer magnitude of the reconstructed record together with the diversity of the successive periods of life revealed by the fossils it contained produced an inescapable impression of vistas of time stretching far beyond the scope of human history.

The concept of geological time

An impression of time, even ‘deep time,’ is not the same thing as a concept of geological time. Nevertheless, a brief examination of four geological treatises from the 1830s may give some insight into how such a concept began to form. The first and most influential of the four was Lyell’s Principles of Geology, published between 1830 and 1833. As is well known, the time of the stratigraphers played little role in the first two volumes of the Principles. Lyell’s concept of time was shaped to serve the ends of his concept of gradual, actualistic geological processes operating in a dynamically balanced, steady-state terrestrial mechanism (Lyell 1830–1833; see also Rudwick 1969a,b, 1971, 1974). Time, indefinite drafts of time, was necessary for Lyell’s gradualism, but in its fervent anti-directionalism, his notion of the Earth’s dynamics was curiously atemporal. When Lyell did turn to what he later referred to as ‘Geology proper’ in the third volume of the Principles (Wilson 1972, p. 503), he still gave only a brief account of the stratigraphy of his peers. Nonetheless, he did address both temporal progression and the quantification of the evidence for geological time in what Martin Rudwick has termed his ‘statistical palaeontology’ (Rudwick 1978). He thus contributed to the temporal classification of the stratigraphic record by introducing his four part subdivision of the Tertiary and coining the terms Newer and Older ‘Pliocene’, ‘Miocene’, and ‘Eocene’. It was unquestionably Lyell’s influence that gave prominence to a sense of ‘deep time,’ but his changeless, temporally indefinite Earth conveyed, at best, an obscure notion of ‘geological time.’

Henry De la Beche presented a very different vision of terrestrial dynamics in his Researches in Theoretical Geology, published in 1834, the year after the third volume of the Principles. Chemistry and physics were essential to De la Beche’s geology, and he devoted considerable attention to the theory of the Earth’s central heat and the hypothesis of its igneous fluid origin. Thus, De la Beche’s idea of finite, directional geological time owed as much to the physics of heat flow as to the record of the rocks. But it was the rocks that conveyed a more substantial sense of duration, and he referred to the ‘millions of years’ needed to produce the layers of strata he had described. The number meant little more than ‘a whole lot’, and in his concluding remarks, De la Beche foreshadowed McPhee’s musing with which I began:

Measuring time as man does in the minute manner suited to his wants and conveniences, a few thousand revolutions of the Earth in its orbit appear to him to comprise a period so considerable, that he feels it difficult to conceive that great lapse of time which geology teaches us has been necessary to produce the present condition of the Earth’s surface. (De la Beche 1834, quotations 371, 397)

For De la Beche, geological time was vast but finite, difficult but perhaps not impossible to comprehend.

The first use that I have found of the term ‘geological time’ appears in volume 1 of John Phillips’ A Treatise on Geology. Published in 1837 as part of Dionysius Lardner’s Cabinet Cyclopaedia, Phillips’ intended audience was broader and no doubt a bit down the scale from the public that had made Lyell’s Principles a bestseller. He started with fundamentals. He started with time. ‘The very first inquiry to be answered,’ he wrote in his opening chapter, ‘is what are the limits within which it is possible to determine the relative dates of geological phenomena? For if no scale of geological time be known, the problem of the history of the successive conditions of the globe becomes almost desperate’ (Phillips 1837, pp. 8–9). Chronology provided the guide to explaining the record of the Earth’s crust, and with its focus on examining the stratigraphic record methodically from the oldest to the most recent formations, volume 1 of Phillips’ Treatise might be considered perhaps the first text in historical geology. In his opening chapter, Phillips briefly remarked that the total length of the stratigraphic scale might be an important ‘element for direct computation of the total time elapsed in the formation of the crust of the globe.’ He made no such calculation. As he had observed a few pages earlier, the periods involved were ‘too great to comprehend’ (pp. 16, 18).

Time and geological history

When Lyell’s Elements of Geology appeared in 1838, it was much more than just an expanded treatment of all that was ‘Geology proper’ in the Principles. Part 2 of the Elements was essentially a
treatise on historical geology. Lyell maintained his allegiance to his steady-state uniformitarian principles by declaring that the chronological sequences of the four classes of rocks—aqueous, plutonic, volcanic and metamorphic—would be ‘considered as four sets of monuments relating to four contemporaneous, or nearly contemporaneous, series of events’ (Lyell 1838, p. 266). In the Elements, Lyell treated the whole of the known European stratigraphic record, not just the Tertiary, as a chronological sequence and made constant reference to the relative ages of the rocks. Lyell’s chronological grouping of the fossiliferous rocks was somewhat out of date. Most of the 18 groups into which he divided the stratigraphic column were taken from the older, lithologically based, divisions, supplemented by his own four-part classification of the Tertiary and by the Silurian and Cambrian systems of Murchison and Sedgwick. More interesting for my purpose, however, was Lyell’s caution that he could not assert that the 18 groups represented equal periods of time, but he continued:

If we were disposed, on Palaeontological grounds, to divide the entire fossiliferous series into a few groups, less numerous than the above table, and more nearly co-ordinate in value than the sections called primary, secondary, and tertiary, we might, perhaps, adopt the six following groups or periods. (Lyell 1838, pp. 280–281)

This is a very tentative statement, and Lyell’s meaning is by no means explicit. But if we assume that ‘more nearly co-ordinate in value’ refers to time, Lyell’s next grouping gives an insight into his idea of the relative duration of the periods of geological time. His groups would give a ratio of 1:4:1 for the duration of the Tertiary, Secondary and Primary. Lyell still ventured no guess as to the magnitude of the time involved, but in giving a history to that part of the Earth’s crust that is most visible to study, he employed at least a utilitarian notion of geological time. A letter written to Andrew Ramsay in 1846 makes clear, however, that for Lyell ‘an indefinite lapse of geological time’ was still required for the deposition of even that part of the strata laid down since the last coal measures of South Wales (Geikie 1895, p. 86).

By 1840 at least the chapter titles for a ‘history’ of the Earth had been established, and the new historical categories of period and development had become part of the conceptual vocabulary of geology. Over the next several decades the content of that history was enormously refined and expanded as the level of geological activity and geological knowledge grew exponentially. The various geological surveys added volumes to the stratigraphic record (see Secord 1986b). Systematic study of the ‘causes’ emphasized in Lyell’s Principles was begun in earnest, and a few attempts were made to measure them (Davies 1969, pp. 225–226). Perhaps most of all, palaeontology served to reinforce an ever more vivid sense of ‘deep time’ with a seemingly endless succession of dramatic discoveries. As Rudwick has shown, the popularity of visual images of the remote past spread the notion of deep time to an ever wider public (Rudwick 1992). But though the concept of geological time was perhaps given greater detail during those years, it was not qualitatively changed; it was vast, perhaps beyond imagination, but it had no definable magnitude. It lacked measure. Charles Darwin’s brief lapse of caution in 1859 changed all that.

Time was as important for Darwin’s theory as it had been for Lyell’s, and he drew on it liberally. But when Darwin decided to illustrate the magnitude of the time he envisioned with a quick and dirty calculation of the time needed for the denudation of the Weald, his result—more than 300 million years for a small portion of recent geological time—drew a deluge of protest (Darwin 1859, p. 287; see Burchfield 1974). John Phillips again provides a pertinent example. In his presidential address to the Geological Society in early 1860, Phillips offered his own quick and dirty estimate of the denudation of the Weald. Assuming fluvial denudation rather than the marine denudation assumed by Darwin, Phillips calculated that Darwin’s 300 Ma could be reduced to a mere 1.3 Ma years (Phillips 1860a, p. lii). Perhaps more significant in the long run, in his Read Lecture a few months later, Phillips followed up on the idea he had alluded to in 1837, and described his calculation of the time needed to erode (and by analogy, to form) the whole sedimentary column. Using one of the few quantitative measures of erosion available, Robert Everest’s 1832 measurements of the sedimentary load of the Ganges, Phillips arrived at a figure of 96 Ma for the total age of the sedimentary rocks. Phillips was well aware that his calculation was as much a ‘guesstimate’ as Darwin’s; the periods involved, he declared, were ‘too vast and we must add too vague for conception’ (Phillips 1860b, pp. 126–127). The method he employed, however, was in broad outline to become the method employed by geologists for nearly half a century in their effort to measure geological time. Meanwhile, the contrast between Darwin’s result and Phillips’ showed just how different the notion of incomprehensibly vast time could appear when expressed in numbers. Darwin quietly dropped the age of the Weald calculation from the later editions of the Origin of Species. Phillips, however, had already written to William Thomson.
Thomson, the future Lord Kelvin, had a long-standing interest in the cosmic evolution implicit in LaPlace’s nebular hypothesis and in the physics of the interior of the gradually cooling and solidifying Earth which would be one of its consequences. He had little interest in what Lyell had called ‘Geology proper’. Possibly stirred by Phillips’ letter to respond to Darwin, or perhaps simply by the relative leisure afforded by a temporarily disabling accident, Thomson, in 1862, produced two short papers containing calculations of the ages of the Sun and Earth, respectively. The methods introduced in the two calculations were necessarily different, but both involved applying the newly developed principles of thermodynamics, on which Thomson was the recognized British authority, to conditions inferred from LaPlace’s hypothesis. Both calculations pointed to a terrestrial age of about 100 Ma – possibly as little as 10 Ma, but certainly no more than 400 Ma (Thomson 1862, 1863; Burchfield 1975, pp. 21–56).

‘Deep time’ had been measured, or at least quantified, but only by invoking the cosmology that Lyell had rejected, and it was hardly deep enough to suit either Lyell’s or Darwin’s requirements. Some of Thomson’s data, to be sure, were as uncertain as those of Darwin and Phillips, but they were also more remote and their faults harder to pinpoint. The methods themselves had an elegant simplicity, and the principles involved seemed irrefutable. The initial response from geology, however, was negligible until Thomson fired off a short broadside against the ‘doctrine of uniformity’ late in 1865 (Thomson 1865). Whether British popular geology was as uniformly ‘uniformitarian’ as Thomson claimed is debatable, but the soundness of his attack on Lyell’s conception of a dynamically steady-state Earth as being contrary to the known laws of physics could hardly be ignored. Geology began to respond. One of the first responses was indirect but significant. In 1864, James Croll proposed a hypothesis linking the onset of the ice ages to changes in the eccentricity of the Earth’s orbit (Croll 1864). By 1867, Croll had developed his hypothesis sufficiently to suggest that the calculated dates of periods of high orbital eccentricity might be used to determine the date of the most recent glacial epoch (Croll 1867). Stimulated by Croll’s theory, Lyell made his own attempt to date the last ice age, choosing as the most likely date, a period of very pronounced eccentricity which, according to astronomical calculations, occurred between 750 000 and 850 000 years ago. Lyell then combined this date with his statistical palaeontology of the tertiary molluscs to suggest that a complete revolution of species would require about 20 Ma. Assuming that approximately equal periods of time were necessary for each of the twelve revolutions that he estimated had occurred since the beginning of the Cambrian, he concluded that the total time required would be 240 Ma. Lyell published this result in volume one of the tenth edition of the Principles in 1867, thus finally giving a quantitative scale to his conception of ‘indefinite time’ (Lyell 1867, pp. 271–301). Lyell’s quantitative scale was an order of magnitude smaller than that implied by Darwin’s quantitative guess, but it was still too large for Croll.

Responding a year later, Croll questioned Lyell’s choice of an early rather than a later period of high orbital eccentricity. Croll doubted that any trace of glaciation would remain if the forces of denudation had been operating at their present rates had the period of glaciation ended 700 000 years ago, as Lyell’s assumption would suggest. If, instead, one chose the more recent period of high orbital eccentricity which occurred about 80 000 years ago, Croll showed that Lyell’s method of calculation would yield an age of only 60 Ma since the beginning of the Cambrian. This result, Croll emphasized, was in good agreement both with what was known about the current rates of denudation and with the 100 Ma that William Thomson had shown to be the time available for the entire history of the Earth (Croll 1868, pp. 363–368). Like Darwin, Lyell quietly removed his one quantitative estimate of time from the later editions of his book.

During the 1850s and 1860s the number of efforts to measure some of Lyell’s ‘causes now in action’ increased. Estimates of the composite maximum thickness of the stratigraphic systems were regularly revised, and measurements of the rates of denudation in several major river basins promised a possible way to estimate the time elapsed in the simultaneous destruction and formation of the Earth’s crust by denudation and sedimentation (see Davies 1969, pp. 317–355). But when Archibald Geikie reviewed the quantitative results of these efforts in 1868, he concluded that the data available were not sufficient for geologists to make an independent calculation of geological time. What the results did indicate to him, however, was that modern denudation was a far more rapid process than geologists had tended to believe, and hence their demands for time had been exaggerated. Geologists, he asserted, had been ‘drawing recklessly upon a bank in which it appears that there are no further funds at our disposal’. Referring finally to Thomson and Croll, Geikie implicitly accepted that ‘the time assigned within which all geological history must be comprised’ was about 100 Ma. (Geikie 1871, pp. 188–189). A year later, T. H. Huxley, then President of the Geological Society of London, also conceded that ‘Biology takes her time from geology. ... If the
geological clock is wrong, all the naturalist will have to do is to modify his notions of the rapidity of change accordingly' (Huxley 1869, p. 331).

When Lyell died in 1875, the Earth had both a history and an age. To be sure, the precise age remained in dispute, but there was broad general agreement as to its magnitude. 'Deep time' had been numbered, and to that extent, at least, geological time had been made comprehensible. The Earth's history, however, still lacked intermediate dates. Some older geologists, such as Lyell's slightly younger contemporaries A. C. Ramsay and Joseph Prestwich, doubted that geological measurements could ever provide adequate data for calculating the duration of geological time in years (Ramsay 1873–1874; Prestwich 1895). A few younger geologist made the attempt. The attitude of some of this new generation was perhaps best summarized by T. Mellard Reade's challenge in 1876 that 'to make Geology essentially a Science, the mathematical method must step in to measure, balance, and accurately estimate' (Reade 1878, p. 211).

By the century's end, both geology and physics had produced a number of methods for calculating the Earth's age and even a few estimates of the duration of the larger divisions of the geological record (Burchfield 1975, pp. 90–156). Most of the geological calculations employed some variation on the method used by Phillips in 1860, and they reflected the constant flux of data and opinion concerning the composite depth of the stratigraphic column, the rates of past and present denudation, and the size and shape of ancient sedimentary basins. Geological time had been measured, but it still required two chronological scales: a biostratigraphic scale of the relative ages of the successive divisions of the stratigraphic record and a far more fragmentary quantitative scale. But if there was little unanimity among geologists on the details of the latter, there was a broad general agreement as to the order of magnitude of the Earth's age and some consensus as to the relative duration of the three major eras of geological time. Perhaps equally suggestive of what I have called a 'meaningful' conception of geological time was the geologists' confidence in their quantitative methods and results. At the century's end, geologists could confidently marshal their own methods, calculations and measurements of geological time against the ever more restrictive results from the physical methods of Thomson (by then Lord Kelvin) and his followers. A decade later, they were equally confident in opposing the inconceivably vast new timescale introduced by the proponents of radioactivity (Burchfield 1975, pp. 121–205). For most geologists in 1900, geological time was vast but finite; it could be measured and comprehended.

I hardly need to add in conclusion that the geologists' confidence was misplaced. The implications of radioactivity did push back the boundaries of 'deep time,' perhaps beyond comprehension. But radioactivity also provided new methods for a more precise determination of the Earth's age, and, ultimately, methods for dating the separate divisions of the biostratigraphic scale. The invention of geological time has now proceeded for yet another century, but it still reflects much of the design sketched in the age of Lyell.

References


