Reading Guide 6

The age of the earth

Background

We're only reading a fraction of the literature on this topic. This reading guide will provide a bit of context, along with key references. The references are for people who want to follow up on this literature, either out of curiosity or because they are writing essays on this topic. Even then, you're not expected to read it all.

In *The Origin of Species*, Darwin tried to calculate how long it would take for erosion to produce "The Weald," a valley in SE England. If you have ever read *Watership Down*, then you have read about this valley—it lies between two ridges of chalk, called the North Down (where Darwin lived) and the South Down. In the book, the rabbits started in The Weald and traveled south to Watership Down, a part of South Down. Fig. 6.1 shows a map of the area.

The cross section in Fig. 6.2 shows that this area was originally a fold (or anticline) in layers of sedimentary rock. The upper portion of the fold has eroded away, and Darwin tried to calculate how long this would take. In the first edition of the *Origin*, he guessed that erosion might remove one inch of sediment per century. At this rate, he concluded, it would have taken 300 million years to produce The Weald. Darwin's calculation was widely criticized, and he removed it from later editions of his book.

In these readings, you will encounter the idea that that the rotation of the earth is gradually slowing, because of friction caused by tides. Today is slightly longer than yesterday, and tomorrow will be longer still. This idea is centuries old and is now well established. For details, see this web site: `http://bowie.gsfc.nasa.gov/ggfc/tides/intro.html`.

During the 19th century, several methods were used to estimate the age of the earth:

Heat calculations It is warmer deep underground than at the surface. This temperature gradient suggests that the earth used to be much hotter, but is gradually cooling. This idea led to estimates that the earth was on the order of 100 million years old. These estimates were influential during the latter half of the 19th century [Thomson, 1862, 1890].

Salinity of ocean River water carries dissolved salt into the oceans, but when that water evaporates, it leaves the salt behind. Therefore, the ocean ought to be getting saltier all the time [Halley, 1715]. To estimate the age of the earth, you only need to divide the amount of ocean salt by the amount introduced each year. John Joly used this idea toward the end of the 19th century [Jackson, 2001].

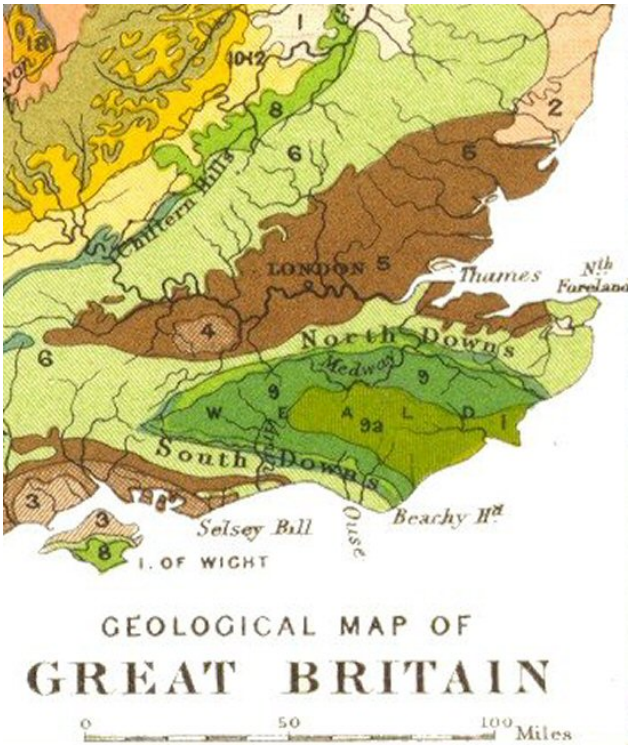

Figure 6.1: Map of SE England. The Weald is at the bottom right in dark green, between the North and South Downs. (Licensed under Public Domain via Wikimedia Commons)

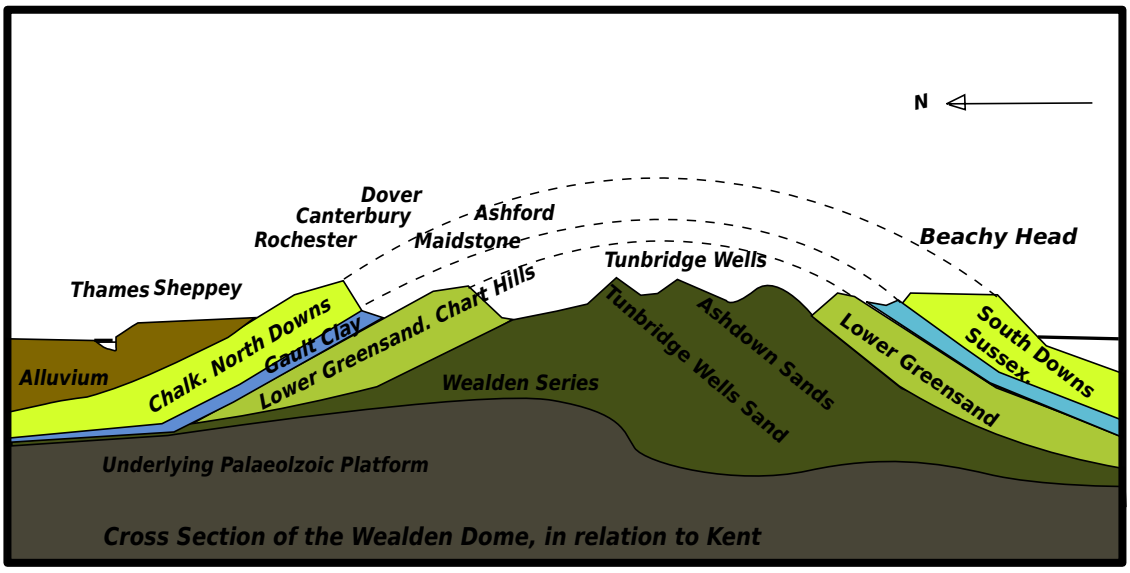

Figure 6.2: Cross section of the Weald. Dashed lines show layers removed by erosion. (by ClemRutter; self-made using Inkscape. Licensed under CC BY-SA 3.0 via Wikimedia Commons)

Thickness of sedimentary rock Divide the total thickness of sedimentary rock by the rate of sedimentation, and you have another estimate of the earth's age. These estimates are reviewed by Eicher [1968] and by Jackson [2001].

Radioactive decay Beginning in the early 20th century, physicists began using radioactive decay to date rocks. Over time, uranium decays into lead and helium, so the ratios of these elements provides information about the ages of rocks. This was a vast improvement over previous methods, although the early literature was still missing a few pieces of the puzzle, as explained below.

Early in the 20th century, it was disturbing that these methods yielded different dates. Four discoveries reconciled these discrepancies:

1. The heat calculations were incorrect because they failed to account for radioactive heat produced insided the earth. This became clear early in the 20th century.

2. Calculations based on sedimentation were incorrect, because oscillations in sea level erase most of the sedimentary record. Joseph Barrell [1917] worked this out. His work is summarized by Eicher [1968].

3. It took much longer to figure out what was wrong with calculations based on salt concentration. It turns out that salt not only enters the ocean but also leaves, a process called the "sodium cycle" [Livingstone, 1963]. The salt in today's ocean is only a fraction of that introduced during the earth's history. Geologists didn't figure out how this works until the discovery of plate tectonics in the mid-1960s.

4. Early in the 20th century, several problems caused radiometric methods to underestimate the ages of rocks by about a factor of 3. Physicists didn't know about isotopes, they didn't know that helium could seep out of mineral grains, and they didn't know how to account for the lead that was in the rock to begin with. Holmes [1913] and Shapley [1918] provide reviews of this early literature. These problems were finally solved when Patterson [1956] got the 3.55-billion-year date that is still accepted. For the history of this research, see Lewis [2000]. For modern summaries, see Rogers [2011, ch. 7] and especially Dalrymple [2004].

Discussion questions

Our reading focus on the debate as it stood in the 19th century.

1. Pritchard [1866, pp. 34–37] assumes that, when Darwin spoke of "millions on millions of years," he must have meant at least one million millions. How many years is this? How does this number compare with current estimates of the age of the earth?

2. Pritchard [1866, pp. 34–37] argues that the earth cannot be as old as Darwin's theory requires. Summarize his arguments.

3. Jenkin [1867, pp. 11–17] discussed arguments about heat, which had been published by William Thomson (later known as Lord Kelvin). Summarize the logic of this argument.

4. Darwin [1872, pp. 266–270, 286, 408] uses various arguments to place bounds on the age of the earth. What are these arguments? How much time do they allow? Does it seem provide scope for evolution to produce all the diversity we see in nature? If you were a 19th-century biologist, would you find Darwin's position credible?

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