Living On Earth, **Online Notes**

Peter Godfrey-Smith

Chapter 2. Earth Enlivened

17 *The age of the universe*: Unsurprisingly, there's some controversy. NASA's number is about 13.8 billion. https://lambda.gsfc.nasa.gov/education/graphic _history/age.html.

18 *Animals might be 650 million years old or so*: Here, as in other cases discussed in this book, there's a gap between estimates based on fossils and those based on molecular genetic data. In the case of animals, the first fossils are around 575 million years old, while estimates of their origin based on molecular genetics stretch back to 800 million years ago, or older. Some of my correspondents are becoming more skeptical about molecular genetic estimates. The dates I use in this book tend to be compromises. For the animal case, see Ross Anderson et al., "Fossilisation Processes and Our Reading of Animal Antiquity," *Trends in Ecology and Evolution* 38 (2023): 1060-1071, https://doi.org/10.1016/j.tree.2023.05.014.

For a skeptical discussion of molecular clocks and a nudging forward of some key dates, see Budd and Mann, "Survival and Selection Biases in Early Animal Evolution and a Source of Systematic Overestimation in Molecular Clocks. I*nterface Focus* 10 (2020): 20190110, doi.org/10.1098/rsfs.2019.0110. They trust the fossils rather than molecular clocks.

19 *One setting in which this might get started*: See Eugene Koonin and William Martin, "On the Origin of Genomes and Cells Within Inorganic Compartments," *Trends in Genetics* 21 (2005): 647-654, doi.org/10.1016/j.tig.2005.09.006

19 *Darwin imagined a warm pond as the site*: See Cairns-Smith, *Seven Clues to the Origin of Life: A Scientific Detective Story* (1985, Cambridge University Press). The Darwin speculation is in a letter to Joseph Hooker, 1871:

> It is often said that all the conditions for the first production of a living organism are now present, which could ever have been present.— But if (& oh what a big if) we could conceive in some warm little pond with all sorts of ammonia & phosphoric salts,—light, heat, electricity &c present, that a protein compound was chemically formed, ready to undergo still more complex changes, at the present day such matter w[d] be instantly devoured, or absorbed, which would not have been the case before living creatures were formed.—

https://www.darwinproject.ac.uk/letter/DCP-LETT-7471.xml

20 *The choice between the origin stories I compared just now*: For a discussion of "metabolism first" and "replicator first" scenarios, see Freeman Dyson, *Origins of Life* (2nd ed., 2010, Cambridge University Press).

20 *the "century of the gene," as the historian of science Evelyn Fox Keller*: See her book *The Century of the Gene* (2002, Harvard University Press).

22 *One place to see this is a coral reef*: Here I draw on J. Scott Turner's book *The Extended Organism* (2000, Harvard University Press).

22 *For Bohr, complementary properties of an object*: See, for example, his "Natural Philosophy and Human Cultures," *Nature* 143 (1939) , 268–272. https://doi.org/10.1038/143268a0, which is discussed in Henry Folse's "Niels Bohr, Complementarity, and Realism," *PSA: Proceedings of the Biennial Meeting of the Philosophy of Science Association* 986 (1986): 96–104. http://www.jstor.org/stable/193111.

23 *I am sitting out in the garden*: This is another area where I was helped by Lenton and Watson's *Revolutions* book, and by discussion with Jochen Brocks.

24 *Andrew Knoll, a Harvard biologist*: See Knoll's "The Geological Consequences of Evolution," *Geobiology* 1 (2003) 3-14, doi.org/10.1046/j.1472-4669.2003.00002.x

24 *James Barber, who admittedly worked*: See Barber, "A Mechanism for Water Splitting and Oxygen Production in Photosynthesis," *Nature Plants* 3, 17041 (2017), doi.org/10.1038/nplants.2017.41

25 *The light-harvesting molecules in bacteria and plants*: See Minik Rosing et al., "The Rise of Continents—An Essay on the Geologic Consequences of Photosynthesis," *Palaeogeography, Palaeoclimatology, Palaeoecology* 232 (2006) 99-113, doi.org/10.1016/j.palaeo.2006.01.007

From their paper:

> On a lifeless planet, the solar energy is converted to heat because the energy of individual photons is too small to break chemical bonds in the planetary surface materials. Blue light, the most energetic part of the visible spectrum, possesses 298kJ/mol photons. In comparison the breaking of the hydrogen–oxygen bond in the water molecule requires 492kJ/mol. A single blue light photon thus possesses far too little energy to dissociate water molecules. For this reason, solar energy is not converted to chemical free energy. With the evolution of chlorophylls in living organisms, this situation was dramatically changed. Chlorophylls have the ability to absorb energy from several consecutive photons and accumulate this energy for focused use. This allows organisms that possess chlorophyll to save up energy and use it for the basic CO2 fixation reaction.

26 *this change was still important enough to be called "The Great Oxygenation"*: See Lenton and Watson, *Revolutions* (though they call it, as some do, the Great Oxidation). The early stages may have seen an "oxygen overshoot" that briefly took the level much higher. This is still controversial. Here, and in other places in this chapter, I have been helped by Andrew Knoll and Jochen Brocks.

26 *New kinds of minerals*: See Robert Hazen et al., "Mineral Evolution," *American Mineralogist* 93 (2008): 1693–1720, doi.org/10.2138/am.2008.2955

27 *The rainforests are the lungs of the Earth*: For clarification of all this, see Scott Denning, "Amazon Fires Are Destructive, but They Aren't Depleting Earth's Oxygen Supply," *The Conversation*, August 26, 2019 (https://theconversation.com/amazon-fires-are-destructive-but-they-arent-depleting-earths-oxygen-supply-122369).

Another article along similar lines is Jean-Pierre Gattuso et al., "Humans Will Always Have Oxygen to Breathe, but We Can't Say the Same for Ocean Life," *The Conversation*, August 12, 2021. (https://theconversation.com/humans-will-always-have-oxygen-to-breathe-but-we-cant-say-the-same-for-ocean-life-165148#:)

They give different numbers for thought experiments where photosynthesis instantly ends and we have to keep breathing. The Gattuso article says we'd be okay for thousands of years, the Denning article for millions of years. They have different scenarios in mind. (I asked the authors for some comments on the comparison – thanks to Scott Denning and to Laurent Bopp for their replies.) The "millions" figure is reached, in the Denning article, by assuming that when photosynthesis ends, respiration ends soon after. So the slow loss of oxygen is due to weathering of rocks, not consumption by living beings. In that scenario, we are not around to use up the stock of oxygen. Suppose we assume, instead, that once photosynthesis stops, other organisms continue to respire, using up oxygen. (We assume that photosynthesizers no longer respire – they are dead.) That takes us to a number of years in the thousands, before the the oxygen is largely gone, but the scenario doesn't make a lot of sense, as once the photosynthesizers have gone, very soon there will be nothing left for the other organisms to eat. Their respiration depends on a source of food, as well as oxygen. The food will run out before the oxygen does.

28 *This slower "inorganic" carbon cycle*: See James Kasting, "The Goldilocks Planet? How Silicate Weathering Maintains Earth 'Just Right,'" *Elements* 15 (2019): 235–240. This is a very helpful article.

30 *Some corals have also been found with cyanobacteria*: See Michael Lesser et al., "Discovery of Nitrogen-Fixing Cyanobacteria in Corals," *Science* 305 (2004): 997-1000. https://doi.org/10.1126/science.1099128;

31 *As oxygen levels increased*: See Douglas Fox, "What Sparked the Cambrian Explosion?," *Nature* 539 (2016): 268–270, doi.org/10.1038/530268a

32 *We are also a* material continuation: In philosophy, Jim Griesemer is the person responsible for pressing the importance of this point. See especially his "The Informational Gene and the Substantial Body: On the Generalization of Evolutionary Theory by Abstraction," *Poznan Studies in the Philosophy of the Sciences and the Humanities* 86 (2005): 59-116.

Here is some more detail: The creation of membranes shows the relationships clearly. When a cell divides, parts of the mother cell exist in the next generation. Membranes come from membranes, budded off. Part of *A* becomes part of *B*, part of *B* becomes part of *C*, and so on. All of *A* is soon gone, but there is a chain of continuity. One sometimes hears that all of the matter in one's body is turned over repeatedly within our own lives. A "natural experiment" in the mid–twentieth century gave a clearer view of what happens with our bodily materials, as was realized decades afterward. In the 1950s and early 1960s, several countries tested nuclear weapons with aboveground explosions. This led to the creation and release of unusual amounts of "carbon 14." This is not a dangerous substance, just a slightly different kind of carbon, one that was put into the atmosphere at higher levels than usual by the tests. It was taken up by plants, and then by animals. Later, it was realized that we could look for this form of carbon in people of various ages in relation to the nuclear testing period; carbon 14 became a signature of the chemistry of that time. Did the extra carbon 14 enter and then disappear from their bodies, or did it remain?

In the picture that emerged, most of the molecules in each of our cells are coming and going, in constant flux, with the exception of DNA. Once a cell has formed, with its DNA in place in the nucleus, those DNA molecules stay put. Most cells are also cycled through, in a process that begins in division and ends in another division, or death. Cells do this at different rates, from a scale of days to a decade or more, in different parts of the body. In a few cells, mostly in the brain and the lens of the eye, there is no cycling at all. (Some heart cells are also special.) In these cases, again, most material in the cells will be turned over even if the cell lives on, but the DNA stays. As someone who has criticized overly "gene-centric" ideas to some extent over the years, I did find it a little spooky to learn that DNA has this material permanence within a cell. The cells that live on through our lives are also interesting—neurons in the cortex of the brain, the lens of the eye, and heart muscles.

32 *Back in the 1970s, James Lovelock and Lynn Margulis*: See Lovelock and Margulis, "Atmospheric Homeostasis by and for the Biosphere: The Gaia Hypothesis," *Tellus* 26 (1974): 2-10. doi.org/10.1111/j.2153-3490.1974.tb01946.x, and Lovelock's *Gaia: A New Look at Life on Earth* (Oxford, 1979).

33 *it was Margulis who rescued this idea*: Her original paper, published under the name Lynn Sagan, is “On the Origin of Mitosing Cells,” *Journal of Theoretical Biology* 14 (1967):255-74. doi: 10.1016/0022-5193(67)90079-3.

34 *Ford Doolittle, one of the early critics of Gaia*: See Doolittle’s “Is Nature Really Motherly?,” *The CoEvolution Quarterly*, 1981, doi.org/10.1016/0732-118X(87)90028-6

34 *Although salt water is in many ways friendly*: For the saltiness of Martian water, see Nicholas Tosca et al., “Water Activity and the Challenge for Life on Early Mars,” *Science* 320 (2008): 1204-1207. DOI: 10.1126/science.1155432

35 *Lovelock wondered whether the Great Barrier Reef*: See *Gaia*, chapter 6. Lovelock said in this book that 6 percent is an upper limit for almost all organisms, but this was perhaps an exaggeration. The water around the stromatolites at Shark Bay is apparently around 6 percent salinity, and there’s quite a lot of life there (including the fish I watched). Ordinary seawater is around 3.5 percent.

Here is some more on this topic. "Almost all" is a vague term, of course. Lovelock has a discussion of brine shrimp in his book, whose salt tolerance is remarkable. From Gajardo and Beardmore, "The Brine Shrimp Artemia: Adapted to Critical Life Conditions," Frontiers in Physiology 22 June 2012. Brine shrimp can handle "up to 10 times the salt concentration of ordinary seawater."

In drafts of this passage, given that I'd seen fish at the Hamelin Pond part of Shark Bay (the part with the stromatolites), I wanted to give a number for the amount of salt that would be just too much for – for example – all fish. But there are some extraordinarily salt-tolerant fish, too. See "The Physiology of Hyper-salinity Tolerance in Teleost fFsh: a review" by R. J. Gonzalez (*Journal of Comparative Physiology B*, 2011, which Doolittle referred me to). "Relatively few species of teleost fish can tolerate salinities much above 50 ppt [ppt is parts per thousand, so 5%], because of the challenges to osmo-regulation, but those that do... show a strong ability to osmoregulate in salinities well over 100 ppt. "A few... can survive extended exposure in water with salinities over 120 ppt," or 12%. "Tolerant fish come from diverse phylogenetic origins" – it is not just one family of oddities. Lovelock treats these cases (back in his 1979 book – brine shrimp and also micro-organisms that can handle extreme temperatures) as made possible "by permission of the rest of the living world," which creates conditions that supply them with what they need. He means: they are not a model for how life could work in general. I came out of all this somewhat uncertain about how much constraint of a constraint salt levels really are. Jochen Brocks wondered, in an email exchange about this, whether, if the salt levels suddenly doubled in all the oceans, (and the Hamelin Pond fish had open fields before them) whether a diverse oceanic ecology would evolve again, or not.

35 *The biologists David Queller and Joan Strassmann*: Queller and Strassmann, "Beyond Society: The Evolution of Organismality," *Philosophical Transactions of the Royal Society B* 364 (2009): 3143–3155, doi: 10.1098/rstb.2009.0095

36 *These acacias build living quarters*: I discuss these cases in "Agents and Acacias: Replies to Dennett, Sterelny, and Queller," *Biology and Philosophy* 26 (2011): 501–515 (2011). doi.org/10.1007/s10539-011-9246-6

37 *That led to objections from evolutionary biologists*: See Doolittle's "Is Nature Really Motherly?" and Richard Dawkins, *The Extended Phenotype* (Oxford, 1982).

39 *Talk of Gaia invites us to think the Earth will* take care of itself: Here's another point along the same lines. The Earth does seem to have a good amount of life-friendly feedback in its processes. If the Earth is not like an organism, then the existence of one feedback process of this kind gives us no reason to expect another. There's no reason why there should be a general pattern. If the Earth is organism-like, then it has been shaped to have a general capacity for self-maintenance, to some extent. Then we *should* expect a pattern—not an exceptionless one, probably one with many gaps, but this is the sort of thing we'd expect to see.

39 *Sometimes people just want to use talk of Gaia*: For a simple discussion of "weak" versus "strong," see Ian Enting's "Gaia Theory: Is It Science Yet?," *The Conversation*, February, 2012 (https://theconversation.com/gaia-theory-is-it-science-yet-4901). For versions of Gaia, see also Tim Lenton and David Wilkinson, "Developing the Gaia Theory: A Response to the Criticisms of Kirchner and Volk," *Climatic Change* 58 (2003): 1–12, doi.org/10.1023/A:1023498212441.

I mentioned Ford Doolittle earlier, as a Gaia critic. Doolittle has been rethinking the question and defends the possibility of Darwinizing Gaia, partly through selection processes based on survival or persistence. Doolittle has a somewhat organism-like way of thinking about Gaia. See his "Making Evolutionary Sense of Gaia," *Trends in Ecology and Evolution* 34 (2019): 889-894, https://doi.org/10.1016/j.tree.2019.05.001.

On the other side, I've seen scientists keep the "Gaia" term around as a nod to Lovelock and the broadening of perspective that he introduced, even if they reject anything like an Earth-as-organism view.

40 *In this case, when conditions are warmer*: For these feedback processes, see Lenton's book *Earth System Science: A Very Short Introduction* (Oxford, 2016). For the effects of life on weathering, see David Schwartzman and Tyler Volk, "Biotic Enhancement of Weathering and the Habitability of Earth," *Nature* 340 (1989): 457–460, doi.org/10.1038/340457a0.

41 *How about the salt in the oceans?*: Here I draw on Eelco Rohling, *The Oceans: A Deep History* (Princeton, 2017). On the question of whether feedback is present, and the uncertainties, this passage is notable, from Stephanie Olson et al., "The Effect of Ocean Salinity on Climate and Its Implications for Earth's Habitability," *Geophysical Research Letters* 49 (2022): 49(10):e2021GL095748, doi: 10.1029/2021GL095748: "The salinity evolution of Earth's ocean is not yet well constrained, but constant salinity through time would be a notable coincidence or imply some currently unknown feedback." I don't think people believe salinity was constant, but it might have been kept in a fairly narrow range.

Also from that Olson paper: "we suggest that an Archean ocean that was saltier than today could play a key role in compensating for the Faint Young Sun, perhaps even allowing an Archean climate that was warmer than today."

I spent quite a lot of time trying to work out whether there is much consensus about the stability of salt levels. Some sources (informal, but serious places) say things like this: "Throughout the world, rivers carry an estimated four billion tons of dissolved salts to the ocean annually. About the same tonnage of salt from ocean water probably is deposited as sediment on the ocean bottom and thus, yearly gains may offset yearly losses. In other words, the ocean today probably has a balanced salt input and output (and so the ocean is no longer getting saltier)."

https://oceanservice.noaa.gov/facts/riversnotsalty.html

Here the authors lean towards the idea that there's an "offsetting," and a consequent balance. I don't know what the reasoning behind this is, if one alternative is that change is just very slow.

42 *Much of it was probably brought in on asteroids*: See Lenton and Watson, *Revolutions*. Rohling, in *The Oceans*, views this as less clear, as a fair bit of water might have been in place when the planet formed.

44 *an event like a flow of adrenaline has a purpose*: This example is used often by Ruth Millikan, in her classic book *Language, Thought, and Other Biological Categories* (MIT, 1984).

45 *the American philosopher Larry Wright*: See his *Teleological Explanations* (University of California Press, 1976). Wright is the main source for me here; Millikan's *Language, Thought, and Other Biological Categories* is also important. The broad way I am applying these concepts is reminiscent of Daniel Dennett's concept of a "design stance," but I see his treatment of these ideas as more instrumentalist. For Dennett, the language of goals and functions provides an interpretive stance, a way of seeing complex phenomena that is justified if it helps us discern patterns. The framework doesn't have to be understood in terms of a definite set of mechanisms. See his *Darwin's Dangerous Idea* (Simon and Schuster, 1996).

47 *This rehabilitation does not carry over*: In a traditional way of using teleological concepts, the function of something is what it is *supposed* to do, and if it does not have that effect, something has gone *wrong*. This link might be seen as a bridge to a moral theory. I am not endorsing inferences of that kind at all.

48 *we can find borderline cases*: Some of these borderline cases were discussed as problems for Wright's analysis of biological functions—see Chris Boorse, "Wright on Functions," *Philosophical Review* 85 (1976): 70-86, doi.org/10.2307/2184255. They

were seen as problems because Wright seemed to be committed to saying that biological functions were present in cases where they appear to be absent. I discussed this as a problem in one of my first papers, “A Modern History Theory of Functions,” *Noûs* 28 (1994): 344-62, doi.org/10.2307/2216063. I wish I’d not approached these interesting cases in this way. It was an opportunity to explore the borderline and marginal cases in themselves, rather than worrying about how they are categorized.

49 *conversations with the evolutionary theorist William Hamilton*: See Lenton et al., “Selection for Gaia Across Multiple Scales,” *Trends in Ecology and Evolution* 33 (2018): 633-645, doi: 10.1016/j.tree.2018.05.006.

50 *The possible snowball Earth events were rare*: In the more powerful kinds of learning by trial and error, a learner adds improvements in stages while keeping the good elements of what they had. The snowball Earth events seem more like a crash plus a new roll of the dice—not with respect to features that make for individual advantage, but those that are helpful to life as a whole.

That, above, is how I had it in the brief note in the book itself. Here is a bit more detail. In these envisaged "crash and restart" processes, some of what was around before will be kept while some (most) is lost. These new events are not a pure case of a "new roll of the dice," because the new roll is affected by what was around before, and what made it through the crash. However, in this process, as I understand it, the elements of the old set-up that are retained in the re-start are not likely to be elements that are helpful to the general viability of the Earth system. This will be a matter of individual advantage – the more resilient forms of life (roughly speaking) will get through, whether they were helpful to the earlier ecology as a whole, or not. If this "Earth learns" process was to be a powerful kind of selection, then there would have to be a way for pieces of an earlier regime to be retained or lost according to their contributions to the viability of the whole. (Compare this to the "crash" due to the asteroid at the end of the Cretaceous. Let's suppose, for the sake of argument, that smaller, more mobile dinosaurs (birds) were more likely to make it through. That advantage does not imply anything about a positive contribution to whole ecologies and larger systems.)