for elevating the continental drift idea into plate tectonics as the geoscience paradigm. Many innovations, including paleomagnetism, sonar mapping, K-Ar geochronology, and submersible ocean-floor vehicles enabled the development of a plausible mechanism for "drift" beyond Wegener's "guess" and Holmes's 1929 almost-correct idea (p. 98).

The third topic (Part III), meteorite impact structures, was initially controversial because such features, as we now acknowledge them, were originally proposed as "crytoexplosives," a blast of igneous origin up from deep below. The counter interpretation of "astroblemes" or extraterrestrial impacts came from careful observation of Earth structures (notably by the USGS luminary Eugene Shoemaker and maverick Robert Dietz) in comparison with those discovered on the moon in the space race days (mid- to late-1960s). Back in 1933, Columbia University's Walter Bucher had followed the lead of G. K. Gilbert, essentially attributing all crater features as volcanic. The book goes on, as in the earlier sections, to show how the old and stubborn hypotheses were worn away by multiple lines of evidence. The stage was then set for a bigger revelation to hit in the 1980 *Science* article "Extraterrestrial Cause for the Cretaceous-Tertiary Extinction" by the Alvarez father and son team. Some researchers still have doubts, but the data in support of a meteorite impact of grand proportion in the Yucatan vicinity has grown to general acceptance as explanation for the close of the Mesozoic. Powell hides little of the rancor involved in opposition to the hypothesis. The sin of pride is all too evident among academic scholars.

As the final section, Part IV brings what I perceive as Powell's main interest into focus. His heading, *Global Warming*, is chosen instead of climate change. That in itself is telling. For the first time, the book covers a controversy significant beyond the scientific. This issue continues to rage today in the public realm, even though its great support from qualified scientists establishes the key hypothesis as firmly as any of the others described. Powell begins this section by introducing us to the brilliant G.S. Callendar, engineer and amateur meteorologist from the UK. His intuition and calculations involving the atmospheric system led to the first correct correlation between CO_2 abundance and temperature regulation in 1938. Svante Arrhenius, who won the Nobel Prize in Chemistry, 1903, had already played with the same idea. Neither the modest engineer nor the famous chemist was much remembered as the significance of an altered atmosphere became a huge ideological battleground.

Powell leads readers carefully through the ups and downs of technical advances in understanding the relationship between human activity, especially the burning of fossil fuels, and the effect on climate systems. Warming is but one result of the extremely rapid (in geological reference) disturbance of the linked atmospheric-oceanic mega-system. Unlike the other three "revolutions," that of global climate change is still developing, trying to overcome opposition from political and vested economic interests (not scientific opposition). There is strong scientific support for the conclusions of the Intergovernmental Panel on Climate Change. Plainly, human beings have caused to increase and continue to increase the amount of atmospheric "greenhouse" gases, such that Earth's climate is growing hotter, less predictable in terms of weather events, and more prone to spawn events of greater severity with risk to life and property. This last of four revolutions needs everyone's attention and willingness to act for reversing destructive lifestyles.

I am aware of many books that seek to popularize the stories behind great scientific advances. Powell's book is comprehensive but not overly long. It probes the personalities involved but without sensationalism. I learned many details that contributed to my understanding as an earth scientist, and am certain that others, scientists or not, will gain interesting and useful insights in the reading. I would recommend the book for general interest as well as a potential asset for a seminar course emphasizing the history of geologic thinking.

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Mathematics

MATHEMATICS WITHOUT APOLOGIES: Portrait of a Problematic Vocation by Michael Harris. Princeton, NJ: Princeton University Press, 2015. xxii + 438 pages, with endnotes, bibliography, and index. Hardcover; $29.95. ISBN: 9780691154237.

Why should we encourage people to study mathematics, and why should scarce resources be allocated for mathematical research? Should mathematics be pursued because it provides a theoretical core for technological applications that make our lives easier and better, the Golden Goose argument? But while abstract theories may one day become practical (number theory gave us modern cryptography, the basis for secure online transactions), there is no guarantee that they will ever lay such an egg. Nor is this the express motivation given for the work pure mathematicians do. Furthermore, mining mathematics for commercial possibilities can be harmful instead of beneficial—recall the crash of 2008 engineered by greedy risk-takers wielding mathematically based financial instruments. (Harris was warned away from indicting the quants who promoted the widespread use of derivatives, but chapter 4 lays out the arguments against them as described in the mathematical press.)

Is mathematics rather to be valued because it provides access to absolutely true knowledge? The notions of truth and certainty, however, are no longer considered central to mathematics. Are arcane results in abstract algebra or topology true, or do they merely follow logically from the axioms and definitions we have chosen? Mathematicians still believe that they are exploring something meaningful, and they want their concepts to carve mathematical reality at its joints, but that reality is taken by many to be socially constructed by experts rather than given in any independent sense.

If we cannot appeal to the Greek ideals of the Good or the True as the ultimate rationale for mathematics, what about Beauty? Do mathematicians create mathematics because they find it beautiful? This ploy likely strikes nonmathematicians as odd—where is the beauty in long division or fraction calculations or in factoring polynomials? Yet those involved in mathematics, especially at more advanced levels, do experience beauty in the simplicity and elegance of certain proofs and in the unexpected ways seemingly disparate ideas combine to produce significant connections and generate meaningful insights. In fact, beauty was G.H. Hardy's main justification for doing mathematics in his well-known booklet *A Mathematician's Apology* (1940).

Readers who pick up Harris's *Mathematics without Apologies* (hereafter: *MWA*) will immediately recognize the allusion to Hardy's classic. While the title's use of negation rightly leads us to expect that Harris will take a somewhat different approach to answering "Why mathematics?," each book is, as C. P. Snow noted in his foreword to Hardy's work, "the testament of a creative artist." In Harris's case, the term *testament* may connote a more settled form than he would prefer. As he says in the preface, "this book pieces together fragments found in libraries, in the arts, in popular culture, and in the media, to create a composite picture of the mathematical vocation." Harris wants to give the reader a sense of what it is like (for him) to be a mathematician in the early twenty-first century. His area of specialty, for which he was awarded a prestigious Clay Research Award in 2007, is in a part of number theory connected to abstract algebra: in 2001, he and a colleague proved the local Langlands conjectures for certain general linear groups. As you might expect, little of this can be explained in a work aimed at the general reader, as *MWA* is. Harris attempts, nevertheless, to discuss key aspects of number theory (solving polynomials in two variables) that underlie his work, presenting this in a series of five interspersed chapters titled *How to Explain Number Theory at a Dinner Party.* He undoubtedly succeeds better here with a mathematically trained reader than with his partly fictitious performing artist, but the mathematical community might benefit from more mathematicians explaining the basics of their research work to the public, at least to their colleagues in academia.

In chapter 9 Harris describes the creative process that produced some of his mathematical results. In addition to talking about the sequence of events, collaborators, and mathematical ideas that moved him away from the topic of his doctoral dissertation into the area in which he contributed to the Langlands program, he describes how a number of key ideas came to him and were further clarified over time, beginning with a mathematical dream that activated his unconscious in an unusual way. Readers familiar with Hadamard's pioneering 1945 *Essay on the Psychology of Invention in the Mathematical Field* will find this autobiographical narrative quite fascinating, as I did.

MWA is a wide-ranging idiosyncratic nonapology for mathematics. A whole chapter is devoted to "An Automorphic Reading of Thomas Pynchon's *Against the Day* (Interrupted by Elliptical Reflections on *Mason & Dixon*)," and Harris also discusses a number of films (e.g., *A Beautiful Mind* and *Pi*) and plays (e.g., *Proof*) that touch on mathematics. These references exhibit the author's familiarity with literature and art and allow him to discuss the extent to which mathematics might be an art as well as or instead of a science. Harris also riffs on various themes (oh, yes; he explores connections between mathematics and music, both classical and rock) pertaining to the sociology and morality of knowledge, philosophy of mathematics, foundations of mathematics, history of mathematics, Eastern metaphysics, twentieth-century Russian mysticism (the mathematical "name-worshippers"), the etymology and significance of words such as *charisma* and *tricks* for mathematical practice, and more. Other reviewers have termed his treatment of such matters "erudite," but Harris insists his approach is more personal than scholarly.

Before I summarize his nonapology for mathematics, I would like to make a few comments about foundations and philosophy of mathematics, which may be of interest to readers of this journal. Given Harris's background in category theory, one might expect him to promote Homotopy Type Theory (Voevodsky's Univalent Foundations of Mathematics) as an alternative contemporary foundation for mathematics. He says only a few things about this in the book, explaining on the book's companion website, https://mathematicswithoutapologies.wordpress.com/, that he is not well versed in homotopy theory. But he does entertain the possibility (pp. 65, 219) that this may eventually become a new implicit foundation of mathematics by providing the conceptual tools and a unifying language for talking about and organizing a broader range of mathematical matters than the present set-theoretic foundation does.

Standard logical Foundations of mathematics (Harris capitalizes this to suggest imperial overreach) was the central focus of Philosophy of mathematics (ditto) for about the first half of the twentieth century. In the last quarter or so of the century, however, philosophy of mathematics (lowercase) has begun to take greater notice of mathematics as it is actually practiced by mathematicians. Harris terms this the philosophy of mathematical practice, and he clearly appreciates what has been accomplished here by Imre Lakatos, David Corfield, and others. Some see this new trend as turning away from Platonism in mathematics and toward postmodernism; not all readers will find this development as welcome as Harris does. Harris thinks philosophy/foundations of mathematics should not be so focused on truth or epistemology or on trying to construct the firm bedrock for grounding all of mathematics. Mathematics is a fully human activity done collectively under the elite leadership of those who have earned their charismatic stripes through successfully introducing and pursuing significant research programs. As such, it is a fallible and not fully rational enterprise, involving ethical motivations, conjectures, and intuitions about dimly perceived realities; disruptive shifts in focus and methodology; changing connections to what is considered central; and so on. Proof and rigor still have a place in confirming mathematical intuitions, but they should not be viewed as the essence or main task of mathematics.

MWA is not Harris's first attempt at answering "Why mathematics?": his twelve-page essay in the highly regarded *Princeton Companion to Mathematics* (2008) under this title introduced some of the same themes. *MWA* greatly expands these ideas within the context of a personal portrait of a working mathematician. And while *MWA* may not be a conventional apology for the existence of mathematics, it does explore why people do it, most pointedly in chapter 10. Mathematics, Harris says, is a free creative activity, subject only to certain social constraints as a tradition-based/tribal activity and (eventually) to the strictures of logical consistency and proof. It may lead to practical applications (one of the reasons why mathematicians should still be employed by universities), but mathematical research is best pursued as a "relaxed field"—for its own sake, unconstrained by utilitarian demands, akin to play. The clearest thing one can say about why mathematicians do mathematics is simply that they experience deep pleasure in uncovering abstract patterns and in solidifying intuitions about conceptual entities that intimate (are "avatars" of) still further realities to be explored. On this note, Harris's nonapology elaborates and refines Hardy's apology in the context of contemporary research mathematics.

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ORIGINS

A NEW HISTORY OF LIFE: The Radical New Discoveries about the Origins and Evolution of Life on Earth by Peter Ward and Joe Kirschvink. New York: Bloomsbury Press, 2015. 400 pages. Paperback; $10.97. ISBN: 160819907X.

A New History of Life is a natural history that stands out because of its large timescale (4.567 billion years, to be precise) and broad intended audience. Overall, it delivers on the promise of its title adjective, describing new findings and hypotheses connecting paleontology and geology, and offering genuine but grounded scientific speculation for future work. For the general reader, it provides a wealth of new information, but because its overall scientific narrative lacks momentum and internal connection, it may be most appropriate for a scientifically literate audience.

It is impressive to watch the authors address the central challenge of this genre, which I have faced myself in my writing for a general audience: How do you filter oceans of information and translate it into general terms? Ward and Kirschvink set up their filter by emphasizing physical evidence, and rocks and bones in particular. Their geological and paleontological emphasis gives this story a different tone and tempo than other natural histories that start with the Big Bang (physics) or the characteristics of life (biology). My own discipline, chemistry, is not as deeply integrated as a result—here, chemistry plays a role in dating the rocks and bones, and in transforming the environment, but the authors focus their attention on the change and flow of continents (and other aspects of geology) and body plans (developmental biology).

The flip side of the authors' emphasis is their de-emphasis. They deemphasize evidence from genetic clocks and other results from molecular biology, leading them to a chain of reasoning that is mostly geological in nature. For example, they favor a very late evolution of water photosynthesis. Personally, I trust the genetic clocks that show how many forms of photosynthesis, including water photosynthesis, evolved much earlier than Ward and Kirschvink allow. But this is a moot point—a few hundred million years one way or the other does not change the story much for the general reader.

A New History of Life reads at the level of an undergraduate science text. Ward and Kirschvink recount