PERSPECTIVES on Science and Christian Faith

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In this issue …

"The fear of the Lord
is the beginning of Wisdom."
Psalm 111:10

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Perspectives on Science and Christian Faith

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Editorial

On Tipping Points and Christian Scholarship

Arie Leegwater

The use of the phrase "tipping point" has become commonplace. A term introduced in epidemiology is now being used by climate scientists, sometimes with apocalyptic warnings. Tipping point describes a critical point in an evolving situation that leads to a new and irreversible development. In short, it is considered to be a turning point. When we look back at the trajectory of our own lives we can undoubtedly identify some intellectual tipping points.

As I compose this editorial during early April, I look back to March with a certain ache in my heart. I experienced the passing of two mentors, two professors who functioned as tipping points in my own academic development. The first was a cantankerous philosopher, a founder of the field of philosophy of biology, Marjorie Glicksman Grene (b. 1910), lately of Virginia Tech; the second, an able physicist turned historian of science, Martin J. Klein (b. 1924) of Yale University. They shaped my thinking in a variety of ways.

Grene doggedly insisted that philosophy mattered in the generation of scientific knowledge, and that thinkers like Michael Polanyi, J. J. Gibson, and Merleau-Ponty offered insights that legitimately challenged the reigning paradigms of reflection in the sciences. She continually stressed the embodied nature and historicity of human beings: it was Descartes' disembodied "cogito" that drew her ire.

Klein demonstrated how, in a close analysis of the development of quantum theories, one can detect different scientific styles which enhance our understanding and assessment of the contributions of a particular thinker. As a historian of science, Klein became a leading expert on the origins of the quantum theory and for ten years served as senior editor of the Einstein Papers Project. Klein was nominated to the National Academy of Sciences in 1977, the only historian of science to hold that honor.

Klein had known and intensively studied many of the leading lights of the new physics. His research dealt with the interrelated developments of quantum mechanics and statistical thermodynamics, and usually concentrated on the work of individual physicists, such as the development of Ludwig Boltzmann's statistical ideas, Josiah Willard Gibb's early work in thermodynamics, Paul Ehrenfest's contributions to the quantum theory, the origins of Erwin Schrödinger's wave mechanics, and the life and work of Niels Bohr and Albert Einstein. If there is a way of describing Klein's work in the history of physics one can do no better than appeal to one of his favorite Herbert Butterfield quotes. Butterfield, the English historian, wrote,

> The value of history lies in the richness of its recovery of the concrete life of the past. It is a story that cannot be told in dry lines, and

Tipping point describes a critical point in an evolving situation that leads to a new and irreversible development … Christian scholarship has a bite to it. It rests on well-grounded beliefs, but also requires engagement with others in interpreting and understanding the common world in which we live.

Editorial

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> its meaning cannot be conveyed in a species of geometry. There is not an essence of history that can be got by evaporating the human and the personal factors, the incidental or momentary or local things, and the circumstantial elements, as though at the bottom of the well there was something absolute, some truth independent of time and circumstance … The thing which is unhistorical is to imagine that we can get the essence apart from the accidents.

When Klein's colleagues presented him with a festschrift entitled *No Truth Except in the Details*, they captured his approach to the history of science. Schrödinger once described his wave mechanical theory as "being stimulated by de Broglie's thesis and by short but infinitely far-seeing remarks by Einstein." Klein is the only person I know who could take these short far-seeing remarks and turn them into a finely tuned forty-three page paper on "Einstein and the Wave-Particle Duality," *The Natural Philosopher* 3 (1964).

And yet, for all my appreciation for the insights and scholarship of Klein and Grene, we differed on fundamental matters. Neither was a Christian believer nor did they desire to become one. For Klein, a variety of ideological influences could not be constitutive of science. For Grene, religion was a nonstarter. What I constantly faced was a nagging question: what might one legitimately learn from them? And still more fundamentally: how do we as Christians continue to have a distinctive voice in scholarship, faithfully working out of a tradition, without becoming insular, satisfied in our own isolation?

It is easy to accede to the idea that Christian scholarship is best characterized as a value-added interpretation of a more or less common set of facts or realities, at best, one of many interpretive slants on an issue. But, in reality, Christian scholarship has a bite to it. It rests on well-grounded beliefs, but also requires engagement with others in interpreting and understanding the common world in which we live. Christian believers will have to discover, to learn, to never stop learning what science and technology are about. We learn with others and from others. Science thrives on an analysis of things and events which we encounter as creational givens. Which things and events? In principle, all things. And what of science's relation to faith? For symmetry there is no place, nor one for a static hierarchy. We can, I think, speak of a certain priority.

The knowledge of faith—its certainty—appears at first glance to be mysterious. But that is just as true of our knowledge of justice and love. Faith can be expressed in words, in propositions. We confess in faith that our world is created. But that a particular constellation of clouds will arrive tomorrow to give us rain is information, a more or less correct and accurate assessment and description of the world. Science thrives on information, but that the world has been lovingly prepared for us, by a word of God, as a place to be lived in, is accepted by faith. That is certainly a different language, a language of which one never gets enough.

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In This Issue

There is a certain symmetry to this issue of *PSCF*. *Ad seriatim* it has two history articles, a creation care article, and finally two articles devoted to geological subjects.

In this year of Darwin celebrations, John H. Brooke introduces us to the topic "Charles Darwin on Religion." Edward (Ted) Davis follows with Part 1 of a three-part series on Arthur Compton, prophet of science. Three Calvin College colleagues describe an institutional carbon neutrality project written with pedagogical intent. Carol Hill and Steve Moshier provide a comparative analysis of flood geology and Grand Canyon geology, and finally Davis Young gives us an essay book review of the latest monumental book by Martin Rudwick, the world's premier historian of geology.

Book reviews and letters provide additional food for thought.

Article

Charles Darwin on Religion

John Hedley Brooke

John Hedley Brooke

What did Darwin have to say about religion? What were his religious, or anti-religious, beliefs? Did he believe that his theory of evolution by natural selection was incompatible with belief in a Creator? Was it his revolutionary science that turned him into an agnostic? These questions have a special urgency in 2009, the year that marks the bicentenary of Darwin's birth and the 150th anniversary of his most celebrated book, On the Origin of Species *(1859). It is important to answer them in a balanced way because Darwin's authority and example are continually invoked to justify metaphysical and theological claims that go far beyond the details of his evolutionary biology and that of his scientific successors.*

Darwin's religious sympathies … changed over time … [H]is trajectory was from the Christian orthodoxy of his Cambridge years to a non-biblical deism at the time the Origin *was published to a more thoroughly agnostic position in later life.*

Darwin's great gift to science was to show how an explanation could be given for what had been described as the mystery of mysteries, the successive appearance of new species discernible in the fossil record. If new species could emerge from preexisting species by a process of natural selection, it was no longer necessary to suppose there had been what Darwin called independent acts of creation.

For atheists and scientific materialists, the plausibility of Darwin's theory was a particularly welcome gift because it could be used to dispel the notion of divine intervention in nature and to challenge the long-cherished belief that each species had been separately and meticulously designed by its Creator. Not surprisingly, there was much apprehension and some downright hostility among religious believers, which in ultra-conservative religious circles still continues today. Darwin's theory has certainly proved divisive within Christendom; but a long tradition of assimilation and accommodation suggests that some at least of Darwin's insights have been received as a gift by religious thinkers as well as scientists.

As the nineteenth-century Anglican theologian Aubrey Moore put it, under the guise of a foe Darwin had done the work of a friend, liberating Christianity from a false image of the deity in which God was only present in the world when intervening like a *deus ex machina*.

Darwin and the Insufficiency of Sound Bites

There is no simple answer to questions about Darwin's religious sympathies. This is partly because they changed over time. To a first approximation, his trajectory was from the Christian orthodoxy of his Cambridge years to a non-biblical deism at the time the *Origin* was published to a more thoroughly agnostic position in later life. This makes a neat

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and ironic story, given Darwin's initial training to become an Anglican priest and given the clerical attacks on his theory that he had to endure. But it means that what was credible for him at certain times in his life was not at others. For example, the sensitivity with which in the early 1830s he responded to the sublime beauty of the Brazilian rain forest, and which he said had been associated with his belief in God, faded in old age. In 1859, at the age of fifty, he could still believe that the laws governing the evolution and diversification of life had their origin in a Creator.

A second reason why Darwin is difficult to pin down concerns the fluctuation of belief. In private correspondence he admitted that his beliefs often fluctuated, even within his most agnostic phases. There were times when, in his own words, he supposed he deserved to be called a theist. At other times the strength of his belief in an ultimate Creator waned. He did, however, insist that he had never been an atheist in the sense of denying the existence of God—a point sometimes overlooked by his fundamentalist critics and his atheistic champions.

The attempt to capture in sound bites such a subtle, honest and imaginative thinker as Darwin is bound to fail. He frequently confessed his conviction that this wonderful universe could not be the product of chance. But, typically, he would add a nuance. He could not think the universe the product of chance alone, but nor could he look at its many life forms and see in them evidence of design. He was caught in a conundrum and in self-effacing mode would say he was in a hopeless muddle. Just as it was necessary to believe both in determinism and free will, despite the problem of reconciling them, he looked for a way of embracing both chance and design. During the early 1860s he toyed with the formula that the great diversity of living things was the result of "designed laws" with the details left to chance.

A further complication concerns the privacy of religious belief. Darwin once reproached all would-be interrogators by saying that he could not see why his beliefs should be of interest to anyone but himself. The complication here is that his writings did contain remarks calculated to cause least offence. He knew there were things he should say and not say, particularly concerning the human mind, if he wished to retain public sympathy. He was also keenly aware that his views, particularly on the evolution of the moral sense, would be distressing to his wife Emma. The upshot is that there are degrees of ambiguity in Darwin's remarks about religion that can make them difficult to interpret. To suggest, however, that his references to a Creator in the *Origin of Species* concealed a private atheism and were simply contrived to placate his audience would be an extreme interpretation. As he confided to the Harvard botanist Asa Gray in a letter of May 1860:

> I had no intention to write atheistically … I can see no reason, why a man, or other animal, may not have been aboriginally produced by other laws; & that all these laws may have been expressly designed by an omniscient Creator, who foresaw every future event & consequence. But the more I think the more bewildered I become.[1]

Darwin's Inheritance of a Christian Natural Theology

The gradual process whereby Darwin abandoned Christianity was certainly complete by the time he composed the *Origin of Species* in the late 1850s. Some of the seeds of doubt were sown during his voyage on HMS Beagle, when he witnessed a degree of violence and instability in nature that jarred with the stable, "happy world" of William Paley's *Natural Theology* (1802). Darwin had been captivated by this book with its detailed descriptions of the adaptations to be found in plants and animals. For Paley they testified to the wisdom and power of their Creator, who had lavished care on even the lowliest creature. For his lifelong fascination with the study of adaptation, Darwin remained indebted to Paley, using him as a sounding board to test his naturalistic theory of how such adaptations could have been accomplished through the perfecting action of natural selection working on random variations.

In South America Darwin saw the devastating effects of an earthquake; he observed nature red in tooth and claw on a grandiose scale; he registered the staggering numbers of species that had become extinct; and he witnessed the terrible struggle for existence faced by the natives of the Tierra del Fuego. Such experiences, when combined with philosophical reflection, eventually made it difficult for him to discern in nature the workings of a beneficent deity. He was particularly struck by the fact that neither the Fuegians nor the aborigines of Australia appeared to have an innate sense of God. This caused him to question one of the most basic assumptions of his day, namely that humans could be sharply differentiated from animals by their possession of that religious sense.

It is commonly supposed that Darwin's science was responsible for his rejection of Christianity. A less common, subtler view is that the rejection of Christianity was a precondition of his innovative science. Both interpretations, however, trade on the same assumption—that of an inherent conflict between science and religion. The reality was more complex. There were features of an emerging scientific naturalism that did contribute to new forms of scepticism on religious matters and Darwin's writings reveal them. The main reasons for his rejection of Christianity, however, lay elsewhere. While his science did play a role in disposing him against an intervening deity, the loss of his earlier Christian beliefs had more to do with issues common to all humanity than with conclusions entailed by his theory of natural selection. The claim that it was his renunciation of Christianity that made his science possible suffers the inconvenience that his theory began taking shape in 1837 and 1838 before he abandoned belief in divine providence.

The Relevance of Darwin's Science to His Rejection of Christianity

Darwin's science did have a bearing on his thoughts about religion in several respects. As his wife, Emma, had perceived before their marriage, a sceptical mentality cultivated in the rigorous examination of evidence could corrode beliefs that were inconclusively attested. The great strides made by Darwin's fellow naturalists in astronomy and the Earth sciences encouraged in him the view that "the more we know of the fixed laws of nature the more incredible do miracles become."[2] The fact that the variations on which natural selection worked appeared randomly, and could not be immediately correlated with a prospective use, predisposed him against the view proposed by Asa Gray that novel variations were micro-managed by the deity.

As many religious commentators would recognise, an emphasis on natural selection and a competitive struggle for existence accentuated the problem of suffering. Darwin himself considered that the presence of so much pain and suffering in the world was one of the most powerful arguments against belief in a beneficent deity—and yet it was to be expected on his theory of natural selection. And in one other crucial respect Darwin's science did contribute to his eventual agnosticism. It even provided a justification for it. If the human mind is itself the product of evolutionary processes, can it be trusted to reach definitive conclusions on metaphysical and theological matters? On the big questions of meaning, purpose and the existence of God, Darwin finally became unsure whether he should trust even his own convictions.

Moral and Existential Issues

When Darwin wrote that he could not see how anyone could wish Christianity to be true, he was not thinking about a supposed incompatibility with science. The issue was rather coherence with a civilised morality. He was thinking about the doctrine of eternal damnation for the unregenerate as it was commonly preached at the time. Freethinkers outside the Christian fold—and these included his grandfather Erasmus Darwin, his father and his brother Erasmus—were destined for eternal perdition if this doctrine were true. For Charles it was the doctrine that was "damnable," not they.

There were philosophical as well as ethical considerations. Darwin was well aware that to posit a first cause for the universe invited a rebellious question concerning the cause of that cause. In common with the sceptical eighteenth-century philosopher David Hume, Darwin also attached weight to the consideration that false religions, notoriously, often spread quickly. He did not find the miracle stories in the New Testament gospels sufficiently compelling to authenticate the Bible as a divine revelation and his general antipathy to claims for revelation was often accompanied by remarks about the ignorance of the biblical writers.

For some scholars, notably Darwin's biographer James Moore, the death of Darwin's favourite daughter Annie, early in 1851, marked the real watershed in Darwin's engagement with Christianity. One cannot read the letters that passed between Charles and Emma at this desolate time, without shedding tears with them. Why should so innocent a child suffer? What pattern could possibly be discerned in such human tragedies? Annie's death was the most heart-rending example, and the one closest to home, of a more general problem Darwin experienced in seeking to rationalise particular events. After the *Origin of Species* was published he entered into a revealing correspondence with Asa Gray in which the question of design in nature was explored in depth. For Gray, natural selection was not inconsistent with a Christian natural theology; Darwin was more sceptical. He asked Gray whether he believed that if a man stood under a tree and was struck by lightning there was design in such an event. In pressing Gray for an answer, Darwin acknowledged that many did believe it; but he could not. By the early 1860s Darwin was sure that the accidents of life (and by extension the countless contingencies in evolutionary processes) should not be ascribed to the immediate control of a divine agent.

This did not mean, however, that an ultimate Creator and designer of the universe was deleted from his philosophy of nature. He did not believe that the universe was self-explanatory and in the late 1850s and early 1860s was still willing to describe the laws of nature as ordained by the Creator in such a way that the highest good we can conceive—namely the production of the higher animals—would be brought about. In his large book on natural selection, of which the *Origin* was a summary, he explicitly defined what he meant by "nature" in order to make this clear: "By nature, I mean the laws ordained by God to govern the Universe."[4] This is not Darwin the atheist of popular caricature.

Darwin's Deism

It is often said that Darwin's science excluded all sense of purpose in nature. This is not strictly correct because the deistic philosophy of nature with which he was comfortable still allowed what his popularizer Thomas Henry Huxley described as a "higher teleology." It was possible to see the creation of the higher animals, and humans in particular with their capacity for appreciating goodness and beauty, as implicit in the way the universe was first set up. It was for this reason that Huxley could say that Darwin's theory had no more to do with theism than the first book of Euclid—meaning nothing at all. It was inappropriate to argue for design from the minutiae of organic structures, but progressive trends in a creative evolutionary process could form the basis of a revised natural theology.

Darwin's references to "laws impressed on matter by the Creator" featured even more prominently in the second edition of the *Origin* than in the first, and he appears genuinely to have believed that this way of looking at the question of design ought to mean that his views on the mutability of species would be exempt from theological criticism. In the second edition he could see "no good reason why the views given in this volume should shock the religious feelings of anyone."[5]

The fact that they did, and the fact that his theory was often attacked for its theological implications rather than judged on the quality of its science, meant that during the 1860s Darwin became increasingly irritated by those who had a religious axe to grind. His frustration is often visible in his correspondence, as in a letter written to Joseph Hooker in September 1868: "I am not sure whether it would not be wisest for scientific men quite to ignore the whole subject of religion."[6] Not that he was able to do so himself. When he addressed the subject of human evolution in *The Descent of Man* (1871), he hypothesised about the origins of religion and the development of the moral sense. He speculated that in primitive human societies a propensity to ascribe natural phenomena to invisible spirits might not be so different from the behaviour of his barking dog, which, Darwin surmised, had imagined an invisible intruder responsible for the movement of an open parasol swayed by the breeze.

The moral sense had developed as a consequence of a basic human desire to enjoy the approval of others. Selfish acts risking, or leading to, the loss of that approbation would induce feelings of anxiety and unease, preconditions of the emergence of conscience. Despite this prescient extension of naturalistic explanation, Darwin did not consider that he was promoting the relativity of moral values. The golden rule that we should treat others as we would wish them to treat us constituted the highest moral principle. Darwin's aim was not to impugn it but simply to explain how it had come about. His explanation gave an important role to religious beliefs in reinforcing moral precepts.

Darwin's Legacy in the Religious Sphere

The religious controversies surrounding Darwin's science have been well documented for the Christian churches, rather less fully for other religious traditions. Attention has been paid, correctly, to the problems that were posed for those who still wished to read the Genesis creation narratives literally or who recognised that the principle of natural selection required, at the very least, a revision of natural theology. For Christianity a distinction has to be drawn between the understandings to be found within popular religion and those of a Christian intelligentsia, which, even before Darwin published, had come to appreciate the many different literary genres to be found in the Bible. One of Darwin's legacies was to reinforce recognition that attempts to harmonise science with Scripture on the premise that the Bible had authority on questions of natural science were inappropriate and counter-productive.

There were other legacies welcomed by Christian commentators. One of Darwin's earliest converts was the Christian socialist Charles Kingsley who in his popular novels could be said to have done more than almost anyone to transmit evolutionary ideas to an English-speaking public. Kingsley delighted Darwin when he concurred that it was

> as noble a conception of Deity, to believe that he created primal forms capable of self development … as to believe that He required a fresh act of intervention to supply the lacunas which he himself had made.

Kingsley implied that he found the former the "loftier thought."[7]

Darwin's most able defender in North America, Asa Gray, also commended the new theory from a Christian point of view. In common with Darwin and with the co-founder of the theory of natural selection, Alfred Russel Wallace, Gray valued the conclusion that all living things were linked together by a single evolutionary story. In contrast to the view that the distinctive human races had been separate creations, which could easily underpin racial prejudice, Gray rejoiced that all humankind constituted a single species united by a common ancestry. Recent research has shown how Darwin's own abhorrence of slavery affected his thinking on the origins and unity of the human species.[8] Gray also believed that Darwin had provided a new resource for addressing the theologians' problem of suffering. While there was a real sense in which Darwin's theory put the spotlight on pain, struggle, cruelty and waste in the works of nature, Gray believed that if they were preconditions of the possibility of a creative process that eventuated in humanity, their presence could be better understood.

This line of argument, in which Darwin's theory became a resource for the construction of theodicies still finds expression today among evolutionary biologists with religious sympathies. To the question why there were so many displeasing, even devilish creatures in the world, Darwin himself had answered that this was a problem of greater magnitude for those who believed in the direct and separate creation of each species—for the deity would then be immediately responsible for vile molluscs and the wasps that lay their eggs in the bodies of caterpillars. But if the only world in which the evolution of human beings had been possible was a world in which the production of these other beings was also possible, might there be a sense in which the deity could be exonerated?

Darwin's repeated appeal to *laws* of nature, with their origin in an ultimate Creator, did resonate with the thinking of the most open-minded religious thinkers. A striking example is Frederick Temple who, as early as 1860, preached a sermon in Oxford in which he welcomed the expansion of scientific explanation and chided those who tried to make theological capital out of phenomena that the sciences could not yet explain. This was an early recognition of the dangers for religious apologists who pinned their hopes on a god-of-the-gaps, whose jurisdiction would forever shrink as the sciences advanced. Temple was a convert to evolution, finding in Darwin's theory a welcome unification of nature and a licence to believe that the history of life on Earth had been progressive and not directionless. The fact that Temple became Archbishop of Canterbury in the 1880s symbolizes the acceptance of Darwin's achievement by the English Church. When Darwin died in April 1882 he was buried in Westminster Abbey, the national newspapers finding no religious obstacle.[9] *The Times* declared the clash between Huxley and Bishop Wilberforce in 1860 a piece of "ancient history"; the Liberal *Daily*

News added that Darwinian doctrine was quite consistent “with strong religious faith and hope.”

That reference to the Wilberforce-Huxley debate at the 1860 meeting of the British Association for the Advancement of Science is a reminder of the diversity of religious reaction. The Bishop of Oxford had found Darwin’s theory offensive with its postulation of continuity between humans and their animal ancestors. Wilberforce’s contention that a graduation from primate to human was incompatible with Christian claims for human uniqueness overlooked the fact that to say humans were derived from ape-like ancestors was not to say they were nothing but apes. To regard his intransigent reaction as fully typical of the religious response is, however, another common mistake.

A Further Legacy?

Darwin’s legacy is far from exhausted in the sciences. It is rightly celebrated in 2009. In the religious sphere it has proved more equivocal. The oppositional stance of fundamentalist groups and the equally aggressive rejoinders from exasperated atheists has contributed to a polarization that the membership of ISSR deeply regrets. There is another legacy from Darwin, which, if appropriated, could only be beneficial in contexts where dogmatism on either side prevails. The manner in which Darwin conducted himself in his dealings with friends and critics alike might still be held up as an example. There was an attractive humility in the self-deprecating way in which he declined to dogmatise on intractable questions such as the existence of God or the existence of transcendent purposes in the universe.

Darwin also displayed an impressive honesty in his rhetoric, conceding the difficulties surrounding his theory as well as underlining its strengths. One of his grievances against the evolutionary biologist St. George Mivart was that, in a severe critique of Darwin’s dependence on natural selection, Mivart dwelled only on the difficulties, disregarding the strengths. Mivart was a convert both to evolutionary thought and to Roman Catholicism, making it easy for Darwin and Huxley to impute a religious motivation to his critique. There were other qualities in Darwin that are often lacking among contemporary antagonists. He knew where to draw the lines on the limitations of his science, recognising that the future would bring fresh insights and a deeper understanding of the processes he sought to understand. Two presuppositions characterise much of his thinking on questions of science and religion. One was that it would be sacrilegious to suggest that the deity was incapable of achieving its creative purposes through natural causes. The other, associated with his agnosticism, was an attitude of tolerance to those whose intimate beliefs he did not share. In so far as he had a creed at the end of his life, it was that each man should hope and believe what he can.

Notes

[1]Darwin to Asa Gray, 22 May 1860, in *The Correspondence of Charles Darwin*. Vol. 8 (Cambridge University Press), 224.

[2]*The Autobiography of Charles Darwin,* ed. Nora Barlow (1958), 86.

[3]Darwin, *Autobiography*, 87.

[4]*Charles Darwin’s Natural Selection, Being the Second Part of His Big Species Book Written from 1856 to 1858*, ed. R. C. Stauffer (Cambridge, 1975), 224.

[5]*The Origin of Species by Charles Darwin: A Variorum Text*, ed. M. Peckham (University of Pennsylvania Press), 748.

[6]Darwin to Hooker, 8–10 September 1868, in *The Correspondence of Charles Darwin*. Vol. 16, 732.

[7]Kingsley to Darwin, 18 November 1859, in *The Correspondence of Charles Darwin*. Vol. 7, 379–80.

[8]Adrian Desmond and James Moore, *Darwin’s Sacred Cause: Race, Slavery and the Quest for Human Origins* (Allen Lane, 2009).

[9]Adrian Desmond and James Moore, *Darwin* (Penguin), chapter 44.

Further Reading

For more on Darwin’s thinking about religion, see the ‘Darwin and religion’ section of the Darwin Correspondence Project website: www.darwinproject.ac.uk

Other recent discussions include Nick Spencer, *Darwin and God* (SPCK 2009) and essays by John Hedley Brooke and Robert J. Richards in *The Cambridge Companion to the Origin of Species* (Cambridge University Press, 2009).

Prophet of Science—Part One: Arthur Holly Compton on Science, Freedom, Religion, and Morality

Edward B. Davis

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American physicist Arthur Holly Compton (1892–1962), who shared the Nobel Prize with C. T. R. Wilson in 1927, was a leading public intellectual in the decades surrounding World War II. A very active Presbyterian, Compton's "modernist" Christian beliefs influenced his views on several important topics: evolution and the design argument, human freedom and the limits of science, immortality, anti-Semitism, and the morality of atomic warfare. Considering his seminal contributions to physics and his strong commitment to writing and speaking about science and religion, it is surprising that no one has previously studied this aspect of his career in detail. Compton wrote a great deal about these topics, and this lengthy article will be published in three parts, continuing in September and ending in December. The opening section follows Compton's family background, education, and early career, emphasizing the strong influence of his father's philosophical and religious views on his attitudes and beliefs, especially on his theology of nature and his understanding of free will.

> Such a solution of the old dilemma of freedom in a world of law means that when the law of causality is replaced by the principle of uncertainty, Socrates' indictment of science as the underminer of morality no longer applies. Man is left by science in control of his own actions within the bounds set by natural law. Moreover, the powerful argument for morality which Pythagoras saw in a world governed by law is emphasized by every advance of science. Instead of removing the foundation of morality, science now presents new reasons why men should discipline their lives, and supplies new means whereby they can make their world more perfect.
>
> –A. H. Compton, 1935[1]

Arthur Holly Compton, the third American to receive the Nobel Prize for physics, was among the most visible public intellectuals of his generation. Author of nearly two hundred scientific papers and review articles and an authoritative textbook on x-rays, he also wrote dozens of essays for the best journals of secular and religious opinion, reviewed important books, and spoke often on the radio.[2] Esteemed by reporters "for his ability to get things said without benefit of polysyllables," he appeared on the cover of *Time* magazine in January 1936, was featured in other major magazines and newspapers, and gave numerous addresses to academics, business organizations, and religious groups—not to mention three books he wrote for the general reader about science, society, and religion.[3]

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Prophet of Science—Part One: Arthur Holly Compton on Science, Freedom, Religion, and Morality

At the height of his scientific career in the early 1930s, Compton used Werner Heisenberg's principle of uncertainty to defend human freedom and responsibility, paralleling the views of Arthur Eddington and Robert Millikan. During World War II, his central role in the Manhattan Project brought him into constant contact with the highest government officials and powerful industrialists, and his postwar position as chancellor of Washington University in St. Louis only enhanced his prestige and widened the audience for his heartfelt pronouncements about morality, education, human dignity, and progress in the atomic age. In all of these activities, Compton sought to bring his religious values to bear on the most pressing problems of the time, while proclaiming his liberal Protestant understanding of God, nature, and humanity to millions of ordinary Americans.

Family Background and Education

Compton belonged to one of the most remarkable families in American history.[4] All three Compton boys—Arthur and his older brothers Karl and Wilson—earned doctorates at Princeton; and all three, together with their sister's husband C. Herbert Rice, served as university presidents at the same time, in the exciting but challenging period following World War II. Education was uppermost in the Compton family, second only to God. It began with Elias Compton, a devout Presbyterian who had graduated first in his class at Wooster University (now the College of Wooster) in 1881, and his Mennonite wife, Otelia Augspurger, who earned the top score on her senior examination on Butler's *Analogy* at the Western Female Seminary (now part of Miami University) at Oxford, Ohio. They were both planning to be missionaries, and Elias was still enrolled at Western Theological Seminary (now Pittsburgh Theological Seminary) when he was unexpectedly asked to return to Wooster in 1883—a sudden illness had left the college in need of someone to teach Latin and English. Having been "providentially brought to Wooster," as he saw it at the time, he stayed for forty-two years, teaching mostly philosophy and psychology and eventually serving as the first academic dean.[5]

Wooster had been founded in 1866 by Ohio Presbyterians as their own coeducational university, and from the start it combined a strong evan-

The Compton family, probably in 1913 or perhaps a bit earlier.
Left to right: Arthur, Mary, Otelia, Wilson, Elias, and Karl.
Courtesy of Arthur Holly Compton Personal Papers, University Archives, Department of Special Collections, Washington University Libraries.

gelical orientation with an open-minded attitude toward science and modern scholarship. This was reflected in its motto, *Scientia et religio ex uno fonte*, science and religion come from a single source—a motto that Arthur Compton liked and attributed to Thomas Aquinas.[6] Wooster's first president, theologian Willis Lord, proclaimed in his inaugural address that the sciences were "the offspring of God" and denied "that the study of the Physical Sciences has any legitimate tendency, antagonistic to moral truth." Evolution had been discussed on campus at least as early as the mid-1870s, but it was probably not viewed too favorably before the 1890s, when Horace Nelson Mateer was lecturing about natural selection and advocating theistic evolution. A physician whom the university recruited in 1886 to teach zoology and geology, Mateer had at first opposed evolution, but the evidence he encountered while preparing his lectures convinced him of its truth. By 1894 his introductory biology course was organized around evolution, and the following year he taught an advanced course on scientific and philosophical aspects of evolution.[7]

Mateer's interpretation of evolution is clearly seen in a talk on "Evolution and Christianity" that he presented to a local reading group in April 1894. Nine months later it was published in *The Post-Graduate and Wooster Quarterly* and issued simultaneously as a pamphlet. Evolution, including human evolution, resulted from "the interaction of certain forces operating in the direction of a progressive change from some unknown primitive condition of things." This was simply "the divine mode of creation whereby God has wrought out the existing order of things through the continuous operation of His creative power." Therefore, he concluded,

> We cease to regard God as sitting idly upon His throne and come to view Him as constantly employing all His powers in the perfection of his works, and thus we come to understand Christ when he said, "My Father worketh hitherto and I work."[8]

Using language that was common among theistic evolutionists of that period (including the specific quotation from John 5:17), Mateer was claiming that evolution was fully consistent with an important element of Christian theology, the immanence of God within the creation. Arthur Compton later held a similar view, and he liked to use the same biblical verse when stating his belief that God used evolution to develop consciousness and responsibility in humans, to the point where we have become God's partners in bringing about God's purposes.[9]

Elias Compton probably did not agree with Mateer's acceptance of evolution at the time, but twenty years later, in 1914, he advanced a similar view himself, in what appears to be a narrative outline of his course on the history of philosophy that was published in *The Bible Magazine*, a short-lived evangelical monthly. "There is no conflict between law and purpose, between uniformity and intelligent will in nature," he proclaimed. "Physical forces are the energy of God. The laws of nature are the habits of God, uniform ways in which He acts." Therefore, "there is no such thing as a self-running nature," and evolution is simply "God's orderly and progressive way of working; and the magnificent product reveals His infinite wisdom and power." Citing *Creative Evolution* (1907) by the great French philosopher Henri Bergson, Elias noted the appearance of something new that cannot be completely explained by prior phenomena, not only "at great exceptional crises, such as the beginnings of life, consciousness, and moral reason, but at every step" of the evolutionary process, and he underscored the reality of divine activity in all of this. "God is in nature, but He is not a prisoner in nature. Evolution is not only His way of working, it is His way of creating."[10] Published just eighteen months after Arthur graduated from Wooster, it is not difficult here to see an important influence of father on son.

Even more significant, however, was Elias Compton's keen, longstanding interest in the interface of philosophy and psychology—an interest shared no less keenly by Arthur. In his valedictory address at Wooster, the young Elias had emphatically rejected psychological determinism and reductionism. He told his classmates,

> The new psychology says that heredity, plus environment, determine the man, thus making him a weather-cock shifting helplessly in the winds of sensibility, a wretched association machine, through which ideas pass, linked together by laws over which the machine has no control.[11]

Elias continued to study the mind/body problem after he returned to Wooster as a faculty member, and at the end of his first year of teaching, Wooster awarded him an M.A.

It was not uncommon then for small colleges like Wooster also to award doctorates, although the work required to earn them does not compare with expectations today. In 1889, the young professor of "mental science" was granted a Ph.D. by Wooster, for a thesis called "Thought Possible without Language." He also spent the summer of 1892 doing graduate work with psychologists G. Stanley Hall and Edmund C. Sanford at Clark University.[12] Elias embraced a philosophical idealism that asserted the fundamental reality of the mind, against the materialism held by most psychologists of the time. His study of William James, for example, led him to conclude that James was "as determined as any Positivist to be rid of the conception of a permanent soul or spirit. He will have psychology a natural science, uncorrupted by metaphysics." This is followed by a significant "Parenthetical query: Why is it unmetaphysical science to assume a substantial material brain, and unscientific metaphysics to assume an abiding spiritual self or soul?"[13] His son would be interested in the same question.

Growing up in such a strongly religious home and respecting his parents as much as he did, Arthur was somewhat hesitant to study science when he was ready for college: he felt instinctively that the mission field was the ideal place for a Compton. But his parents "used the Bible and common sense" to advise their children, and his father had the wisdom and insight to give his blessing. Elias gently told his son that "you can do your best work" in science, and that it "may become a more valuable Christian service than if you were to enter the ministry or become a missionary."[14]

It was obviously the right decision. Before his thirteenth birthday, Arthur had been captivated by the hauntingly beautiful sight of brilliant Sirius close to Orion's belt not long after sunset on a clear winter night. Soon he had purchased a decent telescope from the Sears catalog, constructed a tripod mount, built his own camera, and figured out how to turn an alarm clock into a drive mechanism for the whole apparatus. The hour-long photographs that he made are sufficient proof of his technical ability; a few years later, he used the university's telescope to photograph Halley's comet in May 1910.

The year before the comet appeared, however, sixteen-year-old Arthur had his first three publications, including a letter in *Scientific American*; he published a full article in the same magazine two years later. They all concerned the stability of aeroplanes, a timely subject not six years after the Wright brothers' first flight.[15] He was fascinated by flight, and he wrote from experience: he had built and piloted a glider with a 27-foot wingspan, and he had studied scientific papers by aeronautical pioneer Samuel Pierpont Langley, the recently deceased Secretary of the Smithsonian Institution. But he burned the plane near the end of his first year in college and never again studied aerodynamics with a similar intensity. Arthur recalled many years later,

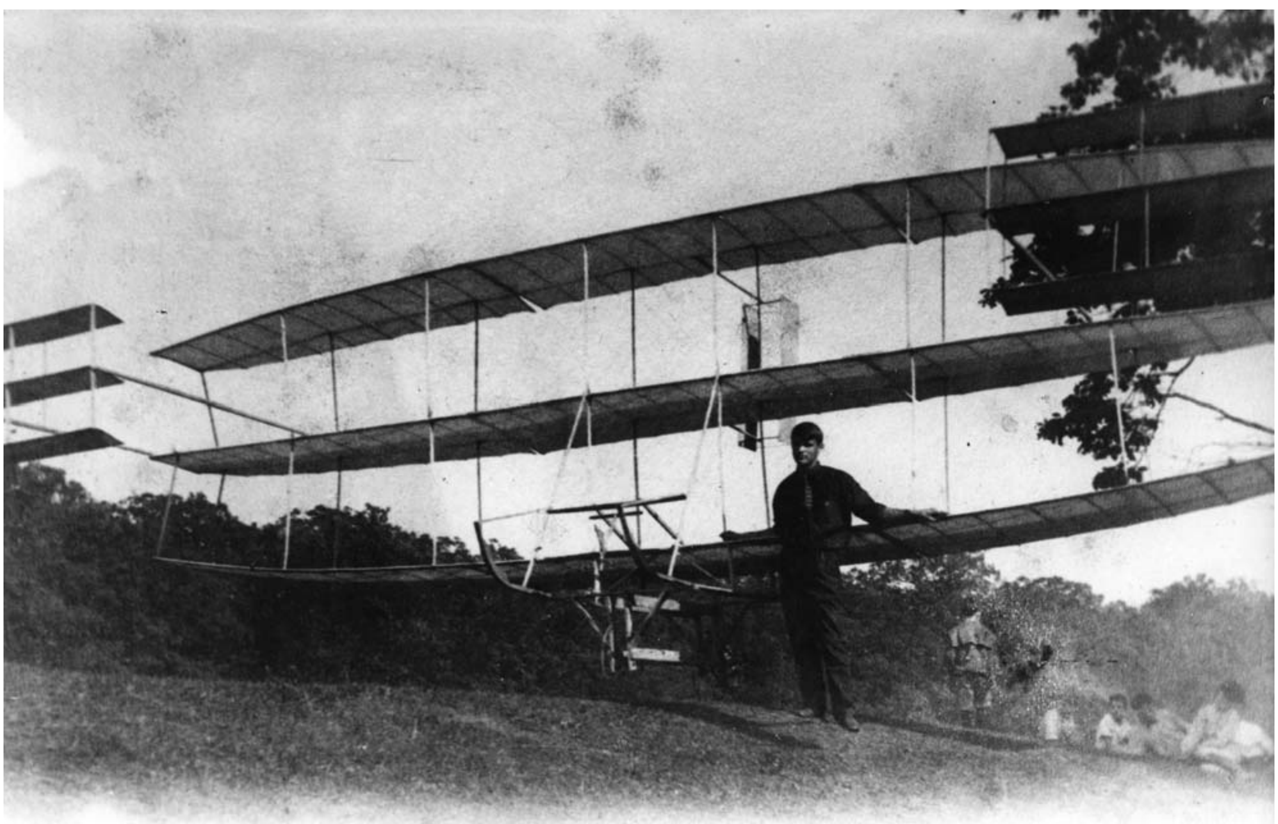
> By the time I reached the age of twenty my interests had become closely confined to research in physics with special regard to the nature of matter and radiation.

Actually he studied as much chemistry as he did physics—but no biology—and it was chemistry professor William Zebina Bennett who had purchased the x-ray equipment that Arthur and his brother Karl used to good effect. In Wooster's alumni magazine a few years earlier, Bennett had pushed the importance of the applied sciences—engineering, architecture, forestry, sanitation, and agriculture—for further progress. Thirteen-year-old Arthur probably resonated with this message. Certainly he read it: his copy, marked to show the passages that caught his attention, survives today among his papers. Mostly he just underlined the occasional word, but two extended passages are delineated in the margins. In one, Bennett advised the young person to consider spending two years at a technical school. The other is about moral character, and in hindsight its significance for Compton is immediately obvious. Character, Bennett said, "is as necessary to success in any line of engineering, as it is in church or Sunday school." The successful person must be trustworthy, and "the world is coming to realize that high moral character, integrity, [and] correct living" garner respect and are commercially valuable. He added,

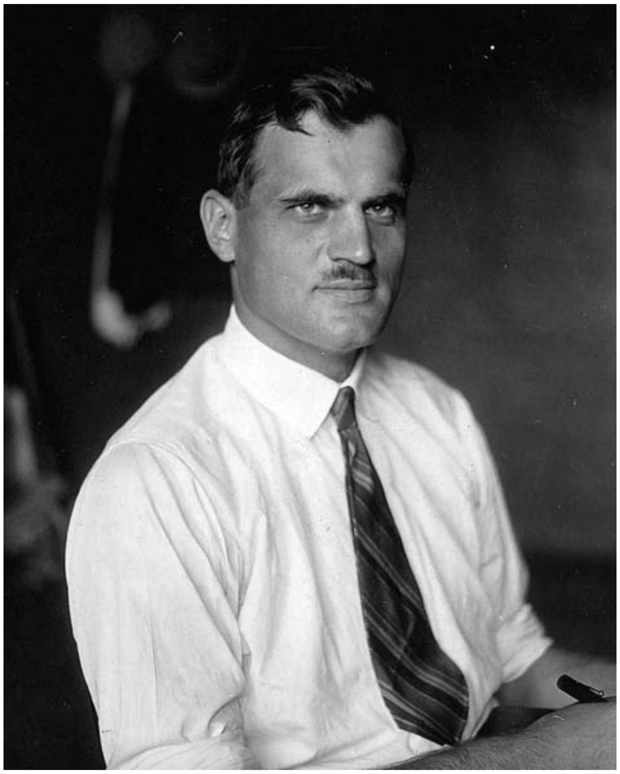
> Develop your character as you develop muscle and intellect, so that you may stand against the manifold temptations which the business world presents. For this end remember that the christian church, the christian school and the christian home are the great agents for the development of such character as the practical engineer will need, and as the successful engineer must have.[16]

In his final year of high school, Arthur had often accompanied Karl to the radiation laboratory—Karl had remained at Wooster to complete a master's degree on the Wehnelt interrupter, part of the electrical equipment needed to operate the x-ray tube. Arthur used the same apparatus for his own experiments about three years later, an experience that "was of substantial help" to him later at Princeton. He also took two years of French, several units of Bible, and a course in apologetics taught by Chalmers Martin, an evangelical Presbyterian who had briefly been a missionary in Laos and had taught Old Testament at Princeton Seminary and Princeton College before joining Wooster's faculty. The text for Martin's course, *The Grounds of Theistic and Christian Belief* (1883) by Yale theologian and church historian George Park Fisher, a former president of the American Historical Association, stressed the reality of miracles and their crucial importance for authenticating Christianity—a position that Arthur certainly did not accept a dozen years later, although I do not know exactly what he thought at the time. Far more influential were six courses in philosophy and psychology—all that Wooster offered, and all probably taught by his father—in which he excelled, earning the philosophy prize; he had a higher grade only in an astronomy course that he took alongside general physics in his junior year.[17]

In class and undoubtedly in numerous informal conversations over many years, Arthur learned his father's views on freedom, dignity, and altruism—and he fully embraced them, from adolescence until death. As valedictorian of the Wooster Preparatory School in 1909, his address on "The Value of a Life" portrayed humanity as sinful creatures, physically insignificant in a vast, impersonal universe. At the same time, we are "a being of infinite possibility," for God has given us "the power to set the law of life in Christ" over "the law of death in sin." Thus, "The only great thing in the world is man, and the only great thing in man is his individual will." Life, Compton told his classmates, "is just what we make it," and "real success" resulted from service



Arthur holding his triplane glider, c. 1909.
Courtesy of Arthur Holly Compton Personal Papers, University Archives, Department of Special Collections, Washington University Libraries.



Arthur Compton,
at an unknown date early in his scientific career.
Courtesy of Special Collections, The College of Wooster Libraries.

to others: "it is he who *gives* the most, not he who *gets* the most, who reaches the highest success."[18]

He reiterated this message in a commencement oration when he graduated third in his college class in June 1913. Using the missionary physician David Livingstone and others as examples of "serving others because of love for their fellowmen," Compton cited the words of Jesus in Matt. 23:11,

> These men and women have heard the message of Him who died to render the greatest of all services to mankind: "He who would be great among you, let him be servant of all."

This contrasted with the pursuit of personal pleasure, which "is as natural as the law of self preservation." Education was the way to instill altruism—especially at the Christian college: "Founded primarily *not* for technical training, but for the building of character, it exists *not* to help its students make a *living* but to help them make a *life*." Such institutions were therefore assets of great value to the nation.[19]

For a more detailed exposition of his views at Wooster, however, I turn to his senior thesis, a remarkable sixteen-page typed essay on God, nature, and humanity that warrants close attention. In the opening paragraph, he announced,

> I feel that unless clearly prevented by logic, I should make my theory of the world agree as far as possible with the principles laid down by the Master Thinker, Jesus Christ.

Then he plunged into a critique of dualism, "the doctrine which I held before I began to study philosophy," according to which "there are in reality two distinct kinds of substances, mind and matter." On this view, God created elementary matter such as electrons "at some definite time" that Compton did not specify. The electrons then "combined and evolved, forming first the chemical elements and chemical compounds, then the stellar universe under the action of gravitation, and finally life was evolved in simple forms." Natural selection "produced all the higher animals and man as we know them." According to Compton, God's role in this picture was only at the beginning "and at such stages as at the beginning of life and the beginning of consciousness where he either inserts a 'new principle,' or starts a 'new force' to work in the universe as it stands."[20]

This was a typical view for theistic evolutionists of the late nineteenth and early twentieth centuries. An influential prototype was (for example) the Scottish philosopher and theologian James McCosh, who had become president of the College of New Jersey (now Princeton University) in 1868, partly owing to his progressive attitude toward modern science. The first theologian in America publicly to support Darwin, McCosh accepted evolution insofar as it was "properly limited and explained."[21] The principal limit to evolution, in McCosh's opinion, was its inability to account for "new powers" such as life, sensation, intelligence, the soul, and morality; these required a vital force of some unspecified type, under divine guidance—thereby preserving a crucial role for God and ensuring human dignity. Compton would shortly contrast this with the view he favored (below).

As for materialism, "which would make mind a direct product in the evolution of matter," Compton held "that there is a very essential difference between mind and matter which makes it impossible that the former should be developed from the latter." As a "free agent," consciousness "is the source of an indefinite amount of spontaneous energy, so that in directing the actions of the body it violates the principle of the conservation of energy on which materialism rests itself." If consciousness were not free, then it would not be able to control our actions and would have "no conceivable use." Such a consciousness could not have developed by evolution. Furthermore, "the universe as we know it is not eternal," Compton added, and "therefore matter must have had a cause to produce it." Applying the second law of thermodynamics, he argued that "the constant dissipation of radiant energy" meant either that "the universe should have long ago cooled to absolute zero," or else that it should at least "be at absolutely uniform temperature throughout. Since neither of these conditions exists, the universe cannot have been eternal."[22]

But dualism did not escape Compton's analysis unscathed. If space is "ontologically real," he argued, then it "must be unlimited and therefore all inclusive, hence [it] must include our souls and God." If God is everywhere, he asked, then "is all of God" or only "a part of Him" in each part of space? Compton was unhappy with the implications of both answers, so for this and other reasons he rejected the idea that space is an ontological reality. Consequently, "dualism in its ordinary sense, that matter is real and spatial and that mind is likewise real and different from matter," had to be given up.[23]

On the dualist view, he reminded himself, it was necessary for God "to intervene by inserting a 'new principle' or starting a 'new force' to work in the universe as it stands." How much "more probable," he suggested, either

> for man to be evolved out of matter without any interference, or that God should be back of the world continually, sustaining it and controlling it in all its development. The first method would be materialism which we have found untenable, while the second, which is personal idealism, seems quite probable.

In addition, "Since God is a spirit, the creation must have been performed in a spiritual manner," and we can understand this only by "analogy with the action of our own minds." But "our minds can produce nothing but thoughts," so "unless God's creation of the world is altogether different from any experiences of ours, it must have been a process analogous to thinking, and matter must be similar to our states of consciousness."[24] Compton therefore felt "compelled to give up both materialism and dualism," turning instead to personal idealism, "the doctrine that mind is the fundamental reality, and that the objective world is a mere product of the activity of the Supreme Mind or Spirit, God."[25]

In his last three paragraphs, Compton advanced the theology of creation that grounded his overall picture of reality, spelling out "what we mean when we say that the world is a product of God's activity …" Just as we cannot conceive "of a thought or volition which exists apart from mental activity," so "we may think of the physical world as being both produced and maintained by God's mental action." Just as we work out our ideas "by means of more elementary ideas," so "we may think of God developing the universe from the elementary electrons through the various stages to man." By "maintaining and controlling the action of certain electrons," he believed, God "has in mind the purpose of developing them into man." On this view, he concluded,

> the difficulties confronting us on the dualistic system with regard to evolution now disappear, for since the development of the world is continually subject to the will of God, the introduction of life and consciousness are no longer mysterious.

Furthermore, "the uniformities of action in nature are easily explained on the supposition that these are uniformities in the way in which God acts." Although he affirmed that God acts freely, at the same time "God the Master Thinker acts uniformly, thus accounting for the laws of nature." Finally, what about immortality? If "we think of it as the final product of the evolution of God's world," and keeping in mind that "the existence of everything depends only upon God's continued care," then immortality seems "more than probable."[26]

By the twenty-first year of his life, then, Compton found his father's philosophy of personal idealism the most convincing way in which to explain both the universe and our own minds. His theology of creation echoed that of Mateer and his father: God acted continually and purposefully, controlling the universe and life as it developed from the original form that God had given it at some point in the distant past—a conception consistent with the orthodox Christian affirmation that God is both immanent within the world and transcendent over it.

Christ represented the supreme example of self-sacrifice, the triumph of spirit over the law of nature. These elements of his faith and the personal idealism he linked them with would have been embraced by several liberal evangelical thinkers of the time, including Borden Parker Browne, George A. Gordon, Francis J. McConnell, and George Albert Coe.[27] I have found no similar documents from the next period of Compton's life.

Fourteen years later, when he was awarded the Nobel Prize in 1927, he and his wife were members of a church whose overall outlook was far more liberal theologically than anything he had experienced in Wooster. Yet while his mature views developed considerably beyond those of his college days, he never completely left them behind.

Physics and the Nobel Prize

Only a few weeks after graduating from Wooster, Arthur published an article about an apparatus he had invented to demonstrate the earth's rotation in *Science*, the leading American scientific journal—a prodigious feat for an undergraduate even then.[28] That fall, he followed his brothers Karl and Wilson to Princeton for graduate work.

The "best scientist" Compton encountered at Princeton was future Nobel laureate Owen Willens Richardson, an Englishman who accepted a professorship at King's College London just a few months after Compton arrived on campus and began working with him. Nevertheless, as his former student Robert Shankland has noted, Compton was the designated beneficiary when Richardson was unable to take his x-ray apparatus with him; they became lifelong friends, and Compton would later spend the summer of 1920 in Richardson's London laboratory. Working as a graduate student under H. Lester Cooke, with active assistance from several other Princeton faculty, Compton completed his dissertation on x-ray diffraction by crystals (this was only shortly after the Braggs pioneered this type of research) in 1916 and published the results a few months later in the *Physical Review*.[29]

Having finished his doctorate, Compton promptly married his Wooster classmate, Betty McCloskey, in a double wedding (Betty's sister was the other bride), with his brother Wilson as best man and his father presiding.[30] He taught physics at the University of Minnesota for only one year before accepting a job in engineering research at the Westinghouse Electric and Manufacturing Company in East Pittsburgh, Pennsylvania. Although he always valued the practical uses to which scientific knowledge could be put—as an undergraduate, he had expected to end up eventually in engineering—he found himself increasingly attracted to pure science. In 1918, in the midst of his work for Westinghouse, he spoke to the Wooster Honors Society on "Our nation's need for scientific research," in which he stressed the importance of pure science as the background for practical applications and something that was "in the long run more useful." It is a worthy goal, he assured the audience, to add something "of eternal material value" to our stock of knowledge. But scientists are usually driven by something more. Most scientific men, he said,

> catch a glimpse of what God was thinking when he planned His world, and they needs must

The first American Nobel laureate for physics, Albert A. Michelson, congratulates the third, Arthur Holly Compton, in the fall of 1927.
Courtesy of John J. Compton

> follow that thought as far as He will permit them. The ambition to know more of the world in which we are placed and to help others to know more of it is the chief source of inspiration for the true man of science. And rightly so. For who can say that the development of a man's spirit in striving to think God's thoughts after Him is not of greater value than the greatest of material blessings?[31]

Thus science, his chosen field of endeavor, was ultimately a spiritual enterprise for Arthur Compton.

During the two years he spent with Westinghouse, Compton first learned about new, unexplained phenomena associated with x-rays.[32] His increasing interest in pure scientific research led him to resign his position at Westinghouse. With the benefit of a fellowship from the National Research Council, the Comptons (with their one-year-old son, Arthur Alan) sailed off to post-war England. Arthur spent much of the next year doing gamma-ray scattering experiments at the Cavendish Laboratory in Cambridge, working with the man whom he regarded as "the greatest of the [Cambridge] physicists," Ernest Rutherford, but he had not lost interest in x-rays. Both are forms of electromagnetic radiation and, as Shankland has emphasized, Compton's work in this period was increasingly focused on "the nature of the basic interaction between radiation and electrons and less concerned with the use of X rays as a tool to determine electron distributions in crystal structures."[33]

On his way back to the United States aboard the RMS *Aquitania* in late summer 1920, Compton envisioned the crucial x-ray scattering experiments that he would carry out in his next academic post, at Washington University in St. Louis.[34] During the next two years he worked on x-rays colliding with electrons, leading him to conclude that x-rays behave like particles in such interactions, for which he shared the Nobel Prize for physics with C. T. R. Wilson in 1927. Thirty years later, Nobel laureate Gerty Cori told him a rumor she had heard several times while working with the National Science Foundation: that he had chosen this particular area "after reading in a survey of physics that the field of x-ray diffraction was a neglected field in this country." Compton's recollection was different. Actually, he replied,

> a survey published by the National Research Council shortly after World War I, and supposed to cover the important fields of physics, did not refer at all to the scattering of x-rays. I myself knew that the field was important and was encouraged by the fact that when an authoritative committee overlooked the field entirely there would be an opportunity for me to get my work well in hand before others crowded into the field. Thus, the report was important to me because of what it failed to say.[35]

Compton himself corrected this omission for the National Research Council. He was added to a committee of its Division of Physical Sciences in 1921, a year after three separate reports on x-ray spectra, written individually by committee members, were published late in 1920, all of which cite papers by Compton, who published his own report on x-ray scattering in October 1922.[36] A year later the great German physicist Arnold Sommerfeld was already referring to "Comptoneffekt," and that autumn Compton succeeded Robert Millikan (who had moved to Caltech the previous fall) as professor of physics at the University of Chicago. The Nobel Prize followed four years later.[37]

Although he began to write and speak much more for the general public after receiving the Nobel Prize, Compton's research activities continued unabated for at least another decade, judging from the steady stream of publications in the best scientific journals that appeared under his name right down to World War II. Apart from further work on x-ray scattering, from the accumulated evidence of many elegant experiments he demonstrated conclusively that cosmic rays are charged particles, contradicting Millikan's vociferously defended opinion that they were gamma rays.

All told, he was a superb experimental physicist who became known for the very active role he took in his laboratory, building his own apparatus, blowing his own glassware, and working closely with his assistants.[38] An indefatigable worker, during the war he took on heavy responsibilities with innumerable interminable meetings at all hours that would have worn down many others—as happened to physicist Samuel K. Allison, who was hospitalized for exhaustion while helping Compton run the Chicago branch of the Manhattan Project.[39]

In late November 1927, about two weeks before he actually received the Nobel Prize in Stockholm, Compton was awarded an honorary doctorate from Wooster at a related celebration. According to Allison, this meant more to him than any other honor, owing to his close ties with Wooster.[40] Elias Compton opened the ceremony with an invocation, in which (among other things) he thanked God

> for the prophets of science, … the seers who add to our knowledge of the world, make possible still further discoveries of truth, enlarge our conception of Thyself, and open the way to more applications of science for human good.[41]

Arthur's activities and writings from this point forward demonstrate that he still shared his father's moral vision of the purpose of science, and soon he would begin sharing it with scientific and lay audiences. Arthur Holly Compton was about to become a prophet of science.

Notes

1Compton, *The Freedom of Man* (New Haven: Yale University Press, 1935), 66.

2Complete lists of his 182 scientific papers are found in *Scientific Papers of Arthur Holly Compton*, ed. Robert S. Shankland (Chicago: The University of Chicago Press, 1973), 763–73, and in *The Cosmos of Arthur Holly Compton*, ed. Marjorie Johnston (New York: Alfred A. Knopf, 1967), 459–68, an excellent anthology cited henceforth simply as *Cosmos*. Many of his other writings are identified below.

3"Cosmic Clearance," *Time* (January 13, 1936): 28.

4No full biography of Compton has yet been written. "Personal Reminiscences," in *Cosmos*, 3–52, is his longest autobiographical statement. His book, *Atomic Quest: A Personal Narrative* (New York: Oxford University Press, 1956), contains some autobiographical passages and is a key source for his religious views. James R. Blackwood, *The House on College Avenue: The Comptons at Wooster, 1891–1913* (Cambridge, MA: The MIT Press, 1968), offers an insightful picture of his immediate family, though little on Arthur himself; Blackwood's essay, "Arthur Compton's Atomic Venture," *American Presbyterians* 66.3 (Fall 1988): 177–93, complements his book nicely. Samuel K. Allison, "Arthur Holly Compton," *Biographical Memoirs of the National Academy of Sciences* 38 (1965): 81–110, surveys his scientific career.

5Quoted in Blackwood, *The House on College Avenue*, 16. On Elias Compton's career at Wooster, see "The Compton Collection," http://library.wooster.edu/services/spc/compton.php (accessed 15 January 2008).

6Compton, "The Effect of Social Influences on Physical Science," in *Cosmos*, 81–100, on 93.

7Lucy Lilian Notestein, *Wooster of the Middle West*, 2 vols. (Kent, OH: The Kent State University Press, 1971), 1.39–40, 45, 120, 143–4, and 184–5. Mateer was still teaching evolution in 1922, when Presbyterian layman William Jennings Bryan spoke at Wooster and subsequently tried to halt denominational funding of the college; ibid., 2.265–8, and L. Gordon Tait, "Evolution: Wishart, Wooster, and William Jennings Bryan," *Journal of Presbyterian History* 62 (Winter 1984): 306–21. Further details about Mateer's courses are in Mark A. Wilson, "Our Origins of Scientific Thought," *Wooster* (Fall 2002): 14–16. For an interesting overview of religion and science at Wooster and other Ohio colleges in the early twentieth century, see Sherman B. Barnes, "Learning and Piety in Ohio Colleges, 1900–1930," *The Ohio Historical Quarterly* 70 (January 1961): 214–43.

8Horace Nelson Mateer, *Evolution and Christianity* (Wooster: The Herald Printing Co., 1895), reprinted in 1908. Quotations from Mateer's article and pamphlet are taken from Wilson, "Our Origins of Scientific Thought," 16; cf. Tait, "Evolution," 310.

9For example, *The Religion of a Scientist* (New York: Jewish Theological Seminary of America, 1938), 28; "A Modern Concept of God," in *Man's Destiny in Eternity: The Garvin Lectures* (Boston: Beacon Press, 1949), 3–20, on 19; *The Freedom of Man*, 2; *The Human Meaning of Science* (Chapel Hill: The University of North Carolina Press, 1940), x, 30 and 88; and "The Moral Meaning of the Atomic Bomb," in *Toward a Better World*, ed. William Scarlett (Philadelphia: The John C. Winston Company, 1946), 157–74, on 174. He quoted the verse again to conclude his inauguration address as chancellor of Washington University in February 1946; see "Compton Asserts Faith," *The Christian Century* 63 (March 20, 1946): 379.

10Elias Compton, "A Short History of Philosophy," *The Bible Magazine* 2.12 (December 1914): 1069–1130, on 1122–4.

11Quoted in Blackwood, *The House on College Avenue*, 14.

12Information about his doctorate is from Compton Collection, Special Collections, The College of Wooster Libraries, folder on "Compton, Elias—Programs—1889 June 18." Denise Monbarren found this on my behalf. On his work at Clark University, see Blackwood, *The House on College Avenue*, 29–30.

13Elias Compton, "What Is the Thinker?" *Transactions* (1910): 51–9, quoted in Barnes, "Learning and Piety in Ohio Colleges," 220.

14"Cosmic Clearance," *Time* (January 13, 1936): 32; Milton S. Mayer, "Mother of Comptons," *Scientific Monthly* 47.5 (November 1938): 458–61, on 459; Compton, "Personal Reminiscences," 16. For a slightly different version of Elias' words of advice, see *Atomic Quest*, 206–7.

15"A Criticism of Mr. C. W. Williams's Article, 'Concerning Aeroplanes,'" *Fly* 1 (February 1909): 13; "Comparison of Wright and Voisin Aeroplanes," *Scientific American* 100 (February 1909): 135; "Striving for Perfect Machine," *Aeronautics* 5 (August 1909): 58ff; and "Aeroplane Stability," *Scientific American Supplement* 72 (August 1911): 100–2.

16Compton, "Personal Reminiscences," 16; W. Z. Bennett, "The Call of Science, or the New Learned Profession," *The Wooster Quarterly* no. 77 (October 1905): 1–14, quoting 11–12 in the marked copy from Arthur Holly Compton Personal Papers, University Archives, Department of Special Collections, Washington University Libraries, series 1, box 1. Further references to this collection are given as AHC Papers. On Bennett, see Notestein, *Wooster of the Middle West*, 1.107–8 and 171–3. I am grateful to Suzanne Bates, Registrar, The College of Wooster, for information about Arthur's course of study.

[17]Compton, "Personal Reminiscences," 17, and note 42:8 on 427. Elaine Smith Snyder, Special Collections Associate at The College of Wooster Libraries, provided information about Elias Compton's teaching load and the content of Martin's course. On Martin, author of *Apostolic and Modern Missions* (New York: Fleming H. Revell, 1898), see Herbert R. Swanson, "Prelude to Irony: The Princeton Theology and the Practice of American Presbyterian Missions in Northern Siam, 1867–1880," doctoral dissertation at The Melbourne College of Divinity, 2003, available at www.herbswanson.com/thesis_irony/thesis.php (accessed October 1, 2007). On Fisher, see *American National Biography,* s.v. "Fisher, George Park."

[18] "The Value of a Life," AHC Papers, series 1, box 1, folder 4, his underlining. John J. Compton shares my view of his grandfather's substantive, ongoing influence on his father.

[19]"The Purpose of the Christian College," AHC Papers, series 1, box 1, folder 4, his emphasis.

[20]"My Philosophy: A Thesis Showing the Comparative Merits of Dualism, Materialism and Personalism," AHC Papers, series 1, box 1, folder 4, dated March 29, 1913, 1–2.

[21]James McCosh, *The Religious Aspect of Evolution*, rev. ed. (New York: Charles Scribner's Sons, 1890), x, quoted by James R. Moore, *The Post-Darwinian Controversies: A Study of the Protestant Struggle to Come to Terms with Darwin in Great Britain and America, 1870–1900* (Cambridge: Cambridge University Press, 1979), 246. I rely here on Moore's analysis of McCosh's views.

[22]"My Philosophy: A Thesis Showing the Comparative Merits of Dualism, Materialism and Personalism," 2–3.

[23]Ibid., 6–8.

[24]Ibid., 10–12.

[25]Ibid., 12–13.

[26]Ibid., 14–16.

[27]I am indebted to Jon H. Roberts for suggesting these specific names.

[28]Compton, "A Laboratory Method of Demonstrating the Earth's Rotation," *Science* 37 (May 23, 1913): 803–6.

[29]Compton, "Personal Reminiscences," 17. For Shankland's study of the relationship between Compton and Richardson, see *Scientific Papers of Arthur Holly Compton*, 751–5. I have also benefitted from Shankland's summary of Compton's early career, on xiii–xxix.

[30]Compton listed details of his family history in an outline dated March 26, 1952, which he sent to his secretary Marjorie Johnson and to his son John J. Compton, AHC Papers, series 3, box 15, folder "Personal."

[31]"Our nation's need for scientific research," holograph essay in a blue book, AHC Papers, series 1, box 1, folder 4. An edited version is found in *Cosmos*, 239–42. I quote the holograph version, corresponding to passages on 240 and 242 in the published version.

[32]George W. Gray, "Compton Sees a New Epoch in Science," *New York Times* (March 13, 1932): 20. Compton told Gray that his interest in x-rays was piqued by reading a paper by an unnamed British scientist at the end of World War I.

[33]Compton, "Personal Reminiscences," 29; Shankland, *Scientific Papers of Arthur Holly Compton*, xvii–xviii.

[34]"Problems to be tackled at Saint Louis," photocopy of incomplete manuscript (missing pages 3 to 9), ACH Papers, series 3, box 1, folder "1921–1922." Roger H. Stuewer draws attention to this in *The Compton Effect: Turning Point in Physics* (New York: Science History Publications, 1975), 160–3.

[35]Cori to Compton, June 2, 1952, and Compton to Cori, June 6, 1952, AHC Papers, series 3, box 15, folder "Personal."

[36]William Duane, "Data Relating to X-ray Spectra," *Bulletin of the National Research Council* 1.6 (November 1920): 383–408; Bergen Davis, "Intensity of Emission of X-rays and Their Reflection from Crystals," *Bulletin of the National Research Council* 1.7 (December 1920): 409–26; and David Locke Webster, "Problems of X-ray Emission," *Bulletin of the National Research Council* 1.7 (December 1920): 427–55; Compton, "Secondary Radiations Produced by X-rays, and Some of Their Applications to Physical Problems," *Bulletin of the National Research Council* 4.2 (October 1922): 1–56, quoting 1. Compton chaired this committee from 1923–1925, according to the information in *American Men of Science*, ed. J. McKeen Cattell and Jacques Cattell, 5th ed. (New York: The Science Press, 1933), 221.

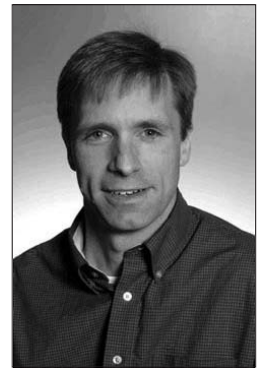
[37]Sommerfeld to Compton, October 23, 1923, AHC Papers, series 3, box 1, folder "1914–1930"; Stuewer, *Compton Effect,* reproduces the original letter with a translation on 247–9. Stuewer argues (pp. 217–8) that Compton was led to his discovery as a consequence of his own evolving experiments and theoretical insights over the preceding six years and not because he was directly influenced by Einstein's light-quantum hypothesis. Indeed, as one support for his claim, Stuewer points out that Compton did not cite Einstein's paper in his own paper of 1923, nor did he even mention Einstein's name in it. Robert S. Shankland points out that Karl Compton's dissertation was based on experiments on the photoelectric effect, but, as Stuewer notes, like his advisor Richardson he did not accept Einstein's light-quantum hypothesis. Shankland agrees that Arthur Compton probably arrived at his conclusions "by a different route, namely, from the classical electrodynamics that he had learned so thoroughly at Princeton …" *Scientific Papers of Arthur Holly Compton*, xix.

[38]"Cosmic Clearance," *Time* (January 13, 1936): 32.

[39]Samuel K. Allison, "Arthur Holly Compton, Research Physicist," *Science* 138 (November 16, 1962): 796.

[40]Ibid., 797.

[41]Elias Compton, "Invocation," in Compton Collection, box 1c, "AHC—Prayers [about] 1927 Nov 28?" Courtesy of Special Collections, The College of Wooster Libraries.


Matthew Kuperus Heun

Campus Carbon Neutrality as an Interdisciplinary Pedagogical Tool

Matthew Kuperus Heun, David Warners, and Henry E. DeVries II

Climate change caused by global warming provided a compelling context to engage engineering and ecology students in a semester-long, interdisciplinary, service-learning activity. We addressed three levels of inquiry throughout the semester: global, institutional, and personal. At the global level of inquiry, traditional classroom lectures and discussions reviewed climate change science and the role of energy systems in climate change policy. At the institutional level of inquiry, students were collectively asked the simple question, "What would it take to make our campus carbon neutral?" The students' response, a detailed final report entitled "The Calvin College Carbon Neutrality Project," was presented in a public seminar with several administration members in attendance. At the personal level of inquiry, students (and faculty) participated in a Carbon Emissions Trading Simulation. Participants were allocated carbon credits for personal carbon-emitting behaviors that were bought and sold in a simulated market. Our efforts benefitted considerably from the involvement of the Vice President for Administration, Finance, and Information Technology, who acted as the customer for the Calvin College Carbon Neutrality project and as the government in the Carbon Emissions Trading Simulation. We realized numerous pedagogical, social, and institutional benefits from this initiative. We believe that interdisciplinary, service-learning experiences as described here provide invaluable tools for preparing today's students to meaningfully address the significant global, institutional, and personal environmental challenges that lie ahead.

Climate change due to global warming is becoming increasingly important to our world, educational and business institutions, and individuals. Recent reports by the United Nations Intergovernmental Panel on Climate Change[1] indicate that the ever-increasing concentration of greenhouse gasses (GHGs) in earth's atmosphere[2] prevents heat from escaping and warms the planet. Climate change due to global warming is an issue with scientific, environmental, economic, development, and political dimensions.[3] Because the major contributing greenhouse gas, carbon dioxide (CO_2), is emitted by fossil fuel combustion when creating electrical and thermal energy for daily living, there are direct links between global warming and the activities of individuals, institu-

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David P. Warners

tions, and nations. (Even if readers consider anthropogenically-caused climate change to be dubious, taking precautionary actions to temper its significant outcomes is the most prudent response.[4])

Net (i.e., emissions less sequestration) CO_2 emissions (or CO_2 equivalent emissions) are fast becoming a proxy for the overall environmental impact of an individual or an organization. Sequestration may be accomplished by planting additional trees or by purchasing emission credits associated with GHG emission reduction or sequestration projects elsewhere. An organization is said to be "carbon neutral" when its CO_2 emissions are equal to its CO_2 sequestration capacity.

Although global warming has become contested territory in public discourse, we believe that the biblical mandate to be stewards of creation provides Christians with the responsibility to seriously consider the scientific evidence and alter behavior to better care for the natural world.[5] An understanding of the deep love our Creator has for the entire cosmos (John 3:16), as well as the mutual interdependency of human and nonhuman flourishing, lead us to believe that the creation has intrinsic, not just instrumental value.

By assigning the Calvin College Carbon Neutrality (CCCN) project and by participating in the Carbon Emissions Trading Simulation (CETS), we sought to engage students in a relevant topic and to cultivate their creation care ethic by developing a deeper understanding of how institutional and personal behaviors contribute to global warming. We did this by asking the simple question, "*What would it take to make our campus carbon neutral?*" (While CO_2 is not the only greenhouse gas, our efforts focused on CO_2 because it is the major contributing greenhouse gas of our college campus.) This was a grass-roots, bottom-up effort by a pair of individual faculty members, not a top-down directive from college administration. As such, it is consistent with a campus culture that encourages faith-based academic service-learning using the institution itself as an educational tool.

David P. Warners *grew up in Grand Rapids, Michigan, and attended Calvin College as an undergraduate student, where he graduated with a major in biology and chemistry in 1985. Dave earned a Masters degree in environmental studies from the University of Wisconsin-Madison and a PhD in botany from the University of Michigan. Between degrees Dave and his wife Teri lived and worked for the Christian Reformed World Relief Committee in Tanzania from 1990–1992. He has been teaching botany and ecology courses at Calvin College since 1997. Dave's research/scholarship interests include restoration ecology, plant systematics, academically-based service learning and Christian environmentalism. Dave enjoys a variety of outdoor activities with Teri and their three children, including camping and gardening. Dave can be contacted at dwarners@calvin.edu.*

Goals

Teaching climate change in a traditional lecture-style classroom format can accomplish several educational objectives. However, the approach we chose allowed us to engage educational objectives unattainable in a traditional classroom. The outcomes we hoped for were beyond academic; we wanted this project to cause our students to see the world, to understand their place within the world, and to think about their future with a more informed mindfulness. We wanted our students to understand this issue in a participatory manner, most importantly because global climate change is a real-life, real-time issue in which they are actual participants. To accomplish these objectives we designed the learning to proceed in an experiential fashion—we wanted our students to familiarize themselves with the concepts and terminology of climate change, learn to appreciate the complexity of this topic, and begin to appreciate the momentous challenge of living carbon-neutral lives.

Our goal was to accomplish these objectives at three levels of inquiry—personal, institutional and global. A significant obstacle for engaging individuals in a topic as broad as climate change is to convict them of their complicity. Focusing our students to think about carbon neutrality on their own campus and in their own lives brings the global issue much closer to home. To do this we had them participate in a Carbon Emissions Trading Simulation (CETS, see p. 92). In recognition of the multidisciplinary nature of climate change, a final goal of this effort was to require students to work in groups of mixed disciplines. For climate change to be meaningfully addressed, a wide variety of interest groups and expertise must come together. The best way for our students to understand the importance and difficulty of such a venture is to provide them with an arena in which they themselves can experience the dynamics, difficulties, and rewards associated with interdisciplinary collaboration.

Project Structure

Achieving carbon neutrality requires assessment of both CO_2 emissions and CO_2 sequestration as a first step. Carbon neutrality provides a rich environment for interdisciplinary learning where, in our situation, engineers could assess emissions and biologists could assess sequestration. To achieve this interdisciplinary learning environment, two upper-level classes, one an engineering class and the other a plant ecology class, participated in the project.

In recent years, the fourth-year Design of Thermal Systems class has utilized a dual-track teaching approach. The first track contains traditional engineering thermodynamics and system design material focused on electricity production from fossil fuel sources. The second track utilizes academically based service-learning group projects covering renewable energy and energy efficiency topics. Each of the past projects[6] for this course had been integrated into the Calvin Environmental Assessment Program (CEAP), a loosely organized faculty group committed to implementing service-learning projects in science classes. The carbon neutrality project was a natural outgrowth of previous engineering class projects and fit well within CEAP.

Investigations in Plant Ecology is a research-focused class for undergraduate junior- and senior-level biology majors. This course is generally taught in the style of a graduate-level seminar, where students lead discussions on papers from the primary literature and also carry out their own scientific experiments. Since the approach of this biology course has always been student led, it fit well into our overall objectives for the carbon neutrality effort.

Semester Schedule

Schedules were arranged so that the two classes overlapped for one hour each week. For these joint sessions, all of the students, both faculty, and the Vice President for Administration, Finance, and Information Technology met together. During the first of these joint meetings, students identified topical groups needed to accomplish this project, after which we assigned students into groups based upon student preference, past academic performance, and background experiences. Each group was composed of at least one engineering student and at least one biology student. As added motivation, students were scheduled to present their findings at a public seminar at the end of the semester.

Henry E. DeVries II

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Administration Involvement

Administrative support was essential for the success of the CCCN project as students navigated the political and financial landscape of the college. The Vice President for Administration, Finance, and Information Technology (Henry DeVries) was an eager participant in the CCCN project. He provided feedback during student presentations and became an information resource for participants. At the vice president's direction, members of the college's physical plant led student tours of facilities, answered questions about operations at the college, and provided current and historical data to the students. Several of the administrative and physical plant personnel who supported CCCN became interested in the project and attended student briefings.

Summary of Pedagogical Approach

We utilized three classroom activities to address the three levels of inquiry (Figure 1). Arrows point away from classroom activities toward project elements addressed by those activities. Traditional lectures allowed us to focus on global issues {A}; a Calvin College Carbon Neutrality (CCCN) project allowed us to address institutional issues primarily {C} and global issues secondarily {B}; a Carbon Emissions Trading Simulation (CETS) allowed us to address the personal level of inquiry primarily {E} and the global level secondarily {D}. In addition, the CCCN project and the CETS informed each other {F} and {G}. Figure 1 provides the framework for the remainder of this paper.

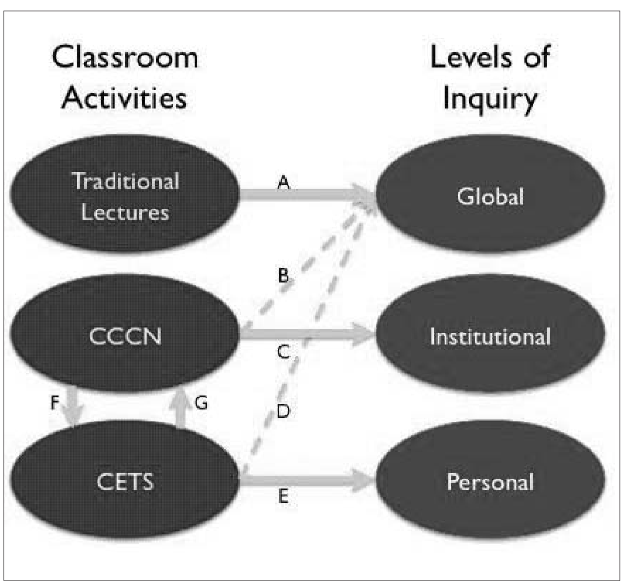

Figure 1. Interactions among project elements. Letters in braces {} in the text refer to labeled arrows on this figure. For example, {A} refers to the arrow from "Traditional Lectures" to "Global."

Traditional Lectures {A}

Traditional lectures in the engineering class focus on advanced heat transfer, thermodynamics, and fluid flow topics. Availability (exergy), combustion, optimization, and economic analysis techniques are employed to evaluate and design a natural-gas–fired co-generation power plant that makes two useful products: electricity and steam. Although natural-gas combustion emits less CO_2 than coal combustion per kW-hr of electricity produced, such plants do contribute to global warming and thus to climate change. And, it is imperative for students to have the tools to assess the contribution of these plants to climate change.

For the traditional biology class time, students began the semester with a brainstorming session, in which they raised questions about global climate change. The questions were then arranged into topical groups (e.g., scientific evidence, climate models, predicted outcomes, human rights, etc.) from which we designed a semester-long discussion schedule.[7] Students took turns identifying specific topical articles for the class to read and led discussions based on the readings they had selected. In this way, all the questions students had identified at the outset of the semester were researched and discussed by the end of the semester.

Calvin College Carbon Neutrality (CCCN) Project {B}, {C}, {F}

Group Assignment Process

After an introductory lecture, students defined an initial list of groups necessary for the project to be successful and identified the group in which they would like to work. The groups were required to be aligned with our college's Statement on Sustainability,[8] a document that outlines thirteen categories for campus sustainability. The students formed five groups covering the following topics:

- Energy Use and Purchase
- Land Use and Waste Water Management
- Recycling and Solid Waste Management
- Construction and Renovation
- Transportation

Professors assigned students to these groups using criteria described in "Semester Schedule" (p. 87).

Group Weekly Meeting

Each group began their work by generating an estimate of how much their particular category contributed to the overall carbon emissions of the campus. After the initial oral progress reports, it was clear that some activities contributed far more to the campus carbon footprint than others. Because emissions contributed by Land Use/Waste Water Management and Recycling/Solid Waste Management were so small, these two groups were reconstituted into a Finance group midway through the semester.

During the semester, groups shifted from assessing the amount of emissions generated by their category to brainstorming solutions for decreasing these emissions. The Finance group served as a filtering reality check on the proposed solutions and selected projects that were both feasible and marketable to be included in the final report. Once these had been selected, the Finance group generated a financial plan, taking into account inflation, the time-value of money, and the college's total budget.

Group Reporting

Weekly combined class meetings provided students with structured time to work together in their groups, with faculty available for guidance. Every third week was reserved for oral progress reports. These proved to be critical times of trying out ideas, coordinating reporting formats among groups, identifying areas that needed further work, and honing public speaking skills. The Vice President for Administration, Finance, and Information Technology provided key input at these times, input that provided a level of project authenticity for the students. Because the final report was to be formally submitted to this administrator, his consistent input gave assurance that the project would provide meaningful information for future college decision making.

After the first oral progress report, students identified a need to better coordinate the work of the various groups, so they formed an executive committee composed of one member from each of the study groups. This executive committee met at least once a week over the duration of the semester and was integral to synthesizing the individual group efforts into a cohesive, integrated product at the end of the semester.

The five individuals (three engineering students and two biology students) from the executive committee produced a presentation for the public seminar. In addition to over one hundred students and professors, the end-of-semester seminar was attended by the college president, the college architect, sustainability directors from two other local colleges, and the sustainability coordinator for the city of Grand Rapids. The students received high praise, including a personal letter of thanks from the mayor of Grand Rapids.

Results

There were two significant results from the CCCN project, the first-ever assessment of our campus carbon footprint and a carbon neutrality action plan.

Campus Carbon Footprint

In assessing the carbon footprint of the college, students were assisted by Physical Plant personnel who provided access to historical utility (both electricity and natural gas) and gasoline purchase records. These purchases were then converted to equivalent CO_2 emissions based on the mix of source fuels in our area (nuclear vs. coal, for example) and their conversion efficiency.

There was substantial debate about whether to count student and professor commuter traffic as contributing to college CO_2 emissions. Some argued that the college does not pay for commuters' fuel, so the college should not be responsible for commuters' emissions. Others held that the college should be accountable for commuters' emissions, because it can influence commuting patterns by providing incentives and disincentives that would reduce commuting emissions. Example actions include subsidizing bus riding, rewarding bike riding, providing financial benefits for living closer to campus, and causing commuters to pay the true cost for building and maintaining parking lots. In the end, students did include commuter emissions in the college's carbon footprint.

The students' analysis of carbon emissions revealed that the biggest contributors are building energy use and transportation (Figure 2). Electricity demand causes more emissions than space heating. And, commuting composes the bulk of our transportation emissions. The "other" category is a minor contributor and includes land maintenance, construction, and waste.

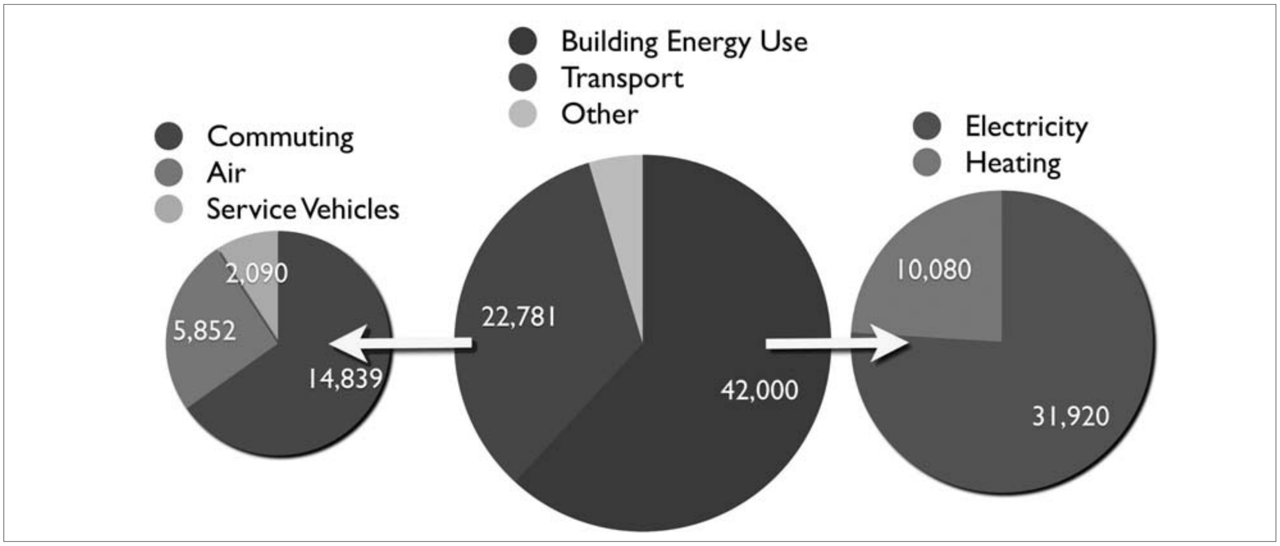

Figure 2. Campus CO_2 emissions (in metric tons of CO_2 emitted per year).

In terms of sequestration, the CCCN project students were assisted greatly by a previous study[9] of the carbon sequestration potential of land owned by the institution. Students refined the results of the previous study and reported the sequestration potential of various vegetation types for our campus (Figure 3).

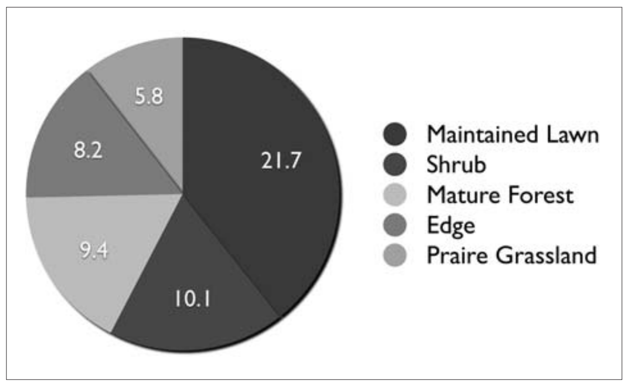

Figure 3. Campus sequestration (in metric tons of CO_2 sequestered per year).

A comparison of the carbon emissions and sequestration for our campus, based on the students' data, was alarming (Figure 4). This evaluation made it clear that increasing sequestration on campus is not a reasonable means of achieving carbon neutrality. Doing so would require a 1235-fold increase in sequestration to neutralize campus

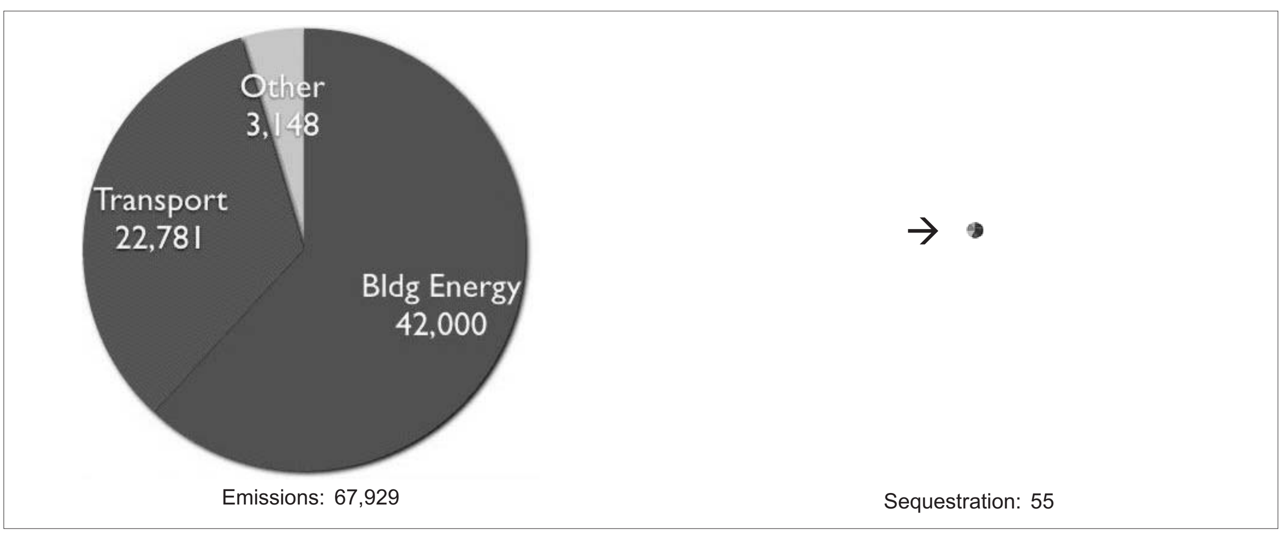

Figure 4. Comparison of CO_2 emissions and sequestration (in metric tons of CO_2/year). Area of pie charts is in relative proportion to CO_2 emissions and sequestration. Sequestration indicated by arrow.

emissions—not remotely feasible in today's world. Thus, the best option for achieving carbon neutrality is reducing CO_2 emissions.

Carbon Neutrality Action Plan

Guided by the results from the campus carbon footprint, students began work on a carbon neutrality plan. The first step was brainstorming a list of options for reducing CO_2 emissions. Table 1 shows a selection of the reduction options developed by the students.

The students developed an evaluation metric for the options: the ratio of dollars spent per emissions reduction. So, for example, a monthly electric vehicle gift to students has a very high ratio of cost to emissions reduction. Ideas at the top of the table are very cost-ineffective ways to reduce CO_2 emissions. In the second row from the bottom, reducing winter building temperatures is economically beneficial for the college due to reduced natural gas purchases. And, the bottom row indicates that enforcing daily "pay as you park" fees with higher parking rates will both provide a disincentive for driving to campus and be revenue-positive for the college.

The students proposed a phased plan wherein the college would slowly move up the table. The first step would be to generate revenue from the temperature drop and parking fees in the short term (10 years or so). These revenues would be saved in a carbon neutrality fund. After a decade or so, the college would purchase land in a suitable location and install renewable energy production machines (wind turbines) to further reduce campus CO_2 emissions. The fund balance would continue to grow over time, because cost savings from electricity that the college would no longer purchase would be reinvested in the fund. In future years, additional turbines could be purchased. The students developed cash flow and carbon emissions diagrams for their plan.

How CCCN Informed CETS {F}

Information gathered for CCCN about CO_2 emission and sequestration rates was essential for determining the campus carbon footprint. We required that the students use the emissions rates to move the Carbon Emissions Trading Simulation (p. 92) accounting system from an activity basis to a mass basis {F}. This assignment ensured that the students utilized (again) the information that they were gathering for the CCCN project.

Table 1. Table of a Selection of the CO_2 Emissions Reduction Options Studied

	Carbon Reduction [MTCe/year]	Cost [$]	Ratio [$/(MTCe/year)]
Monthly EV gift for students	1.25	$240,000.00	$17,454.55
Campus safety in EVs	0.96	$80,000.00	$7,575.76
College-owned bikes	1.258	$3,000.00	$2,385.38
Adding Lake Drive bike lane and path	14.93	$21,000.00	$1,407.00
Full Rapid subsidization	264	$94,492.00	$358.53
Renewable energy production	5548	$820,000.00	$76.00
Green energy purchase*	-19571	$724,000.00	$37.00
Carbon offset purchase	∞		$9.00
Temperature drop	3555	($172,000.00)	($48.00)
Daily commuter fees with increased rates	678	($83,000.00)	($122.58)

* Green energy is not completely carbon free

("EV" is an abbreviation for "electric vehicle," Lake Drive is a road on which many commuters travel to campus, the "Rapid" is the local bus service, and "Temperature Drop" refers to reducing the temperature of campus buildings in the winter by 3 °F.)

How CCCN Informed the Campus Community {C}

The first way in which the CCCN project informed the campus community was administratively. The Vice President for Administration, Finance, and Information Technology attended all the oral presentations and received a copy of the final written report. His active participation supplied meaningful direction to student efforts and kept things focused on the educational, administrative, and financial impacts of moving toward carbon neutrality.

Beyond this formal administrative impact, the project added momentum to campus conversations about sustainability that were underway long before the Fall 2007 semester. Results of the CCCN project were presented at the Fall 2007 Calvin Environmental Assessment Program (CEAP) poster session, where other administration personnel and faculty members became aware of the results of the student project.

Assigning this project in the Fall of 2007 with final presentation occurring in early December 2007 offered a primer for the campus community before our Focus the Nation[10] activities (January 2008). Building upon the momentum from Focus the Nation, consensus arose that a good next step would be to institutionalize campus-wide commitments to creation care and sustainability. So, in April 2008, the faculty Environmental Stewardship Committee (ESC) presented a proposal to the college administration, suggesting a two-year trial of a Sustainability Director who would coordinate the many sustainability activities on campus. In the summer of 2008 (after the Sustainability Summit—see below), the provost awarded teaching release time to a faculty member for sustainability work on campus.

Given the overwhelming interest in Focus the Nation events on campus, several faculty members organized a follow-on Sustainability Summit[11] for faculty, staff, and administration in May 2008. At the summit, small groups discussed Calvin's Statement on Sustainability,[12] shared ongoing efforts toward sustainability within existing campus administrative units, and developed nonbinding sustainability action plans. Several concrete action plans were developed during the summit. Some items on those plans included (1) creating a bike path along Lake Drive (now in planning discussions with the bordering municipality); (2) requesting that the college president attend the President's Climate Commitment Conference (which he did); and (3) improving utility metering for campus buildings (now in process).

While it is difficult to directly link the carbon neutrality project to advances in campus sustainability, this effort certainly was a contributing factor, and it provided significant continuing momentum for ongoing campus conversations. The project was recognized and valued by other local colleges as well as city officials. This work, together with the various initiatives that have been spawned in its wake, have given our college increased credibility in the broader sustainability dialogue in our region.

Carbon Emissions Trading Simulation (CETS) {D}, {E}, and {G}

Two-step Process

The Carbon Emissions Trading Simulation (CETS) was intended to provide a kind of "carbon lens" through which students could recognize their daily complicity in global climate change {E}. We also hoped this activity would help students better understand the dynamics of carbon markets and carbon trading {D}. The simulations began with each student given an allotment of carbon credits and a set of daily activities with associated carbon credit costs (p. 93) to be used over the duration of the simulation. Whenever students engaged in an activity, they were required to retire the associated carbon credits from their total. Participants who retired all of their carbon credits before the end of the simulation were required to purchase credits (with real US dollars) from participants who maintained a surplus. Carbon credit pricing was never explicitly set; instead we allowed our simulated markets to determine the credit price. At the end of both market simulations, participants who made the most money submitted their profits to finance a pizza lunch.

Carbon Credit Tables

The market for CETS version 1 (v1) was based on a cap-and-trade system using allowance-based transactions among students and faculty.[13] Each participant was assigned 110 carbon credits[14] on the first day of the simulation. (Credits were manifested as Monopoly® money dollars, i.e., 110 carbon credits = 110 Monopoly® dollars.) During the first version of the simulation (two weeks), carbon emission credits were activity-based rather than mass-based (Table 2).

Table 2. Carbon Credit Equivalence of Market Participant Activities (CETS v1)

Credits	Activity
2	Ride in a car on a one-way trip anywhere: to campus, to the store, home, etc. (Two people the same car retires one credit per person.)
1	Watch TV for an hour. (Two people watching the same TV retires 0.5 credits per person.)
6	Operate air-conditioning in your house for a day. (No pro-rating for housemates.)
4	Operate the furnace in your house for a day. (No pro-rating for housemates.)
1	Eat a piece of fruit grown outside Michigan.
1	Use or leave a computer on for 2 hours.

CETS version 2 (v2) was designed by students to be a mass-based simulation (Table 3) and therefore closer to how real carbon markets[15] operate. One carbon credit was roughly equivalent to one-half pound of CO_2 emitted. For CETS v2, each participant was given 1600 carbon credits at the outset of a six-week simulation. Carbon credits were assessed according to the table below. Note that two activities allow students to add carbon credits to their account.

Market Tracking Systems

Keeping track of every student's carbon-emitting activities each day was a significant challenge. For CETS v1 we had students fill out a report slip and turn it in each morning, detailing the carbon cost of the previous day's activities. Our administrative assistant constructed a large class database on which she daily kept track of all the individual student accounts. This system was greatly improved by implementing a Google Docs automatic tracking system for the second version of the simulation. Accounting through the Google Docs website allowed students to not only see their own carbon account, but they could also access an updated summary of the overall market of carbon credit behavior for the class (number of credits retired, earned, or traded). This second accounting system, which the students themselves devised, proved to be a significant improvement over the original tallying method.

Individual Behavior Implications {E}

We guided discussions throughout the semester to reinforce two key notions: (1) humans count what they value and value what they count and (2) accounting systems change behavior. Regarding counting things of value, because of the visibility of the Monopoly® money, CETS v1 created a bit of a buzz on campus, and many nonparticipants were discussing the simulation. The play money was a visible signal that something of value was being counted. Market participants noted that the simulation caused some inconvenience, as (a) they were required to monitor their own behavior at an unaccustomed level of detail and (b) taking action to reduce their personal carbon footprint required lifestyle changes.

Table 3. Carbon Credit Equivalence of Market Participant Activities (CETS v2)

Credits	Activity
40	Consume 1 gallon of unleaded gas in a car (20 credits if you carpool)
1	Watch TV (2 hr)
1	Play video game (1 hr. includes having TV on)
80	Operate AC (1 day)
40	Operate Furnace (1 day)
4	Eat a piece of fruit from outside Michigan
40	Eat meat (1 lb beef)
1	Use or leave a computer on (2 hr)
12	50 lbs trash
14	Machine-dry clothes
-10	Install fluorescent light bulbs (saved per light bulb)
-100	Plant a tree (2 ft tall) linear scale: 1 ft = -50 credits

Regarding behavior changes, students reported the following changes in response to participating in CETS:

- Walked, ran, biked, and carpooled more often to campus and grocery stores, because walking, running, and biking counted for zero credits while carpooling reduced credit cost for commuting.
- Watched movies on their computer instead of on a TV, because computer use counted for fewer credits than TV watching.
- Delayed laundry until larger loads were possible.
- Watched TV with friends so they could split the credits.
- Organized tree-planting activities, because that generated credits for the planters.
- Chose to eat locally grown fruit when possible.

Through CETS, students came to grips with the difficulties of achieving carbon neutrality in their own lives. A few comments from student evaluations illustrate this point:

> The CETS simulations helped me to understand how my everyday choices affect my carbon output.
>
> CETS has taught me how much carbon I personally contribute on a daily basis and how nearly impossible it would be for me to eliminate all my carbon emissions.
>
> CETS made me very conscious of the fact that my actions have a consequence not only on myself but also affect the environment, climate, and the survival of organisms around me.
>
> CETS taught me the value and effectiveness of limiting consumption instead of striving to remove harmful emissions retroactively.

Market Behavior {D}

CETS provided enough realistic structure to allow real-life market behaviors to emerge during the simulation. Figure 5 shows credits retired and credits traded over time during CETS v2.

The left graph of Figure 5 shows that as the weather turned colder, market participants tripled the daily rate at which credits were retired, due mostly to increased household heating. The right graph of Figure 5 shows that at the outset, very few market participants thought they would need additional credits at the end. Thus, no trading occurred in the early part of the simulation. However, at the end, market panic set in, and feverish trading took place in the last days.

At the beginning of CETS v1, students quickly "discovered" the concept of market speculation. Shortly after hearing the rules for the simulation, one student asked, "Can I buy credits now (at a low price), even if I know I won't need them at all, just so I can sell them near the end (at a higher price) and make a profit?" The answer, of course, was "Yes." And, we were able to point out that speculators take similar actions in other markets.

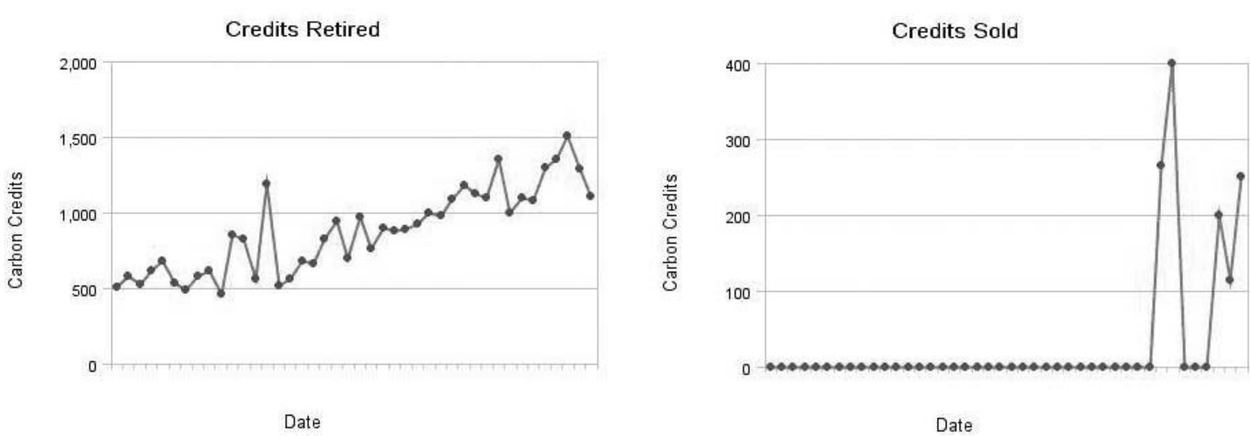

Figure 5. Carbon credit retiring and trading activity.
(Each tic on the horizontal axis represents one day of the simulation.)

We also had an instance of insider trading. Midway through CETS v1, one professor discovered which students had a surplus of credits remaining. Then, he emailed the credit-rich students asking them to compete amongst themselves for the lowest sale price. However, the CETS rules did not include a reporting mechanism obliging market participants to reveal the quantity of credits they held. So, in effect, the professor was using privileged information to manipulate the market to his advantage: insider trading. We used this example as a springboard for discussing the ramifications of insider trading in real markets.

We also had claims of injustice. Like real markets, the rules of CETS were set up to the advantage of some participants and the disadvantage of others. Several students who lived farthest from campus experienced this first-hand and raised the issue. Was it fair, they asked, that the deck was stacked against commuters? We used the commuting distance issue to discuss with students how humans always create the rules under which we are supposed to live, whether those rules are for markets, for politics, or for highways. Those rules are never value-neutral. And, markets are never really "free"; they are always constructed.

Many students noted how the mere fact of having a system that counted their behaviors increased their awareness of those behaviors. Because of the CETS structure, competitiveness caused students to adjust their behaviors in ways that reduced CO_2 emissions. We had different winners for each version of CETS. Both winners succeeded because they lived on campus and made a concerted effort to reduce their activities that led to carbon emissions.

How CETS Informed CCCN {G}

Although not designed explicitly to do so, the trading simulations had a profound effect on the carbon neutrality project {G}. Through the simulation, students became sensitized to those aspects of their daily lives that were most costly in terms of carbon emissions. They were also able to experience the relative difficulty (or ease) of altering behaviors to decrease personal emissions. This effect was most noteworthy in the area of transportation. During the simulation, we noticed a high percentage of our students riding bicycles to campus. Several commented this was not nearly as difficult a transition as they had expected. This experiential backdrop likely contributed to students' suggestions in the carbon neutrality project for more bike lanes and safer bicycle entry points to campus, as well as other transportation-related changes. The simulations, in a sense, gave students the opportunity to "try out" altered behaviors within the relatively safe context of the simulation. These altered behaviors led to informed recommendations for the carbon neutrality action plan.

Impacts

Novel teaching approaches such as those described here carry with them significant risks. The potential for both favorable and unfavorable outcomes is palpable. Some of the positive outcomes we identified for students and faculty/administration are described below.

How the Project Impacted Students

The experience of the CCCN and CETS exercises had many beneficial impacts on students. First, course evaluations indicate that they came to a deeper understanding of climate change issues and possible solutions. One student wrote,

> I now believe that mere technical advances cannot alter the course on which we are heading. I believe that if there is any hope for achieving carbon neutrality, major lifestyle changes need to be made.

The project also deepened personal commitments among several students. One way we saw this expressed was by more intentional active involvement on campus. One of the ecology students agreed to become a resident assistant for a new intentional community dorm floor on campus that will focus on Creation Care.[16] Another student became very active in campus environmental issues and was hired by the college as project manager for a major college forest mitigation and naturalization effort.[17] And a student interested in international development helped organize a week-long workshop on Creation Care in Missions that included faculty and students from the International Development Studies Program.

For other students, involvement with CCCN and CETS was an opportunity for individual growth. One engineering student exhibited emergent leadership skills throughout the CCCN project. He used the project as an opportunity to develop skills at planning, organizing, and motivating. Through his amiable personality, intellectual competence, and continual encouragement, he became the de facto leader to whom others looked for guidance. He took personal responsibility to ensure that groups were communicating essential information. He invested heavily with time and hard work to make the final report as good as possible. This student had the opportunity to develop these skills precisely because the open-ended structure of the project was so different from traditional classroom learning. On end-of-semester peer evaluations, he was unanimously commended for his supererogatory efforts.

By the end of the semester, students understood the value of interdisciplinary cooperation. Here are some of their comments.

> Through cooperation between classes, I realized more that reducing carbon emissions will require an effort from all fields, not just engineering.
>
> The lesson I learned from [the biologists] is that coming up with a solution to a problem does not entirely depend on calculations. In my opinion, the biologists came up with more creative ideas on how to make Calvin's campus carbon neutral.
>
> Engineers viewed the situation as a problem that we are to find a solution for. The biologists viewed it as a learning opportunity. They viewed it as an opportunity to get the public to see the effect they are having on the environment. I think both views are important.

How the Project Impacted Faculty and Administration

This project was a tangible reminder to us that students are much more than simply learners (academic model) or paying customers (business model). Instead, students are better thought of as participants (community model) with vested interests in the place in which they become educated and develop community.[18] Given opportunity and encouragement, students can contribute significantly to their college place and can be conditioned to seeing the value of investing in whichever place and community they eventually reside.

This experience was also a valuable lesson in the importance of varying teaching approaches to cater to all types of learners. We observed several students flourish in this learning context who had previously been challenged by traditional pedagogical approaches. Other students with great aptitude for memorization and individualized learning were more challenged by this activity. It was a strong reminder to us of the importance of offering a variety of learning experiences to accommodate the variety of students that we encounter.

Not knowing the outcome of this assignment a priori, we found our own expectations to be seriously inaccurate with regard to the balance of carbon emissions and carbon sequestration on a campus such as ours. It was very surprising to us how difficult it is to achieve carbon neutrality, in our personal lives and at the institutional level. But having an informed understanding of this goal is critical to developing a meaningful strategy for achieving it.

The element of this project that surprised us most was how little carbon sequestration is possible on our campus. We each had a sense that sequestration (planting trees) would be an important element of a plan to achieve campus carbon neutrality. However, student calculations clearly showed that filling all available campus space with trees would have minimal impact, given our current emissions levels. We learned that decreasing emissions is a far more important driver in attaining carbon neutrality than increasing sequestration capacity.

This classroom project allowed us to expand our impact on campus and in the broader community regarding sustainability and climate change issues and to develop our voice regarding climate change and sustainability in general. Since the CCCN project, we helped organize Calvin's Focus the Nation[19] activities, participated in planning the first-ever Calvin Sustainability Summit,[20] and spoke at the Faculty Conference in the following autumn. Beyond the campus, we presented this project at the 2008 Association for the Advancement for Sustainability in Higher Education (AASHE) conference and were asked to lead a half-day workshop on sustainability related to economic development for an international development organization.

One final unforeseen lesson learned was how disciplinary identities and characteristics are already firmly established among third- and fourth-year students. Ecology students frequently commented how differently they approach a project like this, when compared with their engineering counterparts. Engineering students made similar observations about the ecology students. The important lesson we take from this effort is that students who remain largely within the comfortable confines of their chosen discipline will be less-equipped to meaningfully address interdisciplinary challenges such as climate change after graduation. We believe experiences such as this are invaluable opportunities for preparing our students for post-college vocations.

Conclusion

Climate change caused by global warming will have a significant impact on today's students throughout their lifetimes. International and institutional actions will affect the personal decisions they will make after they graduate. Any activity that involves consumption of energy will be affected: where should I live? what house should I buy? what transportation options will I use? etc.

Many students began the CCCN project with a sense of bewilderment at what they were expected to accomplish in the semester: they had never before been asked to work on such a large and coordinated project. Mid-way through, many students expressed frustration at the lack of direction for the open-ended project: no one could tell them how to achieve carbon neutrality. But in the end, their efforts coalesced into a very fine final product of which everyone was justifiably proud.

Along the way, the CCCN project evolved from a group assignment to a collective responsibility. There are several reasons for the evolution, none of which are necessarily tied to the topic of climate change:

- student names were attached to the project;
- the results were very public due to the poster session, campus-wide seminar, and the final report being posted online;
- the project was *big* and attracted a lot of attention; and
- the college administration was involved, which made it seem to students that their ideas could be implemented.

We sought to expand our students' understanding of the impact that climate change will have in their lives through three types of instruction (traditional lectures, a group project [CCCN], and a participatory simulation [CETS]) that addressed multiple levels of student inquiry (global, institutional, and personal). Instructor and student evaluations indicate that this approach was successful on all three levels of inquiry. Students reported a deeper understanding of global issues related to climate change; the project has had a positive impact on our educational institution; and students reported increased awareness of how personal decisions interact with both institutional and global dimensions of the problem. There are significant risks involved with this type of teaching, not least of which is the possibility of public failure. But the rewards in terms of student success through self-motivated learning in a group setting can be very significant for both students and professors. The goal of campus carbon neutrality provided a rich topic in which these rewards were realized.

Acknowledgments

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Resources

Classroom materials for this project can be found at www.calvin.edu/~mkh2/cccn/. Resources include the assignment given to students, details of CETS, student posters and presentations, the final report, and student project assessment questions. Readers may use any of the resources provided that attribution is given to the authors in any published works.

Notes

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[13] R. Bayon, A. Hawn, and K. Hamilton, *Voluntary Carbon Markets: An International Business Guide to What They Are and How They Work* (London: Earthscan, 2007).

[14] A "carbon credit" is typically defined as a permit to emit 1 metric ton of carbon dioxide. Carbon credit trading on international markets is seen by many as a way to reduce CO_2 emissions globally. Carbon credits are "retired" in response to an activity that causes CO_2 to be emitted.

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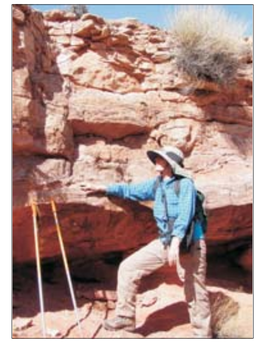

Carol A. Hill

Flood Geology and the Grand Canyon: A Critique

Carol A. Hill and Stephen O. Moshier

Stephen O. Moshier

Four claims of Flood Geology—as they are related to the Grand Canyon and specifically to the book Grand Canyon: A Different View*—are evaluated by directly addressing Young Earth Creationist arguments, by showing rock features that belie these claims, and by presenting the most up-to-date scientific theories on the origin of the Grand Canyon. We conclude that Young Earth Creationism promotes an erroneous and misleading interpretation of the geology of the Grand Canyon. We also conclude that the claim that all (or almost all) of the sedimentary rock in the Grand Canyon and on planet Earth was formed during Noah's Flood is not supported by the Bible.*

About four million people each year visit Grand Canyon National Park to witness one of the most well-known and spectacular geologic features on planet Earth. Visitors typically ask questions like: "How old is the canyon?" or "How did it form?" Explanations for the natural history of the canyon are found on interpretive signs and in books available for purchase at concessions in the park. Official park signage and most books on the topic present the "mainstream geology" position that the rocks exposed by the canyon are hundreds of millions to a billion or so years old, while the canyon itself—carved into these rocks—is millions of years old. In this vein, *Carving Grand Canyon—Evidence, Theories, and Mystery* by geologist Wayne Ranney examines the evidence for the history of the Colorado River and the formation of the canyon, while *Grand Canyon Geology* edited by Stanley Beus and Michael Morales contains chapters written by geoscientists on the origin of the rocks that are exposed in the canyon.[1]

Another book sold at the park—one that has garnered much attention in the media[2]—presents an entirely different age and origin for the canyon and its rocks. *Grand Canyon: A Different View*, consisting of over twenty section authors and compiled by Tom Vail,[3] rejects the idea of a millions-of-years-old canyon and proposes instead an approximately 4500-year-old canyon, wherein the mile-deep sequence of sedimentary rocks formed during the one-year-long Noah's Flood, and with the entire canyon being excavated since that flood event. This position is known as "Flood Geology," which is an essential component of Young Earth Creationism (YEC).

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Critical differences between "Flood Geology" and "Mainstream Geology" that are relevant to the Grand Canyon are listed in Box 1. The "Young-Earth Creationist" position is popular with fundamentalist Christians and has been defended by a number of authors of that persuasion.[4] YEC proponents believe that scientific details of the Earth's creation and early history are evident in the Bible and that examination of the geological record can support a literal biblical narrative. However, other Christians—including many theologically conservative, evangelical Christians—hold the "Old-Earth Creationist" (OEC) position that accepts the mainstream view of geological history.[5] Our purpose in this article is to evaluate Flood Geology claims as they relate to the Grand Canyon, and more specifically to evaluate some of the ideas presented in the YEC book *Grand Canyon: A Different View* and references therein. It is our position that the contributors of this book present misleading information about the geology of the Grand Canyon to support a theological position that is not demanded or even supported by the Bible.

Flood Geology and the Bible

First, we examine how flood geologists, as represented in *A Different View,* come to their position of a young Earth and of sedimentary rock having formed in Noah's Flood. The most significant passages in Scripture bearing on Earth origin and natural history, as understood and applied by flood geologists, are reviewed below.

Age of the Earth and Date of the Flood

The Earth was created approximately 6,000 years ago based on a 24-hour day/six days of creation (Genesis 1) plus the chronologies of Genesis 5 and 11. The Flood is understood to have happened about 4500–5000 years ago (2500–3000 BC).

Changes in Nature after the Fall

Before Adam sinned and ate of the fruit of the tree (Gen. 3:6), a world of perfect harmony existed on planet Earth. Perfection is implied from the declaration by God that his creation was "good" (Gen. 1:25, 31). In this perfect world, there was no death, not even the death of animals. Since no animals died, all animals (created as distinct species in Genesis 1) had to have been herbivores before Adam's fall. Adam's "original sin" brought about a violent imperfect world where both humans and animals died and where some animals became carnivores. This violence is illustrated by the avenging line of Cain (Gen. 4:23–24).

The long ages of the patriarchs before the Flood (Genesis 5) signify decay from a state of perfection in the Garden of Eden to a maximum 120-year life span for humans after the Flood (Gen. 6:3). A vapor

Young Earth Creationist (Flood Geology)	Old Earth Creationist (Mainstream Geology)
• Earth is about 6,000 years old • Radiometric methods for the dating of geological materials are flawed • Noah's Flood occurred about 4,500 years ago and was universal over planet Earth • It never rained on Earth before Noah's Flood • Fossils in sedimentary rocks represent the "all flesh" of Genesis 7:21 • Fossil-bearing sedimentary rock on Earth formed during Noah's Flood in only one year's time • A vapor canopy and/or fountains of the deep supplied all of the water for a universal flood • The Grand Canyon and Colorado River formed as water from the flood retreated from the land • No death of animals before Adam sinned; all animals were herbivores • By implication, all pre-flood land was covered by flood deposits, including the four rivers of Eden	• Earth is about 4.6 billion years old • Radiometric dating methods yield reliable absolute dates on geological materials • Noah's Flood was limited to the Mesopotamian hydrology basin • Abundant evidence exists for its having rained throughout Earth's geologic history • Fossils in sedimentary rocks are plant and animal remains that died and were buried and solidified as sediments turned into rock over millions of years • Sedimentary rock has formed over hundreds of millions of years by the process of sedimentation and compaction • The Colorado River and Grand Canyon have a complex history that is still being investigated, but the canyon's erosion involved millions of years rather than thousands of years • The Garden of Eden is described in Genesis as a modern landscape overlying sedimentary rock

Box 1. Young Earth versus Old Earth Creationist Positions Relevant to the Grand Canyon

canopy may have shielded humans from harmful radiation so that they lived longer in pre-flood days. The violence had become so pervasive by Noah's time that only one man was considered "good" by God and that man was Noah (Gen. 6:9). Consequently, God instructed Noah to build an ark and prepare for a flood, wherein all men and animals and birds would be destroyed from off "the face of the earth" (planet Earth) (Gen. 6:7).

Source of Flood Water

No rain fell on the "earth" (interpreted to be "planet Earth" rather than "ground") before Noah's Flood (Gen. 2:5). Rather, a "mist" (Gen. 2:6) served to moisten the ground from creation to the time of Noah's Flood. Since supposedly it had never rained on planet Earth before the flood, no (or very little) sedimentary rock could have formed before this time, and pre-flood locations (like the Garden of Eden) had to have existed on a crystalline rock basement devoid of sedimentary rock or on a thin cover of sedimentary rock deposited between the Creation week and the Flood.

Some flood geologists—especially those in the middle- to late-twentieth century—have proposed that the mist of Gen. 2:6 refers to a dense vapor canopy that shrouded the earth before the time of Noah's Flood. However, in recent years there has been a growing skepticism among flood geologists of this concept.[6] Genesis 7:11 states that the windows of heaven were opened and all the fountains of the great deep were broken up. From the perspective of most flood geologists who still adhere to the Vapor Canopy hypothesis, this verse is interpreted to mean that all of the water in their proposed vapor canopy fell as rain and that a great amount of water in the Earth's crust was expelled along faults and volcanoes.

Global Extent and Geological Results of the Flood

Since the Bible says that "all the earth" was flooded, with even the mountains being covered to a depth of fifteen cubits (Gen. 7:19–20), and that "all flesh" died (Gen. 7:21), this must mean that Noah's Flood left an immense record of itself in the form of sedimentary rock containing fossils. In addition to being subjected to a worldwide deluge, Earth's tectonic forces must have caused continents to move ("plate tectonics") and mountains to heave upwards because sedimentary rock is found today on the highest mountain peaks (e.g., the summit of Mount Everest is composed of marine limestone). The separation of continental plates (e.g., South America and Africa) was rapid, happening in only one year during Noah's Flood.

Since even the highest mountains were covered, the ark would have landed on the highest peak of the Middle East region, Mount Ararat (elevation 16,803 ft). After landing on Mount Ararat, the floodwaters decreased rapidly due to evaporation (Gen. 8:1), and also because they "*returned from off the earth continually*" (Gen. 8:3) to low elevations relative to mountains raised during the Flood. Exactly one year (365 days) after the Flood started, the post-flood landscape where Noah landed was dry (Gen. 8:14), and the topography of planet Earth was completely changed from its pre-flood landscape.

Critique of Biblical Basis for Flood Geology

The authors of *Grand Canyon: A Different View* affirm the inerrancy of God's Word in its original form as the "one basic premise" informing their understanding of creation history (p. 7). For flood geologists, biblical inerrancy means that words in the Bible are taken literally with little or no regard to how those words may have held different meanings at the time and in the culture when they were written—a position that is contradictory to the Chicago Statement on Biblical Inerrancy, which does not affirm ironclad biblical literalism that disrespects ancient cultural contexts, literary forms, and phenomenological language never meant to convey modern scientific information.[7]

In *A Different View,* readers are warned that nonliteral interpretations of words and phrases like "day" and "all the land" or "all flesh" are compromises to accommodate evolutionary ideas about creation that are in violation of biblical admonitions such as Deut. 4:2: "*You shall not add to the Word which I am commanding you*." However, it is not unusual for flood geologists to make dramatic leaps of meaning from the text to modern scientific concepts, such as in the way Ps. 104:8 is quoted in *A Different View*: "*The mountains rose, the valleys* [ocean basins] *sank down to the place which You established for them*" (p. 5). John Whitcomb, the author of this section of the book, feels free to interpret "valleys" to mean "ocean basins" even though this is not a literal translation and thus is contrary to the book's stated "one basic premise."

Numerous scholars with orthodox or conservative credentials have addressed problems with literal hermeneutics applied to Creation scriptures.[8] They have questioned attempts to fix the date of Creation, establish direct harmony between biblical and scientific descriptions of Creation, or draw conclusions about changes in nature after the Fall beyond what is written in the text. The issue of the age of the Earth and how to interpret Genesis 1–3, 5 and 10 with respect to the numbers contained in these chapters is beyond the scope of this article and readers are referred to the cited reference.[9] The issue of "no animal death before the Fall" is probably most pertinent to Grand Canyon geology because of the YEC claim that fossils buried in the strata could only have perished after the Curse introduced death to all creatures. Not only is it *not* obvious from Genesis 3 that the Curse introduced death to all creatures, the Apostle Paul offers contrary commentary on the matter in Rom. 5:12, 13 (NIV): "*Therefore, just as sin entered the world through one man, and death through sin, and in this way death came to all men, because all sinned—for before the law was given, sin was in the world.*" Here, Paul is specific that death from sin applies to all humans and he does not consider the death of animals as consequential or relevant to his doctrinal point.

Flood geologists have also drawn geological and paleontological conclusions about the extent of the Genesis Flood from many Bible verses without consideration of valid alternative and nonliteral understandings of their meaning. For example, Old Testament scholar John Walton has pointed out that the description in Gen. 7:20 (NIV) that floodwater "*covered the mountains to a depth of more than twenty feet*" could as well be understood, in the context of other applications of the same words elsewhere in the Old Testament, to mean that the mountains were "drenched" and that water rose to a depth of twenty feet against the mountain.[10] Walton also provides examples from the Old Testament and other literature of its time (i.e., Akkadian texts) where the expressions of "all" or "every" could never have been understood as universal. For example, when in Gen. 41:57, "*all the countries came to Egypt to buy grain from Joseph, because the famine was severe in all the world,*" Walton quips that no one believes that the Eskimos were included. Similarly, the senior author of this article has considered that the ancients used expressions like "all," "every," and "under heaven" to describe regional, but non-universal, events.[11] Hill also considered the word "earth" (*eretz*) to mean ground or dry land, rather than the planet Earth, arguing that the misinterpretation of this word in particular has led to the erroneous conclusion that "all the earth" means a worldwide, universal flood.

The Bible and Sedimentary Rock

Does the Bible really claim that all of the sedimentary rock on Earth, such as is exposed in the Grand Canyon, formed in Noah's Flood? Nowhere does it even mention sedimentary rock and it is highly unlikely that the ancient biblical authors distinguished rock types by their origins since this is a modern concept developed only over the last 150 years or so. That the Bible does *not* claim all sedimentary rock formed in Noah's Flood can be deduced from the Genesis text (Gen. 2:10–14) where it describes the pre-flood Garden of Eden as being located near the confluence of the four rivers of Mesopotamia near the Persian Gulf. This mention of rivers raises the first red flag on a flood geology interpretation of the universal nature of "earth" (*eretz*) because if it had never rained over the entire planet Earth before Noah's Flood, then where did the four rivers of Eden receive their water?

Genesis 2:10–14 specifically identifies the four rivers of Eden as being the Euphrates, Hiddekel (Tigris), Pishon, and Gihon. The Euphrates and Tigris are rivers that still exist by those names in Mesopotamia today (modern-day Iraq). The identification of the other two rivers, Pishon and Gihon, is somewhat problematic. Hill identified the Pishon River with what is now the dried-up Wadi Batin, tracing this wadi westward into Arabia (the "land of Havilah") where all three of the commodities identified by the Genesis text—gold, onyx, and bdellium—are found (Fig. 1).[12] The Gihon River was identified as today's river Karun, which takes a zigzagging, circuitous course through the great folded structures of Iran's Zagros Mountains. In the case of the Tigris River, Gen. 2:14 identifies it as "that which goeth toward the east of Assyria." The Tigris was the great river of ancient Assyria, and on its banks stood many of the cities mentioned in the Bible, including Ashur (Fig. 1). The Tigris does (and did) flow east of ancient Ashur (now the mound of

Ashur), in perfect concordance with Gen. 2:14 *if* a *modern landscape* is assumed rather than a pre-Flood landscape. What we mean by this is a landscape that can still be recognized as being the same landscape as the ancient biblical author was identifying for his readership.

Another important biblical clue that fixes a modern landscape for the southern Mesopotamian area in pre-Flood time is Gen. 6:14, "*Make thee an ark of gopher wood; rooms shalt thou make in the ark, and shalt pitch it within and without with pitch*." Pitch (or bitumen) is a thick, tarry, oil product composed of a mixture of hydrocarbons of variable color, hardness, and volatility. Bitumen was used extensively by the ancient peoples of Mesopotamia for every type of adhesive-construction need, including the waterproofing of boats and mortar for buildings (e.g., the "slime" of Gen. 11:3). The center of bitumen production in Noah's time was (and still is) at Hit (Fig. 1), located along the Euphrates River about 80 miles west of Baghdad. The Hit bitumen occurs in "lakes" where a line of hot springs is upwelling along deep faults.[13] These faults connect the surface with the source of hydrocarbons at depth—the source being *sedimentary rock* (Fig. 1). In southern Iraq oil and gas are produced from the limestone and sandstone sedimentary rocks of the Jurassic Najmah Formation; the Cretaceous Yamama, Zubair, Nahr Umr, Mishrif, and Hartha Formations; and the Miocene (Tertiary) Fars and Ghar Formations.[14] The essential point of the above discussion is this: How could Noah have obtained pitch from sedimentary rock for building his ark, if (as claimed by flood geologists) little or no sedimentary rock existed before the Flood?

The biblical author's placement of the Garden of Eden on a *modern landscape* presents a major conflict between Genesis and Flood Geology. There are *six miles* of sedimentary rock *beneath* the Garden of Eden as it is described in the Bible (Fig. 1). Geologists know that six miles of sedimentary rock exist there because this area has been extensively drilled for oil down to the Precambrian basement. The six miles of sedimentary rock below the Garden of Eden area include (downward) Tertiary, Cretaceous, Jurassic, Triassic, and Paleozoic rock to a

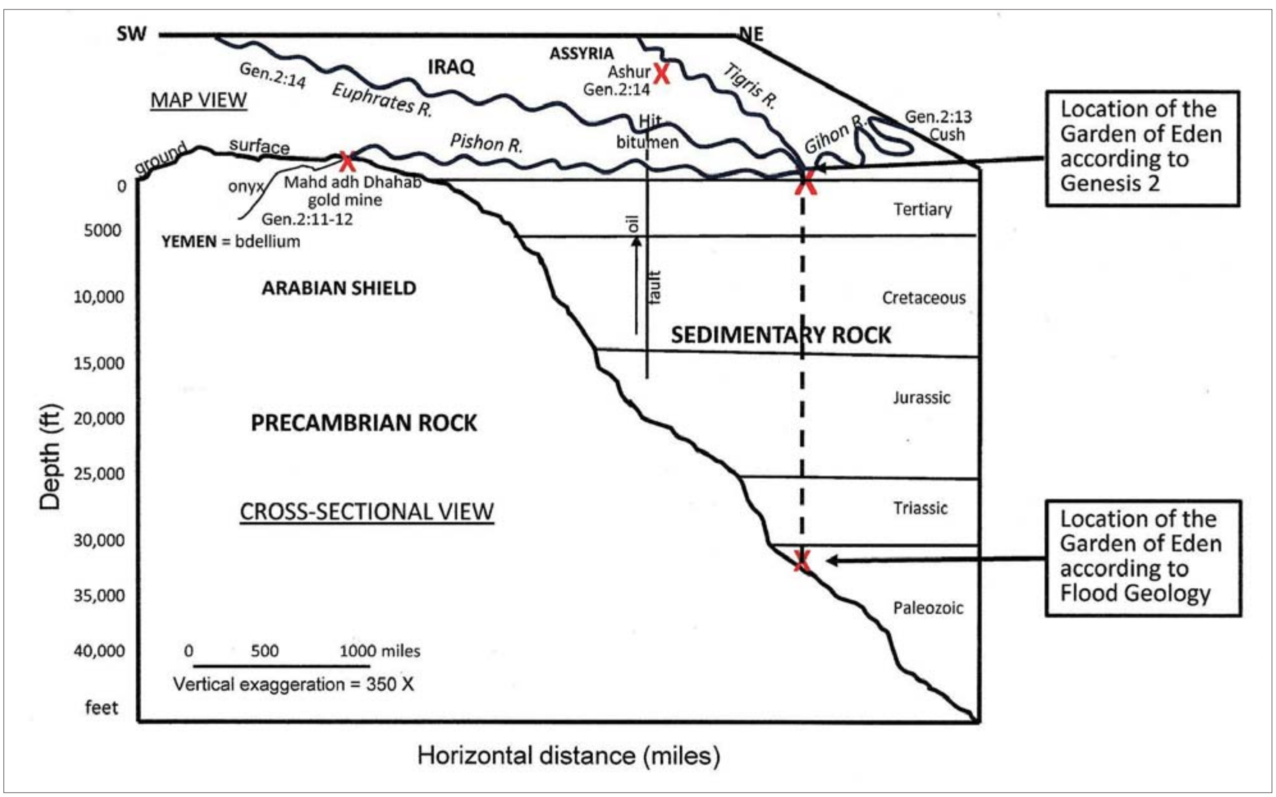

Figure 1. Schematic block diagram of the surface rivers, and cross-section of the subsurface geology, of the Persian Gulf/Garden of Eden area. If all sedimentary rock formed at the time of Noah's Flood, as claimed by flood geologists, then the Garden of Eden would have had to exist on Precambrian basement rock 32,000 feet (six miles) below where the Bible says it was located. Vertical exaggeration is approximately 350 times.

depth of about 32,000 feet before the Precambrian basement is reached.[15] The question then becomes: How could Eden, which existed in *pre-flood* times, be located *over* six miles of sedimentary rock supposedly deposited later *during* Noah's Flood? What flood geologists are implying is that the Garden of Eden existed on a crystalline basement and then Noah's Flood covered up the Garden of Eden with six miles of sedimentary rock. But this is not what the Bible says. It states that Eden was located where the four rivers existed on a modern landscape, which happens to be *on top of* six miles of sedimentary rock. Thus, these sedimentary rocks must have existed in pre-Flood times.

Grand Canyon Geology

The flood geology view of the Grand Canyon, as presented in books such as *Grand Canyon: A Different View,* is appealing to many Christians because it offers a scientific explanation that (1) does not exclude God, and (2) corresponds with what the Bible seems to reveal about Creation history. In this article we evaluate four major claims about the geology of the Grand Canyon made by flood geologists in their literature and videos:

1. *Evidence of Rapid Burial*. Sedimentary rocks contain features that are best explained by rapid deposition by deep, swift currents.

2. *No Time Gaps between Formations*. Contacts between formations lack evidence of protracted, subaerial exposure, such as would be consistent with deposition over hundreds of millions of years.

3. *Massive Tectonic Upheaval*. Deformation of the oldest sedimentary rocks in the Grand Canyon coincides with the initiation of the Flood. Uplift of the Colorado Plateau and deformation of strata in the canyon section (faulting and folding) occurred as the floodwaters receded and before sediment solidified into rock.

4. *Rapid Erosion*. The nature of the canyon and landscape of the Colorado Plateau is consistent with rapid erosion by receding floodwater.

We evaluate these four claims by not only directly addressing YEC arguments, but by also showing rock

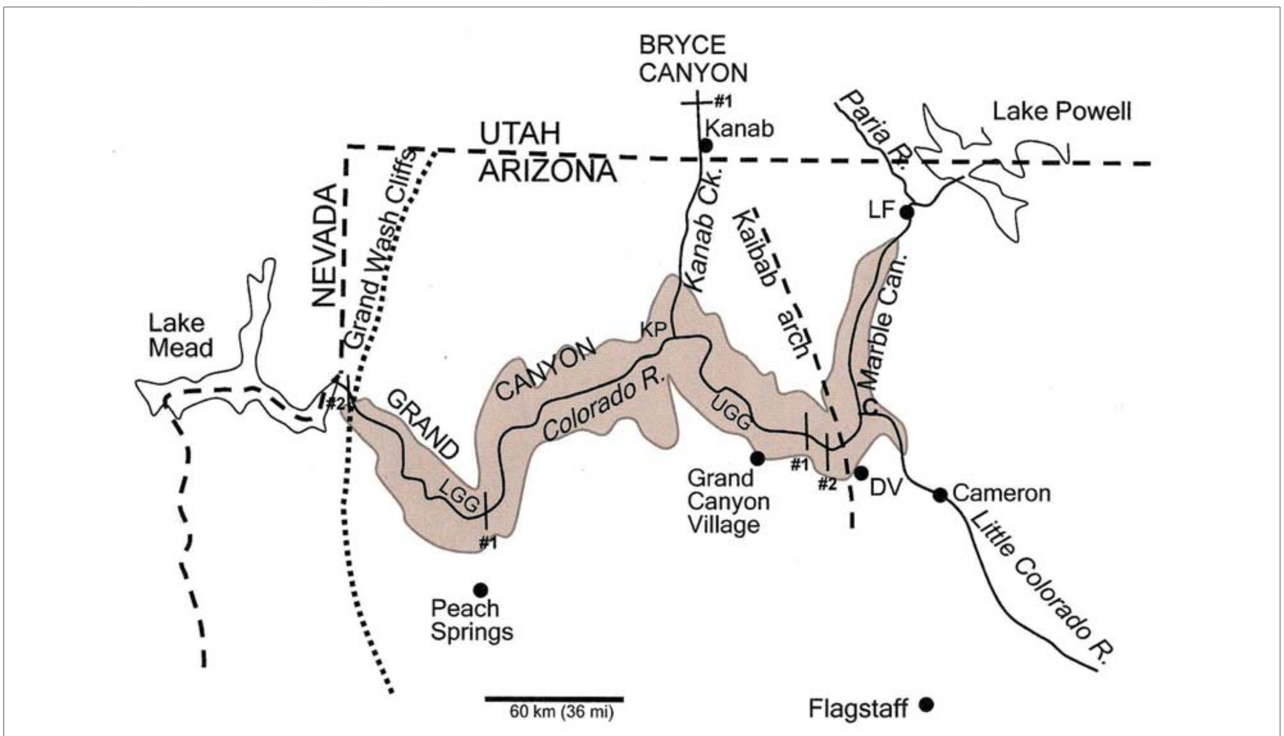

Figure 2. Grand Canyon of northern Arizona, USA. LF = Lees Ferry, C = Confluence, DV = Desert View, UGG = Upper Granite Gorge, KP = Kanab Point, LGG = Lower Granite Gorge. Laramide-age, proto-canyon drainage in the central part of today's Grand Canyon (the extent of which is marked by the three #1 symbols) would have flowed north to the Bryce Canyon area. The western Grand Canyon (the extent of which is marked by the two #2 symbols) would have existed from 16 to 6 million years ago and would have extended from the west side of the Kaibab arch to the Grand Wash Cliffs. East of the Kaibab arch is the eastern Grand Canyon, which is thought to have connected to a western Grand Canyon about six million years ago thus forming an integrated canyon along which the Colorado River flowed from Colorado to the Gulf of California.

features that belie these claims and by presenting the most up-to-date scientific theories on the origin of the canyon. A location map illustrating some of the geographic features of the Grand Canyon is shown in Figure 2, and the stratigraphic sequence of rocks exposed by the Grand Canyon is illustrated in Figure 3. An introduction to the basic rock types in the Grand Canyon is provided in Box 2. Flood geology literature contains many critiques of radiometric dating, which we feel have been capably evaluated by others,[16] and thus this topic will not be covered by us.

Remember in the following discussion what YEC are really claiming for the origin of the Grand Canyon (and for that matter the whole planet Earth): (1) that all (or almost all) of the sediments comprising the canyon's sedimentary rock was deposited by the floodwater of a worldwide Noachian Flood that took place some 4500 to 5000 years ago, (2) that these sediments were compacted into hard rock, and (3) that recession of this floodwater carved the Grand Canyon into this rock. Since Genesis 8 claims that dry land appeared after one year's time, this implies that at least (1) and (2) had to have occurred within a one-year time span, with the carving of the entire Grand Canyon (3) occurring in the last 4500 years or so since Noah's Flood.

Claim #1: Evidence of Rapid Burial

Flood geologist Steven Austin has applied the principle of hydrodynamic sorting to the Tonto Group at the base of the Grand Canyon sedimentary sequence.[17] The Tonto Group consists of, from the base, the Tapeats Sandstone, Bright Angel Shale, and Muav Limestone (Fig. 3). The Tapeats Formation overlies the Precambrian metamorphic and igneous rocks exposed at river level in the Inner Gorge. Austin argues that rising floodwater scoured the igneous and metamorphic bedrock to produce a cover of gravel and coarse sand, corresponding to the Tapeats Formation. As the water deepened in the area, fine sediment settled from suspension, corresponding to the Bright Angel Shale. Then lastly, the overlying Muav Limestone represents the introduction of fine calcareous sediment from an unknown source of eroded limestone bedrock.

Austin's model of hydrodynamic sorting raises a number of questions, the most pertinent one being: Does this model adequately explain the lithologic

Igneous Rock forms from melted material (magma). Igneous rock can form quickly when magma erupts onto the surface of the earth, either as volcanic lava flows or as explosive material. An example of such a volcanic rock is basalt. Other igneous rocks form very slowly when magma cools beneath the Earth's surface, and an example of this type is granite. The Zoroaster Granite is found at the base of the canyon in the Inner Gorge and has been radiometrically dated at between 1.4 and 1.5 billion years. The inner part of the western Grand Canyon contains many volcanic flows and cinder cones, such as Vulcan's Throne. These basaltic rocks have been radiometrically dated from about 20 million years to less than one-half million years.

Sedimentary Rock forms from sediments deposited mainly by water and to a lesser extent by wind. Sediments are eroded off the land, blown by the wind, carried to the oceans by rivers, deposited on the ocean floors, and then slowly compacted into rock. Sediments can also be derived from the shells and exoskeletons of marine invertebrate animals. The Grand Canyon contains an almost-one-mile-thick sequence of sedimentary rocks. These rocks include limestones (e.g., the Redwall Limestone), shales (e.g., the Hermit Shale), sandstones (e.g., the Coconino Sandstone), and evaporites (e.g., gypsum beds in the Toroweap Formation). Sedimentary rocks in the Grand Canyon include the Precambrian Unkar and Chuar Groups, which contain some of the earliest fossils in the sedimentary record anywhere on Earth.

Metamorphic Rock forms when igneous and sedimentary rocks are buried to great depths and are subjected to high temperatures and/or pressures over a long period of time. These processes cause these rocks to undergo a metamorphosis and become new rocks with different minerals, appearance, and structure that are compatible with their new pressure-temperature environment. Examples of metamorphic rock are marble and schist. Metamorphic rocks are found mainly as Precambrian (>570 million year) basement rocks. The metamorphic rocks of the Grand Canyon lie at the base (Inner Gorge) of the canyon and represent the core of a very ancient mountain range. These rocks are sometimes referred to as the "crystalline basement" or "crystalline rock." The crystalline metamorphic rocks in the Grand Canyon have been dated from about 2 billion to 1.5 billion years ago. Crystalline rocks are exposed in the Inner Gorge as the Vishnu Schist (metamorphic rock derived from precursor sedimentary rock) and the Brahma Schist (a metamorphosed basalt), which represents volcanic rock that was originally interbedded with sediments of the Vishnu.

Box 2. Three Different Basic Rock Types Occurring in the Grand Canyon

transitions in Grand Canyon rock involving sandstone, shale, and limestone sequences, such as occur in the Tonto Group and in rocks overlying the Tonto Group up to the rim of the canyon? It certainly does not explain the lithologic transition between the Hermit *Shale* and overlying Coconino *Sandstone*; i.e., this sequence of mud underlying sand is opposite to that expected for hydrodynamic sorting. Furthermore, how could the calcareous sediment for the Muav Limestone have come from a pre-flood source of "eroded limestone bedrock" if there was no (or very little) sedimentary rock such as limestone existing prior to the Flood?

Mainstream geologists agree with flood geologists that the Tonto Group was deposited by rising seawater, the difference being that in the Old Earth view the sea rose over a period of tens of millions of years. The rock at the base of the Tapeats Formation is a conglomerate (pebbles, cobbles and some boulders), such as would be deposited along a rocky coastline with aggressive waves and frequent violent storms eroding the pre-existing Precambrian metamorphic and igneous rocks down to a nearly flat surface. This nearly flat surface between Precambrian rock (age = 1.75 billion years) and the above lying Tapeats Formation (age = 525 million

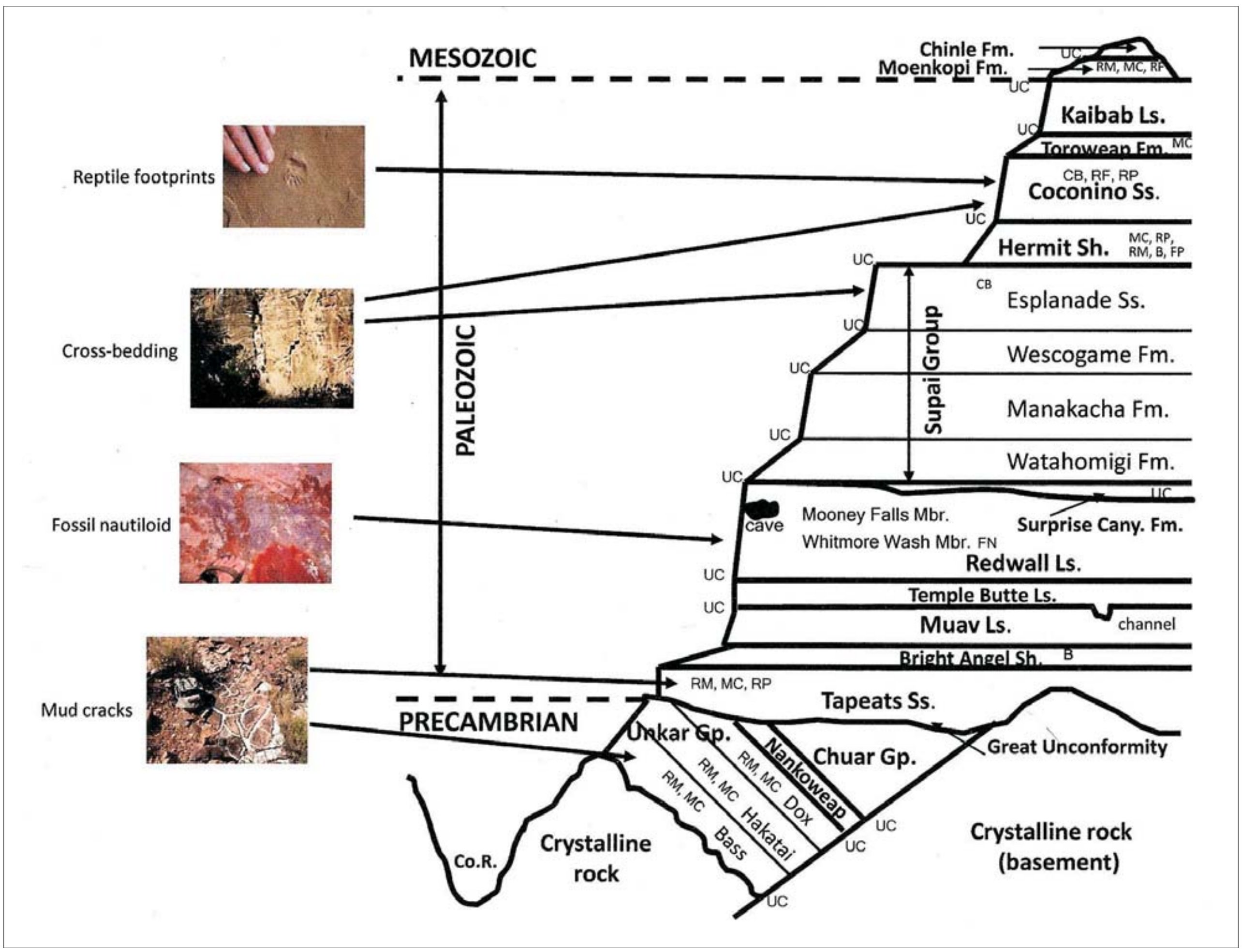

Figure 3. Simplified stratigraphic section of the Grand Canyon of Arizona, USA, showing the approximately 5,000 ft thick sequence of sedimentary and crystalline (igneous and metamorphic) rock. Each of the named layers is a rock division called a member, a formation, or group of formations. The age of this rock ranges from about 2 billion years (Precambrian crystalline rock) to about 200 million years (Mesozoic Chinle Formation). The rim of the canyon is usually capped by the Kaibab Limestone, which is about 260 million years old. The four photos show the location of some of the sedimentary features in the rock. Ss. = sandstone; Sh. = shale; Ls. = limestone; Fm. = formation. UC = unconformities, CB = cross bedding, RF = reptile footprints (tracks), RP = raindrop prints, B = burrows, FP = fossil plants, FN = fossil nautiloids, RM = ripple marks, MC = mud cracks. Many modern caves are developed along an old Mississippian-age paleokarst horizon in the Mooney Falls Member of the Redwall Limestone (black area marked "cave"). Vertically exaggerated about 18 times.

years) is called "The Great Unconformity" by geologists, and represents up to 1.225 billion years of missing geologic time. During this great expanse of time Precambrian crystalline basement rocks, which represent the core of a very ancient mountain range, were being eroded to an almost flat surface before rising seawater inundated this surface and deposited the Cambrian Tapeats Formation.

Above the basal conglomerate of the Tapeats, the rest of the formation is composed of sand about 200 feet thick, with bedding containing sedimentary structures typical of tidal flat, beach, and shallow-shore environments that include ripple marks, mud cracks, and raindrop prints (Fig. 3, RM, MC, RP). The overlying Bright Angel Shale is a mudstone that was deposited in an offshore, low-energy (not high-energy) environment.[18] Fossil animal burrows in the Bright Angel Shale attest to the continuous reworking of fine-grained sediment on the seafloor under slow (not rapid) burial conditions (Fig. 4).

Figure 4. Fossil animal burrows and grazing trails in the Cambrian Bright Angel Shale, Grand Canyon. Photo shows the top of a typical bedding plane decorated with interlaced tubes produced by deposit-feeding invertebrates. Photo by Steve Moshier.

Further offshore, the shallow sea bottom was home to many lime-secreting organisms such as brachiopods, trilobites, and algae—normal marine organisms that also cannot survive under rapid-burial conditions. All of these structures in the Tonto Group do *not* support "rapid deposition by deep, swift currents" as proposed by Austin. Rather, these features in the Tonto—and also in the entire Grand Canyon sedimentary rock sequence above the Tonto Group—indicate deposition in an alternating subaqueous (under water) and subaerial (under air) environment where the sea advanced (transgressed) over the land and then retreated (regressed) time and time again. The reason geologists know the past environments under which these sedimentary structures formed in Grand Canyon rocks is because we can *witness* how these features form today.

Sedimentary Structures in Grand Canyon Rocks

Sedimentary structures—including fossils and tracks—tell geologists about the conditions under which rocks form, such as under shallow-water or deep-water conditions or under subaerial or sand-dune conditions:

Raindrop prints. Raindrop prints are made when droplets of pounding rain impact wet mud, silt, or sand, thus creating imprints of those drops in the sediment. This can only happen when wet sediment is exposed to the atmosphere, because if the sediment is underwater it cannot be impacted by rain drops. In other words, this feature could not have formed in a rapidly rising floodwater environment as proposed by Austin—or even in a body of water greater than a few inches deep. Raindrop prints have been reported as occurring in the Tapeats, Coconino, and Hermit Formations (Fig. 3, RP).

Ripple marks. Ripple marks are typically generated by currents moving in one direction or by the to-and-fro motion of waves in shallow water to depths of a few tens of feet at the most. Figure 5 shows some ripple marks that formed along the bank of the Colorado River in Grand Canyon in September 2004 compared to ripple marks that formed in the Tapeats Formation 525 million years ago (Fig. 3, RM). Ripples have been photographed on the sea floor in very deep

Figure 5. *Left:* Mud cracks and ripple marks formed in 2004 by wave action along the banks of the Colorado River. Photo by Bob Buecher.
Right: Ripple marks preserved in the 525-million-year-old Cambrian Tapeats Sandstone. Photo by Alan Hill.

water, where these features are probably caused by density-driven currents. However, it is unlikely that such delicate ripple marks could have formed and been preserved under conditions of extremely rapid sediment burial at a scale imagined by flood geologists.

Mud cracks. Mud cracks are sedimentary structures that form by the shrinkage of wet mud when it dries out. Usually the mud cracks are preserved by being filled with sediment that covers the mud-cracked layer or by calcite crystals that fill the cracks after deposition. Invariably mud cracks imply baking under the sun (that is, they form under subaerial conditions). Figure 6 shows mud cracks forming today in the Grand Canyon along the Colorado River near its confluence with the Little Colorado River compared with ancient mud cracks formed in the 525-million-year-old Tapeats Formation (Fig. 3, MC).

Figure 6. *Left:* Mud cracks forming today in wet mud along the Little Colorado River near its confluence with the Colorado River in the Grand Canyon. Photo by Bob Buecher.
Right: Mud cracks in the 525-million-year-old Tapeats Sandstone; over geologic time these mud cracks filled with white calcite material. Photo by Doug Powell.

Cross-bedding. Cross-bedding is a feature in sedimentary rock in which strata include internal sets of layers that are inclined at an angle to the original horizontal bedding of the rock unit as a whole (Fig. 7). Cross-bedding usually occurs in sandstone but also sometimes in limestone. In the Grand Canyon the Coconino Sandstone (and some units of the Supai Formation) characteristically display cross-bedded layers of sandstone composed of frosted sand grains (Fig. 3, CB). The angle of repose for loose sand in a sand dune is about 33° to the horizontal, and if

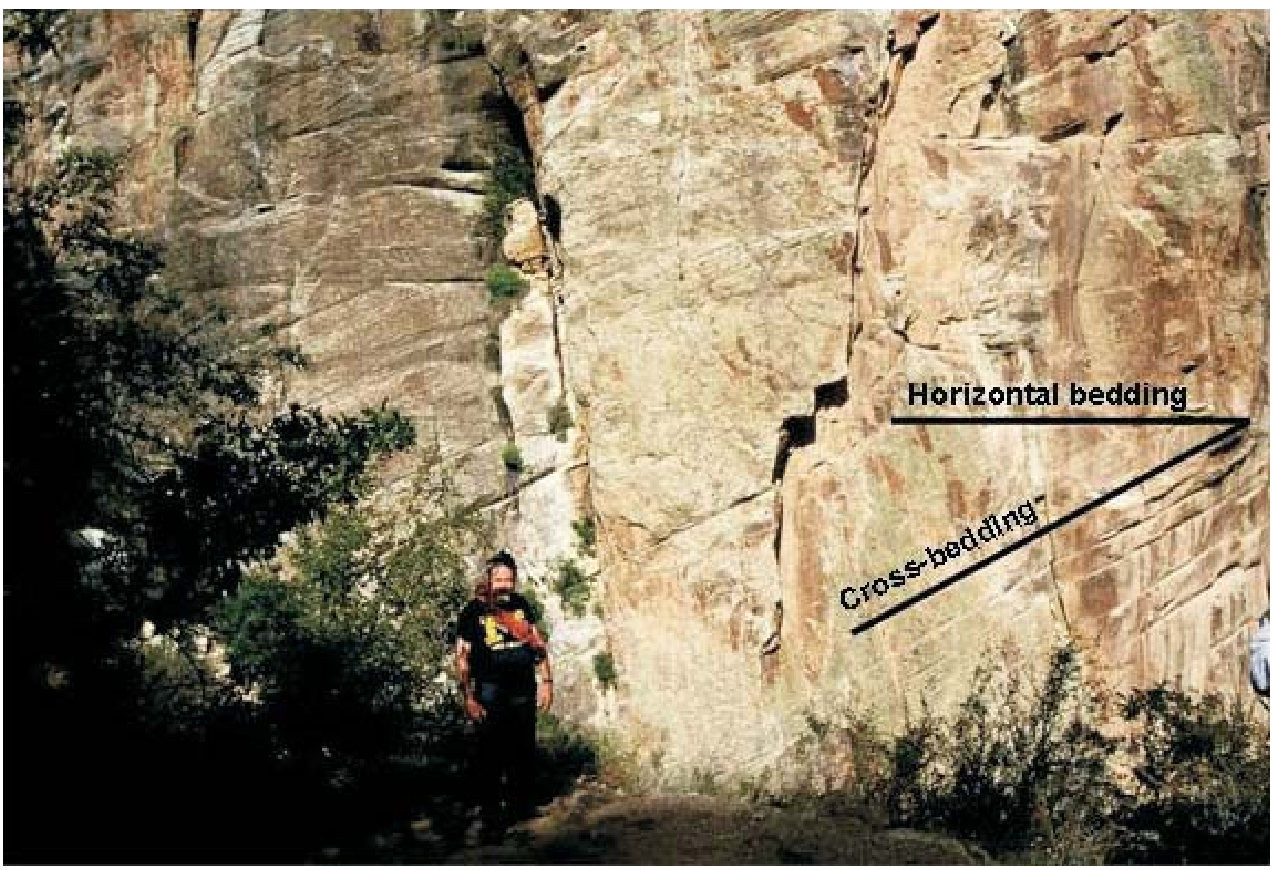

Figure 7. Cross-bedding in the Coconino Sandstone, Hermit Trail, Grand Canyon. Note the wedge-shaped lines in the rock; this is what is referred to as "cross-bedding. The cross-bedding is at an angle to the horizontal bedding, both of which are marked with lines and labels on the photo for clarity. Photo by Carol Hill.

sand is piled any steeper than this, it will avalanche downhill. The cross-beds in the Coconino have been measured between 29–31°. "Frosted" texture in sand grains is caused by the cracking of these grains as they collide when blown about by the wind (natural sand blasting). From all of this evidence geologists have inferred that the Coconino Sandstone originally formed as sand dunes that later became compacted and hardened into rock. These sand dunes likely formed in a vast coastal desert, possibly similar to the Namib Desert of West Africa today.

Flood geologist Steve Austin has proposed an alternative interpretation that cross-bedding in the Coconino Formation was produced by the migration of underwater dunes moving at velocities of three to five meters per second at depths of about 100 meters.[19] These flow and depth parameters were extrapolated from published experimental data produced by observing sand moving in laboratory sediment flumes. In defense of this interpretation, Austin cites a mainstream geologist who also proposed that the Coconino dunes were formed underwater and that the size distribution of Coconino sands is comparable to sands being deposited in the estuary of the Altamaha River along the coast of Georgia. However, that mainstream geologist never envisioned the catastrophic conditions of high-velocity flow prescribed by Austin. Such high velocities cannot possibly account for the preservation of delicate reptile footprints and raindrop prints found in the Coconino Sandstone (Fig. 3, RF, RP).

Tracks. Tracks are impressions left in soft mud or wet sand by the feet of birds, reptiles, or other animals.

Figure 8. Close-up of a footprint (track) made by a small reptile as it made its way up a rain-moistened dune surface in the sands of what was later to become the Coconino Sandstone, Bright Angel trail area, Grand Canyon. Note the tiny, delicate claw marks. Photo by Cyndi Mosch.

Reptile footprints are common in the Coconino Sandstone. These reptile tracks were made by small (lizard-size) to large (Komodo dragon-size) reptiles that crossed the sand dunes about 275 million years ago. These tracks preserve even delicate features such as claw marks (Fig. 8). Incredibly, flood geologists envision these land animals walking on dunes that they propose were moving under currents of 3 m/sec (or more) beneath about 100 m of water!

Burrows. The 500 ft (150 m) thick Bright Angel Shale contains abundant fossils including brachiopods, trilobites, and worm tracks and burrows (Fig. 4). The abundance of worm burrows shows that the accumulating mud was constantly being reworked by these animals at or just below the seafloor surface. A close look at this rock reveals that almost every particle of sediment was ingested and re-deposited by these burrowing and grazing organisms. Flood geologists have suggested that these burrows represent vertical escape trails or structures for organisms that were made during rapid sediment deposition.[20] But marine biologists and geologists know the difference between grazing trails on a normal seafloor (which is what we see in the Bright Angel Shale) and escape trails created under the duress of escaping rapid sediment deposition. Flood geologists must also explain how invertebrate organisms, including soft-bodied types such as worms, could have survived long-distance transport in their postulated turbulent, sediment-loaded currents, where the entire 5,000 ft sequence of Grand Canyon sedimentary rocks was being deposited in only one year's time in a raging flood.

Fossils. Flood geologist Steve Austin in *Grand Canyon: A Different View* concludes that certain fossils found in the Grand Canyon are evidence of "deposits from a flood of truly catastrophic proportions" (p. 53)—presumably Noah's Flood. The fossils being referred to are orthocone nautiloids, *Rayonnoceras sp*., that occur in the top ten feet or so of the Whitmore Wash Member of the Redwall Limestone in Nautiloid Canyon and elsewhere in the Grand Canyon region (Fig. 3, FN).[21] From the scenario illustrated in the Institute for Creation Research's video *Geologic Evidences for Very Rapid Strata Deposition in the Grand Canyon*, Austin speculates that a catastrophic ocean-floor collapse swept the swimming creatures across the seafloor at velocities of four to five meters per second. Remarkably for such a scenario, the skeletons of these creatures are in excellent condition, not showing evidence of breakage or abrasion (Fig. 9). While it may be true that this *ten-foot-thick* layer of the Whitmore Wash Member containing *Rayonnoceras* fossils represents some kind of debris-flow-type deposit, this in no way implies a worldwide cataclysmic flood affecting the entire *5,000-foot-thick* suite of sedimentary rocks exposed in the Grand Canyon! Rather, most of the limestones exposed by incision of the canyon display delicate invertebrate fossils preserved in a manner typical of normal marine conditions.

Figure 9. Orthocone nautiloid fossil in the Whitmore Wash Member of the Redwall Limestone, Nautiloid Canyon. This nautiloid (and other nautiloids in the same vicinity) are not broken up but look perfectly preserved. Photo by Doug Powell.

Why are all of the above-mentioned sedimentary structures in Grand Canyon rocks pertinent to a discussion of flood geology? Because they occur throughout the entire sedimentary rock sequence, from the earliest Precambrian sedimentary rocks up to the canyon rim (Fig. 3). Ripple marks and mud cracks are preserved in the Precambrian Bass, Hakatai, Dox, and Nankoweap Formations. Ripple marks, mud cracks, and raindrop prints can be seen in the Cambrian Tapeats Sandstone. Further up in the stratigraphic sequence, Supai and Hermit rocks display mud cracks, ripple marks, and reptile tracks. The above-lying cross-bedded Coconino Sandstone represents lithified sand dunes that also display reptile tracks. Well-developed mud cracks (polygons 6 inches or more in diameter) have also been observed in the overlying Toroweap Formation, and marine fossils typical of normal marine conditions occur in the Muav, Redwall, and Kaibab Limestones.

Considering all the above evidence, certain critical questions can be asked: If all of the sedimentary rock in the Grand Canyon was deposited in a miles-deep universal flood lasting one year, then why do the sedimentary structures in these rocks indicate a long depositional series of marine to shallow-water to subaerial to sand-dune-forming environments? Why don't *all* of the formations and their fossils throughout the canyon's 5000-foot sedimentary sequence reflect rapid deposition in deep water? How could tiny claw marks in the footprints of reptiles (Fig. 8) have been made and then preserved under turbulent flood conditions? Evidence such as this has convinced mainstream geologists that a Flood Geology interpretation of Grand Canyon rocks is not valid.

Claim #2: No Time Gaps between Formations

Let us now examine the flood geologist's tenet that there was uninterrupted deposition during the year of Noah's Flood and their claim that contacts between formational units do not show evidence of time gaps—or "unconformities" as geologists call these gaps. An *unconformity* in the rock record represents the time that transpires between the erosion of an underlying lithified (changed to rock) unit and the deposition of overlying unlithified sediment. Many such unconformities exist between the major formations in the Grand Canyon (Fig. 3, UC): in fact, they are the rule rather than the exception. However, John Morris in his section of *Grand Canyon: A Different View* uses as his example the contact between the Coconino Sandstone and the Hermit Shale to illustrate his belief that time gaps do *not* exist in the rocks of the Grand Canyon. On pages 42–43, Morris states

> the Coconino … originated in a completely different environment than the Hermit, and according to evolution, was separated in time by about 10 million years. If the Coconino represents a desert … then the ocean bottom which accumulated the Hermit material had to be uplifted, out of the water, to an elevation high enough and dry enough to be a desert.

In a photo on page 43, Morris shows a flat contact between the Coconino Formation and overlying Toroweap Formation and says,

> The existence of the sharp, knife-edge contact between these two beds argues against the passage of long periods of time between their deposition.

How do mainstream geologists interpret the unconformities related to the Hermit, Coconino, and Toroweap Formations? First of all, the contact between the Coconino and Toroweap Formations is *not* unconformable (i.e., on Fig. 3 there is no UC between the Coconino Ss and Toroweap Fm). Or, as it says in *Grand Canyon Geology*: "The boundary (between the Coconino and overlying Toroweap) is conformable in most locations … or the Coconino intertongues with the Toroweap" (p. 207).[22] Second, the Hermit Shale did not form on the "ocean bottom." The Hermit contains mud cracks, raindrop prints, and ripple marks indicative of shallow-water deposition. It formed under sluggish, meandering-stream conditions on a broad, low-lying, arid coastal plain. These fluvial red beds exhibit tracks, fossil-plant remains, and even perhaps the wing impression of a large dragon-fly-like insect—hardly evidence for an "ocean bottom" environment! Over this arid coastal plain, eolian (wind-blown) sands of the Coconino spread southward and accumulated in great dune fields directly overlying the Hermit fluvial deposits. For an excellent book that features colored paleogeographic maps of the Grand Canyon-Four Corners area, showing paleoenvironmental conditions under which sediments were deposited over time from the Precambrian to the present, refer to the newly-released *Ancient Landscapes of the Colorado Plateau* by Ronald Blakey and Wayne Ranney.[23]

In addition to the discussion of the Hermit-Coconino-Toroweap unconformities by Morris, the discussion and photos (on p. 44) by Alex Lalomov of the Great Unconformity in *A Different View* are also misleading. While in this and many other stratigraphic locations the unconformity marks a relatively flat surface over eroded Precambrian crystalline rock, in other places the vertical extent of the Great Unconformity is striking—such as between the Precambrian Shinumo Sandstone and Cambrian Tapeats Sandstone, where remnant ridges of up to 800 ft (240 m) high exist.

Two other types of contact surfaces also demonstrate that long periods of time must have occurred between different formations: channeled surfaces and karstic surfaces. Channeled surfaces exist along the Muav-Temple Butte contact where the Temple Butte Formation fills depressions (old river channels) in the Muav Limestone (Fig. 3, "channel"). A regional karst surface, characterized by sinkholes and caves, and similar to the one forming near sea level today on the Yucatan Peninsula, exists near the top of the Redwall Limestone where the Surprise Canyon Formation has filled ancient (paleo) sinkholes and caves. Prior to the sea advancing in Surprise Canyon time (Fig. 3, UC, Surprise Canyon Formation), karst valleys and sinkholes formed near the top of the Redwall Limestone as the Redwall became exposed to a long period of erosion and karstification—a scenario that begs the question: "How could these karst features have formed in soft sediment in one year's time in the middle of a flood?" Modern caves have developed along this same Mississippian-age (330 million years ago) paleokarst horizon in the Mooney Falls Member because groundwater readily dissolves caves as it moves more freely along this permeable horizon (Fig. 3, black area = cave). All of this is evidence against the YEC claim that there are no time gaps between formations in Grand Canyon rocks.

Claim #3: Massive Tectonic Upheaval

Young Earth Creationists maintain that deformation (tilting) of the oldest sedimentary rocks in the Grand Canyon (the Unkar and Chuar Groups; Fig. 3) coincided with the initiation of Noah's Flood.[24] Or, in other words, all of the sedimentary rock of the Unkar and Chuar Groups had to have been deposited *before* the Flood in order to have been tilted during the initiation of the Flood. However, this claim contradicts one of the basic premises of YEC: that all (or almost all) of the sedimentary rock on planet Earth formed *in* Noah's Flood. The Unkar and Chuar Groups of rock (together comprising the Grand Canyon Supergroup) consist of almost 12,000 ft (3600 m) of sedimentary rock—hardly an insignificant amount of rock to have accumulated between the time of Adam (who, according to YEC lived about 6,000 years ago) and Noah's Flood (about 4,500–5,000 years ago)—especially without any rain being involved in its deposition!

What about a "massive tectonic upheaval" that supposedly took place on the Colorado Plateau as the floodwaters receded? Exactly what this upheaval was, and when it supposedly happened, is unclear from YEC literature. There was compression in the Grand Canyon region during the Laramide orogeny (~60–40 million years ago), and this was the time when the Colorado Plateau was uplifted almost to its present elevation and when most folding occurred. Then there was Basin and Range age extension (starting about 20 million years ago), during which time the Colorado Plateau Province separated from the Basin and Range Province by down-faulting of the Basin and Range along the Grand Wash Cliffs (Fig. 2).

It is presumed that the "massive tectonic upheaval" as hypothesized by YEC occurred during the latter stage of Basin and Range tectonism since supposedly it represents a time when the flood-waters receded. Henry Morris, on p. 4 of *A Different View* describes how the Grand Canyon was carved during this time:

> … a great dammed-up lake full of water from the Flood suddenly broke and a mighty hydraulic monster roared toward the sea, digging deeply into the path it had chosen along the way.

The lake being referred to is Lake Bidahochi, and the work referred to is the "Lake Overflow Model."[25] This model—while popular with some geologists at the moment—is unsubstantiated by the evidence that Lake Bidahochi remained a very shallow lake/playa throughout its history—especially during the time when lake overflow supposedly occurred.[26]

Flood geologists also try to explain tectonic faulting and folding in the Grand Canyon from their position of a very rapid, one-year-long, Noah's Flood. With regard to folding, one (unidentified) contributor to *A Different View* (pp. 32–3) claims that sedimentary layers must have been still soft during episodes of deformation, as evidenced by the tight folds seen along the Butte fault in the Tapeats Formation in Carbon Canyon (Fig. 10). The logic behind this claim is that to account for rocks deforming very rapidly, it is assumed that these rocks were unlithified (still in a wet state) when folding occurred. However, evidence from field studies and rock deformation experiments demonstrate that solid rocks behave in a ductile manner if deformed slowly under great stress. The strata "bend" by microscopic re-orientations of mineral grains and by changes in bedding thickness along the fold. Thus, the tight folds in the Tapeats Sandstone can be explained by mechanical crowding at the synclinal hinge of the East Kaibab monocline.[27] With regard to faulting, it is extremely puzzling to visualize how thousands of feet of offset along Grand Canyon faults could have been achieved in sediments that were still soft! In addition, how could slickensides (polished and smoothed striations made in hard rock by fault action), fault gouge and breccias (pieces of angular rock and earthy material along faults), and the sharply offset rock layers along faults (rather than layers slumping into faults) have formed in rock that was still soft?

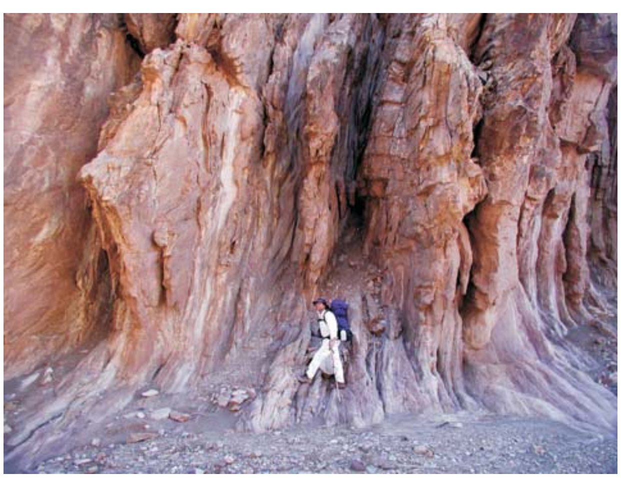

Figure 10. Beds upturned along the Butte Fault, Carbon Creek area, Grand Canyon. The once-horizontal beds of the Tapeats Formation have been folded upwards to a vertical position along the fault zone. Photo by Bob Buecher.

Claim #4: Rapid Erosion

The matter of carving the Grand Canyon into the canyon's sedimentary rocks is covered on pages 30–1 of *Grand Canyon: A Different View*. Essentially, this discussion leads up to the question of "Where did all of the sediment go to that was excavated to form the canyon over the last 70 million years?" "Math calculations" show that "during those 70 million years the river should have eroded a layer more than five miles thick off the top of the entire 137,800 square-mile drainage area of the Colorado River. This massive amount of material is nowhere to be found between the Canyon and the sea, as we would expect." The comments made on these two pages show a lack of knowledge about the geological findings on the Grand Canyon obtained over the last two decades—especially since the Grand Canyon Symposium was held at Grand Canyon Village in 2000.[28] The senior author of this article participated in that symposium and since that time has published a number of articles on the origin of the canyon.[29] The following is a brief summary of her ideas and the ideas of other geologists regarding the most recent geological findings.

(1) From two independent lines of evidence,[30] it has been proposed that a relatively shallow central "proto" Grand Canyon formed during the Laramide orogeny (mountain-building episode 40 to 50 million years ago) when water flowed northward into a broad shallow lake in the Bryce Canyon area (Fig. 2, the proto-canyon existed in the area between the three #1 symbols). This proto-canyon was not nearly as deep or extensive as the Grand Canyon is today.

(2) Basin and Range faulting began along the Grand Wash Cliffs just west of the Grand Canyon about 16 million years ago. This down-to-the-west faulting and lowering of terrain in the Basin and Range Province caused drainage to begin flowing to the west. The canyon at this time (from about 16 to 6 million years ago) occupied the area west of the Kaibab arch (Fig. 2, the area between the two #2 symbols).[31]

(3) At 6 million years ago, the part of the Grand Canyon east of the Kaibab arch "hooked up" with the earlier western canyon to finally become the Grand Canyon traversed by the Colorado River that we see today.[32]

(4) While the above three recent theories are still controversial, it is known from many lines of evidence that the Colorado River has only flowed through the Grand Canyon from Colorado to the Gulf of California over the last six million years.[33]

With respect to the erosion discussion on pages 30–1 of *A Different View*, we have the following three comments to make considering these newer geologic findings:

1. The (unidentified) author of these pages makes the statement that "some geologists claim that the canyon carved by the Colorado River is 70 million years old." But only the central part of the canyon could possibly be this old, and during this time drainage flowed to the north, not to the west as it does today.

2. The math calculations based on a presumed 70 million year old age for the canyon and on the erosion rates and sediment load of today's (pre-Glen Canyon Dam) Colorado River are inapplicable because there was *no* Colorado River flowing through the Grand Canyon before about 6 million years ago. Furthermore, in contrast to the unsubstantiated incision rates used in these math calculations, actual measured incision rates are *too low* (not too high) to explain the carving of the entire Grand Canyon over the last 6 million years.[34] Thus, this "missing mass" must be accounted for by either invoking earlier canyon-erosion episodes (such as a Laramide proto-Grand Canyon) or accelerated erosion rates over the last 6 million years.

3. Therefore, regarding the question asked on page 30 of *A Different View*: "Where did all of the material go to that was eroded from the canyon?" it depends on what time frame one is talking about. Since the Colorado River is implied in the question on page 30, we will consider only the last six million years of erosion. In this time frame geologists know exactly where the Colorado River deposited its sediment load. These sediments are in the Bouse Formation southwest of the canyon (deposited in the time frame of 5.5 to 5.3 million years ago); in the Imperial Formation (of the Imperial Valley in California) deposited in the time frame of 5.3 to 2.8 million years ago; and since 2.8 million years ago, the Colorado River has been depositing its sediments in the Gulf of California.[35]

Conclusion

In this article we have addressed four of the main YEC claims concerning the geology of the Grand Canyon, sometimes specifically using examples from their book: *Grand Canyon: A Different View*. While the Grand Canyon is the "geologic showcase of the world," similar long and complex histories are also written in the rest of Earth's rocks. This consistent and planet-wide evidence is what has convinced geologists over the course of almost two hundred years that Earth's sedimentary rocks are *not* the product of a year-long biblical flood.

If Earth's sedimentary rocks were not deposited in a universal flood, as demanded by flood geologists, should this undermine one's faith in the Bible as God's inspired word? No, because the Bible *never* claims that all sedimentary rock formed in Noah's Flood! Rather, it describes a pre-Flood world that is consistent with a modern landscape overlying sedimentary rock. In our opinion, despite their good intentions, Young Earth Creationists promote an erroneous and misleading interpretation of the geology of the Grand Canyon, if not of the entire planet Earth.

Acknowledgments

We thank the three anonymous reviewers who made this manuscript much better, and we acknowledge the thousands of geologists over the last one hundred fifty years who founded the geologic framework of the Grand Canyon upon which our work is based.

Notes

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Davis A. Young

Essay Book Review

The Historical Reconstruction of Geohistorical Reconstruction

Davis A. Young

WORLDS BEFORE ADAM: The Reconstruction of Geohistory in the Age of Reform *by Martin J. S. Rudwick. Chicago: University of Chicago Press, 2008. xxii + 614 pages, sources, index. Hardcover; $49.00. ISBN: 0226731286.*

If you never read more than one volume on the history of geology, then this is the one you should read.

To initiate a stimulating discussion, ask a gathering of scientists to speculate about the most significant discovery that has been made within their particular discipline. A chemist might point to the periodicity of the elements. A physicist might mention the pivotal role of mathematics. A biologist might call attention to DNA. The ensuing discussion will surely generate many plausible alternatives.

In geology, a strong case can be made that "deep time" is the discovery with the most profound consequences for the study of planet Earth, not so much for the bare fact that Earth is far older than was believed for millennia, but because the discovery of deep time opened up the realization that Earth has a long, dynamic, complex, fascinating *history* all its own that *preceded* human history, not to mention making Darwin's theory of natural selection possible. Until the mid- to late-eighteenth century, a very brief, relatively uneventful Earth history was inextricably linked in the Western world to the human drama that unfolded within the biblical framework of creation, fall, deluge, redemption, and consummation.

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The result of the realization, roughly two centuries ago, that Earth has its own dynamic history is that geologists now almost automatically place the geological phenomena they investigate into a historical context. For example, a buried lava flow provides evidence of a former episode of volcanic eruption, a distinct geological *event* that may be located within a long sequence of events. A fault provides evidence of localized former episodes of earthquake activity, distinct geological *events* that may be located within a long sequence of events. Or a body of stratified sedimentary rock within a larger succession of sedimentary rock layers may provide evidence of the deposition of sediment on a former lakebed, beach, or ocean floor, distinct geological *events* that may be located within a long sequence of events. In every geological mapping project, whether on Earth, Mars, or the moon (the latter two obviously by remote sensing at present), a field investigator seeks not only to establish the relative temporal relationships of the various rock bodies encountered but also to place the geological events that produced those bodies within the larger historical framework of geological time.

Just as US history might be subdivided into discrete, well-defined units such as the Washington presidency, the Adams presidency, the Jefferson presidency, and so on up to the Obama presidency or alternatively into calendar years such as 1787, 1788, and so on up to 2009, so, too, geologists have subdivided geologic time into various units called epochs, periods, eras, or eons. Thus we have *period* names such as Cambrian, Devonian, Permian, Triassic, Cretaceous, and the like or *era* names such as Paleozoic, Mesozoic, and Cenozoic. Every movie buff on the face of Earth knows at least one geologic time period whether or not he or she has taken a course in geology: the Jurassic Period.[1] Thus, geologists may refer to a specific lava flow in northern New Jersey as a *Triassic* basalt or to a lacustrine (lake) sediment in Utah as an *Eocene* mudstone. All geologists understand that a Triassic basalt is a much older rock than an Eocene mudstone. Moreover, geologists will immediately realize that Triassic basalts are on the order of 210 to 240 million years old and that an Eocene mudstone is roughly 40 to 55 million years old.

Geologists, of course, are very much interested in developing general theoretical explanations of various geological processes. They seek to develop general principles of volcanism, tectonics, and sedimentation. Thus, for example, geologists have a theory of partial melting to account for many bodies of magma; a theory of plate tectonics to account for large-scale patterns of volcanism, seismicity, and mountain building; and a theory of marine transgression and regression to explain many sedimentary rock successions. In the end geologists want to apply general principles and theories to specific situations. How, for example, can we apply what we know generally about volcanism to *this* particular group of Triassic basalts in northern New Jersey or knowledge of lacustrine sedimentation to *that* accumulation of Eocene mudstones in Utah?

Most geologists know, in very general terms, the story of the discovery of deep time and of the gradual deciphering of the broad contours of Earth history. Students in the early stages of geology programs are typically introduced to some of the leading players in the story, generally in a course on historical geology. In such a course, fledgling geology majors normally learn the names of such geological luminaries as Georges Cuvier, William Buckland, Adam Sedgwick, Roderick Murchison, Charles Lyell, and Louis Agassiz. Here, too, they encounter the methodological principle that the present is the key to the past, and they also face the daunting prospect of learning the major divisions of the geological timescale. Terms like Paleozoic, Precambrian, Silurian, and Jurassic then become part of their vocabulary.

Introducing Martin Rudwick

A sizeable Anglophone literature has explored the achievements of several key figures in the development of the geological timescale and fundamental concepts of geohistory.[2] But absolutely no one has delved deeper into the historical development of the concept of deep time and what he calls "geohistory" than Martin J. S. Rudwick. Winner of the 2007 Sarton Medal awarded by the History of Science Society, Rudwick is widely regarded as the premier historian of geology. After graduation from Cambridge, Rudwick embarked on a professional career at Cambridge in the Department of Geology and at the Sedgwick Museum as a paleontologist specializing in the morphology and feeding mechanisms of brachiopods. During this work, resulting in his first book, Rudwick's interest in the historical foundations of the Earth sciences began to blossom.[3] He evolved into a historian of geology and migrated to the Department of History and Philosophy of Science at Cambridge where he served as Lecturer. In subsequent years he held appointments as Professor of History and Social Aspects of Science at the Free University of Amsterdam, in the Program in the History of Science at Princeton University, and as Professor of History in the Science Studies Program of the University of California at San Diego. Now in "retirement," Rudwick has returned to Cambridge as Affiliated Research Scholar in the Department of History and Philosophy of Science.

As a historian of geology, Rudwick has not concerned himself with the history of such major geological sub-disciplines as mineralogy, igneous petrology, metamorphism, geochemistry, geophysics, structural geology, tectonics, or economic geology. Virtually all of Rudwick's historical work has concerned the central questions of the discovery of deep time, the development of principles of geohistorical reconstruction, and the construction of the geological timescale. In his own words, Rudwick stated that

> the historical problem at the centre of my research, ever since I turned myself in mid-

> career from a geologist into a historian, has been to try to understand how this new kind of science, with a sense of nature's own history at its core, was first constructed: initially in a quite tentative way, but eventually on such firm foundations that earth scientists now take it completely for granted.[4]

Rudwick's writings are invariably characterized by lucidity, elegance, and thorough research into the original sources. In one of his most significant articles, Rudwick carefully teased apart four distinct senses in which Charles Lyell had incorporated the concept of uniformity in his classic *Principles of Geology*.[5] It was Rudwick who first untangled the strands of the fabric of Lyell's thought so thoroughly.

It is in Rudwick's books, however, where we come to appreciate the remarkable breadth of his knowledge. His major books address several facets of the beginnings of the deciphering of geohistory. These works include the role and significance of a profoundly important group of geological artifacts, namely fossils, that are employed routinely in geohistorical reconstruction *(The Meaning of Fossils*[6]*)*; the establishment of one of the major units of the geological timescale, namely, the Devonian System and Period, named after Devonshire on the south coast of England *(The Great Devonian Controversy*[7]*)*; a critical component in communicating the results of geohistorical reconstruction, namely, the use of illustrations of life forms from the ancient past *(Scenes from Deep Time*[8]*)*; and studies of some of the significant geological texts produced by one of the major participants in the emergence of geohistorical thinking, namely, the great French vertebrate anatomist Georges Cuvier.[9]

Throughout this period of great productivity, Rudwick was blending the great diversity of his research into one vast synthesis of the origins of geohistory. To set the stage for his crowning achievements, under review here, Rudwick published a pair of anthologies of his articles.[10] The first massive volume (708 pages) of his grand synthesis was *Bursting the Limits of Time*, a monumental work that concerned the gradual realization that geohistorical reconstruction is, in principle, a possibility.[11] This volume, noteworthy for its liberal use of original French sources like Horace-Bénédict de Saussure and Jean-André de Luc, examined the period from 1787 (Rudwick's "golden spike"), the year in which French geologist Saussure conquered the summit of Mont Blanc, to 1822, the year in which William Buckland presented a landmark paper before the Royal Society of London describing the discovery of fossil hyena bones in Kirkdale Cave, discovered the previous year. During the period under review, "geology" became a new science, the first *historical* science, and savants who studied Earth processes, phenomena, and history were transformed into "geologists."

Worlds Before Adam

Worlds before Adam, the volume now under review, is a self-contained sequel to *Bursting the Limits of Time*. Rudwick set out to write a narrative that would make his topic familiar even for those who know little about geology or about the England of the first half of the nineteenth century. Rudwick has admirably succeeded in his goal. The reader should come away with an understanding of the evidence that led geologists to their various conclusions. If *Bursting the Limits of Time* concerns the discovery that geological history can be worked out in principle, the narrative of *Worlds* picks up at the point when geologists are beginning to busy themselves with undertaking the grand project of figuring out not only what happened during terrestrial history, but also what were the causes that produced the events.

Rudwick laments the unbalanced Anglophone leaning of much historiography of the era that he investigates, but he has rectified that deficiency by providing a narrative that does justice to the truly international character of the developments described. The reader does meet a plethora of British geologists—after all, they were very much in the thick of the early days of geohistorical reconstruction—but there are also plenty of French, Swiss, Norwegian, Italian, and German geologists in the mix.

Rudwick also admits unabashedly to giving us an elitist account that focuses squarely on the concerns and contributions of leading scientific researchers. Little heed is paid to the popular reception of geological advances or even to the question of the relation of geology to Genesis, a question which, then as now, often exercises lay people much more than professional geologists.

Rudwick stresses that *all* geologists of the time he reviews (and this includes a host of Christians such as Adam Sedgwick, William Buckland, John Fleming, William Conybeare, and Jean-Baptiste Croizet) believed in an earth with a past of "inconceivable magnitude."

Rudwick's masterful narrative highlights several important themes. These include the growing body of information about the details of geohistory, methods of reconstructing geohistory, the relationship between human and geological history, the interlacing of life history with geological history, and the question of transformism and the place of humanity in the history of life. Arguably the dominant issues of the age were the relative importance of actual causes and catastrophic revolutions in reconstructing geohistory, and the directionality or stasis of geohistory. These issues are developed in four parts distributed over thirty-six chapters. Each part surveys several roughly simultaneous but partially overlapping developments. Each chapter is approximately twelve to fourteen pages long and contains an excellent one- or two-page conclusion. A chapter a day is an excellent way to digest this intellectual feast.

Fleshing out Geohistory

In Part I, Rudwick surveys developments in the period between 1817 and 1827 in eight chapters. He begins the narrative with Georges Cuvier, the great French anatomist who founded the science of vertebrate paleontology. In contrast to William Smith, an English surveyor who successfully employed fossil remains as markers of particular rock strata, Cuvier was not content simply to engage in what Rudwick (following Earth specialists of that time) calls *geognosy*, that is, that side of geology concerned with description of the structure and relationships of rock masses.[12] Going beyond simply working out the geometric relations of the relatively youthful Tertiary strata of the Paris basin,[13] Cuvier and Alexandre Brongniart regarded these strata and their fossil content as materials for reconstructing the events of a deep past of "worlds before Adam," a deep past that preceded the advent of the human race. Cuvier saw the potential for doing what Rudwick calls *geohistory*. Moreover, he understood that a significant dimension of geohistory concerned the history of life. From his fieldwork, Cuvier concluded that the geohistory of the deep past preceded human history and was separated from it by a profound revolution that left evidence in the form of extensive gravel deposits and erratic boulders that had been moved far from their source areas.

Similarly, Cuvier's recognition of alternating marine and terrestrial strata in the Paris basin, as indicated by their fossil remains, led him to conclude that previous violent incursions of the sea had also occurred from time to time during the deep past. In essence, his conviction was that the geologic deep past could not be explained entirely in terms of *actual causes*, that is, causes that are observable at present.[14] Knowledge of the fossil record indicated that ancient life forms differed from modern forms, suggesting change in organisms through time, hence implying some directional character to geohistory. But Cuvier, a vigorous champion of the fixity of species, had no use for transformism (what we would today call evolution) such as proposed by Lamarck. And so it was for most of Cuvier's geological contemporaries around the year 1817.

During the years immediately following 1817, many details of the stratigraphic record were filled in. Spectacular discoveries by "fossilists," such as Mary Anning, of ancient marine reptilian creatures, in particular, ichthyosaurs and plesiosaurs in English strata, stimulated research into precise assignment of their stratigraphic position. Building upon William Smith's use of fossils as markers in stratigraphic procedure, several geologists set about to determine local stratigraphic successions and began to correlate English strata with those in continental Europe. Geologic maps continued to improve, and a widely influential compendium of regional British stratigraphy was published by William Conybeare and William Phillips in 1822.[15] These stratigraphic labors laid the foundations for serious geohistorical work.

Alexandre Brongniart and his son Adolphe, Anselm-Gaëtan Desmarest, John Samuel Miller, and Henri Marie Ducrotay de Blainville worked out the precise stratigraphic ranges of individual fossil groups such as trilobites, crustaceans, crinoids, belemnites, and land plants. Increasingly, fossils were regarded as indicators of the history of life, and the strangeness of the life forms of the deep past in relation to modern forms became more striking. That strangeness was emphasized by remains of giant terrestrial vertebrate reptiles found in

Secondary rocks, like *Megalosaur* and *Iguanodon*, along with sparse remnants of small mammalian forms. Growing knowledge of fossils confirmed the realization that life forms extracted from Secondary strata were even less like modern forms than those obtained from the younger Tertiary deposits. Thus the Tertiary age came to be viewed as a means for bridging the gap from the present to the ancient deep past. And yet the widespread unconsolidated superficial deposits (so-called "diluvium") that rested on top of the older Tertiary and still older Secondary strata indicated that an important conceptual gap still remained between the present and Tertiary time.

During these years, work on superficial deposits commonly attributed to a catastrophic geological deluge associated with mass extinction, especially by Cuvier and Buckland (who even linked this event to the Genesis deluge), was supplemented by several studies of cave deposits containing fossil bones of extinct mammals. No *human* remains had been discovered in these superficial and cave deposits. Fleming challenged Buckland's view of the superficial deposits as products of a gigantic deluge, claiming that modern causes, such as several small floods, were sufficient to account for the so-called diluvium.

Geologists intensely debated the adequacy of actual causes to explain the allegedly diluvial deposits and some other rocks from the deep past. The actualistic method was taken for granted by those concerned with geology as a historical science. They agreed that actual causes should be invoked wherever possible. In other words, they wished to explain the past in terms of present observed geological processes wherever that made sense, but most geologists acknowledged that causes no longer operating might also have occurred. From an inventory of historically recorded geological changes, Karl Von Hoff concluded that the cumulative effects of actual causes could have been substantial over long time periods, a view that was reinforced by studies of Mount Etna and volcanoes in the Andes that appeared to have eruption histories clearly preceding the presence of humans or human records. As a result, Cuvier's claim of numerous "revolutions" was no longer considered self-evident. Nonetheless, geologists were still baffled over what present causes could possibly explain the alleged deluge deposits.

Rudwick concludes Part I by describing studies of crustal movements during human history whose effects were visible along the Chilean coastline and at the remains of the Roman Temple of Serapis near Mount Vesuvius. The temple displayed compelling evidence of both up and down local fluctuations of sea level, and a great earthquake that struck Chile in 1822 produced considerable elevation of long stretches of the coast. Geologists pondered whether the Andes could have been uplifted solely as a result of numerous small-scale events or by means of such events punctuated by a handful of enormous cataclysmic uplifts. The adequacy of actual causes to explain the deep past became a hot topic.

Actual Causes under Scrutiny

In Part II, Rudwick examines the years between 1824 and 1831 in nine chapters. During the 1820s, application of Smith's methods of stratigraphy continued to strengthen the framework for geohistorical interpretation, at least for Secondary and Tertiary strata. Paleontological work indicated that life history was directional and progressive. Human history was still regarded as a brief moment topping off a vast span of geological time. Studies of causal Earth physics began to yield important implications for geohistory. The directional character of geohistory was confirmed by Joseph Fourier's application of the mathematics of heat conduction to the cooling of an initially hot earth and by Pierre Cordier's empirical demonstration of Earth's internal heat.

Leopold von Buch and Léonce Élie de Beaumont both deciphered evidence for multiple episodes of folding of strata and crustal disturbance in Europe. Élie de Beaumont worked out the precise timing of these episodes, linked them to drastic revolutions, and envisaged those violent upheavals producing mega-tsunami that resulted in mass extinctions and faunal/floral changes. He attributed the episodes of buckling to crustal shrinking caused by global cooling. For these geologists, actual causes were insufficient to account for mountain-forming events.

Geologists recognized that Tertiary deposits and life forms, being most similar to modern ones, were a good place to start in evaluating the adequacy of actual causes to explain the past. Tertiary strata then might serve as a cognitive gateway to the Secondary. In one significant study, Constant Prévost undercut the reality of Cuvier's alleged alternating marine and terrestrial strata in the Tertiary Paris basin by demonstrating that the different marine and terrestrial deposits interfingered, indicating that both marine and terrestrial environments and faunas had been juxtaposed simultaneously. Studies of other European Tertiary basins further disclosed variations in fossil forms from one basin to another, indicating differences in their precise ages within the Tertiary Period.

On the paleontological front, Prévost showed that mollusk assemblages in Tertiary deposits must have changed through time, while Paul Deshayes identified three successive Tertiary faunas containing an increasing proportion of modern species from older to younger fossil assemblages. Heinrich Bronn developed similar statistics for other fossil groups. These findings gave greater force to the impression of directionality in the fossil record. Geologists proposed that climatic conditions might have changed in response to global cooling, a hypothesis supported by the discovery of fossil corals and tropical plant remains in strata in Arctic regions.

The nature of the "diluvium" persisted as a great puzzle. Geologists continued to accept the reality of a sharp break between the present and the former worlds of the deep past caused by some natural physical event of great intensity. The *diluvium* resulting from such an event was distinguished from *alluvium* along river courses, obviously the product of actual causes. Among the major phenomena marking the putative diluvial revolution were broad U-shaped valleys whose rivers many geologists regarded as incapable of eroding such large valleys, and also erratic blocks scattered across the face of Europe tens to hundreds of miles from their source areas. Henry de La Beche noted the presence of enormous erratics on both sides of the Alps and linked them to sudden uplifts of that range. More puzzling were erratics scattered across northern Europe and in the vicinity of Lake Huron in North America. Fieldwork indicated that these great boulders had been transported from north to south, arguably by an aqueous event of huge magnitude. Jens Esmark suggested glacial origin for erratics, but his idea gained little support. The idea of more extensive glaciation prior to the human era ran counter to widely accepted belief in a gradually cooling earth.

Buckland toured several European caves that had been interpreted as pre-diluvial hyena and bear dens. Meanwhile Fleming suggested the possibility that human hunting led to the extinction of mammals such as the "Irish elk." The youthful Charles Lyell expressed confidence in the directionalism of geohistory thanks to a cooling globe as well as strong advocacy of the explanatory power of actual causes, but he did not rule out violent episodes of sudden change.

George Poulett Scrope as well as the team of Croizet and A. C. G. Jobert closely studied the extinct volcanoes of the Central Massif of the Auvergne in south-central France. Both recognized that the area preserved evidence of an extensive series of phases of fluvial erosion and volcanic eruption, and neither saw any signs that those episodes could be related to a great deluge. Scrope emphasized the importance of vast drafts of time to carry out the uninterrupted sequence of events, whereas Croizet and Jobert argued that extinction in the area must have been gradual, piecemeal, and prior to human presence. To them, actual causes had obviously been adequate in sculpting the terrain.

Questions began to arise about both the antiquity of humans and the transmutation of earlier species (transformism) to form new species. The boundary between the modern and former worlds began to crumble just a bit when Jules de Christol and Paul Tournal both believed that they had found evidence of human remains with ante-diluvial species, but Buckland and Cuvier continued to hold out for exclusively post-diluvian human remains. Although the idea of transmutation of organisms was in the air, the origin of species remained a mystery. Belief in divine design, suggested by the close adaptation of organisms to their environments, was widespread. Cuvier's belief in the extinction of species was also accepted. Étienne Geoffroy Saint-Hilaire suggested that some species might be changed in response to environmental changes during sudden geological revolutions while other species simply went extinct. His view, however, gained little traction because geologists were generally more interested in using various fossil species for precise dating of specific points in geohistory. They wanted to know when a given organism first appeared and when it disappeared. Interest in the history of life overshadowed interest in causation of the origin of species.

Nevertheless, there was enough talk about transformism that Lyell became concerned about its implications for human nature. Wishing to safeguard human dignity, Lyell realized that if the directional character of geohistory proved to be an illusion, then there would be no room for transformism. Within this context Lyell set out to formulate a steady state conception of Earth history.

Lyell's Principles of Geology

In Part III, Rudwick reviews the years from 1827 to 1833 in nine chapters. The focus is entirely on Charles Lyell's famed theory of geohistory and its reception. Lyell planned to write a book that would emphasize the adequacy of actual causes, always acting at the same intensity as at present. In preparation for the ambitious project, he undertook a grand tour of Europe akin to Charles Darwin's voyage on the HMS *Beagle* just a few years later.

Lyell visited the volcanic terranes of the Auvergne, Velay, and Vivarais in France and found the same kind of volcanic evidence in each area. Along the Mediterranean coast of Provence, he was struck by the considerable thickness and substantial amount of elevation of the Tertiary strata. He assessed the proportions of fossil mollusk species in Tertiary sequences for use as time markers. In northern Italy, Lyell examined younger Tertiary rocks of the Apennine region before moving south to visit the Temple of Serapis, Vesuvius, Pompeii, and Sicily. He closely studied Mount Etna and recognized that numerous cinder cones, apparently predating human records, had been constructed on the flanks of an enormously thick pile of lava flows, which in turn had accumulated atop a thick stack of Tertiary strata, all of which contained many fossils of extant species. He concluded that Mount Etna must be unimaginably ancient by human standards, and he came to envision the Tertiary world as continuous with our present world in one unbroken chain of geohistory.

From his observations, Lyell appreciated the adequacy of modern causes for explaining the former world. He also concluded that the operation of actual causes was never more intense than at present. Even as geologists continued to debate the nature of the causes that produced the diluvium, Lyell issued volume 1 of *Principles of Geology* in 1830.[16] He presented an elaborate new "system" of geohistory, a new theory of the earth, à la James Hutton, in an era when most geologists were skeptical of such grandiose theorizing. They were concentrating on establishing and absorbing a wealth of factual geological data rather than indulging in unwarranted speculation. To lay the foundation for his case, Lyell led off with a rather biased and self-serving historical essay followed by an inventory of actual causes that, in his judgment, contributed to both sides of a dynamic equilibrium in a steady-state world. Lyell emphasized the power and violence of modern causes (provided they had been witnessed) to render their successful and exclusive application to the record of the past more convincing and palatable.

Although Lyell's book received much praise for its treatment of actual causes and its firm repudiation of "Scriptural geology,"[17] Scrope, De La Beche, Conybeare, William Whewell, Sedgwick, and others criticized Lyell's rejection of directionalism in favor of a somewhat static model of geohistory. They charged Lyell with confusing highly complex geological processes with the basic physico-chemical laws of nature. His critics all agreed with Lyell on the uniformity of the latter but insisted that the power and intensity of the former had to be established empirically rather than assumed a priori.

Lyell planned to devote a concluding second volume of *Principles of Geology* to his reconstruction of the Tertiary period, which he calibrated on the basis of changing mollusk faunas. However, by continuing his inventory of actual causes and including a discussion of the history of organisms, the projected second volume became so bulky that he and his publisher decided to postpone consideration of the Tertiary reconstruction to a third volume.

In volume 2, Lyell rejected Jean-Baptiste de Lamarck's transformism and adopted the stability of organic species.[18] He expressed skepticism about the reality of mass extinctions (unobserved at present and too drastic for his blood) and argued instead for piecemeal birth and extinction of organisms. To discount the apparent directional character of the history of life, Lyell argued that the fossil record was extremely incomplete, that it was an artifact of systematic biases in preservation, and that higher life forms, preserved only in younger strata, did exist during earlier eras of geohistory but that their remains had either eroded away or had not been preserved, perhaps due to alteration.

Reviewers of volume 2, as did Lyell, also rejected transformism. Whewell thought that species might have a transcendent origin. On the adequacy of actual causes, Whewell postulated the existence of two opposing camps among geologists, those of the "catastrophists" and those of the "uniformitarianists." Implicit in Whewell's discussion was that Lyell was the only member of the latter!

The third volume of *Principles of Geology* contained Lyell's analysis of the Tertiary strata as a test case for his steady-state conception of uniformity with its notion that the identity, power, and intensity of causes of the present remained much the same throughout all of geohistory.[19] Lyell introduced a subdivision of Tertiary strata into Eocene, Miocene, Older Pliocene, and Newer Pliocene groups, from older to younger. He explained the diluvium in terms of modern processes, such as the melting of icebergs at a time of higher sea level or the breaking of ice dams in the Alpine region, rather than a gigantic deluge. He interpreted the old Primary rocks as resulting mostly from plutonic injection and metamorphism, making it impossible to do geohistorical reconstruction because of lack of fossils. The beginning of Earth's history, he said, was a matter of inadequate knowledge. The successive periods of Lyell's geohistory were distinctive, knowable, and datable. Lyell transformed the practice of geohistorical reconstruction by provoking other geologists to articulate their own attitudes to geological method and to geohistory more clearly than they had.

The Aftermath of Lyell's *Principles of Geology*

In Part IV, Rudwick reviews the years from 1830 to 1845 in ten chapters and deals with the aftermath of the publication of Lyell's masterwork. Geologists welcomed Lyell's repertoire of actual causes, acknowledging that he had demonstrated that actual causes successfully explained more aspects of the deep past than they had previously realized, but they never warmed to Lyell's rejection of directionalism or his insistence on the uniformity of intensity of actual causes.

In a cave at Languedoc, France, Tournal found associations of human remains and the bones of extinct mammalian megafauna, leading him to advocate the contemporaneity of humans and extinct animals. Philippe Schmerling found similar associations in a cave at Liège, Belgium. In some cases, stone and possibly bone tools accompanied the remains. On the basis of these findings, Tournal proposed the existence of an ante-historical period preceding the era of recorded human history. However, he was met with skepticism. But then, fossil primate bones were found by Édouard Lartet in France and by others in India and Brazil, finds that reinforced belief in the progressive nature of the fossil record and also raised the troubling question of transformism in relation to human origins.

The directionality of the fossil record was further reinforced by Louis Agassiz's detailed research on fossil fishes. He showed that fish diversity increased through time and suggested that an Age of Fishes in the Carboniferous period preceded an Age of Reptiles which, in turn, preceded a period characterized by mammals. John Phillips did a detailed study of Carboniferous (the lowest part of the Secondary strata) invertebrates, and Roderick Murchison worked downward from the base of the Secondary into the Transition rocks (which he named Silurian). He found abundant fossils of invertebrates but no land plants. Sedgwick investigated even older parts of the Transition rocks, which he termed Cambrian, but found fewer fossils. He proposed the term Paleozoic for the life forms in the Cambrian and Silurian strata.

De La Beche found fossil plants in coal layers beneath the Carboniferous strata in Devonshire. Further study disclosed the existence of flora and fauna that were intermediate between those of Murchison's Silurian rocks and Carboniferous rocks. These deposits of intermediate character were assigned the name Devonian. This finding reinforced Lyell's claim that life forms changed piecemeal without breaks in continuity.

The topic of crustal elevation remained controversial. Élie de Beaumont favored the uplift of the Andes in one sudden violent event, but an 1835 earthquake that produced small elevations all along the coast of Chile was witnessed by Darwin and Captain Robert Fitzroy during their famed voyage on HMS *Beagle.* Darwin returned to England a convinced Lyellian and postulated that elevation and subsidence of landmasses occurred by means of repeated slow vertical movements of large crustal plates, evidence for which he saw in raised beaches, coral reefs, and atolls.

Widespread broad valleys, erratics, poorly sorted gravels, and scratches and grooves on polished bedrock surfaces needed explanation: diluvial currents of water or mud, icebergs melting and dropping embedded rocks, and extended glaciation were all invoked. From field study of modern depositional and erosion features associated with active glaciers, Ignaz Venetz and Jean de Charpentier demonstrated that Alpine glaciers had been much larger in the past. To account for the phenomena, Agassiz proposed the former existence of an ice age during which most of the northern hemisphere as far south as northern Africa had been covered by vast ice sheets. Other geologists began to recognize local examples of former glacial activity. Buckland was convinced of the glacial hypothesis by Agassiz as they toured northern Scotland together. Even Lyell was partly convinced. A major problem for the concept of an ice age, however, was that it ran counter to evidence for a continuously cooling globe, thus conflicting with the directional view of geohistory. On the other hand, an ice age was also akin to a gigantic catastrophe, hence not fitting neatly into Lyell's steady-state view. Debate over the reality of an ice age continued for years, and, of course, Agassiz's theory ultimately triumphed.

The cause of the obviously directional and even progressive sequence of organic remains in the fossil record remained obscure and mysterious. Ironically, even as Lyell continued his attempt to shore up his beleaguered steady-state, uniform model of geohistory, Darwin, his closet ally, was busy working out a causal theory of species origin, thinking that it might help fill a major gap in Lyell's inventory of actual causes. Little did Lyell realize that his major supporter regarding the advocacy of the complete adequacy of actual causes would one day thoroughly annihilate any thought of a steady-state geohistory or history of life.

Final Observations

In *Worlds before Adam*, Martin Rudwick has brilliantly shown how geology became the first of the historical sciences, how early geologists went about deciphering geohistory, and how they came to take the historical nature of geology for granted. While granting due recognition to the importance of social activities and social influences on the development of geology as a historical science, Rudwick parts company from those who would argue that science is simply a social construct. After all, conceptual developments in geology were consistently grounded in solid empirical research, particularly geological fieldwork. Moreover, Rudwick emphasized, the details of Earth history could not and cannot be deduced from a set of first principles, but had to be, and still must be, worked out empirically from what we see in the field. Geohistory could have been different from what it actually is. The lesson, according to Rudwick, is that geology is not the same kind of science as physics. As a result, we ought not hold up any one science as the standard by which others must be judged. The differences among the sciences are real. They must be recognized and then celebrated, not regretted.

The University of Chicago Press has produced a handsome and weighty volume that is worthy of the excellence of this magnificent text. The book is printed on very heavy glossy paper and weighs an intimidating 4.2 pounds (although less than the 5.0 pounds of *Bursting*). The print is clear and very readable. The text is supported by copious, very detailed footnotes. It is also enhanced by 165 original illustrations from early nineteenth-century geological publications, each of which is accompanied by the most comprehensive captions I have ever encountered. Typographical errors are negligible. The headers for chapter 27 were unfortunately continued as the headers for chapter 28. Other than that I noticed only one minor misprint.

Worlds before Adam is a must read for all geologists who desires a better grasp of the roots of the science they love so much. Advocates of flood geology and young-earth creationism would do well to read both this work and its predecessor, *Bursting the Limits of Time*, very carefully. Ideally, such reading would serve as a healthy corrective to the historical errors that abound in the writings of many adherents of that persuasion. And to historians of science who specialize in a science other than geology, I simply say that, if you never read more than one volume on the history of geology, then this is the one you should read. Profuse thanks to Martin Rudwick for providing lovers of planet Earth with such pure intellectual pleasure.

Notes

[1]We should note that *Tyrannosaurus rex*, the villainous dinosaur that wreaked havoc in *Jurassic Park*, never lived during the Jurassic Period, but only during the succeeding Cretaceous Period. *Cretaceous Park*, anyone?

[2]See, for example, Dorinda Outram, *Georges Cuvier: Vocation, Science and Authority in Post-Revolutionary France* (Manchester: Manchester University Press, 1984); Nicolaas Rupke, *The Great Chain of History: William Buckland and the English School of Geology* (Oxford: Clarendon Press, 1983); Leonard G. Wilson, *Charles Lyell, The Years to 1844: The Revolution in Geology* (New Haven: Yale University Press, 1972); James A. Secord, *Controversy in Victorian Geology: The Cambrian-Silurian Dispute* (Princeton: Princeton University Press, 1986); Robert A. Stafford, *Scientist of Empire: Sir Roderick Murchison, Scientific Exploration and Victorian Imperialism* (Cambridge: Cambridge University Press, 1989); and Jack B. Morrell, *John Phillips and the Business of Victorian Science* (Aldershot: Ashgate, 2005).

[3]Martin J. S. Rudwick, *Living and Fossil Brachiopods* (London: Hutchinson, 1970).

[4]Martin J. S. Rudwick, *Lyell and Darwin: Studies in the Earth Sciences in the Age of Reform* (Aldershot: Ashgate, 2005), vii.

[5]Martin J. S. Rudwick, "Uniformity and Progression: Reflections on the Structure of Geological Theory in the Age of Lyell," in D. H. D. Roller, ed., *Perspectives in the History of Science and Technology* (Norman, OK: University of Oklahoma Press, 1971), 209–27.

[6]Martin J. S. Rudwick, *The Meaning of Fossils: Episodes in the History of Palaeontology* (London: Macdonald, 1972).

[7]Martin J. S. Rudwick, *The Great Devonian Controversy: The Shaping of Scientific Knowledge among Gentlemanly Specialists* (Chicago: University of Chicago Press, 1985).

[8]Martin J. S. Rudwick, *Scenes from Deep Time: Early Pictorial Representations of the Prehistoric World* (Chicago: University of Chicago Press, 1992).

[9]Martin J. S. Rudwick, *Georges Cuvier, Fossil Bones, and Geological Catastrophes* (Chicago: University of Chicago Press, 1997).

[10]Martin J. S. Rudwick, *Lyell and Darwin* and Martin J. S. Rudwick, *The New Science of Geology: Studies in the Earth Sciences in the Age of Revolution* (Aldershot: Ashgate, 2004).

[11]Martin J. S. Rudwick, *Bursting the Limits of Time: The Reconstruction of Geohistory in the Age of Revolution* (Chicago: University of Chicago Press, 2005).

[12]Rudwick discussed the contributions of Smith in *Bursting the Limits of Time*.

[13]In the early nineteenth century, investigators of geological phenomena categorized rocks by use of such terms as Primary, Transition, Secondary, Tertiary, and Diluvium. These terms provided a crude geological timescale in that the "diluvium" lay atop Tertiary or older rocks; Tertiary strata lay atop Secondary or older rocks; Secondary strata lay atop Transition rocks or older; and Transition rocks lay atop Primary rocks. In this scheme, then, Tertiary rocks are relatively young.

[14]"Actual" causes were so named on the basis of the French words "actuel, actuelle" meaning "current" or "present."

[15]William Daniel Conybeare and William Phillips, *Outlines of the Geology of England and Wales with an Introductory Compendium of the General Principles of that Science, and Comparative Views of the Structure of Foreign Countries* (London: William Phillips, 1822).

[16]Charles Lyell, *Principles of Geology*, vol. 1 (London: John Murray, 1830).

[17]So-called "Scriptural geology" was the term applied to theories of geology and Earth history that were based primarily on a literal interpretation of the creation and flood narratives. "Scriptural geologists" characteristically rejected the concept of deep time and emphasized the geological capabilities of the Genesis deluge.

[18]Lyell, *Principles of Geology*, vol. 2 (London: John Murray, 1832).

[19]Lyell, *Principles of Geology*, vol. 3 (London: John Murray, 1833).

Anthropology & Archeology

DON'T SLEEP, THERE ARE SNAKES: Life and Language in the Amazonian Jungle by Daniel L. Everett. New York: Pantheon Books, 2008. xviii + 283 pages, plus eight pages of colored plates. Hardcover; $26.95. ISBN: 9780375425028.

This agreeably written account of life among the Pirahã Indians of Brazil is really three books in one. Missionary-linguist-turned-linguist Daniel L. Everett plaits together an account of his life as a North American family man trying to make a go of things in Amazonia, as a linguist whose paradigm-shaking data have sent ripples throughout and beyond linguistics, and as a missionary who experienced a crisis of faith and walked away from Christianity.

Anyone who has had an experience like Everett's attempt to take care of himself and his family in a world that he had never known before, will connect with the adjustments that he made. Everett is self-effacing as he relates his naivete about living in the Amazon, and the effortless prose of the descriptions easily evokes the reader's own analogous anecdotes. Some of the narrative is amusing, as when he sought to eliminate all nonhuman forms of life from his workspace (a Quixotic notion in the tropics). At other times, Everett's tone is somber and panicked, as when he struggled to evacuate his wife Keren, who was suffering from a serious bout with malaria.

If there is a single *raison d'être* for this book, it would have to be the second strand: Everett's saga of discovery of the theory-busting Pirahã language. To put things simply, the Pirahã language lacks elements that linguists had long believed were universal, such as concepts of numbers, adjectives, and the ostensible *sine qua non* of language, recursion. Recursion, simply put, is what allows languages to use embedding to increase the complexity of sentences, as in

> The dog bit the letter carrier.
>
> The dog that I saw bit the letter carrier.
>
> The dog that I saw bit the letter carrier who is new to the route.
>
> The dog that I saw out of the corner of my eye bit the letter carrier who is new to the route because of a retirement.

Contemporary linguistic theory is dominated by—but not restricted to—the ideas of Noam Chomsky who claims that the forms of all human languages are the result of a rather sophisticated feature of the human mind, what Steven Pinker calls the "Language Instinct." Recursion is part of this instinct, or it is supposed to be, and Everett spent years trying to find evidence of this feature before he began to wonder if the shortcoming was not his but that of Chomsky's theory.

We find that Everett was put into the difficult position of having to demonstrate the absence of something. He describes how he wrestled with data and theory, and how he came to conclude that among the Pirahã, a cultural value reduces or eliminates the utility of recursion as a linguistic feature; in other words, culture "impinges on grammar and language in nontrivial ways" (p. 210). This Pirahã cultural value is what Everett refers to as the Immediacy of Experience Principle (IEP). The IEP means that the Pirahã disregard phenomena that are not directly observed (phenomena experienced in dreams qualify as lived experience, by the way). The gist of Everett's claim is that the "shortcomings" of the Pirahã language (for example, no numbers, no adjectives, no recursion) are seen as dependent variables, caused by the IEP. Linguistic forms as dependent variables turn much of the received wisdom of linguistics on its head.

The lack of adjectives in Pirahã presents a clear illustration of Everett's explanation. If I refer to a shirt as "blue," it implies that I am familiar with the larger set of shirts in the world, some of which are blue and some of which are not blue. This generalization is not, of course, grounded in my familiarity with shirts—I have seen only a subset of the world's shirts. But to a Pirahã speaker, to refer to a shirt as "blue" is conceptually—and therefore linguistically—out of bounds since calling a shirt "blue" puts a shirt into a conceptual class in which not all members are known.

Likewise, to refer to "three arrows" wrongly implies that one is familiar with *all* things that share the characteristic of "three-ness." In the example of embedded clauses above, the embedded bit "I saw" in the sentence "The dog that I saw bit the letter carrier" does not work in Pirahã because it implies that I am familiar with all dogs—seen and unseen by me—and, of course, I am not.

Everett does an admirable job of helping the reader through some of the theoretical linguistics that he has to bring in. His synopsis of Ferdinand de Saussure (pp. 198–9) is as good a two-page recap as one will see anywhere. And the set of color portraits of some Pirahã individuals and small groups by photographer Martin Schoeller are striking.

There are, however, two significant drawbacks of the book. The first is the lack of an index, a weakness that reduces the book's utility for classroom use. The second is that if Everett's argument is that culture "constrains" language (p. 236), then the concept of *culture* should receive considerable attention. It does not.

These reservations aside, this is an enjoyable book, with something for everyone, from linguistic neophyte to theory aficionado. It is worth noting that some discomfort is not impossible for the Christian reader because of the third story: Everett's rejection of the faith he once spoke for. This renunciation—if that is the best word for it—is grounded in the Pirahãs' lack of interest in the Christian message as well as Everett's own sense that they did not need it. The parallels in Everett's iconoclasm are striking: increasing familiarity with the Pirahã results in the rejection of orthodoxy in both linguistics and Christianity. They need recursion no more than they need Jesus, Everett seems to argue, and if they do not, then claims of the universal value of linguistic and Christian orthodoxy are empty.

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ETHICS

A SHARED MORALITY: A Narrative Defense of Natural Law Ethics by Craig A. Boyd. Grand Rapids, MI: Brazos, 2007. 272 pages. Paperback; $26.99. ISBN: 9781587431623.

RETRIEVING THE NATURAL LAW: A Return to Moral First Things by J. Daryl Charles. Grand Rapids, MI: Eerdmans, 2008. 346 pages. Paperback; $34.00. ISBN: 9780802825940.

Charles and Boyd both advocate natural law, but for substantially different purposes. For Charles, "natural law thinking will determine our ability to relate to and address surrounding culture" (p. 23). Since all people of goodwill can discern certain basic goods as important to human flourishing, awareness of this natural law allows Christians and non-Christians to engage in moral conversation. Granted, even if there is agreement on what helps human beings to flourish, there is still discussion about which good has the greatest weight in a given situation and how it can best be achieved.

In contrast, while Boyd also sees by natural law an awareness of basic moral norms available to all people, he is more reserved about how much natural law can offer apart from its formative dependence on Christian revelation. Sin has corrupted our apprehension of the natural law, and even if the natural law is to some extent seen by those outside the faith, why should one feel any obligation to follow nature unless one is yielded to nature's designer? Boyd sees attempts beginning with Grotius and continuing to the present day of appealing to natural law as an autonomous secular theory, as fundamentally incomplete. But when natural law is grounded and shaped for Christians by knowing the lawgiver and having godly virtues, the natural law can help guide the Christian life. Boyd credits Protestant pietism with shaping people of virtue who can then better see and live the natural law. In contrast, Charles singles out Protestant pietism for rebuke as too separatist and sin oriented to use natural law effectively in public life.

Charles has a lively, but often dismissive, tone. Authors praised and disparaged match closely the heroes and villains of the journal *First Things*. It is not surprising, and indeed it is fitting, that the phrase "first things" appears in the book title. Charles is a professor at the evangelical Union University in Tennessee and appears to be part of the evangelical movement that has found common cause in bioethics with traditional Roman Catholicism. Most of his quotations and praise are for Roman Catholic thinkers from Thomas Aquinas to John Paul II. The three chapters of the book devoted to applying natural law build from the papal encyclical *Evangelium Vitae*.

Boyd, a professor of philosophy and faith integration at Azusa Pacific University, who completed his doctorate at the Jesuit St. Louis University, critiques incisively ethics associated with sociobiology, divine command theory, postmodern relativism, and analytic moral philosophy. As he tests each view, he looks for understanding and finds insights. Finally, it is virtue theory that he aligns closely with natural law. Natural law offers needed guidance for shaping virtue, and virtue makes natural law livable.

Natural law has twenty centuries of champions adapting it to speak to the personal and social challenges of their times. Both Boyd and Charles know the challenges of our time and offer versions of natural law to help meet them.

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HEALTH & MEDICINE

MEDICINE, RELIGION, AND HEALTH: Where Science and Spirituality Meet by Harold G. Koenig, MD. West Conshohocken, PA: Templeton Foundation Press, 2008. 234 pages, appendix, notes, index. Paperback; $17.95. IBSN: 9781599471419.

Increasing attention has been drawn to the spiritual aspects of patients. This has included studies that explore the role of spirituality and/or religion in both patient care and human health. In *Medicine, Religion, and Health*, Harold Koenig has taken on a difficult task. He has attempted sweeping reviews of several investigative areas that look for correlations between aspects of spirituality and/or religion and various health outcomes. These topics involve a large, complex, and heterogeneous medical literature where the studies vary widely in quality and interpretability.

Koenig's overarching objective is to convince the reader that religion and spirituality can influence health "in a scientifically detectable way" (p. 4). A second formulation of this thesis more specifically states that "psychological, social, and religious aspects of human life can be shown to affect the physical body." He believes that there are aspects of religion and spirituality that are amenable to scientific scrutiny and so can act as "natural" indicators for assessing the impact of religion and spirituality on health. To this end, the bulk of the book is organized according to six areas of physical health: immune and endocrine functions, cardiovascular function, stress and behavior-related disease, mortality, physical disability, and measurable manifestations of mental health.

Koenig begins by presenting his definitions of religion and spirituality. The former he clearly defines as beliefs and practices that involve a relationship with a supernatural being and that are expressed in a community of like believers. Religion is multidimensional, measurable, and quantifiable. However, in the studies that he reviews, the concept of religion is often reduced to single manifestations of religious expression such as worship attendance, belief in an afterlife, or the number of times that Scripture is read per week. This makes his generalizations of the results regarding religion, as a whole, tenuous. His research definition of spirituality includes a "personal relationship to the transcendent" that is rooted in a tradition. His description of tradition is distinctly Christian. Koenig does not make it clear whether he only uses this definition in his own studies or whether he selected for review only the studies that met his definition.

The applicability of the results of his reviews to practice will be more difficult if multiple concepts of spirituality are included in those reviews.

Koenig's stated research method is to review published research in mainstream journals that address the area of physical health. One could call his method a *narrative* review, since it lacks the depth of detail that characterizes most contemporary systematic reviews in medicine. The science of systematic reviews, which includes meta-analysis, has become increasingly rigorous in recent years, with requisite disclosure of considerable methodological detail. Koenig's reviews do not exhibit this rigor. He generally presents the results of his analyses as proportions of positive versus negative study results. While he rightly informs the reader that high quality, randomized trials minimize bias and confounding factors, he does not seem to give greater weight to such studies in his collective interpretations of study results. He does not divulge the criteria for his selection of studies for review, nor does he provide details on the quality of the design, implementation, and analysis of specific studies. No effort has been given to extract data from each study and to combine these data into a true, fresh meta-analysis of all the data from which a "meta-result" could be derived. For example, in the chapter on studies of mental health outcomes, he mentions that five of eight randomized trials showed faster recovery from depression using religious-based interventions compared to secular ones. But he provides no details as to the nature of the interventions used and gives no indicators of the degree of confidence in the results of each study based on their statistical rigor and on the successful implementation of each study as originally planned.

Koenig's consistent conclusion for each area is that the evidence seems to favor various positive health outcomes for those who exercise various practices that are considered religious or spiritual in nature. This may well reflect true positive associations or even causality in some cases, but not giving more weight to results from better quality studies is regrettable. Greater confidence in the results of the studies with negative results would clearly affect the interpretation of the summary result. More attention should have been made to the quality than to the quantity of studies.

There is a need for more and better studies in this area, in order to determine what areas of religion and spirituality can and should be studied (e.g., can/should prayer be studied using scientific methods?) and to prioritize such studies according to clinical need. Researchers could then devise and employ methods appropriate for answering the most pressing questions. Such increased scientific discretion and rigor could help us to identify and apply better interventions and counseling strategies to the spiritual needs of patients.

Koenig's chapter on clinical applicability provides some very helpful suggestions for broaching the issue of spiritual support when seeing patients in clinic or hospital settings. These include the consideration of certain clinical instruments when taking a history of spiritual awareness and need. He demonstrates persuasively that holistic health and spiritual care depend upon the varied roles of chaplains, physicians, and nurses, working along with family, friends, and community. Overall, aside from the methodological deficits observed above, this book provides a good snapshot of a long-neglected and important area of medicine that is of particular interest to many Christians and non-Christians alike.

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History of Science

H. G. BRONN, ERNST HAECKEL, AND THE ORIGINS OF GERMAN DARWINISM: A Study in Translation and Transformation by Sander Gliboff. Cambridge, MA: The MIT Press, 2008. xii + 259 pages, notes, bibliography, index. Hardcover; $35.00. ISBN: 9780262072939.

Just as the first century CE saw no one "pure" Jewish or Christian faith, but multiple Judaisms and Jesus movements, so the nineteenth century saw varieties of evolutionary theories, including different Darwinisms. Sander Gliboff's study is a fresh, well-written, well-researched, and well-argued contribution to the historiography of how Darwin's ideas were introduced, understood, altered, and applied in various national contexts. Gliboff not only breaks new ground in our historical and theoretical understanding of Ernst Haeckel's role in the German assimilation of Darwin (Haeckel's work hugely outsold his intellectual master's), but he also examines the work of Germany's preeminent paleontologist Heinrich Georg Bronn, the person through whom Darwin's *The Origin of Species* first reached its German-speaking readership.

Darwin's own version of evolution (the transmutation of species or descent-with-modification-from-a-common-ancestor-mainly-but-not-exclusively-by-means-of-natural-selection) was centrifugal from the start, as his correspondence, notebooks, drafts, and revised editions of *The Origin* all show. It is well known that selectionism was revised (or watered down, depending on one's perspective) as Darwin made more room in his theory for ideas drawn from Buffon, Lamarck, and others. Remarkable too were the multiple and even incompatible responses of Darwin's readers. Allies and critics, from Thomas Henry Huxley to Samuel Wilberforce, from Baden Powell to George Frederick Wright, from Asa Gray to St. George Mivart, from Alfred Russel Wallace to Aubrey Moore, from George Romanes to William Dawson (to mention but a few) read Darwin in divergent and even unexpected ways. Huxley was skeptical about his friend's gradualism, for instance, and regarded natural selection as a provisional, not yet proven mechanism; Wilberforce accepted natural selection, while offering critiques of evolution more scientific than theological. And that is just a small slice of responses in the English-speaking world. Problems of interpretation mushroomed with the translation of Darwinism into different languages and cultures.

Translation—as we all know from reading different versions of the Bible, if not from personal bilingual experience—is not an exact and mechanical transfer of unambiguous fact, feeling, and meaning between two languages. It can be like a conversation between friends, or lovers, or siblings, or strangers. It can as bad as someone like me, with a tin ear, trying to transcribe what was heard at a live performance of Gabriel Fauré's *Requiem.* Or it can be as good as a trained musician doing the same thing. Much depends on the context, the communicator, and the quality of connection. Much can be missed. And much can be added that was merely implicit, or even absent from the source text. In other words, translation is a kind of interpretation.

Texts are not simply read, they require interpretation, and every interpretation or critical stance carries with it some ideological baggage or personal bias. No interpretation or theory is purely objective or free of philosophical assumption; none is disinterested. According to postmodern hermeneutics, every interpretation is local and particular, and decisively shaped by social and intellectual context. (Traditional theories of interpretation too have long recognized that in the process of textual translation, meanings can be transformed.) And this possibility is increased when the translator acts consciously and explicitly as an interpreter, as was the case with Bronn (1800–1862), who published Darwin's *Über die Entstehung der Arten* in 1860 along with his own notes and commentary, making him a kind of partner in Darwin's project even as interests other than Darwin's ended up being served.

Ernst Haeckel (1834–1919) is known even to casual students of the history of Darwinism for those notorious drawings illustrating his "biogenetic law," a revival of the claim that the anatomical features of modern embryos represent key prior stages of our species' evolutionary past: "ontogeny recapitulates phylogeny" as we used to say. Advocates of Intelligent Design and anti-evolution creationists will be aware of "Haeckel's Embryos," chapter five in Jonathan Wells's *Icons of Evolution: Science or Myth?* (Washington, DC: Regnery [2000], 81–109, with notes at pp. 285–93). And many will remember him as Darwin's leading champion in Germany, as an immensely popular anti-theistic and proto-Nazi philosopher, or as the popularizer of the idea of a "missing link" between apes and humans.

Many with an interest in how Darwinian thought came to be transplanted into a German context will be familiar with such English-language texts as Daniel Gasman's *The Scientific Origins of National Socialism: Social Darwinism in Ernst Haeckel and the Monist League* (New York: American Elsevier, 1971) and his *Haeckel's Monism and the Birth of Fascist Ideology* (New York: Peter Lang, 1997); Frederick Gregory's *Scientific Materialism in Nineteenth Century Germany* (Dordrecht: D. Reidel, 1977); Alfred Kelly's *The Descent of Darwin: The Popularization of Darwinism in Germany, 1860–1914* (Chapel Hill: University of North Carolina Press, 1981); William Montgomery's chapter on Germany, pp. 81–116 in Thomas F. Glick, ed., *The Comparative Reception of Darwinism* (Chicago: University of Chicago Press, 1988 [University of Texas Press, 1974]); Paul Weindling's essay "Ernst Haeckel, Darwinismus and the Secularization of Nature," pp. 311–27 in James R. Moore, ed., *History, Humanity, and Evolution: Essays for John C. Greene* (Cambridge: Cambridge University Press, 1989); Richard Weikart's *From Darwin to Hitler: Evolutionary Ethics, Eugenics, and Racism in Germany* (New York: Palgrave Macmillan, 2004); and Mario Di Gregorio's *From Here to Eternity: Ernst Haeckel and Scientific Faith* (Göttingen: Vandenhoeck und Ruprecht, 2005).

All of the above need now to be re-read and revised in light of two recent studies, Robert J. Richards's magisterial work of rehabilitation, *The Tragic Sense of Life: Ernst Haeckel and the Struggle over Evolutionary Thought* (Chicago: University of Chicago Press, 2008) and the book under review, Gliboff's splendid and nuanced account of the origins of German Darwinism.

In his Introduction—one of the most interesting I have read in a long time—Gliboff explains how it was that Bronn, whose work in the 1840s and 1850s in some ways paralleled that of Darwin, came to translate *The Origin*. Both men sought to explain "the developmental laws of the organic world" (as the title of an 1858 monograph by Bronn put it), and both used the other as authorities in their own work. Both appreciated the appearance of design in nature, even as both sought naturalistic explanations for what they observed. Bronn, however, was a geological rather than biological evolutionist. And differing theoretical commitments represented only one more among other sources of the translation problems faced by Bronn.

In their correspondence (1859–1862) and in Bronn's version of *The Origin*, Gliboff uncovers evidence of negotiation and miscommunication, as well as mutual understanding. There were legitimate questions of technical—scientific and linguistic—meaning. "Natural selection," for instance, was an infamously problematic expression open to varying interpretations, as Darwin was dismayed to discover. How did the old German morphological term *Vervollkommnung* (perfection, or progress toward it) relate to Darwin's use of words such as "progress" and "perfection"? Ideas, and the words employed to express them in their various contexts, have dynamic histories and trajectories. How should "adaptation," "variation," and "selection" best be rendered into German? How could Bronn best capture Darwin's novel or ambiguous uses of well-known words? Gliboff discusses pre-*Origin* German transcendental morphology, including analogies of embryological development with the succession of species found in the fossil record. He introduces how ideal archetypes were, post-*Origin*, turned into biological ancestors. And he shows how Bronn and Darwin were partners in the work of redefining scientific terminology.

Haeckel, we all knew, used Darwinism to transform German biology (morphology, paleontology, taxonomy, and more) as a foundation for philosophical, social, and political reform. Gliboff closes his Introduction by sharply critiquing earlier historians' collectively contradictory views of Haeckel as an anti-Catholic Monist, a Lamarckian, a determinist, an indeterminist, a materialist, an idealist, an advocate of Romantic *Naturphilosophie,* a Darwinist, a pseudo-Darwinist, and, at best, a minor historical curiosity. Haeckel instead is revealed by Gliboff to have been a key participant with Bronn (from whom he learned his Darwin) in a revolutionizing project to re-conceive the sciences of life.

Having situated his main characters in a new narrative, Gliboff proceeds to provide the fine details of the difference Darwinism made in Germany. Chapter One revises our understanding of "The Sciences of Life at the Turn of the Nineteenth Century," that is, before Darwin. Chapter Two, "H. G. Bronn and the History of Nature," serves as an excellent introduction to a scientist too little known outside specialist circles. "Darwin's *Origin*" is the title of Chapter Three, and even specialists will learn from Gliboff's subtle account of the origins, argument, and early responses to Darwin's book. Readers of this journal will be particularly interested in what Gliboff has to say about how Paley's understanding of chance, law, and design affected Darwin's. A careful and illuminating analysis of "Bronn's *Origin*" (his 1860 edition based on Darwin's second, and the posthumous 1863 edition based on Darwin's third) is the subject of Chapter Four. Gliboff rescues the German translation from its unfair "reputation for inaccuracy and distortion" (p. 123). Chapter Five, "Ernst Haeckel as a Darwinian Reformer," is a concise account of the work of a polemical and controversial figure who has been caricatured and condescended to by historians and those offended by his anti-providential and nonteleological interpretation of evolution (among other things). Gliboff succeeds in clarifying Haeckel's views, including his defense of the inheritance of acquired characteristics—which Darwin, remember, accepted as a source of variation—and his rejection of August Weismann's germplasm theory of heredity. In his Conclusion, Gliboff reflects on the changing meanings of "Darwinism" in history—a history complex enough to include the versions of Bronn and Haeckel, a theory thick with multiple uses, meanings, and implications—past, present, and future.

Impressively grounded in the primary sources, and with a keen critical eye on the secondary literature, Gliboff's superb and accessible study is highly recommended for everyone with a serious interest in the history of evolution.

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Natural Sciences

FURNACE OF CREATION, CRADLE OF DESTRUCTION: A Journey to the Birthplace of Earthquakes, Volcanoes, and Tsunamis by Roy Chester. New York: Amacom Books, 2008. xi + 242 pages. Paperback; $24.96. ISBN: 9780814409206.

The majority of this volume is a solid, reasonably accessible overview of the geology that underlies earthquakes, tsunamis, volcanoes, and related phenomena. Several major recent events get particular attention, especially the tsunami of December 2004. There is a lot of attention paid to the human element, so that it could be useful to ministries thinking about disaster preparedness and emergency response.

The book begins, however, with a discussion of historical developments in understanding how the earth works, especially earthquakes and plate tectonics. Unfortunately, this section is rich in science-religion warfare clichés. No matter what the actual theological views of the persons involved, the events are billed as the progress of science and reason against religion and superstition. No matter that many of the early ideas were presented in a clearly religious context—Chester's grasp of Christianity is on par with Richard Dawkins'. Nevertheless, if one ignores the warfare clichés, there is a good review of the major players and events involved in building our modern understanding of how the earth works. Thus, it is a good geology book, but not such a good history book. The book does not have a bibliography or footnotes, but many important publications are cited by author, title, and date in the text, so that a determined reader could track down sources.

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SCIENCE TALK: Changing Notions of Science in American Culture by Daniel Patrick Thurs. New Brunswick, NJ: Rutgers University Press, 2007. 237 pages, index. Hardcover; $44.95. ISBN: 9780813540733.

Founding father John Adams wrote to J. H. Tiffany in March of 1819: "Abuse of words has been the great instrument of sophistry and chicanery, of party, faction, and division of society." The importance of words and their associated meanings was not lost on the Hebrews or on other people in the ancient Near East (and by inference for all those for whom words matter greatly). Jews, Christians and Moslems have always been known as people of the Book.

This interesting volume explores the varied meanings of the word "science" in American culture over the past two centuries. "Science" is an ancient word that has only in modern times been associated with a distinct manner of beholding the world and seeking to ascertain its workings. It is also a word that prompts much reflection, refraction, and reaction. Daniel Thurs seeks to situate the word "science" in its cultural and social contexts, using the lens of the history of science and the manner in which the general public and leading intellectuals have interacted with those who claim to be "scientists." Thurs earned a Ph.D. in the history of science at the University of Wisconsin-Madison in 2004 and concluded a postdoc at Cornell University where he tracked public discussion of nanotechnology. He is presently a member of the faculty in the interdisciplinary master's program in humanities and social thought at New York University.

The puzzle which the author seeks to unravel is why the nation with the largest, most robust scientific enterprise in history has such an ambivalent, even love-hate relationship (my words) with science. He searches for an answer in what he helpfully calls "science talk," namely, how scientists themselves (or those claiming to be scientists) describe what they do, and similarly, how non-scientists describe what science is and what it is that scientists do. Thurs views science as a keyword in understanding American culture and agrees with the noted jurist Oliver Wendell Holmes that "A word is not a crystal, transparent and unchanged; it is the skin of a living thought and may vary greatly in color and content according to the circumstances and the time in which it is used" (p. 6).

Discourse analysis is his chosen method of analysis. Thurs applies it skillfully in a series of five well-chosen, historical vignettes, each of which takes up one chapter: phrenology (a science for everyone), evolution (struggling over science), relativity (a science set apart), UFOs (in the shadow of science), and Intelligent Design (the evolution of science talk). Each chapter has a similar format in which key representatives from the debate are featured. These persons are drawn from popular periodical literature, popular books, and other quotable sources that have formed and influenced public discourse about the nature of science and its relationship to the subject at hand. Each quotation is carefully footnoted, and my own familiarity with four of the five topics leads me to think that Thurs has been judicious in his choices—even if one might disagree with some of his conclusions. He deliberately chose these five examples because they illustrate the complex relationship among scientific claims, scientific disclaimers, persons who merit the moniker of "scientist," the tricky business of demarcating science from other forms of knowledge, public perception of the scientific enterprise which is shaped by public discourse, and a host of other important factors all too frequently overlooked.

The chapters build upon one another to generate an elaborate argument about how the meaning associated with the word "science" has changed in American popular culture. Thurs argues that this public talk is fundamental in understanding America's continuing discomfort with science. Scientists themselves also figure prominently in his presentation and analysis. In fact, he finds scientists as much to blame for current impasses as are members of the general public and public intellectuals: "a science more easily set apart has also been a science more easily set aside; greater distinctness has created novel possibilities for subversion and containment as well as celebration" (p. 3).

Thurs pleads for a more careful and fuller engagement with popular culture from the scientific community. If the goal is clarity and a better understanding of the scientific enterprise, scientists will need to substantially alter their speech to engage the public. This is not because of the impenetrability of science itself, but because of the important role that language, words, meaning, and discourse play in the process. Thurs pleads for all parties to listen more carefully, engage more thoughtfully, exercise more patience, and recognize that none of us can escape our own cultural milieu or the many nonscientific factors that enter into such a discussion. This is a finely nuanced, rich text from which we can learn to think anew about the science and Christianity dialogue, especially in its present representation in American culture.

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PHILOSOPHY & THEOLOGY

EVOLUTION AND EMERGENCE: Systems, Organisms, Persons by Nancey Murphy and William R. Stoeger, eds. New York: Oxford University Press, 2007. 360 pages. Hardcover; $110.00. ISBN: 9780199204717.

One might wonder why emergence is drawing so much attention from scholars across a number of disciplines. Perhaps theologians, computer scientists, biologists, and sociologists are all intrigued by emergence because it depicts a common human experience. These experiences are typically routine, but can also provoke in us a sense of wonder and bewilderment. While chemical reactions, organism organization, and human social behaviors are clearly different, a common logic is inherent to each. That is, at a basic stage, each exhibits a special relationship between parts and a whole. Examples that take these unique parts to whole relationships are all around us. Some would even argue that as you read this sentence an instance of emergence is occurring. Simply put, the parts in your brain (neurons) are interacting in a specific way, giving rise to the whole (ideas) necessary to comprehend this sentence. In addition, the very sentence forms a complex of parts and wholes on several different levels. That common experience is the impetus for exploring emergentism. In *Evolution and Emergence*, the various essays seek to move emergentism beyond mere phenomenological alignment toward a legitimate explanatory option.

This book, edited by Nancey Murphy and William R. Stoeger, offers a collection of essays from philosophers, scientists, and theologians on the topic of emergent evolution. Fittingly, the book's three sections deal with philosophy, science, and theology.

The first section deals with philosophical notions of emergence. The article contributed by Nancey Murphy continues an argument she has made for years. In her view, emergence should be favored over reductionism due to the reality of downward causation exhibited by complex systems. Murphy's chapter is followed by two chapters from Robert Van Gulick. His first chapter is a summary of the primary reductionist, nonreductionist, and emergentist options available in the philosophy of mind. His second chapter addresses the difficult issue of mental causation and its possible reality.

In the final chapter of this section, Terrence Deacon notes that moving from mechanism to teleology requires a massive ontological jump. Instead of trying to reduce phenomenology to physics or to show them to be ultimately incommensurable, he focuses on the possibility that a mediating domain of causal dynamics can fill this gap. To serve this role, he looks to processes in which form generation and propagation are more prominent than either simple mechanistic/thermodynamic processes or fully teleological processes. For Deacon, this means exploring the dynamics of emergence as a naturalistic or "bottom-up" process, much the way other scientific explanations are understood. From this perspective, Deacon strives to demonstrate how semiotic processes—which provide the framework for dealing with such human dilemmas as intention, desire, meaning, and even morality—are both physical processes in every sense of the word and yet can exhibit a causal character that appears to run counter to the most basic tendencies characteristic of other simpler physical processes. Deacon's central contribution is to precisely identify two fundamental inflection points where such fundamental symmetry breaking occurs in dynamic processes of increasing complexity and thus where the apparent "directionality" of causal dynamics diverge. The first inflection point leads to a dynamic dominated by formal rather than energetic relationships (morphodynamics), and the second leads to a dynamic dominated by represented ends and functions rather than mere forms (teleodynamics).

Scientific topics are covered in the second section. Working with the assumption that physics is not a complete explanatory schema, George Ellis adopts emergence as a way to assess causation and existence. Don Howard's chapter walks the reader through an assessment of the relationship between particle physics and condensed matter. He urges us to not be hasty in characterizing this relationship as emergent. Martinez Hewlett discusses the origin and complexity of life as a biological example of the need for "higher-order" explanatory models. The chapter from Alwyn Scott delves into the nature of nonlinear phenomena and their role in what he calls the "cognitive hierarchy."

Warren Brown's chapter describes a "bare bones" outline of a robust model for mental causation. The structure of this model includes a look at several challenging issues, including the nature of learning, the function of action loops, and symbolic representation, among others. His primary claim is that the best way to establish mental causation is to acknowledge that "mind is embodied and embedded in action in the world." By affirming embodied mind, Brown is a physicalist. With the mind embedded in action, he is a proponent of mental causation. Along these lines, Brown's use of emergence is not one of radical discontinuity between mental functions in humans and those in nonhuman animals; instead, he blurs this continuum. It is not that human mental causation is merely quantitatively different from other animals. The emergence of symbolic abilities and language allow for a qualitative difference as well—again, not in any discontinuous sense (human mental abilities find their precursors in our nonhuman relatives). Brown's efforts to establish downward/mental causation is laudable, but many questions remain: Does mental causation operate via efficient causes? If so, how? If not, what kind of cause is it? As an admittedly "bare bones" attempt, Brown's is an intriguing first step.

In section three, we move to theological chapters. William R. Stoeger has contributed an article that assesses the intricate relationship between emergence and reductionism. This interaction, he believes, offers a valuable resource for the wider interaction between theology and science, generally, and issues on divine and human action, specifically. Arthur Peacocke continues an argument he has made consistently for some time now. He believes that the picture of reality set forth through emergence is monistic and hierarchical—features that allow theologians purchase with regards to whole-part causation. Niels Henrik Gregersen explores artificial life as a possible resource for theologians with its emphasis on novelty, its attention to the actual and possible, and its awareness of the emergence of autopoietic systems—all of which have religious and theological repercussions. The final chapter of the volume is Philip Clayton's preliminary attempt to construct a Christian theology of emergence.

Catholic theologian John Haught's chapter describes and assesses the insufficiency of "scientific naturalism." For him, this position is exemplified by two commitments: first, there is nothing beyond nature, and second, the natural sciences are touted as the only accurate explanatory schema for dealing with this reality. Haught believes this "scientistic" view is fatally flawed because it ignores or dismisses the reality of subjective experiences which are clearly part of the natural world. Emergence provides Haught the means for affirming novelty, striving, and subjectivity as real and irreducible aspects of the world. Following the work of Alfred North Whitehead, Bernard Lonergan, Michael Polanyi, and Pierre Teilhard de Chardin, Haught argues for a "richer empiricism" that takes seriously "*the widest possible range of what we actually experience in the world*" (emphasis in original). There is certainly a type of naturalism that fits the model Haught has developed here, but naturalism is not the problem. Instead, it is the eliminative approach that some take—either reducing to "basic" particles or inflating to subjective ideals. Emergence is not a rigorous position because it eliminates reduction, but because it establishes a middle ground between the physicist and phenomenologist.

Overall, this is a helpful addition to the study of emergence. Several of the articles may be a bit challenging for the nonscientific reader, but the struggle is worth overcoming. Oddly, Oxford recently published another book that shares a very similar structure—and even several of the authors (see Philip Clayton and Paul Davies, eds., *The Re-Emergence of Emergence*, 2006). While there are differences between these texts, the exuberant price of each will likely prevent one from purchasing both. Either text will have a similar result: a thorough introduction to the topic of emergence from diverse perspectives.

Reviewed by James W. Haag, Postdoctoral Visiting Scholar, Center for Theology and the Natural Sciences, Berkeley, CA 94709.

Religion & Biblical Studies

MISSION IN THE 21ST CENTURY: Exploring the Five Marks of Global Mission by Andrew Walls and Cathy Ross, eds. Maryknoll, NY: Orbis Books, 2008. 219 pages. Paperback; $25.00. ISBN: 9781570757730.

Science is a worldwide endeavor. We have become accustomed to people and ideas crisscrossing the continents. The Christian faith is increasingly interconnected across the globe as well. Barrett and Johnson estimate that two centuries ago less than five percent of the Christians in the world lived outside Europe and North America. They estimate that today sixty-five percent of Christians live outside Europe and North America. Given that increase outside of traditional centers, the mission outreach that has always been part of the Christian faith is no longer just north to south or west to east. The largest church in Kiev, Ukraine, has twenty thousand members and was founded by a Nigerian. The second-largest sender of missionaries in the world is now Korea. With Christianity a global movement, mission can be from every corner to every corner.

This anthology exemplifies that development. Nineteen chapter contributors from six continents are brought together to describe how the mission of the church is perceived and practiced worldwide. The book contains articulate voices, not only from the USA and the UK, but also from Nigeria, Sierra Leone, Uganda, Ghana, Kenya, South Africa, New Zealand, Brazil, India, Korea, Japan, China, and the Philippines. The authors are connecting life in the historic Christian faith with strikingly different contexts. That offers "a glimpse into how other people follow Jesus in their contexts and listen and learn from other travelers along the way."

Speaking from a plethora of fellowships and places, Part One is organized to address the five marks of mission stated by an Anglican Consultative Council in 1990. Those are to (1) proclaim the Good News of the Kingdom; (2) teach, baptize, and nurture new believers; (3) respond to human need by loving service; (4) seek to transform unjust structures of society; and (5) strive to safeguard the integrity of creation. This framework and two authors addressing each mark lend the anthology significant coherence even as it treasures a diversity of perspectives. Part Two focuses on seven issues for modern missions. Those include, for example, one chapter on the formative role of international migration and another on worship as a point of outreach. Each chapter is insightful, although footnotes (rather than book endnotes) and an index would have added to the utility of both Part One and Part Two.

As the Archbishop of Canterbury writes in the preface, "We see more and more of [the Word's] depths as we see more and more of what it does in diverse lives and worlds." *Mission in the Twenty-First Century* exemplifies the worldwide conversation and shared commission of the Christian faith. We have much to learn from each other and much to do together.

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RELIGION & SCIENCE

BACK TO DARWIN: A Richer Account of Evolution by John B. Cobb Jr., ed. Grand Rapids, MI: Wm B. Eerdmans Publishing Co., 2008. 434 pages. Paperback; $36.00. ISBN: 9780802848376.

The book emerged from a conference on process theology, evolution, and religion. Editor John Cobb Jr. is an expert on Whiteheadian process theology. He has drawn together like-minded contributors who regard this world as reflecting an intelligent purpose. They accept the theory of evolution and humanity's shared, common ancestry with other species, but some contributors questioned the exclusion of subjectivity from science. There are four major sections in the book with an introductory preface to each by the editor. In Section II, Cobb evaluates the alternatives to Darwinism.

The contributors aim to demonstrate a role for God in creation by integrating science and theology. A major thesis of the book is that the radical denial of any role for God in evolution is the consequence of the metaphysics closely associated with, but not required by, science. The contributors introduce Whiteheadian philosophical ideas into the dialogue between evolution and science, an alternative that moves away from issues that have been debated over the last one hundred years. They claim that thoughts provide a better explanation than the mechanistic and materialistic concepts often now employed in science. Life is bound up with an urge to live, and organisms aim to live well and to live even better. Because science is objective, it appears uninterested in considering subjective matters. Yet complex forms of subjectivity have emerged from very simple ones. These writers show that science without subjectivity presents an inadequate explanation of the wonderful world in which we, evolved hominids, live; we are a part of this evolving creation.

Biologist Francis Ayala presents several excellent articles, emphasizing that there is no need to have to choose between evolution and God. He represents a neo-Darwinist approach to biology and agrees that science should have an objective view of the world and Christians should reconcile their faith and science. He sees the need to connect with believers in the church pews if the concepts of science are to change the beliefs of "creationists," because these Christians should see evolution as an ally. He says that scientific knowledge is highly significant in Western cultures as it concerns itself with relationships and the systematic organization of knowledge.

In chapter 3, Ayala examines the idea of reductive thinking as applied to organisms and explores the relationship between the whole and its component parts. He expands his ideas in chapter 4 regarding the frontiers in biology, from egg to adult, brain to mind, and hominid transformation to humans, including the relevance of the FOXP2 DNA sequence and speech. He postulates that morality could be a by-product of other adaptive cognitive capacities. Ayala is firm in maintaining that an expanded neo-Darwinism could explain the biota. He maintains that process theology in cosmic history is concerned with a broad directionality and teleology and not in a detailed preordained goal, where the future is unpredictable and never inevitable, where God leaves alternatives open, for God is a God of persuasion and not of coercion.

Biologist Jeffrey Schloss presents an excellent paper on the current status of Darwinism. Pete Gunter, a process theologian, assesses the evidence relating to neo-Lamarkianism. Many studies have demonstrated that organisms may acquire genes from other organisms, and behavior does affect genes. This Baldwin effect, affecting the phenotype of an organism, is also discussed in other articles in this book. Reg Morrison presents an excellent paper with interesting material on hydrogen's unique chemistry and contribution to organic chemistry. He too draws the reader's attention to the action of other essential elements.

Lynn Margulus expands on the Gaia hypothesis, showing the earth to be a self-regulating system and, in general, neglected by science. This approach transcends traditional biology and shows that neo-Darwinism is an inadequate concept when attempting to explain a "whole earth approach." Margulus and Dorian Sagan delve into symbiogenesis, a valid ecological phenomenon, and discard neo-Darwinism.

Several writers address emergence, a hierarchy or a series of ascending levels that arise from the ones below. Ian Barbour discusses evolution and process thought, suggesting there could perhaps be brief periods of change with many genes involved, followed by long periods of stability. Several papers further explained the issue as to whether evolution can be influenced by the environment, the makeup of the organism, and random genetic mutations. The environment influencing "genetic change" challenges a central dogma of science.

It seems that most of the contributors would consider it as practical wisdom to actively resist teaching "creationist" beliefs in the public schools as science, as this would favor one religious viewpoint. Howard Van Till says that naturalism denies the reality of God and has put nature in God's place. Yet the sciences can say nothing about the being or the nonbeing of God. The fine tuning of the laws of a carbon-based nature run by hydrogen needs to be re-assessed and expanded.

John Green also made a significant contribution to the history of evolutionary thought, again noting that some in science aim to exclude God from his universe. He argues that scientific naturalism has reduced human experience to sensory perceptions and human nature becomes a product of natural processes. R. J. Valenza, a mathematician, presents an excellent paper about the new atheism, saying that the physical world is rational, occupied by autonomous life with consciousness and the ability to be aware of its environment.

Other writers explored the postulate of an encounter with an eternal Mind. Because rationality underlies our world, if anything exists then something preceded it, thus allowing for God, a divine attribute of absolute simplicity. Process theology allows for many levels of activity in humans between molecular structure and personhood, concentrating on what is of value to the organism as a subject rather than Darwinism that limits itself to a study of objects.

The book achieves its aim in demonstrating that a materialistic approach to evolution is inadequate and misleading, and that a rejection of purpose in evolution is to embark on a metaphysical, not a scientific approach. The book shows that there is a better-based metaphysics available. This book has a Contents page, a contributor's profile, extensive footnotes documenting sources, but no bibliography or index. *Back to Darwin* is recommended to readers of this journal.

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Social Science

IN GOD WE TRUST: Understanding the Culture War in a Scientific Age by Victor Shane. Summerland, CA: Para-Anchors International, 2008. 212 pages. Paperback; $19.95. ISBN: 9781878832054.

What is America's culture war really about? Who are the warring factions, and what do they want? What set of beliefs drives the ideology of the Christian right? Conversely, what set of beliefs drives the political left? How do these beliefs divide America when it comes to the Judeo-Christian worldview, abortion, human sexuality, and euthanasia? These are just some of the questions that Victor Shane addresses in the book currently under review.

In a vividly written composition of essays, Shane seeks to demonstrate that America is in need of another religious awakening. He attempts to stir the hearts and minds of the silent majority in American society who realize that the United States was founded upon a biblically based moral code, and contends that if America would lead the way back toward higher moral ground, the world would follow in short measure. Several assumptions and presuppositions underlie the book under review. For example, Shane holds that truth is noncontradictory, is consistent with reality, and is the essence of successful prediction. Moreover, he holds that the cosmos (i.e., the sum of physical reality) is a single, finite system with a definite beginning and end. Further, he contends that there is no separation of cause and effect. He asserts consistently that the Bible uses language of analogy, accommodation, metaphor, and symbolism.

In chapter one, "God and the World: Dichotomy, Not Dualism," Shane notes that there is a dichotomy between Creator and created thing that is apparent in the polarization of the US Congress and the judicial system. He favors the term dichotomy over dualism to mark the proverbial Manichean struggle between left and right, believer and nonbeliever, and conservative and liberal. In chapter two, "Creator and Created Thing: The Dichotomy," Shane seeks to establish the atemporality of the Judeo-Christian God. He notes that only God is original and that the cosmos—and hence everything in it—is derivative. This labeling of derivative versus original begins a consistent contrast throughout the book that demonstrates how (post)modern society continually chooses derivative living over and above original living. He asserts that all of the cultural wars present in American society today are, in fact, due to the clash of these two competing worldviews, whether it is an issue of abortion, same-sex marriage, or death-on-demand. Shane asserts that ethical prescriptions should correspond to physical descriptions of the world in chapter three.

Revealing the obvious influence of Robert Bork's *Slouching towards Gomorrah* (Regan Books, 1966), Shane claims in chapter nine that American Christians must use the American political system to revive the original consensus in the due process of law and to fix the things that are broken in America. Naturalists, humanists, atheists, radical feminists, homosexuals, abortionists, and pornographers all tend to deny the existence of the Creator and give primacy to the created thing, according to Shane. In chapter fifteen, Shane asserts that the challenge before American Christians today is surmountable if they become once more salt and light, swaying society back toward the God of their faith.

In sum, Shane invokes reference to the Ten Commandments in virtually all of the fifteen chapters. One criticism of my own is that Shane is not consistent in his appellation of original to that which is good, and derivative to that which he perceives as bad, which makes the consistent employment of these terms problematic, and somewhat belies the usefulness of this typology of classification. Moreover, Shane's lack of gender neutrality in pronouns perhaps hurts the dissemination of his ideas. I contend that Shane also at times misuses the Scriptures and does not convey its original sense in an appropriate manner. Though I do not agree with his particulars at all times and the language used is often inflammatory, nevertheless, the intent behind this book is well-founded, and its message should be heeded. As such, I deem it a profitable read.

Reviewed by Bradford McCall, Regent University, Virginia Beach, VA 23464.

Letters

The River Pishon Flows Again?

I received an interesting e-mail from a Saudi Arabian who read my article "Garden of Eden: A Modern Landscape" on the *PSCF* website (*PSCF* 52, no. 1 [2000]: 31–46). Here is what his e-mail said:

> I read your article on the Pishon River—this totally amazed me as something interesting happened recently. Just in November 2008 there were very heavy rains in northern Saudi Arabia—the heaviest in 70 years. There was so much water that the desert turned into lakes (still there, and people are jet-skiing in these waters!). The flow cleared a lot of dust and sand from an ancient riverbed that nobody cared much for. This is Wadi Rumma (or Rimah as per the map in your article). I did go there a week later and saw the water was still flowing. Unfortunately my camera conked out on me but I do have pictures taken by others.

This e-mail helps support the idea that the Wadi Rimah-Wadi al Batin was the ancient Pishon River of Gen. 2:11–12, and if climatic conditions were right, it could flow again!

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Chasms in Gaps

Ronald G. Larson, in "Revisiting the God of the Gaps" (*PSCF* 61, no. 1 [2009]: 18), wrote:

> If we apply methodological naturalism to the history of Christianity, and avoid GOG thinking, are we not led to seek the origin of Christianity entirely naturalistically, and so assume that the early church came to believe in the resurrection of Jesus through error, fraud, or legend?

This question tragically assumes that methodological naturalism is philosophical naturalism, dogmatically equivalent to scientism and materialism. But an empirical method does not determine philosophical and theological outcomes. It only provides that science is limited to what is empirically testable, whether directly or indirectly. The resurrection of Jesus is outside of the scope of science, first, because it is unique; second, because it is ascribed to a Power outside of nature. Larson's question involves an egregious error.

A second error that permeates the paper is the unspoken assumption that the explanations filled by God of the Gaps arguments represent places where natural explanations are impossible. It is, for example, the dogmatic assertion that the Almighty God could not have created a universe where natural processes produced life. Is Larson competent to place this limit of the wisdom, knowledge and power of God? The "Summary and Final Thoughts" (pp. 20–21) indicate that he is not aware of the tension between the body of his paper and classical theology.

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Natural Explanation but Half the Story: No Room for God There

The wide-ranging article "Revisiting the God of the Gaps" (*PSCF* 61, no. 1 [2009]: 13–22) by Ronald G. Larson made me uncomfortable because of how often the phrase "argue for the existence of God" appears. I wonder whether a scientific (natural) explanation trumps a Christian explanation. Let me make three points.

First, here is a situation which makes plain that there are always two explanations (if not more). A plane crashes. The first question: Was it pilot error or a system failure? Science deals with things like the system of this plane and the system of the world. The question of pilot error shows that there can also be an explanation in which the agent responsible for the flight made a mistake. Although in this case we have alternative explanations, they are not of the same type.

Consider the following scenario: I walk into a room and see the kettle boiling. I ask, "Why is the kettle boiling?" A wise-acre in the room tells me that electrons running through the heater wires collide with irregularly placed atoms and make them vibrate violently. These vibrations pass to water molecules and when they vibrate with sufficient energy some molecules leave the liquid phase. We say the water is boiling. Of course, I was expecting another explanation, "we are making tea." Here we have two valid explanations, at least two that will always exist when humans do something.

Second, a God-of-the-gaps explanation will always fail if it is offered at the level of science, because proper scientific explanations do not invoke an agent as a factor in the phenomenon considered. The examples of the boiling kettle and the plane crash make it plain that this material kind of explanation is complete in itself.

Since the Christian faith is so utterly materially based (the Creator's choice), I do not think it impossible that there will be a scientific explanation found for everything to which we pay attention. But as Polanyi in *Personal Knowledge* makes clear, both choice and moral questions enter into the doing of science: thus the explanation of even scientists' actions can always be made in terms of the agent's purpose.

Third, since without invoking an agent one cannot discuss design, let us go to a level where both kinds of explanation can be used. At this level, when observing the world around us, we face an ambiguity. I look at the cosmos and assert that God the Creator made and sustains it. The materialist, when looking, retorts that the cosmos just exists; there is no evidence of God. I want to show evidence of God's existence, but then realize that I can only demonstrate his presence in one place in the cosmos by contrasting it with his absence in another. However, I am comforted because I perceive that the materialist has the same difficulty. The conclusion: barring information from another source than the nature we observe, we are stuck with this ambiguity.

Looking at the cosmos, are we looking at an artifact with a designer? Again we have ambiguity unless there are grounds for claiming some communication from the artificer. We are inevitably forced back to Scripture and history, and our personal relationship with God.

For an exciting and detailed discussion, in which the author faces and appreciates all of scientific theory, I recommend *Pascal's Fire: Scientific Faith and Religious Understanding* by Keith Ward. He makes a very complete theistic speculation, using only the revelation common to the monotheistic religions and matches it to the best naturalistic or materialist speculations. For his own reasons, he stops with the theistic case—although, because of other things he has written, I know he could go further.

In sum, let us insist on the existence of the two basic kinds of explanation—it is not a matter of preference or religion. Christians need to recognize the essential ambiguity of all we observe, namely, the cosmos. This ambiguity is an expression of the freedom and responsibility God has given humankind.

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Larson Responds to Taylor and Siemens

C. P. S. Taylor expresses discomfort with my "arguing for the existence of God" and reminds us of the "essential ambiguity of all we observe." I agree that our observations are interpreted in different ways, and I did emphasize that apologetics cannot, on its own, bring us to God. It is also true that for many, no argument from design is necessary for them to believe in God, and for many more, no argument will ever be sufficient. However, there are both Christians and non-Christians who find such arguments to be useful "pointers" or indicators that the material world is not all there is. Some former atheists (such as Antony Flew) have been helped by such arguments. Taylor feels that one can only argue for God's presence in "one place in the cosmos by contrasting it with his absence in another." However, I believe that some of us simply recognize God's design more easily in some phenomena (such as "fine tuning") than in others.

David Siemens takes issue with my suggestion that consistent avoidance of God of the gaps reasoning would lead one to seek to explain the resurrection of Christ naturalistically. He argues that this "assumes that methodological naturalism is philosophical naturalism, dogmatically equivalent to scientism and materialism." He explains that the resurrection of Jesus is "outside the scope of science." I agree that science cannot prove that the resurrection occurred. However, it can, in principle, provide evidence in support of, or, hypothetically, against the biblical account. Carbon dating can be used to establish the antiquity of documents (such as the early fragment of the Gospel of John), or could, again hypothetically, establish the antiquity of any remains that might be claimed to be those of Jesus. While it is highly unlikely that an airtight case can be made either way from such findings, the examination of the physical evidence (e.g., manuscripts or archeological findings) has led a number of initially skeptical individuals, such as Lee Strobel, to embrace the resurrection as historical. In his books and debates, William Lane Craig makes compelling arguments based on evidence and reasoning. Paul, in 1 Corinthians 15, points out that many of the five hundred witnesses to Christ's resurrection were still alive at that time, and, in principle, available to support Paul's claims. Even more significantly, Jesus himself asked Thomas to touch his wounds, thus providing physical evidence of his resurrection.

Siemens' argument, applied to this case, would correctly conclude that even direct physical evidence of this kind would not prove that God had raised Jesus from the dead, since this would involve "a Power outside of nature." But the evidence was convincing to Thomas. To invoke any such evidence, now or then, is to risk a "God of the gaps," since any new evidence, for example, that Jesus had survived the cross without dying, or that the disciples had stolen his body, would undermine the case for the resurrection. "Gaps" lurk in all arguments for the resurrection of Jesus, since one can always claim that strong evidence against the biblical account might arise in the future and its absence at present is a "gap" that can eventually be filled. In this sense, to avoid completely "God of the gaps" arguments is to abandon any rational defense of Christianity, despite the examples of such defenses mounted by the apostle Paul.

Siemens' second point is that I make the "unspoken assumption" that explanations involving God represent situations where "natural explanations are impossible." This assumption was unspoken, because I did not wish to claim such a thing! Design arguments involve not impossibility but implausibility based on what is currently known. Future findings may alter one's assessment of the situation. I do not wish to "dogmatically assert that God could not have created a universe where natural processes produced life." Nor do I wish to assert that God "could not have created" the universe and everything in it only 6,000 years ago, if he wished to do so. I only say that, based on reasoning from the evidence, it does not appear to me that God did either of these.

I thank both Taylor and Siemens for carefully reading and critiquing my article.

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American Scientific Affiliation

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