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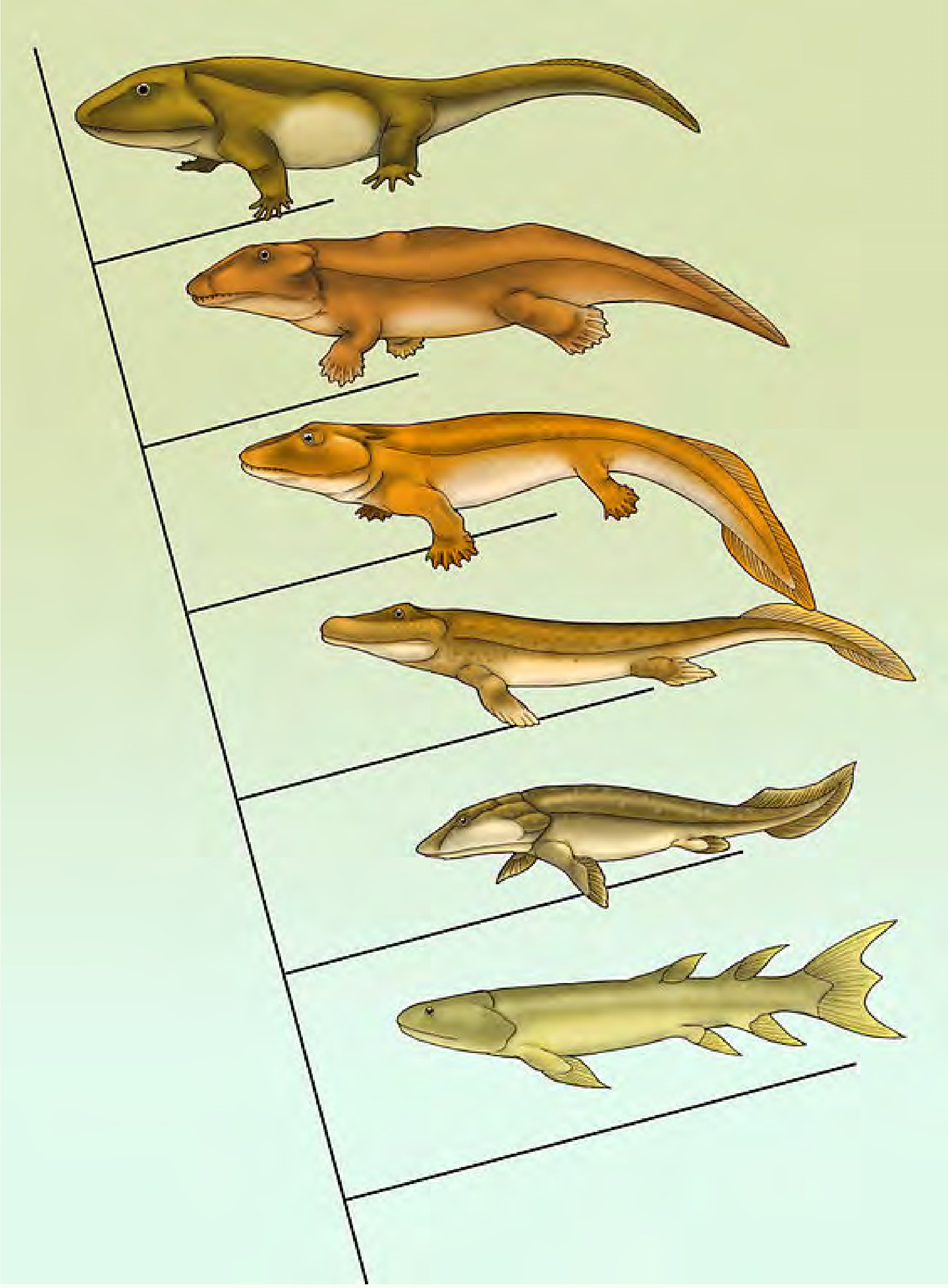

A cladogram of the evolution of tetrapods showing the best-known transitional fossils.
From bottom to top: *Eusthenopteron, Panderichthys, Tiktaalik, Acanthostega, Ichthyostega, Pederpes*.
Illustration: Maija Karala.

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ARTICLE

Transitional Forms

Robert J Raikow and Radmila B Raikow

INTRODUCTION

Evolutionary change is best understood in the context of phylogenetic history. This history is summarized by grouping related organisms into species and further defining their relatedness by grouping species within ever larger and more inclusive taxa. This nested pattern of relatedness is a fundamental characteristic of life on earth. It was recognized by 18th-century naturalists, most notably Linnaeus. For them the pattern had no historical significance; it was simply God's plan.

In the mid-19th century, however, Darwin (1859) saw that this pattern could have a naturalistic explanation. He postulated that groups sharing similarities are descendants of a common ancestor, and isolated groups may become distinct by accumulating different adaptive changes. Thus species multiply by the splitting of lineages from their common ancestor.

Darwin's idea explained certain natural phenomena that are unexpected under the creationist theory. These phenomena include the geographic distributions of organisms, the varying degrees of species distinctiveness, peculiarities of embryonic development, and biotic succession in the geologic record. Recently, nuclear and mitochondrial DNA evidence of relatedness has been added to this list (see Shermer 2005 for a brief summary).

A common theme in today's creationism/evolution debate is the existence and nature of transitional forms. Below we discuss some concepts developed by evolutionary scientists with the hope of clarifying aspects of the debate. We will try to explain how and why biologists use relevant terms and then we will examine creationist arguments about transitional forms. The idea of intermediacy has been applied at two different levels of organization: transitional characters and transitional species.

TRANSITIONAL CHARACTERS

The vertebrate eye is one example that had been cited by creationists as a character that could have only been formed fully developed because intermediate stages could not function. However, eye-like features have been described that form a finely graded series ranging from simple to very complex, each transitional analog functional for the organism possessing it (Salvini-Plawin and Mayr 1977). Furthermore, mathematical simulations have shown that selection can be efficient in driving the evolution of eyes via a series of structural designs that mimic the actual series found in nature (Nilsson and Pelger 1994).

Remarkably, at least one gene important in eye development in insects has been found to serve the same function in vertebrates (Quiring and others 1994). The fact that insects and vertebrates use a homologous gene to control eye development suggests that they have retained such a gene from a common albeit very distant ancestor, and therefore that eyes may have a common origin throughout the animal kingdom. This ancestral eye would have been relatively simple in design and most of the details of extant eyes should be understood to have arisen separately in subsequent character trees.

Transitional species

Studies that focus on transitional species or groups of species analyze multiple characters (Blackburn 1995). Transitional taxa appear to be intermediate between two other groups, and may suggest how one group emerged from a common ancestor to give rise to the other. For example, monotremes with hair and oviparity are examples of species designated transitional because of a set of characters. They are transitional between reptiles, which are hairless and oviparous, and placental mammals, which are hairy and viviparous. A fossil species may be thought of as an intermediate if its location in the geological record satisfies a position on the evolutionary tree that is indicated by an intermediate nature of its character or characters. For example, the fossil bird *Iberomesornis*, which has 11 dorsal vertebrae, appears to be transitional between *Archaeopteryx*, which has 13–14 dorsal vertebrae, and modern birds, which have 4–6 dorsal vertebrae (Sanz and Bonaparte 1992).

However, when a species is classified as transitional, this does not necessarily mean that it gave rise directly to present-day species. The transitional nature of a species may be based on three different phylogenetic relationships: directly transitional, indirectly transitional, and analogous.

Directly transitional

Consider an example where species X has the ancestral state for characters a and b (the ancestral nature of a and b being determined by independent evidence such as the fossil record, out-group comparison, or molecular analysis). Then species Y and Z have derived states because they are different from the ancestral state. Given only the evidence of the two characters, the most parsimonious tree would be the one shown in Figure 1A, where species Y, which has only one derived state, is directly transitional between the ancestral species X and descendant species Z, which has both derived states.

Indirectly transitional

In this relationship (Figure 1B), species Y has one or more derived characters that are lacking in species Z, and therefore Y is not directly ancestral to Z. This pattern postulates the presence of a intermediate ancestor (W), shared by Y and Z, which if found would clarify the pathway of the evolution of the characters involved.

In practice, a distinction is not usually made between directly and indirectly transitional forms because fossils preserve only a small part of the total phenotype, and it is impossible to tell whether a fossil specimen had unique characters in the unpreserved parts that would preclude its being a direct ancestor. Moreover, it is not possible to know all the relevant characters even when extant specimens are studied. For example, one species may possess a different, as yet unidentified metabolic pathway. Therefore the relationships of Figures 1A and 1B would usually be expressed as cladograms shown in Figures 1C and 1D. Cladograms define groups of organisms that appear to share a common ancestor, which in most cases is implied. In practice, cladograms are much bigger than those shown here and are more likely to be accurate because they involve many characters.

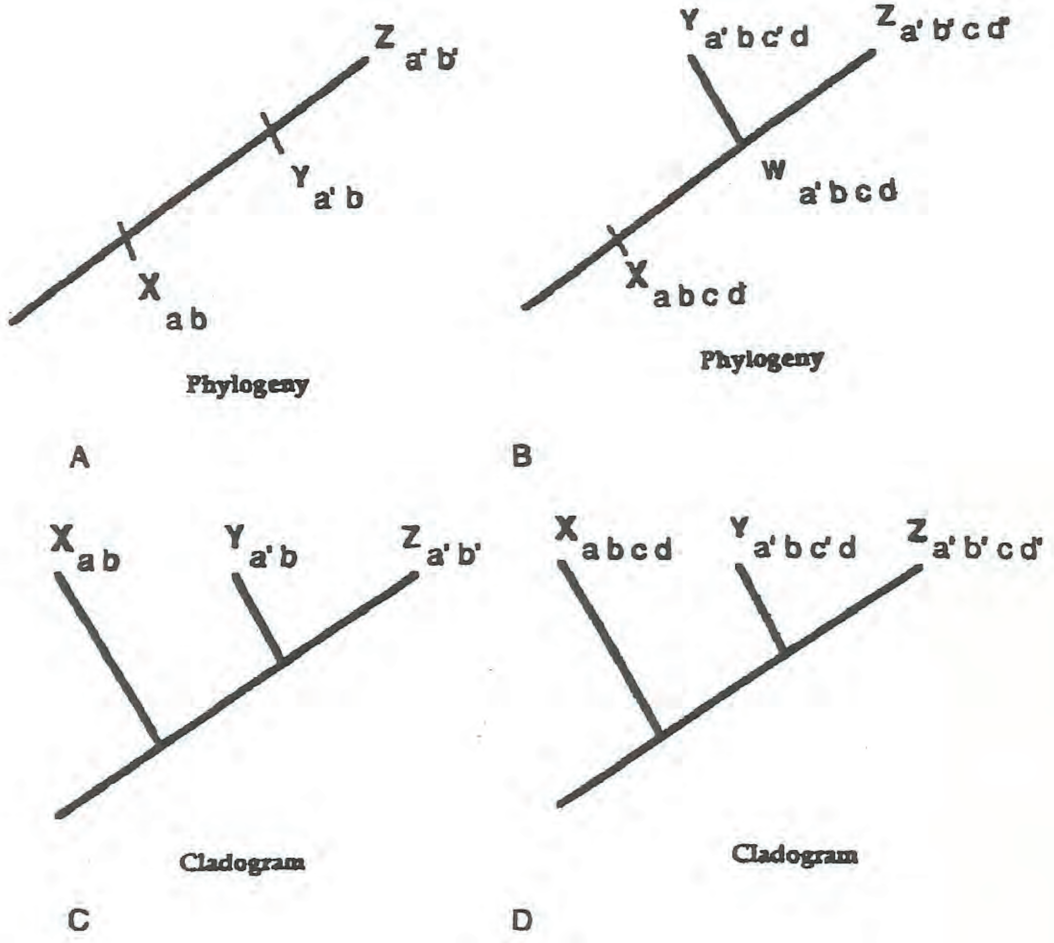

FIGURE 1. *A. Species Y is directly transitional between species X and Z when their hypothetical phylogeny is based on the two characters (a & b). Derived characters are designated with a prime. B. Species Y is indirectly transitional between species X and Z because Y has one derived character that is not found in Z. Species W is postulated to be directly transitional between X and Z. C. and D. The situations presented in A and B as phylogenies are represented as cladograms. See text for discussion.*

Analogous

In this relationship, a transitional species is similar to a directly or indirectly transitional form because of convergence. This means that the derived states evolved separately in the two taxa, and are not inherited by both taxa from their last common ancestor. Analogy is nevertheless useful in certain contexts, because it postulates a possible way that change could have taken place by demonstrating the plausibility of a hypothetical intermediate. For example, we have no fossils that are ancestral to bats and show the early stages of the evolution of flight in mammals, but we do have flying squirrels, which by analogy suggest a possible early stage even though much other evidence shows that squirrels and bats are not directly related.

Three additional concepts also merit discussion here: mosaic evolution, character lineages, and the designation of higher taxa.

Mosaic evolution

People sometimes assume that in an evolving group all characteristics change continuously and at the same rate, so that successive transitional forms should show proportional change in all features. This is not the case. Instead, changes can occur in different parts of the body, at different historical times, and/or at different rates. This is called mosaic evolution. For example, in the Hawaiian honeycreepers, a group of birds endemic to the Hawaiian Islands, the feeding apparatus (bill, tongue, and jaw muscles) underwent extensive evolutionary changes in several directions, while their hind-limb muscles changed very little (Raikow 1976, 1977). In contrast, the woodcreepers, a group of South American birds, evolved only moderate diversity in their feeding apparatus, but great variation in their hind-limb muscles (Raikow 1994, Raikow and Bledsoe 2000.)

Character lineages

Phylogeny is most often depicted as a tree-shaped diagram with a basal root and a pattern of successively branching lineages. The evolution of characters can be followed by starting at the root and tracing along various pathways (branches) to one or another terminal taxon. Since the pace of changes can differ from one character to another, a single character path often cannot illustrate all of the evolutionary changes that occur in any given phylogeny. Consequently authors sometimes present illustrations or discussions of character evolution following only a single pathway, that is, emphasizing only one major evolutionary trend in a group. This method is a valid approach for instructional purposes, but one should not forget that it is a simplification. If possible, it is better to use several characters that evolved in a parallel manner. For example, the evolution of horses can be shown centering on size increase, elongation of legs, and the reduction of side toes.

Higher taxa

Only species, among taxonomic categories, represent actual organisms and therefore only species can be ancestors of higher taxa. Nevertheless, we often see statements such as “birds evolved from reptiles,” or “annelids gave rise to arthropods.” Such statements are useful as a shorthand way of saying, for example, “the ancestral species of the clade of birds was a descendant of a reptilian species.” Because we usually cannot identify ancestral species of higher taxa in the fossil record, the simpler statement is a useful way of expressing our understanding.

CREATIONIST ARGUMENTS ABOUT TRANSITIONAL FORMS

The taxonomic link fallacy

This argument says that a particular species cannot be transitional because it is currently classified within one of the taxa being linked. For example, creationists have argued that *Archaeopteryx* cannot be transitional between theropods and birds because it is already a bird. Transitional relationships may appear to be obscured by the system of classification, which requires all species to be members of one or another higher taxon. Whether *Archaeopteryx* is classified as a bird depends on the characters chosen as key for that taxon.

This creationist argument equates phylogenetic intermediacy and taxonomic intermediacy, but the latter is a meaningless concept. Since the taxonomic rules of nomenclature do not admit any intermediate, this is a problem with labeling, not with phylogeny.

The dysfunctional intermediate argument

Creationists have suggested that a transitional organism or organ could not function until it was fully evolved, and that it could never reach this functional stage because natural selection would not favor it while it had no advantage. This argument as it relates to eyes was discussed above. Another example is the bird wing: "what good is half a wing?" The answer is that intermediate structural stages function in intermediate ways; structure and function evolve together. It is not an all-or-none proposition. Wings can be used for parachuting and for gliding before achieving powered flight.

Gaps in the fossil record

Creationists often claimed that the fossil record lacks the transitional forms predicted by the theory of evolution. However, the shortage of transitional forms in the fossil record has been exaggerated. The fossil record is fragmentary and transitional forms were probably restricted to limited geographic ranges during the early history of adaptive radiations. Nevertheless, new examples of fossil transitional forms are constantly being discovered (Blackburn 1995).

Another point that needs to be emphasized is that it is unlikely that soft-bodied and/or microscopic organisms would be preserved well in the fossil record. Therefore it is not surprising that we don't have transitional forms from the very early periods of evolution: a period in which transitions leading to differences between higher taxa probably occurred.

Survival of ancestral forms

Creationists have claimed that evolution is refuted because ancestral forms may occur together with descendant forms. For example, there was a time when three-toed and one-toed horses coexisted. Creationists argue that the ancestral types should be absent if they evolved into descendant types. However, when lineages split, new characters may evolve in one daughter lineage and not in another while both may continue to exist; that is, collateral lineages may emerge from the same population of common ancestors. Such lineages may find themselves isolated and may accumulate divergent adaptations.

Microevolution vs macroevolution

This is a central argument for the "intelligent design" advocates because many of the changes evolutionists demonstrate appear to be variations within a "kind" (to use their terminology). They state that in order to change one "kind" to another there would have to be addition of genetic material (Davis and others 1999), but there are mechanisms for just such additions. The most obvious one is polyploidization, that is, the multiplication of some or all of the chromosomes. Such changes have been shown to produce viable and fertile offspring in plants. Although this kind of large imbalance is probably always harmful in morphologically complex organisms such as vertebrates, it is likely that it could have contributed to early evolution among simpler organisms.

Another mechanism for increasing genetic material is the duplication of individual genes. In fact there are many examples of families of genes even within vertebrates (for example, histocompatibility genes are related to immunoglobulin genes). Members of such gene families have very similar sequences even though they have divergent functions. This shows that duplicated genes can be selected to produce novel functions once their original jobs are taken care of by the gene of their origin.

Finally, another mechanism for increasing genetic material is gene movement such as that mediated by viruses. Viruses can integrate into a host genome adding their own messages, and they can also pick up some host genetic material and move it to another position or even another host. Arguably most such changes can cause problems, especially in modern "highly tuned" biological systems, but this does not preclude their playing an important role in the past.

CONCLUSION

Despite the ongoing criticism of evolution by creationists on issues related to transitional forms, phylogenetic research has provided us with many examples of the usefulness and validity of this concept in evolutionary research. This ongoing research strengthens evolutionary theory and the expectations of common ancestry among related taxa, just as predicted by Darwin in 1859.

REFERENCES

Blackburn D. 1995. Paleontology meets the creationist challenge. *Creation/Evolution* 15:26–38.

Davis P, Kenyon DH. 1999. *Of Pandas and People: The Central Question of Biological Origins*, 2nd ed. Richardson (TX): Foundation for Thought and Ethics.

Darwin C. 1859. *On the Origin of Species by Means of Natural Selection*. London: John Murray.

Nilsson DE, Pelger S. 1994. A pessimistic estimate of the time required for an eye to evolve. *Proceedings of the Royal Society of London B* 256:53–58.

Quiring R, Walldorf U, Kloter U, Gehring WJ. 1994. Homology of the *eyeless* gene of *Drosophila* to the *Small eye* gene in mice and *Aniridia* in humans. *Science* 265:785–789.

Raikow RJ. 1976. Pelvic appendage myology of the Hawaiian honeycreepers (Drepanididae). *Auk* 93:774–792.

Raikow RJ. 1977. The origin and evolution of the Hawaiian honeycreepers (Drepanididae). *The Living Bird* 15:95-117.

Raikow RJ. 1994. Climbing adaptations in the hind limb musculature of the woodcreepers (Dendrocolaptinae). *Condor* 96:1103–1106.

Raikow RJ, Bledsoe AH. 2000. Phylogeny and evolution of the passerine birds. *Bioscience* 50:487–499.

Salvini-Plawin LV, Mayr E. 1977. Evolution of photoreceptors and eyes. *Evolutionary Biology* 10:207–263.

Sanz J, Bonaparte JF. 1992. A new order of birds (Class Aves) from the lower Cretaceous of Spain. In: Campbell KE Jr, editor. *Papers in Avian Paleontology Honoring Pierce Brodkorb*. Science Series Nr 36. Los Angeles (CA): Natural History Museum of Los Angeles County. p 38–49.

Shermer M. 2005. The fossil fallacy. *Scientific American* 292:32.

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FEATURE

People and Places: Jack T Chick

Randy Moore

FIGURE 1. *A collection of Jack T Chick tracts from NCSE's archives. Photograph: Robert Luhn.*

Jack T Chick was born on April 13, 1924, in Los Angeles, California, as the first of two children to artist Thomas Chick and his wife Pauline. In 1943, Chick enlisted in the Army and served in the Pacific theater during World War II. Chick, who failed the first grade, became a Christian fundamentalist after hearing an anti-evolution sermon that was broadcast on a radio program called Charles Fuller's Old Fashioned Revival Hour.

After working as an illustrator in the aerospace industry, Chick began a kitchen-based business built on publishing religious tracts. One of Chick's most popular publications is *Big Daddy?*, a small, 24-page comic book written with the help of young-earth creationist Kent "Dr Dino" Hovind. *Big Daddy?* is the most widely distributed anti-evolution publication in history.

Big Daddy? begins with an arrogant biology professor humiliating a student who dares to question evolution. In a classic David-versus-Goliath confrontation, the enraged professor screams that the student is a fanatic and threatens him with jail, but the tide turns when the student tells the professor about "amazing findings which are rarely made public". These "amazing findings" expose evolution as a "big lie" and force the professor to admit that the student is "destroying me." The humiliated and repentant professor then pleads for the student to answer the questions that science can't answer. The story ends when everyone becomes a creationist and the professor—admitting that he can no longer teach evolution—is fired by heathen administrators.

Big Daddy? was originally published in 1972, and today appears in many different languages; there are millions of copies in print, and thousands of new copies are distributed each year. More people have seen *Big Daddy?* than all other anti-evolution publications combined.

Chick's opposition to evolution also appears in *In the Beginning*, which uses the Paluxy dinosaur footprints and a talking serpent in the Garden of Eden to attack evolution and promote young-earth creationism. Biologists are described as brainwashed, and evolution as the religion of scientists who laugh at God. Some of Chick's other publications (for example, *The Collapse of Evolution*) allege that there is undeniable scientific evidence proving that evolution is false and videos that force even the most devout evolutionists to reconsider their beliefs. These videos—which are promoted with Lenin's quote "Give me your four-year-olds and in a generation I will build a socialist state"—describe how God cures cancer, how Noah packed dinosaurs and other animals on the ark, and how readers can get evolution out of textbooks.

Chick has more than 500 million books and booklets in circulation, some of which appeared in the Smithsonian Institution's National Museum of American History. His publications, which have been translated into more than 150 languages, link evolution with social ills such as pornography (*Wounded Children*), gay rights (*Doom Town*, *The Story of Sodom*), rock 'n' roll (*Angels*), Catholicism (*The Attack*), Islam (*Allah Had No Son*), and Halloween (*Satan's Big Night*). Chick's *The Ark* describes Russia's attempts to block Christians from finding Noah's Ark atop Mount Ararat, and his *Primal Man?* depicts brainwashed scientists who are making a film about evolution despite the fact that many viewers will lose their souls.

Chick, a recluse who avoids publicity, lives in California.

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Randy Moore is the HT Morse–Alumni Distinguished Professor of Biology at the University of Minnesota. His most recent book (with coauthor Sehoya Cotner) is *Understanding Galápagos: What You'll See and What It Means* (New York: McGraw-Hill, 2003).

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FEATURE

Climate Change Adaptation: Lessons from Unlikely Sources

Courtney St John

INTRODUCTION

Imagine a scenario in which you're trying to save for retirement. You would have to commit to putting away money now in order to yield a benefit that won't be realized for quite a few decades. Or you can spend the money on a new car now—a purchase that isn't totally necessary but would be a nice upgrade. The thought of driving the vehicle all over town provides near-instant gratification. The thought of putting that money into a retirement savings account becomes less appealing by the minute.

The same principle applies to climate change. Many of the solutions required to adapt to future climatic changes—the benefits of which won't become fully apparent until later this century—require modification to business as usual. Resisting the urge to spend money in the near term can take serious willpower. Saving the money will generate long-term benefits (a more enjoyable retirement). In the same way, addressing the challenges of climate change now requires taking actions that can be hard or unfamiliar. Social scientists even have a name for this—temporal discounting. Temporal discounting means that humans have the tendency to place greater emphasis on rewards in the present term, even if a long-term opportunity may be more beneficial (CRED 2009).

The implications of climate change require scientists and non-scientists alike to work together on viable solutions. Scientists agree that climate change is occurring, but some of the impacts in exact locations are harder to identify. The issue becomes more complex when it becomes clear all the ways that our lives may be affected: agricultural productivity, water availability, exposure to extreme events, and ultimately economic productivity and social well-being. Climate change touches everything that we do. It can be tough to know how and when to begin climate change adaptation and what that will mean.

It is clear, however, that adaptation to changes in the climactic system will require a multifaceted approach. That is why so many organizations around the world acknowledge the challenges of climate change and are working toward solutions. The World Economic Forum, the World Bank, the reinsurance industry, and large corporations such as Morgan Stanley are but a few examples. Though they may seem to be unlikely partners, let's explore some of the groups working on the issue—cities around the US, the national security community, and social scientists—and some lessons that can be learned from their approaches.

CITIES

In the US more than 50% of Americans—164 million—live in coastal and Great Lakes watershed counties, and together they help generate 58% of the national GDP (Moser and others 2013). From Miami to New York City to San Francisco, millions of Americans especially live in urban areas along the coast. These cities are home to commerce, science and technology, banking, and innovation. As climate change progresses, cities will become increasingly vulnerable to sea level rise and severe weather. When extreme events like Hurricane Sandy combine with aging infrastructure and sea level rise, the result can directly impact quality of life in an urban area, yielding social and political challenges.

This reality is not lost on city leaders around the US, and many cities are actively developing adaptation strategies to address the challenges that climate change will cause. They are implementing climate adaptation plans, driving energy reduction innovation, and analyzing future infrastructure needs. In the case of climate change adaptation, cities benefit from their size. Cities account for more than seventy percent of global CO_2 emissions and consume over two-thirds of the world's energy, but they are also able to develop close relationships with businesses, institutions, and residents because of smaller government, thus allowing policies to be implemented more quickly (C40 2013).

Shaping today's cities into those urban hubs of the future—ones that will support increasing populations, all while dealing with fewer resources and more exposure to climate change—requires an all-hands approach that starts with the interest of high-level leadership. The approach must communicate the issues clearly to stakeholders and engage citizens in a deliberate process that makes sound decisions based on scientific data. In a similar way, leaders in the US military are coming together to improve energy security and climate change adaptation as crucial pieces of a holistic defense strategy.

NATIONAL SECURITY

In 2010, the Quadrennial Defense Review (DOD 2010), the Defense Department's four-year review of its strategy and priorities, recognized that climate change and energy will play significant roles in the future of national security, stating that "climate change will shape the operating environment, roles, and missions that we undertake" and "while climate change alone does not cause conflict, it may act as an accelerant of instability or conflict" (DOD 2010).

The US Navy in particular recognized this challenge and in 2009 formed its Task Force Climate Change (TFCC) to address the naval implications of a changing Arctic and global environment (US Navy 2010a). After a long-term decline, sea ice fell in 2012 to its lowest level since 1979 when satellite mapping began (NSIDC 2013). Changing conditions in the Arctic mean an increase in commercial traffic and tourism in the region. This will necessitate increased naval presence to maintain freedom of the seas—as the Navy is required to provide in all oceans of the world. The US Navy is working closely with partners from the other Arctic nations to ensure safe and secure Arctic waters (US Navy 2010b).

In addition, sea level rise may compromise the readiness of the Navy's coastal installations to carry out missions and support the fleet. Drought, storm events, and coastal flooding all could reduce a military installation's ability to function at optimum capacity. Exposure to these physical effects can weaken or alter the built and natural infrastructure components of military installations and make systems less reliable or effective. Only by continuously monitoring the scientific data of changing conditions and adapting to the impacts of climate change that directly relate to its mission can the US Navy maintain mission readiness in the 21st century.

SOCIAL SCIENCE

Climate change affects all aspects of our daily life, whether we are urban dwellers, members of the military, farmers, or educators. So how might humans make better decisions to adapt to and accommodate these changes? How can scientists, educators, and politicians clearly communicate policy changes needed to improve resilience to natural hazards, public health, economic well being, and the many other areas of our lives that climate change will touch?

To answer these questions, one must look to social science. Climate scientists provide valuable information about the climate system and the impacts of its changes on our institutions and way of life that can then be distilled into a usable format for decision makers, educators, planners, and the general public. The disciplines of psychology, anthropology, sociology, economics, and other social sciences provide the framework necessary to guide decision- and policy-making under conditions of uncertainty.

Organizations like the Center for Research on Environmental Decisions (CRED) at Columbia University's Earth Institute are doing just that. CRED studies how people use scientific information, the social context in which scientific information is discussed, and how information and choice options are framed to address human responses to climate change and variability. By working with natural scientists, educators, field researchers, and the general public (including policy makers, planners, and private business), CRED aims to understand and improve how people make environmental decisions under conditions of uncertainty (CRED 2009).

This research tells us that for climate science information to be absorbed by audiences, it must be actively communicated with appropriate language, analogy and metaphor; combined with narrative storytelling; made vivid through visual imagery and experiential scenarios; balanced with scientific information; and delivered by trusted messengers in group settings (CRED 2009). By learning how to address scientific and climate uncertainties, practitioners and educators can foster the behavior change necessary for climate change adaptation.

CONCLUSION

The future of climate change can at times seem daunting. Climate science predicts challenges that a planet with seven billion people must overcome to continue to thrive on earth. And yet, as examples from the urban planning, national security, and social science communities show, meeting these challenges will depend on the expertise and actions of many different organizations. Employing expertise at all levels, engaging high-level leadership, relating the challenges back to one's mission, and clearly communicating the benefits of action and the downsides of inaction can contribute toward a robust solution and an improved ability to respond to this challenge, for us and our children.

REFERENCES

C40cities.org. Why cities? [Internet]. C2011. New York: C40Cities Climate Leadership Group. [cited 2013 February 21]. Available from: http://www.c40cities.org/whycities

[CRED] Center for Research on Environmental Decisions. 2009. *The Psychology of Climate Change Communication: A Guide for Scientists, Journalists, Educators, Political Aides, and the Interested Public*. New York: Center for Research on Environmental Decisions. Available from: http://guide.cred.columbia.edu/

[DOD] Department of Defense. 2010. [Internet]. *Quadrennial Defense Review*. [cited 2013 February 21]. Available from: http://www.defense.gov/qdr/

Moser S, Davidson M, Kirshen A, Mulvaney P, Murley J, Newmann J, Petes L, Reed D. 2013. Coastal zone development and ecosystems. In: National Climate Assessment [draft], ch 25:867–920. Available from: http://ncadac.globalchange.gov/download/NCAJan11-2013-publicreviewdraft-chap25-coastal.pdf

[NSIDC] National Snow Ice and Data Center. 2013 [Internet] Quick facts on arctic sea ice. [cited 2013 February 21]. Available from: http://nsidc.org/cryosphere/quickfacts/seaice.html

US Navy. May 2010a. [Internet]. US Navy climate change roadmap. [cited 2013 February 21]. Available from: http://greenfleet.dodlive.mil/files/2010/08/US-Navy-Climate-Change-Roadmap-21-05-10.pdf

US Navy. May 2010b. [Internet]. Navy strategic objectives for the Arctic [cited 2013 February 21] Available from: http://greenfleet.dodlive.mil/files/2010/09/US-Navy-Arctic-Strategic-Objectives-21-May-2010.pdf

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RECAPITULATIONS

Reply to Brandon Haught's review of *No Dinosaurs in Heaven*

Greta Schiller

When you run "reviews" of documentary films—such as Brandon Haught's review of *No Dinosaurs in Heaven* (*RNCSE* 2012;32[4]:7.1–7.3; available from http://reports.ncse.com/index.php/rncse/article/view/139/179)—I think that it is important that the "critic" actually knows something about documentary genres. My film is a particular form of documentary known as the personal essay film. According to the American University Center for Social Media, "[t]hey are particularly good at dramatizing the human implications and consequences of large social forces":

> Personal essay films have been widely diffused to teachers and community organizations, because they so powerfully evoke responses from and make connections for audiences. They are also favorites of film scholars, who use them to demonstrate with all the drama of the personal voice, the formal structures in filmmaking. (http://www.centerforsocialmedia.org/making-your-media-matter/documents/case-studies/teachers-guide-use-personal-essay-films)

The job of a film critic is to critique the film, not propose why the film he would like to see would be a better film. Perhaps Haught would have liked to see a film that looks like a NOVA special or a magazine show. Those are valid documentary styles and it would indeed be a great thing if the mass media took more notice of the importance of science by making more of such TV programs. But that's not the kind of film that I wanted to make.

The most erroneous comment and indeed the moment when the "critic" shows his absolute ignorance of film genre is when he states, "the big flaw in this storyline, though, was Schiller's deep involvement." This line is a priceless example of Haught's lack of media literacy. The brilliant weaving together of two storylines held together by my musings was a directorial choice, not an editing flaw. This is an esteemed form of storytelling, one that is brutally honest and very opinionated. When a filmmaker of my caliber makes use of a campy animated dinosaur motif, it is not amateur—it is an aesthetic decision one may like or dislike but it is one that resonates with many audience members, especially those not well versed in the minutiae of defending the teaching of evolution in the public schools.

One thing Haught and I agree on is that, in his words, "the film certainly explores important concepts concerning science, education, religion, and science literacy." Golly gee, thanks! If we are to win the culture wars, those of us on the side of reason, and of culture, will continue to make creative use of a variety of artistic strategies to get people thinking about science, religion, education, and maybe even media literacy. If *RNCSE* plans to enter the world of "film criticism," please have critics do their homework. Documentary genre is the first thing I teach in my documentary production classes. The next thing I teach is if you want to engage in creative filmmaking, be prepared for criticism, especially from autodidactic critics.

Meanwhile, I can hear my dinosaurs growling; they need to be fed and they love to eat paper pulp.

ABOUT THE AUTHOR

Greta Schiller is an independent director and producer of documentaries for television, festivals, and theatrical and educational distribution. Her *No Dinosaurs in Heaven* premiered in 2010.

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RECAPITULATIONS

Response to Greta Schiller

Brandon Haught

My sincere thanks to the director for offering a response to my review of *No Dinosaurs in Heaven*. It's healthy and educational to have a dialog like this as we offer insights to each other that might have otherwise been left unknown.

No, I'm certainly not a film critic. I'm just an average Joe with an above average interest in the creation/evolution conflict. I have no training in film reviewing and I never suggested that I did. I saw the film and jotted down my initial impressions. A few months later I watched the film again and discussed it with friends. Finally, I wrote a full review and submitted it to *RNCSE* for publication consideration. The editors at *RNCSE* were kind enough to accept it (*RNCSE* 2012;32[4]:7.1–7.3; available from http://reports.ncse.com/index.php/rncse/article/view/139/179).

The article was based on my personal opinions and fairly deep knowledge of the general subject matter. My review reflects how the film looked and felt to me as an average audience member who, admittedly, has none of the documentary film making educational background. However, I would argue that many of the film's viewers share this lack of specific education.

I appreciate the work the director did on this film. It's an important subject deserving of attention and I'm glad the director felt moved to tackle it. But I also stand by my review, uninformed in some aspects as it may be.

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Brandon Haught is the communications director of Florida Citizens for Science and a recipient of NCSE's Friend of Darwin award. His book on the history of creationist attacks on science education in Florida is forthcoming from the University Press of Florida.

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REVIEW

First Life: Discovering the Connections between Stars, Cells, and How Life Began

by David Deamer
Berkeley (CA): University of California Press, 2011. 288 pages

reviewed by Antonio Lazcano

Like many of his contemporaries, Darwin rejected the idea that putrefaction of preexisting organic compounds could lead to the appearance of organisms. Although he favored the possibility that life could appear by natural processes from simple inorganic compounds, his reluctance to discuss the issue resulted from his recognition that at the time it was not possible to undertake the experimental study of the emergence of life. As aptly summarized by David Deamer in *First Life*, we still do not know how life actually originated and what was the actual nature of the first living entities, but framing the problem within the evolutionary perspective provided by Darwin led to the development of a multidisciplinary research program that combines experimental simulations of the prebiotic environment with a wide range of observations that range from the presence of organic compounds in the interstellar medium, comets, and meteorites to the discovery of catalytic activities of RNA molecules. Equally important, as Deamer emphasizes in his book, the dramatic shift in the questions we ask today from those raised only a few decades ago are providing novel perspectives on the origin of the first organisms.

In November 1924, Alexander I Oparin published a small volume in Russian entitled *The Origin of Life*, which proposed that the first life forms were the outcome of a lengthy period of abiotic synthesis and accumulation of organic compounds that had led to the primitive soup. In a second book, Oparin went further and presented in 1936 a revised proposal, arguing for a highly reducing primitive milieu in which iron carbides of geological origin reacted with steam to form hydrocarbons. Oxidation of these hydrocarbons yielded alcohols, ketones, aldehydes, and so on, which then reacted with ammonia to form amines, amides, and ammonium salts. The resulting protein-like compounds and other molecules formed a dilute solution, where they aggregated to form colloidal systems from which the first heterotrophic microbes evolved. Following HG Bungenberg de Jong's ideas on the colloidal nature of protoplasm, Oparin suggested that the evolution of coacervates—droplets of organic macromolecules held together by different charges—formed in the primitive oceans led eventually to the first cells.

Oparin's second book was translated into English in 1938, but more than fifteen years went by before his ideas were tested under laboratory conditions. As Deamer writes, "[o]ne of the first atmospheric simulation experiments transformed origins of life research from speculation to solid experimental science. In the early 1950s, a young graduate student named Stanley Miller began his PhD research at the University of Chicago guided by Harold Urey" (p 66), adding

> Miller and Urey decided to make a chemical model of the primitive atmosphere of Earth. Urey knew that the outer planets were very high in hydrogen content, along with water, methane, and ammonia, and he reasoned that the Earth would have had a similar atmosphere just after it completed the process of planet formation. Taking this to heart, Miller decided to simulate these conditions in the laboratory by enclosing a mixture of gases in a large round flask. As a chemist, he knew that nothing would happen unless some form of energy was driving the reactions, so he chose to use an electrical spark to simulate lightning strikes ... The results were spectacular, and even today remain a touchstone for research on the origins of life. (p 66–67)

As discussed in *First Life*, during the past sixty years the laboratory simulations of the prebiotic earth have yielded many different molecules of biochemical significance under a wide range of environmental settings. We are far from understanding how the first cells evolved, but the empirical and analytical evidence suggests that prior to the origin of life the prebiotic environment was already endowed with many inorganic and organic catalysts, purines, and pyrimidines—the potential for template-directed polymerizations—and membrane-forming compounds, ingredients associated with the activity of cells.

Some were quick to realize the significance of membranes for the origin of life. A few months after Miller published the results of his experiment, the famous British geneticist and polymath JBS Haldane stated in a meeting of the Society for Experimental Biology in Cambridge that "[t]he long-chain polymers found in living organisms have 'back-bones' composed of phosphate [that is, nucleic acids], glycine, or pentose residues. The first seem to be the most catalytically active, and may be the most primitive. The critical event which may best be called the origin of life was the enclosure of several different self-reproducing polymers within a semipermeable membrane" (Haldane 1954:26).

However, it is sometimes forgotten that the results of the 1953 Miller-Urey experiment were published only a few weeks after the Watson and Crick double-helix model of DNA. It is difficult for contemporary scientists and students to understand in full the extraordinary impact that these two publications had on our understanding of the origin and nature of life. Molecular biology quickly became a blooming field and attracted some of the most brilliant scientific minds, leading to a rapid molecularization of our understanding of living phenomena.

Quite understandably, during the decades that followed, attempts to understand the origin of life were shaped, to a considerable extent, by the unraveling of the details of DNA replication and protein biosynthesis. Developments in molecular biology also led to some extreme reductionist approaches and to the idea that life depended on a single living molecule. In 1959 Hermann J Muller, the distinguished geneticist (and intellectual mentor of Carl Sagan), defended the idea that life emerged when a living DNA molecule was formed in the primitive earth and argued that

> the most fundamental property distinguishing a living thing—and that can therefore be used to define life—is its ability to form copies of itself. We call this "reproduction"; but such copies must also include innovations—mutations—that distinguish a given living thing from its parents. … Natural selection could not go on without the necessary basis of an ability or faculty of the material to copy not merely itself but its

> variations. That, I think, is the heart of life, and such material, when it arose, is rightly called "living". (Darwin and others 1959:71)

It is true that the multiple lines of evidence that support the possibility of an RNA World have reinforced a reductionist approach in the study of the emergence of life, but as Deamer underlines in his book, it is useful to put a healthy distance from the idea that living systems depend on one single molecule. Deamer argues instead in favor of the appearance of prebiotic cell-like vesicles made of lipids of abiotic origin, which may have accumulated on the primitive earth either due to endogenous syntheses or delivered during the collisions with meteorites or other similar primitive small bodies.

Such droplets, which are the modern version of Oparin's coacervates, have been observed under laboratory conditions from certain fatty acids. As summarized by Deamer, experimental approaches to vesicle chemistry point to fatty acids as good candidates as the first amphiphilic protocellular constituents. Of course, any strong statement on the transition from abiotically synthesized organic matter into the first living entities is pure conjecture. Whether the earliest genetic polymers were enclosed within membranes is not yet clear, but as summarized in *First Life*, this is a very reasonable possibility.

The formation of membranes and lipidic vesicles under prebiotic conditions is highly plausible. Many examples of self-organizing physical systems that lead to highly ordered structures demonstrate that, in addition to natural selection, there are other mechanisms of ordered complexity that operate. The list includes lipidic molecules that exhibit self-assembly properties that lead to the formation of bilayers, micelles, and liposomes. As Deamer states, "Nothing holds the molecules together in the vesicle except a weak force called the hydrophobic effect. The same force is responsible for stabilizing the soap bubbles we play with as children and the lipid assemblies that form the membranes around every cell in the human body" (p 252). If the origin of life is seen as the evolutionary transition between the nonliving and the living, then it is easy to accept that complex systems of purely physical and chemical nature played a role in the emergence of life. It is true that some advocates of an early emergence of replicators consider the cell as a mere physical compartment for segregating polymers that show differential replicative abilities. However, biological membranes are not mere lipidic containers, but active players in bioenergetic transduction without which extant life could not exist. How they first appeared is still a major, open question.

Deamer has written a well-argued, deeply researched, and thought-provoking book on the origin of life. He is certainly well-qualified to discuss the subject; long before others, he was the first who spotted in contemporary times the significance of lipids and membranes in the origin of life. But *First Life* is neither dismayingly narrow nor unduly technical; its approach is engaging, accessible, and interdisciplinary. Based on his understanding of cell biology, the prebiotic environment, and the significance of Darwin's intellectual inheritance, in this book he advocates an evolutionary approach as the key for understanding the essence of biological phenomena. His book is written as an enticing personal narrative, and ends with an epilogue that is a strong defense of the significance of science for individual and collective development.

REFERENCES

Darwin C, Dobzhansky T, Evans EA Jr, Gause GF, Gerard RW, Muller HJ, Ladd Prosser C. 1959. Panel one: The origin of life. In Tax S, Callender C, editors. *Evolution after Darwin: Issues in Evolution*, vol 3. Chicago: University of Chicago Press. p 69–105.

Haldane JBS. 1954. The origins of life. *New Biology* 16:12–27.

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REVIEW

The Story of Earth: The First 4.5 Billion Years, from Stardust to Living Planet

by Robert M Hazen
New York: Viking Adult, 2012. 320 pages

reviewed by Joseph G Meert

The subtitle of Robert M Hazen's book *The Story of Earth* makes a bold promise: "The first 4.5 billion years, from stardust to living planet". That's a tremendous amount of history to squeeze into 283 pages of text. It requires that at least some parts of Earth history are given brief treatment. In my experience, a standard way of dealing with this usually involves one or two chapters devoted to the bulk of geological time (the Precambrian, from 4.5 to 0.542 billion years ago), with the bulk of attention on the remaining 12% of geological time known as the Phanerozoic (542 million years ago to present). In many respects, such an out-of-proportion treatment of Earth history makes sense. Humans are fascinated by the complexity of life during the Phanerozoic, including the subjects of trilobites, tetrapods, dinosaurs and of course, humans. As someone devoted to the science of the Precambrian, I was delighted to see that Hazen's book turns the standard treatment of Earth history upside down by devoting an almost proportional treatment of space to the Precambrian (90% of the book) and the Phanerozoic (10% of the book).

Hazen, the Clarence Robinson Professor of Earth Science at George Mason University, is a mineralogist-cum-geobiologist who takes an unconventional view of Earth history. His main thesis, woven throughout colorfully named chapters, is that minerals, the Earth, and life "co-evolve". While evolutionary changes of the Earth and especially life are accepted scientific fact, mineral evolution is a very new concept in the geological sciences. Mineralogy is often viewed as a categorical science, where chemistry, crystal shape, and environment of formation are the mainstays of the discipline. Hazen argues cogently that the minerals found on Earth varied temporally not only with chemical changes of the source region (no surprise there), but also with changes in atmospheric composition and biological evolution. In other words, the complexity of mineral species on the Earth is a function of the interplay among life, environment, and chemistry. The concept that mineral species undergo both radiation and extinction is novel. While not yet tested, the hypothesis is advanced that planets where complex life has not evolved will have fewer mineral species than our home planet.

While this may sound technical, once Hazen describes the idea of mineral evolution, it seems to be incorporated seamlessly into the remaining chapters of the book. Indeed, this co-evolutionary theme is at the heart of Hazen's description of Earth history. The book begins with a brief explanation of nucleosynthesis and stellar evolution and how the Earth was built from stardust. We learn that the Earth's composition is a direct consequence of physical processes within stars. Although little is known about the earliest "Hadean" phase of Earth history, the book provides an intriguing synthesis of that first 500 million years of our planet's existence, including the "Big Thwack" that formed our moon. The reader is treated to a deft description of the post–"Big Thwack" Earth evolving from a raging anoxic inferno to a more subdued but no less hostile planet covered first by a thin basaltic (oceanic) and later thicker granitic (continental) crust. Hazen takes the reader on a chemical journey from which the dry land and oceans emerged. The passage of Hadean and Archean time (4.5 to 2.5 billion years ago) is by and large a story of mineral evolution from a suite of dense minerals now locked in the mantle and core to the lighter minerals that make up continental and oceanic crust.

Perhaps there is no more daunting task than to describe the formation of life on Earth from non-living material. As you might expect, Hazen is certain that mineralogy played an important (if not key) role in providing both the template and raw materials for the first self-replicators. The book gives a balanced view of abiogenesis based on current knowledge and adeptly shows how different minerals and regions of the Earth factored into producing the first living organisms. Hazen notes that there was no shortage of material, time or innovation required for life to form.

There is a considerable part of the tome devoted to the changes that took place on the Earth during the "Great Oxidation Event" during the Paleoproterozoic Era (2.1–1.8 billion years ago). This was a transformative time in our planet's history because the addition of even a relatively small amount of oxygen in the atmosphere caused a significant change to both the biosphere and its interactions with surface materials. The Great Oxidation resulted in the radiation of many new mineral species along with the extinction of others.

Hazen even finds a way to turn the so-called "boring billion" interval of Earth history from 1.8 to 0.8 billion years ago into an intriguing narrative. This time period indicates a stasis in the composition of the oceans, atmosphere, and biosphere (hence the name "boring"). However, Hazen notes that the Earth was far from stagnant, for at least two supercontinents formed during this interval. The supercontinents of Columbia (the first supercontinent) and Rodinia (the second) both originated during the "boring billion".

In the chapter entitled "White Earth," we tour the so-called Snowball Earth period in history from about 800 to 635 million years ago. During that interval, the planet endured the most severe climatic swings ever—from a nearly ice-covered planet (from pole to equator) to a global greenhouse where average temperatures may have reached 50°C. As the planet emerged from this transformative time, the complexity of life blossomed along with a wealth of new interactions between the biosphere and the mineral world.

For those readers who are interested in trilobites, tetrapods, dinosaurs, and humans, all are featured in the latter part of the book. In "Green Earth," the most recent 540 million years are reviewed, and we are then also given a glimpse into the near and distant future of our home planet. The future (as did the past) most assuredly contains calamities small and large in the form of earthquakes, cosmic impacts, and large volcanic eruptions. Hazen evaluates our chances for survival and shows how climate change (both normal and anthropogenic) will shape our future.

In fulfilling his promise to deliver 4.5 billion years of Earth history, Hazen uses no illustrations, but rather relies on his brilliant skills as a wordsmith to paint a vivid picture of each interval of time. If you are at all interested in deep time, this book will capture and hold your attention from cover to cover.

ABOUT THE AUTHOR

Joseph G Meert is Professor of Geological Sciences at the University of Florida, where he studies the history of continents, especially those composing Gondwana, from the Mesoproterozoic to the Paleozoic.

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REVIEW

The Rocks Don't Lie: A Geologist Investigates Noah's Flood

by David R Montgomery
New York: WW Norton, 2012. 320 pages

reviewed by Steven Newton

The spectrum of creationism is broad, ranging from those who accept some evolution—so long as it is only "microevolution"—to those who argue that believing in the Bible also requires one to believe the world is flat. Somewhere in between are young-earth creationists, who hold the earth to be only a few thousand years old, and who think the Flood of Noah happened exactly as described in the book of Genesis, covering all the planet in a wrathful deluge. Such a worldwide Flood, these creationists argue, must have left behind clear geologic evidence across the globe, evidence which should be visible to unbiased eyes.

David R Montgomery, a University of Washington geomorphologist, has written an entertaining and very readable book detailing why Flood literalists find so little support in the rock record. Ranging from Mount Everest to the Grand Canyon, from the Creation Museum to ice-dammed Tibetan valleys, Montgomery explains what kind of features a worldwide flood would have created—and why what we see in the real world simply does not match.

Along the way, Montgomery briefly explains how some of the major ideas in geology came about: We learn how Hutton recognized the antiquity of the earth on a sea cliff in Scotland, how Steno realized that fossils really were the remains of long-dead creatures as he dissected the head of a great white shark, and how J Harlen Bretz correctly recognized the evidence for giant floods in Washington, despite stubborn dismissal from the scientific community.

We also learn about how the flood described in the Epic of Gilgamesh scandalized Victorians who imagined that the Biblical story sprung fully-formed from the pen of Moses, rather than being merely the latest of several iterations from cultures near flood-prone rivers.

Montgomery's book covers a lot of territory, and is correspondingly filled with a large cast of characters. We learn how Martin Luther argued for a literal Flood, writing at length on how the Flood should be understood "neither allegorically nor figuratively." We follow Leonardo into caves in Monte Albano, where he discovers the bones of fish and sea shells, high in the mountains. We watch Descartes struggle to fit the "wrecked and ruined" world into a cogent story, where "[f]issures coalesced into large fractures as the undermined and weakened outer crust foundered into the watery abyss, triggering a great flood and forming both mountains and seas" (p 54).

Montgomery explores the Creation Museum in Kentucky, noting that one enters past "a ticket checker dressed up as a Park Ranger stationed at a Grand Canyon National Park sign," a rather egregious appropriation of National Park imagery and copyright for this profit-making enterprise. He notes that the Manichean worldview expressed at the Creation Museum—"Which should we believe—reason or God, the creator of reason?"—fundamentally assumes a conflict between science and religion. As Montgomery characterizes it, "In this view, the dangerous brotherhood of science is humanity's common enemy. Reason threatens us all" (p 180).

Geologic time is front and center at the Creation Museum. Because the depths of geologic time allow for small, incremental changes to effect new species, creationists target the idea of geologic time itself. As Montgomery notes, one of the displays in the Creation Museum shows a wrecking ball demolishing a church, and the lettering on the wrecking ball says, "millions of years." Their attacks on geology are therefore an important part of their broader attacks on evolution.

But to Montgomery's eye, the Creation Museum's take on the Flood is littered with contradictions and omissions. For example, Montgomery asks, "[W]hy does this museum have so many displays showing giant reptiles hanging out with Adam and Eve when the Bible doesn't even mention dinosaurs?" For a museum predicated on a catastrophic worldwide Flood, the presence of dinosaur tracks "present a serious problem for creationists. How could land animals have been walking around on the seafloor during an event that ripped up Earth's surface before depositing their bones in the very stuff they were walking around on?" (p 181). Montgomery lists the geology the Creation Museum misses: tree-ring records, ice core data, plate tectonics. No real evidence supporting a Flood is presented, while the bulk of geologic knowledge—"nearly all of earth history"—is omitted.

And while Flood creationists get the geologic story spectacularly wrong, they also miss what evidence for a real titanic flood would look like. Montgomery details how the Missoula Floods at the end of the last ice age, first recognized in the 1920s by J Harlen Bretz, affected a large area of eastern Washington state, shaping the landscape in dramatic, oversized fashion, forming gigantic ripples best seen from the air, perching boulders high on cliffs, carving potholes the size of houses into bedrock. Yet creationists do not point to such features as evidence for their global Flood, perhaps in part because such features are found so rarely. We know the geologic evidence a catastrophic flood would leave behind, yet creationists ignore this and focus their energies on what was clearly once a meandering river whose twists and turns became incised into the bedrock when its region of the world underwent rapid uplift—in other words, the Grand Canyon.

The Grand Canyon is the prime showcase for creationist interpretations of the Flood. Groups such as Answers in Genesis and Canyon Ministries (whose statement of foundational beliefs declares: "... Genesis is a simple but factual presentation of actual events and therefore provides a reliable framework for scientific research"; http://www.canyonministries.com/beliefs) annually sponsor multiple rafting trips down the Colorado River, where one may experience the Grand Canyon accompanied by a guide who explains how its features were formed by the Flood.

But this requires a stretch of the imagination. As Montgomery notes, there are delicate features preserved in the Grand Canyon, such as worm burrows occupied by creatures who seem to "have been crawling around on and burrowing into the seafloor during a flood powerful enough to remodel the planet." Delicate animal footprints preserved in the Co-

conino Sandstone have been interpreted by creationists such as Leonard Brand as evidence of panicked lizards scampering out of the way of rising Flood waters—yet such a deluge would surely obliterate these gossamer impressions.

While scientists see this sort of thing as a contradiction calling into question the idea of a Flood, creationists think in a fundamentally different way. To paraphrase Lewis Carroll, conclusion first—evidence afterwards. The current statement of faith for Answers in Genesis reads, "By definition, no apparent, perceived or claimed evidence in any field, including history and chronology, can be valid if it contradicts the scriptural record" (http://www.answersingenesis.org/about/faith). That pretty much settles it; no evidence of any kind, from any discipline, no matter how compelling or well-supported, is allowed ever to change their minds about the reality of the Flood of Noah.

Montgomery's book does an admirable job of exploring this strange corner of the evolution-creationism issue. His examples and stories shed light on how geology developed as a science, and how geologic thinking stands so firmly in opposition to a Flood interpretation. Readers will benefit from *The Rocks Don't Lie*, finding it both entertaining and informative.

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REVIEW

Rereading the Fossil Record: The Growth of Paleobiology as an Evolutionary Discipline

by David Sepkoski
Chicago: University of Chicago, 2012. 432 pages

reviewed by Kevin Padian

This is the first book that examines the rise of paleobiology and the emergence of macroevolution as a separate subdiscipline within evolutionary biology. These advances began mainly in the late 1960s and 1970s, and they both shook the fields of biology, geology, and paleontology and established a framework of macroevolutionary questions that have been pursued ever since. The central focus of this work was a problem known since before Darwin: just how good is the fossil record, and how reliable is our reading of it? Before the period described in this book, the answer was generally that it was too fragmentary, episodic, and biased to be of much use. This uselessness was exacerbated during the hegemony of the Modern Synthesis (increasingly through the middle decades of the last century), when it was assumed that no useful theory could come from looking at fossils, and that all the action was at the level of population processes—which could be freely extrapolated to account for and even describe all the patterns of macroevolution.

In short, the fossil record was useless for ideas. It was perhaps amusing to see all the bizarre and giant forms that lived in the past, but really, what could possibly emerge from it that would provide insight about evolutionary processes?

John Maynard Smith was a formidable microevolutionary modeler and theoretician, and I knew him and respected him tremendously, both personally and professionally. When he first acquainted himself with the theory and supporting evidence of punctuated equilibria, he famously declared in *Nature* (1984), “The paleontologists have too long been missing from the high table [of evolution]. Welcome back.” Just as famously, he changed his mind several years later. But it hardly matters. Paleontology is at the high table of evolution, and it has always been. It is the only science that can document how evolution has worked in the long run—not at the (equally important) level of populations that turn over every few years or decades, but at the levels of millennia and millions and tens of millions of years. And we are not watching coat colors or numbers of leg bristles change. We are watching the emergence of wholly new clades, adaptations, physiologies, ecological invasions, and ecosystems. Science needs both macro- and microevolutionary patterns and processes in order to be able to test the general validity and importance of what we see at different levels. The movement in the 1960s and 1970s that David Sepkoski describes so well helped to redress the imbalance in the scientific approach to macroevolution. Now, with the ascendance of evolutionary developmental biology, we are finally able to see into some of the genetic processes that structure and permit the really critical changes in body plan to take place. (In Ernst Mayr's 800-page classic, *Animal Species and Evolution* [1963], the role of development in evolution received one page of treatment.)

David Sepkoski's book is the one book that anyone interested in evolution should buy this year. And next year. And probably the year after. The reason is that, for the first time, the emergence of the modern science of macroevolution receives its due. This is as exciting as the history of the formation of the Modern Synthesis in the early decades of the last century, as gripping as the story of Salvador Luria's experiments with T2 and T4 bacteriophages, as thrilling as the race to sequence the human genome. Everyone who lived through those years remembers the anticipation and excitement that greeted each new issue of the fledgling journal *Paleobiology*, each session of the Paleontological Society at the Geological Society of America's annual meeting, each international conference on macroevolution and paleobiology. We were finally posing and testing hypotheses about what the information in the fossil record could really tell us. In short, evolution in the long run was giving up its secrets, and not just anecdotally.

What were the hypotheses, and what problems did they address? To understand this, you had to know the characters. And what a group they were! My favorite (*primus inter pares*) has always been David Raup, the wry, hard-bitten maverick who revolutionized the science of the past in two ways. First, he insisted on quantifying and testing hypotheses, not simply giving them the superficial eye. Second, he insisted that unless you could show statistically that an apparent pattern in the data deviated significantly from expectations, you had nothing to explain. In short, he pioneered the role of randomness (in the statistical sense), and held paleontologists to their data. This was a change from the more typical paleontological publication of the 1960s (and sometimes beyond, unfortunately) that spent ten pages describing a new fossil critter, then took a page to deliver unconstrained speculation about its life habits, the success or failure of its lineage, and the hope for the future.

In short, here are the major problems that the new science of macroevolution tackled, beginning in the early 1970s. First, diversity through time: how had it changed, how reliable is the fossil record, and how would we know? Two major insights came from this problem: first, that there is an endless range of statistical tests we can perform to help decide how accurate the preserved fossil record is; and second, that the answer to the main question depends on geographic scale (local, regional, or global). A second question was extinction: what are its dynamics? It was soon realized that there are two modes of extinction, background (the constant or "business as usual" extinction rate), and mass extinctions (of which there have been five major ones). It now turns out that at least two of the five resulted not from increased extinction rates but from depressed rates of speciation (origination rates). And that leads us to another very important consideration, which is the interaction of speciation and extinction rates in determining diversity in a lineage, a clade, an ecosystem, or a global flora or fauna.

Beyond these considerations, there were questions of the origins of major groups and adaptations, the mechanisms of adaptive change, and the tempo and mode of change at the level of populations—which is what was addressed by Niles Eldredge and Stephen Jay Gould in their famous theory of "punctuated equilibria." Many scientists, some quite notable, have considered this theory and the evidence for it in completely different ways. Some ways are simply, flat-out wrong (for example, that "stabilizing selection" can explain it).

Others approach the theory from different scales, which is quite possible. Others see it as a question of the deployment of morphology through time, rather than a statement about speciation—which is not possible unless one can see a single lineage give rise to two.

David Sepkoski handles these questions and more, and it was not an easy task. Those principal players still alive sometimes remember their contributions differently than their printed (and sometimes private) words revealed at the time. Questions that loomed large for a year or two soon faded, but left their mark. And what exactly was the role of models such as MacArthur and Wilson's of island biogeography on the nascent science? These are all debatable points, and wonderful in their complexity and historical context. The point is that in a very few years, probably from the late 1960s to the mid-1970s, the science of the past experienced a complete revolution, and the questions that were opened and tested are the same ones that are being tested today. No student of evolution should miss the chance to understand where those questions came from and why. David Sepkoski's book is the first source to synthesize this information, and it is a superb synthesis. His father, one of the greatest paleobiologists ever, would have burst with pride. Waste no time, not merely in adding this to your bookshelf, but in reading it and marveling how so few people revolutionized our view of the past in such a very few years.

REFERENCES

Maynard Smith J. 1984. Palaeontology at the high table. *Nature* 309:401–402.

Mayr E. 1963. *Animal Species and Evolution*. Cambridge (MA): Harvard University Press.

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REVIEW

The Universe Within

by Neil Shubin
New York: Pantheon Books, 2013. 240 pages

reviewed by Alycia L Stigall

In his inaugural book *Your Inner Fish* (2008), Neil Shubin elegantly explained how key features of human anatomy developed during the evolutionary transitions from our fishy ancestors. In this new volume, *The Universe Within*, Shubin takes an even more expansive approach to explaining how humans came to occupy our place in this world—and indeed how this world even came to be a place for us to occupy.

This topic sounds, and indeed is, of epic proportions, and addressing it would seem to be a herculean challenge. But Shubin adroitly approaches it piecemeal, as a series of approachable tasks, each met by revealing a piece of an expertly interwoven tapestry. Moreover, he deftly intersperses his discussion of evolutionary innovations with anecdotes about the scientists and studies that generated these insights. Consequently, the resulting volume is not just an exposition of how human biology and evolution is linked to the cosmos. It is also a narrative—presented in a clear, conversational, and engaging writing style—of how our modern understanding of this relationship came about.

Along the way, we are introduced to scientists old (such as William "Strata" Smith, who developed fossil age correlation in the early nineteenth century) and new (such as Stephen Stearns, who studies natural selection among modern human populations), ideas that worked and failed, and the way that science works in general. This volume is perhaps as excellent for its description of how the scientific insights came to be as it is for the discussion of those insights themselves.

As a paleontologist and geologist myself who is at least broadly familiar with the arguments presented, I was impressed with just how much new scientific history I learned and how artfully the history and science were interwoven. Importantly, Shubin provides a comprehensive set of reading notes that provide resources for the lay reader and scientist alike; the sources discussed cover everything from popular science books to the original peer-reviewed literature. The generosity of the references reflects the excellence of the background research Shubin builds into this volume.

During the course of the volume, Shubin leads the reader to consider at ever more sophisticated levels how human bodies are made. He begins with the most basic aspect of human composition: the atoms that make up our bodies. There are, in fact, surprisingly few kinds of atoms that make up the great percentage of our bodies. Some of these, such as hydrogen, are widespread in the universe, but others, such as carbon, are not. To explain the origin of atoms such as carbon, Shubin takes his readers back in time to the Big Bang 13.7 billion years ago, to the start of all matter in our universe. It is during the early phases of star formation, some hundreds of millions of years after the Big Bang, that most of the atoms in our bodies arose. Only from the fusion of atoms in the centers of stars can elements such as carbon, potassium, and iron form. We owe our very existence to these very early extraterrestrial processes.

Shubin's narrative proceeds from this early starting point to processes and impacts that are more earth-bound: the creation of the moon and the continued impact of its formation on our circadian rhythms, the development of water on earth and the subsequent rise of our very earliest bacterial ancestors, the accumulation of oxygen as a by-product of photosynthesis clearing the way for the rise of animals. Each of these topics is examined in its own chapter, and Shubin explores all of these concepts within a narrative approach that keeps the reader engaged and interested.

Shubin's personal academic heritage as a field paleontologist and evolutionary biologist shines through. The chapters focused on geological and biological data are the strongest of the book. Chapter 6 provides an outstanding account of the development of plate tectonic theory and the impact of these tectonic revolutions on oxygen levels and the evolution of mammals—and ultimately on ourselves. Shubin next turns his attention to how global catastrophes and climatic changes allowed our mammalian ancestors to gain prominence in the terrestrial ecosystem and prompted our primate ancestors to develop color vision. My personal favorite was chapter 9: "Cold facts". In this chapter, Shubin explores the importance of climate change in the Neogene, notably the Plio-Pleistocene glaciations, in shaping our species. His argument leads from the development of Louis Agassiz's theory of glacial ages to Milutin Milankovitch's invocation of orbital cycles to explain changes in solar radiation to Harold Urey and Willard Libby's development of stable isotopes for climate proxies. Shubin then ties this storyline of ever-more detailed understanding of earth's climate to the development of agriculture and stable civilization by humans 11 000 years ago. Simply wonderful!

With the final chapter, Shubin reaches the culmination of his integrative narrative of nearly 14 billion years of environmental impacts that led to the development of our species. In this chapter, we read about the ascent of *Homo sapiens* from a typical species under the pressures of natural selection to the mega-organism—with the ability to alter the earth itself at unprecedented levels and speeds—that we have become. As Shubin writes, "Before our species hit the scene, trillions of algae took billions of years to transform the planet; now change is driven by a single idea traveling at the speed of light" (p 190).

Certainly, the vast impact of our species is astonishing, particularly given our tiny place in the universe and the intensely improbable series of events that transpired to allow our current existence here. If nothing else, this book should impress and astound you with the wonder of the universe and our place within it. Hopefully, you will also consider the role that our species has to play and our responsibilities to this amazing planet in the years and decades to come. Understanding and improving our place on this earth is of paramount importance for our species as we move forward.

I highly recommend this engaging book to anyone who wants to learn more about the science of our world, both how humans came to be and how we, as humans, came to gain the knowledge that we have.

REFERENCES

Shubin N. 2008. *Your Inner Fish: A Journey into the 3.5-Billion-Year History of the Human Body.* New York: Pantheon.

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REVIEW

The Major Transitions in Evolution Revisited

edited by Brett Calcott and Kim Sterelny
Cambridge (MA): MIT Press, 2011. 319 pages

reviewed by Derek Turner

In 1995, with the publication of their book *The Major Transitions in Evolution* (1995a), John Maynard Smith and Eörs Szathmáry introduced a new way of thinking about the "big picture" of the history of life on Earth. The major transitions they focused on all involved "changes in the evolutionary process itself," as Brett Calcott and Kim Sterelny put it in their introduction to this splendid collection of papers. For example, the evolution of sexual reproduction—one of the transitions that Maynard Smith and Szathmáry thought important—was not merely the evolution of some new trait. It meant that *the way evolution works* was changed forever. Or as Calcott and Sterelny put it, "Like a robot that continually reprograms itself, or a factory that manufactures parts to change its own operation, evolution upgrades itself, amplifying the kinds of further change that are possible" (p 4).

Scientists sometimes find it helpful to think of evolutionary history as a pathway that a lineage takes through a multidimensional morphospace—a "space" of possible biological forms. Maynard Smith and Szathmáry's work provoked biologists to think of that space as something that itself is capable of changing over time. Perhaps new realms of biological possibility open up when a major transition occurs. Many of the major transitions, such as the evolution of eukaryotic cells, also seem to involve boosts of biological complexity. Studying these major transitions is thus one way of approaching the evolution of complexity.

Calcott and Sterelny's volume is the product of a workshop sponsored by the Konrad Lorenz Institute for Evolution and Cognition Research (KLI) at the University of Vienna. The contributors include a mix of scientists and philosophers of biology. The quality of the papers is very high, and even those who are already familiar with the issues will learn a great deal from them. The first of the three sections ("A big picture of big pictures of life's history") is largely philosophical, while the second ("The prokaryote's tale") focuses more on microbiology. The third section ("Complexity and the developmental cycle") contains mostly scientific papers that engage with questions about multicellular life. The volume concludes with a short, forward-looking essay by Eörs Szathmáry and Chrisantha Fernando. Oddly, this concluding piece focuses not on the history of life but on evolutionary processes that take place during the development of the nervous system, and whether those processes involve any major transitions.

Be forewarned that this is not an introductory book. Although the introduction by Calcott and Sterelny is accessibly written, as are their introductions to the three sections, most of the contributions presuppose some familiarity with recent work in evolutionary biology and its philosophy. And many of the individual papers are quite demanding. Nevertheless, this collection provides an excellent snapshot of some of the work that Maynard Smith and Szathmáry have inspired. The papers collected here do reward careful study.

In a paper published in *Nature* around the same time as their book, Maynard Smith and Szathmáry (1995b:228) identified the following transitions as the "major" ones:

Replicating molecules to populations of molecules in compartments

Unlinked replicators to chromosomes

RNA as gene and enzyme to DNA and protein (genetic code)

Prokaryotes to eukaryotes

Asexual clones to sexual populations

Protists to animals, plants, and fungi (cell differentiation)

Solitary individuals to colonies (non-reproductive castes)

Primate societies to human societies (language)

Once you start looking at evolutionary history with these major transitions in mind, you encounter a number of challenging empirical and theoretical questions. For example, what caused some of the particular transitions listed above, and how can scientists study those causes empirically, given that most of the major transitions occurred in the distant past? And how might the study of these major transitions intersect with multilevel selection theory? Are there any transitions that should be on this list but aren't? Are there any that don't belong here?

The paper by Daniel McShea and Carl Simpson ("The miscellaneous transitions in evolution") is the only one that openly challenges Maynard Smith and Szathmáry's program. McShea and Simpson argue that the idea of major transitions lacks theoretical unity. Actually, they have some harsher words than that: according to them, there is "something philosophically muddled and scientifically casual" about it (p 32). Their main complaint is that the list of major transitions is a heterogeneous grab bag, and they direct their fire at the idea that the evolution of human societies from primate societies deserves to be considered a distinct transition. Maynard Smith and Szathmáry most likely included it on their list because the evolution of language involves a change in the way information is stored and transmitted—that's one of the three marks of a major transition that they offer in their 1995 paper. Human societies also involve division of labor, which is the second of the three marks. But the third one is this: "Entities that were capable of independent replication before the transition can only replicate as parts of a larger unit after it" (1995b:227). This doesn't seem to apply to human societies. It doesn't seem to apply to the evolution of sex, either (though see Richard Michod's contribution to this volume for a different perspective).

As if to confirm McShea and Simpson's suspicions about the lack of theoretical unity, two (very interesting) papers in this volume—by Lindell Bromham and by Andrew Knoll and David Hewitt—focus on the Cambrian explosion, which was not one of Maynard Smith and Szathmáry's original major transitions at all. In their introduction, Calcott and Sterelny argue that the Cambrian explosion deserves to be added to the list (p 11–12).

McShea and Simpson, are, I think, correct to worry that there is some fuzziness about what counts as a major transition, and why. But then again, it's not entirely clear why we really need a unified theory of the major transitions. Perhaps one conclusion to be drawn from this book is that even without such a unified theory, Maynard Smith and Szathmáry's idea has inspired some fruitful scientific and philosophical work. Calcott and Sterelny's collection should inspire some more.

REFERENCES

Maynard Smith J, Szathmáry E. 1995a. *The Major Transitions in Evolution*. Oxford: WH Freeman.

Maynard Smith J, Szathmáry E. 1995b. The major evolutionary transitions. *Nature* 374:227–232.

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