

EDITORIAL

GENESIS KINDS AND THE SEA URCHIN

The idea that different types of organisms were created and commanded to reproduce “after their kinds” seems widely believed among creationists. It may therefore come as a surprise to many to learn the idea is not stated in the Bible.

I discovered this several years ago as I prepared a lecture on limits to change in species. I looked up all the Bible texts using phrases such as “after its kind” or “according to their kinds,” and identified the verb associated with the phrase. I found three contexts in which nearly all these texts were located. The first context was creation, and, with one exception, the verb was “created.” The various kinds of animals were “created according to their kinds.” This is referring to the origins of the various kinds of creatures, but says nothing about their reproduction.

The one possible exception is found in Genesis 1:11-12, where the text has been translated as “fruit tree making fruit after its kind”.¹ Here, the author appears to be stating that different kinds of fruit trees would have different kinds of fruits, so that a tree could be identified from its fruit (cf. Matthew 12:33). Thus, the type of fruit produced would remain constant, although the text does not prohibit the tree itself from changing in appearance, and common experience shows that plants are quite variable in structure.

The second context using phrases such as “according to their kinds” is in the description of the animals entering the ark. Here the verb refers to entering the ark, not reproduction. The third context is in the listing of clean and unclean animals, and there is no mention of reproduction here either. In fact, the Bible says nothing at all about creatures producing offspring that are the same as their parents. The idea of fixity of species does not come from the Bible, but from the philosophy of Plato and his followers, who emphasized the notion of ideal types. Individuals might vary from the type, but the ideal remained constant, and variation would be limited.

What, then, is the meaning of the phrase “according to their kinds?” First, it must mean that different kinds of creatures were created within each stated category. For example, the creatures moving in the water were created “according to their kinds;” thus there was a diversity of creatures from the beginning of the creation. Similar conclusions can be drawn for the birds, creeping things, and beasts. Diversity is an original feature of creation. The concept of multiple lineages of independent origin is called “polyphyly.”

Polyphyly is a key component of creation theory. This contrasts with “monophyly,” which is the notion that all living organisms share a common ancestry. Monophyly is the dominant idea in evolution theory, although some evolutionists would accept a small number of independent lineages. The idea of “a few” original ancestors was noted as a possibility by Charles Darwin, and can be called “oligophyly.” The phrase “according to their kinds” still contradicts evolutionary theory, not because species cannot change in appearance, but because it rules out monophyly, or even oligophyly.

What position should a creationist hold regarding the extent of change in species? Is it possible that species have changed a great deal since the original creation? The answer to that question must take into consideration the findings of science. But science does not yet know the answer. The problem is that morphological features result from the processes of embryological development, and the genetic basis for these processes is poorly understood. We need an organism for which embryological development has been studied for a long time. Enter the sea urchin.

The sea urchin has been a model organism for the study of embryological development for more than a century. Sea urchins have several features that make them useful for studying development. They produce millions of eggs which are transparent and easy to modify genetically. After about 48 hours of development, the sea urchin embryo reaches the late gastrula stage, with about 800 cells and 10 to 15 cell types. By the end of the third day, the embryo develops into a relatively simple larva called a pluteus. Study of the sea urchin has revealed a great deal about development, although much remains to be discovered.

The genome of the California sea urchin, *Strongylocentrotus purpuratus*, has recently been sequenced, opening up new possibilities for understanding the genetic basis for development in these creatures, and possibly helping understand development in other kinds of organisms.

Although the sea urchin still retains many secrets of the genetic basis of its development, what is known is remarkable. The sea urchin has about 23,000 genes, which is similar to the number of genes reported from humans. More than half these genes, some 12,000, are utilized in the first two days of development. This is all the more astonishing when one realizes that most of the cells from the two-day embryo are discarded when the pluteus larva metamorphoses into the familiar adult form of the sea urchin. This observation suggests that many of the genes are utilized for different functions in the larva and in the adult. If so, it might be very difficult to make drastic changes in sea urchin morphology, because changes that might be tolerated by the pluteus might be lethal to the adult.

Scientists appear to be on the way to discovering the morphological effects of genetic changes. At this point, the outcome is not known. But suppose that it were to be discovered that a few key genetic changes, say twenty, could transform a sea urchin into a starfish or a sea cucumber. Would this disprove creation? Or, suppose scientists uncovered the developmental genetics of mammals and discovered that only a few genetic changes, say ten, could transform a camel into a deer, or a dog into a cat. How would creationists respond? Might the Creator have used a genetic template, and added different details in different lineages? If so, the results might resemble, in many respects, the expectations of evolutionary theory.

On the other hand, suppose scientists discovered that development depends on such exquisite interaction among genes that there is very little room for change. Suppose it is found that there is no way an organism could survive a major change in the anatomical plan of its body, and that variation is limited to relatively minor modifications such as changes in linear dimensions. Would this disprove evolution, and how would evolutionists respond?

If history is a reliable guide, it is likely that the study of development will reveal increasing layers of complexity rather than a simple and clear-cut answer to the questions raised here. Nevertheless, it may be useful to recognize the limitations of our knowledge, even as we seek to increase our understanding of development and the potential limits to change in species. In the end, we should obtain a better understanding of the potential for morphological change among members of a lineage, and improve on our ability to estimate the number and identity of the numerous separately created lineages we often refer to as the “Genesis kinds.”

Jim Gibson

ENDNOTE

1. Kidner D. 1967. *Genesis: An introduction and commentary*. Downer’s Grove, IL: InterVarsity Press, p 48.

ARTICLES

IRREDUCIBLE INTERDEPENDENCE: AN IC-LIKE ECOLOGICAL PROPERTY POTENTIALLY ILLUSTRATED BY THE NITROGEN CYCLE

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ABSTRACT

The nitrogen cycle is an ecochemical¹ pathway distributed on a global scale and including multiple organisms. Reactions comprising the nitrogen cycle are catalyzed by complex protein machines, some of which — like the nitrogen fixing system in legumes — may arguably be Irreducibly Complex (IC). The focus of this paper is not on these systems, but the overarching cycle in which they participate, asking if the cycle itself resembles an IC system, whether the components themselves are IC or not.

INTRODUCTION

Recent arguments for design have made use of information encoded in DNA and of irreducibly complex molecular machines. At the molecular level, enough knowledge has accrued to understand the nature and behavior of atoms and molecules with fair confidence. Thus when atoms are seen to be arranged in specific ways that are not required by their nature, and yet seem remarkably fortuitous, it seems reasonable to infer some kind of intelligent cause. Such is the case when atoms are arranged to encode information as in DNA, and also when atoms are arranged to form complex molecular machines or biochemical assembly lines.

In his groundbreaking book on the subject of Intelligent Design (ID),² Michael Behe popularized the term “irreducible complexity” (IC), and made the case that certain biochemical systems exhibit this property. Behe defined IC as:

A single system composed of several well-matched, interacting parts that contribute to the basic function, wherein the removal of any one of the parts causes the system to effectively cease functioning.³

Thus to understand whether a system is irreducibly complex (IC) requires that:

1. The function be known
2. It be composed of multiple interacting parts
3. These parts be well-matched
4. At least some subset of those parts be indispensable for the system to function at a minimal level (note that not all the parts must be indispensable)

The examples of IC biochemical systems Behe provides range from the machine-like bacterial flagellum to the complex cascade of biochemical events which occur to produce blood clots. Behe also discusses biosynthesis of Adenosine Mono Phosphate (AMP) which might not be irreducibly complex, but also presents problems for incremental construction.

All of Behe's examples reside either within single cells, or at least within the same organism. Clearly this has profound implications if his thesis — that the presence of IC systems precludes a Darwinian explanation — is correct. But Behe did not restrict IC biochemical pathways and systems only to those found in a single organism. In fact, he encouraged examination of more complex systems to see if they exhibit IC-like properties:

Given that some biochemical systems were designed by an intelligent agent, and given the tools by which we came to that conclusion, how do we analyze other biochemical systems that may be more complicated and less discrete than the ones we have so far discussed?⁴

In this paper we attempt to address this question by arguing that the nitrogen cycle (N cycle) exhibits properties that resemble IC, but differ significantly from the examples used by Behe. Since the ecochemical nitrogen cycle is distributed across multiple species, and if Behe's contention that IC precludes a Darwinian origin holds, the nitrogen cycle presents implications that go beyond those inherent in IC systems contained within a single organism.

THE NITROGEN CYCLE

The function of the N cycle is to regulate concentrations of various nitrogen-containing molecules in the environment in such a way that life can thrive. For those accustomed to thinking of the N cycle primarily in terms of nitrogen fixation for production of amino acids and other nitrogen-containing molecules, this may seem counterintuitive. However, when viewed from a global perspective this is precisely what the N cycle

achieves. In nature it works to keep reactive oxides of nitrogen, as well as chemically active reduced nitrogen compounds, particularly ammonia, at levels which allow life to exist while at the same time ensuring availability of reduced nitrogen when it is required for growth.

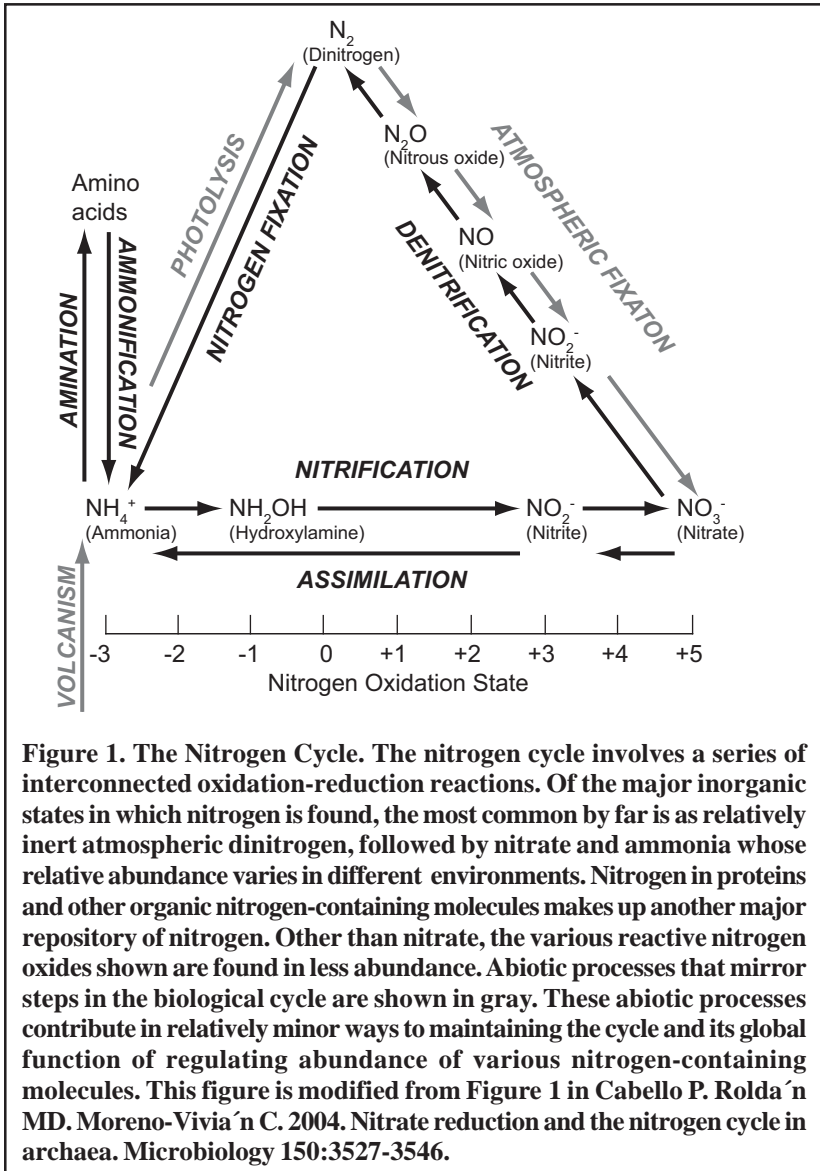


Figure 1. The Nitrogen Cycle. The nitrogen cycle involves a series of interconnected oxidation-reduction reactions. Of the major inorganic states in which nitrogen is found, the most common by far is as relatively inert atmospheric dinitrogen, followed by nitrate and ammonia whose relative abundance varies in different environments. Nitrogen in proteins and other organic nitrogen-containing molecules makes up another major repository of nitrogen. Other than nitrate, the various reactive nitrogen oxides shown are found in less abundance. Abiotic processes that mirror steps in the biological cycle are shown in gray. These abiotic processes contribute in relatively minor ways to maintaining the cycle and its global function of regulating abundance of various nitrogen-containing molecules. This figure is modified from Figure 1 in Cabello P. Roldán MD. Moreno-Vivián C. 2004. Nitrate reduction and the nitrogen cycle in archaea. *Microbiology* 150:3527-3546.

In essence, the N cycle functions to ensure that the vast majority of nitrogen atoms are in the form of the inert gas N_2 , while most of the remaining nitrogen is found in living things or their waste products. The cycle acts as a vital buffer to changes in nitrogen-containing molecules in the environment, while at the same time ensuring availability of reduced nitrogen for biological purposes. Some variation among different biomes on Earth is evident and some deviation from the current relative abundances of nitrogen in various chemical states may have occurred in the past, but life requires limits to the concentrations of various forms of nitrogen in the environment. It is the biological N cycle that prevents these limits from being exceeded under most circumstances. Because the ecological function of the N cycle is known, it meets Behe's first requirement, that the function be known.

Figure 1 gives a typical depiction of the N cycle. It is clear that this cycle has multiple parts, thus fulfilling the second criterion laid down by Behe for a system to be IC. Whether these parts are "well-matched" is a matter of judgment. The bulk of the rest of this paper will examine two issues:

1. Whether some parts of the cycle are indispensable. By this we mean a part is necessary for the cycle to operate and lacking that step, the N cycle would not achieve its overall function.
2. Whether some reasonable step-by-small-step unguided natural process could be expected to produce the N cycle as we find it. In other words, can parts of the cycle be bridged by known inorganic processes in such a way that the cycle could be assembled incrementally as biological mechanisms accrued until the cycle became essentially a completely biological rather than abiotic process? Or are there necessary steps that are not practically bridgeable by inorganic processes?

In short, are the various stages of the nitrogen cycle indispensable to its function and do they represent functions that nature acting alone could not reasonably be expected to bridge?

FIVE STAGES OF THE NITROGEN CYCLE

The nitrogen cycle, sometimes said to be a web, consists of five stages: The first stage, **Nitrogen Fixation**, is the process by which atmospheric nitrogen is reduced to ammonia. This stage is particularly important and is made up of multiple sub-stages. The second stage, **Nitrification**, first converts ammonia to nitrite and then to nitrate. Another stage, **Denitrification**, changes nitrate back to either atmospheric dinitrogen or nitrous

oxide, another gas. The fourth stage, **Assimilation**, converts nitrates back to nitrites and finally to ammonia. This ammonia is used to produce amino acids via amination and these amino acids are used to produce biological compounds such as proteins, or serve as substrates for production of other nitrogen-containing molecules including nucleic acids. The final stage in the cycle is **Decay** or ammonification (also known as mineralization), in which nitrogen from wastes and decaying organic nitrogenous residues are converted back to ammonia and then recycled. This process is usually slow, with most nitrogenous wastes remaining in soil as larger organic molecules (amino acids, for example, as well as protein fragments) which are slowly converted to ammonia. These amino acids and protein residues may even be directly absorbed by plants.⁵

Each stage in the nitrogen cycle involves specialized enzymes housed in widely diverse organisms. The nitrogen cycle, incorporating a broad spectrum of unconsciously cooperating species, operates in a coordinated assembly-line manner that is extraordinary and impressive. Whether it contains steps that are both indispensable and unbridgeable will be examined in the following sections of this paper.

1A. NITROGEN FIXATION — OVERVIEW

Nitrogen fixation occurs in one of three different ways, two of them natural: 1) Atmospheric (Lightning) Fixation, 2) Biological Fixation, and 3) Industrial Fixation (Haber Process), used for synthesizing fertilizers and explosives. In this paper, biological and atmospheric nitrogen fixation will be discussed, but industrial fixation will only be mentioned where it contributes to understanding the impact of unbalancing the natural nitrogen cycle.

Biological nitrogen fixation could be the subject of an entire design argument by itself, but for the purposes of this discussion the most important consideration is the final product: ammonia (NH_3). Within cells, this reactive chemical must be handled with some degree of finesse if it is to react with the appropriate substrate and form an amino acid. It is these amino acid molecules which serve as nitrogen donors during synthesis of other nitrogen-containing organic molecules, like more complex amino acids and the nitrogen-containing bases of nucleotides.

1B. ATMOSPHERIC NITROGEN FIXATION

A relatively small, but not insignificant, amount of nitrogen is fixed by lightning passing through the atmosphere. Other phenomena, including thermal shock from meteorites striking the atmosphere, may have a similar effect. Thermal shock splits atmospheric dinitrogen molecules (N_2), allowing the separated atoms to combine with oxygen, producing highly

reactive nitrogen oxides which ultimately combine with water to form nitric acid (HNO_3). Nitric acid is converted to nitrate in soils. Nitrates derived from atmospheric fixation mix with nitrates of biological origin and are assimilated by microbes or plants, or returned to the atmosphere as dinitrogen via denitrification.

1C. DOES ATMOSPHERIC NITROGEN FIXATION BRIDGE BIOLOGICAL FIXATION?

Because nitrates can be produced in the absence of biological nitrogen fixation, it might be tempting to suggest that this biological step in the nitrogen cycle is dispensable. In real life this is not the case because of three factors: 1) Nitrates from atmospheric fixation must be reduced to ammonia if they are to be biologically useful. 2) Electric storms and other causes of atmospheric fixation are more common in some places than others so nitrate produced by this means is irregularly distributed. 3) The amount of nitrogen fixed by thermal shock is comparatively small, so this method cannot be considered either consistent or sufficient in itself to sustain life as it is now.

One author has estimated (perhaps generously) that atmospheric nitrogen fixation produces as much as 10% of the total nitrogen fixed in nature.⁶ Another reference⁷ suggests that lightning fixes an estimated 3 to 5 Tg⁸ annually, while annual bacterial fixation accounts for 90 to 130 Tg. Thus 10 % appears to be at the high end of estimates and the real percentage could very well be lower. A complicating factor is the contribution of agriculture, particularly intensive cultivation of legumes and rice, which has, over the past century, significantly increased biological nitrogen fixation on the continents. In the past, the contribution of atmospheric nitrogen fixation to total nitrogen fixation may have been higher as a percentage of the total, but the actual amount of nitrogen fixed in this way would be expected to remain relatively constant.

Atmospheric nitrogen fixation could not have been part of a bootstrap mechanism by which life originated because its product, nitrate, is not directly biologically useful. In addition, an abiotic mechanism to convert nitrate to biologically useful forms like ammonia is unavailable to bridge the gap between the products of atmospheric and biological fixation. There are no shared enzymes between biological nitrogen fixation and assimilation, even though their end product — ammonia — is the same. As a consequence, one cannot be explained as a relatively simple adaptation of the other to a different task.

In organisms living today, biological nitrogen fixation requires photosynthesis or chemosynthesis to provide both energy and carbon backbones for amination to produce amino acids. Of particular significance, both

photosynthesis and chemosynthesis require nitrogen-containing proteins; thus, in these organisms a chicken-or-egg conundrum exists which atmospheric nitrogen fixation does not solve (Figure 2). In addition, during assimilation the reducing power may be provided by photorespiration⁹; thus a link exists between photosynthesis and both assimilation and nitrogen fixation.

How nitrates could have been abiotically modified to form biologically useful compounds is unclear. Even if the energy needed for nitrogen fixation or assimilation did not come from photosynthesis or chemosynthesis, some energy source is still required. In addition, enzymes that mediate the necessary reactions are also required. It may be possible to build a bypass around photosynthesis, but it is not clear that this would provide a more plausibly evolved pathway. No matter what the mechanism, complex protein catalysts appear to be required and production of these requires the ultimate products of nitrogen fixation — amino acids and nucleotides.

A further impediment to biological usefulness of atmospheric nitrogen fixation stems from the fact that nitrates form by reacting with oxygen. Nitrogen can exist in positive oxidation states between 1 and 510 (Figure 1). In general, nitrogen oxides are unstable and break down to form nitric oxide (NO) or nitrogen dioxide (NO₂). Both of these oxides of nitrogen are highly reactive free radicals. NO₂ constitutes the brown photochemical smog found in some cities, which serves as a catalyst in producing the potent oxidizer ozone (O₃). Ozone oxidizes organic molecules and, if present in the low concentrations sufficient to destroy abiotically formed organic molecules, would hamper accumulation of the organic soup thought to be necessary for the “natural” origin of life. Therefore, the formation of nitrate as a result of atmospheric nitrogen fixation notwithstanding, life itself appears unlikely to have originated in an oxidizing atmosphere and lightning-induced nitrate production seems improbable as a source of biologically useful nitrogen during alleged evolution of nitrogen fixation systems. In an oxidizing atmosphere, life — if it already existed — must have possessed systems to deal with damage caused by toxic byproducts of atmospheric nitrogen fixation, but life is unlikely to have evolved in the first place due to the impact of some of these byproducts.

This may partly explain why, despite significant evidence to the contrary,¹¹ naturalistic “origin of life” scenarios commonly hinge on reducing primordial atmospheres.¹² Proposed atmospheres commonly contain gases such as ammonia, methane, hydrogen, and water vapor. Research involving atmospheres consisting of various combinations of these gases, but always lacking oxygen, have been shown, when supplied with sufficient energy, to produce a variety of organic molecules including amino acids. Thus, under reducing conditions, early life could freely acquire amino acids

without resorting to biological nitrogen fixation. The problem is that, while this scenario might explain why amino acids serve as nitrogen donors in anabolic biochemical pathways, it still does not explain evolution of the nitrogen cycle itself; at best it renders one step in the cycle superfluous

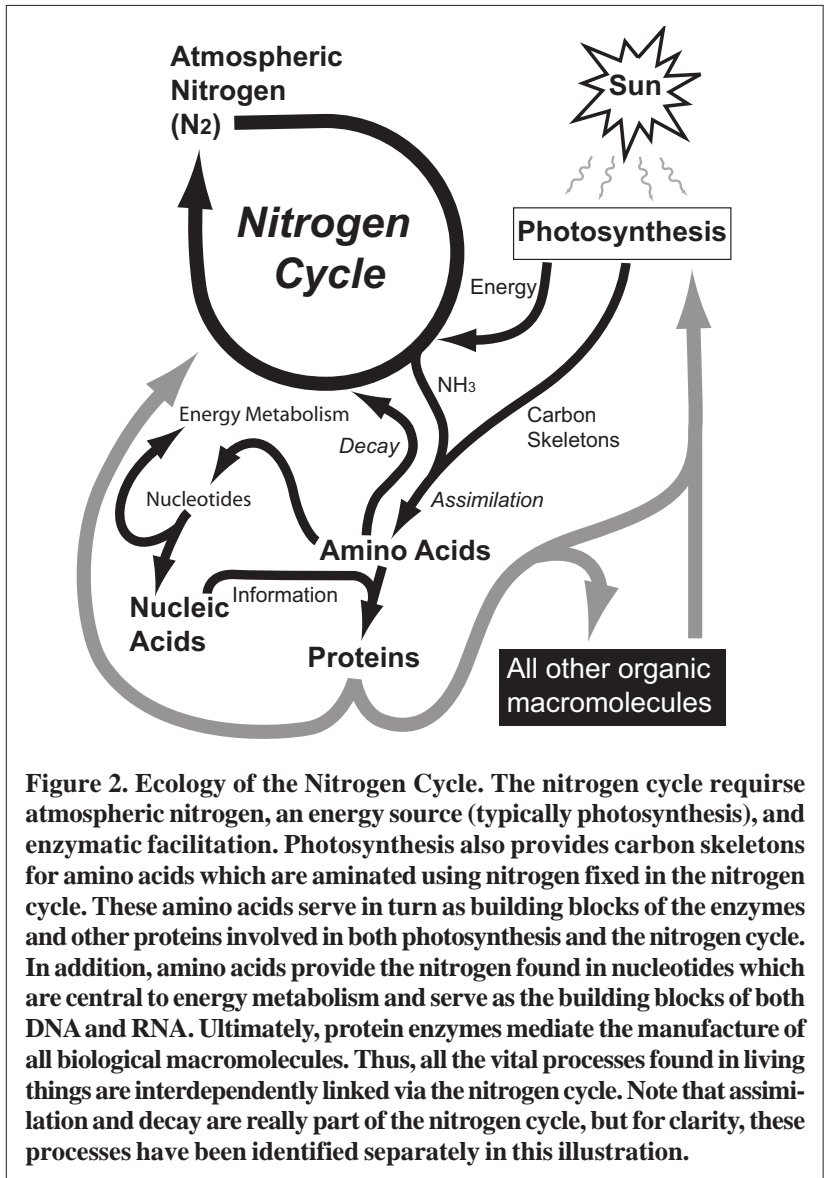


Figure 2. Ecology of the Nitrogen Cycle. The nitrogen cycle requires atmospheric nitrogen, an energy source (typically photosynthesis), and enzymatic facilitation. Photosynthesis also provides carbon skeletons for amino acids which are aminated using nitrogen fixed in the nitrogen cycle. These amino acids serve in turn as building blocks of the enzymes and other proteins involved in both photosynthesis and the nitrogen cycle. In addition, amino acids provide the nitrogen found in nucleotides which are central to energy metabolism and serve as the building blocks of both DNA and RNA. Ultimately, protein enzymes mediate the manufacture of all biological macromolecules. Thus, all the vital processes found in living things are interdependently linked via the nitrogen cycle. Note that assimilation and decay are really part of the nitrogen cycle, but for clarity, these processes have been identified separately in this illustration.

while necessitating evolution of other steps to cycle nitrogen out of organic molecules and back into the atmosphere. In any case, the problems of biochemical evolution and the spontaneous generation of life have been so much discussed that there is no need to repeat them. For an overview, see the chapter on the Miller-Urey experiment in Jonathan Well's *Icons of Evolution*.¹³

Most arguments for evolution of the nitrogen cycle allow for the existence of life before a complete nitrogen cycle existed, but some source of nitrogen in the right form is required for life to exist. This is a major problem. If a reducing atmosphere provides the nitrogen-containing building blocks of life, then biological nitrogen fixation becomes unnecessary raising the question of — at least before the switch from a reducing to an oxidizing atmosphere — what selective pressure would “cause” it to evolve. On the other hand, if nitrate is produced via thermal shock in an oxidizing atmosphere, then some unknown abiotic mechanism must have reduced the nitrate to a biologically useful form before evolution of mechanisms of assimilation. In addition, any reduced organic molecules must be protected in some way from O₃ and other free radicals produced as a byproduct of atmospheric fixation. In either scenario, production of life and evolution of biological nitrogen fixation present conundrums that the neo-Darwinian mechanism does not reasonably resolve.

While any number of scenarios may be suggested to overcome these issues, none actually solves the problems using strictly Darwinian principles. Take the following scenario for example: life evolves in a reducing atmosphere which subsequently changes to an oxidizing atmosphere. Under these new circumstances, bacteria among the few organisms that survived the change evolve the ability to use nitrogen in nitrate thus evolving assimilation before biological nitrogen fixation. Life is sustained by atmospheric fixation until biological nitrogen fixation evolves. Problems with this scenario include: 1) It assumes that assimilation is evolvable and had evolved enough before it was vital to sustain some bacteria that also had the ability to survive an oxidizing atmosphere; 2) it assumes atmospheric fixation at levels sufficient to sustain life, but not so rapid that nitrate accumulated to the point that it caused problems; 3) evidence is lacking for a reducing atmosphere; 4) the concurrent need to develop a means of aminating carbon skeletons to produce amino acids; 5) the concurrent need to deal with radicals produced as part of the process; 6) availability of energy resources and reducing power sufficient to allow assimilation to work and so on. Probably the most troubling assumption is that any organism adapted to living in a reducing environment could survive the transition to an oxidizing environment. Ultimately scenarios of this kind simply split a single big problem into two big problems for Darwinism to explain; they

do not reduce the problem to small steps that unguided nature might reasonably be expected to take via the neo-Darwinian process. In addition, they do not explain biological nitrogen fixation, but instead invoke a different biological means of obtaining nitrogen without addressing the point about nitrogen fixation. Assimilation will be further discussed later in this paper.

1D. BIOLOGICAL NITROGEN FIXATION: NITROGEN MADE AVAILABLE IN MANY HABITATS

Biological nitrogen fixation is the main *natural*¹⁴ method by which nitrogen is made available to living organisms. As already noted, in natural systems over 90 percent of fixed nitrogen comes from biological activity. The ability to fix nitrogen is restricted to certain microbes. Bacteria (including cyanobacteria) that reduce nitrogen to ammonia (NH₃) span a selection of widely disparate genera and lifestyles, examples of which include: *Azotobacter* (aerobic), *Klebsiella* (facultatively anaerobic), *Rhodospirillum* (photosynthetic, anaerobic), *Clostridium* (free-living/anaerobic), *Nostoc* (free living or symbiotic cyanobacterium), *Frankia* (actinomycete, symbiotic with *Alnus*, alder trees), *Anabaena* (photosynthetic cyanobacterium, symbiotic with *Azolla*, water fern; reported as common in rice paddies),¹⁵ and *Rhizobium* (symbiotic with legumes). The latter four genera form symbiotic relationships with several genera of plants, although some species may also be free-living. While several other examples are known,¹⁶ the best understood of such mutualistic relationships is that of *Rhizobium* strains and species in relationship with different legume species.

Anaerobic nitrogen-fixing bacteria are found in the guts of some herbivores including sea urchins¹⁷ and termites.¹⁸ The contribution of these bacteria to the nitrogen needs of their host may be negligible in some cases, but significant in others. Cyanobacteria may form symbiotic relationships (in lichens, for example), but it is as free-living organisms in aquatic and marine environments that they are especially important. *Trichodesmium* is one such marine nitrogen-fixing cyanobacterium.¹⁹

The diversity of nitrogen-fixing bacteria ensures that nitrogen is made available to occupants of many different habitats. In addition, it illustrates the argument in this paper that the nitrogen cycle is not so much about individual species, but about steps in an ecochemical pathway. A step may be necessary and unbridgeable, but an individual species that mediates the step may not be necessary at a given time as the machinery required to accomplish the step — the enzymes involved — may be found in other species, some apparently distantly if at all related. Redundancy is important as a back-up when circumstances preclude the presence or sufficient abundance of individual species that have the same abilities. Ecological systems are replete with redundancies.

1E. BIOLOGICAL NITROGEN FIXATION—NITROGENASE

All known nitrogen-fixing bacteria produce nitrogenase, which is composed of two different protein complexes whose amino acids contain nitrogen. The existence of these protein complexes requires the very reactions they catalyze. When two different nitrogenase subunits from unrelated species are combined, they most often form “active hybrids” with nitrogenase activity.²⁰ Consequently, nitrogenases from even very distinct species appear comparable, although some differences have been noted.²¹ This degree of similarity suggests a similar origin even though, as already noted, nitrogen-fixing bacteria occupy a range of very different habitats. Under these circumstances convergent evolution appears unlikely to have produced similar protein complexes capable of interchanging parts. Lateral gene transfer may represent the most promising evolutionary explanation of the distribution of nitrogenase across species.²²

Nitrogenase expression is reversibly regulated by what is called the “ammonia switch-off.”²³ In addition, nitrogenase expression may be repressed via a complex cascade of events when oxygen levels are high.²⁴ While nitrogenase complexes in different species appear comparable, genetic regulation of nitrogenase expression differs widely in different organisms.²⁵ In addition, strategies for shielding nitrogenase from oxygen vary among organisms.

Interactions between host plants and *Rhizobium* bacteria in root nodules are particularly intimate and elegant.²⁶ When concentrations of nitrogen compounds are elevated in the shoots of host-plants, nitrogenase activity is lowered. Evidently, when no more fixed nitrogen is needed there is a means of communication between the host plant’s shoots and bacteroids, misshapen *Rhizobium* cells in root nodules.²⁷ This is another example of interspecific cooperation, which in this case is believed to involve an amino acid as the inhibitor of nitrogenase.²⁸ Down regulation of nitrogenase is necessary due to its high energy demands and the reactive nature of its product, ammonia. Under normal conditions, free ammonia is essentially absent as it is immediately used to produce the amino acid glutamate and is thus sequestered in a glutamate pool.

Significantly, in all known cases oxygen acts as a poison to the nitrogenase enzyme. If nitrogen fixation had evolved in a reducing atmosphere, this may make some sense, but a reducing atmosphere should eliminate the need for nitrogen fixation as nitrogen would be freely available via abiotically produced amino acids and as ammonia. Thus, selective pressure for developing nitrogen fixation is difficult to conceive, especially given its high energy demands. As a consequence, the sensitivity of nitrogenase to oxygen presents a conundrum; in a reducing atmosphere, nitrogen

fixation should not evolve, while in an oxidizing environment nitrogenase does not work.

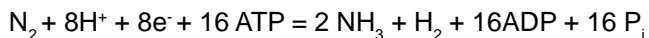
Invoking a neutral atmosphere to circumvent this problem does not solve it and presents the worst of both options. On the one hand, neutral atmospheres are not known to produce nitrogen-containing molecules essential for life and on the other hand, oxygen may still be present in concentrations sufficient to poison nitrogenase. Under these circumstances, nitrogen fixation would need to evolve for life to exist before life could exist, a veritable evolutionary “Catch 22.” In addition, some mechanism for isolating nitrogenase would still need to evolve to protect it from the relatively low levels of oxygen present in such an atmosphere. A simpler and more direct path would be to evolve a nitrogenase that is not as sensitive to oxygen. Clearly the sensitivity of nitrogenase to oxygen is not well explained by invoking its evolution in a reducing atmosphere or in a neutral one. This suggests that there may be a necessary design constraint that is worth looking for in nitrogenase, as that may be the true explanation of its sensitivity to oxygen.

All organisms that fix nitrogen use some mechanism to ensure anaerobic conditions. A notable example of this is leghaemoglobin, which occurs in legume root nodules and has greater affinity for oxygen than mammalian hemoglobin. Leghaemoglobin is cooperatively manufactured, with legume genes determining the globin portion of the molecule, while the porphyrin ring comes from *Rhizobium*.²⁹ However, the central iron ion in the porphyrin ring comes from the plant. Clearly, production of leghemoglobin requires exact coordination between both species. Cooperative synthesis, such as this, challenges Darwinian explanations and is another possible example of a system with IC-like characteristics spread across multiple species.

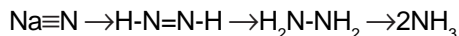
Most biological fixation is accomplished by symbiotic bacteria and photosynthetic nitrogen-fixing cyanobacteria.³⁰ Nitrogen fixation in free-living non-photosynthetic soil bacteria is considered to be relatively low as a result of limited access to energy resources. Consequently, populations of such bacteria are also low.³¹ However, they may be more numerous and productive close to roots, a zone designated as the “rhizosphere,” where they may access photosynthetically produced nutrient exudates. Nevertheless, in the words of Moat & Foster: “Although free-living organisms, in general, appear less efficient in their ability to fix nitrogen, their number, variety, and ubiquitous distribution suggest that they are of major ecological importance.”³²

1F. BIOLOGICAL NITROGEN FIXATION AND PHOTOSYNTHESIS

Biological nitrogen fixation requires hydrogen and large amounts of energy from ATP. The reaction is represented in the following equation:



Notably absent is a stepwise chemical reduction in which oxides of nitrogen are used as intermediates in a biochemical pathway to nitrogen fixation. This precludes the pathway used in assimilation for reduction of nitrates as a stepping stone toward evolution of nitrogen fixation as observed today. Instead, nitrogenase-catalyzed reduction of N_2 involves this complex protein machine directly transferring electrons to N_2 in stepwise fashion.³³



Improbable as it may seem, the sum of the Gibbs free energy (G) in these reactions is -79.0 kJ/mol .³⁴ In other words, the conversion of N_2 to ammonia is exergonic. Among other things, the need for energy stems from the cost of providing hydrogen and electrons to the reaction, and that energy is derived from ATP which is either directly or indirectly produced by photosynthesis or, rarely, chemosynthesis. Moat & Foster³⁵ note that the photosynthetic capacity of plants may be a limiting factor in nitrogen fixation. It is estimated that as much as 20% of ATP produced in photosynthesis may be used for nitrogen fixation.³⁶ In legumes, fixing 1 mg of nitrogen require 4 mg of fixed carbon from the host plant.³⁷ Clearly, there is a necessary relationship between photosynthesis or chemosynthesis to supply energy for biological nitrogen fixation with its large energy requirement. In addition, ATP, contains a nitrogenous base, with its nitrogen traceable directly back to the nitrogen cycle.

Symbiotic rhizobia have direct access to chemical energy from the host-plant's photosynthesis, but free-living bacteria depend upon such energy either provided by their own photosynthetic processes (cyanobacteria), or if non-photosynthetic, from respiration or fermentation of photosynthetically derived reduced organic molecules absorbed from soil, mostly in the rhizosphere. Thus, relationships in the nitrogen cycle appear complex and obligatory, even for free-living species.

1G. IS BIOLOGICAL NITROGEN FIXATION INDISPENSABLE AND UNBRIDGEABLE?

Unquestionably, biological nitrogen fixation is no simple process and a design argument could be made based on this single step in the nitrogen cycle. It is unlikely to have been produced via a step-by-step Darwinian process because nitrogenase itself is immensely complex, requires auxiliary complex mechanisms to maintain low oxygen tension, and also needs reduced carbon backbones as substrates for amination to store ammonia as glutamine. In addition, regulatory mechanisms are needed to coordinate

the entire energetically expensive activity and its chemically reactive product, ammonia.

Of equal importance to asking if biological nitrogen fixation could be produced in some gradual manner is the question of whether known natural abiotic processes — like atmospheric nitrogen fixation — could bridge or by-pass this step in the cycle. As already discussed, the answer in the case of atmospheric fixation is that the product — nitrate — is not directly useful and the chemical intermediates in nitrate production are destructive to organic molecules as is nitrate itself when in the form of nitric acid. Assimilation of nitrate requires a separate photosynthesis-dependent mechanism, at least in plants, which would be unlikely to develop in the absence of nitrogen-containing proteins.

A more promising inorganic work around might be ammonia released by volcanoes, but volcanoes today do not release ammonia in large quantities.³⁸ Even if they did, a secondary problem results from the fact that ammonia is readily subject to photolysis. The high solubility of ammonia in water may protect some ammonia from being broken down by light, but significant quantities of ammonia in water would raise the pH impacting water chemistry in a way that presents challenges for life. Whatever the abiotic source of ammonia, whether from volcanoes, a reducing atmosphere or some other source, none serves as a probable natural bridge over biological nitrogen fixation as, when nature provides nitrogen for free in the form of ammonia or amino acids, selective pressure for an energy hungry metabolic process like nitrogen fixation seems unlikely.

2A. NITRIFICATION

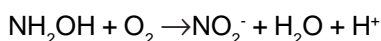
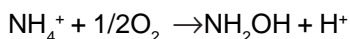
Some ammonia produced in nitrogen fixation, as well as in ammonification (yet to be discussed), is directly taken up by plants through their roots, or from root-nodules, and assimilated, but large quantities of ammonia are also converted to nitrite and nitrate, a process generally known as nitrification. Many plants appear to preferentially take up nitrogen as nitrate (NO_3^-). However, under conditions that are unfavorable for nitrification (low pH, anaerobic soils, etc), plants use ammonia. Use of ammonia as a primary source of nitrogen tends to lower soil pH.³⁹ But even under unfavorable conditions, nitrification still occurs at a relatively slower rate.⁴⁰ Aquatic plants absorb ammonia through their leaves.

Organisms (largely bacteria) that convert ammonia to nitrites and nitrates are referred to as nitrifiers. They are found in a variety of environments — soils, seawater, brackish waters, rivers, lakes, and waste water treatment ponds, etc. Along with some other genera, *Nitrosomonas* converts ammonia to nitrite (NO_2^-). In general, organisms that only oxidize to nitrite are referred to as ammonia oxidizers. Nitrite itself is quickly oxidized so

little of it is available to be absorbed by plants. Since nitrite is toxic, its rapid conversion to nitrate detoxifies while benefiting both organisms that absorb nitrates and bacteria that reap energy in the process.

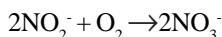
Nitrobacter, along with several other genera, oxidizes nitrite to nitrate.⁴¹ All nitrifiers are aerobic and most are chemoautotrophic, the energy derived from nitrification is used to fix carbon. A few nitrifiers are heterotrophic. For example, in forest litter, it is not bacteria, but saprophytic fungi, which do most of the nitrifying.⁴²

Nitrification is a two-step process, as already indicated. The first step, using the enzyme ammonia monooxygenase, is given in the following equations:



In this initial nitrification reaction, 66 kcal of energy are liberated per mole of ammonia oxidized. Under oxygen limited conditions, the product is N_2O (nitrous oxide) instead of nitrite.

The second step is as follows:



This step liberates 18 kcal per mole of nitrite oxidized.

Why is nitrification essential to the nitrogen cycle when plants and bacteria are able to use ammonia directly? Indeed, even nitrate must be reduced back to ammonia before it becomes biologically accessible. That some organisms even have the enzyme system that enables them to use nitrate when the simpler alternative to use ammonia directly is available, says much about the evident importance of the more roundabout route through nitrate.

As chemoautotrophs, nitrifiers fix carbon and make it available to respiration. However, the process is not very efficient. A more reasonable answer is suggested in defining the function of the nitrogen cycle as it was earlier in this paper: "to regulate concentrations of various nitrogen-containing molecules in the environment in such a way that life can thrive." For three reasons, conversion of ammonia to nitrate is an essential part of the cycle's function of regulating various nitrogen-containing molecules:

1. It prevents accumulation of ammonia to toxic levels
2. It provides a biologically available, but relatively chemically inert reservoir of nitrogen that can be utilized without requiring the complex and energetically expensive mechanisms used in biological nitrogen fixation

3. The solubility of nitrate in water allows it to be relatively mobile, thus distributing biologically available nitrogen to organisms that do not have the ability to fix their own nitrogen.

Nitrification is thus an essential step in recycling nitrogen back to the atmosphere and plays a vital role in the global function of the nitrogen cycle in regulating nitrogen-containing molecules in the environment. It is worth noting that this understanding of the role and necessity of nitrification is driven by a design-oriented view of the nitrogen cycle and not a reductionistic view of nature.

2B. IS NITRIFICATION INDISPENSABLE AND UNBRIDGEABLE?

Total nitrogen in the atmosphere amounts to approximately 3.85×10^{21} g.⁴³ It has been estimated that before significant human involvement in the process, biological nitrogen fixation amounted to 90-140 Tg per year.⁴⁴ Under these rates of fixation, all atmospheric nitrogen would theoretically be fixed as ammonia within approximately 27 to 43 million years. This estimate does not include the relatively small amount of nitrogen fixed in the past via thermal shock, which would shorten the time somewhat. Because current rates of nitrogen fixation are significantly higher due to intensive agriculture of legumes, industrial fixation and industrial combustion among other factors, the number of years at today's rate would be considerably less. But this time span should not be understood as literally true because other factors like dissolved nitrogen in water and ammonia photolysis are not taken into consideration. What estimates like this do show is that the Earth could be expected to become thoroughly unfit for life due to ammonia accumulation in a time span considered short from a Darwinian perspective. This illustrates the necessity of a reverse pathway for removal of excess nitrogen. To the extent that nitrification is a step in this process, it is indispensable.

How might a process like nitrification come about by Darwinian selection or be naturally bridged? In a reducing environment in which nitrogen fixation is not necessary, the reverse process might appear to be unnecessary as well. However, this seems unlikely; nitrogen incorporated into organisms would still need to be recycled when excreted as a waste product or following death. But this might be accomplished by pathways in which nitrogen could be released from amino acids. For example, if nitrogen from amino acids was recycled back into ammonia, as occurs with deamination of glutamate by glutamate dehydrogenase, this would prevent infinite accumulation of amino acids. Whatever the mechanism, in a reducing environment it seems unlikely that "nitrification" would have evolved to be anything like the oxidative process of nitrification seen today.

An oxidizing atmosphere presents an interesting situation. Ammonia in the presence of oxygen burns readily, producing nitrogen oxides and water. In addition, at even relatively low concentrations, ammonia is toxic to life. In the absence of enzymes in living things and at low concentrations, ammonia does not spontaneously oxidize to nitrogen oxides and water at a significant rate. In an oxidizing atmosphere, without nitrification, ammonia would be expected to accumulate in the environment until one of two (possibly both) things happened:

1. Equilibrium between organic ammoniac production and inorganic ammonia degradation was reached, potentially resulting in ammonia concentrations incompatible with life.
2. Catastrophic oxidation set off by lightning or some other spark occurred.

The latter scenario is improbable given the solubility of ammonia in water. More reasonably, ammonia would be expected to accumulate in bodies of water turning them basic. This assumes that photolysis of ammonia in the atmosphere does not break down ammonia fast enough to preclude its accumulation. In our present world, neither of these scenarios occurs because nitrification limits accumulation of ammonia, but allows for a ready supply of nitrogen to organisms in the relatively inert form of nitrate.

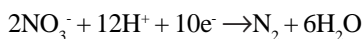
To get around problems resulting from the absence of nitrification, ammonia might be recycled into living material as it is in forests until some other limiting nutrient prevented further growth. As organisms died and the other limiting nutrient was recycled, biomass might be expected to accumulate until some conflagration burns all the accumulated nitrogen-containing biomass, returning the nitrogen to the atmosphere as nitrogen oxides. Nitric oxide (NO) and nitrogen dioxide (NO₂) are both highly reactive gases dangerous to life. Thus it would be expected that biomass would accumulate past some tipping point and, at least on a local scale, destroy life. Nitrification prevents this kind of scenario by shuttling nitrogen in excess ammonia to a relatively benign molecule (nitrate) that can still be used by plants or, alternatively, continue on into denitrification where it is returned to the atmosphere as safe and inert N₂.

3A. DENITRIFICATION⁴⁵

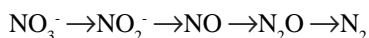
Denitrification is a microbial respiratory process by which nitrate is reduced to atmospheric dinitrogen gas (N₂) or nitrous oxide (N₂O). Without this process, nitrates would accumulate in high concentrations, as has been seen in recent years with the overuse of nitrogenous fertilizers. On a global scale, in the absence of denitrification and sufficiently rapid assimilation by plants and microbes, nitrates would accrue in and acidify bodies

of water while the concentration of atmospheric nitrogen would decline. In fact a mechanism similar to this has been proposed to explain the unexpectedly low nitrogen concentration in the Martian atmosphere.⁴⁶ As it is, under normal conditions on Earth, nitrogen is often limiting in the biosphere as a result of low levels of nitrogen fixation along with denitrification.⁴⁷

Organisms in soils require oxygen, but if soils are waterlogged for protracted periods (greater than 36 hours) and water fills spaces between soil particles usually occupied by air, then oxygen will be excluded. At such times, certain microbes are able to obtain essential oxygen from nitrite and nitrate. The oxygen from nitrate serves as an alternative electron acceptor.⁴⁸ The process is given in the following equation:



Another way of representing the process is:



The last two products, nitrous oxide and dinitrogen, are returned to the atmosphere. Factors influencing denitrification include: the quantity of organic material available, waterlogging and oxygen deprivation, soil temperature, levels of soil nitrates and pH. For example, denitrification is higher during summer when water temperatures are highest.

Under normal conditions, waterlogging induces denitrification, which occurs at a rate amenable to environmental wellbeing. But when there is a nitrate overload, the highest attainable rates of denitrification may not be able to keep pace with demand and thus, nitrates may be carried to the water table and into aquifers. The result is eutrication of surface waters in which organisms grow so rapidly that oxygen is depleted resulting in death of many organisms. Ultimately, this may lead to increased rates of denitrification if nitrate becomes the most abundant electron acceptor available. Thus, even when the system is perturbed, it may be designed to still work to rectify the perturbation.

3B. IS DENITRIFICATION INDISPENSABLE AND UNBRIDGEABLE?

The necessity of denitrification is evident when the logic applied to nitrification is also applied to this step. While nitrates can be recycled into plant material, the heterogeneity of nature and lack of rapid transport mechanisms for nitrate ensure that concentrations would, at least locally, reach high levels. While nitrate is relatively immobile in the absence of water, it is water soluble and can be leached out into bodies of water where it may reach significant concentrations. Excess nitrates have the potential to cause environmental damage as evidenced in the consequences

of over-use of industrially fixed nitrogen for agricultural purposes. Under current conditions, if denitrification was not part of the nitrogen cycle, even under the natural rates of nitrogen fixation and nitrification, nitrate levels could be expected to eventually become excessive.

Compared to other nitrogen oxides, nitrate is relatively stable and does not spontaneously degrade at an appreciable rate to O_2 and N_2 or N_2O . In an oxidizing atmosphere, nitrates are produced via atmospheric fixation with lightning providing a significant portion of the energy driving the reaction. At current rates, approximately 3 to 5×10^{12} g of nitrogen are fixed per year⁴⁹ as nitrate via atmospheric fixation, meaning that, in the absence of biological nitrogen fixation and denitrification, all atmospheric nitrogen would theoretically be fixed as nitrogen oxides in approximately 1 billion years.⁵⁰ Again, this number is meant to be illustrative rather than literal, as it does not take into consideration reverse reactions and the impact of reduced nitrogen and oxygen concentrations in the atmosphere among other factors. In addition, this only takes into consideration abiotic processes. If biological nitrification was occurring, accumulation would be significantly faster. Assimilation does not act as a realistic way of removing nitrate as it simply recycles it into plants. As long as biological nitrogen fixation feeds nitrogen from the atmosphere into the nitrogen cycle, a way of removing nitrogen is necessary.

In the absence of biological denitrification, nitrate would be expected to accumulate. This is exactly what occurs in the Atacama Desert in northern Chile, which is among the driest areas on Earth.⁵¹ Average annual rainfall is between 1 and 2 mm. In addition, when rain does fall, it drains away rapidly as there are no soils as such to become waterlogged. In this arid region, conditions necessary for denitrification rarely occur. It is thus not surprising that, as in several other deserts, nitrate has accumulated. But unlike other deserts, this is the only known place on Earth where nitrate has accumulated to the point that nitrate mining is commercially feasible.

While debate continues about the source of nitrate in the Atacama Desert, this is not relevant to the question of whether nitrate will accumulate in the absence of denitrification. It clearly does. It is, however, worth noting that measurements of oxygen isotope composition of this nitrate suggests that a significant proportion of it accumulated within the past 2,000,000 years as a result of atmospheric deposition resulting from photochemical fixation in the upper atmosphere.⁵² Thus, in the absence of denitrification, nitrate appears to accumulate as a result of abiotic processes. As mentioned previously, low levels of atmospheric nitrogen on Mars may be attributable in part to accumulation of nitrates in the Martian regolith, where a biological nitrogen cycle is not thought to exist.

A Darwinian scenario may be conceivable for this step in the nitrogen cycle if certain assumptions are made. These include the existence of aerobic bacteria — a mechanism for accumulation of nitrate — and niches, like soils from which oxygen is occasionally excluded. In this scenario, some aerobic bacteria might have a weak ability to use nitrate instead of oxygen as an electron acceptor during respiration. Perhaps this could have been related to their ability to utilize nitrate as a nitrogen source and then reduce it to ammonia for amino acid production. Natural selection working on these bacteria, as they survived periods of oxygen starvation better than those that are completely dependant on oxygen, may ultimately have produced the denitrifying bacteria living today.

This scenario presents a number of problems. The first is the obvious appeal to unknowns. Were there bacteria in the past capable of utilizing nitrate as an electron acceptor during anaerobic respiration before there was a fully developed nitrogen cycle? No evidence supports this, and there is a commensurate lack of evidence for nitrate having accumulated significantly in the environment. The way in which organisms both assimilate nitrates (which will be discussed in the next section), and engage in nitrate respiration also suggests no linkage between the two processes. In these organisms, two significantly different nitrate reductases are produced.⁵³ For example, in *E. coli*, the respiratory enzyme is particulate and sensitive to oxygen while the assimilatory enzyme is soluble and the two enzymes are induced and repressed by different substrates. Evidently the processes of nitrate respiration and nitrate assimilation are biochemically distinct, and do not exhibit the kind of convergence needed to support the theory that they share a related evolutionary history.

Evolving nitrogen-reducing systems in a reducing environment appears to be out of the question, given the lack of oxidized nitrogen in such environments. In an oxidizing environment, even in the absence of biological fixation or nitrification, nitrates are likely to be present. In fact, they would presumably be the sole source of nitrogen for organisms lacking the ability to perform steps other than assimilation and amination in the nitrogen cycle. Assuming this to be the case, the ultimate problem of recycling nitrogen to the atmosphere might be temporarily suppressed by accumulation of nitrogen in living organisms and their byproducts, but this does not negate the ultimate need to recycle nitrogen to the atmosphere, and may even exacerbate it once nitrogen as either ammonia or nitrate reached excessive levels. The question then becomes, does this biological sink provide sufficient time for the stepwise evolution of other components of the nitrogen cycle? Ultimately, denitrification appears to be an indispensable part of the nitrogen cycle and unlikely to have evolved in Darwinian fashion independent of the rest of the cycle.

4A. ASSIMILATION⁵⁴

Nitrate serves as a major crossroads in the nitrogen cycle. As already discussed, nitrate is produced via biological nitrification and abiotic atmospheric nitrogen fixation. Once it is in the form of nitrate, nitrogen can either be returned to the atmosphere as N_2 during denitrification, or it can be assimilated by plants and bacteria. While nitrate is readily absorbed by plants and bacteria, it is only as ammonia that it can be utilized. The process of nitrogen assimilation involves conversion of nitrate to ammonia and the incorporation of that ammonia into amino acids.

Nitrates enter plant cells via a “proton-nitrate symport.”⁵⁵ Once in plant cells, nitrates are converted to nitrites by the enzyme, nitrate reductase. Highly toxic nitrite, a metabolite in the process, is rapidly sequestered in chloroplasts, thus protecting plants from harm. Inside plastids, nitrite is quickly converted to ammonia by another enzyme, nitrite reductase. Significantly, in at least some plants, the reducing power is provided by photorespiration which is dependent on the presence of oxygen.⁵⁶ In most organisms, assimilation is repressed by the presence of ammonia and induced by nitrate or nitrite.⁵⁷

Microbial assimilation of ammonia to produce amino acids occurs first through the synthesis of glutamate, alanine, or aspartate.⁵⁸ These then serve as nitrogen donors via transaminases to form other amino acids. Ammonia, for example, may be used to aminate glutamate to produce the amino acid glutamine, by means of the enzyme, glutamine synthetase (GS) plus ATP. GS is the principle means by which ammonia enters the metabolic processes of plants. Then, by means of a glutamate synthase, known as GOGAT (Glutamine 2-OxoGlurate AminoTransferase), one out of two glutamines produced is converted back to glutamate to pick up yet another ammonium molecule. Each turn of the GS-GOGAT cycle results in a profit of one glutamine. From glutamine, nitrogen is passed on by means of transaminases to other molecules to form different amino acids. The process can also go in reverse. Ammonia assimilation occurs in both roots and leaves via this method.⁵⁹ Eventually, assimilated nitrogen is used to produce nucleotides and nucleic acids.

Assimilation is too complex to be considered in detail here. However, the importance of enzymes in transferring nitrogen to various molecules cannot be overstated. Note that nitrogen assimilatory enzymes contain nitrogen, the very element whose assimilation they facilitate. These processes are intimately tied to the actions of genes (whose nucleotides also contain nitrogen) which determine the structure of proteins. The actions of these genes are facilitated by several of the very enzymes, which they have, in fact, encoded. It is difficult to avoid the necessity of

all of these entities being simultaneously present in order for the whole system to function.

4B. IS ASSIMILATION INDISPENSABLE AND UNBRIDGEABLE?

It has been generally thought that plants only take up nitrogen as ammonium or nitrate, but evidence is mounting that plants may also take in partially decomposed organic nitrogen in the form of amino acids, and possibly even more complex nitrogen-containing compounds.⁶⁰ Some evidence suggests that plants may access organic nitrogen by means of mycorrhizae. Given that the highest proportion of soil nitrogen is organic, organic nitrogen absorption should not be surprising.

Could assimilation be bridged by absorption of amino acids or other nitrogen-containing organic molecules? On the surface such an idea looks plausible, and it is not surprising that scenarios have been built around this idea as a way to entirely bridge the nitrogen cycle. However, on closer examination, simply bridging assimilation and nitrogen fixation by appealing to a reducing atmosphere in which amino acids, nitrogenous bases and other nitrogen-containing molecules are freely available creates its own set of problems.

The first and most obvious problem is that evidence favoring such a reducing atmosphere in the distant past is absent, and that the existence of such an atmosphere might have existed seems incredible. However, the purpose of this paper is not to argue against a reducing atmosphere; as already mentioned, these arguments have been convincingly made elsewhere.⁶¹

A second issue arises from the assumption that nitrogen-containing organic molecules could cross primitive cell membranes. This presents a significant issue as presumably more than one or two simple molecular pumps would be needed to transport any freely-available nitrogen-containing molecules. Pumps would be necessary as, even given some sort of primordial soup, the concentrations of amino acids and other nitrogen-containing molecules would be expected to be higher inside cells than outside.

Energy for pumping an array of nitrogen-containing molecules across primitive cell membranes would presumably not be available from photosynthesis as this requires the presence of the very amino acids that need to be pumped. Chemosynthesis, if it was hypothesized to have evolved before photosynthesis, would suffer from the same difficulty. It is not clear how any realistic energy source would circumvent this problem. In addition, proteins from which the pumps would be made are composed of amino acids. A scenario of this sort presents another chicken-or-egg dilemma. Organic membranes across which amino acids freely flow from areas of lower concentration to areas of higher concentration are unknown;

membranes lacking protein pumps that concentrate amino acids on one side seem impossible. In addition, powering pumps is typically tied in some way to the use of nitrogen-containing nucleotides like ATP, which serve as the currency of energy metabolism within cells.

Accumulation of ammonia within cells presents a third issue. Energy to drive any kind of metabolism comes from the catabolism of molecules and ultimately from photosynthesis, or, less commonly, from chemosynthesis. In modern organisms some portion of this energy is derived from catabolism of nitrogen-containing molecules. How the waste nitrogen is handled will be dealt with in the next section. If a system for pumping amino acids across cell membranes existed in primitive cells, it would require energy from some source. If that source happened to be the amino acids themselves, then a mechanism would be required to be simultaneously in place to deal with the waste ammonia. This ammonia could not be consumed as a source of ammonia for amination, as these organic molecules would not yet be available without further complex protein-dependent biochemical pathways. In any case, there seems to be little reason for cells to make amino acids if they were freely available. Presumably waste ammonia would have to be pumped or diffuse out of the cells via some sort of protein channel. This presumes that a mechanism for getting energy from reduced organic molecules could serve as a source of energy in a reducing environment via either anaerobic respiration or fermentation.

Within certain biomes, for example boreal forests, organic nitrogen is cycled rapidly through ammonia which is absorbed directly by plants. In the absence of denitrification, organic material accumulates and is ultimately recycled via fires or goes on to form peat. Taken as a whole, some areas in the biosphere can do this without upsetting the overall balance of the nitrogen cycle, but, as noted in the discussion of denitrification, on a global scale such a system appears to be catastrophic in the end.

Ultimately, easier ways of getting nitrogen into organic molecules inside cells other than assimilation seem improbable, although they would be necessary in a reducing environment. Given that the current atmosphere is an oxidizing one, and this seems to have been the case in the ascertainable past as well,⁶² assimilation is clearly necessary under current conditions, and presumably historically as well.

5A. EXCRETION AND DECAY

Plants make use of nitrogen in an efficient manner and usually do not excrete it. Animals present a very different situation. To obtain amino acids they are unable to make, they must consume plants, or other animals that consume plants. In this way, they acquire excess nitrogen that must be excreted. Nitrogen is excreted in different forms by different animals.

Fish excrete nitrogen as ammonia, which though highly toxic, is greatly diluted in surrounding water. Mammals excrete less toxic urea, which still requires significant quantities of water and energy; producing urea uses 4 ATPs per urea molecule. Birds and reptiles excrete uric acid as a solid, which does not waste water, but uses even more energy. Excess pyrimidines and purines from nucleic acids are also treated and excreted, pyrimidines as ammonia or urea, but purines must be converted first to uric acid and, in mammals, farther modified to allantoin for excretion. Because primates are unable to produce allantoin they are consequently subject to gout when they consume purines in excess.⁶³ Excretion not only rids animals of excess nitrogen, but also returns nitrogen to the nitrogen cycle.

Both plants and animals die and leave remains that require recycling. Even while alive, they shed tissues; plants shed leaves and bark, for example, while animals shed skin cells and hair. Additionally, when animals eat other organisms, not all parts are consumed or assimilated. The excess, either the uneaten parts or the eaten unassimilated parts expelled as fecal waste, must still be recycled including any excreted waste nitrogen. All plant and animal parts ultimately undergo decay in which they are broken down to simpler molecules. Decay is facilitated by numerous soil organisms: algae and cyanobacteria on the surface, with many other varieties of organisms just beneath — bacteria, fungi, different kinds of worms, mites, many insects and even burrowing mammals, to mention only a few. Nitrogenous organic compounds, along with other organic molecules, are first broken down physically when they are consumed by a number of different soil animals. Nitrogenous wastes are eventually converted back to ammonia and thence into nitrites and nitrates (mineralization), and so on, in the continuing nitrogen cycle.

At any given moment, however, more than 90 percent of nitrogen in healthy natural soil is in the form of organic compounds — such as amino acids. In fact, a study in Alberta showed that only 2 to 5% of soil nitrogen is inorganic.⁶⁴ Soils with high organic content have higher overall nitrogen levels. A recent study of pristine riverine systems showed that an average of 80% of nitrogen in those waters was organic.⁶⁵

The gradual breakdown of organic nitrogen maintains a long-term readily available and manageable nitrogen source that would eventually be lost to mineralization with subsequent loss to leaching should the breakdown occur too quickly, as may occur in moist tropical regions. Tropical forest plants quickly absorb available nutrients, so that those nutrients are usually tied up in living tissues. Widespread destruction of tropical forests leaves too few plants to quickly assimilate soil nutrients and very swift breakdown of organic molecules follows. Mineral nutrients — including

nitrates and ammonia — rapidly leach from the soil, leaving behind only an insoluble and infertile hardpan.

Ultimately, nitrogenous waste products are all recycled, either back into the atmosphere or back into organisms via ammonia and nitrate, with nitrate serving as a major crossroads point in the nitrogen cycle. When the natural situation is perturbed by either overwhelming natural systems as when excessive amounts of nitrogen fertilizer are used, or by speeding up mineralization as when tropical forests are destroyed, the results are inevitably negative. A minimal set of organisms capable of performing each necessary step in the cycle must be present for a healthy functioning ecosystem. Even when this occurs it may still be difficult to reestablish a damaged ecosystem, as in the case of the hardpan left after rainforest degradation.

Establishing the nitrogen cycle in the first place would have been a remarkable feat no matter how it came about.

5B. ARE EXCRETION AND DECAY INDISPENSABLE AND UNBRIDGEABLE?

Animals require a mechanism to handle nitrogenous waste. That this is true is supported by the observation that no animal lacks a system to deal with these wastes, these systems are expensive to maintain and when they fail, animals die. Might it be possible to evolve a system in which nitrogen wastes were not recycled? The simple answer is no; logic precludes this. Nitrogenous wastes cannot be reasonably expected to accumulate forever without grinding nitrogen-containing life to a halt. This would be true for life composed only of simple bacteria, in an RNA world, in an oxidizing or in a reducing environment. Even with no actual waste production, whatever life or the precursors of life were, they cannot accumulate forever without exhausting all resources and creating stagnation.

In a Darwinian scheme, death is necessary to eliminate the less fit and components of dead organisms must be recycled for use by those that survive and produce more offspring. Dead or unfit organisms cannot accumulate forever, or Darwinian evolution would come to a halt. The necessary recycling of organic nitrogen is achieved by excretion and decay. Ultimately excretion and decay are indispensable, but are they unbridgeable?

Note that there is a difference between being bridgeable at the time life came into existence and in the present when there may be multiple redundant organic systems capable of doing the same or related tasks. For example, in theory it should be possible to drive biochemical pathways both forward and backward. Thus an anabolic pathway might hypothetically be adapted to work as a catabolic pathway if necessary or vice versa. While there are practical reasons why this does not happen, still, with no other options, this might be all that could be achieved. If this was

the case, if an organism already had the ability to make certain kinds of polymers, then it might be able to use the same biochemical pathway to degrade those polymers. Whether the pathway worked anabolically or catabolically might depend on the circumstances in which it existed. The very same organism might make organic polymers under one set of circumstances and consume them under others. Over time different populations in different environments might be able to adapt their particular metabolism to the different tasks to which they put their biochemical systems.

The problem with this scenario is that it presupposes an anabolic pathway in the first place. It could not start out as a catabolic pathway as, without an abundance of polymers to breakdown, it would not be useful to have one. If an anabolic pathway already existed, would there be sufficient time to adapt it to do catabolic work — or for a separate catabolic system to evolve — before metabolite buildup overwhelmed the pathway, causing it to grind to a halt? Getting a precise answer to this question seems unlikely, but it is not necessary, as to get to this point involves a miracle in the first place — an anabolic pathway that is adaptable to a catabolic pathway in small steps that are all adaptive. Still, of all the various steps in the nitrogen cycle, this one may be the most amenable to being bridged in some way, either by adapting a biochemical pathway or by simply relying on occasional fires to return nitrogen to the atmosphere or soil as nitrogen oxides.

The process of excretion is not as easily bridged and seems to require mechanisms for the detoxification of nitrogen-containing waste products and their removal from cells and/or bodies. This is no trivial matter, whatever the waste product. Even in those animals that directly excrete ammonia, it requires specific protein channels or pumps and thus is not an easily bridgeable step.

DISCUSSION

Much of the argument made in this paper hinges on high reaction rates resulting from biological enzymes acting as catalysts and on the way in which biological systems drive reactions in specific directions. In theory, every component of the set of chemical reactions we call the nitrogen cycle occurs without biological intervention. But do these abiotic reactions occur at rates sufficient to maintain a cycle essential to life like the N-cycle? And are the reactions shifted in the necessary directions to make them work without accumulation of intermediate products at specific points in the cycle? With the possible exception of photolysis of ammonia, which is not a major component of the cycle, this does not appear to be the case. Obviously, if an abiotic nitrogen cycle existed that could sustain life; there

would be no real need for a biological nitrogen cycle, just as there is no need for a biological water cycle.

A detailed critique of current Darwinian theories about nitrogen cycle evolution has not been undertaken. A careful search of the literature reveals many papers that mention evolution of the nitrogen cycle, but examination of them has not revealed a detailed model. Rather than discussing how the entire cycle could have evolved via some Darwinian mechanism, these papers generally discuss only the evolution and genetics of specific stages in the nitrogen cycle,⁶⁶ or they present what is imagined to be necessary assuming some Darwinian mechanism.⁶⁷ Inorganic nitrogen cycles have been proposed, but how they transitioned to the organic nitrogen cycle seen today is unclear, as is whether specific conditions under which these cycles are thought possible ever actually existed. In essence, the biological nitrogen cycle appears to present a naturalistic conundrum similar to Leslie Orgel's observation about the citric acid cycle: "In my opinion, there is no basis in known chemistry for the belief that long sequences of reactions can organize spontaneously – and every reason to believe that they cannot. The problem of achieving sufficient specificity, whether in aqueous solution or on the surface of a mineral, is so severe that the chance of closing a cycle of reactions as complex as the reverse citric acid cycle, for example, is negligible."⁶⁸

If the general argument made in this paper is true — that the various steps in the nitrogen cycle all appear to be necessarily present within a limited temporal span, and do not appear to be the product of a Darwinian process — two possible evolutionary scenarios seem to be the best conjectures in the absence of some intelligent cause. The first is that the complete cycle evolved in a single organism and that, subsequently, this organism gave rise to the diverse groups of organisms that today participate in various steps of the nitrogen cycle. Over time some groups in this ancestral population may have lost various components and specialized in others. This scenario seems incredible given the profoundly different organisms involved. Lateral gene transfer might be invoked to explain away some of this problem, but in either case it requires evolution of the entire cycle in a single organism extremely early in the history of life. Given the complexity of the nitrogen cycle, such a scenario stretches credulity.

A second scenario would be to have various components of the nitrogen cycle evolve in different taxa which all happened to evolve them at around the same time or at least before accumulation of the products of one step accumulated to toxic levels. This would mean that, without any goal in mind, Darwinian mechanisms produced everything necessary for the cycle to work, while at the same time achieving enough coordination between

the various steps in the N cycle to avoid the inevitable problems that logically follow from having at least some steps missing or out of balance with the others. This again seems incredible, given the finite window of time available, questionable selective pressure to produce all stages at once, and the need for a complete cycle to sustain the production of proteins in anything other than a hypothetical reducing atmosphere for which evidence is lacking.

Essentially this second scenario is similar to those explanations which invoke cooption in the production of irreducibly complex cellular machines and shares their speculative weaknesses. The difference is that an ecological system like the N cycle requires a number of organisms all evolving independently to achieve a fortuitous outcome necessary for their existence rather than a number of components serendipitously combining in a single organism.

It seems optimistic to suggest that organisms alone, without some intelligent guidance which cannot be provided by natural selection, could build a coordinated ecochemical cycle like the N cycle. Given the number of highly reactive nitrogen compounds possible, significant good fortune would be required to prevent evolution of biochemical pathways with products that preclude life. For example, why organisms would not evolve that produce cyanide (CN⁻) as a waste product is not obvious. Thus, there are significant constraints on how the N cycle could come into being.

It is also worth mentioning that both scenarios, evolution in a single organism or evolution in multiple organism, suffer from the problem that evolution of the biological nitrogen cycle could only take place in protein-dependent organisms.

Reasons why powerful arguments to design in nature can be made based on biochemistry were outlined by Behe and may be summarized as:

1. Biochemistry allows examination of the “rock-bottom level of life”⁶⁹
2. Chemistry and physics are sufficiently understood to allow evaluation of claims about the behavior of atoms
3. Significant differences exist between what Darwinism claims atoms did, and what atoms are actually known to do.

In short, atoms are known to arrange themselves according to certain relationships we call physical laws. None of these laws or combinations of these laws is known to produce either machines like the protein machines found in living cells, or information like that found in the orderly arrangement of molecules in DNA.

In this paper we ask whether characteristics of design recognized by Behe in biochemical pathways and molecular machines inside individual organisms may be evident in “ecochemical” pathways where organisms

interact in complex patterns of interdependence. The primary focus has been on whether a rigorous argument, equivalent to Irreducible Complexity (IC), as defined by Behe, can be made for the nitrogen cycle.

Should such a system be evident at the ecological level, it would be similar to IC, but would also exhibit significant differences from biochemical IC. For example, instead of macromolecules interacting within single organisms, these systems involve whole organisms and potentially communities of organisms interacting both with each other and with the inorganic constituents of the niche they occupy. We propose the term “Irreducible Interdependence” (II) to describe this kind of ecological system. To exhibit II, an ecological system must exhibit the following characteristics, which parallel and add to those outlined by Behe for IC systems:

1. The system must not exhibit obvious plausible inorganic work-arounds. In other words, potential gaps in the system cannot be reasonably bridged or bypassed by inorganic nature alone.
2. It must exhibit a degree of specification indicating that there are not so many solutions to the problem that a solution is a probable product of chance.
3. A given function or step in the system may be found in several different unrelated organisms. In the specific case of ecochemical pathways, it is not a specific organism that is irreducible, but the ability to perform a biochemical reaction necessary to the ecochemical pathway. The enzymes necessary to catalyze the reactions must exist somewhere in nature in sufficient quantities and be appropriately distributed to maintain the function of the system whether in one species or many species. Redundant species are not necessarily expendable as they may prove indispensable in forwarding the process under circumstances when other species have diminished abilities or are absent. Ultimately, it is not the species, *per se*, but the enzyme functions that count; “redundant” species constitute a vital buffer against perturbation of the system.
4. While leaving the rest of the system intact, the removal of any one of some, but not necessarily all, individual biological steps must result in loss of function of the system. Note that this does not mean that every step must be essential to the system, but some must be. In addition, the steps that are removed must be too complex to have resulted from one or a very few serendipitous mutations. The more steps or components that are necessary for the system to function, the more compelling the argument that no direct path

exists to build the system in a step-by-step manner via a series of relatively small opportune mutations, it does not mean that the possibility of building the system via some circuitous step-by-step process must be proven impossible, as eliminating an essentially infinite number of complex indirect imaginary paths would be unfeasible.⁷⁰

5. Individual steps in an II system may be adaptive for the individual species that carry them out and natural selection may be capable of acting on those individuals. Natural selection is not generally conceived as a process that can work on a global scale to construct a cycle like the N cycle in a teleological way. Because individual steps in an II system may be adaptive for individual species that evolve them (although the steps themselves may be IC) this constitutes a major difference between II and IC systems.

In the environment, II systems act in ways similar to biochemical systems within organisms, but they are different in that perturbations of biochemical systems typically results in reduced fitness or death of individual organisms, while disruption of II systems may result in local or even global collapse of ecosystems. Because individual steps in II systems may be spread across multiple organisms, as in the case of nitrogen fixation, disruption of II systems, especially on a global scale, may be more difficult than the relatively simple IC systems found in individual organisms. The natural redundancy built into II systems, along with their temporal and spatial distribution, may make their empirical study more challenging than biochemical systems within individual organisms.

Another difference between biochemical and ecochemical systems is that the sink for specific metabolites may be much larger in ecological systems than is possible within individual cells or organisms. For example, as mentioned in this paper, ammonia is highly soluble in water, thus the oceans represent a large sink for ammonia. This might allow life to exist for some time in the absence of systems to recycle ammonia back into organisms or back into the atmosphere as is done by the nitrification and denitrification steps that convert ammonia back into dinitrogen. Ultimately the question arises, is there sufficient time and does unguided nature possess the capacity to produce a solution to problems caused by buildup of reaction products before they make life impossible? Given the vastly increased reaction rates produced by enzymes, the time available must be relatively short, at least by conventional geological standards. In addition, no amount of time causes chemical reactions to do anything other than go to equilibrium whether at a rapid or slow rate. The ability to drive reactions in

specific directions seems to be the purview of clever chemists in complex laboratories and biochemical/ecochemical pathways in living things.

Whether they are II or not, the intimate interdependencies of ecochemical systems are worth noting. Mechanisms of carbon fixation, and particularly photosynthesis, are tightly dependent on nitrogen fixation, and nitrogen fixation is dependent on them as well. This different kind of interdependence on a grander scale is illustrated in Figure 2. At least as currently understood, photosynthesis and nitrogen fixation appear to be vital to life. While the N cycle can be isolated and studied independently, its relationship to other biological and geological processes cannot be ignored if one wishes to gain an appreciation of how the cycle works in nature. Ultimately this ecochemical cycle has an ecology of its own!

The nitrogen cycle appears to meet the criteria listed for an II system. However, caution is warranted in drawing hard conclusions about this ecochemical pathway. Much of the argument made in this paper depends on what appear to be logical inferences, but not all of these have been tested, and testing, if possible, should take place before grand claims are made.

For example, while it is obvious that steps in the cycle, like denitrification, can be overwhelmed by the use of chemical fertilizers, it is not necessarily obvious that this is what would happen in the absence of denitrifying bacteria. It seems reasonable to expect that eutrophication would result, but this has not been tested. Thus, it seems that model systems need to be developed. In this specific case, perhaps self-contained communities of bacteria, which lack denitrifying bacteria, could be tested to see what the actual results might be. This would help to determine whether removal of denitrifying bacteria really does result in an increase in nitrate followed by a burst of growth and ultimately death of the system.

Despite the attractive and apparent simplicity of an ecochemical pathway like the nitrogen cycle, when spread across multiple organisms in the natural environment they are never as simple as a single pathway in an individual organism. With this caveat in mind — which should serve as a motivator for further laboratory research — the nitrogen cycle does give the appearance of potentially being an II system. This has profound implications for the timing of the appearance of organisms. Unlike other systems which might appear in individual organisms as a result of intelligent causes, if the nitrogen cycle and/or other ecological systems ultimately prove to be II, they would require a much grander action on the part of any Intelligence involved because all organisms making up this cycle must have obtained the components of the system they contribute within the time constraints imposed by the ability of inorganic sources and sinks to supply substrates and absorb products in such a way that life remains

possible. In other words, the complete system is most reasonably understood as one that came into existence within a relatively short span of time. II systems, if they exist, appear to preclude the neo-Darwinian mechanism and are best explained as the product of a purposeful plan that was the product of Intelligence.

ENDNOTES

1. By “ecochemical” we mean a series of biochemical reactions resembling a biochemical pathway, but distributed across multiple species instead of within an individual organism. Each step in the pathway may be mediated by a single species or multiple species all of which can do that particular biochemical reaction.
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ANNOTATIONS FROM THE LITERATURE*

ECOLOGY: OCEANIC BIODIVERSITY ENHANCES PRODUCTIVITY

Worm B, Barbier EB, Beaumont N, Duffy JE, Folke C, Halpern BS, Jackson JBC, Lotze HK, Michelik F, Palumbi SR, Sala E, Selkoe KA, Stachowicz JJ, Watson R. 2006. Impacts of biodiversity loss on ocean ecosystem services. *Science* 314:787-790.

Summary. Oceans provide useful services to humans, such as supporting fisheries and other sources of food, and improving water purity through filtering and detoxifying activities. Loss of diversity results in reduced quality of services. In areas where diversity has been depleted, establishment of reserves and closure of fisheries has increased biodiversity an average of 23%, based on study of four fishery closures and 44 marine reserves. Preservation of biodiversity is needed if the oceans are to continue to serve humanity as they have in the past.

Comment. Conservation involves more than merely preserving species for sentimental reasons. Biological productivity helps sustain human needs, and this productivity is negatively impacted by reductions in biodiversity. Christian stewardship includes the obligation that our interactions with our environment, including other species, be guided by informed and responsible principles.

GENETICS: PSEUDOGENES

Mira A, Pushker R. 2005. The silencing of pseudogenes. *Molecular Biology and Evolution* 22:2135-2138.

Summary. Pseudogenes fall into several different classes. This paper deals with what were once clearly functioning bacterial genes which are currently nonfunctional as a result of mutations. While these specific pseudogenes may be nonfunctional in one strain of a bacterial species, they are functional in others. The authors concentrated on sequences essential for transcription and translation of genes and found evidence of selection for mutation of pseudogene control sequences which prevent their expression as truncated proteins. This evidence is particularly strong in the Shine-Dalgarno sequence, a nucleotide sequence on mRNA that

*Other annotations are available on our website: www.grisda.org

signals for ribosome attachment and thus translation of the sequence that follows it.

Comment. Pseudogenes have been presented as evidence of common ancestry. For example, the L-gulonogamma-lactone oxidase (GLO) gene, essential for production of vitamin C is a pseudogene in humans, primates and — strangely — guinea pigs, but not in other vertebrates. Darwinists interpret this as a synapomorphy connecting humans and apes to a common ancestor with a mutated GLO gene. However, evidence is mounting for functionality which may be selected for in some pseudogenes¹ and that at least some similar mutations may be the result of a mechanism of some kind and not simply random.

The theory that specific mutations may be “targeted” in some way or that specific mutations may be selected for appears to be well supported in this paper. Caution is warranted in comparing bacterial pseudogenes with eukaryotic pseudogenes, but clearly some portions of bacterial pseudogenes do not reflect the actions of random mutations alone. Whether this is because of positive selection — as suggested in this paper — or some other mechanism remains to be determined, but one thing is certain, bacteria possess elaborate mechanisms to mitigate the impact of damaged genes. These mechanisms include a tagging system to remove truncated gene products from pseudogenes should they be produced.² It is not unreasonable to expect similarly elegant mechanisms in eukaryotic cells and thus that some mutations interpreted as a product of common ancestry may be better explained as the product of mechanisms designed to minimize the impact of broken genes. (TGS)

ENDNOTES

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GEOLOGY: TRENDS IN SEDIMENTATION

Peters SE. 2006. Macrostratigraphy of North America. *Journal of Geology* 114:391-412.

Summary. Gaps in deposition mark boundaries between sedimentary rock packages that have histories of continuous deposition. Such gap-bound rock packages have distinct starting and ending points, with specific lithologies, fossil content, etc. A total of 4,173 such packages were identified from charts produced by the American Association of Petroleum Geologists.

Analysis of these rock packages can provide information useful in reconstructing the depositional history of North America. The study revealed a number of interesting trends. The number of rock packages is highest in the Neogene and lowest at the Permo-Triassic boundary. Other peaks occur in the Upper Cambrian, the Middle Ordovician, the Upper Devonian, the Upper Carboniferous, and the middle Cretaceous. Another interesting pattern is the shift from carbonates dominant in the Paleozoic to mostly terrestrial sediments in the Cenozoic. Evaporites are confined to the interval from the Silurian to the Cretaceous, with a peak in the Permian. A dramatic increase in terrestrial sediments occurs in the Cenozoic. There is a major discontinuity in deposition between the Paleozoic and the Mesozoic. Paleozoic basins are slowly subsiding while Mesozoic basins are more rapidly subsiding. Paleozoic volcanics are mostly submarine, while Cenozoic volcanics are most terrestrial.

Comment. Compilations such as this one may be useful in efforts to reconstruct Earth history within a shorter time frame than normally considered. Continental-based compilations are likely to be more useful than global compilations, because global compilations do not distinguish between potentially different histories on different continents. Conceptual models of the Biblical flood typically assume a worldwide transgressive sea and then a worldwide regression. A worldwide transgression would cause mainly marine sedimentation, including carbonates, whereas a worldwide regression would cause large amounts of terrestrial deposits to accumulate in inland basins. These expectations fit with the general patterns reported here.

PALEOBIOGEOGRAPHY: EUROPEAN BIRDS

Mayr G. 2005. The Paleogene fossil record of birds in Europe. *Biological Reviews* 80:515-542.

Summary. The fossil record of birds in the Paleogene of Europe is summarized. Although perching birds comprise somewhat more than half of living species, they are not found in sediments below the Oligocene in Europe. All pre-Oligocene birds appear to be on different evolutionary branches from the living members of any of the modern families of birds. Several European Paleogene fossil birds are now restricted, or nearly so, to Central and South America. These include the probable ancestors of the seriemas, potoos, hummingbirds, motmots, and New World vultures. Other biogeographic anomalies include frogmouths and possibly magpie geese, now found only in the Australian region, and mousebirds and secretary birds, now restricted to Africa. Several modern groups, including

grebes, falcons, doves and cuckoos are not found in the European Paleogene.

Comment. Creationist theory includes the proposition that all terrestrial vertebrates dispersed from southwestern Asia after the flood. Restriction of several families of terrestrial vertebrates to distant regions such as Australia and South America is a biogeographical problem that has been much discussed but not resolved. Identification of several bird families that are presently restricted to Australia or South America may indicate that the fossil record of birds is not sufficiently complete to enable us to trace the history of dispersal of terrestrial vertebrates after the flood.

PALEONTOLOGY: COMPLETENESS OF THE FOSSIL RECORD OF BIVALVES

Valentine JW, Jablonski D, Kidwell S, Roy K. 2006. Assessing the fidelity of the fossil record by using marine bivalves. *Proceedings of the National Academy of Sciences (USA)*103:6599-6604.

Summary. Many studies of trends in the fossil record depend on the completeness of the fossil record. It is not possible to measure the completeness of the fossil record when the total number of taxa for the source area is not known. For living bivalves, the number of living genera is reasonably known, and includes 1,292 living genera and subgenera. Of these, 308, or 24%, are not known as fossils. Most of the missing genera have one or more of the following properties: small size (less than 1 cm in length); aragonitic shell (as opposed to calcitic); restricted to deep sea (>200 m); or live within the substrate instead of upon it. Studies of fossil bivalves should take into account the nature of the taxa in the study in order to estimate the potential effects of missing taxa.

Comment. Completeness of the fossil record has significant implications for theories of common ancestry. Estimates of completeness based on the proportion of living taxa known as fossils seem superior to other methods of estimating completeness. If the fossil record of bivalves is 76% at the generic level, one would expect to be able to find roughly 76% of all the genus-level evolutionary steps in purported bivalve lineages. Similar statements could be made for other taxa with good fossil records.

PALEONTOLOGY: DINOSAUR TRACKS AND POSSIBLE POLYPHYLY OF DINOSAURS

Thulborn T. 2006. On the tracks of the earliest dinosaurs: implications for the hypothesis of dinosaurian monophyly. *Alcheringa* 30(2):273-311.

Summary. Dinosaurs are widely believed to be monophyletic. Numerous synapomorphies have been proposed as evidence for their monophyly, but nearly all of them are dubious or equivocal, according to recent studies. The best, and perhaps only, remaining proposed synapomorphy is the fully perforated acetabulum. Evidence from dinosaur tracks and foot structure are more easily explained by proposing separate ancestries for each of three dinosaurian clades: theropods; sauropods; and ornithischians. Each of these clades has an arrangement of bones in the foot that is not readily derivable from a single common ancestor, but is more readily explained as evolving independently from three separate ancestors. If true, this would make dinosaurs polyphyletic, and require that the term “dinosaur” be expanded to include some archosaur fossils that are currently classified as thecodonts.

Comment. The term, “dinosaur,” has become so familiar to everyone that it would take some adjustment to either replace it with three separate names, or to include some fossils that are obviously different from anything now called a dinosaur. Yet there is no a priori reason to assume that dinosaurs must derive from a single common ancestor, and splitting them into three groups might stimulate additional study to determine whether each of these three groups is truly a natural group, or whether there might be additional separate ancestries represented. Dinosaurs appear in the fossil record fully formed, without any known ancestors, and there is no actual physical evidence either for monophyly or for three lineages.

PALEONTOLOGY: MORPHOLOGICAL STASIS IN LAMPREYS

Gess RW, Coates MI, Rubidge BS. 2007. A lamprey from the Devonian period of South Africa. *Nature* 443:981-984.

Summary. A fossil lamprey found in Devonian sediments of South Africa is the geologically oldest lamprey fossil known. It shares many similarities with living species of lampreys, more so than other Paleozoic lampreys. Although the fossil record includes greater morphological diversity than seen among living members of the group, lampreys much like living species have been in existence as far back as their fossil record extends. Lampreys can rightly be called “living fossils.”

Comment. Fossil lampreys seem to be morphologically more diverse than living lampreys, with living species representing only a remnant of the former diversity. The living lampreys represent another example of morphological stasis, and could suggest that lampreys have an ancestry separate from other groups.

PALEONTOLOGY: STASIS IN MICROBES

Schmidt AR, Ragazzi E, Coppelotti O, Roghi G. 2006. A microworld in Triassic amber. *Nature* 444:835.

Summary. Triassic amber found in Italy contains fossil bacteria, fungi, algae and protozoans. Some of these amber fossils are identifiable as genera still living. These include desmids similar to the living genus *Cosmarium*, ciliate protozoans of the genus *Coleps*, and testate amoebae identical to *Centropyxis hirsuta*. The amber is thought to come from conifers in the extinct family Cheirolepidiaceae.

Comment. Microorganisms, because of their simple structure and short life-span, might be expected to be subject to relatively rapid changes in morphology over long periods of time. The persistence of genera, and perhaps even species, since the Upper Triassic seems remarkable, and suggests either that there has been much less time since the Upper Triassic than is generally believed, or that protozoa may be more resistant to morphological change than is generally believed, or both.

SPECIATION: GENES CAUSING HYBRID STERILITY IN *DROSOPHILA*

Brideau NJ, Flores HA, Jun Want, Maheshwari S, Xu Wang, Barbash DA. 2006. Two Dobzhansky-Muller genes interact to cause hybrid lethality in *Drosophila*. *Science* 314:1292-1295.

Summary. Dobzhansky and Muller independently proposed that hybrid sterility might result when two species experienced different mutations in genes that functionally interact. This would cause hybrid sterility due to failure of the two gene products to interact appropriately. This seems to have happened in two species of *Drosophila*. The gene, Lethal hybrid rescue (Lhr) produces a protein that interacts with the protein produced by the gene Hybrid male rescue (Hmr). Mutations of the first gene have occurred in *D. similans* and mutations of the second gene have occurred in *D. melanogaster*. The result is that hybrids receive a combination of genes that no longer can work together, and the resulting hybrid are not viable. Genetic changes such as this could create a barrier to reproduction and produce a new species.

Masly JP, Jones CD, Noor MAF, Locke J, Orr HA. 2006. Gene transposition as a cause of hybrid sterility in *Drosophila*. *Science* 313:448-1450.

Summary. The gene JYAlpha is necessary for male fertility in *Drosophila*. This gene is located on chromosome four of *D. melanogaster*, but on chromosome 3 of *D. simulans*. This difference sometimes results in a lack of the JYAlpha gene in some hybrid individuals, which are then sterile. The resulting reduction in fertility can lead to speciation without any change in nucleotide sequence of the gene.

Comment. Speciation occurs when two or more populations become reproductively isolated, which means they lose the ability to interbreed with each other due to genetic changes. Many different genetic changes may produce reproductive isolation, and it has been difficult to isolate which factors might be responsible. The two studies reported here offer two different mechanisms whereby reproductive isolation may be established, or strengthened: divergence of interacting genes in different populations, or changes in chromosomal location of the same gene in different populations. Speciation is consistent with creation theory, and these studies show that it can result from relatively minor genetic changes.

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FRIEND OR FOE?

Beginnings: Are Science and Scripture Partners in the Search for Origins? Leonard Brand. 2006. Nampa, ID: Pacific Press Publishing Association. 176 p. Paper, \$15.99.

*Reviewed by Jerry Bergman, Ph.D.
Department of Geology and Chemistry, Northwest State College
Archbold, Ohio*

Beginnings is an excellent brief and balanced summary of the case for creation and the work that still needs to be done in this area. This readable, well-illustrated 176-page book covers major topics ranging from geology to molecular biology. Also covered are a history of the development of modern day Neo-Darwinism, why the origins issue is important, short age chronology models and directions for the future.

Dr. Brand has a Ph.D. from Cornell University in biology, numerous publications in the refereed scientific literature, and 35 years teaching experience at the university level. He honestly looks at both the strengths and weaknesses of both sides, making this book useful for creationists and Darwinists alike. Although Brand takes the creation position, he effectively shows why many people accept Darwinism, a view that he treats with respect, objectively and accurately.

The problem of terminology is handled in chapter one. A critical need exists for a discussion of definitions because terms such as *creation*, *evolution*, *Darwinism* and others related to the controversy are rarely defined, often leading proponents of both sides to talk past each other. The term *creation* once meant the means of producing something, and the term *creationism* a theistic theory of how the natural world was produced. Today it has become a term of derision to refer to a narrow discredited theological view held by those ignorant of the relevant science fields. Brand notes that some creation advocates, to some degree, fit this now-common definition. The solution he proposes is to use the term “interventionists.”

This approach has its advantages, but the media and the Darwinist elite will likely cause this term to become a one of derision as they have done with the terms *intelligent design* and *abrupt appearance theory*. Nonetheless, this chapter will be useful in helping both sides understand the relevant issues.

In Chapter 2, Brand shows how important Darwinism was in the 1800s in overturning the traditional Christian worldview and that much of the resistance to Darwinism was from scientists. For example, it was not until around the 1940s that a majority of biologists accepted Darwin's major contribution to transformationism theory, natural selection (p 21). Brand accurately notes that if Darwin had proposed his naturalistic theory of evolution for the first time today, our understanding of the cell and its working would preclude most scientists from accepting it.

One example of many that effectively illustrates this point is the kinesin system of transporting materials, such as proteins, around the cell to where they are needed. The system must pick up the correct load and transport it to the proper location in the cell. Kinesin transport carriers use two "legs" powered by ATP to "walk" along a cellular highways made up of microtubules. Each kinesin type carries a specific load, like a bus that goes to one location only; to arrive at the correct destination, cellular materials must board the correct "bus." Thus kinesin is both a molecular transportation and an information processing machine.

Major scientific problems with Neo-Darwinism are briefly summarized, as are some of the problems with the interventionist view. Brand explains the strengths and weaknesses of three models (flood geology, holistic geology, and conventional geology), showing much more work is needed in these areas. Brand notes specific problems with the interventionist model, such as the observation that many modern life forms are not found in the Cambrian rock layers while others are found *only* in certain rock strata (p 199). In contrast to the claims of some creationists, much work needs to be done to understand the history of life—and we may never answer all possible questions in this area, even some major ones.

One point that could be clarified is the uncritical use of the term "Dark Ages," a term Francis Schaefer and others claim was invented by anti-religionists in an effort to discredit the Catholic church. Stark (2005, p 35-68) documents the significant progress that was made at this time in many fields, including science. One of the most significant innovations of this time was "the creation of the first economies that depended primarily on nonhuman power" (Stark 2005, p 38).

I highly recommend this book for both neophytes and seasoned researchers, and for both creationists and Darwinists. It could go a long way to facilitate constructive dialogue between both sides. The controversy will not go away and will become more active in the future due to new research, especially in molecular biology. Consequently, some resolution, or at least accommodation, requires constructive dialogue so that each side can at least understand, and, ideally, respect, the position of the other side. Brand's work is a humble approach that avoids unnecessary confrontation which will help to begin much-needed dialogue among the various advocates of the different positions. He also shows that a good case can be made in favor of the Biblical worldview.

Literature Cited

Stark R. 2005. *The Victory of Reason: How Christianity Led to Freedom, Capitalism, and Western Success*. NY: Random House.

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EVO-DEVO NOT

Why is a Fly Not a Horse? Giuseppe Sermonti. 2005. Seattle, WA: Discovery Institute Press. 165 p. Paper \$14.95.

*Reviewed by David N. Mbungu, Ph.D.
Department of Biology, Andrews University
Berrien Springs, Michigan*

In *Why Is A Fly Not A Horse?* Giuseppe Sermonti, a retired professor of genetics and chief editor of the journal *Rivista di Biologia*, questions the legitimacy of evolutionary theory and provides evidence from biology to highlight its flaws. Because of his strong antievolutionary views, the author is conscious of being labeled a creationist. However, he disavows creationism and expresses his desire to remain “only a creature” (p 18).

Throughout the book Sermonti interweaves concepts from genetics, molecular biology, paleontology and other methods of scientific inquiry to illuminate contradictions between Darwin’s evolutionary postulates and current empirical evidence. He expresses dismay at speculation that natural selection has diversified life through a gradual process of germ-line mutation capture and transmission; a view he considers both conjectural and a philosophical fiction. Instead, natural selection is a conservative force stabilizing populations by resisting change: “only oscillations deriving from genetic variability enable a species to remain faithful to its type” (p 49). Further, he contends, mutations cannot account for genetic variability in organisms because most are either deleterious or neutral.

Richard Dawkins’ *Blind Watchmaker* is used by Sermonti to illustrate how advocates of Darwinism employ evolutionary dogma as a guiding factor in experimentation and data interpretation. Sermonti cautions against bending data to support preconceived views and argues that an objective

Original pagination was p 50-53.

evaluation of Dawkins' results leads to conclusions opposite to those Dawkins draws: "unless there is a preestablished design, nothing-nothing at all!-can come into existence" (p 56).

Evidence from molecular genetics features prominently throughout the book including reflections on progress made in mapping chromosomes. Many hoped that such an accomplishment would facilitate construction of objective kinship patterns between organisms. However, these studies have not revealed any correlation between chromosome numbers and kinship. For example a donkey has 31 chromosomes and a horse 32 while zebras, which resemble donkeys morphologically, have only 16. The author concludes that these studies have only succeeded in eclipsing the organisms they were meant to illuminate.

Next, Sermonti evaluates the success of biochemical, morphological and paleontological studies in elucidating relationships among organisms. Can genetic endowment account for species identity and diversity of organisms? Here again, he argues against this supposition by highlighting the remarkably high degree of biochemical similarity in phylogenetically distinct and morphologically diverse groups of organisms. For example, cytochrome *c* protein is highly conserved in all species studied so far, demonstrating evolutionary "stasis" in this protein. He questions reliance on comparative anatomy studies to construct phylogenies given that such studies reveal structural similarities or differences but not the "meaning" of the parameters studied and cautions against explaining morphological adaptations in organisms based on their perceived needs.

Contrary to expectations, Sermonti observes, studies attempting to harmonize human and ape molecular phylogenies with paleoanthropology have been impeded by paucity of primate fossils and lack of intermediate forms in man's supposed evolutionary path. The discovery of fossils of presumed human progenitors long before primates diverged from the ancestral tree according to molecular data nullifies Darwin's assertion that man descended from apes and begs for an alternative explanation. "The truth," Sermonti says, is that man has "remained what he had always been. At the parting of ways the molecules and chromosomes of human beings were already there" (p 77).

Just as uniform color has nothing to do with team sportsmanship or ability Sermonti argues that molecular life is governed by "conventions" defined as: "rules not dictated by situational needs" of an organism (p 82). Conventions are just as crucial for life as the genetic code is and conventions are inter-linked with identities. This he illustrates with two examples: 1) the species-typical orientation behavior of migrating birds

raised in isolation which will take to the sky the very first time they have the opportunity and 2) trypanosome cells which can start with truncated RNA genes transcripts and produce mRNA transcripts that are translated to normal active enzymes. Both of these examples reveal the existence of “hidden knowledge” in organisms that is inaccessible through empirical investigation.

Giving as an example prions, which are inherited independent of DNA, the author relegates DNA to only a secondary role in determining morphological features. He argues that development is guided by one or more of the “morphological destinies, lying in wait somewhere” to propel change (p 103). Specific structures he mentions that are formed without DNA templates include mollusk shells in their many variations. He contends that sudden appearance of strikingly similar patterns in different organisms without DNA involvement — and therefore no cumulative selection — is consistent with DNA playing only a secondary role in the emergence of such processes. Morphological differences, Sermonti posits, can arise without underlying genetic differences as illustrated by termite castes whose members differ morphologically yet retain genetic identity.

Sermonti ponders the impact of the Roman Catholic Church’s endorsement of organic evolution on the “mind-body” debate. He finds troubling the papal decree that the mind and the body had separate and independent existence with the body evolving organically until it was invaded by the soul through an “ontological leap.” Contrary to this view, Sermonti expresses his conviction that “man was born all of a sudden in a great leap” (p 114).

Towards the end of the book, Sermonti highlights evidence from the fossil record that refutes Darwinian evolution: leaf insects in fossils that predate plant evolution, sudden explosion of complex life in the Cambrian and lack of intermediate fossils. He concludes that the commitment of evolutionary advocates to their dogma has led them to ignore data that does not conform to their cherished theory.

Although the author does not answer the rhetorical question “Why is a fly not a horse?” his candid and objective evaluation of the evolutionary theory in a style that is both provocative and entertaining, makes this book an invaluable resource for biologists.

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WHO CREATED ALL THESE?

The Privileged Planet: How Our Place in the Cosmos is Designed for Discovery. Guillermo Gonzalez and Jay W. Richards. 2004. Washington, DC: Regnery Publishing. 444 p. Cloth, \$27.95.

*Reviewed by Mart de Groot, Sc.D.
Retired astronomer/pastor, Northern Ireland*

This unique and interesting book is authored by an Iowa State University assistant research professor of astronomy (Gonzalez) and a former Discovery Institute vice president and senior fellow (Richards). Collaboration between a scientist and a researcher at an institute actively promoting Intelligent Design may appear unusual. Remember, though, that astronomy is a discipline that provides much evidence for design through the precise way many natural quantities seem to be fine-tuned in order to facilitate the origin and existence of life. However, this book is not about life *per se*.

The authors have set a novel goal that does not seem to have been pursued before using the direct approach adopted in this book. They contend that, beyond the remarkable signs of fine-tuning for life, there is another at least equally interesting, phenomenon. Our planet is not only a good place for life, it is also a good place for discovering the many and varied aspects of our Universe. In this sense, the coincidence on Earth between the presence of intelligent technological life — *habitability* in their jargon — and the best possible conditions for discovery of the wider cosmos — *measurability* — is to be noted, benefited from and meditated upon.

The text comes in three sections, the first dealing with our local environment. The near-equal angular sizes of the Sun and the Moon give rise to solar eclipses which form the basis of ancient chronology. They also allow us to study the Sun's outer atmosphere. The knowledge thus obtained can then be extended to understand the stars. The Moon is essential

for the stability of Earth's inclination (which assures regular seasons), the tides, ocean currents, Earth's magnetic field and plate tectonics. Phenomena like tree rings, layers in the (ant)arctic ice caps with the elements found therein, and coral reefs, among various others, give us insight in Earth's history. Geological research informs us about yet other aspects of the past of our planet.

Looking at our neighbors in the Solar System makes us realize their crucial importance. For example, Jupiter acts as a 'watchman' keeping the inner Solar System relatively free from major comet and asteroid impacts. And, while Earth's atmosphere may not always give astronomers a clear view of the cosmos, it does protect us against cancer-producing ultraviolet and other high-energy forms of radiation: another one of the many examples of how measurability and habitability go hand in hand.

Section 2 deals with investigation of the wider cosmos: stars, galaxies, and the large-scale structure of the Universe. Our location at the periphery of a spiral arm far from the center of the Milky Way is another indispensable requirement for maximizing our observational studies of the Universe as well as a safeguard for the existence and protection of life.

Observations of this type along with the fine-tuning of a host of physical quantities essential for the origin and existence of life are discussed along with concepts like the Circumstellar Habitable Zones, Circumstellar Continuously Habitable Zones, and Galactic Habitable Zones — all of which emphasize the close link between measurability and habitability. While some see these observations as a mere coincidence explained by the Anthropic Principle, others interpret them as a product of design.

The authors explain very well how the Big Bang theory gives an acceptable scientific picture of the cosmos. At first sight the time periods involved in the Big Bang theory are extremely long compared with the short time scale reported in the first chapters of the Bible. The authors seem to favor the picture of naturalistic science. I suggest that the reader do his or her own thinking about this issue by restudying the early chapters of Genesis and noting carefully how much the Bible says or does not say about the time involved in the creation of the Universe. Unfortunately the authors shy away from engaging on this issue.

Section 3 deals at length with subjects ranging from the history of science to questions about the existence of extraterrestrial intelligent life, arguing that the Copernican Principle — the notion that "we should assume that there is nothing special or exceptional about the time or place of Earth in the cosmos" — is a false premise. They present six predictions on the basis of the Copernican Principle that are not fulfilled in the

Universe. As a result, they maintain, Earth is not just an ordinary and insignificant planet in a very ordinary planetary system centered on a very ordinary star in a very typical region of a very common galaxy. In fact, Earth is a very special planet and quite possibly the only one harboring life in the Universe.

Those who find Biblical evidence for extraterrestrial life (other than angels) may find it useful to think in terms of other universes — hypothetical as these may be as our place in the Universe appears the best possible for a planet populated by curious intelligent beings. This is where Gonzalez and Richards' design argument is strongest and where a more direct statement about the nature of the designing intelligence and, maybe, why the design included placing life on the best observing platform in the Universe would be useful. Did the designer intend that we should find out about him through the study of the Universe? Texts like Psalm 19:1 and Isaiah 40:26 come to mind.

The authors have done a thorough job explaining scientific issues at a semi-popular level. Those who want to dig deeper will find much of value in seventy pages of bibliographical and other notes, and the 24-page index is very useful. One need not agree with everything the authors say, but there is much to ponder in this book. Surely, the Universe is not just fine-tuned to provide a habitat for human life; it is also designed to help us meet the Designer.

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AN UNFINISHED CONVERSATION

Before Darwin: Reconciling God and Nature. Keith Thomson. 2005. New Haven, CT: Yale University Press. 314 p. Cloth, \$27.00.

*Reviewed by Gary Land, Ph.D.
Department of History and Political Science
Andrews University, Berrien Springs, Michigan*

Since publication of Michael Denton's *Evolution: A Theory in Crisis* (1986), the Intelligent Design (ID) movement has inspired many publications, both pro and con. The ID debate prompted Keith Thomson, professor emeritus of natural history at Oxford University and author, among other works, of *Morphogenesis and Evolution* and *H.M.S. Beagle*, to take a new look at the seventeenth- to nineteenth-century development of this argument. Thomson seeks to understand why the argument from design came apart some one hundred and fifty years ago and the implications this failure has for its more recent iteration.

The author sets the stage by noting connections between William Paley, the most famous formulator of the modern argument from design, and Charles Darwin, whose theory of natural selection replaced Paley's teleological interpretation. Darwin not only lived in the same rooms at Christ College in Cambridge as had Paley seventy years previously; he also studied the latter's *Natural Theology*, later describing it as "the most use to me in the education of my mind" (p 6).

Paley wrote his works in response to the increasingly materialistic and mechanistic science developed in the eighteenth century which was already suggesting that life emerged through purely natural processes. As Thomson humorously writes, "Paley read Erasmus Darwin, recoiled, and

Original pagination was p 55-58.

reached for his pen” (p 38). Furthermore, James Hutton’s *Theory of the Earth* had put forward evidence that the planet itself was extremely old, its geological features produced by a balance of physical forces that seemed incompatible with the Genesis account of creation.

Paley’s minimalist argument, which addressed only God’s existence, arose from the increasingly tortured attempts of earlier natural theologians to accommodate new scientific thinking. John Ray, described as the “founding father” of modern natural theology, argued in the 1660s that the complexity of nature revealed its supernatural origin. Although Ray’s concept of species suggested that nature was static and unchanging, the discovery of fossils, followed by identification of Earth’s underlying structure, and finally, a growing understanding of the relationship between particular fossils and certain rocks presented empirical challenges to orthodox religious understanding. In response, such writers as Steno, Robert Plot, Thomas Burnet, John Woodward, William Whiston and others developed “sacred theories” that sought to reconcile the evidence for such phenomena as mountain building with traditional ideas of special creation and one or more deluges. Thomson argues that the absence of a theory of plate tectonics — described as “a realistic and testable mechanism” (p 190) — allowed these sacred theories to flourish.

Meanwhile, through the work of Erasmus Darwin, Comte de Buffon, and Jean Baptiste de Lamarck, evolutionary theories emerged which postulated that nature held within itself a normative “causal generative process” that produced variations “shaped by chance or circumstance” (p 215). Although inadequate genetic understanding limited nineteenth-century knowledge of biological change, Charles Darwin’s theory of natural selection, by concentrating on “common-sense phenomena,” provided a causal mechanism that seemed to explain change and variation in nature.

Turning back to Paley, Thomson argues that his natural theology also supported the preservation of an oligarchical society, a view reinforced by his reading of Thomas Malthus’s theory of population growth. This connection with Malthus produced one of history’s interesting ironies. “In adopting Malthus’s ideas so strongly and so early,” Thomson writes, “Paley helped promulgate them and ultimately contributed to the promotion of atheism in the form of the evolutionary theory of Darwin, who acknowledged that both Paley and Malthus had had a profound influence on his thinking” (p 259).

Rather than writing a straightforward chronological account of the rise and fall of natural theology, Thomson has constructed his history more in the fashion of a dialogue between Paley and his fellow natural

theologians and their scientific challengers. Entering the conversation himself, the author suggests the controversy over evolution is part of a long conflict between rational explanation and acceptance of mystery. Although stating that “the fact of evolution as a process of change over time is constantly tested, and has never failed” (p 203), he also regards religious explanations sympathetically, even seeking to rescue them from their strongest supporters. “The trouble with using terms like ‘intelligent’, ‘design’, and ‘good’ as anything more than metaphors is that it becomes easy to think that they can be applied literally in a human sense,” he writes. “While to portray God as too mysterious is always to risk making him too remote, making him too accessible and too much like us risks trivializing him” (p 235).

Thomson suggests science and religion are complementary enterprises that thus far “have not been able to agree upon the reformulation of a set of questions that they can attack jointly.” The book closes with a description of the unfinished Oxford University Museum, financed by the Oxford University Press’s Bible publishing account and site of the famous Wilberforce-Huxley debate over Darwinism, which the author regards as a “metaphor about the work of science and the reconciliation of science with religion” (p 279).

Before Darwin reflects the author’s deep reading in the primary sources, including both the historically significant works by such authors as Burnet, Paley, and Darwin as well as more recent writers ranging from Owen Gingerich and Davis Young to Ronald L. Numbers. Thomson also reveals a close acquaintance with Scripture, quoting it occasionally but effectively. Yet he wears this scholarship lightly, for the beautiful and engaging prose and the book’s structure encourage the reader to become a participant in the dialogue rather than merely an observer.

Thomson’s sympathetic but critical account of the conflicted development of natural theology, including the intellectual connections between Paley and Darwin, is convincing. Anyone seeking to understand either the historical development or recent reformulation of the argument from design will find this volume indispensable. Although the author writes from an evolutionary perspective, making no effort to establish its validity, creationist and/or intelligent design proponents will nonetheless find his historical analysis helpful. Furthermore, *Before Darwin*’s suggestion that science and religion are engaged in an unfinished conversation offers a subdued but hopeful outlook for religious, particularly Christian, believers who take science seriously.

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GIVING AWAY THE STORE AGAIN?

The Evolution-Creation Struggle. Michael Ruse. 2005. Cambridge, MA: Harvard University Press. 327 p. Cloth, \$25.95.

*Reviewed by Tristan Abbey
Stanford University, Palo Alto, California*

Michael Ruse is a familiar name to those involved in the controversy surrounding evolution. *The Evolution-Creation Struggle* is his latest in a long line of highly-respected works concerning the origins debate. This philosopher of science is possibly best known for his testimony in the infamous 1981 Arkansas trial, which concluded that creationism falls short of science. In this book, Ruse argues forcefully that “in both evolution and creation we have rival religious responses to a crisis of faith” (p 3). Both evolutionism and creationism are, ultimately, separate religions.

Ruse prefaces his book with a brief discussion of the debate, explaining that it exists for reasons larger than the simple assertion that creationists fail to grasp the science. Setting the context, he gives a brief history of Christianity, outlining the Reformation and Enlightenment, and discusses Descartes, Hobbes, Paley, and others. He introduces the idea of progress, which “was at sharp odds with any ideology, Christian or otherwise, that denied human autonomy and our ability to work things for the better” (p 24). Progress as a philosophical drive is a recurrent theme throughout the book. He notes that, for the French philosophers, “the very point of progress was to oppose Christianity directly” (p 24).

Exhibiting an astonishing command of the history of science, Ruse brings to the forefront the idea that, rather than pure science, philosophical and religious motivations drive both sides. By the time Darwin published *On the Origin of Species*, Ruse argues, “Evolution had been in the air for a long time and many people had been looking for a reason to believe it” (p 85).

Ruse answers a question many have asked: Was Darwin a Christian? He explains that Darwin's views evolved from Christianity to Deism to, by the time of his death, agnosticism. He also provides details on the religious beliefs of other important players, including John Henry Newman and Richard Owen. These details bolster his case that evolution was fueled by predetermined philosophical views.

Describing the work of evolutionists in the 1940s and beyond, Ruse explains that, although they were committed to rigorous research, they were also committed to progress: "Evolution was their profession. Evolutionism was their obsession" (p 187). They "would publish two sets of books. One professional, with no hint of progress. One popular, with much talk of progress. Two messages, for two audiences" (p 187).

Ruse also discusses Spencer's "social Darwinism," the growth and decline of progress throughout the centuries, and the various trends in Christianity (fundamentalism, pre-millennialism, post-millennialism, theistic evolutionism, etc.). Periodically, Ruse reminds the reader of historical contexts: the French revolution, World Wars I & II, the Cold War, and Vietnam.

The reader is further treated to a refreshing version of the Scopes Monkey Trial, which differs markedly from the standard Hollywood-based interpretation. *Inherit the Wind*, a film derided by many as a gross distortion, "took many liberties in telling the tale" (p 166). Ruse points out that William Jennings Bryan "was made to look like a buffoon when asked [about] the actual length of the days of creation. In true life Bryan always believed that the days were periods of time" (p 167).

An exciting history is given of how Intelligent Design (ID) has developed, from Phillip Johnson's *Darwin on Trial* through Michael Behe and irreducible complexity up to William Dembski's explanatory design filter. His explanation of ID is surprisingly fair (p 251-255) acknowledging that "it would be a mistake simply to categorize the intelligent design movement as creationist without qualification" (p 256), and explaining that many design theorists accept various aspects of evolution. He does point out, however, "one has good reason to see the group as part of this ongoing tradition" (p 261). Fair enough.

Ruse's summary of the current status of evolutionary theory however, leaves a lot to be desired. According to Ruse, "fossil discoveries of the past half century have been absolutely stupendous" (p 198), providing new evidence for evolution. But he admits the origin of life "has always been a major headache for evolutionists" (p 200), and claims that the chief obstacle is that origin of life researchers suffer from an abundance

of ideas. Ultimately, he acknowledges that “large gaps in our knowledge of evolutionary mechanisms...persist” (p 200-201).

One fascinating aspect of this book is the parallels readers can draw (although Ruse does not) between evolution’s fight for recognition as a “professional science” and the work currently being done to advance ID. Until the time of Huxley and Darwin, according to Ruse, evolution was merely a pseudoscience. It wasn’t until the work of Ronald Fisher and Sewall Wright decades later that a “professional science” of evolution developed. How far along the intelligent design community is in this process remains to be seen.

What makes this book appealing is its warm, good-natured tone. Ruse’s dry wit more than compensates for occasional tiresome poetic interludes. Discussing the Catholic Church’s response to evolution, for example, he explains its reluctance to join the fray: “Their fingers had been burned two centuries before, over that mess with Galileo, and they were glad to let the Protestants run with this one” (p 142). Other one-liners include: “God is notorious for moving in mysterious ways” (p 163) and his description of Robert Chambers’ *The Vestiges of the Natural History of Creation* as “the Big Mac of popular science — very tasty, very filling, very accessible and (in the opinion of the authorities) of very dubious value to one’s health” (p 48).

Concluding with a call to arms, Ruse laments that while the anti-evolution community is able to work together despite religious differences, evolutionists are bitterly divided between theistic evolutionists and the Richard Dawkins of the world, who “are but the tip of a very chilling iceberg” (p 273). He exhorts his colleagues to go beyond bashing creationism and intelligent design to discovering “why others have (often) legitimate concerns...a more informed and self-aware approach to the issues” (p 288) in this controversy that simply won’t go away.

GENERAL SCIENCE NOTE

GENOMES AND DESIGN

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In recent years the publication of new genomes has become almost routine. During November of 2006, *Science* published the genome of the purple sea urchin, *Strongylocentrotus purpuratus*.¹ Because of the purported relationship between sea urchins and chordates, this creature's genome is of particular interest due to the information it brings to bear on the origin of these creatures and their genetic makeup. Current taxonomies classify echinoderms, including sea urchins, with the deuterostomes which also include hemichordates and chordates. Within a Darwinian framework, this means that all genes shared by humans and sea urchins must have been present in a common ancestor shared sometime before Cambrian strata, which contain both chordate and echinoderm fossils, formed.

Perhaps the most surprising discoveries during comparison of the *S. purpuratus* genome with other sequenced genomes have been the number of genes present and the similarity between those genes and the genes of other deuterostomes. The estimated number of genes in *S. purpuratus* is 23,300, which is very similar to estimates from other genomes including the human genome. This is particularly surprising from an evolutionary perspective because two whole genome duplications resulting in four copies of the ancestral genome are thought to be necessary to account for the chordate genome. Because genome duplications are not invoked in echinoderms, the number of genes must be accounted for by a different mechanism in which many small duplications occurred. Thus, the Darwinian explanation for gene number similarity results in an explanation that is unparsimonious despite the similarity in the gene number estimates.

Comparison of gene families between the *S. purpuratus* genome and genomes of other deuterostomes reveals a remarkable lack of novelty. "[T]he distribution of proteins among those conserved families shows the trend of expansion and shrinkage of the preexisting protein families, rather than frequent gene innovation or loss."² This means that the truly difficult task of inventing new kinds of genes must have occurred before the split between chordates and echinoderms. Within a conventional framework, this removes over half a billion years from the time available for genes shared among deuterostomes to evolve via the neo-Darwinian mutation-selection mechanism.

It has been shown that gene duplication is not a viable mechanism for production of genes with new functions, even within gene families.³ Presumably this means that creation of the truly novel genes from which the various gene families are supposed to have developed via duplication and modification would be a significantly more difficult achievement. Thus, production of the original genes from which Darwinists hypothesize gene families are derived must be that much further beyond the capacity of Darwinian processes. The truly surprising finding is that *S. purpuratus* shares genes thought to be vertebrate specific. These include genes involved in adaptive immunity and virtually the entire set of genes involved with Usher syndrome, a genetic disorder affecting hearing, balance and sight. But the situation is made worse by comparison of the *S. purpuratus* genome with protostome bilaterians. It turns out that “bilaterian genes are more broadly shared”⁴ than previously thought, further reducing the window of time for mutation and selection to produce these genes.

Some genes are unique to *S. purpuratus* and a subset of these provide unique opportunities to examine the time available for their evolution within a Darwinian framework. Among the most informative of these unique echinoderm genes are those involved in forming stereom, the distinctive endoskeletal tissue found in all echinoderms.⁵ It is now proposed that “the specific stereom matrix gene battery (i.e., the variety of structural functions encoded in its diverse proteins, plus its regulatory controls) must have been assembled as such in Early Cambrian time.”⁶ The time span suggested for evolution of this suite of genes and its regulatory controls is from 542 – 520 Ma or approximately 22 million years. This brings much more focus to questions about how much time and what has to be achieved given Darwinian assumptions of mechanism and time. Publication of this genome allows for more realistic evaluation of what the neo-Darwinian mechanism is claimed to have achieved, even within a framework of long ages.

An unusual aspect of publication of this particular genome was the co-publication of papers detailing when specific genes are active in the genome.⁷ This was made possible in part by the fact that *S. purpuratus* has been a model organism for the study of development for some time. This study revealed that about half the identified genes in this organism are active during embryogenesis. On the surface this might appear to support the hypothesis of Lynn Margulis that creatures may expand their genomes by “fusing” their genomes with those of other organisms. Thus “Acquired traits can be inherited not as traits but as genomes.”⁸ In developing this “symbiotic” version of evolutionary history, she embraces the ideas of Donald I. Williamson who explains organisms that have distinctly different larval and adult stages as the product of blended

genomes of two distinctly different organisms and specifically cites sea urchins as an example of an organism which acquired the genes for its larval stage from another organism.⁹ The problem is that certain classes of genes, (e.g., most transcription factors and signaling proteins) are expressed during embryogenesis,¹⁰ making the theory that genes from one genome are expressed early in development while those from the “adult” genome are expressed later untenable.

Since publication of the first multicellular eukaryotic genome, *Caenorhabditis elegans*, in 1998,¹¹ publication of each successive genome has invariably revealed findings which are surprising within a Darwinian framework and almost unavoidably described in terms of design. The sea urchin genome is no exception to this. For Biblical creationists, “unexpected sophistication in the urchin genome”¹² is expected, not unexpected. The idea that in different organisms “the same [genes] are used in different ways,”¹³ much as engines and pumps may use pistons in different ways is unlikely to leave those familiar with how machines are designed “scratching their heads.”

Most creationists will be impressed with the design language used when describing the sea urchin genome. The *S. purpuratus* genome will help us “understand on sight the logic functions they execute in response to the sets of transcription factors in given cells at given times.” “The sea urchin genome will directly contribute to solving the principles of design of gene regulatory networks for embryonic development.” “Such principles can only be obtained by comparing network architecture in different animals developing in similar or different ways.” “The genome will not only provide the ‘code’ for development but will also contribute to linkage between gene regulatory networks and the actual realization of developmental events.” “It remains to connect the genes that execute these functions to the control circuitry that specifies their occurrence.”¹⁴ As with previously published genomes, the sea urchin genome makes Darwinian explanations appear significantly less tenable while at the same time exhibiting the characteristics of a brilliantly designed creation.

ENDNOTES

1. Sea Urchin Genome Sequencing Consortium. 2006. The genome of the sea urchin *Strongylocentrotus purpuratus*. *Science* 314:941-952.
2. *Ibid.*, p 943.
3. Behe BJ, Snoke DW. 2004. Simulating evolution by gene duplication of protein features that require multiple amino acid residues. *Protein Science* 13:2651-2664.
4. Sea Urchin Genome Sequencing Consortium, p 950.
5. Bottjer DJ, Davidson EH, Peterson KJ, Cameron AR. 2006. Paleogenomics of Echinoderms. *Science* 314:956-960.

6. Ibid., p 958.
7. See the December 1, 2006 issue of *Developmental Biology* 300:1-496.
8. Margulis L, Sagan D. 2002. *Acquiring Genomes: A theory of the origins of species*. Basic Books, p 41.
9. Williamson DI. 2006. Hybridization in the evolution of animal form and life-cycle. *Zoological Journal of the Linnean Society* 148:585-602.
10. Samanta MP, Tongprasit W, Istrail S, Cameron RA, Tu Q, Davidson EH, Stolc V. 2006. The transcriptome of the sea urchin embryo. *Science* 314:960-962.
11. *C. elegans* Sequencing Consortium. 1998. Genome sequence of the nematode *C. elegans*: a platform for investigating biology. *Science* 282:2012-2018.
12. Pennisi E. 2006. Sea urchin genome confirms kinship to humans and other vertebrates. *Science* 314:908-909.
13. George Weinstock quoted in Pennisi E. 2006. Sea urchin genome confirms kinship to humans and other vertebrates. *Science* 314:909.
14. All quotes in this paragraph are from column 3 on p 939 of Davidson EH. 2006. The sea urchin genome: Where will it lead us? *Science* 314:939-940.