Chapter 2

The Basic Structure of Planetary Biology Theory

2.1 Introduction

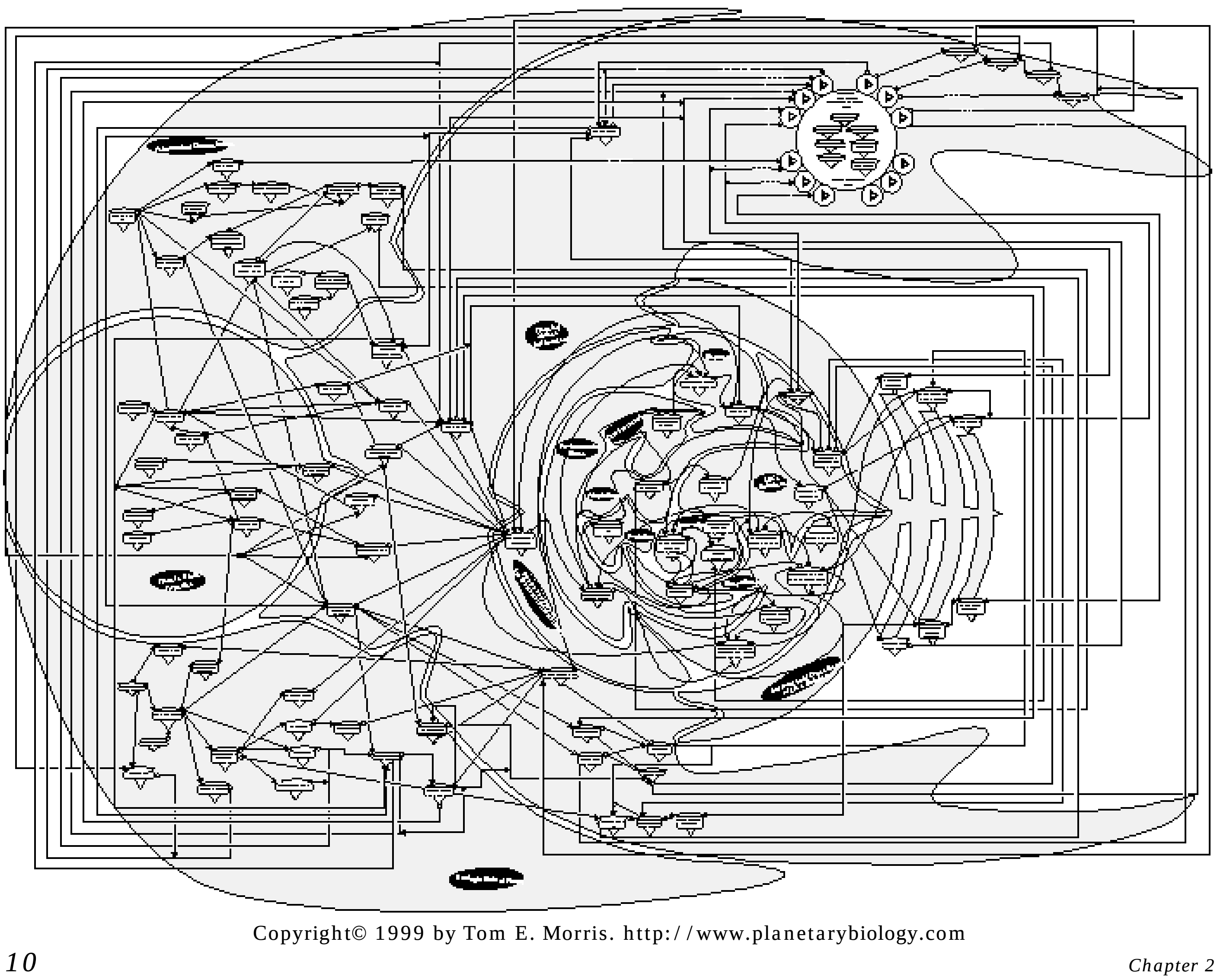
I developed the theory of planetary biology out of necessity, to help me better comprehend the dynamic and historical nature of planetary surface environments – especially planets with life.

In short, the theory of planetary biology exists in two main levels of organization: 1) an intricate network of phenomena (the 'phenomenal network') (fig. 1); and 2) a model of interlocking pieces (the 'trilobite model') (fig. 2) that overlies the phenomenal network in an attempt to extract its essence.

2.2 Planetary biology's phenomenal network

First, the phenomenal network is composed of 80 different kinds of physical and biological phenomena that contribute to shaping worlds. For example, phenomena on this network include things like the brightness of the primary star, the vigor of the planet's internal heat engine, life's biosynthetic chemistry, and the degree to which life has colonized the planet. More than anything else, the phenomenal network establishes the web-like infrastructure for the theory of planetary biology.

Figure 1. Planetary Biology theory's Phenomenal Network. Readable version not included in this edition.



Think of the phenomenal network as a road map. The individual phenomena are the centers of activity laid out across the countryside. The lines on the phenomenal network are like the roads on a map that show how the phenomena are interconnected, spatially and dynamically.

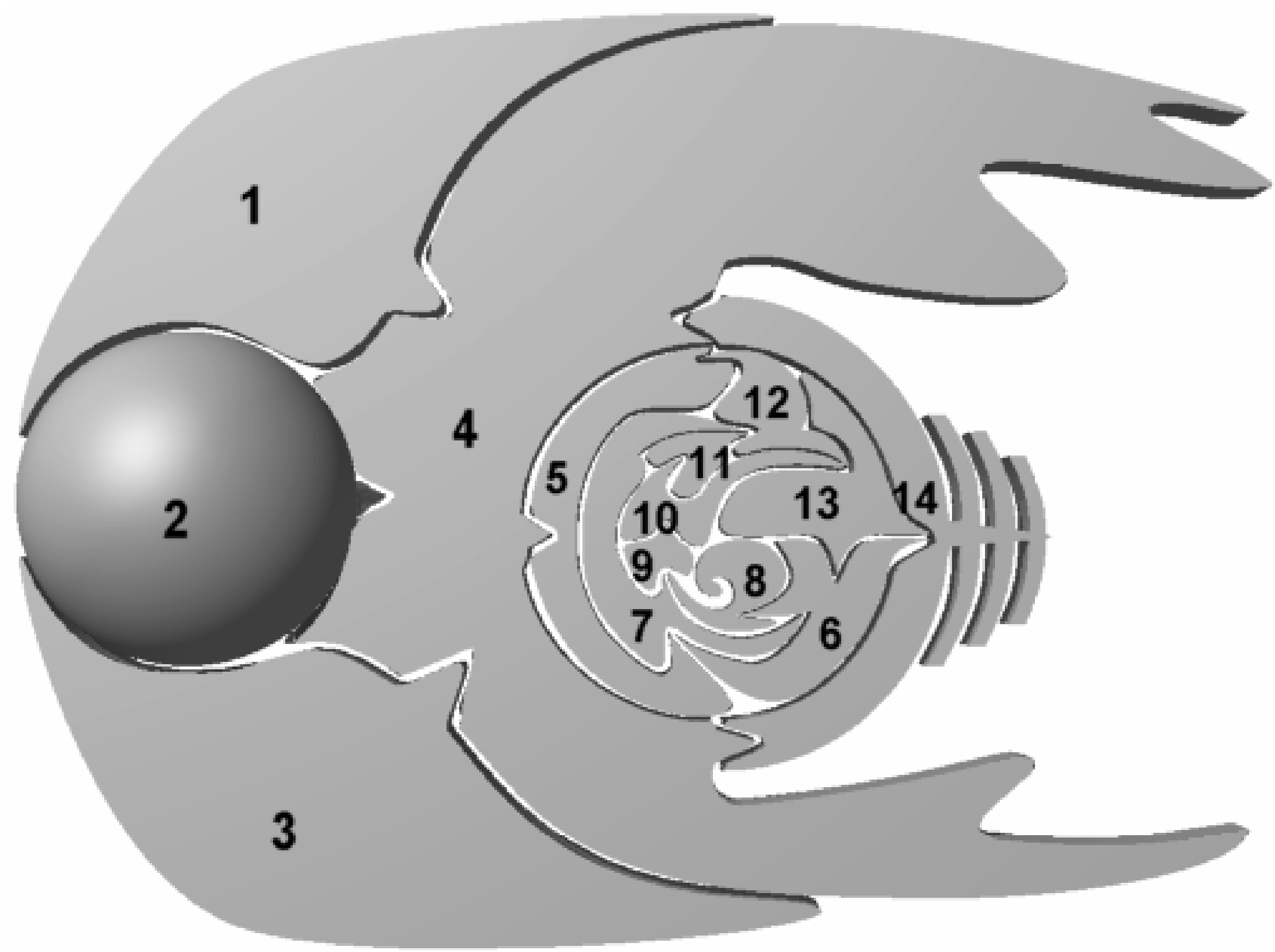
With the use of planetary biology's phenomenal network, we now have a more direct way to navigate this complex terrain. Now, we can instantly establish context when considering any individual phenomenon. For example, looking at the phenomenal network, how important is a given phenomenon in the shaping of a world? How does a particular phenomenon relate to all the other phenomena in the network? Which other phenomena does it influence? Which other phenomena influence it?

By acting as a map, the phenomenal network establishes a powerful visual structure that we may constantly refer to in our quest to understand the unavoidable complexity of worlds. It also can help us to make predictions about the fate of worlds under different conditions. As a result, the phenomenal network eliminates much of the confusion, mystery and frustration that frequently accompanies such inquiries, making them more inviting and productive.

2.3 Planetary biology's trilobite model

Planetary Biology theory's trilobite model is an extension and consolidation of the phenomenal network (which constitutes the real nuts and bolts of the theory). Like the graceful body of a beautiful automobile, the trilobite model communicates the essence of its powerful machinery while shielding us from the details. The beauty of the trilobite is that it shows us a more

Figure 2. Planetary Biology theory's Trilobite Model.
1. Astronomical circumstances
2. Planet's orbital properties
3. Geologic state of the planet
4. Planetary surface environment
5. Diverse and dynamic environmental circumstances
6. Biosynthesis
7. Environmental stress
8. Innovation
9. Evoluton
10. Adaptations
11. Preadaptations
12. Dispersal
13. Life's abundance
14. Environmental consequences of life's abundance



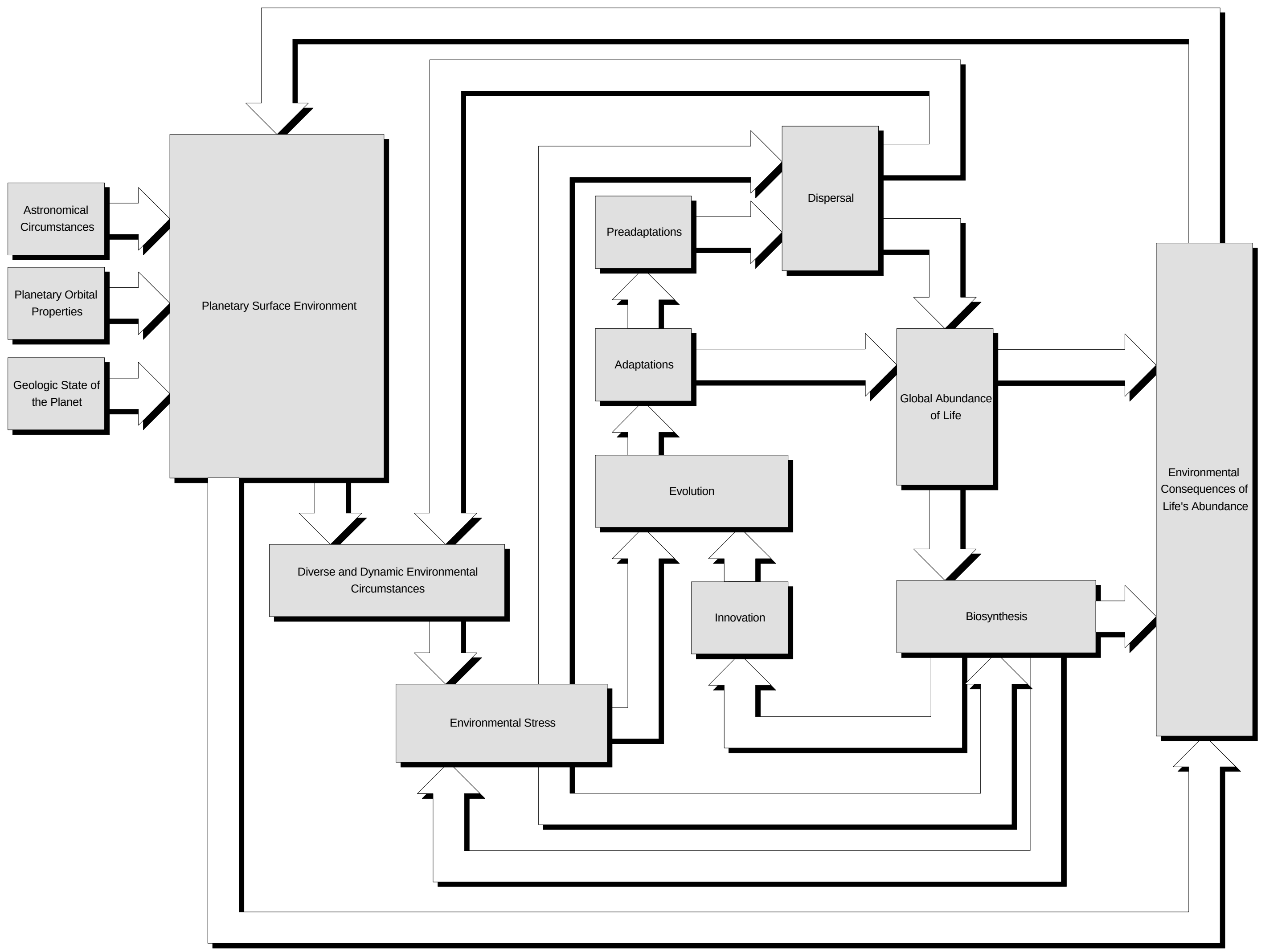


Figure 3. A representation of the trilobite model's phenomenal zones in a conventional flow diagram.

comprehensible organization of the phenomenal network. Put in this form, we can see and appreciate the larger landscape of planetary biology theory. The details are still accessible if we want them. They are embedded in the trilobite as the phenomenal network. But they become visible only if we choose to see them. As a result, the trilobite shields us from the assault, seduction, and tyranny of endless detail that characterizes each phenomenon in the phenomenal network. It allows us to step back and observe the workings of the whole.

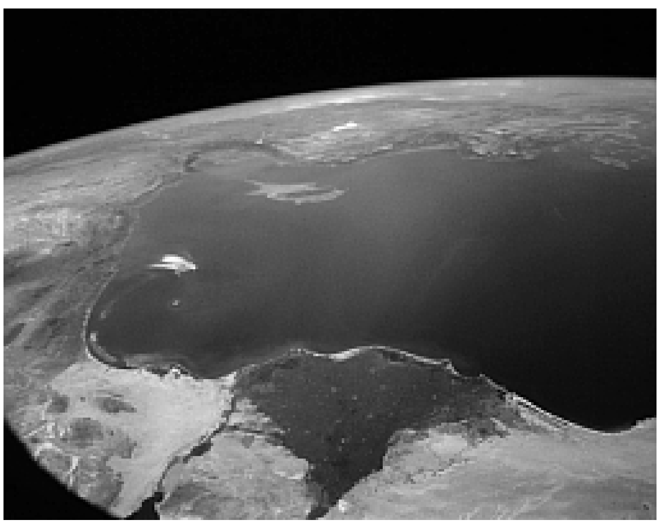
Although based on planetary biology's phenomenal network, the trilobite model by far is the most elegant and useful part of planetary biology theory. Primarily, planetary biology theory and this book are about understanding the trilobite model: what essential pieces make up the model, how those model pieces are arranged, and how they interact to result in interesting worlds. The trilobite model distills down the essence of what is happening on a world.

On its face, the phenomenal network is overwhelming if not plain confusing. But despite its intensity, there is a natural structure that lurks there. It shows itself if we consider not just individual phenomena, but groups of phenomena. In order to draw out the essence of the phenomenal network, I have organized its 80 individual elements into 14 groups of related phenomena. These phenomenal groups (zones) are: 1) astronomical circumstances; 2) planetary orbital properties; 3) geologic state of the planet; 4) planetary surface environment; 5) diverse and dynamic environmental circumstances; 6) biosynthesis; 7) environmental stress; 8) innovation; 9) evolution; 10) adaptation; 11) preadaptation; 12) dispersal; 13) life's abundance; and 14) the environmental consequences of life's abundance. Starting with the phenomenal network, I drew borders around these groups. Then, with the application of a little artistic flair, an astonishing visage surfaced. Almost quite by accident, the provincial map for planetary biology theory assumed the shape of an odd trilobite – an eminently appropriate if whimsical icon for the inquiry of life on worlds.

According to the trilobite model, there are 14 different phenomenal zones. Below, I will present some explanation as to how each zone contributes to the world-shaping process. For easier comprehension, figure 3 presents the zones of the trilobite model in a conventional block-type flow diagram .

2.3 Planetary Surface Environment

The planetary surface environment includes the thin outer shell of the planet's hard body and all three-dimensional space outward from that shell. For example, Earth's planetary surface environment consists of the geologic crust, the hydrosphere (oceans), the surfaces of all dry land, and the atmosphere.



2.3.1 The planetary surface environment is directly influenced by:

1. Astronomical circumstances. The planet's primary star can influence the planetary surface environment by heating it, illuminating it, subjecting the planet to ever-increasing light and heat exposures, driving the weather system, influencing ocean tides, eroding its atmosphere, determining the orbital distance and orbital period of habitable planets, determining the overall time available for life to exist on the planet, and finally engulfing the planet as the star goes red giant.
2. Planetary orbital properties. The way a planet spins on its axis and orbits its star can influence the planetary surface environment by influencing the day length, day/night temperature extremes, seasonal temperature extremes, the vigor of ocean currents and atmospheric winds, ocean tidal extremes (should a moon be present).
3. The geologic state of the planet. The geologic state of the planet influences the planetary surface environment by influencing the mix and mass of atmospheric gases, the vigor and longevity of volcanism, the surface temperature, the distribution and movement of continents and oceans, planetary albedo, the amount of territory eligible for life to occupy, the strength of the planet's magnetic field, and the strength of the planet's surface gravity.
4. The environmental consequences of life's abundance. The environmental consequences of life's abundance influences the planetary surface environment by influencing the mix and mass of atmospheric gases, oceanic and continental cloud formation, rock weathering rates, planetary albedo, surface temperature, planetary water conservation, and ultraviolet radiation exposure.

2.3.2 The planetary surface environment directly influences:

1. The diverse and dynamic environmental circumstances that living things experience. The planetary surface environment directly influences the diverse and dynamic environmental circumstances that living things experience by representing the mix of physical factors that living things experience in any given territory that living things might occupy.

We will pay close and constant attention to the planetary surface environment. This is a dynamic and vulnerable place where many things are happening. Basically, the planetary surface environment is the boundary layer where so many powerful forces collide and express themselves. On Earth, the planetary surface environment is warped by moving continents and irradiated by the sun. The planet's orbital motions determine how the surface environment will be periodically heated and chilled. It is swept by atmospheric storms and stirred by ocean currents. In addition to being a changeable place, the planetary surface environment is the realm of greatest opportunity. Living things can have simultaneous access to the surface water, crustal minerals, atmospheric gases, and the sun. If ever there was a dynamic place of diverse and frequent opportunity, it is a planet's surface environment.

We are also interested in the planetary surface environment for purely selfish reasons. It is the realm that is most inherently interesting to us. Given a choice of exploring Mars or Pluto, most of us would choose Mars. Of all the other planets in our solar system, Mars is most like our own – mostly because of its surface environment. This may be chauvinistic but so what!? One of the main driving forces behind our space explorations is to seek out worlds like our own. That one tantalizing prospect beckons us into our extended environment more than any other reason.

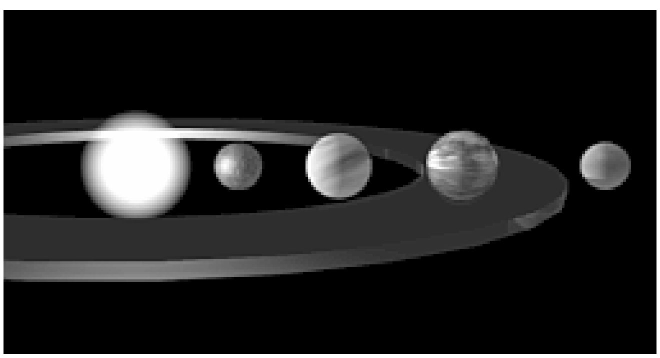
And finally, planetary biology theory is not interested in subterranean life. Not to say the subterranean life is uninteresting. It's just that planetary biology theory assumes that the underworld presents fewer opportunities for life to accumulate sufficient mass and vigor to cause planet-wide environmental changes. I hope that we later discover how wrong this assumption is. But for now, the place of greatest interest is the planetary surface.

Regarding other biases, planetary biology theory primarily, if not exclusively worries about life on terrestrial type worlds. That is, rocky planets like Earth, Mercury, Mars and the Moon. For now the theory ignores gaseous type planets like Jupiter and Saturn.

Chapter 2 discusses issues regarding the planetary surface environment in greater detail.

2.4 Astronomical Circumstances

This phenomenal zone focuses on the influence of a planet's primary star. For example our sun is Earth's primary star. Although about half of the stars in the Milky Way Galaxy are part of binary systems (two stars orbiting each other), the huge complexity of planetary orbital motions around binary stars is beyond the scope of the current version of planetary biology theory. So, we will consider planets orbiting single stars.



2.4.1 Astronomical circumstances are directly influenced by:

1. Nothing that the theory of planetary biology is concerned with.

2.4.2 Astronomical circumstances directly influence:

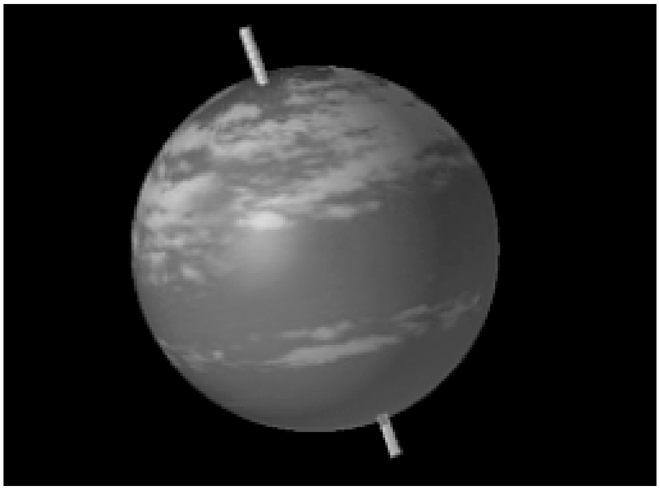
1. The planetary surface environment. The planet's primary star can influence the planetary surface environment by heating it, illuminating it, subjecting the planet to ever-increasing light and heat exposures, driving the weather system, influencing ocean tides, eroding its atmosphere, determining the orbital distance and orbital period of habitable planets, determining the overall time available for life to exist on the planet, and finally engulfing the planet as the star goes red giant.

Stars come in different sizes. Large stars tend to burn bright and hot. Small stars tend to burn dimmer and cooler. That means the habitable zone for a large star will be farther from the star than the habitable zone for a small star. A planet orbiting in the habitable zone for a large star would have a larger orbit. The larger orbit translates into a longer year, and perhaps less protection from asteroid and comet impacts. Larger stars also burn out faster than small stars. That means if life gets started on a world orbiting a big bright star, its window of opportunity will be short. This will be further exacerbated by the occurrence of fewer seasonal cycles per unit time and by more cataclysmic interruptions by falling asteroids and comets.

Chapter 3 considers astronomical circumstances in greater detail.

2.5 Planetary Orbital Properties

Planets don't just sit in space. They move in a variety of different ways. And those movements can have profound impacts on the surface environment. For example, if a planet has an extremely eccentric orbit, this could cause big temperature differences at different stages of its orbit – different times of year. Another way to get a seasonal temperature difference is to tilt the planet on its axis. That's mainly why Earth has seasons.



2.5.1 Planetary orbital properties are directly influenced by:

1. Nothing that the theory of planetary biology is concerned with.

2.5.1 Planetary orbital properties directly influence:

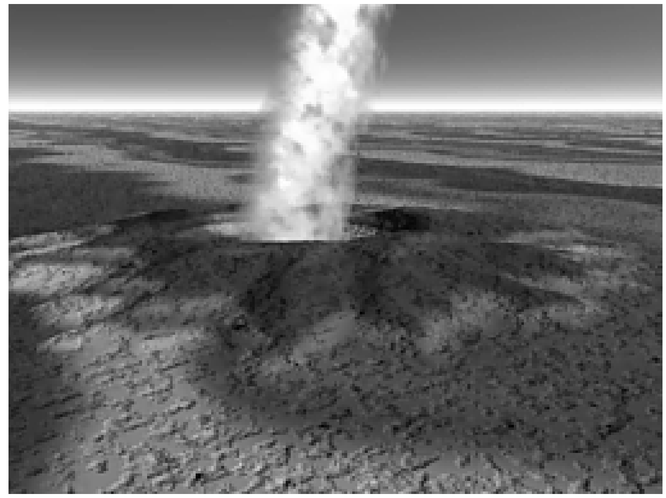
1. The planetary surface environment. The way a planet spins on its axis and orbits its star can influence the planetary surface environment by influencing the day length, day/night temperature extremes, seasonal temperature extremes, the vigor of ocean currents and atmospheric winds, ocean tidal extremes (should a moon be present).

If the planet rotates quickly, day and night temperatures will be similar. If the planet rotates very slowly, night will tend to be really cold and day really hot. Moons of sufficient mass could eventually lock the planet's rotational period to match the moon's orbital period. Think what Earth would be like with a 680-hour day.

Learn more about the significance of planetary orbital properties in chapter 4.

2.6 Geologic State of the Planet

This phenomenal zone describes how the intrinsic geologic properties of the planet influence the planetary surface environment. I consider such factors as the overall mass of the planet, the mass of the oceans, and the ocean-to-continent ratio of coverage. For instance, the mass of the planet can influence the vitality and longevity of the planet's internal heat engine – the churning caldron of metal and hot rock that makes up the planet's core and mantel.



2.6.1 The geologic state of the planet is directly influenced by:

1. Nothing that the theory of planetary biology is concerned with.

2.6.2 The geologic state of the planet directly influences:

1. The planetary surface environment. The geologic state of the planet influences the planetary surface environment by influencing the mix and mass of atmospheric gases, the vigor and longevity of volcanism, the surface temperature, the distribution and movement of continents and oceans, planetary albedo, the amount of territory eligible for life to occupy, the strength of the planet's magnetic field, and the strength of the planet's surface gravity.

An active internal heat engine can stimulate the formation of volcanoes that spew out and replenish atmospheric gases. It can move crustal plates by pushing them up and down (changing the global topography) or escorting them around the outer shell of the lithosphere (plate tectonics). An active crust can recycle atmospheric gases that previously had been pulled out of the atmosphere by life and buried in the rocks.

A planet's geologic endowment can help maintain a planet's atmosphere in a couple of other ways too. A massive planet will have strong gravity that will tend cling to atmospheric gases that would otherwise drift off into space. Smaller planets will be less successful in supporting a thick atmosphere. And if the core spins vigorously enough, it will generate a strong magnetic field that will reach thousands of miles into space. A strong planetary magnetic field will divert the stellar wind that would otherwise erode the atmosphere and blow it into space. The magnetic field also will recapture atmospheric gases split apart by the stars strong radiation.

Chapter 5 presents more details on the importance of the geologic state of the planet.

2.7 Diverse and Dynamic Environmental Circumstances

All of the physical and biological forces that shape the planetary surface environment may be well and good, but how do individual living things experience their surroundings? What is the nature of the circumstance that the planetary surface environment presents to living things? To living things, the environment is two things: a resource for the things they need; and 2) a source of stress should the resources be in short supply or should they themselves be considered a resource for some *other* living thing.

2.7.1 Diverse and dynamic environmental circumstances are directly influenced by:

1. The results of an individual's dispersal. When an individual disperses to another geographic region, the individual will be exposed to a new and different mix of physical and biological circumstances. This could include new and different kinds of food resources, predators, parasites and diseases, as well as a physical environment with unique climate, topography and soils.
2. The planetary surface environment. The planetary surface environment directly influences the diverse and dynamic environmental circumstances that living things experience by representing the mix of physical factors that living things experience in any given territory that living things might occupy.

2.7.2 Diverse and dynamic environmental circumstances directly influence:

1. Environmental stress. Diverse and dynamic environmental circumstances essentially represent the situation that living things are obliged to cope with. Since life is an inherently needy state of being, an environment that is diverse and dynamic will present living things with a non-constant set of circumstances and a non-constant set of challenges or stresses – that living things must overcome in order to fulfill their biosynthetic needs.

It is important to consider to what degree the environment is a diverse and/or a dynamic entity. The reason has to do with my interest in making predictions about the evolution of life on the planet. The nature of the environmental circumstance can have a big impact on how life evolves and intensifies on a world.

For example, let's consider a world in which the living things are presented with an environment that is uniform all over and never changing. If life is possible at one location, then life is possible everywhere. In such a situation, life will quickly colonize the planet. But how intense will life's occupation be? And how might life evolve under such circumstances?

On world in which the environmental circumstances are uniform and constant, there is virtually no opportunity. And that can slow down evolutionary change. If there are fewer toeholds for innovations to exploit, then life will remain flat and weak, and its planet uninteresting.

On the other hand, when life is confronted with a circumstance of a diverse and dynamic environment, there is no end of opportunity. A certain measure of chageability presents opportunities for innovations. Each new circumstance represents a new opportunity and each new opportunity gives new innovations a chance to express themselves. On such worlds, the pace of evolution should go a bit faster.

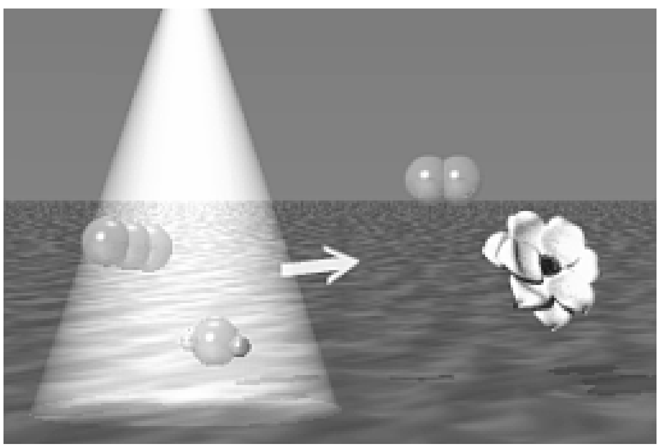
Dynamic physical factors (like the astronomical circumstances, orbital characteristics and the planet's geologic state) contribute to making a living thing's environmental circumstances diverse and dynamic. It gets really interesting when we consider that life itself can change environmental circumstances. Life can do this individually by virtue of individuals dispersing to new and different territories. There they will experience a new and different environmental circumstance. Or, life can do it collectively by changing the planetary surface environment as a consequence of life's global activities.

In any case, the environment is a constantly changing entity. It is never the same from moment-to-moment. True, there are cycles like our days and years. But despite these cycles, no day has ever been nor will it ever be exactly like another. While you are reading this sentence, your environmental circumstances have just changed. Now, how will you cope with it?

Learn more about the significance of diverse and dynamic environmental circumstance in chapter ?

2.8 Biosynthesis

The phenomenon of biosynthesis refers to the collective biochemistry of life that is engaged in building useful molecules. Biosynthesis represents the fundamental essence of life. Biosynthesis lays down the basic pattern of activity for life, which has become fractally copied on larger and larger sales. Referred to above as part of life's biosynthetic toolbox, biosynthesis represents life's mix of chemically-based planet-changing capabilities. Biosynthetic chemistry exploits the planetary surface environment as a source of energy and raw materials.



2.8.1 Biosynthesis is directly influenced by:

1. The global abundance of life. In this case, the level of quantitative biosynthetic activity is a function of the mass of life. Biosynthetic churning of the planetary surface environment will be more vigorous on a planet fully colonized compared to a planet on which life is rare.
2. Environmental stress. Environmental stress can hamper the success of biosynthetic chemistry mostly as a consequence of physical environmental stresses. This can take the form of materials shortages, or environmental harshness including dryness, too hot, too cold, too salty, too windy, and too much ultraviolet radiation.

2.8.2 Biosynthesis directly influences:

1. Innovation. Innovation is a consequence of the introduction of errors or other anomalies in the deep biosynthetic processes that make DNA. Therefore, the frequencies in which innovations appear are a function of the number of instantiations of DNA production per unit time. In other words, as the abundance of life increases, the opportunities for introducing innovations increase.
2. Environmental stress. Biosynthesis contributes to environmental stress mainly because it is an inherently demanding process. That is, biosynthesis creates a state of biological hunger within living things. Hunger is a stressful phenomenon. The degree to which the individual experiences this stress depends upon how easy or hard it is to satisfy the hunger.
3. Environmental consequences of life's abundance. Biosynthesis. Normally, biosynthetic chemistry perfectly recycles the materials it consumes from the planetary surface environment. If allowed to proceed unhampered, biosynthetic chemistry might only cause mild environmental consequences to the planetary surface environment. If this recycling gets interrupted, the result will be a net movement of materials from one environmental realm of the planet to another. Biosynthesis contributes to the environmental consequences of life's abundance as a result of the interruption of biosynthetic recycling due to the construction of the standing crop of living things and as a result of the burial of biosynthetic products – namely the bodies and wastes from living things.

I am interested in biosynthesis primarily because it gives life the potential to change the planetary surface environment and, therefore, the environmental circumstance that living things are obliged to experience. This ability gives life the potential to install interesting feedback loops.

Planetary biology theory reorganizes traditional biochemistry topics into three categories that are more relevant to the study of life's chemistry from a planetary perspective. They are: 1) contact biosynthesis; 2) intermediate pool; and 3) deep biosynthesis.

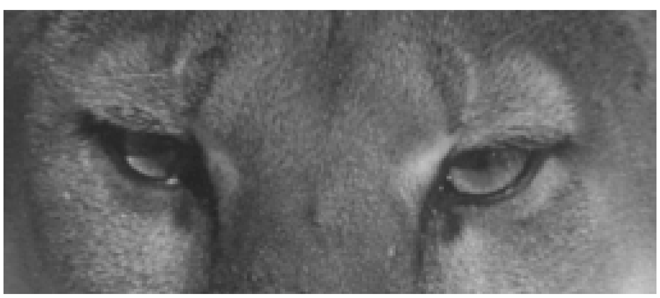
First, I am most interested in the individual chemical processes that actually exchange materials with the physical environment. It turns out that, relative to the planetary environment, biosynthesis happens on several levels. 'Contact biosynthesis' is that collection of familiar biochemical processes that includes photosynthesis, nitrogen fixation and respiration. Collectively, contact biosynthetic processes perform the three following services for life: 1) carbon fixation; 2) nitrogen fixation; and 3) energy extraction. In order to perform these three services, contact biosynthesis exchanges compounds of carbon, nitrogen, oxygen and sulfur with the surrounding environment. When present in abundance, it is contact biosynthesis that can change a world.

The products of contact biosynthesis are fed into a hypothetical 'intermediate pool'. The materials in the intermediate pool then are available for other contact biosynthetic processes, or they are fed downstream to the ultimate point of biosynthesis, 'deep biosynthesis.'

Deep biosynthesis includes processes that assemble the really big molecules of life, including polysaccharides, proteins, fats, nucleic acids and hordes of large specialty molecules like pigments and certain hormones. It is these products of deep biosynthesis that living things are striving to assemble. One very important product of deep biosynthesis is the DNA molecule. DNA is the primary structure for information storage and the main vehicle for innovations so important in the evolution of life.

2.9 Environmental Stress

Environmental stress could be just about anything that inhibits or stops the normal biochemical or behavioral conduct of a living thing – including reproduction and day-to-day living. The origins of stress can come from the planetary surface environment or from living things themselves. Stress can occur on all size scales. It can result from the inhibition of molecular biosynthetic activity or the blockage of herds of migrating wildebeests.



2.9.1 Environmental stress is directly influenced by:

1. Diverse and dynamic environmental circumstances. Individuals will encounter diverse and dynamic environmental circumstances in a combination of ways: 1) They will experience changes or diversity in the environmental circumstances of their established territory; and 2) They will experience changes or diversity in environmental circumstances in the new and different surroundings that dispersing individuals encounter after arriving at their destination.
2. Biosynthesis. Biosynthetic demand is a major source of environmental stress. To one individual, stress can come in the form of its own unsatisfied and urgent internal biosynthetic hunger. Or that individual could experience stress as a consequence of the competitive, predatory or parasitic efforts by other individuals.

2.9.2 Environmental stress directly influences:

1. Dispersal. Environmental stress at home can justify efforts to disperse into new frontiers. Stress can provide sufficient incentive for individuals to become pioneers.
2. Evolution by natural selection. Environmental stress supports the phenomenon of Evolution by natural selection. Evolution by natural selection basically is a phenomenon that results when innovative traits experience environmental stress.
3. Biosynthesis. In the end, biosynthesis is a chemical phenomenon. Biosynthesis is utterly dependent upon and, therefore, vulnerable to the circumstances in its surrounding environment. For example, extreme cold or extreme heat will represent harsh environmental stresses to this biochemistry. The imposition of environmental stresses upon biosynthesis could slow down or stop the processes temporarily. Or, certain extreme environmental stresses could disrupt and destroy the physical infrastructure that make biosynthesis happen (such as the molecules themselves or the cell's physical parts).

2.10 Innovation

Innovation is the phenomenon in which something new is introduced into the world. I focus on innovative traits. A trait is one feature of many that make up individual living things. Examples of traits include: the shape and flexibility of the lens inside your eye, your body height, and the curliness of your hair. An innovation can manifest itself as a modification of an existing trait, or perhaps a new trait altogether.

The introduction of newness can be beneficial to any entity that is trying to 'be' while confronted with stressful and changing environmental circumstances.

On a nuts and bolts level, the innovations I am talking about mainly are of a genetic nature. Generally speaking, a gene is a section of DNA that carries information. This genetic information codes for a certain trait. Individuals are made up of thousands of traits. And each trait may occur in many different variants.

For example, your particular skin color is because you possess a certain mix of different varieties of skin color genes. Your neighbor has a different mix of skin color genes and different skin color.

It is a bit more complicated than this but during the reproductive event, innovative genes are produced and introduced into the world. Innovative genes are random experiments that life introduces to each new generation. It is an extremely wasteful and carnal phenomenon because most innovations are either harmful or just plain useless. Despite the heavy losses, life can have a certain success with this method. This is because out of the millions of useless innovations produced in a generation, there may be one or two good ones. Life on Earth has prospered despite such extremely thin profit margins.

Still, the odds favoring innovations can improve dramatically if the innovations enter a world in which the environmental circumstances are diverse and dynamic. A diverse and changing environment may represent *stress* to the existing population of living things, but it also represents *opportunity* to newcomers. In this way, innovations help life cope and exploit a changing world environment.

2.10.1 Innovation is directly influenced by:

1. Biosynthesis. Genes are the primary vehicles of innovation. The strands of DNA that make up the gene are products of deep biosynthesis. This being the case, then if biosynthesis is abundant and vigorous, the quantity of innovations should be high. If biosynthesis is lethargic and rare, the quantity of innovations will be low.

> Another way to think about this is that as life becomes more abundant, its ability to produce innovations increases. On the other hand, if for some reason, the environment is so stressful as to inhibit biosynthesis, then innovation output will be low.

2.10.2 Innovation directly influences:

1. Evolution by natural selection

As we will see below, evolution by natural selection is a phenomenon that is driven by: 1) environmental stress; and 2) innovation. Innovation's contribution to the phenomenon of evolution is a steady stream new variants that are 'tested' by the mix of stresses presented to them in their particular environmental circumstance.

2.11 Evolution by Natural Selection

The theory of evolution by natural selection simply is a way to consolidate certain genetic and ecological knowledge to help us understand two phenomena: 1) the origin of new species; and 2) the origin of adaptations.

Planetary biology theory is interested in how life can colonize a diverse world. The best explanation so far is that life has developed special adaptations that help individuals cope with the world's different kinds of environments. Planetary biology theory recognizes that evolution can happen in a variety of ways – most of which will not lead to adaptations. Only one kind of evolution will – evolution by natural selection.

In short, the phenomenon of evolution by natural selection is a consequence of the phenomena of innovation and environmental stress. During the reproductive event, innovative genes are introduced into the next generation. The individuals that possess those genes then must cope with the environmental stresses that prevail at the time. If the innovative gene helps to reduce environmental stress, it has a greater chance of being passed on to the following generation, where it will be tested again. If an innovative gene gets passed on to the next generation, then an instance of evolution by natural selection has just happened.

Innovations that help reduce environmental stress, in the individuals of which the genes are a part, are adaptations. More below about adaptations and how they assist in the dispersal and intensification of life on a world.

2.11.1 Evolution by natural selection is directly influenced by:

1. <u>Innovation.</u> Evolution by natural selection cannot happen if there is no innovation. Genetic innovations are the newcomers that are tested in the stressful environment of everyday life. Every innovation gets its chance. But, like fresh slaves fighting for their freedom in the ancient Roman coliseum, most innovations are no match for the seasoned gladiators who regularly do battle their. But occasionally, a newcomer survives at the expense of a veteran warrior. And as a result, the show is elevated to a more vigorous level.
2. <u>Environmental stress.</u> The planetary surface environment presents living things with a mix of diverse and dynamic circumstances. Depending upon their particular and unique genetic makeup, each individual living thing will experience a given set of environmental circumstances as a unique mix of environmental stresses. Different individuals will experience the same environmental circumstance in unique ways. As a result, some individuals will be better able to cope with these stresses better than will others.

2.11.2 Evolution by natural selection directly influences:

1. Adaptations. Adaptations are the outcome of evolution by natural selection. Successive rounds of evolution by natural selection may continue to shape and refine an adaptation, making it more sophisticated, more appropriate to the ambient environmental circumstances and more effective.

2.12 Adaptation

When we think about all of the wonderful and amazing creatures that inhabit this world, we are unwittingly paying tribute to life's diversity of adaptations. In general, any feature that is shaped by the phenomenon of evolution by natural selection can be classified as an adaptation. [NOTE: For now, I am ignoring sexual adaptations, produced by evolution by sexual selection.] Adaptations come in all sizes and modes.

For example, on the molecular level, the pigment, melanin, protects the skin of humans and other creatures from the harmful effects of ultraviolet radiation. Contractile proteins band together to make powerful moving muscles. Potato plants make biologically active molecules that are poisonous to would-be predators. And the carrot survives cold winters in dormancy by storing energy-filled carbohydrates in its root.

Still on the molecular level, DNA is probably the most remarkable molecular adaptation of all. It stores coded information that can be used as a set of instructions for the construction, operation, and maintenance of a whole organism. It is able to do this in a dense format that is smaller than the point of a pin. And the structure of the DNA molecule also makes it easy to copy this information with digital fidelity millions and millions of times.

Adaptations also can appear on larger structural levels. For instance, the anatomy of a bird's wing, or a bird's eye, for that matter, are examples of adaptations. Behavior also can be an adaptation. When the swallows return to Capistrano, it is not at the behest of Father Juniperro Serra's spirit. It is because these birds migrate annually between North America and South America – an adaptive behavior that ensures them the maximum exposure to spring time.

In summary, adaptations are the collection of molecular, physiological, cellular, anatomical, and behavioral features that help living things succeed in spite of the environmental stresses they may encounter during their lives.

2.12.1 Adaptation is directly influenced by:

1. Evolution by natural selection. As I have already discussed, adaptations are an outcome of evolution by natural selection. There is no other reasonable, scientific explanation for the origin of adaptations.

2.12.2 Adaptation directly influences:

1. The global abundance of life. Adaptations directly influence the global abundance of life by assisting in the intensification of life in an occupied territory. In a given territory, successive rounds of evolution by natural selection can refine adaptations to more thoroughly exploit the surrounding environment. Or new adaptations can emerge that can increase the penetration and vigor of life's exploits. For example, the development of root systems enable life to more aggressively exploit the soil resources of the continental interiors.

   Adaptations also indirectly assist in the global abundance of life by being the only source of preadaptations. More about preadaptations below.

2.13 Preadaptation

A feature that could be considered an adaptation in one territory quite accidentally might be useful in similar or different ways in a distant territory. (Distant territories will have different environmental circumstances). When this happens, biologists refer to the useful feature as a 'preadaptation.'

The idea of preadaptation is an interesting one because dispersing individuals have no way to anticipate, prepare for, or even determine what new territory they will end up pioneering. Pioneers bring with them only the adaptations grown in their home territory. As they settle new and distant places, pioneering individuals are exposed to great risks and uncertainty.

The diverse and dynamic environmental circumstances in the newly colonized territory will be different when compared to their home territory. Their chances of survival improve if the dispersers bring with them a collection of adaptations that have a measure of tolerance and versatility. That is, they will do better if their adaptive features can operate under widely different environmental circumstances, and/or if they can be put to use in a variety of ways that may be different from the primary function shaped in their home territory.

2.13.1 Preadaptations are directly influenced by:

1. Adaptations. Adaptations are the source of preadaptations. An adaptation ascends to preadaptation status if it helps the individual survive under new and different circumstances. The more adaptations there are, the more potential preadaptations there are. Also, as adaptations become more tolerant and more versatile, they also become better preadaptation candidates.

2.13.2 Preadaptations directly influence:

1. Dispersal. Dispersal is utterly dependent upon the successful transition of an individual's possessed features from 'adaptation' to 'preadaptation' status. If dispersing individuals cannot successfully bring their suite of adaptations to bear in their new destination, then they will die and dispersal will not happen.

2.14 Dispersal

Dispersal is the phenomenon in which individuals move away from the environment of their 'birth' and colonize new and different territories. Dispersal can happen in a variety of ways. Some dispersal is somewhat passive. For instance, in the sea, water currents will carry jellyfish thousands of miles. And the winds of the atmosphere will disperse spores, pollen, bacteria, seeds and tiny spiders to distant lands and different environmental circumstances. Even icebergs will carry transport loads of life from the icy poles and deposit them into warmer waters.

Some dispersal is more active, driven by biological forces. For example, bacteria can simply cell divide themselves into new territory. A tree root can do the same thing, growing by cell division into wetter and more fertile soil far away from tree center. Wandering animals can seek out new territory in an effort to escape the crowds, shortages, and predators at home. And along the way, they will unwittingly help to disperse the sperm (pollen) and embryos (seeds buried in fruit) of flowering plants.

2.14.1 Dispersal is directly influenced by:

1. Environmental stress. If the current circumstances of an individual's environment are particularly stressful, then there may be sufficient 'incentive' to try to escape from those stresses. Dispersal may not be the best solution for all kinds of environmental stress. But dispersal may be one of several options available to the individual. In any case, new territories may provide relief from the stresses at home. If they do, then the act of dispersal will be rewarded. If the new territory is more stressful than the home territory, then the act of dispersal will not solve the individual's dilemma of how to cope with environmental stress.
2. Preadaptations. Dispersal will have greater chances of success if the pioneering individuals possess adaptations that can help them survive under new and different environmental circumstances. That is, if their possessed features can successfully make the transition from 'adaptation' status to 'preadaptation' status. For example, a fox's coat of thick fur, useful primarily as insulation in northern forests might also serve as protection against the assault of stickers and thorns in the dry, hot chaparral scrub. Or, the ability for a desert cactus to store water for later use during the summer drought might find the ability to be useful on the sandy beaches of a tropical island.
3. Vigor of surface winds and ocean currents. Surface winds and ocean currents can rapidly carry dispersers away from their home environment and deposit them onto distant lands. Severe storms can even carry large birds away from their normal migratory paths. As a consequence, they are obliged to encounter and cope with new territories.

2.14.2 Dispersal directly influences:

1. The global abundance of life. Dispersal increases life's territorial coverage of the planet and, therefore the overall abundance of life.
2. Diverse and dynamic environmental circumstances. Dispersing individuals will unavoidably encounter new and different environmental circumstance in their destination territory. This experience will produce a cascade of new environmental stresses, new opportunities for innovation and evolution, new adaptations, and more pressure individuals of future generations to disperse still farther.

2.15 Global abundance of life

The global abundance of life increases as a function of two factors: 1) the proportion of the planetary surface occupied by life; and 2) the density of life in the territory it occupies.

As the global abundance of life increases, so does life's measure of environmental influence. But as we have already seen, planetary surface environments can present life with a formidable array of obstacles that can inhibit or prevent planetary colonization. Just because life might become established in some small spot on a planet, there is no guarantee it will successfully colonize the entire planet.

Are planets with uniform environments better candidates for abundant life than are planets with diverse and dynamic environments? It depends on how much time is available and how extreme the range of environmental conditions are. For example, planets with uniform environments may become 'instantly' colonized by the simple kinds of living things that start up there. But then what? There is no more territorial or environmental opportunity for new innovations to exploit. As a consequence, the products of evolution may be dull and uninventive.

Planetary biology theory predicts that over the long run, planets with diverse and dynamic surface environments will support a more robust evolution and a denser planetary colonization. Ironically, a certain mix of environmental hardships (by virtue of a diverse and dynamic environment) also provides an equal mix of opportunity for innovations.

Learn more about how this phenomenon works in chapter?

2.15.1 The global abundance of life is directly influenced by:

1. Dispersal. The consequence of dispersal is that it can increase the total planetary surface area that is occupied by life. All things being equal, this will result in an increase in the mass of life on the planetary surface.
2. Adaptations. The development of adaptations will help life to become denser in newly colonized territories. Adaptations are features that help individuals better exploit and survive in their environment. In new and sparsely populated frontiers, the pioneers could experience many new environmental stresses. But there will also be many new opportunities for many different kinds of new adaptations. Such territories support an evolutionary race in which the pioneering species have the ecological opportunity to invent and test new adaptations that will more fully exploit the newly acquired territory. As a consequence of these new adaptations, life will become denser.

2.15.2 The global abundance of life directly influences:

1. The environmental consequence of life's abundance. It is clear that the magnitude of life's influence on the planetary surface environment is dependent upon the degree to which life is present on the planet. The more life becomes present on a world, the more it becomes eligible to participate with ongoing physical processes in the planet's surface environment. As a consequence of its growing participation, life can begin to leave its imprint on the planetary surface environment.
2. Biosynthesis. As the quantity of living things increases, life gains more planet-changing 'horsepower'. As life becomes more present on a planet, the number of instances of biosynthesis will increase. Since biosynthetic chemistry exchanges materials with the surrounding environment, more instance of biosynthesis will churn more of the planetary environment.

2.16 The Environmental Consequences of Life's Abundance

The big question is, what are the consequences of life's occupation of a planet? The answer depends upon: 1) the nature of life's biosynthetic chemistry; 2) the overall abundance of life; and 3) the nature of the planetary surface environment.

Keep in mind that even if life is abundant and churning the surface environment like mad, its influence on the planetary surface environment could be negligible. This is because, on Earth at least, life's biosynthetic chemistry elegantly recycles the materials it consumes. Under ideal circumstances, life would cause no net movement of materials from one realm to another (except for the mass of materials tied up in the standing crop biomass). But if certain processes in the planetary surface environment interrupt life's perfect recycling scheme, then life could act as a *de facto* pump vigorously moving materials from one realm to another.

2.16.1 The environmental consequences of life's abundance is directly influenced by:

1. Biosynthesis. Life's main planet-changing potential resides in its diverse toolbox of biosynthetic processes. On Earth, biosynthetic processes move carbon, oxygen, hydrogen, nitrogen, sulfur, phosphorous and dozens more elements from one environmental realm to another – and back again. Biosynthesis is the animation of matter in very deliberate ways, which is the reduced essence of life itself.

So, with the advent of a diverse biosynthesis, life has the potential to set the planetary surface environment in motion – in very deliberate ways.

2. The global abundance of life. The instances of life's biosynthetic chemical activity increase as life becomes more abundant on a world. As life becomes more abundant, three main things happen: 1) the overall intensity of planetary churning increases; 2) the geographic distribution of planetary churning increases; and therefore 3) the opportunity increases for life to participate in the net movement of materials from one environmental realm to another.
3. The planetary surface environment. Without help from the planetary surface environment, life's overall impact on the planet could be limited and unremarkable – even if life was very abundant on a world. Ironically, the planetary surface environment can help life influence… the planetary surface environment.

Here is just one example. On the continents fixed carbon (the remains of once-living things – like leaves and sticks) gets washed into lakes where it fails to entirely decompose. The burial of fixed carbon is a phenomenon that happens as a consequence of the presence of fixed carbon (supplied by life) and the abundance of continental rainfall (provided by the planetary surface environment). As we will see below, this phenomenon can contribute to big changes in global climate.

Here is another example. Consider the proportion of the planet covered by continents. Then imagine that along the margins of continents living things are precipitating calcium carbonate washed in from the continents. In the long run, the precipitation of calcium carbonate can reduce atmospheric carbon dioxide.

2.16.2 The environmental consequences of life's abundance directly influences:

1. The planetary surface environment. Getting back to the example I started above. The consequence of the burial of fixed carbon is the net movement of carbon out of the atmosphere and into the crust. This reduces the concentration of atmospheric carbon (carbon dioxide). And since atmospheric carbon dioxide helps warm the planet, a reduction of atmospheric carbon dioxide could cause the planetary surface environment to become cooler.

Here lies the potential for a grand feedback loop. A cooler planetary surface environment presents new environmental circumstances to life such that life's abundance and/or photosynthetic vigor could drop. This would reduce the amount of carbon being fixed. In addition, cooler climates would reduce the vigor of continental groundwater pumping by forests, which could reduce the amount of continental cloud formation and rainfall. Reduced carbon fixation (by photosynthesis) and reduced continental rainfall would reduce the rate at which fixed carbon is buried, resulting in a slowing of the movement of carbon from the atmosphere to the crust. And the rate of planetary cooling would be slowed.

Now back to the calcium carbonate precipitation example. Let's compare two planets with the same continental areas, but with different configurations. Planet X has a single continent. Planet Y's continental area is fragmented into 10 different continents. All things being equal, Planet Y will suck down atmospheric carbon dioxide much faster than planet X because of it possess more continental margin area, and the calcium carbonate precipitating life that resides there.

These are just two examples of how planetary biology theory considers the impact of life on a world. Please note that I am not implying that life has ultimate control over the amount of carbon dioxide in the atmosphere. Physical processes such as rock weathering and volcanism also powerfully influence the abundance of atmospheric carbon. Also, not all of life's consequences would necessarily involve negative feedback loops (control mechanisms).

In any case, the most interesting aspect of the consequence of life's abundance is the large feedback loop between life and the planetary surface environment. To summarize, the planetary surface environment sets the physical stage, upon which life resides and to which life churns. Acting in collusion with the physical processes going on in the planetary surface environment, life's activities can produce net changes in the planetary surface environment, presenting life with a new set of circumstances to which it is obliged to cope. And the wheel turns round and round. This is an exciting and frustrating phenomenon to try to understand. Yet understanding the details of life's intimate relationship with the planet is what planetary biology theory is all about.