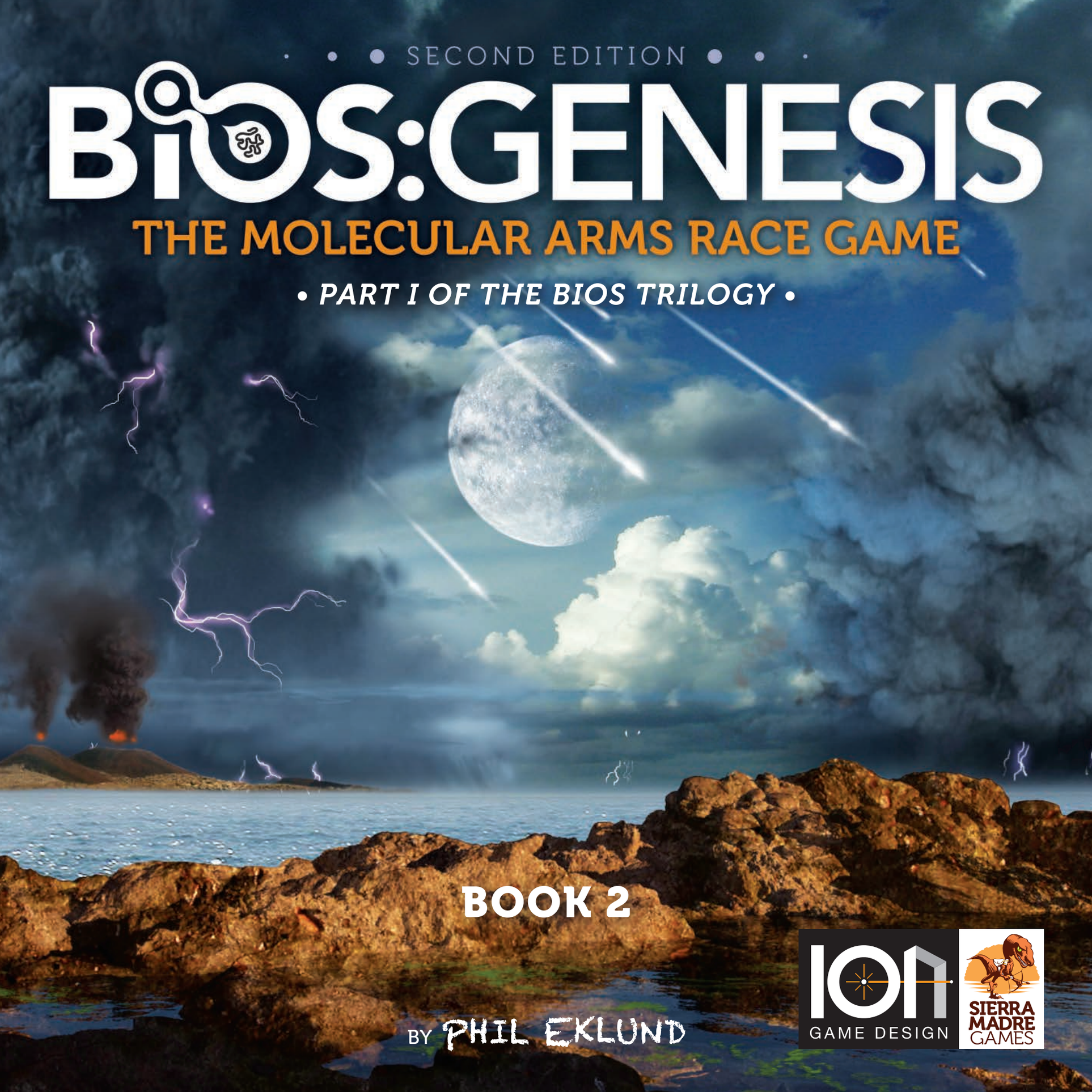
SECOND EDITION

BIOS:GENESIS

THE MOLECULAR ARMS RACE GAME

• PART I OF THE BIOS TRILOGY •



BOOK 2

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ION GAME DESIGN
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WHAT'S THIS GAME ABOUT?

One to four players start as organic compounds shortly after Earth's formation, represented by up to four **Biont** domes. The Amino Acids (**Player Red**) command Metabolism, the lipids (**Player Yellow**) create cells, the pigments (**Player Green**) control energy absorption and storage, and the nucleic acids (**Player Blue**) control templated replication.[1] Their goal is a double origin of life: first as **Autocatalytic Life** (a metabolic cycle reproducing its own constituents yet not replicating),[2] and the second as **Darwinian Life** (an Organism using a template to replicate in an RNA world). Warning, this is a brutal game of survival. The players may decide to cooperate rather than compete, see **C2**, for your first game the introductory variant may be of use see **C3**. A less brutal variant is found in **C4**.

The **Event Phase** starts the turn. Each event card encapsulates 200 million years, and the game may last 21 events (about 18 turns, the first 4 billion years of Earth's 4.6 billion year history). Each event depicts which **Landforms** (cosmic, ocean, coastal shelf, or continent) are **active** for the turn.

In the **Assignment Phase**, players attempt to create autocatalytic life by assigning one starting Biont to one of the **Refugia**, placards representing suitable hatcheries for life either on Earth or in space. These sites contain "building block" cubes called **Manna**, which reside in either disorganized (dead) or organized (metabolically-alive) populations. You may also assign a Biont to become a **Parasite**, if there are any **Hosts** available. To be suitable, a Host must have Mutations or Organs that you can invade as a **Disease**. If any of your Organisms has a **HGT** (horizontal gene transfer) Mutation, you may move your Bionts from one Microorganism to another. You always have at least one Biont available to assign to Refugia or to a Parasite, unless all of your Bionts are already employed inside Organisms.

In the **Autocatalytic Phase,** a roll is made for each Refugium which may move Manna from disorganized to organized, or vice versa. The number of dice rolled is equal to the number of organized Manna, plus two dice for each Biont, either friendly or enemy. If you roll doubles, you may flip the Refugium (placard) and move it, along with organized Manna, to start your **tableau**. This side of the card, called **Bacteria**, represents Darwinian Life. Bacteria and Parasites are collectively called **Microorganisms**.

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1 BIOS: GENESIS postulates an extensive pre-LUCA (Last Universal Common Ancestor) evolution of life, where four parallel lineages are represented by the four players. Although Player Blue is the only player starting with exacting replication with heredity and portable templates, all four undergo natural selection using reproduction, specificity, or immortality. To use a computer analogy, the metabolism, specificity, and energy is provided by the hardware, and the heredity is provided by the software. The hardware was already in place when the LUCA invented RNA, an upgrade which spread by HGT to all the other bits of hardware floating around. In other words, the LUCA did not supplant all the other life, but merely provided a software upgrade. In computers as in life, software is subservient to hardware. The LUCA reproduced by RNA, and so is simulated in the game with the first purchased mutation (unpromoted mutations are RNA-based). The first mutation promotion simulates the upgrade to DNA (promoted mutations are DNA-based).

2 REPLICATION is the ability of a molecule to make a copy of itself by a specific chemical process, with a specific margin of error. Modern biological replication uses the bases on a nucleic acid strand as a template to form a complementary base-paired strand, built from manna-like raw materials. Replication is <u>not</u> the same as reproduction. Replication ends up with two approximate equal-sized copies, while reproduction ends up with two "half-lings". Soap bubbles (and presumably the earliest protocells) can reproduce merely by being split into two halves, each daughter cell with part of the cellular constituents. But only molecules with templates can replicate.

Four critical life parameters are tracked by **Chromosome** cubes on your Microorganism or its Mutations:

1. **Metabolism (red)**: how well you manufacture Catalysts,
2. **Specificity (yellow):** the error rate of inappropriate Catalysts admitted into the cell,
3. **Entropy (green):** how many Bionts you can have assigned to Refugia, and
4. **Heredity (blue):** fidelity of templated transmission into daughter populations.

In the **Darwin Phase**, each of your Microorganisms makes a **Darwin Roll**, rolling a number of dice equal to the number of Chromosome cubes on it or on its Mutations plus two times the number of Biont domes. If your Heredity is not high enough to survive **Error Catastrophe**, your Microorganism suffers an **Atrophy** (Chromosome loss, see Glossary) for each excess error.

With a sufficiently good Metabolism, both the Autocatalytic and Darwin Rolls generates disks called **Catalysts**. In the Assignment Phase, spend these as **Enzymes** which helps organize more Manna for future Chromosomes in the **Autocatalytic Roll**. Catalysts are also used in the **Purchase Phase** to make one purchase for each Biont, which can be for a Mutation, Mutation promotion, Macroorganism upgrade, Red Queen, or Organ. A **Mutation** is a card placed in your tableau alongside a Microorganism, giving it Chromosomes and Abilities. Photoautotroph Mutations[3] add to your Entropy, but also **pollute** the air with oxygen. You will need **Antioxidants** to survive this **oxygen spike**. **Red Queen** acts against your Host or Parasite, making Chromosomes either Diseased or undiseased.

Each player maintains a tableau, and a pool of Catalysts tied to that tableau. Each Biont in an Organism, even ones belonging to other players (Parasites, **Foreign Genes**, and **Endosymbionts**), may make one expenditure per turn for that Organism, all using the same pool of Catalysts in the tableau that Organism resides in. If you produce Catalysts, these also go to the tableau pool the Organism reside in.

The game ends when the events run out, or Earth becomes uninhabitable (Armageddon). The winner is the player with the most number of cubes in his Organisms, plus Bionts of his color in play. If playing the <ADVANCED> game, each Macroorganism gets bonus VP according to how high it is in the food chain in both land and sea. Solitaire (**C1a**) and cooperative (**C2**) games have special victory conditions.

The **<ADVANCED> Game** introduces **Macroorganisms**, cards that elevate Bacteria from single cell to multi-cell which gives you VP. If the elevated Bacteria had Parasites or Foreign Genes, they now become **Endosymbionts**, hybridized to the Macroorganism and sharing equally its VP. The Endosymbionts and **Organs** also give the Macroorganism extra powers such as **shielding** from catastrophes. New Parasites can attach to

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3 AN AUTOTROPH is able to thrive from simple mineral nutrients, such as carbon dioxide, sulfate, or molecular nitrogen or nitrate. There are two types: **chemoautotrophs** use a mineral donor, while **photoautotrophs** use sunlight energy as the donor. Both types use energy provided by the transfer of electrons from their donor to either oxygen or a mineral acceptor. Supplying an electron to water obtains the hydrogen needed for photosynthesis (see footnote n.16). The first lifeforms were not autotrophs because they depended on manna for their energy. But autotrophy must have developed when the manna was all eaten up, for continued survival. Apologia: all the photosynthesis cycles in this game are assumed to use oxygen as an acceptor. However, only photosystem II, as used by cyanobacteria and green plants using chloroplasts derived from Endosymbiont cyanobacteria, actually exhale oxygen and could have caused the oxygen crisis.

a Macroorganism by infesting its Organs. Since Parasites don't share VP like Endosymbionts do, they should attach to a Bacterium BEFORE it becomes multicellular.

- **The Style Rule.** Terms being defined are listed in **bold**, or *italicized* if defined elsewhere. Capitalized terms are defined in the glossary.
- **The Golden Rule.** If the text on a card contradicts these rules, the card takes precedence.

J. EXTENDED 2-PLAYER EXAMPLE OF PLAY (updated by William Hutton)

J1. MARS PALEO-OCEAN EVENT : "Failure below and success above."

a. **Events.** The IDP (interplanetary dust particles) and DHB (deep hot biosphere)[4] appear from the heavens.

b. **Assignment.** Player Blue assigns to the IDP and spends her Catalyst as an Enzyme. Player Green assigns to the DHB spending his Catalyst to the soup to get in.[5]

***Note**: For simplicity, this example assumes players have 3 instead of 4 bionts.*

***Phirax Tips:** There are two reasons to assign to refugia: (1) create life, or (2) generate catalysts (money). If you wish (1), make sure that if your opponent decides to contest the card, that you will be the progenote, not him. To resolve a progenote contest, count the number of bionts, organized manna, and enzymes of each player's color on the card. The player with the most is the progenote, who gets to roll the dice and make all the decisions for that refugium during the autocatalytic phase. If there is a tie, resolve it by looking at the colors printed on the disorganized side, with the leftmost color winning the tiebreaker. Remember, it is the printed colors you are looking at — the big and little squares, from left to right — ignoring any cubes on the disorganized field. Since it's early in the game, I (Player Blue) went for (2) by placing in the IDP and investing a blue enzyme for the future. The dilemma for Green: should he contest the IDP, or go alone to the DHB? He makes an error by opting for the latter. If he had contested the IDP, as long as he did not invest his green enzyme, he would not have been the progenote, and would have made money (2) at my expense instead of breaking even.*

c. **Autocatalytic Rolls.** Player order for Autocatalytic Rolls is top-down, then left-right. Since both cards are in the same row we look from left to right and see that Blue rolls first (the IDP is to the left of the DHB). Blue rolls (3,4), which in the cold climate animates two

4 DHB. The deep hot biosphere is so alien and immune to surface events that I count it as cosmic, even though it is not.

5 THE CONCEPT OF SOUP as a static bowl of ingredients has been criticized by Wächterhäuser since life needs a continuous flow to deliver carbon and empty the garbage. These functions are provided by Player Yellow, and failing that one needs an external flow (such as in hydrothermal or geothermal vents).

Manna, then kills off one of them. She decides to animate two yellow and then kill off one of them, receiving a yellow Catalyst for the Biosynthesis. Finally, the 4 causes Enzyme death which sends the blue Enzyme to the soup. Green rolls (3,5), which kills off his Biont. He gains a green Catalyst in compensation, but ends the turn exactly as he started it.

Phirax Tips: *If I hadn't spent a catalyst to block the first enzyme, I would have disorganized two manna instead of one. Green hoped for 1s and 2s and no 5s or 6s so that he can organize some manna for a long term investment in the DHB. But she fails.*

J2. THEIA BIG WHACK + METEORIC ACCRETION : "Life created on postapocalyptic Earth."

a. **Events.** The Theia Big Whack events have no effect, because the cosmic Refugia are immune to smite and neither player has any lifeforms. The Mars paleo-ocean and green rust fumarole appear from the heavens.

Phirax Tips: *The IDP and the DHB are two of only three refugia immune to "smite" events that remove manna cubes from refugia. This durability allows you to patiently invest in them (for the whole game, if necessary) before taking them flipped into your tableau as an organism.*

b. **Assignment.** Green assigns to the fumarole and Blue reassigns from the IDP to the Mars ocean. The reassignment is legal because the Cosmos is active.

c. **Autocatalytic Rolls.** Blue rolls doubles (4,4), which animates two Manna and then kills both, generating two Catalysts (blue & green). Blue declines to create martian life. Green also rolls doubles (2,2) which animates two Manna (blue & yellow). He decides to create amyloid hydrolysis Bacteria with three Chromosomes; green (Biont), blue, and yellow.

Phirax Tips: *Green has a big advantage in starting any kind of life, even doomed life, because as long as it survives, its green Chromosome allows him to assign two Bionts to Refugia, doubling his presence.*

d. **Darwin Roll.** Green's amyloid-life rolls four Darwin dice (1,3,4,6) and survive. Lacking Metabolism or the possibility of triples, there is no profit in re-rolling a single dice.

J3. TROPICAL WATERWORLD (1ST ARCHEAN CARD) : "For dust thou art, and unto dust shalt thou return."

a. **Events.** None.

b. **Assignment.** Thanks to the Entropy (green Chromosome) of his Bacteria, Green can assign two Bionts. Unfortunately, he has nowhere to assign, because his home row (ocean) has no Refugia, and the cosmic row is now inactive. But the cosmic Refugia remain open to Blue, who still has a Biont on Mars. She decides to remain there, investing a yellow Enzyme.

Phirax Tips: *The Hadean is over Igor, time to create life! Because I have a monopoly to access in space, I don't have to worry about Green contesting me there. Mars is a reasonable choice, with an assortment of all four colors of manna, and a favorable life-to-death ratio with modest investment. The Martian ocean won't last forever, but the first manna to go will be blue, the one I need the least (since I am Player Blue).*

c. **Autocatalytic Roll.** Blue rolls (1,4), organizing the first Manna (green & yellow) for her martian protolife.

d. **Darwin Roll and Purchases.** Green rolls (2,2,4,5), so amyloid-life treads water in the ocean. Green only has one Catalyst (green), but there are no green Mutations available for purchase.

J4. LATE HEAVY BOMBARDMENT + SUPERCONTINENT UR : "Life on Mars".[6]

a. **Events.** The aftershock ends a very short waterworld. The cratering event slams a double Atrophy on the unshielded amyloid-life, and it loses two Chromosomes (blue & yellow). Only its green Biont remains, but as long as it lives, it will give Green a strong double Biont presence in the Refugia. The UV events cause no harm since nothing has any Mutations yet.[7] The warm pond and tholin storm clouds appear on the earth.

b. **Assignment.** Green sends both unassigned Bionts to the newly created warm pond. Blue patiently stays on Mars.

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6 PANSPERMIA: The idea that organic material or life itself could have seeded the Earth from outer space. Sources include interplanetary dust, Mars, or even (following the ideas of Jack Green) lunar tidal fumaroles. This idea remains popular because it explains how terrestrial life appeared just one turn after the late heavy bombardment, practically as soon as it possibly could appear. Studies have shown that organics and extremophile organisms deep in a meteorite stay cool and can survive the transit, shock, and atmospheric entry to Earth. Amino acids, nucleobases, and PAHs have been discovered in the Murchison meteorite. A meteorite blasted off Mars, called ALH84001, contains structures speculatively interpreted as nanobacteria. Phosphorus, a bottleneck element for ATP and nucleotides but not present in the oceans because of its insolubility, could have been made available to the organic soup by the meteoric compound schreibersite. Interstellar dust consists of a large component of organic molecules.

7 LHB. When the Apollo moon rocks were dated, they all clustered in age from 4.1 to 3.8 Ga. Nobody expected this. There are so many craters on Luna that everyone figured it must have occurred over billions of years, not just 1.5 game turns! This brief carpet bombing of Luna implies what is called the Late Heavy Bombardment (LHB), when the Earth as well would have suffered a mega-dinosaur stomper every century. According to the Nice model, the cause of the LHB is the orbital migration of the gas giants and the ensuing perturbation of the young asteroid belt. The first fossils (from the Apex Chert of Australia) are filamentous forms dated at 3.5 Ga. (Older chemical signs of life at 3.85 Ga in Greenland have been discredited by 21st century re-evaluation.) It seems that protolife exhibiting both cellular (yellow) and metabolic (red) properties had appeared just two turns after being carpet bombed by the LHB. Was life widespread before the LHB (no Earth rocks have been discovered of this age)? Then was it driven down into the DHB or blasted into the IDP by the LHB? Or into hydrothermal vents deep in the acidic oceans? Or did the LHB somehow create life?

c. **Autocatalytic Rolls.** Blue rolls (1, 2, 2, 3) and creates promising sugar-driven life on Mars, with one Chromosome of every color plus a blue Biont. Green rolls (5,5,6,6). Fortunately the warm pond is a green placard, allowing him a re-roll (2,4,6,6). This is a much better roll with doubles, but it kills off three Manna, including one of his Bionts. He decides against creating life. Green gains three Catalysts (blue, green, & red).

d. **Darwin Roll.** Green's amyloid-life is on the edge of extinction, but survives another 200M years. Blue's Mars-Bug does fine, but fails to metabolize any Catalysts, even with a Specificity re-roll.

e. **Purchases.** Green finally has several Catalysts, but the only Mutations available would make his marginal life even less viable. Blue also declines to purchase anything.

J5. CLATHRATE GUN : "A tale of two oceans and two planets."

a. **Events.** The smite flushes the blue Manna from the warm pond and a yellow Manna from the tholin storm clouds. Green swears next time he will animate a more rugged Refugium. Both Organisms have oxygen protection against the O_2 event. Geothermal zinc appears in the continent row.

b. **Assignment.** Blue assigns both unassigned Bionts to the warm pond. Green assigns a Biont to the geothermal zinc. The other Biont remains in the warm pond.

c. **Autocatalytic Rolls.** Despite rolling 6 dice, blue fails to create life in the warm pond. Green rolls well in the geothermal zinc (2,2) and creates PNA-based Bacteria with two green and one blue Chromosome.

d. **Darwin Roll.** Blue's Mars-Bug rolls (1,2,3,4,4,6), finally generating a Catalyst (red). Green's Organisms remain unchanged.

e. **Purchases.** Blue buys the tmRNA Mutation for its Red Queen Ability. This pollutes Mars with hydrogen sulfide, but nobody cares what it smells like on Mars.[8] Green purchases the RNA Ribozyme Mutation for his PNA Bacteria.

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8 SOFTWARE UPGRADE HYPOTHESIS. Are you old enough to remember the Betamax versus VHS wars? (If not, google "Videotape format war"). By the 1990's, almost all the videotape hardware produced was using the VHS format. Fast backward 7000 years, when the Linearbandkeramik culture of central Europe acquired agriculture, along with set of unique tools and pottery. How did this happen? Did a culture of technologically superior humans invade and take over? Or did a villager marry a foreign daughter, who came with knowhow and some seeds? Archeologists can't decide. Fast backward 3 billion years, the time of LUCA. According to Cairns-Smith, this "genetic takeover" occurred when a cell, containing encapsulated clay crystals, discovered that RNA makes a much better template than clay. The simplest explanation is that then the superior RNA lifeform then ate its clay-based competition out of existence. But stubbornly I cling to a Betamax vs. VHS scenario, whereby the hardware stayed the same, but the superior software was adopted. To envision this, suppose the new RNA replicator spammed the ocean with encapsulated RNA. (A gross simplification, for reasons mentioned in footnote 5, RNA is so fickle that a lot of protein-like baggage will be necessary). Suppose this replicator never

J6. HURONIAN SNOWBALL : "The amyloid pioneer falls."

a. **Events.** Again, all lifeforms have protection against the O_2 event. The hydrogen volcano and eutectic brine continent Refugia appear on earth.

b. **Assignment.** Green is first and reassigns his Biont in the warm pond to the fresh brine. Blue sends both Bionts to the IDP.

c. **Autocatalytic Rolls.** Blue animates two Manna, then loses two Manna, gaining two Catalysts (green & yellow); lamenting that she did not invest any Enzymes (that could have resulted in a great Darwin startup). As it is, she sits in the dust another turn.

d. **Darwin Roll.** Green rolls poorly (5,6), finally losing his amyloid-life (but is compensated a green disk). His PNA life loses its only Mutation.

e. **Purchases.** Blue promotes her Mutation to helicase by spending two green Catalysts using the chemoselectivity rule. Green has three Catalysts (2 green & 1 red). He can either buy a fairly useless green Mutation for one green Catalyst, or spend two green Catalysts for a yellow Mutation – cytochromes. He unwisely opts for the latter.

J7. HYDROCARBON FOG : "Player Green versus the volcano."

a. **Events.** All lifeforms have heat shield protection against the event. The hydrothermal vents appear from the heavens.

b. **Assignment.** Because the cosmos is inactive, both of Blue's Bionts are stuck in the IDP. Green opts for the hydrogen volcano with both Bionts; a sure money-maker.

c. **Autocatalytic Rolls.** Blue gains two more catalysts in the IDP. Green gains three Catalysts (1 green & 2 red).

d. **Darwin Roll.** All is steady.

e. **Purchases.** Green buys the ribosome RNA Mutation for his PNA.

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had "green" chromosomes, so the spammed RNA is looking for places with controlled entropy dissipation, like vents or radioactive beaches. But supposing these Refugia are inhabited already, by protolife metabolising using fixed energy sources. In game language, it has green and red but no yellow or blue. Will the yellow-blue viroid packages wipe out or be adopted by the nascent green-red life? Will they fight or exchange daughters? With its newly acquired RNA, a hybrid lifeform might have instructions on how to make cells, plus instructions on how to read and make RNA. The proteins could at first replicate by folding styles, in the manner of today's prions. And its energy management could at first replicate using compositional heredity. But natural selection would favor extensions in the RNA role to encode for both these vital functions.

J8. VAALBARA BREAKUP : "A Parasite is born."

a. **Events.** Nervously, the players note this is the third cold event; one more and the game will end with a Snowball earth. The cosmos is active, and a seemingly innocuous meteor will allow the Mars-Bug (assumed to have fallen to Earth) to be parasitized. Two new biomes appear, both from the coastal landform deck since the cosmos is empty.

b. **Assignment.** Green stays in the volcano with one Biont. His other Biont initiates a salmonella parasite attached to the now Earthbound Mars-Bug. Two Disease cubes (blue & yellow) are seized from the helicase. Blue remains in the IDP with both Bionts.

c. **Autocatalytic Rolls.** Blue gains some Manna and patiently declines to start life. Green rolls snake eyes, and creates thioester-life with blue, green (Biont), & red Chromosomes.

d. **Darwin Roll.** All is steady.

e. **Purchases.** Green's PNA buys the superoxide dismutase mutation. The Parasite and Host each buy a Red Queen Mutation; quorum sensing for salmonella, and RNA polymerase for the Mars-Bug. The Parasite cheekily spends his Host's yellow Catalyst for the quorum sensing Mutation.

J9. T TAURI SUPER FLARE (1ST PROTEROZOIC CARD) : "The Red Queen becomes a Red Wedding."

a. **Events.** Most Refugia are degraded by cosmic rays. The events cause the unshielded Parasite to lose its quorum sensing mutation and its yellow disease cube. The PNA Bacteria has two red cubes plus one heat shield from its Mutations, and so is shielded. The thioester-life loses a blue Chromosome. Because the Mars-Bug has two red Chromosomes it does not suffer any Atrophies, but its helicase mutation is demoted because of the loss of its associated yellow disease cube in the Parasite. The 2nd degree UV radiation event forces the PNA Bacteria to surrender two of its four Mutations, leaving cytochromes and superoxide dismutase.

b. **Assignment & Autocatalytic.** Green has all 3 Bionts assigned to lifeforms. Blue reassigns to the hydrothermal vents with 2 Bionts, and organizes one green Manna.

c. **Darwin Roll.** No changes.

J10. OCEAN OVERTURN : Pollution deliberately used as an antibiotic.

a. **Events.** The Canfield Ocean removes a Manna from everything except the immune ones (events & cosmos). The first degree UV ozone event removes one of the Mars-Bug mutations. At this point Mars-bug mutations were tmRNA <blue, diseased> and RNA Polymerase <red>. Lacking Immunology, the non-diseased Mutation is lost. A new coastal landform tectonically emerges.

b. **Assignment & Autocatalytic.** Deep in the vents, Blue gains two Catalyst (green & yellow).

c. **Darwin Roll & Purchases.** The Host buys chloroplast symbiont, which has pollution. Having two green Chromosomes, the Host creates a double-spike pollution. The polluted salmonella loses its biont, going extinct.

J11. NITROGEN FAMINE : "Sterile Earth."

a. **Events.** The triple smite kills a majority of earth's Refugia.

b. **Assignment & Autocatalytic.** Deep in the vents, Blue gains a yellow Catalyst from Biosynthesis.

c. **Darwin Roll & Purchases.** The remaining lifeforms, although degraded, survive the Darwin Rolls. The thioester-life metabolizes a red Catalyst. At this point, the players are tied at 7 VP! Green has 2 VP from Thioester Bacteria (green biont and red chromosome) + 4 VP from PNA (Biont, internal blue and green chromosomes, and red chromosome from a mutation) + 1VP from the dead amyloid. Blue has 7 Chromosomes on her single lifeform. However, this will suddenly change. Blue purchases a game-winning Mutation (mitochondria) with the fission Ability for the Mars-Bug.[9]

J12. CRYOGENIAN SNOWBALL : "Armageddon!"

a. **Events.** Snowball Earth! This is the fourth cold sun in a row, and the players decline a Gaia vote, so the game will end after this turn. The thioester-life loses a red Chromosome to the double O_2 spike.

b. **Assignment & Autocatalytic.** Blue has a hard assignment choice. She has an organized two Manna in the vents already, plus her two Bionts. Should she stay in the vents with both Bionts, hoping to create a healthy lifeform? Or should she use one of her Bionts to create a viroid Parasite? She decides to put all her eggs in the vent basket. Green uses his unassigned Biont to create another salmonella parasite on the Mars-Bug. Blue rolls (1, 1, 3, 6, 6), creating Metal-Glycolysis life with four Chromosomes [2 blue (Bionts), a red, and yellow Chromosome] and gaining two Catalysts (blue & green).

c. **Darwin Roll & Purchases.** The Host uses its fission Ability to make a double Red Queen attack, stealing back both Diseased cubes from the Salmonella. Green purchases the Calvin cycle Mutation for PNA, and mRNA (using chemoselectivity) for the thioester-life.

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9 MITOCHONDRIA, an eukaryote invention, are the reason eukaryotes have been free to become extremely complex and large, while prokaryotes have remained small and morphologically simple. Mitochondria are the sites of ATP synthesis, and lacking these, prokaryotes are intrinsically limited in the amount of ATP they can manufacture—and thus, in the number of proteins they have the power to build. —Lane & Martin, 2010.

d. **Ending Score.** The game ended 7 events early, with the Earth still at the bacterial stage. In a major upset, Blue wins with 12 VP; 8 VP on her Mars-Bug Host and 4 VP on the newly arisen vent-bacteria, while Green only has a total of 9 VP: 7 VP on his two surviving lifeforms, 1 VP from his Salmonella parasite and 1VP from his amyloid trophy.

Jeremy's Tips: *In our mature games of 4 very experienced players, we often see a second wave of parasitism after the first dies out. When three out of four players have aquatic organisms, and it is obvious the oceans will be overcrowded, parasites are being used essentially to deplete catalysts and organs in a bid for trophic dominance. One thing I'm noticing (which is true of all Phil's games) is the strategy learning curve. As I caught up on reading some of the other game logs I can see other folks hitting the same "roadblocks" as I did early on. But then with experience comes the ability to anticipate what comes up next, and less frustration.*

K. THE SUCCESSOR GAME - BIOS MEGAFAUNA[10]

If you have the successor game ***Bios: Megafauna*** (either the 1st or 2nd edition), you may seamlessly continue playing, starting with your Macroorganisms and Catalysts leftover at the end of a ***Bios: Genesis*** game. Record and add the VPs you attained in *Bios Genesis* (**I1**) to your final ***Bios: Megafauna*** score to determine the overall winner.

a. **Macro Variant.** It is highly recommended to use the *Macro Variant* (**C4**) for the combined Genesis-to-Megafauna game. [11]

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10 BIOS: MEGAFAUNA, the successor to ***Bios: Genesis***, covers the "salad days" of the history of Earth. The planet was blanketed by a few percent of carbon dioxide, keeping it ice-free and its continents solid green from pole to pole. This marked the peak of Earth's productivity (i.e. carbon fixation), and when flowers, fruits, insects, dinosaurs, and mammals developed. Since this peak, Earth has been getting browner and browner as it loses its precious supply of CO_2. Levels fell from parts per hundred to less than parts per thousand, leaving today's plants literally gasping for breath. Furthermore, since CO_2 is a mild greenhouse gas, its loss caused today's Ice Age. Within the memory of man, ice has covered $^2/_3$ of the northern and southern continents. The villain is not Medea but erosion, especially silicate weathering from mighty well-washed mountains such as the Himalayas. The CO_2 removed from the air by erosion is sequestered by plate tectonics deep into the crust. Volcanoes return some, but not enough (see footnote 14). Even the heroic mining efforts of mankind have only raised CO_2 levels a few hundred parts per million, enough to make the planet noticeably greener but not enough to stave off snowball Earth for very long. And we are perilously close to 150 ppm, the photosynthesis threshold for most plants. Once CO_2 drops below this, the plants will suffocate and Earth will enter her second Age of Bacteria.

11 BIOS: MEGAFAUNA covers the Phanerozoic Eon , the next half billion years following the first four billion years covered by ***Bios: Genesis***. The first two eras of this eon are the Paleozoic and Mesozoic Eras, each roughly one turn long, as ***Bios: Genesis*** counts turns. These are the glory days of the planet, with the rise of flowers, insects, dinosaurs and mammals. The final game in the Bios series, ***Bios: Origins***, covers the final millennia of the subsequent Era we live in, the Cenozoic. It features the exciting development of conscious beings, but which kingdom of life will they develop from? That brings us to now. And after now? In 1.6 billion years (8 game turns) the sun, which has been warming since its formation, will have raised global surface temperatures to 120°C and the ensuing moist greenhouse effect will stream the oceans into space. But long before that, only half a game turn from now, the Earth's precious supply of carbon dioxide will run too low to support 90% of plant life, and Earth will enter its second microbial age.

L. MACRO PARASITE CHIMERA VARIANT (Pawel Garycki)

L1. PARASITES BECOMING MACROORGANISMS[12 13]

A parasite can also purchase a macroorganism. In this case, host's diseased cubes which are taken by that macroorganism for the purpose of becoming system chromosomes or organs are considered lost for the host. This may result in removal of some of its mutations, if host is a microorganism.

a. **Multiple Bionts.** Should there be more than one biont on the parasite, they become endosymbionts or otherwise they are returned to their owner. Bionts from the microorganism hyperparasite are also incorporated this way and its card is returned to the owner (all mutations and cubes are lost). If the host is a microorganism, its bionts are incorporated as endosymbionts if there are free slots, otherwise they stay in the organism. This may result in host's extinction or changing of its ownership. A macroorganism host or macroorganism hyperparasite are immune to biont incorporation.

b. **Hyperparasite.** A Hyperparasite may not become a Macroorganism.

So the total expected span of life of Earth is only 30 turns: 20 turns of bacteria only, then 2.5 turns of plants and animals, then 7.5 turns of bacteria only again. As a habitable planet, Earth is already in its old-age senescence. When the surface life dies, will humans still be around, huddled in ice caves sealed to preserve carbon dioxide, growing crops under sulfur lamps? I sincerely hope so.

12 MACRO LIFE AS CHIMERAS. All the quirky features of macroorganisms, including the eukaryotic nucleus, morphological complexity, sex, large size and genomes, and multicellularity, may have started with the serendipitous chimera of an archaeal host and its bacterial mitochondrial endosymbiont. Because the mitochondria multiplied the available energy per gene, the new eukaryote could be profligate with genes - able to afford even introns and junk DNA - compared with the prokaryotes which are notoriously stingy with their tiny but efficient genomes. —Nick Lane, *The Vital Question*, 2015.

13 ENTROPY-FIRST SCENARIO. Previous footnotes described the "cell-first" (yellow), "metabolism-first" (red), and "replication-first (blue)" abiogenesis scenarios. Placard 62 illustrates "entropy-first" (green), the hypothesis that life began, and persists today, as a catalyst for the absorption and dissipation of sunlight at the surface of shallow seas. The resulting heat is then efficiently harvested by other irreversible processes such as the water cycle, hurricanes, and ocean and wind currents. RNA and DNA are the most efficient of all known molecules for absorbing the intense ultraviolet light that could have penetrated the dense early atmosphere, and are remarkably rapid in transforming this light into heat in the presence of liquid water. The fact that the aromatic amino acids have been shown to have chemical affinity to their codons, or anti-codons, and that they also absorb strongly in the UV-C, suggests that they might have originally acted as antenna pigments to increase dissipation and to provide more local heat for UVTAR replication of RNA and DNA as the sea surface temperature cooled. From this perspective, the origin and evolution of life, inseparable from water and the water cycle, can be understood as resulting from the natural thermodynamic imperative of increasing the entropy production of the Earth in its interaction with its solar environment. —Karo Michaelian, 2010.

L2. RELATION WITH NEIGHBORS

The affected organisms still need to live together in the same environment and tableau, although the rules about enzyme donation are still in force.

a. **The relation with a hyperparasite** is similar to the relation of a macroorganism host to the microorganism parasite.

b. **The parasitic macroorganism** may never be supplanted nor may it ever try to attach to another organism. Only 2 levels of parasitism are allowed (so we have the host, the parasitic macroorganism and a possible hyperparasite).

L3. RED QUEEN ATTACKS

Stealing from macroorganism parasite to microorganism host: If there are empty mutation slots, an organ may be stolen as a mutation cube.

a. **If both organisms are macro**: If there is a free organ slot, it is possible to steal an organ. The host, if having a free endosymbiont slot, may steal an endosymbiont from the parasite.

b. **Stealing from microorganism host to macroorganism parasite**: Provided there are free slots, first steal mutation cubes as organs. Then it is possible to steal bionts as endosymbionts, even if there are no free slots. In this case a biont is returned to the owner with compensation. The stealing of bionts may change host's ownership or make it go extinct.

L4. DEATH

a. **Host death.** If the host dies (also in the situation when its last biont is made an endosymbiont), the bacteria is not made extinct. Instead, it loses all remaining mutations and cubes and its card is moved under the macroorganism, freeing the parasite card to its owner. The new organism is finally moved to the owner's tableau (together with a possible hyperparasite) and ceases to be parasitic (a hyperparasite becomes now a standard parasite).

b. **Parasite death.** If the parasitic macroorganism goes extinct, it reverts back to the microorganism parasite state (with a compensation) and the system chromosomes may fill in the two available slots. The surplus cubes are returned to the soup. The endosymbionts may also fill the two available biont slots and the surplus ones are removed to the owners with compensation. If the parasitic microorganism ends up without a biont of its own colour for whatever reason, it immediately goes extinct (it can never be owned by a foreign player).

L5. LANDFALL

a. **Order.** When performing landfall, first consider the host organism, and then the parasite.

b. **Organ Count.** The landfalling organism may count organs from its neighbour.

c. **Macroorganism Parasite & Hyperparasite.** You may count diseased organs.

d. **Macroorganism Parasite & Microorganism Host.** You may count host's mutation cubes.

e. **Two Macroorganisms.** You may count your neighbour's organs. If only one macroorganism makes a successful landfall, the other one goes extinct (back to the microorganism phase). In that case, the successful land organism may incorporate bionts from its macro-extinct neighbour, with a possibility to make them extinct or switching ownership. The parasite requires free endosymbiont slots for this but the host does not.

f. **Terrestrial Restrictions.** If there is a land macroorganism in a parasitic chain, achievement of macroorganism state by a neighbour is only possible if this is an automatic landfall, however no counting on neighbour's organs is allowed.

L6. CHIMERA

A chimera is a macroorganism host linked to the macroorganism parasite.

a. **Trophic dominance.** Sum up belongings of all macroorganisms involved. All involved organisms share exactly the same trophic level and chimera surplus members do not add towards overcrowding. In a very rare cases of overcrowding extinction or mandatory landfalls, all members are affected (beginning with the host).

b. **Plants as a basis of ecosystems.** Regardless if chimera or not, any macroorganism (or chimera) that has the highest sum of blue plus green chromosomes is considered to be at least at the Plant trophic level. In case of ties, sum of all colours counts. This rule, being so universal, may be used even if not using other macroorganism parasites rules.

c. **Victory points.** Both chimera members are awarded 6 or 12 VP, depending on trophic dominance. Multiply it by two if chimera is a land organism, which constitutes a major achievement. The value of each member is equally shared between biont owners.

L7. SOLO PLAY

a. **Purchases.** AI parasite will try to buy a macroorganism whenever available. Choose at random if there is more than one to choose. AI will then try to buy organs, beginning from the top.

b. **Red Queen.** AI will try to perform Red Queen attacks at the topmost victim's organs that can be put into free slots in case of a Chimera.

c. **Immunology.** AI will use immunology to get rid of player's endosymbionts.

d. **Landfall.** AI will try to make landfall.

e. **Host Extinction.** AI may end up with its own macroorganism if player's host goes extinct. If this happens, AI's organism also goes extinct but it becomes AI's trophy.

f. **Victory.** At the end of the solo game, add one biont requirement to the victory condition for each AI's living macroorganism or trophy. As an alternate challenge, try to end the game having a maritime chimera, or, better, a land chimera.

GLOSSARY

Definitions of capitalized game terms and their biological analogues:

Ability (H4). Icons on Mutations, Organs, and Endosymbionts indicate special things the Organism holding it can do, beginning immediately (with the exception of fission, which is available at the start of the next turn). Abilities include:

Syringe. Allows you to control token discard order, see Immunology.

Heat shield. Indicates shielding from Extremophile events (**D5a**).

O_2 shield. Indicating shielding from oxygen spikes (**D6a**).

Cancer shield. reduces the risk of cancer (**D8a**).

Drought shield. Avoid drought (**D9**).

Spore. You can assign Bionts & Enzymes (**E2**) or purchase Mutations (**H1**) anywhere (not limited to active or home rows).

HGT. You may move Bionts per **E6**.

Fission. May make two purchases instead of one (**He**).

DNA. Errors are generated only on '6' instead of a '5' or '6' (**G3**)

Nucleus. May consider your Catalysts to be chameleons able to change to any color (**Hd**).

Sex. Before buying a Mutation, you may *roil* a deck (**D2b**).

Red Queen. May make attacks per **H4**.

Amino Acids. Red Bionts and Manna. The folding of proteins to maintain homeostasis is the domain of Player Red, who commands Parasites (prions) able to fold proteins to its own benefit, and in higher Macroorganisms controls the nervous system for high Metabolism.[14]

Antioxidants (E5a).[15] A Catalyst disk placed on an Organism to protect it from an oxygen spike (**D6**). The Antioxidant is sacrificially expended in the oxygen spike. The green Antioxidants, called Vitamins, are exceptional in that they add to the Organism's Antioxidant shield as well as can be expended in the Oxygen Spike (**D6b**).

Atrophy. Loss of a Chromosome (either cube or Biont) from an Organism, caused by some events or Error Catastrophe. Mutation cubes must be lost first, then Chromosome and Organ cubes, then Bionts (Chromosomes, Foreign Genes, or Endosymbionts), and finally Trophic Bionts. In the case of oxygen spike attacks (D6b), each Antioxidant or Vitamin may be discarded to reduce the atrophy losses by one to a minimum of zero.

Atrophied Mutations. If a promoted Mutation suffers an Atrophy, it is flipped (i.e. demoted) if its Mutation cube marked with a "+" is lost, and remains unflipped if its other cube is lost (but will be discarded if it is ever demoted). A Mutation cube atrophied from an unpromoted Mutation discards it. All Mutations discarded are placed face-up on the bottom of the Mutation deck in the Microorganism's home row. The discarding player chooses the order discarded.

Atrophied Diseased Cubes. If your Parasite atrophies a *Diseased cube* (**E3e**), this causes the Mutation which lost the cube originally to be discarded or unpromoted per the previous bullet. A Diseased Cube (Mutation or Organ) may never be atrophied by the Host it was stolen from.

***Atrophy Example**: Your viroid Parasite attached to a Bacterium has one promoted Mutation (two Mutation cubes), a Mutation (one Mutation cube), and two Diseased cubes. Therefore it rolls 7 Darwin Dice. If it suffers an Atrophy, you can either take it from the unpromoted Mutation (which discards it), or from the promoted one. If it suffers 5 atrophies, it loses all cubes, leaving just its blue Biont. The lost Diseased cubes remove the two Host Mutations (or one promoted Mutation) that originally lost their Mutation cubes to the Parasite.*

Autocatalytic Roll (F).[16] A roll representing the success or failure of a

14 AMINO ACIDS are the stuff of Metabolism, and the ingredients of peptides, proteins, and enzymes. Chemically, they contain an amino group and a carboxyl group. Of the vast numbers of amino acids, only twenty kinds are found in proteins. Presumably the others, with rather similar and uninteresting side groups, or unable to form regular chains, were weeded out by specificity long ago.

15 ANTIOXIDANTS, by being oxidized themselves, sacrificially inhibit the oxidation of other molecules, which would otherwise release destructive free radicals.

16 AUTOCATALYST is a reaction which maintains organized populations by yielding a reaction product which is itself the catalyst for that reaction. "*Autocatalytic sets also have the ability to replicate themselves if they are split apart into two physically separated spaces. Computer*

Biont in a Refugium to maintain itself and produce Catalysts.

Bacterium (pl. Bacteria) (F3).[17] A Microorganism placard in a tableau that does not have a Macroorganism card on it.

Biont (B4).[18] A wooden dome with a player color indicating which property of life it possesses, simulating an ingredient in the primordial soup. Each player controls 3 or 4 Bionts of his color. Each Biont requires two dice to be rolled in the Autocatalyst or Darwin Rolls, and if on an organism counts as a Chromosome.

Biosynthesis (B4, F2b, G2). Generation of Catalysts from the soup to the pool of the tableau you reside in. This can be from an *Autocatalytic Roll* (**F**), a *Darwin Roll* (either protein dice or triples, see **G2**), or in *compensation* (**B4a**) for a Biont lost by Manna death, Atrophy, or Extinction. The number of Catalysts you can have unassigned for each color is limited per (**B3b**). For every full two Biosynthesis Catalysts you cannot take because of the pool limit, you can substitute one Catalyst of any other color that does not exceed the limit.

• **Special Macroorganism Biosynthesis.** For every '1' rolled during a cancer roll (**D8b**), you generate one Catalyst of the color of your choice, added to your tableau pool.

Catalyst (B3). Each disk in a player's tableau pool represents a *Catalyst*, a substance that facilitates chemical reactions without itself being consumed. The four kinds of Catalysts are red = peptides, yellow = lipid micelles, green = thioesters, and blue = nucleotides. A special Catalyst is an Enzyme.

Chromosome (F3a).[19] A cube or Biont dome on an Organism or its Mutations indicating genetically stored properties and *shielding* (**D5a**, **D6a, G3**) according to its color. Mutation cubes, Organs, Diseased cubes, Foreign Genes, Endosymbionts and Trophic Bionts are all Chromosomes. The colored squares printed on a Macroorganism are special Chromosomes called **system chromosomes**. The number of Chromosomes indicates your Organism's **Metabolism** (red), **Specificity** (yellow), **Entropy** (green), and **Heredity** (blue).

Darwin Roll (G).[20] A roll testing the capacity of a Microorganism to replicate an imperfect copy of itself into the next generation.

Disease (E3c).[21] A Diseased Mutation or Organ is one whose cube has been stolen as a Chromosome by a Parasite. A Mutation is never lost or demoted by Disease, rather it remains and its Abilities remain active (for the Host, not the Parasite). A Diseased Organ is completely lost unless stolen back by a Red Queen action.

Endosymbiont (H3d).[22] A Biont on a Macroorganism acting as a Foreign Gene. It often confers shielding or immunology to the hybrid Organism, as indicated by the icons on the Macroorganism card.

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models illustrate that split autocatalytic sets will reproduce all of the reactions of the original set in each half, much like cellular mitosis. In effect, using the principles of autocatalysis, a small metabolism can replicate itself with very little high-level organization. This property is why autocatalysis is a contender as the foundational mechanism for complex evolution." -Wikipedia

17 BACTERIA are one of the three domains of life, in which the other two are Archaea and Eukarya. Archaea and Bacteria are both prokaryotes, and Eukarya include the eukaryotes (including all multicellular organisms). Bios:Genesis uses the term "bacteria" in its older sense, as all prokaryotes or even preprokaryotes in the history of life.

18 BIONT is a game term for a 'progenote', the hypothetical preprokaryotic organization in cellular evolution, earlier than the last common ancestor (currently thought to be a prokaryote rather than a preprokaryote).

19 CHROMOSOME is the threadlike cell structure of nucleic acids and proteins containing genetic information in the form of genes.

20 DARWIN ROLL. The central problem for any theory of replication is that if the replicative apparatus does not function perfectly, it will accumulate errors from generation to generation. This deterioration, called the "Error Catastrophe" eventually collapses the system into total disorganization. Only if a stable error rate is achieved can a population with a selective advantage be maintained.

21 DISEASE is a microorganism invasion which has commandeered a particular biological function for its own gene-spreading purposes.

22 ENDOSYMBIONT THEORY holds that mitochondria, chloroplasts, and peroxisomes started as parasitic prokaryotes, but were assimilated inside the larger eukaryotic host cells to their mutual advantage. The parasite lost most or all of its genetic material as its reproduction was taken over by the eukaryotic nucleus. This idea, like the Gaia concept, was championed by Lynn Margulis, a brilliant biochemist (and the first wife of Carl Sagan).

An Endosymbiont is able to make a purchase for the Organism it resides in, using the Organism's Catalysts and its Abilities (spore, HGT, chameleon and fission, as long as fission was available from the beginning of the turn). Endosymbionts are formed whenever a new Macroorganism is created containing multiple Bionts, including Parasites and Foreign Genes.

Entropy (E2a).[23] One of the four properties of life (Player Green), increasing the number of Bionts you can support in Refugia. The pigmented absorption of energy and its controlled release is the domain of Player Green, who commands chloroplast Endosymbionts able to fix carbon for its own benefit, and in higher Macroorganisms controls the digestive or photosynthetic systems.

Enzyme (E1).[24] A Catalyst disk assigned to one of the "Enzyme slots" of Refugia, serving to increase the amount of organized Manna and keep autocatalytic cycles operating productively.

Error Catastrophe (G3).[25] An Atrophy that occurs if the number of errors in a adjusted Darwin Roll is greater than the Microorganism's Heredity (its number of blue Chromosomes).

Extinction. An Organism goes **extinct** if it either loses all its Bionts (e.g. by Atrophy or HGT), or it is a Parasite whose Host goes extinct or takes its last Biont in a Red Queen attack. A lost Bacteria placard or Macroorganism card is awarded to its owner as a **trophy**, worth a VP at the end of the game. A lost Parasite card is returned to its owner for possible reuse, beginning next turn. Each Biont lost during Extinction is *compensated* (**B4a**).

• **Extinction (Microorganism).** Discard its Mutations to the bottom of the Mutation deck in its home row. AAll disks and cubes are lost to the soup, except a Parasite's diseased cubes are returned to its Host.

• **Extinction (Macroorganism).** <ADVANCED> If the Trophic Biont from a marine or terrestrial Macroorganism is lost, resurrect it on the Bacteria placard underneath. Any system Chromosomes printed on it, plus any surviving organ cubes, are replaced as Chromosome cubes on the new Bacteria, as well as any other disks that were on the Macroorganism. All its parasites (along with their disease cubes) become extinct.

Extremophile Crisis (D5).[26] An event indicated by the icon, indicating temporary extreme temperatures.

Foreign Gene (F4d).[27] A Biont of one player color residing as a Chromosome in the Organism of another player. A Foreign Gene is able to make a purchase for the Organism it resides in, using the Organism's Catalysts and its Abilities (spore, HGT, chameleon, and fission, as long as fission was available from the beginning of the turn).

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23 ENTROPY is a measure of disorder and the inability to do useful work. Entropy is gained as a system approaches equilibrium, the point where it has maximum disorder and degrees of freedom. Life regulates entropy generation by holding its system far from equilibrium. This involves not just energy storage, but also collecting fuel and emptying trash and bioproducts. For photoautotrophs, "trash" includes the reaction product oxygen.

24 ENZYME is a large (usually protein) catalyst used in metabolism.

25 ERROR CATASTROPHE. Replication cannot be sustained unless the number of copying errors in each generation is less than the bits of information supplied by the selective action of the environment. If the error rate is too high, then errors will accumulate from generation to generation until the entire system collapses in disorganization, the so-called the Error Catastrophe discovered by Manfred Eigen. To avoid it, a system with N bits of information must have an error rate no more than N-1. Modern DNA organisms have a remarkably low error rate $\approx 10^{-8}$, and $N \approx 10^{8}$. RNA replications have an error rate $\approx 10^{-2}$, implying $N \approx 10^{2}$. One hundred bits of information is far too few to describe any interesting catalytic chemistry, let alone replication. If an RNA world existed, it must have teetered on the very verge of Error Catastrophe.

26 EXTREMOPHILES are microorganisms able to survive in extreme conditions. Temperatures as high as 100°C can be withstood through the deployment of special protein folding arrangements and struts. The microorganisms with this shielding are mainly certain unicellular prokaryotes known as archaea. The few extremophile bacteria are believed to have acquired this shielding via HGT from archaean genes.

27 FOREIGN GENES. Many fungi, plants, and insects have acquired foreign genes from their endosymbiotic bacteria, using viruses as vectors during HGT. The animal with the greatest percentage of foreign genes is the millimeter-long water bear (tardigrade), with 17.5% "borrowed" DNA.

Gaia (D10b).[28] A special procedure by which players can cooperatively nullify an event that would destroy all life on Earth (Armageddon).

Heredity (D8).[29] This is the number of blue Chromosomes on a Microorganism. This imparts an *error shield* (**G3**), signifying the number of errors that can be blocked in the Darwin Roll. Heredity is one of the four properties of life (Player Blue), representing transmitting templated information for replication, especially information stored in the sequence of Nucleotide Bases on a gene.

HGT (E6). Abbreviation of Horizontal Gene Transfer[30], by which you can move your Bionts among Microorganisms as Foreign Genes or Chromosomes. HGT applies to all of your Bionts, even if the organism they're in doesn't have the HGT ability. The sum of all the HGT icons you have on your Microorganisms and Microorganisms you reside in (as a Foreign Gene) is called your **wantonness**, so named because bacteria are noted for having HGT sex with just about any other living thing.

Host (E3). An Organism with an attached Parasite. See (**E3b)** for Host suitability.

Hyperparasite (E3d). A Parasite of a Parasite. Even a parasite of a parasite of a parasite is allowed.

***Easily missed rule**: when attaching to a parasite, a hyperparasite can can only take the parasite's mutation cubes, not diseased cubes.*

Immunology. An Ability conferred by a Mutation or Organ with the **syringe icon.** If an Organism has Immunology, it may discard tokens in any order during an Atrophy, and Mutations in any order (**D7b**). Remember that loss of the Trophic Biont drives the macroorganism extinct.

• **Immunology & AIDS.** If Immunology in a Macroorganism is conferred by an Endosymbiont, then the Endosymbiont owner controls the order of Atrophy losses, even if the Macroorganism also has an organ conferring Immunology. However, the Trophic Biont cannot be atrophied unless there are no organs or endosymbionts in the Macroorganism.

***Immunology Example**: Your amphibian suffers an Atrophy during a drought. It has an Organ and two Endosymbionts: gut Bacteria (green Biont) and antibodies (blue Biont). The syringe Ability on the antibodies allows Player Blue to Atrophy his rival Endosymbiont (the gut Bacteria). Alternatively, he can Atrophy the organ. He can't Atrophy the Trophic Biont and commandeer the frog (**E6c**).*

Landform (D2).[31] A card in a column of four cards indicating a particular location. From uppermost to lowermost the four Landforms are:

• cosmic 
• oceans 
• coastal 
• continents 

All cards in the row of a Landform or with a Landform icon are located in that Landform. Landforms are double-sided, either active or inactive. The active side means that all Bionts can travel to Refugia in that row.

Macroorganism (H3).[32] A special kind of Organism, formed by placing

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28 GAIA HYPOTHESIS is the idea that microorganisms cooperate as a superorganism to keep the Earth habitable, as proposed by James Lovelock and Lynn Margulis. The opposite hypothesis, that microorganisms cooperate to destroy multicellular life, is called the Medea hypothesis. This idea, as proposed by paleontologist Peter Ward, explains why Earth suffered the oxygen catastrophe, methane poisoning, and snowball conditions to remain in a microbial-dominated state for its first 4 billion years.

29 HEREDITY. Even without templated heredity, early life could have used crude versions of reproduction, immortality, or compositional heredity to perpetuate itself.

30 HGT is a method by which an organism can trade plasmids and other genetic material non-reproductively by mere contact. As if you could acquire night vision by stroking your cat. It is distinct from Vertical Gene Transfer, such as that between a parent and child. The prevalence of HGT suggests a substantial evolutionary history preceding LUCA (the Last Universal Common Ancestor). Such a history would have involved the extensive chimerism of lineages that evolved from different environments.

31 LANDFORMS transport organics via a specific vehicle: meteors, hypercanes, tsunamis, and deluges. A hypercane is an extreme hurricane that can hypothetically form by runaway processes in warm (>50°C) oceans. Oceans could be this hot as a result of a supervolcano, asteroidal impact, or runaway greenhouse.

32 MACROORGANISM. It is unknown why cells remained single for so long, over three billion years. Bacteria are still single today; even bacterial colonies such as stromatolites are not true multicellular organisms. Even eukaryotes, originating a billion years ago, did not leave any multicellular fossils until the Avalon Explosion of a half billion years ago. Once it took hold, the advantages of cellular col-

a Macroorganism card over a Bacterial placard. It can be marine (blue side) or terrestrial (brown side). It represents an eukaryote protist that has become multicellular in a DNA-protein world, either as a plant, animal, or fungus. Because of DNA's ultrahigh precision, no Darwin Roll is necessary for Macroorganisms.

Manna (F1a).[33] Cubes and Bionts on Refugia represent *Manna*, the building blocks of life that were likely present or easily formed on the early Earth. Manna comes in four colors: red = Amino Acids (proto-proteins), yellow = lipid vesicles (proto-fats), green = PAH (polycyclic aromatic hydrocarbons) and pteridine pigments, and blue = Nucleotide Bases (proto-RNA). If in the lower row of Refugia, they are disorganized, and organized if in the upper row.

Metabolism (G2).[34] One of the four properties of life (Player Red). It consists of protein-based catalyzed chemical reactions that maintain *homeostasis*. Expressed thermodynamically, Metabolism extracts negative Entropy from its surroundings. The **metabolic rate** of a Macroorganism is defined as its number of red and yellow *Chromosomes* (i.e. all wooden tokens on the card and all system Chromosomes printed on the card of these two colors).

Microorganism (F3).[35] A type of Organism represented by either a Bacterial placard or a Parasite card. Chromosomes on a Microorganism track its Metabolism, Specificity, Entropy, Heredity, and shielding. Once a Microorganism acquires a Macroorganism card, it becomes a multicellular Organism.

Mutation (H1).[36] A card representing an adaptation for your Microorganism. It has either one (if unpromoted) or two (if promoted) Mutation cubes on the card. If the Mutation is Diseased, these cubes sit on the attached Parasite, as Diseased cubes. A Mutation is in lockstep with its Mutation cubes: loss of its card (e.g. in a UV event) means loss of its cubes as well, and loss of its cubes (e.g. in an Atrophy) loses its card well. This lockstep is honored even if the card is with a Host and the cubes with a Parasite.

• **Discarding Mutations.** When a mutation is discarded, place it face up (non-promoted side) on the bottom of the Mutation deck in the Microorganism's home row. The discarding player chooses the order discarded.

• **"+" Mutation Cubes.** A non-promoted Mutation that loses its Mutation cube is discarded. A promoted Mutation that loses the Mutation cube marked with a "+" is flipped (i.e. demoted) to it's non-promoted side (immediately losing promoted abilities but gaining the non-promoted ones). A promoted Mutation that loses its non-"+" cube is unaffected, but will be discarded if it is ever demoted.

• **Diseased Mutation Cubes**. Cubes stolen by a Parasite never cause a Mutation to be discarded or demoted unless the Parasite later loses the cube.

Nucleotide Bases.[37] Blue Bionts and Manna. Templated information is the domain of Player Blue, who commands parasitical genetic templates (viroids and viruses) able to spread by usurping the metabolic machinery of Hosts, as well as the reproductive systems of higher Macroorganisms.

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lectivism rapidly expanded into today's macroscopic eukaryote world of fungi, plants, and animals.

33 MANNA are biological building blocks from preformed organic products of abiotic syntheses. They include thioesters, and energy-rich inorganic pyrophosphate or polyphosphates. They may have derived from an Urey-Miller atmosphere, but this could have lasted at most a turn or two.

34 CENTRAL DOGMA of molecular biology, as formulated by Francis Crick, states information always flows from nucleic acids to proteins, and never the reverse. As should now be obvious, I do not believe in Francis Crick's dogma.

35 MICROORGANISM is an individual single cell with the four properties of life including templated replication.

36 MUTATION is an alteration of a gene, transmissible by replication. In this game, all the unpromoted mutations are from pre-RNA or RNA replication.

37 NUCLEOTIDE has one base, one phosphate, and (for RNA and DNA) a sugar backbone. The sequence of bases along the nucleotide backbone forms a template containing the information of life, as used both for protein assembly instructions and in base-pairing for replication. Although ancient polynucleotides likely had many base-pairs, today's DNA and RNA have been winnowed down to just two base-pairs, which encodes all life from bacteria to humans. All known microorganisms today replicate using DNA, but it is possible that RNA-based life from the putative RNA world still live in Refugia such as hydrothermal vents or the deep hot biosphere. Many RNA viruses and RNA phages, perhaps derived from the RNA world, never use DNA in their life cycles.

Organ (H5).[38] A Chromosome cube on a Macroorganism. Some Organs confer the *shielding* (**D5a**, **D6a**, or **D8a**) or other Abilities indicated by the bubble. Note: If a bubble points to two Organs, having either Organ gives you the Ability, and having both gives you the Ability twice.

Organism (B1).[39] An Organism is a Bacteria, Parasite, or Macroorganism card or placard with at least one Biont. You are allowed four Organisms, which can be bacteria or Macroorganisms in your tableau, or the Parasite of your color in an opponent's tableau.

Oxygen Crisis (H3g).[40] If you are the first to create a Macroorganism, it becomes a plant and you accelerate the game into the Age of Oxygen. In other words, the game is accelerated and often the next event will be the first event of the final Proterozoic Eon. This Oxygen Crisis is a one-time event.

Parasite (E3).[41] A two-sided Microorganism card, in each of the four player colors. During the Assignment Phase, you can animate either side of your Parasite by assigning a Biont to it and attaching it to another Organism called the **Host**. See (**E3b)** for Host suitability. A Parasite steals one or two Mutation cubes (called Diseased cubes) from its Host. Either a Host or Parasite can use Red Queen purchases to grab Diseased cubes to or from the Parasite. A Parasite may use the Chromosomes on its Parasite card, plus those on its Mutations, for Biosynthesis, Abilities, and shields. When purchasing Mutations (**H1**), a Parasite uses the Catalysts but not the Abilities of its Host. A Parasite can later become an Endosymbiont. However, it can also be *supplanted* (**E4**) by a better adapted Parasite.

Red Queen (H4).[42] A purchase that seizes control of Mutation cubes or Organs of your Host or Parasite. You must have more Red Queen icons than your victim (or permission, see **H4**) to make the attack.

Refugium (pl. Refugia) (D3). A card representing a "hatchery" region in the early Earth or space where autocatalytic cycles can be powered and maintained despite changes in external environments. The four types are cosmic, ocean, coastal, and continent. The reverse side of its placard is a derived Bacterium.

Roil (D2b). Remove the top card of a Mutation deck and add it to the bottom of that deck.

Specificity (G1).[43] The admittance discrimination of a cell membrane, one of

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38 ORGAN is a collection of tissues with a common function. Organs are found in multicellular life; the equivalent in single-celled life are called organelles. Functionally related organs participate in organ systems, such as the nervous, respiratory, and reproductive systems.

39 ORGANISM is something targeted by natural selection. However, the target of mutations is the progenitor cell, since only mutations affecting a progenitor cell is relevant to the evolutionary fate of a multicellular organism.

40 OXYGEN CRISIS. All cells, even those living in high oxygen habitats, have highly reduced cell interiors and cytoplasms. This indicates that the major biochemical pathways were fixed before the atmosphere became oxygenated as a result of cyanobacteria pollution approximately 2.5 Ga. Instead, cellular life have evolved numerous energy-requiring membrane transport systems to sustain redox and electrochemical gradients between their interior and the environment.

41 PARASITES have fewer than the four properties of life, so they need to utilize the host's cellular machinery for the missing vital property. Parasites include viruses (no metabolism), puddle syncytium (no cellular specificity), crystalbiont (no energy maintenance), and prions (no heredity). Virus and prion parasites actually exist, while the puddle syncytium and crystalbionts are hypothetical "immortal" lifeforms I dreamed up. Because these parasites lack all four vital properties, they are not categorized as "life" by most biologists.

42 RED QUEEN refers to Lewis Carroll's Red Queen from "Through the Looking-Glass", a character who must keep running to stay in the same place. This monarch has been used by Leigh Van Valen as an analogue to the tight evolutionary embrace between creatures and their internal parasites, both of them madly mutating and counter-mutating to stay in the same place. Matt Ridley has popularized the idea that the Red Queen has created the need for sex (and males) because this arms race demands gene shuffling every generation.

43 SPECIFICITY allows a cell membrane to be choosy about its own constituents, giving the cell a specific nature with specific attributes. This nature allows it to live or die as an individual Organism in a Darwinian competition. It also allows self-recognition or (in higher animals) species recognition (this is necessary, for instance, so a jellyfish doesn't sting itself, or so an amoeba doesn't eat others of its own kind). Contrary to mainstream belief, it is specificity and not heredity that allows natural selection. In modern lifeforms, Specificity is conferred to the

the four properties of life (Player Yellow). For every yellow Chromosome you have, you may re-roll one Darwin dice.

Trophic Level (H3c).[44] Hierarchical levels in an ecological food chain, starting with the energy-producing plants (**P**) at the bottom, then herbivores (**H**) eating the plants, and finally carnivores (**C**) at the top. The oceans and land each have these three Trophic Levels in this game. Each Trophic Level can hold one Macroorganism, so a maximum of 6 Macroorganisms are in the game.

Trophic Biont (H3c). A Biont used to indicate both the owner and the Trophic Level of a Macroorganism. A Trophic Biont is created when Bacteria becomes a multicellular Macroorganism. If your Bacteria becomes a Macroorganism containing two of your Bionts, one becomes the trophic Biont and the other becomes an Endosymbiont. The red Trophic Bionts, along with Organs, and system Chromosomes, impart heat shielding per **D5a**, and the green Trophic Bionts, Organs, and system Chromosomes impart Antioxidant shielding per **D6a**. The blue Trophic Bionts, along with Organs, and system Chromosomes, impart Error shielding per **D8a**.

Vitamins (E5b).[45] A green Catalyst disk placed on an Organism to add to its Antioxidant shield during an oxygen spike attack. Like other Antioxidants, they can additionally be expended by an Oxygen Spike (**D6**).

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other three properties of life by cellular encapsulation. This acts as gatekeeper to admit and concentrate specific molecules inside for metabolism (Player Red), uses ionic gradients across its membrane to power the cell's machinery and charge its ATP "batteries" (Player Green), and segregates and maintains a private genome along with any favorable mutations (Player Blue).

44 TROPHIC LEVEL. If you have trouble thinking of animals sitting in the lowermost plant trophic level, remember that there are a number of solar-powered animals and fungi. Sea slugs, flatworms, coral reefs, jellyfish, sea anemones, sponges, giant clams, and lichens incorporate ingested chloroplasts into their transparent bodies, and thus derive energy from photosynthesis. Recently, a photosynthetic wasp and salamander have been discovered. Green animals have the advantage that they can move to stay in the sun.

45 VITAMIN is an essential substance that an organism is unable to itself synthesize and so must obtain from its food.

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ROSETTA STONE

PHASE 1 : EVENTS (D)

Aftershock. Draw another event card and apply its effects immediately. **(D1)**

Player order. **(A2)**

Cosmic Landform. Active/Inactive. **(D2)**

Ocean Landform. Active/Inactive.

Coastal Landform. Active/Inactive.

Continental Landform. Active/Inactive.

Heaven. Draw Refugium placard from topmost active Landform deck. **(D3)**

Earth. Draw Refugium placard from bottom-most active Landform deck. **(D3)**

Extremophile Crisis / Heat Shield. All organisms suffer atrophies equal to number of - heat shield (red chromosomes). **(D5)**

Oxygen Spike / Antioxidant shield. All organisms suffer Atrophies equal to number of - antioxidant shield (green chromosomes & Vitamins). **(D6)**

UV Radiation (Shield). All organisms without an UV Shield remove mutations up to level of UV Radiation. **(D7)**

Cancer (Shield). Each Macro rolls one die for each organ and two for each biont. Suffers one Atrophy for each '5' or '6'. Macro with Cancer shield suffers Atrophy only on '6' **(D8)**.

Smite (Resiliency). All refugia without Resiliency lose an Enzyme or else a Manna. **(D4)**

Drought (Shield). All terrestrial Macro without drought shield suffer an Atrophy. **(D9)**

Global Warming (Cooling). Accumulation produces Armageddon. **(D10)**

DNA error shield. Organism with Error shield suffers Atrophy only on '6'. **(G3)**

Immunology. Organism with Immunology ignores atrophy order. **(Glossary)**

PHASE 2 : ASSIGNATION (E)

Spore. All rows are home rows for the purpose of assigning. **(E2)**

Catalyst. Disks in a player's tableau pool. Can be assigned as Enzymes on an active Refugium. **(E1)**

Assignment cost. Must discard one catalyst to assign a biont to this Refugium. **(E)**

Antioxidant. Expend catalysts on an organism to deflect damage from a spike attack. **(E5)**

Vitamin. Assign green catalyst to an organism to deflect spike attack. **(E5)**

Enzyme. Assign disks to Enzyme slots on a Refugium placard to protect against dice effects in a Darwin Roll. **(E1)**

HGT. May reassign your biont from one Micro to another Micro or to an active Refugium. **(E6)**

PHASE 3 : AUTOCATALYCTIC ROLL (F)

Life dice climate icons. Displays the dice that animate depending on climate. **(F1)**

Enzyme Death. Discard the rightmost Enzyme on the Enzyme row of the Refugium. **(F2)**

Death and biosynthesis. Slide Manna to the disorganized side, gain one catalyst. **(F2)**

Bacterium Creation. If a player rolls doubles, he may claim the Refugium as a Bacterium. **(F3)**

PHASE 5 : PURCHASE (H)

Catalyst. Disks in a player's tableau pool. Can be spent on purchases. **(H)**

Chameleon. Any organism with a nucleus may perform any purchase with a single catalyst of any color. **(H)**

Fission. Any organism with a fission ability may perform two sequential purchases. **(H)**

Sex. May roil one deck before you purchase from it. **(H1)**

Spore. All rows are home rows for the purpose of purchasing. **(H1)**

Red Queen. Organism with target's permission or more red queen icons may perform a Red Queen Attack. **(H4)**

TURN SEQUENCE

1. EVENT (Part D).
Turn over next event card, flip Landforms & Roil Mutation decks (D2), apply events (D3 to D10).

2. ASSIGNMENT (Part E).
Assign or Move Bionts and Catalyst tokens (E1), Parasite Biont

3. AUTOCATALYTIC ROLL (Part F).
Make an Autocatalytic Roll for Bionts in Refugia. Organize & Disorganize Manna (F1), create life (F3).

4. DARWIN ROLL (Part G) in Player Order.
Make a Darwin Roll for each Microorganism. Catalyst creation (G2), Atrophies (see glossary).

5. PURCHASE (Part H).
Each Biont makes a purchase.

6. NEXT TURN.