

• • SECOND EDITION • •

# BIOS:GENESIS

THE MOLECULAR ARMS RACE GAME

BY PHIL EKLUND



## A. WHAT'S THIS GAME ABOUT?

One to four players start as organic compounds shortly after Earth's formation, represented by up to three **Biont** tokens. 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.<sup>1</sup> Their goal is a double origin of life: first as **Autocatalytic Life** (a metabolic cycle reproducing its own constituents yet not replicating),<sup>2</sup> 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 **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 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 not the same as reproduction. Replication ends up with two approximate equal-sized copies, while reproduction ends up with two "halflings". 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: **Metabolism** (how well you manufacture Catalysts), **Specificity** (the error rate of inappropriate Catalysts admitted into the cell), **Entropy** (how many Bionts you can have assigned to Refugia), and **Heredity** (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 tokens on it or on its Mutations. If your Heredity is not high enough to survive **Error Catastrophe**, your Microorganism suffers an **Atrophy** (token loss) 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<sup>3</sup> 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. 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 how high it is in the food chain in both land and sea. Solitaire (**C2**) and cooperative (**C3**) 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 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 has preference.

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<sup>3</sup> 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.

## A1. BIOS GENESIS<sup>4</sup> SEQUENCE OF PLAY (FIVE PHASES PER TURN)

### 1. EVENT (Part D).

Turn over the next event card.

Flip Landforms & *Roil* Mutation decks (**D2**).

Apply event icons to all players (**D3** to **D10**).

### 2. ASSIGNMENT (Part E - in player order).

Assign Biont and Catalyst tokens (**E1**) respecting Entropy limits (**E2**).

Assign Parasite Biont to *attach* (**E3**) or *supplant* (**E4**).

Assign Catalyst tokens as *Antioxidants* or *Vitamins* (**E5**).

Move Bionts from one Microorganism to another using *HGT* (**E6**).

### 3. AUTOCATALYTIC ROLL (Part F - in refugia order).<sup>5</sup>

Make an *Autocatalytic Roll* for Bionts in Refugia.

See how many Manna become organized (**F1**).

See how many Manna become disorganized, generating a Catalyst (**F2**).

Doubles creates life (**F3**).<sup>6</sup>

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<sup>4</sup> The term for the origins of life from non-biological processes and inorganic ingredients is called **abiogenesis**. "Genesis" is the name for the first book of the Bible containing a famous creation myth. Some game terms (manna, wanton, deluge, smite, Armageddon, Heaven and Earth) are from the King James Bible. And having life formed from clay (placard 12) or dust (placard 15) is just what the Bible ordered.

<sup>5</sup> Which came first, the chicken or the egg? If chickens represent metabolism, and eggs represent replication, among abiogenesis biologists there are more "egg-first" than "chicken-first" theories. Nevertheless, this sequence of play assumes a "chicken-first" origin of life. This premise follows from the observation that replication is parasitic on metabolism. Take viruses for example. They are pure 'egg' with no coding for ribosomes or cell membranes and can't thrive without the metabolic machinery of their host. Further evidence for chicken-first is that amino acids are easily produced both in simulated reducing prebiotic environments on Earth and in UV-irradiated icy space dust. To assemble an 'egg' (i.e. nucleotide), you need a base, a sugar backbone, and a phosphate. All three suffer very poor yields in simulated prebiotic conditions. Moreover putting together the three parts randomly will produce a stereochemically-correct nucleotide only 1% of the time, and there is no known prebiotic process that can discriminate the correct one from its 99 misshapen brethren. Once created it is easily destroyed by hydrolysis or UV radiation (this is why in Refugia exposed to UV, blue is often in the leftmost position, the first to be lost to radiation). Modern genetic material are protected by a protein blanket and by being twisted into chromatin. Freeman Dyson, 1999.

<sup>6</sup> The NASA definition of **life**, following a suggestion of Carl Sagan, is "a self-sustaining chemical system capable of Darwinian evolution." This definition embodies a theory of life as consisting of both metabolism and replication. (Note that the Viking lander on Mars ignored the NASA definition in favor of a "reduced-carbon" definition, and thus concluded no

#### 4. DARWIN ROLL (Part G) in Player Order.

Make a *Darwin Roll* for each Microorganism.

Roll modification for *Specificity* (G1).




Catalyst Creation for *Biosynthesis* (G2).

Atrophies (token losses) & Extinctions (see glossary).

#### 5. PURCHASE (Part H) in Player Order (except Parasites purchase immediately after their Host).




Each Biont makes a purchase: a new Mutation (H1), Mutation promotion (H2), Macroorganism (H3), Red Queen (H4), or Organ (H5).


#### 6. Then go to the next turn. Two hundred million years have passed.

JARGON TABLE	 Cube	 Disk	 Dome
Bacterium Placard	Chromosome	Vitamin (green) Antioxydant (red, yellow or blue)	Chromosome Biont (own) Foreign Gene (opponent's biont)
Macroorganism Card	Organ (Chromosome)	Vitamin (green) Antioxydant (red, yellow or blue)	Chromosome Trophic Biont Endosymbiont Chromosome Biont
Mutation Card	Mutation (Chromosome)		
Parasite Card	Diseased cube (Chromosome)		Chromosome Biont Foreign Gene (opponent's biont)
Refugium Placard	Manna	Enzyme	Manna Biont
Tableau Pool		Catalyst	Unassigned Biont

life was present even though signs of Metabolism were detected.) For this game, I have expanded the NASA definition to include two more properties of life: cell-based selectivity (follows the biologists' definition that non-cellular entities such as viruses are not alive) and nonequilibrium maintenance (follows the Erwin Schrödinger definition of life). I further suggest that all four may have had separate origins, but have since adopted the same RNA-DNA replication software, starting with the LUCA (Last Universal Common Ancestor). These four properties correspond to the four players in the game: red = Metabolism (self-sustaining feedback loops), yellow = Specificity (discrimination about its own constituents, allowing individual identity and natural selection), green = negative Entropy (non-equilibrium energy), and blue = Heredity (the capacity to pass on attributes to a new population).

## A2. PLAYER ORDER

On each event card, just above the event icons, is a row of three colored icons. For **1**    *aftershock events (D1)*, it's the event after the aftershock(s) that has these icons. (But if the very last game card is an aftershock, use the player order of the previous turn). The leftmost icon indicates the color of the **first player**, who is the first to perform his actions in each phase. Then play goes to the next player color in the row.

- **Two or Three Player Game.** If the first player is a color who is not in the game, the second color in the row is the first player, etc.
- **Wanton First Player.** At the beginning of any phase, if there is a player with more *wantonness* than any other, he may declare himself to be the first player that phase (then proceed in Player Order with the next player the color of the leftmost icon). A player's **Wantonness** is defined as the number of HGT icons on all his Microorganism's Mutations and Microorganisms he resides in (as a Foreign Gene). 
- **Parasite Exception.** During **Phase A1.2** (purchases) a parasite purchases immediately after its Host.
- **Pass.** During **Phase A1.2** (assignment) or **A1.5** (purchases), a player may elect to do nothing.

## B. COMPONENTS



**16 wooden domes represent Bionts.** You start the game with three or four in your player color: **red = metabolic biont**, **yellow = cellular biont**, **green = energy-absorbing biont**, and **blue = replicative biont**.<sup>7</sup>



**64 wooden cubes represent Manna if on a Refugium, a Chromosome if on an Organism or Mutation, and an organ if on a Macroorganism.** There are 16 in each of the player colors: **red = Amino Acids**, **yellow = lipid vesicles**, **green = PAH (polycyclic aromatic hydrocarbons)**<sup>8</sup> and **blue = nucleobases**.

<sup>7</sup> The evolutionary path in this game starts with 'soup ingredients' (the Refugia and Bionts), leading to non-replicative autocatalytic cycles, to RNA-world bacteria-like cells (Darwinian Microorganisms on the brink of Error Catastrophe), to DNA-protein nucleated cells (eukaryotes replicating with high fidelity, using enslaved prokaryote cells as organelles).

<sup>8</sup> PAHs, components of an oily material found in meteorites, could have been separated by geochromatographic processes on porous substrates such as zeolites or beach sand. If so, they would have been common in the primordial soup. They have also been found on Titan. The PAH world hypothesis speculates that PAHs mediated the synthesis of RNA, lead-

*Note: Even though Manna/Chromosomes come in player colors, they are not necessarily controlled or counted for victory by the player of its color.*



**48 plastic disks represent Catalysts.** They come in the four player colors (12 of each color): **red = peptides**, **yellow = lipid micelles**, **green = thioesters**, and **blue = nucleotides**. A disk played into a Refugium is called an **Enzyme**, and onto an Organism is called an **Antioxidant/Vitamin**.

- **60 cards.** There are 4 **Landforms**, 24 **Events**, 20 **Mutations** (double-sided, *prokaryote* on the unpromoted side, and *eukaryote* on the promoted side)<sup>9</sup>, 4 **Parasites**, and 8 **Macroorganisms**. See card anatomy on the side of the box.
- **16 placards.** The front side is a **Refugium**, and the reverse is a **Bacterium**. See placard anatomy on the side of the box.
- **12 six-sided dice (12d6).** Use for **Autocatalytic**, **Darwin**, and **Cancer Rolls**.

## B1. TABLEAU MANAGEMENT

An **Organism** is a Bacteria, Parasite, or Macroorganism with at least one Biont. Your **tableau** consists of the placards and cards for your Bacteria and Macroorganisms, plus (to the right) the cards for their *Mutations* (**H1**), plus (to the left) the cards for their Parasites (which belong to other players).

- **Tableau Size Limit.** In your tableau, you can have up to three Organisms plus up to one Parasite (which belongs to another player) for each one.
- **Cards in hand.** There is no hand.

## B2. CUBE LIMITS

Store all unused cubes in a public bowl or area called the **soup**. If cubes run out, then use substitutes.

*Easily missed rule: Return all cubes lost in the game to the soup.*

ing to the RNA world.

<sup>9</sup> Promotion elevates you from a **prokaryote** (small simple cells) to an **eukaryote** (nucleated hybrid cells). Eukaryote cells are huge and feature all sorts of gizmos: a fenced-off nucleus, a cytoskeleton, enslaved Endosymbionts. These give you enormous potential in multicellular variation and control of the environment. Every fungus, plant and animal are multicellular eukaryotes. However, this advance sacrifices the extremophile capacity enjoyed by many prokaryotes. Should the Earth ever return to extreme conditions, either too cold as it loses its precious CO<sub>2</sub>, or too hot as the sun gets hotter, the prokaryotes will rule once again.

### B3. DISK LIMITS

Store all unused disks in the soup, along with the cubes.

- **Tableau Pool.** Each player maintains a pool for his unassigned Bionts and Catalysts. This pool is tied to his tableau, so that any Biont in the Tableau (including foreign ones such as Parasites) spends from it. Any Organism in this tableau that produces Catalysts through Biosynthesis adds to this pool.

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*Easily missed rule:* For your Parasite, you may pay with your own Catalysts, the host's Catalysts, or some combination thereof.

- **Pool Limit.** The number of Catalysts in each color in each tableau pool is limited to 12 divided by the number of players in the game

*Example:* In a 3-player game, your tableau pool is limited to 4 red disks.

During Biosynthesis, for every full two Catalysts you cannot take because of the pool limit, you can substitute one Catalyst of any other color that does not exceed the limit.

If disks run out, then use substitutes.

### B4. BIONT LIMITS

You start with three bionts in the 4-Player game, and four otherwise. Your **Bionts** are initially stored in your **tableau pool**. You never gain or lose Bionts to the soup, but normally you are allowed to have only one assigned to Refugia (see **E2**) and any number assigned to Organisms.

- **Compensation Biosynthesis.** Whenever one of your Bionts is returned to your pool as a result of *Manna death* (**F2**), *biont cull* (**E2**), Atrophy, or Extinction, add one Catalyst of your color to your pool as **compensation**.

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*Easily missed rule:* Bionts moved to another Organism (e.g. a Trophic Biont is lost), or moved by HGT to your pool, are not compensated.



## C. SETUP

- 1. Player Color.** Each player is randomly assigned a color. He receives the three or four wooden domes (Bionts) and the one Parasite card of his color. Place one biont upside down (to indicate at the game start he has one available unassigned Biont).
- 2. Soup.** Provide a bowl to serve as a “public deadpool”. Place all the cubes and Catalysts of all colors into this bowl, called the **soup**.
- 3. Starting Catalyst.** Each player receives one disk of his color from the soup and places it in a **tableau pool** with his Bionts. This is his starting unassigned Catalyst.
- 4. Event Deck.** Separate the 24 event cards (hereafter called **events**) into the three **eons**: Hadean (black), Archean (red), and Proterozoic (blue).



called **events**) into the three **eons**: Hadean (black), Archean (red), and Proterozoic (blue).

Shuffle each deck facedown. Randomly remove (without looking at them) 3 Hadean events<sup>10</sup>, leaving 3 remaining. Place the Proterozoic Deck on the bottom,



<sup>10</sup> The earliest segment of Earth's history, beginning when it was freshly accreted and lasting 600 million years, is called the **Hadean** Eon. This name suggests hell on Earth, with a sky streaked with meteors, floods of lavas from the thin unstable crust, bolts of lightning sparking the thin reducing atmosphere, unchecked UV radiation, and culminating in the Earth-Theia planetary collision. The idea of Hadean life seems impossible. And yet, under the “faint early sun” (70% as intense as today's sun), the magmas quickly cooled and evidence from today's ancient zircons shows Earth's oceans were already forming by the end of game turn 1. Some indications are that the primordial atmosphere was 40% hydrogen, plus methane, nitrogen, ammonia, and water, a mixture highly favorable for the formation of prebiotic soup ingredients. This so-called reducing Urey-Miller atmosphere would have been lost in a turn or two, perhaps plenty of time for abiogenesis to occur. It is an open question whether Hadean life ever existed or could have survived the late heavy bombardment on game turn 4.

then the Archean, then Hadean.<sup>11</sup> Remove the bottommost card without looking at it, so that the Proterozoic has only 10 cards.


- **Optional Short Game.** Remove the bottommost 4 cards instead of 1 card.
- 5. Refugia Decks.** The 16 Refugia placards (hereafter called **Refugia**) are separated into four decks according to their **Landform icons** (left edge): cosmic, ocean, coastal, or continent. Shuffle each deck and arrange them in a column of four decks. The 3 cosmics are in the uppermost, followed by the 3 oceans, the 5 coastals cards, and the 5 continents at the bottom. All the placards have the Refugia side up.
  - 6. Landforms.** Place each of the four Landform cards (hereafter called **Landforms**) on top of its corresponding placard deck: cosmic, ocean, coastal, or continent. Landforms are placed on their inactive (dim) side in “landscape” orientation, see illustration. The Refugia under the Landform card are not yet in play.
  - 7. Mutation Decks.** Shuffle the 20 Mutation cards (hereafter called **Mutations**) and make 4 decks of 5 cards each. The single-strand (RNA) side is faceup. Arrange the 4 decks in a column just to the left of the Refugia-Landform column (Parts 5 - 6).
  - 8. Public Stack.** The 8 Macroorganism cards are put into a **public stack** somewhere on the table. Any card in the public stack (not just the top) can be examined or purchased by a player during his purchase phase.
- 9. To start the game, reveal the first event per Part D.** The *first player* is per **A2**.

## **C1. THE SOLITAIRE GAME (PARASITE AI DEVELOPED BY JON MANKER OF ION GAME DESIGN)**

The solitaire player chooses two of the four player colors, maintaining separate tableaus and tableau pools for both of his colors. He is allowed a turn for both of the colors in each phase. He follows the rules for two players (e.g. *pool limits*, **B3**).

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<sup>11</sup> The 4.6 billion year history of the Earth is divided into four **eons**, as derived from geological stratigraphy and the fossil record. The game covers the first three eons (sometimes informally called the “Precambrian”). This span is divided into the Hadean (ending with the late heavy bombardment about 4 billion years ago), Archean (ending with the oxygen crisis about 2.5 billion years ago), and Proterozoic (ending with the Cambrian explosion about a half billion years ago).

- **Solitaire Victory Conditions.** Achieve a **marine win** by ending the game with Bionts of both colors in marine Macroorganisms, either as two marine Macroorganisms or as a single Macroorganism with an Endosymbiont. Achieve a **terrestrial win** by doing the same in terrestrial Macroorganisms.
- **Parasite AI.** One Biont of each of the two colors not chosen is used to enable one non-player controlled (NPC) Parasite. The turn order for these two NPC Parasites follows the rules for their color. Each is hostile (making its own automated purchases) until assimilated as an Endosymbiont or Foreign Gene. Right after a player color takes his assignment phase, a random side of the NPC Parasite of that color will try to attach to the Host that will give it the most allowed Diseased cubes. However, it can't become a Hyperparasite.
- **AI Biont.** For the NPC Biont, set a dome on top of a cube. In this fashion the NPC Biont can be distinguished from the Player Bionts.
- **AI purchasing.** As usual, the NPC Biont uses its Host's Catalysts for its purchase. Determine which Mutations it has Catalysts to buy, then randomly select among them with dice. The NPC Parasite always upgrades its Mutations first before buying a new one. AIs will use fission to buy two mutations if they can. 
- **AI Specificity.** AIs will only use Specificity re-rolls to re-roll errors, starting with 6's.
- **AI Sex.** AIs will use sex to roil a mutation deck that they can't buy the top card from. (The choice is random if there is more than one such deck in active rows.)
- **AI Red Queen.** AIs always refuse Red Queen attacks if they can. They cannot themselves perform Red Queen attacks.

## C2. THE COOPERATIVE GAME

Each player has only two Bionts (the third will be used for a NPC Parasite). Players are not given a Parasite card (it is under hostile AI control). The players collectively win if they all end the game with Macroorganisms, with at least one is terrestrial.

- **Parasite AI.** The unused Biont of each player in the game is used to enable an NPC Parasite per C1. Thus, in a three player game, there will be three NPC Parasites. Players are not given a Parasite card (it is under hostile AI control).

### C3. THE INTRODUCTORY GAME

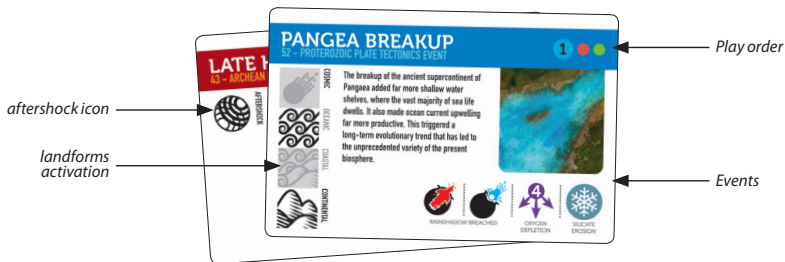
This simpler variant ignores climate change (the climate is always warm), and Macroorganisms, and thus plays only in the microworld. Ignore all rules marked [ADVANCED]. For your first games, I recommend that the use of Parasites, Red Queen actions, Endosymbionts, and Foreign Genes be prohibited. Instead of Bionts becoming Foreign Genes or Endosymbionts, they are returned to their owners with compensation.

### C4. THE MACRO VARIANT (COURTESY KYRILL MELAI)

In this “kinder gentler” variant, an Error Catastrophe in the Darwin Roll (**G3**) occurs only on a 6 instead of 5 and 6, and the DNA icon counts as an error shield. Accordingly, players have a better chance of reaching the Macroorganism stage.

## D. PHASE 1, EVENTS

Reveal the top **event** by placing it face-up into the **event discard pile**.





## D1. AFTERSHOCK, TROPICAL WATERWORLD, OZONE LAYER FORMATION

These three types of events have special or enduring effects:



**Aftershock.** The next event card is drawn and its icons are combined with this event, so that both event cards are effective. Several aftershocks can occur in a row. See **A1.1** for the icon resolution order.

- **Tropical Waterworld.** [ADVANCED] After performing the events on this card, place it on top of the continent Landform. While this card is present, the continent Landform remains inactive (the result of plate tectonics shutting down)<sup>12</sup>, all  (+earth) events (**D3**) skip over the continents row and go to the next Refugia deck higher (therefore no roiling of continent Mutations or adding of continent Refugia), and a runaway greenhouse *Armageddon* (**D10**) occurs with three  instead of four. Remove the card and its effects (restarting plate tectonics) when the next aftershock occurs.<sup>13</sup>
- **Ozone Layer Formation.** When this occurs, for the rest of the game ignore *UV events* (**D7**), except that if the Comet Impactor (card 51) occurs, it punches a hole in the ozone layer allowing UV events for that turn only.

## D2. LANDFORMS AND ROILING

On the left edge of the event, the four Landform icons are shown in a column. If an icon is bright, ensure that the landform is flipped to its **active** side, and its corresponding Mutation deck is *roiled*, see below. If it's dim, it is flipped to its **inactive** side.




<sup>12</sup> Plate tectonics drives the carbon cycle by sweeping carbon deep into the crust, where it is slowly released back into the atmosphere by volcanoes. If it had stalled, Earth would have avoided the fate of Venus only by heroic Gaian measures. Furthermore, there would be no continents of granite, only an archipelago of volcanic islands like Hawaii. Hence "Tropical Waterworld". Other "what ifs" in this game: what if Earth had no moon, what if it had no oceans or the oceans were frozen solid?

<sup>13</sup> For the billion years dubbed the "boring billion", nothing much happened on Earth. It began about 2.8 billion years after formation and lasted until a snowball Earth period and the Avalon explosion. Both biology and geology seem to have stalled, "characterized by environmental, evolutionary and lithospheric stability that contrasts with the dramatic changes in preceding and succeeding eras. ...The period is marked by ...a lack of orogenic gold and volcanic-hosted massive sulfide deposits, and an absence of glacial deposits and iron formations." A possible reason is 'lid tectonics', a stalling of plate tectonics with the formation of a stagnant lid punctured by volcanism. Professors Peter Cawood and Chris Hawkesworth, 2014


- **Activation Effects.** An active Landform means that you can assign Bionts and Enzymes to Refugia in its row.<sup>14</sup>
- **Roiling.** To **roil** a deck means to take its top card and put it on the bottom of the deck. Roil each Mutation deck next to an active Landform. Easily forgotten rule!

### D3. IN THE BEGINNING...



Each  (+heaven) indicates the creation of a new **Refugium**, coming down from above (such as comets delivering ocean water). For each +heaven icon, draw the top Refugia placard from under the Landform card from the uppermost active Refugia deck with cards remaining.



For each  (+ earth, indicating the creation of mountains etc. by plate tectonics), draw the top Refugia placard from under the Landform card from the lowermost active Refugia deck with cards remaining.<sup>15</sup>

- **Setup.** Place all new Refugia as the new rightmost Refugia in the rows they came from.
- **Dead Population.** Then take from the soup all the Manna indicated by the colored squares and place where indicated by the “Manna structure” in the “disorganized” field. The Manna must be cubes of the colors indicated.

*Easily missed rule: Refugia emerge only if their row is active.*

**Example:** Two  events occur, and the cosmic deck has one card left. This last card comes out, as well as the top card in the next active deck down (the oceans deck).

<sup>14</sup> Thematically, «inactive» means not that biochemistry is shutdown, but that the «vehicles» that move organic materials between the landforms are shutdown. For instance, if outer space is inactive, there are no convenient meteors to shuttle you from space to Earth's surface. If the oceans are inactive, there are no convenient hypercanes or tidal waves to deposit your marine chemicals to the shores, atmosphere, or continents, etc.

<sup>15</sup> The Earth formed without landforms or water. But soon global oceans appeared, most likely delivered by impacting comets and carbonaceous chondrite asteroids (deuterium to hydrogen ratios indicate at least 90% delivered by the latter). Plate tectonics was underway starting on turn 3, but the first known continent, called “Vaalbara”, did not appear until turn 5 followed by “Ur” around turn 8. This is because large continental platforms require the formation of granites, a slow multi-step process using water liberated in the mantle. Granites are low density compared to basalt, allowing continents and continental shelves to “float” on the oceanic crust.

#### D4. SMITE EVENT



The **smite** event icon indicates a radiation surge that causes all Refugia to lose their rightmost Enzyme. If it has no Enzymes, it loses one Manna cube. The color lost is the leftmost color depicted on the placard that still has Manna remaining. Should the same color Manna be both organized and disorganized, remove the disorganized first.

- **Deserted Refugium.** Should a Refugium ever be left without any Manna cubes, it is removed from the game, returning any bionts without compensation.



**Resiliency.** Three Refugia, as marked on the card, are immune from the effects of smite crisis.

#### D5. EXTREMOPHILE CRISIS



The **X icon** indicates temporary extraordinary temperatures affecting all Organisms. The number of **X**'s indicates the **extremity**. In the case of an *aftershock* (D1), the extremity is the summation of the **X** events from all cards, and applied as soon as the first **X** event occurs. In player order, each player subtracts the *heat shield* of each of his Organisms from the extremity. If this is a positive number, that Organism suffers that many Atrophies (**See Glossary**).



**Heat Shield.** Each Microorganism has a **heat shield** equal to the number of its **red Chromosomes** plus the number of red shield icons found on its Mutations. For Macroorganisms, the heat shield include all red system Chromosomes (printed on the card), other **red Chromosomes** (i.e. red Organs, Endosymbionts, and Trophic Bionts), and any Organs or Endosymbionts with the red shield icon.

**Example:** Your viroid has a red Diseased cube, two red Bionts, and a blue ribozyme Mutation with one red shield. Its heat shield is four, strong enough to survive the most extreme **X** aftershocks in the game.

## D6. OXYGEN SPIKE<sup>16</sup>



An **O<sub>2</sub> icon** causes an **oxygen spike attack** on all Organisms, with the number of **O<sub>2</sub> icons** indicating its **extremity**. In the case of an *aftershock* (**D1**), the extremity is the summation of the **O<sub>2</sub>** events from all cards, and applied as soon as the first **O<sub>2</sub>** event occurs. In player order, each player subtracts the *Antioxidant shield* of each of his Organisms from this extremity number. If this is a positive number, that Organism suffers that many Atrophies.



**Organism Antioxidant Shield.**<sup>17</sup> Each Microorganism has an **Antioxidant shield** equal to the number of its **green Chromosomes**, its green shields on Mutations, plus its Vitamins. For Macroorganisms, the Antioxidant shield includes all green system Chromosomes (printed on the card), other **green Chromosomes** (i.e. green Organs, Endosymbionts, and Trophic Bionts), and any Organs or Endosymbionts with the green shield icon.

For this event type only - To satisfy Atrophy damages, Antioxidants or Vitamins may be discarded instead of cubes. See example below.

**Example:** *The 'oceans rust out' aftershock event is drawn, generating two **O<sub>2</sub>** spike attacks. A flatworm Macroorganism has one green system Chromosome and an Antioxidant disk. Since the **O<sub>2</sub>** level is one over the shielding, the flatworm suffers an Atrophy, killing its Antioxidant. If it did not have its Antioxidant, the flatworm would go extinct, reverting to Bacteria.*

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<sup>16</sup> Some prokaryotes adopted light-absorbing pigments called porphyrins into their cell membranes, becoming the first chlorophylls. The early ones were purple, but other hues developed including the shades of green that color Earth today. Photosynthesis requires a source of hydrogen, which the first photoautotrophs obtained from the Manna. But as the Manna gave out, a prokaryote called cyanobacteria evolved the ability to absorb hydrogen direct by splitting the water molecule into hydrogen and oxygen, exhaling the latter. At first the oxygen was consumed as fast as it was exhaled, through oxidation of the iron in the oceans and seabed rocks. By the beginning of the Proterozoic at 2.5 Ga, the "iron oceans" were all rusted out (becoming "sulfide oceans"), and the resulting advent of free oxygen called the **oxygen crisis**, the deadliest event since the Hadean, perhaps even surpassing the Big Whack! The copious oxygen production, with nothing breathing it, may have spiked to several bars of O<sub>2</sub> (this is called the Lomagundi-Jatuli Excursion). As CO<sub>2</sub> was replaced by O<sub>2</sub>, anaerobic metabolism was poisoned just as effectively as it had with the loss of the Urey-Miller reducing atmosphere in the Hadean.

<sup>17</sup> The final eon in the game, the Proterozoic, is also known as 'The Age Of Oxygen'. This reactive gas was particularly harsh on Manna, the building blocks of life, and most of the smite events in this eon are actually the effects of oxygen destroying the primal refugia.



## D7. ULTRAVIOLET RADIATION<sup>18</sup>



The **UV icon** contains a number from 0 to 4, indicating the **limit** to number of Mutations or Organs each Organism can have. In player order, each player discards Mutations or Organs from each of his Organisms until the limit is reached.

- **Mutations Cube.** Each Mutation card, promoted or unpromoted, counts as one Mutation. Each Mutation card lost also loses its associated Mutation cube(s). The cube is lost even if it's a Diseased cube on a Parasite.
- **Order Lost.** You choose which Mutations or Organs are lost from your Organisms, except that, if the Organism has no Immunology (see glossary), it must lose healthy Mutations before Diseased ones.
- **All Mutations discarded are placed face-up on the bottom of the Mutation deck in the Organism's home row, in the order of your choice.**



**UV Shield.** [ADVANCED] If a Macroorganism has an Organ or occupied Endosymbiont space with the UV Shield icon, the entire organism is safe from UV.

***Example:** The late heavy bombardment (LHB) occurs, which is a limit = 1 UV event. A Bacterium with three Mutations loses two of them, a Macroorganism with two Organs loses one, but a Parasite with only one Mutation is safe. But if the Parasite happened to be attached to the Bacterium, in particular to the two Mutations lost by the Bacterium, it would lose its two Disease cubes. The follow-up to the LHB aftershock happens to be hydrocarbon fog, a limit = 2 UV event. This event has no effect, being eclipsed by the deadlier limit = 1 UV event.*

## D8. CANCER [ADVANCED]



If the **crab icon** appears, then every Macroorganism must make a **Cancer Roll**, rolling one dice for each Organ and two dice for each Biont. Each '5' or '6' rolled will generate an error. If the number of errors is greater than its **error shield** (i.e. the number of its **blue Chromosomes**), then the Macroorganism suffers one Atrophy for each excess error.<sup>19</sup>

18

Ultraviolet radiation from the sun is the principle source of high energy for protolife, but it is also the most destructive.

19

All multicellular life faces the problem of unregulated cancerous growth, a case of every cell for itself. Death by cancer must have been commonplace until effective regulators evolved. These regulators stem not from a central processor (such as the brain), but are mostly internal to each cell. In a human, perhaps 60 billion cells commit suicide every day,



**Cancer Shield.** If the Macroorganism has the crab shield icon (found on certain Organs), errors are generated only on '6' instead of a '5' or '6'.<sup>20</sup>

- **Macro Biosynthesis.** For every '1' rolled, you generate one Catalyst of the color of your choice, added to your tableau pool.

***Example:** A crab event occurs. You have a sea star with mitochondria (an endosymbiont with the cancer shield), brain, eyes, and kidney. With 2 bionts and 3 organs, you roll 7 dice for your Cancer Roll. You have 2 blue system chromosomes, so you are allowed two errors (6's). But the roll is 1,1,2,5,6,6,6, so you lose one organ but gain two catalysts.*

## D9. DROUGHT [ADVANCED]



If the **drought icon** appears, then every terrestrial Macroorganism suffers an Atrophy unless it has an Organ or Endosymbiont providing a **drought shield (H3)**.

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***Easily missed rule:** Droughts only impact terrestrial creatures.*

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## D10. GLOBAL WARMING AND COOLING [ADVANCED]



A red sun in the lower right corner indicates a warming climate, and a blue snowflake indicates a cooling climate. If the climate is warming, the red sun **animation (F1)** will be in effect during Autocatalytic Rolls, and this warm climate

will persist until the climate changes to cool with a blue snowflake event. A cooling climate puts the blue snowflake animation into effect, again until the climate changes.

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and a leading cause of cancer is the disruption of PCD due to accumulated genetic damage. The cell's mitochondria plays a central role in the integration of the PCD (Programmed Cell Death) pathways. Since the mitochondria developed from symbiotic bacteria, in this game bacterial parasites are necessary for cancer protection. Consider a liver cell in your body. All your ancestors had livers, but none of the cells in these ancestral livers ever left any descendants. In fact, all liver cells present and past are expected to stop dividing in order to do their job. And yet, each liver cell ordered not to divide is derived from an embryonic germ cell that has been dividing for untold generations (or else it would have left no descendants). Your life depends on how good each and every cell follows orders. Randolph Nesse, M.D., 1994

**20** Although not in the game, bacteria use PCD (Programmed Cell Death) to commit suicide if infected with a virus, so as not to infect their kin. PCD is an example of **epigenetics**, by which genes can be activated or repressed by environmental factors, e.g. binding with chemicals introduced from the outside. These changes may or may not be heritable. Pseudoscience new-agers like to testify that all bad and evil choices that one makes is due to epigenetics. In other words, my genes made me do it. But bad choices are based on a bad philosophy, not bad epigenetics.

- **Armageddon.** If by the end of the event phase the last four climate change icons are red suns, then the game ends in **runaway greenhouse** after this turn's purchase phase. If the last four climate change icons are blue snowflakes, then the game ends in **snowball earth** after this turn's purchase phase. See **Part I** for the winner.

*Tip: Stagger the discard pile to show the string of climate change icons on the right edge of the card, so all can see how close to Armageddon the game is.*



- **Gaia.** Just before a climate change icon would be enacted that will cause Armageddon to occur or persist, any player can call for a blind **Gaia vote** to cooperatively negate it. Each player secretly places a cube into his hand (indicates a “Gaia” vote) or no cube (indicates a “Medea” vote). If everyone says Gaia, those who have Catalysts or Organisms must either spend a Catalyst to the soup or suffer one Atrophy (see glossary). This cancels Armageddon, and the game proceeds.
- **Medea.** Any player who votes “Medea”, and thus ends the game with the destruction of the Earth, suffers the loss of half his VP, rounding in his favor.

*Example: Global cooling occurs during the “Huronian Snowball”. The previous five events had three global cooling and two with no climate change, so the Earth goes snowball. The trailing player calls for a Gaia vote. The first player that turn is **Player Red**, who happens to be in the lead. However, he says “Gaia” because he would not be the winner with his VP halved. The other players also say “Gaia”, and Armageddon is averted. However, if the next event is either a global cooling, or no climate change at all, another Gaia vote is necessary to avert Armageddon.*

## E. PHASE 2, ASSIGN BIONTS & CATALYSTS (player order)

In *player order* (**A2**), each player may assign any or all of his Bionts and Catalyst disks, as he chooses. Each Biont may be *assigned* (**E1**, **E3**), used to *supplant* (**E4**), or *moved* (**E6**) only once during this phase.<sup>21</sup>

<sup>21</sup> In this game, life evolves through 4 stages. The first stage, represented by your Biont, is a competitive autocatalytic cycle (sometimes called a progenote). The manna is in limited supply, and the autocatalytic cycle best able to utilize it will prevail and spread using natural drift, a crude version of natural selection. The second stage is a preprokaryote microorganism, which has acquired either a genetic template or gated cell membrane capable of replicating or reproducing crude copies of its metabolic system. An organism with a mutation card is in the so-called RNA world (3rd stage), using short

## E1. ASSIGNING BIONTS AND CATALYSTS TO REFUGIA

Assign one or more of your Bionts to a Refugium by placing it in the **organized** field. This is the upper field on the Refugium card. Respect *Entropy limits* (**E2**) when assigning. You may assign one or more Catalysts to a Refugium as **Enzymes** by placing it in the leftmost unoccupied **Enzyme slot**.

- **Biont Source.** Your Biont token can come from your *unassigned Bionts* (**B4**) or from any Refugium in an *active row* (**D2**). You must respect Entropy limits per **E2**. If any of your Organisms have the *HGT Ability* (**E6**), or if you have a Foreign Gene with access to HGT, you can remove your Bionts from any Microorganism (e.g. Foreign Genes). If this leaves any Microorganism without a Biont, it goes Extinct.
- **Biont Target.** You can only assign Bionts and Enzymes to Refugia in an *active row* (**D2**) or a row where you have a Biont, either in a Refugium or in an Organism with that *home row* (**E2**). You may also assign Bionts from an active Refugium back to your pool.
- **Catalyst Source.** Catalysts assigned as Enzymes come from your tableau pool.

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***Easily missed rule:** Enzymes remain until enzyme death and organized Manna remain until manna death (F2). Both are potentially removed via the smite event (D4).*

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***Example:** At the start of the game, you assign your one available Biont and Catalyst to Mars. They survive the Autocatalysis Roll, but on turn 2 the Cosmic Landforms are inactive, so this turn your Biont is trapped on Mars. You could assign Enzymes or a second Biont there, assuming your entropy limit (E2) was not exceeded.*

## E2. ASSIGNMENT RESTRICTIONS AND HOME ROWS

A Microorganism's **home row** contains the Landform icon matching the one in the left edge of its placard. A Macroorganism's home row is the ocean if marine, or the continent if terrestrial. The home row of a Parasite, Foreign Gene, or Endosymbiont is the same as its Host.

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(70-100 nucleotide) strands of RNA both to catalyze metabolism and to accurately transcribe a genotype to the next generation. A macroorganism is in the final stage, the modern DNA-RNA-protein world that includes multicellular eukaryotes. In a cell of the previous RNA world, hundreds of RNA "minigenes" competed for translation and replication services, both performed by RNA. This logistical bottleneck limited diversity, solved with a division of labor. An RNA-variant called DNA now performs all the replication, relegating the RNA to pure translation, transcription, and assembly roles.

**Entropy Limit.**<sup>22</sup> The number of your Bionts that you are allowed to have in Refugia is always at least one. If one of your Bionts lives in an Organism with one or more **green Chromosomes** (including green Organs), then starting next turn you are allowed to assign X Bionts to Refugia instead of one, where X is equal to the number of **green Chromosomes** plus one.

- **Biont Cull.** Whenever all the Organisms in which your Bionts reside have no **green Chromosomes** (including green Organs), and you have more than one Biont assigned to Refugia, immediately remove all but one of them of your choice (with *compensation* per **B4**). In other words, if no Organisms you occupy have green cubes, all your Bionts in Refugia but one die.
- **Other Limits.** The number of Catalysts on a Refugium is limited to the number of Enzyme slots. There is no limit to the number of Bionts on a Refugium other than the Entropy limit of the players.

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**Easily missed rule:** *Your Entropy limit applies only to Bionts assigned to Refugia. You can have any number of Bionts assigned to Organisms.*

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- **Deep Hot Biosphere.** For each Biont assigned to the Deep Hot Biosphere, spend a Catalyst to the soup (due to the high subterranean temperatures).
- **Spore.** If any of your organisms have a Mutation with the spore icon, you may assign anywhere and are therefore not limited to active rows or home rows.

**Example:** *As the game begins, Player Green can only assign one Biont into Refugia. He starts a Bacterium, and the green Biont on this Organism allows him to assign two Bionts to Refugia next turn (instead of one). They can both be assigned to the same Refugium, or two different ones.*

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<sup>22</sup> The energy management of all known organisms is performed in either the membrane (that encapsulates the cell) or in the substrate (i.e. the cellular fluid called the cytoplasm). The former uses **chemiosmosis**, i.e. the use of pumps in the cell membrane to drive ions against a gradient, thus building up a potential useful for driving other reactions (such as phosphorylation). The "cell-first" theorists believe the chemiosmosis (corresponding to **Player Yellow**) is primal, and the cytoplasm "substrate level" mechanism (corresponding to **Player Green**) is derived. They point out that all extant free-living fermenters, even those thought to be the most ancient, are tied to chemiosmosis. However, the "thermodynamics first" theorists hold the opposite, and postulate the first organisms as heterotrophs powered by fermentation, with the substrates needed (sugars, organic acids, etc.) provided by manna. They emphasize that substrate level phosphorylation is simpler than oxidative phosphorylation, and there are several substrate level steps in the fermentation process.

### E3. ATTACHING A PARASITE AND ASSIGNING A BIONT TO IT

Each player has one Parasite Card of their color. During this phase you can attach it as a Parasite to a Host Organism in a foreign tableau, or as a Hyperparasite in any tableau, and assign one or two of your Bionts to it. You choose which side of the Parasite card to play. Your new Parasite is a Microorganism which must make Darwin Rolls, and can make purchases (Mutations, Mutation promotions, and Red Queens).<sup>23</sup>

- **Source.** Your Biont(s) can be taken from the places specified in **E1**. See example below.
- **Host Suitability.** Place the new Parasite to the left of its Host's card. The Host must be in the tableau of another player and must be in an active row (**D2**) or a row where you have a Biont (i.e. either in a Refugium or in an Organism with that home row (**E2**)). The Host must have at least one cube that can be stolen by the Parasite as a *Diseased cube* (see next bullets). If the Host already has a Parasite, either become a Hyperparasite or see **E4**.

***Easily missed rule:** You cannot attach a Parasite to an Organism in your tableau, only in a foreign tableau.*

- **Diseased Mutations.** Each Parasite has two colored slots labeled **Diseased cubes**. To attach to a Bacterial Host, the Parasite must steal at least one of its *Mutation cubes* (**H1**) and put them into the Diseased slots of the correct color. It can steal up to two cubes from one or two of the Host's Mutations. Losing mutation cubes to disease does not demote or remove the Host's Mutations, or affect its Ability icons. However, a lost diseased cube sitting on the Parasite is not useful to the Host.

***Easily missed rule:** Although a Parasite needs at least one Diseased cube to attach, it does not detach if it later loses all its Diseased cubes. There is also no voluntary detachment. It only detaches if liberated (**E4**) or goes Extinct.*

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<sup>23</sup> Parasites most likely arose as aberrations from within, like cancers, not as degenerate freeloaders which were once free-living. Computer simulations clearly show genetic aberrations to be serious threats to early life. For example, the "selfish RNA" catastrophe, when a single RNA molecule learns to replicate faster than its competitors by forgetting its function as a catalyst, and quickly chokes the others to death.

- **Hyperparasite.** If the Host is another Parasite, steal the Diseased cubes from the Host Parasite's mutation cards per the preceding bullet. You can have your hyperparasite in your own tableau, attached to a parasite of one of your organisms.
- **Diseased Organ.** [ADVANCED] If the Host is a Macroorganism, steal the Diseased cubes from *Organs (H5)*.
- **Pollution.** If the Parasite is a polluter, see **H1**.
- **Ownership.** Even though the Parasite resides in a foreign tableau, the card color and moniker identifies that the Parasite is under your control as long as you have at least one Biont on it.
- **Host Death.** A Parasite goes Extinct if its Host goes Extinct. See "Extinction" in the glossary.

***Example:** **Player Blue** starts with three unassigned Bionts, and is Entropy-limited to one Refugia assignment. He assigns one to a Refugium, leaving two left. Although these can't be assigned to Refugia, he assigns one to animate his virus, and attaches it to a Host with a green Mutation. This steals the green Mutation cube from its Host. Since **Player Blue** now has a green Chromosome, he is allowed two instead of one Biont assigned to Refugia per **E2**. He may assign both his Bionts to Refugia starting next turn (assuming his Parasite is still alive). He can assign to the home row of his Host, or to an active row.<sup>24</sup>*

#### **E4. SUPPLANTING A PARASITE**

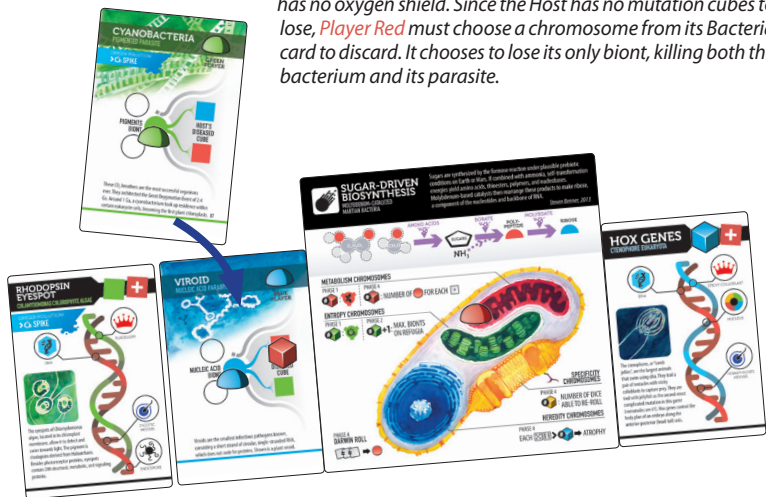
Each Host may have only one Parasite. However, your Parasite may attempt to **supplant** an already attached Parasite, so that you become the new Parasite. If so, the old Parasite is **liberated**, returning any Diseased cubes to its Host, but retaining its Mutations and Hyperparasites, and able to immediately (i.e. out of turn order) attach or supplant in an active row (**D2**) or a row where you have a Biont, either in a Refugium or in an Organism with that home row (**E2**) including the home row of the original host. If it fails to attach or supplant, it goes Extinct.

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<sup>24</sup> Viruses are parasites unable to reproduce on their own. Nevertheless, they might be ancient and have co-evolved with archaea, bacteria, and eukaryotes back to the time of LUCA or even earlier. Some have postulated that viruses could have induced the emergence of the three cellular domains, promoted the evolution of defensive cell walls, formed the first eukaryotic nucleus, or even invented DNA.

- Supplant success.** The supplanting Parasite takes his Diseased cubes from the Mutation cubes of the Host and/or the Diseased cubes of the incumbent Parasite. Supplantation succeeds if the supplanting Parasite now has more Diseased cubes per **E3** than the incumbent Parasite did before being liberated. Accordingly, a Parasite with its maximum of two Diseased cubes can't be supplanted.

**Example:** *Player Red* has a Bacterium with one promoted blue-red Mutation “*hox genes*”. This Mutation is missing its red “+” cube, stolen by an attached viroid Parasite. *Player Green* sends his cyanobacteria to supplant the viroid. This is successful, because the cyanobacteria takes two Diseased cubes from the Mutation, one blue and one red. The viroid is dissolved, and *Player Blue* gets compensation for the lost blue Biont (which can be reassigned when *Player Blue* takes his turn). Tragically, the new cyanobacteria Parasite is a level one polluter, and its Host has no oxygen shield. Since the Host has no mutation cubes to lose, *Player Red* must choose a chromosome from its Bacteria card to discard. It chooses to lose its only biont, killing both the bacterium and its parasite.





## E5. ASSIGNING A NEW ANTIOXIDANT



You may assign a Catalyst as an **Antioxidant** by placing it directly on your Organism's placard (next to the Macroorganism card if present). This gives advantages during *oxygen spike attacks* (D6). You may assign multiple Antioxidants per turn.

- **Antioxidants.** Each red, yellow, or blue Antioxidant can be expended to deflect damage during a spike attack.
- **Vitamins.** Each green Antioxidant is called a **Vitamin**, and it adds to its Antioxidant shield as well as being able to be expended during a spike attack. Thus a Vitamin can deflect two oxygen atrophies.
- **Parasites.** These are not allowed Antioxidants or Vitamins.
- **Terrestrial Macroorganisms.** [ADVANCED] These are also not allowed Antioxidants or Vitamins (they usually don't need them).

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***Easily missed rule:** Assigning Antioxidants occurs during Phase A1.2, not Phase A1.5.*

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## E6. MOVING BIONTS VIA HGT (MICROORGANISMS ONLY)

HGT is the only way to move or reassign a Biont from or to a Microorganism. You have this Ability for all your Bionts if any of your Microorganisms, or Microorganisms you reside in (as a Foreign Gene), have the **HGT icon**. Your Biont must move from one Microorganism (in any row) to another Microorganism or Refugium in either an active row (D2) or a row where you have a Biont (either in a Refugium or in an Organism with that home row (E2) including the microorganism it just moved from). Alternately, you can move your Biont into your pool (without compensation).<sup>25</sup>

- **The Wanton Block.** If you attempt to HGT into an opponent's Organism, he can announce this move to be **blocked** if he has more *wantonness* (i.e. more HGT icons, see A2). The blocked Biont must move to another Microorganism or the pool. It can move back to the Organism it originally came from but this will count as the Biont's one and only move and use one of your allowed HGT moves.

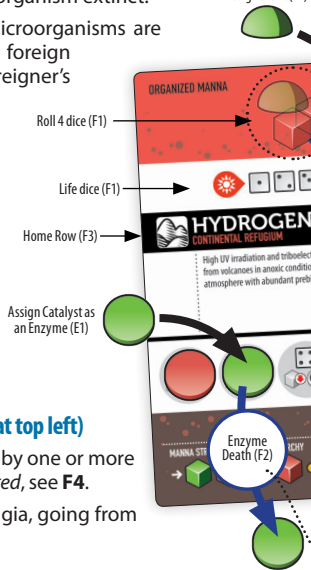
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<sup>25</sup> Two unrelated bacteria can form a bridge between them to shuttle genetic material, an HGT process called **conjugation**.

- **Extinction.** Note that HGT allows you to drive your Microorganism extinct.
- **Commandeering.** If all your Bionts from one of your Microorganisms are lost, but it has a Foreign Gene, it becomes part of the foreign player's tableau. If it is Bacteria, physically move it to the foreigner's tableau, but if it is a Parasite it stays put. If more than one player's Biont remain, you choose whose tableau it moves to.
- **Macroorganisms.** HGT cannot be used to transfer to or from a Macroorganism.<sup>26</sup>
- **No Double Move.** A Biont may not use HGT if it has been assigned (E1, E3) or used to supplant (E4) this phase.

**Example:** You have two of your Bionts in a Bacterium, and send one via HGT to *Player Yellow's malaria parasite*. He cannot block this move because he has no HGT icons in any of his organisms, and thus is not as wanton as you.

Assign Biont (E1)



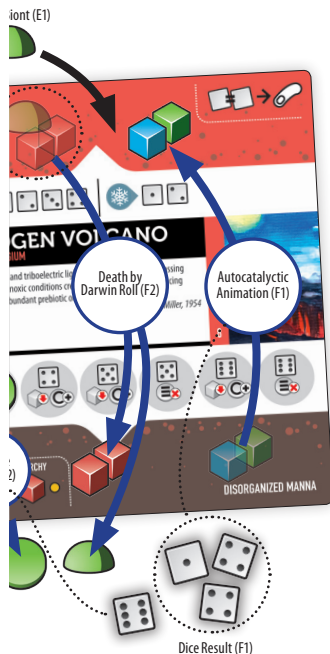
## F. PHASE 3, AUTOCATALYTIC ROLL (row by row order, start at top left)

An **Autocatalytic Roll** is made for each Refugium occupied by one or more Bionts. See **F1**, **F2**, and **F3** for results.<sup>27</sup> If the Refugium is *contested*, see **F4**.

- **Refugia Resolution Order.** Start with the top row of Refugia, going from left to right. Then on to the next row.

<sup>26</sup> Multicellular life does not normally utilize HGT, but there are exceptions. I know you were taught your genes come from your mother and father, but a very few come from your gut bacteria. HGT (horizontal gene transfer), sometimes jocularly called “fondling”, is rampant form of sex among bacteria, but rare in higher lifeforms.

<sup>27</sup> Once the soup ingredients concentrate in a puddle or protocell, the next step is to self-organize metabolic cycles that create the catalysts necessary to perpetrate the cycles. All sorts of substrates have been proposed as a template, such as clays, zeolites, or FeS/FeS<sub>2</sub> minerals. These cycles must have been far simpler than the reductive citric acid cycle fundamental to today's metabolism. A promising candidate is the “open” acetyl-CoA pathway. This is not only one of the five recognised ways of carbon dioxide fixation in nature today, it is the only one that has zero energy cost, so it requires no ATP. It takes only one step, and can be catalyzed by a iron monosulfide mineral surface. Hydrogen is electron donor and the CO<sub>2</sub> is both an electron acceptor as well as a building block for biosynthesis.



- **Procedure.** Make a roll by rolling one dice for each organized cube and two dice for each organized Biont.

**Easily missed rule:** *Each Biont counts as only one Manna, yet rolls two dice instead of one for the Autocatalytic Roll.*

- **Re-rolls.** If your Biont is on an uncontested Refugium card that is in your player color, immediately after the Autocatalytic Roll you are allowed to make one re-roll of all dice involved. This roll is final.

## F1. ANIMATION

After the roll, consult the upper center of the placard. To the right of the ☀️ icon are the **life dice** for a warm climate (**D10**), and to the right of the ❄️ are life dice for a cool climate. For each life dice rolled, you must slide one Manna from disorganized (lower field) to organized (upper field), if there are any to slide. You choose which color.

- **Manna.** All Bionts and cubes on a Refugium, whether organized or not, are called **Manna**.

## F2. DEATH AND BIOSYNTHESIS

After life comes death. The dice faces depicted in uncovered **Enzyme slots** are called **death dice**. There are two sorts, **Manna death** (marked with a square and a disk), and **Enzyme death** (marked with a disk only). Only the dice faces visible and not hidden by Enzymes before the dice roll are in effect. So if all the Enzyme slots are occupied, then there are no deaths.<sup>28</sup> If the Refugia is contested, see instead (**F4**).

<sup>28</sup> As Freeman Dyson points out, an important property of life is that it can and will die. This game takes the view that the creation of life was rather common and not a one-shot serendipity. Soup populations drifted into death as often as they drifted into life. Life had to remain on the edge, because being permanently frozen into a crystalline ordered state or an amorphous disordered state were equally catastrophic from an evolutionary view. Darwinian selection requires the possibility for death, or else life could not evolve beyond a primitive state maintained by natural drift. [Michael Lynch and

- **Manna death.** For each Manna death, you must remove one Manna from the organized field. Cubes slide down to the disorganized field, while Bionts are returned to your tableau pool with compensation (**B4**). You choose which color.



**Biosynthesis.** Each Manna death sending a cube to the disorganized field adds an unassigned Catalyst of the same color, taken from the soup, and stored in your tableau pool. You cannot take a Catalyst if your pool is at its limit (**B3**) for that color.



**Enzyme death.** After Manna death comes Enzyme death. For each Enzyme death, the rightmost Enzyme is lost to the soup.

- **Death Dice.** Each dice face may cause both Manna and Enzyme death. For instance, for all Refugia except eutectic brine, each “6” rolled will kill one Enzyme and disorganize one Manna (assuming the 6 is not covered by Enzymes).

***Example:** The climate is warm, allowing the hydrogen volcano to animate on rolls of 1,2,3,4. On its disorganized side is a green and blue Manna, and on the organized side are two red Manna and a green Biont. It also has two Enzymes. Player Green rolls 4 dice (2 for the organized cubes and 2 for the green Biont): 1,4,4,6. This animates three Manna, so both the green and blue Manna are shifted to organized. At this point, all the Manna is organized. But both the 4’s cause Manna death, and the 6 causes one more Manna death plus one Enzyme death. Player Green chooses his own Biont to die, and both red Manna to disorganize, earning him one green and two red Catalysts.*

### F3. CREATION OF DARWINIAN LIFE<sup>29</sup>

If any doubles were rolled in your Autocatalytic Roll, and your Biont remains on the Refugium after applying the results, you may optionally (!) take its placard into your tableau, flipped to its Microorganism side. This card is now your **Bacterium**, a type of Darwinian life.

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others would argue that genetic drift is the primary cause of complexity, it’s an interesting debate].

<sup>29</sup> Once an autocatalytic cycle stabilizes on an inorganic template, the next big step is to form its own portable template. Natural selection (or natural drift) is already at work here, since a cycle able to create its own template is made mobile, able to spread and multiply at the expense of other cycles still tied to their mineral templates.

- **Chromosome Cubes.** All organized Manna are taken from the former Refugium and placed according to color into the Microorganism's four **Chromosome fields**. Your Biont(s) are also counted as Manna. While in these fields, the cubes and bionts are called **Chromosomes**. Disorganized Manna are lost to the soup.
- **Enzyme Cost.** All Enzymes on the card go into the soup.
- **Bacterial Anatomy.** In a Bacteria's left edge is its *home row* (**E2**).

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***Easily missed rule:** Organized Manna during the creation of life or during the extinction of macroorganisms are the only times that chromosome cubes are added to the Bacteria placard itself. After creation, your Bacteria placard may lose cubes, but not gain them. The placard however can gain Bionts by HGT (**E6**) or Red Queen (**H4**), and the entire organism can add Chromosome cubes by purchasing Mutations (**H1**).*

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***Example:** Player Green, with two green Bionts on the alkaline seep, makes an Autocatalytic Roll of 3,3,3,3. This allows him to take the seep, inverted to pyrite reduction bacteria. The starting Chromosomes are two green Bionts.*

#### **F4. CONTESTED REFUGIA**

If this phase starts with more than one Biont color on a Refugium, the players involved are called **contestants**. The contestant with the most Enzymes of his color plus organized Manna of his color is called the **progenote**. In case of ties, look at the left-to-right order in the "**MANNA STRUCTURE**" printed on the placard (including the 'dots'). The contestant with the leftmost color becomes the progenote.

- **Dominance.** The progenote makes the Autocatalytic Roll, and the other contestants do not roll.
- **Progenote Life and Death Decisions.** The progenote makes all decisions on which Manna to animate and which to disorganize. If he chooses to kill a Biont, that contestant receives his Biont plus *compensation* (**B4**). If the progenote sends a Manna cube to the disorganized field, he gives the Catalyst created to another contestant.

***Easily missed rule:** A player who started this phase as a contestant remains a contestant even if his Biont has been killed.*

- **Origin of Darwinian Life.** If doubles were rolled, the progenote makes the decision whether to take the placard as Bacteria per (F3).
- **Foreign Genes.** If the progenote takes a placard with one or more foreign Bionts on it, the Bionts remain as Chromosomes in the progenote's new Bacteria. These Bionts are called **Foreign Genes**.
- **Ersatz Progenote.** If the progenote rolls doubles, and choses to kill off all his own Bionts, but leaves Bionts of other players alive, he must pick one of them who is allowed to claim the Bacteria.

***Example:** The clay mound is contested by a green, red, and blue Biont. It has two Enzymes, red and blue, but no organized Manna, so there is a tie between red and blue. Since red is the leftmost printed Manna, **Player Red** becomes the progenote. He rolls 6 dice (for the three Bionts), and causes two blue Manna to live. He also causes two deaths, and chooses to kill both blue Manna and give one blue Catalyst to each of the other two contestants. He rolled doubles and creates Darwinian Bacteria with one Biont from all three contestants. He could have instead killed off both foreign Bionts, giving them both a Catalyst of their color, and the new Bacteria would have had two blue cubes, plus the red Biont.*

## G. PHASE 4, DARWIN ROLL (player order)

In player order, each player must make one **Darwin Roll** for each of his Microorganisms (i.e. Bacteria and Parasites). If they have multiple Microorganisms, they choose the order. This roll can create Catalysts through Biosynthesis, and/or cause Extinction through Error Catastrophe.<sup>30</sup>

- **Procedure.** Make a roll by rolling one dice for each cube on the Microorganism and its Mutations and two dice for each Biont. A Host never makes a Darwin Roll for its attached Parasite, nor for the Parasite's Diseased cubes or Mutations.

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<sup>30</sup> The two drivers of evolution are **natural drift** (evolution by random statistical fluctuations) and **natural selection** (evolution of inherited features being passed to the next generation by survivors). Natural selection is represented in this game by the Darwin Roll, while natural drift is represented by the Autocatalytic Roll. Before Bionts and life had genes to play with, natural drift was more important than natural selection. Today natural drift, usually known as genetic drift when it operates on inheritance, is still sometimes more important than natural selection in short time periods.

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**Easily missed rule:** Each Biont counts as only one Chromosome, yet rolls two dice instead of one for the Darwin Roll.

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**Example:** Your Bacteria has its Biont, a foreign Biont as a 'guest', and one Chromosome. It also has two Mutations, each with a Mutation cube. Roll 7 dice for its Darwin Roll. Your Parasite has its Biont, two Disease Chromosomes, and one promoted Mutation with two Mutation cubes. Roll 6 dice for its Darwin Roll.

## G1. SPECIFICITY RE-ROLLS



After you make the Darwin Roll, you may make one re-roll of some of the dice rolled. The number of dice you may re-roll is equal to the number of **yellow Chromosomes** (Specificity) your Microorganism (Bacteria or Parasite) has.

**Example:** Your Microorganism with a red Biont, plus a blue and two yellow Chromosomes rolls 5 dice, obtaining 1,2,3,4,6. You decide to re-roll both the '6' and the '4', obtaining a '3' and '4' instead.

## G2. BIOSYNTHESIS<sup>31</sup>



Each '1' rolled is a **protein dice**. For each protein dice rolled in a Microorganism's Darwin Roll, add a number of Catalysts equal to the number of **red Chromosomes** (Metabolism) it has. For each triple you roll, additionally add one Catalyst. All Catalysts are added to the tableau pool your Organism resides in.

- **Color.** The Catalyst color earned by Bacteria Biosynthesis is indicated by the color of the disk shown by the "METABOLISM CHROMOSOMES" (upper left of placard). For Parasite Biosynthesis, it is the color of the Parasite Card. You cannot take a Catalyst if the pool is at its *limit* (**B3**) for that color.

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**Easily missed rule:** A Microorganism with no Metabolism (**red Chromosomes**) will yield Biosynthesis only if you roll triples.

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<sup>31</sup> The characteristics of life, known as its phenotypic expression, are governed by the catalytic powers of its proteins, the machinery of life. (Proteins are similar to peptides, except peptides can be made of any number of naturally available amino acids, while proteins are assembled from among just 20 specific ones). The biosynthesis of protein catalysts, called enzymes, is performed by the ribosomes. Today these little factories are composed of half protein machinery and half RNA guidance.

**Example:** *Player Red* rolls for GNA Lipid World life (a blue placard). He has a red Biont in the Metabolism field, plus a red, blue, and green cube sitting on Mutations. His Darwin Roll is 1,2,2,2,2. The '1' is a protein dice, giving him two blue Catalysts. The triple 2 gives him an extra blue Catalyst. If he instead rolls 1,1,1,4,5, then he would get six blue Catalysts for the three protein dice, plus one for the triples. Assuming a 2-player game however, he is limited to 6 blue Catalysts per **B3**.

### G3. ERROR CATASTROPHE



Every '5' or '6' rolled in a Microorganism's Darwin Roll generates an error. These dice faces are called **error dice**. If the number of errors is greater than its **error shield** (i.e. the number of its **blue Chromosomes**), then the Microorganism suffers one Atrophy for each excess error.



**DNA Ability.** If the Microorganism has the DNA Ability (found on all promoted Mutations), errors are generated only on '6' instead of a '5' or '6'. The DNA Ability is not an additional error shield.<sup>32</sup>

**Example:** *A Salmonella Parasite has a green Biont and a Diseased blue cube, and rolls 1, 5, 5 for its Darwin Roll. Since it rolled two errors, but one is shielded, it suffers one Atrophy. Since it has no Mutations, it must kill off its Diseased cube, which discards the Mutation it is attached to (i.e. the blue Mutation with no Mutation cube).*

### G4. CRYSTAL CATASTROPHE VARIANT (COURTESY DR. KENYON DANIEL)<sup>33</sup>

Life is messy. In this variant, Mutations are acquired only by suffering an Error Catastrophe. Therefore, purchases or promotions of Mutations during **Phase A1.5** are disallowed. Instead, if any uncanceled error dice remain in your Darwin Roll, before suffering Error Catastrophe you may cancel 1 error dice by purchasing or promoting a Mutation, using the procedure of **H1** or **H2**. Discard 1 Catalyst of the Mutation's color or 2 Catalysts of the same color.

<sup>32</sup> Over the past 60 years, DNA has risen from being an obscure molecule with presumed accessory or structural functions inside the nucleus to the icon of modern bioscience. Since the 18th century proteins had been assumed to be the essence of life, which is how they got their name. But in 1869 the young physician Miescher discovered that sperm was almost entirely composed of what he called "nucleins". This was strange, why would proteins, the very stuff of life, be present in sperm only in the tiny amount needed to wag their tails? Miescher reasoned that these "nuclein acids" must have a function in heredity, confirmed in 1944. Yet is heredity the fundamental to life? I argue that proteins deserve their name.

<sup>33</sup> A **crystal catastrophe** occurs when life reproduces with too few errors. The result is an immortal crystal, which is as bad as too many errors (the Error Catastrophe).



- **Citizenship.** Foreign Genes may not purchase or promote Mutations for the Microorganism they reside in (exception to **H**).



**Fissioning.** The fission (double purchase) Ability may be used to cancel two errors for two purchases instead of one.

## H. PHASE 5, PURCHASES (player order except a Parasite after its Host)

Each player may make one purchase for an Organism for each Biont he has in that Organism, either per **H1** through **H4** (for Microorganisms), or [ADVANCED] per **H4** and **H5** (for Macroorganisms).<sup>34</sup>

- **Cost.** Each purchase discards one Catalyst. In the case of purchasing or promoting *Mutations* (**H1**, **H2**), the color of the Catalyst must match the card color of the Mutation purchased or promoted. If purchasing *Organs* (**H5**), the Catalyst color must match the cube purchased. For *Red Queen* actions (**H4**) you must pay the color of the cube attacked.
- **Order.** Purchases are in player order (**A2**), except a Parasite makes its purchase immediately after the purchases of all the bionts in the Host (e.g. foreign genes).
- **The Chemoselectivity Rule.**<sup>35</sup> For any purchase, you may pay two Catalysts of the same color and consider them to be one Catalyst of any other color.



**Nucleated Cells.** An Organism with one or more nucleus Mutations has the **chameleon** Ability, allowing any purchase for it to be made with a single Catalyst of any color.

<sup>34</sup> It's not hard to get plain organic (i.e. carbon-based) molecules, but how do you generate nitrogen-containing organic compounds? Any scheme for the origin of life must find such a geochemically plausible pathway. Purchases in the game represent **fixation**, the biochemistry which converts inorganic nitrogen and carbon dioxide in the air into organic nitrous compounds. Organisms that grow by fixing carbon are called **autotrophs**. Autotrophs include photoautotrophs, which synthesize organic compounds using the energy of sunlight, and lithoautotrophs, which synthesize organic compounds using the energy of inorganic oxidation. The fixation of carbon in the carbon cycle is today performed mainly by cyanobacteria, marine algae and plants. The fixation of nitrogen in the nitrogen cycle is performed mainly by bacteria (rather inaccurately simulated in the game as antioxidant shielding on certain Mutations). All life would quickly go extinct without the fixation of these organisms.

<sup>35</sup> A reagent has a high chemoselectivity if reaction occurs with only a limited number of different functional groups.

- **Foreign Purchases.** All expenditures for an Organism must spend from the pool of the Tableau it resides in. Parasites spend from the tableau pool of their Host, Hyperparasites from the Host of their Host, and Foreign Genes and Endosymbionts from the Organism owner (!). These purchases may use the Organism's spore, HGT, fission, and/or chameleon Abilities. For instance, when it is your turn to purchase, each of your Bionts in an Organism starting with one or more **fission Mutations** may make two sequential purchases instead of one.<sup>36</sup>
- **Parasites.** Parasites may use Abilities in their own Mutations, but not those of their Host. For instance, your Parasite may not purchase using the fission ability on a Mutation of its Host, even if that Mutation is the source of its Disease cube.
- **Gene Transfer Agents.**<sup>37</sup> A Parasite player, Foreign Gene, or Endosymbiont can donate Catalysts to the tableau pool it resides in at any time.



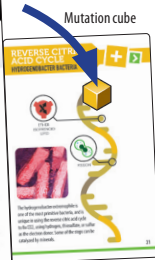
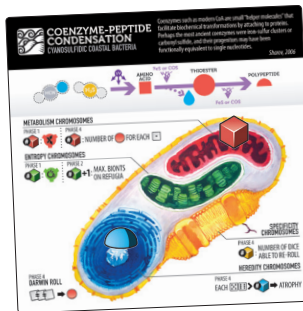
**Example:** As *Player Yellow*, your *Foreign Gene* inside *Player Red's Bacteria* is in danger of getting killed off by its RNAi immune system (ATP synthase). Noting that the *Bacteria* has enough *Chromosome cubes* to become a *Macroorganism*, during your purchase phase, you buy the *lamp shell* with one of your Host's *Catalysts* and install it on the *Bacteria*. You install the *red Biont* as the *Trophic Biont* and your *yellow Biont* as a *mitochondrial Endosymbiont*, and assign the extra cubes as *Organs*. If the *Bacteria* had a *Mutation* with *fission*, you may make a second purchase for the *lamp shell*. If *Player Red* has not taken his turn, he may also make a purchase for the *lamp shell*, using his own *Catalysts*.

<sup>36</sup> In the game, this double purchase ability is limited to unpromoted cellular mutations (prokaryotic), which multiply much faster than the more complicated eukaryotic ones. Bacteria (and other single-celled prokaryotes) can cover the entire Earth in two days, assuming unrestricted exponential growth. This is because it multiplies by **fissioning**, a fast and furious process. Protists (single-celled eukaryotes) would require more than 2 months for the same result. Multicellular eukaryotes (e.g. all of today's plants, animals and fungi) would require years. Eukaryote cells have a nucleus which needs either mitosis or meiosis to multiply, which is slow and laborious. **Mitosis** creates cells with the same number of chromosomes as the parent cell (e.g. for growth and asexual reproduction). **Meiosis** creates cells each with half the number of chromosomes as the parent cell (e.g. to produce the sex cells in sexual reproduction).

<sup>37</sup> Gene transfer agents are produced by certain bacteria. These package random segments of DNA present in the Host bacterium, which can be transduced to a recipient cell. This is a form of horizontal gene transfer (HGT).

## H1. NEW MUTATION PURCHASE (MICROORGANISMS ONLY)


To purchase a Mutation for a Microorganism, pay a Catalyst and take the top card off a Mutation deck. The deck must be either in the *home row* (E2) of the recipient Organism or in an active row, and the Mutation color must match the Catalyst paid. Place the Mutation on its unpromoted (one color) side into the tableau of the recipient. Mutations lie in a row, either to the right (bacteria), or to the left (parasite).



The first mutation of the bacterium

**Easily missed rule:** *You are not allowed to look at the other side of a Mutation before you make your purchase. The card indicates (in its upper right corner) what color is added by its promotion.*

**Easily missed rule:** *A Mutation deck that runs out is refilled only when an Organism in this home row discards Mutations or goes extinct.*

 **Sex.** If your Organism has a sex Ability Mutation, before you make a purchase for this Organism you may *roil* (D2) one Mutation deck in an active row or its home row. You may roil multiple times if it has multiple sex Abilities.

- **Mutation Cube.** Add one cube matching the card color where indicated on the Mutation. This cube, called a **Mutation cube**, is used by the Microorganism as a Chromosome.
- **Abilities.** The Abilities of newly purchased / promoted Mutations are only in effect starting next turn.

- **Pollution.** If you purchase a Mutation or attach (**E3**) a Parasite with the “Pollution!” effect, that mutated Organism makes an immediate *oxygen spike attack* against all other Organisms (including Hosts and Parasites) that share its home row. The spike attack is per (**D6**) except the attack *extremity* is equal to the number of the polluter’s green Chromosomes (Entropy).<sup>38</sup>

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**Note:** *Pollutants other than oxygen (e.g. methane etc.) are treated like oxygen polluters.*<sup>39</sup>

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**Example (pollution):** See J10.

## H2. PROMOTING A MUTATION (MICROORGANISMS ONLY)

By spending a Catalyst of the color of the unpromoted Mutation, flip it to its **promoted** side.<sup>40</sup>

- **Second Mutation Cube.** Promotion adds one *Mutation cube* matching the new color (marked with a “+”) on the Mutation, alongside the original Mutation cube.<sup>41</sup>

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38 All creatures pollute their environment. Indeed, it is part of the metabolic definition of life that it changes its environment to suit its own well being and propagation. Contrary to popular belief, humans are one of the lowest impact polluters in proportion to their biomass. One reason is technology, which has reduced the human ecological footprint by four orders of magnitude. A modern human utilizing green revolution farming requires only 0.22 Ha land area to survive, compared to a paleolithic hunter-gatherer who requires 2800 Ha.

39 Throughout the boring billion the oceans were stratified, with a thin surface layer of green algae, and the depths dominated by purple sulfur bacteria. Both bacteria used photosynthesis, but the greens split water (with oxygen by-products) while the purples split H<sub>2</sub>S (with toxic hydrogen sulfide byproducts). The rotting of the dominant purples kept oxygen out of the atmosphere, and turned the oceans into a purple near-boiling polluted miasma. Peter Ward & Joe Kirschvink, 2015.

40 Promoting a Mutation simulates evolving from a prokaryote in an RNA world to an eukaryote in the DNA-protein world. DNA (DeoxyriboNucleic Acid) differs from RNA (RiboNucleic Acid) mainly by a small change in its backbone structure. Removing the oxygen (the “deoxy” part of DNA) makes the backbone stiffer, less flexible. This makes DNA much better for information storage (a million times better fidelity), but not so good for all the various stuff RNA does (especially “translation”, converting the DNA information into a protein).

41 My game assumes that the first all-four-color life was a bacteria-like prokaryote. The far larger and more complex eukaryotes surely came much later. Accordingly, all the unpromoted Mutations are based on extant bacteria and archaea, with the flip side based on protist and other eukaryote attributes. But before this game goes to press, a genetic analysis indicates my game is all wrong, and I am sorry you wasted your money on it. The title says it all: “Eukaryotes first: how could that be?”, Mariscal & Doolittle, 2015. The implications are such that I can hardly fathom them: the LUCA as a complex community of proteo-eukaryotes with a RNA template and lipid membranes, the first life as living in moderate temperatures, with extremophile archaea emerging from this with a new heat-resistant membrane composed of ether isoprenoid lipids, bacteria as a reductive form of the eukaryote LUCA, the word “prokaryote” to be abandoned as “epistemologically unsound”, bacteria far less “wanton” as generally supposed, RNA as having risen under natural selection pressures from “catalytic closure” or “compositional heredity” precursors, the nucleus

- You lose any Abilities listed on its unpromoted side, starting next turn.
- **Pollution.** If the promotion is a “polluter”, see H1.

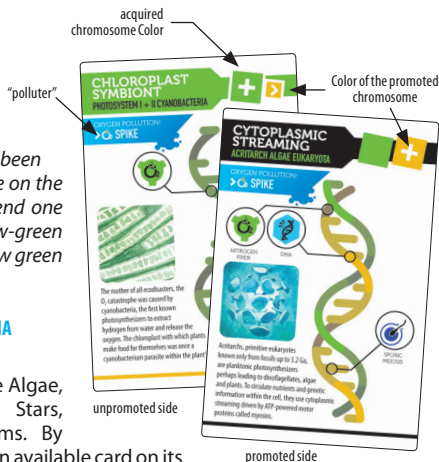
**Easily missed rule:** Any Abilities acquired by the purchase or promotion of a Mutation are not active until the turn after purchase.

**Example:** Your Bacterium has the reverse citric acid cycle, a yellow Mutation. It has been parasitized, so there is no Mutation cube on the card, but that does not matter. You spend one yellow Catalyst to flip this to its yellow-green side (oxygen respiration), and place a new green Mutation cube there.

### H3. MACROORGANISM PURCHASE (BACTERIA ONLY)<sup>42</sup> [ADVANCED]

The eight marine **Macroorganisms** are Algae, Plankton, Lamp Shells, Opabinia, Sea Stars, Flatworms, Trilobites, and Arrow Worms. By spending a Catalyst (any color), purchase an available card on its unpromoted (marine) side. Place it in portrait orientation on top of a Bacteria Placard where you have a Biont, replacing its tokens.

- **Purchase Prerequisites.** On its left edge, each Macroorganism lists purchase prerequisites called **system chromosomes**. These represent its nervous (red), circulatory (yellow), digestive (green) and reproductive (blue) systems. To purchase a Macroorganism, your Microorganism must have this number and color of undiseased



with primal role in protecting and orientating RNA and since lost in bacteria and archaea.

<sup>42</sup> A menagerie of multicellular forms evolved during a geologically brief period called the Avalon explosion. This must have been enabled by some development allowing the genetic programming of elaborate multicellular body-plans, using “indirect development”, whereby an adult metamorphoses out of a pouch of cells that has no function during the life of the embryo.

cubes (including Mutation cubes but not Bionts). Discard these cubes, so that the new lifeform will have only its system chromosomes plus the Bionts and cubes in excess to what is printed on the card.

- **Organs.** The colored squares are used to hold cubes called **Organs**. If you have more Chromosomes than required to purchase, convert each into an Organ cube of the same color, placed on the card in a square of the right color (if any. If not, then they are discarded). If all the Organs are filled, you make *landfall* (**H5**) without paying any catalysts.

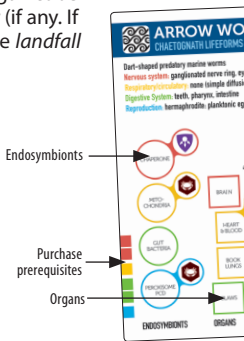


**Trophic Level Entry.** The **pacman icons** in the lower right corner are the three **Trophic Levels**. From lowest to highest they are **P** (“plants”), **H** (“herbivores”), and **C** (“carnivores”). Put your Biont, now called a **Trophic Biont**, into the lowest unoccupied Trophic Level. If all three Trophic Levels are occupied (counting all Macroorganisms of that landform), place it next to the Trophic Level icons. At the end of this phase, the Trophic

Levels of all the Macroorganisms will get rearranged per **H6**.<sup>43</sup>

**Easily missed rule:** *The red Trophic Bionts, Organs, and system chromosomes impart heat shielding per **D5**, the green Trophic Bionts, Organs, and system chromosomes impart oxygen spike shielding per **D6**, and the blue Trophic Bionts, Organs, and system chromosomes impart cancer error shielding per **D8**.*

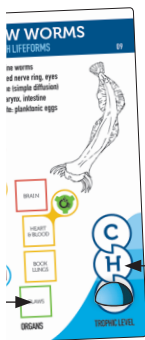
- **Parasites And Foreign Genes Into Endosymbionts.** When Bacteria becomes a Macroorganism, all Bionts it supported (e.g. Parasites and Foreign Genes) become assimilated as **Endosymbionts**. Place these Bionts into the appropriately colored circles in the column indicated. If there is more than one Biont of a color, return the extras to their owners (with *compensation* per **B4**). Any remaining tokens of the now defunct Parasite are returned to the soup, except for its card that is returned to its owner’s pool, and its Mutations which go to the bottom of the Host’s home row.



<sup>43</sup> In the game, each microorganism lives either in freshwater ponds, the deep ocean, in tidepools, or on Mars. Before the microorganism becomes macroscopic, it is assumed to have become widespread in Earth’s ocean, where it can form a food chain with other players.

**Easily missed rule:** If your Bacteria becomes a Macroorganism containing two of your Bionts, one becomes the Trophic Biont and the other becomes an Endosymbiont.

- **Cascade.** A Hyperparasite becomes a Parasite of the Macroorganism (without Disease cubes) if its Host becomes an Endosymbiont.<sup>44</sup>
- **Shed Mutations.** A Macroorganism discards its Mutations, which are returned to the bottom of its home row deck. Discard any previously placed Antioxidants and Vitamins.
- **Oxygen Crisis.** If you are the first to create a Macroorganism, it becomes a plant and you accelerate the game into the Age of Oxygen. If the events are not yet in the Proterozoic Eon (the third and final eon), discard out of the game all the events on top of the event deck until only the Proterozoic cards remain. Therefore, the next event drawn will be Proterozoic (when the air was heavily polluted with oxygen).<sup>45</sup>



Carnivore  
Herbivore  
Plant





**Easily missed rule:** A Macroorganism no longer makes a Darwin Roll. Its purchases can only be for Red Queens (H4) or Organs (H5).

44 "In short, if all the matter in the universe except the nematodes (see card 33) were swept away, our world would still be dimly recognizable, and if, as disembodied spirits, we could then investigate it, we should find its mountains, hills, vales, rivers, lakes, and oceans represented by a film of nematodes. The location of towns would be decipherable, since for every mowing of human beings there would be a corresponding mowing of certain nematodes. Trees would still stand in ghostly rows representing our streets and highways. The location of the various plants and animals would still be decipherable, and, had we sufficient knowledge, in many cases even their species could be determined by an examination of their erstwhile nematode parasites." Nathan Cobb, 1914

45 Oxygen exhaled by cyanobacteria was bubbling out of the oceans by the beginning of the Proterozoic, which quickly oxidized the Earth's supply of methane. Methane is a powerful greenhouse gas, and its loss plummeted the Earth into cataclysmic snowball conditions for hundreds of millions of years. Moreover, the buildup of an O<sub>3</sub> layer in the stratosphere shut down the solar UV flux and the UV production of free nitrogen. The resulting nitrogen famine was also bad news for biology because fixed nitrogen is essential for biochemistry. Finally, oxygen is a highly reactive gas. Most of the life on Earth must have perished from being frozen, starved, and poisoned. An exception was cyanobacteria, which figured out a way both to protect itself from oxygen and evolve an anaerobic means of fixing nitrogen. Somehow Earth recovered from the snowball, but after a billion years (5 game turns) of photosynthetic O<sub>2</sub> production, all the land O<sub>2</sub> sinks had been filled. Atmospheric oxygen spiked to new highs, beyond today's levels, and the Earth fell into a new snowball called the Cryogenian. Again the Earth somehow recovered after about one game turn, and the very next game turn brought the Cambrian explosion, the rise of plants and animals, and a new adventure in the story of life.

**Example:** Your Bacteria has one red Biont, one yellow cube, three green cubes, and three blue cubes, including its Mutation cubes. You spend a Catalyst and buy the Dickinsonia,<sup>46</sup> a marine Macroorganism with the following system prerequisites: yellow: 1, green: 2, blue: 3. After removing these cubes, you have only the red Biont and a green cube remaining. After installing the Macroorganism card on top of the Bacteria placard, you put the green cube into the green rhizomorph slot, thus gaining UV protection. Because you created the first Macroorganism, the red Biont is put into the bottom Trophic Level (plant). This discards event cards until the game enters the Age of Oxygen.

#### NUMBER OF CHROMOSOME CUBES NEEDED TO PURCHASE A MACROORGANISM

	Seaweed	Flatworms	Lamp Shells	Arrow Worms	Dickinsonia	Opabinia	Sea Stars	Tribolites	Mosses	Earthworms	Snails	Eurypterids	Mushrooms	Velvet Worms	Amphibians	Insects	
		2	1	2		2	2	2		2	2	3		3	4	2	
			1	2	1	1	2	2	3		3	4	3	1	2	3	3
	3	1	1	1	2	2	2	1	2	4	3	3	3	4	3	4	3
	1	1	1	1	3	1	2	1	3	2	2	1	4	2	2	2	2
total	4	5	5	6	6	7	7	8	7	10	11	10	9	10	13	10	

#### H4. RED QUEEN ABILITY



This action can be purchased by a Host against its Parasite, or vice versa. Unlike other purchases, your Organism needs to have an icon to make a Red Queen purchase. Furthermore, it needs to have either the permission of the owner of the target organism

<sup>46</sup> This is one of the Ediacaran biota, the first known multicellular life. They originated in the Avalon explosion of 575 mya, after the Earth had thawed from the Cryogenian Snowball (card 50). They seem to have disappeared when the Cambrian explosion occurred, but I postulate here that Dickinsonia is a type of primitive fungi.



or more Red Queen icons than the targeted organism.

- **Red Queen against a Microorganism Parasite.** Steal one of the Parasite's *Diseased cubes* as a Mutation cube back to your Mutation that originally lost it. If there are no Diseased cubes, you can steal one of its Bionts as a Foreign Gene. If you steal its last Biont, the Parasite goes Extinct. Because the Biont is still alive, it is not *compensated* (B4).
- **Red Queen against a Macroorganism Parasite.** [ADVANCED] Steal one of the Parasite's *Diseased cubes* as a healthy Organ, if you have an empty organ slot of the right color to put it. If there are no Diseased cubes, you steal one of its Bionts as an Endosymbiont. If you steal its last Biont, the Parasite goes Extinct.
- **Red Queen against a Host.** Steal one of the Host's Organ or Mutation cubes as a Diseased cube, if you have an empty 'Host's Diseased Cube' slot of the right color to put it. For Disease effects, see **Glossary**.
- **Red Queen Cost.** Spend one Catalyst of a color matching the cube being stolen. As always, spend from the tableau pool where the Organism resides. **Player Yellow** may perform Red Queen against Parasites for no Catalyst cost (because cell walls are the first line of parasite defense).
- **Trophic Level Change.** [ADVANCED] After everyone has finished purchasing, check **H6** to see if these purchases changed your *Trophic Level*.

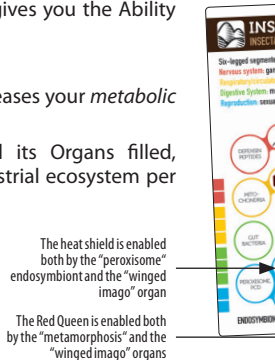
***Example 1:** Your cyanobacteria parasite has the cAMP pheromones mutation, giving it one Red Queen. Since your Host (an earthworm belonging to **Player Green**) has no Red Queen capacity, you spend one of **Player Green's** red Catalysts and steal the earthworm's red organ, infesting its brain. The red cube is moved to your red Diseased cube spot.*

***Example 2:** Your malarial parasite has one Biont, one Diseased cube, and 2 Mutations, 1 of which has a Red Queen. Your Host is a Bacteria with two Red Queens, and on his turn he purchases a Red Queen attack. This attack steals your Diseased cube and returns it to the Host. The Host has a Foreign Gene, who also purchases a Red Queen action against you. As you have no more Disease cubes, this attack steals your one and only Biont as a Foreign Gene and drives malaria extinct.*

## H5. ORGAN PURCHASE (MACROORGANISMS ONLY) [ADVANCED]

By spending one Catalyst of the organ's color, add an Organ cube to any empty spot on your Macroorganism.

- **Shielding.** Some Organs and some Endosymbionts confer the *shielding* (D5, D6, or D8) 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.
- **Diseased Organs.** An Organ can be parasitized per E3.
- **Trophic Level Change.** Purchasing red or yellow Organs increases your *metabolic rate* (H6).
- **Landfall.** If you have a marine Macroorganism with all its Organs filled, automatically flip it to its **terrestrial** side and enter the terrestrial ecosystem per H6. All cubes for Organs and all disks for Vitamins and Antioxidants are lost to the soup. All Bionts become either the Trophic Biont or an Endosymbiont.
- **Landfall with Parasites.** If your marine Macroorganism has a Parasite, you can count its Diseased cubes as Organ cubes when seeing if all your Organ slots are filled to go to the terrestrial side. If so, the Parasite loses these cubes, but continues as a Parasite.<sup>47</sup>



<sup>47</sup> Life has dwelled in the oceans for most of its history, but could it have originated in fresh water and then invaded the ocean? Oceans represent a stable and sheltered suitable for hatcheries, but for this very reason have proven to be an evolutionary backwater. Life emerged from the ocean during the Cambrian, but since that day hardly anything else has emerged. Why is there so much traffic returning to the ocean, such as eelgrass, turtles, crocodiles, mosasaurs, sea snakes, penguins, whales, etc., and so little traffic coming out? There are some indications that even fish, the paradigm of the seas, originated first in freshwater and then, after being tempered for harsh conditions, re-invaded the oceans. Could the very first life have done the same, emerging from the warm little ponds favored by Darwin? Unlike hydrothermal vents, terrestrial geothermal fields are "conducive to condensation reactions and enable the involvement of solar light as an energy source. Geochemical reconstruction shows the ionic (chemical) composition conducive to the origin of cells could not have existed in marine settings but is compatible with emissions of vapour-dominated zones of inland geothermal systems...The pre-cellular stages of evolution might have transpired in shallow ponds of condensed and cooled geothermal vapour that were lined with porous silicate minerals mixed with metal sulfides and phosphorous compounds." Prof. Mulikidjanian, 2012



**Example:** You create a sea star per **H5**. This Macroorganism has 2 red, 2 yellow, 1 green, and 2 blue system chromosomes, and you are endowing it with a Trophic Biont (yellow) and a kidney (green). However, all three marine Trophic Levels are full. At the bottom is seaweed, eaten by a *Dickinsonia protofungus*, eaten by an arrow worm.<sup>49</sup> Your sea star has the highest metabolic rate (5), followed by the arrow worm (3), the *Dickinsonia* (1), and the seaweed (0). Luckily for the seaweed, the *Dickinsonia* opts to pay for the emergency development of its missing 3 Organs, and becomes a terrestrial mushroom.

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<sup>49</sup> Digestion was born when some hapless bacteria suicidally produced the deadly enzyme hydrolase. Since this chemical fragments proteins into amino acids, nucleotides into sugars, bases, and phosphate molecules, phospholipids into their constituents, it tended to destroy any organism that made it. But eventually a bacterial mutant was born which survived hydrolase production by immediately ejecting it. This secretion gave the cell an advantage - the ability to externally digest organic materials in its neighborhood. Eukaryotes have a complicated internal cytomembrane structure allowing the envelopment and internal digestion of prey, thus becoming the first predators. The trick was to trap prey in a fold of the cellular membrane, and pinching it off so that it became a mini-cell within the eukaryote cell.

## I. GAME END & VICTORY

The game ends at the end of the last turn of the Proterozoic Event Deck, or when *Armageddon* occurs (**D10**).<sup>50</sup>

### 11. VICTORY POINTS

- **Cube VP.** Each cube on your Organisms (Bacteria, Parasites, Macroorganisms) and their Mutations is worth 1 VP. Your *system chromosomes* (**H3**) are 1 VP each, just as if they were actual cubes.
- **Biont VP.** Each Biont of your color in an Organism earns you 1 VP, even if it is in an Organism owned by another player.
- **Trophy VP.** [ADVANCED] Each trophy (the cards and placards of Extinct Organisms) held by a player is worth 1 VP.
- **Trophic Dominance VP.** [ADVANCED] Each Macroorganism is worth 6 VP extra, or 12 VP extra if it occupies the highest *Trophic Level* (**H6**) (relative to other Macroorganisms) in its ecosystem (land or sea). However, any Macroorganism that has multiple Bionts splits the Trophic Dominance VP it achieved equally among each player with at least one Biont present.
- **Tiebreaker.** In case of a victory tie, the one with the most Catalysts is the winner. Further ties is a shared victory.

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<sup>50</sup> The Precambrian ended with the so-called “Cambrian Explosion”, the brief evolutionary radiation that produced most of today’s animal phyla. The fossil evidence is found especially in the Burgess Shale in Canada. The late Steven J. Gould interpreted these fossils as “weird wonders”, failed experiments unrelated to any living organism. Since then, Cambrian fossils from China and Greenland indicate that the weird wonders were actually very modified members of today’s kingdoms. For instance, *Opabinia* (card 13) seems to be a lobopodian close to the velvet worms and possibly the arthropods. However, Gould’s interpretation of life as a dense bush of mostly failed experiments may have been more accurate for early unicellular life. The game’s extinction rules represent setbacks which kills-off only those creatures with overly complicated genomes, leaving behind their not-so-specialized relatives just barely below the error threshold.

**Example:** You have one marine seaweed being eaten by another player's herbivore. Since it is not the highest Trophic Level, it receives 6 VP. It has a green Endosymbiont, so both you and *Player Green* receive 3 VP. Seaweed has 4 system chromosomes, worth 4 VP. It has one Organ (leaves), worth another VP. It has your Trophic Biont, plus a green Biont (endosymbiotic chloroplast), each worth 1 VP to their owners. Your total VP =  $6/2 + 4 + 1 + 1 = 9$  VP. *Player Green* earns  $6/2 + 1 = 4$  VP for your seaweed.

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

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

- **Events.** The IDP (interplanetary dust particles) and DHB (deep hot biosphere)<sup>51</sup> appear from the heavens.
- **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.<sup>52</sup>

**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.

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

52 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).

- **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 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."

- **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.*

- **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.
- **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.*

- **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 (1<sup>ST</sup> ARCHEAN CARD):** "For dust thou art, and unto dust shalt thou return."

- **Events.** None.
- **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 as Player Blue need the least.*

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



#### 14. LATE HEAVY BOMBARDMENT 🌍 + SUPERCONTINENT UR 🌞: "Life on Mars".<sup>53</sup>

- **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.<sup>54</sup> The warm pond and tholin storm clouds appear on the earth.
- **Assignment.** Green sends both unassigned Bionts to the newly created warm pond. Blue patiently stays on Mars.
- **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).
- **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.

<sup>53</sup> The idea that organic material or life itself could have seeded the Earth from outer space is called panspermia. 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.

<sup>54</sup> 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?

- **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."

- **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.
- **Assignment.** Blue assigns both unassigned Bionts to the warm pond. Green leaves one of his Bionts in the warm pond, but moves the other to geothermal zinc.
- **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.
- **Darwin Roll.** Blue's Mars-Bug rolls (1,2,3,4,4,6), finally generating a Catalyst (red). Green's Organisms remain unchanged.
- **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.<sup>55</sup> Green purchases the RNA Ribozyme Mutation for his PNA Bacteria.



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<sup>55</sup> 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 Linear-banckceramik 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 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 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.

## J6. HURONIAN SNOWBALL ❄️: “The amyloid pioneer falls.”

- **Events.** Again, all lifeforms have protection against the  event. The hydrogen volcano and eutectic brine continent Refugia appear on earth.
- **Assignment.** Green is first and reassigns his Biont in the warm pond to the fresh brine. Blue sends both Bionts to the IDP.
- **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.
- **Darwin Roll.** Green rolls poorly (5,6), finally losing his amyloid-life (but is compensated a green disk).
- **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.”

- **Events.** The  event kills off the PNA's only (expensive) Mutation. The hydrothermal vents appear from the heavens.
- **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.
- **Autocatalytic Rolls.** Blue gains two more catalysts in the IDP. Green gains three Catalysts (1 green & 2 red).
- **Darwin Roll.** All is steady.
- **Purchases.** Tired of being trashed by  events, Green buys the ribosome RNA Mutation for his PNA.

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

- **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.
- **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.
- **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.
- **Darwin Roll.** All is steady.
- **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. TAURI SUPER FLARE (1<sup>ST</sup> PROTEROZOIC CARD): "The Red Queen becomes a Red Wedding."

- **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 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 disease cube in the Parasite.
- **Assignment & Autocatalytic.** Green has all his Bionts assigned to lifeforms. Blue reassigns to the hydrothermal vents with both Bionts, and organizes one green Manna.
- **Darwin Roll.** No changes.
- **Purchases.** The Host seizes the remaining Diseased cube (blue) from the Parasite in a Red Queen fight.

### J10. OCEAN OVERTURN : “Pollution deliberately used as an antibiotic.”

- **Events.** The Canfield Ocean removes a Manna from everything except the immune ones (events & cosmos). The Canfield Ocean removes a Manna from everything except the immune ones (events & cosmos). The “UV limit one” event removes one of the Mars-Bug mutations.
- **Assignment & Autocatalytic.** Deep in the vents, Blue gains two Catalyst (green & yellow).
- **Darwin Roll & Purchases.** The Parasite buys a Red Queen Mutation (riboswitches) and the Host buys chloroplast symbiont, which has pollution. Having two **green Chromosomes**, the Host creates a double-spike pollution. The polluted salmonella loses its new riboswitches.

### J11. NITROGEN FAMINE : “Sterile Earth.”

- **Events.** The triple smite kills a majority of earth’s Refugia. Lacking heat shields, the PNA Bacteria loses a **blue Chromosome**, and the Parasite is killed off.
- **Assignment & Autocatalytic.** Deep in the vents, Blue gains a yellow Catalyst from Biosynthesis.
- **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 separated by just 2 VP! Each wooden piece is worth 1 VP; Green has 6 tokens on his two lifeforms and Blue has 7 tokens on her single lifeform. However, this will suddenly change. Blue purchases a game-winning Mutation (mitochondria) with the fission Ability for the Mars-Bug.

### J12. CRYOGENIAN SNOWBALL ❄️ : “Armageddon!”

- **Events.** Snowball Earth! This is the fourth cold sun in a row, and both players decline a Gaia vote, so the game will end after this turn. The multimers lose a **blue Chromosome** to the double 🌀 spike.
- **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).

- **Darwin Roll & Purchases.** The Host uses its fission Ability to make a double Red Queen attack, stealing back both Diseased cubes from the Salmonella. The Host then upgrades mitochondria to ATP Synthase and chloroplast symbiont to cytoplasmic streaming, with the resulting oxygen pollution killing the salmonella. Green purchases the Calvin cycle Mutation for PNA, and mRNA (using chemoselectivity) for the thioester-life.
- **Ending Score.** The game ended 7 events early, with the Earth still at the bacterial stage. In a major upset, Blue wins with 14 VP; 10 VP on her Mars-Bug ex-Host and 4 VP on the newly arisen vent-bacteria, while Green only has a total of 6 VP on his two surviving lifeforms and 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 MEGAFUNA<sup>56</sup>

If you have the successor game **Bios Megafauna** (either the 1st or not-yet-published 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.

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

The second edition of *Bios Megafauna* includes rules for starting with your existing Macroorganisms. If using the first edition *Bios Megafauna*, set-up is per **Part C** except:

- **Player Color Assignment.** The player with the highest VP Macroorganism gets to choose the player color, after viewing the biome set-up on the map (**3.5**). Players without any Macroorganisms choose last. In case of a tie, the higher overall VP score wins.
- **Convert Catalysts to Genes.** The player ending with the most Catalysts receives 5 genes, and the next most gets 4 genes, etc. (**3.2**). Ties receive equal numbers of genes.

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<sup>56</sup> **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<sub>2</sub>. Levels fell from parts per hundred to less than parts per thousand, leaving today’s plants literally gasping for breath. Furthermore, since CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> drops below this, the plants will suffocate and Earth will enter her second Age of Bacteria.

- **Endosymbiont.** For an accurate simulation, a Host and Endosymbiont should jointly play a side in the next game, perhaps taking alternate turns. Alternately, they each claim a meeple, with one being the predator of the other, and the Host taking the first pick.<sup>57 58 59</sup>

**57** Bios:Genesis covers the first four billion years of Earth, and Bios:Megafauna covers the next half billion years, called the Phanerozoic Eon. 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, will cover 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. 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.

**58** In his engaging book "The Vital Question", Nick Lane provides the evidence that all features of macroorganisms, including the eukaryotic nucleus, morphological complexity, sex, large size and genomes, and multicellularity, started with the serendipitous chimera of an archaeal host and its bacterial mitochondrial endosymbiont. The mitochondria multiplied the available energy per gene to the point that 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.

**59** 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.



## GLOSSARY

Definitions of underlined game terms and (in italics) their biological analogues

**Ability (H4).** Icons on Mutations, Organs, and Endosymbionts indicate abilities of the Organism, beginning the turn after the Mutation, Organ, or Endosymbiont is created. Abilities include:



**Syringe.** Control token discard order, see Immunology (**Glossary**).



**Heat shield.** Indicates shielding from Extremophile event-induced atrophies (**D5**).



**O<sub>2</sub> shield.** Indicates shielding from oxygen spike-induced atrophies (**D6**).



**Cancer shield.** Cancer atrophies are generated on '6' instead of a '5' or a '6' (**D8**).



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



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



**UV Shield.** Blocks UV Radiation (**D7**).



**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 (**H1**).



**Nucleus.** May consider your Catalysts to be able to change into any color (**H**).



**Sex.** Before buying a Mutation, you may roll a deck (**H1**).



**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. This is the stuff of Metabolism, 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.

**Antioxidants (E5).** 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 (**E5**).

**Note:** By being oxidized themselves, Antioxidants sacrificially inhibit the oxidation of other molecules, which would otherwise release destructive free radicals.

**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 (**D6**), each Antioxidant or Vitamin may be discarded, 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 is unaffected 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 (**E3**), 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 (F0).** A roll representing the success or failure of a Biont in a Refugium to maintain itself and produce Catalysts.

**Note:** Autocatalysis is a reaction which maintains organized populations by yielding a reaction product which is itself the Catalyst for that reaction.

According to wikipedia: "Autocatalytic sets also have the ability to replicate themselves if they are split apart into two physically separated spaces. Computer 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."

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

**Life is divided into three domains:** *Archaea, Bacteria, 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.



**Biont (B4).** 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.

**Note:** The biological term for a Biont is 'progenote', denoting a hypothetical preprokaryotic organization in cellular evolution, earlier than the last common

ancestor (currently thought to be a prokaryote rather than a preprokaryote).

**Biosynthesis (B4, F2, G2).** Generation of Catalysts from the soup to the pool of the tableau you reside in. This can be from an Autocatalytic Roll (F2), a Darwin Roll (either protein dice or triples, see G2), or in compensation (B4) for a Biont lost by Manna death, Atrophy, or Extinction. The number of Catalysts you can have unassigned for each color is limited per (B3). 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.

**Macroorganisms have a special biosynthesis.** For every '1' rolled during a cancer roll (D8), 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 (F3).** A cube or Biont token on an Organism or its Mutations indicating genetically stored properties and shielding (D5, D6, 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).

**Note:** This threadlike cell structure of nucleic acids and proteins contains genetic information in the form of genes.

**Darwin Roll (G0).** A roll testing the capacity of a Microorganism to replicate an imperfect copy of itself into the next generation. 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.

**Disease (G0).** 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.

**Note:** Biologically, a disease is a microorganism which has commandeered a particular biological function for its own gene-spreading purposes.

**Endosymbiont (H3).** A special type of Foreign Gene Biont on a Macroorganism. It often confers shielding or immunology to the hybrid Organism, as indicated by the icons on the Macroorganism card. An Endosymbiont is able to make a purchase for the Organism it resides in, using the Organism's Catalysts. Endosymbionts are formed whenever a new Macroorganism is created containing multiple Bionts, including Parasites and Foreign Genes.

**Note:** The 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).



**Entropy (E2).** 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.

**Note:** 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.



**Enzyme (E1).** 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.

**Note:** Biologically, an enzyme is a large (usually protein) catalyst used in metabolism.

**Error Catastrophe (G3).** 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).

**Note:** 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 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.

**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. 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 (B4).

**Extinction, Microorganism.** Discard its Mutations to the bottom of the Mutation deck in its home row. All 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 or Bionts that were on the Macroorganism. All its parasites (along with their disease cubes) become extinct.



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

**Note:** *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.*

**Foreign Gene (F4).** 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, fission, and chameleon), as long as these Abilities were available from the beginning of the turn.

**Note:** *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 (D10).** A special procedure by which players can cooperatively nullify an event that would destroy all life on Earth (Armageddon).

**Note:** *The idea that Microorganisms cooperate as a superorganism to keep the Earth habitable is called the Gaia hypothesis, 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.*

**Heredity (E6).** 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.

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



**HGT (E6).** Abbreviation of Horizontal Gene Transfer, 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.

**Note:** *Biologically, 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.*

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

**Hyperparasite (E3).** A Parasite of a Parasite.

**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 (D7). 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 (E6).*

**Landform (D2).** A card in a column of four cards indicating a particular location. From uppermost to lowermost the four Landforms are cosmic (meteor icon), oceans (waves icon), coastal (shore icon), and continents (mountain icon). 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.

**Note:** *Each landform transports 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.*

**Macroorganism (H3).** A special kind of Organism, formed by placing 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.

**Note:** *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 collectivism rapidly expanded into today's macroscopic eukaryote world of fungi, plants, and animals.*

**Manna (F1).** 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.

**Note:** *These building blocks came from preformed organic products of abiotic syntheses, and included energy-rich inorganic pyrophosphate or polyphosphates, and thioesters.*

**Metabolism (G2).** 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).

**Note:** *The 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.*

**Microorganism (F3).** 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.

**Note:** *Biologically, it's an individual single cell with the four properties of life including templated replication.*

**Mutation (H1).** 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 as 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 its non-promoted side. 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.

**Note:** *A mutation is an alteration of a gene, transmissible by replication. In this game, all the unpromoted mutations are from pre-RNA or RNA replication.*



**Nucleotide Bases.** 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.

**Note:** *Each 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).** A Chromosome cube on a Macroorganism. Some Organs confer the shielding

(D5, D6, or D8) 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.

**Note:** *An 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.*

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

**Note:** *The organism is the target of 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.*

**Oxygen Crisis (H3).** 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.

**Note:** *All cells, even those living in high oxygen habitats, have highly reduced cell interiors and cytoplasm. 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.*

**Parasite (E3).** 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 (E3) for Host suitability. A Parasite steals one or two 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 (H2) or become an Endosymbiont. However, it can also be supplanted (E4) by a better adapted Parasite.

**Note:** *Because parasites have fewer than the four properties of life, 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.*



**Red Queen (H4).** 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.

**Note:** *This term 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.

**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.



**Specificity (G1).** The admittance discrimination of a cell membrane, one of the four properties of life (Player Yellow).

For every yellow Chromosome you have, you may re-roll one Darwin dice.

**Note:** This discrimination allows it 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 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).

**Trophic Level (H3).** 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.

**Note:** 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.

**Trophic Biont (H3).** 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 **D5**, and the green Trophic Bionts, Organs, and system Chromosomes impart Antioxidant shielding per **D6**. The blue Trophic Bionts, along with Organs, and system Chromosomes, impart Error shielding per **D8**.



**Vitamins (E5).** A green Catalyst disk placed on an Organism to add to its Antioxidant shield during an oxygen spike attack. Unlike other Antioxidants, they are not expended by an Oxygen Spike.

**Note:** Biologically, a vitamin is an essential substance that an organism is unable to synthesize and must find in its food.

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Rules in German, French, Spanish, and Japanese can be downloaded in the download section of [www.sierra-madre-games.eu](http://www.sierra-madre-games.eu)

## ICON REFERENCE

### PHASE 1 : EVENTS (D)



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

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**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 bottommost 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)

## ICON REFERENCE (CONTINUED)



**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 : AUTOCATALYTIC 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 roll 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.