# Bios:Genesis (living rules, all editions)

**OBSOLETE**: Instead See:
https://assets.adobe.com/id/urn:aaid:sc:US:cc74c182-95f3-41e0-8864-b3e84dd0cd0b?view=published

**The First Game in the Bios Trilogy.**

**A card game of the origins of life for 1 to 4 players.** Updated: Feb 24, 2020. InDesign Updated 22.06.2021

 1st edition published: Oct. 2016, 2nd edition published Oct. 2017.

Red font = changes from 1st edition, purple font = changes since 2nd edition, 1st printing. Green font = changes since 2nd edition, 2nd printing.

Vassal Module: Sam Williams http://www.vassalengine.org/wiki/Module:Bios:_Genesis

TableTop Simulator: Samuel Williams

https://steamcommunity.com/sharedfiles/filedetails/?id=1808505929

Spanish Translation: Manuel Suffo **BIOS: GENESIS. EJEMPLO EXTENSO.**

**Card errata:**

**2nd edition Extremophile Condensation placard:** Disk color should be red instead of yellow, as shown on the reverse (DHB) side. (Issue was fixed in 2nd edition 2nd printing). The disk color for triples should be red - it is still yellow in the 2nd edition 2nd printing

**2nd edition Pangea Breakup: Cosmic** is in boldface and *Oceanic* is grayed out, contradicting the inactive and active states of their respective symbols. The refugium activity state is correct (Cosmic inactive, Oceanic active). (Issue was fixed in 2nd edition 2nd printing)

2nd edition: **Calvin cycle** mutation card provides green mutation cube, but has a red background. Should be green. No effect on gameplay. (Issue will be fixed in 2nd edition 3rd printing)

## EXPERIENCING THE ORIGINS OF LIFE, by Ryan Spangler

Ambitious? You will try to capture the entire conception and evolution of life over the first 4 billion year history of our planet. And not just throw some cards and tokens around with molecular art, but actually express the dynamics and relationships of life struggling to find purchase in a hostile world. I love this designer. The sheer audacity makes the whole thing that much greater, because he actually does it. This is as close as you will get to being a biological compound evolving over 4 billion years of geologic time.

What is *Bios:Genesis*? Here is a sketch:

1. **Draw Event Card:** Terrible things happen (also, refugia come out).
2. **Assignment:** "Bionts" and catalysts to refugia and elsewhere (you haven't heard of bionts? It's because he made up this word. That is actually not true, I just checked. It was already a word! Just not a word anyone has ever used before. All hail the biont!). You can also assign a biont as a parasite, which turns out to be super-significant once you have figured out what is going on with just normally playing the game.
3. **Autocatalytic Roll:** Roll dice for each refugium to see if you organize or disorganize the manna (or both!). Organized manna contribute dice, but disorganized manna give you catalysts (which you can assign as enzymes to prevent disorganization). If you roll doubles, you can take it as an organism! Flip it over and distribute all the colored cubes into the colored spaces. This is now your organism.
4. **Darwin Roll:** Roll a bunch of dice for each of your organisms to see how screwed they are, or if they metabolize anything useful during this 200 million year period of earth's history.
5. **Purchases:** Each biont can make one "purchase", which is either getting a mutation, evolving a mutation, attacking parasites (or attacking the host if you are a parasite!), or becoming a macroorganism! As a macroscopic worm or bug you can start purchasing organs...

That's it! Simple, really. You roll a lot of dice, hang out in the Green Rust Fumarole, and create life. Enjoy your world!

## WHAT'S THIS GAME ABOUT?

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

The **Event Phase** starts the turn. Each event card encapsulates 200 million years, and the game may last 20 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**, you and your opponents 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 an **HGT** (horizontal gene transfer) Mutation, you may move your Bionts from one Microorganism to another. You always have at least one Biont available to assign to Refugia or to a Parasite, unless all of your Bionts are already employed inside Organisms.

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

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

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

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

---

[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 exact 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 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.

each excess error.

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

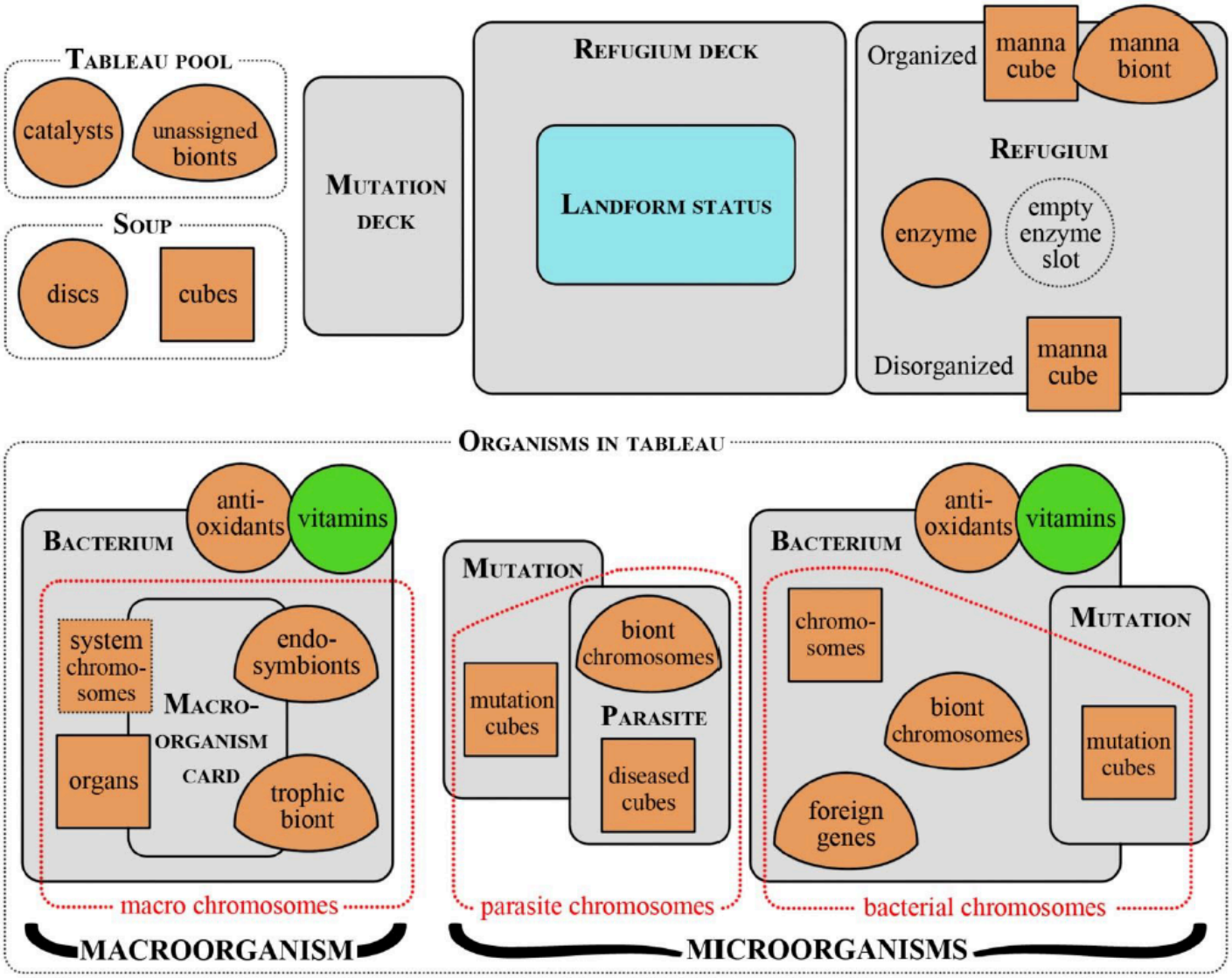
Each player maintains a Tableau, and a pool of Catalysts tied to that Tableau. Each Biont in an Organism, even ones belonging to other players (Parasites, **Foreign Genes**, and **Endosymbionts**), may make one expenditure per turn for that Organism, all using the same pool of Catalysts in the Tableau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

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

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

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

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




## A. BIOS:GENESIS SEQUENCE OF PLAY (five phase per turn)[4]

Apply each of the 5 phases to every player before proceeding to the next phase. ~~For all phases except the first, the players complete the phase in the specified order before proceeding to the next phase~~.

**A1. EVENT (Part D).**

a. **Turn over the next event card**.
b. **If a Landform is dimmed**, flip its card to its inactive side and the others to their active side. *Roil* Mutation decks next to active Landforms (D2b).
c. **Events**. Apply from left to right each of the card's event icons to all players (D3 to **D10**). If it is an *aftershock* (D1a), apply from left to right the aftershock card, summing any X or $O_2$ events from all cards per D5 and D6, and then from left to right the next card's event icons as well.

**A2. ASSIGNMENT (Part E) in Player Order (A6).**

a. **Refugia**. In any order, assign your Bionts (domes) and Catalysts (disks) to occupy active or home Refugia (E1). You are normally limited to just one Biont that can be assigned to Refugia, although this limit can be increased by having a lifeform with Entropy (E2).
b. **Parasites**. Assign your Biont to start a new Parasite *attached* to a suitable Host (E3), or *supplanting* an enemy Parasite (E4).
c. **Antioxidants**. Assign Catalyst disks on Organisms as *Antioxidants* or *Vitamins* (E5).
d. **HGT**. Move Bionts from one Microorganism to another using *HGT* (E6).

[4] ABIOGENESIS is the term for the origins of life from non-biological processes and inorganic ingredients. "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.

**A3. AUTOCATALYTIC ROLL (Part F) in row by row order per F0.**[5]

Make an *Autocatalytic Roll* using a number of dice = number of organized Manna (cubes) on the Refugium, plus two dice for each Biont (domes), either friendly or enemy. Only one roll is made per Refugium, even if multiple players occupy it.

a. **Life.** Use this roll to see how many Manna become organized (F1).
b. **Death & Biosynthesis.** Then use the same roll to see how many Manna become disorganized. Each one disorganized *creates* one Catalyst (Biosynthesis F2b).
c. **Darwinian Life Creation.** If you rolled doubles, you may (optionally) take the placard into your Tableau flipped to its Bacteria side. If you take it, use all tokens in the organized row as Chromosomes or Foreign Genes. Enzymes are lost to the soup (F3).

**A4. DARWIN ROLL (Part G) in Player Order (except Parasites roll immediately after their Host).**

Make a *Darwin Roll* for each **Microorganism** (including Parasites) using a number of dice = number of Chromosomes on the Microorganism and its Mutations, except that each Biont rolls two dice instead of one.

a. **Specificity Re-roll.** You may modify the roll by making one re-roll of a number of dice up to the number of the Microorganism's yellow Chromosomes (G1).
b. **Catalyst Creation.** For each '1' rolled, or triplets rolled, create a certain number of Catalysts through *Biosynthesis* (G2).
c. **Atrophy.** If the number of 5's and 6's in the roll > Heredity, the Microorganism suffers a number of Atrophies (Chromosome losses).
d. **Extinction.** If it runs out of Bionts, a Bacterium dies but is preserved as a trophy, while a Parasite also dies but its card is returned to its owner. See EXTINCTION.

**A5. PURCHASE (Part H) in Player Order (except Parasites purchase immediately after their Host).**

a. **Limit**. Each player may make one purchase for each of his Bionts, for the organism the Biont resides in.
b. **Purchase**. You may purchase a new *Mutation* (H1), *Mutation promotion* (H2), *Macroorganism* (H3), *Red Queen* (H4), or *Organ* (H5).
c. **Cost**. The cost is one Catalyst of a color matching the color of the card or cube affected (exception, you may use any color Catalyst to purchase a Macroorganism card).
d. **Chemoselectivity.** You may spend 2 Catalysts of the same color in place of any other color Catalyst.
e. **Exchange Medium.** The Catalyst for the purchase comes from the pool that the organism resides in. So Parasites spend from the tableau pool of their Host.

**Then go to the next turn. Two hundred million years have passed.**[6]

---

[5] CHICKEN VS. EGG PRIMACY? 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 macromembranes 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 is protected by a protein blanket and by being twisted into chromatin. —Freeman Dyson, 1999.

[6] LIFE, as defined by NASA 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 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 aylife). 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).

**A6. PLAYER ORDER**

On each event card, just above the event icons, is a row of four colored icons. For *aftershock events* (**D1a**), 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.

a. **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.

b. **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 in that phase (then proceed in Player Order with the next player the color of the leftmost icon, remembering that parasites purchase after their host). 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).

c. **Parasite Exceptions.** During **Phase A4** (Darwin Rolls) and **Phase A5** (purchases) a parasite acts immediately after its Host.

d. **Pass.** During **Phase A2** (assignment) or **A5** (purchases), a player may elect to do nothing.

# B. COMPONENTS

**12 wooden domes** represent **Bionts** (16 in 2nd edition). 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.[7]

**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)[8] and blue = nucleobases.

***Easily missed rule**: 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)[9], 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**.

**1 Folding Player Aid** (2nd edition).

**B1. TABLEAU MANAGEMENT**

An **Organism** is a Bacterium, 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)

---

[7] 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 prokaryotic cells as organelles).

[8] 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, leading to the RNA world.

[9] 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 $CO_2$ or too hot as the sun gets hotter, the prokaryotes will rule once again.

the cards for their Parasites (which belong to other players).

a. In your Tableau, you can have up to 4 Organisms. Each Organism can have a single Parasite (which belongs to another player) along with 1 or more Hyperparasites (which belong to any player).
b. Your Tableau also contains your Catalysts, from which you (or the Parasites you host) make *purchases* (**H**).
c. 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.

a. Return all cubes lost in the game to the soup.

**B3. DISK LIMITS**

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

a. **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 that produces Catalysts during *Darwin Rolls* (**G**) adds to this pool.

***Note:*** *For your Parasite, you must pay using the host's Catalysts.*

b. **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.*

c. **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.
d. 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 **E2a**) and any number assigned to Organisms.

a. **Compensation Biosynthesis.** Whenever one of your Bionts is returned to your pool as a result of *Manna death* (**F2a**), Atrophy, or Extinction, add one Catalyst of your color to your pool as **compensation**. See **B3b** for limits.
b. **Compensation Exceptions.** Bionts moved to another Organism (e.g, a Trophic Biont is lost), or moved by HGT to your pool, are not compensated.

# C. SETUP

a. **Player Color.** Each player is randomly assigned a color. He receives the three or four (see **B4**) 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).
b. **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**.
c. **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.
d. **Event Deck.** Separate the 24 event cards (hereafter 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[10], leaving 3 remaining. Place the Proterozoic Deck on the bottom, then the Archean, then Hadean. [11] Remove the bottommost card without looking at it, so that the Proterozoic has only 10 cards.

---

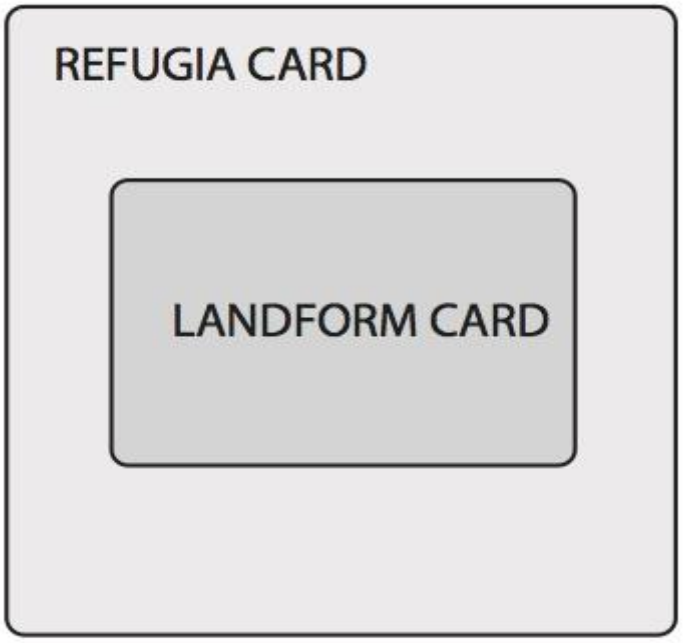
[10] HADEAN EON is the earliest segment of Earth's history, beginning when it was freshly accreted and lasting 600 million years. "Hadean" suggests hell on Earth, with a sky streaked with meteors, floods of lavas from the thin unstable crust, bolts of lightning sparking the thin reducing atmosphere, 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.

[11] FOUR EONS divide the 4.6 billion year history of the Earth, as derived from geological stratigraphy and the fossil record. The game covers the

• **Optional Short Game.** Remove the bottommost 4 cards instead of 1 card.

e. **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, and the 5 continents at the bottom. All the placards have the Refugium side up.

f. **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 below. The Refugia under the Landform card are not yet in play.




g. **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.

h. **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.

i. **To start the game**, reveal the first event per **Part D**. The *first player* is per **A6**.

**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*, **B3b**).

a. **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 the more difficult **terrestrial win** by ending with a marine win plus at least one terrestrial Macroorganism with both colors of Bionts. The victory must be achieved before Armageddon if it occurs.

b. **Parasite AI.** Each of the two colors not chosen uses a single Biont to enable it's associated Parasite as a non-player controlled (NPC) organism. During setup both NPCs start with their respective Parasite card. 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 (whereupon it becomes an ally you can use to make purchases). During each NPC Parasite's assignment phase, a random side of the NPC Parasite will try to attach to the Host that will give it the most allowed Diseased cubes (roll dice to break ties). Just as a standard

---

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).

parasite, if supplanted or goes Extinct an NPC parasite can come back into play starting next turn. However, it can't become a Hyperparasite.

c. **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.
d. **AI Purchasing.** The NPC Biont always 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.
e. **AI Specificity.** AIs will only use Specificity re-rolls to re-roll errors, starting with 6's.
f. **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.)
g. **AI Red Queen.** AIs always refuse Red Queen attacks if they can. They cannot themselves perform Red Queen attacks.
h. **Crystal Catastrophe**. Play with variant G4 (valid for both player and AI).

**C2. THE COOPERATIVE GAME**

Each player has only three Bionts (the fourth 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.

a. **Parasite AI.** The unused Biont of each player in the game is used to enable an NPC Parasite per C1b**,** except that NPC Parasites take their turns directly after the player of that color. Thus, in a three player game, there will be three NPC Parasites.

**C3. THE INTRODUCTORY GAME (solitaire or multiplayer)**

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.

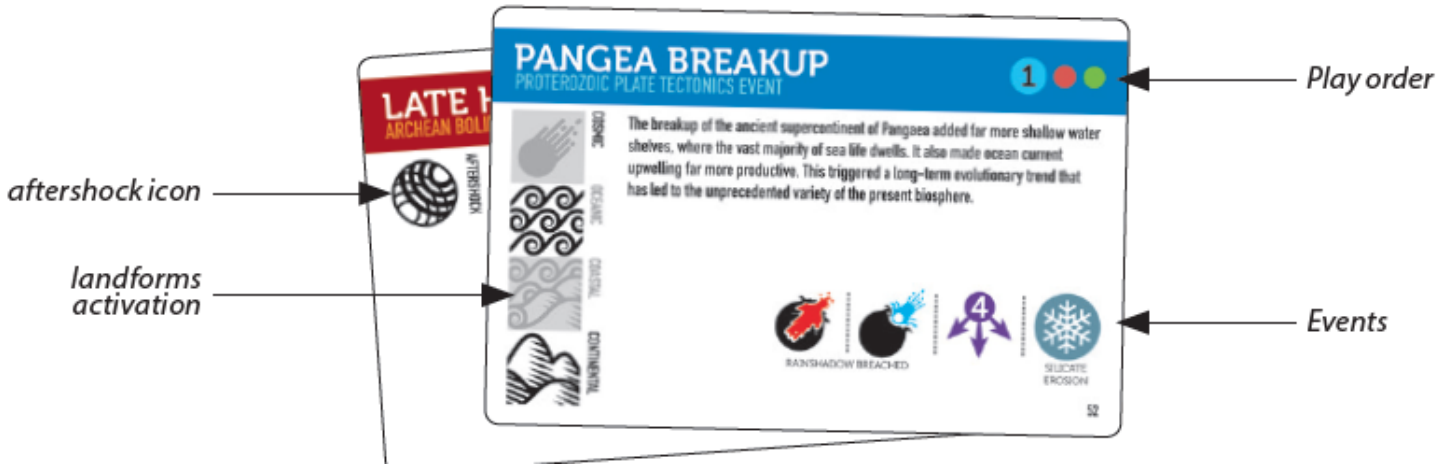
a. **Solitaire**. Ignore parasite AI and warming/cooling cycle. Win if you attain 10 VP (**I1**) or more.

**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. Events apply to all refugia and organisms, even in inactive landforms.



**D1. SPECIAL EVENTS**

These four types of events have special or enduring effects:

a. **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** for the icon resolution order.
*__Note:__ If the very last game card is an aftershock, use the player order and landforms of the previous turn.*

b. **Tropical Waterworld.** <advanced> After performing the tasks on this card (landform flipping and roiling), 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)[12], all *+earth events* (**D3**) skip over the continents row and go to the next active Refugia deck higher (therefore no roiling of continent Mutations or adding of continent Refugia), and a runaway greenhouse *Armageddon* (**D10a**) occurs with three suns instead of four. Remove the card and its effects (restarting plate tectonics) when the next aftershock occurs.[13]

c. **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.

d. **The Big Whack.** This aftershock has the special "Comet Shield" icon, which indicates that all Cosmic Refugia and Lifeforms are immune to the Theia Big Whack events (since extraterrestrials don't care if the Earth gets split into two pieces).

**D2. LANDFORMS AND ROILING (meteor, ocean, shore, and hills icons)**

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.

a. **Activation Effects.** An active Landform means that you can assign Bionts and Enzymes to Refugia in its row.[14]

b. **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... (+heaven and +earth icons)**

Each **+heaven icon** 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 icon** (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. The turn's (non-aftershock) event card will specify the active Refugia decks (**D1a**).[15]

a. **Setup.** Place all new Refugia as the new rightmost Refugia in the rows they came from.

b. **Dead Population**. Then take from the soup all the Manna indicated by the colored cubes and place where

---

[12] 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?

[13] LID TECTONICS is a stalling of plate tectonics with the formation of a stagnant lid punctured by volcanism. For the billion years dubbed the **boring billion**, lid tectonics 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."* —Professors Peter Cawood and Chris Hawkesworth, 2014

[14] INACTIVE LANDFORMS. 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.

[15] CONTINENTS & OCEANS. 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.

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 +heaven events occur, and the cosmic deck has one placard left. This last placard comes out, as well as the top placard in the next active deck down (the oceans deck).*

**D4. SMITE EVENT (Green sun icon)**

The **smite** event icon indicates a radiation surge that causes all Refugia (including inactive) 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.

a. **Deserted Refugium**. Should a Refugium ever be left without any Manna cubes, it is removed from the game, returning any bionts without compensation.
b. **Resiliency**. Three Refugia, marked on the placard with a **green shield icon**, are immune from the effects of smite crisis.

**D5. EXTREMOPHILE CRISIS (X icon)**

The **X icon** indicates temporary extraordinary temperatures affecting all Organisms. The number of **X**'s indicates the **extremity**. In the case of an *aftershock* (**D1a**), the extremity is the summation of the **X** events from all cards drawn in this event phase, 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 ATROPHY).

a. **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 ($O_2$ icon)**[16]

An **$O_2$ icon** causes an **oxygen spike attack** on all Organisms, with the number of **$O_2$** icons indicating its **extremity**. In the case of an *aftershock* (**D1a**), the extremity is the summation of the **$O_2$** events from all cards, and applied as soon as the first **$O_2$** 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.

a. **Organism Antioxidant Shield.**[17] 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.
b. **Atrophy**. During an O2 spike event, Antioxidants or Vitamins may be discarded instead of cubes or Bionts to satisfy Atrophy damages. A discarded Vitamin counts as a double shield.

---

[16] FIRST CHLOROPHYLLS were likely formed when some prokaryotes adopted light-absorbing pigments called porphyrins into their cell membranes. 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 directly 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 $O_2$ (this is called the Lomagundi-Jatuli Excursion). As $CO_2$ was replaced by $O_2$, anaerobic Metabolism was poisoned just as effectively as it had with the loss of the Urey-Miller reducing atmosphere in the Hadean.

[17] PROTEROZOIC, also known as 'The Age Of Oxygen', is the final era in this game. 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.

***Example:*** *The 'oceans rust out' aftershock event is drawn, generating two O2 spike attacks. A flatworm Macroorganism has one green system Chromosome and an Antioxidant disk. Since the O2 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. If the Antioxidant disk was green (i.e. a Vitamin), it would be part of the shield and survive.*

**D7. ULTRAVIOLET RADIATION (UV icon)**[18]

The **UV icon** contains a number from 0 to 4, indicating the **limit** to the 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.

a. **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.
b. **Order Lost.** You choose which Mutations or Organs are lost from your Organisms, except that, if the Organism has no Immunology (see IMMUNOLOGY), it must lose healthy Mutations before Diseased ones. Note that UV radiation does not cause Atrophies.
c. **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.**
d. **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 (crab icon) <advanced>**

For each **crab icon** that 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.[19]

a. **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'.[20]
b. **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 (drought icon) <advanced>**

If the **drought icon** appears, then every terrestrial Macroorganism suffers an Atrophy unless it has an Organ or Endosymbiont providing a **drought shield** (**H3b,d**).

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

---

[18] ULTRAVIOLET RADIATION from the sun is the principal source of high energy for protolife, but it is also the most destructive.

[19] CANCER. 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, 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 obediently each and every cell follows orders. —Randolph Nesse, M.D., 1994

[20] PCD (Programmed Cell Death) is occasionally used by bacteria to commit suicide if infected with a virus, so as not to infect their kin.

**D10. GLOBAL WARMING AND COOLING (red sun and blue snowflake icons) <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.

a. **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.*

b. **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 votes 'Gaia', those who have Catalysts and/or Organisms must either spend a Catalyst to the soup or suffer one Atrophy. This cancels Armageddon, and the game proceeds.

c. **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* (A6), 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* (E6e) only once during this phase. [21]

***Easily missed rule:** Once placed, a Biont can't be moved further this phase.*

**E1. ASSIGNING BIONTS AND CATALYSTS TO REFUGIA**

Assign one or more of your Bionts to a Refugium (or multiple Refugia) by placing it in its **organized** field. This is the upper field on the Refugium card. Respect *Entropy limits* (E2a) when assigning. You may assign one or more Catalysts to a Refugium as **Enzymes** by placing it in the leftmost unoccupied **Enzyme slot**.

a. **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 E2a. 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.

b. **Biont/Catalyst 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 (without compensation) from an active Refugium back to your pool.

c. **Catalyst Source.** Catalysts assigned as Enzymes come from your tableau pool.

***Easily missed rule:** Enzymes remain until enzyme death and organized Manna remain until manna death (**F2a**). Both are potentially*

[21] FOUR STAGES OF LIFE. 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 (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.

*removed via the smite event (**D4**).*

***Example:** At the start of the game, you assign your one available Biont and Catalyst to Mars. They survive the Autocatalytic 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 (**E2a**) 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.

a. **Entropy Limit.**[22] The number of your Bionts that you are allowed to have across all Refugia is limited, but 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. Count only the Organism with the most green Chromosomes.

***Easily Missed Rule**: If you have no organisms, you can only have 1 Biont in Refugia. If you have Bionts in a Parasite or an opponent's organism with green Chromosomes, it still increases the Bionts you can have in Refugia.*

***Note**: If you have more Bionts in Refugia than your Entropy Limit allows, you are never forced to remove any of them. Your Entropy Limit simply prohibits you from assigning more to Refugia.*

**b. Other Limits.** The number of Catalysts on a Refugium is limited to the number of Enzyme slots, or per **B3**. There is no limit to the number of Bionts on a Refugium other than the Entropy limit of the players.

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

**c. Deep Hot Biosphere.** For each Biont assigned to the Deep Hot Biosphere, spend a Catalyst to the soup (due to the high subterranean temperatures).

**d. Spore.** If any of your Bionts is in an organism having a Mutation with the **spore icon**, you may assign your Bionts 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 to different ones.*

**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 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).[23]

***Note**: The number of Bionts you assign to the Parasite is not related to the number of cubes you steal. Use the "open" biont circles on the card for installing Foreign Genes in the Parasite, not the Bionts assigned here.*

a. **Source.** Your Biont(s) can be taken from the places specified in **E1a**. See example below.

b. **Host Suitability.** Place the new Parasite to the left of its Host's card. The Host must be in the Tableau of another player (except in the case of a Hyperparasite) 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

[22] 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.

[23] 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.

become a Hyperparasite or *supplant* the incumbent Parasite in a foreign Tableau (**E4**).

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

c. **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.*

d. **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.

e. **Diseased Organ.** <advanced> If the Host is a Macroorganism, steal the Diseased cubes from *Organs* (**H5**). This disables any Ability icons.

f. **Pollution.** If the Parasite is a polluter, see **H1d**.

g. **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.

h. **Host Death.** A Parasite goes Extinct if its Host goes Extinct. See EXTINCTION.

***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 **E2a**. 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.*[24]

**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 new Parasite **liberates** the old one, 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.

a. **Supplant success.** The supplanting Parasite takes his Diseased cubes from the Mutation or Organ cubes of the Host and/or the Diseased cube of the incumbent Parasite. Supplantation succeeds if the supplanting Parasite now has more Diseased cubes per **E3c** than the incumbent Parasite did before being liberated. Accordingly, a Parasite with its maximum of two Diseased cubes can't be supplanted.

b. **Host Suitability.** Your Parasite can't supplant a Parasite that is attached to a Host in your Tableau, unless it is supplanting a Hyperparasite. See **E3b**.

***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 can't find a host elsewhere and 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. Player Red can choose to lose its only Biont only if it has 'immunology' or the Biont is the last Chromosome left on the card. For Atrophy loss order, see* ATROPHY.

[24] 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.

**E5. ASSIGNING A NEW ANTIOXIDANT**

You may assign one or more Catalysts as **Antioxidants** by placing each Catalyst directly on your Organism's ~~card or~~ placard (next to the Macroorganism card if present). This gives advantages during *oxygen spike attacks* (D6).

a. **Antioxidants.** Each red, yellow, or blue Antioxidant can be expended to deflect damage during a spike attack.
b. **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.
c. **Parasites.** These are not allowed Antioxidants or Vitamins.
d. **Terrestrial Macroorganisms.** <advanced> These are also not allowed Antioxidants or Vitamins (they usually don't need them).

***Easily missed rule.*** *Assigning Antioxidants occurs during Phase A2, not Phase A5.*

**E6. MOVING BIONTS VIA HGT (Microorganisms only)**

HGT is the only way to move or reassign a Biont from or to a Microorganism (e.g. from a Bacteria to a Parasite). 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**. You may move one Biont of your color for each **HGT icon** you have. 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). Alternatively, you can move your Biont into your pool (without compensation).[25]

a. **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 A6). 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.
b. **Extinction.** Note that HGT allows you to drive your Microorganism Extinct.
c. **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 your Parasite is commandeered, you regain control if your Biont returns, or if the Parasite goes Extinct. If more than one player's Biont remains, you choose whose Tableau it moves to.
d. **Macroorganisms.** HGT cannot be used to transfer to or from a Macroorganism.[26]
e. **No Double Move**. A Biont may not use HGT if it has been *assigned* (E1, E3) or used to *supplant* (E4) this phase.

***Easily missed rule:*** *Unless you have permission from the owner, the only microorganism you can commandeer is a parasite, since red queen attacks against them can steal their biont*.

***Example****: You have two of your Bionts in a Bacterium, and send one via HGT to Player Yellow's malaria parasite. You may place it in one of the two blank circles on the card (although a parasite may have any number of bionts). He cannot block this move because he has no HGT icons in any of his organisms, and thus is not as wanton as you. You then purchase a Red Queen against the malaria. It has no disease cubes, so you are allowed to steal the yellow biont as a foreign gene (**H4a**), commandeering the malaria.*

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

An **Autocatalytic Roll** is made for each Refugium occupied by one or more Bionts. Apply each roll in this strict order for

[25] CONJUGATION is an HGT process in which two unrelated bacteria can form a bridge between them to shuttle genetic material.

[26] HGT is not normally utilized by multicellular life, 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. For instance, a single cell of *E. coli* may contain 4000 genes, but its "metagenome" through HGT is more like 18000 genes. As much as 30% of the *E. coli* genome can vary, from the pathogenic strain to the useful gut symbiont strain. For all its promiscuity, HGT is piecemeal, unidirectional, and does not combine traits within populations. Suppose this rulebook were a microbe's genome. If rules were crudely inserted and removed from the rules of other games, that's HGT. Compare this to sex, the preferred eukaryotic means of genetic recombination. In sex, all the rules would be compared to all the rules of another copy of this game, with both copies a bit marked up according to gaming experience. The new rulebook would retain all the rules, with each rule randomly coming from one or the other copy.

results: F1, F2, and F3.[27] If the Refugium is *contested*, see F4.

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

c. **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.
d. **Inactive.** This roll is made even if the Refugium is inactive.

### F1. ANIMATION[28]

After the roll, consult the upper center of the placard. To the right of the **red sun** icon are the life dice for a *warm climate* (D10), and to the right of the **blue snowflake** 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.

a. **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 cube 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.[29] If the Refugium is *contested*, see instead (**F4**).

a. **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* (B4a). You choose which color.
b. **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. During Biosynthesis, for every full two Catalysts you cannot take because of the *pool limit* (B3b), you can substitute one Catalyst of any other color that does not exceed the limit.
c. **Enzyme death**. After Manna death comes Enzyme death. For each Enzyme death, the rightmost Enzyme is lost to the soup.
d. **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.*

---

[27] AUTOCATALYTIC CYCLES. 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 $FeS/FeS_2$ 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 an iron monosulfide mineral surface. Hydrogen is electron donor and the $CO_2$ is both an electron acceptor as well as a building block for biosynthesis.

[28] ANIMATION."Life behaves and evolves in such a way to preserve its existence. Non-life doesn't." This implies that life has metabolism and energy (otherwise it couldn't behave), reproduction (otherwise it couldn't evolve), and cellularity (otherwise it couldn't exist independently).

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

**F3. CREATION OF DARWINIAN LIFE**[30]

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 placard is now your **Bacterium**, a type of Darwinian life.

a. **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.
b. **Enzyme Cost.** All Enzymes on the card go into the soup.
c. **Bacterial Anatomy.** In a Bacteria's left edge is its *home row* (**E2**).

***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**).*

***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 Refugium, 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, and remains so for the entire phase.

**a. The progenote makes the Autocatalytic Roll, and the other contestants do not roll.**
**b. 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* (**B4a**). 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.*

c. **Origin of Darwinian Life.** If doubles were rolled, the progenote makes the decision whether to take the placard as Bacteria per (**F3**).
d. **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**.
e. **Ersatz Progenote.** If the progenote rolls doubles, and chooses 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 in 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.[31]

---

[30] TEMPLATES. 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.

[31] NATURAL DRIFT is evolution by random statistical fluctuations. It differs from the other driver of evolution, 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

a. **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.

b. **Order Of Dice Application (G4 Variant Only).** Resolve dice after re-roll from low to high, which means Biosynthesis is handled first and can be used to buy Mutations to cancel Atrophies.

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

***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.

***Easily missed rule:*** *Yellow Chromosomes are used only for Darwin Rolls, not for other rolls (e.g. Autocatalytic or Cancer).*

***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**[32]

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 to the tableau pool your Organism resides in.

a. **Color.** The Catalyst color earned by Bacteria Biosynthesis is indicated by the color of the disk shown by the "METABOLISM CHROMOSOMES" (upper left). For Parasite Biosynthesis, it is the color of the Parasite Card. You cannot take a Catalyst if the pool is at its *limit* (**B3b**) for that color.

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

***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 seven 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* ***B3b****.*

**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.

a. **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.[33]

b. **Macro Variant.** If using this optional rule (**C4**), Error Catastrophe occurs only on a 6 instead of 5 and 6, and the DNA icon *does* count as an error shield.

---

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.

[32] PHENOTYPIC EXPRESSIONS are the characteristics of life as 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.

[33] THE PERCEPTION OF DNA has risen over the past 60 years 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.

***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)**[34]

Life is messy. In this variant, Mutations are acquired only by suffering error dice. Therefore, purchases or promotions of Mutations do not occur during **Phase A5** (purchase). Instead, purchases or promotions of Mutations occur in **Phase A4** (Darwin Roll) as follows: If any uncancelled 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. Any reductions of error dice achieved by the purchase also are applied before suffering Error Catastrophe.

a. **Fissioning.** The fission (double purchase) Ability may be used to cancel two errors for two purchases instead of one.
b. **Using Error Dice Cancelation** to purchase/promote a Mutation counts as a Biont's purchase for the turn.

***Tip**: Having more than one Biont or Foreign Gene in an organism does not increase its mutation purchases, but it still increases the number of purchases in total, e.g. for red queen or becoming macro. It still allows Gene Transfer Agents of Catalysts between player colors, which is always super helpful in solo.*

***Example**: After re-rolls, your final error result during a Darwin roll is 2 errors. This allows you to purchase one Mutation to cancel one of the errors, but the second error would immediately Atrophy your new Mutation. This assumes that you don't have fission or immunology, and you didn't purchase a blue Chromosome that would block the second error.*

# 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).[35] The following general rules apply to all purchases:

a. **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.
b. **Order.** Purchases are in *player order* (**A6**), except a Parasite makes its purchase immediately after the purchases (if any) of all the Bionts in the Host (e.g. Foreign Genes).

***Example**: The red Tableau has a red Bacterium with a blue Parasite. The blue Tableau has a blue Bacterium with a red Foreign gene and a red Parasite. Player order is red, blue, so the purchases go in this order: Player Red Bacterium and Red Foreign gene (red chooses order), Player Blue Parasite (immediately after Red Bacterium since all genes have purchased), Player Blue Bacterium, Player Red Parasite.*

c. **The Chemoselectivity Rule.**[36] For any purchase, you may pay two Catalysts of the same color and consider them to be one Catalyst of any other color.
d. **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.

---

[34] 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).

[35] FIXATION. 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.

[36] CHEMOSELECTIVITY is high for a reagent if reaction occurs with only a limited number of different functional groups.

e. **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.[37]

f. **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.

g. **Gene Transfer Agents**[38] (multiplayer competitive games only). A Parasite player, Foreign Gene, or Endosymbiont can donate Catalysts to the tableau pool it resides in at any time. It must spend from this pool per **B3a**.

***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.*

**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).

***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.*

a. **Sex.** If your Organism has a sex ability mutation, before you make a purchase for this Organism you may *roil* (**D2b**) one Mutation deck in an active row or its home row. You may roil multiple times if it has multiple sex Abilities.

b. **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.

c. **Abilities.** The Abilities of newly purchased/promoted Mutations are in effect immediately, except for fission which is not active until the turn after purchase.

d. **Pollution.** If you purchase a Mutation or attach (**E3f**) 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).[39]

***Note:** Pollutants other than oxygen (e.g. methane etc.) are treated like oxygen polluters.*[40]

---

[37] PROKARYOTE MULTIPLICATION. 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).

[38] 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).

[39] POLLUTION is caused by all organisms. 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.

[40] BORING BILLION, the billion stagnant years in which the oceans were stratified, with a thin surface layer of green algae, and the depths

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

***Example (pollution):*** *An Organism with no green chromosomes purchases a blue tRNA mutation which is a methane polluter. Since it has no green chromosomes, the $O_2$-Spike extremity = 0 and no spike occurs.*

**H2. PROMOTING A MUTATION (Microorganisms only)**

By spending a Catalyst of the color of the unpromoted Mutation, flip it to its **promoted** side.[41]

a. **Second Mutation Cube.** Promotion adds one *Mutation cube* matching the new color (marked with a "+") on the Mutation, alongside the original Mutation cube.[42]
b. **You immediately lose any Abilities listed on its unpromoted side.**
c. **Pollution.** If the promotion is a "polluter", see **H1d**.

***Easily missed rule:*** *Any Abilities acquired by the purchase or promotion of a Mutation are immediately active, except for fission, which is not active until the turn after purchase. Abilities that appear only on the unpromoted side are immediately lost upon promotion.*

d. **Diseased**. You can still promote a mutation whose cube has been taken by a Parasite and is now diseased.

***Example****: Your Bacteria has the chloroplast symbiont, a green Mutation. It has been parasitized, so there is no Mutation cube on the card, but that does not matter. You spend one green Catalyst to flip this to its yellow-green side (cytoplastic streaming), and place a new yellow Mutation cube there.*

**H3. MARINE MACROORGANISM PURCHASE <advanced> (Bacteria only)**[43]

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.

a. **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 marine macroorganism, your Bacteria must have this number and color of undiseased 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.
b. **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* (**H5d**) without paying any catalysts.
c. **Trophic Level Entry.** The **pac-man icons** in the lower right corner are the three **Trophic Levels**. From lowest to

---

dominated by purple sulfur bacteria. Both bacteria used photosynthesis, but the greens split water (with oxygen byproducts) while the purples split $H_2S$ (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.

[41] MUTATION PROMOTION 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).

[42] FIRST LIFE. 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 protoeukaryotes 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 with primal role in protecting and orienting RNA and since lost in bacteria and archaea.

[43] AVALON EXPLOSION was a geologically brief period (575 Mya) in which the first known menagerie of multicellular forms evolved. 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. Recent (2021) findings hint that sponges existed 890 Mya.

highest they are **P** (= plants), **H** (= herbivores), and **C** (= carnivores). Put the organism owner's 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 **H6a**.[44]

***Easily missed rule:*** *The red Trophic Bionts, Endosymbionts, Organs, and system chromosomes impart heat shielding per **D5a**, the green Trophic Bionts, Endosymbionts, Organs, and system chromosomes impart oxygen spike shielding per **D6a**, and the blue Trophic Bionts, Endosymbionts, Organs, and system chromosomes impart cancer error shielding per **D8a**.*

d. **Parasites And Foreign Genes Into Endosymbionts**. When Bacteria becomes a Macroorganism, all Bionts it supports (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 **B4a**). 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.

***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.*

e. **Cascade.** A Hyperparasite becomes a Parasite of the Macroorganism (without Disease cubes) if its Host becomes an Endosymbiont.[45] This may create your own Parasite on a Macroorganism in your own Tableau.

f. **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.

g. **Oxygen Crisis.** If you are the first to create a Macroorganism, it becomes a *plant* (**H3c**) which accelerates 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).[46]

***Easily missed rule:*** *A Macroorganism no longer makes a Darwin Roll. Its purchases can only be for Red Queens (**H4a**) or Organs (**H5**).*

***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,[47] 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.*

**THE NUMBER OF CHROMOSOME CUBES NEEDED TO PURCHASE A MACROORGANISM**

---

[44] THE OCEAN WOMB. 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 migrated to become widespread in Earth's ocean, where it can form a food chain with other players.

[45] NEMATODES. *"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 massing of human beings there would be a corresponding massing 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.

[46] 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 $O_3$ 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 $O_2$ production, all the land $O_2$ 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.

[47] DICKINSONIA 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.

| Marine | Cubes Required | | | | total | Terrestrial | (Additional)Total Cubes | | | | total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Seaweed | | | 3 | 1 | 4 | Mosses | | | (1)4 | (2)3 | 7 |
| Flatworms | 2 | 1 | 1 | 1 | 5 | Earthworms | 2 | (2)3 | (2)3 | (1)2 | 10 |
| Lamp Shells | 1 | 2 | 1 | 1 | 5 | Snails | (1)2 | (2)4 | (2)3 | (1)2 | 11 |
| Arrow Worms | 2 | 1 | 2 | 1 | 6 | Eurypterids | (1)3 | (2)3 | (1)3 | 1 | 10 |
| Dickinsonia[46] | | 1 | 2 | 3 | 6 | Mushrooms | | 1 | (2)4 | (2)4 | 9 |
| Opabinia | 2 | 2 | 2 | 1 | 7 | Velvet Worms | (1)3 | 2 | (1)3 | (1)2 | 10 |
| Sea Stars | 2 | 2 | 1 | 2 | 7 | Amphibians | (2)4 | (1)3 | (3)4 | 2 | 13 |
| Trilobites | 2 | 3 | 2 | 1 | 8 | Insects | 2 | 3 | (1)3 | (1)2 | 10 |

***Note:*** *Terrestrial cube values include marine cube values.*

**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 (the **red crown icon)** to make a Red Queen purchase. Furthermore, it needs to have either the permission of the owner of the target organism or more Red Queen icons than the targeted organism.

a. **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).

b. **Red Queen against a Macroorganism Parasite.** <advanced> Steal one of the Parasite's *Diseased cubes* as a healthy Organ. If you don't have an empty organ slot of the right color to put it, discard 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.

c. **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 DISEASE.

d. **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).

e. **Trophic Level Change.** <advanced> After everyone has finished purchasing, check **H6a** 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 Mutation, 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 <advanced> (Macroorganisms only)**

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

a. **Shielding.** Some Organs and some Endosymbionts confer the *shielding* (**D5a**, **D6a**, or **D8a**) or other Abilities indicated by the bubble. Note: If a bubble points to two Organs, having either Organ gives you the Ability, and having both gives you the Ability twice.

b. **Diseased Organs.** An Organ can be parasitized per **E3e**.

c. **Trophic Level Change.** Purchasing red or yellow Organs increases your *metabolic rate* (**H6b**).

d. **Landfall.** If your marine Organism has filled all its Organs, as an automatic effect flip it to its **terrestrial** side and enter it into the terrestrial ecosystem. At this point, all cubes for Organs and all disks for Vitamins and Antioxidants are lost to the soup. All Bionts remain as either the Trophic Biont or an Endosymbiont. You may spend any extra Catalysts to establish terrestrial Organs (to help your newly-flipped land creature survive the next event).
e. **Landfall with Parasites.** If your marine Macroorganism has a Parasite, you must count its Diseased cubes as Organ cubes when seeing if all your Organ slots are filled to go to the terrestrial side. The Parasite's biont(s) then become Endosymbionts of the new Terrestrial organism and the Parasite card is returned to its owner.[48]

***Example**: A trilobite acquires the chitin cuticle organ (green), but then is parasitized by a prion that steals this cube. The trilobite then acquires the shelled egg, which fills all its organ spots except for the stolen green cube. This cube counts towards its organ repertoire, so the trilobite immediately flips to become a terrestrial insect. The prion is assimilated, becoming the defensin peptides of the insect.*

**H6. TROPHIC LEVELS <advanced> (Macroorganisms only)**

There are three Trophic Levels in the marine ecosystem, and three more in the terrestrial ecosystem. These three are carnivore **C** (at top), herbivore **H** (middle), and plant **P** (at bottom). Each level can hold only one Macroorganism, as indicated by the position of the Trophic Biont on each Macroorganism.

a. **Food Chains, Sea & Land.** The first Macroorganism to arrive at a marine or terrestrial ecosystem goes on the lowermost (plant) Trophic Level. At the end of each purchase phase that a Macroorganism is added, goes Extinct, or changes its red or yellow Chromosomes, rearrange the Trophic Bionts in order of increasing *metabolic rate* (next bullet), with the lowest metabolic rate being the plant. If two metabolic rates are tied, roll the dice to resolve.
b. **Metabolic Rate.** This is equal to the Macroorganism's number of red and yellow Chromosomes (including red and yellow *system chromosomes* printed on the card).
c. **Overcrowded Ocean.** If all three marine Trophic Levels are full and a fourth marine Macroorganism is created, all four Organisms are given an opportunity to go *terrestrial* per **H5d**.[49] In player order, each can spend any or all of its Catalysts to buy Organs if this is enough to go terrestrial (with extras going to establish terrestrial Organs). It can even count the Diseased cubes of its Parasite as Organs for this purpose. All of the Endosymbionts can contribute Catalysts for this purpose.[50]
d. **Extinction.** If either the ocean or the terrestrial ecosystems remain overcrowded, the Macroorganism with the lowest metabolic rate goes Extinct. If tied, roll the dice to resolve.

***Example**: You create a sea star per **H3**. 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.*[51] *Your*

[48] 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 environment 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. Mulkidjanian, 2012

[49] LANDFALL by macroorganisms seems to have first been accomplished by fungi, based upon one billion old fossils from the Proterozoic. The fossils indicate chitinous cytoskeletons. Fungi, unlike plants and animals, seem to have originated on land, living on organic material washed ashore.

[50] UV PROTECTION is easier in the ocean than on land. Ocean water is a screen for UV, and the intense UV radiation on land is still a leading cause of cancers today, even with the ozone layer in place.

[51] DIGESTION was born when some hapless bacteria suicidally produced the deadly enzyme hydrolase. Since this chemical splits proteins into amino acids, nucleotides into sugars, bases, and phosphate molecules, phospholipids into their constituents, it tends 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.

*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.*

# I. GAME END & VICTORY

The game ends at the end of the last turn of the Proterozoic Event Deck, or when *Armageddon* occurs (**D10a**).[52]

### I1. VICTORY POINTS

a. **Cube VP.** Each cube on your Organisms (Bacteria, Parasites, Macroorganisms) and their Mutations is worth 1 VP. Your *system chromosomes* (**H3a**) are 1 VP each, just as if they were actual cubes.
b. **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.
c. **Trophy VP.** <advanced> Each trophy (the cards and placards of Extinct Organisms) held by a player is worth 1 VP.
d. **Trophic Dominance VP.** <advanced> Each Macroorganism is worth 6 VP extra, or 12 VP extra if it occupies the highest *Trophic Level* (**H6a**) (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 (rounded down) among each player with at least one Biont present.
e. **Ties**. In case of a victory tie, the one with the most Catalysts is the winner. Further ties are a shared victory.

***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 (cold) *Failure below and success above.*

- **Events.** The IDP (interplanetary dust particles) and DHB (deep hot biosphere)[53] 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.[54]

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

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

[52] CAMBRIAN EXPLOSION is the brief evolutionary radiation that produced most of today's animal phyla and ended the Precambrian. 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.

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

[54] 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).

*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.*

• **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 (aftershock) + METEORIC ACCRETION (hot)** ***Life created on post-apocalyptic 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 survives. Lacking Metabolism or the possibility of triples, there is no profit in re-rolling a single dice.

**J3. TROPICAL WATERWORLD (the first 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 on access to space, I don't have to worry about Green contesting me there. Mars is a reasonable choice, with an assortment of all four colors of manna, and a favorable life-to-death ratio with modest investment. The Martian ocean won't last forever, but the first manna to go will be blue, the one I need the least (since I am Player Blue).*

• **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.

**J4. LATE HEAVY BOMBARDMENT (aftershock, hot) + SUPERCONTINENT UR** ***Life on Mars.***[55]

- **Events.** The aftershock ends a very short waterworld. The **XX** 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.[56] 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.
- **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 (hot)** ***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 assigns a Biont to the geothermal zinc. The other Biont remains in the warm pond.
- **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.** After a re-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.[57] Green purchases the RNA Ribozyme Mutation for his PNA Bacteria.

---

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

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

[57] SOFTWARE UPGRADE HYPOTHESIS. Are you old enough to remember the Betamax versus VHS wars? (If not, google "Videotape format war"). By the 1990's, almost all the videotape hardware produced was using the VHS format. Fast backward 7000 years, when the Linearbandkeramik culture of central Europe acquired agriculture, along with a 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, 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 (cold)** ***The amyloid pioneer falls.***

- **Events.** Again, all lifeforms have protection against the $O_2$ 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 by a green disk). His PNA life loses its only Mutation.
- **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 (cold)** ***Player Green versus the volcano.***

- **Events.** All lifeforms have heat shield protection against the **X** event. The hydrothermal vents appear from the heavens. [58]
- **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 rolls triple 2's and gains three Catalysts (1 green & 2 red).
- **Darwin Roll.** All is steady.
- **Purchases.** Green buys the ribosome RNA Mutation for his PNA.

**J8. VAALBARA BREAKUP (cold)** ***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. T TAURI SUPER FLARE (the first Proterozoic Card)** ***The Red Queen becomes a Red Wedding.***

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

---

[58] IMPACT ORIGINS OF LIFE. The 2016 discovery of fossil hydrothermal vents formed by the Chicxulub crater in Yucatan has led to speculation that perhaps life originated in an earlier impact-created hydrothermal system. The impact energy of the "dinosaur-stomper" bolide formed a 3 kilometer thick magma pool under the crater's center, This was surrounded by the peak ring of the crater, composed of fractured granite-like rocks and impact debris that were uplifted from a depth of approximately 10 kilometers by the impact. Hot water, at 300-400°C, percolated through this ring into the ocean. Here, microbial life might have gotten started, had the oceans been sterile instead of already filled by hungry microbes. However, the system lasted only 150,000 years, very brief given the game scale of 200,000,000 years each turn.

• **Assignment & Autocatalytic**. Green has 3 Bionts assigned to lifeforms. Blue reassigns to the hydrothermal vents with 2 Bionts, and organizes one green Manna.
• **Darwin Roll.** No changes.

**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 first degree UV ozone event removes one of the Mars-Bug mutations. At this point Mars-bug mutations were tmRNA <blue, diseased> and RNA Polymerase <red>. Lacking Immunology, the non-diseased Mutation is lost. A new coastal landform tectonically emerges.
• **Assignment & Autocatalytic**. Deep in the vents, Blue gains two Catalysts (green & yellow).
• **Darwin Roll & Purchases.** The Host buys chloroplast symbiont, which has pollution. Having two green Chromosomes, the Host creates a double-spike pollution. The polluted salmonella has 1 shield (its green Biont) and narrowly avoids Extinction.

**J11. NITROGEN FAMINE** ***Sterile Earth.***
• **Events.** The triple smite kills a majority of earth's Refugia.
• **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 tied at 7 VP! Green has 2 VP from Thioester Bacteria (green biont and red chromosome) + 4 VP from PNA (Biont, internal blue and green chromosomes, and red chromosome from a mutation) + 1VP from the dead amyloid. Blue has 7 Chromosomes on her single lifeform. However, this will suddenly change. Blue purchases a game-winning Mutation (mitochondria) with the fission Ability for the Mars-Bug.[59]

**J12. CRYOGENIAN SNOWBALL (cold)** ***Armageddon!***
• **Events.** Snowball Earth! This is the fourth cold sun in a row, and the players decline a Gaia vote, so the game will end after this turn. The thioester-life loses a red Chromosome to the double $O_2$ spike.
• **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. 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 12 VP; 8 VP on her Mars-Bug Host and 4 VP on the newly arisen vent-bacteria, while Green only has a total of 9 VP: 7 VP on his two surviving lifeforms, 1 VP from his Salmonella parasite and 1VP from his amyloid trophy.

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

[59] MITOCHONDRIA, an eukaryote invention, are the reason eukaryotes have been free to become extremely complex and large, while prokaryotes have remained small and morphologically simple. Mitochondria are the sites of ATP synthesis, and lacking these, prokaryotes are intrinsically limited in the amount of ATP they can manufacture—and thus, in the number of proteins they have the power to build. - Lane & Martin, 2010. In 2020 a jellyfish-like parasite was discovered without a mitochondrial genome - the first multicellular organism known to have this absence, and thus the only animal known to be able to live without oxygen.

# K. THE SUCCESSOR GAME - BIOS:MEGAFAUNA[60]

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

a. **Macro Variant.** It is highly recommended to use the *macro variant* (**C4**) for the combined Genesis-to-Megafauna game.[61] [62] [63]

# L. MACRO PARASITE CHIMERA VARIANT (Paweł Garycki)

### L1. PARASITES BECOMING MACROORGANISMS

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

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

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

---

[60] **BIOS:MEGAFAUNA,** the successor to **Bios:Genesis,** covers the "salad days" of the history of Earth. The planet was blanketed by a few percent of carbon dioxide, keeping it ice-free and its continents solid green from pole to pole. This marked the peak of Earth's productivity (i.e. carbon fixation), and when flowers, fruits, insects, dinosaurs, and mammals developed. Since this peak, Earth has been getting browner and browner as it loses its precious supply of $CO_2$. Levels fell from parts per hundred to less than parts per thousand, leaving today's plants literally gasping for breath. Furthermore, since $CO_2$ is a mild greenhouse gas, its loss caused today's Ice Age. Within the memory of man, ice has covered ⅔ of the northern and southern continents. The villain is not Medea but erosion, especially silicate weathering from mighty well-washed mountains such as the Himalayas. The $CO_2$ removed from the air by erosion is sequestered by plate tectonics deep into the crust. Volcanoes return some, but not enough (see footnote 12). Even the heroic mining efforts of mankind have only raised $CO_2$ levels a few hundred parts per million, enough to make the planet noticeably greener but not enough to stave off snowball Earth for very long. And we are perilously close to 150 ppm, the photosynthesis threshold for most plants. Once $CO_2$ drops below this, the plants will suffocate and Earth will enter her second Age of Bacteria.

[61] 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.

[62] MACRO LIFE AS CHIMERAS. 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.

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

## L2. RELATION WITH NEIGHBORS

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

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

## L3. RED QUEEN ATTACKS

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

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

## L4. DEATH

a. **Host death.** If the host dies (also in the situation when its last biont is made an endosymbiont), the bacteria is not made Extinct. Instead, it loses all remaining mutations and cubes and its card is moved under the macroorganism, freeing the parasite card to its owner. The new organism is finally moved to the owner's Tableau (together with a possible hyperparasite) and ceases to be parasitic (a hyperparasite becomes now a standard parasite).
b. **Parasite death.** If the parasitic macroorganism goes Extinct, it reverts back to the microorganism parasite state (with a compensation) and the system chromosomes may fill in the two available slots. The surplus cubes are returned to the soup. The endosymbionts may also fill the two available biont slots and the surplus ones are removed to the owners with compensation. If the parasitic microorganism ends up without a biont of its own colour for whatever reason, it immediately goes Extinct (it can never be owned by a foreign player).

## L5. LANDFALL

a. **Order.** When performing landfall, first consider the host organism, and then the parasite.
b. **Organ Count.** The landfalling organism may count organs from its neighbour.
c. **Macroorganism Parasite & Hyperparasite.** You may count diseased organs.
d. **Macroorganism Parasite & Microorganism Host.** You may count the host's mutation cubes.
e. **Two Macroorganisms.** You may count your neighbour’s organs. If only one macroorganism makes a successful landfall, the other one goes Extinct (back to the microorganism phase). In that case, the successful land organism may incorporate bionts from its macro-extinct neighbour, with a possibility to make them Extinct or switching ownership. The parasite requires free endosymbiont slots for this but the host does not.
f. **Terrestrial Restrictions.** If there is a land macroorganism in a parasitic chain, achievement of macroorganism state by a neighbour is only possible if this is an automatic landfall, however no counting on neighbour’s organs is allowed.

## L6. CHIMERA

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

a. **Trophic dominance.** Sum up belongings of all macroorganisms involved. All involved organisms share exactly the same trophic level and chimera surplus members do not add towards overcrowding. In very rare cases of overcrowding Extinction or mandatory landfalls, all members are affected (beginning with the host).
b. **Plants as a basis of ecosystems.** Regardless if chimera or not, any macroorganism (or chimera) that has the highest sum of blue plus green chromosomes is considered to be at least at the Plant trophic level. In case of ties, the sum of all colours counts. This rule, being so universal, may be used even if not using other macroorganism parasites rules.
c. **Victory points.** Both chimera members are awarded 6 or 12 VP, depending on trophic dominance. Multiply it by

two if chimera is a land organism, which constitutes a major achievement. The value of each member is equally shared between biont owners.

**L7. SOLO PLAY**

a. **Purchases**. AI parasite will try to buy a macroorganism whenever available. Choose at random if there is more than one to choose. AI will then try to buy organs, beginning from the top.
b. **Red Queen.** AI will try to perform Red Queen attacks at the topmost victim's organs that can be put into free slots in case of a Chimera.
c. **Immunology**. AI will use immunology to get rid of player's endosymbionts.
d. **Landfall**. AI will try to make landfall.
e. **Host Extinction.** AI may end up with its own macroorganism if the player's host goes Extinct. If this happens, AI's organism also goes Extinct but it becomes AI's trophy.
f. **Victory**. At the end of the solo game, add one biont requirement to the victory condition for each AI's living macroorganism or trophy. As an alternate challenge, try to end the game having a maritime chimera, or, better, a land chimera.

**GOLDILOCKS & THE BIG WHACK**

When it comes to life and the living world, stability is death. Life is quasistable and mortal. Nonlife is stable and immortal.

The same can be said of planets, such as Earth and Venus, two twin planets of similar size in the goldilocks zone of Sol. Both likely started with a thick carbon dioxide, carbon monoxide, and methane. The CO and $CH_4$ reacts with oxide minerals and were transformed into $CO_2$. CO2 is a triatomic atom, and thus atmospheric pressures on the surface were perhaps as high as 90 bar, where 1 bar is the surface pressure on Earth today. Temperatures under this sort of atmospheric load were extremely hot.

Venus is still like this today: hot, dry and dead. Both its lithosphere and its atmosphere are stable: no plate tectonics, and no unstable molecules in the air such as oxygen. But Earth is quite unstable, both in its crust churned by plate tectonics and its ever changing highly combustible atmosphere. What happened?

The answer may be the Big Whack, the titanic collision is believed to have formed Luna. Luna is the same density as the Earth's crust, and its composition is about what you would be left with if you took crustal rocks from Earth and cooked out all the volatiles. This has led to the leading theory about how Luna formed, with a "Big Whack" between the Earth and an errant planet the size of Mars. Most of the ejected material that formed Luna came from the Earth's crust, leaving it thin and unstable. Today it is 5 to 30 km thick, but before the Big Whack it must have been 42 km thicker.

The thinner crust of the Earth started plate tectonics, the formation of granite and the "floating" continents, and a lithospheric cycle that implacably nibbled the carbon out of its own atmosphere. Eon after eon, the carbon content of the atmosphere has decreased, from 90 bar after the Big Whack, to the virtually zero that it is today. The circulating lithosphere brings up fresh minerals at mid-ocean ridges, including oxides of calcium, magnesium, and other elements, up from Earth's interior. The oxides dissolve in ocean water and then combine with dissolved $CO_2$ to form carbonate deposits.

A detailed analysis by Hay (*6*) of the extensive measurements taken from around the world by Ronov and Yareshevsky (*10*) shows that if all the limestone sequestered in the continents were released, the $CO_2$ pressure of our atmosphere would rise from nearly zero to 38 bar. This would increase to 55 bar if the carbonates on the ocean floor were also released. These deposits were formed by the progressive depletion of $CO_2$ from the atmosphere. Even as recently as the dinosaur era, the amount of carbon in the air must have been several bar. This is enough pressure to support the flapping wings of giant flying reptiles creatures too big to fly in today's 1 bar atmosphere..

Although it is widely accepted that the early Earth was high in carbon dioxide, it is controversial that it began as

a twin of Venus with tens of bars of pressure. Yet the atmosphere must have once contained all the carbon locked up in carbonates today. It is also suggestive that no ancient limestone caves have been discovered. It is also uncontroversial that carbon-based life thrives in a high carbon atmosphere, and declines as the carbon is sequestered. Like millions of aquarists, I inject carbon dioxide into my aquarium to make the plants grow vigorously, Pine and aspen have been shown to grow 30% faster at double the normal $CO_2$ levels (700 ppm). Although hyperbaric oxygen therapy is a standard procedure for scuba divers, what is more controversial is the ability of prehistoric plants and animals to thrive under hyperbaric carbon dioxide. The experimental response of plants to multiyear exposure to hyperbaric carbon dioxide has been mixed, possibly due to the accumulation of product gasses in sealed containers.

If the Earth really started as a second Venus, ever since the Big Whack the Earth has been eating its own carbonaceous atmosphere. The more mainstream view is that Earth started at about 1 bar, the same as today, and the Earth has been eating its own carbonaceous atmosphere only since the Cretaceous. In either case, this gluttony continues today, slowed down only because there is so little carbon remaining in the air. There is barely enough carbon left in the air to support photosynthesis, and a fatal consequence of the instability of the Earth is that it limits its lifespan as a habitable planet. The day will come when insufficient carbon is available to support most plants, and macro life will die out in the open. One hopes that they will still flourish in high carbon greenhouses built by future humanity.

This theory has important consequences for the Drake Equation, the estimation of the number of active, communicative extraterrestrial civilizations in our galaxy, The Big Whack is a very chancy game of billiards, with nothing of this magnitude known elsewhere in the Solar System. If a planet in the goldilocks zone needs a Big Whack to become unstable, and such instability is necessary for life, and the habitability lifespan of the destabilized planet is only barely enough for advanced life and civilizations to form, then the odds of another such occurrence in the entire Milky Way would be almost zero.

This theory was proposed by Levenspiel, Fitzgerald, and Pettit, Earth's atmosphere before the age of dinosaurs, 2000.
https://pubsapp.acs.org/subscribe/archive/ci/30/i12/html/12learn.html#ref6

# GLOSSARY

Definitions of Capitalized game terms and their biological analogues:

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

- (syringe icon) allows you to control token discard order, see Immunology,
- (heat shield icon) indicates shielding from Extremophile events (**D5a**),
- ($O_2$ shield icon) indicating shielding from oxygen spikes (**D6a**),
- (Cancer shield icon) reduces the risk of cancer (**D8a**),
- (drought shield icons) avoid *drought* (**D9**),
- (spore icon) You can *assign* Bionts & Enzymes (**E2**) or *purchase* Mutations (**H1**) anywhere (not limited to active or home rows),
- (HGT icon) you may move Bionts per **E6**,
- (DNA icon) errors are generated only on '6' instead of a '5' or '6' (**G3**)
- (fission icon) may make two purchases instead of one (**He**),
- (nucleus icon) may consider your Catalysts to be chameleons able to change to any color (**Hd**),
- (sex icon) before buying a Mutation, you may *roil* a deck (**D2b**),
- (Red Queen icons) may make attacks per **H4**.

**Amino Acids**.[64] Red Bionts and Manna. The folding of proteins to maintain homeostasis is the domain of Player Red, who commands

[64] AMINO ACIDS are the stuff of Metabolism, and the ingredients of peptides, proteins, and enzymes. Chemically, they contain an amino group and

Parasites (prions) able to fold proteins to its own benefit, and in higher Macroorganisms controls the nervous system for high Metabolism.

**Antioxidants (E5a).**[65] 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 (**D6**).

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

- **Atrophied Mutations.** If a promoted Mutation suffers an Atrophy, it is flipped (i.e. demoted) if its Mutation cube marked with a "+" is lost, and remains unflipped if its other cube is lost (but will be discarded if it is ever demoted). A Mutation cube atrophied from an unpromoted Mutation discards it. All Mutations discarded are placed face-up on the bottom of the *Mutation deck* in the Microorganism's home row. The discarding player chooses the order discarded.
- **Atrophied Diseased Cubes.** If your Parasite atrophies a *Diseased cube* (**E3e**), this causes the Mutation which lost the cube originally to be discarded or unpromoted per the previous bullet. A Diseased Cube (Mutation or Organ) may never be atrophied by the Host it was stolen from.

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

**Autocatalytic Roll (F0).**[66] A roll representing the success or failure of a Biont in a Refugium to maintain itself and produce Catalysts.

**Bacterium** (pl. **Bacteria**) **(F3)**.[67] A Microorganism placard in a Tableau that does not have a Macroorganism card on it.

**Biont (B4)**.[68] A wooden dome with a player color indicating which property of life it possesses, simulating an ingredient in the primordial soup. Each player controls 3 or 4 Bionts of his color. Each Biont requires two dice to be rolled in the Autocatalyst or Darwin Rolls, and if on an Organism counts as a Chromosome.

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

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

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

---

a 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.

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

[66] AUTOCATALYST is a reaction which maintains organized populations by yielding a reaction product which is itself the catalyst for that reaction. *"Autocatalytic sets also have the ability to replicate themselves if they are split apart into two physically separated spaces. Computer models illustrate that split autocatalytic sets will reproduce all of the reactions of the original set in each half, much like cellular mitosis. In effect, using the principles of autocatalysis, a small metabolism can replicate itself with very little high-level organization. This property is why autocatalysis is a contender as the foundational mechanism for complex evolution."* —Wikipedia

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

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

A special Catalyst is an Enzyme.

**Chromosome (F3a)**.[69] A cube or Biont dome on an Organism or its Mutations indicating genetically stored properties and *shielding* (**D5a**, **D6a, G3**) according to its color. Mutation cubes, Organs, Diseased cubes, Foreign Genes, Endosymbionts and Trophic Bionts are all Chromosomes. The colored squares printed on a Macroorganism are special Chromosomes called **system chromosomes**. The number of Chromosomes indicates your Organism's **Metabolism** (red), **Specificity** (yellow), **Entropy** (green), and **Heredity** (blue).

**Darwin Roll (G)**.[70] A roll testing the capacity of a Microorganism to replicate an imperfect copy of itself into the next generation.

**Disease (E3)**.[71] A Diseased Mutation or Organ is one whose cube has been stolen as a Chromosome by a Parasite. A Mutation is never lost or demoted by Disease, rather it remains and its Abilities remain active (for the Host, not the Parasite). A Diseased Organ is completely lost unless stolen back by a Red Queen action.

**Endosymbiont (H3d)**.[72] A Biont on a Macroorganism acting as a Foreign Gene. It often confers shielding or immunology to the hybrid Organism, as indicated by the icons on the Macroorganism card. An Endosymbiont is able to make a purchase for the Organism it resides in, using the Organism's Catalysts and its Abilities (spore, ~~HGT,~~ chameleon, and fission, as long as fission was available from the beginning of the turn). Endosymbionts are formed whenever a new Macroorganism is created containing multiple Bionts, including Parasites and Foreign Genes.

**Entropy (E2a)**.[73] One of the four properties of life (Player Green), increasing the number of Bionts you can support in Refugia. The pigmented absorption of energy and its controlled release is the domain of Player Green, who commands chloroplast Endosymbionts able to fix carbon for its own benefit, and in higher Macroorganisms controls the digestive or photosynthetic systems.

**Enzyme (E1)**.[74] A Catalyst disk assigned to one of the "Enzyme slots" of Refugia, serving to increase the amount of organized Manna and keep autocatalytic cycles operating productively.

**Error Catastrophe (G3)**.[75] An Atrophy that occurs if the number of errors in an adjusted Darwin Roll is greater than the Microorganism's Heredity (its number of blue Chromosomes).

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

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

---

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

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

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

[72] 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).

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

[74] ENZYME is a large (usually protein) catalyst used in metabolism.

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

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

**Extremophile Crisis (D5)**.[76] An event indicated by the **X** icon, indicating temporary extreme temperatures.

**Foreign Gene (F4d)**.[77] A Biont of one player color residing as a Chromosome in the Organism of another player. A Foreign Gene is able to make a purchase for the Organism it resides in, using the Organism's Catalysts and its Abilities (spore, HGT, chameleon, and fission, as long as fission was available from the beginning of the turn).

**Gaia (D10b).**[78] A special procedure by which players can cooperatively nullify an event that would destroy all life on Earth (Armageddon).

**Heredity (D8)**.[79] This is the number of blue Chromosomes on a Microorganism. This imparts an *error shield* (**G3**), signifying the number of errors that can be blocked in the Darwin Roll. Heredity is one of the four properties of life (Player Blue), representing transmitting templated information for replication, especially information stored in the sequence of Nucleotide Bases on a gene.

**HGT (E6)**. Abbreviation of Horizontal Gene Transfer,[80] by which you can move your Bionts among Microorganisms as Foreign Genes or Chromosomes. HGT applies to all of your Bionts, even if the organism they're in doesn't have the HGT ability. The sum of all the HGT icons you have on your Microorganisms and Microorganisms you reside in (as a Foreign Gene) is called your **wantonness**, so named because bacteria are noted for having HGT sex with just about any other living thing.

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

**Hyperparasite (E3d).** A Parasite of a Parasite. Even a parasite of a parasite of a parasite is allowed.
***Easily missed rule**: when attaching to a parasite, a hyperparasite can only take the parasite's mutation cubes, not diseased cubes.*

**Immunology.** An Ability conferred by a Mutation or Organ with the **syringe icon.** If an Organism has Immunology, it may discard tokens in any order during an Atrophy, and Mutations in any order (**D7b**). Remember that loss of the Trophic Biont drives the macroorganism Extinct.
• **Immunology & AIDS.** If Immunology in a Macroorganism is conferred by an Endosymbiont, then the Endosymbiont owner controls the order of Atrophy losses, even if the Macroorganism also has an organ conferring Immunology. However, the Trophic Biont cannot be atrophied unless there are no organs or endosymbionts in the Macroorganism.

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

**Landform (D2)**.[81] 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

---

[76] 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.

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

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

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

[80] HORIZONTAL GENE TRANSFER 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.

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

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

**Macroorganism (H3)**.[82] 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.

**Manna (F1a)**.[83] Cubes and Bionts on Refugia represent *Manna*, the building blocks of life that were likely present or easily formed on the early Earth. Manna comes in four colors: red = Amino Acids (proto-proteins), yellow = lipid vesicles (proto-fats), green = PAH (polycyclic aromatic hydrocarbons) and pteridine pigments, and blue = Nucleotide Bases (proto-RNA). If in the lower row of Refugia, they are disorganized, and organized if in the upper row.

**Metabolism (G2)**.[84] One of the four properties of life (Player Red). It consists of protein-based catalyzed chemical reactions that maintain *homeostasis*. Expressed thermodynamically, Metabolism extracts negative Entropy from its surroundings. The **metabolic rate** of a Macroorganism is defined as its number of red and yellow *Chromosomes* (i.e. all wooden tokens on the card and all system Chromosomes printed on the card of these two colors).

**Microorganism (F3)**.[85] A type of Organism represented by either a Bacterial placard or a Parasite card. Chromosomes on a Microorganism track its Metabolism, Specificity, Entropy, Heredity, and shielding. Once a Microorganism acquires a Macroorganism card, it becomes a multicellular Organism.

**Mutation (H1)**.[86] 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 it's non-promoted side (immediately losing promoted abilities but gaining the non-promoted ones). A promoted Mutation that loses its non-"+" cube is unaffected, but will be discarded if it is ever demoted.
- **Diseased Mutation Cubes.** Cubes stolen by a Parasite never cause a Mutation to be discarded or demoted unless the Parasite later loses the cube.

**Nucleotide Bases**.[87] 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.

**Organ (H5)**.[88] A Chromosome cube on a Macroorganism. Some Organs confer the *shielding* (**D5a**, **D6a**, or **D8a**) or other Abilities

---

[82] MACROORGANISM. It is unknown why cells remained single for so long, over three billion years. Bacteria are still single today; even bacterial colonies such as stromatolites are not true multicellular organisms. Even eukaryotes, originating a billion years ago, did not leave any multicellular fossils until the Avalon Explosion of a half billion years ago. Once it took hold, the advantages of cellular collectivism rapidly expanded into today's macroscopic eukaryote world of fungi, plants, and animals.

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

[84] 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.

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

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

[87] 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.

[88] ORGAN is a collection of tissues with a common function. Organs are found in multicellular life; the equivalent in single-celled life are called

indicated by the bubble. Note: If a bubble points to two Organs, having either Organ gives you the Ability, and having both gives you the Ability twice.

**Organism (B1)**.[89] An Organism is a Bacteria, Parasite, or Macroorganism card or placard with at least one Biont. You are allowed four Organisms, which can be bacteria or Macroorganisms in your Tableau, or the Parasite of your color in an opponent's Tableau.

**Oxygen Crisis (H3g)**.[90] If you are the first to create a Macroorganism, it becomes a plant and you accelerate the game into the Age of Oxygen. In other words, the game is accelerated and often the next event will be the first event of the final Proterozoic Eon. This Oxygen Crisis is a one-time event.

**Parasite (E3)**.[91] A two-sided Microorganism card, in each of the four player colors. During the Assignment Phase, you can animate either side of your Parasite by assigning a Biont to it and attaching it to another Organism called the **Host**. See (**E3b**) for Host suitability. A Parasite steals one or two Mutation cubes (called Diseased cubes) from its Host. Either a Host or Parasite can use Red Queen purchases to grab Diseased cubes to or from the Parasite. A Parasite may use the Chromosomes on its Parasite card, plus those on its Mutations, for Biosynthesis, Abilities, and shields. When purchasing Mutations (**H1**), a Parasite uses the Catalysts but not the Abilities of its Host. A Parasite can later become an Endosymbiont. However, it can also be *supplanted* (**E4**) by a better adapted Parasite.

**Red Queen (H4)**.[92] A purchase that seizes control of Mutation cubes or Organs of your Host or Parasite. You must have more Red Queen icons than your victim (or permission, see **H4**) to make the attack.

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

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

**Specificity (G1)**.[93] 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.

**Tableau**. See **B1**.

**Trophic Level (H3c)**.[94] Hierarchical levels in an ecological food chain, starting with the energy-producing plants (**P**) at the bottom,

---

organelles. Functionally related organs participate in organ systems, such as the nervous, respiratory, and reproductive systems.

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

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

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

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

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

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

then herbivores (**H**) eating the plants, and finally carnivores (**C**) at the top. The oceans and land each have these three Trophic Levels in this game. Each Trophic Level can hold one Macroorganism, so a maximum of 6 Macroorganisms are in the game.

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

**Vitamins (E5b).**[95] A green Catalyst disk placed on an Organism to add to its Antioxidant shield during an oxygen spike attack. Like other Antioxidants, they can additionally be expended by an Oxygen Spike (**D6**).

# TEXT ON BACK OF BOX

THE FIRST 4 BILLION YEARS OF LIFE ON EARTH

The Earth has seen dramatic events, lava oceans, a great collision that formed its moon, the filling of its oceans by impact bolides, the rising of continents with plate tectonics. Among these noisy events, life got started, perhaps many times and in many forms. The players, representing "soup ingredients", must find a sheltered refuge in order to start autocatalytic cycles and accumulate catalysts. Once they achieve templated replication, they can share their progress by swapping genetic material or becoming parasites or chimeras. The game ends in the Cambrian Explosion, with the advent of multicellular life and the invasion of the land.

1 - 4 PLAYERS, AGE: 14+
1 - 2 HOUR
Small pieces can be swallowed, not for children under 3 years.
CE Spiel Direkt, Made in China, Art Nr. SMG36
www.sierra-madre-games.eu

## CREDITS

**Design & Development**: Phil Eklund
Playtesters: Bryan McNeely, Peter Holmes (paid copy), Drake Immortalis, Tim Park, Adam Gastonguay, William Hutton, Phirax (essen pickup).
Advisors: Dr. Jeremy Kua, Dr. Michael Markey, Dr. Kenyon Daniel, Jon Manker (essen pickup), Pablo Klinkisch (statistics)
Rules: Kyrill Melai, Brett Burleigh II, Tom Kassel, Andy Graham, David Fenton
Art & Layout: Karim Chakroun (essen pickup),
Cover Painting: Ron Miller www.black-cat-studios.com

THESE PERSONS ABOVE TO RECEIVE A FREE GAME OF Bios:Genesis, Green = Address label made
**German Translation**: Carla Hillebrand and Ingo Backert (see download section of www.sierra-madre-games.eu)
**French Translation:** Jerome Quelin (see download section of www.sierra-madre-games.eu) Link to the cards in French: https://docs.google.com/spreadsheets/d/1YDczI9Q8g2bFg7TM9fhtO2ALKFly8tQd_4hRDTxp29k/edit#gid=0, link to the living rules in French: https://docs.google.com/document/d/1DJYZ-FmHaIb6O5qdMJxaxkWcMvjIQQWRAVZq8DaW5n8
**Spanish Translation:** Manuel Suffo Pino (download in the download section of www.sierra-madre-games.eu)
**Italian Translation:** Davide effe.df@gmail.com and Emanuele (kalelema78@gmail.com) (work in progress)
**Polish Translation:** Pawel **pawel.bedz@gmail.com** Link to the Polish rules: https://docs.google.com/document/d/1Oiu5QlkMf4CKj6oB7jAuhN2LkKBhvPjBmpLMKcTEByE/edit?usp=sharing

**Chemists**: Jeremy Kua kua.jeremy@gmail.com (report received), Mike Markey mikepmarkey@gmail.com
**Biologists**: anushree.sanyal@gmail.com, tindalos@verizon.net Kenyon (PhD in Biochemistry and Molecular Biology)

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

Kyrill Melai k.melai@online.nl
2015 Playtesters Essen: tbowtrash@gmail.com (Thibaut), p.pfeifer@gmx.at (Philipp), fil.riva@gmail.com (Filippo), dnkserotinavalo@gmail.com (Alex)
Michael Jean atomike@gmail.com,
Brian brian.burnley@gmail.com
Cole cwehrle@gmail.com
dominicrougier@googlemail.com, Jon Manker jon.manker@gmail.com
don_du@yahoo.com, gert.keijerspaink@gmail.com, guppyprof@yahoo.com, ian_wakeham@yahoo.co.uk, nicolai_thorning@hotmail.com; niravraval@yahoo.com, quinn.rusnell@gmail.com, rick.heli@gmail.com, yvestourigny@gmail.com, info@doris-frank.de, sue.haslehurst@gmail.com; andrewdoull@gmail.com; email@daniel.brooke-gandhi.co.uk (Daniel) permanentfiction@hotmail.com (Nicholas), gschmidl@gmaill.com (Gunther), totonchyms@gmail.com (Matthew)
SMG@thought-crime.co.uk,Peter (report received).
brr.rocket@gmail.com (Brett) rules editing
tindalos@verizon.net (Kenyon) (report received)
drakeimmortalis@gmail.com (Derek) (report received)
thomas.kassel@ntlworld.com (Tom) rules editing
vospark@comcast.net (Tim) (report received)
domin8ingcats@yahoo.com (Bryan) (report received)
lawrence.abbandando@gmail.com (Phirax) (report received)
agraham2410@gmail.com (Andrew) (report received)
Magicfromastranger@gmail.com (Adam) (report received)
pklinkisch@gmail.com (Pablo) (statistics sheet received)

**List of Frequently Asked Questions (FAQ), recommended!**
https://docs.google.com/document/d/10xhc9iJPEZBHpkDXo1JHnXtNnHBN7VxXw_dh4uybTMU/edit#heading=h.mkp8dpxy5z9u

**Card List and list of science background text in Googlesheets:**
https://docs.google.com/spreadsheets/d/1r8B4Phs8MPRVPHT93zO0pi3BV3oK1TuALZkdLxDmgA4/edit#gid=0
https://docs.google.com/spreadsheets/d/1Ks_0BC2rbKsDhQ9t5scOYo0GkDjQvpAPM_vugLJhUU4/edit#gid=0

**Log your playtest sessions here:**
**https://docs.google.com/spreadsheets/d/1rvKhlrfjK012gKWSsWPWrfcsceAethjPUAZf_FTTtn/edit#gid=0**

**Vassal Module**, Samuel Williams <samuelw3@gmail.com>
Version 1.4 and later posted to the vassal website. http://www.vassalengine.org/wiki/Module:Bios:_Genesis
Please email sam with errors.

**Recommended Reading**. Nick Lane, *The Vital Question*, 2015. Why is life the way it is?

It is likely that the building blocks of life were formed photochemically from hydrogen cyanide on the surface of the Early Earth. This requires both sufficient UV light and a source of hydrogen cyanide (HCN). Flares and coronal mass ejections (CMEs) on stars are not always detrimental to habitability. CMEs ionize and dissociate molecular nitrogen, providing a source of atmospheric HCN that is orders of magnitude more efficient than photochemistry near a planet's surface, where the HCN is needed. Additionally, when considering the rates to form sugars in the presence of the UV light and HCN, and the rates at which inert adducts form in the dark, and comparing with UV spectra of cool stars, we find that sufficiently active M dwarfs, with flares of energy greater than 5^34 erg with frequency greater than than once every 50 days, may provide enough energy to drive the formation of sugars.- Dr. Paul Rimmer (University of Cambridge, UK), *How Stellar Activity can be Good for Life,* 2018.

| | |
|---|---|
| C3 (Publication version) | New cards by Karim. Terminology changes: extraterrestrial > cosmic. Removed blue sun from card 44. Cannot assign antioxidants to Parasites. Added Kyrill's macro variant (C4). Medea rule returns to one half VP penalty. Parasites produce Catalysts only for their tableau pool, not for themselves. Terminology: domes instead of hemispheres. Version C3 submitted for publication. |
| C2 | Comet impactor causes ozone hole. Trophic Bionts and Organs are now Chromosomes. Eliminate Darwin re-rolls if the creature color matches your color. Simplified HGT, adding conjugal transfer swap. Change Armageddon to specify only cards with climate change icons count. Trophic change changed to the Assignment Phase instead of a purchase. Terminology change: Lifeforms becomes Macroorganisms. Personal Catalyst Soup bowls optional, Catalyst limits are now 12/number of players, use substitutes if run out. Trophic Level change removed as an action. Added wanton first player (**A6**). Gaia changed to be blind. Endosymbionts and Foreign Genes no longer need permission to make purchases for an Organism. |

| | |
|---|---|
| C1 | Changed lightning smite to remove Manna from all Refugia. Removal is of the leftmost color depicted on the placard with Manna remaining. Added 'Pass Option' to **A6**. Added Compensation Biosynthesis to **B5** (you get compensated for Bionts lost during atrophies and Extinctions). Also added trophies to **B6**. Lifeform cards added as trophies if they go Extinct. Continents inactive during Waterworld. Added UV event and Ozone Layer. Changed Entropy Limit, was max Bionts in play, now is max Bionts in Refugia. Lifeforms updated with UV protection Organs and Endosymbionts. Changed Atrophy B5 from card loss to token loss. Changed how Mutations are lost and Diseased. Added solitaire and cooperative games (**C2, C3**). Gaia altered to avert Armageddon only. |
| C0 | Changed Yellow Darwin Ability. New Ability is to re-roll one Darwin dice for each yellow cube. Darwin Dice Procedure Changed to be like Autocatalytic Roll; Roll a number of dice = number of cub2 Catalystses on the Microorganism, where each Biont counts as two cubes. Antioxidant, Vitamins, HGT moved from purchases to assignment phase. Terminology change, Die-Off to Atrophy. Added fondling permission to HGT. Modified Red Queen. Killed the Cat event. Added DNA Ability. Each player starts the game with the single Parasite of his color. Delete Chromosome Limit (**B4**). Altered I1 to count cubes in your Organisms for VP, not Bionts. Shared cubes changed to Diseased cubes. Diseased cubes can come from Mutations or Organs only. Parasites no longer cost anything to install. Added E4, supplanting Parasites. |
| B2 | Added immune system Ability and the dagger icon. Added aftershock to events. Added Oxygen crisis forewarning. Red queen change to stealing Diseased Chromosomes. Only one Organism per Trophic Level. Waterworld simplified. Added C4, Introductory Game. *Foreign genes* (**F4**) and *Endosymbionts* (**H3**) of your color do not count against your entropy limit. Formalized Gaia procedure. |
| B1.2 | Added option to exchange 2 Catalysts of the same color for 1 Catalyst of any available color. Change new Refugium introduction to heaven and earth biblical. Change deep hot biosphere to extraterrestrial. Place dot on front of Mutations to show color of backside. Changed effects of Tropical Waterworld. Added chameleon Catalyst for nucleated cells, double purchase for fissioning cells. Changed sex to a 'roil first' procedure, which should move the game faster. +cat icon means one Catalyst for every Biont in play. Players start with one Catalyst. Parasites use their Host's red and green shields during extremophile and oxygen spike attacks. Victory boost if creature is in the highest Trophic Level, land or sea. |
| B1.1 | Increased the system prerequisites for lifeforms by one for each color. Added cancer. |
| B1 | EVENTS: Added Drought, Tropical Waterworld and boring billion events, also events to reduce Enzymes and Catalysts. Killed weird wonder events. Changed runaway greenhouse from 3 to 4 in a row. Introduction of Refugia change, bottom up or top down (this is designed to increase the number of Refugia in the game). Tracking warm and cool Refugia by having a warm or cool side has been discarded, and warm and cool side discarded as a concept.<br><br>MUTATIONS: Added pollution.<br><br>LIFEFORMS: Organs changed to cubes, added to terrestrial lifeforms. Added Parasite Biont spaces to all the lifeforms, including spaces for viruses, gut bacteria, prions, and lichens. Add Organ creation purchase.<br><br>AUTOCATALYST BID PROCEDURE: Biosynthesis of Catalysts happens upon Manna death, enormously increasing 'money supply'. Number of dice = organized Manna, not all Manna, with organized Bionts counting as two dice. Greenland style first player. Vulnerable Refugia now = to all organized Refugia, removing climax as a game concept. Bidding removed as a game concept, the progenote takes the placard if doubles are rolled. Progenote determined by the most number of Enzymes and organized Manna of his color. Manna order on Refugia to determine tiebreaker. Non-progenote contestants get biosynthesized Catalysts distributed among them. Deaths kill Enzymes as well as Manna. Successful Darwinian creature can be created with Foreign Genes.<br><br>DARWIN ROLL: Replaced protein dice with Catalyst generation for each one rolled, according to the number of red Chromosomes.<br><br>PARASITES: Parasites must use the Host's Catalysts when paying for purchases. Removed Red Queen shielding. Red Queen is an even exchange instead of 2 for 1. Revised HGT so that it can be used to remove Foreign Genes. Added Gene Transfer Agents.<br><br>REFUGIA: Doubled the number of Enzyme slots on all Refugia some are Enzyme death. Revised Parasite card backside, was a promoted version, is a basic version of another color (gives more flexibility for a professional Parasite player). Deep Hot Biosphere entry fee is one Catalyst, not one red Catalyst.<br><br>Added Steven J Gould variant.<br><br>TERMINOLOGY CHANGE: public pool becomes soup. roller becomes progenote, Refugia to biomes? habitat? This last not yet done, waiting for results of an opinion poll. |
| **B0** | Sweden Playtest. Terminology change: Progenote Disk replaced by **Biont**, bioinformatics changed to **Chromosome**, Homeostasis replaced by **Autocatalytic**, Shelf replaced by **coastal**, progenote and Organism replaced by **Microorganism**, lifeform replaced by Organism. Refugia and Progenotes (16 cards) become Placards instead. Now possible for players at Biont stage to become Parasites. Eliminate saturation concept. Predator concept replaced by Trophic Levels on Lifeforms cards. Entropy changed from max Catalysts to max Bionts. Bionts used as Manna rather than Catalysts on Refugia. Crystal catastrophe removed. Add Red Queen purchases and Vitamins. Each player allowed up to 3 Organisms. Added 4 Landform cards, eliminating the Vehicle & volcano terms. Landforms have a static side. Landforms, Lifeforms, Red Queen reworked. |

# ICON REFERENCE

## PHASE 1 : EVENTS (D)

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

Player order. (**A2**)

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

Ocean Landform
Active / Inactive

Coastal Landform
Active / Inactive

Continental Landform
Active / Inactive

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

Earth. Draw Refugium placard from bottommost active Landform deck. (**D3**)

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

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

Oxygen Spike / Antioxidant Shield. All organisms suffer Atrophies equal to n. of O2 - 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'. (**D8**)

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. (**see glossary**)

## PHASE 2 : ASSIGNATION (E)

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

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

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

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**)

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

HGT. May re-assign 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 disorganised side, gain one catalyst. (**F2**)

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

## PHASE 4 : DARWIN ROLL (G)

Specificity re-rolls. You can re-roll as many dice as your body has yellow chromosomes. (**G1**)

Biosynthesis. Each '1' rolled generates as many catalysts as red chromosomes. Color generated is at upper left of the Bacteria. Add one catalyst by 'triple'. (**G2**)

Error Catastrophe. Each '5' and '6' obtained generates an error, each blue chromosome cancels one die. Organism suffers 1 Atrophy for each excess error. (**G3**)

## PHASE 5 : PURCHASE (H)

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

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

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

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

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

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

# TURN SEQUENCE

### PHASE 1 : EVENT (D)

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

### PHASE 2 : ASSIGNMENT (E)

Assign or Move Bionts and Catalyst tokens (**E1**). Attach your parasite with one or two of your Biotes (**E3**).

### PHASE 3 : AUTOCATALYTIC ROLL (F)

Make an Autocatalytic Roll for Bionts in Refugia. Organize & Disorganize Manna (**F1**), create life (**F3**).

### PHASE 4 : DARWIN ROLL (G) in Player Order.

Make a Darwin Roll for each Microorganism. Catalyst creation (**G2**), Atrophies (**see glossary**).

### PHASE 5 : PURCHASE (F)

Each Biont makes a purchase.

### NEXT TURN