

• • • SECOND EDITION • • •

BIOS:GENESIS

THE MOLECULAR ARMS RACE GAME

• PART I OF THE BIOS TRILOGY •

BOOK 1

BY PHIL EKLUND



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:

- a. **Draw event card:** Terrible things happen (also, refugia come out).
- b. **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.
- c. **Autocatalytic roll:** Roll dice for each refugia 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.
- d. **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.
- e. **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!

HEAVY CARDBOARD TUTORIAL

This rulebook is a comprehensive presentation of the *Bios:Genesis* rules, but for actually learning the game, you may find a video tutorial helpful. We have contracted with the Youtube channel Heavy Cardboard to provide a well-produced video tutorial of this game and others. Links to these are found in our webshop www.sierra-madre-games.com under the section "Video". Or google "*Bios:Genesis* Heavy Cardboard".

A. BIOS: GENESIS SEQUENCE OF PLAY (FIVE PHASES PER TURN)¹

A1. EVENT (PART D)

- Turn over the next event card.**
- 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**).
- 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 O₂ 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)

- 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**).
- Parasites.** Assign your Biont to start a new Parasite *attached to* a suitable Host (**E3**), or *supplanting* an enemy Parasite (**E4**).
- Antioxidants.** Assign Catalyst disks on Organisms *Antioxidants* or *Vitamins* (**E5**).
- HGT.** Move Bionts from one Microorganism to another using *HGT* (**E6**).

A3. AUTOCATALYTIC ROLL (PART F - IN ROW BY ORDER PER F)²

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.

¹ ABIOTENESIS 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.

² 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 membranes and can't thrive without the metabolic machinery of their host. Further evidence for chicken-first is that amino ac-

- 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 or 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.




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)**.

ids are easily produced both in simulated reducing prebiotic environments on Earth and in UV-irradiated icy space dust. To assemble an 'egg' (i.e. nucleotide), you need a base, a sugar backbone, and a phosphate. All three suffer very poor yields in simulated prebiotic conditions. Moreover putting together the three parts randomly will produce a stereochemically-correct nucleotide only 1% of the time, and there is no known prebiotic process that can discriminate the correct one from its 99 misshapen brethren. Once created it is easily destroyed by hydrolysis or UV radiation (this is why in Refugia exposed to UV, blue is often in the leftmost position, the first to be lost to radiation). Modern genetic material are protected by a protein blanket and by being twisted into chromatin. —Freeman Dyson, 1999.

- 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.³

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

³ 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 life). I further suggest that all four may have had separate origins, but have since adopted the same RNA-DNA replication software, starting with the LUCA (Last Universal Common Ancestor). These four properties correspond to the four players in the game: red = Metabolism (self-sustaining feedback loops), yellow = Specificity (discrimination about its own constituents, allowing individual identity and natural selection), green = negative Entropy (non-equilibrium energy), and blue = Heredity (the capacity to pass on attributes to a new population).

A6. PLAYER ORDER

- 1** ● ● ● ● 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.

- Two or Three Player Game.** Two or Three Player Game. If the first player is a color who is not in the game, the second color in the row is the first player, etc.
- Wanton First Player.** At the beginning of any phase, if there is a player with more *wantonness* than any other, he may declare himself to be the first player that phase (then proceed in Player Order with the next player the color of the leftmost icon). A player's **Wantonness** is defined as the number of HGT icons on all his Microorganism's Mutations and Microorganisms he resides in (as a Foreign Gene).
- Parasite Exception.** During **Phase A5** (purchases) a parasite purchases immediately after its Host.
- Pass.** During **Phase A2** (assignment) or **A5** (purchases), a player may elect to do nothing.



B. COMPONENTS



- 16 wooden domes represent Bionts.** You start the game with three or four in your player color: red = metabolic biont, yellow = cellular biont, green = energy-absorbing biont, and blue = replicative biont..⁴
- 64 wooden cubes.** Represents **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)**⁵ 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.

⁴ THE EVOLUTIONARY PATH in this game starts with 'soup ingredients' (the Refugia and Bionts), leading to non-replicative autocatalytic cycles, to RNA-world bacteria-like cells (Darwinian Microorganisms on the brink of Error Catastrophe), to DNA-protein nucleated cells (eukaryotes replicating with high fidelity, using enslaved prokaryote cells as organelles).

⁵ PAHs, components of an oily material found in meteorites, could have been separated by geo-chromatographic 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.



c. **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**.

- d. **60 cards.** There are 4 **Landforms**, 24 **events**, 20 **Mutations** (double-sided, *prokaryote* on the unpromoted side, and *eukaryote* on the promoted side)⁶, 4 **Parasites**, and 8 **Macroorganisms**. See card anatomy on the side of the box.
- e. **16 placards.** The front side is a **Refugium**, and the reverse is a **Bacterium**. See placard anatomy on the side of the box.
- f. **12 six-sided dice (12d6).** Use for **Autocatalytic** and **Darwin Rolls** and **Cancer Rolls**.
- g. **1 Folding Player Aid.**

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.

B1. TABLEAU MANAGEMENT

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

- a. **Your tableau.** In your tableau you can have up to 4 Organisms plus up to one Parasite (which belongs to another player) for each one.
- 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.

⁶ 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 CO₂, or too hot as the sun gets hotter, the prokaryotes will rule once again.

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 **B3** 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 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 events⁷, leaving 3 remaining. Place the Proterozoic Deck on the bottom, then the Archean, then Hadean.⁸ Remove the bottommost card without looking at it, so that the Proterozoic has only 10 cards.
- **Optional Short Game.** Remove the bottommost 4 cards instead of 1 card.



- e. **Refugia Deck.** The 16 Refugia placards (hereafter called **Refugia**) are separated into four decks according to their **Landform icons** (left edge): cosmic,



⁷ 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.

⁸ 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 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).

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 Refugia 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. 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 **A2**.
 - **Optional Short Game.** Remove the bottommost 4 cards instead of 1 card.

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 tableaux 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 a 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.** One Biont of each of the two colors not chosen is used to enable one non-player controlled (NPC) Parasite. The turn order for these two NPC Parasites follows the rules for their color. Each is hostile (making its own automated purchases) until assimilated as an Endosymbiont or Foreign Gene (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 parasite, if supplanted 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.** As usual, the NPC Biont uses its Host's Catalysts for its purchase. Determine which Mutations it has Catalysts to buy, then randomly select among them with dice. The NPC Parasite always upgrades its Mutations first before buying a new one. Als will use fission to buy two mutations if they can.
- e. **AI Specificity.** Als will only use Specificity re-rolls to re-roll errors, starting with 6's.
- f. **AI Sex.** Als 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.** Als 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 MULTI-PLAYER)

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.

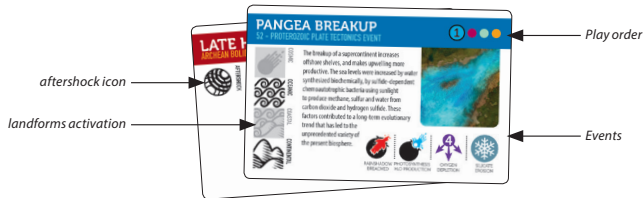
- a. **Solitaire.** Ignore parasite AI and warming/cooling cycle.

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 of the previous turn.

- b. **Tropical Waterworld.** <ADVANCED> After performing the events on this card, place it on top of the continent Landform. While this card is present, the continent Landform remains inactive (the result of plate tectonics has shutting down)⁹, all (+earth) events (**D3**) skip over the continents row and go to the next Refugia deck higher (therefore no rolling of continent Mutations or adding of continent Refugia), and a runaway greenhouse *Armageddon* (**D10a**) occurs with three ☀ instead of four. Remove the card and its effects (restarting plate tectonics) when the next aftershock occurs.¹⁰

⁹ 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?

¹⁰ 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

- 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

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.¹¹
- 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  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  (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.

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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.” —Peter Cawood and Chris Hawkesworth, 2014.

11 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.

12 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

- 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 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 card left. This last card comes out, as well as the top card in the next active deck down (the oceans deck).

D4. SMITE EVENT



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, as marked on the placard with a **green shield icon**, are immune from the effects of smite crisis.



D5. EXTREMOPHILE CRISIS



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



- 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.

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.

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 🌪️ aftershocks in the game.

D6. OXYGEN SPIKE¹³

An 🌪️ icon causes an **oxygen spike attack** on all Organisms, with the number of 🌪️ icons indicating its **extremity**. In the case of an *aftershock* (D1a), the extremity is the summation of 🌪️ the events from all cards, and applied as soon as the first 🌪️ 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.**¹⁴ 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.** For this event type only - to satisfy Atrophy damages, Antioxidants or Vitamins may be discarded instead of cubes or Bionts. See example below.

Example: The 'oceans rust out' aftershock event is drawn, generating two spike 🌪️ attacks. A flatworm Macroorganism has one green system Chromosome and an Antioxidant disk. Since the 🌪️ 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.

13 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 O₂ (this is called the Lomagundi-Jatuli Excursion). As CO₂ was replaced by O₂, anaerobic Metabolism was poisoned just as effectively as it had with the loss of the Urey-Miller reducing atmosphere in the Hadean.

14 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.

D7. ULTRAVIOLET RADIATION¹⁵



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

- Mutations Cube.** Each Mutation card, promoted or unpromoted, counts as one Mutation. Each Mutation card lost also loses its associated Mutation cube(s). The cube is lost even if it's a Diseased cube on a Parasite.
- Order Lost.** You choose which Mutations or Organs are lost from your Organisms, except that, if the Organism has no Immunology (see glossary), it must lose healthy Mutations before Diseased ones. Note that UV radiation does not cause Atrophies.
- All Mutations discarded** are placed face-up on the bottom of the Mutation deck in the Organism's home row, in the order of your choice.
- UV Shield.** <ADVANCED> If a Macroorganism has an Organ or occupied Endosymbiont space with the UV Shield icon, the entire organism is safe from UV.



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

D8. CANCER <ADVANCED>



For each **crab icon** appears, then every Macroorganism must make a **Cancer Roll**, rolling one dice for each Organ and two dice for each Biont. Each '5' or '6' rolled will generate an error. If the number of errors is greater than its **error shield** (i.e. the number of its blue Chromosomes), then the Microorganism suffers one Atrophy for each excess error.¹⁶

¹⁵ ULTRAVIOLET RADIATION from the sun is the principal source of high energy for protolife, but it is also the most destructive.

¹⁶ 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



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'.¹⁷

- 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 PCD shield), brain, eyes, and kidney. With 2 bionts and 3 organs, you roll 7 dice for your Cancer Roll. You have 2 blue system chromosomes, so you are allowed two errors (6's). But the roll is 1,1,2,5,6,6,6, so you lose one organ but gain two catalysts.

D9. DROUGHT <ADVANCED>



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

Easily missed rule: Droughts only impact terrestrial creatures.

D10. GLOBAL WARMING AND COOLING <ADVANCED>



A red sun in the lower right corner indicates a warming climate, and a blue snowflake indicates a cooling climate. If the climate is warming, the red sun **animation (F1)** will be in effect during Autocatalytic Rolls, and this warm climate will persist until the climate changes to cool with a blue snowflake event. A cooling climate puts the blue snowflake animation into effect, again until the climate changes.

- 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.



cells in these ancestral livers ever left any descendants. In fact, all liver cells present and past are expected to stop dividing in order to do their job. And yet, each liver cell ordered not to divide is derived from an embryonic germ cell that has been dividing for untold generations (or else it would have left no descendants). Your life depends on how good each and every cell follows orders. —Randolph Nesse, M.D., 1994.

¹⁷ PCD (Programmed Cell Death) is occasionally used by bacteria to commit suicide if infected with a virus, so as not to infect their kin.

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 says Gaia, those who have Catalysts or Organisms must either spend a Catalyst to the soup or suffer one Atrophy (see glossary). This cancels Armageddon, and the game proceeds.
- 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* (**A2**), each player may assign any or all of his Bionts and Catalyst disks. Each Biont may be assigned (**E1**, **E3**), used to supplant (**E4**), or moved (**E6e**) only once during this phase.¹⁸

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**.

18 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.

- 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)*, 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 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 Autocatalysis Roll, but on turn 2 the Cosmic Landforms are inactive, so this turn your Biont is trapped on Mars. You could assign Enzymes or a second Biont there, assuming your entropy limit (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.**¹⁹ 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.

¹⁹ 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.

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 anywhere and are therefore not limited to active rows or home rows.

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

E3. ATTACHING A PARASITE AND ASSIGNING A BIONT TO IT

Each player has one Parasite Card of their color. If it is unassigned, 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).²⁰

²⁰ 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.

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 and must be in an *active row* (**D2**) or a row where you have a Biont (i.e. either in a Refugium or in an Organism with that *home row* (**E2**)). The Host must have at least one cube that can be stolen by the Parasite as a *Diseased cube* (see next bullets). If the Host already has a Parasite, either become a Hyperparasite or 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, either from two Mutations or one promoted Mutation. A Diseased Mutation 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 only if liberated (**E4**) or goes Extinct.

- d. **Hyperparasite.** If the Host is another Parasite, steal the Diseased cubes from the Host’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 an 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” in the glossary.

Example: *Player Blue* starts with three unassigned Bionts, and is Entropy-limited to one Refugia assignment. He assigns one to a Refugium, leaving two left. Although these can't be assigned to Refugia, he assigns one to animate his virus, and attaches it to a Host with a green Mutation. This steals the green Mutation cube from its Host. Since *Player Blue* now has a green Chromosome, he is allowed two instead of one Biont assigned to Refugia per **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.²¹

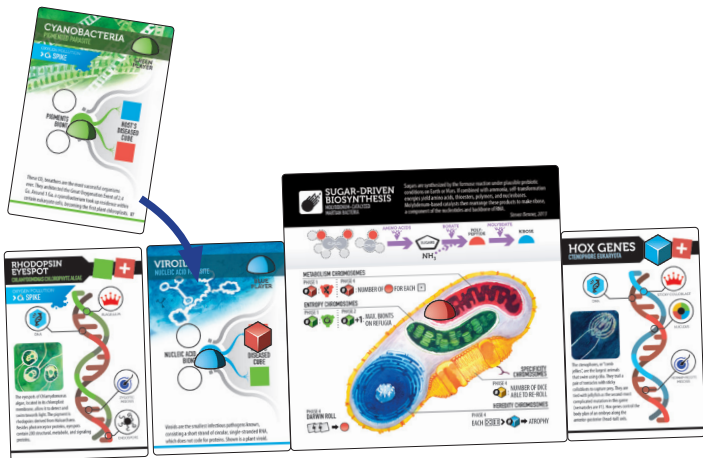
E4. SUPPLANTING A PARASITE

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.

²¹ 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 Catalyst as an **Antioxidant** by placing it directly on your Organism's placard (next to the Macroorganism card if present). This gives advantages during oxygen spike attacks (D6).

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

E6. MOVING BIONTS VIA HGT (MICROORGANISMS ONLY)



HGT is the only way to move or reassign a Biont from or to a Microorganism. You have this Ability for all your Bionts if any of your Microorganisms, or Microorganisms you reside in (as a Foreign Gene) have the **HGT icon**. 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). Alternately, you can move your Biont into your pool (without compensation).²²

- The Wanton Block.** If you attempt to HGT into an opponent's Organism, he can announce this move to be **blocked** if he has more *wantonness* (i.e. more HGT icons, see **A2**). The blocked Biont must move to another Microorganism or the pool. It can move back to the Organism it originally came from but this will count as the Biont's one and only move and use one of your allowed HGT moves.
- Extinction.** Note that HGT allows you to drive your Microorganism extinct.
- Commandeering.** If all your Bionts from one of your Microorganisms are lost, but it has a Foreign Gene, it becomes part of the foreign player's tableau. If it is Bacteria, physically move it to the foreigner's tableau, but if it is a Parasite it stays put. If your Parasite is commandeered, you regain control if your Biont returns, or if the Parasite goes extinct. If more than one player's Biont remain, you choose whose tableau it moves to.
- Macroorganisms.** HGT cannot be used to transfer to or from a Macroorganism.²³

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

23 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.

- 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. 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, start at top left)

An **Autocatalytic Roll** is made for each Refugium occupied by one or more Bionts. Apply each roll in this strict order for results: **F1**, **F2**, and **F3**.²⁴ If the Refugium is *contested*, see **F4**.



- Refugia Resolution Order.** Start with the top row of Refugia, going from left to right. Then on to the next row.
- Procedure.** Make a roll by rolling one dice for each organized cube and two dice for each organized Biont.

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

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

²⁴ **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/FeS₂, minerals. These cycles must have been far simpler than the reductive citric acid cycle fundamental to today's metabolism. A promising candidate is the "open" acetyl-CoA pathway. This is not only one of the five recognised ways of carbon dioxide fixation in nature today, it is the only one that has zero energy cost, so it requires no ATP. It takes only one step, and can be catalyzed by a iron monosulfide mineral surface. Hydrogen is electron donor and the CO₂ is both an electron acceptor as well as a building block for biosynthesis.

F1. ANIMATION



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

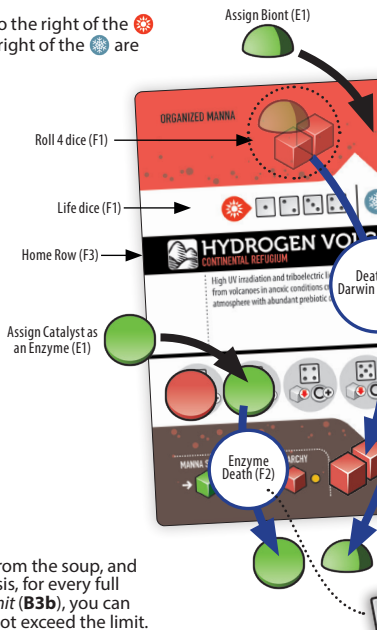
- a. **Manna.** All Bionts and cubes on a Refugium, whether organized or not, are called **Manna**.

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.²⁵ If the Refugia 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.



25 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].



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

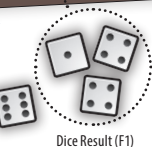
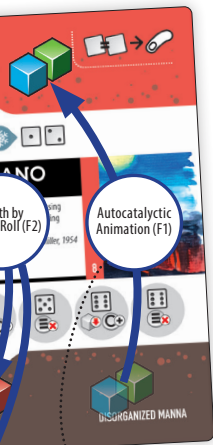
d. **Death Dice.** Each dice face may cause both Manna and Enzyme death. For instance, for all Refugia except eutectic brine, each "6" rolled will kill one Enzyme and disorganize one Manna (assuming the 6 is not covered by Enzymes).

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.

F3. CREATION OF DARWINIAN LIFE²⁶

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

- 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 rows, the cubes and Domes are called **Chromosomes**. Disorganized Manna are lost to the soup.
- Enzyme Cost.** All Enzymes on the card go into the soup.
- Bacterial Anatomy.** In a Bacteria's left edge is its *home row* (E2).



²⁶ **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.

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 a Darwin 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 the 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.

- 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 to claim the Bacteria.

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

G. PHASE 4, DARWIN ROLL (player order)

In player order, all players 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.²⁷

- 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.

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.

²⁷ 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 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.

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. BIOSYNTHESIS²⁸



Each '1' rolled is a **protein die**. For each protein die 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 die, 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.



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

²⁸ 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.

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)³⁰

Life is messy. In this variant, Mutations are acquired only by suffering an Error Catastrophe. Therefore, purchases or promotions of Mutations do not occur during **Phase A5**. Instead, purchases or promotions of Mutations occur here in **Phase A4**, as follows: If any uncanceled error dice remain in your Darwin Roll, before suffering Error Catastrophe you may cancel 1 error dice by purchasing or promoting a Mutation, using the procedure of **H1** or **H2**. Discard 1 Catalyst of the Mutation's color or 2 Catalysts of the same color.



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

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

Each player may make one purchase for an Organism for each Biont he has in that Organism, either per **H1** through **H4** (for Microorganisms), or **<ADVANCED>** per **H4** and **H5** (for Macroorganisms).³¹ The following general rules apply to all purchases:

29 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 "nucleic acids" must have a function in heredity, confirmed in 1944. Yet is heredity the fundamental to life? I argue that proteins deserve their name.

30 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).

31 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

- 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* (**A2**), except a Parasite makes its purchase immediately after the purchases 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.**³² For any purchase, you pay two Catalysts of the same color and consider them to be one Catalyst of any 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.



- e. **Foreign Purchases.** All expenditures for an Organism must spend from the pool of the Tableau it resides in. So Parasites (but not necessarily Hyperparasites) must spend from the tableau pool of their Host (!), and Foreign Genes and Endosymbionts spend from the pool of the Organism owner (!). These purchases may use the Organism's spore, 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.³³



antioxidant shielding on certain Mutations). All life would quickly go extinct without the fixation of these organisms.

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

33 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).

- 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.**³⁴ 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 an 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 an Organism, 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.

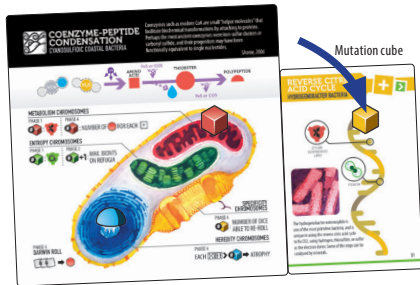
Easily missed rule: A Mutation deck that runs out is refilled only when an Organism in this home row discards Mutations or goes extinct.



- a. **Sex.** If your Organism has a sex ability mutation, before you make the next purchase 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.

³⁴ 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).

- 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).³⁵



The first mutation of the bacterium

Note: Pollutants other than oxygen (e.g. methane etc.) are treated like oxygen polluters.³⁶

Example (pollution): See J10.

H2. PROMOTING A MUTATION (MICROORGANISMS ONLY)

By spending a Catalyst of the color of the unpromoted Mutation, flip it to its **promoted** side.³⁷

35 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.

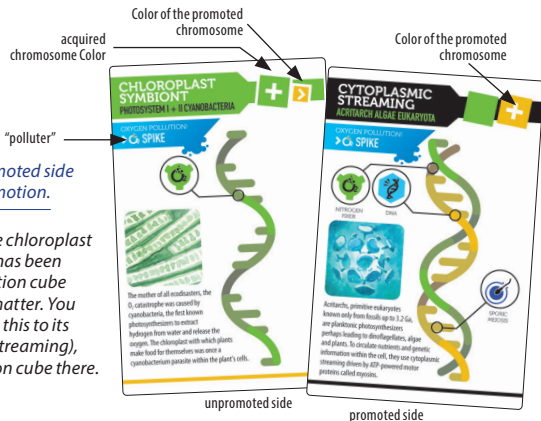
36 BORING BILLION, the billion stagnant years in which the oceans were stratified, with a thin surface layer of green algae, and the depths dominated by purple sulfur bacteria. Both bacteria used photosynthesis, but the greens split water (with oxygen byproducts) while the purples split H₂S (with toxic 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.

37 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).

- Second Mutation Cube.** Promotion adds one *Mutation cube* matching the new color (marked with a “+”) on the Mutation, alongside the original Mutation cube.³⁸
- You immediately lose any Abilities listed on its unpromoted side.**
- 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.

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 (cytoplasmic streaming), and place a new yellow Mutation cube there.

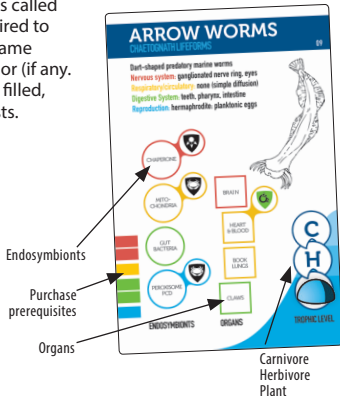


³⁸ FIRST LIFE. My game assumes that the first all-four-color life was a bacteria-like prokaryote. The far larger and more complex eukaryotes surely came much later. Accordingly, all the unpromoted Mutations are based on extant bacteria and archaea, with the flip side based on protist and other eukaryote attributes. A recent genetic analysis suggests this game assumption is wrong, and eukaryotes came first. The authors propose (1) LUCA as a complex community of proteobacteria with a RNA template and lipid membranes, (2) 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, (3) bacteria as a reductive form of the eukaryote LUCA, (4) the word “prokaryote” to be abandoned as “epistemologically unsound”, (5) bacteria as far less “wanton” as generally supposed, (6) RNA as having risen under natural selection pressures from “catalytic closure” or “compositional heredity” precursors, and (7) the nucleus as having the primal role in protecting and orientating RNA, a capacity since lost in bacteria and archaea. —Mariscal & Doolittle, *Eukaryotes first: how could that be?*, 2015.

H3. MARINE MACROORGANISM PURCHASE <ADVANCED> (BACTERIA ONLY)³⁹

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

- Purchase Prerequisites.** On its left edge, each Macroorganism lists purchase prerequisites called **system chromosomes**. These represent its nervous (red), circulatory (yellow), digestive (green) and reproductive (blue) systems. To purchase a 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.
- 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.
- Trophic Level Entry.** The **pacman icons** in the lower right corner are the three **Trophic Levels**. From lowest to highest they are **P** (= plants), **H** (= herbivores), and **C** (= carnivores). Put the organism owner's Biont, now called a **Trophic Biont**, into the lowest unoccupied Trophic Level. If all three slots are occupied, place it alongside the other 3 Tropic Bionts. At the end of this phase, the Trophic Levels of all the Macroorganisms will get rearranged per **H6a**.⁴⁰



³⁹ **AVALON EXPLOSION** was a geologically brief period 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.

⁴⁰ **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.

Easily missed rule: *The red Trophic Bionts, Organs, and system chromosomes impart heat shielding per D5a, the green Trophic Bionts, Organs, and system chromosomes impart oxygen spike shielding per D6a, and the blue Trophic Bionts, 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 supported (e.g. Parasites and Foreign Genes) become assimilated as **Endosymbionts**. Place these Bionts into the appropriately colored circles in the column indicated. If there is more than one Biont of a color, return the extras to their owners (with *compensation* per 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.⁴¹ 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) and you accelerate the game into the Age of Oxygen. If the events are not yet in the Proterozoic Eon (the third and final eon), discard out of the game all the events on top of the event deck until only the Proterozoic cards remain. Therefore, the next event drawn will be Proterozoic (when the air was heavily polluted with oxygen).⁴²

41 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

42 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 O₂ 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.

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,⁴³ 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.

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 O₂ production, all the land O₂ 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.

43 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.

THE NUMBER OF CHROMOSOME CUBES NEEDED TO PURCHASE A MACROORGANISM (ADDITIONAL CUBES)

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

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 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.

- Red Queen against a Microorganism Parasite.** Steal one of the Parasite's *Diseased cubes* as a Mutation cube back to your Mutation that originally lost it. If there are no Diseased cubes, you can steal one of its Bionts as a Foreign Gene. If you steal its last Biont, the Parasite goes Extinct. Because the Biont is still alive, it is not *compensated* (B4).
- Red Queen against a Macroorganism Parasite.** <ADVANCED> Steal one of the Parasite's *Diseased cubes* as a healthy Organ. If you 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 glossary.
- 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 putation, giving it one Red Queen. Since your Host (an earthworm belonging to **Player Green**) has no Red Queen capacity, you spend one of **Player Green**'s red Catalysts and steal the earthworm's red organ, infesting its brain. The red cube is moved to your red Diseased cube spot.

Example 2: Your malarial parasite has one Biont, one Diseased cube, and 2 Mutations, 1 of which has a Red Queen. Your Host is a Bacteria with two Red Queens, and on his turn he purchases a Red Queen attack. This attack steals your Diseased cube and returns it to the Host. The Host has an 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 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.

- 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.
- Diseased Organs.** An Organ can be parasitized per **E3e**.
- Trophic Level Change.** Purchasing **red** or **yellow** Organs increases your *metabolic rate* (**H6b**).
- Landfall.** If you have a marine Macroorganism with all its Organs filled, automatically flip it to its **terrestrial** side and enter the terrestrial ecosystem per **H6c**. All cubes for Organs and all disks for Vitamins and Antioxidants are lost to the soup. All Bionts become either the Trophic Biont or an Endosymbiont.



- 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. If so, the Parasite loses these cubes, but continues as a Parasite. In other words, when making landfall, a number of cubes must be lost, equivalent to the number of system Chromosomes gained.⁴⁴

Example: A trilobite needs two Organs to become a terrestrial insect: a chitin cuticle and a shelled egg. It has the egg, but its chitin organ (green) is empty. However, it is parasitized by a prion with a green Diseased cube. This indicates it has a Diseased chitin cuticle, which immediately removes both the Organ cube and the Diseased cube and flips the Macroorganism to its terrestrial side. This landfall is automatic and involuntary, and does not count as a purchase.

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** (top), herbivore **H** (middle), and plant **P** (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 die 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).



44 LIFE has dwelled in the oceans for most of its history, but could it have originated in fresh water and then invaded the ocean? Oceans represent a stable and sheltered suitable for hatcheries, but for this very reason have proven to be an evolutionary backwater. Life emerged from the ocean during the Cambrian, but since that day hardly anything else has emerged. Why is there so much traffic returning to the ocean, such as eelgrass, turtles, crocodiles, mosasaurs, sea snakes, penguins, whales, etc., and so little traffic coming out? There are some indications that even fish, the paradigm of the seas, originated first in freshwater and then, after being tempered for harsh conditions, re-invaded the oceans. Could the very first life have done the same, emerging from the warm little ponds favored by Darwin? Unlike hydrothermal vents, terrestrial geothermal fields are "conductive 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." —Armen Mulkidjanian, 2012.

- c. **Overcrowded Ocean.** If all three marine Trophic Levels are full, all four Organisms are given an opportunity to go *terrestrial* per **H5d**. 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.⁴⁵
- 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.⁴⁶ Your sea star has the highest metabolic rate (5), followed by the arrow worm (3), the Dickinsonia (1), and the seaweed (0). Luckily for the seaweed, the Dickinsonia opts to pay for the emergency development of its missing 3 Organs, and becomes a terrestrial mushroom.

⁴⁵ 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.

⁴⁶ DIGESTION was born when some hapless bacteria suicidally produced the deadly enzyme hydrolase. Since this chemical fragments proteins into amino acids, nucleotides into sugars, bases, and phosphate molecules, phospholipids into their constituents, it tended to destroy any Organism that made it. But eventually a bacterial mutant was born which survived hydrolase production by immediately ejecting it. This secretion gave the cell an advantage - the Ability to externally digest organic materials in its neighborhood. Eukaryotes have a complicated internal cytomembrane structure allowing the envelopment and internal digestion of prey, thus becoming the first predators. The trick was to trap prey in a fold of the cellular membrane, and pinching it off so that it became a mini-cell within the eukaryote cell.

I. GAME END & VICTORY

The game ends at the end of the last turn of the Proterozoic Event Deck, or when *Armageddon* occurs (D10a).⁴⁷

1. VICTORY POINTS




- Cube VP.** Each cube on your Organisms (Bacteria, Parasites, Macroorganisms) and their Mutations is worth 1 VP each. Your *system chromosomes* (H3a) are 1 VP each, just as if they were actual cubes.
- Biont VP.** Each Biont of your color in an Organism earns you 1 VP, even if it is in an Organism owned by another player.
- Trophy VP.** <ADVANCED> Each trophy (the cards and placards of Extinct Organisms) held by a player is worth 1 VP.
- Trophic Dominance VP.** <ADVANCED> Each Macroorganism is worth 6 VP extra, or 12 VP extra if it occupies the highest *Trophic Level* (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.
- Ties.** In case of a victory tie, the one with the most Catalysts is the winner. Further ties is 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.

⁴⁷ 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.

THE NUMBER OF CHROMOSOME CUBES NEEDED TO PURCHASE A MACROORGANISM (ADDITIONAL CUBES)

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

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