The History of Life On Earth - Origins[1]

What we are about here is a scenario and theory for how life could have appeared and evolved on this planet.

⇨ This is a very complex topic, about a witheringly intricate process.

> The literature is vast, and often highly technical.
> There are significant disagreements.
> The problems are formidable.
> But despite the difficulties knowledge and theories continue to advance at a very high rate.

Overhead - Major Developments in the History of Life and Earth

⇨ We have already outlined the major parts of the record, and the sequence of events.

⇨ Now it is time to develop a more theoretical argument.

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[1] These notes accompany the handout ABio- and Geochemistry, the Strategies of Life, and the Evolution of Ecosystems.@

. . . modern living system that we are familiar with must do two things.

1. Obtain and dissipate energy - (traditionally as ATP)
2. Obtain and dissipate information for their biochemistry - (traditionally as RNA and DNA.)

That is, they must, as any open system must, dissipate energy and information.

SLIDES - 4 - ATP; Bioelemental cycles; ADP⇨ATP; Protein synthesis

It is then axiomatic that once such a system comes into existence it will increase the quality of its information (and complexity.)

⇨ We saw this in WORDEVOL and the Genetic Algorithms.

Begin with an initially random selection of information or binary code of information for genes, place them in an environment with a ***selection agent***, and they will evolve by bottom-up processes to contain information more consistent with the selection agent.

⇨ These mechanisms are not only essential to life, they are ***life itself***

? How did these ***selection agents*** come about?

? Where are the stratified stabilities (adaptive strategies) which mark the evolutionary process?

? Can we trace a logical sequence which demonstrates continuity across the entire history?

Historically, the answer to this is not simple, and we are in a period of paradigm change right now.

THE BIASES of origin of life studies have always been that . . .

1. ***Life information systems must be RNA or DNA.***

⇨ In all living systems today, even the very simplest like viruses, this comes about through RNA or DNA.

⇨ RNA codes protein enzymes which mitigate the chemical reactions which build complex cell components.

⇨ Beyond the chemical kinetics then we need mechanisms that will generate nucleic acid sequences spontaneously in the organic soup.

2. ***Life energy systems must be mediated by energy derived from organic processes, and carried by ATP.***
3. ***Earliest organisms were heterotrophs, feeding on the organic molecules produced in the organic soup.***

OVERHEAD - The 16 phyla of the Monera Kingdom

Plus, we have tended **TO ASSUME** that . . .

4. ***Life has a structure similar to living organisms.***
5. ***Early life lived under environmental conditions we would find comfortable; i.e. the idea of a "warm little pond".***
6. ***Life arose by a series of highly improbable events which given enough time were bound to happen.***
7. ***The development of life's complexity was solely the result of natural selection processes.***

Recent studies are leading to the conclusions that none of these are true.

- Each of these topics is a large subject all its own, requiring many books worth of knowledge to understand and explore.
- We can only touch on a few of these subjects.

6. Life arose by a series of highly improbable events which given enough time were bound to happen.

CHANCE IS NOT ENOUGH:

We are not supposed to be here. Life cannot have occurred. Consider this argument made by Robert Shapiro in his book *Origins*. He calculates that in the history of the earth there could conceivably have been 2.5 x 10^{51} attempts to create life by chance. That is one hell of a lot of trials. But is it enough?

Rather than estimate the chances of obtaining an entire bacterium, what are the chances for obtaining a single functioning enzyme. Begin with a set of 20 amino acids that are used to construct enzymes. If the amino acids were selected at random and arranged in random order, what would be the chances for obtaining an actual bacterial enzyme with 200 amino acids?

The answer is obtained by multiplying the probability for each correct amino acid in the sequence, 1 in 20, together 200 times, yielding 1 in 20^{200}*, a vastly low probability. But since more than one amino acid sequence might be able to function to catalyze a given reaction, we might concede a probability of 1 in* 10^{20}*.*

But now the coup de grace: to duplicate a bacterium, it would not suffice to create a single enzyme. Instead it would be necessary to assemble about 2000 functioning enzymes. The odds against this would be 1 in $10^{20 \times 200}$*, or 1 in* $10^{40,000}$*.*

This exponential notation is easy to state, but difficult to take to heart. The total number of hydrogen atoms in the universe is something like 10^{60}*. So,*

$10^{40,000}$ is vast beyond vast, unimaginably hyperastronomical. And 1 in $10^{40,000}$ is unthinkably improbable.

If the total number of trials for life to get going is only 10^{51}, and the chances are 1 in $10^{40,000}$, then life just could not have occurred.
We the lucky.
We the very, very lucky.
We the impossible. In Kauffman, At Home in the Universe, p 44

The trouble with all these arguments is that they cannot conceive of any self-organizing principles, any way that order could spontaneously arise.

In terms or origin of life studies the major obstacle has been that, although simple organic molecules are demonstrated easy to create in Stanley Miller type experiments, it has been extremely difficult to experimentally develop the more complex molecules which compose life by purely random, natural selection driven processes.

For this reason all types of schemes have been proposed for how the long polymers essential for life (e.g. RNA) could have been generated.

- Cairns-Smith: clay as a substrate.

5. "The development of life's complexity was solely the result of natural selection processes."

NATURAL SELECTION IS NOT ENOUGH

The bias in studies of biological evolution is that evolution is dominantly the result of Darwinian natural selection operating on random mutations.

- Is the dominant response to the Watchmaker argument.
- Is emphasized in the modern synthesis.
- Is illustrated in the programs WordEvol and Microants.

But just because it is necessary does not mean it is sufficient.

OVERHEAD - The Adaptive (Fitness) Landscape of Sewell Wright

Review how the fitness landscape diagram works.

"Biologists see organisms as tinkered together contraptions, and evolution as a tinkerer . . . organisms are ad hoc contraptions." (Kauffman, 150)

"Selection is power, but not all powerful (Kauffman, 152) Adaptation is usually thought of as a process of "hill climbing" through minor variations toward "peaks" of high fitness landscapes. And natural selection is thought of as "pulling" and adapting populations toward such peaks.

We can imagine a mountain range on which populations of organisms (or in this case, programs) are feeling their ways to the summits. Depending on whether it is beneficial, a random change in the genome (the computer code) puts a mutant higher or lower on the terrain. If the mountain terrane *is rugged, but looks like familiar mountains, the terrain is still smooth enough to produce clues in the immediate vicinity about the direction to take.*

There are pathways uphill to the distant peaks and natural selection in sifting for the fitter variants, pulls the population up toward them. (Kauffman, 154)

We can think of the population as sending out "feelers" by generating, at random, various mutations. If a mutation occupies a position higher on the terrain, it is fitter, and the population is pulled o the new position, then random mutations from that position feel in all directions. Selection again pulls the population one step farther uphill. Here is gradualism at work in Darwin's sense. (Kauffman, 154)

The problems with this concept is that it does not work.

1. Cannot apply to the development of organic molecules in the origin of life.
2. Works in landscapes only when they posses certain properties of smoothness/ruggedness.
3. Is not observed in the punctuated nature of the fossil record.

NK FITNESS LANDSCAPES, AUTOCATALYTIC NETWORKS AND SELF ORGANIZING SYSTEMS

The idea of self-organizing systems through bottom-up processes is primarily the work of the Santa Fe Institute, and the people associated with it.

Is especially the work of Stuart Kauffman, a theoretical biologist, who developed the idea of, autocatalytic networks, and NK fitness landscapes.

Is a vast concept grounded in mathematics, but applicable to everything from cellular automata systems, to living organisms, to communities, to ecosystems, to the entire biosphere.

What they observe in their cellular automata and genetic algorithm studies is that self-organization is a inherent outcome of bottom-up processes.

And as these studies have been applied to the analysis of real systems, such as economies, etc. it is seen that self organization is natural.

Biology is just beginning to appreciate this component to evolution, but has yet to give it anywhere near equal status to natural selection.

Evolution then has three components:

1. Self-organization through autocatalytic networks and NK fitness.
2. Natural selection which works on the results of self-organization.
3. Historical accident - where what precedes directs what can come.

AUTOCATALYTIC NETWORKS

An autocatalytic network is one in which the molecules speed up the very reactions by which they themselves are formed.

OVERHEAD - Autocatalytic Networks

"The key is to get catalytic closure among a collection of molecular species. Alone each molecular species is dead. Jointly, once catalytic closure among them is achieved, the collective system of molecules is alive." (Kauffman, p)

"Each cell in your body, every free-living cell, is collectively autocatalytic. No DNA molecules replicate nude in free-living organisms. DNA replicates only as part of a complex, collectively autocatalytic network of reactions and enzymes in cells. . . Except for "food molecules" every molecular species of which a cell is constructed is created by catalysis of reactions, and the catalysis is itself carried out by catalysts created by the cell. ***TO UNDERSTAND THE ORIGIN OF LIFE, I CLAIM, WE MUST UNDERSTAND THE CONDITIONS THAT ENABLED THE FIRST EMERGENCE OF SUCH AUTOCATALYTIC MOLECULAR SYSTEMS"*** (Kauffman, p 50)

The key is to get catalytic closure among a collection of molecular species. Alone each molecular species is dead. Jointly, once catalytic closure among them is achieved, the collective system of molecules is alive.

That is, they become autopioetic networks.

AUTOPOIESIS - *auto* = self; *poiesis* = making. Term coined by Maturana and Varela to refer to the distinctive circular organization of living systems.

- "Living systems . . .[are] organized in a closed causal circular process that allows for evolutionary change in a way the circularity is maintained, but not for the loss of circularity itself." (Capra)
- The key characteristic of a living network is that it continually produces itself Thus, "being and doing of [living systems] are inseparable, and this is their specific mode of organization."
- Autopoiesis is a net work pattern in which the function of each component is to participate in the production or transformations of other components in the network. In this way, the network continually makes itself. It is produced by its components and in turn produces those components." (Capra, p 162)
- The properties of autopoietic network include (ala Fleishaker):
  - Self-Bounded - means that the system's extension is determined by a boundary that is an integral part of the network.
  - Self-Generating - means that all components, including those of the boundary, are produced by processes within the network.
  - Self-Perpetuating - means the production processes continue over time, so that all components are continually replaced by the system's processes of transformation.
- According to Maturana and Varela the concept of autopoiesis is necessary and sufficient to characterize the organization of living systems. However, this characterization does not include any information about the physical constitution of the systems components. (Capra, p 99)

These must be open systems - dissipative structures:

Can become limit cycle open systems, which oscillate.

But if the system has enough components which interact in non-linear ways, then the can undergo a phase transition into a large connected cluster.

"The analogue in the origin of life theory will be that when a large enough number of reactions are catalyzed in a chemical reaction system, a vast web of catalyzed reactions will suddenly crystallize.

Such a web, it turns out, is almost certainly autocatalytic - almost certainly self-sustaining, alive (Kauffman, p 58)

Life emerges as a phase transition (Kauffman, p 64)

> Life crystallizes at a critical molecular diversity because catalytic closure itself crystallizes. (Kauffman, p 64)
>
> Life emerges whole, not piecemeal . . . (as) catalytic closure in collectively autocatalytic sets of molecules. (Kauffman, p 69)

The key is to get catalytic closure among a collection of molecular species. Alone each molecular species is dead. Jointly, once catalytic closure among them is achieved, the collective system of molecules is alive.

SUBCRITICAL AND SUPRACRITICAL BEHAVIOR

THE EXPLOSION OF MOLECULAR SPECIES IN AUTOCATALYTIC NETWORKS

But it is not just enough to get these catalytic networks.

- ☞ **The earth presumably began with few or no organic molecules.**
- ☞ **Yet today organic molecules exist in the billions and trillions, and have expanded in number and diversity with the evolution of life.**
- ☞ **Where does all this stunning molecular diversity come from?**

How many kinds of large polymers exist? It we limit ourselves to proteins, we can make . . . very crude estimates . . . We will not be too far off if we guess that the biosphere harbors about 1 trillion different proteins. (Kauffman, p 115).

The striking possibility is that the very diversity of molecules in the biosphere causes its own explosion! The diversity feeds on itself, driving itself forward. (Kauffman, p 114)

"This explosion of molecular species is what I mean by supracritical behavior." (Kauffman, p 116).

This driving forward becomes a necessity because it would be impossible for all these molecules to appear by chance in the organic soup. Some mechanism must create all the complex molecules that life needs.

Chemicals can be catalysts that act on other chemical substrate to create still further chemical products. These novel chemical products can catalyze still further reactions involving themselves and all the original molecules to create still further molecules. these additional new molecules afford still further new reactions with themselves and all the older molecules as substrates, and all the molecules around may serve as catalysts for any of these newly available, reactions . . . (Kauffman, p 116).

> *Systems tend to evolve to the subcritical-supracritical boundary. If they go to far above they become chaotic and begin to disintegrate. If they go too far below they go static.* (Kauffman, p 127)
>
> *The subcritical-supracritical boundary must have always set an upper limit on the molecular diversity that can be housed within one cell. A limit exists, then, on the molecular complexity of a cell.* (Kauffman, p 126).

In terms of a complexity system, all these catalytic reactions are spewing out an enormous diversity of new molecules, most of which are probably useless. But this great diversity is what natural selection can work on to find a good molecule. And once it is found and incorporated into a catalytic network then it becomes an integral part of the system.

But neither protocells, nor today's cells live alone. Cells live in complex communities that always have shared and always will share the molecules each cell creates. *(Kauffman, p 114)*.

☞ *Ten million small organic molecules and 1 trillion proteins? Nothing like that was around the neighborhood 4 billion years ago. Where did all this diversity come from?* (Kauffman, p 115)

The biosphere as a whole may be collectively autocatalytic and - somewhat like a nuclear chain reaction - collectively supracritical, collectively catalyzing the exploding diversity of organic molecules we see. (Kauffman, p 115)

But while the biosphere as a whole is supracritical, . . . The individual cells that make up the biosphere must be subcritical. Otherwise, the internal cellular explosion of diversity would be lethal. (Kauffman, p 115)

If cells are subcritical, this must be a fact of enormous importance . . . Suppose cells were actually supracritical. Then the injection of a novel molecule Q would unleash a cascade of molecular novelty: Q, R, S. . . Almost certainly, many of these novel molecules would disrupt the homeostatic molecular coordination within the cells, leading to cell death . . . What protection might cells have evolved? Cells might use carefully wrought membranes to exclude all "foreign" molecules, or they might develop an immune system. But the simplest defense, surely is to remain subcritical. (Kauffman, p 126)

There must be a creative tension, a dynamic balance between supracriticality out there, and subcriticality in the cell. And this is obtained by selecting the right rules (local rules/global behavior) by which the system is operating.

- ☞ **The structures of cells, and organisms, and communities compose some of these rules.**
- ☞ **And we find this showing up in the dynamic balance between speciation and extinction.**

OVERHEAD - Autocatalytic Networks: Supracritical/Subcritical Figures

Ecosystems may evolve to the sub-critical-supracritical boundary (Kauffman, p 129).

If local ecosystems are metabolically poised at the subcritical-supracritical boundary, while the biosphere as a whole is supracritical - then what a new tale we tell. Of life cooperating to beget ever new kinds of molecules, and of a biosphere where local ecosystem are poised a the boundary, but have collectively crept slowly upward in total diversity by the supracritical character of the whole planet.

The whole biosphere is broadly, collectively autocatalytic, catalyzing its own maintenance and ongoing molecular exploration. (Kauffman, p 130).

If life crystallizes as collectively autocatalytic sets . . . then the first life was already supracritical, already exploding.

(Kauffman, p 116).

HYPERCYCLES AND QUAZISPECIES

OVERHEAD - Hypercycles and Quazispecies

SS-4: Hypercycle Organization - Competition of Quazispecies

An example of a biological autocatalytic network are the hypercycles developed by Manfried Eigen.

⇨ are ***coupled RNA protein (enzyme) systems***.

⇨ RNA codes for catalytic proteins which make more RNA, which make more proteins.

Hypercycles exist as a series of RNA sequences and variety of enzymatic proteins existing is a dynamic system

⇨ Proteins catalyze growth of a number of RNA sequences, and RNA sequences generate variety of proteins.

⇨ They are in a dynamic equilibrium all reinforcing each other allowing the hypercycle as a whole to evolve.

⇨ At this stage, however, proteins cannot check or control how the RNA is sequenced, it just speeds up the reaction.

⇨ Thus, the system is not as efficient as it could be if the RNA and protein were tightly coupled with the information of each locked into the other.

This coupled system introduces information feedback as part of the system.

⇨ In essence it is a self referencing system and non-linear and thus chaotic.

⇨ They are:

1. Capable of much faster growth rates than non-enzymatic systems and thus take over.
2. And they are like coupled RAMPS ANTIRAMPS.

Hypercycles allow . . .

1. Faster autocatalytic growth.
2. Stable coexistence of a variety of genes.
3. Expanded amount and variety of information coded.

SS-2: Small RNA Sequences

This is the wrong question, for.

both together since RNA carries information in its very structure.

⇨ Developed through a series of stratified stabilities which is expressed as physical chemistry.

⇨ We can see this by analogy with the genetic algorithms. The structure, the binary code is there even if the information content is low.

⇨ But, even if information is random there is some information there, and it is only refining that information that is necessary.

⇨ Natural selection processes analogous to WORDEVOL are perfectly capable of doing it efficiently.

”

⇨ Process is selection of “right” RNA by chemical kinetics.

⇨ This is based on a molecule with the “right” ***homogeneous stereochemistry*** and correct covalent bonding in the backbone, which leads to . . .

1. Stable secondary foldings which resist hydrolysis.

2. Ability to self replicate - because self replication is based on symmetry in the molecule which allows. . .
   > Sequence to unfold without tangling, and
   > To line up the replicating counterpart easily.

In addition, primitive mixtures of amino acids have been shown to have enzymatic functions.

⇨ That is, some of these molecules would have been capable of catalyzing the very reactions that produced more of themselves.

BUT DESPITE their stability and efficiency they could not ***evolve*** toward life like systems until they could:

1. Self replicate
2. Conserve information

An intricate series of laboratory experiments have reconstructed the kinds of steps by which this could occur (Eigen. Et. Al.)

1 Components + Master sequence + Enzyme = Replication
2 Components + Enzyme = Replication
3 Components + Zn = Constructions and Replication

(10^{12} in one simple nucleotide sequence).

⇨ "Right sequence" is, of course, a teleological value judgement.

⇨ It clearly cannot be a deterministic process (as occurs when a template {a preexisting "right" RNA molecule} already exists to guide the replication).

⇨ Must result from chance stratified stabilities in stochastic chemical processes.

⇨ But, "right" in this case is a molecule which is capable of evolving to the next stratified stability on the way to life.

SS-3: Stable Quazispecies

The right sequence is the ***quazispecies*** (***self replicating strands of RNA generated without enzymes***) (but with a catalyst like Zn) resulting from the simple probabilities of different chemical reactions.

⇨ In the experiments each environment (set of experimental conditions) produced an optimal product {quazispecies} (one of which was a minivariant present in a functioning virus {although note that the enzyme was specific for that virus}]

⇨ In this situation this is like the Microants GA, or like RAMPS climbing up a fitness peak.

Under any set of conditions the best ("right") quazispecies "competitor" is the one which . . .

1. Competes best for available "food" (ATP energy molecules).
2. Is the most resistant to degradation because of its folding pattern.

In the steady state reached under any set of conditions the best competitor (the ***Master Sequence***) coexists with all its mutant sequences derived from it by erroneous copying (all together are the quazispecies)

⇨ Whole process has very high efficiency, i.e. reproduction rates are high.

⇨ Stability exists until a new sequence (mutant) has a higher growth rate (or until the environmental conditions change). . .

⇨ Then a new quazispecies evolves.

⇨ In this way it is like a GENE or MICROANT survivor of an extinction with all its mutant offspring existing simultaneously.

Further experiments have demonstrated that even in the absence of enzymes (but in the presence of Zn) highly accurate self replication does take place.

⇨ All this took place within the organic soup (i.e. it was non-cellular)

Darwinian competition in a quazispecies was based on selection according to the chemical kinetics of the sequence; what the sequence "meant" played no role (p 107)

If life is a dissipative structure, and it follows the principles of chaos theory, then it is inherent in the system for order to emerge. Chaotic systems are self organizing - order arises spontaneously out of the working of the laws of complexity.

We saw this in the Life3000 demonstrations. There, when the information flow was just right centers of organized, dynamic complexity arose spontaneously from the working out of the simple deterministic laws of the system.

In the laboratory these principles have already been worked out at the biochemical level. Beginning with Stanley Miller's experiment, and continuing through a wide range of increasingly sophisticated experiments we see that complex molecular structures can arise spontaneously. Some of the most important are those of Eigen, et.al leading to the theory of hypercycles, which are functioning on chaos principles.

More advanced A-Life experiments beyond Life3000 similarly demonstrate that self-organization is a principle of all chaos systems.

What we are seeing here is the interaction of chaos and symmetry hybrids. The symmetry operating here is functional morphology and the biomechanical constraints which limit, direct, or control the broad patterns which morphology can take. Over this symmetry a lot of individual variation is possible, varying, say, from optimal design to designs which are on the very edge of optimum.

NK FITNESS LANDSCAPES

For a dynamical system, such as an autocatalytic set to be orderly, it must exhibit homeostasis (Kauffman, p 79)

The most sophisticated theory to date about self-organizing systems are the NK Fitness Landscapes developed by Stewart Kauffman.

OVERHEAD - NK Fitness Landscapes

Are analogous to Sewell Wright's fitness landscape.

THE REQUIREMENTS FOR ORDER: two features of the way networks are constructed can control whether they are in an ordered regime, a chaotic regime, or a phase transition between these - "on the edge of chaos."

1. How many inputs control any one component. The more inputs the more chaotic.

   Sparsely connected networks exhibit internal order; densely connected ones veer into chaos, and networks with a single connection per element freeze into mindless dull behavior (Kauffman, p 85).

2. Biases in the control rules.

   Some control rules tend to create orderly dynamics. Other rules create chaos

What controls how easily an organism can move from one peak to another?

Genetic Information Flow

- Two little, no ability to jump to nearby peaks
- Too much, movement is so random probability of moving to a less common higher peak is much less than landing on somewhere lower.

Key is to find balance between too much order, and too much chaos.

"I suspect that the fate of all complex adapting systems in the biosphere, from single cells to economies, is to evolve to a natural state between order and chaos, a grand compromise between structure and surprise. (Kauffman, p 15).

TYPES OF FITNESS LANDSCAPES

Random Fitness - high K

Because so many constraints are in conflict, there is a large number of rather modest compromise solutions rather than an obvious superb solution. There are, in other words, many local peaks with very low altitudes. Because landscapes are more rugged, adaptation becomes harder.

As K increases, the heights of the peaks decreases, their number increase, and evolving over the landscape becomes more difficult.

Quote on page 178

Correlated Fitness - low K

Sparsely connected networks, with K=1 or K=2, spontaneously exhibit powerful order; networks with higher numbers of inputs per light bulb, K=4, show chaotic behavior. (Kauffman, p 86).

4. "Early life lived under environmental conditions we would find comfortable; i.e. the idea of a "warm little pond."

THE EARLY EARTH WAS A HOSTILE PLACE

Extremophiles

"They are as alien as anything imaginable. They thrive above boiling-hot vents on the deep-sea floor, and thousands of feet below the polar ice, and more than 9000 feet beneath Virginia's top soil. They can swim in acid, eat sulfur, and draw energy from rock."

Washington Post, Sunday, April 6, 1997

OVERHEAD - Universal Tree of Life

All the deepest and shortest branches within the phylogenetic tree are occupied by groups of hyperthermophilic bacteria and Archaea, which appear, therefore, still rather primitive. In addition, these organisms are chemlithoautotrophs. This suggests a thermophilic autotrophic origin of life. *Ketter*

OVERHEAD - The Diversification of Eubacteria and Archaea . . .

During the last years extremophilic prokaryote have been isolated from environments some of which are reminiscent of the primitive Earth, and may have remained chemically and physically almost unchanged during billions of years.

Hyperthermophilic prokaryotes have been isolated from geo- and hydrothermal areas. Terrestrial biotopes are mainly solfataric fields. They consist of soils, mud holes., and surface waters heated by volcanic exhalations from magma chambers below.

Solfataric soils are usually:

- *Acidic (pH 0.5-6.*
- *Rich in sulfate and elemental sulfur.*
- *Appear ocher colored because of the presence of ferric iron.*
- *At depth are blackish because of ferrous sulfide.*

Marine hydrothermal systems are situated in shallow and abyssal depths. They consist of:

- *Hot fumaroles.*
- *Springs*
- *Deep-sea vents (smokers).*
- *Gas exhalations of steam, CO_2, H_2S, S^o, some CO, hydrogen, methane, nitrogen, and traces of ammonia.*

Submarine hydrothermal systems similar to sea water, usually contain high concentrations of NaCl and sulfate and exhibit a slightly acidic to alkaline pH.

2. "Life energy systems must be mediated by energy derived from organic processes, and carried by ATP."
3. "Earliest organisms were heterotrophs, feeding on the organic molecules produced in the organic soup."

ENERGY YIELDING REACTIONS

Most of these extremophilic organisms from the deepest branches of the universal tree of life are strict chemlithoautotrophs.

OVERHEAD - Energy Yielding Reactions

Heterotrophy (obtaining food from the environment) appears later, although still early in the tree. But this indicates that the earliest organisms are represented almost exclusively by strictly chemlithoautotrophic organisms.

- That is, these are organisms that take in carbon probably in the form of CO2, and from it metabolize all their own organic molecules.
- *"Therefore, autotrophy appears to be a very ancient feature, supporting theories about an autotrophic origin of life."*
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CELLULARIZATION

OVERHEAD - Scheme of Early Diversification of Precellular Founder Groups Undergoing Allopatric Speciation by Parallelophyly