Polynucleotide structure. In DNA and RNA, the phosphodiester bridges link the 3’-hydroxyl of one nucleotide to the 5’-hydroxyl of the next.
What are we made of?

The “Big Six” elements

H, C, N, O, P, S

What are the forms of these elements in “organic” matter?

What makes a compound “organic”?

Are all organic molecules formed from biological processes?

What are early sources of organic matter on Earth?

What is “life”?

When did life begin?
\[
\begin{align*}
\text{CH}_2\text{OH} & & \text{CHO} & & \text{CHO} \\
\text{C}=\text{O} & & \text{HCOH} & & \text{CH}_2 \\
\text{HCOH} & & \text{HCOH} & & \text{HCOH} \\
\text{HCOH} & & \text{HCOH} & & \text{HCOH} \\
\text{CH}_2\text{OH} & & \text{CH}_2\text{OH} & & \text{CH}_2\text{OH} \\
\text{D-ribulose} & & \text{D-ribose} & & \text{2deoxy-D-ribose}
\end{align*}
\]

The S C sugars
Table 9.1 Major Ion Composition of Seawater, Showing Relationships to Total Salinity and Mean Residence Times for the Elements with Respect to River Water Inputs

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Concentration in seawater&lt;sup&gt;a&lt;/sup&gt; (mg/kg)</th>
<th>Chlorinity ratio&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Concentration in river water&lt;sup&gt;b&lt;/sup&gt; (mg/kg)</th>
<th>Mean residence time (10&lt;sup&gt;6&lt;/sup&gt; yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium</td>
<td>10,760</td>
<td>0.5561</td>
<td>5.15</td>
<td>75</td>
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<tr>
<td>Magnesium</td>
<td>1,294</td>
<td>0.0668</td>
<td>3.35</td>
<td>14</td>
</tr>
<tr>
<td>Calcium</td>
<td>412</td>
<td>0.0213</td>
<td>13.4</td>
<td>1.1</td>
</tr>
<tr>
<td>Potassium</td>
<td>399</td>
<td>0.0206</td>
<td>1.3</td>
<td>11</td>
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<tr>
<td>Strontium</td>
<td>7.9</td>
<td>0.00041</td>
<td>0.03</td>
<td>12</td>
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<tr>
<td>Chloride</td>
<td>19,350</td>
<td>1.0000</td>
<td>5.75</td>
<td>120</td>
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<tr>
<td>Sulfate</td>
<td>2,712</td>
<td>0.1400</td>
<td>8.25</td>
<td>12</td>
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<tr>
<td>Bicarbonate</td>
<td>145</td>
<td>0.0075</td>
<td>52</td>
<td>0.10</td>
</tr>
<tr>
<td>Bromide</td>
<td>67</td>
<td>0.0035</td>
<td>0.02</td>
<td>100</td>
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<tr>
<td>Boron</td>
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<td>0.00024</td>
<td>0.01</td>
<td>10.0</td>
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<td>Fluoride</td>
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<td>0.000067</td>
<td>0.10</td>
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<td>Water</td>
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<td>0.034</td>
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<sup>a</sup> Holland (1978).
<sup>b</sup> Meybeck (1979) and Holland (1978).
<table>
<thead>
<tr>
<th>Volcano</th>
<th>H₂O</th>
<th>H₂</th>
<th>CO₂</th>
<th>SO₂</th>
<th>H₂S</th>
<th>HCl</th>
<th>HF</th>
<th>N₂</th>
<th>NH₃</th>
<th>O₂</th>
<th>Ar</th>
<th>CH₄</th>
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<td>Kudryavy, Russia</td>
<td>95.00</td>
<td>0.56</td>
<td>2.00</td>
<td>1.32</td>
<td>0.41</td>
<td>0.3700</td>
<td>0.03</td>
<td>0.21</td>
<td>—</td>
<td>0.03</td>
<td>0.002</td>
<td>0.002</td>
<td>Taran et al. (1996)</td>
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<tr>
<td>Nevado del Ruiz, Columbia</td>
<td>94.90</td>
<td>2.91</td>
<td>2.74</td>
<td>0.80</td>
<td>0.0052</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Williams et al. (1994)</td>
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<td>Kamchatka, Russia</td>
<td>78.60</td>
<td>3.01</td>
<td>4.87</td>
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<td>0.16</td>
<td>0.5700</td>
<td>0.056</td>
<td>11.87</td>
<td>0.11</td>
<td>0.01</td>
<td>0.060</td>
<td>0.440</td>
<td>Dobrovolsky (1995)</td>
</tr>
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</table>
The Initial Condition Problem

• Was the early Earth hot or cold?

• Was there NH$_3$ in Earth’s atmosphere?

• What was the redox potential of the ocean?
The Amino Acid World

• Amino acids are stable for long periods even at relatively high temperatures. However, the abiotic formation of amino acids requires NH₃.

• NH₃ was not stable in the Archean atmosphere.
The RNA World

• Given a supply of ribose (a major caveat), RNA can self replicate. However, RNA stability is very much reduced at high temperature.
The Redox Reaction Hypothesis

- Oxidation/reduction reactions are catalyzed by transition metals independent of proteins.
- In a “Primordial Soup” with organic molecules, redox reactions can mediate “metabolic pathways” without organisms.
Life is Electric

• All organisms derive energy for growth and maintenance by moving electrons from a substrate to a product.
• All substrates and products must ultimately be cycled.
• Biological processes are paired (e.g., photosynthesis and respiration)
Redox Reactions are Couple on a GLOBAL SCALE

Oxygeonic Photosynthesis
\[ 2\text{H}_2\text{O} + \text{CO}_2 \rightarrow (\text{CH}_2\text{O})_n + \text{O}_2 \]

Aerobic Respiration:
\[ (\text{CH}_2\text{O})_n + \text{O}_2 \rightarrow 2\text{H}_2\text{O} + \text{CO}_2 \]

Q. Are photosynthesis and respiration balanced on a global scale?
Redox Reactions Are Coupled On

General Reaction

\[ \text{A(ox)} + n \text{ (e)}^- \longrightarrow \text{A(red)} \]
\[ \text{B(red)} - n \text{ (e)}^- \longrightarrow \text{B(ox)} \]

Photosynthesis

\[ 2\text{H}_2\text{O} + \text{light} \longrightarrow 4\text{H}^+ + 4\text{e}^- + \text{O}_2 \]
\[ \text{CO}_2 + 4\text{H}^+ + 4\text{e}^- \longrightarrow (\text{CH}_2\text{O}) + \text{H}_2\text{O} \]
Early Proterozoic Ocean

circa 2000 Mybp

- $\text{N}_2$
- $\text{CO}_2$
- $\text{O}_2$
- Cyanobacteria
- Nitrifiers
  - $\text{NO}_3^-$
  - $\text{Fe}^{(III)}$
- $\text{PO}_4^{3-}$
- N/P < 16
<table>
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<th>Continent</th>
<th>HCO₃⁻</th>
<th>SO₄²⁻</th>
<th>Cl⁻</th>
<th>NO₃⁻</th>
<th>Ca²⁺</th>
<th>Mg²⁺</th>
<th>Na⁺</th>
<th>K⁺</th>
<th>Fe</th>
<th>SiO₂</th>
<th>Sum</th>
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<td>8</td>
<td>1</td>
<td>21</td>
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<td>9</td>
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<td>0.16</td>
<td>9</td>
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<td>31</td>
<td>4.8</td>
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<td>4</td>
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<td>3.7</td>
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<td>2.9</td>
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<td>1</td>
<td>15</td>
<td>4.1</td>
<td>6.3</td>
<td>2.3</td>
<td>0.67</td>
<td>13.1</td>
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<tr>
<td>Arctics</td>
<td>0.958</td>
<td>0.233</td>
<td>0.220</td>
<td>0.017</td>
<td>0.750</td>
<td>0.342</td>
<td>0.274</td>
<td>0.059</td>
<td>1.428</td>
<td>1.425</td>
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</tbody>
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*Kingston (1963); concentrations in mg/liter.*

*Equivalents of strongly ionized components.*
Late Proterozoic Ocean

circa 800-500 Mybp

Cyanobacteria and Eukaryotes

- De-nitrifiers
- Nitrifiers
- O₂
- NO₃⁻
- Fe(III)
- N/P < 16
- PO₄²⁻