Figure 5.7 Structures of substrates and products of reactions catalyzed by Rubisco.
\[(^{18}\text{O}/^{16}\text{O})_c = \alpha_{c-w} = 1.0286 \text{ @ } 25 \degree \text{C} \]

\[(^{18}\text{O}/^{16}\text{O})_w \]

Differences in isotopic fractionation between samples are small and delta values are a convenient way of expressing small differences.

\[\delta^{18}\text{O} = 1000 \times \left( ^{18}\text{O}/^{16}\text{O} \text{ sample} - 1 \right) / ^{18}\text{O}/^{16}\text{O} \text{ standard} \]

Temp = 16.9 - 4.38 (δc - δw) + 0.1 (δc-δw)^2

Simplified version:

Temp = 16.9 - 4.0 (δc-δw)
A  CARBONATE ROCK WEATHERING
\[ \text{CO}_2 + \text{H}_2\text{O} + \text{CaCO}_3 \rightarrow \text{Ca}^{2+} + 2\text{HCO}_3^- \]

B  SILICATE ROCK WEATHERING
\[ 2\text{CO}_2 + \text{H}_2\text{O} + \text{CaSiO}_3 \rightarrow \text{Ca}^{2+} + 2\text{HCO}_3^- + \text{SiO}_2 \]

C  CARBONATE FORMATION IN OCEANS
\[ 2\text{HCO}_3^- + \text{Ca}^{2+} \rightarrow \text{CaCO}_3 + \text{CO}_2 + \text{H}_2\text{O} \]

D  SILICATE WEATHERING PLUS CARBONATE FORMATION (B & C)
\[ \text{CO}_2 + \text{CaSiO}_3 \rightarrow \text{CaCO}_3 + \text{SiO}_2 \]

E  METAMORPHIC / MAMMATIC BRIDOWN OF CARBONATE
\[ \text{CaCO}_3 + \text{SiO}_2 \rightarrow \text{CaSiO}_3 + \text{CO}_2 \]
Redox Reactions are Coupled on a GLOBAL SCALE

Oxygenic Photosynthesis:

$$2H_2O + CO_2 \rightarrow (CH_2O)_n + O_2$$

Aerobic Respiration:

$$(CH_2O)_n + O_2 \rightarrow 2H_2O + CO_2$$

Q: Is Photosynthesis and Respiration balanced on a global scale?
THE EVOLUTION OF OXYGEN ON EARTH

FROM HOLLAND AND RYE. NATURE (in press)
Figure 3-25 Animal phylogeny, showing the division of coelomates into protostomes and deuterostomes.
Without Atmosphere

\[ T_E = 255 \text{ K} \ (\text{-18C}) \]

With Atmosphere

\[ T_E = 286 \text{ K} \]

\[ \therefore \text{“Greenhouse” effect} = 31 \text{ K} \]
GLOBAL RADIATION BUDGET
AT TOP OF THE ATMOSPHERE

Reflected Solar = 100 Wm^{-2}

Incident Solar = 340 Wm^{-2}

Absorbed Solar = 240 Wm^{-2}

Emitted Infrared = 240 Wm^{-2}
WITHOUT CLOUD FEEDBACK

CLIMATE SENSITIVITY

MODEL NUMBER

1 3 5 7 9 11 13 15 17 19
CLOUD OPTICAL THICKNESS

\[ \delta_C = \pi r_e^2 Q_{ext} N z_C \]

\( \delta_C \) is the optical thickness of the cloud
\( z_C \) is the physical thickness of the cloud
\( r_e \) is the effective radius of the cloud droplets
\( Q_{ext} \) is the average extinction efficiency \( \approx 2 \).
\( N_C \) is the concentration (number density) of the cloud droplets.
DEPENDENCE OF CLOUD-TOP ALBEDO ON CLOUD THICKNESS AND DROPLET CONCENTRATION

Central curve relates to fairly clean maritime conditions. Effects of halving and doubling drop diameter (8-fold increase and reduction in droplet concentration, respectively) are shown in the upper and lower curves. From Twomey, *Atmospheric Aerosols*, 1977.
EVALUATION OF PERTURBATION IN GLOBAL MEAN CLOUD RADIATIVE FORCING DUE TO ANTHROPOGENIC SULFATE

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Value</th>
<th>Units</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta \ln N$</td>
<td>0.15</td>
<td></td>
<td>(1)</td>
</tr>
<tr>
<td>$F_T$</td>
<td>1370</td>
<td>W m$^{-2}$</td>
<td></td>
</tr>
<tr>
<td>$A_{\text{inst}}$</td>
<td>0.3</td>
<td></td>
<td>(2)</td>
</tr>
<tr>
<td>$T$</td>
<td>0.76</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_{\text{CT}}$</td>
<td>0.3 - 0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta F_C$</td>
<td>-0.7</td>
<td>W m$^{-2}$</td>
<td></td>
</tr>
</tbody>
</table>

Based on comparison of mass concentrations of non sea-salt sulfate aerosol at remote locations of the Northern and Southern Hemispheres and the assumption that CCN concentration scales linearly with non sea-salt sulfate mass (Schwartz, 1988).

Fraction of atmosphere occupied by non overlapped marine stratus and stratocumulus, (Charlson et al., 1987).