Primary Producer Carbon

Elemental Ecology

Week Three

Transition metals

1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8	9 8B	10	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	8A
1 **H** 1.00794																	2 **He** 4.00260
3 **Li** 6.941	4 **Be** 9.01218											5 **B** 10.81	6 **C** 12.011	7 **N** 14.0067	8 **O** 15.9994	9 **F** 18.998403	10 **Ne** 20.1797
11 **Na** 22.98977	12 **Mg** 24.305											13 **Al** 26.98154	14 **Si** 28.0855	15 **P** 30.97376	16 **S** 32.066	17 **Cl** 35.453	18 **Ar** 39.948
19 **K** 39.0983	20 **Ca** 40.078	21 **Sc** 44.9559	22 **Ti** 47.88	23 **V** 50.9415	24 **Cr** 51.996	25 **Mn** 54.9380	26 **Fe** 55.847	27 **Co** 58.9332	28 **Ni** 58.69	29 **Cu** 63.546	30 **Zn** 65.39	31 **Ga** 69.72	32 **Ge** 72.61	33 **As** 74.9216	34 **Se** 78.96	35 **Br** 79.904	36 **Kr** 83.80
37 **Rb** 85.4678	38 **Sr** 87.62	39 **Y** 88.9059	40 **Zr** 91.224	41 **Nb** 92.9064	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.07	45 **Rh** 102.9055	46 **Pd** 106.42	47 **Ag** 107.8682	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.710	51 **Sb** 121.757	52 **Te** 127.60	53 **I** 126.9045	54 **Xe** 131.29
55 **Cs** 132.9054	56 **Ba** 137.33	57 ***La** 138.9055	72 **Hf** 178.49	73 **Ta** 180.9479	74 **W** 183.85	75 **Re** 186.207	76 **Os** 190.2	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.9665	80 **Hg** 200.59	81 **Tl** 204.383	82 **Pb** 207.2	83 **Bi** 208.9804	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** 226.0254	89 **†Ac** 227.0278	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (266)	107 **Bh** (264)	108 **Hs** (269)	109 **Mt** (268)	110 (271)	111 (272)	112 (277)		114 (289)		116 (289)		118 (293)

*Lanthanide series	58 **Ce** 140.12	59 **Pr** 140.9077	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.36	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.9254	66 **Dy** 162.50	67 **Ho** 164.9304	68 **Er** 167.26	69 **Tm** 168.9342	70 **Yb** 173.04	71 **Lu** 174.967
†Actinide series	90 **Th** 232.0381	91 **Pa** 231.0359	92 **U** 238.0289	93 **Np** 237.048	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

H. Craig

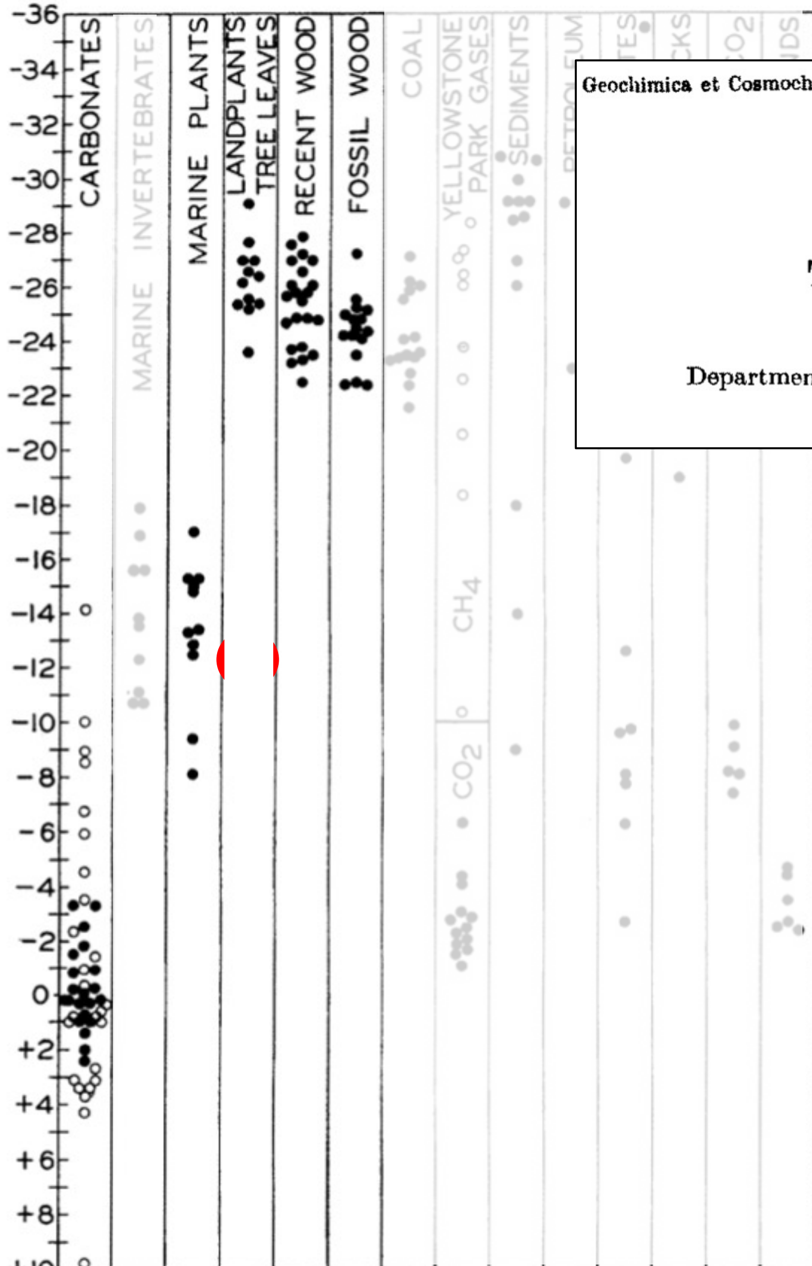


Fig. 3. δ C^{13}/C^{12} in ‰, of various carbonaceous samples.

Geochimica et Cosmochimica Acta, 1953, Vol. 3, pp. 53 to 92. Pergamon Press Ltd., London

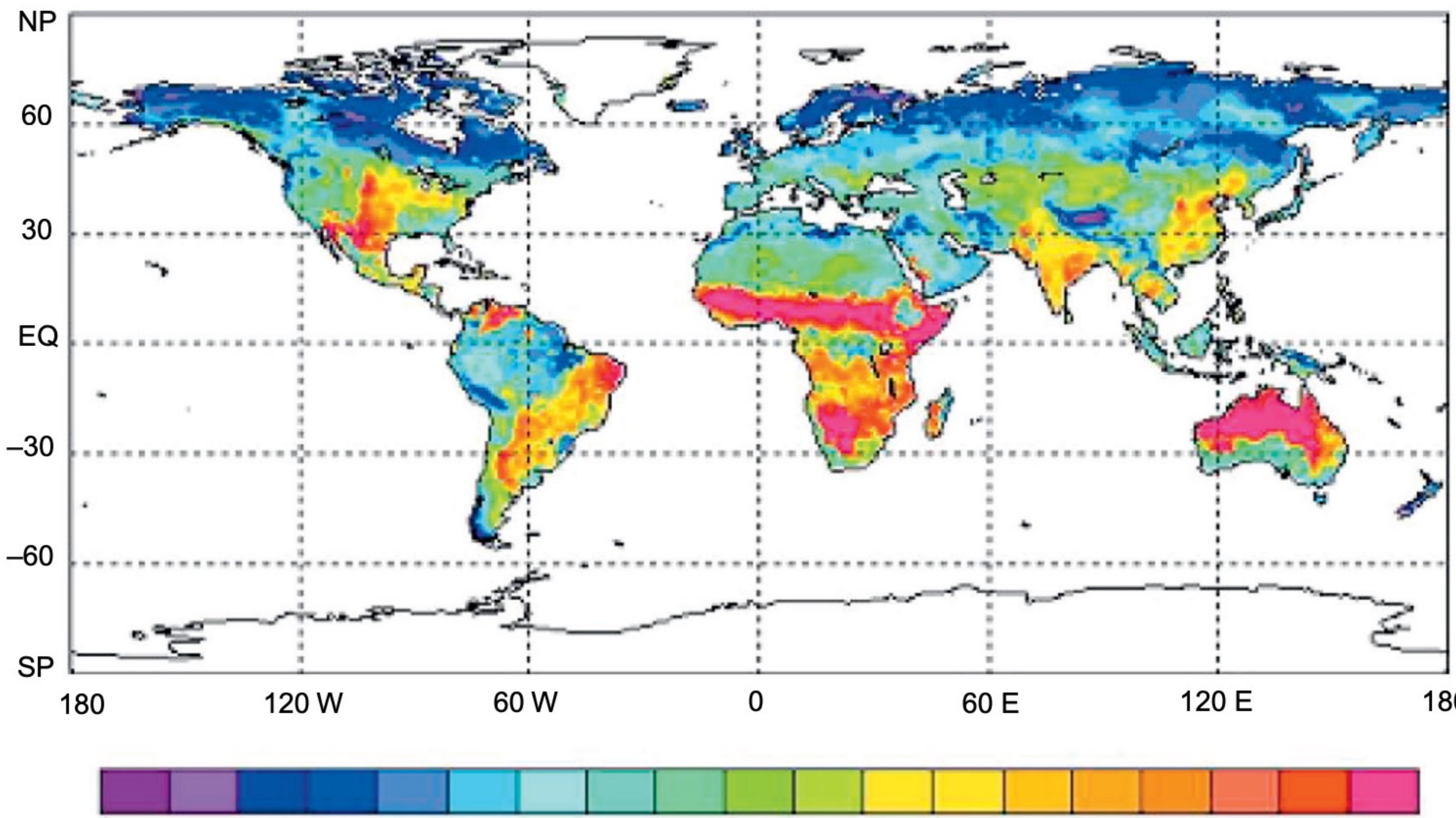
The geochemistry of the stable carbon isotopes*

Harmon Craig

Department of Geology and Institute for Nuclear Studies, University of Chicago

(Received 25 May 1952)

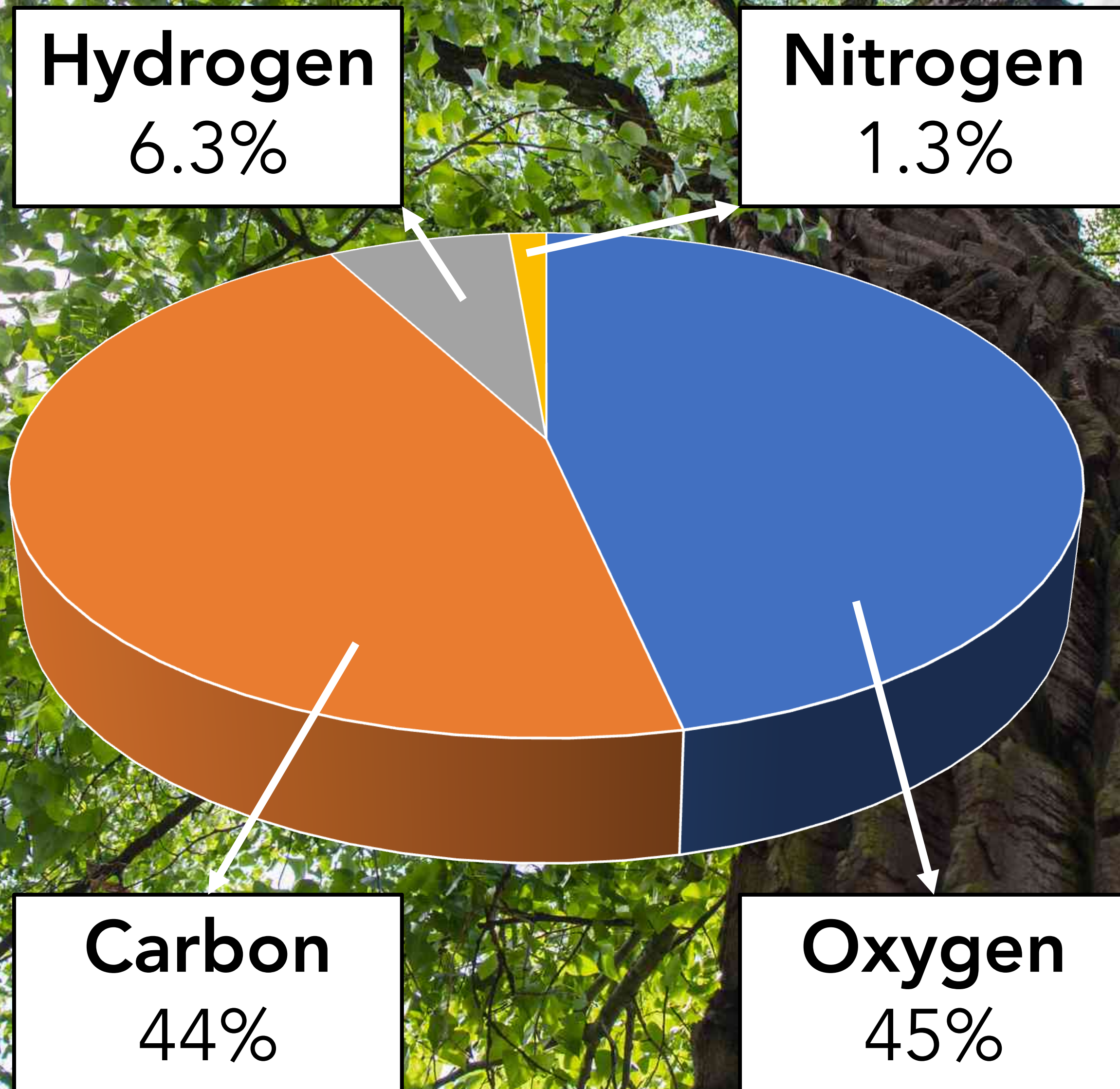
"Sample 125 poses another problem. This is a sample of grass from southwestern Kansas and the analysis is far heavier than all the others."



Mean annual plant $\delta^{13}C$

Bowen & West 2019

What are plants made of?

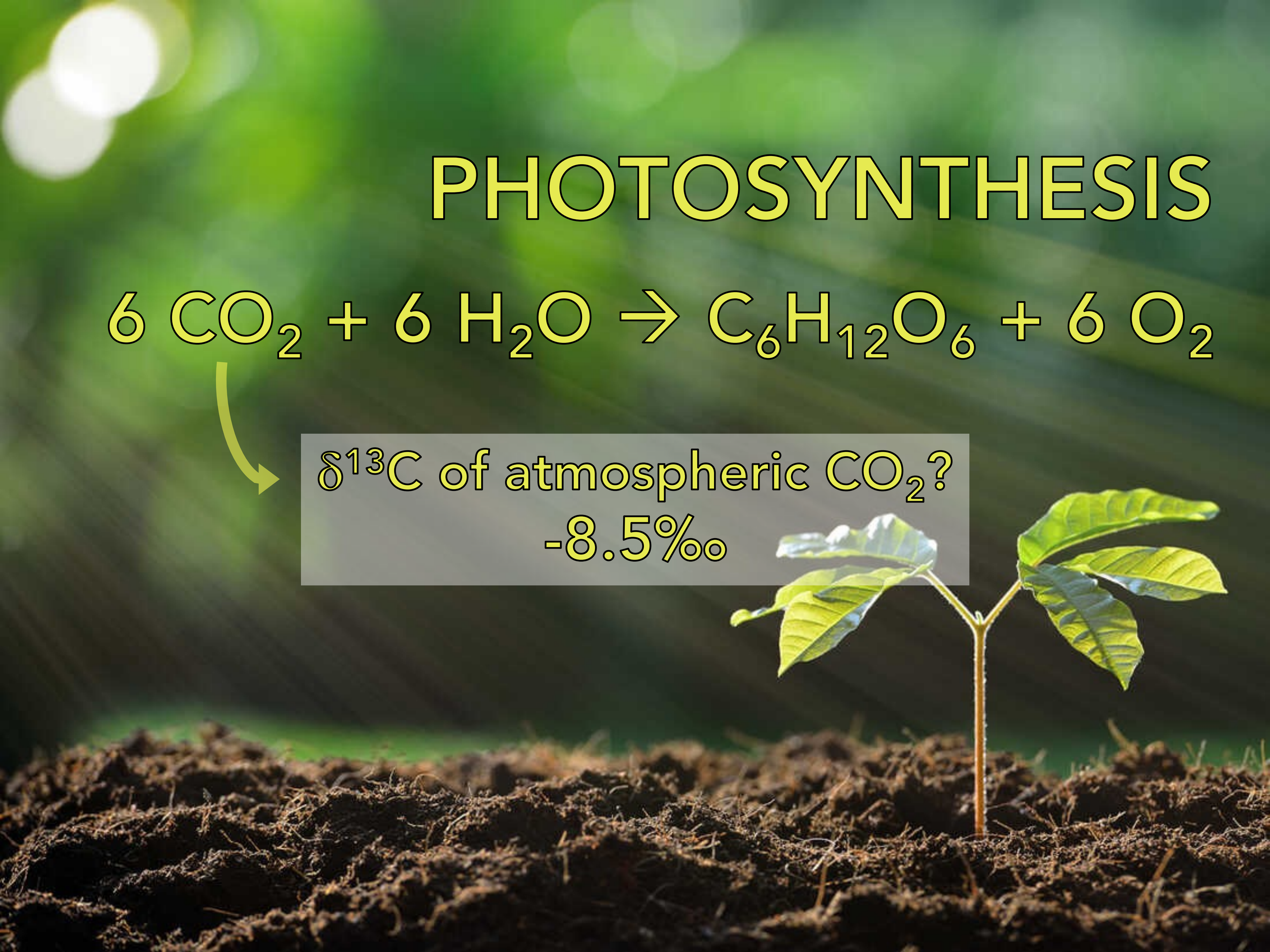


PHOTOSYNTHESIS

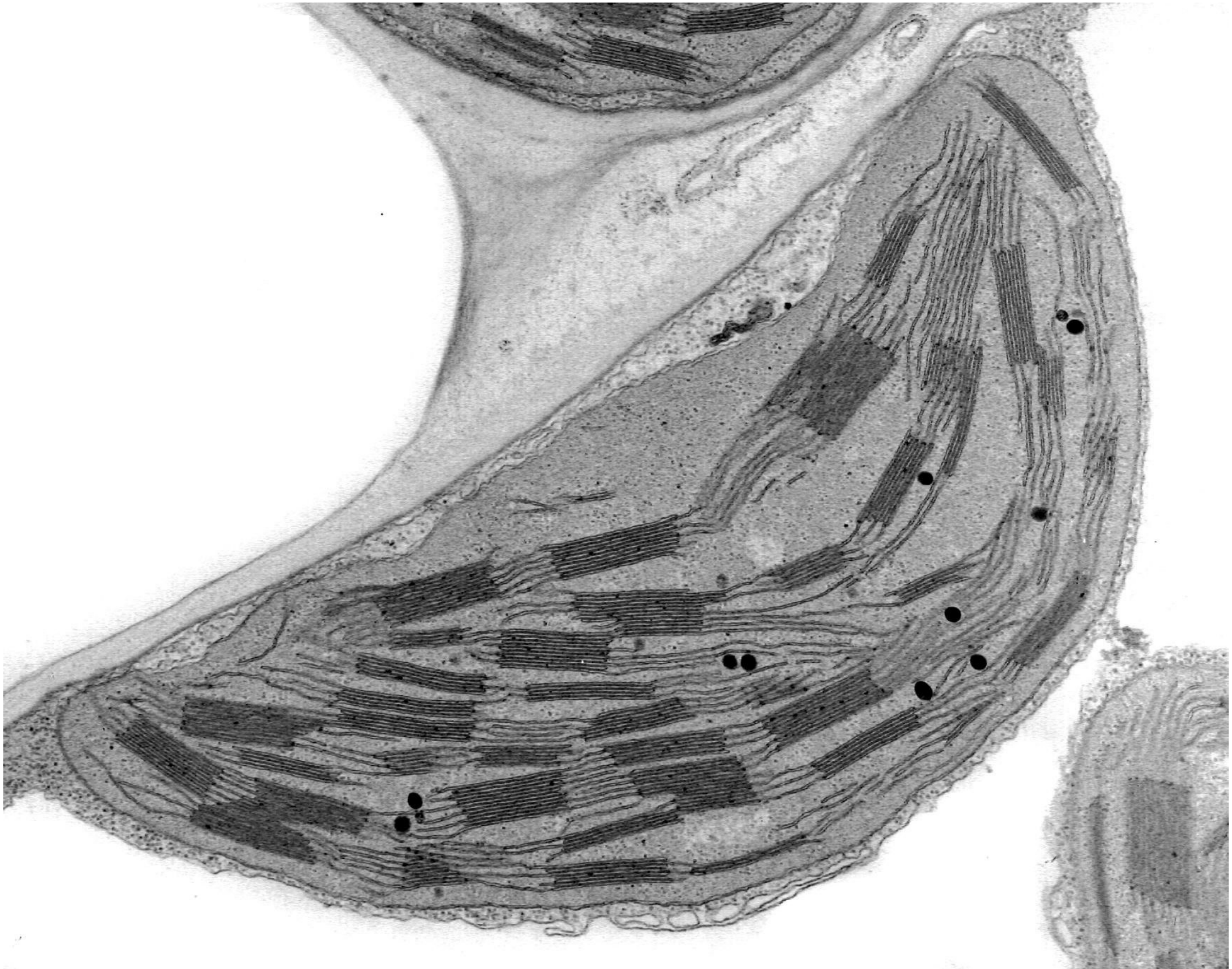
$$6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2$$

$\delta^{13}C$ of atmospheric CO_2?

-8.5‰



Photosynthesis takes place in chloroplasts



Light Reactions

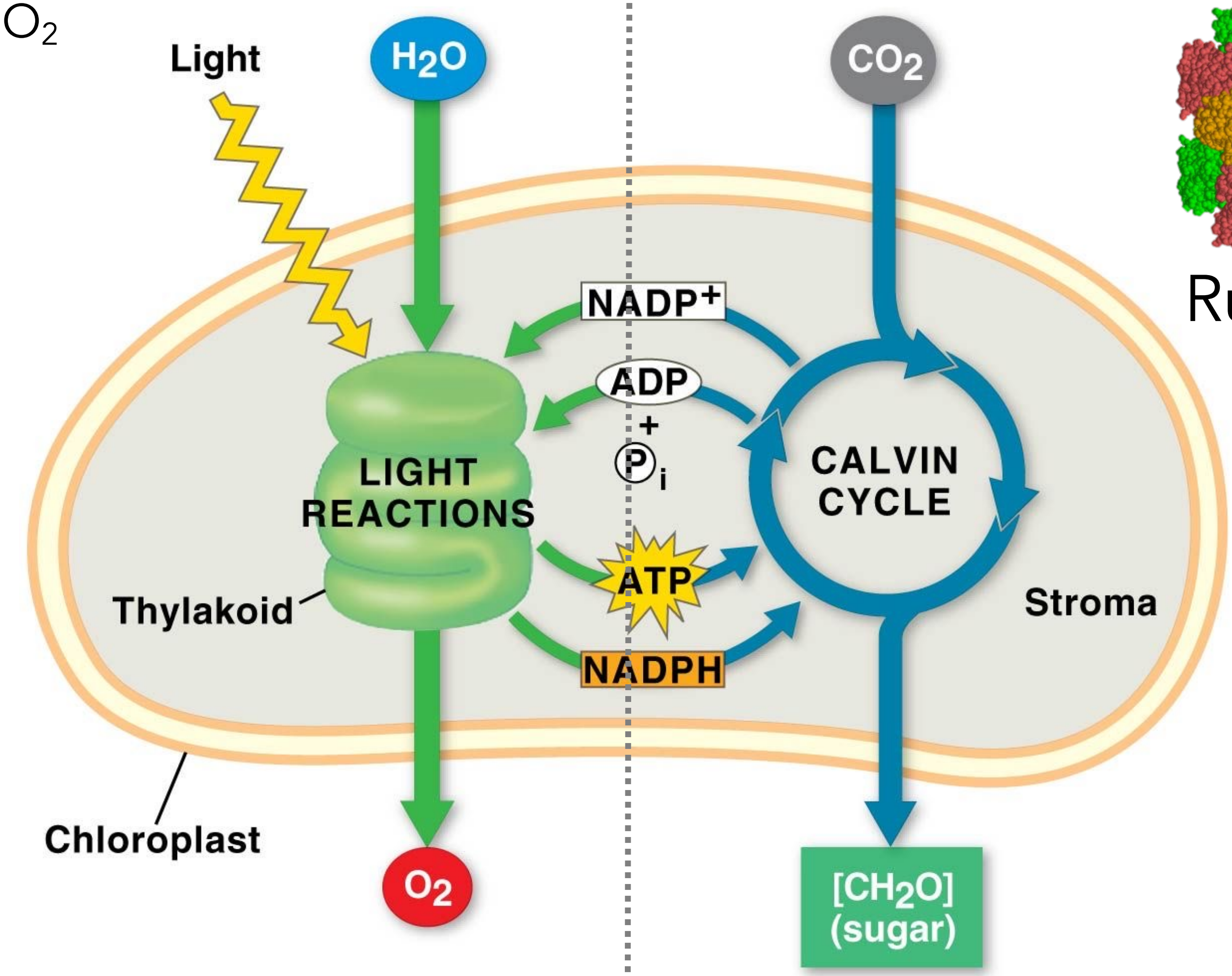
convert light energy to chemical energy

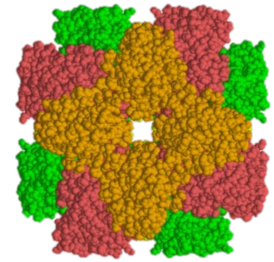
produce O_2

Dark Reactions

fix CO_2

produce carbohydrates



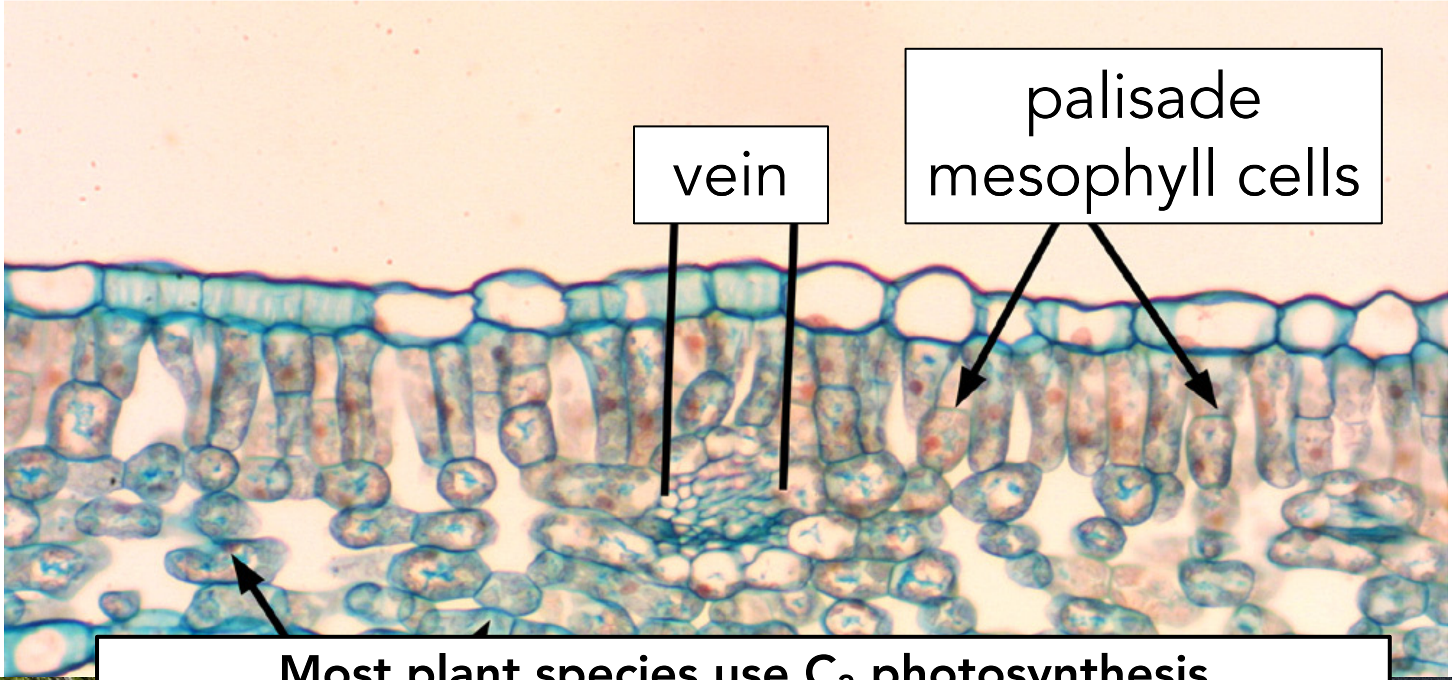


Rubisco!

$$6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2$$

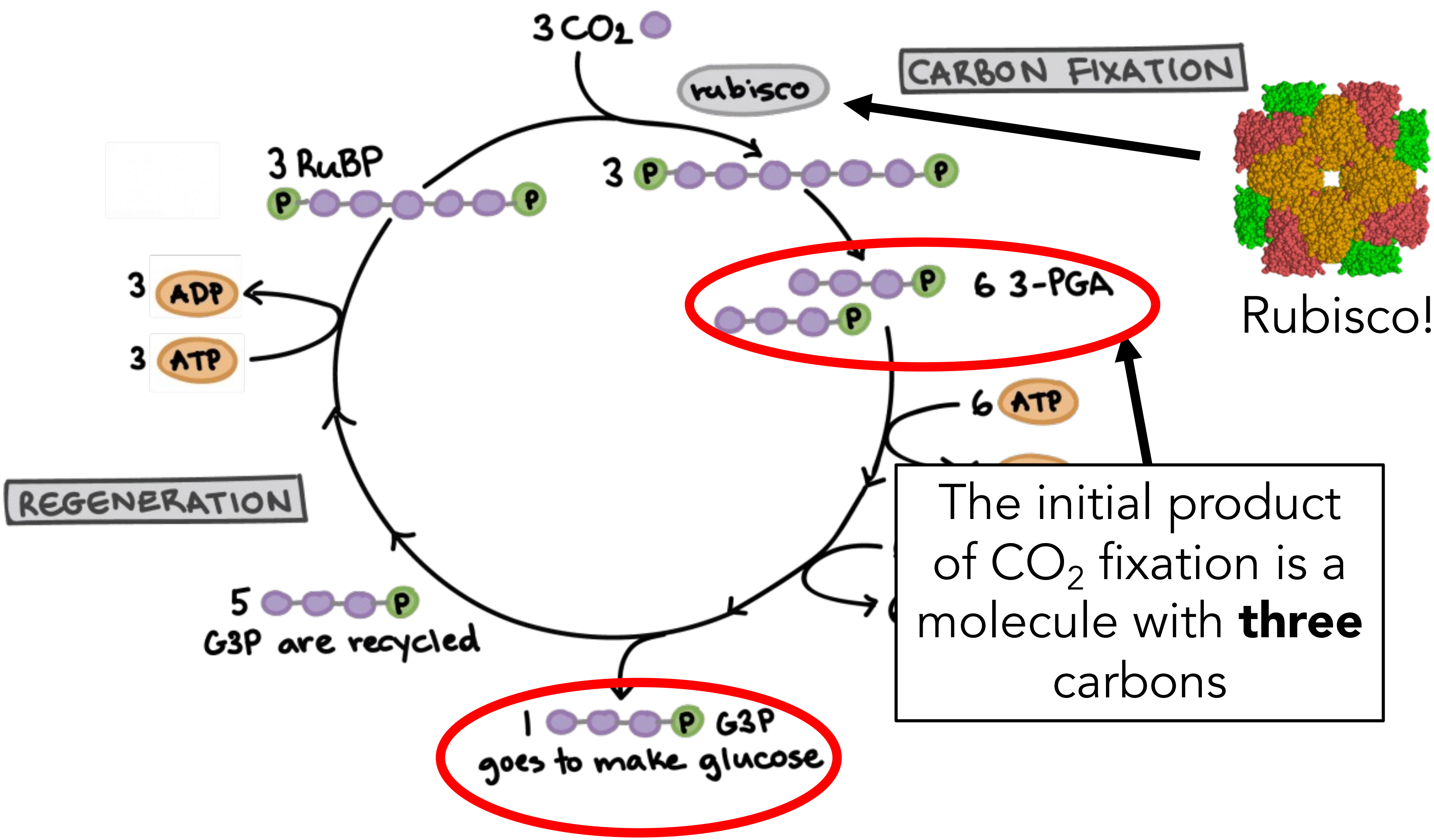
Photosynthesis on land:

C_3 Photosynthesis



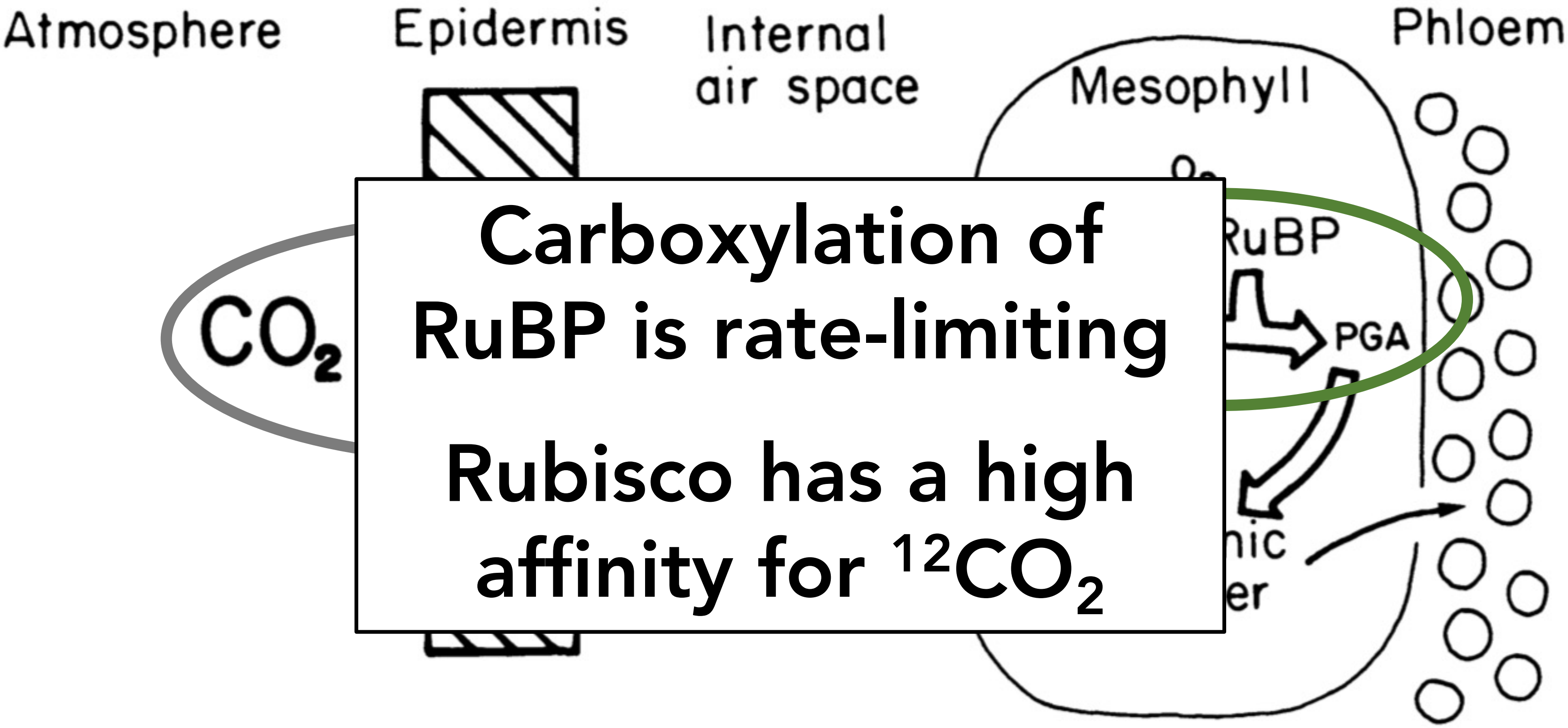
Most plant species use C_3 photosynthesis

C_3 Photosynthesis



The initial product of CO_2 fixation is a molecule with **three** carbons

C_3 Photosynthesis & Fractionation



Carboxylation of RuBP is rate-limiting

Rubisco has a high affinity for $^{12}CO_2$

CO_2 diffusion in air
$\alpha = 1.0044$
$\varepsilon = 4.4‰$

CO_2 fixation by Rubisco
$\alpha = 1.0270 – 1.0030$
$\varepsilon = 27.0 – 30.0‰$

O'Leary 1988

C_3 Photosynthesis & Fractionation

CO_2 diffusion in air
$\varepsilon = 4.4‰$

$$\Delta^{13}C = a - (b - a)(c_i / c_a)$$

Ratio of intracellular to atmospheric partial pressures of CO_2

CO_2 fixation by Rubisco
$\varepsilon = 27.0‰$

C_3 Photosynthesis & Fractionation

CO_2 diffusion in air
$\varepsilon = 4.4‰$

$$\delta^{13}C_{plant} = \delta^{13}C_{air} - a - (b - a)(c_i / c_a)$$

-8.4‰

CO_2 fixation by Rubisco
$\varepsilon = 27.0‰$

Try it!

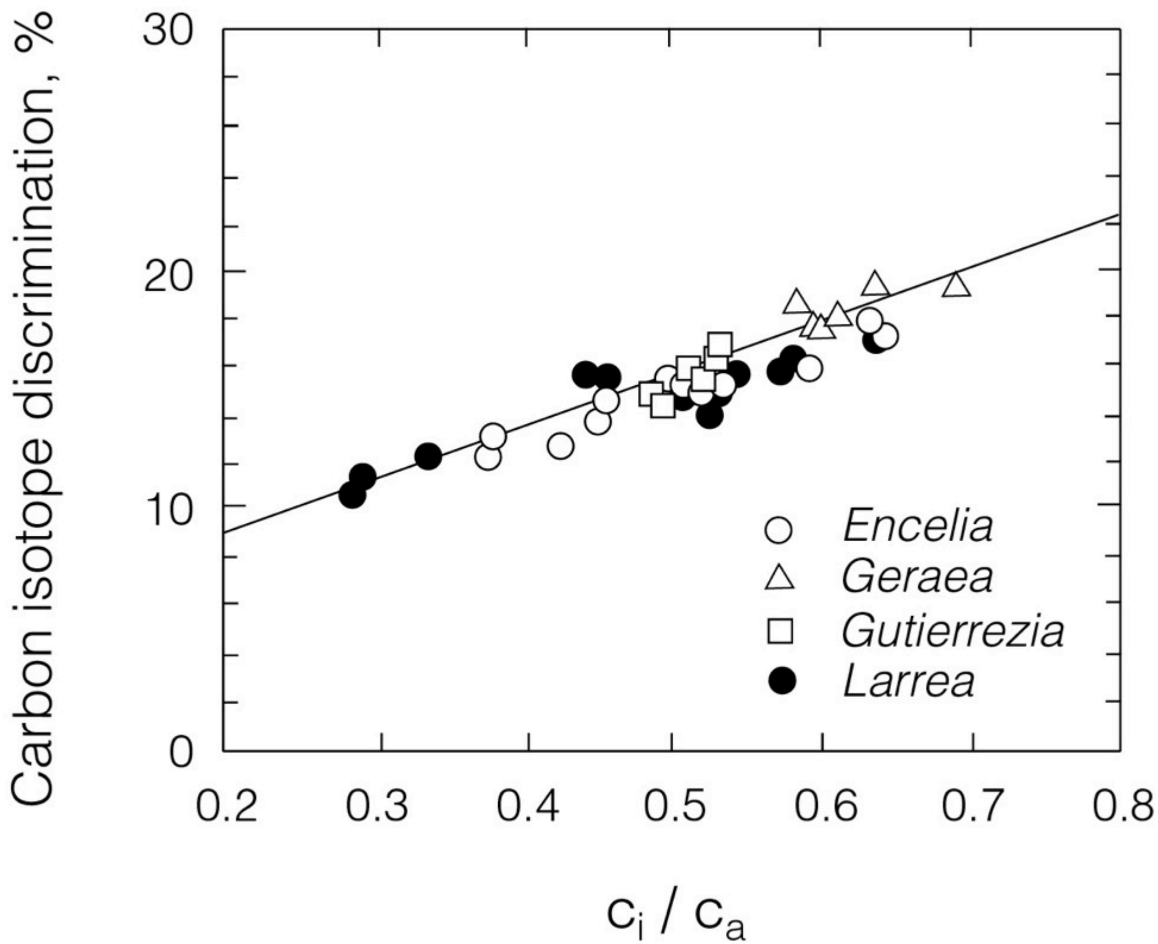
$$\delta^{13}C_{plant} = \delta^{13}C_{atm.} - a - (b - a)(c_i / c_a)$$

$\delta^{13}C_{atm.}$ = -8.4‰
a = 4.4‰
b = 27.0‰
c_i / c_a = 0.7

$\delta^{13}C_{atm.}$ = -8.4‰
a = 4.4‰
b = 27.0‰
c_i / c_a = 0.9

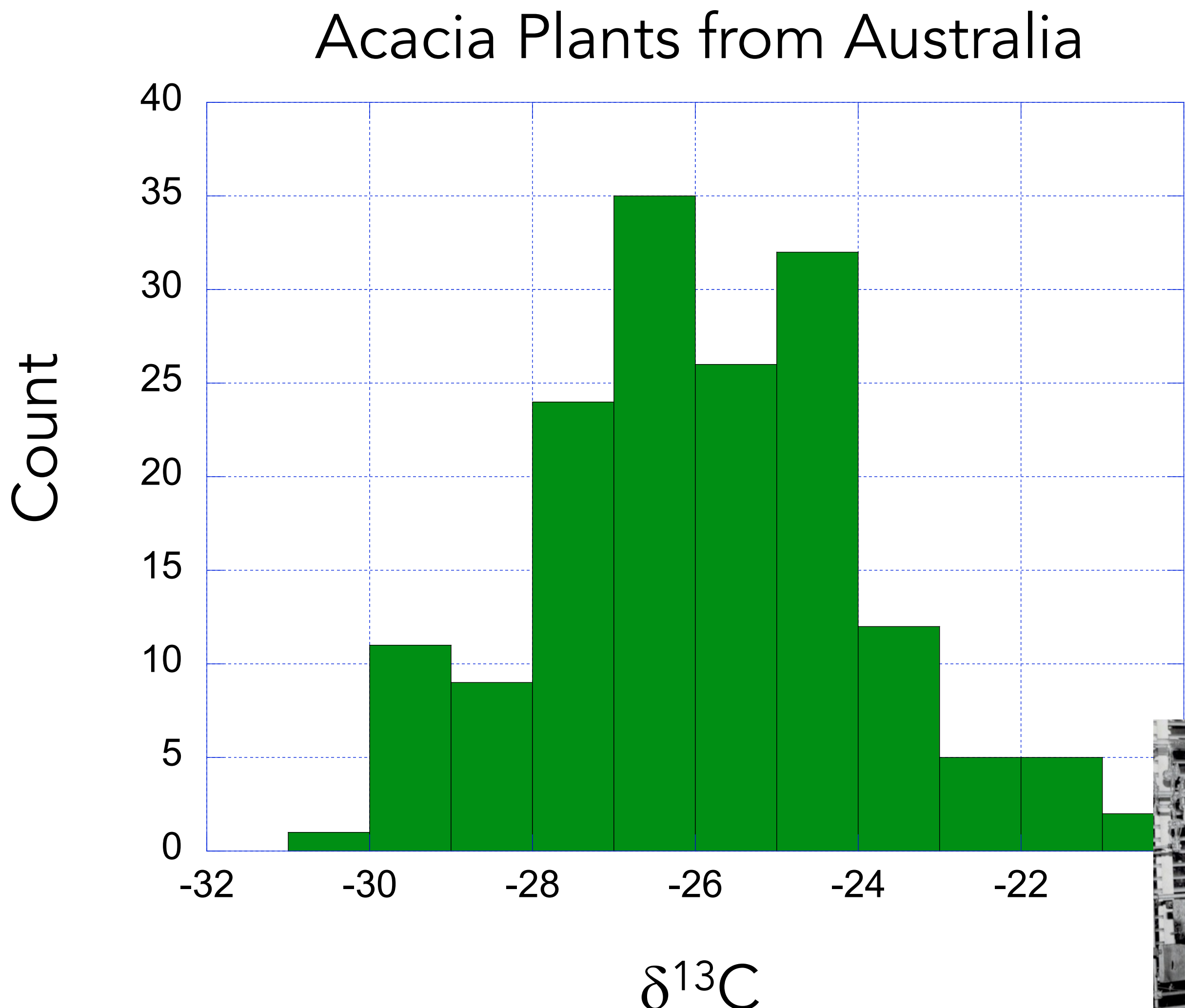
Impact of c_i / c_a on $\Delta^{13}C$

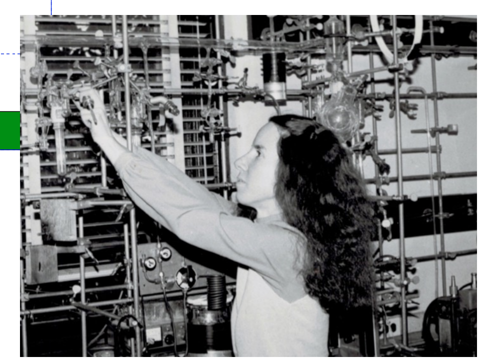
$$\Delta^{13}C = a - (b - a)(c_i / c_a)$$



Ehleringer et al. 1980

Why is there so much variation in the $\delta^{13}C$ values of C_3 plants?





Fogel et al. unpublished data

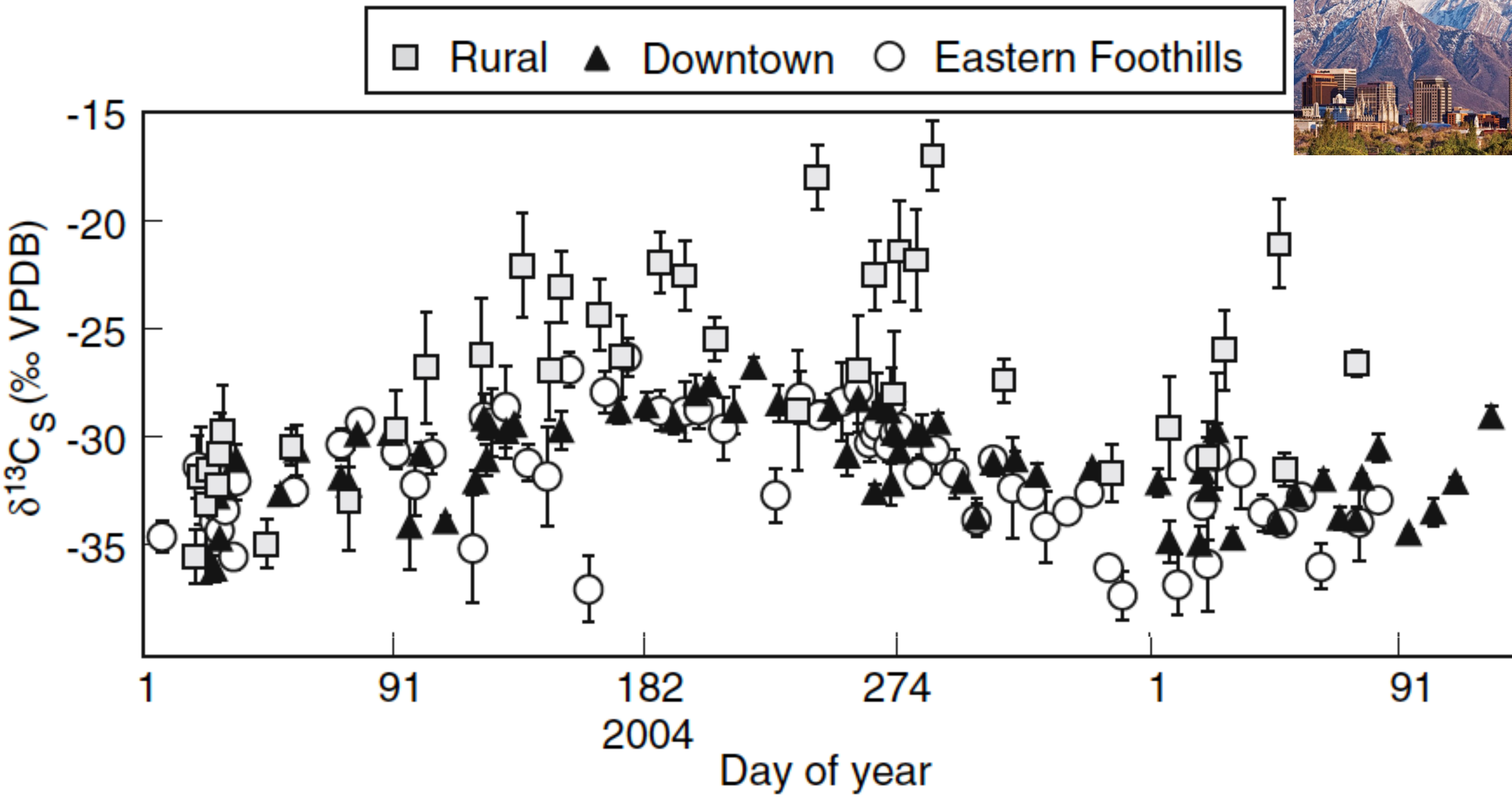
Why is there so much variation in the $\delta^{13}C$ values of C_3 plants?

Factors that impact Δ and $\delta^{13}C$ in C_3 plants:

- CO_2 Source
- Salinity
- Precipitation
- Degree of Shading
- Level of Aridity

The sources and $\delta^{13}C$ values of CO_2 impact plant $\delta^{13}C$ values

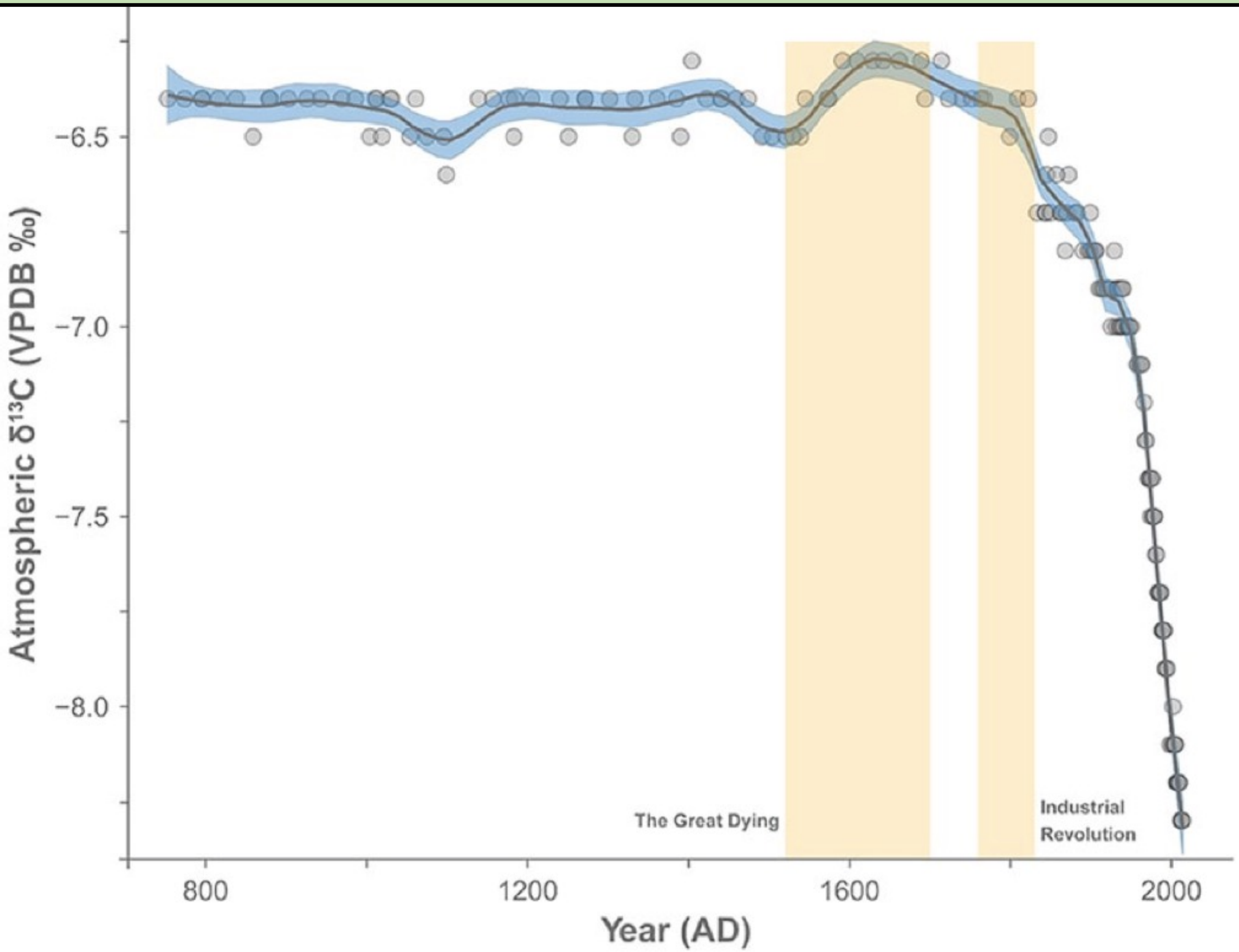
Salt Lake City, Utah



Burning fossil fuels can decrease local atmospheric CO_2 $\delta^{13}C$ values

Pataki et al. 2007

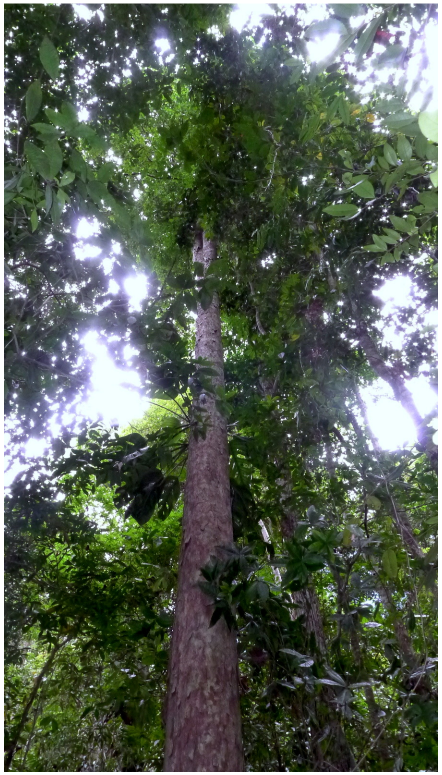
The sources and $\delta^{13}C$ values of CO_2 impact plant $\delta^{13}C$ values

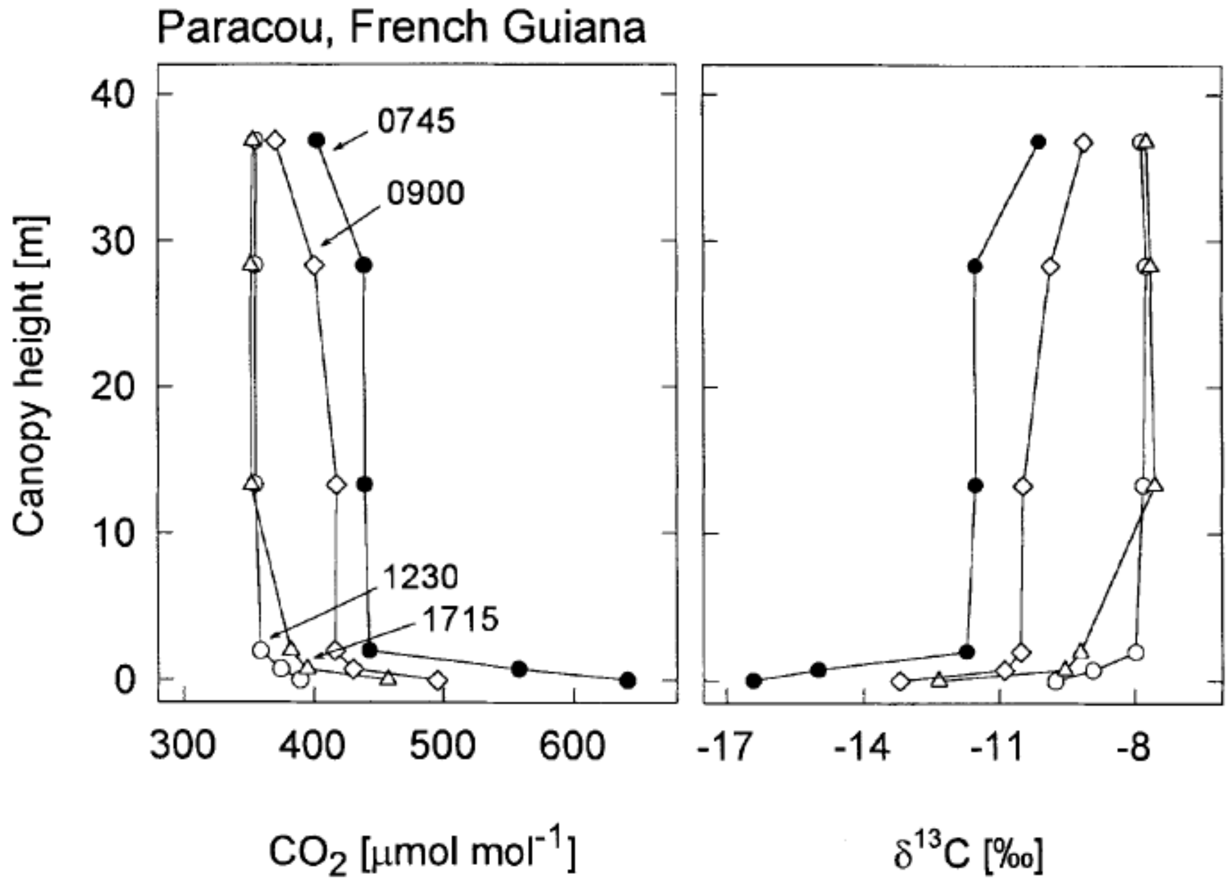


Burning fossil fuels has decreased global CO_2 $\delta^{13}C$ values

Dombrosky 2020

The sources and δ^{13}C values of CO_2 impact plant δ^{13}C values



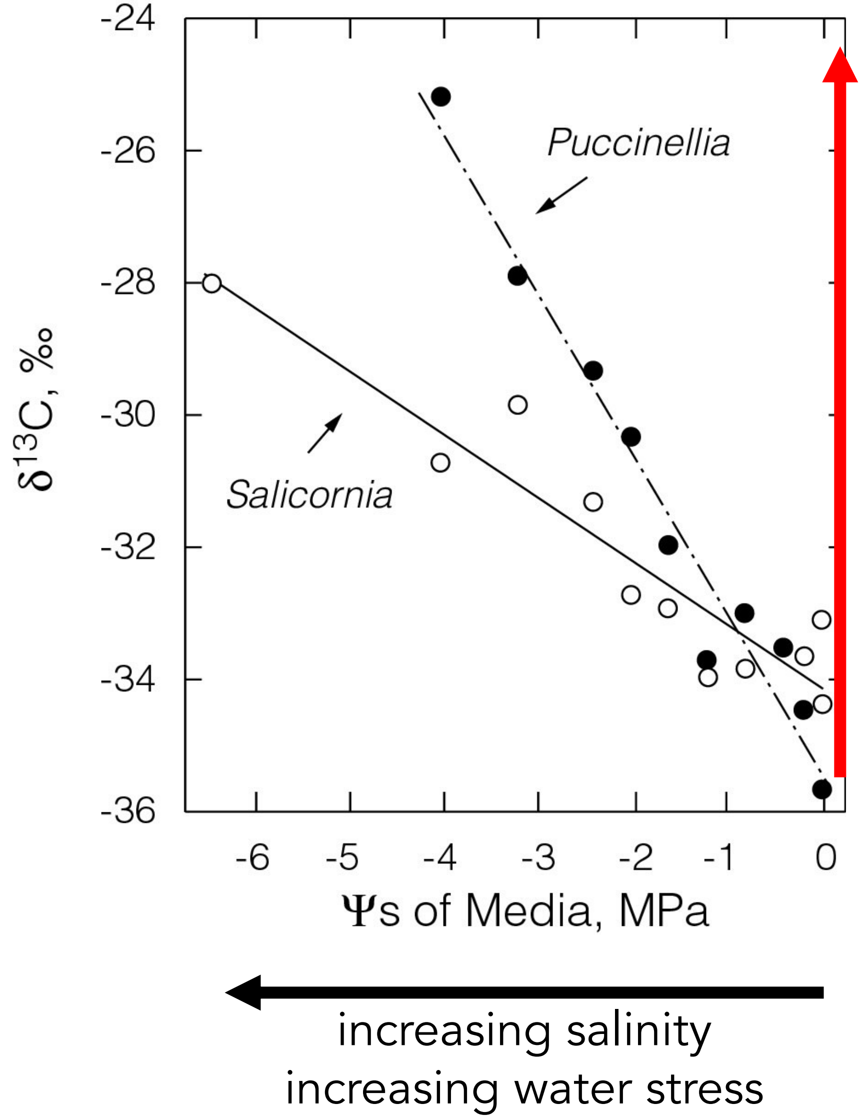


Use of respired CO_2 can decrease δ^{13}C values of understory plants

"The Canopy Effect"

Buchmann et al. 1997

Increasing salinity increases $\delta^{13}C$ values

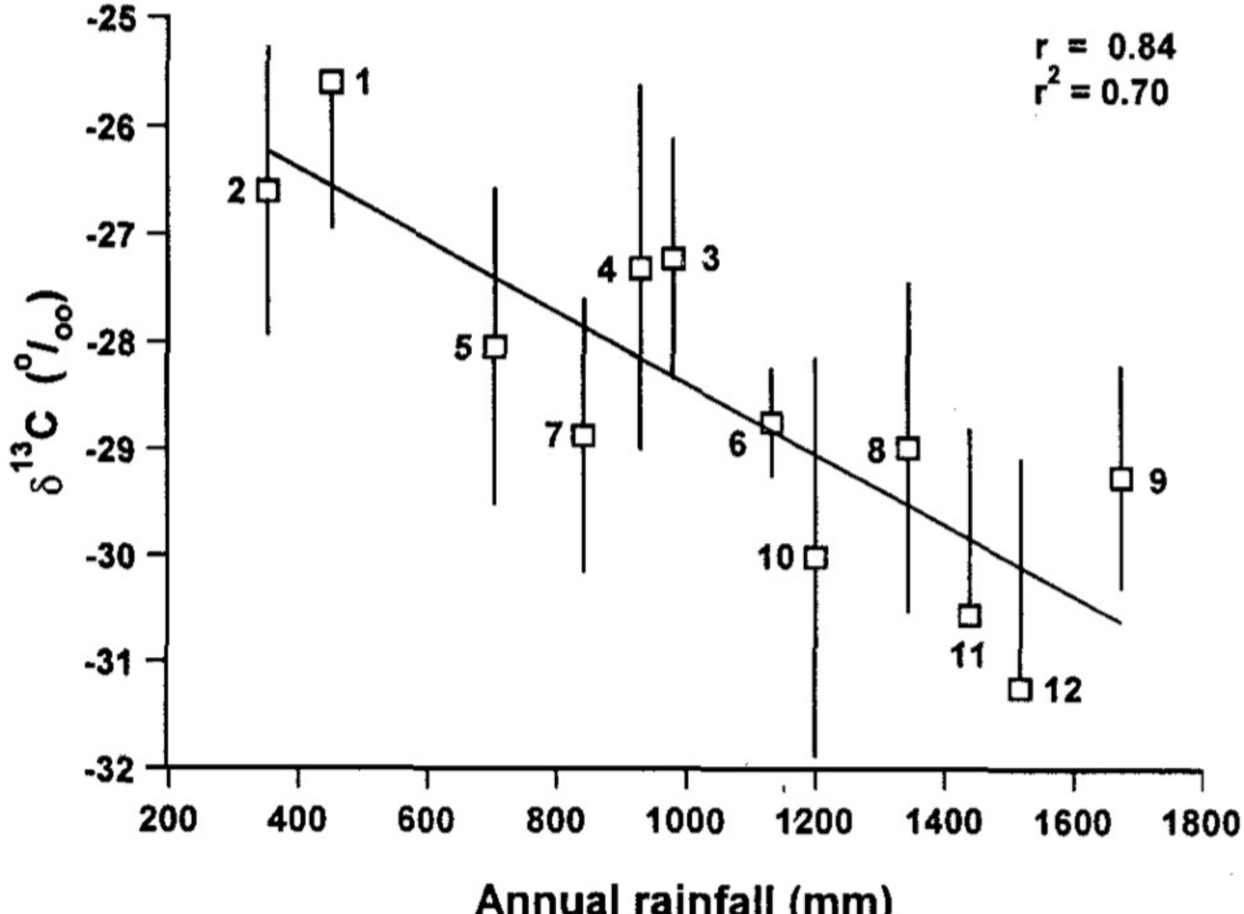


If a plant is water-stressed, it will **close its stomata** to prevent water loss.

This decreases c_i / c_a and thus, decreases isotopic discrimination.

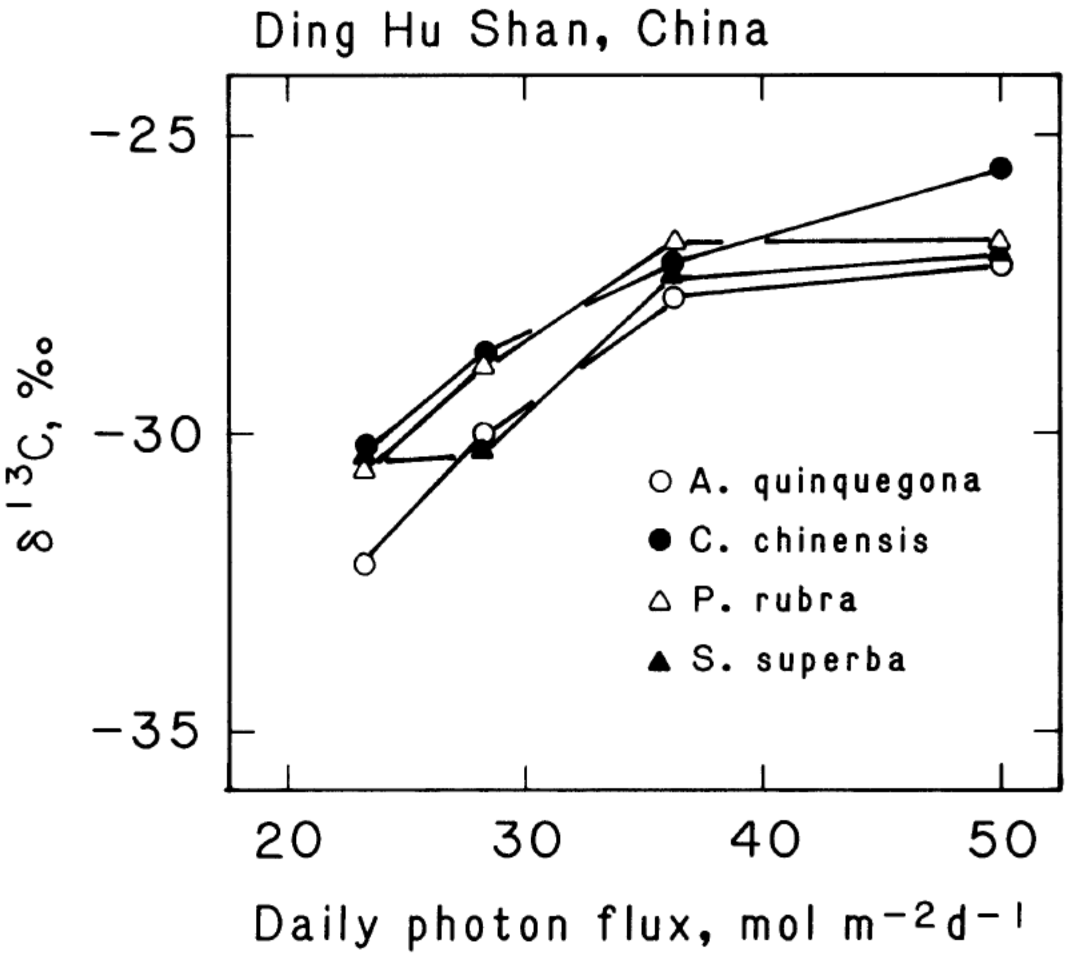
Guy et al. 1980

Increasing precipitation decreases $\delta^{13}C$ values



Stewart et al. 1995

Increasing light increases $\delta^{13}C$ values

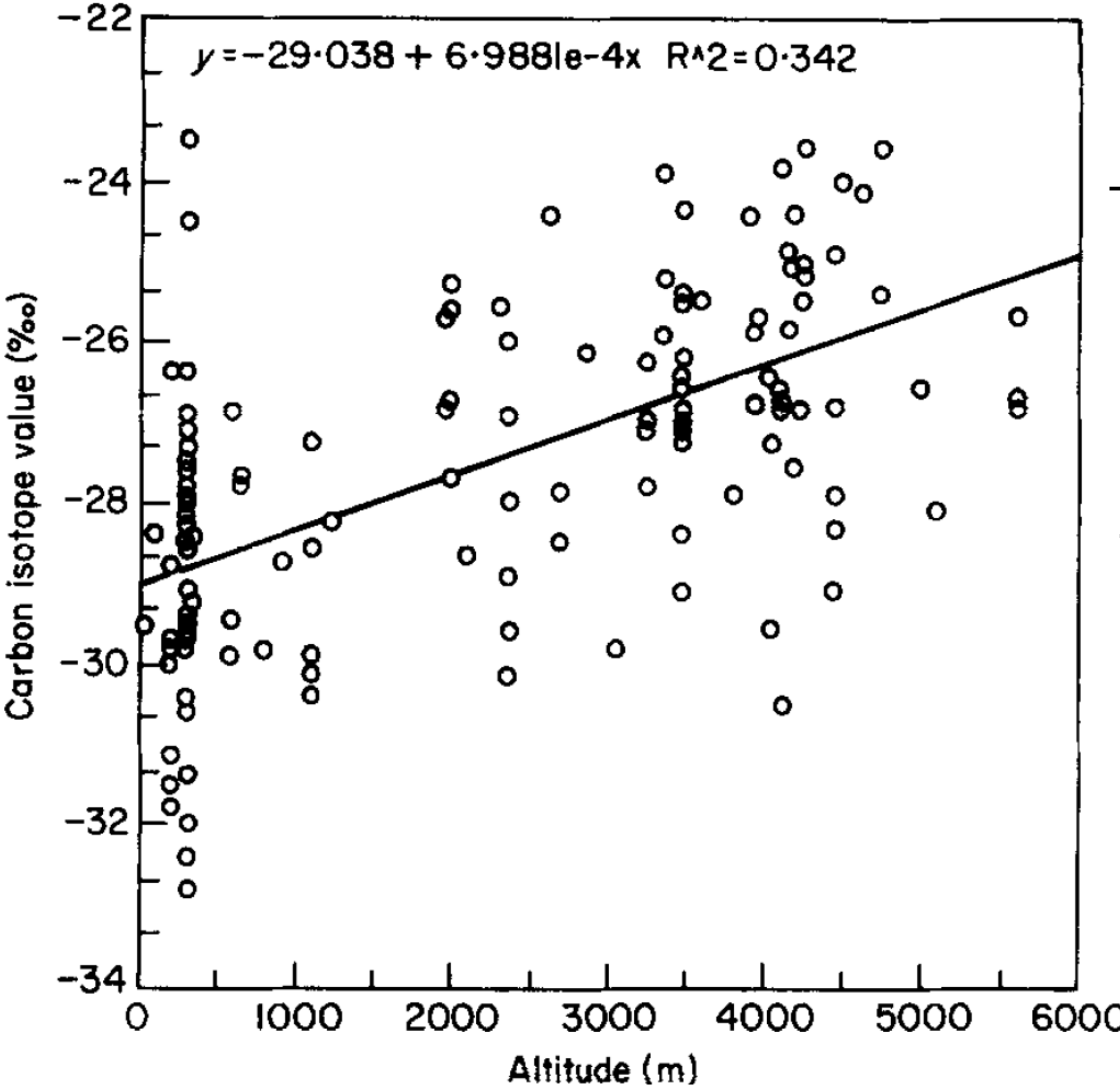


Increasing light increases photosynthetic rate.

This decreases isotopic discrimination by reducing c_i/c_a

Ehleringer et al. 1986

Increasing altitude increases $\delta^{13}C$ values



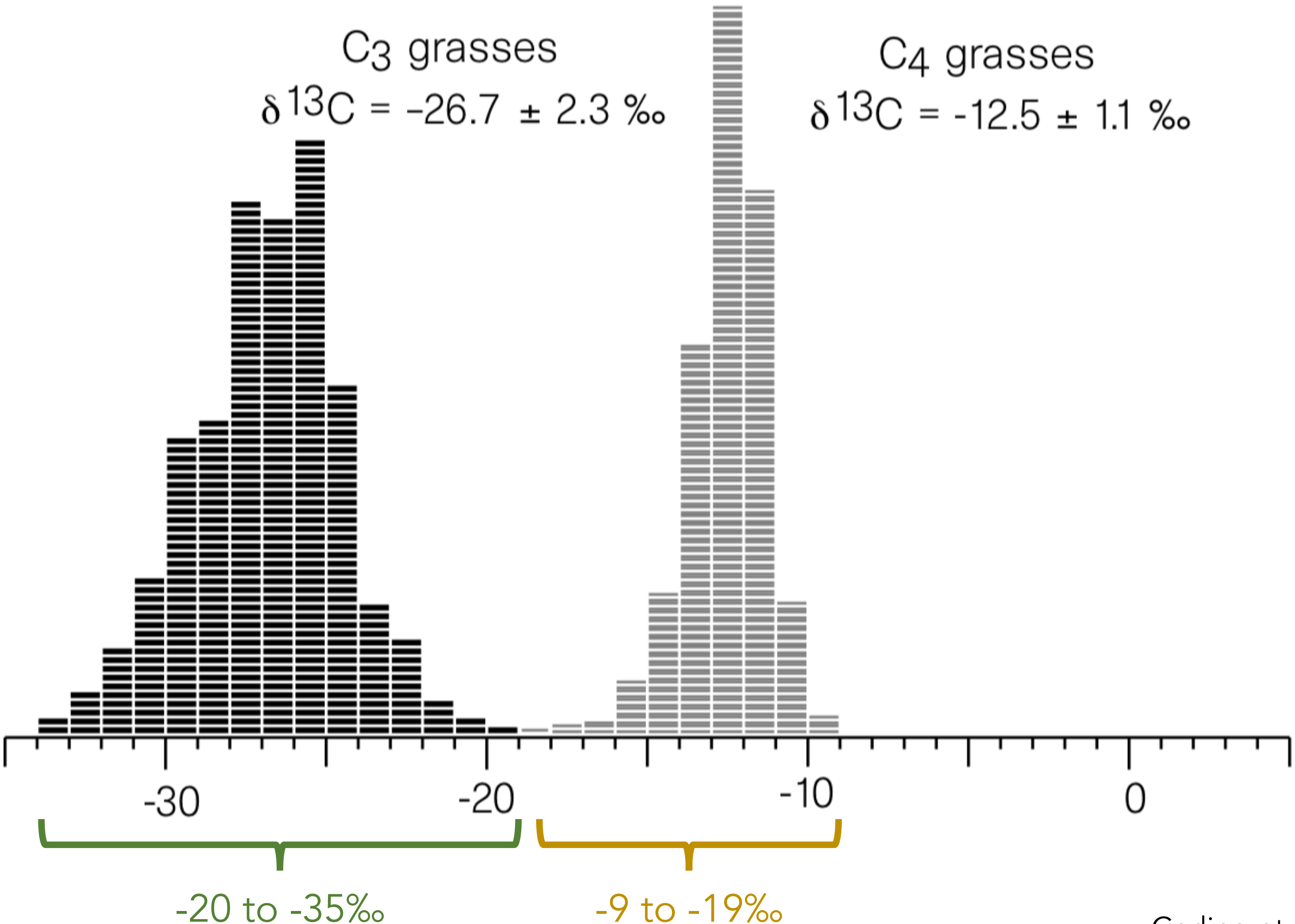
The atmospheric partial pressure of O_2 decreases with increasing altitude.

This leads to increased photosynthetic efficiency, and lower c_i/c_a ratios.

Körner et al. 1988, 1991

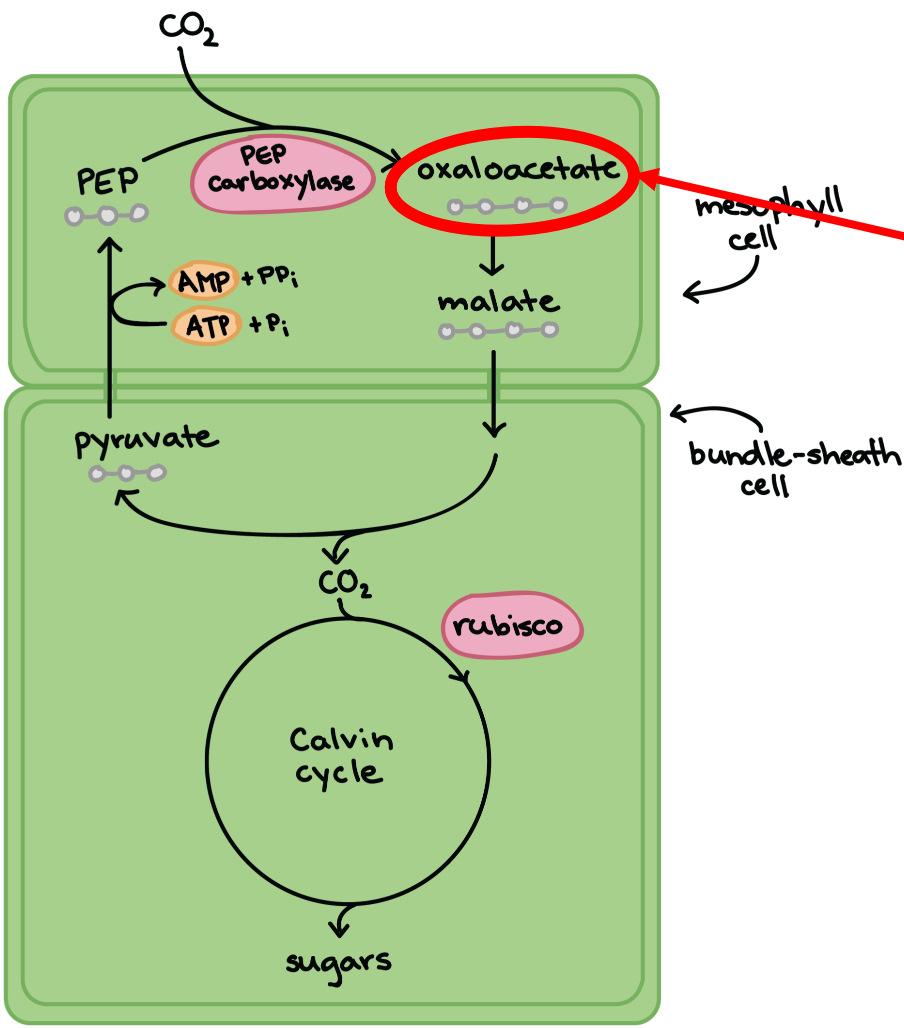
How might aridity influence $\delta^{13}C$ values?

How might aridity influence $\delta^{13}C$ values?



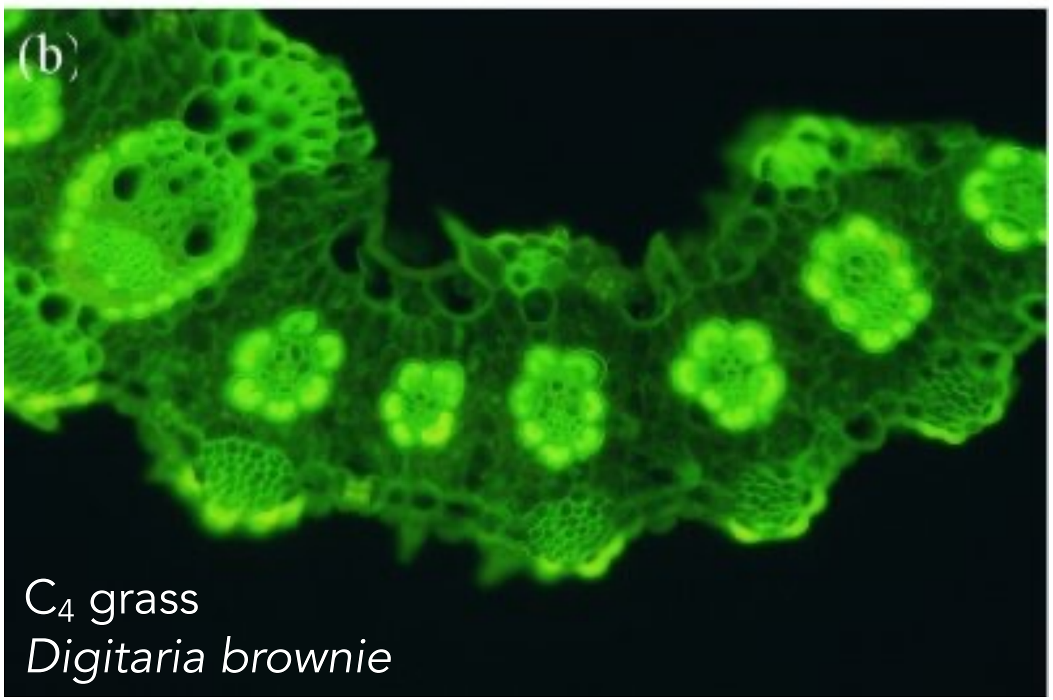
Cerling et al. 1997

C_4 Photosynthesis



The initial product of CO_2 fixation is a molecule with **four** carbons

Typically, malate or aspartate is sent to the bundle sheath cell to be decarboxylated



Kranz Anatomy and C_4 Photosynthesis

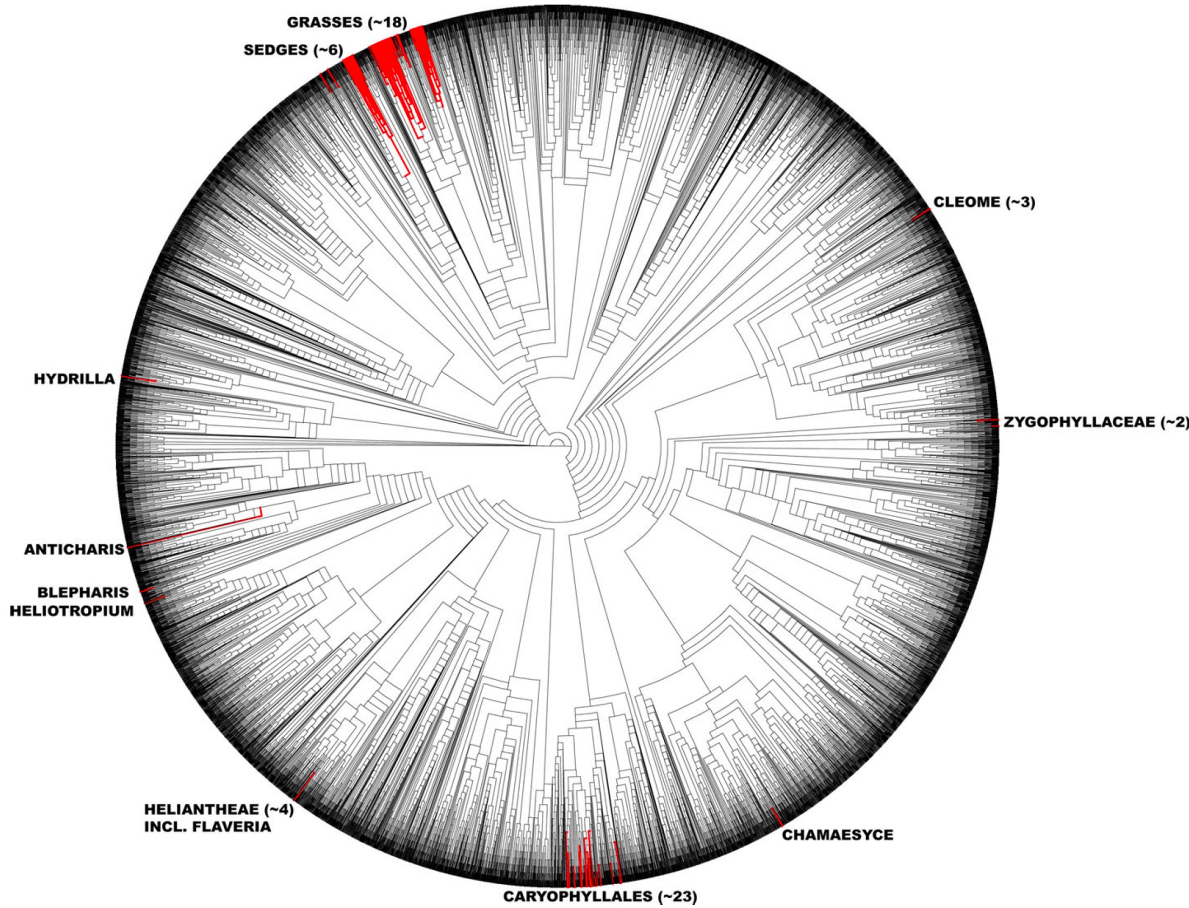
C_4 photosynthesis now accounts for almost 25% of terrestrial gross primary productivity despite only occurring in < 5% of plants!

C_4 photosynthesis evolved independently many times

C_4 photosynthesis evolved independently in over 60 plant lineages within both Eudicots and Monocots

The evolution of C_4 photosynthesis depends on the co-occurrence of the necessary external (e.g., climatic conditions) and internal factors (e.g, genetic, structural, and biochemical conditions)

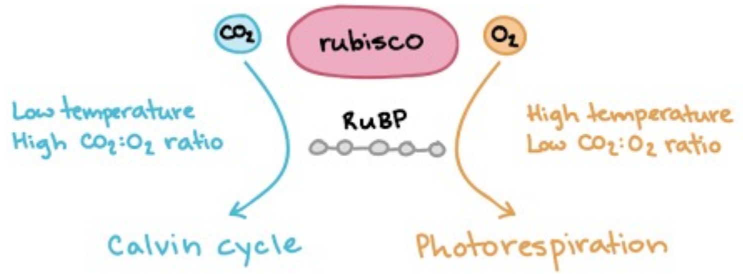
The oldest C_4 lineage (Chloridoideae) is ~30 million years old



Sage et al. 2011

C_4 photosynthesis evolved in a low $[CO_2]$ atmosphere

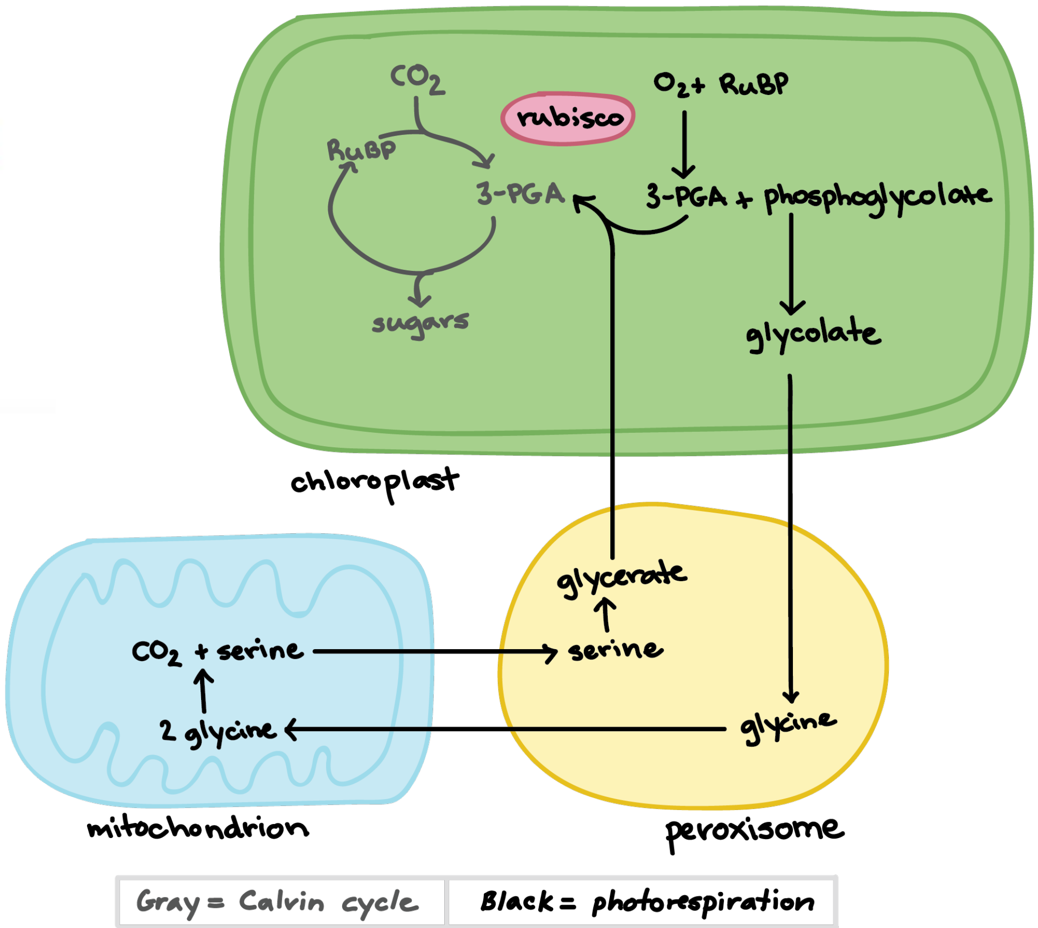
Rubisco is both a *carboxylase* (yay!) and an *oxygenase* (boo!)



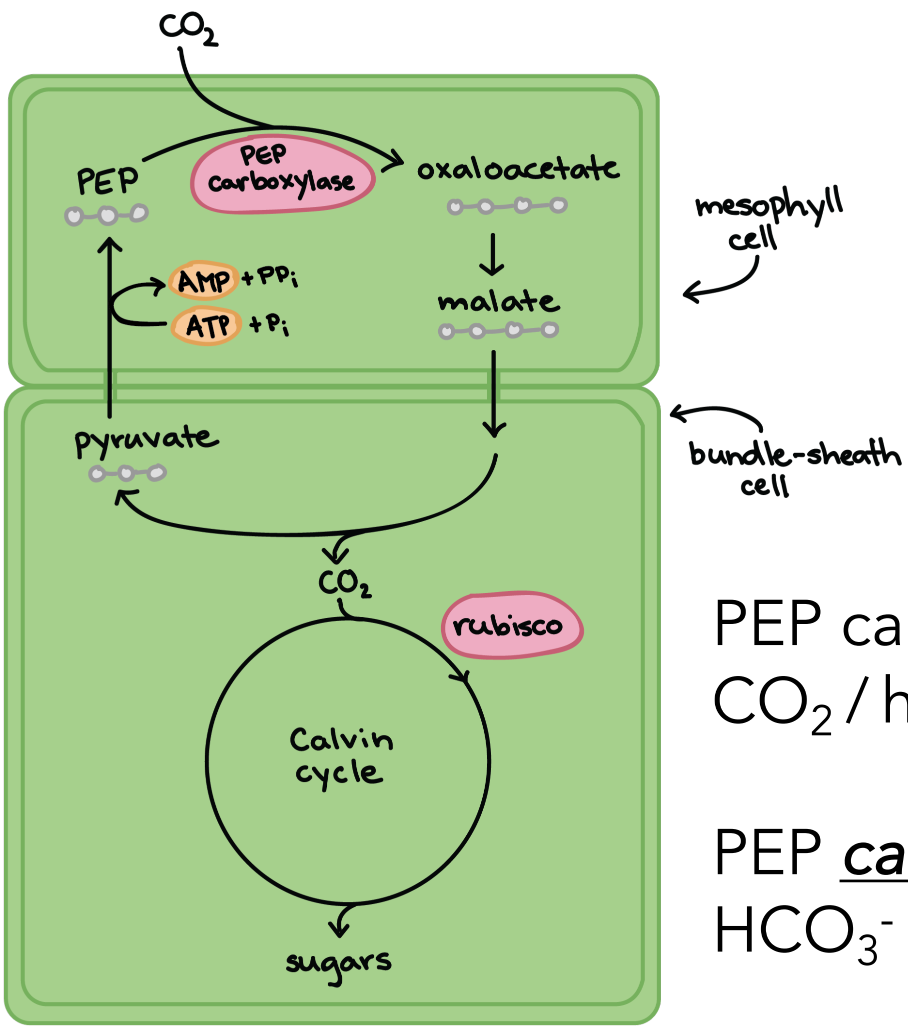
Photorespiration occurs when Rubisco fixes O_2 instead of CO_2

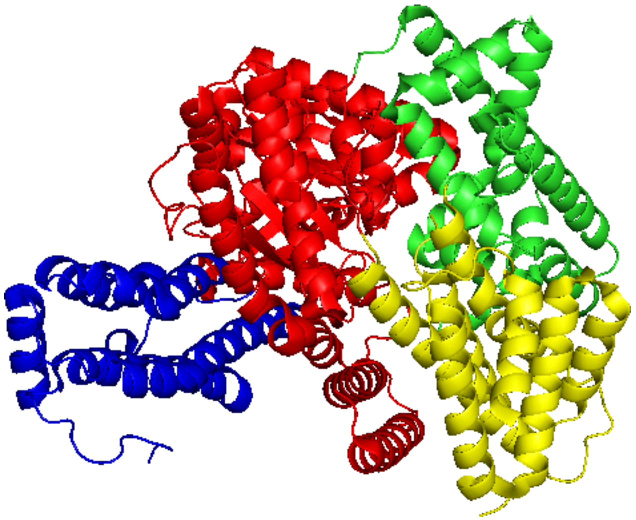
Photorespiration is wasteful and energetically expensive

Photorespiration occurs more frequently as $[CO_2]/[O_2]$ decreases



Avoiding photorespiration with C_4 photosynthesis

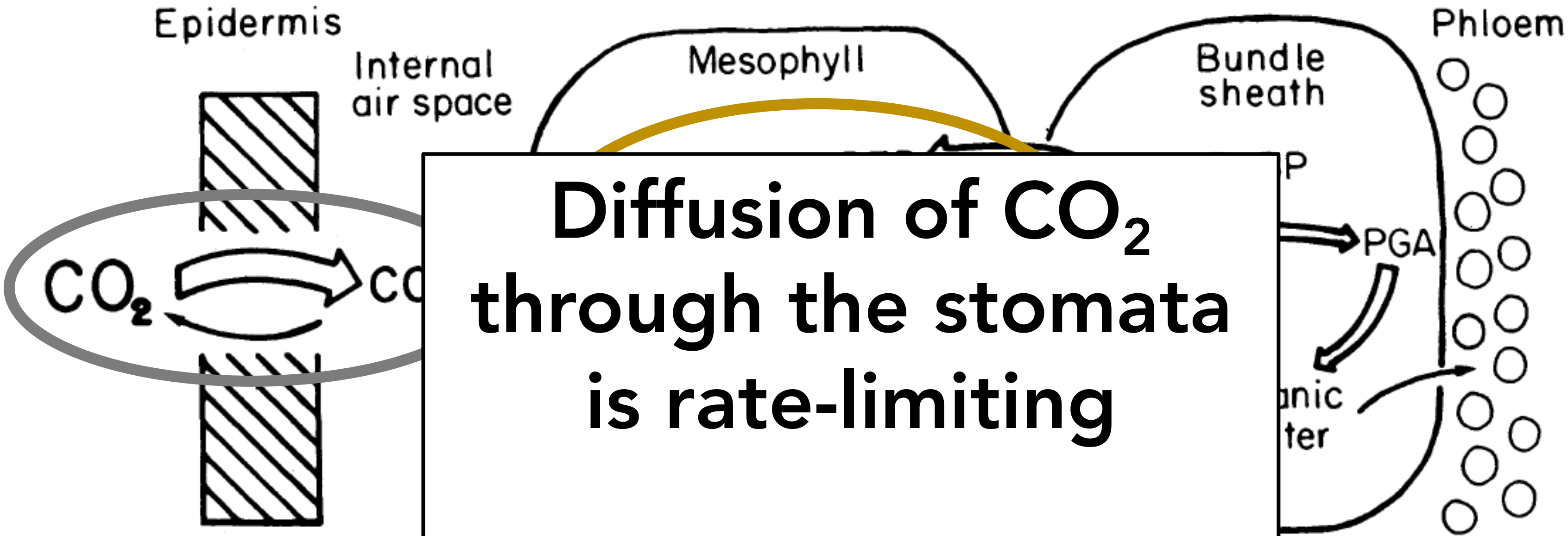




PEP carboxylase evolved in a low CO_2 / high O_2 atmosphere

PEP ***carboxylase*** fixes CO_2 and HCO_3^- (it never interacts with O_2)

C_4 Photosynthesis



Diffusion of CO_2 through the stomata is rate-limiting

PEP carboxylase is not as picky as Rubisco

CO_2 diffusion in a

$\alpha = 1.0044$

$\varepsilon = 4.4‰$

O'Leary 1988, Farquhar et al. 1989

C_4 Photosynthesis

CO_2 diffusion in air
$\varepsilon = 4.4‰$

$$\Delta^{13}C = a - [b_{PEP} + b_{RUB}(\phi) - a](c_i / c_a)$$

effective discrimination by PEP carboxylase
$\varepsilon = -5.7‰$

bundle sheath cell "leakiness"
$\phi = 0.2–0.3$

CO_2 fixation by Rubisco
$\varepsilon = 27.0‰$

C_4 Photosynthesis

-8.4‰

CO_2 diffusion in air
ε = 4.4‰

$$\delta^{13}C_{plant} = \delta^{13}C_{atm.} - a - [b_{PEP} + b_{RUB}(\phi) - a](c_i / c_a)$$

effective discrimination by PEP carboxylase
ε = -5.7‰

bundle sheath cell "leakiness"
ϕ = 0.2–0.3

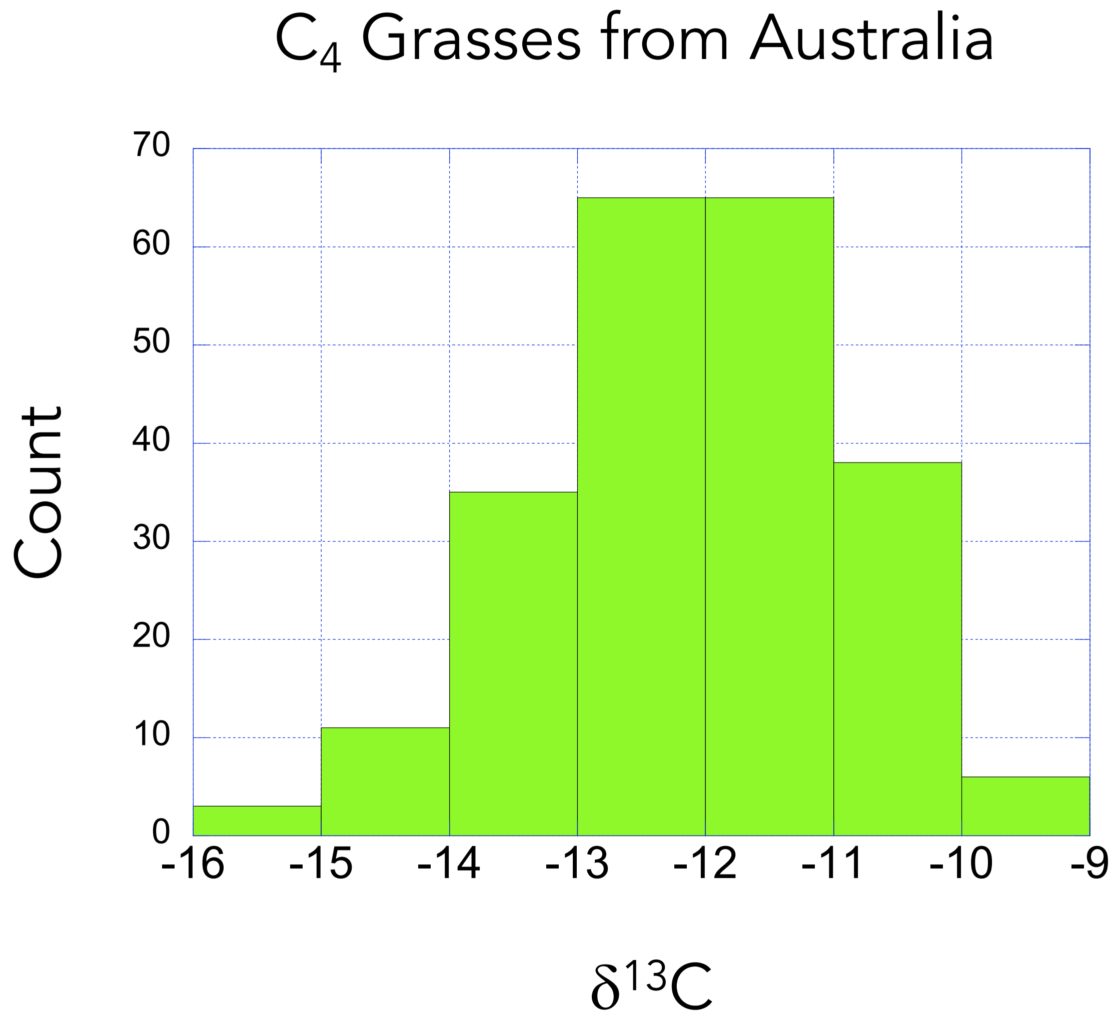
CO_2 fixation by Rubisco
ε = 27.0‰

Try it!

$$\delta^{13}C_{plant} = \delta^{13}C_{atm.} - a - [b_{PEP} + b_{RUB}(\phi) - a](c_i / c_a)$$

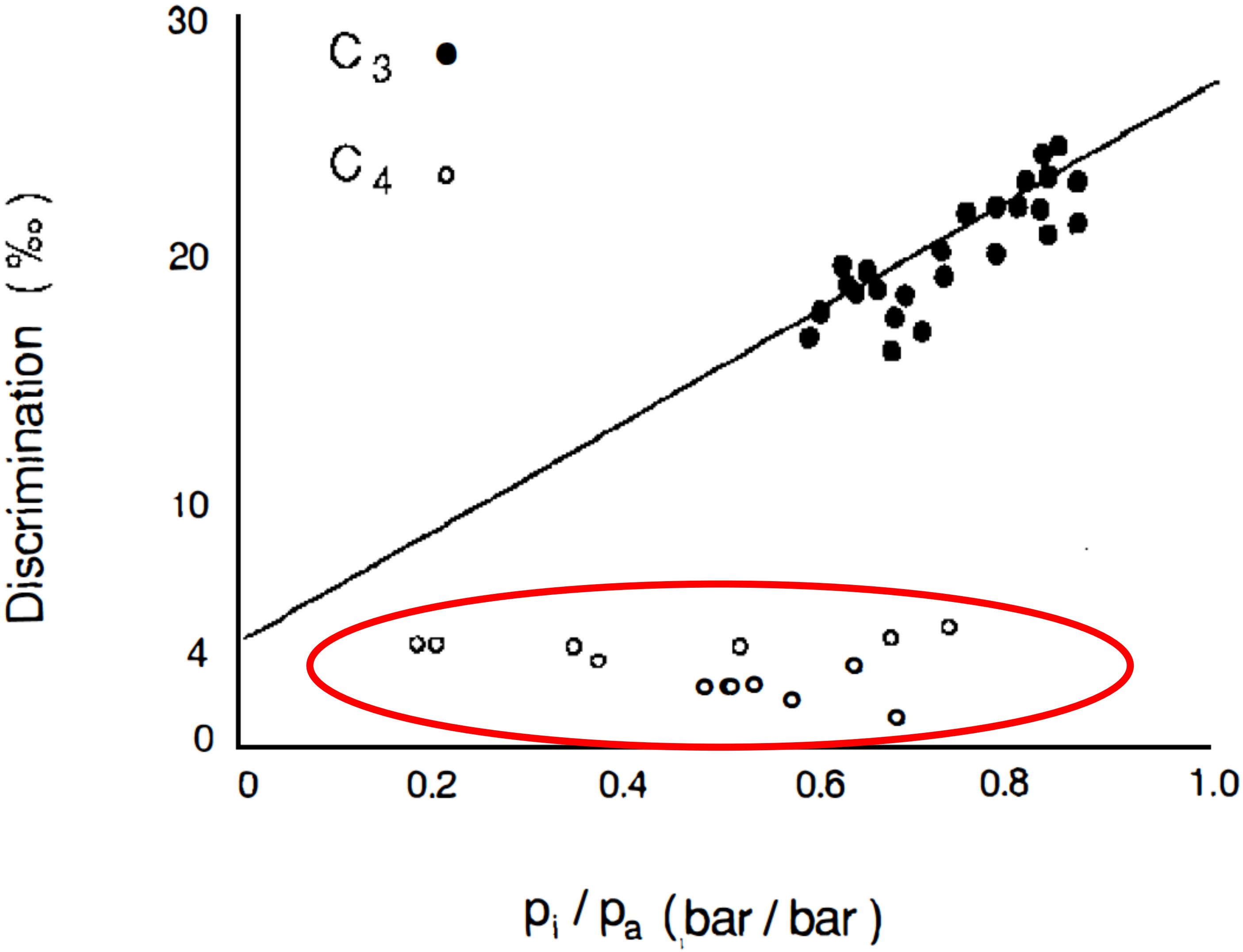
$\delta^{13}C_{atm.}$ = -8.4‰
a = 4.4‰
b_{PEP} = -5.7‰
b_{RUB} = 27.0‰
ϕ = 0.3
c_i / c_a = 0.4

What leads to variation in $\delta^{13}C$ values in C_4 plants?

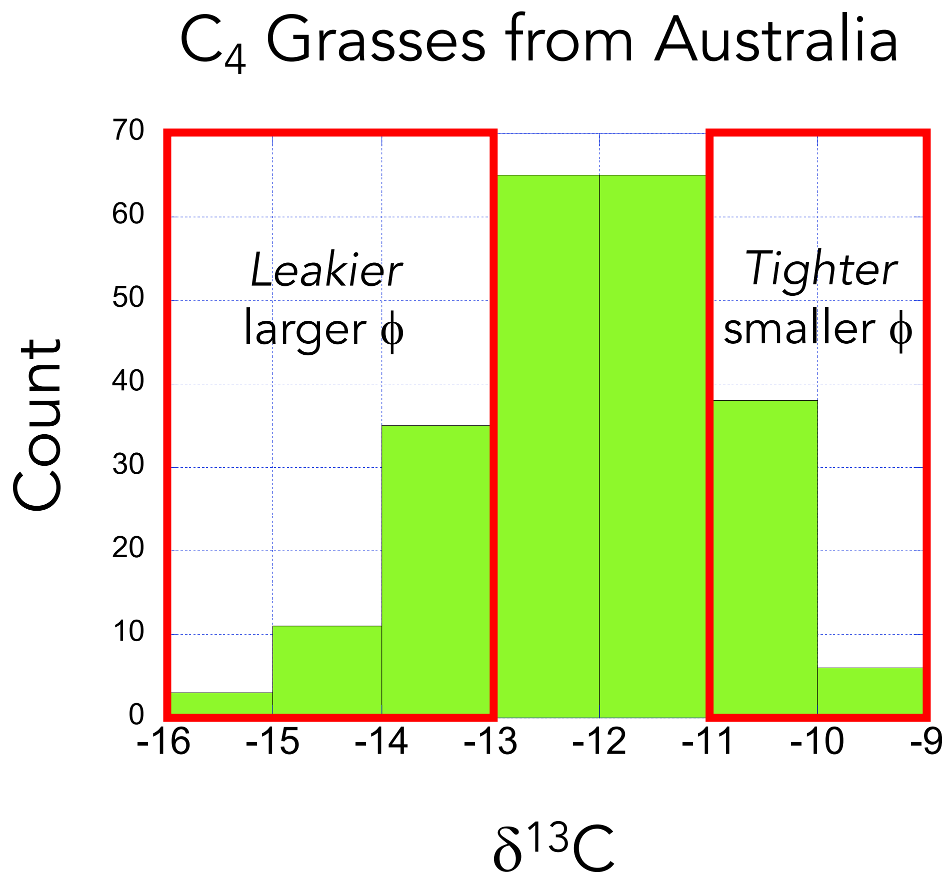


Fogel et al. unpublished data

What leads to variation in $\delta^{13}C$ values in C_4 plants?



What leads to variation in $\delta^{13}C$ values in C_4 plants?



Bundle Sheath Cell "Leakiness"

Metabolic Subtype (e.g., NAD-ME, NADP-ME)