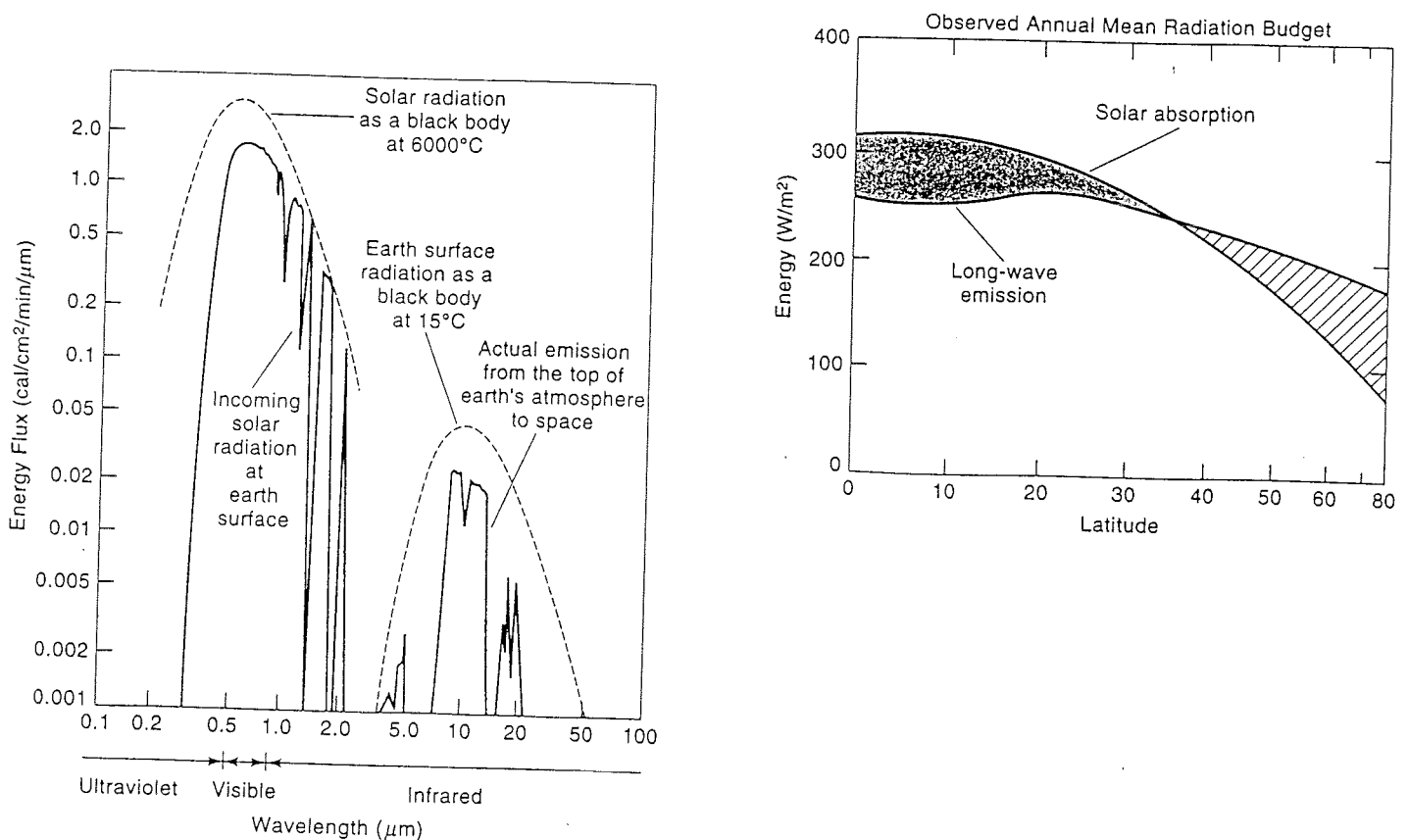
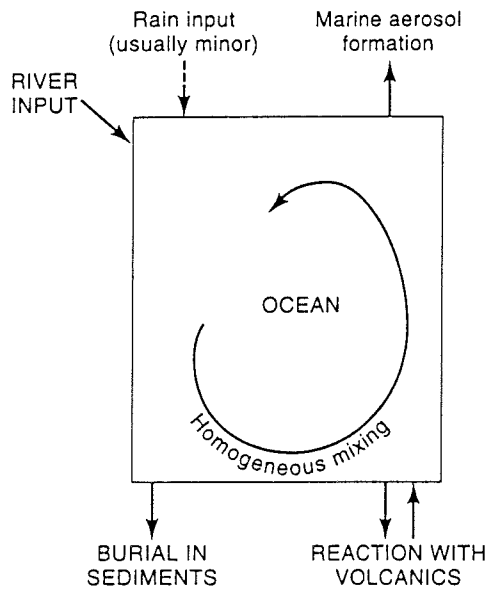


Figure 1.9 Schematic representation of the general circulation of the atmosphere. (Frederick K. Lutgens/Edward J. Tarbuck, *The Atmosphere*, 5th ed., Copyright © 1992, p. 170. Adapted by permission of Prentice Hall, Englewood Cliffs, New Jersey.)

Figure 1.8 Annual zoned mean estimates for both hemispheres, which are nearly the same, of absorbed solar radiation and outgoing long-wave radiation emission obtained by satellites. Shaded regions denote net heating and dashed region denotes net cooling. (After V. Ramanathan, *Journal of Geophysical Research* 92, pp. 4076, 1987, copyright by the American Geophysical Union, based on data from Ellis and Vonder Haar 1976.)





Simple box model appropriate for conservative elements in seawater. Note that, compared with the Sillén model of Figure 8.2, fluxes enter and leave the box, and the atmosphere and sediments are considered to be outside the box. Also note that, in contrast to lakes, there is no outlet, so dissolved materials carried in by rivers can be removed only by sea-air transfer (marine aerosol formation), burial in sediments, or reaction with volcanics.

Minor Dissolved Components of Seawater (Excluding Trace Components <math><1\mu\text{M}</math>), Showing Ranges in Concentration

Component	Concentration Range	
	$\mu\text{g}/\text{kg}$ or ppb	μM^a
Br^-	66,000–68,000 ^b	840–880
H_3BO_3	24,000–27,000 ^b	400–440
Sr^{++}	7,700–8,100 ^b	88–92
F^-	1,000–1,600 ^b	50–85
CO_3^{--}	3,000–18,000	50–300
O_2	320–9,600	10–300
N_2	9,500–19,000	300–600
CO_2	440–3,520	10–80
Ar	360–680	9–17
$\text{H}_4\text{SiO}_4\text{-Si}$	<30–5,000	<0.5–180
NO_3^-	<60–2,400	1–40
NO_2^-	<4–170	<0.1–4
NH_4^+	<2–40	<0.1–2
Orthophosphate ^c	<10–280	<0.1–3
Organic carbon	300–2,000	—
Organic nitrogen	15–200	—
Li^+	180–200	26–27
Rb^+	115–123 ^b	1.3–1.4

^a μM = micromoles per liter.

^b For a salinity of 35‰.

^c Includes PO_4^{3-} , HPO_4^{--} and H_2PO_4^- ; concentrations expressed as $\mu\text{g P}/\text{kg}$.

Rates of Addition via Rivers of Major Elements to the ocean (as Dissolved Species) and Rates of Net Loss from the Ocean by Transfer of Sea Salt to the Continents via the Atmosphere

Species	Rate of Addition from Rivers ^a (Tg/yr)	Rate of Net Sea Salt Loss to Atmosphere (Tg/Yr)
Cl^-	308	40
Na^+	269	21
$\text{SO}_4\text{-S}$	143	4
Mg^{++}	137	3
K^+	52	1
Ca^{++}	550	0.5
HCO_3^-	1980	—
$\text{H}_4\text{SiO}_4\text{-Si}$	180	—

Note: Tg = 10^{12} g.

^a Based on river water input of $37,400 \text{ km}^3/\text{yr}$; includes pollution

Major Dissolved Components of Seawater for a Salinity of 35‰

Ion	Concentration		Percent Free Ion
	g/kg	mM^a	
Cl^-	19.354	558	100
Na^+	10.77	479	98
Mg^{++}	1.290	54.3	89
SO_4^{--}	2.712	28.9	39
Ca^{++}	0.412	10.5	99
K^+	0.399	10.4	98
$\text{HCO}_3\text{-}^b$	0.12	2.0	80

^a mM = millimoles per liter at 25°C.

^b For pH = 8.1, $P = 1 \text{ atm}$, $T = 25^\circ\text{C}$.

Sources: Wilson 1975; Skirrow 1975; Millero and Schreiber 1982.

Replacement Time with Respect to River Addition, τ_r , for Some Major and Minor Dissolved Species in Seawater

Component	Concentration (μM)		τ_r^a (1,000 yr)
	River Water	Seawater	
Cl	230	558,000	87,000
Na^+	315	479,000	55,000
Mg^{++}	150	54,300	13,000
SO_4^{--}	120	28,900	8,700
Ca^{++}	367	10,500	1,000
K^+	36	10,400	10,000
HCO_3^-	870	2,000	83
H_4SiO_4	170	100	21
NO_3^-	10	20	72
Orthophosphate	1.8 ^b	2	40

^a $\tau_r = ([\text{SW}]/[\text{RW}]) \tau_w$, where τ_w = replacement (residence) time of $\text{H}_2\text{O} = 36,000 \text{ yr}$; RW = river water; SW = seawater, and [] = concentration in $\mu\text{moles per liter} = \mu\text{M}$.

^b Includes input from solubilization of solids.

Sources: Based on Tables 8.1 and 8.2 and data of Meybeck (1979, 1982) for world average river water.

Major Processes Affecting the Concentration of Specific Components of Seawater Numbered in Order of Approximate Decreasing Importance

Component	Input Processes	Output Processes
Chloride (Cl ⁻)	1. River-water addition (including pollution)	1. Evaporative NaCl deposition (in past) 2. Net sea-air transfer 3. Pore-water burial
Sodium (Na ⁺)	1. River-water addition (including pollution)	1. Evaporative NaCl deposition (in past) 2. Net sea-air transfer 3. Cation exchange 4. Basalt-seawater reaction 5. Pore-water burial
Sulfate (SO ₄ ²⁻)	1. River-water addition (including pollution) 2. Polluted rain and dry deposition	1. Evaporative CaSO ₄ deposition (in past) 2. Biogenic pyrite formation 3. Net sea-air transfer
Magnesium (Mg ²⁺)	1. River-water addition	1. Volcanic-seawater reaction 2. Biogenic Mg-calcite deposition 3. Net sea-air transfer
Potassium (K ⁺)	1. River-water addition 2. Volcanic-seawater reaction (high temp.)	1. Low-temperature volcanic-seawater reaction or slow K ⁺ fixation or reverse weathering 2. Fixation on clays near river mouths 3. Net sea-air transfer
Calcium (Ca ²⁺)	1. River-water addition 2. Volcanic-seawater reaction 3. Cation exchange	1. Biogenic CaCO ₃ deposition 2. Evaporitic CaSO ₄ deposition (in past)
Bicarbonate (HCO ₃ ⁻)	1. River-water addition 2. Biogenic pyrite formation	1. CaCO ₃ deposition
Silica (H ₄ SiO ₄)	1. River-water addition 2. Basalt-seawater exchange	1. Biogenic silica deposition
Phosphorus (HPO ₄ ²⁻ , PO ₄ ³⁻ , H ₂ PO ₄ ⁻ , organic P)	1. River-water addition (including pollution) 2. Rain and dry fallout	1. Burial of organic P 2. CaCO ₃ deposition 3. Adsorption on volcanogenic ferric oxides 4. Phosphorite formation
Nitrogen (NO ₃ ⁻ , NO ₂ ⁻ , NO ₄ ⁻ , organic N)	1. N ₂ fixation 2. River-water addition (including pollution) 3. Rain and dry deposition	1. Denitrification 2. Burial of organic N

The Oceanic Chloride Budget (Rates in Tg Cl⁻/yr)

Present-Day Budget			
Inputs		Outputs	
Rivers (natural)	215	Net sea-air transfer	40
Rivers (pollution)	93	Pore-water burial	25
Total	308	Total	65

Long-Term (Balanced) Budget			
Inputs		Outputs	
Rivers	215	NaCl evaporative deposition	163
		Net sea-air transfer	40
		Pore-water burial	12
		Total	215

Note: Tg = 10¹² g. Replacement time for Cl⁻ is 87 million years.

The Oceanic Sodium Budget (Rates in Tg Na⁺/yr)

Present-Day Budget			
Inputs		Outputs	
Rivers (natural)	193	Cation exchange	42
Rivers (pollution)	76	Net sea-air transfer	21
		Pore-water burial	16
Total	269	Total	79

Long-Term Budget			
Inputs		Outputs	
Rivers	193	NaCl deposition	106
		Net sea-air transfer	21
		Cation exchange	21
		Pore-water burial	8
		Basalt-seawater reaction	37
		Total	193

Note: Tg = 10¹² g. Replacement time for Na⁺ is 55 million years.

The Oceanic Magnesium Budget (Rates in Tg Mg⁺⁺/yr)

(Balanced) Budget for Past 100 Million Years

Inputs		Outputs	
Rivers	137	Volcanic-seawater reaction	119
		In biogenic CaCO ₃	15
		Net sea-air transfer	3
		Total	137

Note: Tg = 10¹² g. Replacement time for Mg⁺⁺ is 13 million years.

The Oceanic Potassium Budget (Rates in Tg K⁺/yr)

Long Term (Balanced) Budget

Inputs		Outputs	
Rivers	52	Fixation on clay near river mouths	6
		Sea-air transfer	1
Volcanic-seawater reaction (high-temperature)	53		
Total	105	Low-temperature volcanic-seawater reaction or slow fixation in deep sea or reverse weathering	98
		Total	105

Note: Tg = 10¹² g. Replacement time for K⁺ is 10 million years.

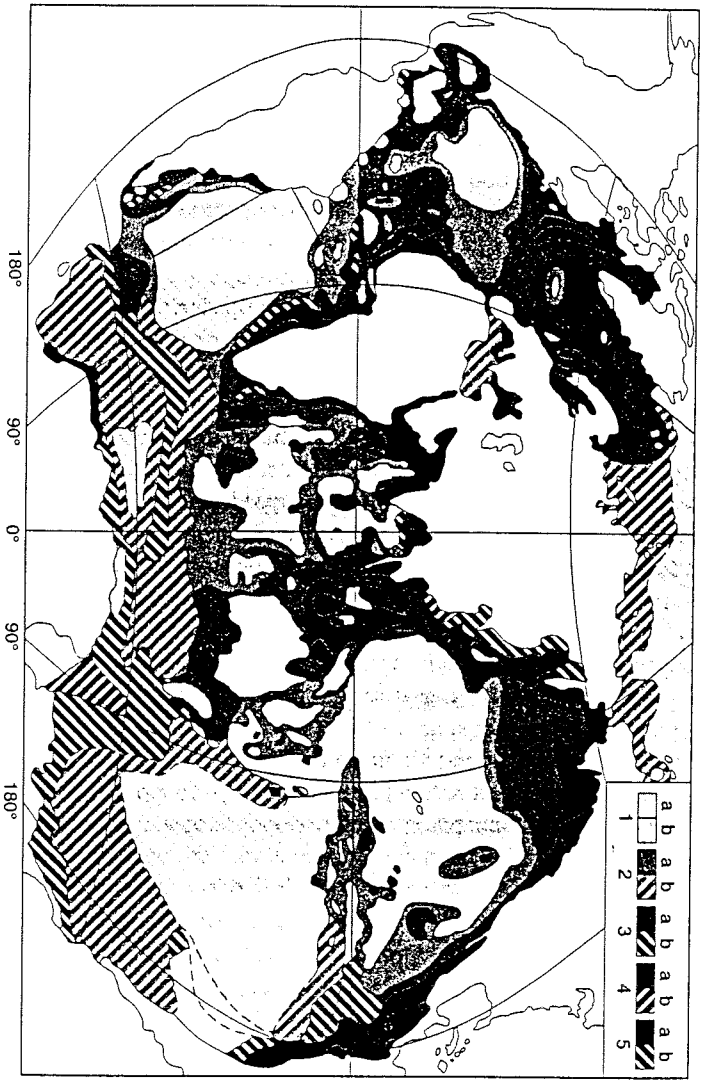
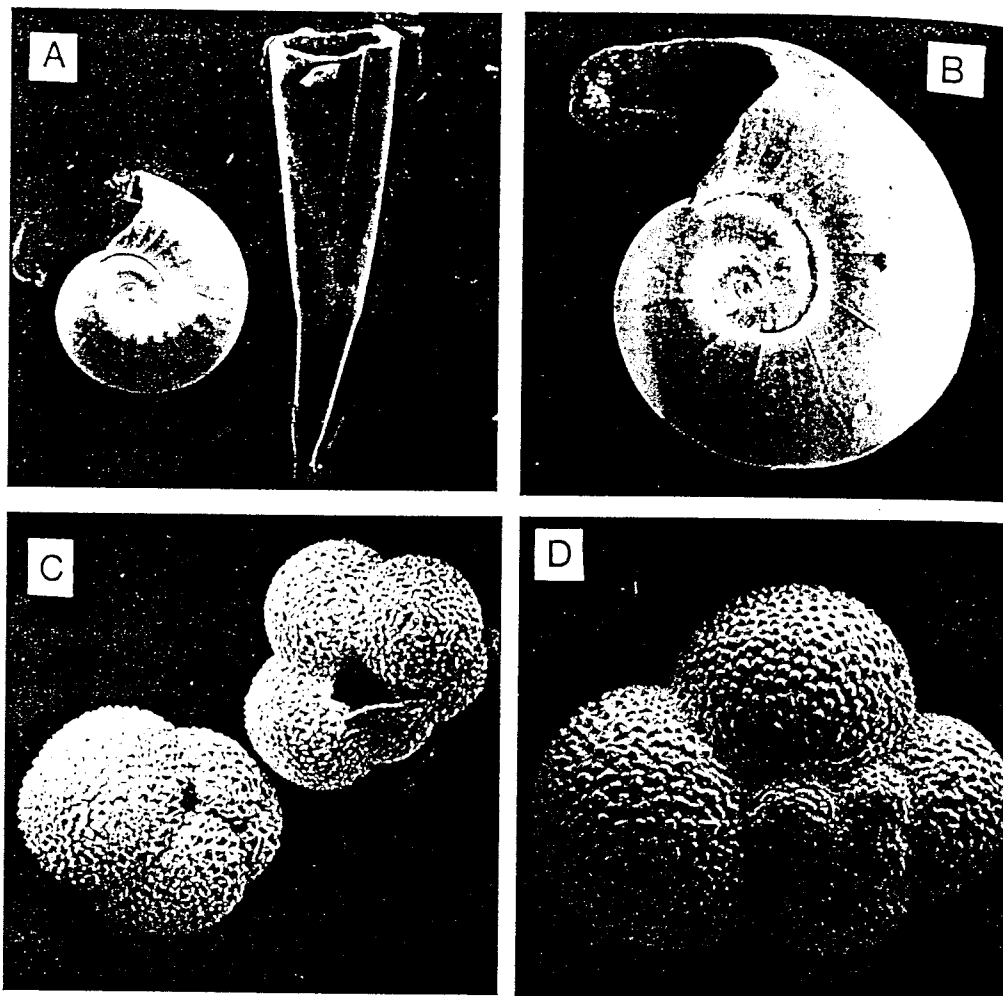


Figure 8.4. Rates of organic matter production (in mg C/m²/day) for the oceans: (1) less than 100; (2) 100–150; (3) 150–250; (4) 250–500; (5) more than 500. a = data from direct ¹⁴C measurements; b = data from phytoplankton biomass, hydrogen, or oxygen saturation. (After O. J. Koblentz-Mishke, V. V. Volkovinsky, and J. G. Kabanova, "Plankton Primary Production of the World Ocean." In *Scientific Exploration of the South Pacific*, ed. W. S. Wooster, p. 185. Copyright © 1970 by the National Academy of Science, reprinted by permission of the publisher.)



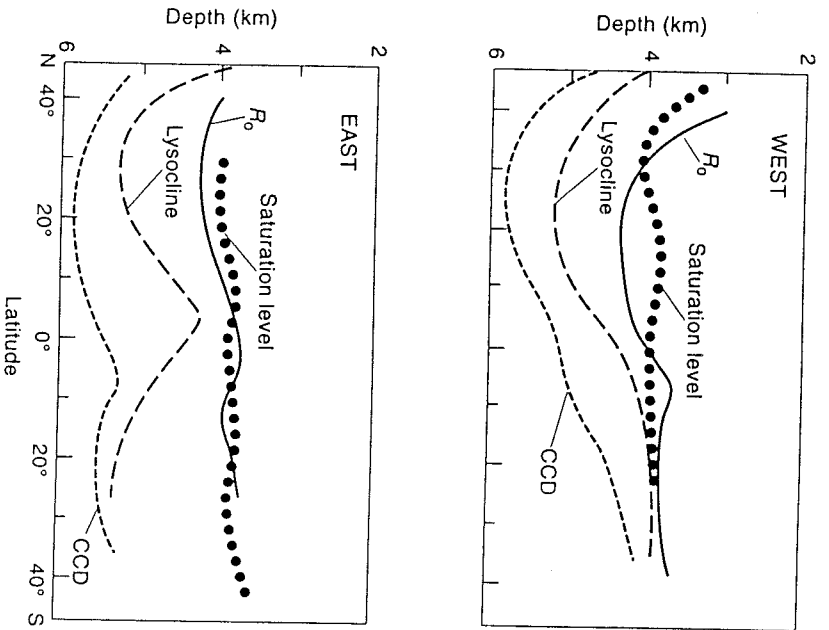
Photomicrographs of some planktonic CaCO_3 -secreting organisms: (a) pteropod shells (aragonite) $\times 20$; (b) pteropod shell (aragonite) $\times 10$; (c) foram tests (calcite) $\times 70$; (d) foram test (calcite) $\times 100$.

Quantitatively Important Plants and Animals That Secrete Calcite, Aragonite, Mg-calcite, and Opaline Silica

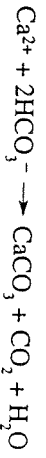
Mineral	Plants	Animals
Calcite	Coccolithophorids ^a	Foraminifera ^a
		Molluscs
Aragonite	Green algae	Bryozoans
		Molluscs
		Corals
		Pteropods ^a
Mg-calcite	Coralline (red) algae	Byzoans
		Benthic foraminifera
		Echinoderms
		Serpulids (tubes)
Opaline silica	Diatoms ^a	Radiolaria ^a
		Sponges

^a Planktonic organisms.

Sources: For further information on skeletal mineralogy consult Lowenstam 1981.



Plots of the depth of the carbonate compensation depth (CCD), lysocline, saturation level, and R_0 depth for surface sediments of the Atlantic Ocean as a function of latitude. The R_0 depth is that where evidence for dissolution is first encountered, and the saturation level is that depth in the water column below which calcite becomes undersaturated and can therefore dissolve. (After W. H. Berger, "Carbon Dioxide Excursions in the Deep Sea Record: Aspects of the Problem." In *The Fate of Fossil Fuel CO₂ in the Oceans*, ed. N. R. Andersen and A. Malahoff, p. 512. Copyright © 1977 by Plenum Press, reprinted by permission of the publisher.)



The Oceanic Calcium Budget (Rates in Tg Ca⁺⁺/yr)

Present-Day Budget		Budget for Past 25 Million Years	
Inputs	Outputs	Inputs	Outputs
Rivers	520	Rivers	520
Volcanic-seawater reaction	440	Volcanic-seawater reaction	440
Cation exchange	960	Cation exchange	960
Total	1920	Total	1920
Budget for Past 25 Million Years			
Rivers	240	CaCO ₃ deposition:	1580
Volcanic-seawater reaction	440	Shallow water	1340
Cation exchange	49	Deep sea	2920
Total	729	Total	2920

Note: Tg = 10¹² g. Replacement time (rivers only) for Ca⁺⁺ is 1 million years.

The Oceanic Bicarbonate Budget (Rates in Tg HCO₃⁻/yr)

Present-Day Budget		Budget for Past 25 Million Years	
Inputs	Outputs	Inputs	Outputs
Rivers	1580	Rivers	1580
Biogenic pyrite formation	1340	Biogenic pyrite formation	1340
Total	2920	Total	2920
Budget for Past 25 Million Years			
Rivers	730	CaCO ₃ deposition:	1340
Biogenic pyrite formation	1340	Shallow water	1340
Total	2070	Deep sea	2920
Total	2070	Total	2920

Note: Tg = 10¹² g. Replacement time for HCO₃⁻ (river input only) is 83,000 years.

TABLE 8.20 The Oceanic Silica Budget (Rates in Tg Si/yr)

Present-Day Budget			
Inputs		Outputs	
Rivers	180	Biogenic silica deposition:	
Basalt-seawater reaction	56	Antarctic Ocean	117
Total	236	Bering Sea	13
		N. Pacific Ocean	7
		Sea of Okhotsk	7
		Gulf of California	5
		Walvis Bay	3
		Estuaries	38
		Other areas	<13
			190-203

Notes: Tg = 10^{12} g. To convert to Tg of SiO_2 , multiply by 2.14. The replacement time for river-borne H_4SiO_4 is 21,000 years. The removal value for estuaries may be a maximum—see Chapter 7.

Source: Outputs from De Master 1981.

Table 2.3 Some Characteristics of the Inner Planets

	Mars ^a	Earth	Venus ^b
Distance to the sun (10 ⁶ km)	228	150	108
Surface temperature (°C)	-53	16	474
Radius (km)	3390	6371	6049
Atmospheric pressure (bars)	0.007	1	92
Atmospheric mass (g)	2.4 × 10 ¹⁹	5.3 × 10 ²¹	5.3 × 10 ²³
Atmospheric composition (% wt.)			
CO ₂	95	0.035	98
N ₂	2.5	78	2
O ₂	0.25	21	0
H ₂ O	0.10	1	0.05

^aFrom Owen and Biemann (1976).

^bFrom Nozette and Lewis (1982).

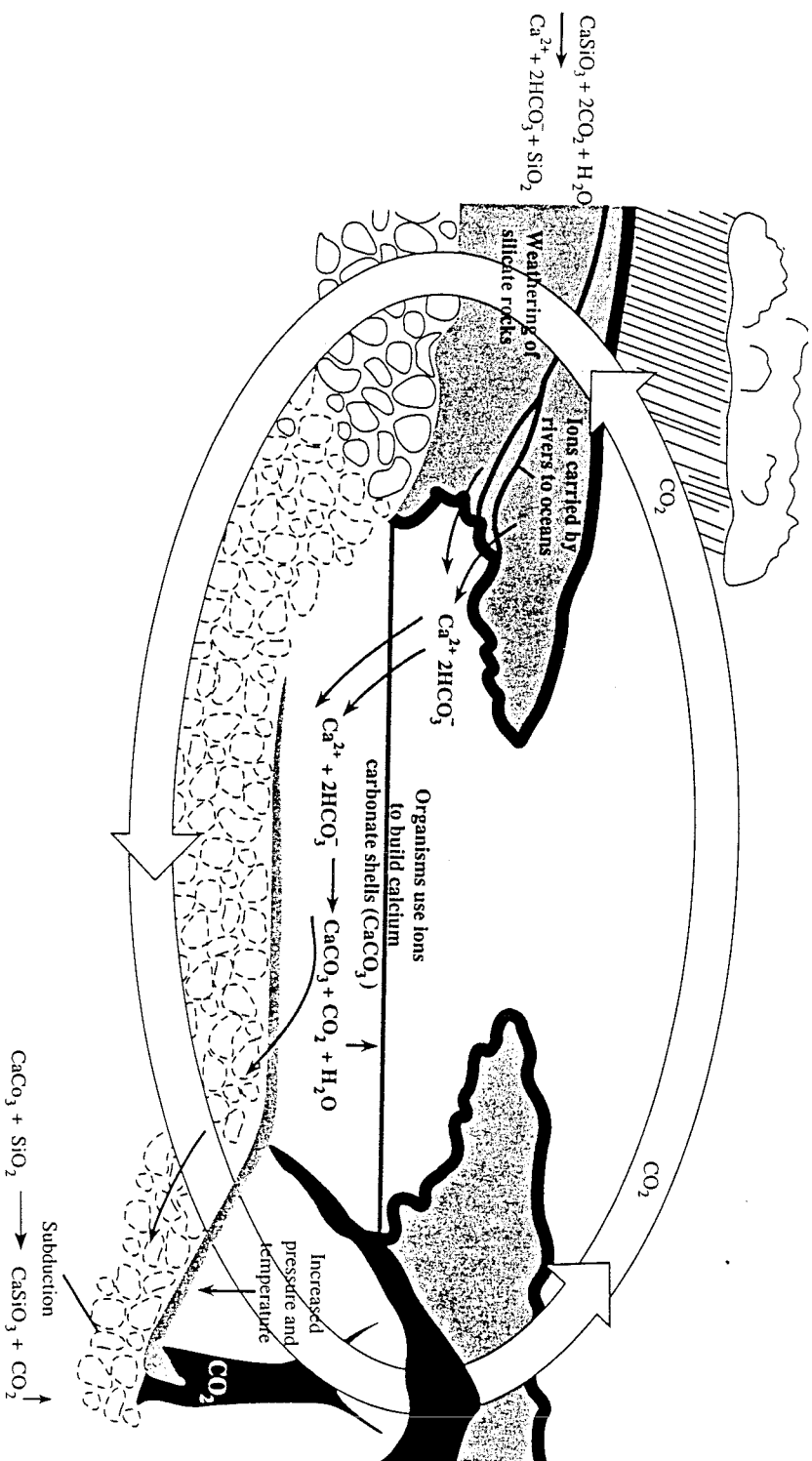


Figure 2.8 The interaction between the carbonate and silicate cycles at the surface of the Earth. Long term control of atmospheric CO₂ is achieved by dissolution of CO₂ in surface waters and its participation in the weathering of rocks. Eventually carbon is buried as part of carbonate rocks in the oceanic crust. CO₂ is released to the atmosphere when these rocks undergo metamorphism at high temperature and pressure in the Earth's crust. Modified from Kasting et al. Copyright © 1988 by Scientific American, Inc.

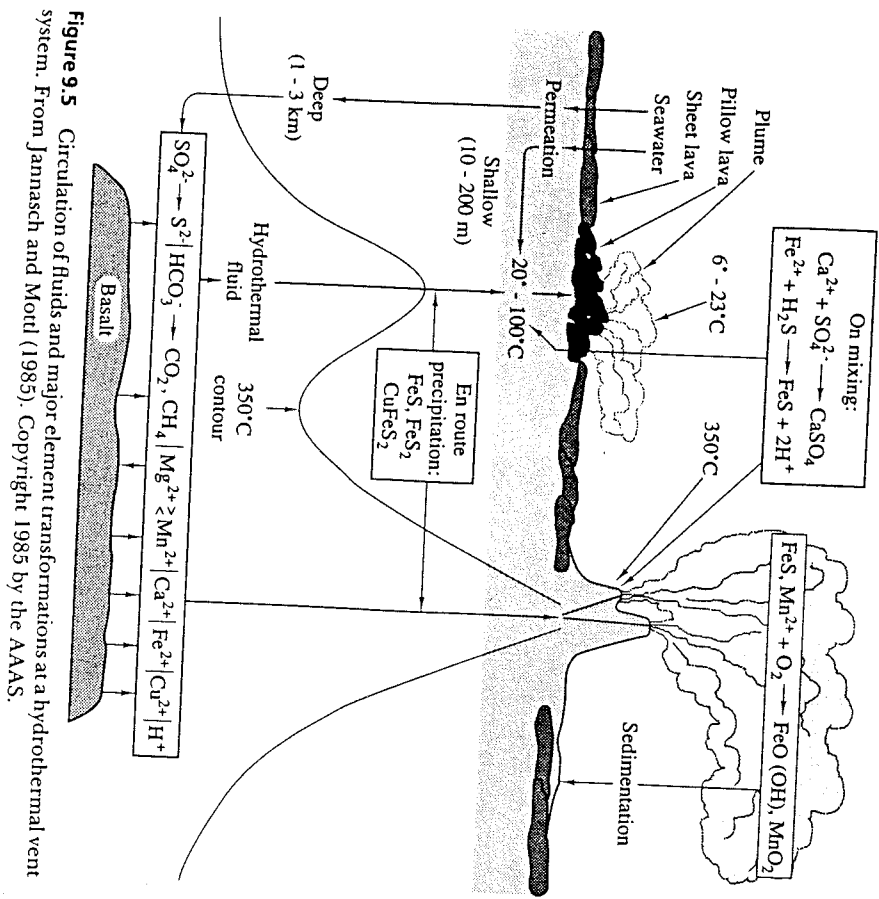


Figure 9.5 Circulation of fluids and major element transformations at a hydrothermal vent system. From Jannasch and Mottl (1985). Copyright 1985 by the AAAS.

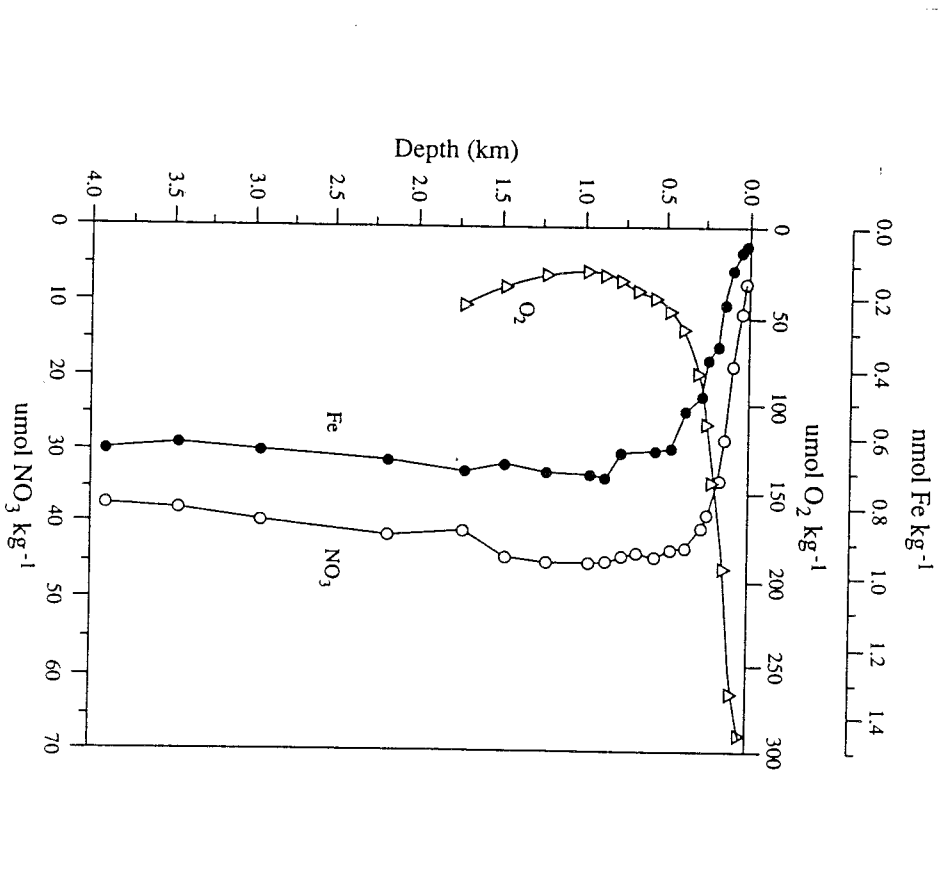
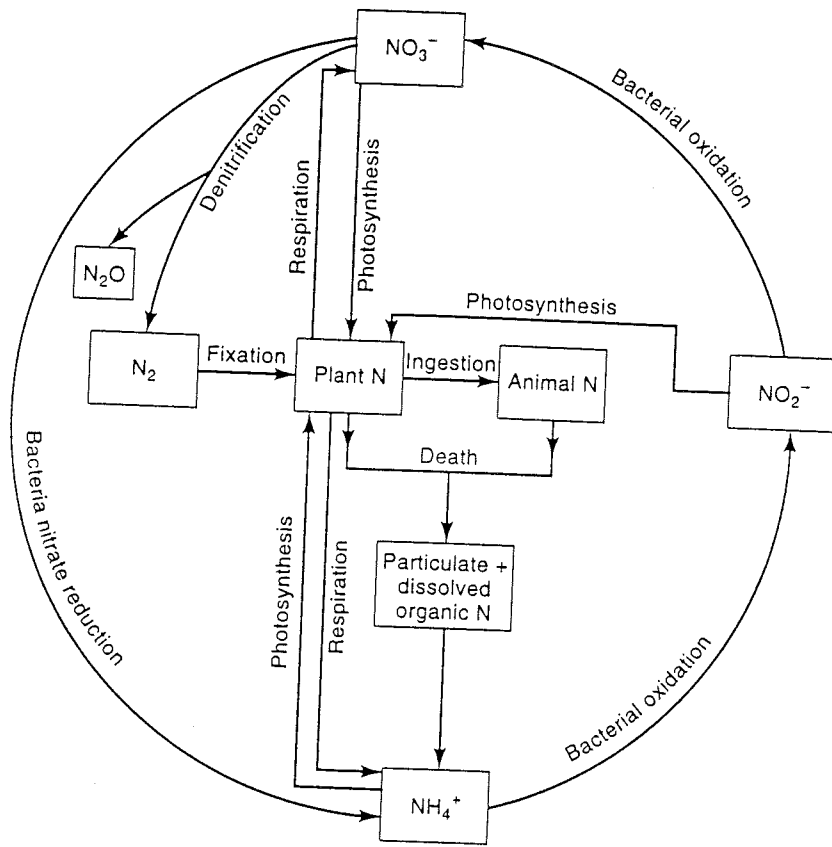
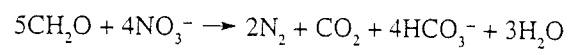


Figure 9.13 Vertical distribution of Fe, NO₃, and O₂ in the central North Pacific Ocean. From Martin et al. (1989).



Schematic representation of the marine nitrogen cycle.



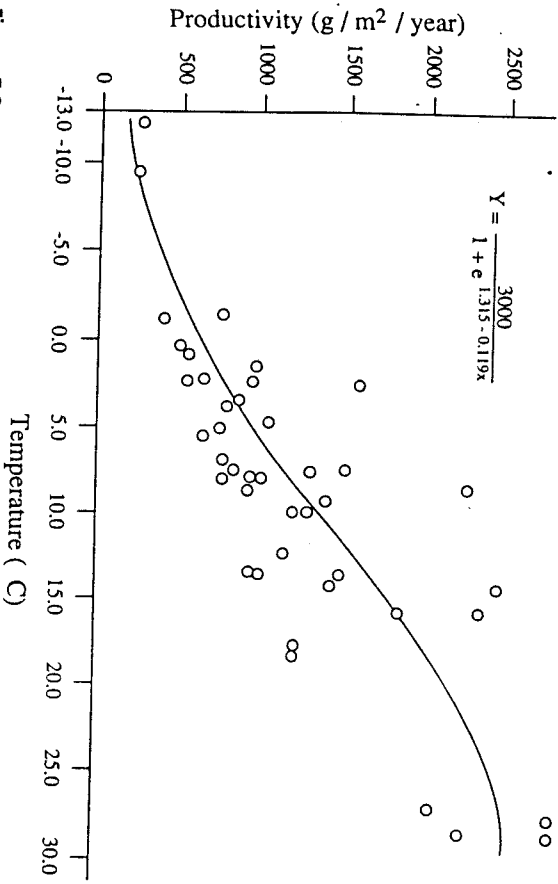


Figure 5.8 Relationship between NPP determined by harvest and mean annual temperature for 52 studies on various continents. From Lieth (1975).

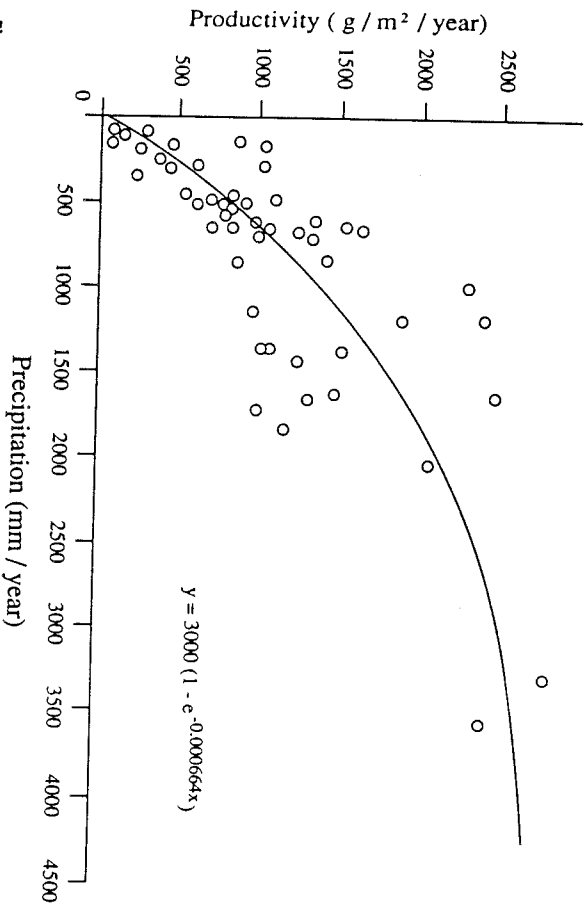


Figure 5.9 Relationship between NPP and mean annual precipitation for 52 locations around the world. From Lieth (1975).

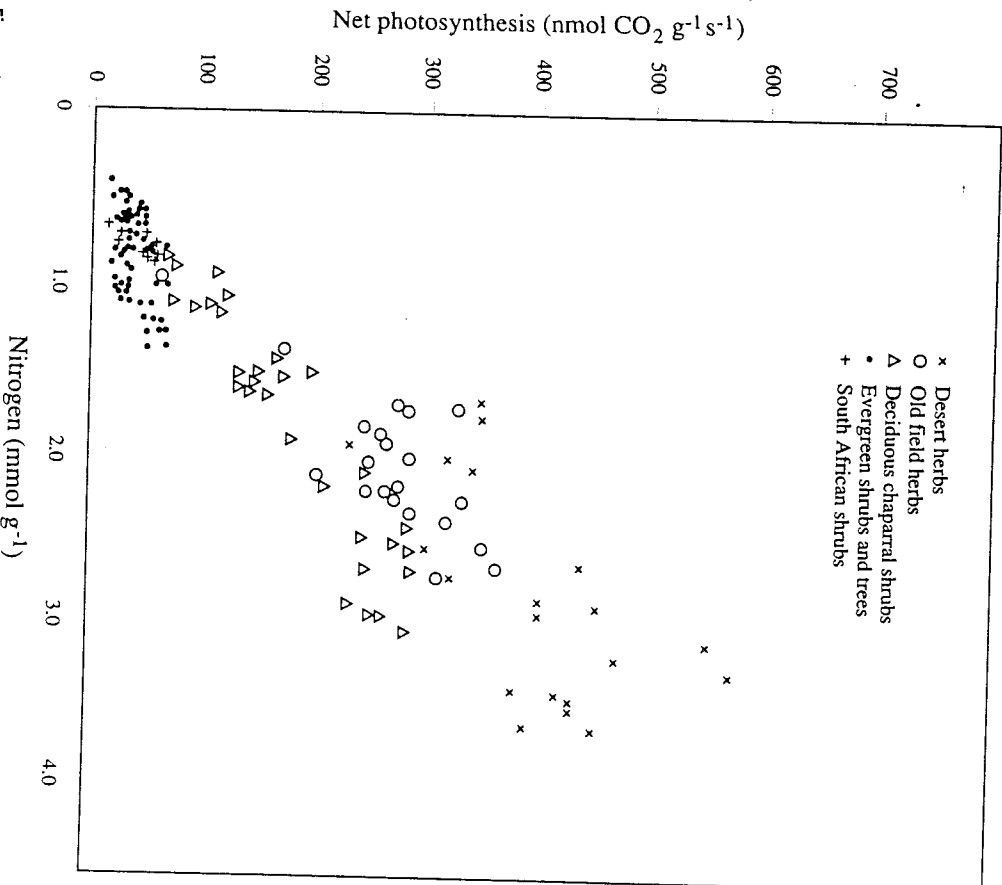


Figure 5.3 Relationship between net photosynthesis and leaf nitrogen content among 21 species from different environments. From Field and Mooney (1986).

Table 5.2 Primary Production and Biomass Estimates for the Biosphere^a

Ecosystem Type	Area (10 ⁶ km ² = 10 ¹² m ²)	Mean Net Primary Productivity (g C/m ² /yr)	Total Net Primary Production (10 ⁹ metric tons C/yr)	Mean Plant Biomass (kg C/m ²)	Total Plant Mass (10 ⁹ metric tons C)
Tropical rain forest	17.0	900	15.3	20	340
Tropical seasonal forest	7.5	675	5.1	16	120
Temperate evergreen forest	5.0	585	2.9	16	80
Temperate deciduous forest	7.0	540	3.8	13.5	95
Boreal forest	12.0	360	4.3	9.0	108
Woodland and shrubland	8.0	270	2.2	2.7	22
Savanna	15.0	315	4.7	1.8	27
Temperate grassland	9.0	225	2.0	0.7	6.3
Tundra and alpine meadow	8.0	65	0.5	0.3	2.4
Desert scrub	18.0	32	0.6	0.3	5.4
Rock, ice, and sand	24.0	1.5	0.04	0.01	0.2
Cultivated land	14.0	290	4.1	0.5	7.0
Swamp and marsh	2.0	1125	2.2	6.8	13.6
Lake and stream	2.5	225	0.6	0.01	0.02
Total continental	149	324	48.3	5.55	827
Open ocean	332.0	57	18.9	0.0014	0.46
Upwelling zones	0.4	225	0.1	0.01	0.004
Continental shelf	26.6	162	4.3	0.005	0.13
Algal bed and reef	0.6	900	0.5	0.9	0.54
Estuaries	1.4	810	1.1	0.45	0.63
Total marine	361	69	24.9	0.0049	1.76
Full total	510	144	73.2	1.63	829

^aFrom Whittaker and Likens (1973).

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Processes and Reactions

Table 9.2 Calculation of the Sources of Nutrients to Sustain a Global Net Primary Production of 45×10^{15} gC/yr in the Surface Waters of the Oceans^a

Flux	Carbon (10 ¹² g)	Nitrogen (10 ¹² g)	Phosphorus (10 ¹² g)
Net Primary Production ^b	45,000	6500	1000
Amounts Supplied			
By rivers ^c		36	21
By upwelling ^d		542	71
Recycling (by difference)		5922	908

^a Based on an approach developed by Peterson (1981).

^b Assuming a Redfield atom ratio of 120 : 15 : 1.

^c Meybeck (1982).

^d Assuming 3 m/yr following Wollast (1981), as modified by more recent data.

9. The Sea

Table 9.4 Ratio of the Concentration of Elements in Phytoplankton to the Concentration of Elements in Seawater^a

Element	Ratio
Al	25,000
Cd	910
Cu	17,000
Fe	87,000
Mg	0.59
Mn	9400
N	19,000
Na	0.14
P	15,000
S	1.7
Zn	65,000

^aFrom Bowen (1966).

Table 6.1 Percentage of the Annual Requirement of Nutrients for Growth in the Northern Hardwoods Forest at Hubbard Brook, New Hampshire, That Could Be Supplied by Various Sources of Available Nutrients^a

Process	N	P	K	Ca	Mg
Growth requirement (kg/ha/yr)	115.6	12.3	67.3	62.2	9.5
Percentage of the requirement that could be supplied by:					
Intersystem inputs					
Atmospheric	18	0	1	4	6
Rock weathering	0	13	11	34	37
Intrasystem transfers					
Reabsorptions	31	28	4	0	2
Detritus turnover (includes return in throughfall and stemflow)	69	81	86	85	87

^a From Waring and Schlesinger (1985). Reabsorption data are from Ryan and Bormann (1982). All other data are from Likens et al. (1977) and Wood et al. (1984).

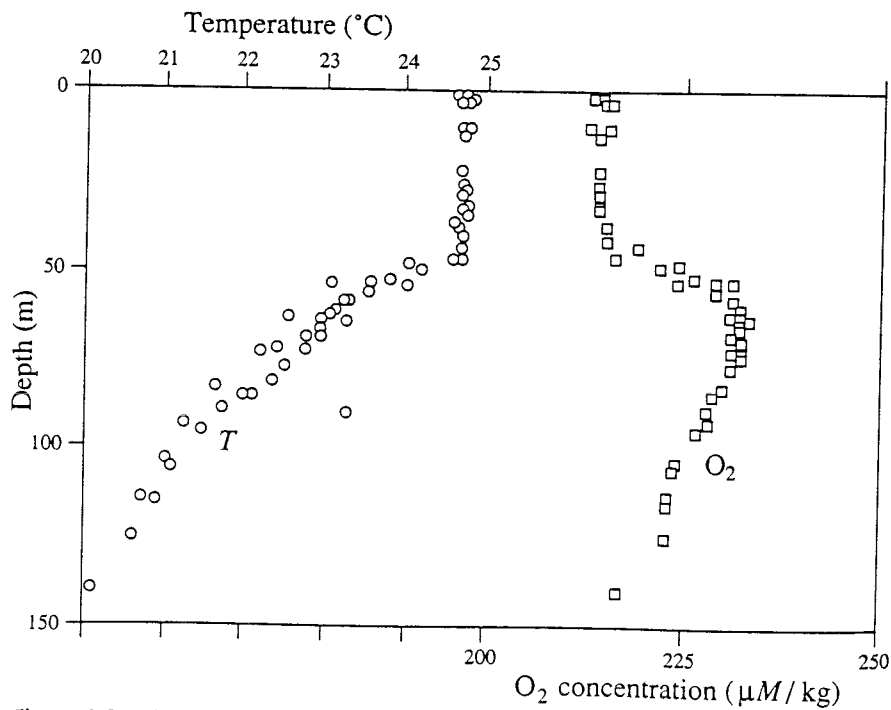


Figure 9.6 Distribution of temperature and O₂ with depth in the North Pacific Ocean. From Craig and Hayward (1987). See also Figure 9.13 for the distribution of O₂ to 1700 m. Copyright 1987 by the AAAS.

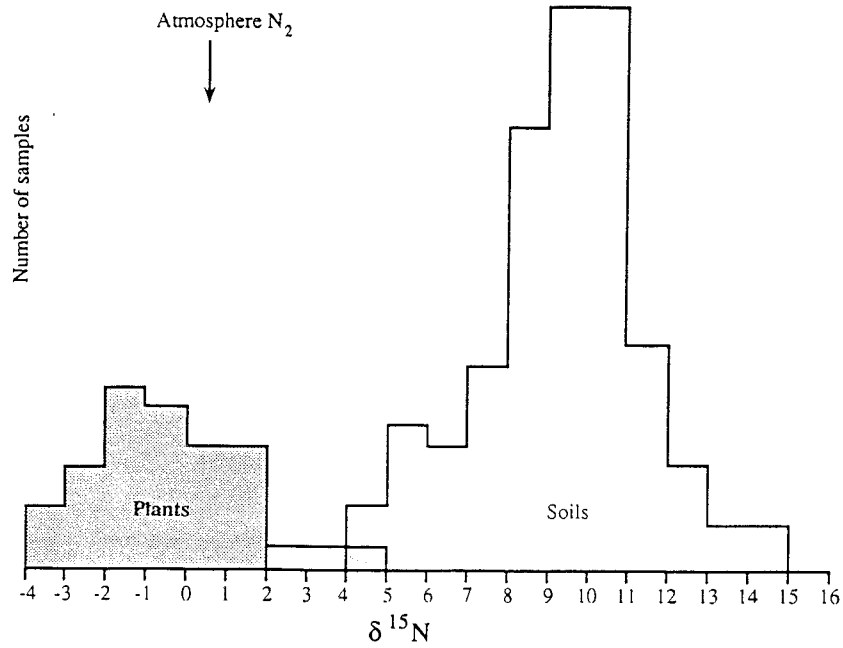


Figure 6.4 Frequency distribution of $\delta^{15}\text{N}$ values in the plant tissues of 20 nitrogen-fixing species and in the organic matter of 124 soils from throughout the United States. From Shearer and Kohl (1988, 1989).

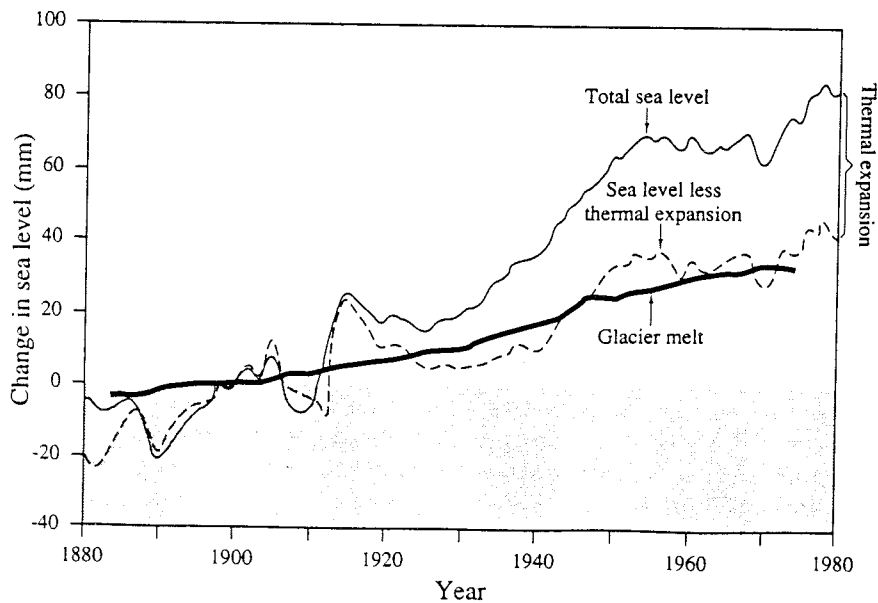


Figure 9.4 Change in sea level during the last century (Gornitz et al. 1982), indicating the proportion due to thermal expansion of the oceans and that due to melting of glaciers. From Jacobs (1986) after Meier (1984). Copyright 1984 by the AAAS.

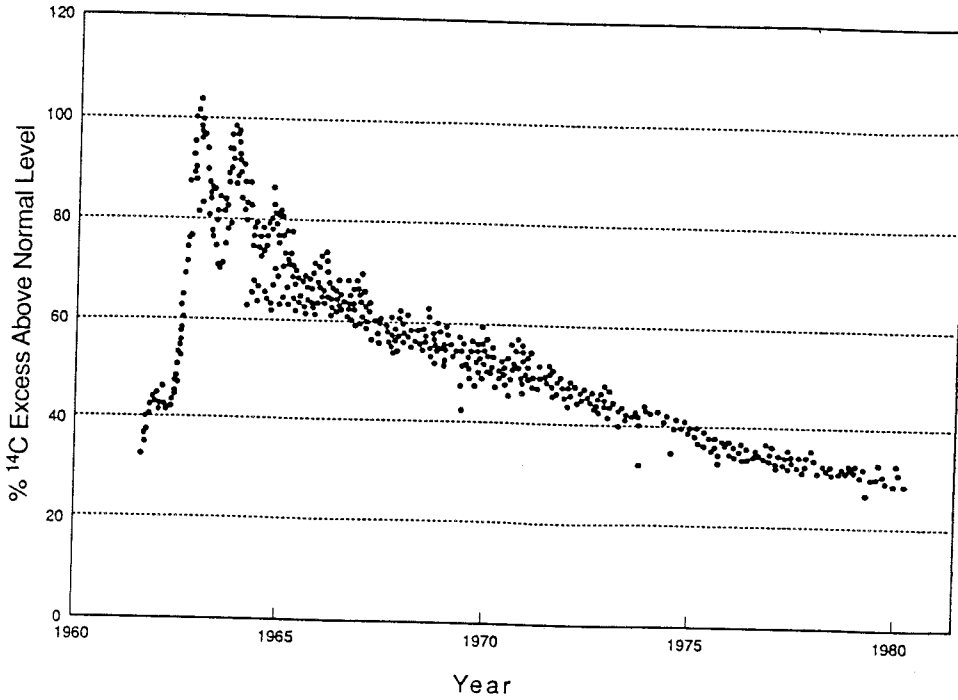


Fig. 11-20 ^{14}C in the troposphere 1962–1981. Modified from Nydal and Lovseth (1983) with the permission of the American Geophysical Union.

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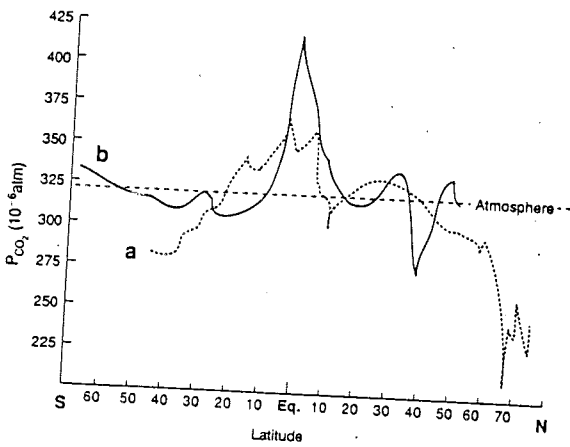


Fig. 11-11 Partial pressure of CO_2 (P_{CO_2}) in surface ocean water along the GEOSECS tracks: (a) the Atlantic western basin data obtained between August 1972 and January 1973; (b) the central Pacific data along the 180° meridian from October 1973 to February 1974. The dashed line shows atmospheric CO_2 for comparison. The equatorial areas of both oceans release CO_2 to the atmosphere, whereas the northern North Atlantic is a strong sink for CO_2 . Modified from Broecker *et al.* (1979) with the permission of the American Association for the Advancement of Science.

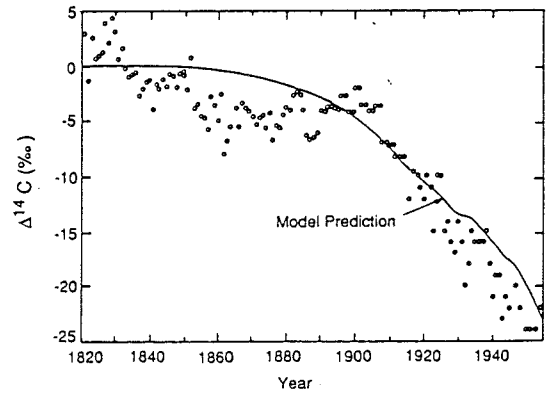


Fig. 11-19 Comparison between the Peng *et al.* (1983) model-derived Suess effect curve (solid line) and the observed $^{14}\text{C}/^{12}\text{C}$ trend (points) for atmospheric CO_2 as reconstructed by Stuiver and Quay (1981) from measurements of tree rings. Reproduced from Broecker *et al.* (1983) with the permission of the American Geophysical Union.

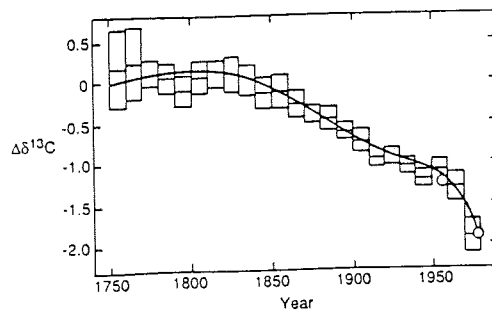


Fig. 11-21 Decade-averaged $\Delta^{13}\text{C}$ data of northern hemisphere tree ring records from 1750 to 1979 and 7th-degree polynomial fit of the data. The vertical extension of blocks represents 95% confidence limits of the mean. The open circles give the ^{13}C change of -0.65% in atmospheric CO_2 observed from 1956 to 1978 by Keeling *et al.* (1979). Adapted from Peng *et al.* (1983).

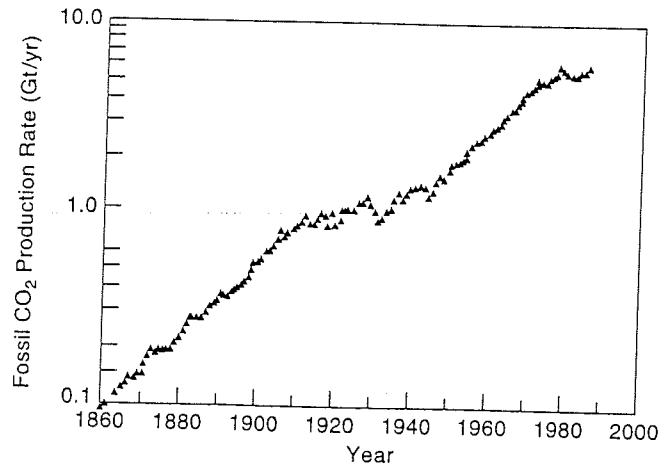


Figure 2.2. Global annual emissions of CO₂ from fossil fuel combustion and cement production in gigatons of carbon per year (plotted on a log scale). Gt = 10⁹ tons. [After Watson et al. (1990), *Greenhouse gases and aerosols*. In *Climate change: The IPCC scientific assessment*, ed. J. T. Houghton et al., p. 10, copyright World Meteorological Organization, from Rotty and Marland (1986) and Marland (1989).]

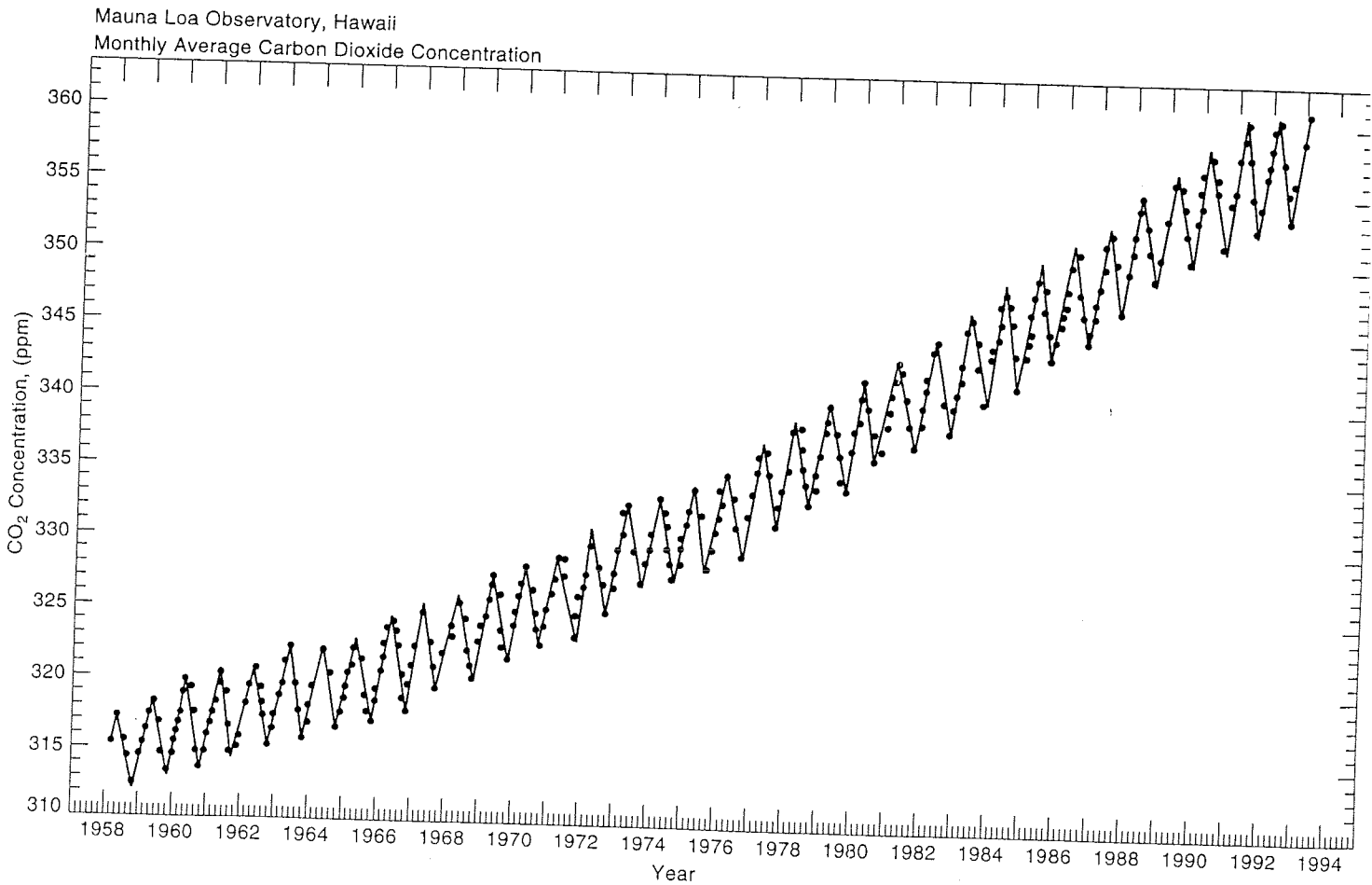


Figure 2.1. Mean monthly concentration of atmospheric CO₂ at Mauna Loa, Hawaii, 1958–late 1993 (C. D. Keeling, personal communication, 1994). The yearly oscillation is explained mainly by the annual cycle of photosynthesis and respiration of plants in the Northern Hemisphere. (Note: 1 ppm CO₂ = 2.12 Gt C, where 1 Gt C = 10⁹ tons C = 10¹⁵ g C.)

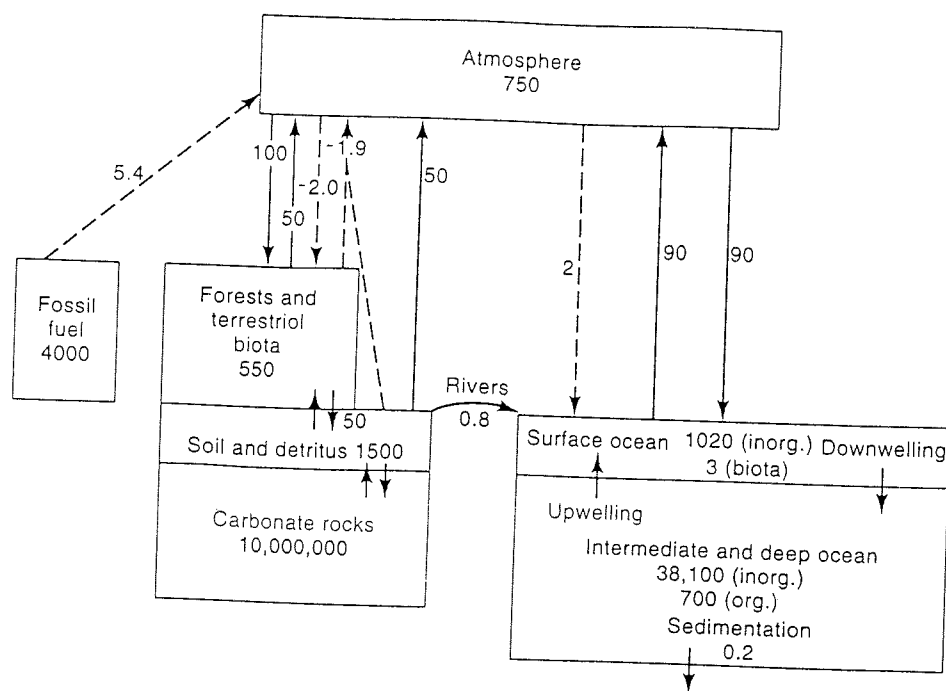


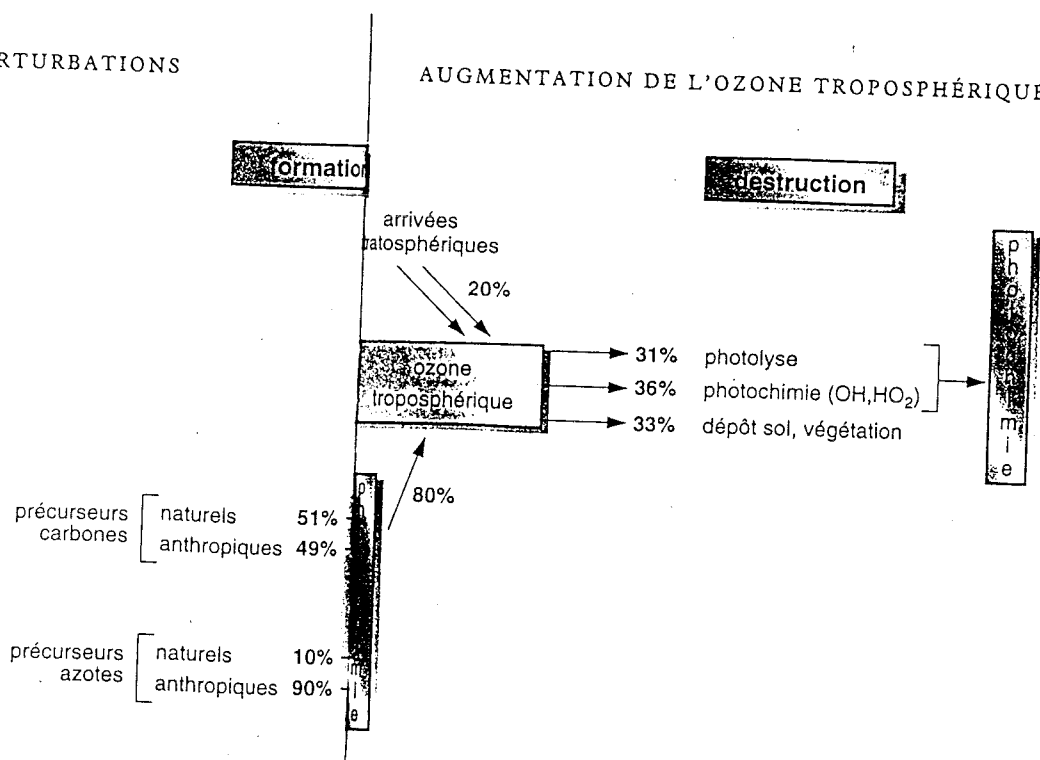
Figure 2.3. The carbon cycle. Reservoirs in 10^{15} g C = 10^9 t C = Gt C. Fluxes in Gt C/yr (dashed fluxes due to human activity; solid fluxes, natural). (Modified from Siegenthaler and Sarmiento 1993; NRC 1983; Bolin et al. 1979.)

CONSÉQUENCES DES PERTURBATIONS

AUGMENTATION DE L'OZONE TROPOSPHÉRIQUE

Bilan global de l'ozone troposphérique.

Sur ce schéma apparaissent les différentes sources de l'ozone troposphérique (arrivées stratosphériques, photochimie des précurseurs, composés organiques volatils, oxydes d'azote) et ses puits (photolyse directe, réactions photochimiques, dépôt au sol et sur la végétation) avec leurs contributions respectives. Si, pour les sources, on observe une action prépondérante de la photochimie, les puits en revanche ont une action à peu près équivalente.



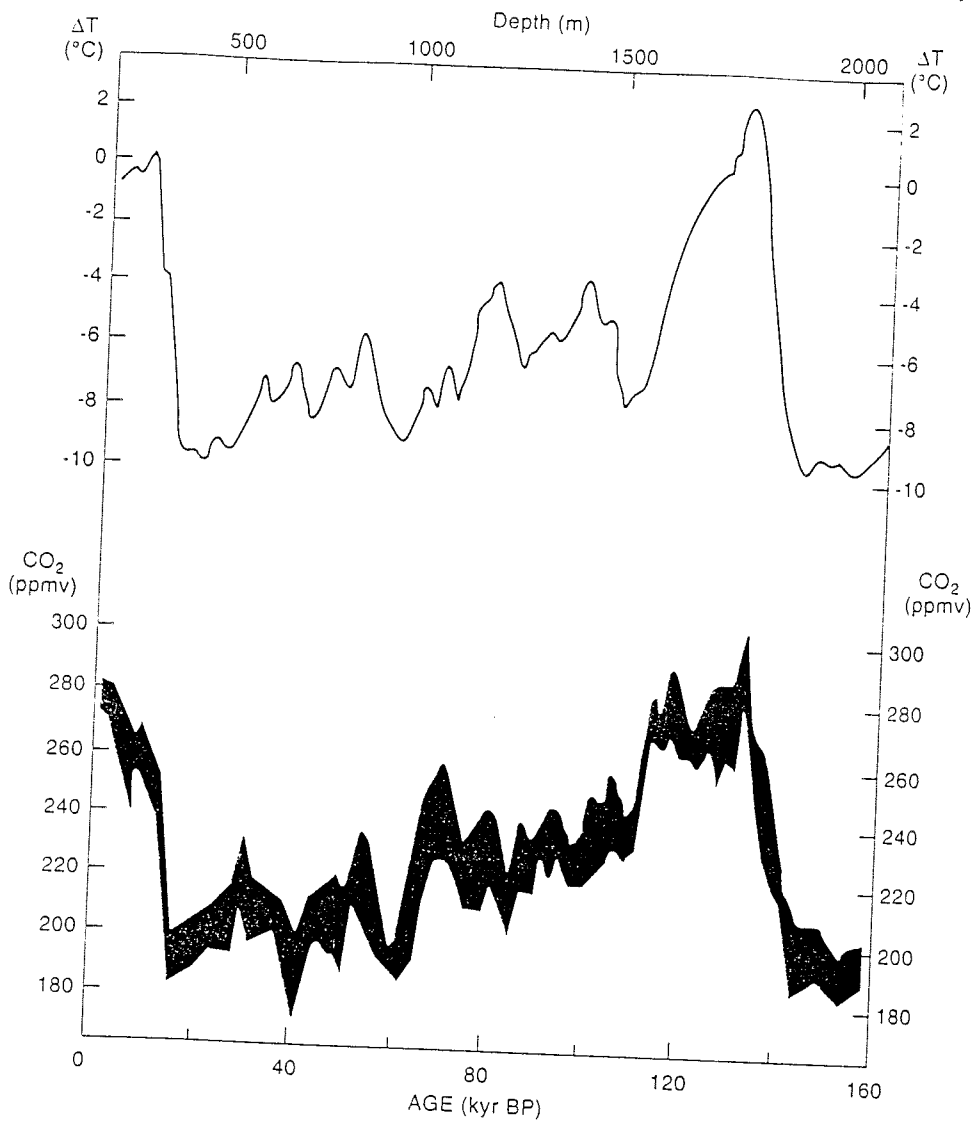
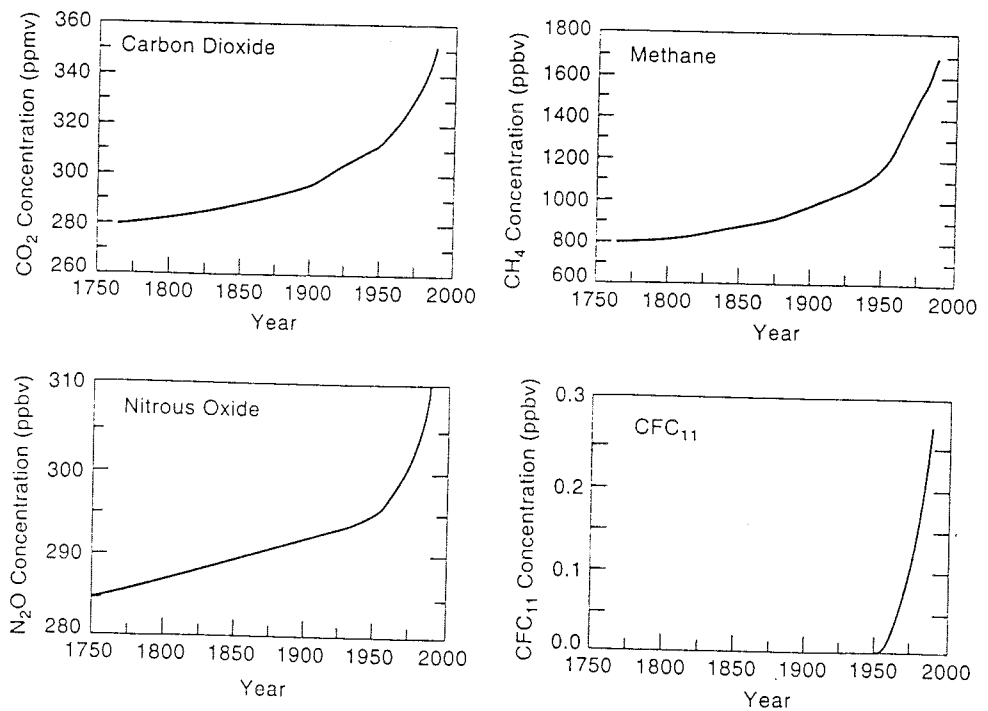


Figure 2.4. Variations in CO_2 concentration (bottom curve) and estimated Antarctic temperature changes (top curve) during the past 160,000 years, as determined from air bubbles in an ice core from Vostok, Antarctica, by Barnola et al. (1987). Temperature changes were estimated from measurements of deuterium concentrations in the ice (Lorius et al. 1990). (After R. T. Watson et al. 1990, *Greenhouse gases and aerosols*. In *Climate change: The IPCC scientific assessment* ed. J. T. Houghton et al., p. 11, copyright World Meteorological Organization.)



Graphes

