
Contents

Introduction	1
Acknowledgements	2
References	2
1 Biogeochemical Provinces: Towards a JGOFS Synthesis	3
1.1 Plankton Community Structure and Distribution	3
1.2 Partitioning the Oceans	5
1.3 Primary Production in Ocean Domains and Provinces	8
1.3.1 Adding up Global PP Observations	11
1.4 Bacterial Production and DOC Flux	11
1.5 A Provincial Outlook	14
Acknowledgements	14
References	14
2 Physical Transport of Nutrients	
and the Maintenance of Biological Production	19
2.1 Introduction	19
2.2 Global Overturning Circulation and Nutrient Transport	21
2.2.1 Overturning Circulation and Water-Mass Distributions	21
2.2.2 Southern Ocean	22
2.2.3 Nutrient Supply to the Northern Basins	24
2.2.4 Summary	25
2.3 Convection	25
2.3.1 Vertical Transfer of Nutrients	25
2.3.2 Biophysical Interactions and Convection	25
2.3.3 Limited Role of Convection	28
2.3.4 Summary	28
2.4 Wind-Driven Circulations: Gyres and Boundary Currents	29
2.4.1 Wind-Induced Upwelling and Gyre Circulations	29
2.4.2 Gyre-Scale Circulations	29
2.4.3 Subduction and Fluid Transfer into the Seasonal Boundary Layer	30
2.4.4 Oligotrophic Subtropical Gyres	31
2.4.5 Western Boundary Transport of Nutrients	33
2.4.6 Summary	35
2.5 Smaller-Scale Circulations:	
Mesoscale Eddies, Waves and Sub-Mesoscale Fronts	35
2.5.1 Formation of Mesoscale Eddies and Sub-Mesoscale Fronts	35
2.5.2 Local Response to Planetary Waves, Eddies and Fronts	36
2.5.3 Far Field Effects: Eddy Transport and Diffusion	40
2.5.4 Summary	41
2.6 Interannual and Long-Term Variability	42
2.6.1 Coupled Atmosphere-Ocean Changes: ENSO	42
2.6.2 North Atlantic Oscillation	43
2.6.3 Changes in Overturning Circulation	45
2.6.4 Summary	46

2.7	Conclusions	46
	Acknowledgements	47
	Notes	47
	References	49
3	Continental Margin Exchanges	53
3.1	Introduction	53
3.2	Recycling Systems	56
3.3	Export Systems	59
3.4	Coastal Upwelling Systems	60
3.5	California Current System	61
3.6	Humboldt Current System	62
3.7	Benguela Current System	63
3.8	Monsoonal Upwelling Systems	63
3.9	Biogeochemical Budgeting	64
3.10	The Arctic Shelves	67
3.10.1	Introduction	67
3.10.2	The Arctic Ocean As a Mediterranean, Shelf-Dominated Sea	69
3.10.3	The Shelves of the Arctic Ocean	71
3.10.4	Barents Shelf	73
3.10.5	Kara Shelf	73
3.10.6	Laptev Shelf	74
3.10.7	East Siberian and Chukchi Shelves	74
3.10.8	Beaufort Shelf	74
3.10.9	The Mackenzie Shelf of the Beaufort Sea as a Case Study	75
3.10.10	Shelf to Basin Sediment Transport in the Arctic	76
3.10.11	CH ₄ , DMS (Dimethyl-Sulphide) Production in the Arctic	77
3.10.12	A Budget for the Arctic Shelves	77
3.10.13	Global Change; Speculation on Consequences for Arctic Shelves	78
3.11	Marginal Seas	79
3.11.1	High Latitude Marginal Seas	79
3.11.2	Semi-Enclosed Marginal Seas	80
3.11.3	Initial Synthesis	82
3.11.4	Future Research	84
3.11.5	Summary	88
	Acknowledgments	89
	References	89
	Appendix 3.1 – Continental Margins: Site Descriptions	95
4	Phytoplankton and Their Role in Primary, New, and Export Production	99
4.1	Introduction	99
4.1.1	A Brief Introduction to Phytoplankton	99
4.1.2	Photosynthesis and Primary Production	101
4.1.3	Measuring Photosynthesis and Net Primary Production in the Sea	102
4.1.4	A Brief History of the Measurement of Primary Productivity in the Oceans	102
4.1.5	Quantifying Global Net Primary Productivity in the Oceans	103
4.1.6	Export, New and 'True New' Production	106
4.1.7	Elemental Ratios and Constraints on New Production	107
4.1.8	New Production, Export Production, and Net Community Production	107
4.1.9	Measurement of New Production	108
4.1.10	Measurement of Net Community Production	109
4.1.11	Measurement of Export Production	109
4.1.12	Summary of Methods	111

4.2	Synthesis	112
4.2.1	Physical Controls of Export Fluxes: the Importance of Functional Groups	115
4.2.2	Calcium Carbonate Precipitation	116
4.2.3	Primary, New and Export Production and the Global Carbon Cycle on Longer Time Scales	116
	References	118
5	Carbon Dioxide Fluxes in the Global Ocean	123
5.1	Introduction	123
5.2	The Oceans' Influence on Atmospheric CO ₂	123
5.2.1	The Ocean Sets the Steady-State Atmospheric CO ₂ Concentration ..	123
5.2.2	The Pre-Industrial Steady State	125
5.2.3	Pre-Industrial North-South Transports	126
5.3	How Big is the Global Ocean Sink?	127
5.3.1	1-D Models Calibrated with ¹⁴ C	127
5.3.2	3-D Models of the Ocean Carbon Cycle	127
5.3.3	¹³ C Changes with Time in the Ocean	128
5.3.4	Atmospheric Observations	128
5.3.5	Observations of the Air-Sea Flux	129
5.3.6	Preformed Total Carbon Methods and the Ocean Inventory of CO ₂	130
5.3.7	Summary of Recent Estimates of the Ocean Sink	132
5.4	What Processes Control Air-Sea CO ₂ Flux?	132
5.4.1	Patterns in the Global Survey	132
5.4.2	Comparison Using Models	133
5.4.3	Modelled Future Uptake of Anthropogenic CO ₂	138
5.5	Variability in the CO ₂ Signal	138
5.5.1	Seasonal Variation	138
5.5.2	Inter-Annual Variation	138
5.6	The Gas Transfer Velocity	140
5.7	Conclusion: the Next Ten Years	141
	Acknowledgements	141
	References	141
6	Water Column Biogeochemistry below the Euphotic Zone	145
6.1	Introduction	145
6.2	The Twilight Zone: Biology, Biogeochemical Processes and Fluxes	146
6.2.1	Biology of the Twilight Zone	146
6.2.2	Nature of the Exported Material and Processes	147
6.2.3	Microbial Production of Nitrous Oxide	148
6.3	The Fluxes of Biogenic Matter versus Depth	149
6.3.1	The Export Flux out of the Euphotic Zone	149
6.3.2	The Export Flux towards the Ocean's Interior (>1 000 m)	150
6.4	The Variable Composition of the World Ocean Waters along the Conveyor Belt .	151
6.5	Conclusions and Perspectives	152
6.5.1	The Ventilation Depth and the ν -Ratio	153
6.5.2	The Role of Mineral Ballasts in the Export of Carbon to the Ocean Interior	153
	References	153
7	The Impact of Climate Change and Feedback Processes on the Ocean Carbon Cycle	157
7.1	Introduction	157
7.1.1	Climate and Change – Present Status	157
7.1.2	Examples of Feedbacks in the Present and the Geological Past	159
7.2	Feedbacks	159

7.2.1	Definition	159
7.2.2	Identification	159
7.2.3	Classification	160
7.2.4	Magnitude	160
7.2.5	Evolution	161
7.2.6	Interactions between Feedbacks	161
7.2.7	Scales and Response Times	161
7.2.8	Degree of Confidence – Understanding Feedbacks	162
7.3	What do Current Models Predict?	162
7.4	Status of Our Understanding of Feedbacks	164
7.5	Nutrient Dynamics	164
7.6	Phytoplankton and Carbon Limitation	164
7.6.1	Atmospheric Supply of Nutrients	164
7.6.2	Nitrogen Fixation	165
7.6.3	Changes in Nutrient Uptake Stoichiometry – the Redfield Ratio	166
7.6.4	Export Production and Remineralisation in the Deep Ocean	167
7.7	The Calcifiers	167
7.7.1	Biogeochemistry and Feedbacks	168
7.7.2	Global Distributions	168
7.7.3	Controlling Factors, Forcing and Modelling	169
7.7.4	A Case Study – the Bering Sea	169
7.8	Iron Supply to the Oceans	170
7.8.1	How Much of the Ocean Is Iron-Poor?	170
7.8.2	The Supply of Iron to the Ocean	170
7.8.3	Atmospheric Deposition of Iron versus Upwelling Supply	170
7.8.4	Dust Supply – Global Maps and Fluxes	171
7.8.5	Dust Transport – from Soil to Phytoplankton	171
7.8.6	Response by the Biota – Detection	171
7.8.7	The Future – Climate Change and Dust Deposition	172
7.8.8	A Case Study – Uncertainties in Projection	174
7.9	Dimethyl Sulphide and the Biota	174
7.9.1	The CLAW Hypothesis	174
7.9.2	What Produces DMSP/DMS?	175
7.9.3	Global Distributions of DMS	175
7.9.4	The Haptophyte Connection	176
7.10	UV-B and Ozone Depletion	176
7.10.1	Present Status of Ozone Depletion	176
7.10.2	Phytoplankton and Primary Production	177
7.10.3	Dissolved Organic Matter and Heterotrophic Bacteria	177
7.10.4	Pelagic Community Response	178
7.10.5	The Future	178
7.11	Summary of Biotic Feedbacks	178
7.12	Climate – Variability versus Change	179
7.12.1	Climate Change	179
7.12.2	Climate Variability	180
7.12.3	Regime Shifts	181
7.12.4	Unexpected Biological Responses to Climate Change	183
7.13	Modeling – Future Goals	183
7.14	The Future	185
7.14.1	Detection and Projection	185
7.14.2	Does the ‘Initial’ Condition Still Exist?	185
7.14.3	The Need for a Regional Approach	185
7.14.4	A New Definition of Biogeochemical Provinces?	186
7.15	Summary	186
	Acknowledgements	187
	References	187

8	Benthic Processes and the Burial of Carbon	195
8.1	Introduction	195
8.2	Processes of Transport and Turnover of Material in the Deep Ocean	196
8.2.1	Transfer of Organic Material from the Surface to the Deep Ocean	196
8.2.2	Benthic Carbon Turnover Processes	197
8.3	Quantitative Estimates of Carbon Deposition and Carbon Turnover	199
8.3.1	Strategies for Quantification of Benthic Fluxes	199
8.3.2	Regional Assessments of Deep-Ocean Fluxes	200
8.3.3	Global Estimates of Deep Ocean Carbon Deposition and Remineralization	201
8.4	Proxy Indicators of Paleoproductivity	204
8.4.1	Estimates Based on Organic Carbon Burial Rates	204
8.4.2	Estimates Based on Biomarker Accumulation Rates	205
8.4.3	Estimates Based on Barium Accumulation Rates	205
8.4.4	Estimates Based on Radionuclide Ratios	206
8.4.5	Estimates Based on Redox-Sensitive Trace Elements	208
8.4.6	Estimates Based on Benthic and Planktonic Foraminifera	208
8.4.7	Estimates Based on Coccolithophorids and Diatoms	209
8.4.8	Proxies of Surface Nutrient Concentration	209
8.4.9	Proxies of Surface Nutrient Utilization Efficiency	210
8.5	Conclusions	211
	References	212
9	Global Ocean Carbon Cycle Modeling	217
9.1	Introduction	217
9.2	Anthropogenic Carbon Uptake, Transient Tracers, and Physics	218
9.3	Global Biogeochemical Cycles	222
9.4	Ecosystem Dynamics	225
9.5	Other Topics	231
9.5.1	Mesoscale Physics	232
9.5.2	Climate Variability and Secular Change	232
9.5.3	Land, Coastal Ocean, and Sediment Interactions	233
9.5.4	Inverse Modeling and Data Assimilation	234
9.6	Summary	234
	Acknowledgements	235
	References	235
10	Temporal Studies of Biogeochemical Processes Determined from Ocean Time-Series Observations During the JGOFS Era	239
10.1	Introduction	239
10.2	The Oceanic Carbon Cycle and the Biological Carbon Pump	240
10.3	Global Inventory of JGOFS Time-Series Programs	244
10.3.1	Bermuda Atlantic Time-Series Study (BATS)	245
10.3.2	Dynamique des Flux Atmosphérique en Méditerranée (DYFAMED)	246
10.3.3	European Station for Time-Series in the Ocean Canary Islands (ESTOC)	247
10.3.4	Hawaii Ocean Time-Series (HOT)	247
10.3.5	Kerguelen Point Fixe (KERFIX)	248
10.3.6	Kyodo Northwest Pacific Ocean Time-Series (KNOT)	248
10.3.7	Ocean Station Papa (OSP or Sta. P)	249
10.3.8	South East Asia Time-Series Station (SEATS)	249
10.4	Some Practical Lessons Learned from the JGOFS Time-Series Programs	250
10.5	Cross Ecosystem Habitat Comparisons: Nutrient, Chlorophyll and Production-Export Relationships	251
10.5.1	Case Study 1: Estimates of the Biological Carbon Pump at Ocean Times Series Sites	255

10.5.2 Case Study 2: A 'Bermuda Triangle' Carbon Mystery with Global Implications	257
10.5.3 Case Study 3: Decade-Scale, Climate-Driven Changes in the N ₂ -Primed Prokaryote Carbon Pump	258
10.5.4 Case Study 4: OSP Ecosystem Dynamics and the Role of Iron	262
10.6 Beyond JGOFS: a Prospectus	263
Acknowledgements	264
References	265
 11 JGOFS: a Retrospective View	269
11.1 The JGOFS Science Plan	269
11.2 The Process Studies	269
11.3 Iron Fertilisation Experiments	271
11.4 The Time Series Stations	271
11.5 The Global Survey	272
11.6 Remote Sensing	272
11.7 Benthic Studies	273
11.8 Continental Margins	273
11.9 Data Archiving	273
11.10 Models and Synthesis	274
11.11 Overall Conclusions	274
References	275
 Index	279

Ocean Biogeochemistry

The Role of the Ocean Carbon Cycle in Global Change

Fasham, M.J.R. (Ed.)

2003, XVIII, 301 p., Hardcover

ISBN: 978-3-540-42398-0