Proposal for a SCOR Working Group

ANALYSING THE LINKS BETWEEN PRESENT OCEANIC PROCESSES AND PALEO-RECORDS

Background and Rationale

In the last decade, studies at increasing spatial and temporal resolutions have highlighted that many of the key ocean processes show variabilities on all time scales from short events over seasonal to decadal or longer term. In most cases, the temporal scale of these variations and their feedbacks to different components of the Earth System cannot be observed adequately by direct observation. Modern oceanographic observations can only provide a snapshot of the present variability of the ocean, but over time scales exceeding the past few decades, this variability is not known. For example, the biogeochemical significance for carbon draw-down of major surface blooms cannot be assessed without examining evidence of their occurrence and variability in the past from the sediments. Although much progress in our understanding of the functioning of the ocean system has been gained by modern process studies, a much broader insight into the role and response of the ocean to climate change can only be achieved, if the period of direct observation can be extended to include past changes of the ocean system. Ocean properties of the past can be reconstructed from naturally occurring biological, geochemical and sedimentological indicators that are collectively known as 'proxies' and by the direct observations of ancient flux events preserved in laminated sediments.

Recent oceanographic experiments have highlighted the importance of certain key species as major drivers of biogeochemical processes, such as export of particulate organic carbon, nitrogen fixation, production of dissolved organic matter, and calcification. An example with major consequences for the oceanic pCO_2 is the evolution of plankton systems dominated by siliceous or carbonaceous species. Observations over the past few decades suggest that carbonaceous species are increasing in the North Atlantic (Deuser et al. 1995, Antia et al. 2001), but the underlying causes are not understood nor do we know whether such shifts have occurred regularly in the past due to variable preservation of these biominerals. Other examples are the long-term shift in nitrogen-fixing organisms observed at the time series station HOTS (Hawaii Ocean Time Series Station) (Karl et al. 1997, Karl et al. 2001) or an ecosystem shift detected in many variables in the Bering Sea (Coyle and Pinchuk 2002, Macklin et al. 2002, Iida et al. 2002) and Northern Pacific Ocean (Hare and Mantua 2000). Several recent oceanographic experiments have observed intriguing blooms of diatoms associated with nitrogen fixing cyanobacteria (e.g. Carpenter et al. 1999; Scharek, et al. 1999), but we rely on recent studies of ancient sediments (Kemp et al. 1999) to learn that such species have sedimented massively in the past and may, therefore, be key players in biogeochemical cycling. Changes in biodiversity, from plankton to higher organisms, are critical sources of information on pre-anthropocene ecosystems' evolution. Documenting the shifts between these ecosystem states and understanding their causes, using combined insights from modern oceanographic experiments and proxies from the sediment record will provide insights into the physical and geochemical processes that drive ecological change and into biogeochemical feedback processes. Unfortunately, there is still a considerable lack of proxies preserved in sediments for key plankton functional groups and species that do not leave an easily recognized fossil record, such as soft-bodied organisms without shells, although recent

findings look promising (e.g. Dahl et al. 2003).

The knowledge of changes in paleoproductivity is a key to understanding how external factors affect biogeochemical cycles. Unfortunately, the intuitively-obvious approach to reconstruct past changes in ocean productivity from the profiles of organic carbon in the sediments is not valid, as there is no simple, direct relationship between the burial rate of organic carbon and the biological productivity of the overlying waters. Therefore, a range of different indicators of past productivity and nutrient utilisation have been developed, including specific organic biomarker compounds (e.g. alkenones from coccolithophorids; dinosterol from dinoflagelates; brassicasterol from diatoms or pigment transformation products of chlorophyll), barium (e.g. Dymond et al. 1992, Francois et al. 1995), $^{231}Pa/^{230}Th$ and $^{10}Be/^{230}Th$ ratios (e.g. Kumar et al. 1995, Anderson et al. 1998), species composition of planktonic and benthic foraminifera (e.g. Mix 1989, Herguera and Berger 1991, Thomas et al. 1995), diatom species assemblages (e.g. Sancetta 1992; Abrantes, 2000) and flux of diatom shell material (opal) (Ragueneau et al. 2000). Nutrient availability in the paleo-ocean has been reconstructed from the carbon isotopic composition and the Cd/Ca ratio of planktonic foraminifera (e.g. Labeyrie and Duplessey 1985, Ninnemann and Charles 1997), N isotopes (e.g. Calvert et al. 1992, Francois et al. 1992, Altabet and Francois 1994, Ganeshram et al. 1995, Sigman et al. 1999) and recently also Si isotopes (De la Rocha et al. 1998). Careful calibrations of such methods are essential and severe limitations inherent in these methods have been highlighted in many studies. Progress has been made through the comprehensive biogeochemical process studies of JGOFS. However, because this research was not always afforded high priority during the design of JGOFS programmes, progress occurred at a limited pace and much more remains to be done.

Paleoceanographic studies are an important approach to understand past biogeochemical states of the ocean, but they are also inflicted by a considerable degree of uncertainty. At present, the relationship between proxies and ocean properties are usually derived empirically. The danger with these empirical relationships is that they maybe valid only within the restricted parameter space of their calibration. Unequivocal interpretation of a proxy record requires a mechanistic understanding of the processes that control its formation and its preservation in the fossil archives. Such a mechanistic approach has been achieved only in few cases, as for instance for carbon isotope fractionation in foraminifera (Wolf-Gladrow et al. 1999, Zeebe 1999, Zeebe et al. 1999). This understanding of the genesis of a proxy signal is unfortunately not available for most proxies.

The rationale behind the formation of this SCOR Working Group is the recognition that considerable advances can be achieved, if a mechanistic understanding of the genesis of proxies as well as development of new proxies can be promoted. This, in turn, would allow the test of current hypotheses on the linkages between ocean biogeochemical cycles and climate. Expertise of scientist studying the modern ocean processes and those focussing on past changes in the ocean can be fruitfully combined to achieve progress in this important aspect of ocean research. Based on the considerable progress made in both fields in the last decade of IGBP research within the core projects PAGES, JGOFS and GLOBEC such a collaboration is timely and much supported by experts of both disciplines.

The proposed SCOR Working Group arises from a small task team initiated between JGOFS and

PAGES/IMAGES, the Paleo-JGOFS Task Team (PJTT) with the following objectives: (i) improve the collaboration between the two core projects, (ii) identify regions of specific interest for future research and (iii) propagate these issues into the next phase of IGBP II ocean research programs. In the marine core projects of IGBP and WCRP, links between paleo- and present day oceanographic studies are included, for instance in CLIVAR, GLOBEC, SOLAS, LOICZ and OCEANS. However, these groups tend to narrowly focus on specific aspects and there is little or no exchange of information between them.

The development of a SCOR Working Group which can form a link between present and past ocean studies in all the different marine IGBP and WCRP programs it is now logical and timely. Such a working group could:

-provide a common platform for scientific exchange between the different marine disciplines,
-foster the joint development or refinement of proxies between the different programs,
-bring together a wide range of expertise necessary to better interpret the paleo-records in the light of our present understanding of ocean ecosystem behavior,
-convey benefit to a wide scientific community within Global Change.

This proposal is addressed to SCOR as one of the governing bodies for all marine science programs within IGBP and WCRP.

Terms of Reference

The main objective of the proposed working group is to combine new insights gained from the study of modern biogeochemical processes and ecosystem dynamics, with paleoceanographic studies aiming to improve our understanding of past oceanic processes. In turn, accurate interpretation of the sedimentary record extends the temporal baseline of observation, thus allowing to better gauge the impact of anthropogenic disturbances against natural variability. To achieve this unifying vision, we must:

1) Use the new insights gained from contemporary ocean biogeochemical studies to identify or refine our understanding of key oceanic processes and develop or improve proxies for these processes for subsequent use in paleoceanographic studies.

2) Refine established proxies, provide mechanistic understanding and foster the development of new proxies within integrated multidisciplinary process studies in the modern ocean.

3) Use proxy evidence from the sedimentary records to test hypotheses of the oceanic response to climate change.

ad 1) The importance of key oceanic processes, such as nutrient utilization, nitrogen fixation, changes in plankton communities, atmospheric input of iron, inputs from terrestrial sources and changes in components of the higher food chain, have been highlighted by modern process studies. In particular, the potential biogeochemical significance of modern blooms has to be evaluated using key ancient sequences with resolution of fluxes on the time scales of modern ocean processes. Episodic sedimentation makes up the major part of the export to the deep ocean

and of the sedimentary record. The sedimentological record has informed us about the significance of these surface events for carbon export and the frequency of their occurrence beyond the time coverage of modern observations. A correct assessment of this earlier variability and how it is linked to the type of production, export and biodiversity is critical as a reference for understanding our pre-industrial world. Proxies need to be refined or developed to reconstruct the history of these key processes. Biomarkers (including their isotopic composition) and molecular genetics are two new tools that are particularly promising for identifying changes in the biological components, which warrant further development.

The working group will address this question by identifying key processes and key organism groups which are major drivers of biogeochemical changes in the ocean and major carriers of paleo-signals into the sedimentary record. If deficiencies in the proxies are recognized, suggestions will be developed on how to improve them or which type of new proxies are most urgently required.

ad 2) Since the relationships between proxies and ocean properties are usually derived statistically, the interpretation of any proxy record is associated with large uncertainties. Therefore, in order to improve the interpretation and to deconvolute several processes indicated by one proxy, several proxies are often analysed in parallel. Many unresolved issues remain to be addressed and require a mechanistic understanding of the processes that control proxy formation and its preservation in the fossil archives. This can only be achieved by integrating process studies, field data basis and modelling. Such approach needs to be applied to a wide and growing range of proxies including siliceous, calcareous and organic microfossils, biomarkers, isotopes and geochemical markers.

Integrating the development and validation of paleoceanographic proxies carried out in different Global Change programs is a cost-effective way of refining their interpretation, and the working group will provide a platform for information exchange between scientists in the different programs. This may include: providing links between groups involved in proxy validation; integration of experimental work and proxy analysis; critical evaluation of proxies in a broad disciplinary context.

ad 3) Investigators have sought evidence in marine sediments for the ocean's role in regulating the atmospheric concentration of CO_2 as an important greenhouse gas. It has long been recognized that a change in the efficiency of the biological pump, which is manifest as a change in the inventory of dissolved inorganic nutrients residing in global-ocean surface waters, translates directly into a change in the concentration of CO_2 in the atmosphere (e.g., Broecker 1982; Sarmiento and Toggweiler 1984). Various factors, ranging from changes in wind-driven upwelling (Pedersen and Bertrand 2000), ocean nutrient inventory (Falkowski 1997; Ganeshram et al. 2000) to fertilization by eolian input of iron (Martin 1990) have been hypothesized to induce climate-related changes in ocean productivity. Much of the recent paleoproductivity research has been designed to test these hypotheses. The response of ocean ecosystems to changing environmental boundary conditions are also related to changes in species composition. However, the sensitivity of ocean ecology to perturbations driven by climate change in the past is yet difficult to understand.

The working group will bring together the expertise of modern ocean process studies and paleoceanography to critically evaluate whether the hypotheses and interpretations developed in both fields of research are fully compatible. The results of such discussion groups will be published as joint review papers.

Proposed Working Group Composition
(at this point still tentative)

Co-Chairs

Karin Lochte (Institut für Meereskunde, Kiel, Germany) *Expertise*: plankton ecology, nitrogen cycle, microbial transformation of sinking material, benthic microbial ecology.

Marie-Alexandrine Sicre (LSCE, Gif sur Yvette; France) *Expertise*: Organic geochemistry, biomarkers, proxy calibration, oceanography, paleoceanography.

Members

Fatima Abrantes (IGM-DGM; Portugal), *Expertise*: paleoceanography, micropaleontology, diatoms.

Carina Lange (Universidad de Conception, Chile) *Expertise:* Diatom specialist, export production from the photic zone to the sediment, preservation/dissolution, late Quaternary paleoceanography.

Tim Baumgartner (CICESE, Mexico) *Expertise:* Paleoecology, paleoclimatology, investigation of stable isotopes in fish scales (member of GLOBEC) (to be confirmed)

Pedros-Alio, Carles, (Spain), *Expertise*: molecular biology (to be confirmed)

Frank Dehairs, (Belgium), *Expertise*: Stable isotopes, compound specific stable isotopes, trace elements in biogenic carbonates, proxies of new and export production.

Roger François (Woods Hole Oceanographic Institution, USA) *Expertise*: geochemistry, late Quaternary paleoceanography, radiochemical approaches, carbon and nitrogen isotope geochemistry, trace element proxies (redox-sensitive elements; paleoproductivity tracers).

Raja S. Ganeshram (University of Edinburgh; UK) *Expertise*: stable isotopes, paleo-nitrogen cycles (to be confirmed)

Alan Kemp (School of Ocean and Earth Science, University of Southampton; UK) *Expertise*: High resolution palaeoceanography and palaeo-biogeochemistry from laminated sediments. The role of diatoms in biogeochemical cycling.

Aldo Shemesh (Weizmann Institute Rehovot, Israel) *Expertise:* paleoceanography, geochemistry of isotopes, isotopic composition of biogenic silica, carbonate (to be confirmed)

Ein Fen Yu (National Taiwan Normal University, Taiwan) *Expertise*:

Dieter Wolf-Gladrow (AWI, Germany), *Expertise*: mechanistic models of paleo-proxies, in particular of isotopic signals.

Corresponding Members

F. Partensky (France)
R. Anderson (USA)
Jelle Bijma (Germany)
Christina De La Rocha (Cambridge, UK)
Richard Zeebe (AWI, Germany)
..and more

Literature cited:

Abrantes, F. (2000) 200 000 yr diatom records from Atlantic upwelling sites reveal maximum productivity during LGM and a shift in phytoplankton community structure at 185 000 yr. Earth and Planetary Science Letters 176**:** 7-16.

Altabet, M. A. and Francois, R. (1994) Sedimentary nitrogen isotope ratio as a recorder for surface ocean nitrate utilization. Global Biogeochemical Cycles 8: 103-116.

Anderson, R. F., Kumar, N., Mortlock, R. A., Froelich, P. N., Kubik, P., Dittrich-Hannen, B. and Suter, M. (1998) Late-Quaternary changes in productivity of the Southern Ocean. Journal of Marine Systems 17**:** 497-514.

Antia, A.N., Koeve, W., Fischer, G., Blanz, T., Schulz-Bull, D., Scholten, J., Neuer, S., Kremling, K., Kuss, J., Hebbeln, D., Bathmann, U., Fehner, U. and Zeitzschel, B. (2001) Basin-wide particulate carbon flux in the Atlantic Ocean: regional export patterns and potential for atmospheric CO_2 sequestration. Global Biogeochemical Cycles 15: 845-862.

Broecker, W. S. (1982) Glacial to interglacial changes in ocean chemistry. Progress in Oceanography 2**:** 151-197.

Calvert, S. E., Nielsen, B. and Fontugne, M. R. (1992) Evidence from nitrogen isotope ratios for enhanced productivity during formation of eastern Mediterranean sapropels. Nature, 359**:** 223-225.

Carpenter E.J., Montoya J.P., Burns J., Mulholland, M.R., Subramaniam and A. Capone, D.G. (1999). Extensive bloom of a N-2-fixing diatom/cyanobacterial association in the tropical Atlantic Ocean. Marine Ecology Progress Series, 185: 273-283.

Coyle, K. O. and Pinchuk, A. I. (2002) Climate-related differences in zooplankton density and growth on the inner shelf of the southeastern Bering Sea. Progress in Oceanography, 55: 177-194.

De La Rocha, C. L., Brzezinski, M. A., DeNiro, M. J. and Shemesh, A. (1998) Silicon-isotope composition of diatoms as an indicator of past oceanic change. Nature, 395: 680-683.

Deuser, W.G., T.D. Jickells, P. King and J.A. Commeau (1995) Decadal and annual changes in biogenic opal and carbonate fluxes to the deep Sargasso Sea. Deep-Sea Res. I, 42: 1923-1932.

Dymond J., Suess, E. and Lyle, M. (1992). Barium in deep-sea sediment: A geochemical proxy for paleoproductivity, Paleoceanography, 7: 163 -181.

Falkowski, P. G. (1997). Evolution of the nitrogen cycle and its influence on the biological sequestration of CO_2 in the ocean. Nature, 387**:** 272-275.

Francois, R. and Altabet, M. A. (1992) Glacial to interglacial changes in surface nitrate utilization in the Indian sector of the Southern Ocean as recorded by ^{15}N. Paleoceanography, 7: 589-606.

Francois, R., Honjo, S., Manganini, S.J. and Ravizza, G.E. (1995) Biogenic barium fluxes to the deep sea: Implications for paleoproductivity reconstruction, Global Biogeochemical Cycles, 9: 289-303.

Ganeshram, R.S., Pedersen, T.F., Calvert, S.E., Murray, J.W. (1995) Large changes in oceanic nutrient inventories from glacial to interglacial periods. Nature, 376: 755-758.

Ganeshram, R.S., Pedersen, T.F., Calvert, S.E., McNeill, G. W. and Fontugne, M.R. (2000) Glacial-interglacial variability in denitrification in the world's oceans: Causes and consequences. Paleoceanography, 15:361-376.

Hare, S.R. and Mantua, N.J. Empirical evidence for North Pacific [climatic] regime shifts in 1977 and 1989. Progress in Oceanography, 47: 103-145, 2000.

Herguera, J.C. and Berger, W.H. (1991) Paleoproductivity from benthic foraminifera abundance: Glacial to postglacial change in the West-Equatorial Pacific. Geology 19: 1173-1176.

Iida, T., Saitoh, S.I., Miyamura, T., Toratani, M., Fukushima, H. and Shiga, N. (2002) Temporal and spatial variability of coccolithophore blooms in the eastern Bering Sea, 1998-2001. Progress in Oceanography, 55: 165-175.

Karl, D., R. Letelier, L. Tupas, J. Dore, J. Christian and D. Hebel (1997) The role of nitrogen fixation in biogeochemical cycling in the subtropical North Pacific Ocean. Nature, 388: 533-538.

Karl, D.M., Bidigare, R.R. nad Letelier, R.M. (2001) Long-term changes in plankton community structure and productivity in the North Pacific Subtropical Gyre: The domain shift hypothesis. Deep-Sea Research II, 48: 1449-1470.

Labeyrie, L. D. and Duplessy, J. C. (1985) Changes in the oceanic $^{13}C/^{12}C$ ratio during the last 140 000 years - high-latitude surface-water records. Palaeogeography Palaeoclimatology Palaeoecology, 50, 217-240.

Kemp, A.E.S., Pearce, R.B., Koizumi, I., Pike, J. and Rance, S.J. (1999) The role of mat forming diatoms in formation of the Mediterranean sapropels. Nature, 398: 57-61.

Kumar, N., Anderson, R. F., Mortlock, R. A., Froelich, P. N., Kubik, P. W., Dittrich-Hannen, B. and Suter, M. (1995) Iron fertilization of glacial-age Southern Ocean productivity. Nature, 378: 675-680.

Macklin, S. A., Radchenko, V. I., Saitoh, S. and Stabeno, P. J. (2002) Variability in the Bering Sea ecosystem. Progress in Oceanography, 55: 1-4.

Martin, J. H. (1990) Glacial-Interglacial CO_2 Change: The iron hypothesis. Paleoceanography, 5: 1-13.

Mix, A. C. (1989) Pleistocene paleoproductivity: Evidence from organic carbon and foraminiferal species. In: Berger, W. H., Smetacek, V. S.and Wefer, G. (eds.) „Productivity of the Ocean: Present and Past“, pp. 313-340.

Ninnemann, U. S. and Charles, C. D. (1997) Regional differences in Quaternary Subantarctic nutrient cycling: Link to intermediate and deep water ventilation. Paleoceanography, 12: 560-567.

Pedersen, T.F. and Bertrand, P. (2000) Influences of oceanic rheostats and amplifiers on atmospheric CO_2 content during the Late Quaternary. Quaternary Science Review, 19: 273-283.

Ragueneau, O., Tréguer, P., Leynaert, A., Anderson, R.F., Brzezinski, M.A., DeMaster, D.J., Dugdale, R.C., Dymond, J., Fischer, G., François, R., Heinze, C., Maier-Reimer, E., Martin-Jézéquel, V., Nelson, D. M. and Quéguiner, B. (2000). A review of the Si cycle in the modern ocean: recent progress and missing gaps in the application of biogenic opal as a paleoproductivity proxy. Global and Planetary Change, 26: 317-365.

Sancetta, C. (1992) Primary Production in the glacial North Atlantic and North Pacific Oceans. Nature, 360: 249-251.

Sarmiento, J.L. and Toggweiler, J.R. (1984) A new model for the role of the oceans in determining atmospheric pCO_2. Nature, 308: 621-624.

Scharek R.., Tupas L.M., Karl D.M., Bidigare, R.R. (1999) Diatom fluxes to the deep sea in the oligotrophic North Pacific gyre at Station ALOHA. Marine Ecology Progress Series, 182: 55-67.

Sigman, D. M., Altabet, M. A., Francois, R., McCorkle, D. C. and Gaillard, J. F. (1999) The isotopic composition of diatom-bound nitrogen in Southern Ocean sediments. Paleoceanography, 14: 118-134.

Thomas, E., Booth, L., Maslin, M. and Shackleton, N. J. (1995) Northeastern Atlantic benthic foraminifera during the last 45,000 years: Changes in productivity seen from the bottom up. Paleoceanography, 10**:** 545-562.

Wolf-Gladrow, D.A., J. Bijma and R.E. Zeebe (1999) Model simulation of the carbonate system in the microenvironment of symbiont bearing foraminifera. Marine Chemistry, 64: 181-198.

Zeebe, R.E., J. Bijma and D.A. Wolf-Gladrow (1999) A diffusion-reaction model of carbon isotope fractionation in foraminifera. Marine Chemistry, 64: 199-227.

Zeebe, R. E. (1999) An explanation of the effect of seawater carbonate concentration on foraminiferal oxygen isotopes. Geochim. Cosmochim. Acta, 63: 2001-2007.