2-166

2.3.5. Working Group on Hydrothermal energy transfer and its impact on the ocean carbon cycles

Summary

The importance of hydrothermal energy transfer to the biosphere through chemosynthetic primary production has long been recognized. Initially, this was only considered to occur at discrete, isolated, hydrothermally active hotspots around the global ridge crest and to have minor impact on the global ocean carbon cycles. But recent results suggest that this assumption may not be correct. We now know that hydrothermal venting can be widespread throughout all oceans, along the entire thermohaline conveyor, and that both the local fixation of carbon and the export of bio-limiting nutrients to the broader ocean may be much greater than previously recognized. For too long, fragmentation of our understanding of bio-geochemical interactions in hydrothermal systems has prevented any quantitative estimation of hydrothermally driven primary production. Now, however, recent advances in molecular methods as well as *in situ* and *in vivo* experimentation provide us with new opportunities for a coordinated, integrating effort in which interdisciplinary approaches and modelling can be brought to bear. Consequently, we believe that it is very timely to plan a revised consideration of the diverse pathways of biomass generation driven by hydrothermal processes and the potential contribution that they may make to the global ocean carbon cycle.

Terms of reference

The objective of the proposed SCOR WG is to bring together an interdisciplinary group of marine scientists, ranging from geochemists to biologists to modellers, with three key goals:

- to **synthesize** current knowledge of chemical substrates, mechanisms and rates of chemosynthetic carbon fixation at hydrothermal systems as well as the transfer of phytoplankton-limiting micronutrients from these systems to the open ocean.
- to **integrate** these findings into conceptual models of energy transfer and carbon cycling through hydrothermal systems which would lead to quantification of primary production in view of a future assessment of the contribution of these systems to the global-ocean carbon cycle.
- to **identify critical gaps** in current knowledge and proposing a strategy for future field, laboratory, experimental and/or theoretical studies to bridge these gaps and better constrain the impact of deep-sea hydrothermal systems on ocean carbon cycles.

Objectives and Timeliness

Our approach will focus on the mechanisms and rates of chemosynthetic carbon fixation in the subsurface, at the seafloor, and in the overlying water column of hydrothermal systems, as well as appraising the extent of iron/nutrient transfer to the global ocean. Such an interdisciplinary and integrative approach is now timely because 1) the recent discovery of widespread hydrothermal venting indicates that such systems may be more important to ocean budgets than previously assumed, 2) the recent developments of deep-sea *in situ* instrumentation and molecular biological techniques provide new methods for investigating the energy transfer pathways used to fix inorganic carbon at hydrothermal vents, 3) we can develop integrative models that will explore critical limits to current knowledge and generate preliminary quantitative estimates of primary production from hydrothermal activity. The ultimate goal will be to identify an integrated body of new research that needs to be conducted, to bridge gaps in our current knowledge and allow us to better constrain the role of hydrothermal venting in global-scale ocean carbon cycling.

<u>Scientific background and rationale</u>

A huge amount of energy (~1 TW of heat-flow and approximately 10^{14} kJ available from hydrothermal fluids for biomass production per year) is delivered from the geosphere to the ocean at mid-ocean ridges. Magmatic and tectonic processes drive hydrothermal circulation which leads to both the extraction of some chemical constituents from seawater into altered oceanic crust as well as the export of heat and crustal elements from beneath the seafloor into the overlying water column (see review by German and Von Damm, 2003).

At any site where hydrothermal circulation brings reduced components from the Earth's interior into contact with oxidising (electron acceptor-rich) seawater, chemical disequilibria arise; from these, energy can be gained by microbes to fix inorganic carbon into biomass. This microbial process is termed *chemosynthesis*. Wherever large fluxes of thermogenic methane are supplied to the seafloor, methane could also constitute a significant carbon source for chemosynthesis. At hydrothermal vents, chemosynthetic primary producers fuel large animal communities with standing crops as high as those of the most productive ecosystems on Earth. Many vent invertebrates and microbial communities on the seafloor display exceptionally fast growth and high production rates for organic biopolymers (Gaill et al. 1997, Taylor et al., 1999; Girguis and Childress, 2006).

Chemosynthetic primary production is now known from a wide range of submarine geotectonic settings, such as mid-ocean ridges, intraplate volcanoes, forearcs, backarc basins, submarine arc volcanoes, and ridge flanks. Additionally, hydrothermally derived dissolved and particulate material has the potential to sustain chemosynthetic carbon fixation in hydrothermal plumes as they disperse through the water column, tens or even hundreds of kilometres away from vent sites (Bach et al. 2006).

Even at sites remote from spreading axes and thermal vents, chemosynthesis is now recognized to play an important role wherever oxidized seawater comes into contact with cooling oceanic crust (Edwards et al., 2005; Santelli et al., 2008).

Despite its potential relevance to ocean-wide ecosystems and the ocean carbon cycle, the quantitative importance of hydrothermally driven carbon fixation and its biogeochemical implications has been largely overlooked. In addition to the potential importance of *chemosynthetic* primary production, recent studies have revealed that vent-derived compounds, such as organic iron complexes, could have residence times in the water column that are longer than originally predicted (Statham et al., 2005; Bennett et al., 2008) such that this vent-derived iron may even impact upon *photosynthetic* primary production in the upper ocean.

In the last decade, the widespread use of molecular techniques and the development of *in situ* and *in vivo* experimental approaches have provided important clues to the pathways involved in carbon fixation or nutrient export, improving our understanding, at the molecular level *and* at the micro-habitat scale, of the interactions between microbes and the chemical environment. Our challenge, now, is to integrate these discoveries at the systems level to provide a mechanistic basis for modelling hydrothermally driven primary production.

Proposed work and products

We propose a coordinated effort that will provide the framework to assess the contributions of submarine hydrothermal venting to the ocean carbon cycles and which will be documented through review papers in a special issue of a peer-review journal or a book. Specifically, we plan to: *i)* synthesize current knowledge on carbon cycling in the different components of hydrothermal systems and integrate these findings into conceptual models; *ii)* use these models to quantify hydrothermal primary production and assess the contribution of hydrothermal systems to the ocean carbon cycles; and *iii)* identify the key novel investigations needed to better constrain these models.

We will achieve this by bringing together key marine biologists, biogeochemists and modellers with a range of field, laboratory, experimental and theoretical expertise to ensure a thorough integration of the current state of the art that can be captured into robust conceptual models. There is no doubt that even this activity, in isolation, would already be enough to stimulate the development of a wealth of original international and interdisciplinary efforts. What we also expect to achieve in the proposed Working Group, however, is to use the resulting numerical models to obtain first-order quantification of the carbon flux through hydrothermal systems on the global-ocean scale. Finally, by testing the sensitivity of this model, we will identify key gaps in our current knowledge. From this knowledge base the WG will then be in a position to recommend which aspects of deep-sea hydrothermal ecosystems are most in need of concerted future studies to better constrain their global oceanic significance.

Timeline of the group's activities

The working group will meet three times over a four-year period. To ease travel and equilibrate costs for members (including associated members), meetings will be organised in Asia, Europe and the USA. We will also combine these meeting with international conferences of interest to the WG participants, such as the regular AGU, ALSO and EGU meetings held in North America & Europe.

At the first meeting we will finalize the agreed agenda and timeline for the WG activities as a whole and organise our discussions into multidisciplinary sub-groups dedicated to the seafloor, sub-seafloor and water column compartments of the hydrothermal system.

At the second meeting we will set up an outline and time schedule for the publication of a special issue or monograph on the role of deep sea hydrothermalism on global ocean carbon cycles. Candidate journals for this special issue include *Limnology and Oceanography*, *PLoS*, *Deep-Sea Research* and *Biogeosciences*.

The third meeting will identify and plan new interdisciplinary initiatives which would benefit from SCOR support for a large-scale international programme of deep-ocean research. Combined with the third meeting we will organise a workshop (seeking sponsorship from, among others, SCOR, InterRidge and national programs) on chemosynthetic primary productivity and mechanisms of CO_2-fixation. Such a meeting would allow many more scientists, including from developing countries *and* from a wider spectrum of the marine sciences to participate in, benefit from, and contribute to, our initiative.

Why a SCOR Working Group?

While international coordination already exists for both the multidisciplinary study of mid-ocean ridges as a whole (InterRidge), chemosynthetic ecosystems' biogeography and biodiversity (ChEss program, Census of Marine Life), and for some aspects of the deep-biosphere research (IODP), this is the first time that an integrative interdisciplinary effort has been focussed upon the impact of hydrothermalism on the global carbon cycle. We are convinced that a dedicated SCOR working group would provide the most efficient vehicle to achieve this goal, by providing an ideal context for cross-cutting discussions between scientists from different disciplines and research areas on this focussed issue.

Within SCOR, we will benefit from the complementary expertise of other SCOR groups and panels of experts dealing with the issues of carbon biogeochemistry, energy transfer in marine ecosystems and trace element cycling in the oceans. Favouring collaborations between scientists from largely separated communities, approval of this SCOR WG would help provide the basis for a new field of research at the interface between the mid-ocean ridge and open-ocean science domains. Including an established ocean carbon cycling modeller in our group is just one action we propose to help facilitate the development of this interaction. We do not expect to achieve full integration within the lifetime of the WG but to educate our own community on how to prepare to integrate more fully with other global-scale ocean programs.

In addition, much can be gained from our proposed integrative effort for the definition and coordination of future interdisciplinary projects. Simultaneously, newly discovered vent sites, with highly heterogeneous chemistries, provide natural laboratories in which to investigate modes of carbon fixation in a variety of environmental and/or biological settings (Takai et al. 2006). Given the inherent difficulties in gaining access to the deep seafloor, as well as the large facilities and state-of-the-art instrumentation required for the work envisaged (both in the deep-sea and in the laboratory), our community will need strong international leadership and collaboration. Focussing our efforts through the auspices of a SCOR working group presents the ideal opportunity to help this proceed in a timely fashion and bring our efforts to the wider global ocean science community's attention.

We are expecting that this integrative and coordination effort will be encouraged by national agencies and international organisations through complementary funding. Furthermore, an increased emphasis is put on integration and synthesis in the final phase of the US Ridge2000 NSF programme and efforts directed on interdisciplinary model conception and testing are explicitly recommended. It can therefore be expected that proposals related with the activity of this SCOR WG may benefit from NSF support.

Relevance to other SCOR activities

There are obvious links between our program and other SCOR programs. In terms of current activity we are relevant to, but different from, both InterRidge and the Census of Marine Life ChEss program. There are also clear links with the new GEOTRACES initiative, particularly in terms of understanding the export from hydrothermal systems of trace elements and isotopes that play key roles in global ocean – e.g., Fe as a bio-limiting micronutrient. As currently conceived, however, the scope and ambitions of GEOTRACES (in particular, a long section extending across the south Pacific from the East Pacific Rise) will need to focus upon ocean chemistry with little opportunity to expand the emphasis to include microbiology and *bio*geochemical cycling. On a much larger scale, where our group would differ from all of InterRidge, CoML and GEOTRACES is that we would focus on ocean-scale carbon cycling. From that perspective, our group represents a natural "dark energy" complement to past and present SCOR programs focussing on *photosynthetically* driven carbon cycling, primary productivity and ecosystem functioning, such as JGOFS and IMBER. We will keep InterRidge, ChEss, GEOTRACES, IMBER and other relevant programs informed of the group's activities.

Composition of the group

Only a few nations to date possess major oceanographic fleets and technologies suitable to access hydrothermal environments at great depths: the composition of the core membership of our proposed WG reflects this (N. America: 3; Europe: 4; Asia: 3). By contrast, our gender balance is much more even (Female: 5; Male: 5) and an effort will be made to associate, wherever possible, more scientists from developing countries which have recently joined the group of nations conducting ridge-research programmes.

<u>Full Members</u>

1. Nadine Le Bris (IFREMER, FR) (co-chair)
2. Chris R. German (WHOI, USA), (co-chair)
3. Wolfgang Bach (Uni. Bremen, Germany)
4. Loka Bharathi (National Institute of Oceanography, Goa, India)
5. Nicole Dubilier (Max Planck Institute-Marine microbiology, Bremen, Germany)
6. Katrina Edwards (U. South Cal., USA)
7. Peter Girguis (Harvard Univ., USA)
8. Xiqiu Han (2nd Institute of Oceanography, SOA, Hangzhou, China)
9. Louis Legendre (LOV-UPMC-Paris 6, Villefranche, France)
10. Ken Takai (JAMSTEC, Japan)

<u>Associate Members</u>

We identified here key scientists whose expertise is required for the WG, for whom funding will be seek from other sources. More associated members, particularly from emerging countries, will be proposed at the first working group meeting.

1. Françoise Gaill (CNRS, Paris, France)
2. Julie Huber (Marine Biology Laboratory, Woods Hole, USA)
3. Stefan Sievert (WHOI, USA)
4. Margaret K. Tivey (WHOI, USA)
5. Andreas Thurnherr (U. Columbia, USA)

References

Bach, W., K. E. Edwards, J. M. Hayes, J. A. Huber, S. M. Sievert, and M. L. Sogin. (2006). Energy in the Dark: Fuel for Life in the Deep Ocean and Beyond. Eos, Vol. 87, No. 7, 14

Bennett, S. A., E. P. Achterberg, D. P. Connelly, P. J. Statham, G. R. Fonesa, C. R. German (2008). The distribution and stabilisation of dissolved Fe in deep-sea hydrothermal plumes. *Earth and Planet. Sci. Lett.*

Gaill, F., B. Shillito, F. Ménard, G. Goffinet and J. J. Childress (1997). The rate and process of tube production by the deep sea hydrothermal vent tubeworm *Riftia pachyptila*. Mar. Ecol. Prog. Ser. 148: 135 - 143.

German, C. R. and K. L. Von Damm (2003). Hydrothermal Processes, in Treatise on Geochemistry, The Oceans and Marine Geochemistry, vol. 6, edited by H. Elderfield, Elsevier, Oxford.

Girguis, P. R., and J. J. Childress (2006). Metabolite uptake, stoichiometry and chemoautotrophic function of the hydrothermal vent tubeworm *Riftia pachyptila*: responses to environmental variations in substrate concentrations and temperature. J. Exp. Biol. 209, 3516-3528

C. M. Santelli, B. N. Orcutt, E. Banning, W. Bach, C. L. Moyer, M. L. Sogin, H. Staudigel and K. J. Edwards (2008). Abundance and diversity of microbial life in ocean crust. Nature 453, 653-656.

Statham, P.J., C.R.German, and D.P. Connelly (2005). Iron(II) distribution and oxidation kinetics in hydrothermal plumes at the Kairei and Edmond vent sites, Indian Ocean. *Earth and Planetary Science Letters*, 236, 588-596.

Takai, K., S. Nakagawa, A.-L. Reysenbach, and J. Hoek. (2006). Microbial ecology of mid-ocean ridges and back-arc basins. Pp. 185–214 in Interpretations among Physical, Chemical, Biological, and Geological Processes in Back-Arc Spreading Systems. D. Christie, C.R. Fisher, S.-M. Lee, and S. Givens, eds, American Geophysical Union, Washington, DC

Taylor, C. D., C. O. Wirsen, and F. Gaill. (1999). Rapid microbial production of filamentous sulfur mats at hydrothermal vents. Appl. Environ. Microbiol. 65:2253-2255.