SUNY Stony Brook CARIACO Annual Report for Period:12/2009 - 11/2010

Principal Investigators: Scranton, Mary I. and Taylor, Gordon

Title: Collaborative Research: The Cariaco Basin Oceanographic Time Series Program

Findings (2009-2010)

As a part of our expanding efforts to look at the long term time series data sets, we have been collaborating with scientists (Konovalov and Samodurov and their colleagues with CRDF funding) to create a physical model for the Cariaco Basin which includes both vertical diffusive mixing and the effects of intrusions of water from outside the basin. Ultimately this model will be expanded to include a parameterization of the chemistry of the basin as well. Samodurov and colleagues have noted that density trends between 1995 and 2007 in the basin below 150 m can be divided into two periods. From 1995 to mid-2002, densities tended to increase with time, consistent with intrusions of denser water from outside the basin. The time period 1997-2002 was the time period our geochemical data also suggest intrusions (based on maintenance of a relatively thick suboxic zone and deep interface between oxygen and sulfide).

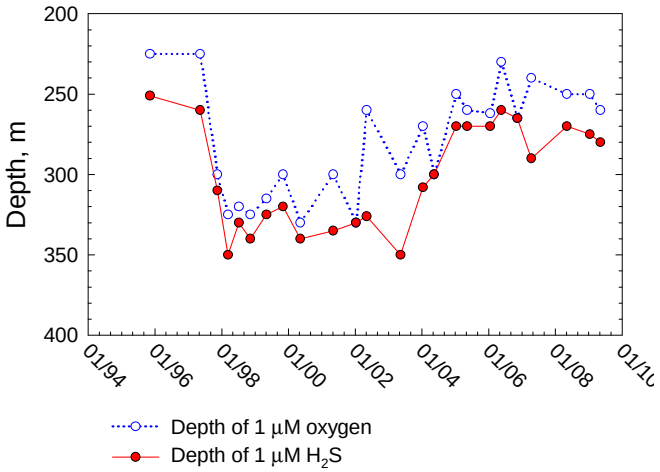

Figure 1: Depth of the last appearance of oxygen and first appearance of sulfide at the CARIACO station. Both the thickness of the suboxic zone and depth of the appearance of sulfide have changed with time.

In contrast beginning in mid- to late 2002, densities below the sill started to decrease with time. A trend of this sort is consistent with minimal intrusions (as warm salty water is mixing down) and with narrow suboxic zones and shallower interfaces. In the last year we have started to again see evidence for intrusions in the form of sulfide minima in the upper part of the anoxic zone, so we may start to see a widening of the suboxic zone in future years. We will be very interested to see the impact this process has on the microbiology and sulfur geochemistry.

Trend analyses have revealed that sea surface temperatures at the CARIACO station have increased significantly over last 14 years at a rate of 0.07°C y^{-1}. The mean depth of the 21°C isotherm has been increasing over the observation period, illustrating weakening upwelling. Inorganic nutrient inventories upwelled to photic zone are declining through time while increasing at depth. Annual phytoplankton productivity has declined over same period, resulting from weaker Trade Winds and less intense/sustained upwelling of nutrients. Time series data illustrate prokaryoplankton inventories are as dynamic as phytoplankton in the mixed layer, but are weakly correlated with [Chl *a*] and primary productivity. Comparing integrated prokaryoplankton biomasses among layers reveals that variance in the photic zone explains less than 18% of variance in deeper layers. Below sill depth (90-150 m), inventories of reduced chemical species produced by OM decomposition, such as NH_4^+, appear to be growing and shoaling over time. Within the redoxcline, both chemoautotrophic and heterotrophic production appear to be declining (Fig. 2). Chemoautotrophic production across the redoxcline appears responsive to the position

and thickness of the suboxic zone (Fig. 3). Prokaryoplankton abundances in the redoxcline and below are not well correlated with any measured variables. Spectral analyses reveal that variance in water density, $[O_2]$, $[PO_4^{3-}]$, and prokaryoplankton abundances in the redoxcline and below all share a ~110 day periodicity, suggesting a common forcing function. Microbial communities in waters deeper than 500 m appear dynamic, but are poorly described by our FISH surveys. Radiotracer studies with amino acids, acetate and glucose have revealed minimal assimilation and sulfate reduction is not empirically demonstrable. The dominant metabolism of deep communities is currently unknown and awaits further exploration.

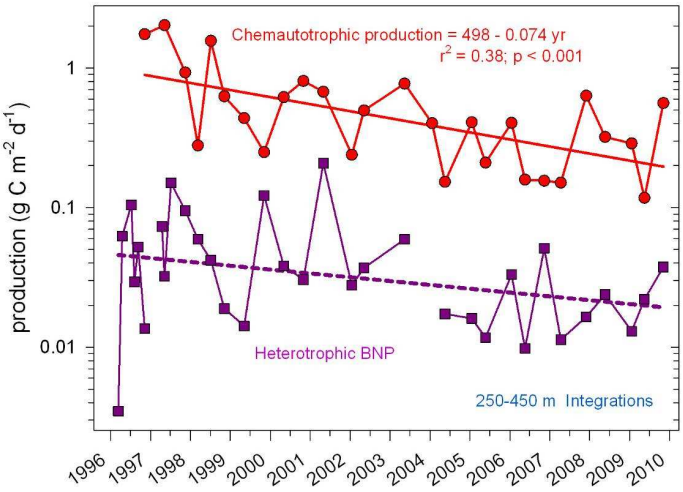

Figure 2. Long-term trends in semiannual observations of chemoautotrophic and heterotrophic production within the redoxcline.

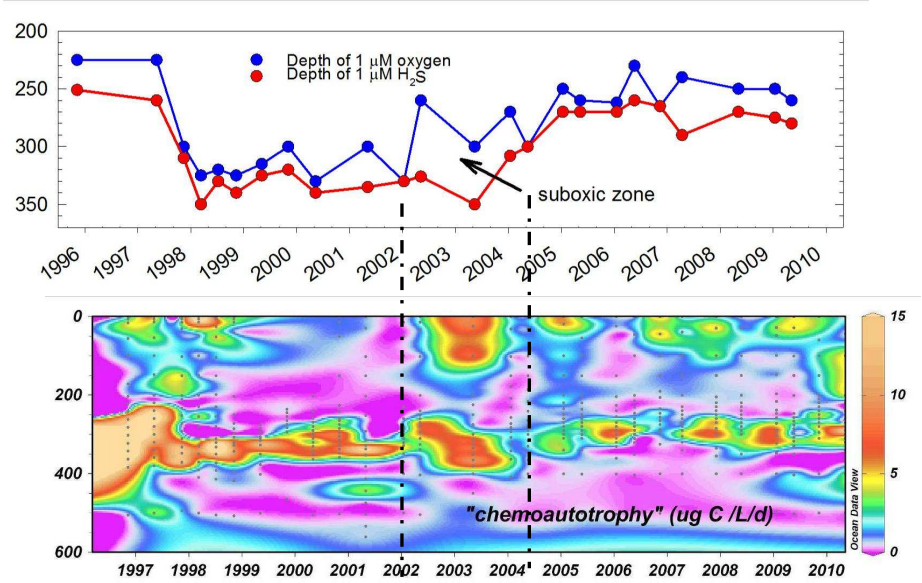

Figure 3. Comparison of position and extent of interface/suboxic zone with intensity and extent of chemoautotrophic production.

Findings (2008/2009)

During the 2008/2009 funding period, we completed two additional cruises to the time series site. Distributions of thiosulfate, sulfite and elemental sulfur were measured and profiles resembled those previously obtained. Additional samples for particulate sulfur minerals and sulfur isotope analyses were obtained in January. Using these data, and data from previous cruises, we found that sulfate ($\delta^{34}S_{SO4}$) and sulfide ($\delta^{34}S_{H2S}$) isotopic patterns were similar to trends observed in the Black Sea water column: $\delta^{34}S_{H2S}$ and $\delta^{34}S_{SO4}$ were constant in the deep anoxic water (varying within 0.6‰ for sulfide and 0.3‰ for sulfate), with the $\delta^{34}S_{H2S}$ roughly 54‰ depleted in ^{34}S relative to $\delta^{34}S_{SO4}$. Near the oxic-anoxic interface, however, the $\delta^{34}S_{H2S}$ value was ~3‰ heavier than that in the deep water, which we interpret to reflect sulfide oxidation and/or *in situ* sulfide production through rapid sulfate reduction. Observed $\delta^{34}S_{H2S}$ and $\delta^{33}S_{H2S}$ at the redoxcline in this environmental study did not provide unequivocal evidence to support the important role played by sulfur intermediate disproportionation, as suggested by previous studies. An increase in $\delta^{34}S_{SO4}$ values with depth indicates a reservoir effect associated with removal of ^{32}S-enriched sulfur during sulfide production through bacterial sulfate reduction (BSR) at deeper levels. Repeated observation of a minimum $\delta^{34}S_{SO4}$ values near the interface suggests 'readdition' of ^{32}S during sulfide oxidation at the chemocline. Our results which do not establish (or disprove) a role for sulfur intermediate disproportionation in the deep anoxic water column, may reflect fractionations during sulfate reduction that are larger than those observed to date in culture experiments. These data are reported in the manuscript submitted to Geochimica Cosmochimica Acta.

Our data also have allowed us to examine the source of particulate sulfur minerals using samples from previous cruises. Concentrations of particulate sulfur species, including acid volatile sulfur, greigite, pyrite and particulate elemental sulfur, were determined with high resolution near the oxic-anoxic interface. In Nov 2007 (non-upwelling season), acid volatile sulfur was low throughout the water column, with the highest concentration just at the depth where sulfide was first detected, and with a second peak at 500 m. Greigite, pyrite and particulate elemental sulfur also showed distinct maxima near the interface. In comparison, in May 2008 (upwelling season), acid volatile sulfur was not detected in the water column. Maxima of greigite, pyrite and particulate elemental sulfur again were observed near the interface. We also studied the iron sulfur mineral flux from the sediment trap materials at the Cariaco station. Reduced sulfur comprised 0.2-0.4 % of the total particulate flux in the anoxic water column, with a pyrite flux of 1.7-6.0 mg m^{-2} d^{-1}. Consistent with the iron sulfur mineral concentration profile, the sulfur isotopic composition of particulate sulfur found in traps was similar to that of dissolved sulfide near the chemocline. We concluded that pyrite was mainly formed at the oxic-anoxic interface where sulfur cycling imparts a distinct isotopic signature compared to dissolved sulfide in the deep anoxic water. This is consistent with our previous study of sulfur species and chemoautotrophic production, which suggested the reaction of sulfide with FeOOH is an important pathway for sulfide oxidation and sulfur intermediate formation near the interface. Pyrite and elemental sulfur distributions favor a pyrite formation pathway via the reaction of FeS with polysulfides or particulate elemental sulfur near the interface. Comparison of the thermodynamic prediction with the actual concentration profile of iron sulfur minerals, we argue that microbes may mediate this precipitation. This manuscript, almost ready for submission to Chemical Geology also contains a

preliminary sulfur budget for the anoxic water column of the Cariaco Basin is presented. This model suggests that the sulfide loss term is dominated by sulfide oxidation at the chemocline, while the major source of sulfide is the sulfide supply from the sediment to the water column, although in situ sulfide production can't be neglected. The imbalance between the sources and sinks of sulfide suggests that either a significant sulfide loss term is missing or our calculation based on 1-D diffusive flux of sulfide to the interface is an underestimate of sulfide loss near the chemocline.

We have also been collaborating with Sergey Konovalov and Anatoly Samodurov from MHI in the Ukraine to model the biogeochemistry of the Cariaco Basin in a manner similar to what has been done previously for the Black Sea. Sergey Konovalov is spending the month of October at Stony Brook University and we anticipate at least one manuscript to come from this visit.

We continue to explore bacterial community dynamics using genetic probes and fluorescent in situ hybridization (FISH) protocols to enumerate major phylotypes throughout the water column. Surprisingly, β-proteobacteria remain more common than previously reported by other authors for marine environments. This work was done through both the present project and our Microbial Observatory project in collaboration with Andrei Chistoserdov. Not only do we observe a high abundance of β-proteobacteria, we can selectively stimulate their prevalence in redoxcline communities by adding thiosulfate, elemental sulfur or sulfite to incubations. Similar enrichments are observed for ε–proteobacteria, Crenarcheota and Euryarcheota**.**

Our Venezuelan graduate student, Mariela Lopez-Gasca has made significant progress towards isolating chemoautotrophic prokaryotes that can disproportionate thiosulfate or elemental sulfur. Working with anoxic media in a glove box with a N_2/CO_2 atmosphere, she has isolated colonies that appear to be pure cultures or very simple consortia. To isolate S_2O_3 disproportionaters from environmental enrichments, she has also employed an anaerobic chemostat which should dilute out slower growing contaminants. She has phylotyped putative isolates to determine their relationship to known organisms. Within the chemostat, she and X. Li compared cell biomass production with sulfur transformations to determine C:S cell stoichiometry and optimal environmental conditions (results pending). During the 2008/2009 cruises, Lopez-Gasca performed MPN (most probable number) profiles for S_2O_3 and S^0 disproportionaters and oxidizers across the redoxcline. While MPN suggests that total abundances of these ecotypes only account for a few percent of the total community, they are highly enriched in the redoxcline compared to overlying and underlying depths.

We have analyzed temporal and vertical trends in microbial parameters and compared with nutrient and phytoplankton dynamics over the course of the entire CARIACO time series. Very few direct correlations are apparent among these variables which we attribute to inherent time lags not resolved by monthly sampling strategy. Bacterial cell size analyses (necessary for biomass estimates) revealed distinct size frequency distributions in oxic, redoxcline and anoxic layers, but no clear seasonal trends. In collaboration with Digna Rueda and Laura Lorenzoni (USF), we have performed Monte

Carlo simulations to determine the dominant frequencies of variation in all microbially-related variables. Of the 36 variables analyzed, 12 to 24 of them had relatively strong cycle modalities of 0.54, ~1.0 and 4.2 years. These analyses continue and will be the focus of a manuscript in preparation.

Activities (2009/2010)

In the current reporting period, we participated in two cruises (November 2009 and May 2010). We are almost finished with chemical analyses for these cruises, although processing is slightly detailed due to the need to train a new graduate student in the analytical techniques. Our time series of thiosulfate and sulfite is now 7 years long at the CARIACO site and the time series for elemental sulfur data is 5 years long. We also are continuing measurements of total zerovalent sulfur and now have several years of data for that parameter.

Publication of data collected in earlier years by Xiaona Li has continued and we now have one published paper and two accepted manuscripts from her dissertation. The new graduate student being supported on the chemical portion of the grant only began at the start of the summer and has not yet developed a thesis project, although we expect it will be related to the zero-valent sulfur and/or iron sulfide pools.

Two student "volunteers" participated in our cruises following the departure of Xiaona Li in summer 2009. These students (Shaily Rahman and Paula Rose) participated in field sampling for the chemical constituents.

Under CRDF funding, Sergey Konovalov visited Scranton in Stony Brook and Scranton visited Sergey Konovalov and Anatoly Samodurov at MHI in Sevastopol. This collaboration is supported under separate funding but is using data and knowledge generated with NSF funding to develop models for the physical processes involved with intrusions of oxygenated water. Konovalov presented some preliminary results at the Ocean Sciences meeting in Oregon and two papers are in preparation. He also gave a talk at Stony Brook during his visit here, and Scranton gave a talk at MHI in Sevastopol during her visit to the Ukraine.

In addition to our core bacterial productivity and biomass measurements, we continued to address community dynamics by collecting samples for FISH, MICRO-FISH, and TRFLP as well as performing stable isotopic probing (SIP) experiments during the Nov 2009 and May 2010 cruises. SIP experiments were designed to link functionality in the carbon, sulfur, and nitrogen cycles with taxonomic groups. As the focus of her Ph.D. dissertation, Agnieszka Podlaska, now has samples for these analyses from eight consecutive cruises. Their processing is ongoing.

Our Venezuelan M.S. student, Mariela Lopez-Gasca, completed her degree in December 2009. Her thesis is entitled, "Anaerobic Thiosulfate and Sulfur Oxidation/ Disproportionation Mediated by Autotrophic Prokaryotes in the Cariaco Basin's Rdoxcline". Thesis describes efforts to isolate sulfur-fueled chemoautotrophs by a variety of techniques, including a chemostat, and their characterization using molecular techniques.

Taylor spent much of the year performing statistical analyses of variability and long-term trends of physical, chemical and biological variables from the entire CARIACO program and drafting manuscripts on the results. He also participated in preparation of four

manuscripts derived from the MCB-sponsored Cariaco Protistan Microbial Observatory (Epstein, Edgcomb, Taylor, co-PIs), contributing contextual data from the CARIACO timeseries. Taylor was a co-organizer of the special session entitled "Oxygen Minimum Zones and Climate Change: Observations and Predictions" at the 2010 Ocean Sciences meeting in Portland, Oregon in which he reported on long-term trends observed at station CARIACO. He was also an invited speaker at the International Society for Microbial Ecology (ISME13) Meeting in Seattle, WA (08/27/10), where he presented CARIACO data in the "Systems Ecology of Expanding Marine Oxygen Minimum Zones" invited session.

Conference Presentations (2009-2010)

Scranton, M.I., Y. Astor, G.T. Taylor, X.N. Li (2010) Sulfur cycling at the CARIACO redox interface: conundrums and surprises. AGU/ASLO Ocean Sciences Meeting, Portland OR.

Konovalov, S., M.I. Scranton, A. Samodurov, V. Belokopytov, L. Ivanov, and Y. Astor (2010) Numerical studies of physical exchange and biogeochemical transformations in the oxic/anoxic Cariaco Basin. AGU/ASLO Ocean Sciences Meeting, Portland OR.

Taylor, G.T., M. Lopez-Gasca, A. Podlaska, X.N. Li, L. Lorenzoni, D. Rueda, F. Muller-Karger, R. Thunell, K. Fanning, R. Varela, Y. Astor, M.I. Scranton. (2010) Temporal variations in the biogeochemistry of the permanently anoxic Cariaco Basin. Ocean Sciences Mtg., Portland, OR 21-26 Feb 10

Podlaska, A., S. Wakeham, K. Fanning, G.T. Taylor (2010) Microbial community structure and chemoautotrophic activity in the oxygen minimum of the eastern tropical North Pacific. Ocean Sciences Mtg., Portland, OR 21-26 Feb 10

Daly, K.L., R.H. Byrne, C. Cass, G.R. DiTullio, M.M. Elliott, K. Fanning, C.N. Flagg, A. Maas, B. Olson, A. Podlaska, A.W. Remsen, B. Seibel, G.T. Taylor, S.G. Wakeham, K.F. Wishner (2010) Do OMZs alter the biological pump? Ocean Sciences Mtg., Portland, OR 21-26 Feb 10

Olson, B., K.L. Daly, A. Podlaska, G.T. Taylor (2010) Microzooplankton dynamics across oxygen gradients in the eastern tropical North Pacific. Ocean Sciences Mtg., Portland, OR 21-26 Feb 10

Taylor, G.T. (2010) Microbiological and geochemical dynamics in the permanently anoxic Cariaco Basin: Deconvoluting a fifteen year time series. ISME13, Intern'l. Soc. Microb. Ecol. Mtg., Seattle, WA 22-27 Aug 10.

Published Papers (2009-2010)

Taylor, G.T., R. Thunell, R. Varela, C. Benitez-Nelson and M.I. Scranton. Hydrolytic ectoenzyme activity associated with suspended and sinking organic particles within the

anoxic Cariaco Basin. 2009. Deep-Sea Research, 56, 1266-1283. doi:10.1016/j.dsr.2009.02.006

Muller-Karger, Frank. E., R. Varela, R. C. Thunell, M. I. Scranton, G. T. Taylor, Y. Astor, C. R. Benitez-Nelson, L. Lorenzoni, E. Tappa, M. A. Goñi, D. Rueda, and C. Hu. 2010. The CARIACO Oceanographic Time Series. *In:* Carbon and Nutrient Fluxes in Continental Margins: A Global Synthesis. JGOFS Continental Margins Task Team (CMTT) Editors: K.-K. Liu, L. Atkinson, R. Quinones, L. Talaue-McManus. Springer-Verlag New York. Pp 454-463.

Wakeham, S.G., C.. Turich, G.T. Taylor, A. Podlaska, M.I. Scranton, X.N. Li, R. Varela, Y. Astor. 2010. Methoxylated fatty acids in the water column of the Cariaco Basin: a chemoautotrophic source? Organic Geochemistry, 41, 498-512.

Accepted/In press

Li, X.N., W.P. Gilhooly, A.L. Zerkle, T.W. Lyons, J. Farquhar, J. Werne, R. Varela and M.I. Scranton (In revision Geochimica Cosmochimica Acta) Stable sulfur isotopes in the water column of the Cariaco Basin.

Li, X.N., G.A. Cutter, R.C. Thunell, E. Tappa, Y. Astor and M.I. Scranton (In revision Geochimica Cosmochimica Acta) Particulate sulfur species in the water column of the Cariaco Basin

In preparation

Samodurov A.S., Scranton M.I., Astor, Y., Ivanov L.I, Chukharev A.M., Belokopytov V.N., Globina L.V. (to be submitted to Deep Sea Research) Modeling vertical exchange of heat, salt, and other dissolved substances in the Cariaco Basin

Konovalov, S.K., V.N. Belokopytov, A.S. Samodurov, Y. Astor and M.I. Scranton (To be submitted to Deep-Sea Research) Numerical studies of the biogeochemical structure of the Cariaco Basin

Astor, Y., Lorenzoni, L and Scranton, M. (editors) Handbook of Methods for the Analysis of Oceanographic Parameters at the CARIACO Time-series Station.

Taylor, G.T., F. Muller-Karger, R.C. Thunell, R. Varela, M.I. Scranton, Y. Astor, L. Lorenzoni, D. Rueda, K. Fanning. Decadal decline in coastal production in the southern Caribbean Sea: Report from the CARIACO biogeochemical timeseries. Nature.

Taylor GT, Lin X, Iabichella-Armas, M, Podlaska A, Lopez Gasca M, Varela R, Astor Y, Muller-Karger F, Lorenzoni L, Rueda D, Thunell RC, Scranton MI. Temporal variability in microbial communities and activities within the physico-chemical context of the Cariaco Basin. Deep-Sea Res.

Activities (2008/2009)

During the 2008-2009 reporting period, we participated in two cruises (January 2009 and May 2009) to the CARIACO time series site. Chemical analyses from these two cruises are largely complete. We have continued our time series of thiosulfate, sulfite and elemental sulfur at the time series site, and now have 6 years of data for these variables (four years for elemental sulfur). We also collected samples for total zero-valent sulfur, for iron sulfur minerals and for stable isotopes in various sulfur pools in an effort to assess the processes controlling sulfur cycling in this system. Xiaona Li arranged low cost collaborations with the research groups of Greg Cutter (for iron sulfide mineral analysis) and Tim Lyons (for stable isotope analysis of different sulfur pools). She also collected large volume samples for total zero-valent sulfur.

During the reporting period Xiaona Li completed her PhD dissertation, having one published papers (on distributions of thiosulfate, sulfite and elemental sulfur measured during a number of cruises), two which are in the final stages of preparation for submission and one which will be submitted over the next year. Two of her papers are based on measurements she made while visiting Greg Cutter, Tim Lyons and Jim Farquahar. One paper addresses the major and minor sulfur isotope composition of the dissolved sulfide and sulfate pools while a second focuses on the abundance of iron sulfide minerals (greigite, pyrite) and their isotope composition. The final paper synthesizes a large amount of data on oxidant and reductant fluxes in comparison with interface chemoautotrophy rate and tries to reconcile the two with some simple models.

In addition to continued collection of time series data (bacterial numbers, BNP, chemoautotrophy rates, sulfur species measurements) we carried out two more sets of large volume enrichment experiments using stable isotope probing to attempt to identify the important microbial groups in the interface region. During both January 2009 and May 2009, we added ^{13}C-bicarbonate and ^{15}N-ammonium to label actively growing biomass. Our goal is to separate ^{13}C/^{15}N-DNA from ^{12}C/^{14}N-DNA by gradient ultracentrifugation and subject it to ribotyping (stable isotopic probing) to "identify" stimulated chemoautotrophic phylotypes. This work is part of the proposed dissertation of Agnieszka Podlaska. Replicate samples have been examined by Stuart Wakeham's lab for diagnostic lipid biomarkers. Wakeham has recently submitted a paper to Organic Geochemistry on some unusual methoxylated fatty acids which were strongly enriched in ^{13}C after incubation, suggesting they might be diagnostic of the organisms responsible for chemoautotrophy in the system.

Mariela Lopez Gasca, a student from Venezuela, also participated in both cruises and in analysis of time series samples. Her MS thesis is focused on enrichment and isolation of novel ecophysiotypes of chemoautotrophs by modifying "classical" cultivation techniques. She has employed the Most Probable Number (MPN) approach with selective media to assess vertical distributions of several sulfur- and methane-oxidizing groups. She is expected to graduate in Fall 2009.

Taylor's lab has focused on understanding how microbial communities relate to the geochemical distributions and to sites of chemoautotrophic and heterotrophic activity. This project is working closely with Microbial Observatory (MCB-0348442) and Microbial Interactions and Processes (MCB-0347811) programs led by Slava Epstein and Andrei Chistoserdov, respectively. Both these projects expired on 31 Aug 2009 and were not renewed because of the demise of the MO/MIP program at NSF. Nonetheless our collaborations continue. The Stony Brook group continues time series measurements of heterotrophic production, chemoautotrophic production and cell counts, and has extended studies using fluorescent in situ hybridization (FISH, CARD-FISH) and microautoradiography in addition to standard epifluorescence microscopy. We are exploring phylogenetic dynamics of community structure throughout the water column using terminal restriction fragment length polymorphism (T-RFLP) and FISH.

We also participated in a CARIACO project meeting at EDIMAR/Fundacion La Salle in May 2009 and in a PI meeting at Dartmouth MA in July 2009.

Conference Presentations

X. N. Li,, G. A. Cutter, R. C. Thunell, E. Tappa, Y. Astor, M. I. Scranton (2009) Particulate sulfur species in the water column of the Cariaco Basin. Chemical Oceanography Gordon Conference, Tilton NH.

S.G. Wakeham, C. Turich, A. Podlaska X. Li, Y. Astor, R. Varela, G.T. Taylor, M.I. Scranton (2009) Stable isotope probing of sulfur-oxidizing chemoautotrophic bacteria in the Cariaco Basin, Gordon Research Conference on Chemical Oceanography, Tilton School, 2-7 Aug 09

G.T. Taylor, A. Podlaska, M. Lopez Gasca, X.N. Li, M.I. Scranton (2009) Quest for the chemoautotrophs dominating the Cariaco redoxcline: a multi-faceted campaign, Gordon Research Conference on Applied and Environmental Microbiology, Mt. Holyoke, MA, 12-17 July 09

M.I. Scranton, G.T. Taylor, X.N. Li, A. Podlaska, M. Lopez-Gasca (2009) Biogeoquimica y microbiologia de la Fosa de Cariaco, U.S. and Venezuelan CARIACO PI Meeting, Margarita, VE, 16 May 09

G.T. Taylor, A. Podlaska, M. Lopez-Gasca, X.N. Li and MI Scranton (2009) Quest for the chemoautotrophs dominating the Cariaco redoxcline: a multifaceted campaign. ASLO Ocean Sciences meeting, Nice.

Turich, C., A. Podlaska, X.N. Li, Y. Astor, R. Varela, G. Taylor, M.I. Scranton, and S. Wakeham (2009) Stable isotope probing of sulfur-oxidizing chemoautotrophic bacteria in the Cariaco Basin. ASLO Ocean Sciences meeting, Nice.

Li, X.N., WP Gilhooly, AL Zerkle, TW Lyons, J. Farquhar, J. Werne, MI. Scranton (2008) Fractionation of sulfur isotopes in the Cariaco Basin. AGU fall meeting, San Francisco.

Scranton, MI, XN Li, M. Lopez-Gasca, A. Podlaska, Y. Astor, K. Fanning, L. Lorenzoni, GT Taylor (2008) Effects of non-steady state injection of oxygen into waters of the Cariaco Basin, Venezuela. AGU fall meeting, San Francisco.

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2008 Percy, D., X. Li, G.T. Taylor, Y. Astor, and M. I. Scranton. Controls on iron, manganese and intermediate oxidation state sulfur compounds in the Cariaco Basin. Marine Chemistry, 111, 47-62.

Lin X, MI Scranton, AY Chistoserdov, R Varela & GT Taylor. Spatiotemporal dynamics of bacterial populations in the anoxic Cariaco Basin. Limnol Oceanogr. 53(1): 37-51.

Thunell, R. C. Benitez-Nelson, F. Muller-Karger, L. Lorenzoni, K. Fanning, M. Scranton, R. Varela and Y. Astor. The Si Cycle in the Cariaco Basin, Venezuela: Seasonal Variability in Silicate Availability and the Si:C:N Composition of Sinking Particles. Global Biochemical Cycles, 22, GB4001, doi:10.1029/2007GB003096.

Li, X.N., G.T. Taylor, Y. Astor and M.I. Scranton (2008) Relationship of sulfur speciation to hydrographic conditions and chemoautotrophic production in the Cariaco Basin. Marine Chemistry, 112, 53-64

2009 Taylor, G.T., R. Thunell, R. Varela, C. Benitez-Nelson and M.I. Scranton. Hydrolytic ectoenzyme activity associated with suspended and sinking organic particles within the anoxic Cariaco Basin. Deep-Sea Research, 56, 1266-1283. doi:10.1016/j.dsr.2009.02.006

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Muller-Karger, Frank. E., R. Varela, R. C. Thunell, M. I. Scranton, G. T. Taylor, Y. Astor, C. R. Benitez-Nelson, L. Lorenzoni, E. Tappa, M. A. Goñi, D. Rueda, and C. Hu. The CARIACO Oceanographic Time Series. *In:* Carbon and Nutrient Fluxes in Continental Margins: A Global Synthesis. JGOFS Continental Margins Task Team (CMTT) Editors: K.-K. Liu, L. Atkinson, R. Quinones, L. Talaue-McManus. Springer-Verlag New York.

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Li, X.N., W.P. Gilhooly, A.L. Zerkle, T.W. Lyons, J. Farquhar, J. Werne, R. Varela and M.I. Scranton (Submitted to Geochimica Cosmochimica Acta) Stable sulfur isotopes in the water column of the Cariaco Basin.

Wakeham, S.G., C.. Turich, G.T. Taylor, A. Podlaska, M.I. Scranton, X.N. Li, R. Varela, Y. Astor (submitted to Organic Geochemistry). Methoxylated fatty acids in the water column of the Cariaco Basin: a Chemoautotrophic Source?

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Li, X.N., G.A. Cutter, R.C. Thunell, E. Tappa, Y. Astor and M.I. Scranton (to be submitted to Chemical Geology) Particulate sulfur species in the water column of the Cariaco Basin

Rodriguez-Mora, M.J., M.I. Scranton, G.T. Taylor and A.Y. Chistoserdov. (to be submitted to FEMS Microbiology Ecology) The bacterial community composition in a large truly marine anoxic basin: a time-series survey.

Rodriguez-Mora, M.J., M.I. Scranton, G.T. Taylor and A.Y. Chistoserdov. (to be submitted to PLoS One Biology) Microbial diversity in the redox and anoxic zones of the Cariaco Basin assessed by massive parallel tag sequencing.

Taylor GT, Iabichella-Armas, M, Lin X, Podlaska A, Lopez Gasca M, Varela R, Astor Y, Muller-Karger F, Lorenzoni L, Rueda D, Thunell RC, Scranton MI. Temporal variability in microbial communities and activities within the physico-chemical context of the Cariaco Basin. Deep-Sea Res.