ANNUAL REPORT ON GEOTRACES ACTIVITIES IN the U.S.

April 1st, 2019 to March 31th, 2020

U.S. GEOTRACES Meetings

The U.S. GEOTRACES Scientific Steering Committee (SSC) met on 20-21 June 2019 in Alexandria, VA, thereby facilitating interaction with the US National Science Foundation (NSF) program officers who oversee support of U.S. GEOTRACES activities. Cruise leaders from GA03, GP16, GN01, as well as GP15 attended the SSC meeting. The SSC reviewed the publication of results from completed cruises and discussed the experiences of GP15 and the lessons learned from the expedition.

A large part of the meeting was devoted to planning the next U.S. GEOTRACES section (GP17). The SSC reviewed preliminary calculations of the duration of an expedition that would encompass the entire section plan, including sections from Tahiti to Antarctica, work in the Amundsen Sea, and a section from the Amundsen Sea to Chile. The SSC concluded that the duration required to complete all of the objectives on a single expedition was prohibitively long and approved plans for a two-ship operation. Additional details are provided below.

The SSC also discussed plans for U.S. GEOTRACES operations beyond GP17. Two activities have been proposed. As described in last year's annual report, Alan Shiller is leading the planning for a field program in the Gulf of Mexico. During the SSC meeting, Kathy Barbeau presented a case for the US to work off the coast of California, roughly following the proposed track of GP05. U.S. GEOTRACES cannot mount both of these expeditions concurrently without partners. Once the GP17 plans are finalized, U.S. GEOTRACES will look for partners for each of the expeditions cited above in hopes that both can be undertaken.

U.S. GEOTRACES sponsored an Arctic Synthesis workshop on 16 February 2020 in San Diego, California. This workshop was held the day before the Ocean Sciences Meeting to take advantage of the fact that many GEOTRACES investigators were attending. More than 40 participants gathered for the workshop. Most of these were from U.S. institutions but representatives from the Canadian and European Arctic expeditions attended as well. The principal goal of this workshop was to form sub-groups to organize the synthesis of findings related to topics that encompass the work of multiple investigators and multiple expeditions.

The largest workshop sponsored by U.S. GEOTRACES in the past year was the planning workshop for GP17 on 6-8 May of 2020; this was held remotely due to the travel and shelter in place restrictions imposed by the coronavirus. Altogether approximately 100 participants attended the cruise-planning workshop which served to inform prospective investigators of the scientific goals and of the anticipated logistics of a two-ship operation. During the first day, representatives from the US NSF described the current situation associated with the pandemic and the accompanying uncertainty in both funding and ship scheduling. In addition, eight plenary presentations described the principal oceanographic features of the region that provide motivation for a GEOTRACES study there. During the second day, approximately 48 interested investigators gave five-minute advocacy talks in which each speaker presented a rationale for including specific chemical parameters in the study while also indicating the logistical needs for each type of study (e.g., volume of water and number of berths required). The last day was devoted to breakout sessions to assess the sampling needs for the various shipboard sampling systems as well as to coordinate common interests related to each of the major scientific themes that are part of GP17. Each of the cruise leaders took part in leading discussion, hosting break-out rooms, and moderating the question-and-answer periods in plenary. For a remote meeting of its size, it was remarkably interactive and effective. Many participants remarked on the success of the meeting, and the Zoom recordings comprise a valuable record of plenary talks, advocacy talks, and discussions for future proposals.

In 2020 the U.S. GEOTRACES SSC attended the planning workshop for the GP17 expedition rather than having a stand-alone meeting at NSF as was done in previous years. At the request of NSF program officers, and following the precedent started with GP15, the SSC held a virtual meeting on 12 May to set priorities for essential parameters that must be measured on GP17, in addition to the key parameters listed in Table 2 of the GEOTRACES science plan, in order to achieve the scientific objectives of the section. The prioritized list of essential parameters is still being finalized at the time that this report is being written.

Cruise-related Activities (in chronological order of the expeditions)

GA03

The primary studies describing original datasets from GA03 have largely been published and reported on, by now. Therefore, this first section undertaken by US GEOTRACES now serves primarily as a reference of comparison for subsequent studies, e.g., Shelley et al. (2018), cited in the publications list at the end of this report. In addition, modeling activities continue to exploit and help interpret GA03 results, e.g., Pham and Ito (2019) and Lerner et al. (2020), which modeled iron and protactinium and thorium respectively.

GP16 Synthesis

GP16 publications continue to come out with original results from the expedition. In addition, we are starting to see synthesis papers that combine multiple datasets to gain insights into the processes of trace element and isotope (TEI) supply and removal as well as the rates of those processes. For example, Ohnemus et al. (2019) examined the associations of multiple TEIs to infer processes responsible for their removal from the water column. In a paper described in last year's report, Black et al. (2018) combined ^{234}Th data with inventories of trace metals to estimate their residence times along the GP16 transect. More recently, Kadko et al. (2020a) combined ^{7}Be with trace metal inventories to also estimate their residence times. As pointed by Kadko et al., the two approaches provide consistent estimates of residence times in the western portion of the section but differ by a large amount near the coast of Peru. Kadko et al. conclude that the rate of supply of trace elements by upwelling was underestimated by Black et al. This comparison illustrates one of the strengths of GEOTRACES, and the philosophical underpinning of the program, in that measuring a broad suite of TEIs along the same section allows important properties such as residence times to be estimated by multiple independent approaches. Where the results of these approaches agree we can have confidence in the findings. However, where inconsistent results are obtained, we can conclude that processes affecting the distributions of TEIs are missing from our conceptual models.

GN01

Most of the papers produced by U.S. GEOTRACES investigators during the past year (see appended list) incorporate results from the Arctic expedition. Although the workshop designed to launch synthesis activities was not held until February 2020 (see above), some synthesis activities were well under way before this workshop. For example, Charette et al. (2020) described novel features of the Transpolar Drift (TPD), a layer of surface water approximately 50 m thick that flows from the Siberian shelf across the North Pole to exit the Arctic Ocean through the Fram Strait. Elevated concentrations of iron and manganese in the TPD were observed during the GEOTRACES International Polar Year expedition in 2007. Charette et al. expand on those early observations to show that a broad suite of trace elements is enriched in TPD waters relative to regions outside the TPD. Furthermore, they show that concentrations of many of these trace elements are positively correlated with the fraction of meteoric water, reflecting input from Siberian rivers. They also found a positive correlation with the concentration of dissolved organic carbon, much of which is derived from terrestrial ecosystems and delivered to the Arctic Ocean by large Siberian rivers. These findings will stimulate future studies to examine the extent to which terrestrial organic matter acts as a ligand to inhibit the scavenging and removal of these trace elements from the upper ocean.

<u>GP15</u>

The sampling expedition for GP15 was completed in November 2018. Results are beginning to be released, with two publications to date (see below) and nearly 20 presentations at the 2020 Ocean Sciences meeting. In addition, five investigators have indicated that they plan to submit data from GP15 for IDP2021. While some labs have completed their analyses of GP15 samples, at other labs the analyses were still underway in 2020 when most university campuses in the US were closed due to the COVID-19 pandemic. This closure is expected to delay the interpretation and publication of GP15 results. Also reflecting this delay, the GP15 data workshop planned for late July 2020 has now been deferred until at least early 2021.

Despite this setback, some very interesting results have appeared in the first papers to come out of this section. For example, Kadko et al. (2020b) used ^{7}Be results from aerosols and from the water column to show that the overall deposition velocity (i.e., wet plus dry deposition) of aerosols is related to the annual average rainfall as estimated from satellite products. This finding will enable aerosol concentrations of TEIs to be converted to deposition fluxes using satellite rainfall products even in cases where ^{7}Be was not measured. In a concurrent paper, Jenkins et al. (2020) used ^{3}He to trace the plume of hydrothermal iron emanating from the Lo'ihi seamount located at a depth of about 1000 m near Hawaii. Modeling results described in this paper suggest that the iron could upwell within the productive eastern boundary system off the west coast of the United States and Mexico. Future studies of the far-field distribution of this plume will test whether or not these model predictions are accurate.

In addition to these published studies, a number of promising datasets were presented at the Ocean Sciences meeting in 2020 and shared here with the authors' permission. One dataset that we'd like to highlight is the dissolved cobalt data collected at sea by graduate student Rebecca Chmiel from the Saito lab at WHOI. The results illustrate a number of inputs and internal processes critical to dissolved cobalt distributions (Figure 1). The dissolved cobalt concentration shows maxima in the Alaskan shelf in the far north of the section, as well as in the intermediate waters of the North Pacific. Local maxima are also observed in the distal ends of the Eastern Tropical North Pacific (10 N) and Eastern Tropical South Pacific (5 S), as well as in the Lo'ihi plume near 20 N. High dissolved cobalt concentrations are also observed in deeper waters, potentially coinciding with regions of high export production (e.g., 40 N). These observations show the influence of uptake and remineralization, as well as inputs from hydrothermal activity at Lo'ihi, redox processes in oxygen minimum zones, and removal by scavenging in the deep sea.

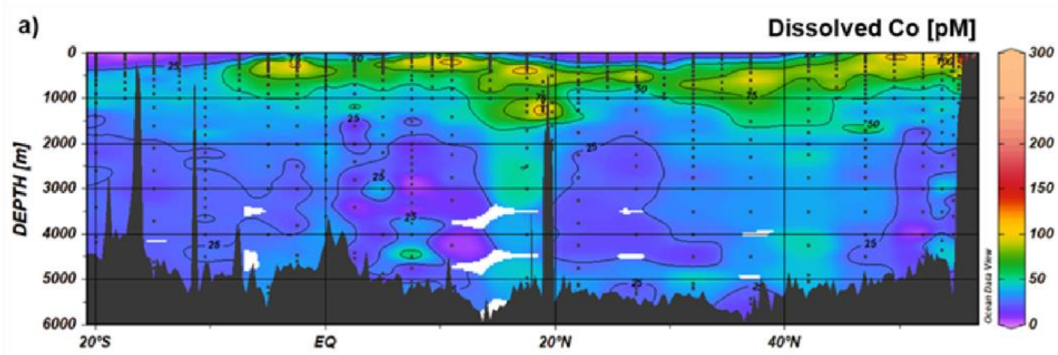

Figure 1. *Dissolved cobalt concentration (pM) on the GP15 Pacific Meridional transect. Contributed by Rebecca Chmiel and Mak Saito.*

The second highlight of work in progress from GP15 derives from Jessica Fitzsimmon's lab at Texas A&M University. Contrasting with the behaviors of cobalt, shown above, distributions of cadmium (Figure 2) show typical nutrient-like behavior, mirroring that of phosphate (Figure 3) and apparent oxygen utilization. Cadmium shows high concentrations in old Pacific Deep Water, where nutrient-like elements show strong remineralization signals. In contrast, manganese inputs appear to be dominated by shelf inputs, with small hydrothermal signals, while dissolved iron tracks both shelf and slope inputs and strong hydrothermal inputs from Lo'ihi seamount (not shown). The different behaviors of the trace elements measured on this section will help disentangle the influence of the very inputs and loss terms that GEOTRACES has set out to investigate.

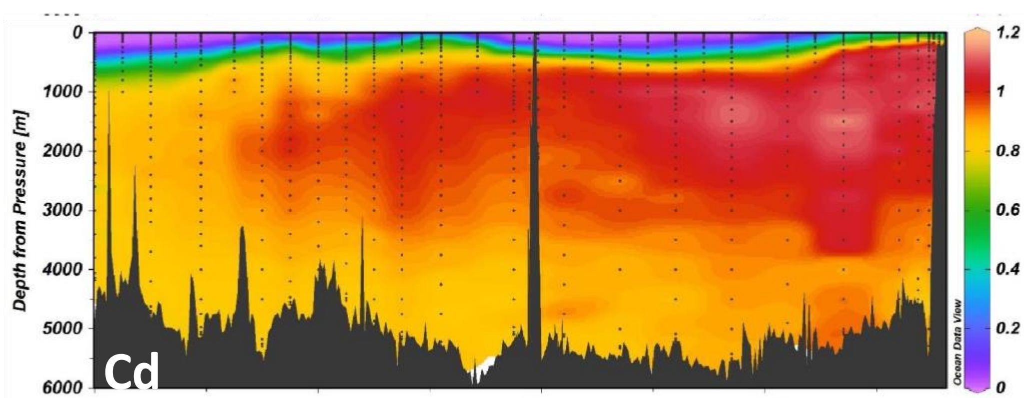

Figure 2. *Dissolved cadmium concentration (pM) on the GP15 Pacific Meridional transect. Contributed by Jessica Fitzsimmons.*

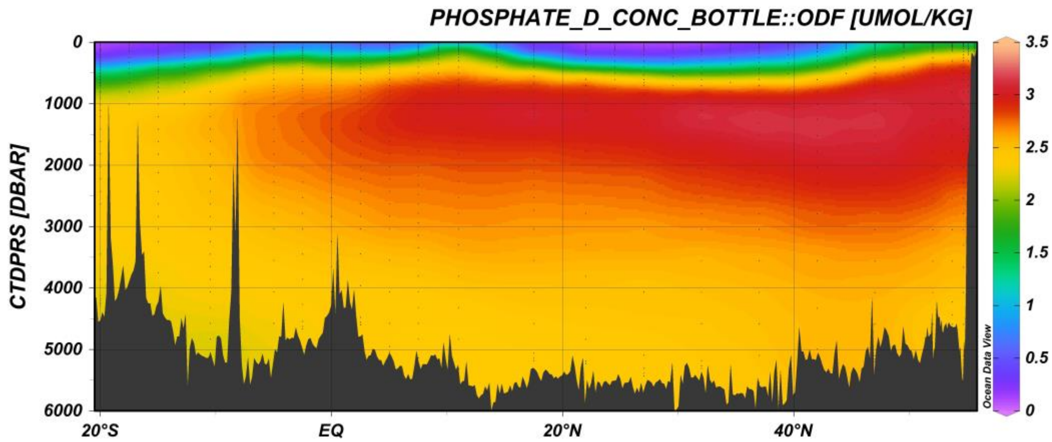

Figure 3. *Phosphate concentration (umol/kg) on the GP15 Pacific Meridional transect. Data from Scripps Ocean Data Facility (ODF).*

GP17

As noted above, US GEOTRACES proposes to undertake GP17 as a two-ship operation. One ship will continue the Pacific meridional section started as GP15 and extend it southward from Tahiti to Antarctica (Figure 4). After reaching 67°S the ship will transit eastward completing crossover stations with the second ship and then angle northwest toward the southern tip of South America. The second ship will transit from Punta Arenas, Chile, into the Amundsen Sea where it will undertake closely spaced sampling to assess the supply of trace elements from melting ice shelves and from benthic sources. Much of the operation of the second ship will occur in ice-covered waters so the RVIB Nathanial B. Palmer has been requested.

Two separate proposals, one for each ship, were submitted to the US NSF for the 15 February 2020 deadline. If all goes according to schedule, funding decisions on the two proposals should be conveyed to the principal investigators sometime in June. Principal investigators for the voyage from Tahiti to Antarctica and then to Chile are Ben Twining (chief scientist), Jessica Fitzsimmons, and Greg Cutter. Principal investigators for the cruise into the Amundsen Sea are Pete Sedwick (chief scientist), Phoebe Lam, and Rob Sherrell. The tentative cruise track and station locations for the two cruises are shown in Figure 4. The transits to and from the Amundsen Sea on the icebreaker are not shown in this map.

Although there is a great deal of uncertainty in the schedules of the US research fleet due to delays caused by the coronavirus, we have been advised by NSF to continue with our original timeline until told differently. That schedule calls for back-to-back cruises with a global class research vessel leaving Tahiti in November 2021 and arriving in Punta Arenas in January 2022. Gear would be immediately transferred to the Palmer and the second cruise would take place from January to March 2022.

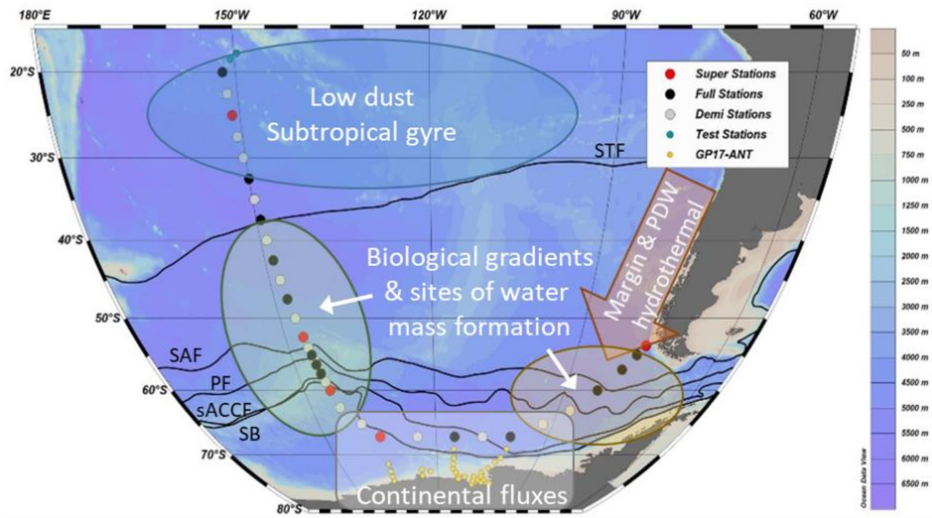

Figure 4. Station locations for the proposed two-ship operation constituting GEOTRACES section GP17. The legend shows the different types of stations to be sampled from the global class research vessel. In yellow near the coast of Antarctica are the proposed stations for the icebreaker. The principal oceanographic features targeted for study are also indicated.

New Funding

No new funding for US GEOTRACES was awarded during the past year. As noted above, two proposals are pending at the US NSF, one for the management of each of the two cruises contributing to GP17. If there are no delays in the review process, then we hope to hear the funding decisions by the end of June 2020. Proposals to support the work of individual investigators would then be submitted to the US NSF for the 15 August 2020 proposal submission deadline.

Synthesis

Investigators from the US are contributing to the growing effort to synthesize GEOTRACES data. Synthesis publications led by US investigators are highlighted above under specific sections (Kadko et al., 2020a, b; Charette et al., 2020).

Anderson (2020) published an overview of the GEOTRACES program, including select scientific discoveries.

Papers are proceeding from the synthesis workshop (https://geotracespages.sciencesconf.org) on geochemical tracers used as proxies in paleoceanography, co-sponsored by GEOTRACES and PAGES (Past Global Changes program), that was held in Aix-Marseille France (3-5 December 2018). US investigator Kassandra Costa led the first publication. Her paper covers several aspects of the geochemical proxy ^{230}Th: it reviews the principles underlying its use to quantify accumulation rates of marine sediments, provides a compilation of historical results obtained using this method, identifies challenges to the method, and highlights strategies that exploit GEOTRACES data to address those challenges (Costa et al., 2020). Additional papers initiated at this workshop are currently at various stages of production.

Outreach and Capacity Building Activities

GN01

The U.S. GEOTRACES Float Your Boat Outreach Project.

The following text was adapted from a newsletter published by David Kadko, chief scientist of the GN01 expedition, in the *Arctic Research Consortium of the United States* (ARCUS), Volume 23, December 2019:
https://www.arcus.org/witness-the-arctic/2019/2/article/30146?utm_source=wtav23i2&utm_medium=email&utm_campaign=wta
Further details, pictures, and maps describing this novel project can be found there.

During the 2015 US Arctic GEOTRACES cruise, small wooden boats that had been decorated by school groups and scout troops from around the country were packed into cardboard boxes and deployed on ice floes between 87.5° N and 80° N on the 150° W meridian, each with a small satellite buoy (deployed by the University of Washington Applied Physics Laboratory to study ice movement). The iridium satellite-linked buoys provided an opportunistic chance for high resolution, real-time tracking of the boats for about a year and a half. After drifting with the Arctic ice, it was hoped that the boats would eventually be freed from its grasp, the cardboard boxes would disintegrate, and the small boats would float to a distant shore to be discovered and reported. Indeed, four groups of boats ran aground in northern Canada, while two groups, deployed near the North Pole, were entrained in the Trans Polar drift and traveled through Fram Strait into the East Greenland Current.

In October, 2018, three years after deployment, one of the small wooden boats was found by a gentleman in Iceland, Bolli Thor. He wrote: "These are the coordinates 63.9622285, 22.734055 where I found one of your little wooden boats, near the small town called Sanderõi in Iceland where I live. I found it at my favorite spot, where I usually walk with my dog called Tyra." Later, on April 16, 2019, another boat was found by Guðmundur Örn Benediktsson who wrote: "Greetings from Kópasker, Iceland. Hello! One of your floatboats was found at Harðbaksvík, NE Iceland, April the 16th 2019; co-ordinates very close to
66.5150 N and 15.994040 W."

GP15

Outreach stemming from GEOTRACES GP15 has continued since the cruise was completed in fall of 2018. Online and in social media, we have continued to have a presence. In the 2019-2020 period, visits to our website www.geotraces-gp15.com have continued (from 2018 levels of 15,000 views) with nearly 5,000 views in 2019 and 2020 to date. Jim Bishop's @OC_Explorer Twitter feed discusses the oceanographic context of the cruise track and the history of the *R/V Roger Revelle* for a wide audience.

Research projects have also continued to involve and support graduate and undergraduate student researchers in most funded laboratories, including a student exchange between Humboldt State University and Texas A&M. Over 20 presentations were made at the 2020

Ocean Sciences Meeting about GP15, including at least 10 undergraduate and graduate student talks and posters. Papers resulting from this cruise (Kadko et al. 2020 and Jenkins et al 2020) are included in the publication list at the end of this report.

The researchers involved with GP15 have also developed course materials for wide audiences, with college courses at UC Berkeley (340 students) and UC Santa Cruz (200 students) reaching large numbers of general education students. Outreach has also reached K12 elementary education, with graduate student Lydia Babcock-Adams (MIT/WHOI) running a workshop for 7th and 8th graders where she talked about oceanography and showed the students how we collect seawater on a ship. Afterwards, the students did a hands-on activity where they processed the seawater as on GP15, where water was filtered using an SPE column in line to extract the organic compounds. A UCSC undergraduate minoring in STEM education (Sophie Rojas) is working with Phoebe Lam, the UCSC CalTeach program (https://calteach.ucsc.edu/), and a focus group of local middle and high school science teachers to develop a high school curriculum on the ocean carbon cycle based in part on results and experiences from the GP15 cruise. The goal is to have 1-2 teachers test the curriculum in the coming school year, and a wider deployment later.

Finally, in the arts, Joann Mullins' art series 'Salute to Science' was recently released (https://www.uconnbfa2020.com/gallery/joan-mullins), in which her paintings featured scenes from shipboard laboratories, including those from the GP15 cruise. In addition, graduate student Colette Kelly (student in the Casciotti lab and ODF supertech on GP15), together with a group of PhD students at Stanford, led a workshop on communicating science through dance. The goal of the workshop was to develop short vignettes that aimed to crystallize and highlight for the viewer important concepts more thoroughly understood through movement. To explain aspects of the nitrogen cycle and nitrogen isotopes (including questions investigated on GP15), Colette generated a series of short dances that engaged with isotopes, nitrogen cycling, and mass spectrometry, which were shared on social media. These vignettes are currently being further developed (via Zoom) into a longer work, to be performed as part of a full evening of science-dance in winter, 2021. An example of these nitrogen dances can be found here: https://www.youtube.com/watch?v=yxWHIVvgUik&feature=youtu.be

Publications (GEOTRACES, GEOTRACES Compliant and GEOTRACES-related)

During the past year US GEOTRACES investigators published a total of 47 peer-reviewed journal articles, including papers published by lead authors in other nations for which U.S. GEOTRACES investigators serve as co-authors.

In addition, 4 PhD dissertations were completed.

- Agather, A. M., K. L. Bowman, C. H. Lamborg, and C. R. Hammerschmidt (2019), Distribution of mercury species in the Western Arctic Ocean (U.S. GEOTRACES GN01), Marine Chemistry, 216, 103686, doi:https://doi.org/10.1016/j.marchem.2019.103686.
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