

# TWENTY YEARS OF GEOTRACES

## AN INTERNATIONAL STUDY OF THE MARINE BIOGEOCHEMICAL CYCLES OF TRACE ELEMENTS AND ISOTOPES

By Tim M. Conway, Jessica N. Fitzsimmons, Rob Middag, Taryn L. Noble, and H el ene Planquette

### INTRODUCTION

This special issue of *Oceanography* celebrates the transformational findings of the international GEOTRACES program in chemical oceanography, 20 years after drafting of the GEOTRACES Science Plan in 2004 (GEOTRACES Planning Group, 2006). With the section cruise phase of the program ending soon, and a planned pivot toward smaller-scale process studies, this is an opportune time to look back at the achievements of GEOTRACES during the last two decades and to highlight some of the advances in our understanding of the processes that determine the oceanic distributions of trace elements and isotopes (TEIs).

### GEOTRACES

GEOTRACES is a cooperative international effort comprising scientists from 35 countries, supported by national funding agencies, and guided by international steering committees. Since 2008, the program has carried out oceanographic, World Ocean Circulation Experiment (WOCE)-style “section” cruises throughout all the ocean basins. Rigorous intercalibration efforts stand at the foundation of GEOTRACES to ensure that basin-scale analyses made by individual nations can be compared without question. This has been achieved

primarily by occupation of “crossover” stations between cruises hosted by different countries—perhaps the most evocative was a meeting of German and US GEOTRACES Arctic cruises at the North Pole in 2015. Moreover, the drive for publicly available synthesized datasets has resulted in the production of an online electronic atlas (<https://www.egeotraces.org/>) and the release of three intermediate data products to date, with a fourth expected in 2025. These efforts have led to a sea change in the quantity of high-quality TEI data available for the ocean, coupled with many advances in our understanding of the biogeochemical processes that determine these distributions (Anderson et al., 2014).

### ARTICLES IN THE SPECIAL ISSUE

This special issue begins with reflections from junior and senior scientists on the GEOTRACES program, the benefit of a multi-tracer approach for answering biogeochemical questions, and what life is like aboard a GEOTRACES section cruise (Anderson, Halbeisen, and Jeandel). A key success of GEOTRACES lies in the rigorous intercalibration of all data incorporated into its products, a process overseen by the Standards and Intercalibration

Committee. This achievement is based on crucial cooperation among scientists who openly shared protocols, as discussed in Aguilar-Islas et al., and allows for both a holistic view of TEI cycling within a basin (e.g., Arctic Ocean; Jensen and Colombo) and synthesized intermediate data products that are valuable for research, education, and outreach efforts (as outlined by Schlitzer and Mieruch-Schn ulle). In addition, from an education and outreach perspective, the GEOTRACES program office has produced a series of short educational videos, which are highlighted by Masferrer Dodas et al.

Several articles in this issue focus on “key parameters,” tracers that are deemed essential to the GEOTRACES program. For example, Anderson and Conway et al. both focus on dissolved iron and how GEOTRACES has elegantly demonstrated the utility of a multi-tracer approach and the unexpected and persistent nature of iron from deep boundary sources such as marine sediments and hydrothermal venting. Fitzsimmons and Steffen take a deeper dive into how GEOTRACES research on hydrothermal plumes have transformed our understanding of which TEIs are supplied or consumed by hydrothermal systems before influencing the wider

ocean. **Hayes** provides an overview of the unique value of the thorium radio-nuclides as timekeepers for rates in the ocean and how they aid understanding of manifold biogeochemical processes, while **Casciotti et al.** describe recent advances in our understanding of the marine nitrogen cycle that have come from GEOTRACES and other efforts. **Rafter** then looks at how linking together elements such as iron and nitrogen can enhance insights into oceanic nutrient cycling.

The proliferation of GEOTRACES datasets has sparked renewed appreciation for the role of physical circulation in influencing global TEI distributions. The paper by **de Souza and Morrison** takes a close look at our increasing understanding of the role of the Southern Ocean “hub” in driving global nutrient and TEI distributions. However, it is not just knowledge of oceanic “dissolved” TEIs and circulation that are needed to understand marine biogeochemical cycles; GEOTRACES has also provided numerous advances in our knowledge of elemental speciation and organic complexation, marine particles, and aerosols as featured by several articles in this issue (**Whitby et al.**, **Twining**, and **Buck et al.**, respectively). **Tagliabue and Weber** provide an overview of how a range of different ocean biogeochemical modeling approaches have been stimulated by—and become invaluable in the interpretation of—GEOTRACES datasets. Lastly, we look to the future with **Saito et al.** describing the nascent BioGeoSCAPES program, which aims to build on advances from programs such as GEOTRACES and stimulate a research program designed to enhance understanding of the linkages between microbes, climate change, and biogeochemical cycles. We eagerly anticipate the development of this new program and the continuing discoveries to come from GEOTRACES.

## REFERENCES

- Aguilar-Isles, A., H. Planquette, M.C. Lohan, W. Geibert, and G. Cutter. 2024. Intercalibration: A cornerstone of the success of the GEOTRACES program. *Oceanography* 37(2):21–24, <https://doi.org/10.5670/oceanog.2024.404>.
- Anderson, R.F. 2024. GEOTRACES reflections. *Oceanography* 37(2):8–12, <https://doi.org/10.5670/oceanog.2024.405>.
- Anderson, R., E. Mawji, G.A. Cutter, C.I. Measures, and C. Jeandel. 2014. GEOTRACES: Changing the way we explore ocean chemistry. *Oceanography* 27(1):50–61, <https://doi.org/10.5670/oceanog.2014.07>.
- Buck, C.S., S. Fietz, D.S. Hamilton, T.-Y. Ho, M.M.G. Perron, and R.U. Shelley. 2024. GEOTRACES: Fifteen years of progress in marine aerosol research. *Oceanography* 37(2):116–119, <https://doi.org/10.5670/oceanog.2024.409>.
- Casciotti, K.L., T.A. Marshall, S.E. Fawcett, and A.N. Knapp. 2024. Advances in understanding the marine nitrogen cycle in the GEOTRACES era. *Oceanography* 37(2):85–101, <https://doi.org/10.5670/oceanog.2024.406>.
- Conway, T.M., R. Middag, and R. Schlitzer. 2024. GEOTRACES: Ironing out the details of the oceanic iron sources? *Oceanography* 37(2):35–45, <https://doi.org/10.5670/oceanog.2024.416>.
- de Souza, G.F., and A.K. Morrison. 2024. The Southern Ocean hub for nutrients, micronutrients, and their isotopes in the global ocean. *Oceanography* 37(2):46–59, <https://doi.org/10.5670/oceanog.2024.414>.
- Fitzsimmons, J.N., and J.M. Steffen. 2024. The “net” impact of hydrothermal venting on oceanic elemental inventories: Contributions to plume geochemistry from the international GEOTRACES program. *Oceanography* 37(2):102–115, <https://doi.org/10.5670/oceanog.2024.421>.
- GEOTRACES Planning Group. 2006. *GEOTRACES Science Plan*. Scientific Committee on Oceanic Research, Baltimore, MD, [https://geotracesold.sedoo.fr/libraries/documents/Science\\_plan.pdf](https://geotracesold.sedoo.fr/libraries/documents/Science_plan.pdf).
- Halbeisen, D.J. 2024. A young scientist’s perspective on GEOTRACES. *Oceanography* 37(2):13–16, <https://doi.org/10.5670/oceanog.2024.403>.
- Hayes, C.T. 2024. Timekeepers for trace elements in the global ocean: The thorium stopwatches. *Oceanography* 37(2):156–161, <https://doi.org/10.5670/oceanog.2024.412>.
- Jeandel, C. 2024. The value of going to sea on big ships and the advantage of multiple tracers for GEOTRACES style programs. *Oceanography* 37(2):17–20, <https://doi.org/10.5670/oceanog.2024.408>.
- Jensen, L., and M. Colombo. 2024. Shelf-basin connectivity drives dissolved Fe and Mn distributions in the western Arctic Ocean: A synoptic view into polar trace metal cycling. *Oceanography* 37(2):60–71, <https://doi.org/10.5670/oceanog.2024.410>.
- Masferrer Dodas, E., C. Jeandel, and A. Artis. 2024. Three-minute videos to learn about marine geochemistry. *Oceanography* 37(2):34, <https://doi.org/10.5670/oceanog.2024.401>.
- Rafter, P.A. 2024. On the variability of equatorial Pacific nitrate and iron utilization. *Oceanography* 37(2):72–84, <https://doi.org/10.5670/oceanog.2024.411>.
- Saito, M.A., H. Alexander, H.M. Benway, P.W. Boyd, M. Gledhill, E.B. Kujawinski, N.M. Levine, M. Maheigan, A. Marchetti, I. Obernosterer, and others. 2024. The dawn of the BioGeoSCAPES program: Ocean metabolism and nutrient cycles on a changing planet. *Oceanography* 37(2):162–166, <https://doi.org/10.5670/oceanog.2024.417>.

- Schlitzer, R., and S. Mieruch-Schnülle. 2024. The GEOTRACES intermediate data products: Rich resources for research, education, and outreach. *Oceanography* 37(2):25–33, <https://doi.org/10.5670/oceanog.2024.402>.
- Tagliabue, A., and T. Weber. 2024. Novel insights into ocean trace element cycling from biogeochemical models. *Oceanography* 37(2):131–141, <https://doi.org/10.5670/oceanog.2024.418>.
- Twining, B.S. 2024. An ocean of particles: Characterization of particulate trace elements by the GEOTRACES program. *Oceanography* 37(2):120–130, <https://doi.org/10.5670/oceanog.2024.407>.
- Whitby, H., J. Park, Y. Shaked, R.M. Boiteau, K.N. Buck, and R.M. Bundy. 2024. New insights into the organic complexation of bioactive trace metals in the global ocean from the GEOTRACES era. *Oceanography* 37(2):142–155, <https://doi.org/10.5670/oceanog.2024.419>.

## ACKNOWLEDGMENTS

We thank Robert Anderson, the US GEOTRACES Program Office, and the US National Science Foundation for supporting this Special Issue through NSF award OCE-2219888. We also thank each of the authors of the original GEOTRACES Science Plan (GEOTRACES Planning Group, 2006), whose vision brought us to the outstanding discoveries described in this special issue. The international GEOTRACES program is possible in part thanks to the support from the US National Science Foundation (Grant OCE-2140395) to the Scientific Committee on Oceanic Research (SCOR).

## AUTHORS

**Tim M. Conway** ([tmconway@usf.edu](mailto:tmconway@usf.edu)) is Associate Professor, College of Marine Sciences, University of South Florida, St. Petersburg, FL, USA. **Jessica N. Fitzsimmons** is Associate Professor, Department of Oceanography, Texas A&M University, College Station, TX, USA. **Rob Middag** is Research Leader, Royal Netherlands Institute for Sea Research (NIOZ), Den Burg, the Netherlands, and Honorary Professor, Centre for Isotope Research - Oceans, University of Groningen, Groningen, the Netherlands. **Taryn L. Noble** is Senior Lecturer, Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, Tasmania, Australia. **Hélène Planquette** is Senior Researcher, CNRS, Université de Bretagne Occidentale, IRD, Ifremer, LEMAR, Plouzané, France.

## ARTICLE CITATION

Conway, T.M., J.N. Fitzsimmons, R. Middag, T.L. Noble, and H. Planquette. 2024. Introduction to the special issue on twenty years of GEOTRACES: An international study of the marine biogeochemical cycles of trace elements and isotopes. *Oceanography* 37(2):6–7, <https://doi.org/10.5670/oceanog.2024.415>.

## COPYRIGHT & USAGE

This is an open access article made available under the terms of the Creative Commons Attribution 4.0 International License (<https://creativecommons.org/licenses/by/4.0/>), which permits use, sharing, adaptation, distribution, and reproduction in any medium or format as long as users cite the materials appropriately, provide a link to the Creative Commons license, and indicate the changes that were made to the original content.