FINAL REPORT PROGRAM LEFE

Program LEFE/ CYBER-GMMC	Project Title	Years 2018-2023
	TONGA : Shallow hydroThermal sOurces of trace elemeNts: potential impacts on biological productivity and the bioloGicAl carbon pump	

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Contribution to *GEOTRACES, IMBER*

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ANR, A-MIDEX, FOF-fonds de soutien, IRD

Context

The Western subtropical South Pacific (WTSP) is a recognized hotspot of N_2 fixation activity, with an estimated contribution of ~21% to the global fixed N input. N_2-fixing organisms have high iron (Fe) quotas relative to non-diazotrophic plankton and their success in the WTSP is hypothesized to be due to the alleviation of Fe limitation in this region. Shallow hydrothermal Fe sources (<500 m) were indeed discovered during the OUTPACE campaign in the WTSP, resulting in high dissolved Fe concentrations (> 4 nM) into the euphotic layer (~ 0-100 m). To date, the potential impact of such shallow hydrothermal inputs on Fe regional budgets and on the biogeochemical cycles of biogenic elements (C, N, P) has never been studied.

Objectives / scientific questions

The objective of the TONGA project and campaign was to study the control of ocean productivity and carbon sequestration by micronutrients of shallow hydrothermal origin by **(1)** accurately quantifying Fe (and other biogeochemically-relevant compounds) input from shallow submarine volcanoes and associated hydrothermal vents along the Tonga volcanic arc (20 and 25ºS) for the photic zone in comparison with atmospheric deposition, **(2)** studying the fate of shallow hydrothermal plumes in the water column at the local and regional scales, and **(3)** investigating the bioavailability and the potential impact of such hydrothermal inputs on planktonic communities and biogeochemical cycles in the WTSP.

Main results

The highlight of the project was an expedition (37 days, R/V L'Atalante, nov-dec 2019) with the challenge of localizing shallow hydrothermal sources and assess their impact on biogeochemical stocks and fluxes. The expedition was successful: we identified and explored two contrasted sites emitting fluids up to the euphotic layer. This interdisciplinary project involved ~100 scientists from 21 international institutions (including 15 PhD, 7 post-doc and 9 Master students).

Two post-cruise meetings (~70 people each) took place after the campaign and several sub-groups meetings were also organized on line, that maximized collaborations between scientists. Here are few results that were in part supported by the LEFE-CYBER and GMMC funding: we revealed that the cumulative impact of multiple hydrothermal sources along the Tonga arc fertilized the entire Lau Basin with dissolved Fe, with concentrations reaching up to ~10 nM in the photic layer (Tilliette et al., 2022, Figure 1). Along the west to east zonal transect, total chlorophyll-a (Chla) and particulate organic nitrogen stocks peaked in the naturally Fe-fertilized waters. N_2 fixation rates and Trichodesmium abundances increased by a factor of 10 and 90, respectively in these Fe-fertilized waters (Bonnet & Guieu et al., 2023) compared to adjacent waters. In situ group-specific Fe uptake rates - measured here for the first time- showed that diazotrophs cell-specific Fe uptake rates were ~100 times higher compared to those of the non-diazotrophic plankton, which translated into these very high abundances close to the Tonga volcanic arc (Lory et al., 2022). Through novel trace metal clean mixing experiments in minicosms, we explored in details the mechanisms behind this fertilization: we showed that hydrothermal fluids had an initial toxic effect and that some phytoplankton detoxified the environment through the production of ligands, making the toxic metals in the fluids less available; after this initial period, we observed a strong stimulation of primary production, N_2 fixation and carbon export rates, in line with in-situ observations (Tilliette et al., 2023). In situ, export production was mostly (~80%) supported by N_2 fixation in Fe-fertilized waters (Bonnet et al., 2023), consistent with the massive export of diazotrophs observed in the traps during the expedition (Bonnet et al., 2023, Figure 2) that sunk fast and were still alive for *Trichodesmium* (Benavides et al., 2022). Finally, we show that carbon sequestration efficiency by hydrothermal Fe is much higher than those from artificial mesoscale Fe-addition experiments and in the range of values measured in well-recognized shelf driven natural fertilizations occurring in the southern ocean around Kerguelen and Crozet Islands (Bonnet & Guieu et al., 2023), confirming that natural Fe

fertilizations are more efficient for carbon sequestration than purposeful Fe additions. Therefore, attention must be paid in future studies to the timescale of delivery of this newly-recognized mode of Fe supply through shallow hydrothermalism, especially in biogeochemical models.

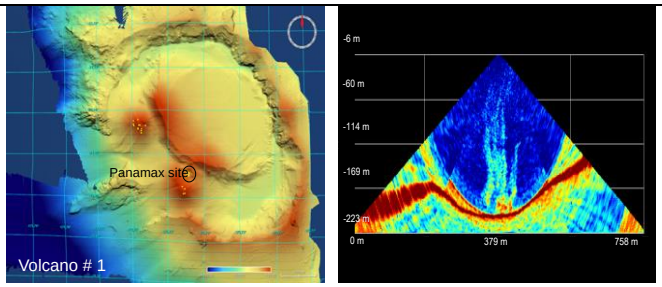

Figure 1. Bathymetry of one of the explored volcanoes performed during TONGA (left). Multibeam echo sounder image showing hydrothermal gas and fluid emissions from the seafloor rising up to ~10 m below the surface (right) (Bonnet, Guieu et al., 2023, Science).

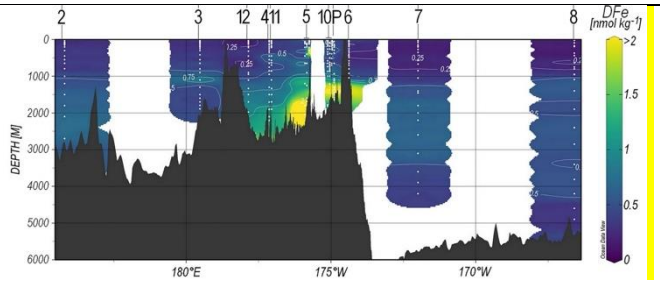

Figure 2. DFe concentrations distribution along the TONGA transect (Tilliette et al., 2022, GBC).

Figure 1. During an acoustic survey above Volcano #1, we detected multiple acoustic plumes rising from the sea floor up to ~20 m below the surface. We focused our study on a site located near the caldera on the southwestern edge of the volcano, where the acoustic anomaly, also associated with intense gas bubble emissions, was strong and continuous. Repeated CTD casts at this site revealed that acoustic plumes were also associated with strong anomalies in pH, turbidity, and redox potential (Eh) from the seafloor (195 m depth) up to ~160 m. Methane concentrations that reached >100 nmol liter^{-1} and the excess of ^{3}He and ^{4}He concentrations confirmed the hydrothermal origin of the plumes.

Figure 2. DFe distribution along the TONGA transect (Tilliette et al., 2022, GBC). The project revealed for the first time the DFe distribution over the whole water column and over a distance of more than 3000 km at ~20.5 S in the SW Pacific. In addition to indicating the anomalies due to hydrothermal inputs, highlighted in the Arc and Lau Basin section, this work represents an important contribution to the GEOTRACES program. TONGA was endorsed as a process study: TONGA cruise is GEOTRACES GPpr14.

Future of the project. The consortium is currently in the data valorization phase, which will constitute the bulk of its activity in 2023. We also work on several direction emanating in part from TONGA: **(1) short term**: thanks to data collected during TONGA, using meta-omic analyses and modeling, we obtained a new project to link patterns of genetic and functional diversity of microbial organisms to environmental conditions, including concentrations of a large number of metals (projet METAL-OMICS, Institut de l'Océan –Sorbonne U.); **(2) Medium term:** thanks to preliminary results obtained during TONGA, we recently obtained an ERC project (HOPE 2023-2027, PI: S. Bonnet) exploring the role of diazotrophs in the biological carbon pump, (3) **in the long term**, we are working on several strategies to quantify at the global scale the impacts of these newly-recognized sources of 'new Fe' on the ocean ecosystem. Interestingly, this is a transdisciplinary approach involving the 'terre-solide' and 'ocean-atmosphere' communities from INSU and other CNRS Institutes (INEE, INS2I etc.).

Publications

-11 articles published, 3 submitted

-24 more articles expected in the **TONGA Research Topic** (Special issue) opened in Frontiers up to the end of 2023 (abstract submitted, see: https://www.frontiersin.org/research-topics/49099/hydrothermal-and-submarine-volcanic-activity-impacts-on-ocean-chemistry-and-plankton-dynamics.

-1 "highlight paper" (Bonnet & Guieu et al.) in Science.

20 communications to international conferences: ASLO 2021, ASLO 2022, ASLO 2023, Goldschmidt 2021, Goldschmidt 2022, Goldschmidt 2023.

See full list of publications/Communications here:
https://docs.google.com/spreadsheets/d/1VuU-d-xc-em3-lURRAD6oNBr3CzS0Ag5/edit#gid=620464097

Data availability

LEFE-CYBER Data Base : http://www.obs-vlfr.fr/proof/php/TONGA/tonga.php

SEANOE Data base https://www.seanoe.org/data/00770/88169/ (DOI: 10.17882/88169)

Pages des campagnes et données SISMER:

TONGA: https://campagnes.flotteoceanographique.fr/campagnes/18000884/

TONGA RECUP : https://campagnes.flotteoceanographique.fr/campagnes/18001357/