Volcanic Ocean Acidification and Coral Reef Ecosystem Study at Maug, Commonwealth of Northern Mariana Islands

Science Partners:
Pacific Marine Environmental Lab-Earth Ocean Interactions
Dave Butterfield, Joe Resing, Bill Chadwick

Pacific Islands Fisheries Science Center, Coral Reef Ecosystem Division
Rusty Brainard, Chip Young, Bernardo Vargas-Angel,
Oceanography and Coral Ecology Teams

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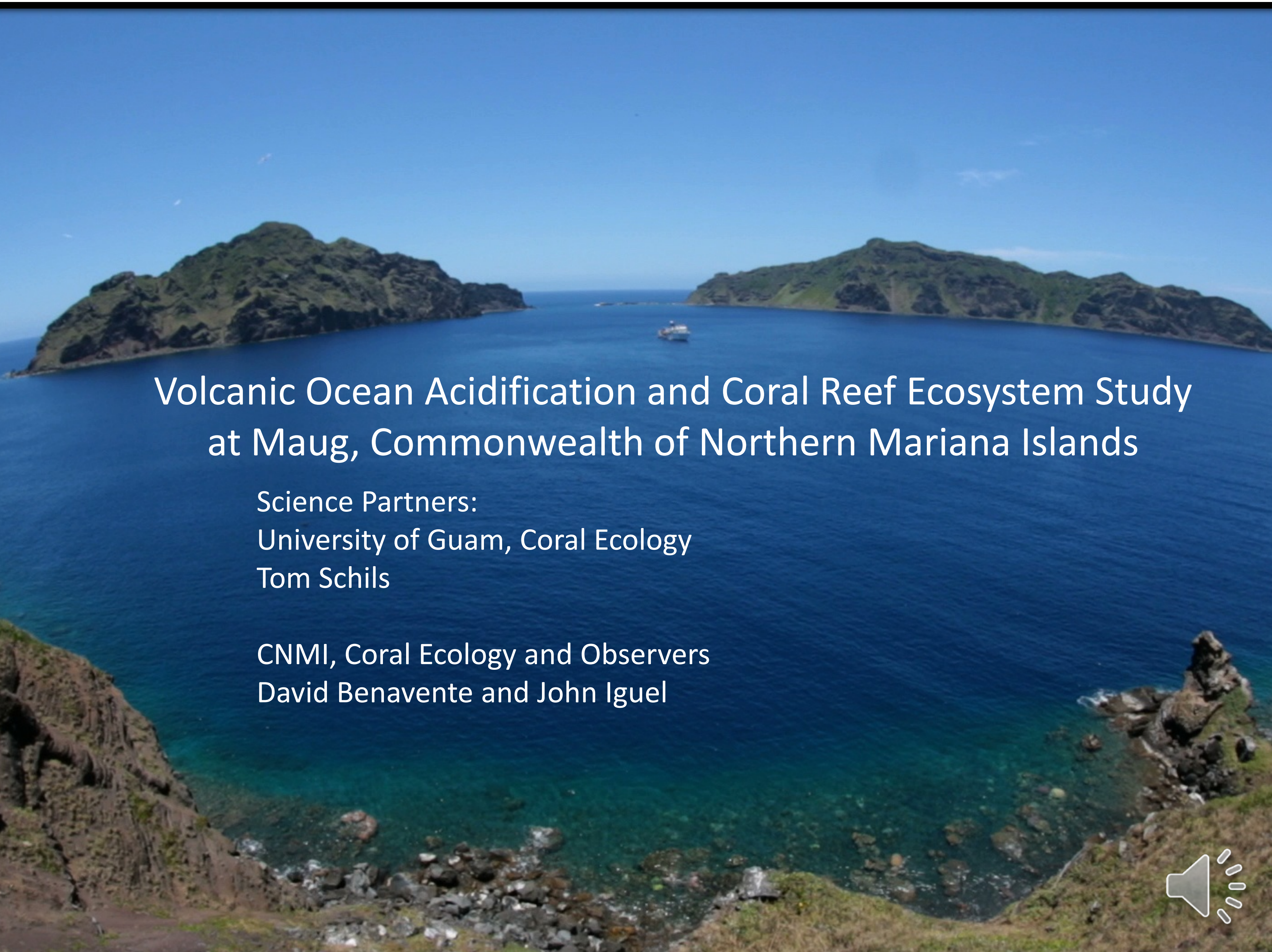
Science Partners:
Atlantic Oceanographic and Meteorological Lab, Coral Reef Monitoring
Ian Enochs

National Institute of Standards and Technology, Hollings Marine Lab, Coral Geochemistry/Biology
Russell Day



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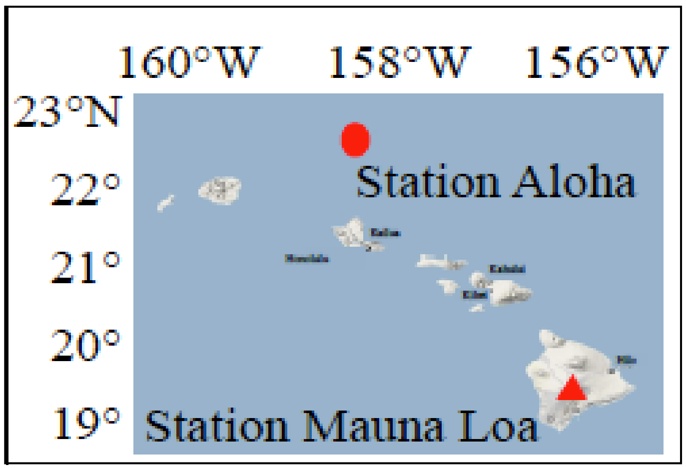
Science Partners:
University of Guam, Coral Ecology
Tom Schils

CNMI, Coral Ecology and Observers
David Benavente and John Iguel

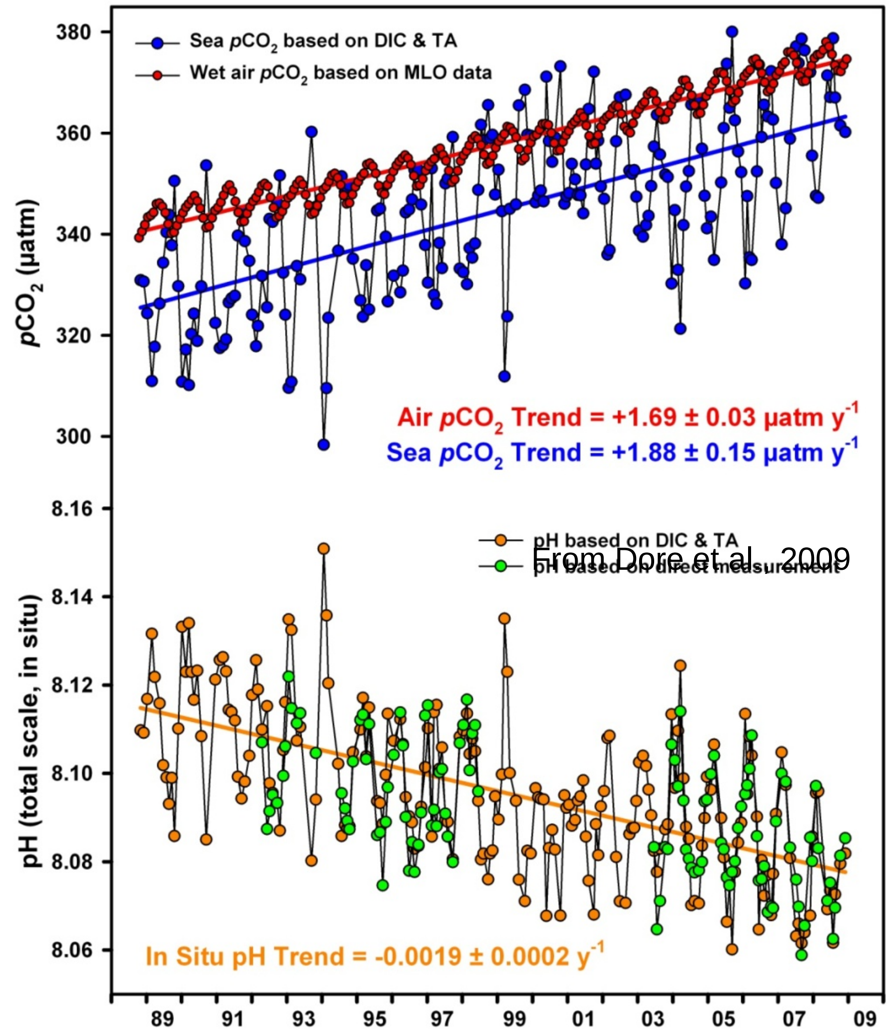

Volcanic Ocean Acidification and Coral Reef Ecosystem Study
at Maug, Commonwealth of Northern Mariana Islands
Collaborative Science Funding:
NOAA Ocean Exploration and Research Program
Pacific Marine Environmental Lab
NOAA Coral Reef Conservation and Monitoring Program
NOAA Ocean Acidification Program

The Oceanic Response to increasing CO_2

"Ocean acidification refers to a reduction of the pH of the ocean over an extended period… caused primarily by the uptake of CO_2 by the atmosphere." – Gattuso and Hansson, 2011



Open Ocean time series document the rate of acidification



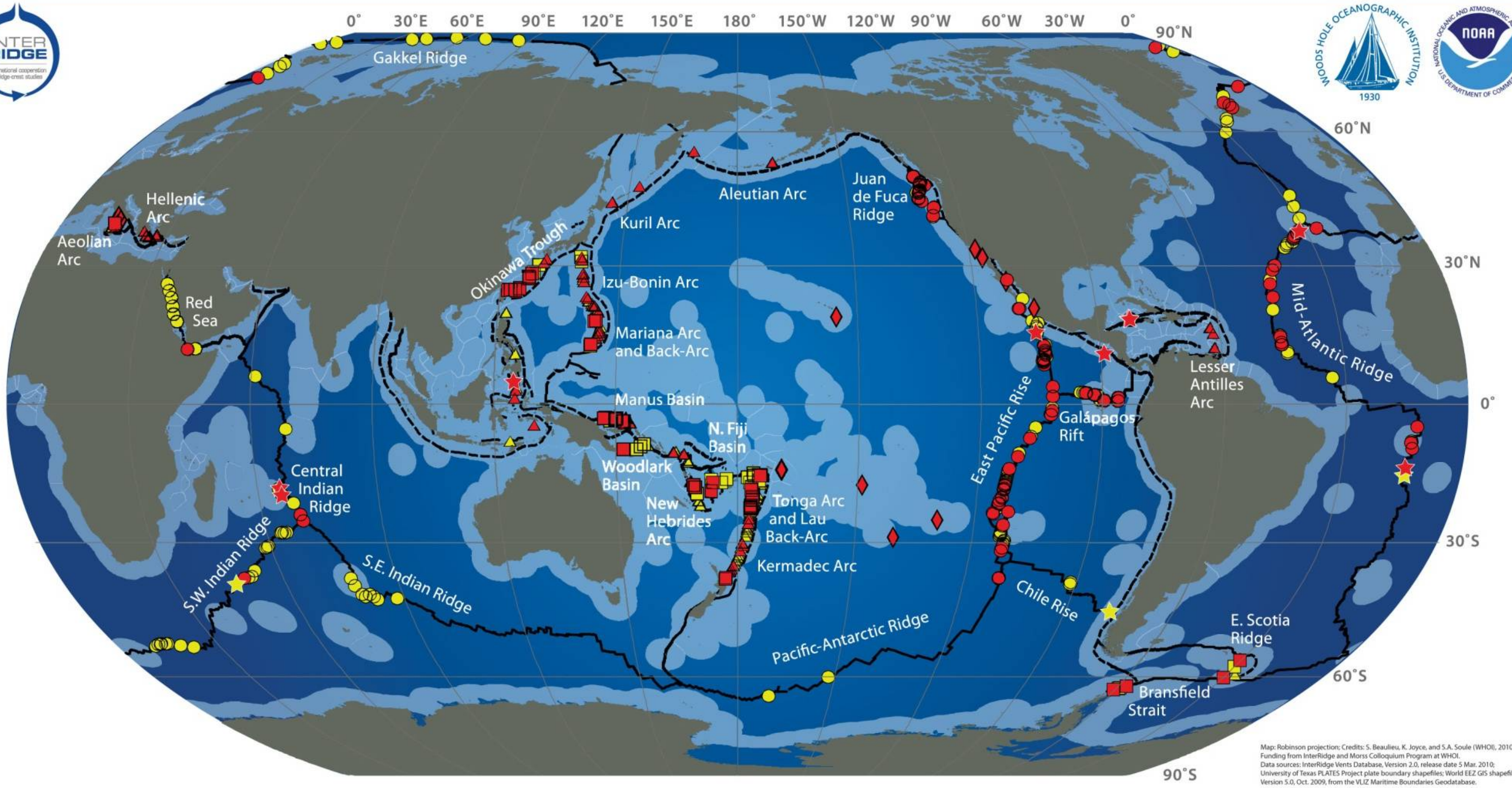
↑pCO_2 ↓pH ↓ Saturation state or $CaCO_3$ Minerals (Ω)

Saturation State

$$\Omega_{phase} = \frac{[Ca^{2+}][CO_3^{2-}]}{K^*_{sp,phase}}$$

Global Distribution of Hydrothermal Vent Fields

Stace E. Beaulieu1, Edward T. Baker2, and Christopher R. German1
1Woods Hole Oceanographic Institution, Woods Hole, MA 02543 (stace@whoi.edu)
2NOAA PMEL, Seattle, WA 98115-0070



Map: Robinson projection; Credits: S. Beaulieu, K. Joyce, and S.A. Soule (WHOI), 2010; Funding from InterRidge and Morss Colloquium Program at WHOI.
Data sources: InterRidge Vents Database, Version 2.0, release date 5 Mar. 2010; University of Texas PLATES Project plate boundary shapefiles; World EEZ GIS shapefiles, Version 5.0, Oct. 2009, from the VLIZ Maritime Boundaries Geodatabase.

Discoveries 2009/2010
- ★ Active
- ★ Unconfirmed

Mid-ocean ridge
- ● Active
- ● Unconfirmed

Arc volcano
- ▲ Active
- ▲ Unconfirmed

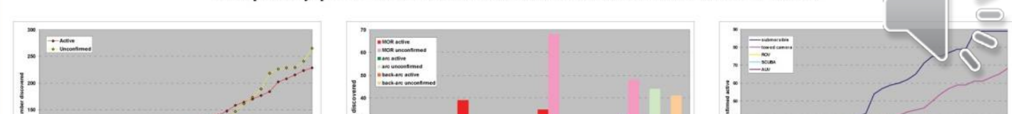
Back-arc spreading center
- ■ Active
- ■ Unconfirmed

Intra-plate volcano & Other
- ♦ Active

Ridge & Transform (——)
Trench (-----)
Exclusive Economic Zones

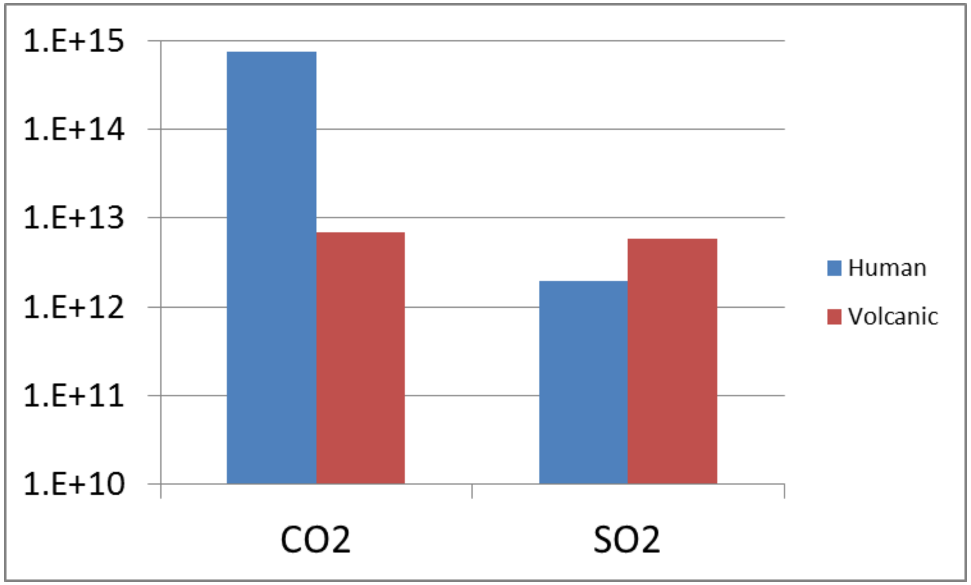
Since the visual confirmation of deep seafloor hot springs, or hydrothermal vents, at the Galapagos Rift in 1977, submarine hydrothermal activity has been studied in all ocean basins, at a wide range in depth, and in a variety of volcanic and tectonic settings. In 2004 Baker and German undertook a review of the global distribution of hydrothermal vent fields (in Mid-Ocean Ridges: Hydrothermal Interactions Between the Lithosphere and Oceans, Geophysical Monograph Series 148, German, C.R., et al., eds., 245-266). As InterRidge Coordinator, Beaulieu combined Baker's global listings of vent fields with several other listings, incorporated new findings including from commercial industry, and in 2010 released the revised InterRidge Global Database of Active Submarine Hydrothermal Vent Fields (http://www.interridge.org/IRvents). The database provides a comprehensive listing of confirmed (visually, from seafloor observations) and inferred (based on water column measurements and/or seafloor sampling) active hydrothermal fields. As of

Frequency plots of confirmed active and unconfirmed vent fields



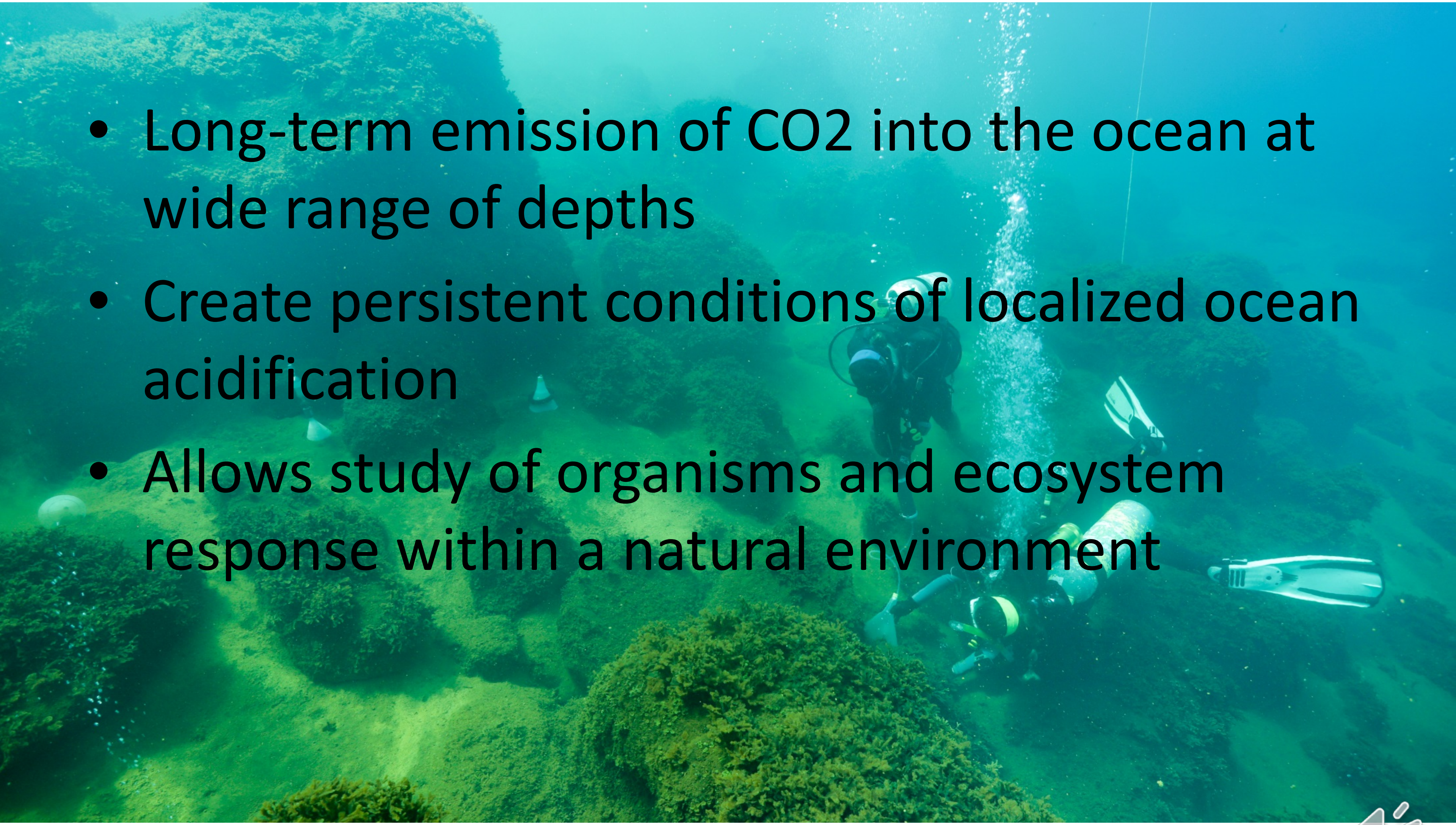
Scale of Human & Volcanic Activity
Total Inputs to Atmosphere/Hydrosphere

Annual Flux: Humans Versus Volcanoes		
	CO_2	SO_2
Human	7.5×10^{14}	1.9×10^{12}
Volcanic	6.8×10^{12}	5.8×10^{12}
Ratio Volcanic/ Human	1%	300%
Fluxes in mol/year		



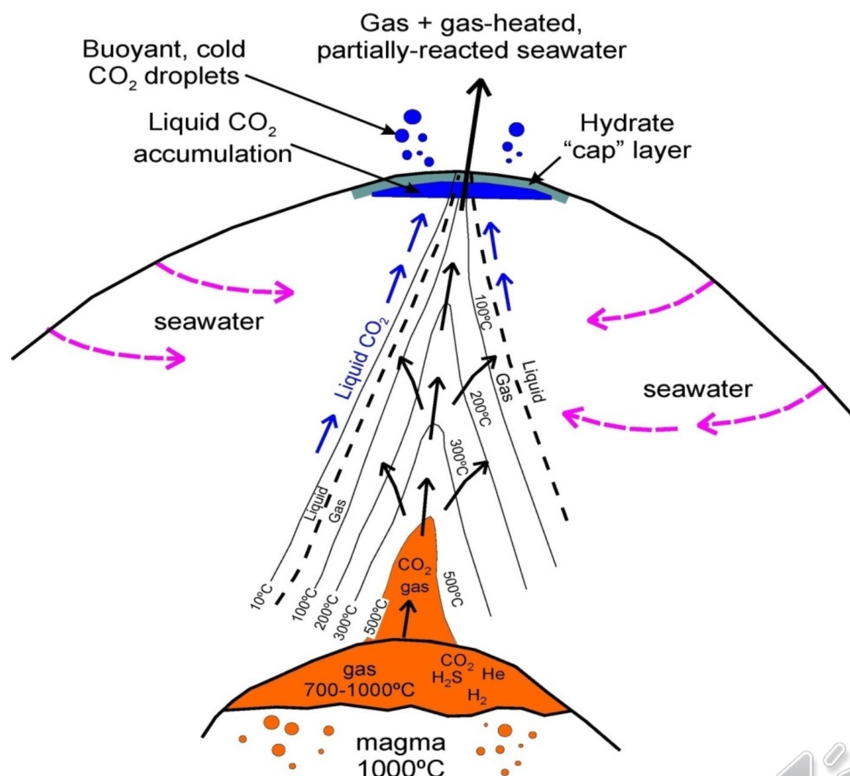
Total fossil fuel +cement + land use from Le Quere 2010
Volcanic CO_2 and SO_2 from Fischer 2008 and Morner et al. 2002
Total anthropogenic SO_2 from EDGAR database v4.1 for 2005

Volcanoes as Natural Laboratories



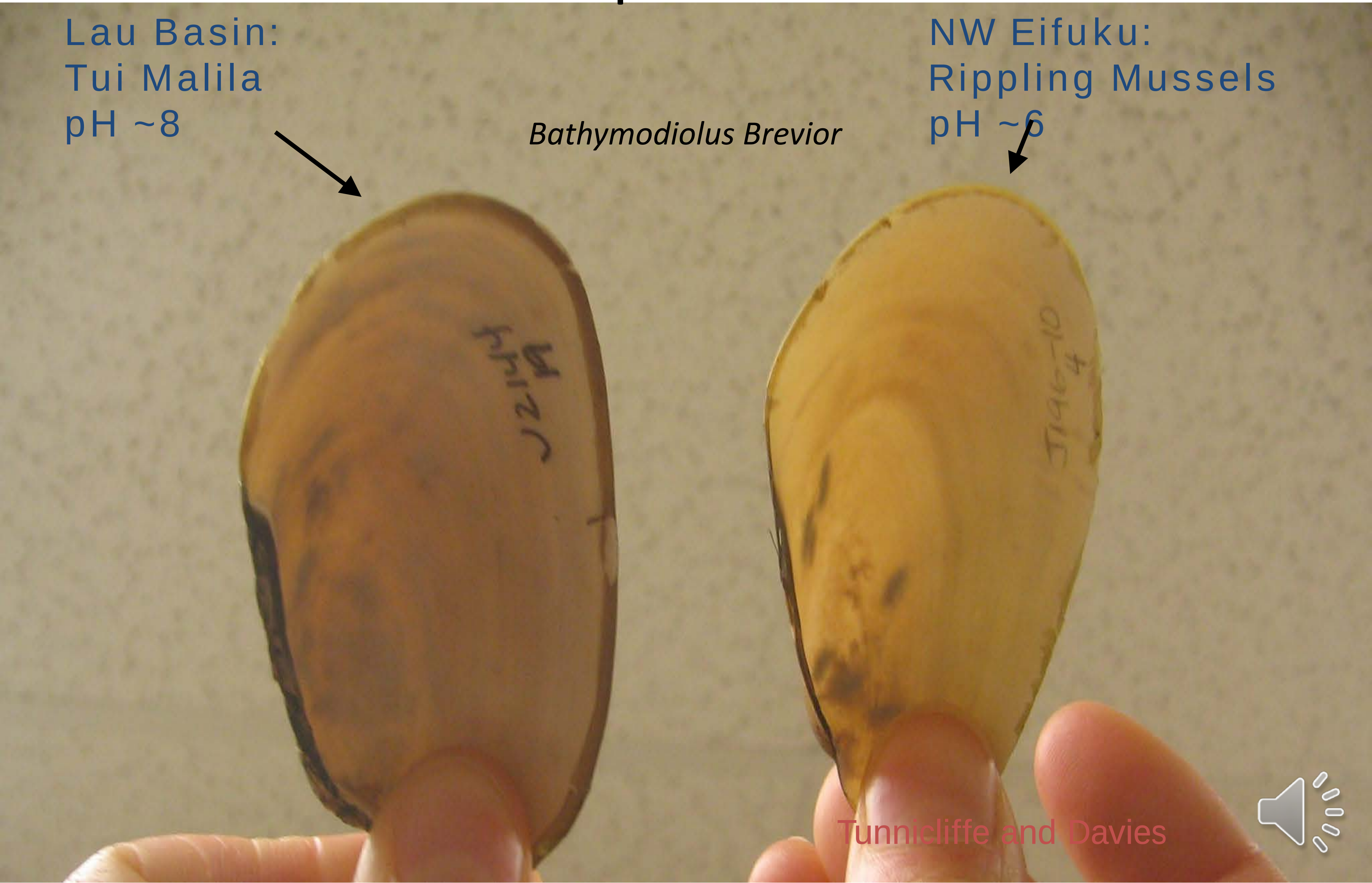
- Long-term emission of CO_2 into the ocean at wide range of depths
- Create persistent conditions of localized ocean acidification
- Allows study of organisms and ecosystem response within a natural environment

Magmatic CO2 is common and effects can be extreme

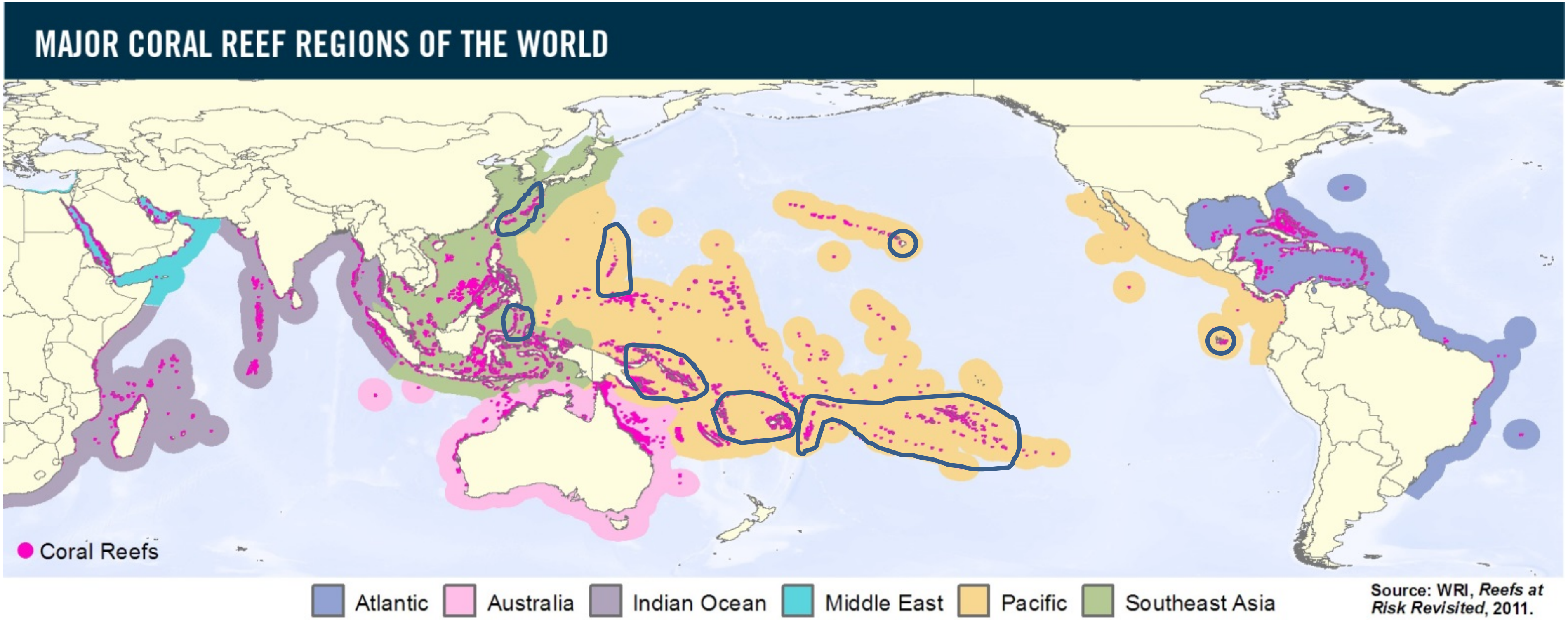


Lupton et al. 2006

Mussels Survive High CO2 at Eifuku Adaptation?



Volcanoes and Coral Reefs Overlap



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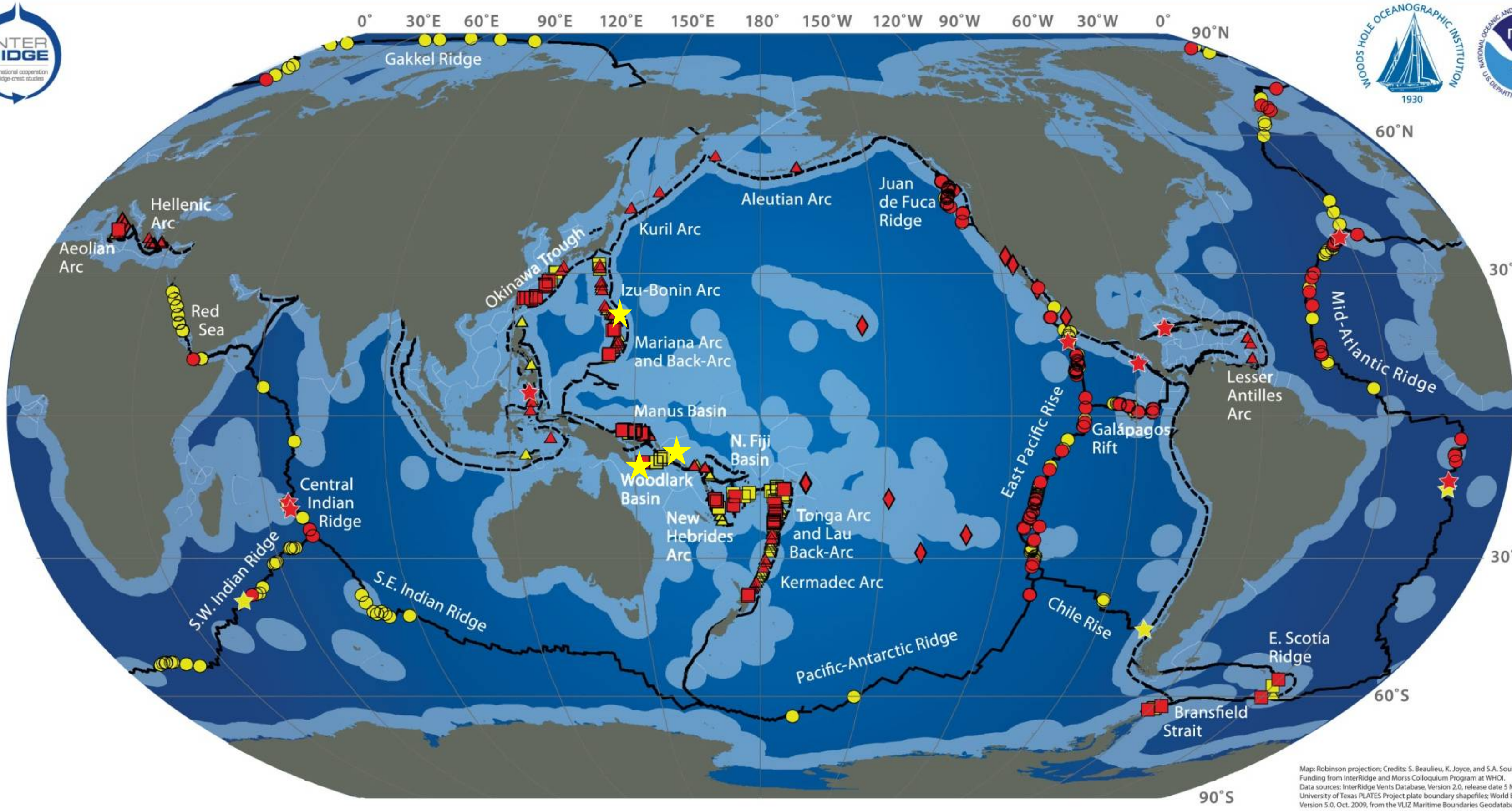

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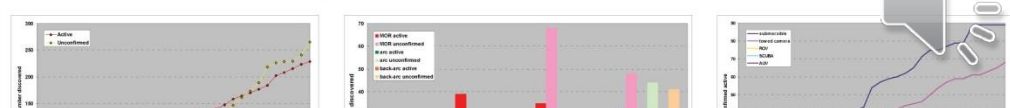


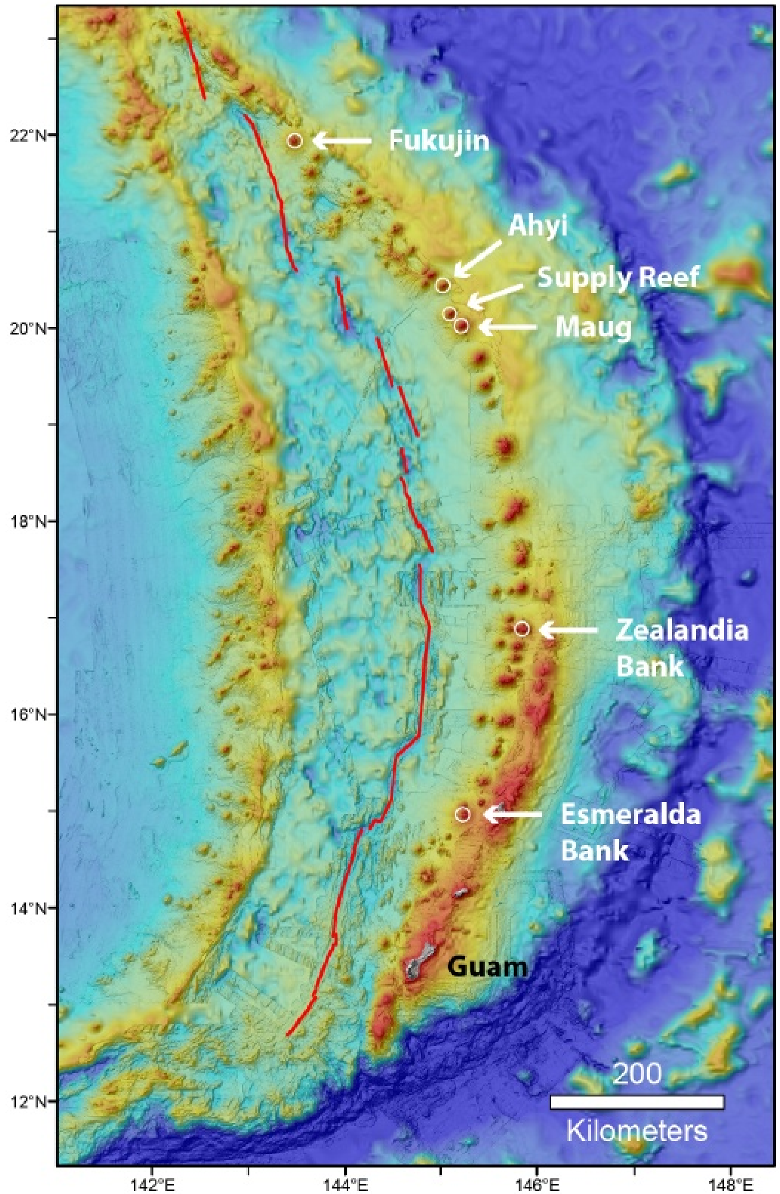


Figure 2. Bathymetric map of the Mariana region showing our study sites in the volcanic arc where shallow CO2 vents are known or suspected.

Maug is the most accessible of the 6 known sites in the Mariana Arc with active hydrothermal venting in the photic zone.

Is Maug a good natural lab for OA??

May 2014 Study Goals:

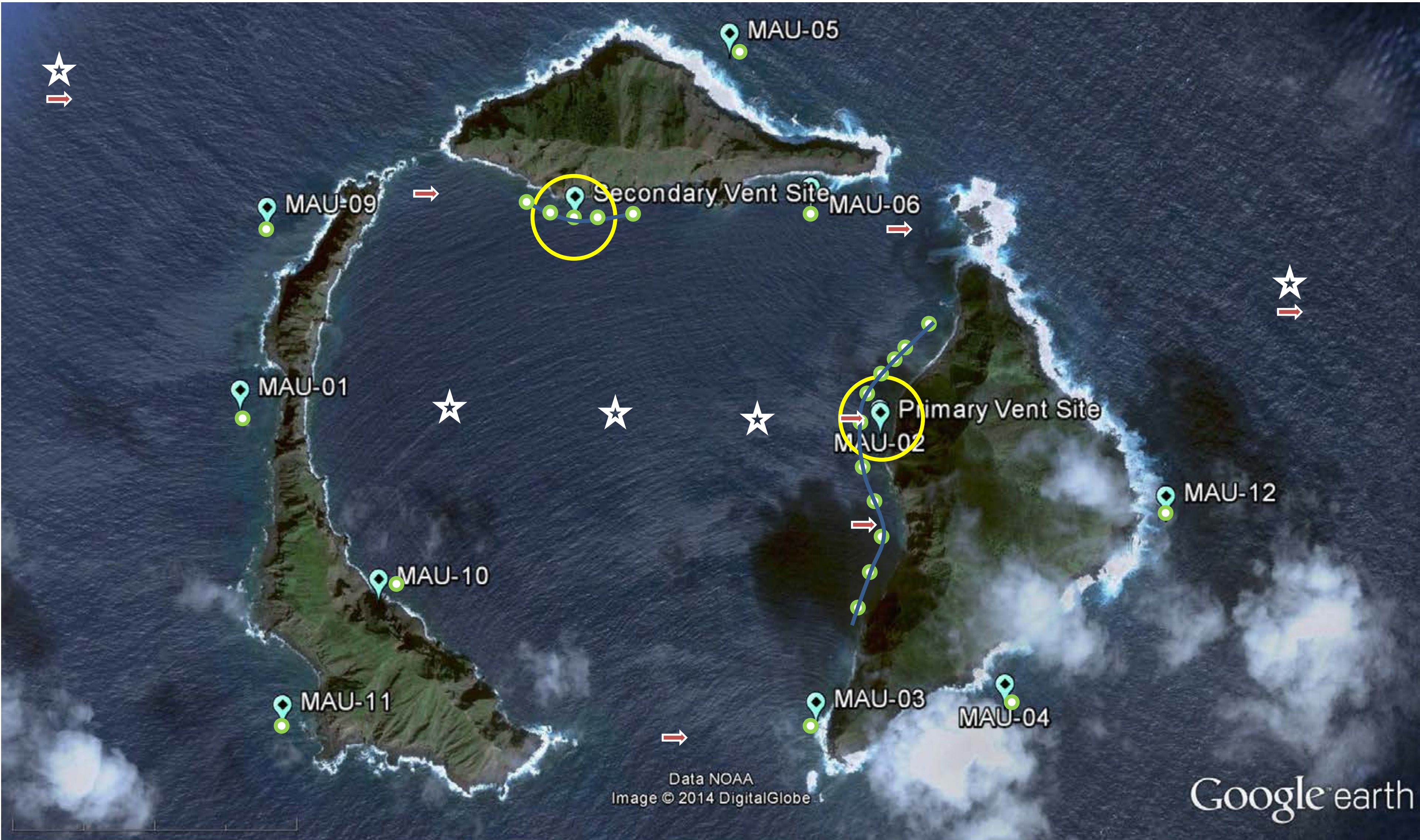
1. Determine pH & CaCO3 saturation gradients
2. Other Impacts of Venting
3. Coral experiments

Ship CTD

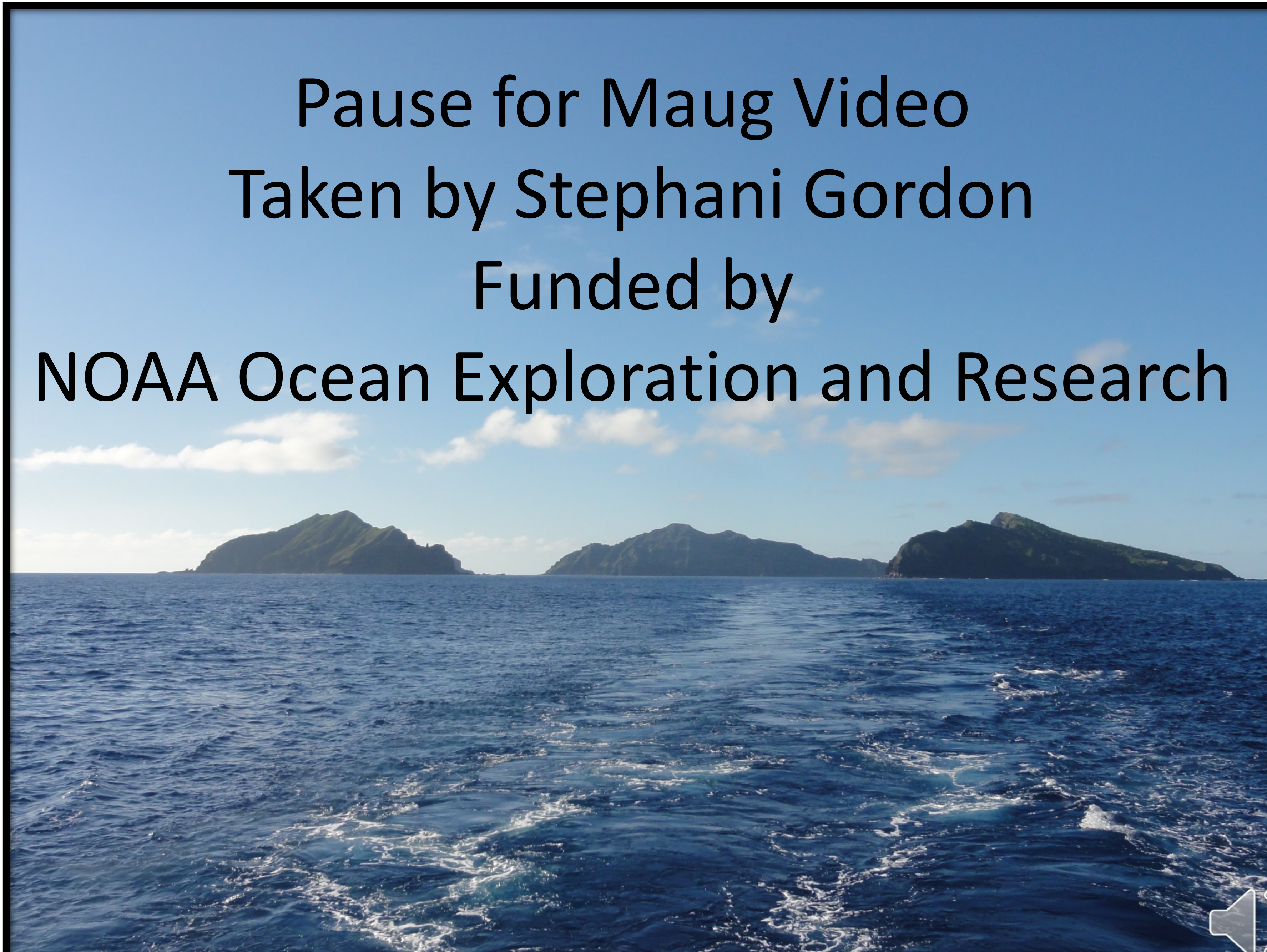
Transect along 15m depth profile

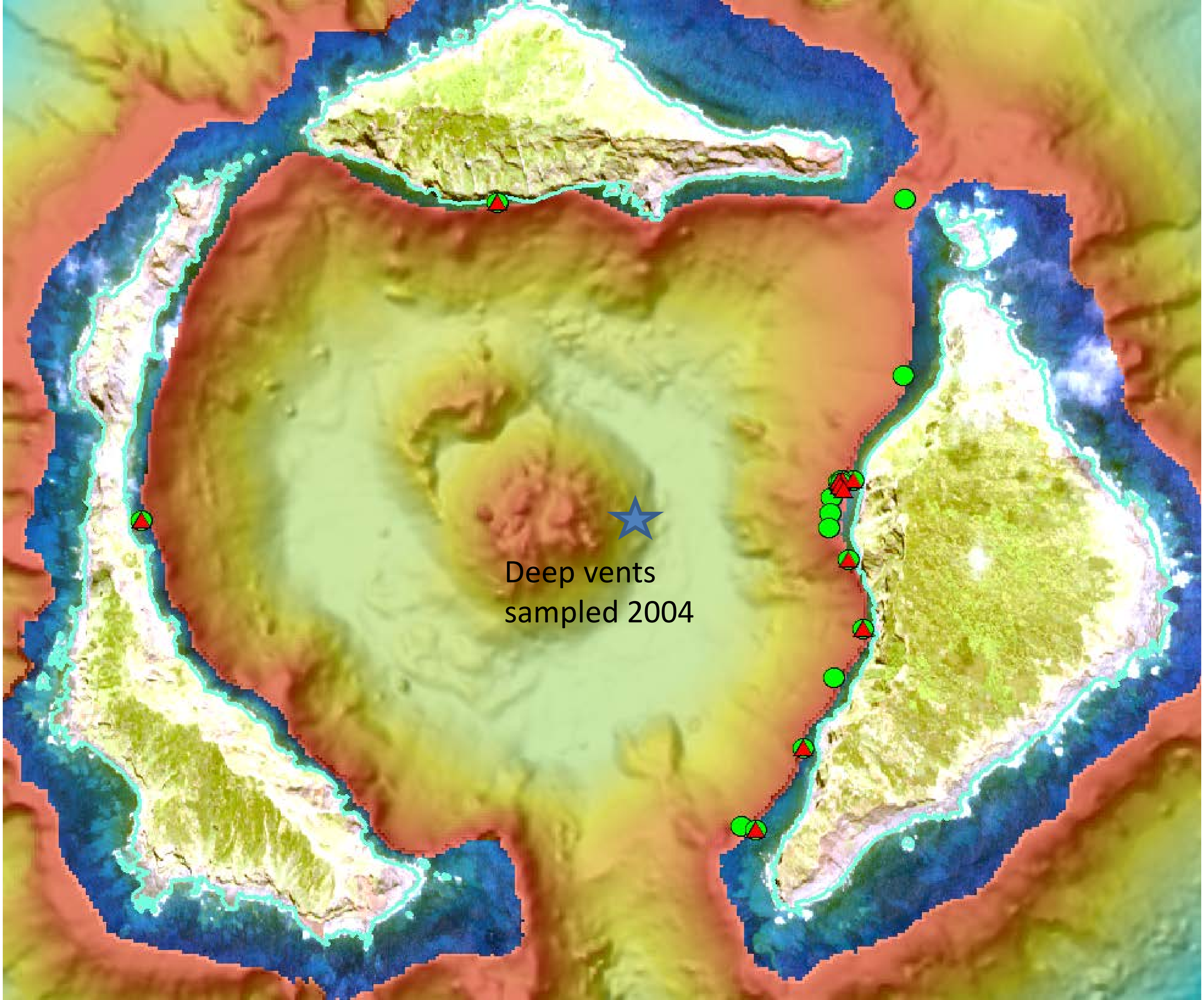
In-situ pH/O2 profile, CTD, Niskin, sediment

Intensive fluid/gas sampling

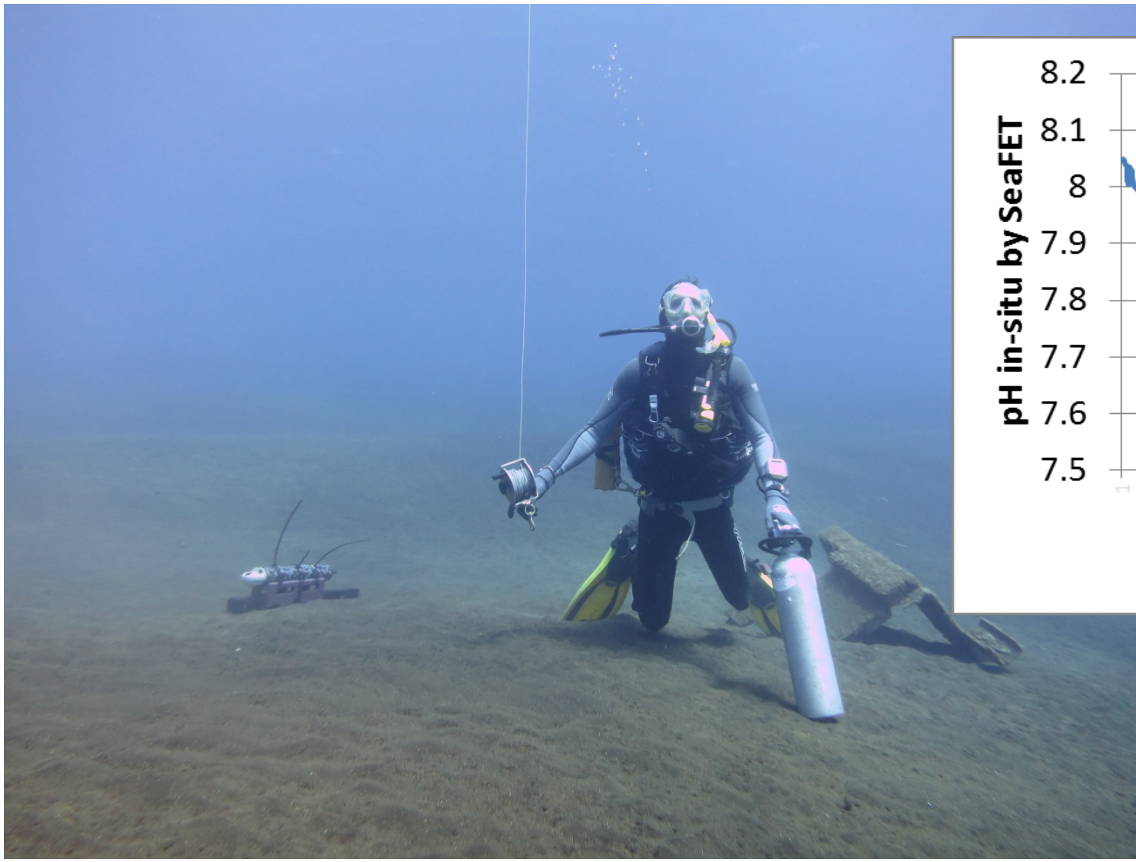


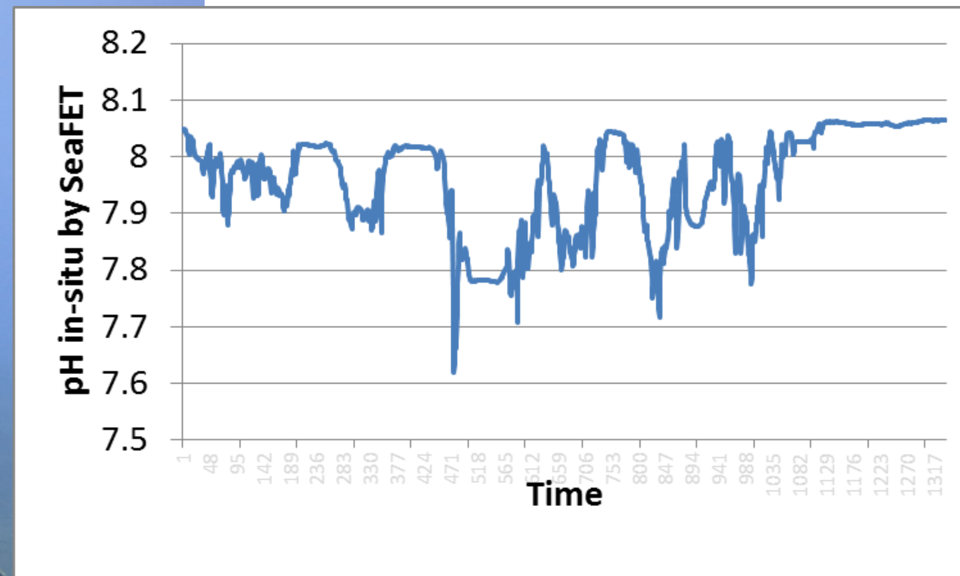
ADCP current measurement


Pause for Maug Video
Taken by Stephani Gordon
Funded by
NOAA Ocean Exploration and Research

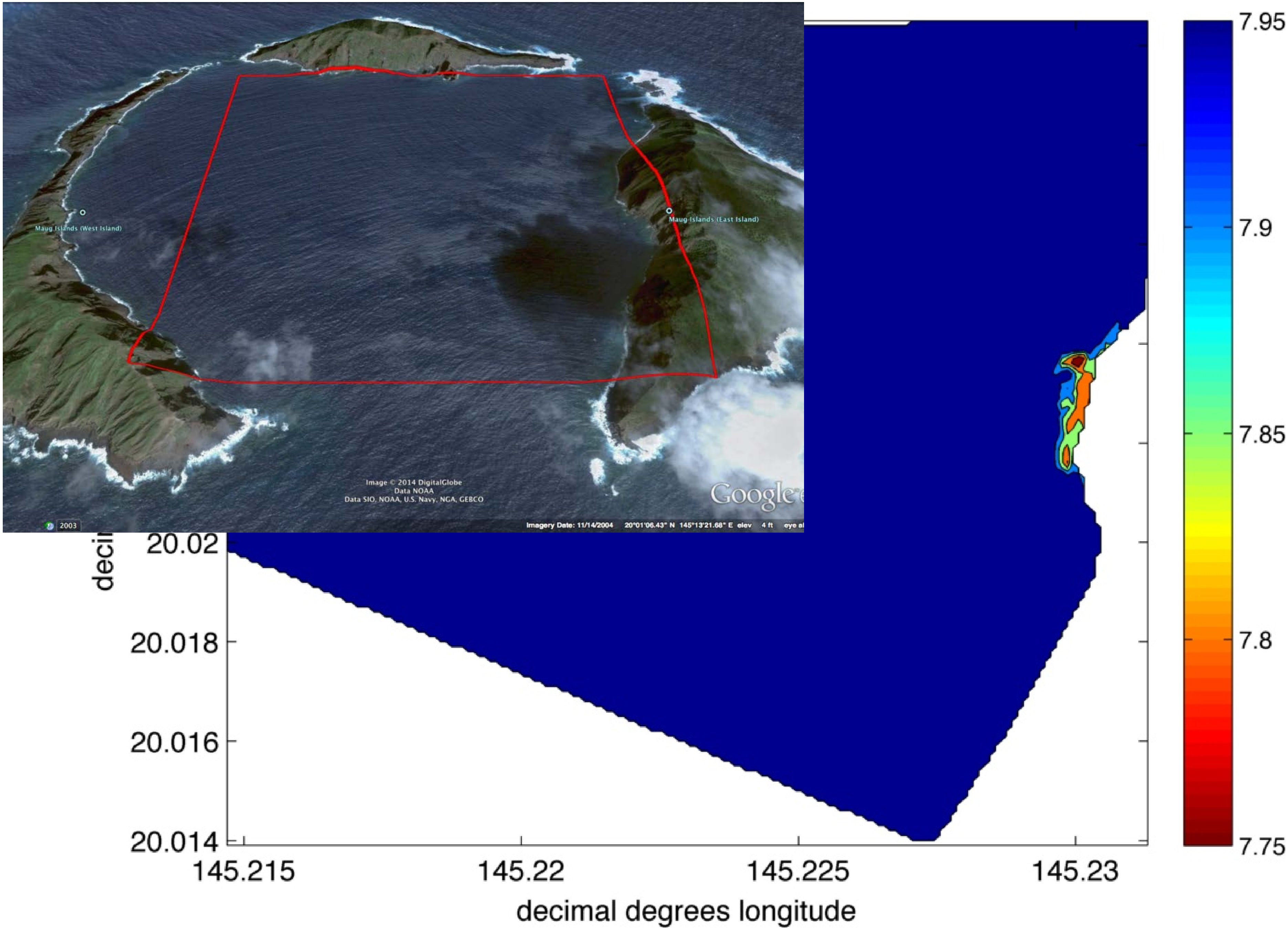

Deep vents
sampled 2004

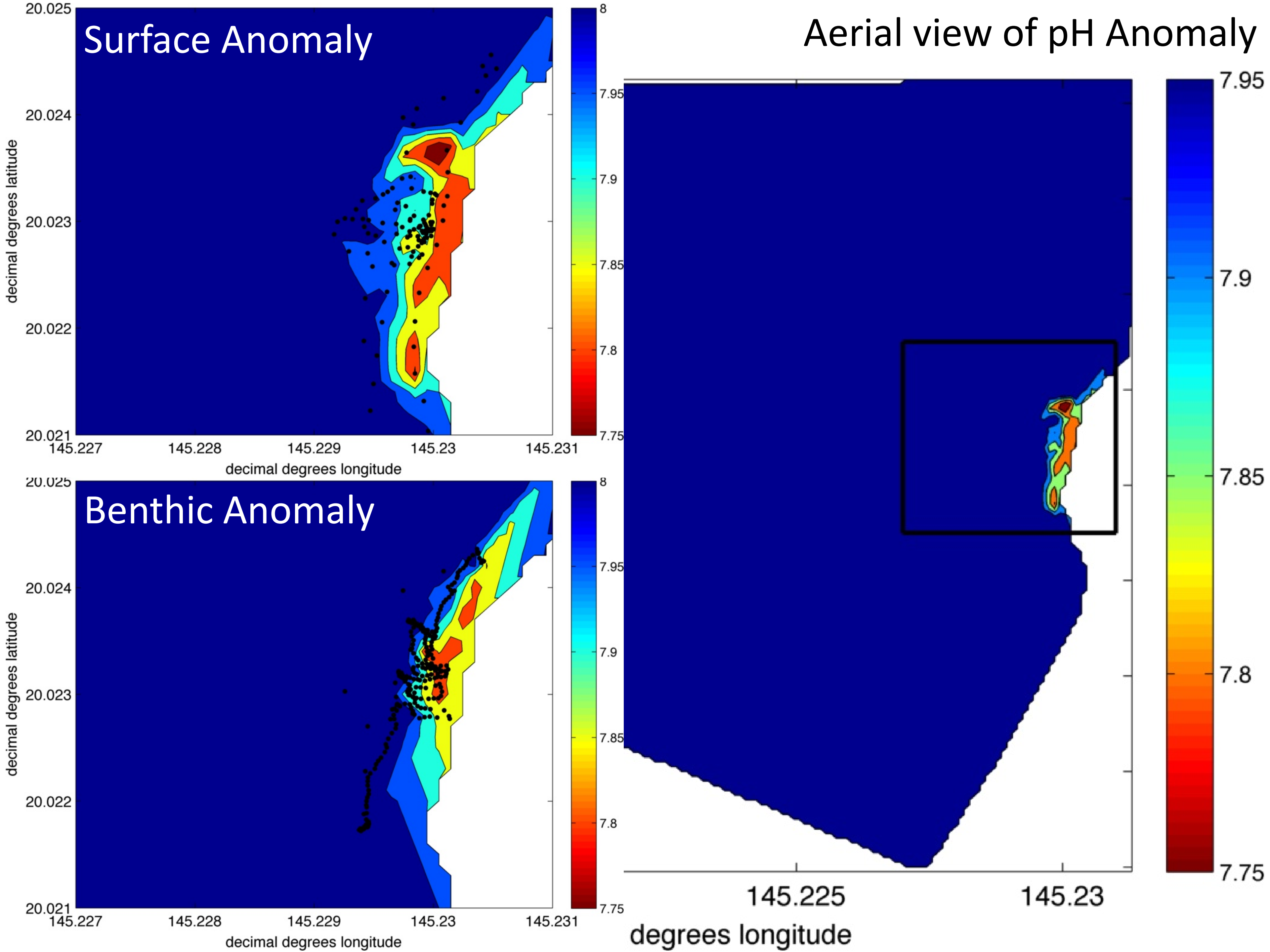
Diver Transect with SeaFET pH



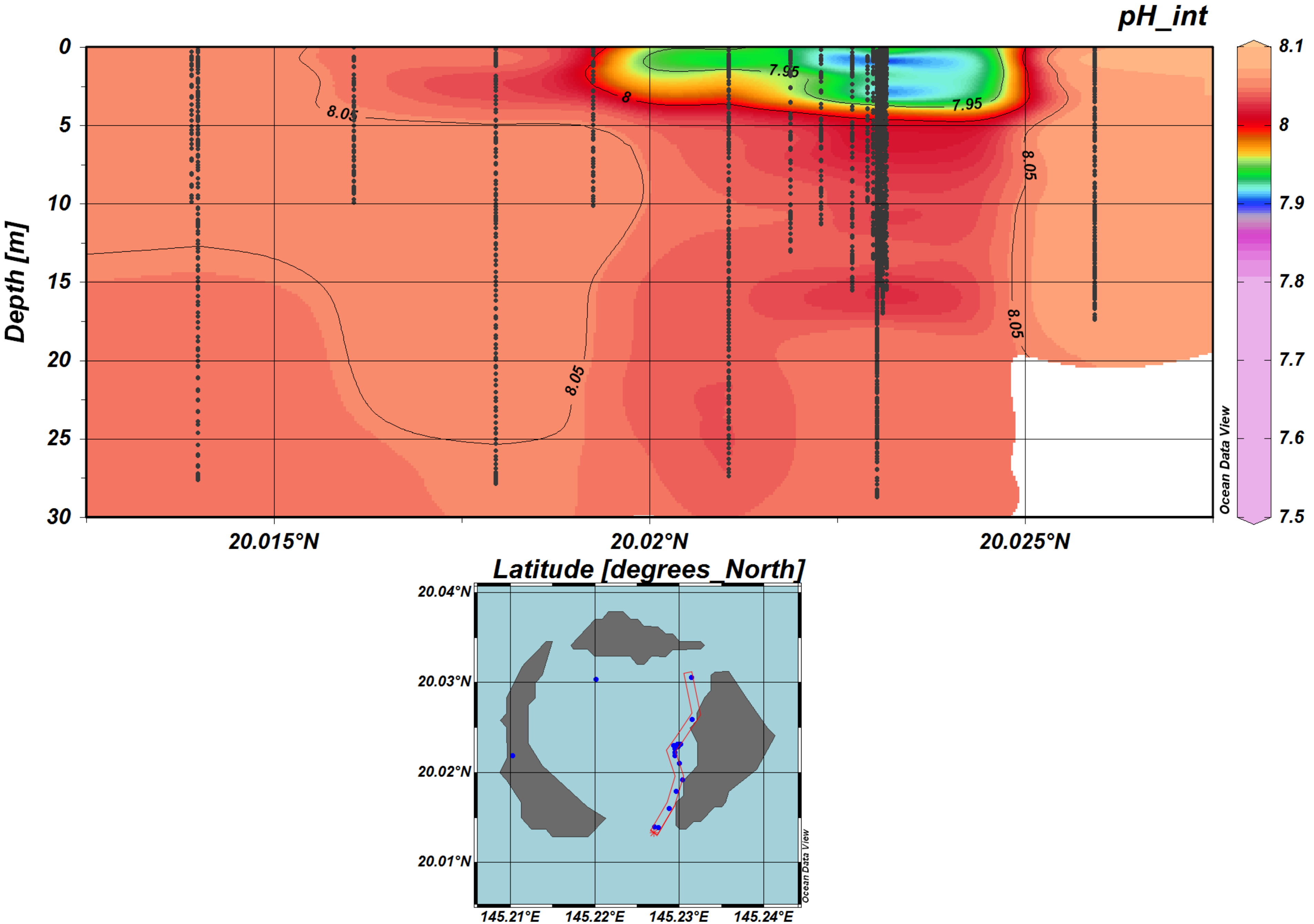


Aerial view of pH Anomaly





Surface Anomaly
decimal degrees latitude
20.025
20.024
20.023
20.022
20.021
145.227
145.228
145.229
145.23
145.231
decimal degrees longitude
8
7.95
7.9
7.85
7.8
7.75
Benthic Anomaly
decimal degrees latitude
20.025
20.024
20.023
20.022
20.021
145.227
145.228
145.229
145.23
145.231
decimal degrees longitude
8
7.95
7.9
7.85
7.8
7.75
Aerial view of pH Anomaly
145.225
145.23
degrees longitude
7.95
7.9
7.85
7.8
7.75

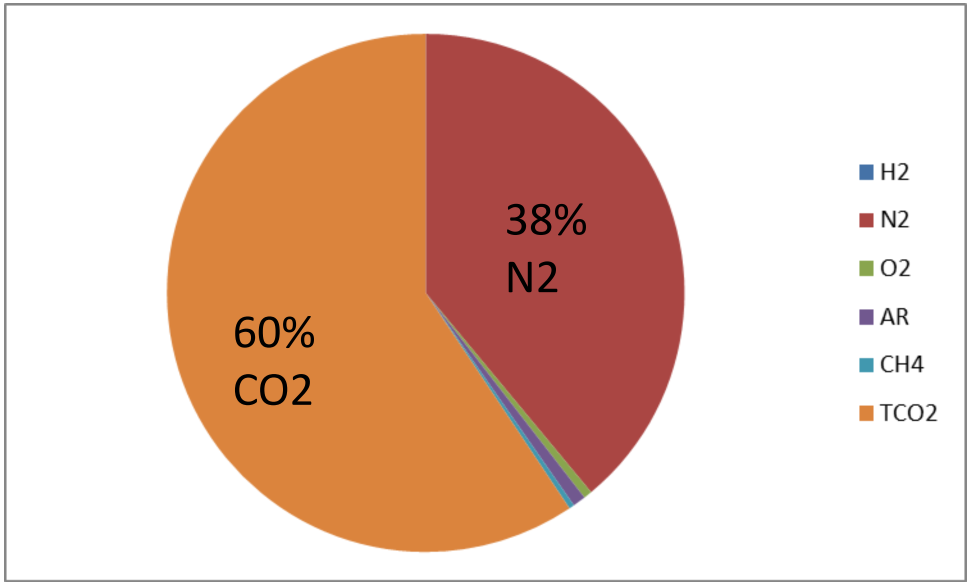


pH_int
Depth [m]
Latitude [degrees_North]
20.015°N
20.02°N
20.025°N
0
5
10
15
20
25
30
8.1
8
7.9
7.8
7.7
7.6
7.5
8.05
8
7.95
Ocean Data View
20.04°N
20.03°N
20.02°N
20.01°N
145.21°E
145.22°E
145.23°E
145.24°E

Sampling Warm Vent Fluids

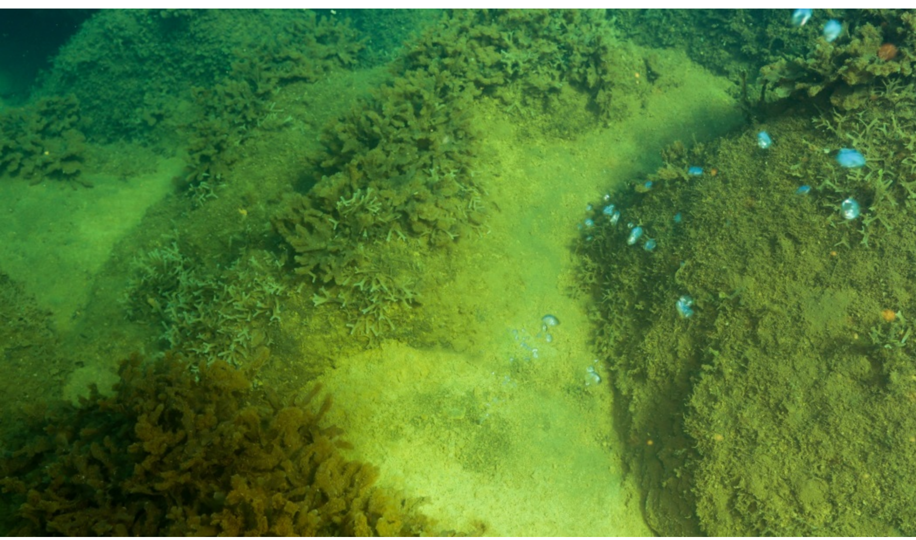
Sampling Gas Bubbles

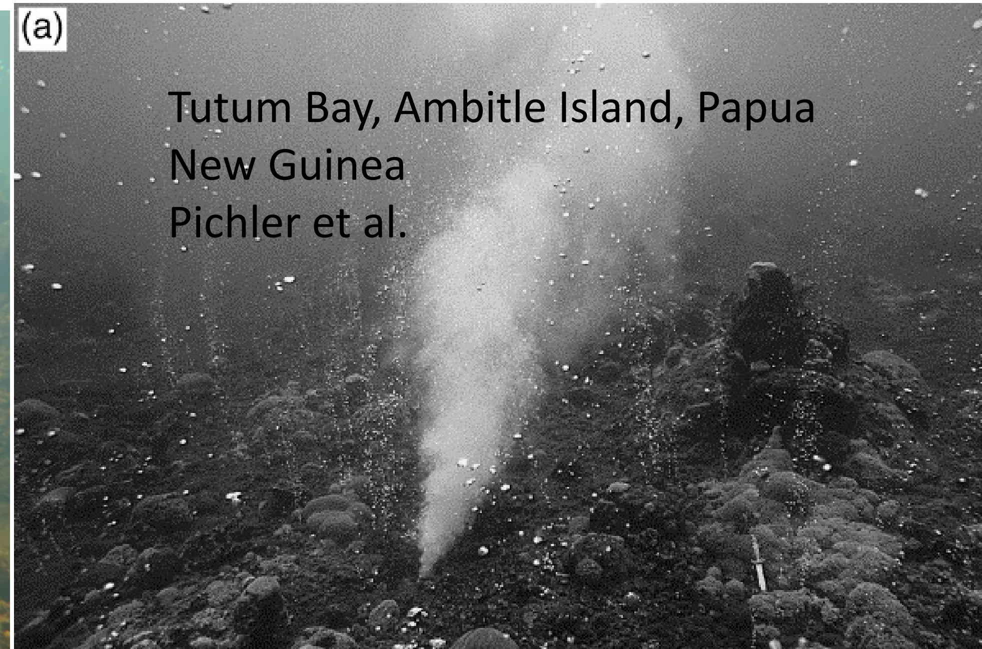
Maug Average Vent Gas



Compare to 90-99% CO_2 at Papua New Guinea Sites


Maug, East Island Vents




(a)
Tutum Bay, Ambitle Island, Papua
New Guinea
Pichler et al.


(b)

Shallow Gas Vent Sites

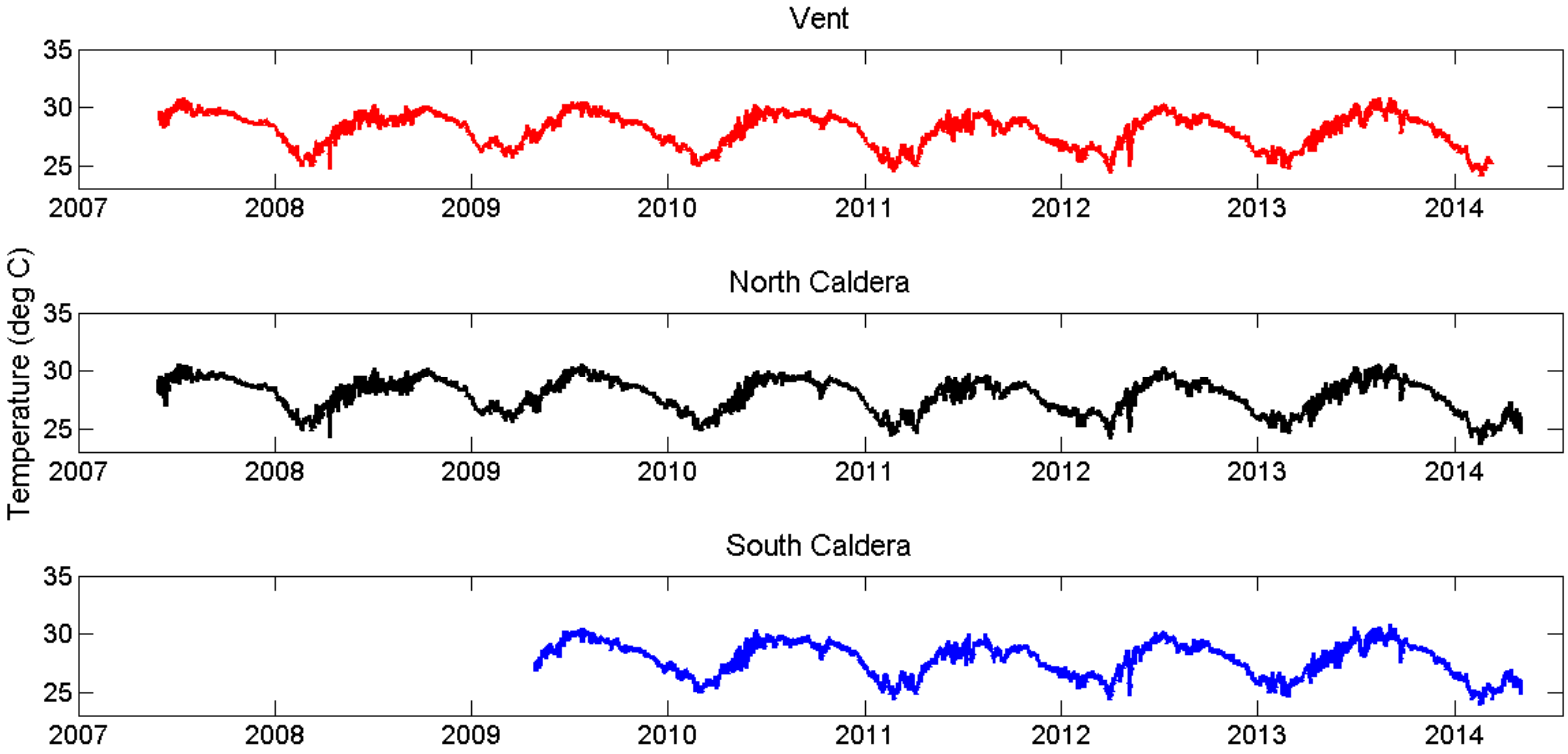
Site		pH range	Chemistry	Coral	Reference
Tutum Bay (reef)	Papua New Guinea	8.0 to <7.7	94-98% CO_2, meteoric water, High As and Fe, pH 6.2, Alk>12meq/L, boiling	Massive Porites near vents	Pichler et al 1999
Milne Bay (reef)	Papua New Guinea	8.1 to 6.9	High CO_2	Massive Porites near vents	Fabricius et al 2011
Maug (reef)	CNMI, Mariana Trench Marine Monument	8.07 to 7.7 Vents: 5.5	60% CO_2 gas, seawater, high As and Fe, pH 5.4, Alk>3meq/L, 70°C	Massive Porites near vents	This study and CRED reports
Milos (rocky)	Greece		High CO_2	None	Dando et al 1995
Ischia (rocky)	Italy	8.1 to 6.57	>90% CO_2	Absent when Ω_{arag}<2.5	Hall-Spencer et al 2008

Gradients of Carbonate Saturation at Maug

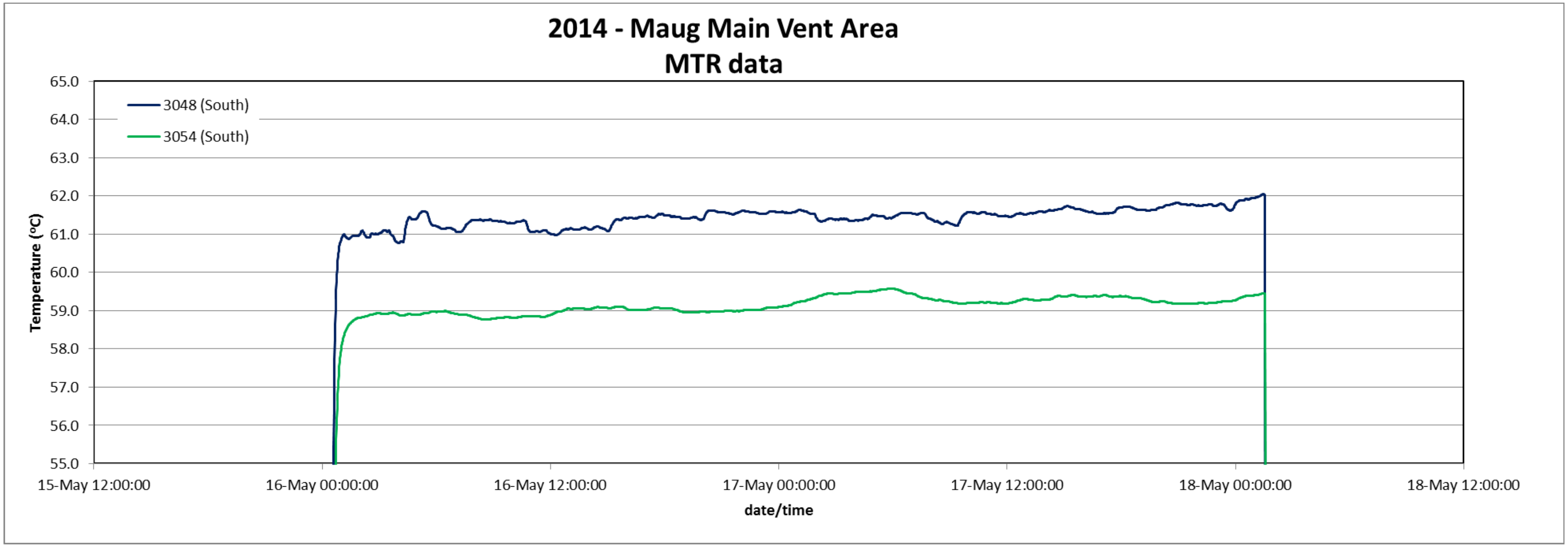
	Back-ground	Moderate	Near-Vent	60°C Vent Fluid
pH	8.07	8.0	7.8	5.4
Tot DIC	1980	2000	2300	12,000
$\Omega_{Calcite}$	4.6	4.1	3.1	0.02
Ω_{Arag}	3.0	2.7	2.1	0.02

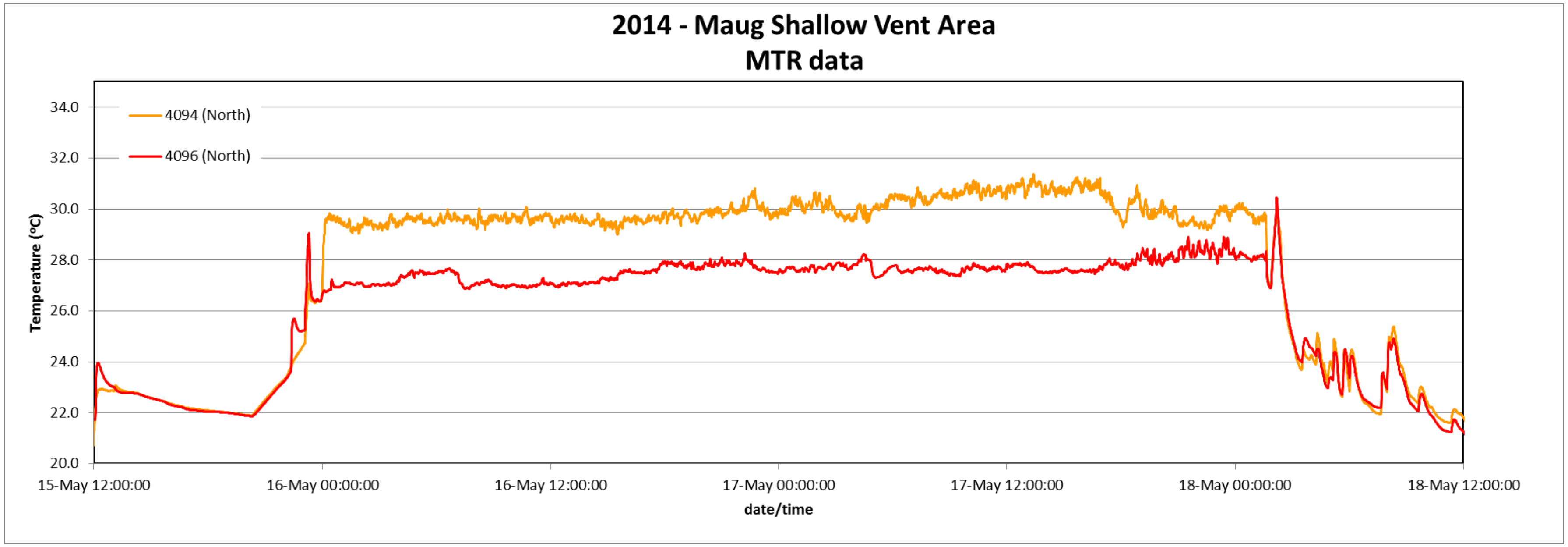
Gradients around the vent site provide an ideal range of pH/saturation conditions for coral ecology studies. AOML, PIFSC/CRED and NIST have begun coral experiments.

Maug Time-series temperature data from PIFSC/CRED monitoring



Data from Chip Young


2014 - Maug Main Vent Area
MTR data
3048 (South)
3054 (South)
Temperature (ºC)
65.0
64.0
63.0
62.0
61.0
60.0
59.0
58.0
57.0
56.0
55.0
15-May 12:00:00
16-May 00:00:00
16-May 12:00:00
17-May 00:00:00
17-May 12:00:00
18-May 00:00:00
18-May 12:00:00
date/time


2014 - Maug Shallow Vent Area
MTR data
4094 (North)
4096 (North)
Temperature (ºC)
34.0
32.0
30.0
28.0
26.0
24.0
22.0
20.0
15-May 12:00:00
16-May 00:00:00
16-May 12:00:00
17-May 00:00:00
17-May 12:00:00
18-May 00:00:00
18-May 12:00:00
date/time

Coral Generic Richness and Abundance from PIFSC-CRED

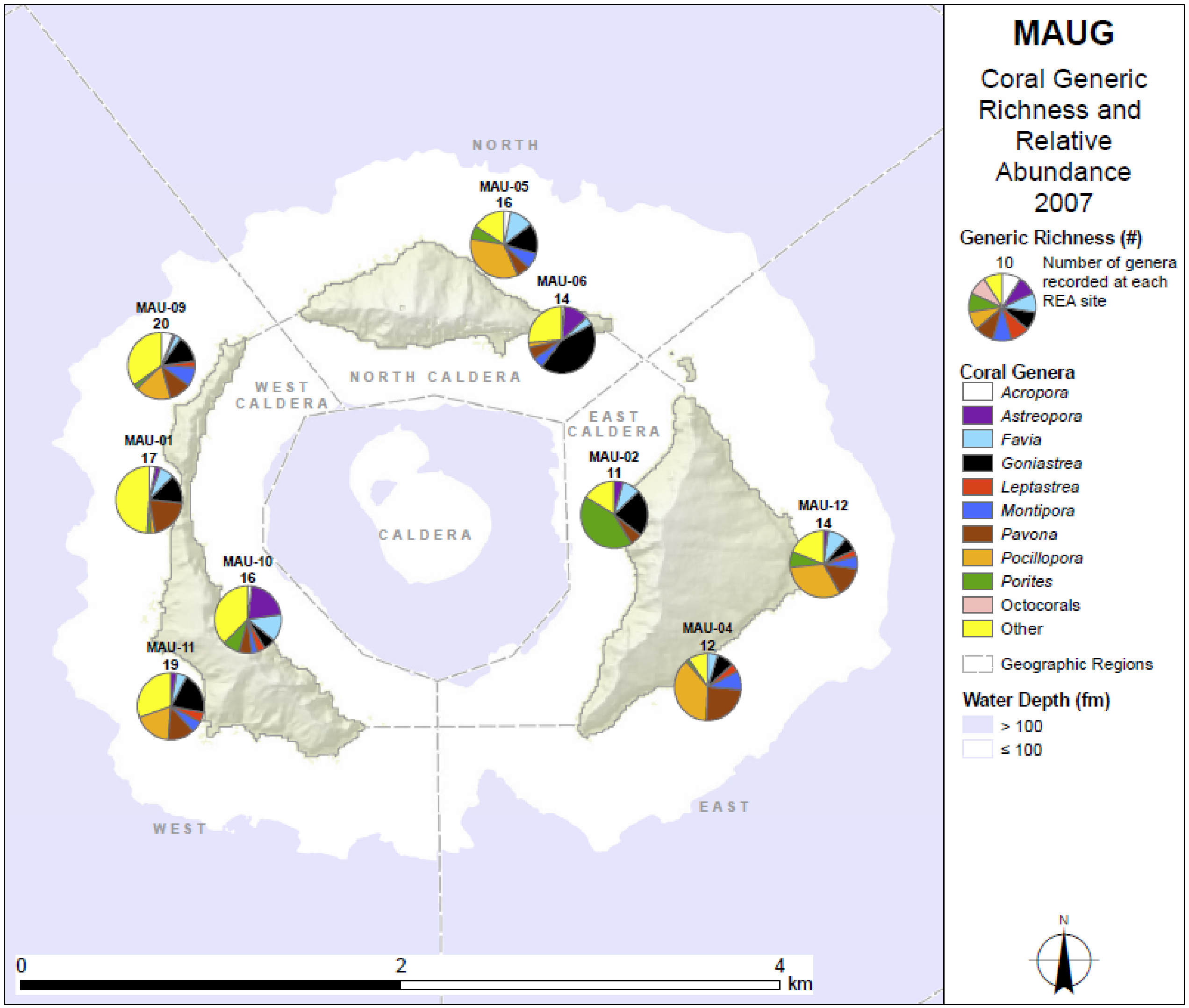


Figure 16.5.1k. Observations of coral generic richness and relative abundance of coral genera from REA benthic surveys of forereef habitats conducted at Maug during MARAMP 2007. The pie charts indicate percentages of relative abundance of key coral genera. The quadrat method was used in 2007 to survey coral genera.

Porites genera most abundant near the vent site.
Below average generic richness near vent site.

Percent Live Coral Cover, MARAMP

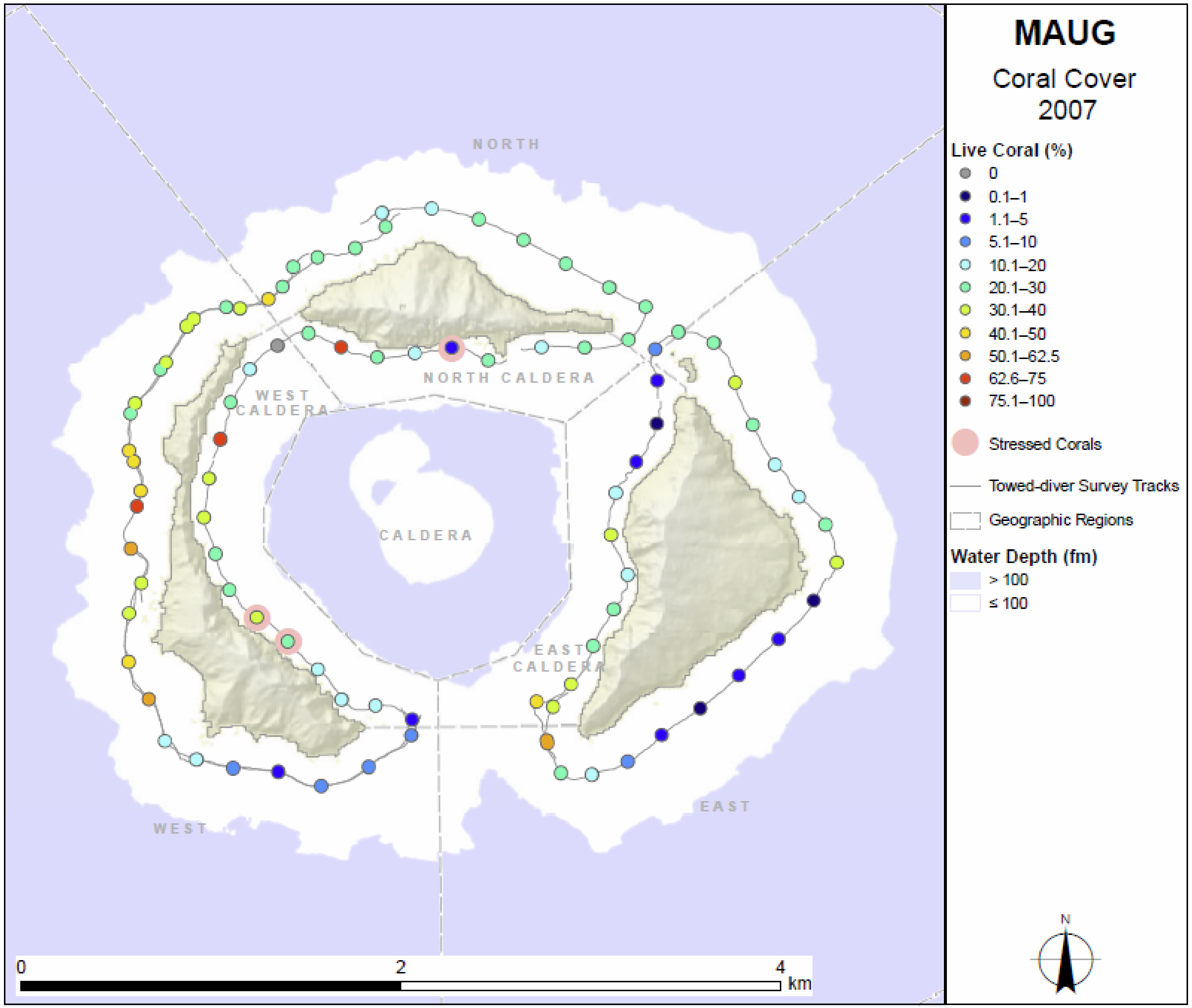
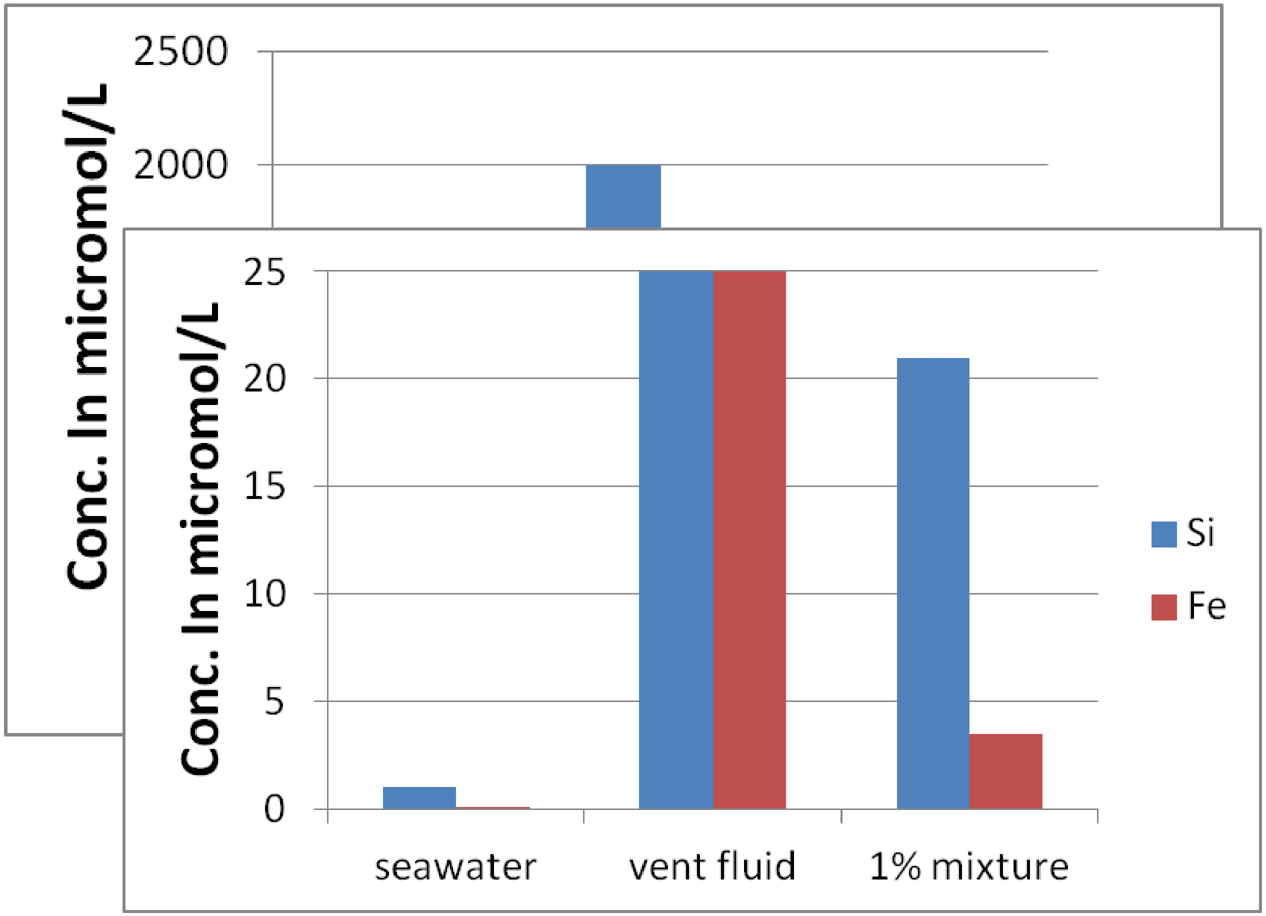


Figure 16.5.1e. Cover (%) observations of live and stressed hard corals from towed-diver benthic surveys of forereef habitats conducted around Maug during MARAMP 2007. Each colored point represents an estimate of live coral cover over a 5-min observation segment with a survey swath of ~ 200 × 10 m (~ 2000 m²). Pink symbols represent segments where estimates of stressed-coral cover were > 10%. Stressed-coral cover was measured as a percentage of overall coral cover in 2007.

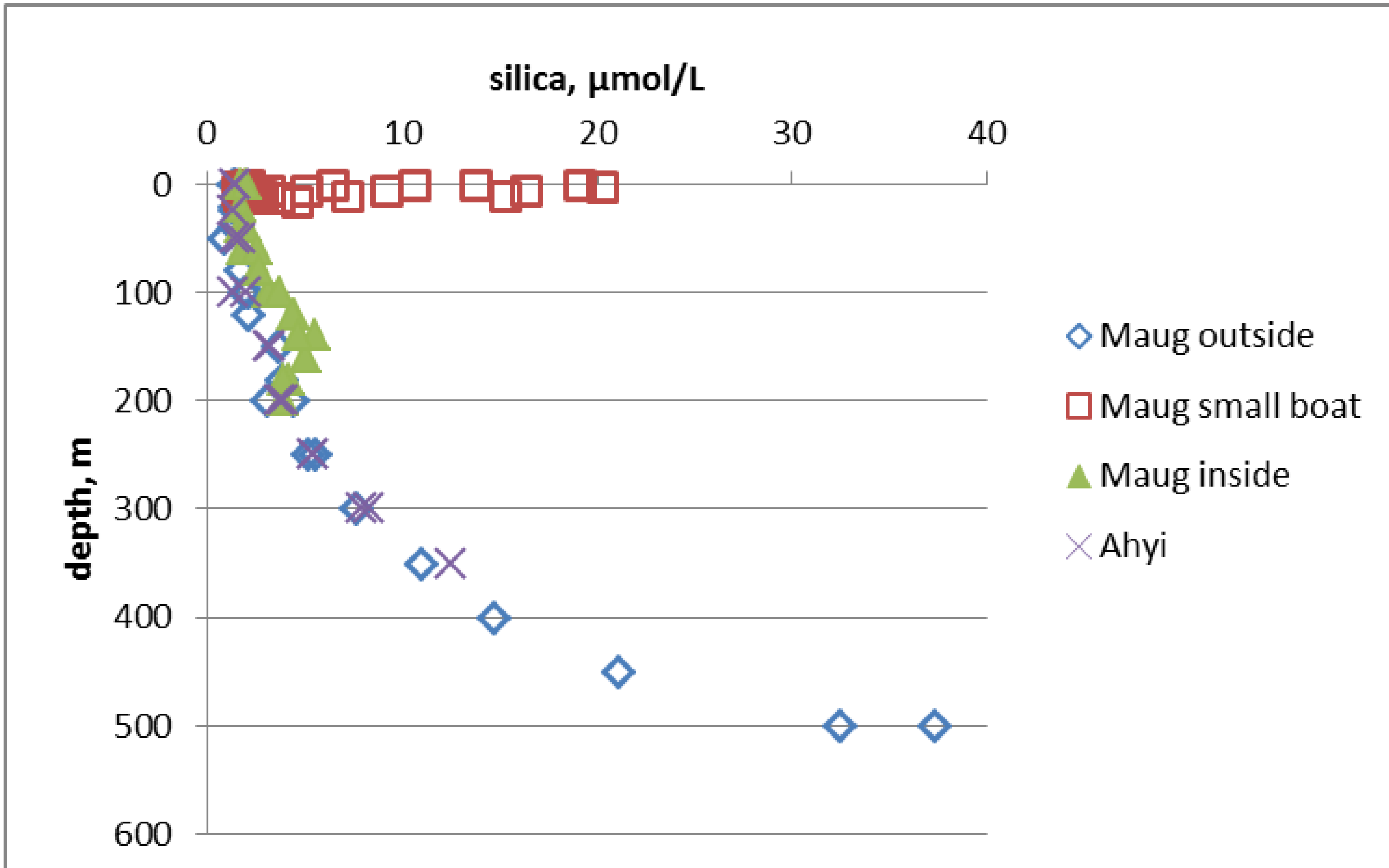
Very low coral cover north of the vent site

Vent Chemistry

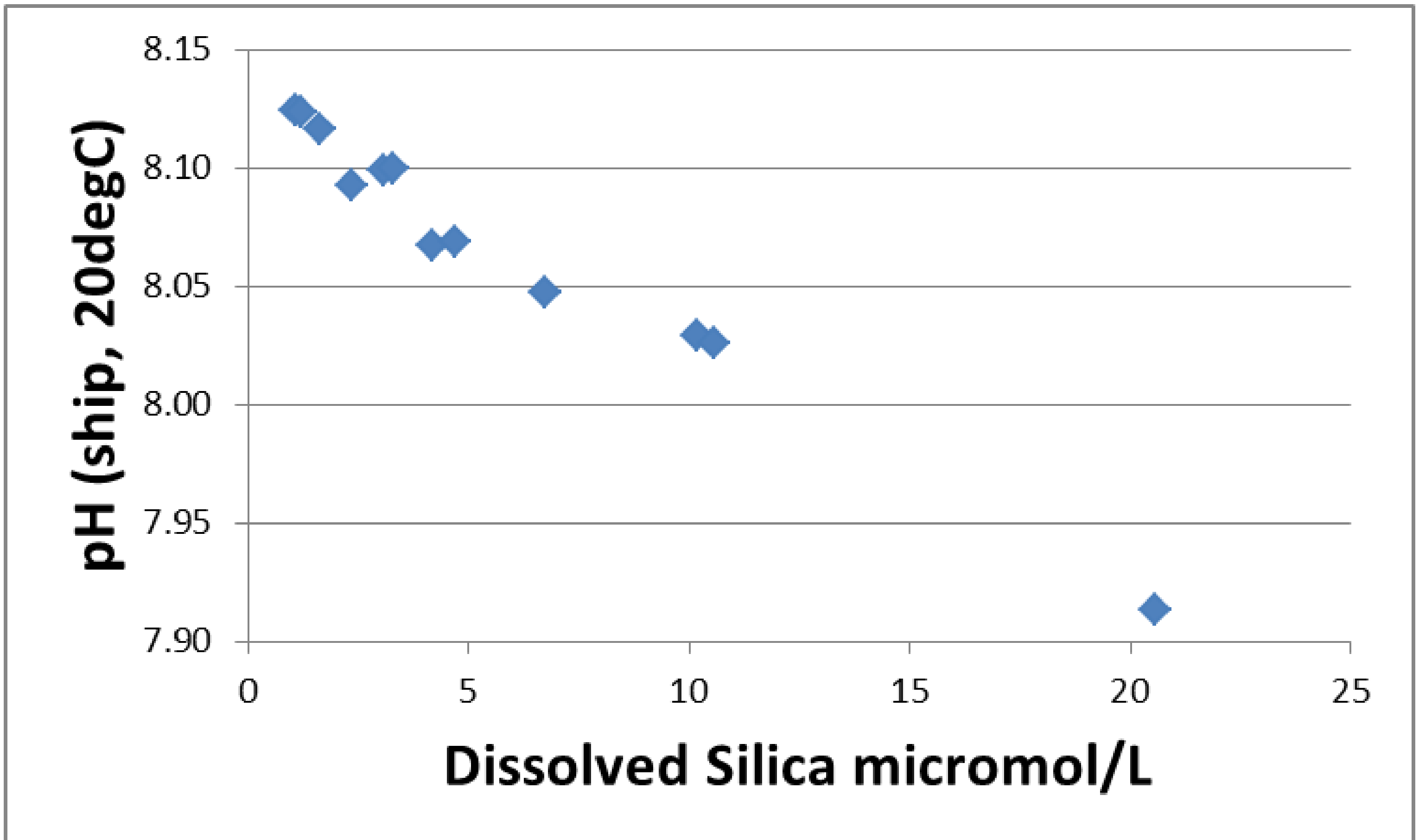


Vent waters are highly enriched in dissolved silica and iron

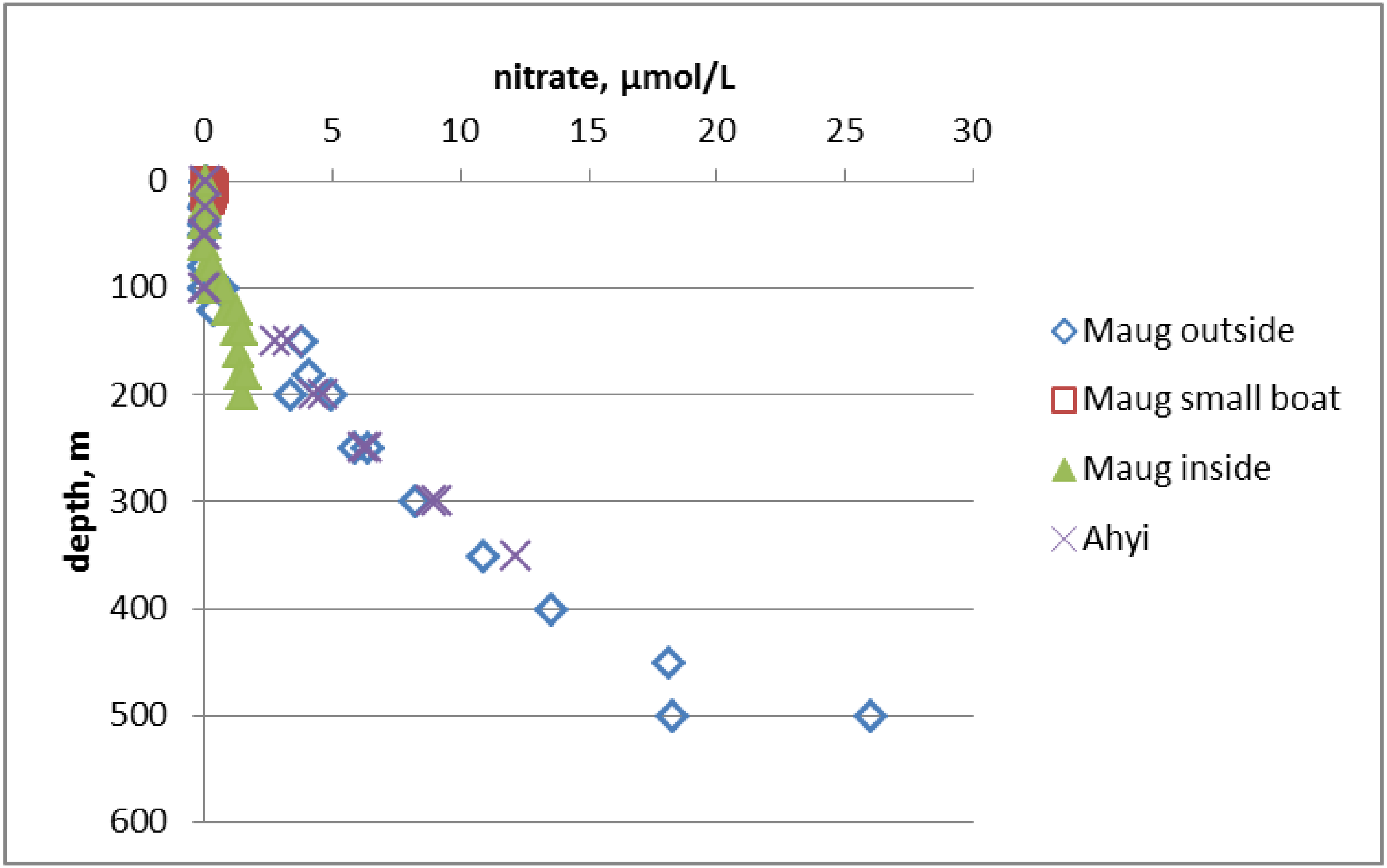
Silica Enriched in Surface From Hydrothermal Input



Strong Correlation of Si and pH



Nitrate and Phosphate Not Enriched



Sediment Sampling and Analysis

- Sediment scoop samples analyzed by XRF
- Fine fraction is 60-75% iron

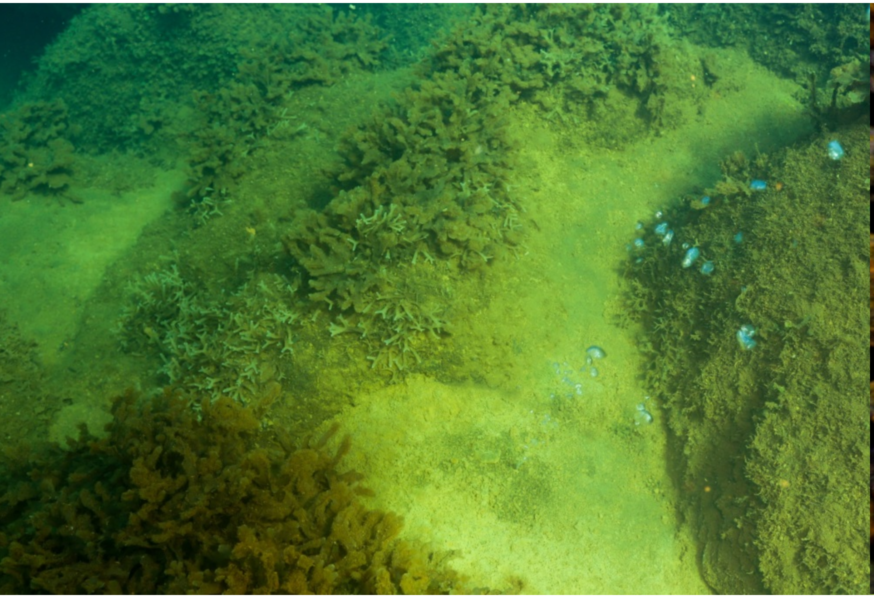
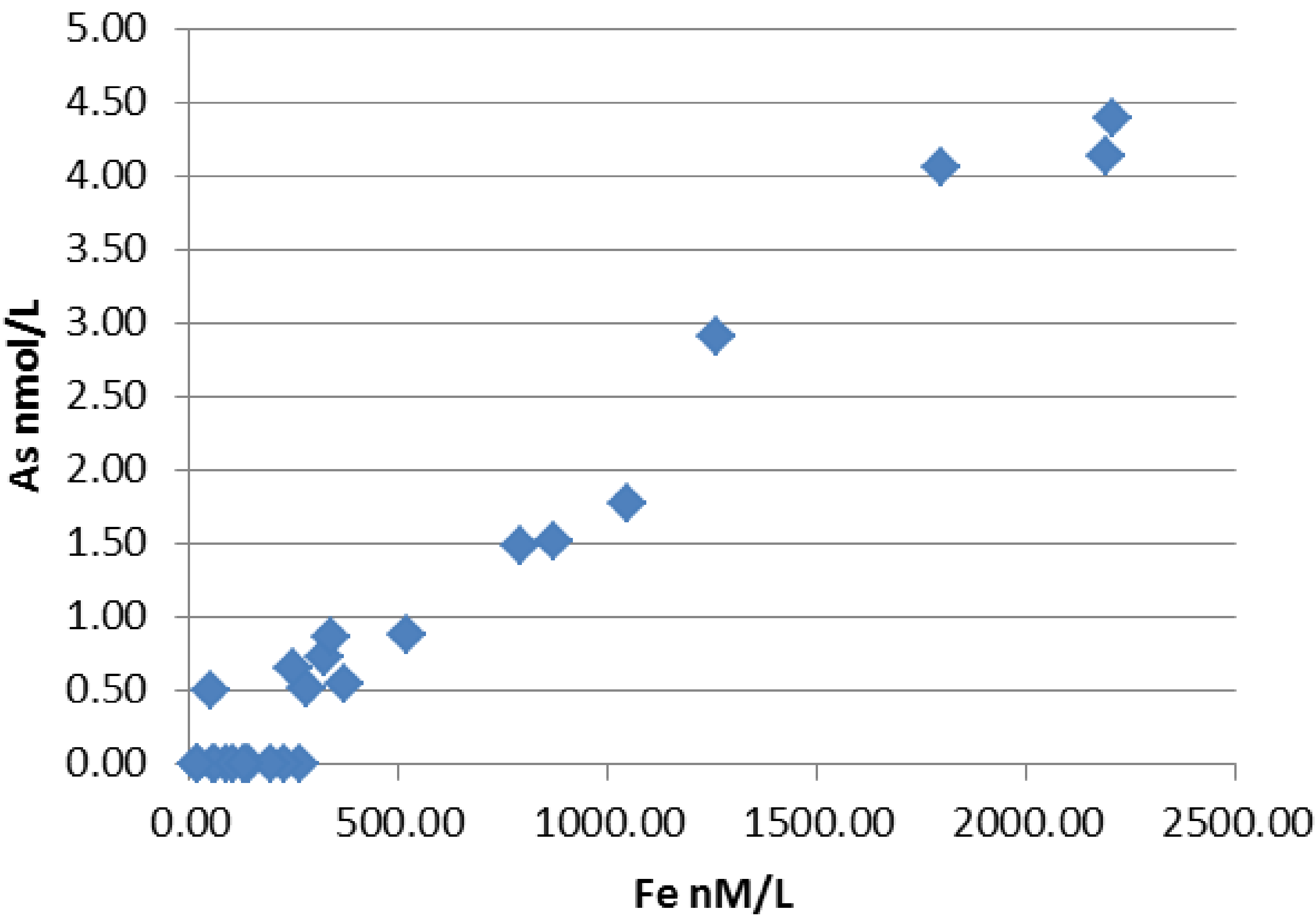


Image of sediment taken from just outside the venting field, image width ~ 1cm

Total Suspended Matter Chemistry



Suspended particles and fine sediments are mostly iron, with high arsenic content

Relevant Experimental Results: Metals Can Affect Growth/Mortality; Need data on arsenic toxicity

- Cu concentrations of 10-20 µg/L (0.15-0.30 µmol/L) caused decreased growth and bleaching in coral *Acropora cervicornis* (Bielmyer et al. 2010) and 80% mortality of *Acropora* at 40µg/L (Jones 1997), while other species (*Monastraea, Pocillopora*) were not significantly affected.
- 50µmol/L concentrations of Cd, Cu, and Pb caused inhibition of photosynthesis and growth in pure cultures of a *Symbiodinium*, with different metals having different effects (Kuzminov et al 2013).
- LC50 values of 15 µmol/L Cd, 50 µmol/L Pb, 60 µmol/L Ni, and 15 µmol/L Zn reported by Howe et al. 2014 for cnidarian representative.
- Therefore expect a wide range of coral responses to increased metal concentrations across coral species.

Conclusions

- Volcanic vents create long-term natural laboratories to study ocean acidification.
- Field work in May of this year demonstrates that Maug has excellent potential as a long-term study site.
- The full range of chemistry and temporal variability must be considered when evaluating hydrothermal impacts.