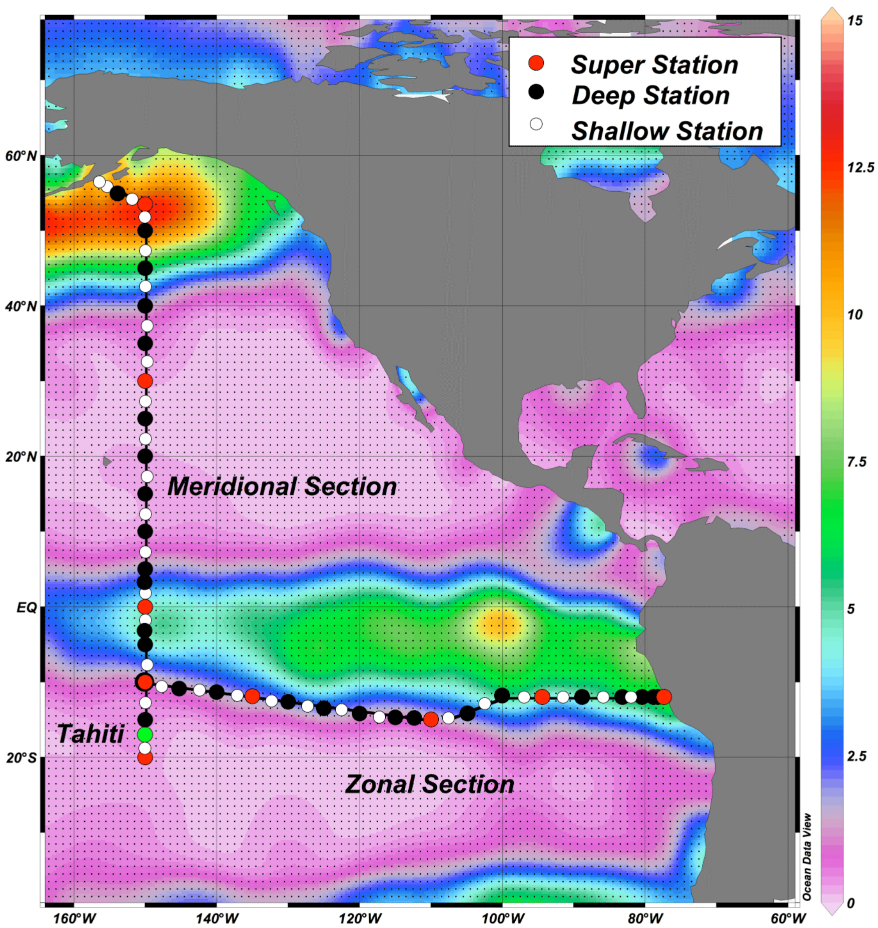
U.S. GEOTRACES

Pacific Implementation Workshop Report



Based on proceedings of a workshop
University of Southern California
1 -3 October, 2008

Edited by Jim Moffett and Chris German

U.S. GEOTRACES Pacific Section Implementation Workshop

Conveners: James Moffett (*jmoffett at usc.edu*) and Chris German (*cgerman at whoi.edu*)

Introduction

A workshop was held at The University of Southern California from October 1 to October 3 2008, to plan the first two US GEOTRACES sections in the Pacific, which will take place between 2012 and 2014. Approximately 30 scientists were present, most of whom expressed an interest to participate in one or both of these sections. This report summarizes the outcome of the meeting, including proposed transects, station locations, and approximate dates.

SSC Prioritization and Rationale

In May, 2008, the US GEOTRACES Scientific Steering Committee (US SSC) met at the Lamont-Doherty Earth Observatory. A principal objective of that meeting was to examine sections that had been proposed for the US to carry out in the three basin workshops held the previous year <http://www.geotraces.org/Workshops.html>, and prioritize them in order to determine the first three. The US SSC used the following criteria to determine each section.

1. High Impact Science, both as a part of the complete program, but also from that section alone (important to generate excitement and establish the program as a whole, both nationally and internationally.
2. Science product that underscored the value of multiple core parameters being measured on the same ship (see Science Plan), with Boundary Scavenging highlighted as a case in point.
3. Logistics. While we are confident we have the ability to carry out all the proposed sections successfully, simpler logistics are an important, albeit secondary, condition for the early sections.
4. Complement International Efforts

Using this prioritization, the US SSC selected a North Atlantic Zonal Section as the first expedition, to take place in 2010. That cruise was the subject of the preceding workshop, in Woods Hole, Sept 22-24, 2008. The objective of that workshop was to formulate a specific plan and draft a proposal to be submitted to NSF by February 15, 2009.

The SSC also highlighted two Pacific Sections, a zonal section originating in Peru and a meridional section from Tahiti to Alaska, as the second and third cruises. The order was not decided, but there was a recommendation that the cruises be run sequentially in a single year as a big “L”.

Goals of Workshop

This workshop was charged with developing a science plan for the two Pacific Sections, including specific cruise tracks, station locations and determining which section should be carried out first. The workshop was also charged with determining the feasibility and science merit of running the “Big L” as a single section. While the first cruise will not take place before 2012, an important task was to develop a plan that could be referenced in the Atlantic Zonal Proposal.

Approach

Several participants gave overview presentations of the physics and geochemistry of each section, followed by a series of advocacy talks. Subsequently, breakout groups developed detailed plans for the hydrothermal and OMZ components of the zonal section and also for the tropical and high-latitude components of the meridional section.

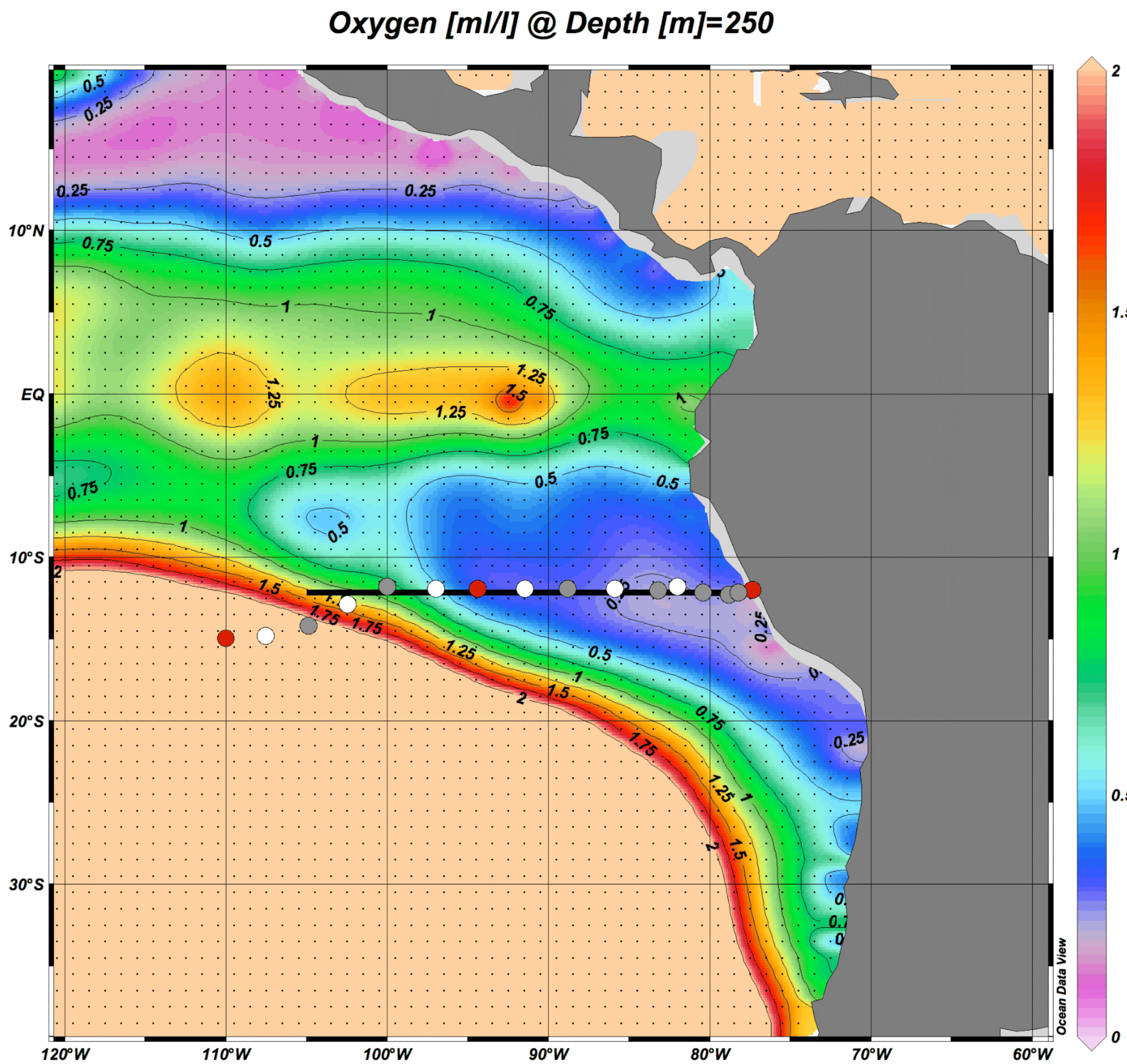


Figure 1. Proposed OMZ half of the Zonal section, showing Super Stations (red), Regular deep Stations (grey) and shallow stations (white).

Findings

A. Zonal Section

Rationale
A section from Peru to Tahiti was proposed which would include the Peru Margin, upwelling and oxygen minimum zone (Figure 1), as well as the large hydrothermal plume originating from the southern East Pacific Rise (EPR) (see Figure 3 below). Proposed cruise tracks were developed by two breakout groups addressing the Peru Upwelling/OMZ and Hydrothermal Plume components, respectively, followed by a discussion in Plenary.

The scientific rationale for the section from Peru to the EPR centered around the highly productive upwelling region, associated with boundary scavenging and an extensive oxygen minimum zone. Indeed, $^{230}Th/^{231}Pa$ data suggest that this may be one of the best places in the world to study the relationship between trace element scavenging and particle chemistry. Other core parameters like Ra will provide important information about margin sources versus internal cycling for elements like Fe and Mn that are enriched in low oxygen regimes. The section cuts across a large gradient in N/Si ratios that will enable us to study how Si availability, and related changes in phytoplankton taxa, influence metal:nutrient ratios.

The section is also an excellent place to study the relationship between paleoproxies and carbonate ion concentration in a region where carbonate ion and temperature are not strongly correlated. While DIC data are not explicitly listed as core parameters, one possibility is to collect 2 DIC system parameters to calculate carbonate ion concentration. Subsequent core top collection, possibly by Peruvian colleagues, can complete the proxy calibration.

The N cycle provides an important rationale for this section. The cruise track crosses one of the three main regions for denitrification in the ocean, and a nitrate-depleted region offshore that has been proposed to be an important area for N fixation. The coupling of N-cycle processes with TEIs is largely understudied as well, yet important relationships may exist. For example, regions of active denitrification have elevated Fe concentrations associated with high nitrate depletion. Residual, elevated iron present in these waters when they reach the surface may fuel N fixation. Strong lateral and vertical gradients in many core parameters are anticipated, so an important objective of the workshop was to develop an intense but realistic sampling plan. Peru upwelling is one of the best places where oxygen isotopes in phosphate can be used to learn about P cycling.

Cruise Track and Logistics

It was decided the section should start on the Peruvian side at 12°S to begin the section with a time series site maintained by the Peruvians (Figure 2). A further advantage of staying this far south is that the temporal variability of OMZ increases northward; for a more stable OMZ, we must stay in the south, near 12°S. Both ENSO and coastal trapped waves cause a lot of variability in the OMZ further north.

The transect from Peru to Tahiti requires 17-18 d of transit time, allowing for 30 days of station time. This allowed for 15 days of station time for each half of the zonal section. A breakdown for the Peru OMZ component was proposed consisting of: 6 days for 3 super stations with the balance of time given over to 7 full depth stations plus a similar number of shallow stations and a test station (assuming we ran the transect in an E-W direction).

Intense sampling is proposed across the shelf-slope break, where we anticipate strong gradients in primary production, redox gradients and iron concentrations. We anticipate large fluxes of Fe oxides and biogenic particles in this region that may be important in boundary scavenging. Several of these stations will coincide with Peruvian time-series stations inside and outside the upwelling front.

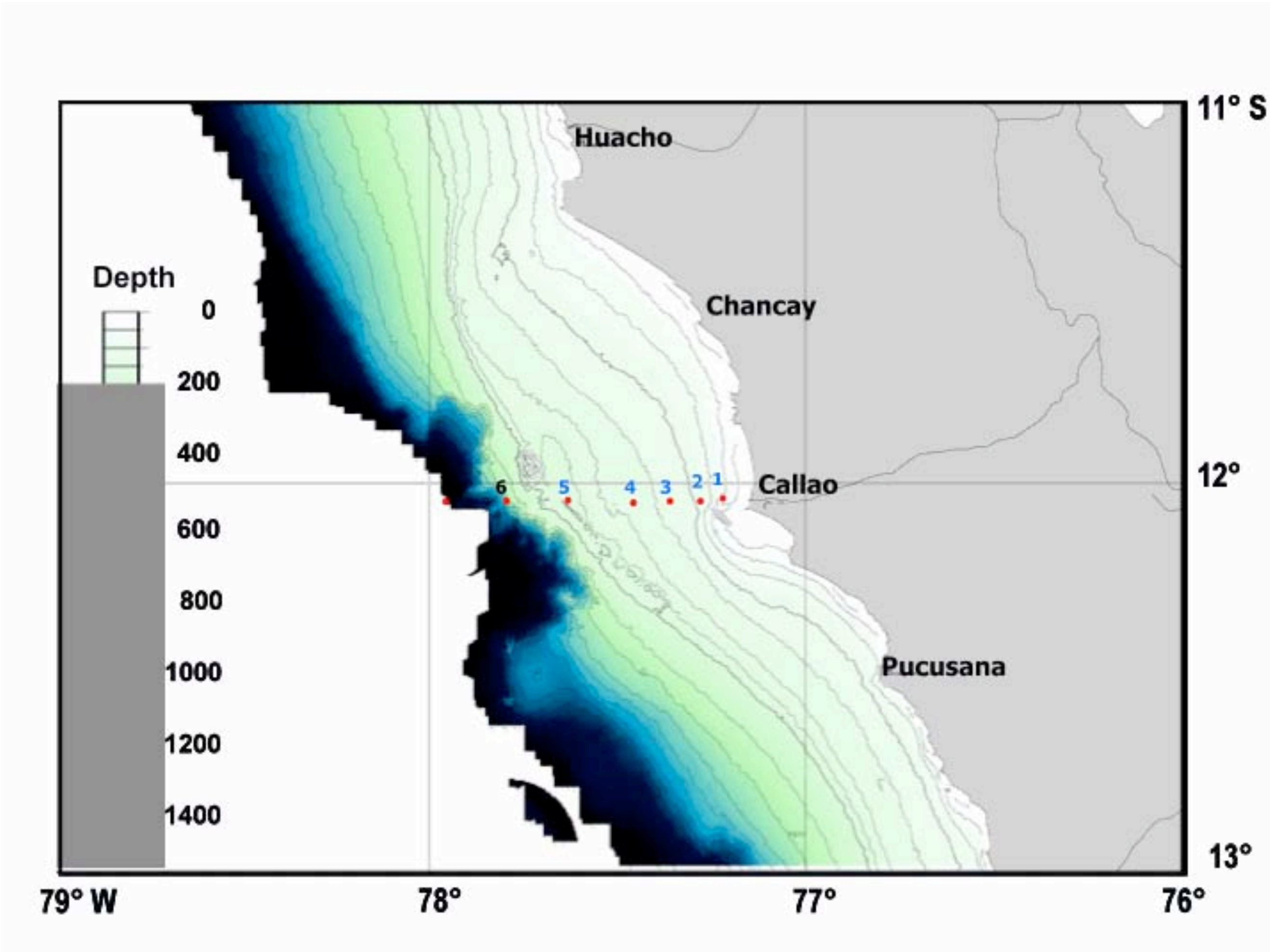


Figure 2. Time Series Stations (designated 1-7 on this map) maintained by El Instituto del Mar del Perú (IMARPE). Those closest to shore are occupied monthly; further offshore occupied every 6 months.

The scientific rationale for the second half of the zonal section lies primarily with the fact that this section would afford GEOTRACES the best opportunity, world-wide, to study hydrothermal impacts on ocean biogeochemistry at the basin scale. Simultaneously, it would provide excellent opportunities for complementary process studies at the ridge-crest where, on the southern East Pacific Rise, ridge spreading rate is at its fastest and hydrothermal venting is anticipated to be at its most intensive.

Geochemically, the fate of Fe discharged from hydrothermal systems would be a primary focus because recent work has suggested that dissolved Fe, complexed in hydrothermal plumes, could represent the source of as much as 15% of all deep ocean Fe, globally, and perhaps even more of the Fe content of the deep Pacific Ocean. What is also the case, however, is that the process of Fe oxidation and precipitation can also lead to extensive particle scavenging in the deep ocean on a par with that in high-productivity upwelling zones.

A further advantage of the proposed section, therefore, is that it would provide a compelling opportunity to compare and contrast the behavior of key tracers in the SEPR hydrothermal plume and the Peru OMZ – notably, the redox cycling of Fe and Mn (released in high concentrations, 10^6-fold higher than seawater, in high-temperature hydrothermal vent-fluids) as well as TEI scavenging, particle dynamics and particle geochemistry when polymetallic sulfides and Fe/Mn oxyhydroxides precipitate in the resulting hydrothermal plumes.

Two further opportunities provided by this section were recognised:
a) This section, extending west across the Central South Pacific Ocean to Tahiti, would allow sampling of some of the most extreme open-ocean oligotrophic waters on Earth;
b) By better constraining the global He-3 budget of the Pacific Ocean, this section would allow us to better resolve hydrothermal inputs of heat and chemicals to the *global* ocean, not just the South Pacific.

Cruise Track and Logistics

For the Western half of the Zonal section, starting at the East Pacific Rise, we chose to apportion the available time, assuming a 28h window for regular stations, to occupy ten stations, total, between 110°W (at the ridge crest) and 150°W. Three of these would be selected as "Super Stations" for large-volume sampling. Their locations were selected to lie along the core of a previously defined ^{3}He rich hydrothermal plume, dispersing at ca. 2500m depth, which extends beyond 150°W, where the westernmost limit of this Zonal section would intersect our planned Meridional section (see later).

To conduct such sampling at a regular 5° of Longitude spacing would require a total of 9 full-depth stations. Thus, within the time available, only one additional station could be proposed - at 112°W - to provide higher resolution sampling in the youngest section of the plume, closest to the ridge-crest. Any more detailed near-vent sampling would be conducted during a proposed follow-on, submersible-led process study that would be focused, exclusively, at and close to the southern EPR ridge-axis.

The proposed station locations for the western half of the Zonal section are shown in Figure 3:

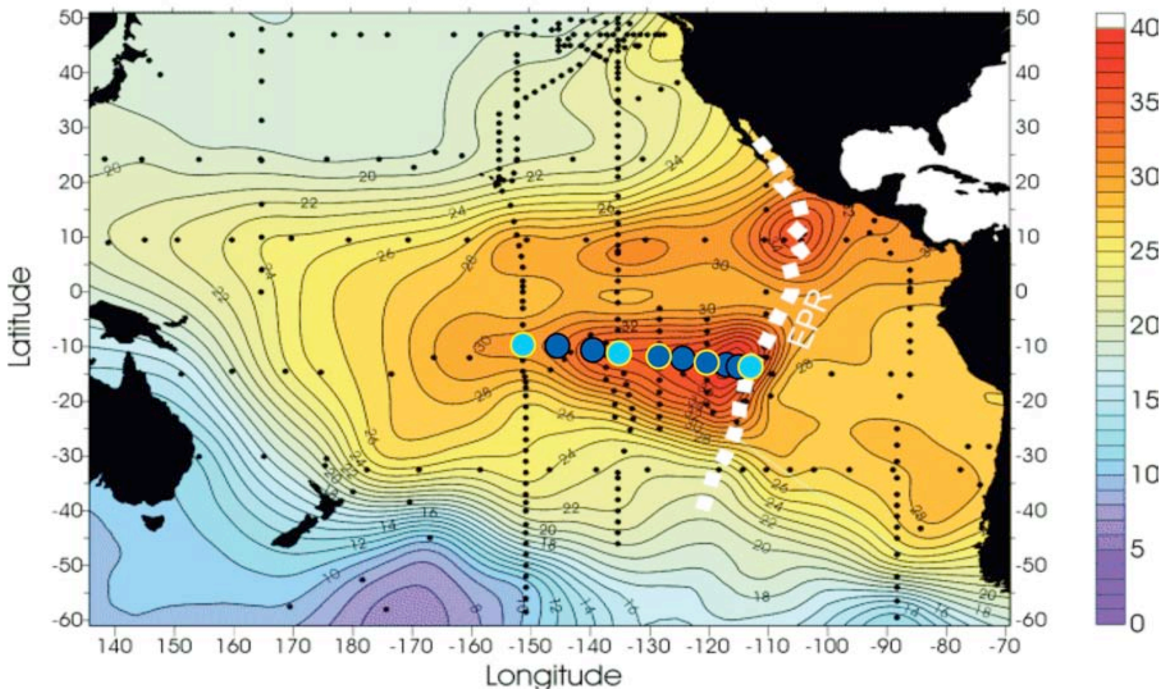


Figure 3. Proposed hydrothermal half of the zonal section, showing Super Stations (pale blue), and regular deep Stations (blue).

There are three proposed "super-stations" - one each on the ridge-axis, at 135°W and at 150°W. The last of these is also proposed as a potential intercalibration station between the Zonal and Meridional high-priority Pacific US GEOTRACES sections. Dark blue circles represent the 7 further full-ocean depth stations proposed. Of these, two stations, in addition to the three super-stations, can be located, precisely, to lie along maxima in prior cross-axis deep-water hydrothermal $^{3}He/^{4}He$ plume surveys (South-Tow, HELIOS & WOCE: data compilation courtesy of John Lupton, NOAA-PMEL).

At all stations we propose one further departure from "typical" full ocean depth stations elsewhere in the broader US GEOTRACES program. For the upper water column, we propose CTD casts that will take samples from 0-1500m, rather than 0-1000m. The reasoning for this is that it would allow us to conduct higher resolution sampling in the deep waters at each station associated with the dispersing hydrothermal plume. Close to the ridge axis (assuming a section progressing from East to West) we will be able to define the depth and, more exactly, the isopycnal surface associated with the maximum non-buoyant hydrothermal plume signal using in situ optical back-scatter sensors mounted on the CTD-rosette. Then, at that and all subsequent stations, our deep-water casts will include three samples from each station at, just above (order 100m) and just below (order 100m) the depth of the dispersing hydrothermal plume.

B. Meridional Section
Rationale

A meridional section from south of Tahiti to Alaska along the 150°W meridian (the WOCE P16 line) was accorded a high priority by the steering committee and the participants of this workshop. Strengths included the oldest water/ ^{14}C age, inputs from high oxygen intermediate waters, and from the Sea of Okhotsk. Atmospheric inputs from Asia may have a strong signal which could be observed in the section. The section would start in the most oligotrophic waters on earth and end up in the HNLC waters south of Alaska and the productive Alaska margin waters. Exceptionally high vertical and horizontal (north of 50°N) gradients in NO_3^- and $Si(OH)_4$ provide outstanding opportunities to study metal-nutrient stoichiometries and transport processes, and their relation to low oxygen and high AOU in the oldest waters. The largest radiogenic Nd signatures in the oceans will be encountered on this transect. It provides an opportunity to study the far end of the OMZ extent, and deconvolve multi-dimensional processes, like the origin of the sub-surface Mn maxima, that are still controversial. Hydrothermal inputs would be encountered at four locations along the transect (10°S, 10°N, 20°N, 35°N), intercepting a major basin-crossing hydrothermal plume at each of these four latitudes.

Discussion of this section focused on three areas – the long, central gyre transects, and the areas where the section crosses the equatorial upwelling and the Alaska margin.
Basic calculations assumed a nominal 50 day cruise with 18 days transit and 32 days for station work. First, without considering intensive sampling near the equator or Alaska:

• From 20°S to 53.5°N @ 5° separation = 16 stations
• 12 "full" stations @ 28h + 4 superstations @ 48h = 22 days {Superstations at 20°S, (10°S), Equator, 30°N, 53.5°N}
• interspersing 1000m stations at 15 locations = 15 additional hours
• adding 4 additional deep casts (4 bottles x 6 depths) = 24h

These would take 28 days, leaving 8 days for extra stations at the equator and northern end of the transect.

Equatorial Upwelling Component
Summary of processes of interest:

Zonal circulation patterns are significant and complex (Figure 4, from Wyrtki and Kilonsky, 1984). The major components are the westward flowing North and South Equatorial Currents (**NEC** and **SEC**), which occupy most of the region. The Equatorial Intermediate Current (**EIC**) is a subsurface band of intensified westward movement between 2°S and 2°N at depths between 300 and 1000 m.

All other components of the system are narrow (200–400 km) bands of eastward flow: the North and South Equatorial Countercurrents (**NECC** and **SECC**), found at depths between 0 and 200 m and located between 5° and 10°N and 5° and 10°S, respectively; the Equatorial Undercurrent (**EUC**), found on the equator at a depth of 200 m; and the North and South Subsurface Countercurrents (**NSCC** and **SSCC**), found on either side of the EIC at depths between 400 and 700 m. This complex circulation pattern will be very important for TEIs. For example, the EUC originates along the "Ring of Fire" and may have a significant signature reflecting that source. However, meridional circulation on decadal timescales may be as/more important for the TEIs. This circulation pattern is like a Hadley Cell (downwelling in both subtropics and upwelling in the tropics). The subsurface countercurrents (SCCs, also known as Tsuchiya jets) would be an interesting feature to study. Nd in AABW and the westward extension of the OMZ are also interesting features here.

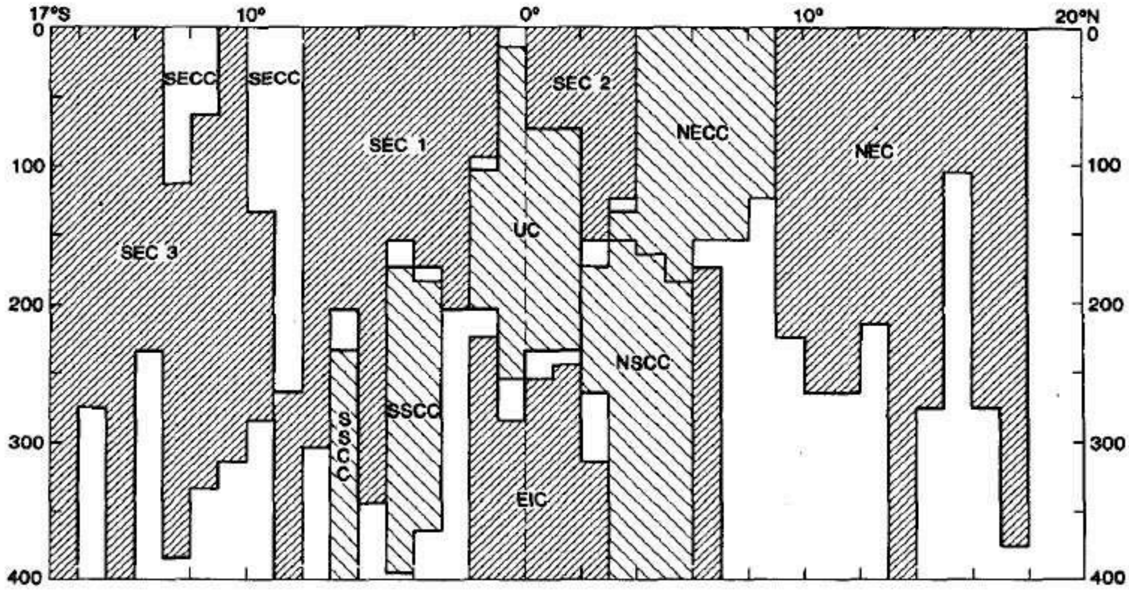


Figure 4   Areas occupied by the main zonal currents between Hawaii and Tahiti. Dark shading is westward flow, light shading is eastward flow.   From Wyrtki and Kolonsky, 1984.

Station recommendations:

The working group recommended two "super duper" stations, plus eleven 28h stations and 13 shallow stations. Six stations, including both "super duper" stations, would include casts to 6000m.   These details are summarized in Figure 5. The highest resolution is near the equator, since, from Figure 4, this is where the greatest structure is.   Given the significant and fine scale structure station/bottle spacing will need to be "dynamic" rather than follow a set plan. Use of ADCP will be critical for feature driven rather than schematic driven sampling.

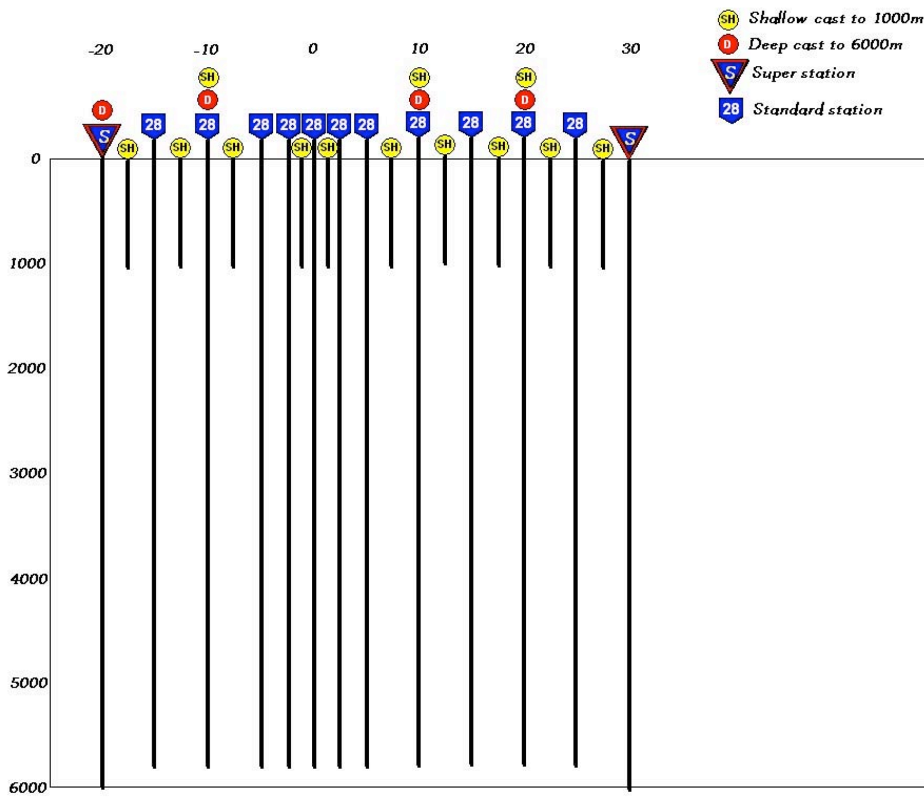


Figure 5. Proposed Stations Across the Equator. Latitudes are shown across the top.

Northern Segment of the meridional section.

Key Objectives

This group defined objectives and used these to prioritize where the section would end as well as where the stations would be located. Most importantly, the cross-margin section should encounter the island arc signature by being diverted toward the NW (approximately) from 53.5°N, 150°W (Figure 6). However, any final decision concerning the northern terminus of the meridional section should me made after consulting with the Canadian GEOTRACES planning group. Another important objective is to hit the Juan de Fuca Plume at 150°W which lies between 30°N and 35°N.

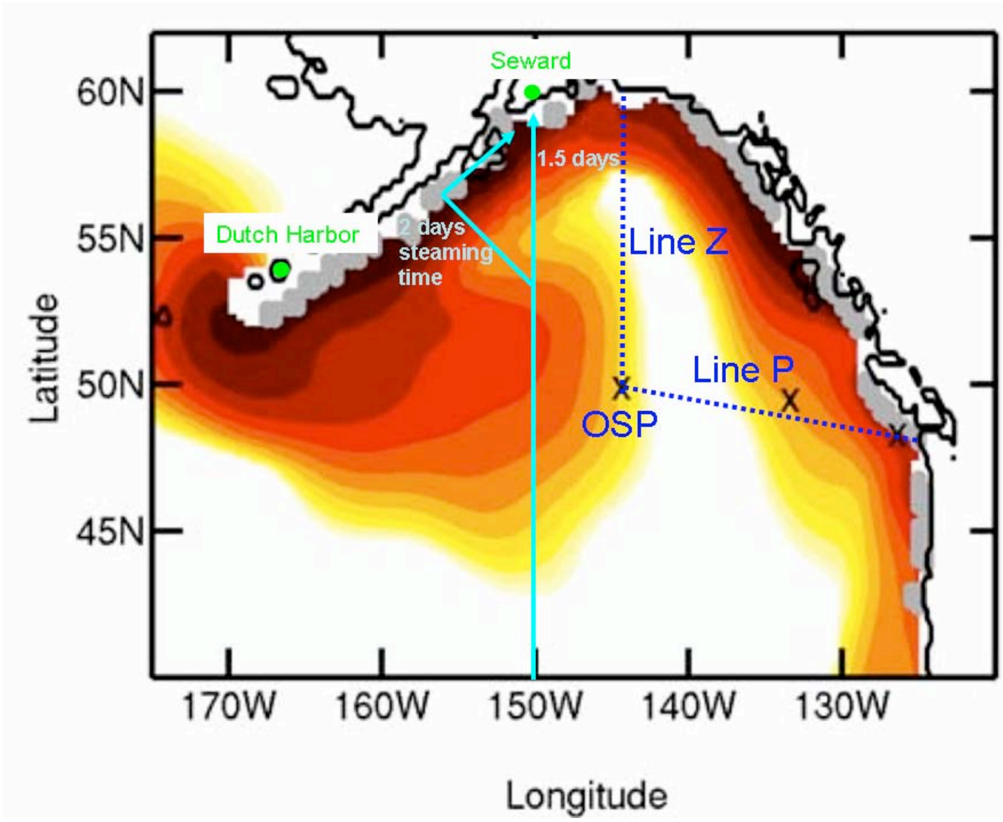


Figure 6. Map showing north end of meridional transect, including the NW excursion. Also shown are proposed Canadian Sections (dotted lines). Colored contours indicate modeled dispersion of particulate iron from margin sediments (Lam et al., 2006).

C. Section Schedule

One option is to combine both sections into a single "Big L" cruise in 2013 of two sections separated by a port call in Tahiti (Figure 7) The Big L is superior to two sections. From a scientific perspective, the most compelling reason is that the Big L goes from continent to continent, so it enables closure to be put on mass balances for TEIs within the area it closes off. It is for this reason that zonal sections often have more scientific impact than meridional sections. Also, these two sections would be more difficult to inter-compare if they were carried out 2 years apart and at different phases of the ENSO cycle. Conversely, running the Big L could put too high a burden on the NSF budget. It could also tax the participants and gear. However, the latter argument was perceived to have a positive side. It could force the work to be spread amongst more participants, making the "Big L" more of a community-wide effort. It was also felt that there would be some cost savings in having back-to back operations, though the workshop was unable to assign a dollar value to this saving.

D. Order of Sections

In the event that the Big L proves impractical, the alternative is to stage one section in 2012 and the other in 2014. The final task of the workshop was to make a recommendation to the US SSC about which of these sections should take place first. Both sections are compelling scientifically and are likely to lead to major advances that will provide ongoing community enthusiasm and support for the

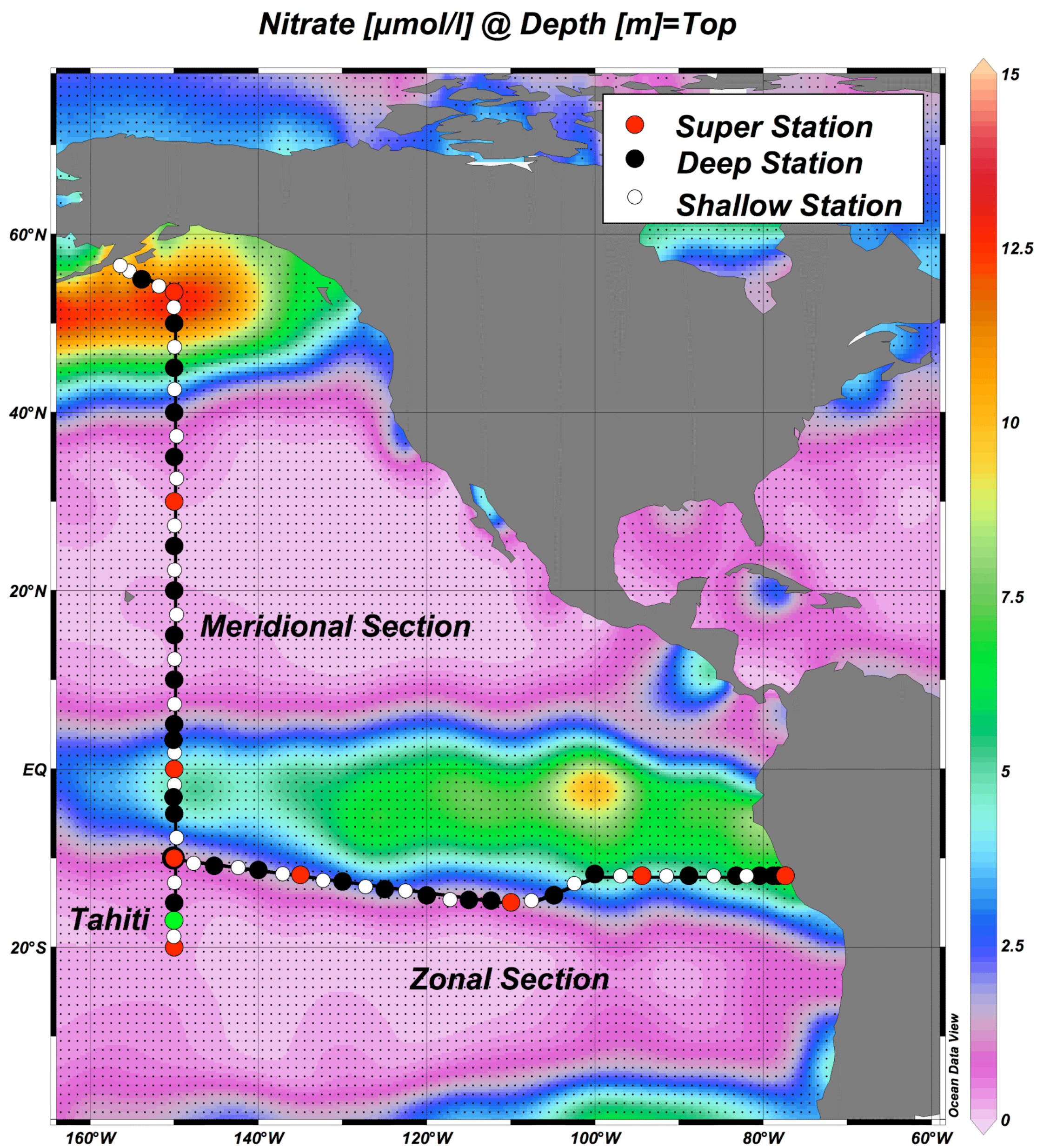


Figure 7. The "Big L" superimposed over surface nitrate concentrations. Note that in this version a potential NW "jog" at the northern end of the meridional section is included.

program. It was felt that ultimately, the relationship of GEOTRACES to other programs may be decisive, and we did not have enough information to make a specific recommendation. Examples include:

CLIVAR: The CLIVAR P16 (the 150°W meridian) line will be run in 2014, so there is a strong logistical argument to run the meridional section back-to back. However, since Fe will probably be measured on CLIVAR, it may be advantageous to run the meridional in 2012 so that interannual variability in Fe could be assessed.

The meridional section could be extended to 70°S if OPP could be persuaded to cost-share, perhaps under the auspices of the ETBC program. That would favor 2012 for the meridional, since we can't be sure the ETBC program will continue beyond that date. Realistically, however, staging both parts of the entire pole-to-pole Meridional section back to back would never be logistically tractable because both of the high latitude regions could not be occupied during the desired local summer seasons in that case. Returning to the zonal section, G&G programs that might cost-share in the hydrothermal work could also be influential, but we had no direct information on that at the workshop. More pertinent, however, was the recognition among the "Plume" break-out group that no complementary process-study using submersibles could sensibly implemented until AFTER the Zonal section had been run. Consequently, that sub-group argued that the sooner Zonal section could be implemented the better.

In conclusion, The most important outcome of the workshop was the development of two section plans that are exciting, tractable and complement each other. They are the basis for a long term plan that can be articulated in the proposal for the Atlantic zonal section. There is sufficient input here for the steering committee to decide on a plan.

References

Lam, P.J., Bishop, J.K.B., Henning, C.C., Marcus, M.A., Waychunas, G.A. and Fung, I.Y., 2006. Wintertime phytoplankton bloom in the subarctic Pacific supported by continental margin iron. Global Biogeochemical Cycles, 20(1): GB1006, doi:10.1029/2005GB002557.

Wyrtki, K. and Kolinsky, B. , 1984. Mean Water and current structure during the Hawaqii to Tahiti Shuttle Experiment. Journal of Physical Oceanography, 14(2) : 242-254

APPENDIX A: Participant List

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APPENDIX B: AGENDA

WEDNESDAY:
8:00-9:00 Breakfast
9:00-9:15 Welcome & Logistics (Jim Moffett)
9:15-10:00 Overviews of circulation and climatology (Bill Jenkins)
10:00-10:15 Coffee Break
10:15-10:45 Trace Metal Overview (Jim Moffett)
10:45-11:15 A GEOTRACES Compliant Section in the S. Atlantic (Mak Saito)
11:15-11:45 Gulf of Alaska (Ken Bruland)
11:15-12:00 Particulates and U-Th series Overview (Bob Anderson)
12:00-13:00 Lunch
13:00-13:15 NSF Perspectives (Simone Metz)
13:15-13:45 Hydrothermal Inputs (Chris German)
13:45-1400 Intercalibration Report (Greg Cutter
1400-15:00 Advocacy talks (5 min each): *We reserved a series of 5 minute slots for individuals to make brief presentations on specific measurements or scientific themes.*
15:00-15:30 Coffee Break
15:30-16:00 Advocacy talks continued
16:00-18:00 Plenary Discussion: Major Cruise Objectives & Relation to Program
18:30 Taxis back to Grand Kyoto Hotel
THURSDAY:
8:00-9:00 Breakfast
9:00-10:00 Plenary discussion and breakout group formation
10:00-10:15 Coffee Break
10:15-12:15 Breakout groups (1& 2) meet
12:15-13:00 Lunch
13:00-14:00 Breakout groups (1& 2) meet
14:00-14:30 Coffee Break
14:30-17:30 Breakout Groups (3&4) meet
18:00 Taxis depart for Ciudad Restaurant
FRIDAY:
8:00-8.45 Breakfast
8:45-10:00 Reports from all 4 working groups
10:00-10:30 Coffee Break
10:30-12:00 Plenary Discussion of working groups' Report
12:00-13:00 Lunch
13:00-15:00 Plenary Discussion: Development of a Unified Plan and prioritization of sections
15:30 Taxis depart for Grand Kyoto Hotel and LAX