Report of the GEOTRACES Pacific Basin Planning Workshop

Introduction

The Pacific Basin Planning Workshop, held in Hawaii, June 26-29, 2007, brought together 58 scientists (see Appendix 2) representing 14 countries from around the Pacific Basin and elsewhere to plan the GEOTRACES sections in the Pacific Ocean. Participants for the workshop were solicited by broad announcements in a variety of ways. This included town meetings held during the Fall AGU meeting (December 2006, San Francisco) and during the ASLO winter meeting (February 2007, Santa Fe). Additionally, announcements were made electronically via the GEOTRACES email list that had been assembled from people who had responded to earlier requests for input to the GEOTRACES Science Plan as it evolved, and announcements of the workshop were posted on the GEOTRACES web site hosted at LDEO.

The workshop (see Appendix 1 for initial workshop programme) commenced with a plenary session during which the background and development of the GEOTRACES Science Plan was described and this was followed by a presentation outlining the specific goals of the workshop. A series of presentations followed during which a representative of each participating country described how their national interests might relate to GEOTRACES and what level of ship availability and expertise they might be able to call upon to execute elements of the program. Additionally, presenters described funding and ship scheduling processes for their countries and what opportunities existed for international collaboration on proposed cruises.

A plenary presentation on iron and trace element biogeochemistry was followed by two talks on intercalibration and aerosol collection plans during GEOTRACES rounded out the first day.

The second day commenced with two plenary presentations on the physical oceanography and the geochemical gradients within the Pacific which were intended to help guide cruise track development later. These talks were followed by an open microphone session open to all participants who were encouraged to make short (5 minutes, 5 slides) presentations suggesting appropriate regions, geochemical parameters or processes that would be suitable targets for GEOTRACES cruises in the Pacific. A total of 26 such presentations were made and the overlap of ideas in many of these presentations was used to define the first set of four working groups.

The titles of working groups are listed below, the individual membership of each is listed at the beginning of the reports which are in a following section.

Marginal Seas (in the NW Pacific)
Pacific Redox/Hydrothermal
North Pacific
Zonal Equatorial Group

These groups met separately starting towards the end of the second day and they continued their deliberations into the first part of the third day. When all groups were ready, a plenary session of the workshop was reconvened and the rapporteur from each group made a brief report outlining the proposed cruise track(s) and the scientific rationale for its choice. Each of these proposals was discussed in detail by all workshop participants and in some cases proposed cruise tracks were adjusted as a result of suggestions offered from the floor.

The plenary session then shifted its focus to identifying the topics for the next set of working groups, the titles of which are listed below.

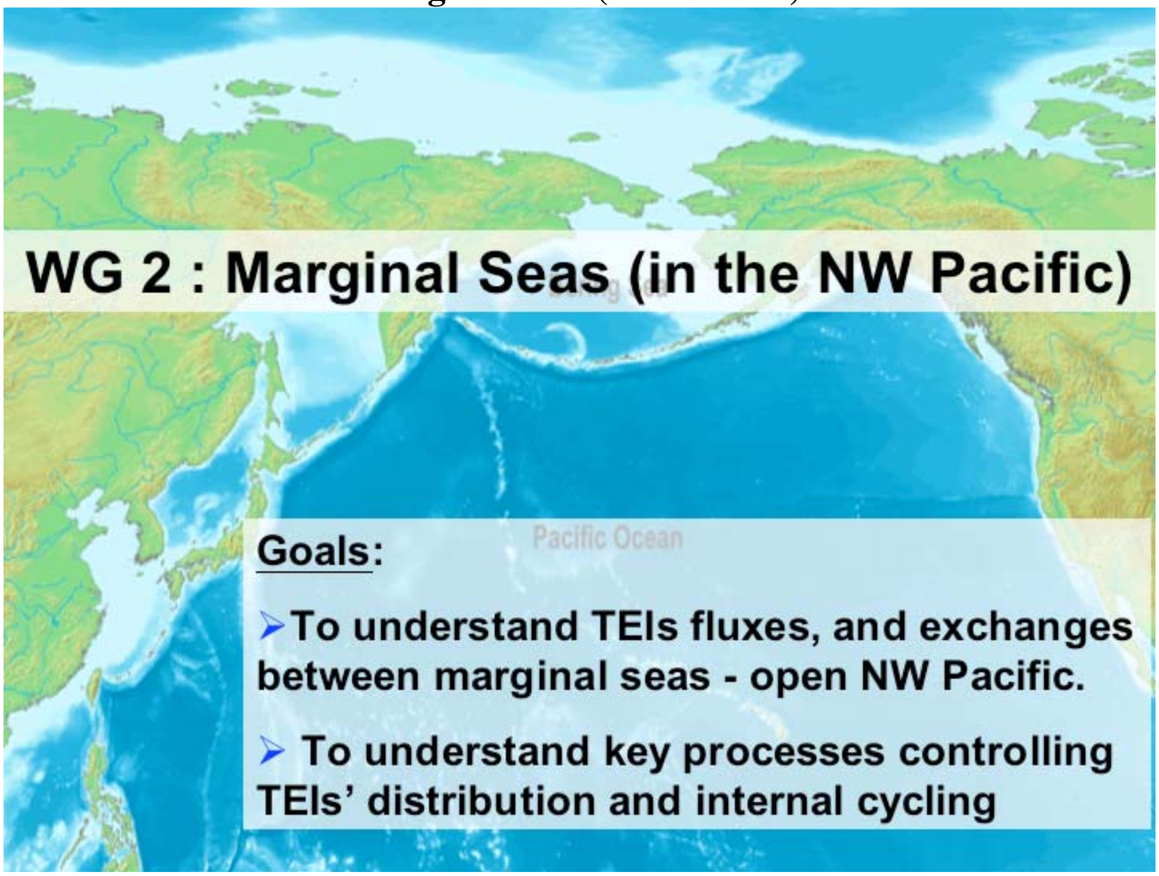
Oxygen Minimum Zone
SE Pacific
SW Pacific
Southern Ocean
Meridional sections

These groups led by their Chair's and rapporteurs met and discussed cruise tracks through the end of the third day and for approximately an hour at the beginning of the final day.

When the groups were ready the plenary session was reconvened and the rapporteurs presented their recommendations to the entire workshop where suggestions and adjustments to cruise tracks were made. In addition, to discussing the second group's objectives some meshing of the first and second set of cruise tracks was discussed and suggestions were made as to how various elements of individual cruises could be recombined to facilitate cruise logistics such as availability of ports, cruise duration etc. The workshop then broke up into groups led by the Chair's and rapporteurs of each of the nine groups to develop a written summary of the rationale for each of the proposed cruises (reproduced in the section below). These reports were then presented to a final plenary session where further suggestions and discussion about overall strategies occurred. This latter process was engaged in with such enthusiasm by the participants that the meeting was not finally adjourned until 17:30 on Friday, June 29th.

Working group reports

Marginal Seas (NW Pacific)



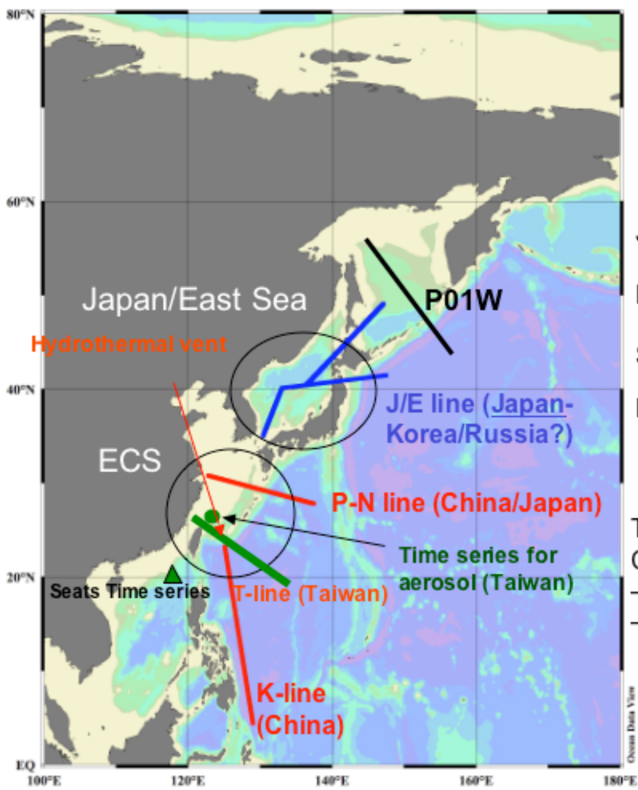
WG 2 : Marginal Seas (in the NW Pacific)

Five marginal seas proposed for GEOTRACES

1. Okhotsk Sea
2. Japan/East Sea – september, 2009
3. East China Sea – planning
4. South China Sea – under discussion

5. Bering Sea?

Study area and proposed cruise lines



Variable interests and responsibilities by surrounding nations

five transect lines for the marginal seas in the Northwest Pacific:

P01W line

J/E line :
ECS (the Korea/Tsushima strait) - NW Pacific(□ Tsugaru strait)/Okhotsk Sea (Soya Strait)

P-N line :
Yangtze estuary – ECS shelf
Okinawa Trough – the NW Pacific

T- line :
Coast of China – north coast of Taiwan – Okinawa Trough (hydrothermal vent) – the NW Pacific

K- line :
East coast of the Philippine – Southern part of Okinawa Trough

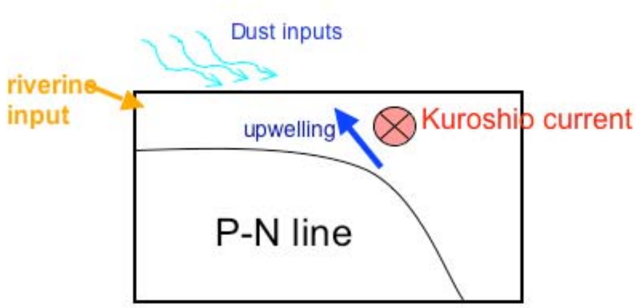
East China Sea

Objectives:

1. To quantify the key fluxes and processes (rivers, dust, vent, erosion, etc) for the TEIs' distribution.

2. To understand processes that influence the internal cycling of TEIs (Kuroshio current – upwelling, scavenging, subsurface water exchange between marginal sea – open ocean, etc.)

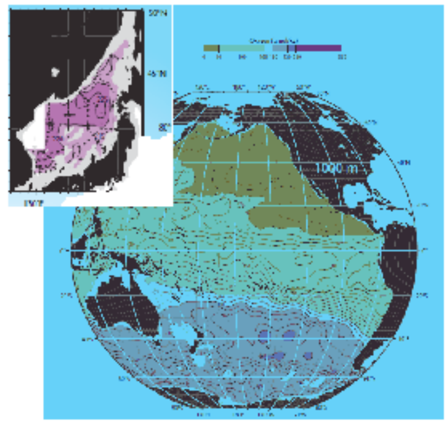
3. Calibration of paleoproxies for the Western Pacific Warm Pool and NW Pacific



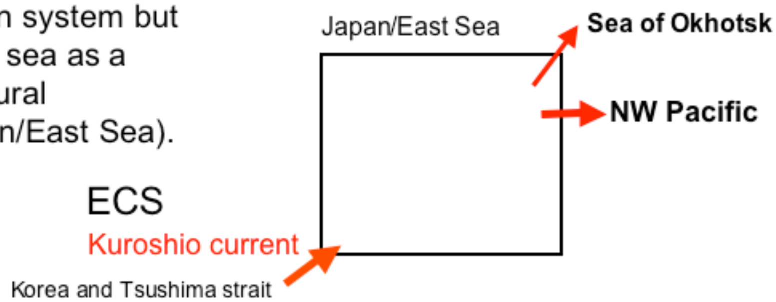
Japan/East Sea (September, 2009 – Japan/Korea/Russia?)

Objectives:

1. To quantify the key fluxes and processes for the TEIs' distribution in the semi-closed marginal sea system (East/Japan Sea)
2. To understand the internal cycling of TEIs in open ocean (i.e. Pacific Ocean) using a similar circulation system but much small-size sea as a semi-closed natural laboratory (Japan/East Sea).



A miniature ocean



Questions

- 1. EEZ problems, a S-N section in the Okinawa Trough is not planned for now, need to work with governments to resolve
- 2. Funding for most of the interested countries are uncertain, planning for most lines is flexible.
- 3. Bering Sea and Okhotsk Sea lines are under discussion, linked with J-GEOTRACES triangle cruise track
- 4. Most lines are designated as process studies due to the DM.

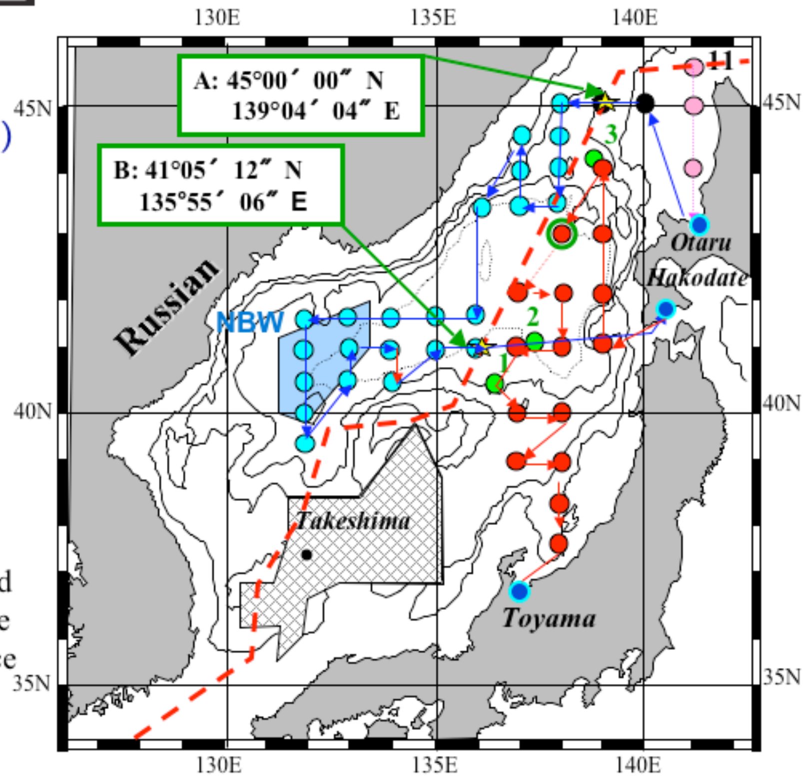
East Asian GEOTRACES project

KH09-02

September 2009

(Tentative cruise plan)

- 1st Leg
- 2nd Leg
- 3rd Leg
- St. in Russian EEZ
- Previous Stations



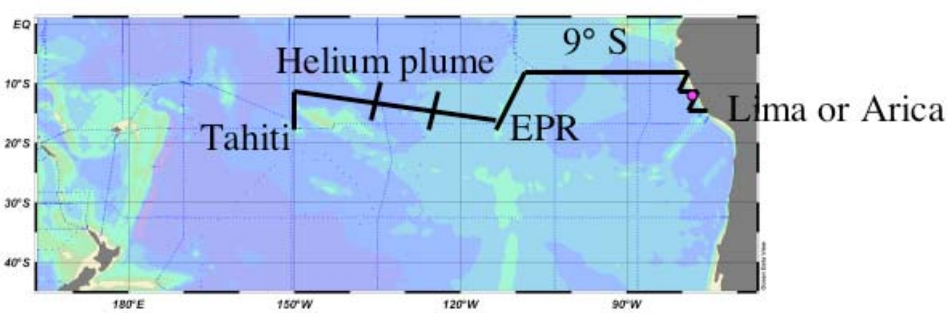
The specialist meeting on the ocean-scientific investigation between Japan and Russia was held 16 Nov. in Moscow, at the Russian Education Science Ministry.

Hydrothermal Processes

Pacific Redox/Hydrothermal Working Group

Greg Ravizza
Bob Anderson
Jim Moffett
Bill Landing
Olivier Rouxel
Dimitri Gutierrez
Juan Carlos Miquel
Marco Salamanca
Evgueni Shoumiline
Karen Casciotti

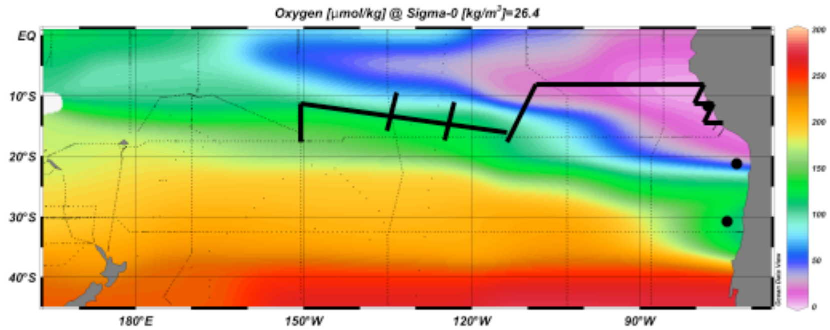
REDOX/HYDROTHERMAL SECTION PROPOSAL



Features:
- Peru Margin
- Tracking attenuation of ODZ plume
- Cross through Bauer Basin
- Mapping hydrothermal input from EPR
- Tracking fate of hydrothermal plume

GEOTRACES processes:
- Oxygen minimum zones
- Hydrothermal
- Boundary scavenging

Examine sources/sinks of redox-sensitive TEI's in ODZ, track fate of elements in low O_2 plume



- Characterization of coastal "source" region of redox active TEI's
  - Changes in shelf width/supply of TE's to surface for productivity
  - Changes in intensity of ODZ
  - Tied into Callao time series station
  - Significant paleo work on Peru margin
- Follow "plume" offshore to examine fate of elements sourced in this region

Mapping hydrothermal inputs/scavenging and plume fate

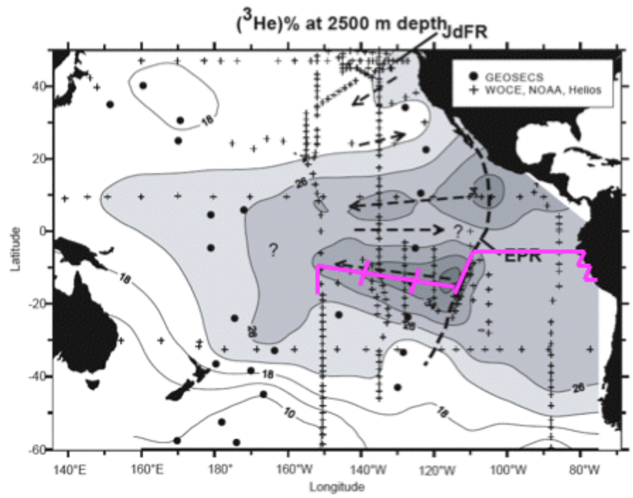


Figure 20: Map of del^{3}He (%) contoured on a surface at 2500m depth in the Pacific. Contour interval is 4%. The major helium sources lie along the East Pacific Rise (EPR) and Juan de Fuca Ridge (JdFR) systems. The dashed arrows indicate areas where the helium plumes define regional circulation patterns. Data long WOCE sections P4 and P6 from W.J. Jenkins (unpublished data). All other data from Lupton (1998). Reprinted from *Ocean Circulate and Climate*, Schlosser, P., J.L. Bullister, R. Fine, W.J. Jenkins, R. Key, J. Lupton, W. Roether, and W.M. Smethie, Jr., Transformation and age of water masses, Pages 431-452, Copyright (2001), with permission from Elsevier.

- Along-ridge axis component from 9S to 15S
  - Detailed investigation of TEI's in near-field hydrothermal plume
  - Fate of chalcophile metals (Cd and Zn), dissolved and particulate Fe, REE's, Nd isotopes
  - Scavenging of TEI's derived from seawater
- Ridge-perpendicular component westward to 150W
  - Track compositional evolution of plume particles (Fe and Mn oxyhydroxides) and ambient water
  - Does hydrothermally derived Fe leak out of the system?

Biogenic Particle Scavenging

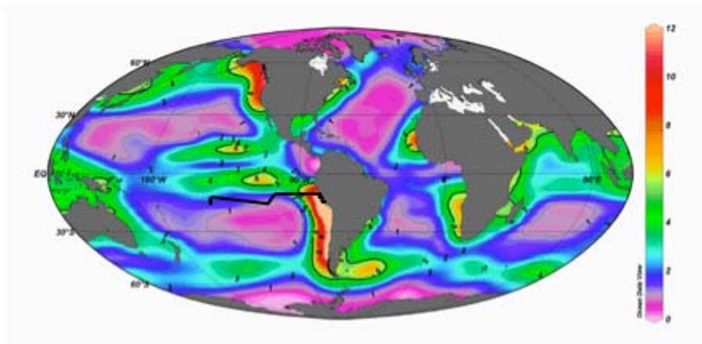


Figure 28: Export production of particulate organic carbon POC (mol C m^{-2} yr^{-1}) in the world ocean determined by an inverse model from water column oxygen, nutrient and carbon distributions. From R. Schlitzer, Applying the adjoint method for global biogeochemical modelling. In: P. Rayner (Editor), *Inverse Methods in Global Biogeochemical Cycles*. AGU Geophys. Monograph Series, Vol. 114, pp. 107-124, 2000.

- Strong gradients in POC export
- Endmember for Thorium export and other particle-reactive TEI's
- Drawdown of bioactive trace metals offshore
- Drawdown of NO_3^-, paleo productivity proxies

Other points of discussion

- Plume sampling:
  - Fe contamination
  - Large particle loads

- International participation/leadership:
  - Equipment, sampling gear
  - National interests

Unresolved

- Temporal variability of features of interest
- Cruise length--20 days of transit time??
- Sampling resolution--time on station trade off with # of stations

North Pacific

North Pacific Section Working Group Report
Chair: Kristin Orians
Rapporteur: Phoebe Lam

Working Groups Members:
Hiroshi Amakawa (Japan)
Kathy Barbeau (USA)
Ed Boyle (USA)
Ken Bruland (USA)
John Crusius (USA)
Steve Emerson (USA)
Roger Francois (Canada)
Celine Gallon (USA)
Toshitaka Gamo (Japan)
Dennis Hansell (USA)
Phoebe Lam (USA)
Brad Moran (USA)
Kristin Orians (Canada)
Yoshiki Sohrin (Japan)
Tina van de Flierdt (USA)
Jing Zhang (Japan)

Processes to consider:
Boundary scavenging
Shelf processes
Volcanic sources (Nd endmember)
Atmospheric input
Hydrothermal input
Thermocline ventilation
Margin influences on deep sea
Margin influences on upper 200m

4 baseline stations: K2, OSP, HOT, SAFe

<u>JAPAN</u>
<u>47°N line (WOCE repeat):</u>
This long zonal section follows the P1 WOCE line and has been committed by the Japanese, and has the highest priority of the Japanese-GEOTRACES. This line goes along a decreasing gradient of atmospheric input of Asian dust from west to east. The eastern end of this line will intersect with the Juan de Fuca hydrothermal system. Both ends will be interesting to study for boundary scavenging. Finally, this transect is almost entirely within the Subarctic High Nutrient Low Chlorophyll region, and contrasts the observed several-fold difference in Fe concentrations, productivity, and carbon export

between the Western Subarctic Gyre and the Eastern Subarctic Gyre. A time-series station K2 (47°N, 165°E) is located on the western side of the line, and another time-series station Ocean Station Papa (OSP) (50°N, 145°W) is located just 3° further north on the eastern part of the line. The Japanese would also visit the OSP site for a baseline intercalibration station with the Canadians and US GEOTRACES program.

165°E meridional line (Toshitaka Gamo/Jing Zhang):
This long meridional section, proposed by the Japanese (with a roughly 10-yr funding/implementation horizon), follows the P13 WOCE line. It is the northern half of a Western Pacific meridional line, a critical transect to characterize northward deep water and southward intermediate water circulations, and extends between the Bering Sea exchange chokepoint with the Northwest Pacific at the northern end to 10°N at the southern end. This line crosses with the zonal section line (47°N) at the time-series station K2, creating a baseline station (Japanese) for GEOTRACES.

Triangle sections in the NW Pacific (Jing Zhang):
This section plan, paired with the 47°N zonal section, will be proposed for different observation seasons. This cruise track starts from Tokyo, turns northeast though the subarctic area off the Okhotsk Sea, follows the Zonal P13 WOCE eastward path to the time series station K2 and to 180°W, and then south to 42°N, and then westward back to Tokyo. The purpose is to determine the TEI fluxes from the surrounding marginal seas and the Sea of Japan, especially the influence by the Dense Shelf Water formed during sea ice production in the Sea of Okhotsk; and to quantify and identify the processes of the detailed TEIs distribution and their seasonal variation via NPIW/NPDW eastward flow though the Northwest Pacific Seamount Chain. The station sampling consists of both high-resolution (shallower than 1000m; closely spaced) and low resolution (deep to bottom; widely spaced). The stations would be chosen to overlap with CLIVAR stations. There is a high likelihood that this cruise track will be approved and implemented. See the Hokkaido to HOT section in the USA section for further justification for GEOTRACES activity in this area.

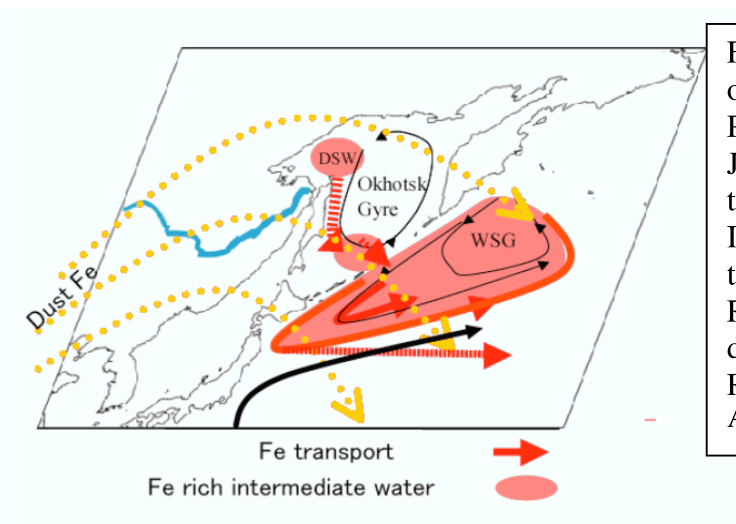


Figure 1. Schematic depiction of dust deposition over the NW Pacific Ocean. From Nishioka J., et al. (2007), Iron supply to the western subarctic Pacific: Importance of iron export from the Sea of Okhotsk, J. Geophys. Res., 112, C10012, doi:10.1029/2006JC004055. Reproduced by permission of American Geophysical Union.

CANDA

Vancouver Island, BC to OSP to Aleutians (Dutch Harbor, AK) (Kristin Orians):
This section connects the mouth of the Juan de Fuca Strait, though Ocean Station Papa (OSP) and to the Aleutians (Dutch Harbor, AK). This crosses from a productive coastal region (influenced by the Fraser River input and seasonal upwelling) out into an HNLC region in the subarctic North Pacific (where productivity is limited by Fe and potentially other TEI's) and to the Aleutian Island Arc. The first half of this transect follows the Canadian repeat line (Line-P), which has been sampled 3 times a year for the past couple of decades, and has a 50 year history as a time series. Input from the coast to the open ocean in this region is important for a number of TEI's, and is influenced by mesoscale eddies (ie. Haida and Yakutat Eddies) which form along the coast of British Columbia and Alaska.

The extension from OSP to the Aleutian shelf will aim to characterize the sources of TEI's from this volcanic arc margin to the Fe-limited subarctic North Pacific (at shallow depths). Model simulations suggest that this volcanic arc margin is a significant source of particulate Fe to the surface at OSP (there is evidence that this Fe source stimulates winter phytoplankton blooms - Lam et al. 2006 GBC). The Northeast Pacific has no Nd isotope measurements. Volcanic margins are also postulated to be an important region for boundary exchange, which may explain the Nd isotopic end-member observed in the north Pacific (Jeandel et al. 2007 Chem. Geo.).

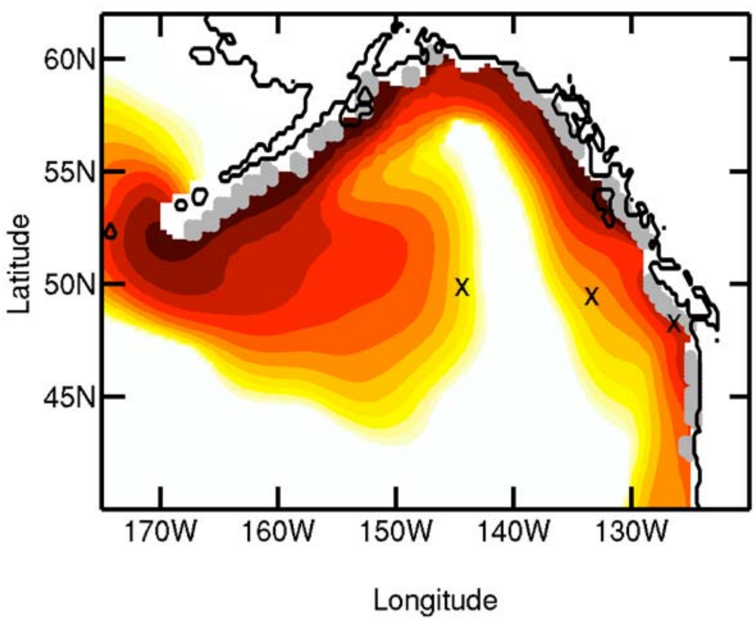


Figure 2. Model result showing the distribution of a passive tracer with a constant flux source at the continental shelf, and run forward on a ocean general circulation model. From: Lam P. J., J. K. B. Bishop, C. C. Henning, M. A. Marcus, G. A. Waychunas, I. Y. Fung (2006), Wintertime phytoplankton bloom in the subarctic Pacific supported by continental margin iron, Global Biogeochem. Cycles, 20, GB1006, doi:10.1029/2005GB002557. Reproduced by permission of American Geophysical Union.

This transect through different particle type regimes (diatom-dominated at the coasts to an increased presence (or influence) of coccolithophore and nano and picoplankton at OSP) provides an ideal opportunity to look at ^{230}Th and ^{231}Pa scavenging behaviours.

<u>"Line Z": OSP to Seward, AK (Kristin Orians)</u>
The northern extent of the eastern Pacific meridional section will also pass through OSP, and extend to the Alaskan margin (near Seward, AK) along the Canadian Line-Z. This section is sampled periodically (but not as regularly as line-P), and will capture the fluvial input from the major Alaskan rivers, and contrast the section to the zonal transect from OSP to the Aleutians.

These sections will most likely be Canadian sections, sampled from the CCGS J.P. Tully, coordinated by Roger Francois, Kristin Orians and/or Jay Cullen.

<u>USA</u>
<u>HOT to Pt Conception, CA--eastern N.Pac. Zonal transect (Ken Bruland):</u>
The transect from the Hawaiian Ocean Time Series (HOTS) to Point Conception, California (within the CalCOFI time series grid) is justified on the basis of a number of factors. These include the fact that the transect covers a wide range in productivity (primary, new, and export production) moving from the oligotrophic gyre of the North Pacific to a productive boundary of the eastern North Pacific coastal upwelling regime The transect should take place in late spring or summer to take advantage of the full range in productivity, with enhanced productivity in the coastal upwelling regime during this time period. This range in productivity and export flux will be valuable to address the concept of enhanced boundary scavenging for the particle reactive tracers. This boundary is a high productivity eastern boundary that should provide a nice contrast with the terrigenous particle rich western boundary of the North Pacific.

This transect involves two of the baseline stations - HOTS and SAFe. The surface water will be under a gradient of atmospheric input with a greater input of dust to the west and decreasing to the east. There will be elevated dissolved Fe (and in surface waters near Hawaii, a minimum in dissolved Fe concentrations in the vicinity of the SAFe station and an increase again near Pt Conception.

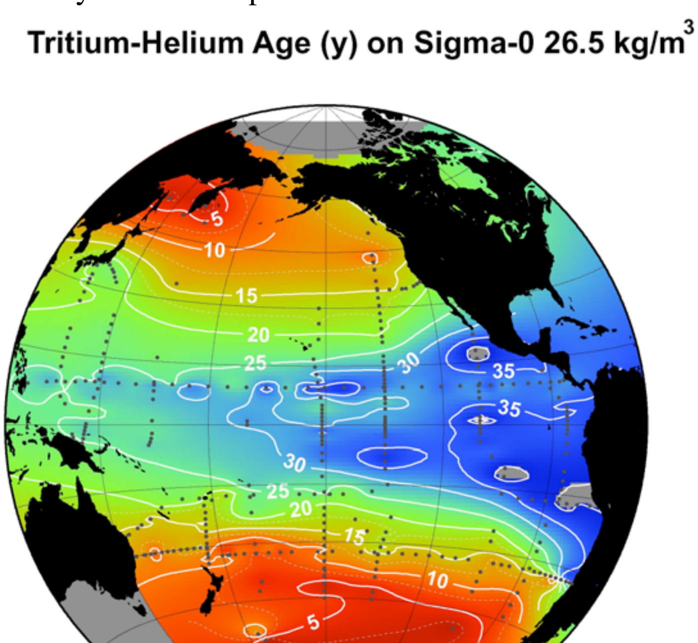


Figure 3. Tritium Helium Age (y) on Sigma-0 26.5 kg/m3

The transect will also provide a chance to observe changes taking place in the North Pacific Intermediate waters since forming in the western North Pacific. The upper zones of these thermocline or intermediate waters (sigma theta ~26.5 – see Figure 3) are the nutrient rich waters surfacing in the upwelling regions of the eastern boundary. A relatively intense oxygen minimum zone also occurs in the eastern North Pacific along this transect. Although not as intense as those in the eastern tropical Pacific, these oxygen minimum zones can be intensified as the North Pacific Intermediate waters move up over shelf regions off Washington, Oregon and California coast.

Deep waters encountered on this transect are some of the oldest in the world ocean lying at the end of the deep water global circulation pattern (Figure 4, below) and this transect is through large deep water region free of any islands or ridges and under a variable particle flux from the surface. As a result, it should be one of the most straight forward transects to examine the influence of boundary scavenging and eastern boundaries on the chemistry of deep water.

<u>OSP (47°N) to HOT (Brad Moran):</u>
The scientific rationale for the proposed OSP-HOTS line is that it represents the northern component of the US Pacific meridional section, which is a central objective of the GEOTRACES Pacific program. Sampling along this section will improve understanding of the role of margin-basin interactions, for example as defined by core tracers ^{230}Th and ^{231}Pa, volcanic sources (Nd end-member), and the role of shelf processes on other core TEI's (Fe, Al). The OSP-HOT line also cuts across intermediate mode waters, which meets the objective of defining TEI gradients in these water masses as well as improved understanding of thermocline ventilation (noble gases).

A specific scientific rationale for the OSP-HOT line is based on observed differences in deep water dFe (<0.4 μm), ranging from 0.4 nM in the central North Pacific to 0.6 nM in the northern North Pacific. Evidence points to colloidal Fe as a possible explanation for the reported changes in deepwater "dissolved" Fe between the central and northern North Pacific. Occupation of the OSP-HOT line will provide an opportunity to examine; 1) how the deep northeast Pacific obtains higher Fe than the deep central north Pacific, and; 2) the importance of colloidal Fe as a controlling factor.

In addition, based on samples collected at HOT, SAFe, and by Schaule and Patterson, there is evidence for a temporal evolution in Pb in surface waters of the North Pacific from ca. 1975 to 2005. These changes are based on only a few profiles collected using highly specialized clean sampling equipment, however greater sample coverage is now attainable using the trace metal clean rosette sampling system as part of GEOTRACES. The OSP-HOT-Equator section would allow a more detailed study of Pb throughout the water column in the North Pacific to address the question of why Pb in the central North Pacific thermocline is not decreasing in response to the phaseout of leaded gasoline.

<u>Hokkaido, Japan to HOT--western N.Pac. zonal transect:</u>
This transect follows a ventilation pathway for the upper thermocline: it starts in the Northwest Pacific in the region of North Pacific Intermediate Waters formation, and cuts southeast across the region of subtropical mode water formation, and along the aging pathway of subtropical mode water. Further, the northwest portion off the coast of Japan

of this transect crosses the flow path of the northward flow of Circumpolar Deep Water (see ECCO figure). This transect is also meant to be the western half of a subtropical Pacific zonal track. Steve Emerson volunteered to take the lead for this section. However, given the intense proposed activity by the Japanese in the Northwest Pacific, the primary justifications for this track may already by covered, particularly by the "Triangle sections".

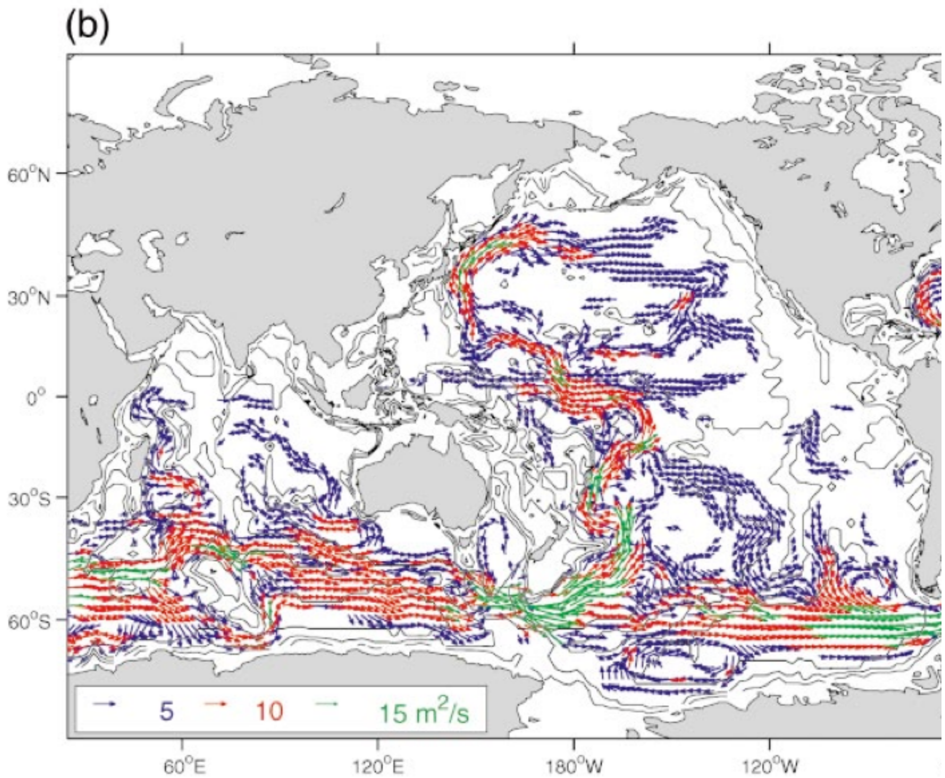


Figure 4. Volume transport in the deep ocean from 2200 m to the seafloor. Isobaths of 2000, 3000, and 4000 m are shown by black curves. From Lu, Y., and D. Stammer, 2004: Vorticity Balance in Coarse-Resolution Global Ocean Simulations. *J. Phys. Oceanogr.*, **34**, 605–622; Courtesy of the American Meteorological Society.

Zonal Equatorial Group

Zonal Equatorial Group

Chris Measures
Mak Saito
Bill Jenkins
Ken Buesseler
Andrew Bowie
Ed Butler
Jim McManus
Gideon Henderson
Kathy Barbeau

Three major science foci

- Equatorial Undercurrent
  - TEI inputs/sources of metals from western boundary
  - Scavenging rates of Fe relative to Al (and all other TEIs)
  - Evolution of HNLC conditions and source waters
- Equatorial HNLC
  - Importance of Fe for 1° prod, need to characterize region
- Oxygen minimum zone N of equator (P4)
  - Strong case that it is unique from OMZ south of equator
  - Lots of interesting chemistry for TEIs

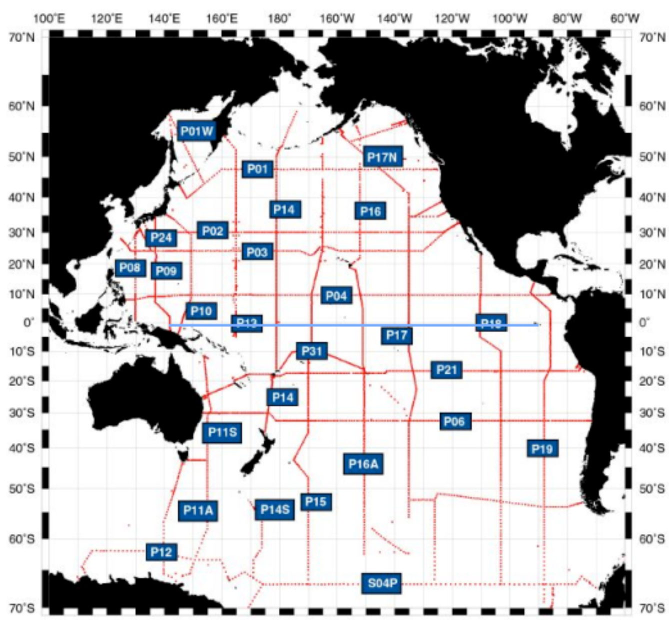


Figure 0-1 WOCE sections. eWOCE figure provided Chris Measures; Schlitzer, R., Electronic Atlas of WOCE Hydrographic and Tracer Data Now Available, Eos Trans. AGU, 81(5), 45, 2000; Schlitzer, R., Electronic Atlas of WOCE Data, http://www.ewoce.org/, 2008.

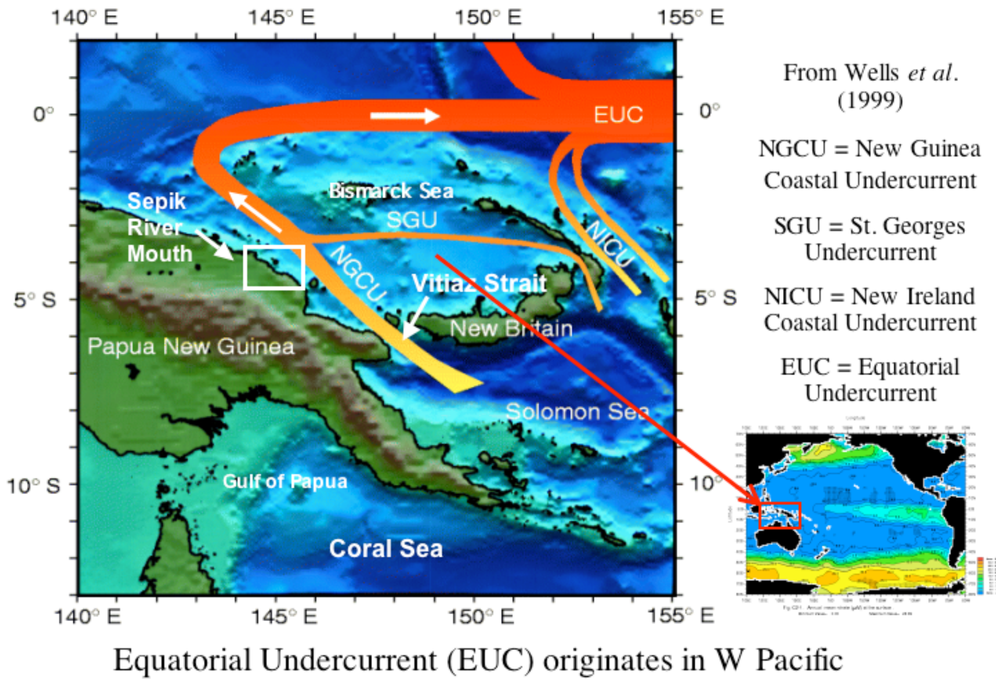


Figure 0-2 Sources of the Equatorial Undercurrent. Reprinted by permission from Macmillan Publishers Ltd: Nature, Wells, M.L., Vallis, G.K., Silver, E.A. Tectonic processes in Papua New Guinea and past productivity in the eastern equatorial Pacific Ocean. Vol. 398, 601-604, 1999. http://www.nature.com/.

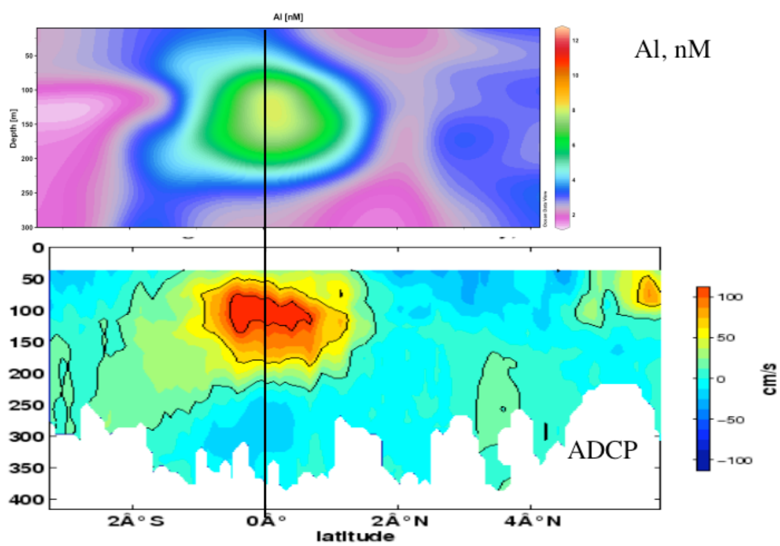


Figure 0-3 Concentration of dissolved Al (top) and zonal velocity (bottom) along a section normal to the equator. Figure provided by Chris Measures

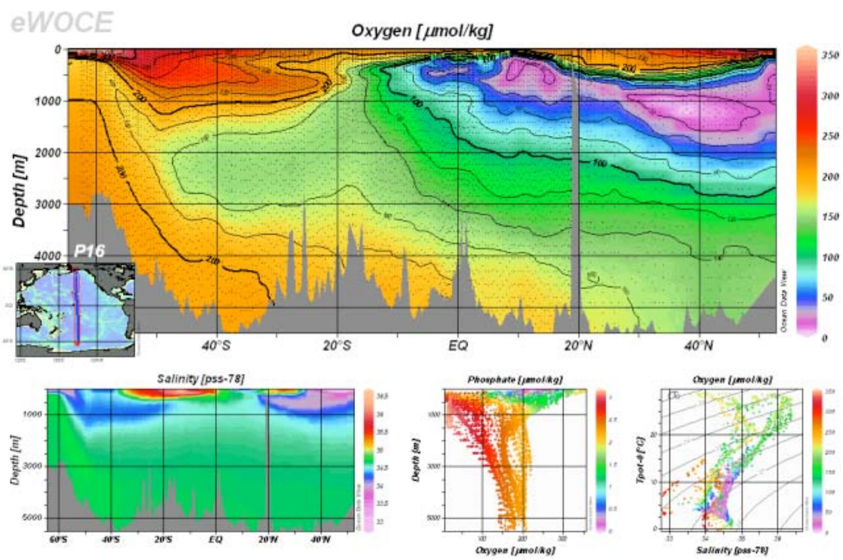


Figure 0-4 Oxygen distribution along a meridional section in the Pacific (see insert). eWOCE figure; Schlitzer, R., Electronic Atlas of WOCE Hydrographic and Tracer Data Now Available, Eos Trans. AGU, 81(5), 45, 2000; Schlitzer, R., Electronic Atlas of WOCE Data, http://www.ewoce.org/, 2008.

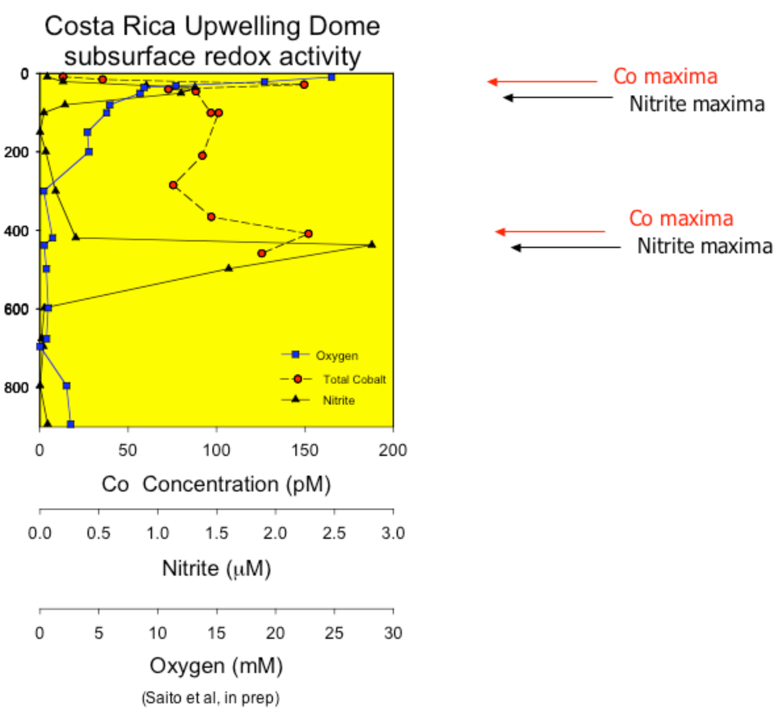
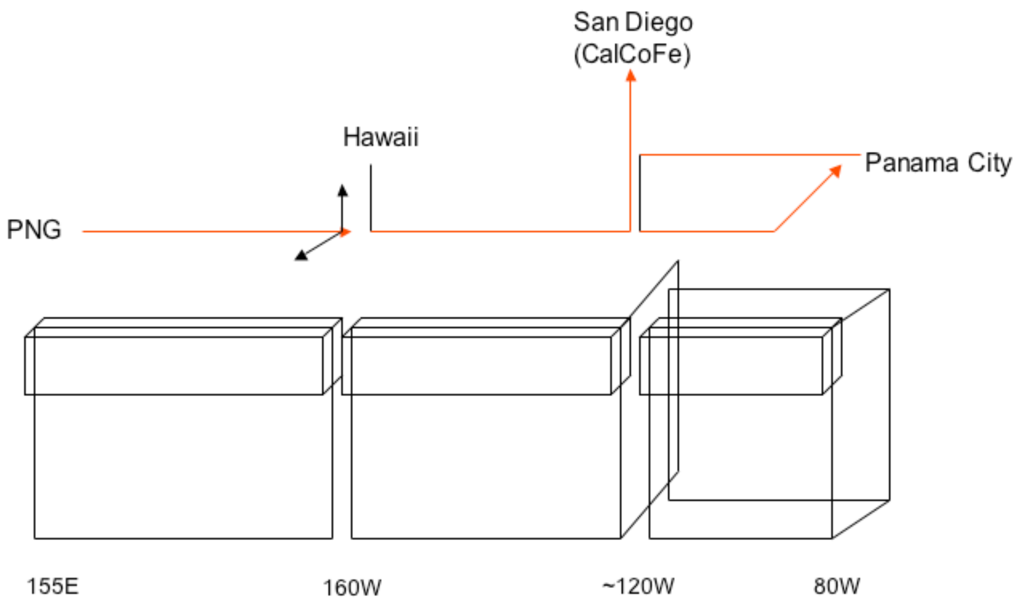
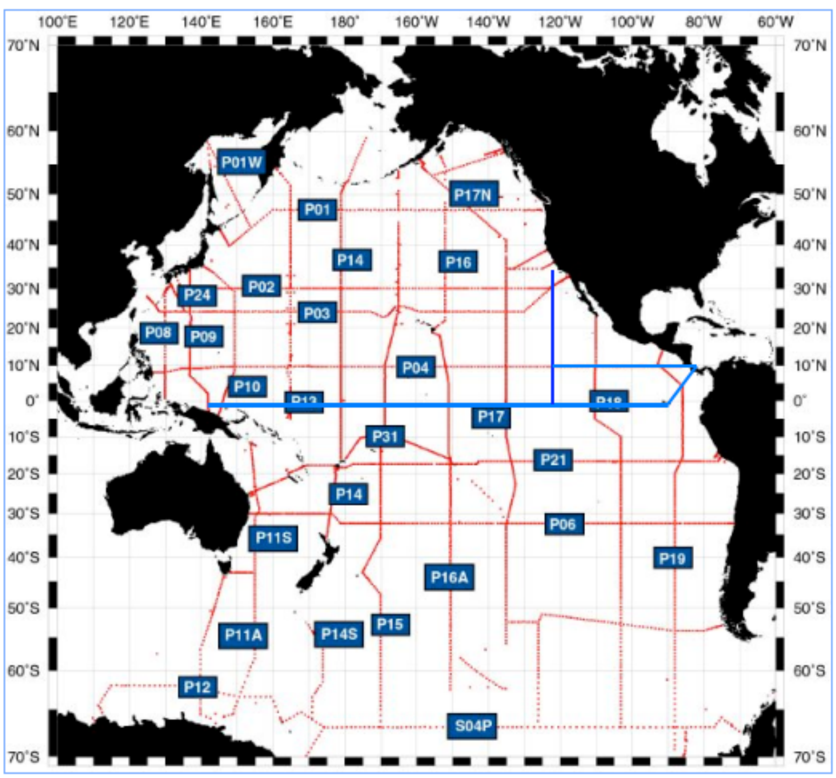


Figure 0-5 Concentration profiles of total Co and nitrite at a station in the Costa Rica Dome. Figure (unpublished) provided by Mak Saito et al.

Potential Plan: 3 Legs ~40-45 days each

Practical problem of transits and lack of ports creates opportunities;
Deep 2D sections across the equatorial Pacific
And shallow 3D rectangles to characterize the EUC and HNLC 3N to 3S
Short Meridonal section crosses OMZ at 110 or 120W *and* connects to CalCoFE
Possible Australian ship for first leg (>2010)?





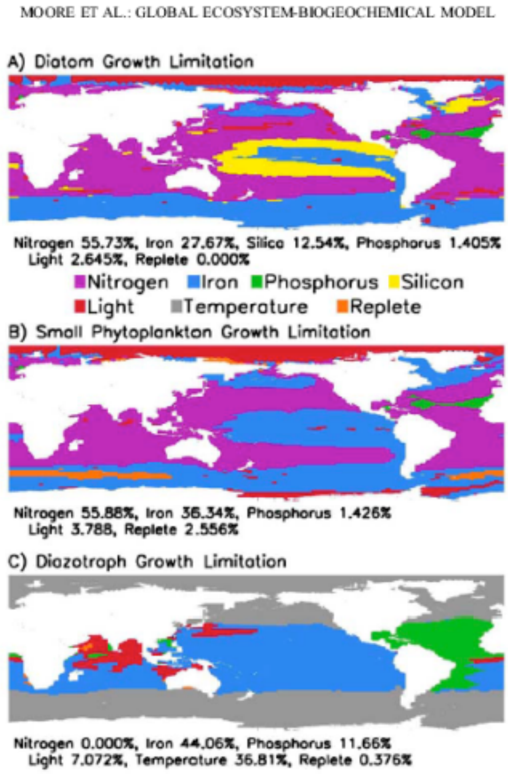


Figure 0-6 Moore, Factors most limiting growth rates of different phytoplankton taxa. J.K., Doney, S.C., and Lindsay, K.: Upper ocean ecosystem dynamics and iron cycling in a global three-dimensional model, Global Biogeochemical Cycles, 18, GB4028, doi: 10.1029/2004GB002220, 2004. Reproduced with permission of the American Geophysical Union.

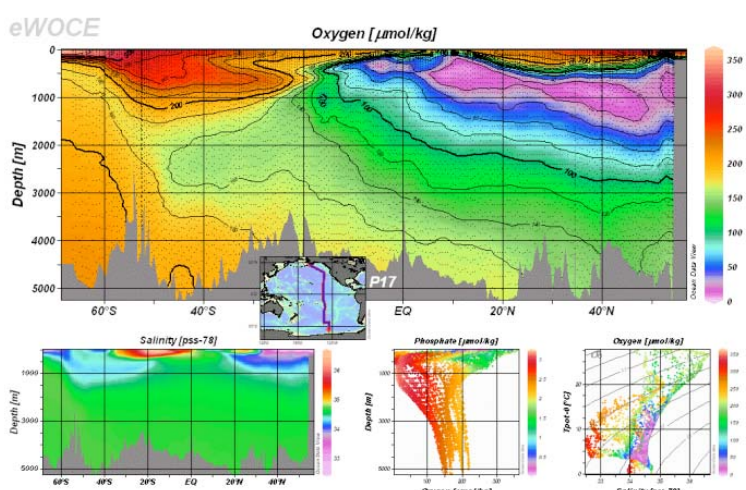


Figure 0-7 Meridional oxygen section (see inset). eWOCE figure provided Chris Measures; Schlitzer, R., Electronic Atlas of WOCE Hydrographic and Tracer Data Now Available, Eos Trans. AGU, 81(5), 45, 2000; Schlitzer, R., Electronic Atlas of WOCE Data, http://www.ewoce.org/, 2008.

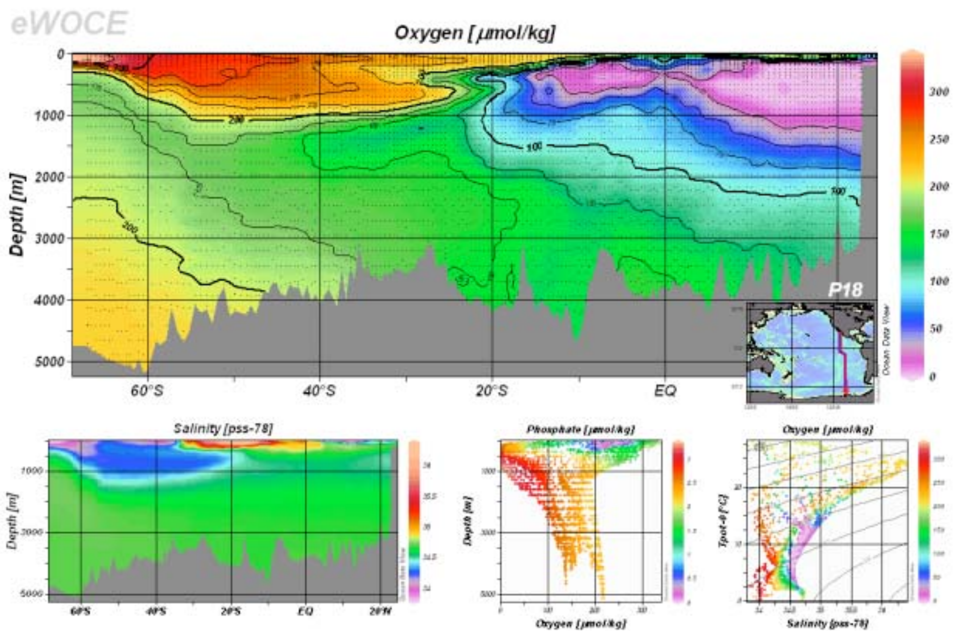


Figure 0-8 Meridional oxygen section in the eastern Pacific Ocean (see inset for location). Schlitzer, R., Electronic Atlas of WOCE Hydrographic and Tracer Data Now Available, Eos Trans. AGU, 81(5), 45, 2000; Schlitzer, R., Electronic Atlas of WOCE Data, http://www.ewoce.org/, 2008.

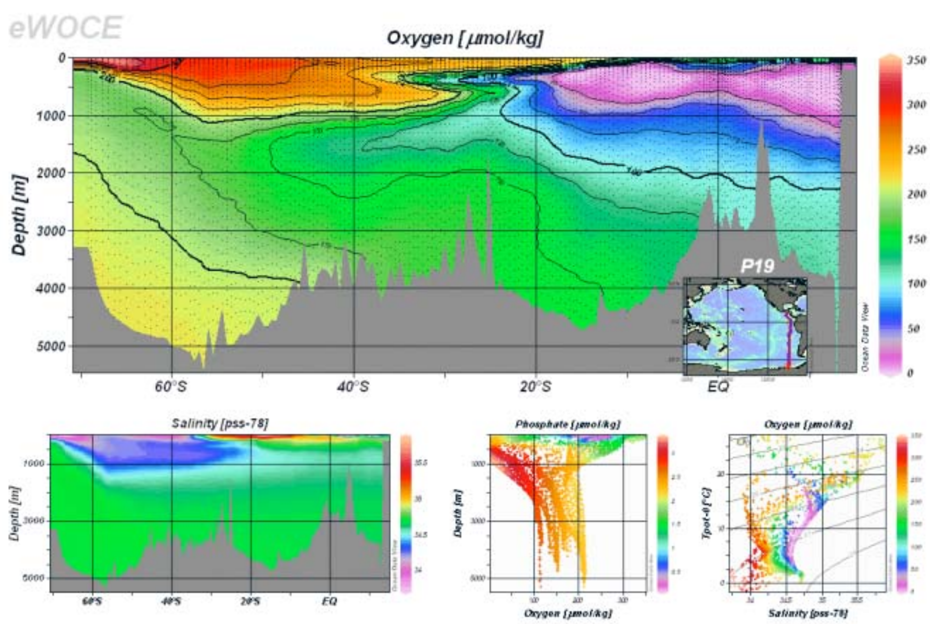


Figure 0-9 Meridional oxygen section in the eastern Pacific Ocean (see inset for location). Schlitzer, R., Electronic Atlas of WOCE Hydrographic and Tracer Data Now Available, Eos Trans. AGU, 81(5), 45, 2000; Schlitzer, R., Electronic Atlas of WOCE Data, http://www.ewoce.org/, 2008.

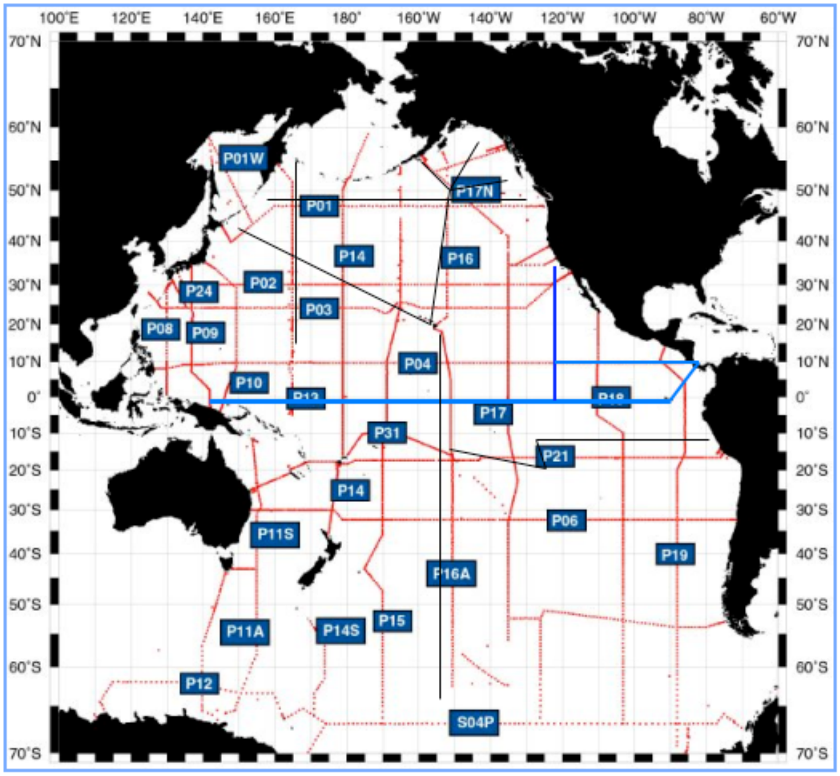


Figure 0-10 Location of proposed equatorial section and eastern extensions to potential ports (blue lines) superimposed on WOCE repeat sections.

Oxygen Minimum Zone

Pacific OMZ Section and Working Group Report

Participants:
Greg Ravizza (Chair), Karen Casciotti (Rapporteur), Bob Anderson, Jim Moffett, Bill Landing, Olivier Rouxel, Dimitri Gutierrez, Juan Carlos Miquel, Marco Salamanca, Evgueni Shoumiline.

This working group was originally tasked with discussing the oxygen minimum zone (OMZ) and hydrothermal input questions in the south pacific. The hydrothermal report will be written up separately and this report will focus on discussions pertaining largely to the rationale for GEOTRACES research in the OMZ regions in the northern and southern tropical Pacific.

1) Scientific Rationale

The principal rationale for this section (Figure 1) is to understand the role of the eastern tropical Pacific OMZs as source and sink regions for trace elements and isotopes (TEIs). The solid line represents a section running from the heart of the eastern tropical south Pacific, out along the trajectory of low O_2 waters extending away from the South American continent. The section along the Equator was justified by discussions in the equatorial working group to examine the tail end of the equatorial undercurrent. The section then continues northward and into the heart of the oxygen deficient region in the eastern tropical north Pacific.

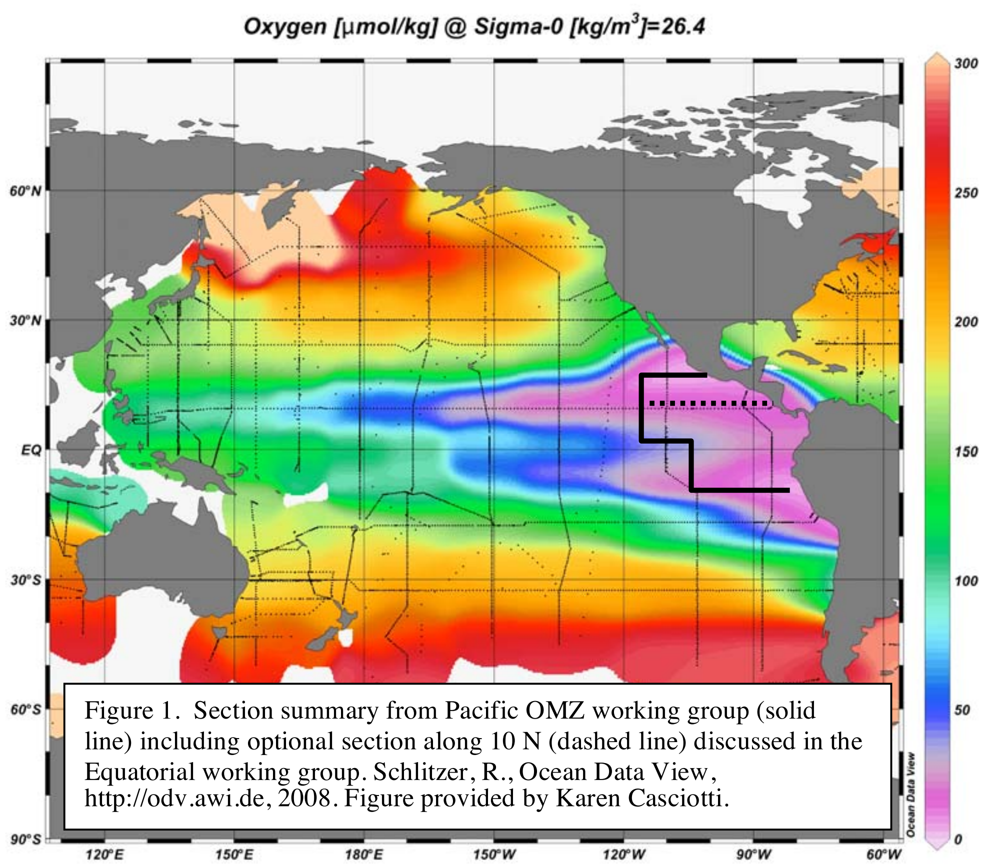


Figure 1. Section summary from Pacific OMZ working group (solid line) including optional section along 10 N (dashed line) discussed in the Equatorial working group. Schlitzer, R., Ocean Data View, http://odv.awi.de, 2008. Figure provided by Karen Casciotti.

The section is designed to trace the advection of high $\delta^{15}N-NO_3^-$ and redox-sensitive trace metals, as well as to examine their behavior and attenuation along gradients in dissolved oxygen, productivity, and POC export in the two largest and most intense oxygen minimum zones in the Pacific. The high POC export in the Peruvian margin and steep gradient in POC export along this section (Figure 2) also provides an end member for thorium-based assessments of POC export and scavenging of other particle-reactive TEI. Thus, this section fulfills GEOTRACES objectives of examining the effect of oxygen minimum zones and boundary scavenging processes on the distribution of TEIs.

These OMZ regions are important for the global N budget, serving as sites of nitrogen loss through sedimentary and water column denitrification. As a result of denitrification, some of the highest enrichments of $\delta^{15}N$ (and $\delta^{18}O$) in NO_3^- are observed in these OMZs (Casciotti and McIlvin, 2007; Sigman et al., 2005; Voss et al., 2001) and the processes enabled by the extremely low oxygen content of these waters play a critical role in the distribution of $\delta^{15}N-NO_3^-$ (and $\delta^{18}O-NO_3^-$) in the Pacific. Moreover, the Peru upwelling system host high rates of primary production, C export, and abundant fisheries.

The trace elements in the GEOTRACES list of key parameters may affect the rates of primary production, as well as nitrogen cycling (Granger and Ward, 2003), and may influence community structure and the rates of C and N transformations. Large spatial gradients in water chemistry (including dissolved oxygen) and particle scavenging (Figure 2) provide an excellent opportunity to show how scavenging processes for trace elements and particle-reactive actinides are related. Their comparative behavior will also be useful as we evaluate paleoproxies that are proposed to study shifts in OMZ boundaries and intensities on glacial-interglacial timescales (e.g., (Altabet et al., 1995; Ganeshram et al., 1995). In addition, drawdown of nitrate and bioactive trace metals in surface waters along these sections will provide information about productivity-driven stable isotopic fractionation of these TEI which may be of use for records of past surface productivity (Altabet and Francois, 1994).

Climate change may have a significant impact on the extent and intensity of corresponding processes in both regions, so the unprecedented, detailed data set arising from this cruise will be very valuable. Many TEIs on the GEOTRACES key parameter list may provide insight into decade-scale changes in ocean circulation and primary productivity, and the sections proposed here will be a useful springboard for coastal time series and process studies carried out with the participation of Peru, Mexico, and Chile.

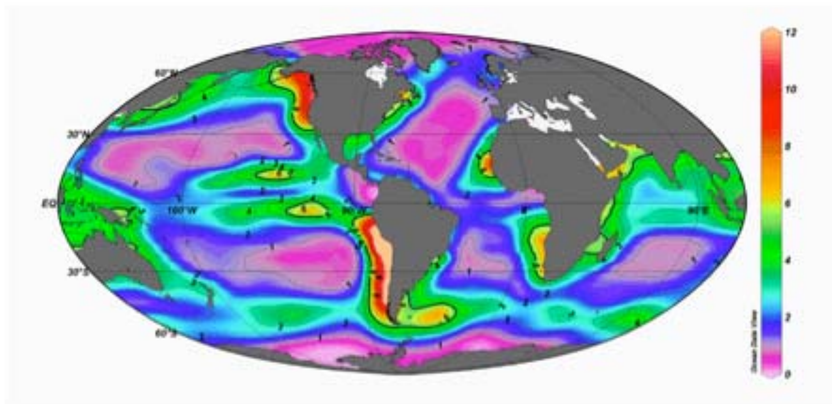


Figure 2
: Export production of particulate organic carbon POC (mol C m^{-2} yr^{-1}) in the world ocean determined by an inverse model from water column oxygen, nutrient and carbon distributions. From R. Schlitzer, Applying the adjoint method for global biogeochemical modelling. In: P. Rayner (Editor), *Inverse Methods in Global Biogeochemical Cycles*. AGU Geophys. Monograph Series, Vol. 114, pp. 107-124, 2000. Copyright (2000) American Geophysical Union. Reproduced by permission of American Geophysical Union.

2) How Cruise track meets this rationale

The principal GEOTRACES parameters will be measured along zonal gradients in dissolved O_2 centered at 12ºS and 15ºN. In addition, principal TEI with redox chemistries (Fe, and Mn) will be characterized in near real time to determine their oxidation states. The section will originate at the Callao Time Series Station in Peru (12º S, 77.12º W), transecting shelf waters characterized by very high productivity, a shallow OMZ extending to the sediments, and very high dissolved Fe levels. Beyond the shelf slope break, much of this Fe is removed (Figure 3), presumably by oxidation and scavenging. Therefore, we may have a great opportunity to study particle reactive isotope behavior in areas of high POC flux, and high Fe flux.

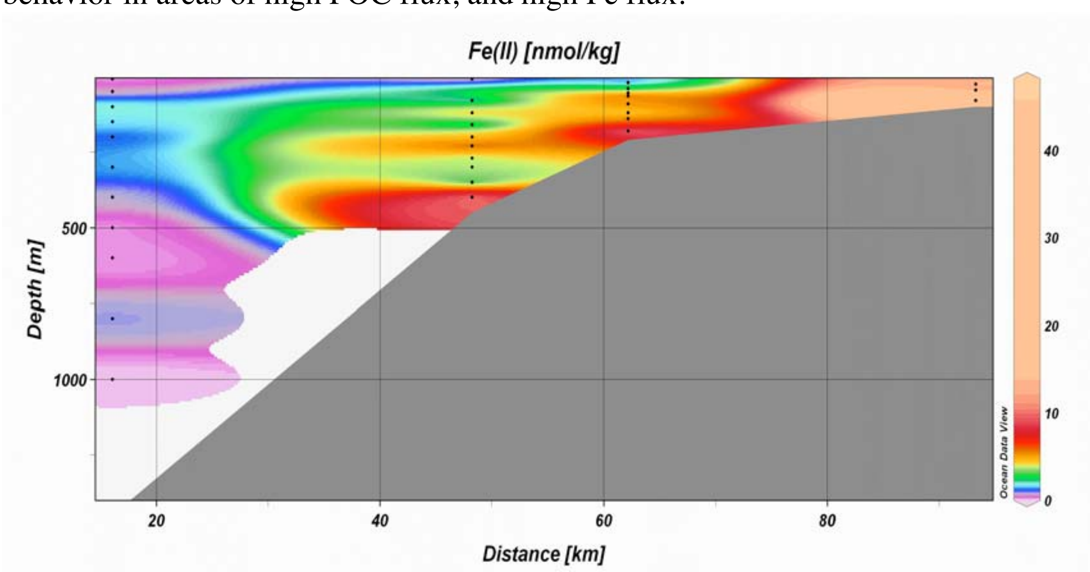


Figure 3. Distribution of Fe(II) along a section off the coast of Peru.

Low N* values are attenuated as waters flow out of the OMZ along the 26.4 isopycnal. The section proposed crosses through region predicted by Deutsch et al (Deutsch et al., 2007) to support non-Redfield uptake of PO_4^{3-} in surface waters, possibly by nitrogen fixing cyanobacteria. There are no $\delta^{15}N$-NO_3^- measurements from this OMZ plume flowing westward away from the Peru margin. Measurement of $\delta^{15}N$ and $\delta^{18}O$ in nitrate along this section may help resolve whether the distribution of surface nutrients, and the attenuation of N* in the subsurface are consistent with nitrogen fixation. The track follows the core of the OMZ that extends westward along 12ºS to 110ºW. Redox reactive elements like Fe extend out along a narrow depth horizon at the top of the OMZ characterized by low oxygen, high nitrite and a dense microbial community. Most likely, the metals accumulate as they are reduced to soluble forms by constituents of the microbial community. This potentially important source of Fe to the eastern tropical Pacific will be tracked by this section.

At 110ºW this feature begins to fade. The cruise will then head northward to cover the equatorial undercurrent feature between 110ºW and 120ºW, completing the eastern end of the equatorial transect described elsewhere. Then we will proceed northward to 15ºN along 120ºW and sample on an eastward transect along 15ºN into the heart of the OMZ off the coast of southern Mexico. This OMZ has very different dynamics, with much lower particle fluxes and primary production in the overlying waters. The two sections will provide a useful contrast between these two distinct OMZ regimes.

3) Unresolved Issues

In some discussions it was suggested that the northern zonal section be placed at 10ºN (dashed line, Figure 1). This is a plausible alternative to the proposed section at 15 N since this section would also capture some features of the low oxygen “plume” in the eastern tropical north Pacific. This section misses the core of the oxygen minimum zone in southern Mexico, but crosses the Costa Rica Upwelling Dome (CRUD) an interesting seasonal feature in the eastern tropical north Pacific. However, in later discussions amongst the OMZ working group, it was felt that feature might not have the basin-scale significance of the OMZ in Mexico, and is complicated by spatial and temporal variability. Moreover, such a transect misses the opportunity to end in Mexico, where a significant local community is poised to become actively involved in GEOTRACES OMZ work. It was not deemed necessary to make a final recommendation on the alternatives, but instead present both plausible and justifiable sections in the eastern tropical north Pacific.

This working group report has a companion document that reflects the additional discussion surrounding national interests of Mexico, Chile, and Peru in developing capabilities and collaborations for GEOTRACES work in the eastern tropical Pacific.

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Altabet, M.A. and Francois, R., 1994. Sedimentary nitrogen isotopic ratio as a recorder for surface ocean nitrate utilization. Global Biogeochemical Cycles, 8(1): 103-116.

Altabet, M.A., Francois, R., Murray, D.W. and Prell, W.L., 1995. Climate-related variations in denitrification in the Arabian Sea from sediment $^{15}N/^{14}N$ ratios. Nature, 373: 506-509.

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SE Pacific
Working Group Report on the Southeastern Pacific

Chair: Steve Emerson
Rapporteur: Tina van de Flierdt

Participants:
Ken Bruland, Karen Casciotti, Dimitri Gutierrez, Dennis Hansell, Juan Carlos Miquel, Jim Moffet, Mak Saito, Marco Salamanca, Evgueni Shoumiline

(1) Scientific rationale

For many TEIs the southeast Pacific Ocean is recognized as one of the least characterized regions of the world's ocean. Through discussion we identified three major scientific objectives, which would be addressed with a GEOTRACES section through the region. (a) examination of TEI distributions through the ultraoligotrophic south Pacific subtropical gyre, (b) characterization of south Pacific mode water and intermediate water formation region, and (c) examine the characteristics of the Pacific deep water return flow. A forth objective (d) extends the discussion to the central south Pacific area and may therefore be better imbedded in cruise tracks suggested by the other working groups.

(a) Ultra-low oligotrophic area

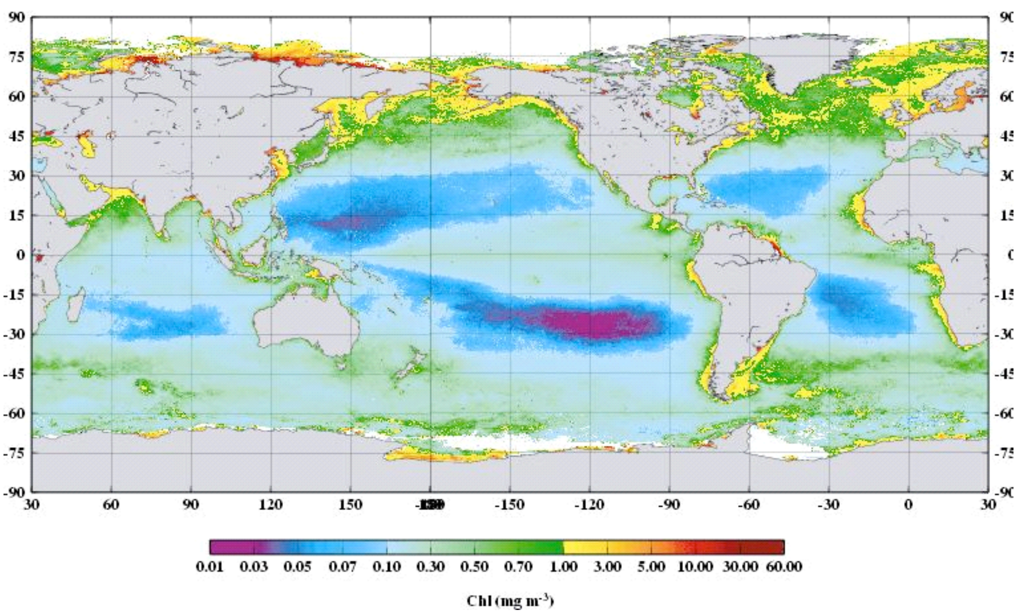
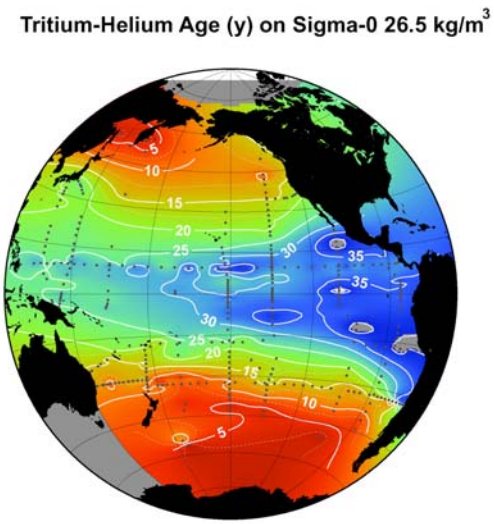


Figure 1: SeaWiFS derived chlorophyll distribution in the global ocean. Claustre and Miquel, personal communication, 2007.

The southeast Pacific includes the core of the most oligotrophic region in the ocean (from about 100°W westwards between 30° and 15°S, Fig. 1). Sampling this "bluest water on earth" would be very important as little is known about many of the TEIs of interest, including distributions and dynamics implied by those distributions. TEI-relevant processes of interest in the middle of the subtropical gyre include nitrogen fixation, particle scavenging (low dust flux and low biological productivity), and trace metal residence times in a stratified subtropical gyre.

(b) South Pacific mode and intermediate water formation area



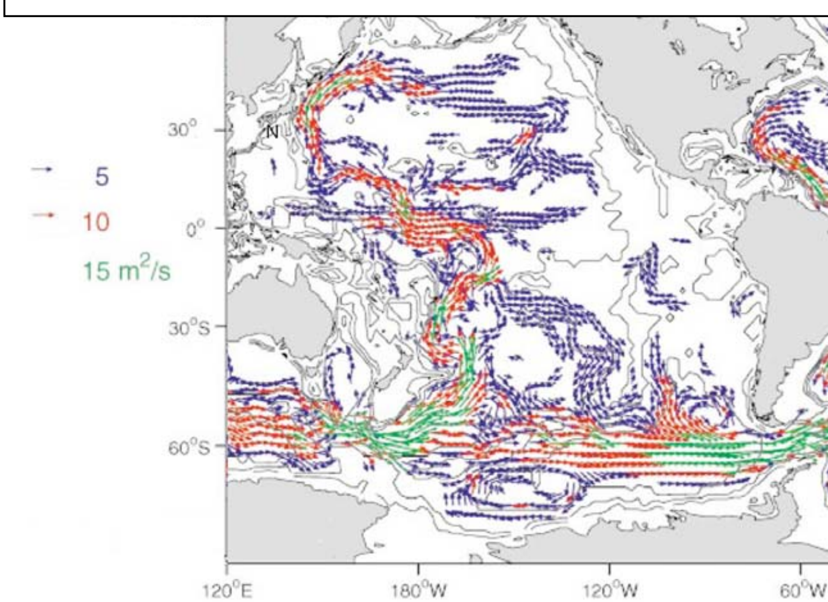
The southeast Pacific is the key formation area for South Pacific mode and Antarctic intermediate waters. These sites of ventilation act as large sinks of anthropogenic CO_2, and function as major conduits of nutrients to the subtropical ocean. The sites of formation also define the initial conditions for TEIs being imported into the ventilated Pacific Ocean (besides the deep and intermediate inflow in the SW Pacific). Figure 2 shows tritium-helium ages on sigma- θ 26.5 kg/m^3, highlighting that a transect in the southeast Pacific samples widely varied ages of intermediate and mode waters, from recently formed water masses to ~25 year old water masses.

Figure 2: Tritium-helium age on sigma-θ 26.5. Bill Jenkins, personal communication.

(c) Pacific deep water return flow area

A third major objective in the southeast Pacific is to capture the main return flow of Pacific Deep Water to the Southern Ocean. Pacific Deep Water fills the entire Pacific basin at depths between about 2000 and 4000 meters. This water mass develops a distinct signature for some TEIs while in transit through the Pacific Ocean, and

Figure 3: Volume transport in the deep Pacific Ocean from 2200 m to the seafloor (Lu and Stammer, 2004) From Lu, Y., and D. Stammer, 2004: Vorticity Balance in Coarse-Resolution Global Ocean Simulations. *J. Phys. Oceanogr.*, **34**, 605–622; Courtesy of the American Meteorological Society.



is ultimately exported to the Southern Ocean. One major exit pathway is located near 40 to 50° S and 110°W. Characterizing this water mass at its exit from the Pacific Ocean will be complemented by characterization of the major inflow of bottom waters into the Pacific Ocean in the southwest Pacific.

(d) Area devoid of sediment

A forth objective in the South Pacific (though not strictly in the southeast Pacific) is to capture a sediment-devoid area of the size of the Mediterranean Sea (Fig. 4). The "South Pacific bare zone" was discovered on a Melville cruise in 2005 led by researchers from the University of Michigan (Rea et al., 2006) and seems to have been free of sediment (<2 - 7 m sediment cover) for more than 80 million years. This implies very low biological productivity, a shallow calcite compensation depth, no dust input, and no deposition of hydrothermal material. This combination of conditions has not been found elsewhere, thus presenting a unique environment for studying TEIs, their behavior in the water column, and the TEI signature in seawater resulting from long-term low-temperature alteration of uncovered oceanic crust.

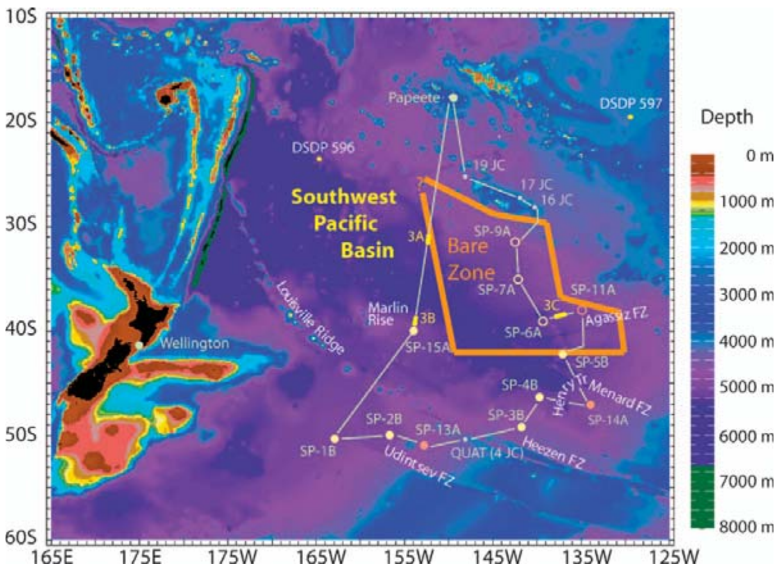


Figure 4: Bathymetric map of the SW Pacific, showing the outline of the South Pacific bare zone. Filled circles indicate full or partial sediment cover and open circles indicate bare seafloor. Thin line: Melville cruise track line (Rea et al., 2006). Courtesy of the Geological Society of America.

(2) How cruise tracks meets objectives

The final map (Fig. 5) suggests two potential cruise tracks in the southeast Pacific.

(a) L-shaped track starting east of Tahiti going south and west to about 140°W and 45°S and then eastward along 45°S into Punta Arenas

This track would start in the western part of the ultra-oligotrophic waters in the subtropical gyre (Fig. 1) and would cut into the sediment-devoid area further south

(Fig.4). On the zonal section the major return flow of Pacific deep water and the area of mode water and Antarctic intermediate water formation would be sampled (Figs. 2, 3).

(b) V-shaped track from east of Tahiti down to Antarctica at about 100°W and up from there to Punta Arenas

This track was not directly suggested by the working group but resulted from plenary discussion and would also start in the western part of the ultra-oligotrophic waters in the subtropical gyre (Fig. 1). Going southwards to Antarctica and up to Punta Arenas, we would miss the sediment-devoid area, we would not transect through the focused area of return flow of Pacific deep water shown in Figure 3, and we also would also not capture the major formation area of mode and intermediate waters in the SE Pacific. However, the cruise track would still transect a range of intermediate water ages (Fig. 2) and capture the more diffuse return flow of Pacific deep water.

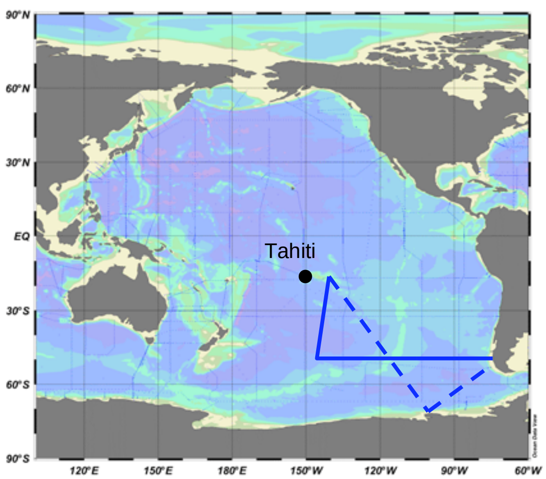


Figure 5: Proposed cruise tracks. Rational for each of the two potential tracks is given in the text.

(3) Unresolved issues/ future decisions

No agreement could be reached in the plenary section as to which of the two proposed lines should be pursued in the SE Pacific. However, the forth objective presented in this report was only added in the plenary discussion, and adds further weight to choosing the L-shaped track recommended by this working group. The V-shaped track was promoted by the Southern Ocean working group; they present their reasoning in a separate report.

(4) References

Lu, Y. and D. Stammer, 2004, Vorticity balance in coarse-resolution global ocean simulations, J. Phys. Oceanogr., 34, 605-622.

Rea, D.K., M.W. Lyle, L.M. Liberty, S.A. Hovan, M.P. Bolyn, J.D. Gleason, I.L. Hendy, J.C. Latimer, B.M. Murphy, R.M. Owen, C.F. Paul, T.H.C. Rea, A.M. Stancin, and D.J. Thomas, 2006, Broad region of no sediment in the southwest Pacific Basin, Geology, 873-876.

SW Pacific

South-West Pacific Group

Edward Butler (Chair)
Mariko Hatta (Co-Rapporteur)
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Bill Hiscock (Co-Rapporteur)
Bill Landing
[Philip Boyd — *ex session*]

Introduction

The surface-waters of the SW Pacific (Fig. 1a) grade from those of the oligotrophic tropical Coral Sea, through the subtropical northern Tasman Sea to the seasonally productive regions of the subtropical convergence zone (characterised by the complex mixing and interleaving of subtropical and subantarctic waters) in the southern Tasman Sea (Fig. 1b) and over the Chatham Rise to the east of New Zealand. Further poleward lies the vast expanse of HNLC waters of the Southern Ocean.

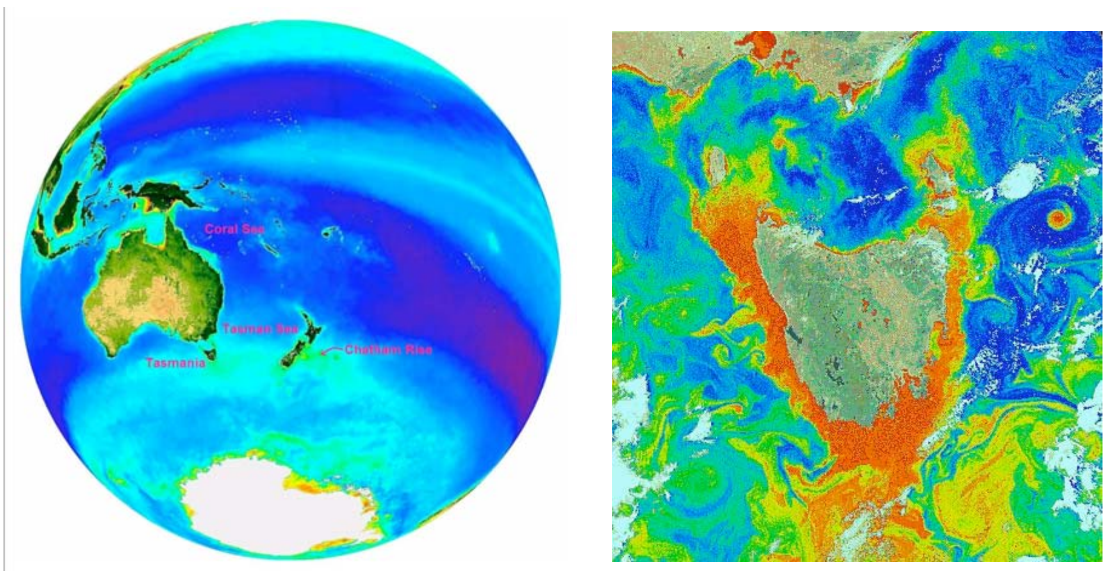

Fig. 1. a) Chlorophyll composite for austral summer (SeaWiFS). b) Estimated chlorophyll concentrations around Tasmania, south Tasman Sea (modified by coloured dissolved organic matter in coastal waters) from an image collected on 27 November 1981 (Coastal Zone Colour Scanner). In both images, hues toward the blue end of the spectrum are low levels of chlorophyll, while those toward the red end depict high levels of the pigment. Courtesy of Goddard Space Flight Centre, NASA. Courtesy of NASA/GeoEye (www.geoeye.com) Copyright 2008. All rights reserved.

The surface circulation in the region has as one of its most prominent features the East Australian Current (EAC). Current views of physical oceanographers also well summarised in SPICE — Scientific Background, May 2007 <http://www.ird.nc/UR65/SPICE/SPICEscienceplan_bkgnd.pdf>. The EAC results from the South Equatorial Current moving through the Coral Sea under the influence of the Trade Wind Drift. This flow bifurcates at the Australian coast (~18°S – Sokolov & Rintoul 2000), the southern branch becomes the EAC; the northern branch recirculates in the Gulf of Papua to supply undercurrents that feed water back to the Equator. The EAC is topographically steered as a narrow shelf-edge current moving south along the Australian coast between about 25°S and 33°S. In comparison to its western-boundary-current counterparts in the Northern Hemisphere — the Kuroshio and Gulf Stream — it is both weaker and seasonally variable (maximum southward component in summer, 36.3 Sv; minimum in winter, 27.4 Sv – Ridgway & Godfrey 1997). In the vicinity of Sydney, the current moves away from the coast to become a zonal, meandering jet forming the boundary between the Coral and Tasman Seas (the Tasman Front, Fig. 2). Not all flow is to the east — the EAC has a tongue that extends southward down the east coast of mainland Australia and intermittently to Tasmania (EAC Extension); it also spawns eddies that continue further south. The extent of the tongue and the frequency of these eddies vary seasonally, peaking in summer. In winter, they are curtailed by the extension of the Leeuwin Current flowing from the west, across the Great Australian Bight, around the bottom of Tasmania into the southern Tasman Sea (Ridgway & Condie 2004).

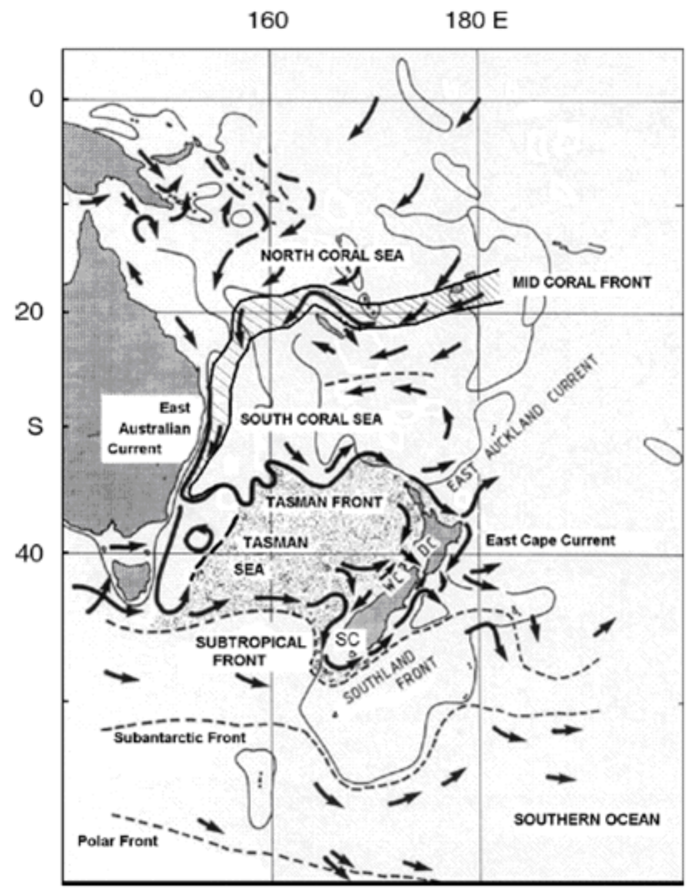

Fig. 2. Surface current systems of the South-West Pacific (SC – Southland Current, WC – Westland Current, DC – D'Urville Current). Reprinted from Deep Sea Research Part I: Oceanographic Research Paper, Vol. 53, No. 12, L. J. Hamilton, Structure of the Subtropical Front in the Tasman Sea, p. 19989-2009, 2006, with permission from Elsevier http://www.sciencedirect.com/science/journal/01980149.

The outflow of EAC water along the Tasman Front continues around the north of New Zealand, where it is becomes the East Auckland Current, and ultimately the East Cape Current (Hamilton 2006 – Fig. 2). The zonal flow of mostly subtropical waters in the central Tasman Sea is much weaker; it bifurcates at the west coast of New Zealand. One branch moves northward along the coast, with some flow diverting through Cook Strait; the other moves southward to become the Southland Current. The latter is a starkly defined coastal current that in flowing around the south and up the east coast of the South Island forms a sharp front (a segment of the Subtropical Front—STF) between the admixture of subtropical waters deriving from the Tasman Sea and subantarctic waters to the south. Transport of surface waters along the east coast of New Zealand—from the north and south—merge at the latitude of the Chatham Rise to resume the characteristic zonal flow to the east. The gradation from subtropical waters north of the Chatham Rise to subantarctic waters to the south of this topographic feature is tightly constricted.

Further south — to the Subantarctic Front (SAF, Fig. 3b) and poleward in the Southern Ocean — the Antarctic Circumpolar Current (ACC) dominates circulation (Rintoul & Sokolov 2001). It is manifest effectively from top to bottom in the water column.

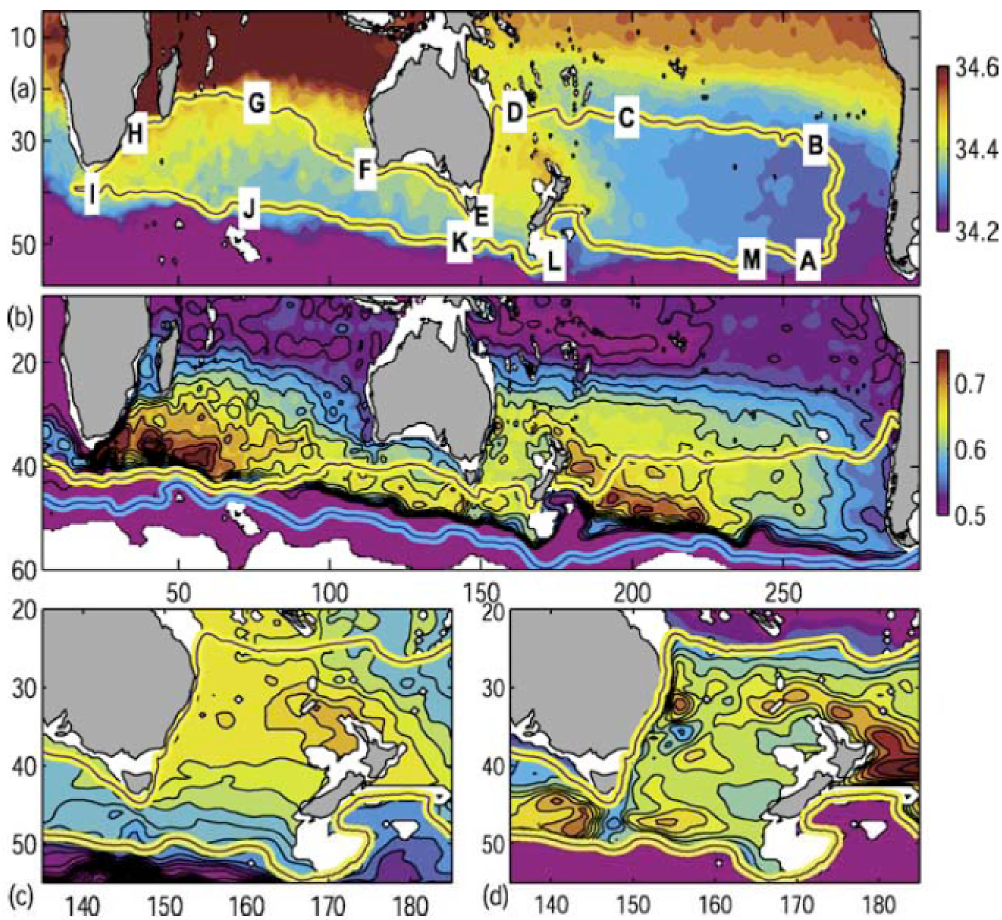

Fig. 3. (a) Salinity averaged on the 27.35 neutral surface, this represents the salinity minimum associated with AAIW. The yellow curve represents the edge of the 'supergyre' as determined from the acceleration potential field in (b). (b) The acceleration potential on the 27.35 surface (relative to the 27.9 surface, roughly equivalent to 2000-m). The yellow and cyan lines show the STF and SAF as determined from CSIRO Atlas of Regional Seas, CARS. (c, d) As for (a, b) but focused on the Tasman Outflow region. Diagram from Ridgway & Dunn 2007; courtesy of American Geophysical Union.

The flow of intermediate waters in the SW Pacific (broadly approximating to 1000 m, Ridgway & Dunn, 2007 – Fig. 3), in fact for the bulk of mid-latitude waters in the Southern Hemisphere, has recently been confirmed as a 'supergyre'. Its circulation extends from South Africa most of the way across the Pacific Ocean (Fig. 3a). The eastward flow is at the SAF, with the return westward flow at lower latitudes, although deflected around the bottom of Australia.

Deep-water flow into, around and out of the Pacific Basin is depicted in Fig. 4. The apparent excess of deep inflow is balanced by the global thermohaline circulation ('oceanic conveyer belt') via the Indonesian Throughflow at shallower depths into the Indian Ocean. The focal entry point for deep waters into the Basin is in the SW Pacific, where they move around the Campbell-Bounty Plateau and Chatham Rise off New Zealand, and then northward along the Kermadec Trench. This bottom transport is referred to as the Deep Western Boundary Current (DWBC)

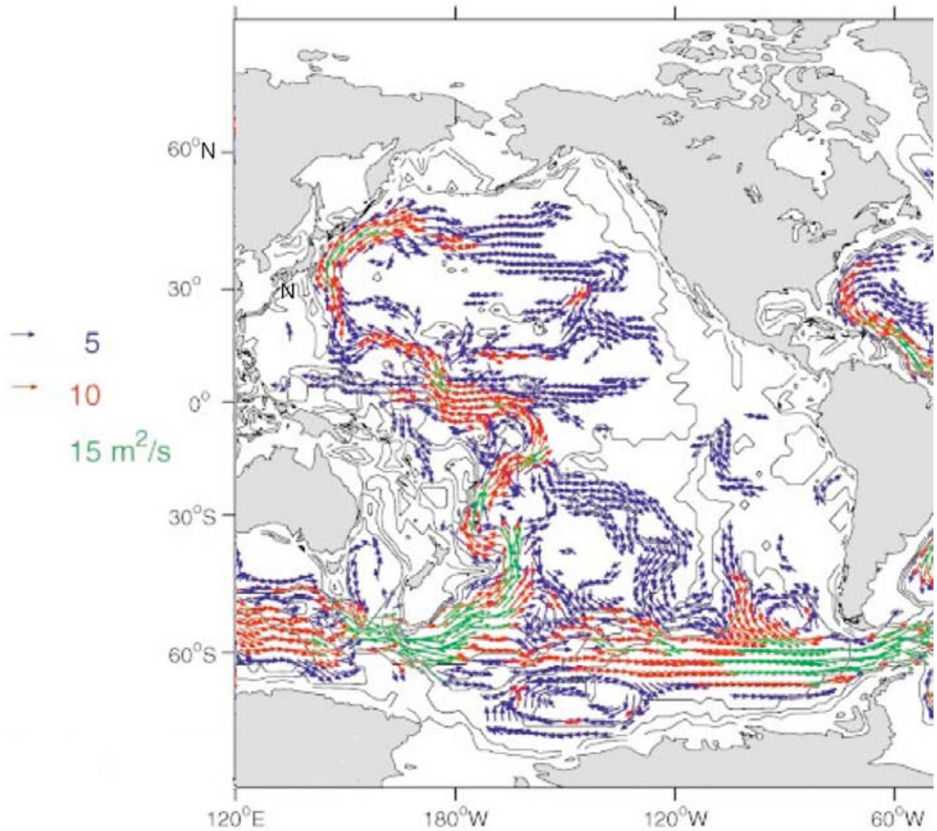

Fig. 4. Deepwater circulation in the Pacific Basin depicted by current vectors. Courtesy of ECCO 'Estimating the Circulation & Climate of the Ocean' Consortium. From Lu, Y., and D. Stammer, 2004: Vorticity Balance in Coarse-Resolution Global Ocean Simulations. *J. Phys. Oceanogr.*, **34**, 605–622; Courtesy of the American Meteorological Society.

We have alluded to the importance of the bottom topography in directing the flow of deep waters above. Other features of the abyssal SW Pacific Basin include several isolated, or partly isolated, bodies of deep water within a number of bathymetric features of the region. The 3000-m isobath delineates these features (Fig. 5): they are the East Australian Basin (also known as Tasman Basin or Tasman Abyssal Plain), Coral Sea Basin, New Caledonia Trough, Norfolk Basin and South Fiji Basin. Waters filling these depressions have salinities and potential temperatures characterised by their sources (Pacific Deep Water and Antarctic Bottom Water). The higher salinity bottom waters of the Coral Sea and Solomon Basins originate from the East Australian Basin. Whereas, those of the South Fiji and New Hebrides Basins, and the New Caledonia

Trough are derived from the Central Pacific Basin (Wyrtki 1961). The latter two are also influenced by some inputs of higher salinity water from the western basins. The smaller Norfolk Basin is believed to receive water from the South Fiji Basin. It was not studied in Wyrtki's (1961) surveys, but data from Chiswell (1995) supports this contention.

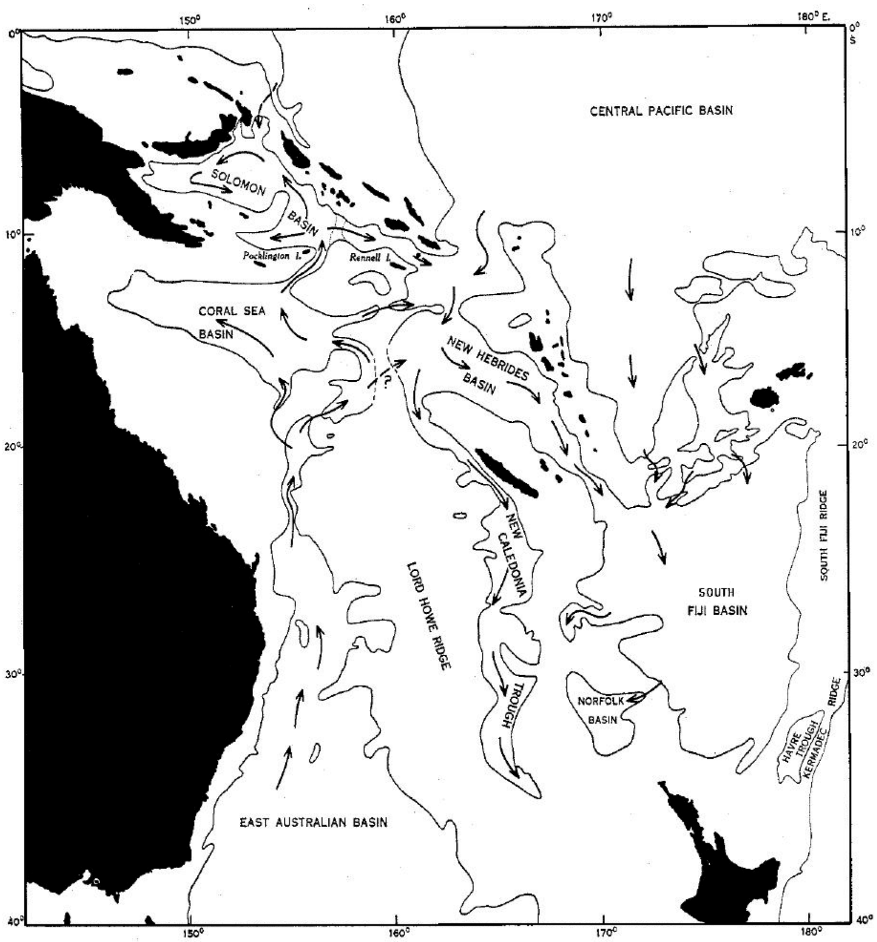

Fig. 5. Abyssal features in the SW Pacific. Arrows indicate the supply of deep water to the various basins and troughs (after Wyrtki 1961). Reproduced by kind permission from the Australian Journal of Marine and Freshwater Research 12(1): 1-16 (K Wyrtki). Copyright CSIRO 1961. Published by CSIRO PUBLISHING, Melbourne Australia; http://www.publish.csiro.au/nid/127/issue/2750.htm.

Material sources to the seas of the SW Pacific include wind-blown dusts from the continental Australia, terrestrial run-off from southern Papua New Guinea, eastern Australia and the islands of New Zealand, and sedimentary input from a relatively small area of shelf sediments in the region.

Continental Australia is logically thought to be the main wind-blown dust source to the oceans in the Southern Hemisphere, although it is a smaller source than the three main regions in the Northern Hemisphere — northwestern Africa, eastern Asia and Arabia (Rea 1994). This view is based on the marine sedimentary record (Hesse & McTainsh 2003) and global dust models (e.g. Mahowald et al. 1999, Moore & Braucher 2007). The main dust paths are to the southeast — over the Tasman Sea to New Zealand and beyond, and to the northwest — over the North West Shelf and toward the Indonesian archipelago. Nevertheless, it is acknowledged that information on the extent and intensity of aeolian transport of Australian dust long distance is insufficient (Marx et al.

2005). Attempts to link Australian dust as a vector for iron fertilisation and stimulation of phytoplankton blooms in SW Pacific surface waters has proved inconclusive (Boyd et al. 2004), but evidence is accruing of the long-range transport of Australian dust and tell-tale signs of it deposition (Marx et al. 2005) and dissolution in remote parts of this region (e.g. along the WOCE/CLIVAR P16 line, Brown et al. 2006). Furthermore, most long-range dust events in eastern Australia are associated with the passage of atmospheric cold fronts (Leslie & Speer 2006), some of which are initiated by pre-frontal north to northwesterly winds that would drive dusts down over the Southern Ocean. Another factor leading to more diffuse dispersal of dusts than might be predicted by the sedimentary record is the often complex trajectories of air parcels in the region (Boyd et al. 2004); they have been suggested as the basis for Australian dusts being deposited on subantarctic Macquarie Island and being inferred as the origin of dust deposits in Antarctic ice-cores (McGowan et al. 2000).

Riverine discharge to the SW Pacific is not globally significant in volume. Australia's rivers are highly variable in flow (especially those of the tropical and subtropical north); only episodically, during high-flow events or infrequent floods, do they contribute a significant amount of material to the continental shelf (Eyre 1998). In contrast, the island of New Guinea, with its tectonically active mountainous terrain, erodible rock and high rainfall has rivers that are significant globally in the transport of sediments to the ocean (Milliman et al. 1999). The Fly River is one such example: it is the largest of the rivers discharging into the Gulf of Papua. However, these river-borne sediments are either deposited locally, or transported toward the Equator by the New Guinea Coastal Undercurrent (as established by Rare Earth Element tracers – Sholkowitz et al. 1999). The topography and geology of New Zealand are not unlike New Guinea; its rivers are estimated to carry a sediment load five times the global mean (Milliman et al. 1999).

The continental shelves around land masses of the SW Pacific are not extensive [Australia does have larger expanses of continental shelves along the northern and northwestern coastlines]. However, deeper plateaux (Campbell, Bounty and Challenger) and the Chatham Rise around New Zealand, and to a lesser extent the South Tasman Rise below Tasmania, constitute a sizeable domain at <1000 m. The recent 'Biogeochemical Elemental Cycling' model of Moore and Braucher (2007) depicts a plume of elevated dissolved iron streaming eastward from the New Zealand features in the depth range 502–945 m. Conceivably, intermediate water circulation in the supergyre mentioned above, or at the northern extremity of the ACC, could provide the conduit to transport the plume. Lam et al. (2006) observed a strong peak in particulate (1–51 μm) iron at 900-m depth, 650 km downstream of the Campbell Plateau (at 55°S, 172°W) — both dissolved and particulate forms of the micronutrient are likely to originate from this same source. This is tantalising support for input of iron from the continental margin and its subsequent advective transport.

The Chatham Rise is the shallowest of the continental margin features around New Zealand. Its depth is <500 m for much of its 1000-km length east-west. Mesoscale eddies, which impinge on the ridge have the capacity to stir material from the bottom into surface waters. Even the tidal currents passing over the Chatham Rise have sufficient strength to resuspend finer sedimentary material to within 200 m of the surface (Nodder 1997). Although the high biological productivity associated with this region has been observed to affect the meridional distribution of micronutrient metals (Michael Ellwood – unpublished results), insufficient data has been gathered to establish if release from resuspended material, or efflux from the sediments themselves, add iron and other metals to the water column. Higher levels of iron are delivered to the surface waters from terrestrial run-off entrained in the Southland Current (Tian et al. 2006).

Scientific Rationale

The key questions for GEOTRACES in the SW Pacific are those regional attributes and processes that are unique or distinctive in the context of oceanography or marine biogeochemistry. Of slightly lesser importance are features, which provide a useful contrast to others elsewhere in the Pacific Basin, or globally.

The transport of wind-blown dusts to Southern Hemisphere seas has already been referred to in the GEOTRACES Science Plan as an area for investigation. As described earlier, the main 'dust corridor' into the SW Pacific is from central and eastern Australia southeastward over the Tasman Sea. However, the broader extent and the range of Australian dust deposition is scarcely known. The significance of its dispersal in fertilising primary production in the Southern Ocean, the prime global HNLC water body, must be resolved; even dust deposition to oligotrophic waters (LNLC) to the east of Australia may seed them for subsequent primary production.

To evaluate the extent and intensity of dust transport, and also the TEI composition and solubility, an integrated program of cruise tracks (both oceanographic sections and repeat lines, with the latter likely being done by volunteer observing ships) and ground stations is required. The minimum for oceanographic sections would a zonal track out into the Pacific Ocean from the east coast of Australia, a meridional section from Tasmania into the Southern Ocean, and a another meridional section further to the east in the Pacific Ocean. With this arrangement, the decay in dust deposition away from its source is profiled by the first two tracks (east and south sectors), while the last is a track that traverses the breadth of the southeast Australian dust plume, at distance and in a likely depositional zone (Brown et al. 2006). Since these oceanographic tracks can only provide intensive snapshots, they must be combined with time-series observations at sea and on land. For the latter, sampling of continental wind-blown dusts is proposed at the Cape Grim Baseline Air Pollution Station (NW Tasmania — part of the global network of BAPS) and on Macquarie Island.

The other major subject for the SW Pacific is the routes of entry of deep and intermediate water (SH circulation), located in this region. They need to be characterised as the primary advected sources of TEIs to subsurface waters, down to the bottom, in the Pacific Basin. In turn, the use of tracers, such as neodymium (ε_{Nd}) and uranium-series radionuclides (e.g. $^{231}Pa/^{230}Th$ ratio), in these current systems will give insight into the circulation patterns and the rates of transport. $^{231}Pa/^{230}Th$ data present an interesting possibility for proxy development for enhanced understanding of present-day ocean circulation (and ultimately, incorporating bottom-sediment studies, the circulation of the palaeo-oceans). The AABW is anticipated to have a low ratio, because it is younger, faster moving water.

Surveying the 'choke-point' between Tasmania and Antarctica is a very effective means for upstream characterisation of the Antarctic Circumpolar Current (Circumpolar Deep Water in which supplies the DWBC) and the adjacent eastward stream of the Southern Hemisphere 'supergyre' (intermediate waters). Since this is destined to be a 'Southern Ocean' section, we shall not consider it further here.

A combination of a meridional section, tracking a little to the east of New Zealand, and a zonal section just to the north of New Zealand will efficiently characterise both subsurface currents. The meridional section (through the entire Pacific Basin) will cut across both the eastward inflow and lower-latitude western return flow of the SH supergyre loop of intermediate waters (Fig. 3). By a slight diversion (as practised in the original WOCE P15 line) in and out of Chatham Island, two closely spaced crossings of the DWBC can be made, freshly after it has begun its travel into the Pacific Basin around the Campbell Plateau (Fig. 4). The recommended zonal section will also traverse the DWBC as it moves through the Kermadec Trench further north. The western extremity of this same section will pass through intermediate–water recirculation down the east coast of Australia, as well as shallower EAC closer to the Australian coast.

Other GEOTRACES tasks, of a lower priority for the region, that can be accomplished in league with the primary goals in the SW Pacific include: observations of boundary processes (margin sediments as sources or scavengers of TEIs) and across productivity gradients, and measurement of diagnostic TEIs and tracers for deep circulation into small, restricted basins. These will be discussed in the next section in outlining cruise tracks

How Cruise Tracks Meet Objectives

In selecting cruise tracks for the region, it was seen as beneficial to use past oceanographic transects (WOCE, CLIVAR, etc.)—particularly if they have been selected for ongoing repeat sections (Fig. 6)—since the GEOTRACES results can then be evaluated against a background of enhanced oceanographic knowledge and placed in a temporal sequence. Traversing of the Tasman Sea, itself, was omitted from consideration, because it will continue to be a focus for national studies by Australia and New Zealand that will have direct relevance to GEOTRACES. Such studies will either be shorter transects or process studies, which are likely to be promoted as GEOTRACES-associated projects.

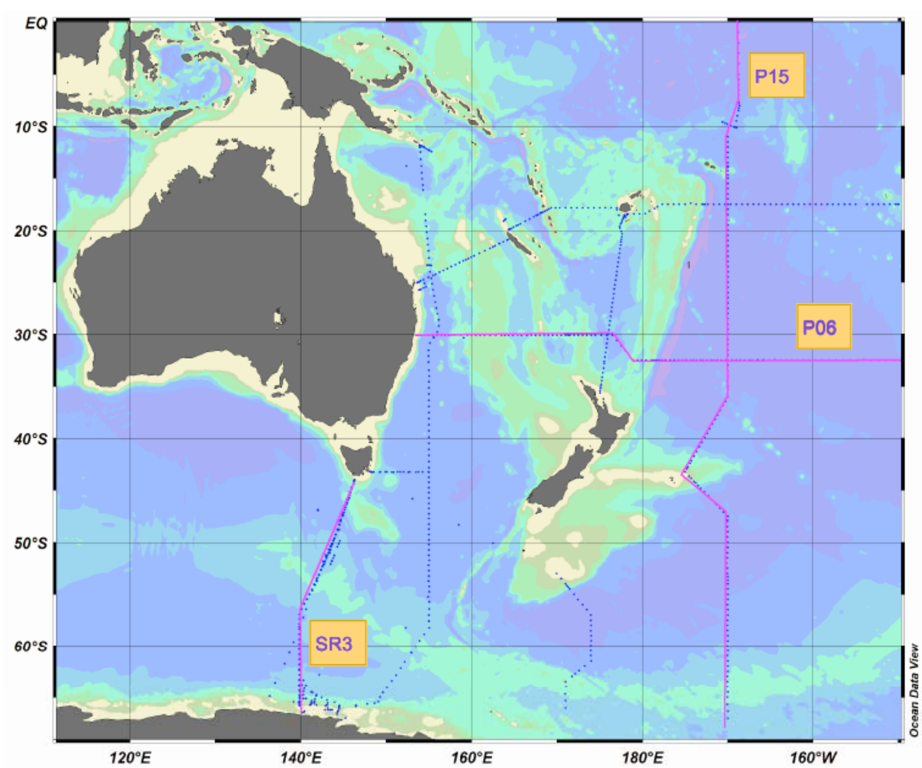

Fig. 6. WOCE/CLIVAR sections in the SW Pacific. Blue dots designate individual bottle casts, and labelled lines are CLIVAR repeat sections. Schlitzer, R., Ocean Data View, http://odv.awi.de, 2008.

P6 Line

The zonal line P6 (Fig. 6) is a repeat section that delineates a number of the oceanographic and biogeochemical features identified above as requiring investigation. Of the key objectives, it cuts across and highlights major current systems, and tracks beneath the dust plume coming out of Australia. At the surface, P6 cuts the EAC where it is a narrow coastal current (perhaps helping to resolve how important it is as a transport of riverine- and shelf-sediment-derived TEIs[1] to higher latitude waters), and likely also intersects the current in meanders along the Tasman Front toward New Zealand. Deeper, this section will cross the return flow of the SH 'supergyre' as it turns southward along the shelf-break off eastern Australia; profoundly deeper, in the Kermadec Trench waters, P6 provides a narrow cross-section of the DWBC entering the Pacific Basin. Further east, this section continues to access waters deeper than 5000 m in the southern lobe of the Central Pacific Basin.

P6 provides an important along-track gradient for the deposition of terrestrial dusts from the Australian continent. The Tasman Sea has been specifically identified for this evaluation in the GEOTRACES Science Plan (p. 20). As discussed above, the Australian dust plume is likely to have a more extensive influence, yet to be characterised, on TEI in the SW Pacific and Southern Oceans. In concert with P15 and SR3, this track will assist in demarcating the breadth of the southeastern dust corridor from Australia. In contrast to the intensively studied deposition zone in the tropical Atlantic Ocean for dusts from the Saharan and Sahel deserts (e.g. Sarthou et al. 2007, Sedwick et al. 2005), the deposition zones in Australasian waters are poorly studied. It is suggested that because the Australian dust plume usually travels at a lower altitude, its zone of distribution will be more localized than its Northern Hemisphere counterparts originating in Africa and China/Mongolia. The P6 transect along its length should provide information on relative scavenging intensity for the elements Al, Fe, Mn and other TEI moving west to east away from the dust source. Eastward of New Zealand, this has been seen in patchy distribution of Al, with almost negligible Fe surface-water concentrations remaining from dust deposition (Brown et al. 2006).

This zonal transect also transits some deeper, isolated or semi-isolated basins in the northern Tasman Sea (Figs 5, 6—i.e. New Caledonia Trough, Norfolk Basin and South Fiji Basin; but also information from the more open Tasman Basin should serve as a useful hydrological reference). These deeper water masses have potential for studies with isotopic tracers—in particular, corroborating the deep-water circulation that fills their depths, as suggested by earlier, traditional oceanographic techniques (see above and Fig. 5).

The intersection of P6 line with the P15 meridional line will produce a useful SW Pacific 'cross-over' reference site for intercalibration of TEI measurements.

Regional Support for P15 Meridional Line

The P15 line along 170°W meridian, and specifically the P15S component, provides a very useful perspective on the Australian dust plume. It will traverse a major portion of the likely depositional zone, and thus, will provide a constraint for longer term dust deposition in the SW Pacific. As referred to above, evidence of Australian dusts has been seen along the more eastward P16 line. P15 data on the natural components (Al,

[1] Although the EAC does not interact with a broad shelf environment, nor does it have a regular, sizeable riverine input, preliminary evidence still suggests that it carries iron to the southern Tasman Sea fuelling primary production there (SAZ-SENSE, unpublished data)

Fe, Mn, etc.), as well as associated pollutants (Pb and Pb isotopes—Marx et al. 2005; also conceivably Hg) will provide valuable data on the decay in dust transport and deposition moving away from its continental origin.

In regard to oceanic circulation, P15S is valuable because it traverses both arms of the intermediate water circulation (~1000 m, Fig. 3a) known as the Southern Hemisphere 'supergyre'—the westward flow-path at ~25°S, and the eastward flow-path at ~50°S. In general, this section lies close and parallel to the main axis of the DWBC inflow around New Zealand (or what in reality are the remnants of the submerged continent Zealandia) and along the Kermadec Trench. However, the original WOCE P15 cruise track has a westward deviation into Chatham Island (Fig. 6); we strongly recommend that this navigation is retained for two reasons. The first is that the DWBC is crossed on both the inward leg to Chatham Island, and the outward leg.

The second advantage of the kink into Chatham Island/Rise in the original WOCE P15 line is that it enters into a zone that has appreciable interaction with the shelf sediments of this feature. It is also possible that surface waters along the southern flank of the Chatham Rise retain a TEI signature from the terrestrial run-off captured in the loop of the Southland Current around the South Island of New Zealand (Fig. 2; Tian et al. 2006). If the southernmost leg of P15 is completed with stations along the track coming out from New Zealand (Lyttel7ton?) to link to P15 at ~48°S—as indicated in the section summary slide and the Southern Ocean draft report from the Workshop—it will provide further scope for studying the interaction with these shelf/slope sediments.

Regional Support for SR3 (P12) Meridional Line
The WOCE/CLIVAR SR3 line has been heavily studies by Australia. The characteristics of the section are well understood, and provide an excellent basis for GEOTRACES to build on. The section will be repeated in at the end of 2007 as part of the IPY-GEOTRACES Bipolar Project. The TEI and associated biogeochemical studies will exceed any previous work on this section, but it is will not be possible to encompass the breadth of measurements intended later for a full GEOTRACES section. Other recent or planned activities that will improve the knowledge of TEI processes in the vicinity of the SR3 line are the results coming out of the SAZ-SENSE voyage completed early this year, and the upcoming deployment of the Southern Ocean Time-Series (SOTS) mooring with its array of biogeochemical instruments. This mooring will be located at 47°S, essentially on the SR3 line.

In the GEOTRACES context, the SR3 line provides a picture of the ACC circulation immediately upstream of its branching to feed both the deep and to a lesser extent the intermediate circulation of the Pacific Ocean. In addition, as noted in the GEOTRACES Science Plan (Fig. 29), the section transits a spectrum of water masses, and in particular the zone of Antarctic Intermediate Water (AAIW) formation—in common with the P15S line.

Unresolved Issues / Future Decisions
One of the main challenges for this region is research vessel availability. Presently, Australia does not have a vessel with sufficient scientific complement to mount a cruise track beyond the Southern Ocean. The Australian Marine National Facility Vessel *'Southern Surveyor'* has berths for a maximum of 15 scientific personnel and an endurance of 21–26 days, both of these attributes make it unsuitable for the GEOTRACES program. It is envisaged that the *'Southern Surveyor'* will be replaced in the

next 3–4 years; the strong recommendation is that the replacement vessel will fit GEOTRACES requirements.

In the Southern Ocean, the research and resupply vessel '*Aurora Australis*' is adequate for the work, but it is also unlikely to be in operation for the duration of GEOTRACES. It is the vessel that will undertake the IPY-GEOTRACES SR3 voyage later this year.

The only regional vessel that is presently suitable for a GEOTRACES section in lower latitude waters is New Zealand's '*Tangaroa*' with a scientific complement of 25 and a maximum endurance of 60 days. Hence, it has been the vessel tentatively identified with carrying out P6, particularly if this line is to be done before 2010–11. At this point, this suggestion has not been placed before any NIWA (NZ) representative, so it remains notional.

A significant hurdle for Australian participation in GEOTRACES activities is the lack of a public-good funding apparatus to support such international programs. This not only pertains to proposing and carrying out oceanographic sections for TEI study, but also to important associated research, such as regional process studies and supporting measurements (e.g. aerosol monitoring at land stations).

In regard to education/extension activities, efforts will be made to marine scientists from Pacific Island nations on GEOTRACES voyages in the region. The mechanisms to facilitate this practice are yet to be identified.

It is advised here that GEOTRACES in the SW Pacific liaises / integrates well with SPICE (Southwest Pacific Ocean Circulation and Climate Experiment-see <www.ird.nc/UR65/SPICE>), a proposal of the International CLIVAR program. Obvious synergies would result from effective collaboration.

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Southern Ocean

GEOTRACES Pacific Workshop 29 June 2007

Report of Southern Ocean Working Group *

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Background and Rationale

The Southern Ocean is the world's largest High Nutrient-Low Chlorophyll region. Approximately 90% of the global inventory of unused surface nutrients exists there. Only about half of the nutrients that upwell in the Southern Ocean are consumed and exported as biogenic detritus. Since the Southern Ocean is the principal region of deepwater ventilation, the low nutrient utilization efficiency there establishes the global average efficiency of the ocean's biological pump, which, under modern conditions, is roughly 50% (Marinov et al., 2006).

Many modeling studies, beginning in the early 1980s (Knox and McElroy, 1984; Sarmiento and Toggweiler, 1984; Siegenthaler and Wenk, 1984), have indicated that changes in nutrient utilization in the Southern Ocean could have been responsible for Pleistocene climate-related changes in atmospheric CO_2 levels. John Martin linked nutrient utilization in the Southern Ocean to the limited availability of micronutrients such as iron (Martin, 1990). Many subsequent studies have examined the impact of Fe on phytoplankton physiology and nutrient utilization in the Southern Ocean (Boyd et al., 2007), while entrepreneurs have suggested iron fertilization as a geoengineering strategy to sequester CO_2 from the atmosphere (information about a recent workshop on this issue can be found at <http://www.whoi.edu/conference/OceanIronFertilization>). However, despite this widespread interest, the distribution of Fe in the Southern Ocean is poorly constrained, and even less is known about its sources and sinks. Furthermore, work to date on TEIs in the Southern Ocean has focused primarily on Fe, and little attention has been afforded to other TEIs, including micronutrients.

Potential sources of micronutrients include glacial weathering of Antarctica, diagenesis of Antarctic margin sediments, and dust. Micronutrients mobilized along the coast of Antarctica can be transported seaward by sea ice as well as by ocean mixing. Upwelling of deep water, the principal source of macronutrients, supplies micronutrients as well.

Recent studies have shown clear evidence for sedimentary sources of Fe along the margin of Antarctica (Figure AA1). However, these studies did not include the complete suite of TEIs that would (a) constrain sources of other micronutrients (e.g., Co, Zn), (b) provide diagnostic tracers of sources of micronutrients (e.g., Nd, Os and Hf isotopes), or (c) radionuclides to constrain rates of scavenging and loss of TEIs. Furthermore, existing work does not constrain micronutrient distributions in regions of extreme (i.e., high vs. low) phytoplankton biomass, nor does it examine systematically regions of contrasting continental bedrock terrain.

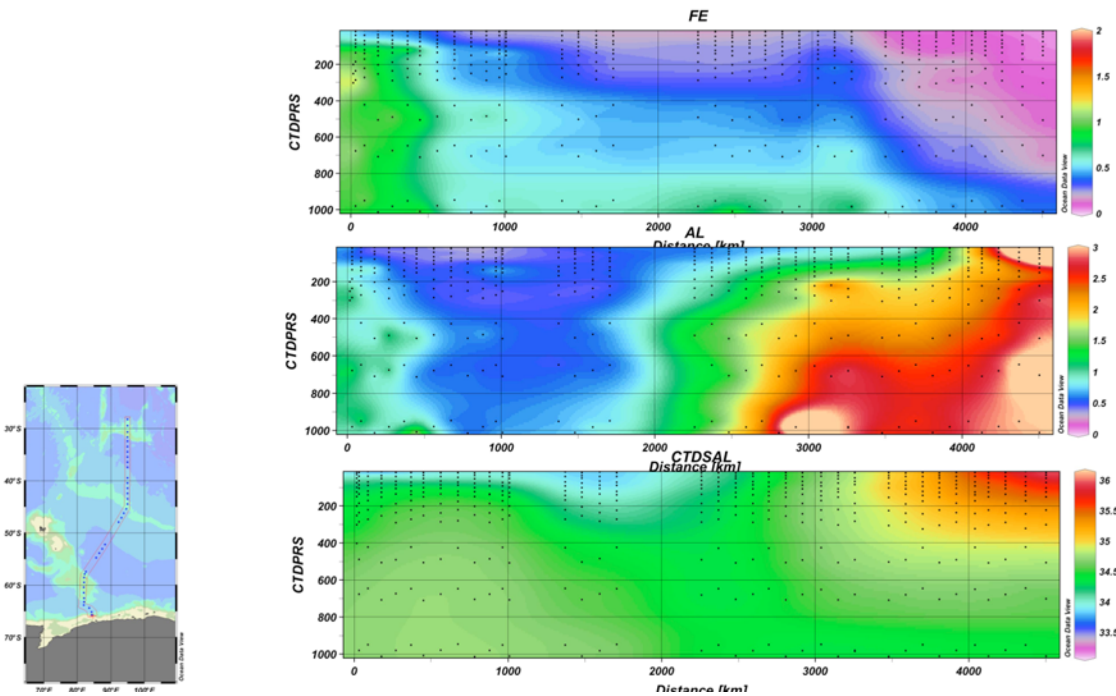

Figure AA1: Concentrations of dissolved iron and aluminum, together with salinity, along a quasi-meridional section in the Indian sector of the Southern Ocean (location shown in the inset). Elevated concentrations of iron (top panel section) near the coast of Antarctica (left hand side of section) indicate release from continental margin sediments. Figure courtesy of Chris Measures.

Three meridional sections crossing the Antarctic Circumpolar Current will collect information about the distributions of a more complete suite of TEIs in the Southern Ocean as part of the GEOTRACES contribution to the International Polar Year:

1) A reoccupation of the WOCE SR3 line south of Tasmania (approx 145°E), led by Australia;

2) A section south from the tip of Africa as part of the BONUS-GOOD HOPE program, led by France; and

3) A section across the Drake Passage (Zero and Drake Program), led by Germany and The Netherlands.

The reoccupation of SR3 will provide an important contribution to GEOTRACES research on sources and internal cycling of TEIs in the Pacific sector of the Southern Ocean, as well as to research on continental sources of TEIs. The other two transects are more relevant to objectives pertaining to the Atlantic sector, and are not considered further here.

First-order features of the Southern Ocean guiding the strategy to study the biogeochemical cycles of TEIs in the Pacific Sector include:

1) Satellite ocean color images regularly show a strong west to east gradient of decreasing phytoplankton biomass in the Pacific sector of the Southern Ocean (Figure AA2). It is hypothesized that this gradient reflects regional differences in the supply of micronutrients, and GEOTRACES could produce the data needed to test this hypothesis.

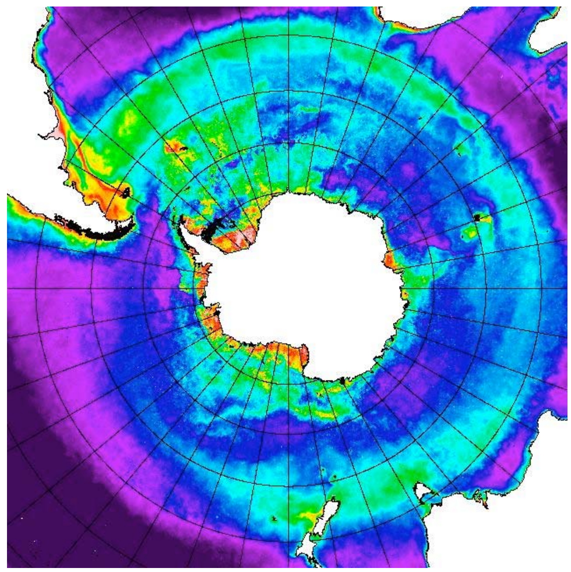

Figure AA2: Composite SeaWiFS image representing phytoplankton biomass in the Southern Ocean. In the Pacific Sector, biomass decreases systematically from west to east, except near the coast of Antarctica. We are grateful to the SeaWiFS Science Project for the SeaWiFS data set. Courtesy of NASA/GeoEye (www.geoeye.com) Copyright 2008. All rights reserved

2) East and West Antarctica have very different geological terrains, with west Antarctica being characterized by much younger rocks, often of volcanic origin, in contrast to east Antarctica, which is dominated by old continental craton (Figure AA3). The influence of bedrock type on supply of micronutrients, and on the TEI signature of different deep water masses formed around the margin of Antarctica related to these different terrains, has not been explored.

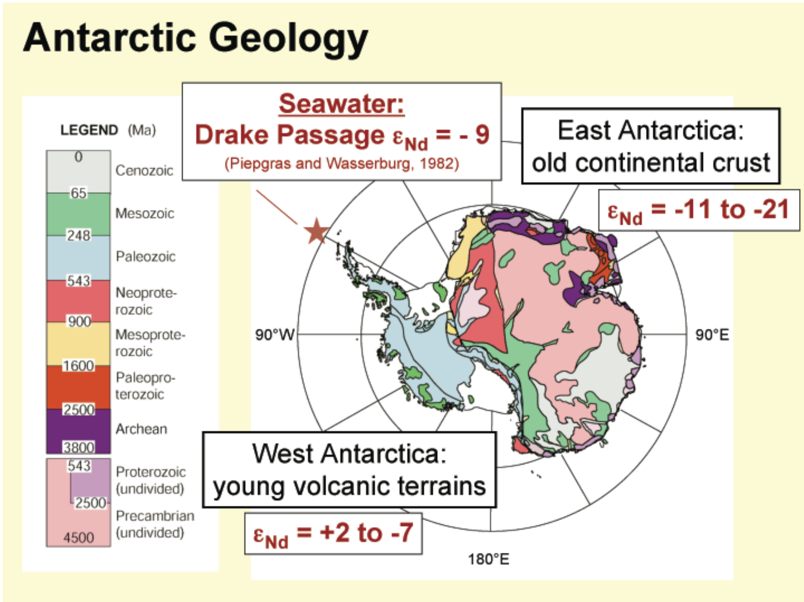

Figure AA3: Map of Antarctica showing ages of the different terrains. Ages are based on information in Kirkham and Chorlton (1995). Continental neodymium isotope compositions from Roy et al. (2007) and van de Flierdt et al. (2007); seawater Nd data from the Drake Passage from Piepgras and Wasserburg (1982). Figure courtesy of Tina van de Flierdt.

3) The impact of glacial weathering will not be felt uniformly around Antarctica because transport of ice is concentrated in rapidly-flowing ice streams that enter the ocean at specific locations (Figure AA4).

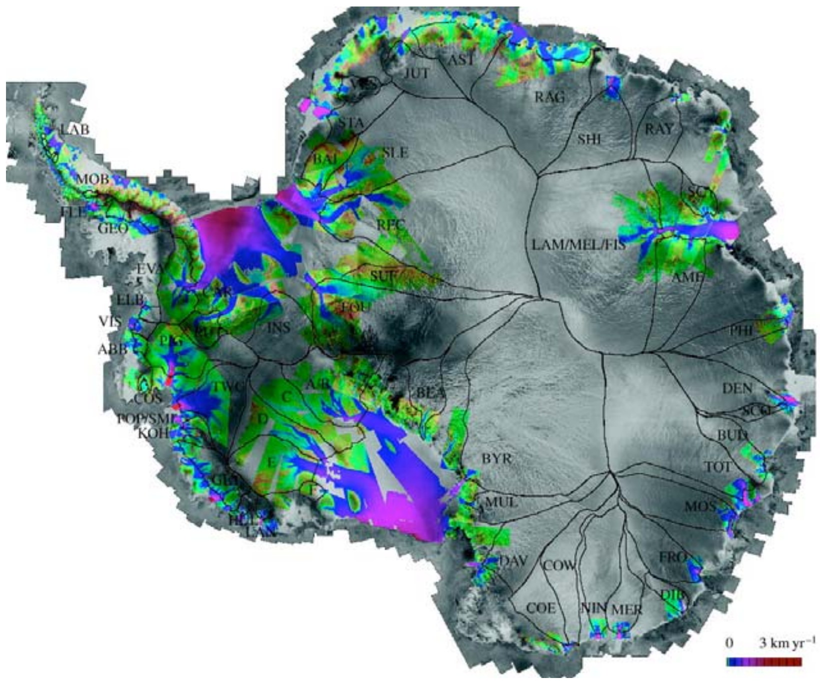

Figure AA4: Ice dynamics in Antarctica expressed in terms of flow speed (see color bar). Figure from Rignot (2006). Rignot, E. 2006. Changes in ice dynamics and mass balance of the Antarctic ice sheet. Philopsopical Trnascatiosn of the Royal Society a-Mathematical Physical and Engineeering Sciences, 364 (1844): 1637-1655. Courtesy of The Royal Society.

Strategy

With this background in mind, three meridional sections to the coast of Antarctica are recommended to examine these first-order issues:

1) SR3, from Tasmania to the coast of Antarctica at ~140°E, will examine low biomass waters in the ACC (Figure AA 2), and it will intersect the continental margin in an area with crust of Proterozoic to Archean ages (Figure AA3). This section will terminate to the east of the Mertz glacier, which is one of the fastest flowing glaciers in East Antarctia (Figure AA4). It is also the area where Adelie Coast Bottom Water is formed, which is potentially a major contributor to Antarctic Bottom Water.

2) A section out of Christchurch, New Zealand, running SE to 170°W and then down to Antarctica, which covers (a) the region of high biomass potentially influenced by micronutrients from shelf sediments surrounding New Zealand (Figure AA2), (b) inflow of Antarctic Bottom Water (AABW) into the Pacific around the base of the Campbell

Plateau (See Report of the SW Pacific Working Group, where a study of AABW further downstream is proposed), (c) the region of maximum ACC biomass in the Pacific sector (Figure AA2), and (d) the Ross Sea where there are high discharge rates of ice that scours young terrain of west Antarctica (Figure AA4).

3) A section into the Bellingshausen Sea (approx. 80-90°W) or Amundsen Sea (approx. 100-120°W) would cross a region of the ACC with minimum biomass between 90 – 120 W (Figure AA2) to determine micronutrient distribution and, potentially, measures of the physiological state of phytoplankton cells. It would then be of interest to compare and contrast the TEI distribution and physiology of organisms in the low-biomass ACC region with those in regions of high biomass near the coast (Figure AA2).

The three sections also cover a range of sea ice conditions (Figure AA5), ranging from minimum annual ice (SR3) to maximum winter ice (~170W) to maximum summer ice (Bellinghausen and Amundsen Seas).

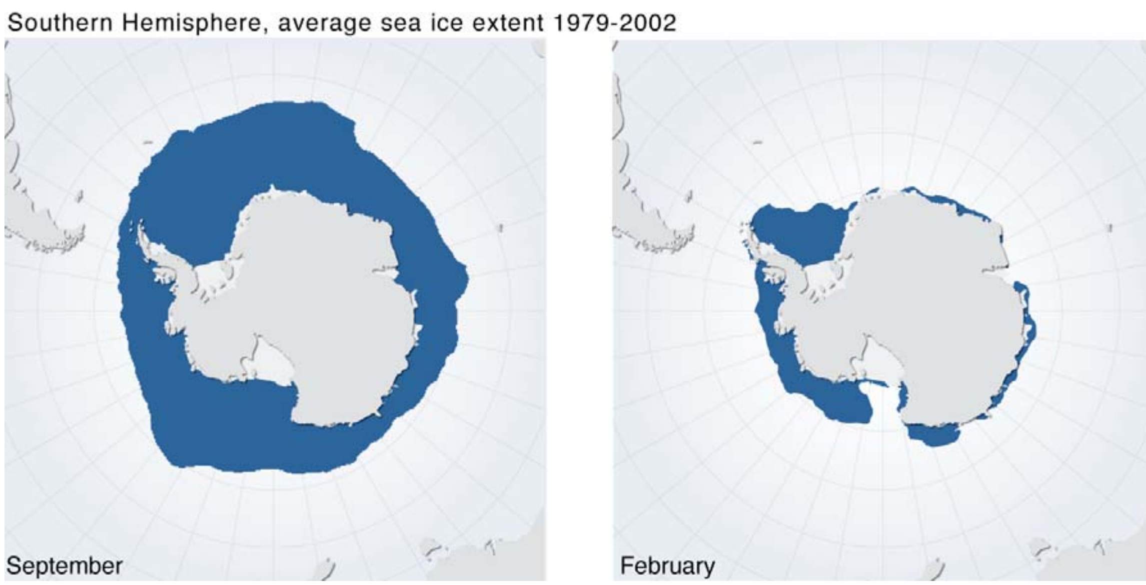

Figure AA5: Average sea ice extent in the Southern Ocean at times of maximum and minimum sea ice cover. Maps designed by Hugo Ahlenius, UNEP/GRID-Arendal and avilable from http://maps.grida.no/go/graphic/maps-of-average-sea-ice-extent-in-the-arctic-summer-september-and-winter-march-and-in-the-antarctic-summer-february-and-winter-september

Issues and Logistics:

SR3 is regularly occupied by Australia. A GEOTRACES cruise along this section is planned for late 2007/early 2008 (Contact Ed Butler for further information; Edward.Butler@csiro.au).

The US RVIB Palmer regularly runs between Christchurch, New Zealand and McMurdo Station (Ross Sea). A slight eastward departure from this normal route could cover the recommended section at 170°W. Support from the US NSF Office of Polar Programs would be needed.

The Bellingshausen and Amundsen Seas are remote areas that are difficult to access. Three options for gaining access to this region include:

1) Entering the area as the southern terminus of a section that crosses the ultra-oligotrophic South Pacific gyre (See report of the Southeast Pacific Working Group),

2) Running a southward transect from the RVIB Palmer when it transits between Punta Arenas and McMurdo, or

3) Running a southward transect from the Oden during its transit from Punta Arenas to McMurdo to break ice. The US NSF leases the Oden from Sweden to break the channel into McMurdo station. It is anticipated that up to 20 days of science time will be made available during each transit between Punta Arenas and the Ross Sea. An advantage of this option is that it would engage Swedish colleagues in GEOTRACES research in the Southern Ocean. A disadvantage of this option is that it is unlikely that sufficient berths would be available to allow scientists to study all TEIs of interest during a single cruise. Since the Oden is anticipated to be used for up to 5 years, perhaps GEOTRACES could use the Oden for multiple years and different TEIs could be studied in different years.

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Meridional Sections

The Meridional Sections

Scientific Rationale: A primary driver for the GEOTRACES program is to provide a high quality global scale characterization of the distributions of TEIs. The meridional sections in the Pacific are the primary means of accomplishing this objective. In combination they transect the major geochemical regions within the Pacific, and address a number of key processes of importance to the large scale distributions of TEIs.

How the cruise tracks meet the objectives: Two meridional sections were selected, one in the western Pacific that will be executed by Japan, and one in the central to eastern Pacific to be carried out by the U.S. The primary objectives of these sections include the large-scale characterization of the broad geochemical provinces in the Pacific, establishing the TEI characteristics of the primary source waters to the basin (ventilated thermocline waters, NPIW/AAIW and mode waters, and AABW/NADW complex) and the measuring TEIs in the returning deep waters that exit the basin in the southeast corner.

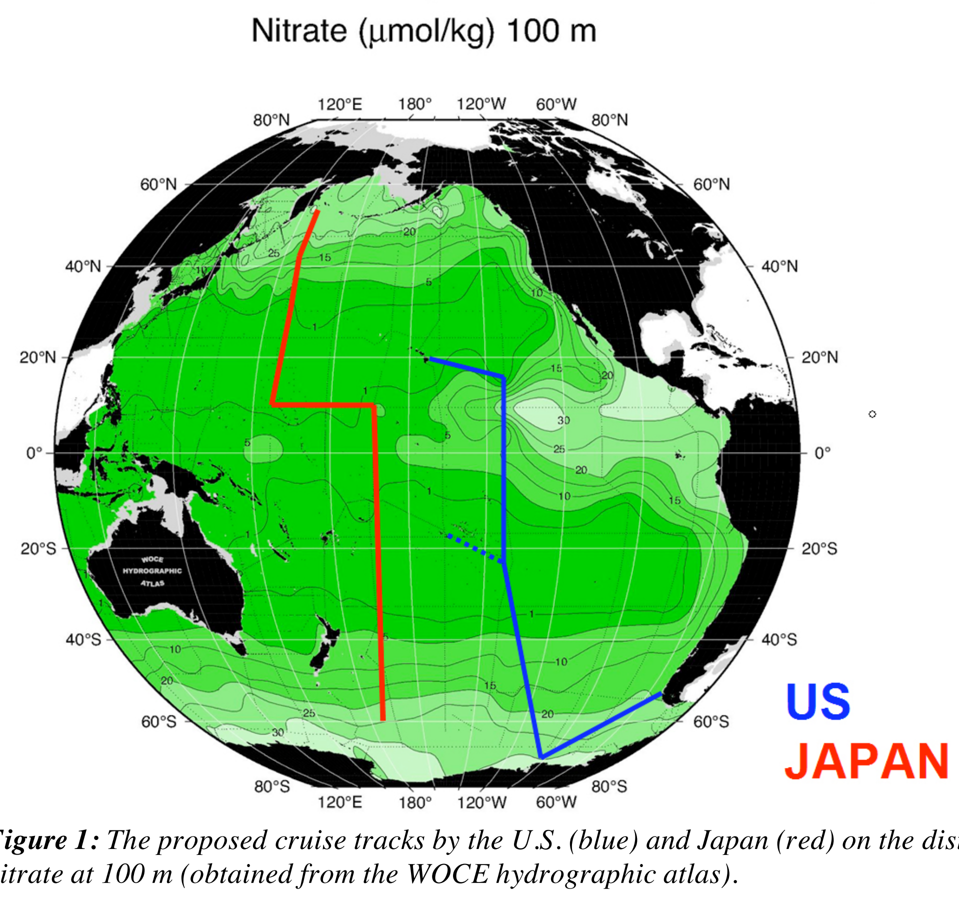

Figure 1: The proposed cruise tracks by the U.S. (blue) and Japan (red) on the distribution of nitrate at 100 m (obtained from the WOCE hydrographic atlas).

The U.S. section is meant to dove-tail with the U.S.-Canadian sections centered on OWSP, and consists of a diagonal section between Hawaii and 135W and 10N, then a meridional transect southward along 135W to approximately 25S, then diagonally to the Antarctic continent at 110W, followed by a section to the southern tip of South America. We consider that the short sections from Hawaii to Ocean Station "P" and beyond as the northern extension of this section. Following that logic, the section starts in HNLC waters at the northeastern boundary of the Pacific, moves into an oligotrophic gyre (the North Pacific), then cuts through the extensive OMZ/HNLC equatorial region, transecting the deep ^{3}He plume at 15S, entering the central portion of the South Pacific ultra-oligotrophic region, then finishing in the high nutrient gradient (and southwards HNLC waters) of the Southern Ocean. The subtropical South Pacific contains some of the "bluest", low trace metal water of the world ocean and hence forms an important end-member to the contrasting HNLC/OMZ and nutrient rich Antarctic Circumpolar Current. The section through the extremely oligotrophic subtropical region constitutes the effective terminus of Australian dust plume, and coverage is especially important in that there is a large "data gap" in the measurement of TEIs in this area.

The largely meridional portion within the South Pacific also serves to transect the anticyclonic movement of the Antarctic Intermediate Water (Russell and Dickson, 2003) that is forming and entering the gyre in the southeast Pacific near South America (Iudicone et al., 2007). At about 20S, this section crosses the largely zonal flow of ~ 13C water (Reid, 1997) that comes from the southeast, and ultimately feeds the Equatorial upwelling cell (Karstensen, 2004; Toggweiler and Dixon, 1991). Inasmuch as this water ultimately sources the Indonesian Throughflow (e.g., Brown et al., 2007), characterization of TEIs in this water is key to understanding the global transport of these properties, especially for the Indian Ocean thermocline (e.g., Fine, 1985; Vranes et al., 2002).

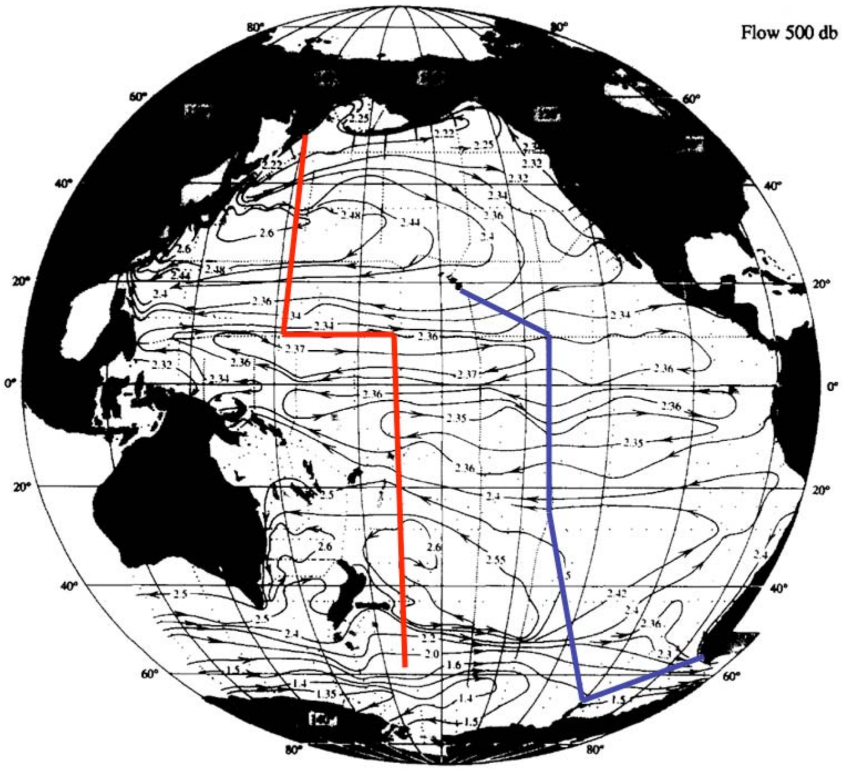

Figure 2: *The meridional sections on Reid's 1997 geostrophic flow field at 500 db*. Reprinted from Progress in Oceanography, Vol. 39/Issue 4, On the total geostrophic circulation of the pacific ocean: Flow patterns, tracers, and transports, pp. 263-352, 1997, with permission from Elsevier; http://www.sciencedirect.com/science/journal/00796611.

The sections into the Antarctic continent are intended to characterize the evolving TEI composition of the AACC as it accumulates glacial weathering output from the continent. The final diagonal between the Antarctic continent and South America provides a useful cross section of the intrusion of old Pacific deep water exiting the basin into the Antarctic Circumpolar current (Well et al., 2003).

The Japanese section consists of two meridional lines, one at 165E north of 10N, and another at 170W south of 10N, with a zonal connector at 10N. The northern segment provides us with a valuable transect of the western North Pacific gyres (both subtropical and subpolar), characterizing the North Pacific Intermediate Water very near its source in the Okhotsk Sea/Kurils passages. The section also complements the work proposed in the western North Pacific as part of the Canadian/US cooperation (centered at OWSP). The southern part of the northern segment also transects the mode waters (Roemmich and Cornuelle, 1992) as well as the largely zonal flow in the ventilated subtropical thermocline that almost directly feeds the Indonesian Throughflow, completing the characterization provided by the southern segment of this cruise (along 170W) and the U.S. section at 135W (see Figure 2). The southern section also characterizes the inflow of AAIW into the western Equatorial region, and cuts through the center of the inflowing tongue (Ganachaud, 2003) of relatively young (radiocarbon rich) AABW into the abyssal

Pacific near the Kermadec trench. In this respect this section is crucial to characterizing the basin-wide inventories and budgets of TEIs.

Another valuable contribution of the P15 line is that it provides us with a more close-up snapshot of the presence and effect of the Australian dust plume, for comparison to the Al/Fe data obtained along P16 (150W) by Landing and Measures, and with the more easterly US line along 135W that we proposing. Multiple TEI measurements will be invaluable in characterizing the transport, deposition and scavenging of TEIs at a number of locations away from the continental origin. Also of interest is the portion of the section that extends onto the Chatam Rise, where interaction of bottom currents with extensive sedimentary cover offers strong potential for modification (supply and removal) of a number of TEIs.

In tandem, these sections also provide a reoccupation of previous lines (e.g., WOCE/CLIVAR, GEOSECS and Hakuho-Maru expeditions), and thus contribute information on decade time-scale variations in nutrients, dissolved oxygen and other properties.

Some of the TEI-relevant processes that are important in these meridional sections are: (1) boundary scavenging (at the northern and southern ends as well as the seafloor throughout), (2) particle-specific scavenging (perhaps most importantly the carbonate-silica particle transitions but including other big transitions in the nature of other sinking particles), (3) glacial weathering in the Antarctic, and its consequences for TEI properties, and (4) Fe scavenging (as deep waters “age” by hundreds of years over their trajectories) balanced by regeneration from sinking particles, release from reducing sediments, and hydrothermal inputs.

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Summary

At the end of the four-day meeting an initial plan, with cruise tracks and logic for each region covered had been assembled. Countries were identified that would take the lead in trying to obtain logistical and financial support to implement the sections and partnerships between countries were outlined that would permit studies to be completed across regions with intersecting EEZ claims, thus permitting continuous tracks across regions of scientific interest, without compromising national interests.

The proposed cruise tracks for the Pacific Basin are shown in Figure 1, with an expanded version of the marginal seas shown in Figure 2.

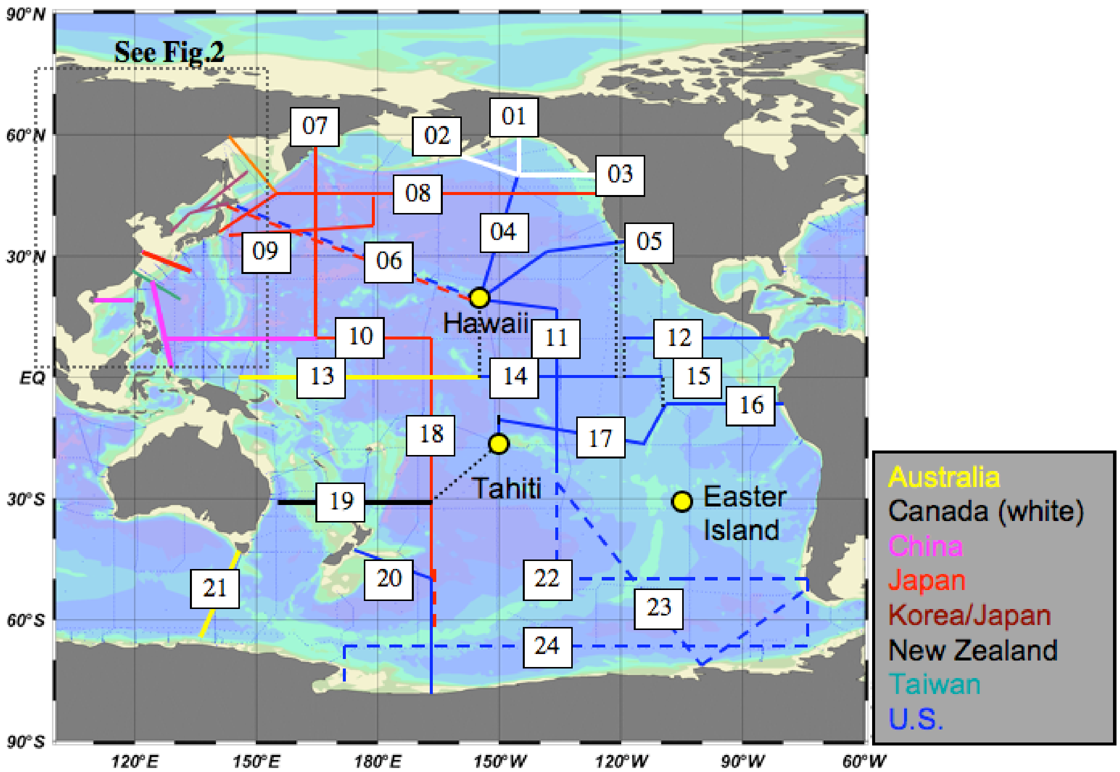

Figure 1. Proposed GEOTRACES cruise tracks in the Pacific Ocean. Black dotted lines represent transits to ports. Dashed lines (blue and red represent alternative routes or alternative proposers.

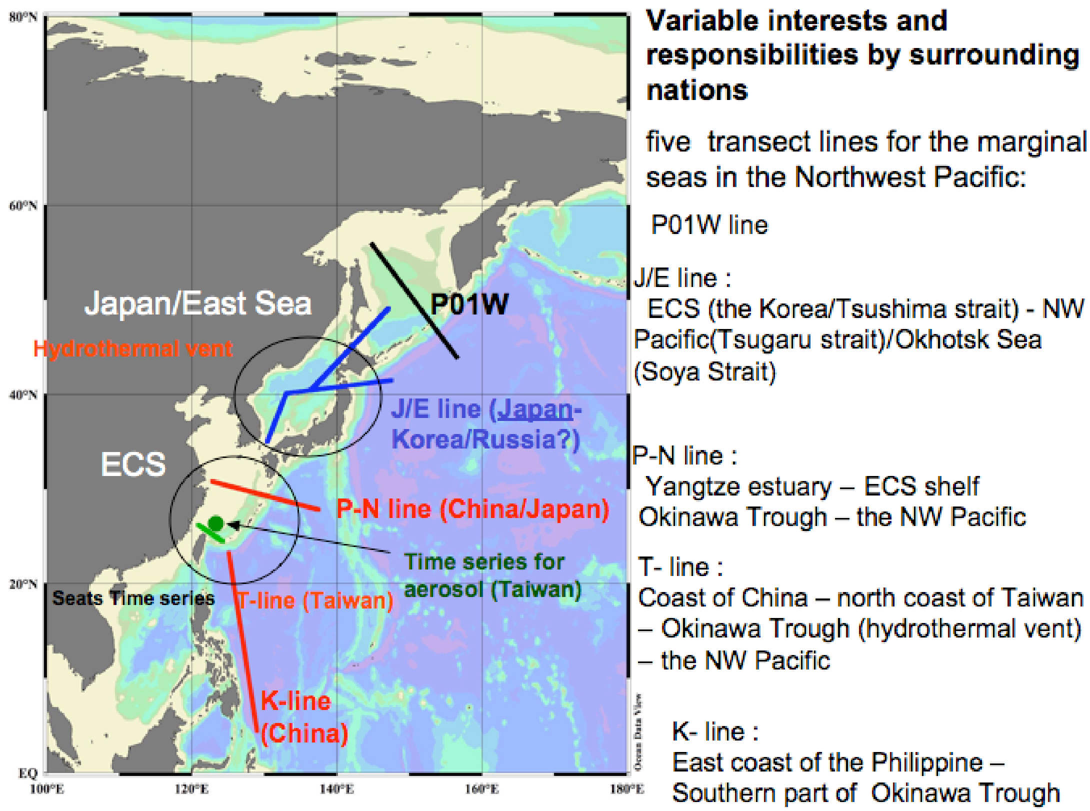

Figure 2. Proposed GEOTRACES cruise tracks in the marginal seas of the NW Pacific.

Wherever possible cruise tracks were designed to intersect existing time-series stations, affording the opportunity to establish these places as GEOTRACES calibrated stations. The presence of such stations will allow participating nations to intercalibrate during shared GEOTRACES sections as well as providing well characterised reference stations permitting post facto intercalibration as the program continues. Additionally, where cruise tracks intersect it was anticipated that ad hoc intercalibration points would be established.

Below is a summary of the goals of each particular cruise track and countries that have volunteered to pursue their implementation.

Pacific Basin

Section name	Processes	Country	Comments
01	HNLC to coastal, Alaskan fluvial input	Canada	All three sections go through Ocean Station P. Component of E. meridional section
02	HNLC to volcanic arc, source of particulate Fe to HNLC region	Canada	
03	Productive coastal region to HNLC	Canada	Is same as line P, 50 year history as time-series. Terminates at time series station
04	Intermediate and mode waters. Shelf basin exchange	USA	Component of E. meridional line made up of 01, 04, 11 and 22 or 23
05	Basin to boundary scavenging		Connects HOT time series to SAFE station
06	Chemical evolution along thermocline ventilation pathway	USA/Japan	Cuts across intermediate water pathway
07	Bering Sea exchange	Japan	Component of W meridional section
08	HNLC, boundary scavenging, hydrothermal input J de Fuca	Japan	Repeat of WOCE 47N line
09	Marginal sea and shelf water contributions to basin. Dust deposition	Japan	Component of triangle section, seasonal re-occupation
10		China/Japan	Component of W meridional section
11	Oligotrophic gyre, intermediate and mode water formation regions	USA	Component of W meridional section possible route, alternate joins 22 or 23
12	Oxygen minimum	USA	Component OMZ section, low particle flux OMZ
13	Shelf basin exchange/scavenging along advective flow path of Eq undercurrent	Australia	Component of Eq undercurrent zonal section
14		USA	Component of Eq undercurrent zonal section
15		USA	Component of Eq undercurrent zonal section and OMZ section

16	OMZ high productivity high particle flux,	USA	Component of OMZ section, starts at Peru time-series station
17	Hydrothermal fluxes	USA	
18		Japan	Component of W meridional section
19	Dust deposition, deep water flow into N Pacific	New Zealand	Repeat of WOCE PO6
20			Repeat of USJGOFS line
21	ACC upstream of its contribution to deep water masses	Australia	Not full GEOTRACES, repeat of WOCE/CLIVAR SR3
22	Oligotrophic gyre, intermediate water formation regions, deep water return flow, low T alteration of oceanic crust	USA	Alternate route to 23. Will also connect 11 with 17. 22 is favoured route across gyre if 24 is occupied
23	Shelf micronutrient inputs. Glacial weathering, sea ice TEI release, basin gradients, AABW	USA	Alternate route to 22. This route preferred if 24 is not occupied.
24	Shelf micronutrients, glacial weathering, sea ice, TEI release, paleo proxies. AABW	USA	Oden transect to McMurdo

NW Pacific Marginal Seas

Section name	Processes	Country	Comments
J/E	Fluxes/processes and TEI distributions in ECS. Miniature ocean.	Japan Korea Russia?	
P-N	Fluxes to ECS from Yangtze, dust deposition, Kuroshio upwelling	China Japan	
K	Shelf Basin exchange	China	
T	Shelf basin exchange Hydrothermal sources	Taiwan	
	Bering Sea inputs		Possible inclusion with PO1W, needs Russian collaboration

Appendix 1

GEOTRACES Pacific Basin Workshop June 26-29th
University of Hawaii at Manoa, Honolulu, Hawaii

Meeting rooms:

Plenary:
Pacific Ocean Science and Technology building (POST) 127
Section working group rooms:
Marine Science Building (MSB): 305, 306, 307, 315
Breakfast/Lunch and coffee breaks MSB 203

Transportation from Hotel to UH
Shuttles will run from the street outside hotel lobby to UH please be ready to board your assigned van at your assigned time

- First pick up: 07:15
- Second pick up approximately: 07:45
-

A buffet style **breakfast** will be provided at UH each morning prior to the meeting.

Tuesday, June 26, 2007

Plenary POST 127

09:00 - 09:30	Welcome and logistics
09:30-10:15	GEOTRACES introduction and goals *Bob Anderson*
10:15- 10:45	Coffee break
10:15 - 10:45	Specific Workshop goals
10:45-12:00	National presentations, identifying national interests related to GEOTRACES, ship and expertise availability, funding and scheduling processes, collaboration opportunities.
12:00 - 13:00	Catered lunch
13:00 - 15:00	National presentations continued
15:00 - 15:30	Coffee break
15:30- 16:15	*Phil Boyd*: Pacific GEOTRACES - Iron and trace metal biogeochemistry
16:15-16:35	*Ken Bruland*: Intercalibration in GEOTRACES
16:35- 16:55	*Bill Landing*: Aerosol collections during GEOTRACES

Party at 2436 Lamaku Place (Chris and Karen's house).
Vans will transfer you to the party we will announce arrangements in the meeting

Wednesday, June 27, 2007

Plenary POST 127

08:30- 09:15	*Bill Jenkins*: Pacific Ocean Circulation from a GEOTRACER's perspective
09:15- 10:00	*Chris Measures*: Geochemical tracers in the Pacific: where should we look, what are we after?
10:00-10:30	Coffee break
10:30- 12:30	"Open microphone"Section Proposers
12:30 - 13:30	Catered lunch

GEOTRACES Pacific Basin Workshop June 26-29th
University of Hawaii at Manoa, Honolulu, Hawaii

13:30 - 14:30*	"Open microphone"Section Proposers continued only if necessary
15:00 - 15:30	Coffee break
14:30*-17:30	Establish and commence first set of section working groups (WG)

* These times are estimates. Actual start of WG will be as soon as possible after finish of section proposers

20:00	Group dinner: Chiang Mai. Vans will transfer you to the restaurant we will announce pick up times at the hotel during the meeting

Thursday, June 28, 2007

Plenary POST 127

08:30- 12:00	1st section working groups report Define second section working groups.
10:00-10:30	Coffee break
12:00 - 13:00	Catered lunch
13:00- 15:00	Second set of section working groups (WG)
15:00-15:30	Coffee break
15:30-17:30	WGs continue
	Dinner on your own

Friday, June 29th, 2007

Plenary POST 127

08:30 - 12:00	Second section groups report to plenary session, Finalise all sections and logic
10:00-10:30	Coffee break
12:00-13:00	Lunch on your own
15:00-15:30	Coffee break
13:00-17:00	Proponents from grant submitting countries write straw proposal outlines and coalesce common information. Begin preparation of draft Pacific Basin Science Implementation Plan.

Appendix 2

Workshop Participants

Participant	**Affiliation**	**Country**
Hiroshi Amakawa	Ocean Research Institute, University of Tokyo	Japan
Robert Anderson	LDEO	USA
Kathy Barbeau	University of California	USA
Andrew R Bowie	ACE CRC & ACROSS, University of Tasmania	Australia
Philip Boyd	University of Otago	New Zealand
Ed Boyle	MIT	USA
Kenneth Bruland	UC Santa Cruz	USA
Ken Buesseler	Woods Hole Oceanographic Institution	USA
Edward Butler	CSIRO Marine & Atmospheric Research	Australia
Karen Casciotti	Woods Hole Oceanographic Institution	USA
John Crusius	USGS	USA
Steve Emerson	University of Washington	USA
Roger Francois	University of British Columbia	Canada
Céline Gallon	UC Santa Cruz	USA
Toshitaka Gamo	Ocean Research Institute, The University of Tokyo	Japan
Gwo-Ching Gong	National Taiwan Ocean University	Taiwan
Dennis Hansell	University of Miami	USA
Mariko Hatta	University of Hawaii	USA
Gideon Henderson	University of Oxford	UK
William Hiscock	University of Hawaii	USA
Tung-Yuan Ho	Academica Sinica	Taiwan
Chin-Chang Hung	National Taiwan Ocean University	Taiwan
William Jenkins	Woods Hole Oceanographic Institution	USA
Phoebe Lam	Woods Hole Oceanographic Institution	USA
William Landing	Florida State University	USA
James McManus	Oregon State University	USA
Chris Measures	University of Hawaii	USA
Simone Metz	NSF	USA
Juan Carlos Miquel	International Atomic Energy Agency	Monaco
Jim Moffett	USC	USA
Bradley Moran	University of Rhode Island	USA
Kristin Orians	University of British Columbia	Canada
Gregg Ravizza	University of Hawaii	USA
Jingling Ren	Ocean University of China	China
Olivier Rouxel	Woods Hole Oceanographic Institution	USA
Kathleen Ruttenburg	University of Hawaii	USA

Mak Saito	Woods Hole Oceanographic Institution	USA
Marco Salamanca	Universidad de Concepción	Chile
Evgueni Shoumiline	CICIMAR, La Paz	Mexico
Yoshiki Sohrin	Institute for Chemical Research, Kyoto University	Japan
Ed Urban	The Johns Hopkins University	USA
Tina van de Flierdt	LDEO	USA
Jingfeng Wu	University of Alaska	USA
Rejun Yang	Ocean University of China	China
Jing Zhang	Toyama University	Japan
Meixun (Max) Zhao	School of Ocean and Earth Sciences,Tongji University	China
Dimitri Gutierrez	Instituto del Mar del Perú	Peru
Seung Kyu Son	KORDI	S Korea
Se Jong Ju	KORDI	S Korea
Rebecca Briggs	University of Hawaii	USA
Nicole Charney	University of Hawaii	USA
Eric DeCarlo	University of Hawaii	USA
Laura Gelleke	University of Hawaii	USA
Angelos Hannides	University of Hawaii	USA
Cecelia Hannides	University of Hawaii	USA
Zackary Johnson	University of Hawaii	USA
Yuan-Hui (Telu) Li	University of Hawaii	USA
Brian N. Popp	University of Hawaii	USA