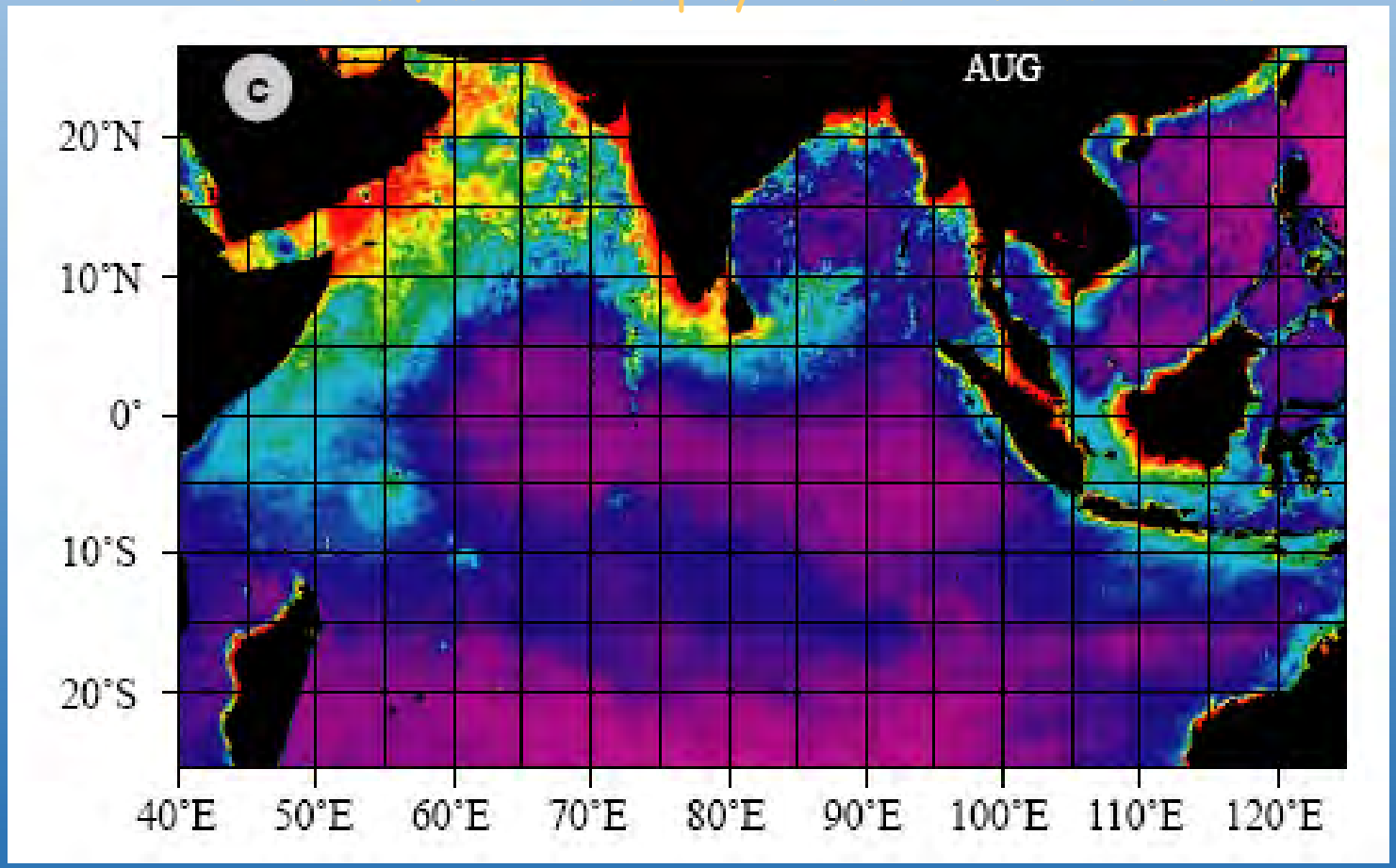
Insights into IO Biogeochemistry from GEOTRACES

Jim Moffett
University of Southern California

Outline

- Monsoon-driven processes and iron limitation in the Arabian Sea
- Dynamics of metal cycling within the Arabian Sea OMZ
- Importance of the OMZ and Hydrothermal inputs of iron into the basin
- Analogy with the Eastern Tropical South Pacific
- Assessment of hydrothermal sources of iron to the Southern Ocean
- Major unanswered questions

Sea Surface Chlorophyll in the Indian Ocean

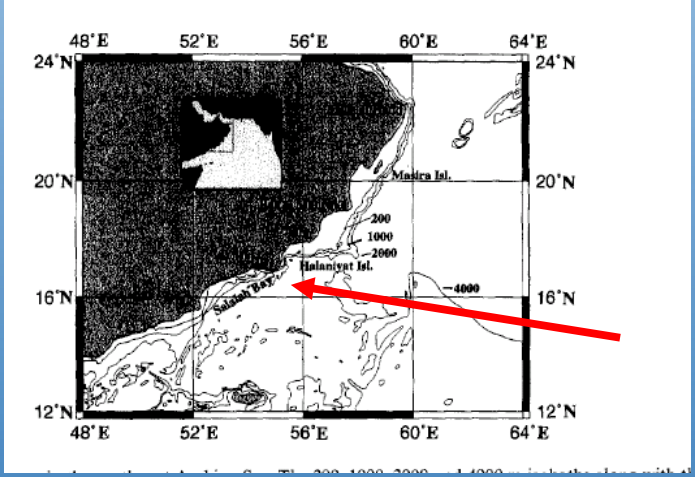


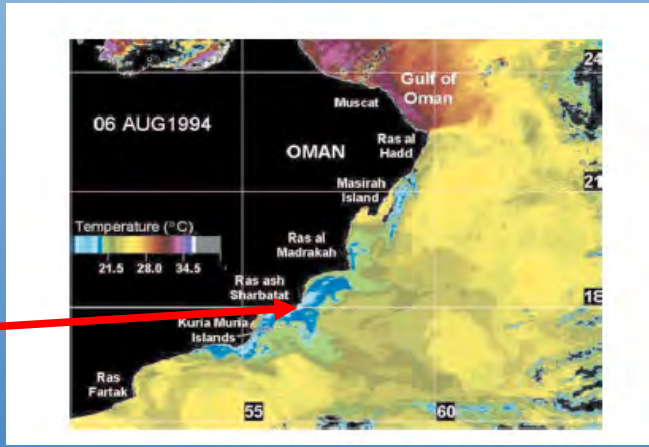
Motivation

JGOFS concluded Fe limitation not important during SW monsoon

But – I noted several similarities with other Fe limited coastal areas :

1. In upwelling areas in California and Peru, bottom topography is the critical determinant. Note: narrow shelf in southern Oman!

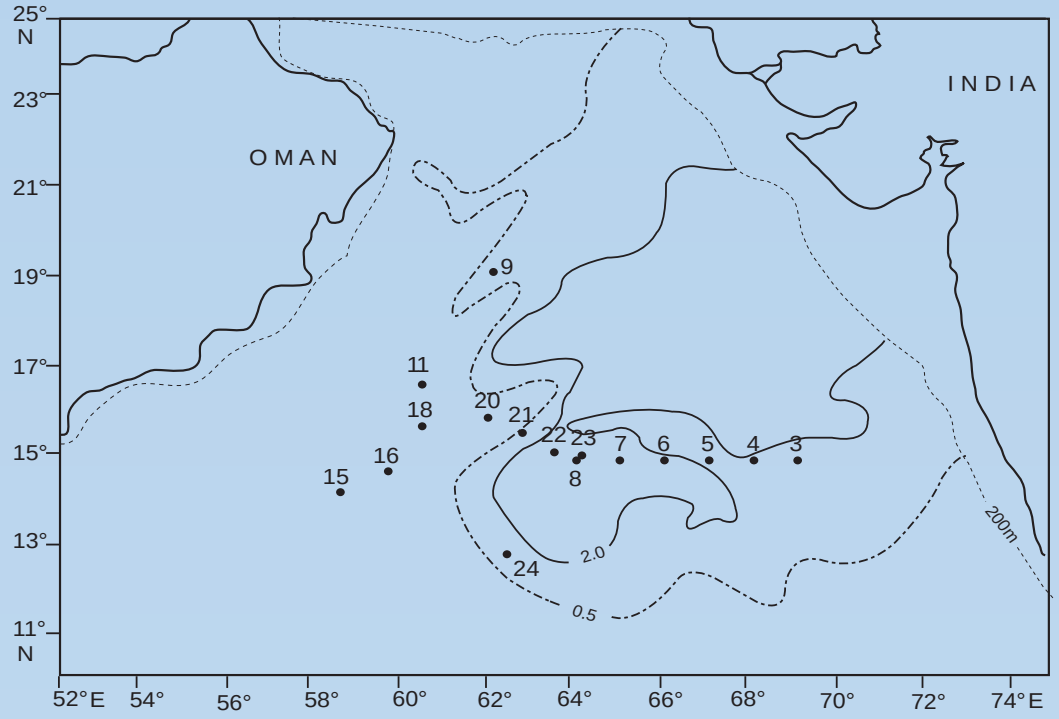




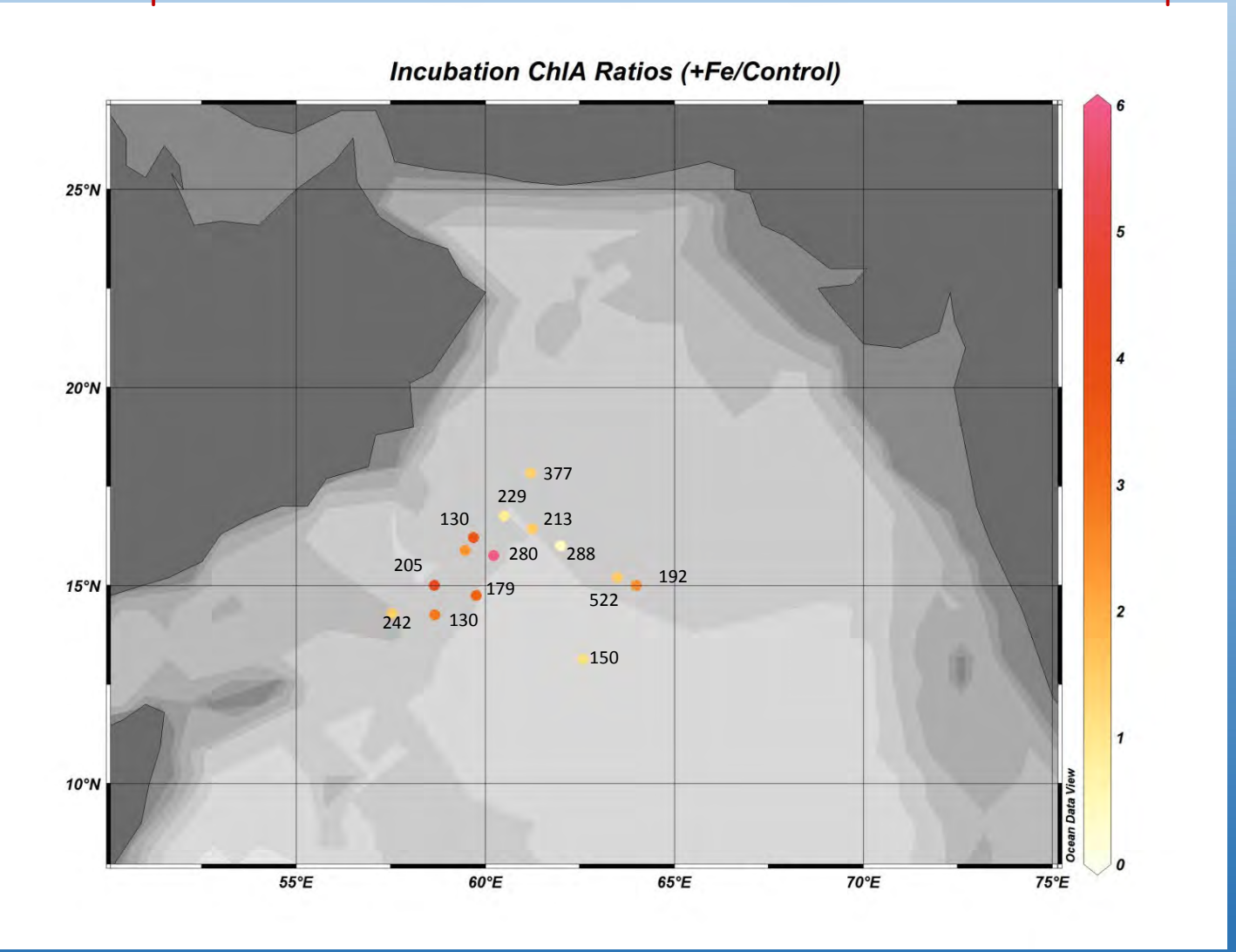
2. Si is very strongly depleted relative to nitrate during the SW Monsoon, a diagnostic of preferential drawdown by Fe-limited diatons

September 2007 Cruise on Roger Revelle to assess the role of Fe limitation during the SW Monsoon

Chief Scientist: Wajih Naqvi



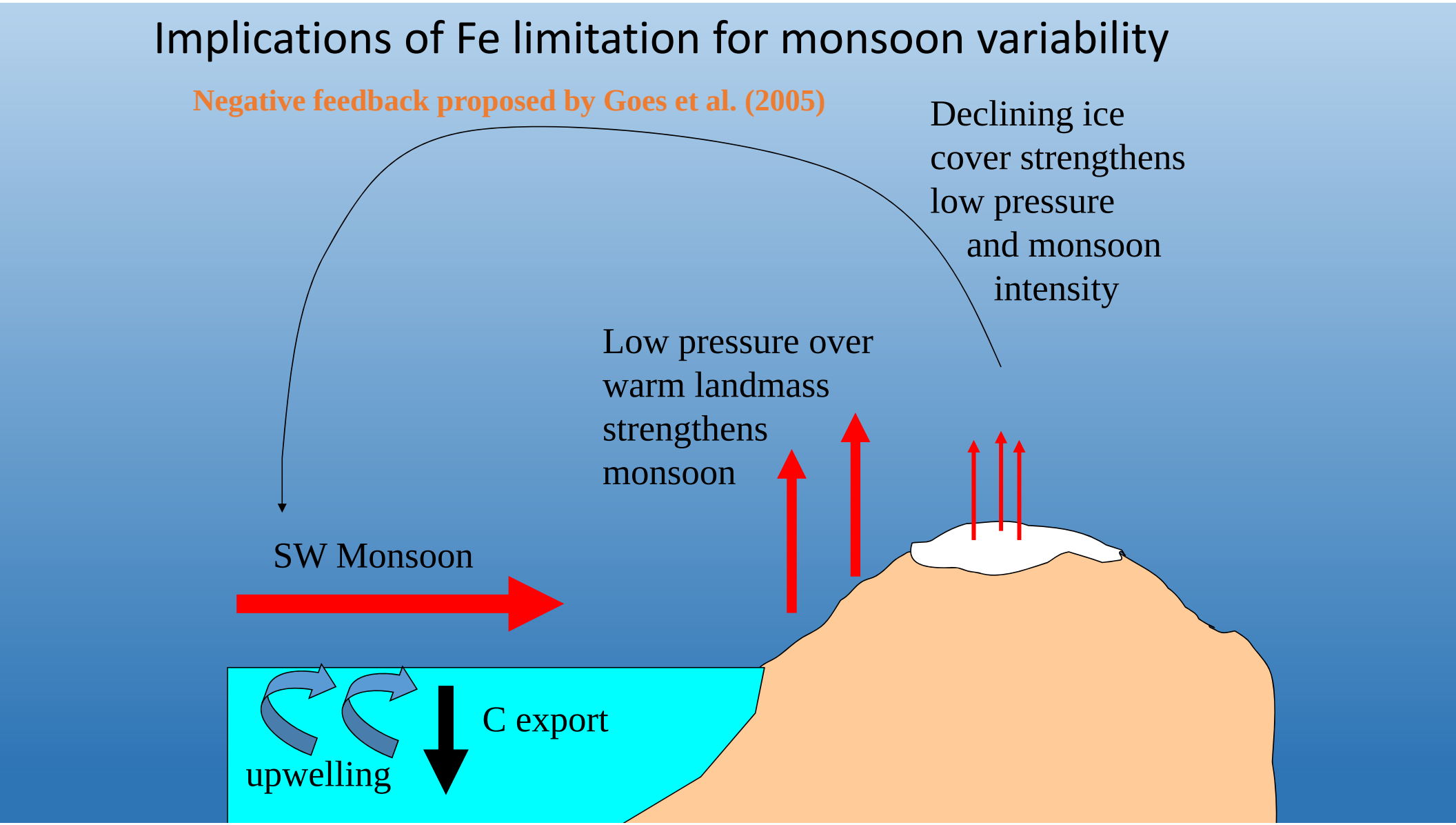
Fe addition experiments and total dissolved Fe concentrations in surface samples



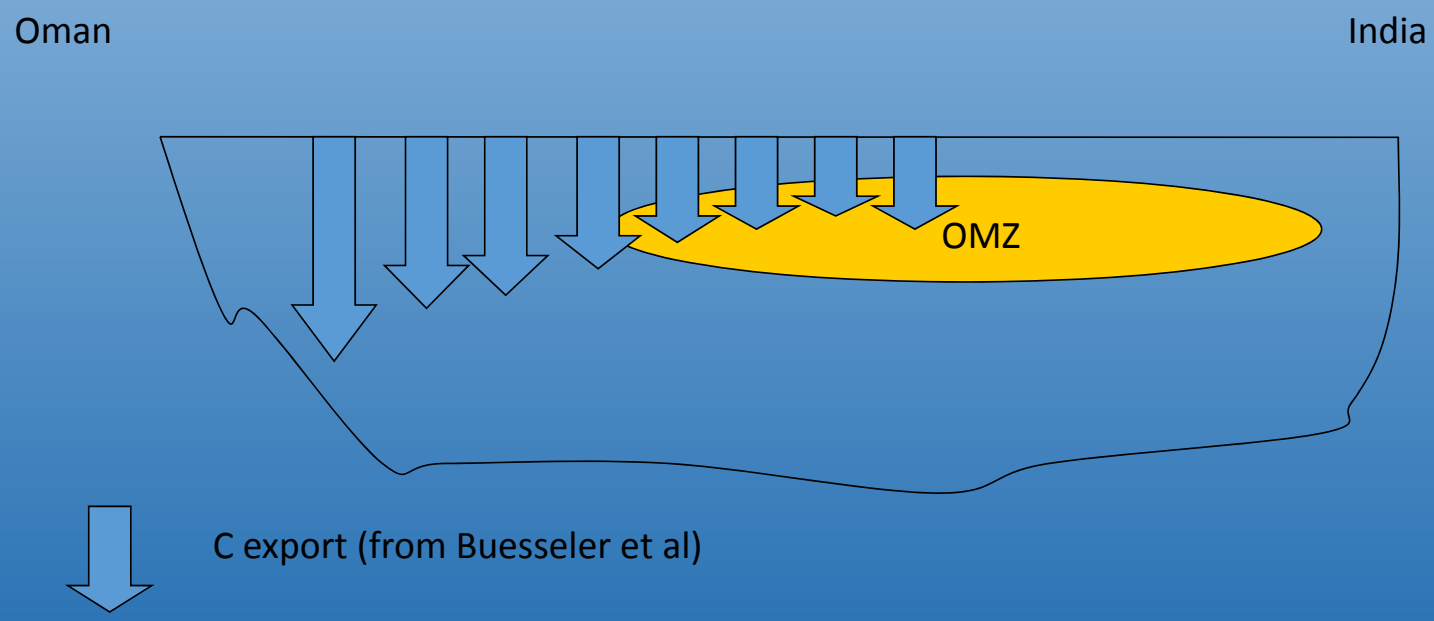
Conclusions

- Fe limitation throughout Arabian Sea during the SW monsoon
- Extreme Si limitation; as a consequence Phaeocystis predominates in Fe enrichment experiments – suggests a close coupling between dust inputs, C export and DMS production.
- Dissolved Fe in surface waters lower than reported by Measures and Vink (2000) but similar to recent data from Japanese GEOTRACES

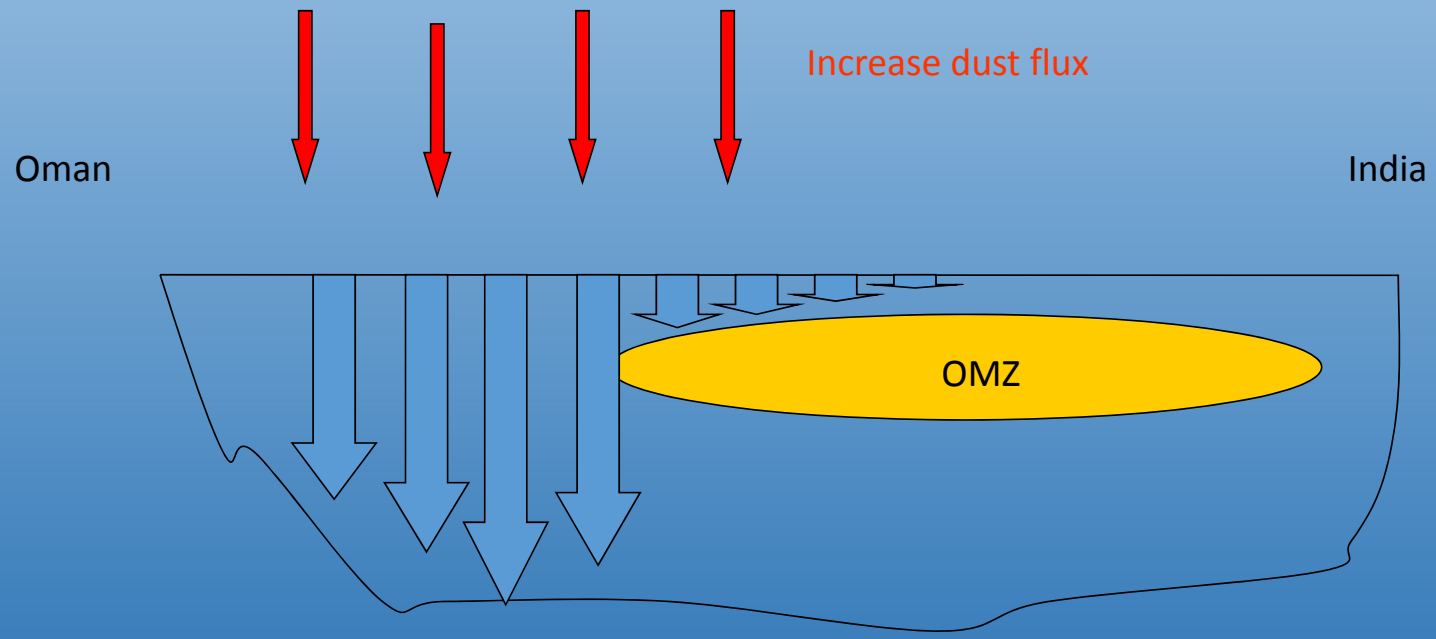
Implications of Fe limitation for monsoon variability



Section at 15 N showing decoupling between C export associated with the Omani upwelling and the permanent OMZ to the east.

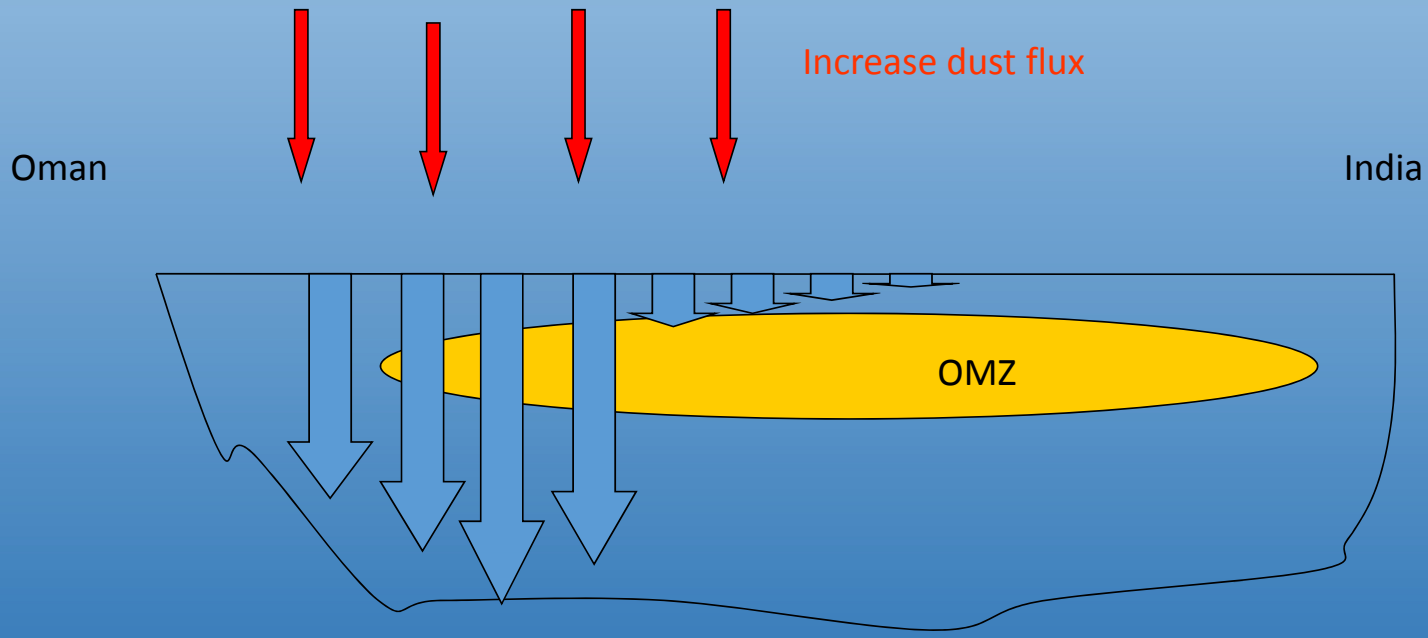


Section at 15 N showing decoupling between C export associated with the Omani upwelling and the permanent OMZ to the east.



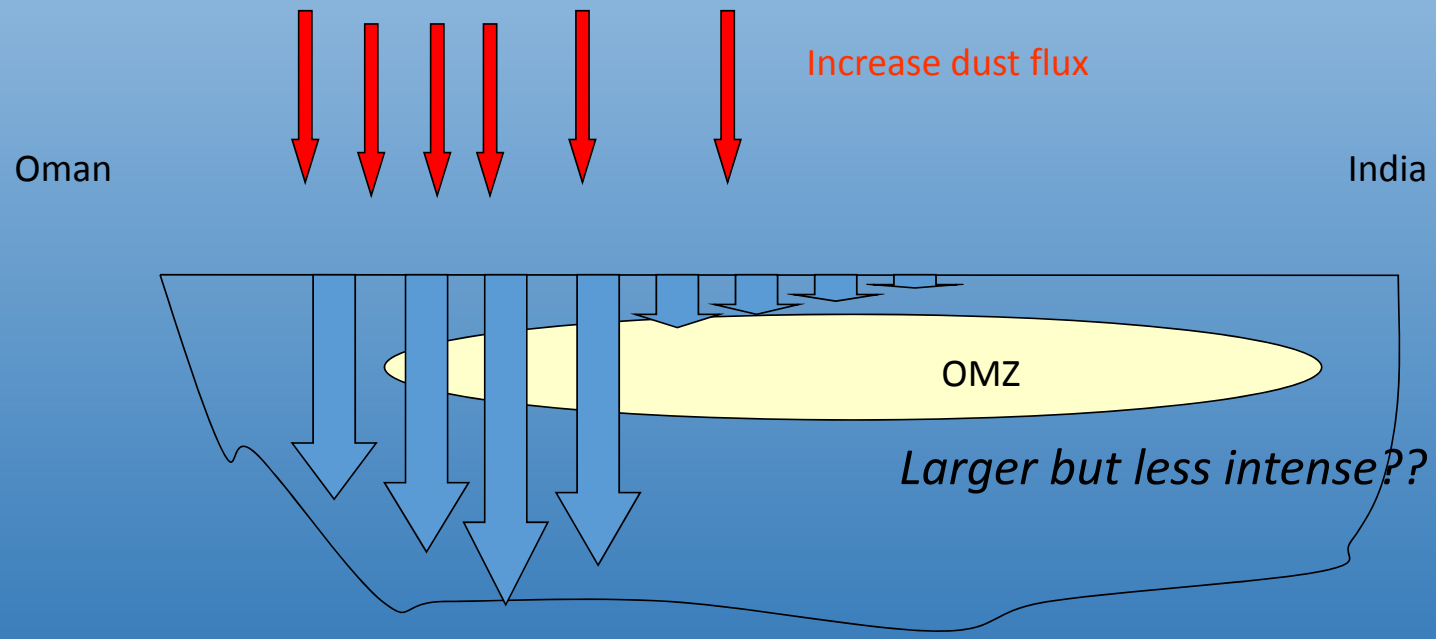
Section at 15 N showing decoupling between C export associated with the Omani upwelling and the permanent OMZ to the east.

SCENARIO 1



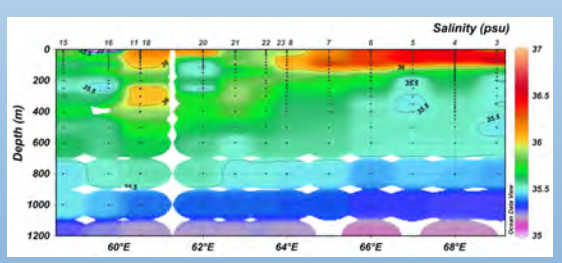
Section at 15 N showing decoupling between C export associated with the Omani upwelling and the permanent OMZ to the east.

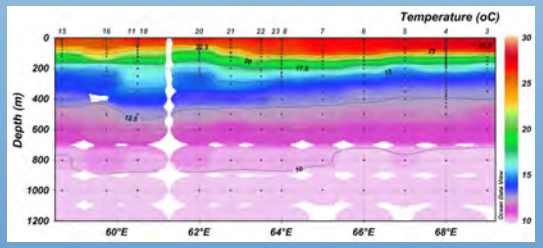
SCENARIO 2

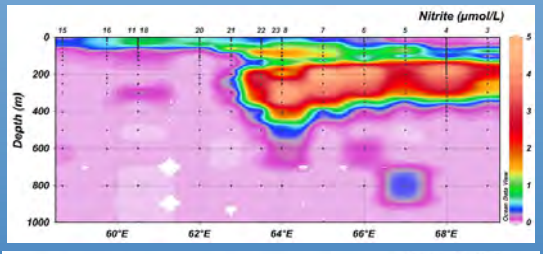


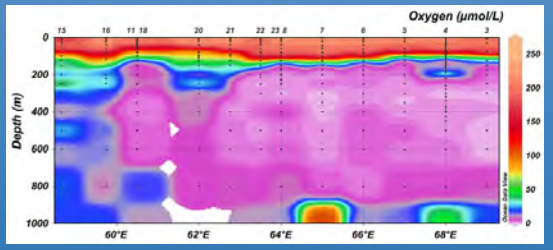
Dynamics of metals within the OMZ

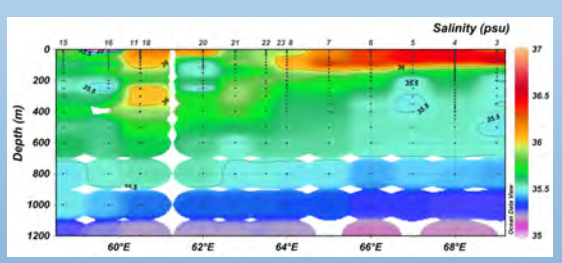
- Previously, I didn't know much about what metals were doing within this feature to assess how contraction or expansion (of a weaker?) OMZ might affect iron supply to surface waters or export from the basin
- Analysis of Fe and other metals from the section through the OMZ provides a much better assessment and links well with recent GEOTRACES activities

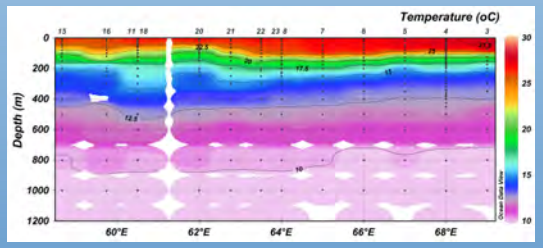

Salinity (psu)
Depth (m)
0
200
400
600
800
1000
1200
60°E
62°E
64°E
66°E
68°E
37
36.5
36
35.5
35

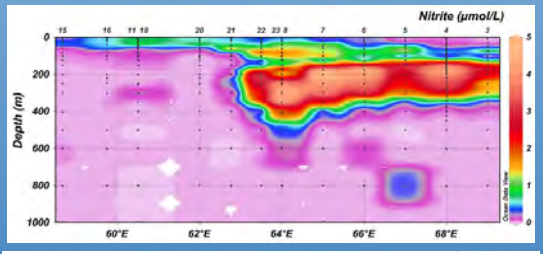

Temperature (oC)
Depth (m)
0
200
400
600
800
1000
1200
60°E
62°E
64°E
66°E
68°E
30
25
20
15
10

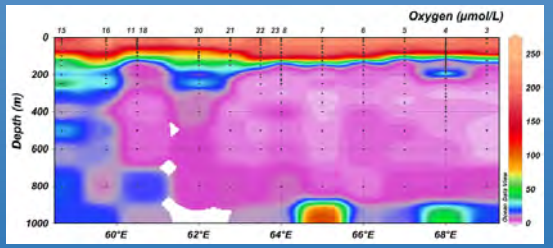

Nitrite (µmol/L)
Depth (m)
0
200
400
600
800
1000
60°E
62°E
64°E
66°E
68°E
5
4
3
2
1
0

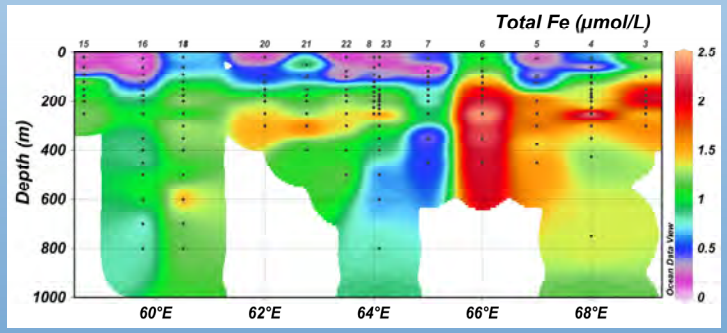

Oxygen (µmol/L)
Depth (m)
0
200
400
600
800
1000
60°E
62°E
64°E
66°E
68°E
250
200
150
100
50
0

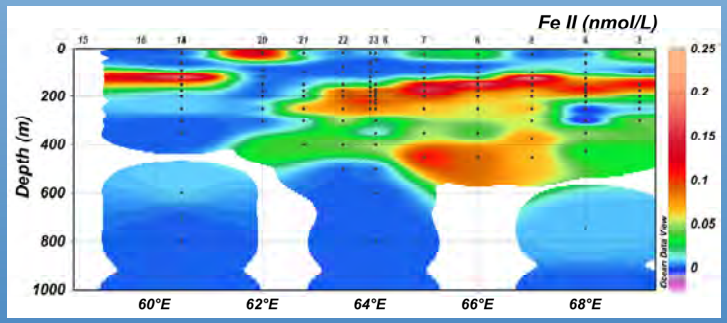

Salinity (psu)
Depth (m)
60°E
62°E
64°E
66°E
68°E


Temperature (oC)
Depth (m)
60°E
62°E
64°E
66°E
68°E

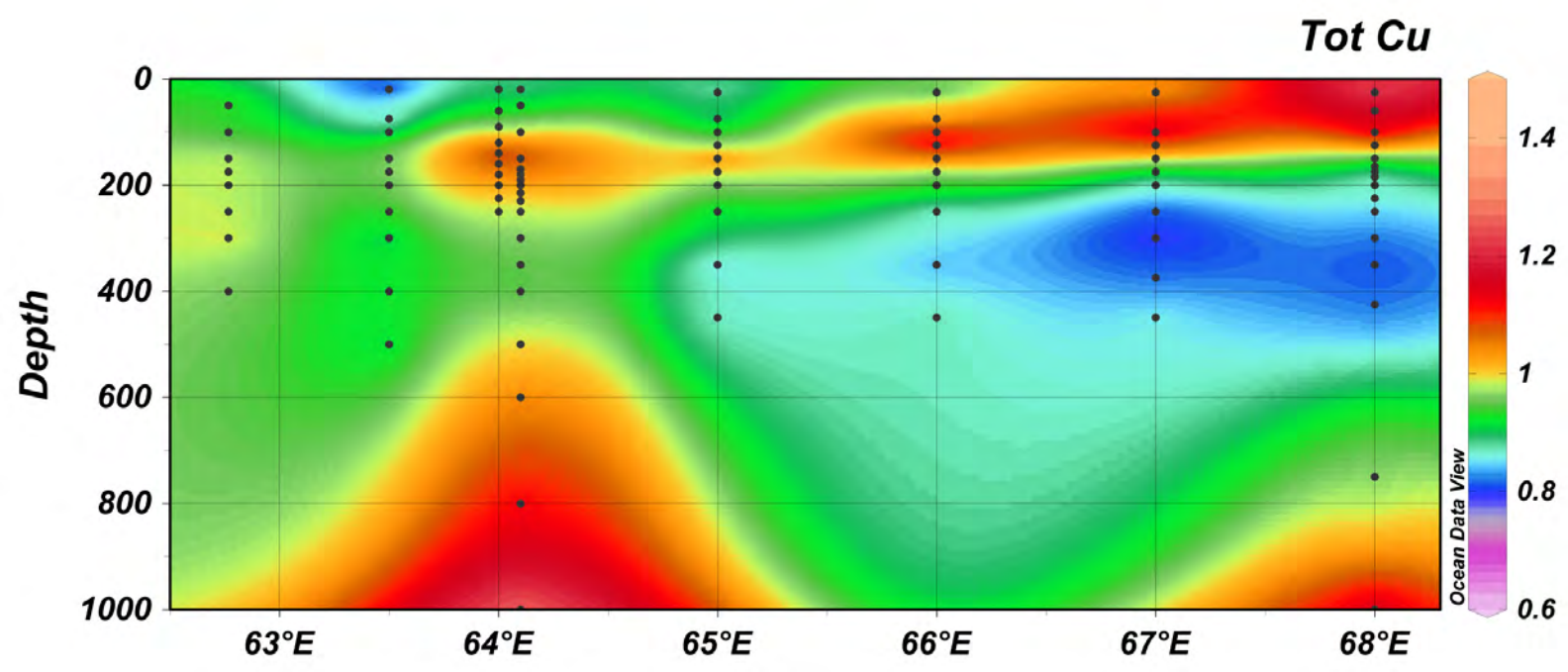

Nitrite (µmol/L)
Depth (m)
60°E
62°E
64°E
66°E
68°E


Oxygen (µmol/L)
Depth (m)
60°E
62°E
64°E
66°E
68°E


Total Fe (µmol/L)
Depth (m)
60°E
62°E
64°E
66°E
68°E


Fe II (nmol/L)
Depth (m)
60°E
62°E
64°E
66°E
68°E

Subsurface tongue of copper within oxicline most dramatic feature I have ever seen for copper



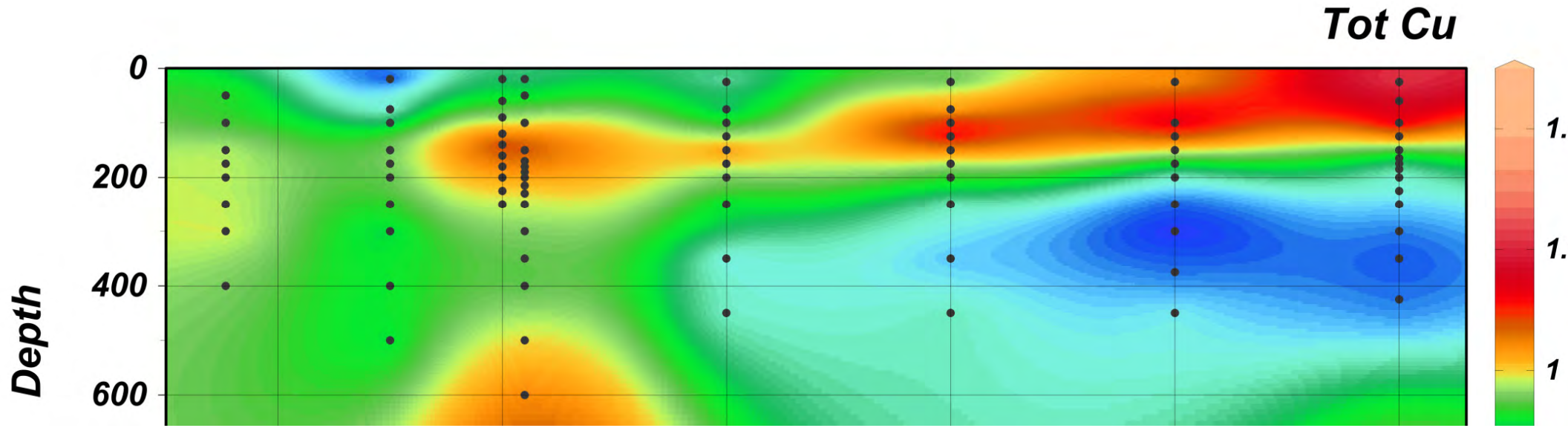
- Subsurface maxima probably associated with export and remineralization of Phaeocystis biomass, high C:Cu ratio
- Minima within the OMZ due to high Cu requirements of denitrification? Scavenging by sulfide on

Subsurface tongue of copper within oxicline most dramatic feature I have ever seen for copper

Phaeocystis bloom

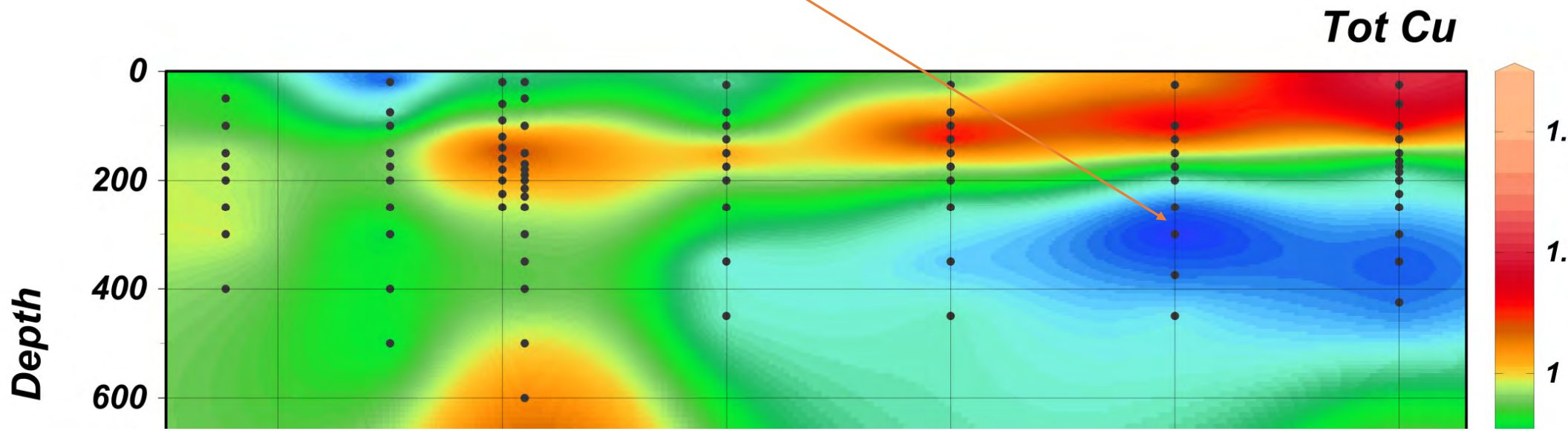
Export of organic matter with a high Cu:C ratio

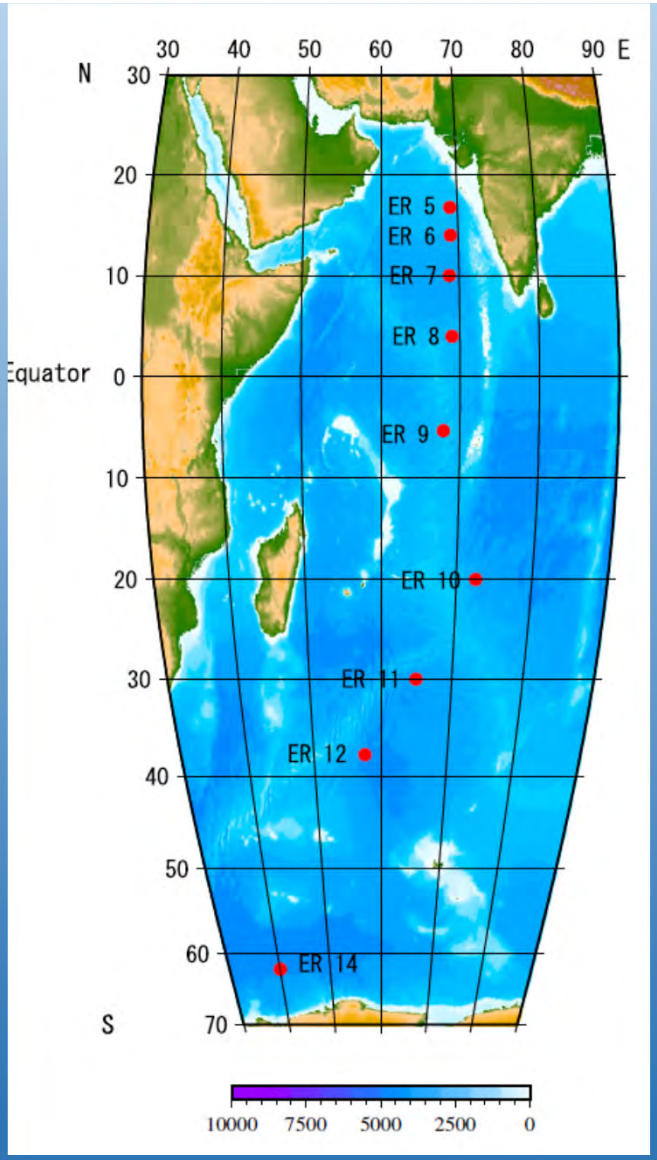
Shallow remineralization releases Cu



Subsurface tongue of copper within oxicline most dramatic feature I have ever seen for copper

Uptake of Cu within the core of the OMZ by denitrifiers and/or sulfide-containing particles





Japanese GEOTRACES Cruise Nov 2009

First meridional section

Included Arabian Sea OMZ and Rodriguez Triple Junction Hydrothermal System

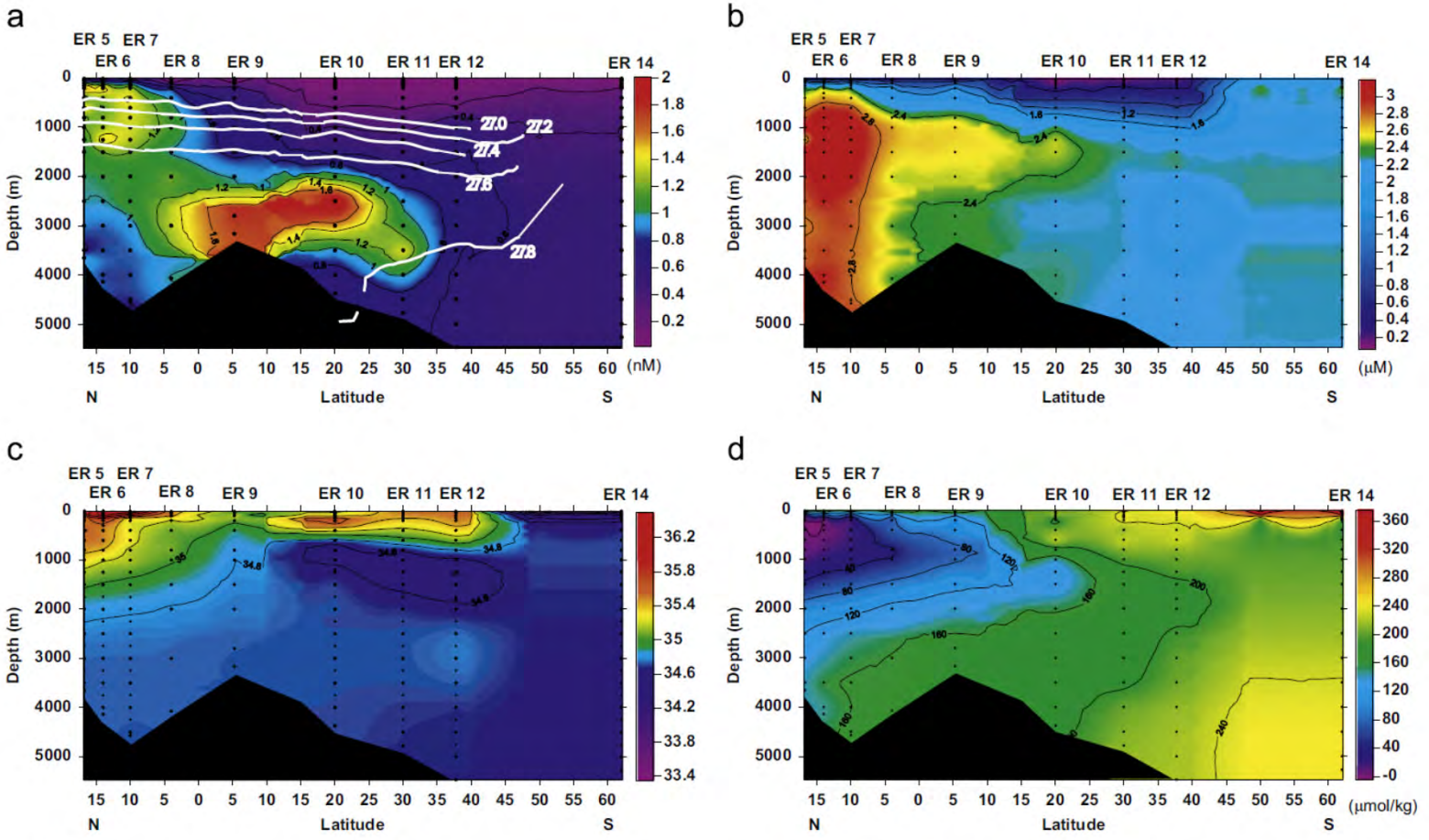
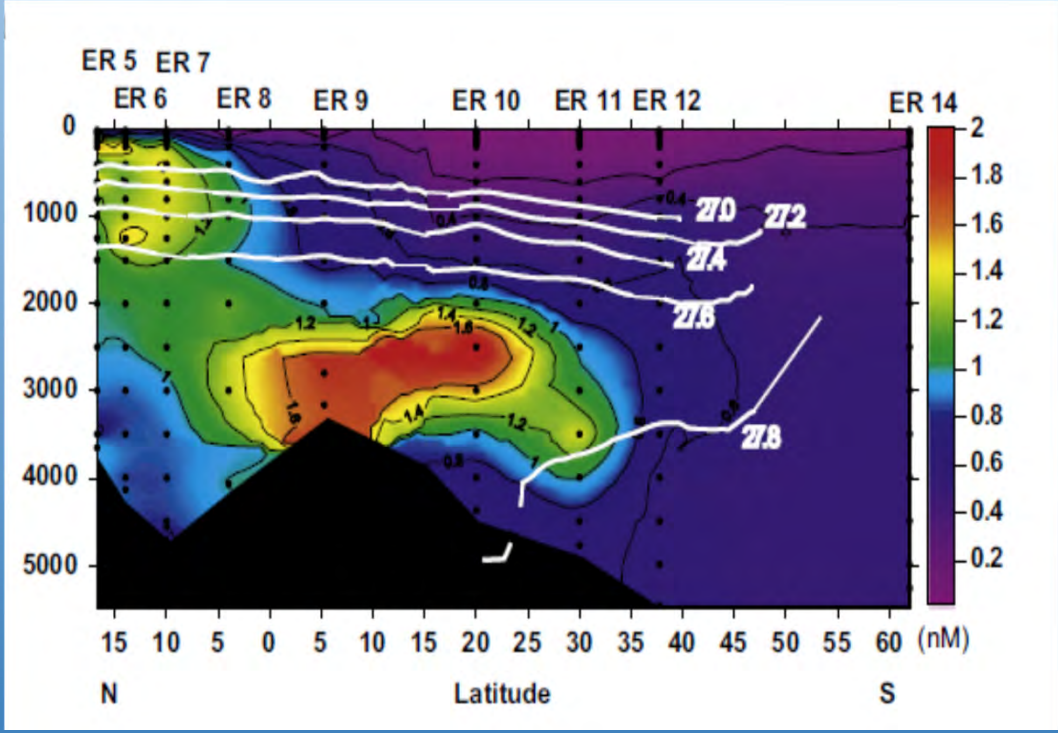


Fig. 2. Vertical section profiles of (a) dissolved Fe concentration, (b) phosphate, (c) salinity, (d) dissolved oxygen along the transect which is indicated in Fig. 1. White number and line in (a) indicate isopycnal surface.



Three Key Features

High Fe within OMZ (150m to 800m) drops off rapidly south of the OMZ.

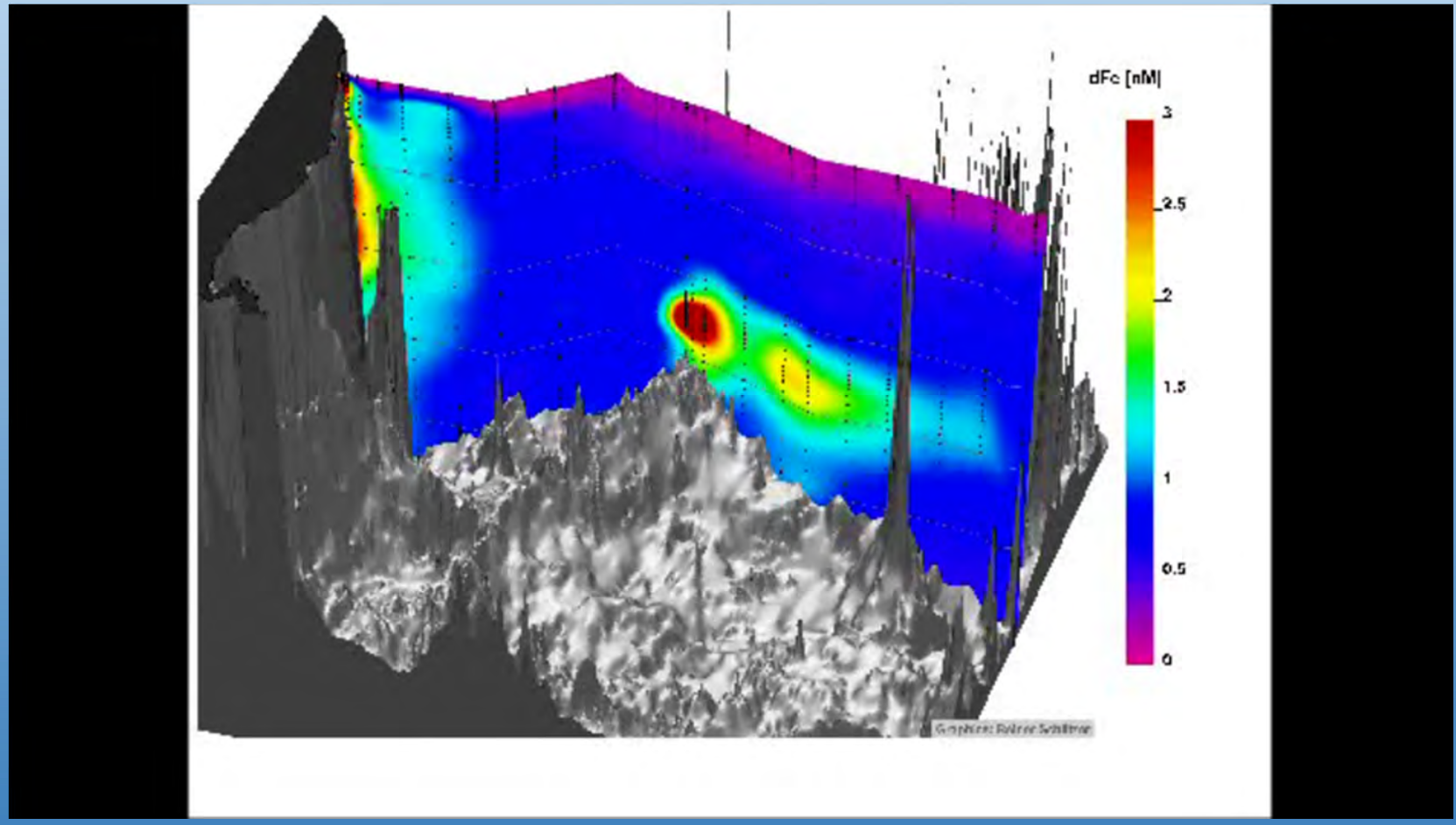
Deeper plume from OMZ (1000m to 3000m) extends further offshore

This plume merges with another plume associated with hydrothermal inputs

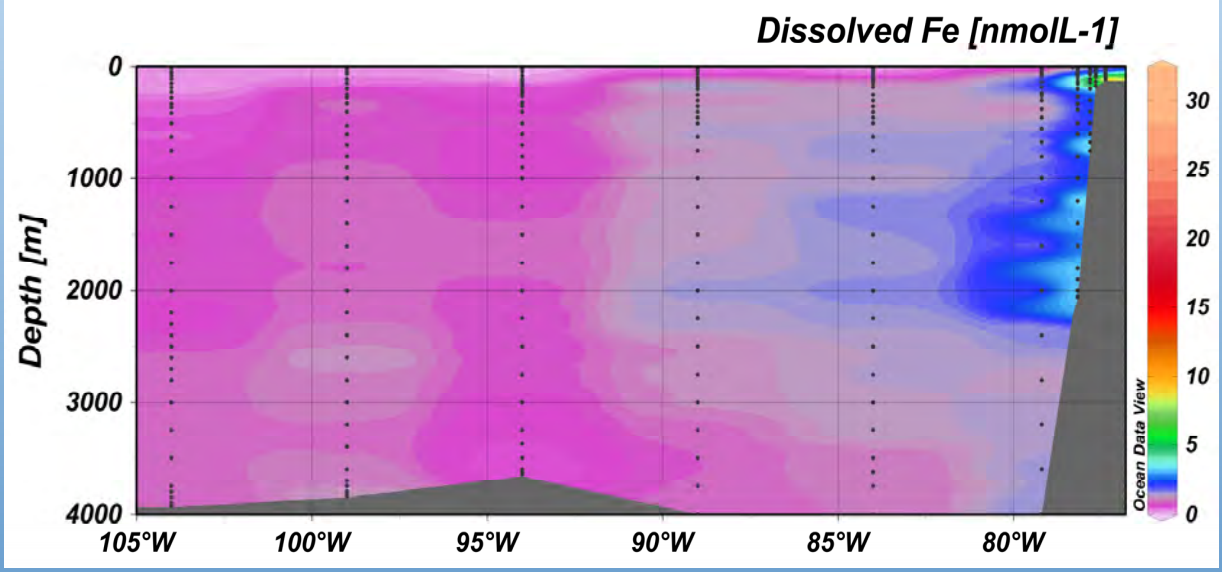
Sound familiar???

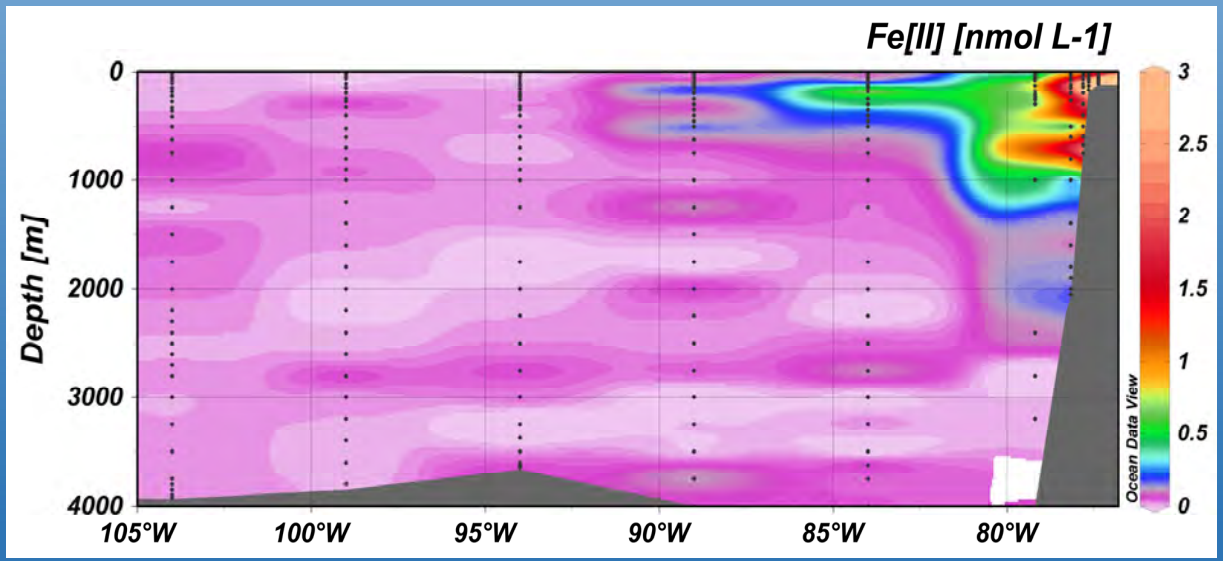
2013 US GEOTRACES

GP16 Section



Major highlight was two plumes of dissolved iron – one off the coast of Peru and one off the East Pacific Rise – a spreading center with intense hydrothermal activity – *generated by Reiner Schlitzer (AWI) using ODV*



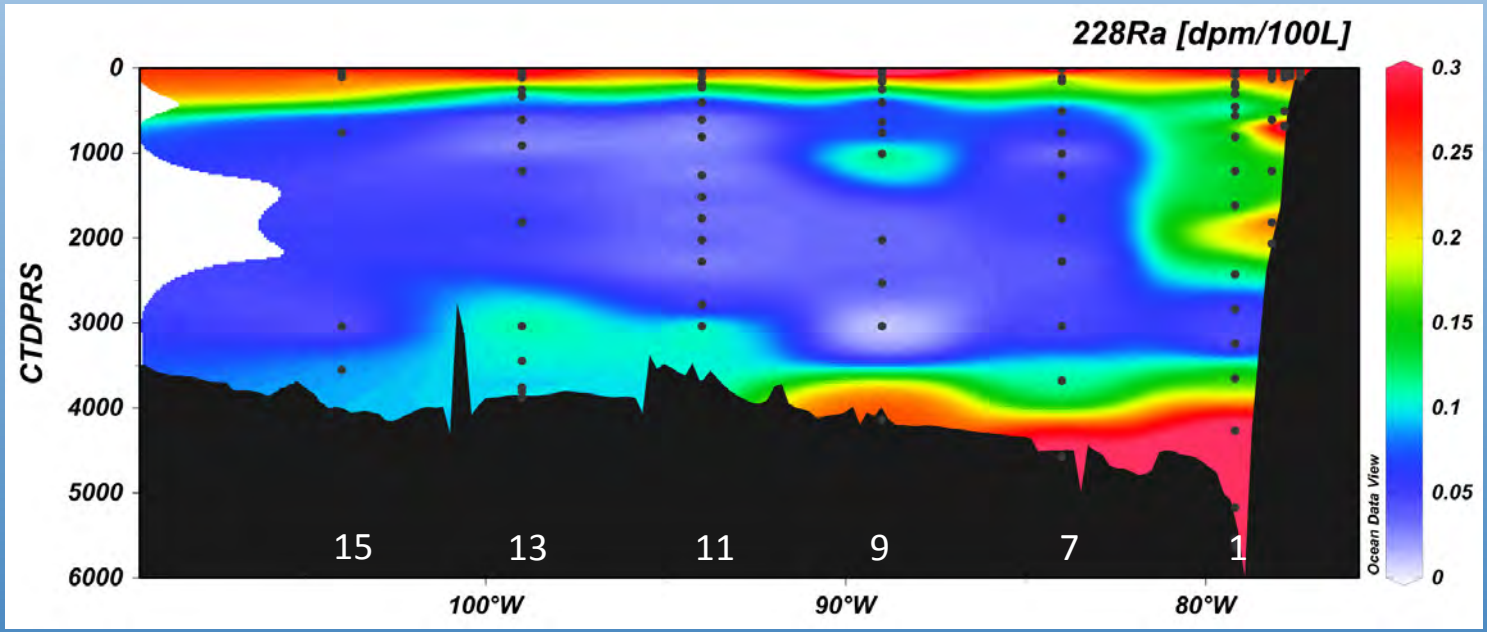


Core of plume below the OMZ, in oxygenated waters

Fe(II) facilitates transport of Fe off shelf

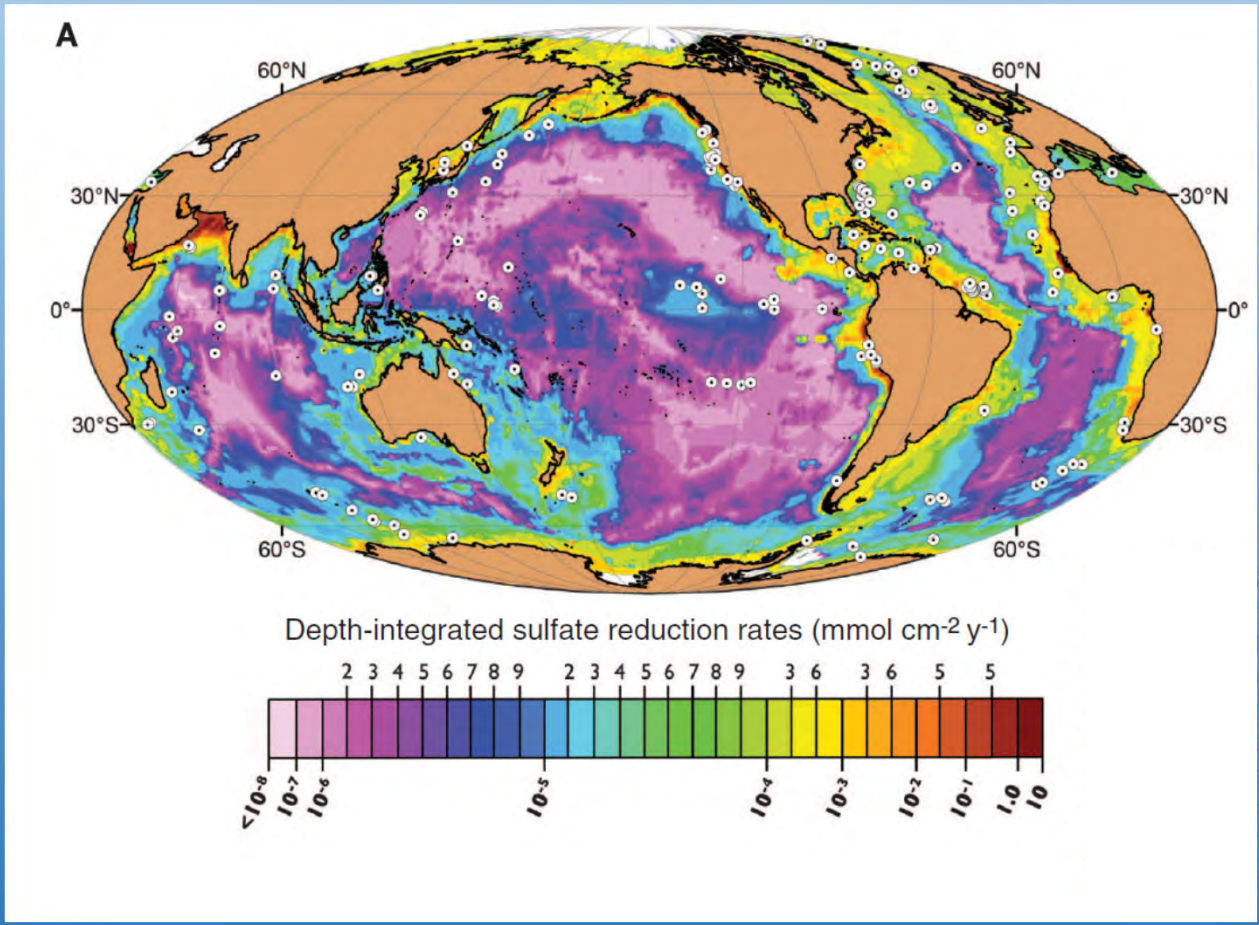
Formation of particulate Fe (Phoebe Lam), sinking and re-reduction from reducing sediments on slope supplies Fe to the plume

Pacific Ocean
- EPZT Section of ^{228}Ra -



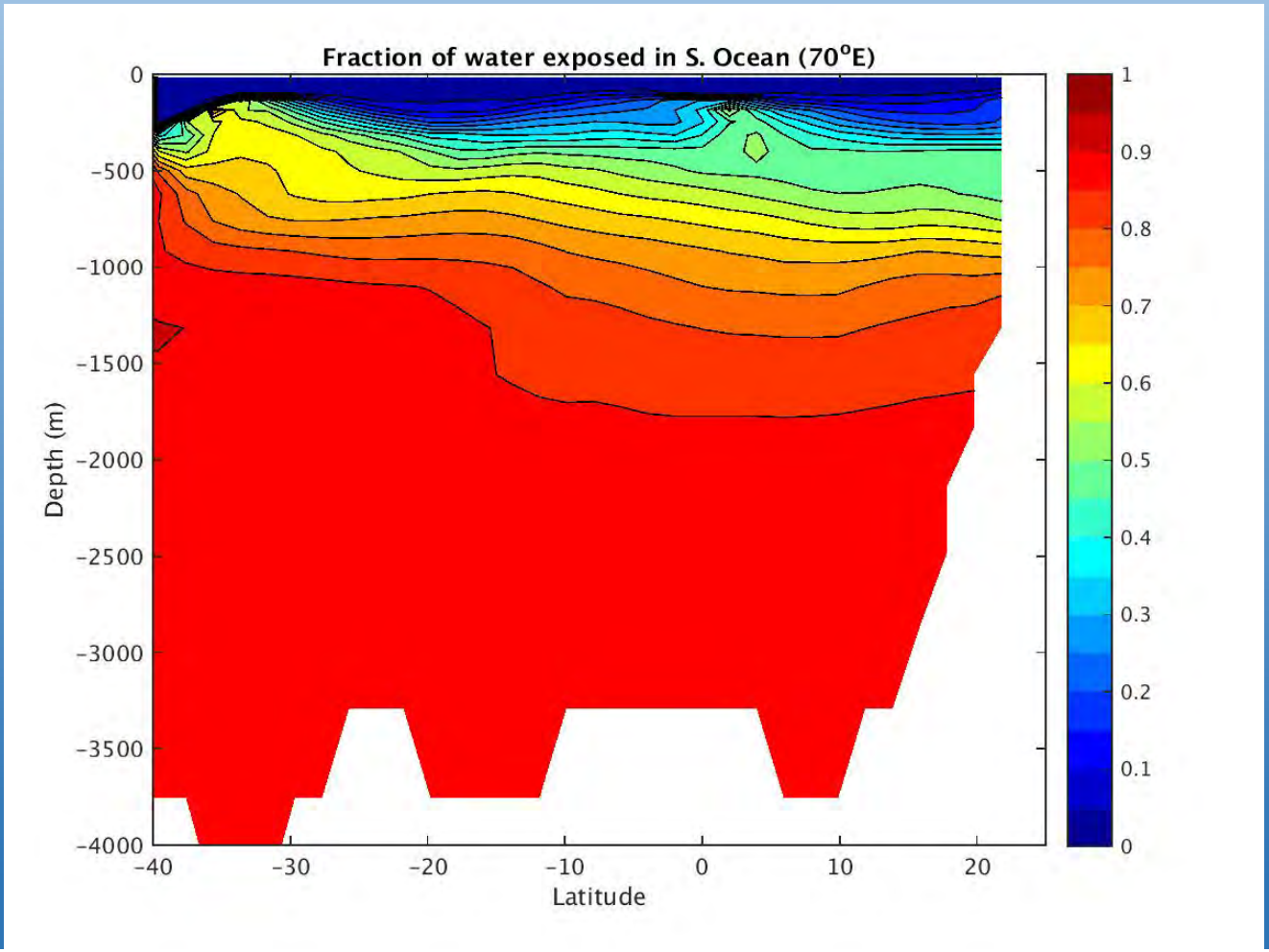
- High ^{228}Ra activities in surface waters (lateral advection + diffusion) and close to the bottom (diffusion from sediments)

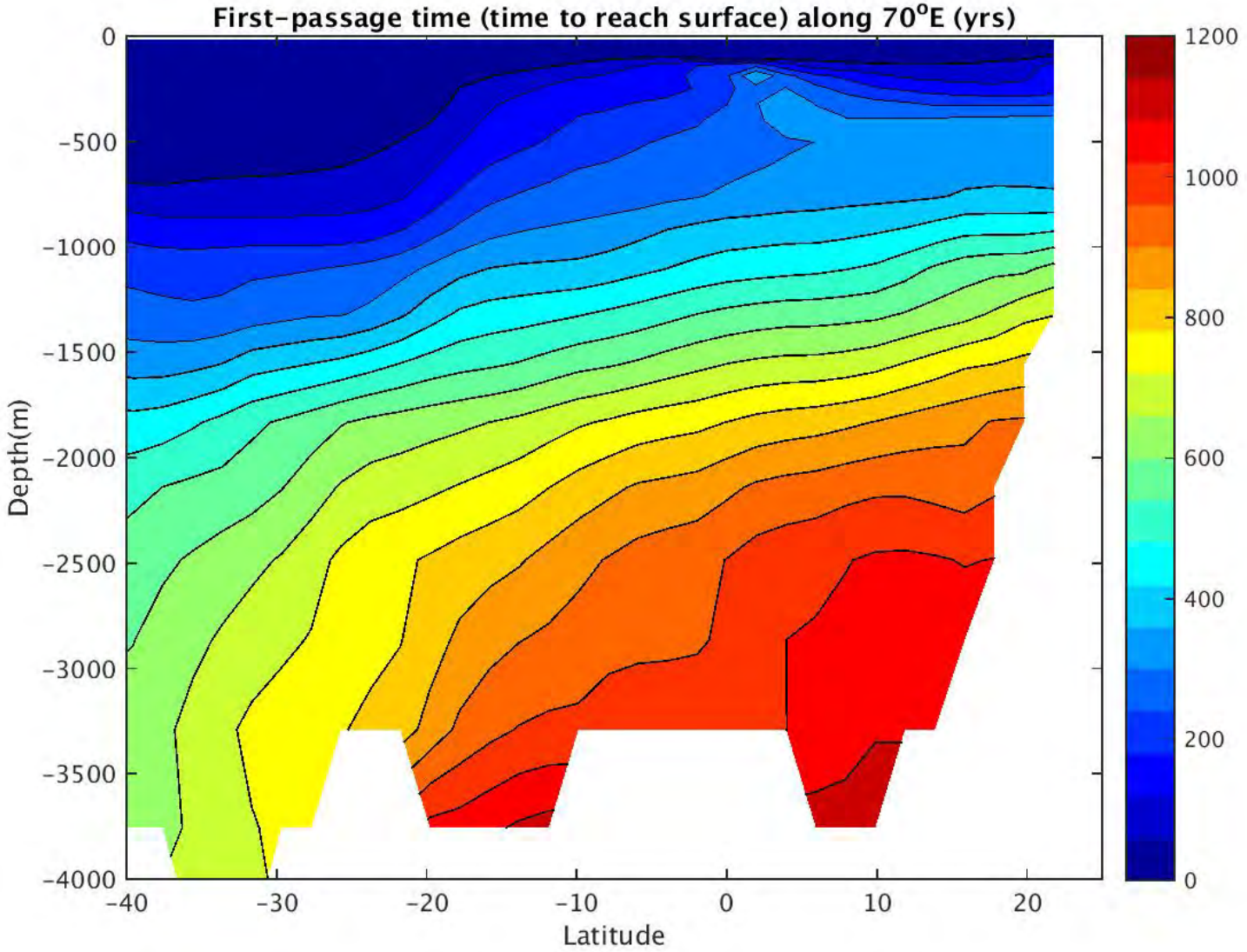
From Charette Lab

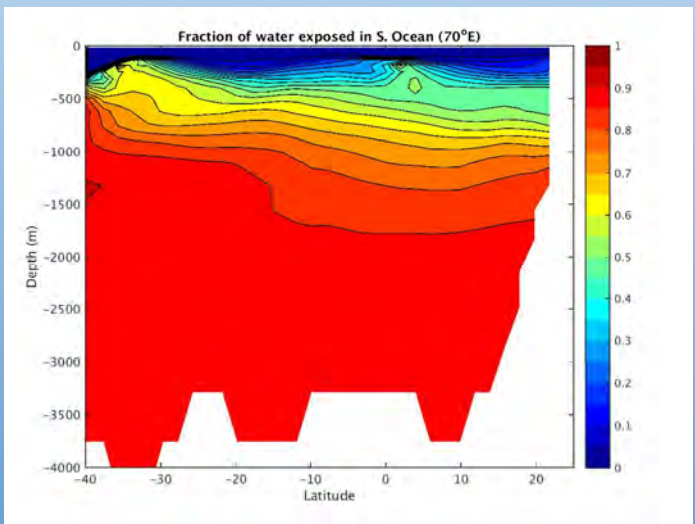


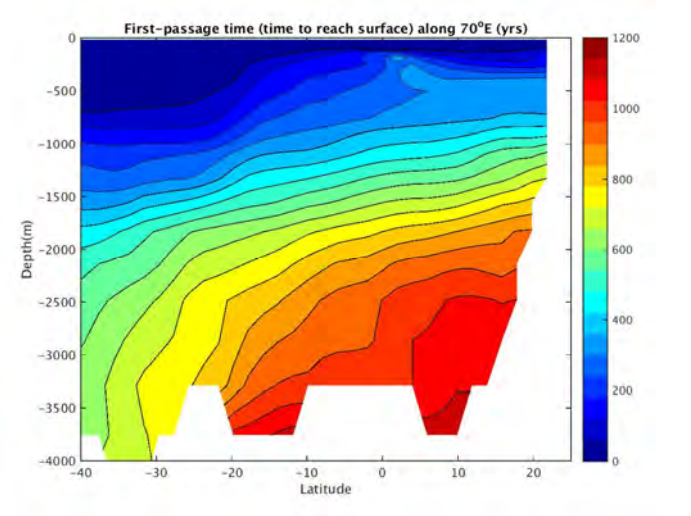
Model estimates of benthic sulfate reduction rates developed by Bowles et al., Science 2014 doi: 10.1126/science.1249213

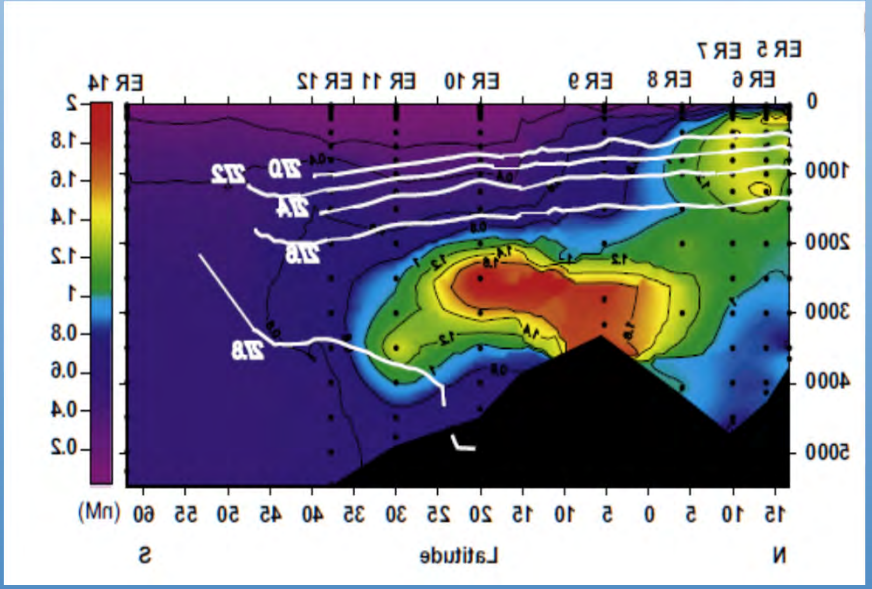
Inverse model analysis provided by Tim De Vries (UCSB)




First-passage time (time to reach surface) along 70°E (yrs)
Depth(m)
0
-500
-1000
-1500
-2000
-2500
-3000
-3500
-4000
-40
-30
-20
-10
0
10
20
Latitude
1200
1000
800
600
400
200
0


Fraction of water exposed in S. Ocean (70°E)
Depth (m)
Latitude


First-passage time (time to reach surface) along 70°E (yrs)
Depth(m)
Latitude

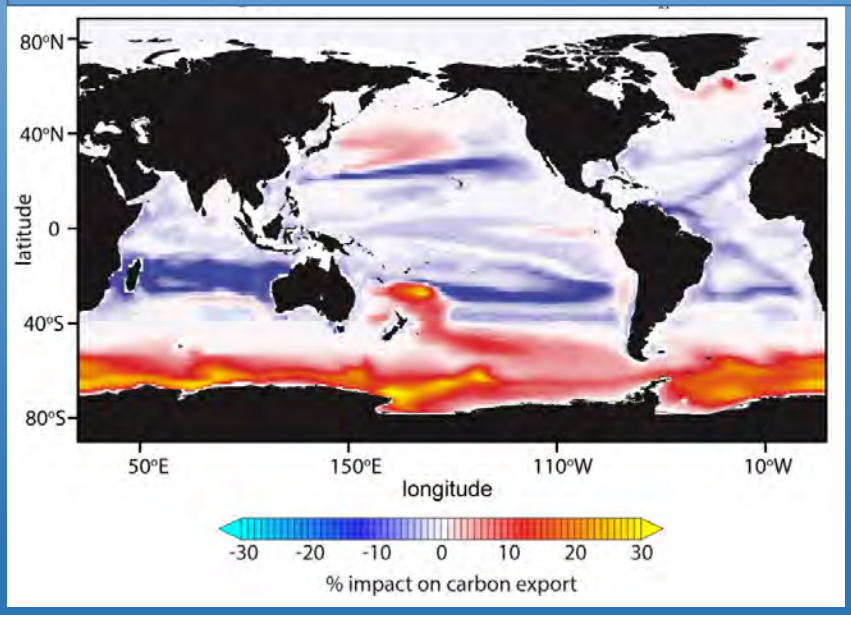

Latitude
(nM)

Model simulations: Transport and impact of hydrothermal DFe

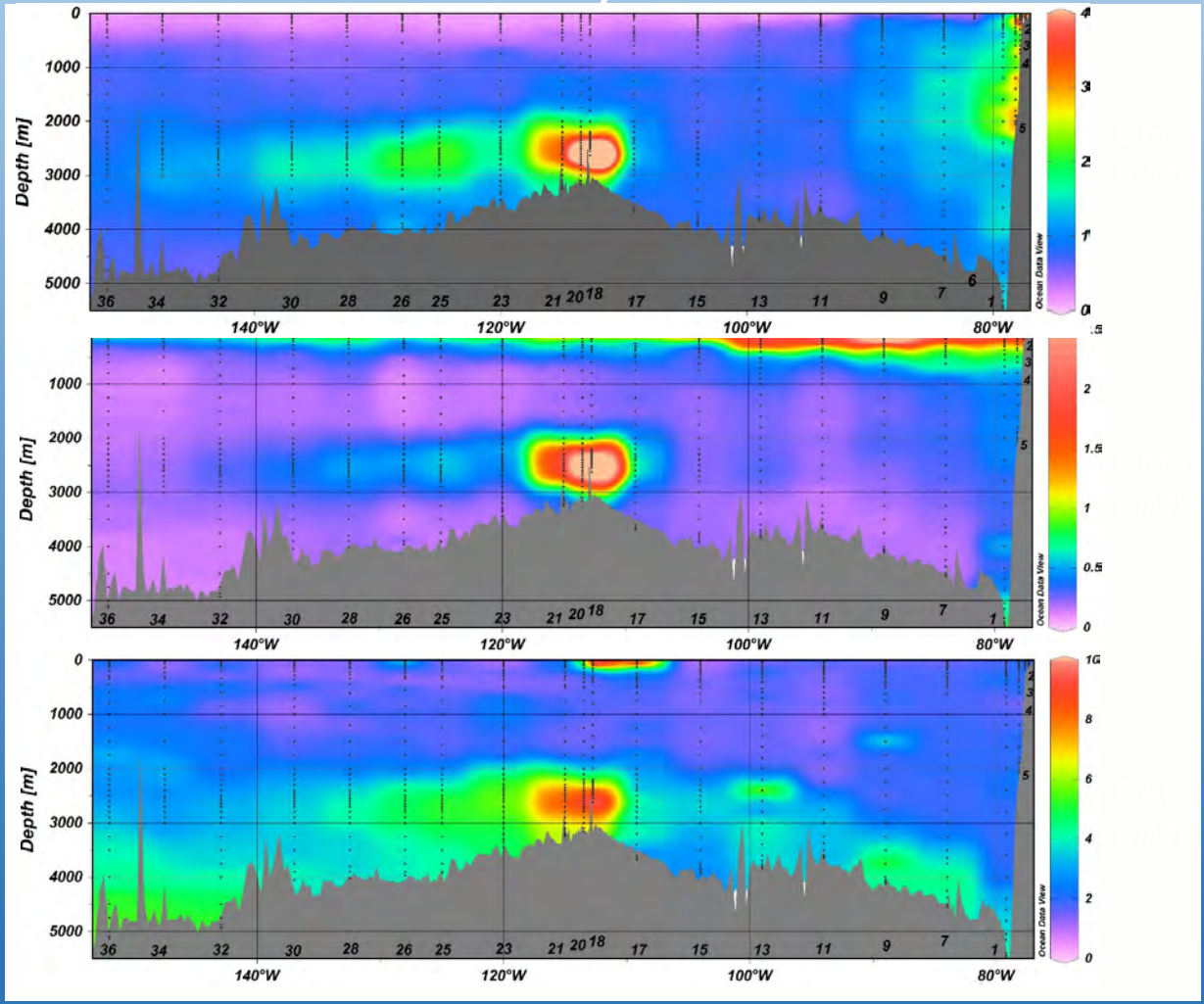
Alessandro Tagliabue, using *NEMO-PISCES* model with dynamic ligands

Includes impact of hydrothermal vents but not the OMZ plumes

Modeled impact of hydrothermal DFe flux on Southern Ocean NCP is large: ~20-30% greater export south of APF versus case without hydrothermal Fe

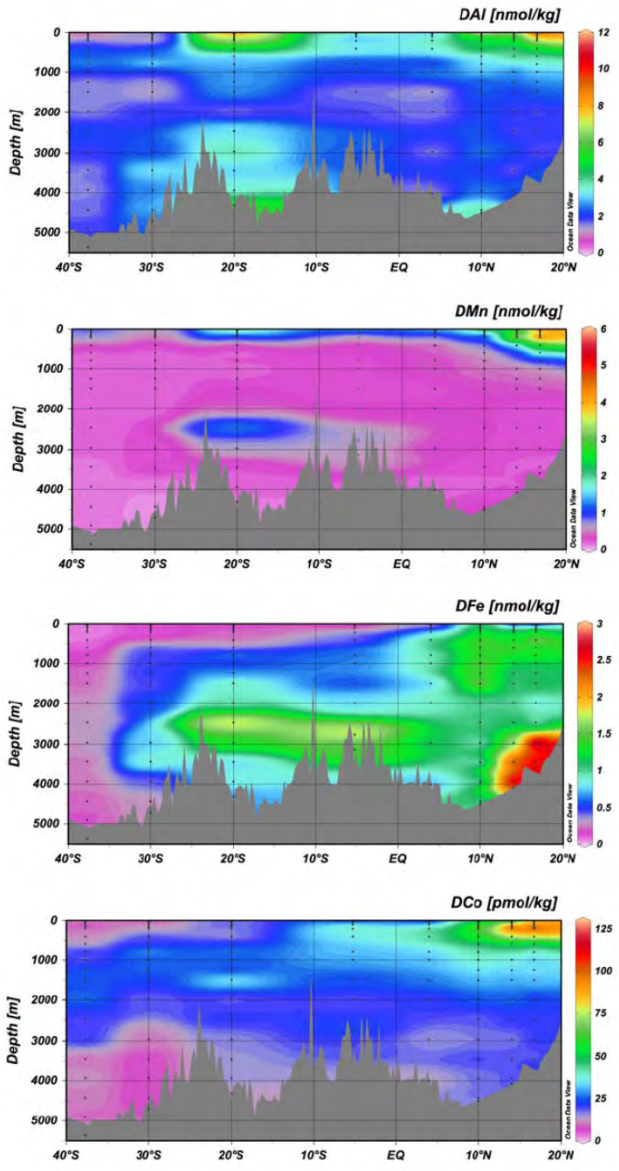


The shipboard data: Dissolved Fe (Sedwick), Mn, Al (Resing)(DFe, DMn, DAl)



Japanese GEOTRACES

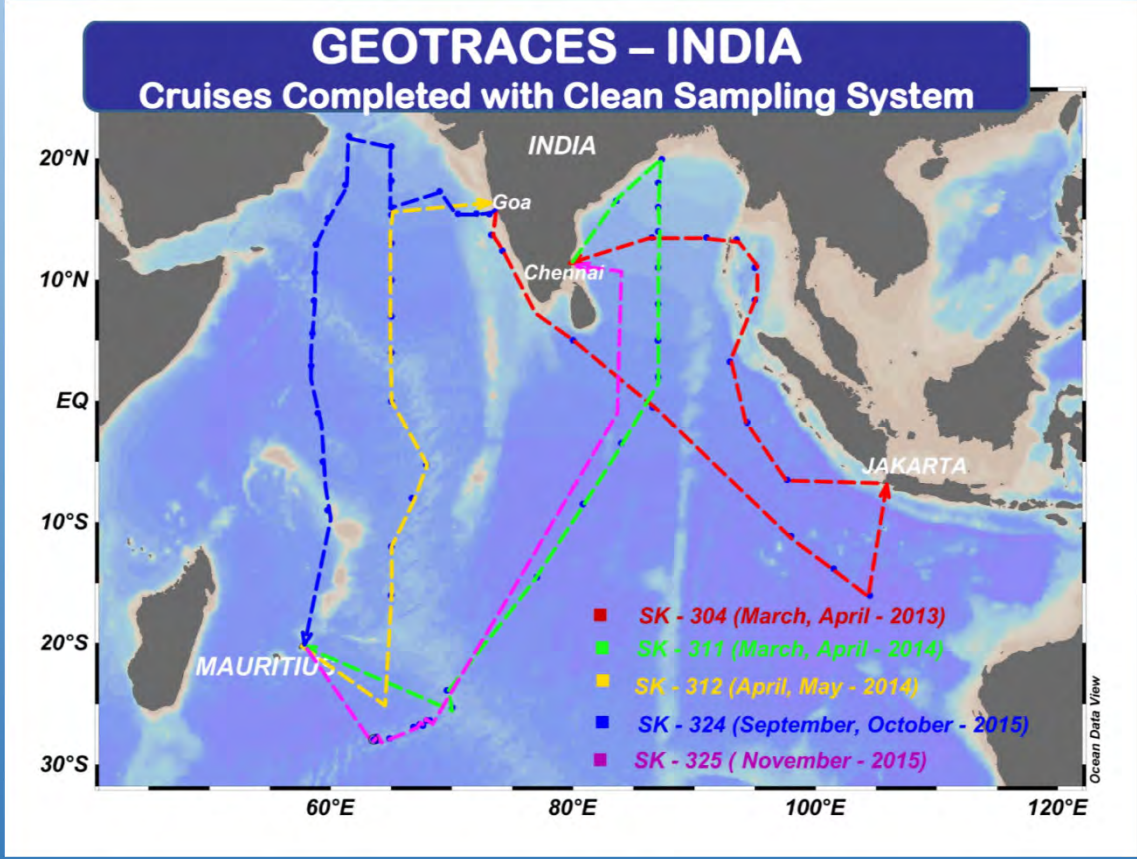
Iron and Aluminum from Hydrothermal Sources in the Arabian Sea
From Sohrin et al (2015)



Future Work

- Meridional Sections across Southern Ocean to assess where the Hydrothermal Plume goes and how quickly Fe is removed.
- Data from Shelf and slope regions of the Arabian Sea to assess benthic and riverine sources – coupled with Ra-228 data.
- Full water column sections from the Bay of Bengal are needed
- Characterization of chemistry of Red Sea Overflow water is important but not practical for the foreseeable future.
- More work needed to characterize the diversity of hydrothermal sources

Sunil Singh, PRL is leading GEOTRACES India



Summary

- ***Dissolved Fe (DFe)***
  - ➢DFe measured in about 50 full water columns in the Indian Ocean
  - ➢DFe supply from Shelf of the Arabian Sea and the Bay of Bengal
  - ➢High DFe in OMZ in BoB and AS
  - ➢High DFe from hydrothermal and subduction regions

- ***Dissolved Mo and its isotope composition***
  - ➢Dissolved Mo and its isotope composition are highly conservative in the Arabian Sea, even in OMZ
  - ➢Mo isotope is non-conservative in the northern BoB due supply of lighter Mo from Fe-Mn coating of the sinking particulate matters

- ***Dissolved REEs and Nd Isotopes***
  - ➢Massive release of dissolved REEs and other TEs in the Indian Estuaries
  - ➢Release of dissolved Nd in the Bay of Bengal from the sinking particles and shelf sediments of the Ganga-Brahmaputra origin
  - ➢Indus sediments supply dissolved Nd to the Northern Arabian Sea
  - ➢Release of dissolved Nd from dust in the surface waters of the Arabian Sea
  - ➢Dissolved REEs distributions are influenced by OMZ in the Arabian Sea
  - ➢Significant supply of the Indonesian Water in the Indian Ocean

Acknowledgments

Captain and Crew of RV Revelle. Dan Ohnemus and Tyler Goepfert, Jagruti Vedamati

Wajih Naqvi, Jerry Wiggert.

Yoshiki Sohrin and Toshi Gamo

Tim De Vries

Chemical and Biological Oceanography Programs at NSF

USC