



# Deep-sea biodiversity and biogeography: perspectives from the abyss

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ISA, Sloan Foundation, CoML**



## **OUTLINE:**

**1) Nature of the Abyssal Seafloor Habitat**

**2) General Abyssal Biogeographic Patterns**

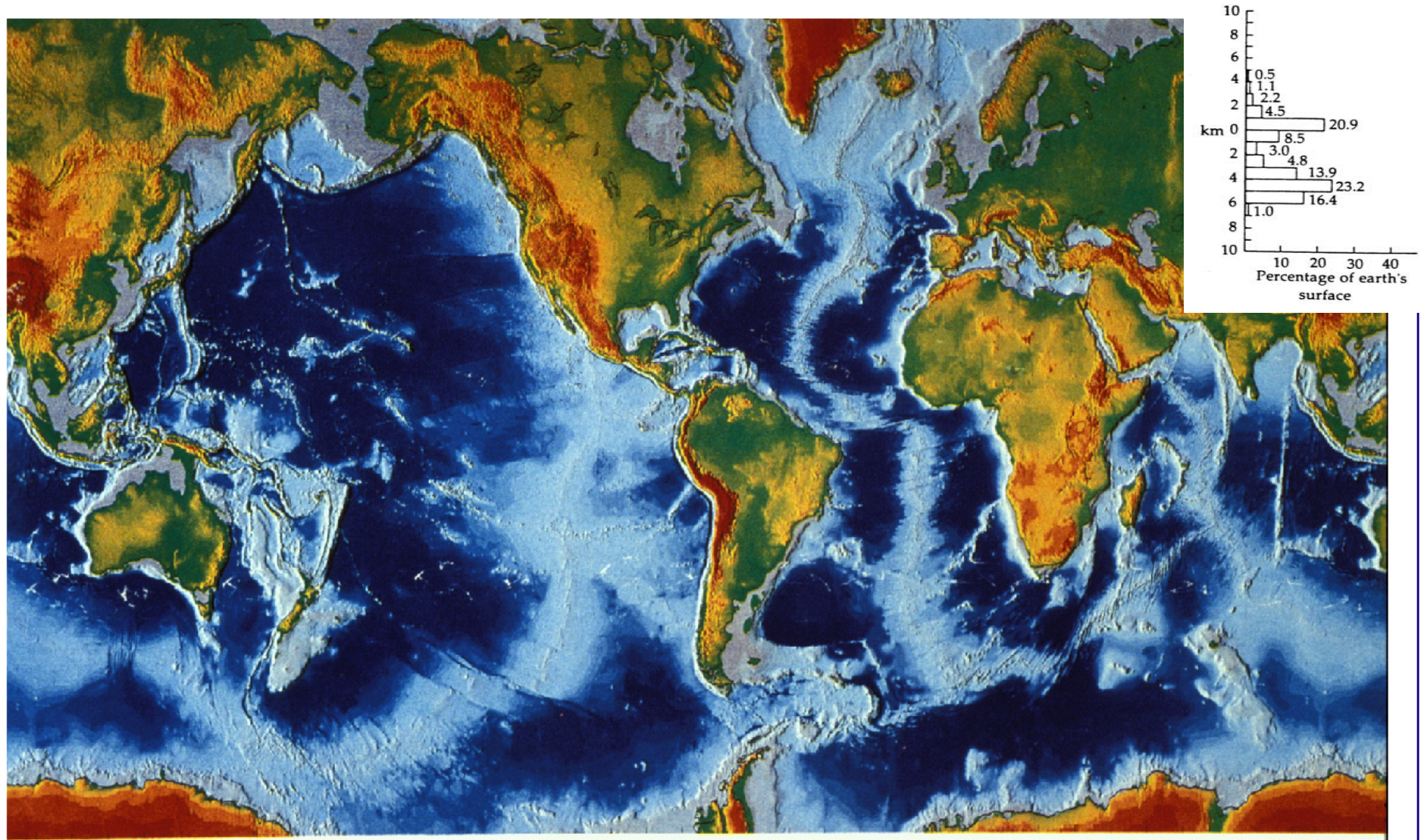
**3) Obstacles to Abyssal Biogeographic Synthesis**

**4) Census of Diversity of Abyssal Marine Life (CeDAMar)**

**5) Conclusions**

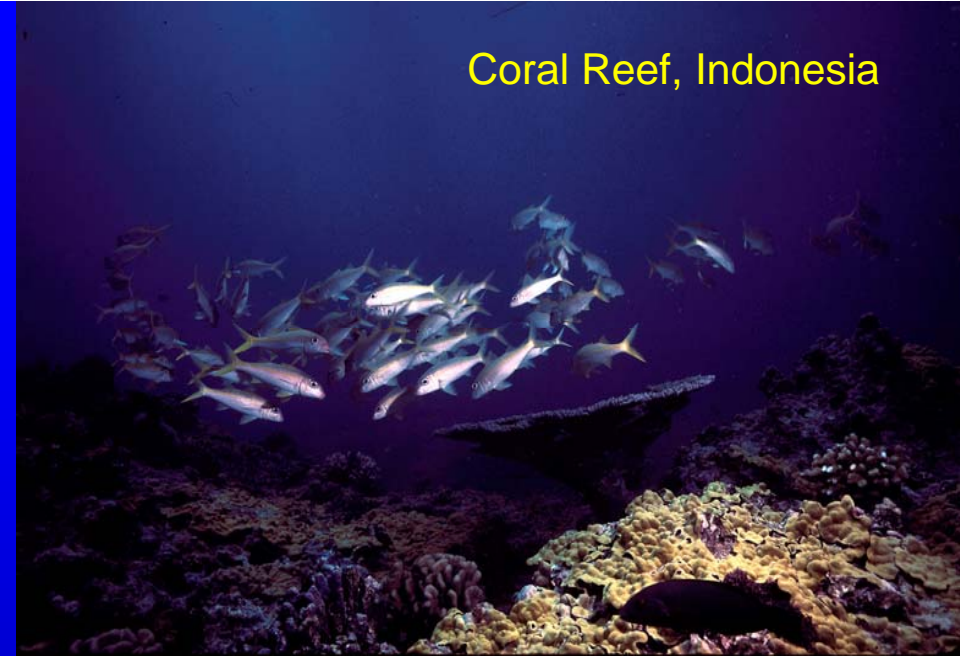
# Nature of Abyssal Benthic Ecosystem - Seafloor (3000 – 6000 m) = Vast (the big blue)

54% of Earth's surface!  
(inverse of seamounts)





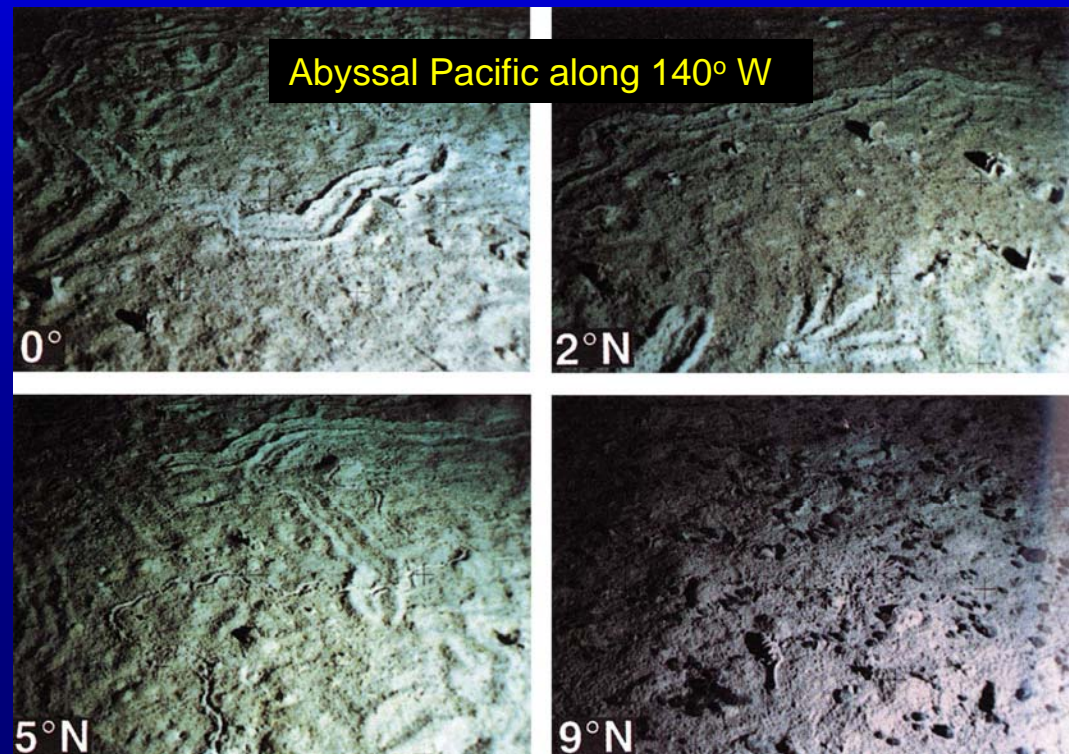
Rainforest, Costa Rica



Coral Reef, Indonesia

-High local diversity but low habitat complexity compared to many other locally diverse ecosystems

~ 100 species  
macrofaunal  
species  $m^{-2}$   
sediment



# Ecological Characteristics of Abyssal Seafloor –

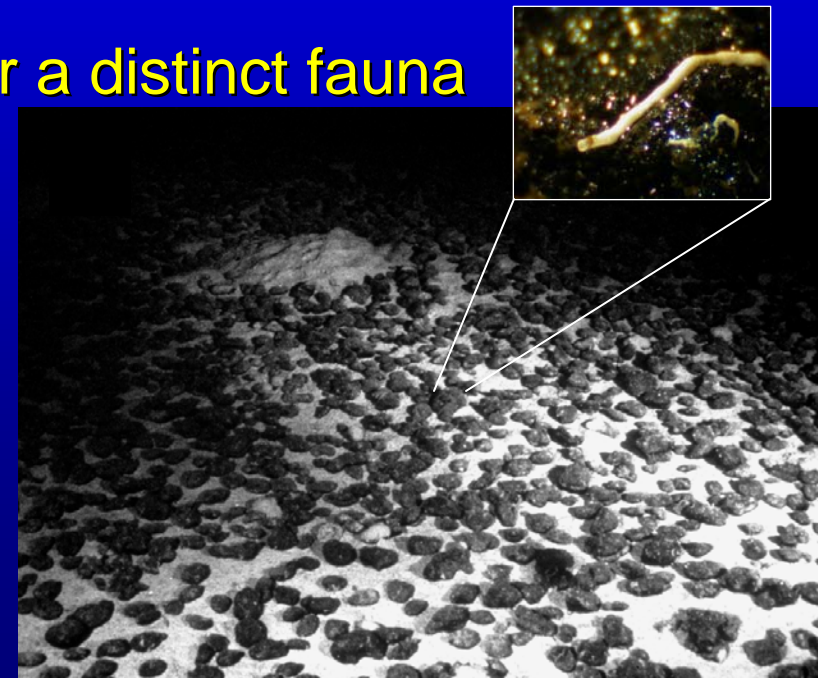
- Mostly plains of fine sediment
- Low temperature (-1.0 to 2.0 °C)
- High hydrostatic pressure
- Often physically very stable
- Much of structure biogenic (fragile) or nodules
- Hard substrates (nodules) harbor a distinct fauna



L. Levin



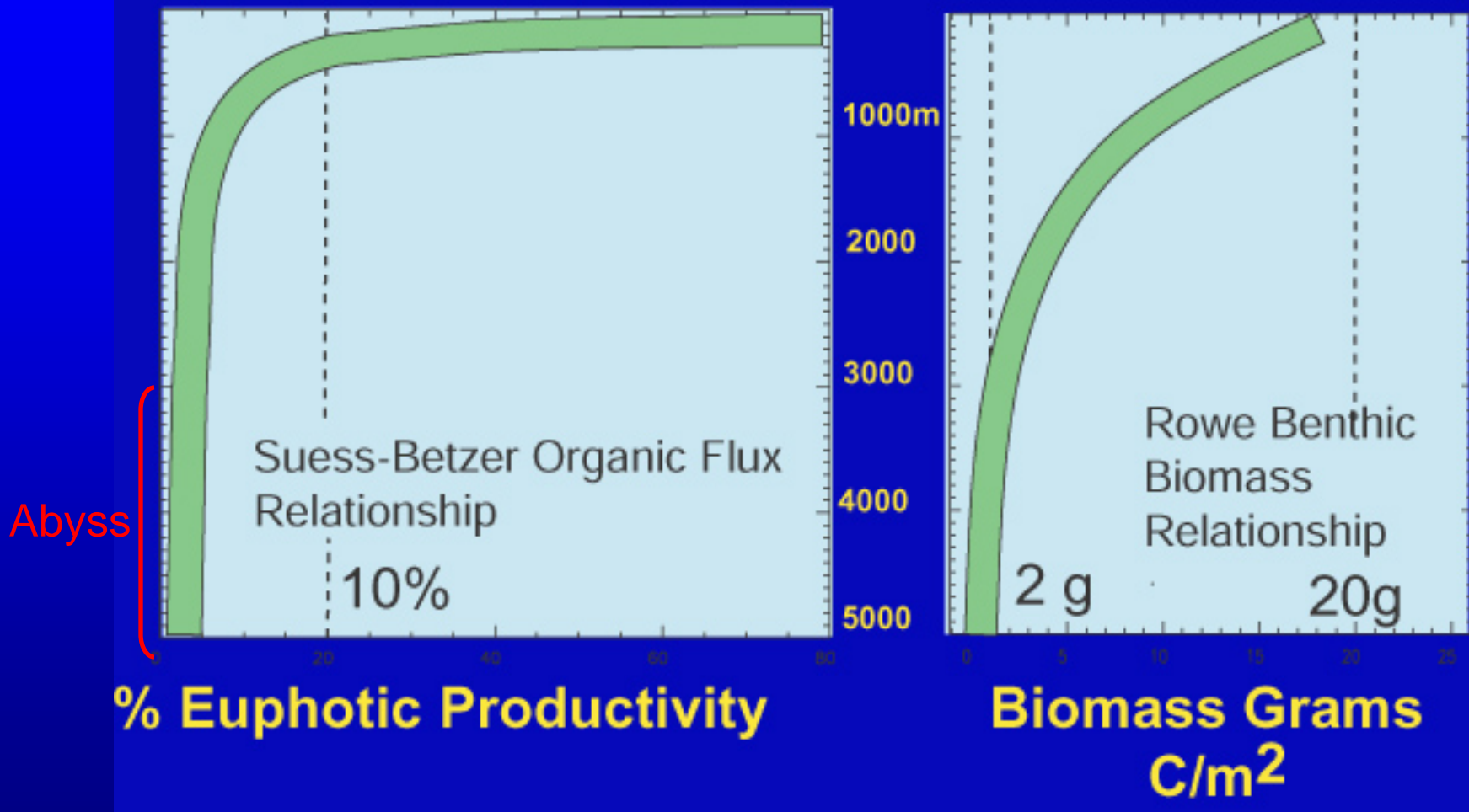
4500 m Equatorial Pacific



5600 m Central North Pacific

Food from sinking POC flux → “Food Limited”

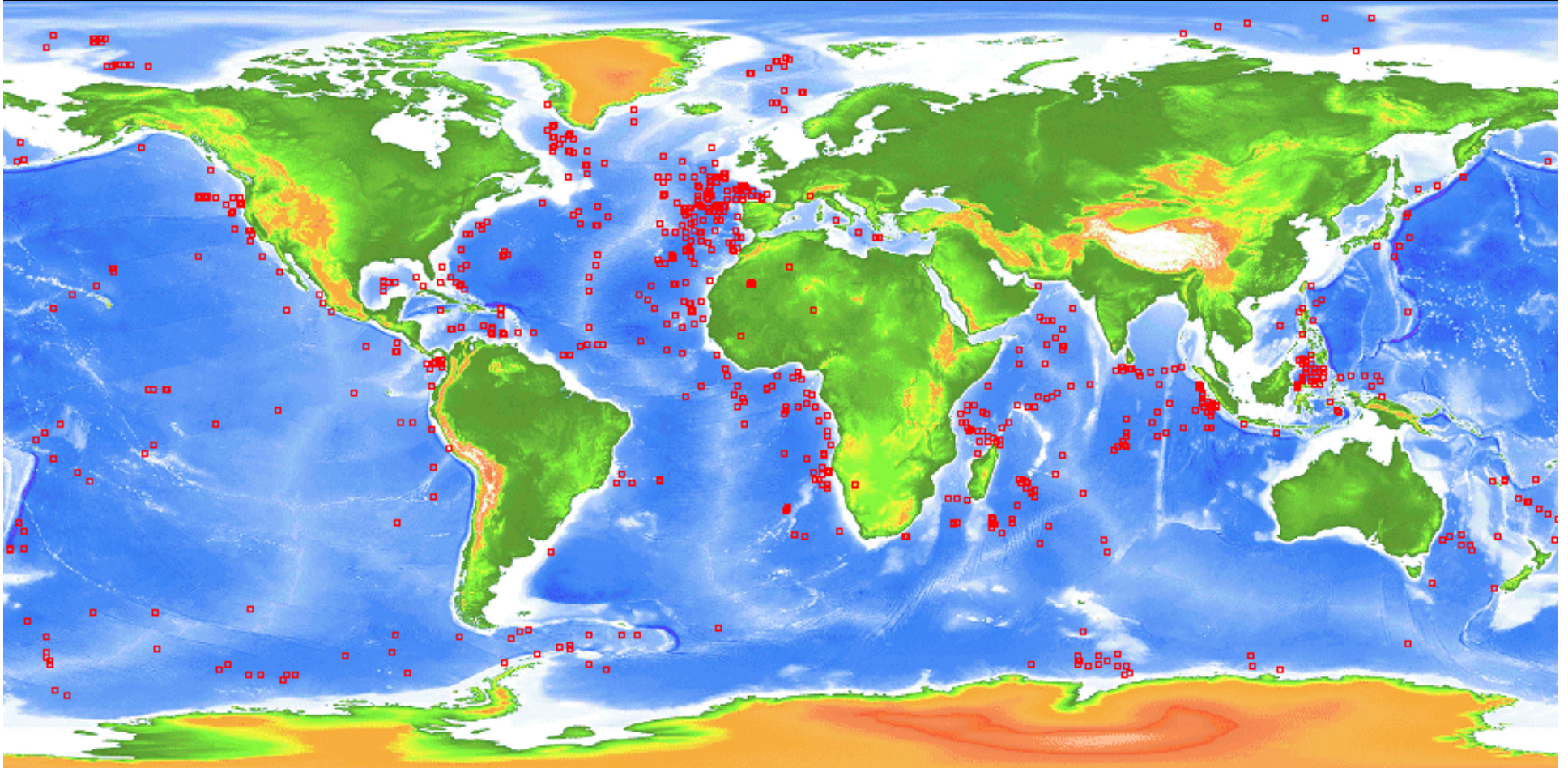
DEPTH



- Biomass, production, growth rates, recolonization rates very low

# Abyssal fauna very poorly sampled and described!

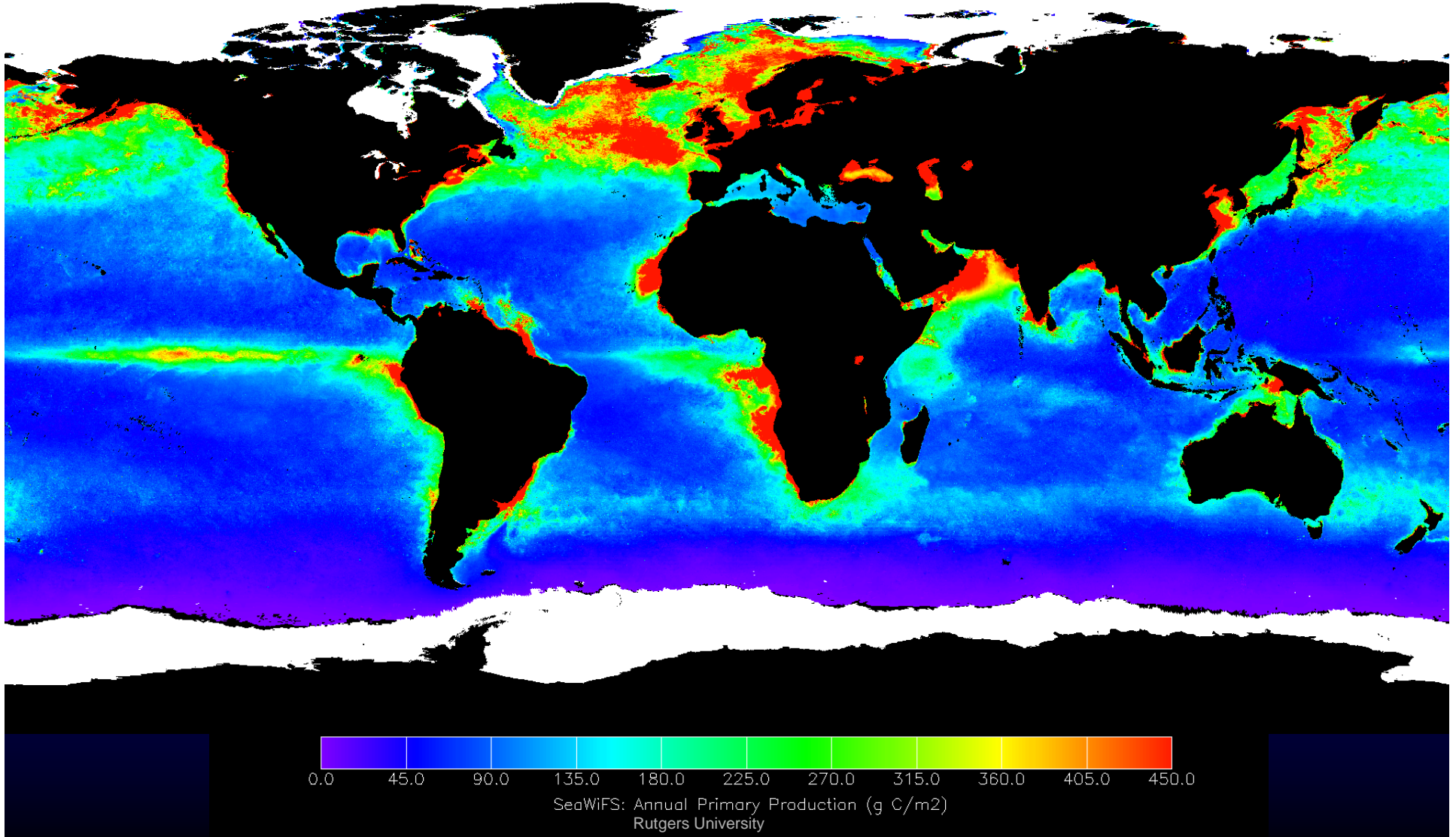
Total abyssal records (3000 – 6000 m) at species/genus level in OBIS



# What Controls Abyssal Biogeography?

1) Particulate organic carbon flux - probably most important

Annual Primary Production - 1997 - 1998

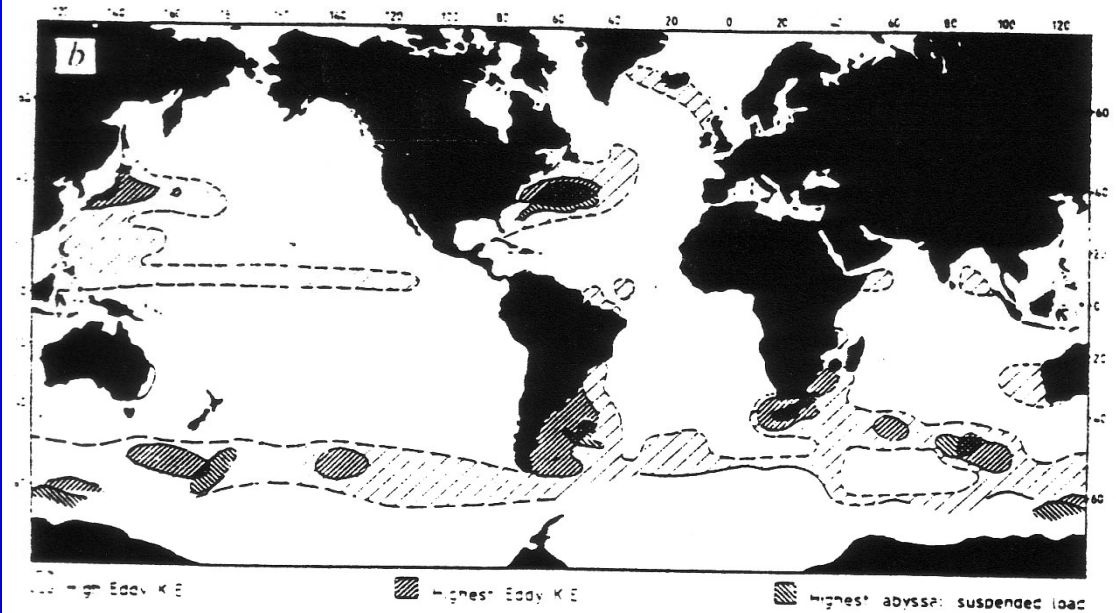




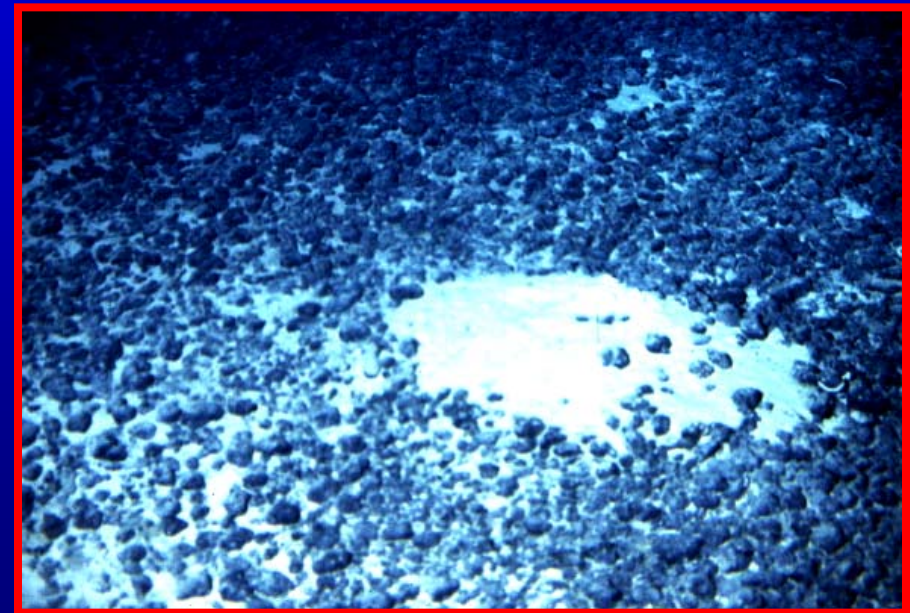
## 2) Flow regime

Abyssal areas of potentially high flow and sediment transport

Hollister and McCave, 1984



## 3) Substrate type (especially presence/absence of hard substrate)

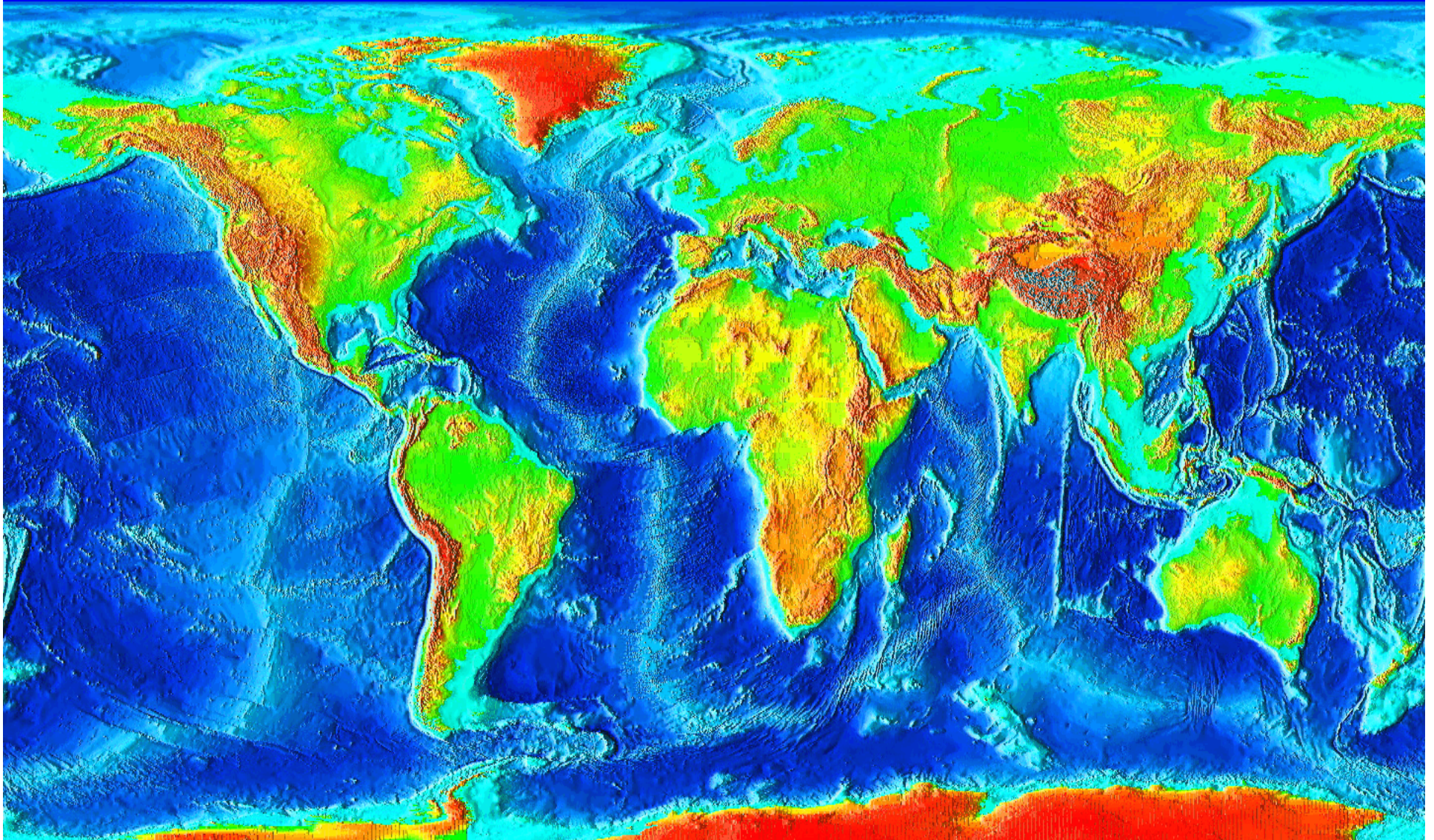


Nodules, 4100 m Pacific

4) Hydrostatic pressure??? (upper and lower limits to the abyss?)

5) Flow/topography interactions -- Isolation by continents, sills and mid-ocean ridges

[ 6) Historical processes ]



# General Abyssal Biogeographic Patterns of Soft Sediments

(Brief survey – more complete synthesis = goal of CeDAMar.)

Also, keep in mind very poor sampling coverage!

“Regional” species diversity:

North Atlantic – upper  
abyssal max

? Other Basins?

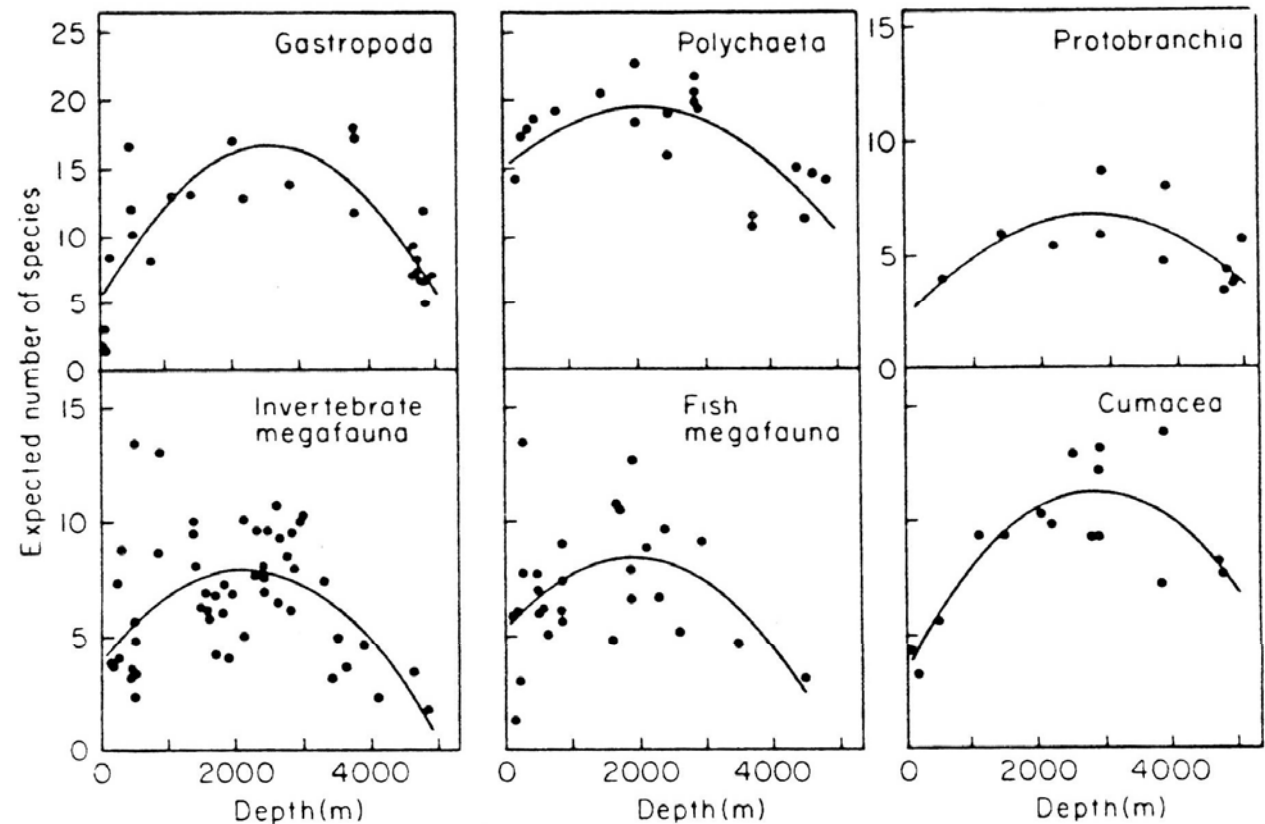


Figure 19-5 Variation in species richness along the depth gradient of the ocean (data compiled by Rex, 1981). Species richness is an estimate for samples of 50 individuals. (See Hurlbert, 1971, for method)

## Species level patterns?

In most ecosystems – biogeographic patterns related to body size and dispersal abilities

→ How do biogeographic patterns vary with size class (and dispersal ability) in the abyss?

For representative taxa in each size class will (try to) ask:

- 1) *How many deep-sea species are known?*
- 2) *Are there abyss endemics?*
- 3) *Are there cosmopolitan abyssal species?*
- 4) *What proportion are restricted to single basins?*
- 5) *Are there local endemics?*

**MEGAFUNA** (> 2 cm) –

**Benthopelagic fishes – use as e.g. Macrouridae (rattails)**

(Source: Jeff Drazen compiled from many references)



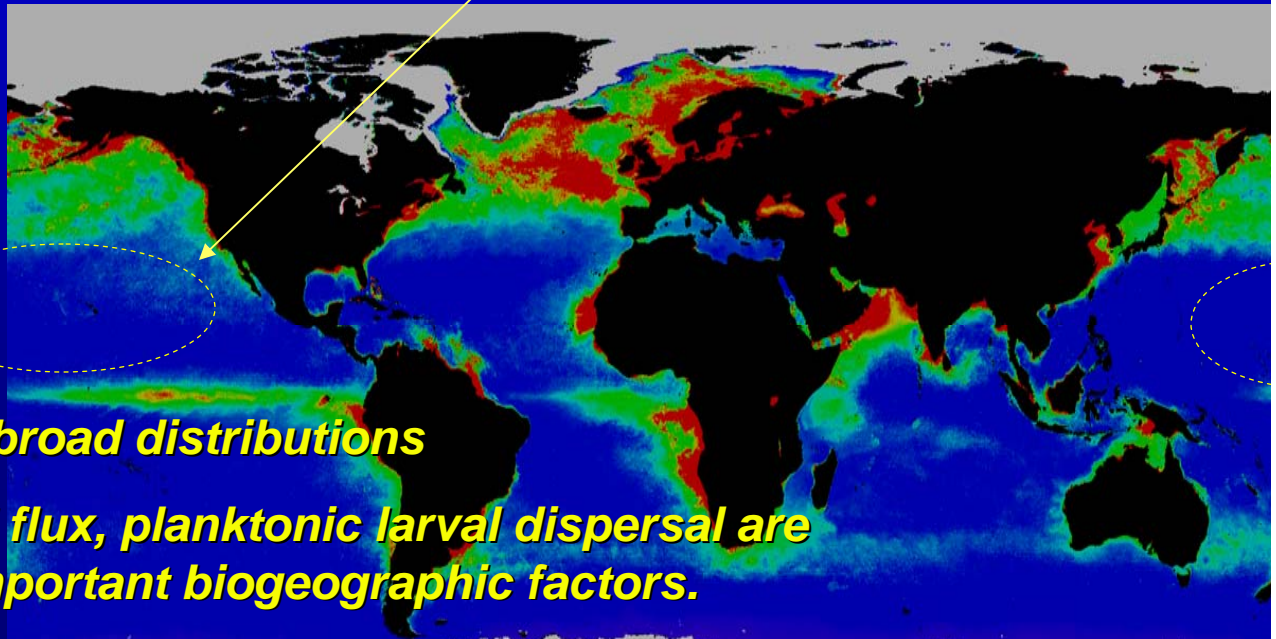
1) *300 deep-sea species (only 9 abyssal species)*

2) *One abyssal endemic (beneath N. Pacific oligotrophic gyre)*

*(Coryphaenoides yaquinae)*

3) *One cosmopolitan species*

4) *4 species restricted to  
single basins*



**Fishy Conclusions:** - *Very broad distributions*

- *Food flux, planktonic larval dispersal are  
important biogeographic factors.*

# Invertebrate megafauna – e.g., Elasipod holothurians (Hansen, 1975;

Billet, 1991; Bluhm and Gebruk, 1999)

From widespread trawling stations (mostly)

1) > 100 deep-sea species

2) ~40 abyssal endemics (spp. radiation?)

3) 6 cosmopolitan species (15%)

4) 18 spp. restricted to single basins  
(4 rare)

5) 3 local endemic abyssal species beneath upwelling zones

## Elasipod Conclusions:

- Well developed abyssal fauna
- Most spp. widely distributed
- Endemism related to high POC
- Pelagic dispersal of lecithotrophic larvae important

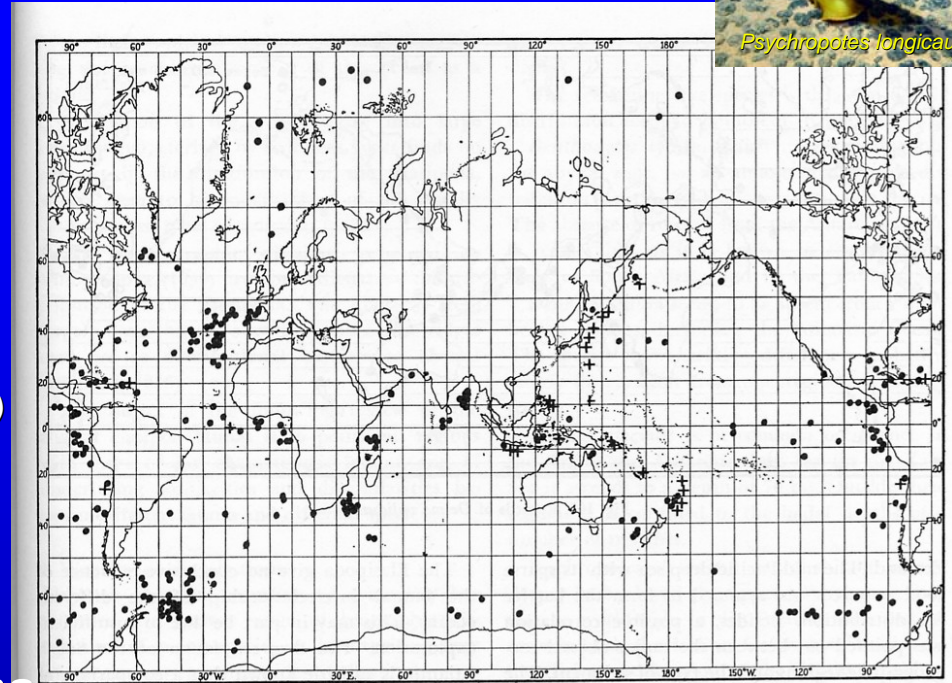
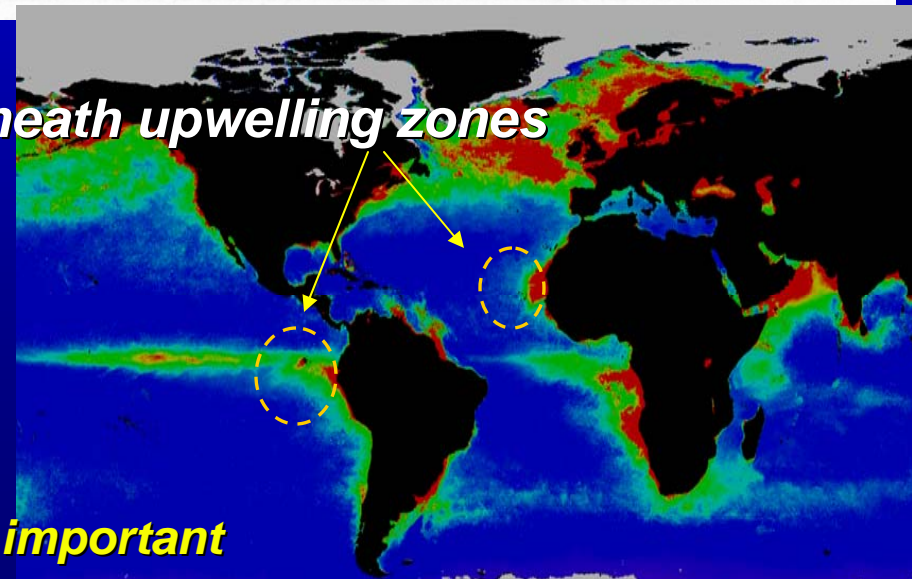


Fig. 108. Same. Depth 2500–6000 m (•) and 6000–11000 m (+).

Hansen, 1975



**MACROFAUNA** (2 cm - 300  $\mu$ m) – more speciose, more restricted ranges than megafauna

**Asellote Isopods (peracarid crustaceans, or “pouch shrimp”)**

1) >500 deep-sea species (Wolff, 1962; Wilson, 1987; Brandt, 2005)

2) Potentially hundreds of abyssal species (adaptive radiation)

3) Cosmopolitan species few percent of abyssal diversity

4) Local endemism very common –

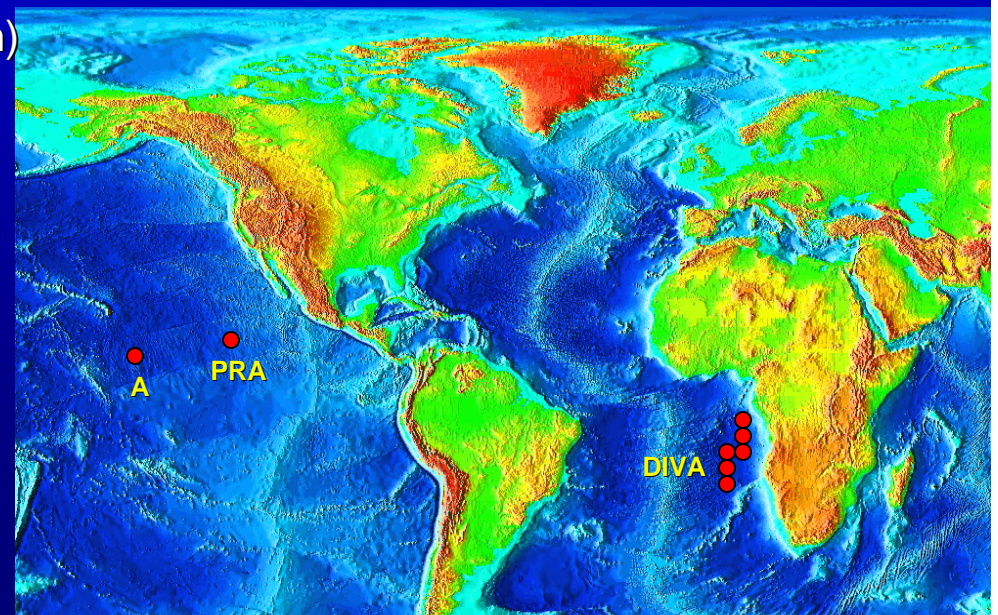
- Wilson, 1987 – only 20% overlap between sites A and PRA (131 spp., spacing ~ 2000 km)

- Brandt et al., 2005 - DIVA (spacing ~500 km)  
- 100 spp. isopods (240 spp. peracarids)  
~ 50% from only one station (most rare)



**Isopod (peracarid) Conclusions:**

- **Species richness very high**
- **Abyssal radiation evident**
- **Endemism common?**
- **Grossly undersampled**



## Polychaete worms – broad range of repro. strategies

1) >200 species from single deep-sea regions – global richness?? (e.g., Glover et al., 2001, 2002)

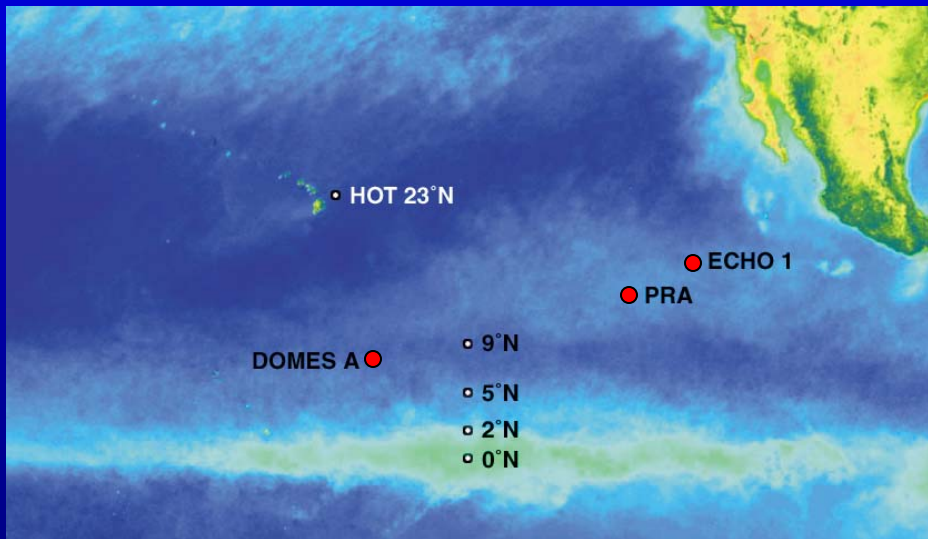


Ampharetid

2) Abyssal endemics? - likely, but taxonomy poorly known (>90% undescribed)

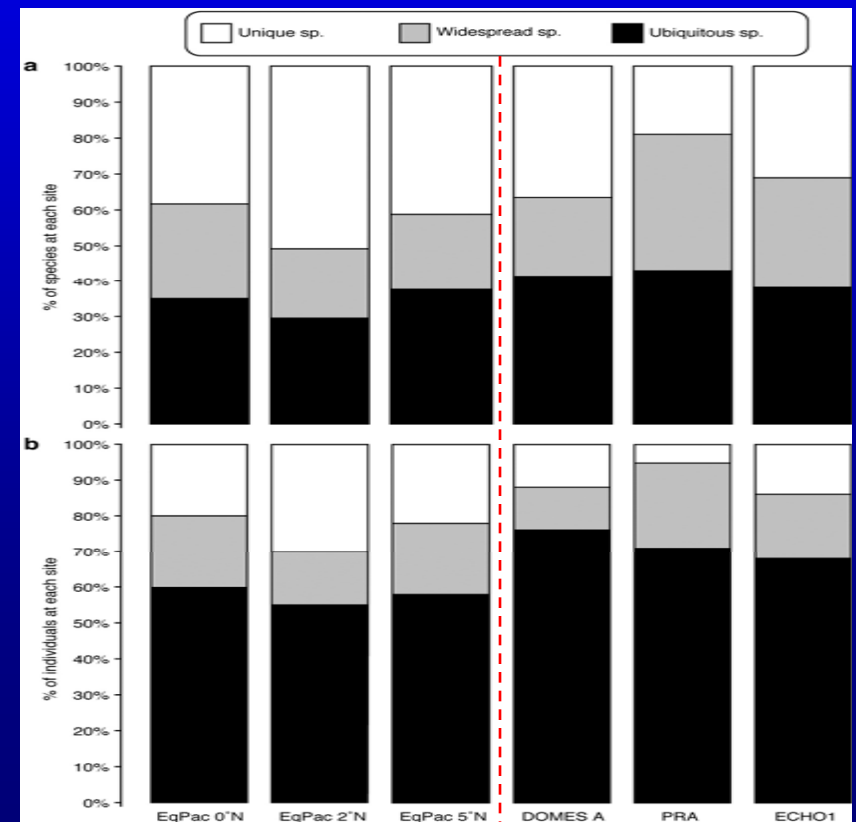
3) Some abyssal species could be cosmopolitan – *Aurospio dibranchiata*  
(Glover, Paterson, Smith – unpublished data)

4) Species turnover over 500-1000 k seems high – 20-50% endemism?



May be due to very poor sampling - most species are rare and at no site is species accumulation asymptote approached

Glover et al., 2002

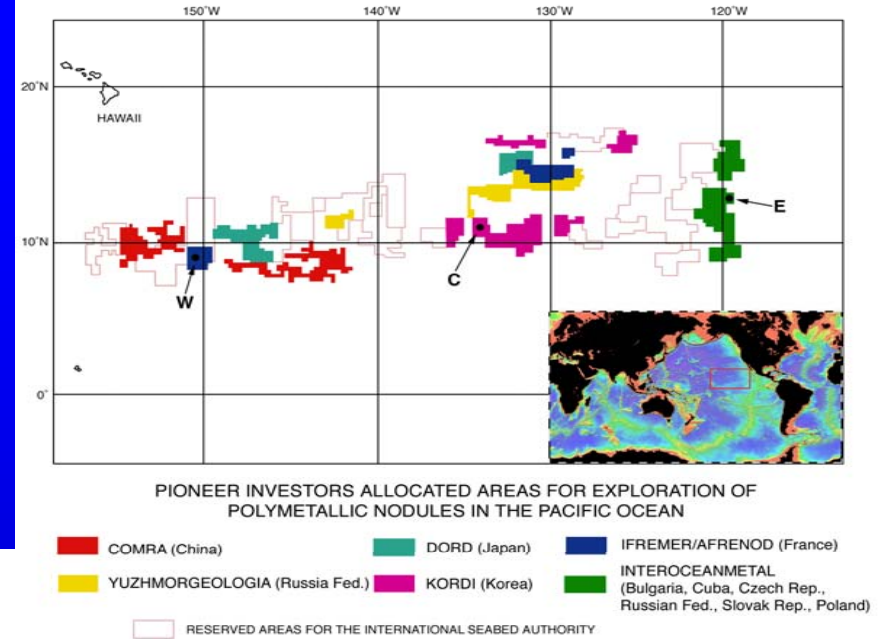




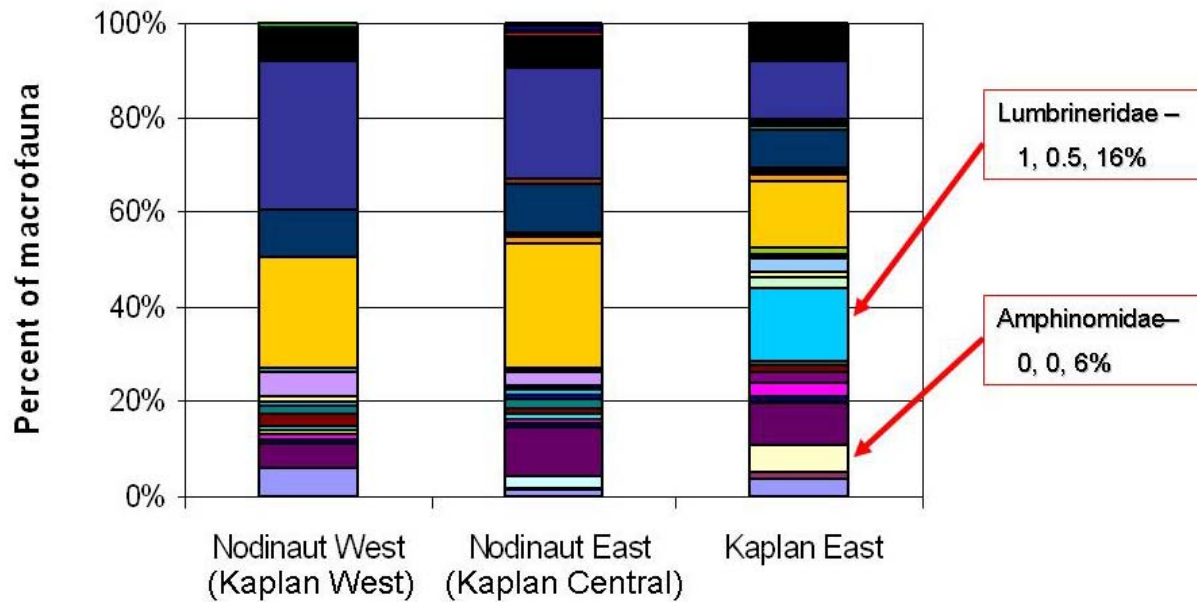
However, three sites in CCZ (~1500 km apart)

- Major differences in polychaete fauna at family level (Kaplan Project, unpub.)

- Driven by productivity gradient?



### Polychaete families



Proportion of lumbrinerids significantly lower in Kaplan Central and West ( $p \leq 0.05$ , Chi square test)

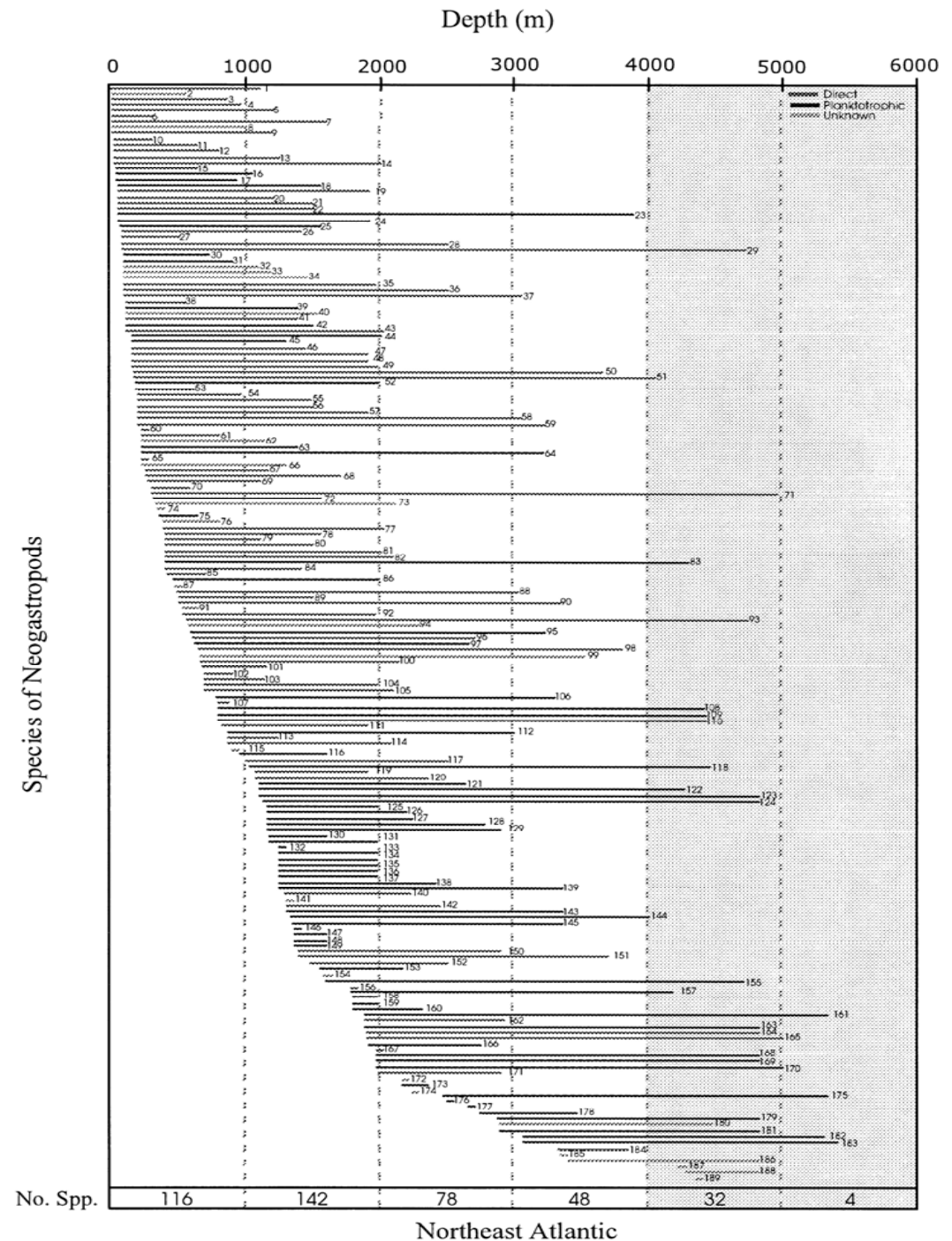
Proportion of Amphinomids significantly lower in Kaplan Central than Kaplan East ( $p < 0.025$ )

## Neogastropods in North Atlantic – different pattern

- Broad depth distributions
- Few species restricted to abyss → abyssal sink!
- Are most non-reproductive refugees from shallow depths?
- Many with planktotrophic development

NEEDS TESTING IN PACIFIC!!!

Rex et al., 2005



## **MEIOFAUNA – limited species-level data, mixed picture**

(42 – 300  $\mu\text{m}$ ) (From Gooday, pers. comm.)

### **Foraminifera –**

1) *~500 deep-sea species known*

2) *High local diversity (> 250 spp. per site)*

3) *Some species cosmopolitan (depth ranges > 4000 m!)*

*? High local, but low global diversity?*

### **Nematoda – deep-sea biogeography very poorly known**

1) *High local diversity (100's of spp. per site)*

2) *Abyssal endemics? Kaplan Project 18s rRNA gene sequences of 97 inds.*

→ *70 news species in new, abyssal genera, i.e., Abyssal Radiation*



Foraminifera



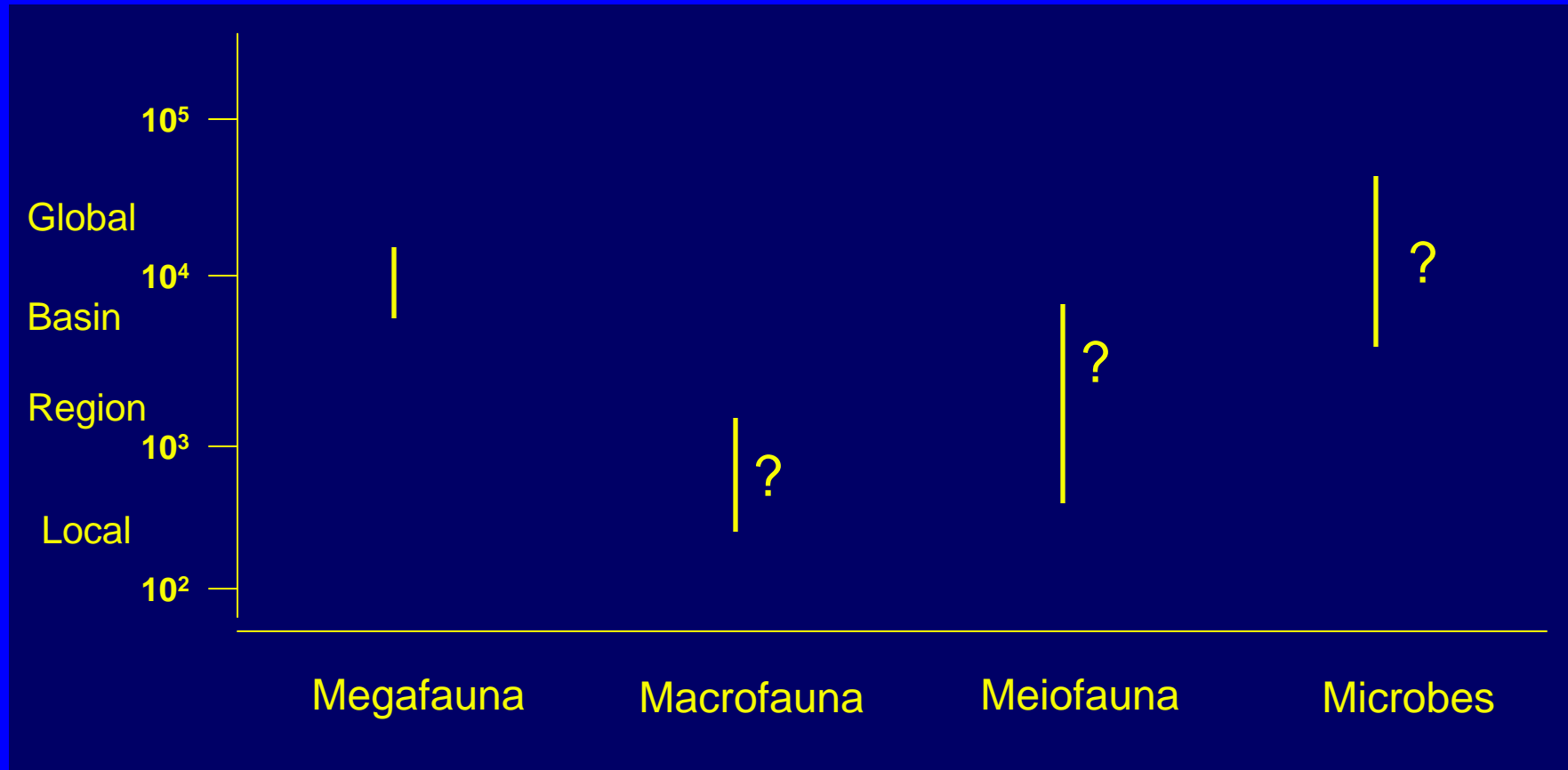
Nematode

# MICROBES – High diversity , but “everything is everywhere”?!?

(Atkins, 200; Schenkenberg et al., 2005)

## GENERAL SPECULATIONS?:

### Modal Abyssal Species Ranges by Size Class

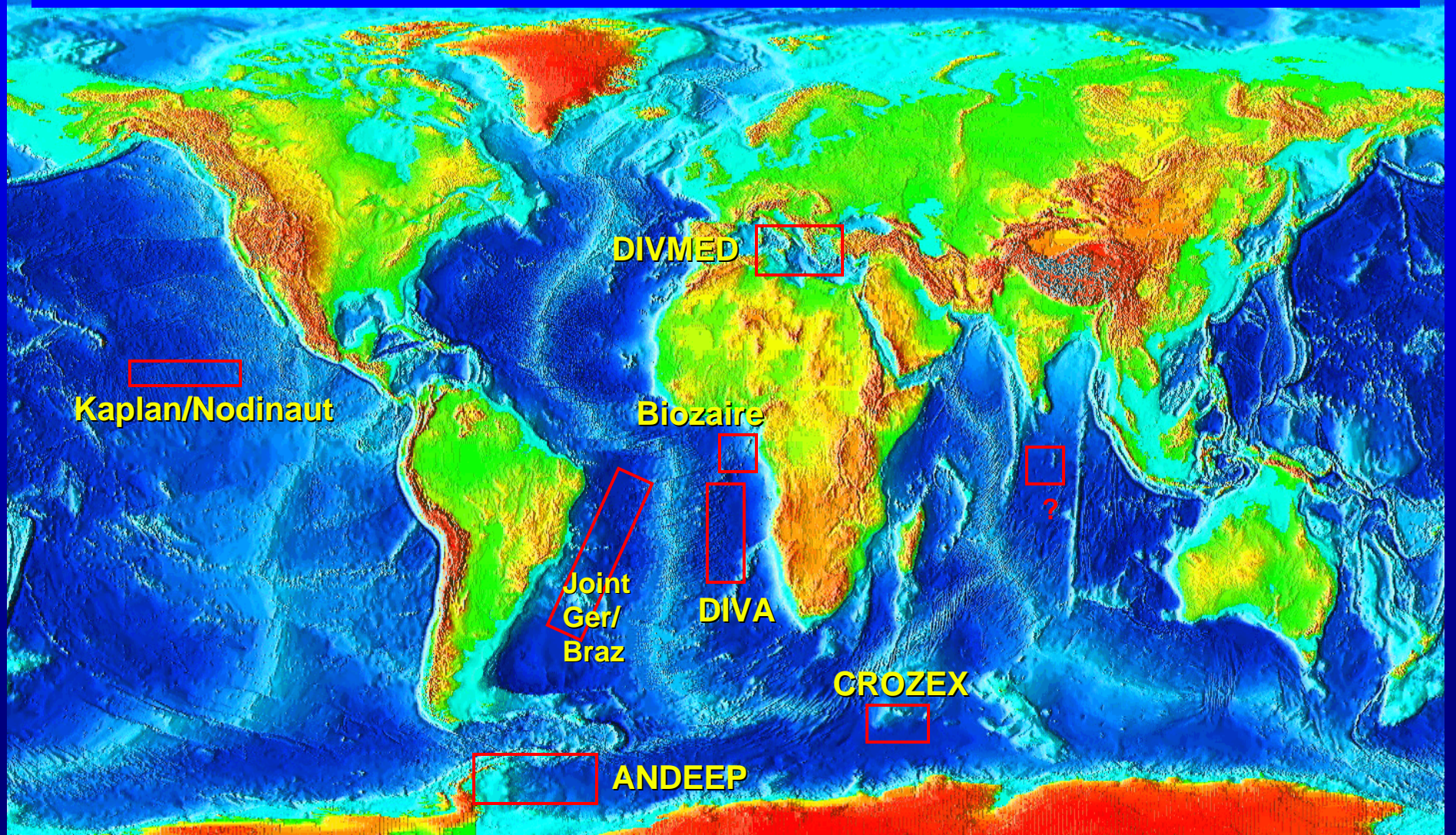


## Obstacles to Abyssal Biogeographic Synthesis:

- 1) > 90% of abyssal diversity is in undescribed species, and there is little intercalibration of working species between programs
- 2) Undersampling: How can we distinguish rarity from endemism?
- 3) Potentially large number of cryptic species, especially in polychaetes and nematodes - need combined studies of morphological and molecular taxonomy (DNA barcoding)
- 4) Patterns of population connectivity are wholly unknown, making it very difficult to recognize source and sink populations

## Census of Diversity of Abyssal Marine Life (CeDAMar)

- GOALS:**
- Coordination of standard field sampling programs
  - Synthesis of abyssal biodiversity and biogeography  
(including intercalibration of “working species” collections)



## Conclusions from the Abyss:

- 1) Biogeographic patterns vary with body size, taxon and life histories → need to study representative range of the organisms.
- 2) In some groups (isopods, nematodes?) there is evidence of abyssal radiation and novel evolutionary lineages, in others (e.g., neogastropods) there may be an abyss “sink”.
- 3) Some groups (e.g., peracarids) could have surprisingly restricted distributions, but at present we cannot resolve rarity from endemism.
- 4) Intercalibration of working species collections, and merging of morphological and molecular taxonomy, urgently needed.



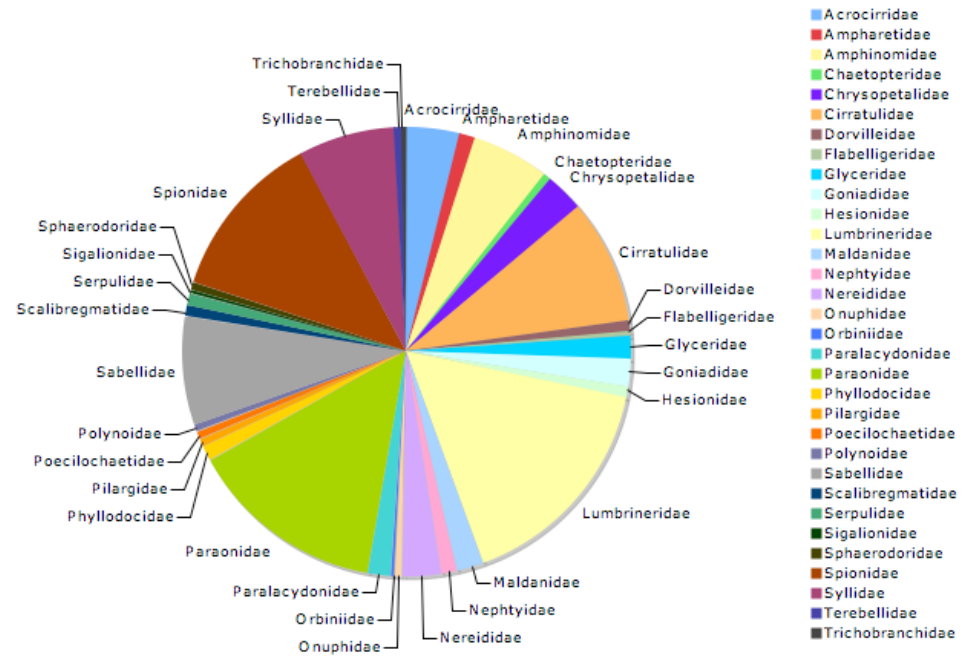
Questions ?

**NODINAUT**

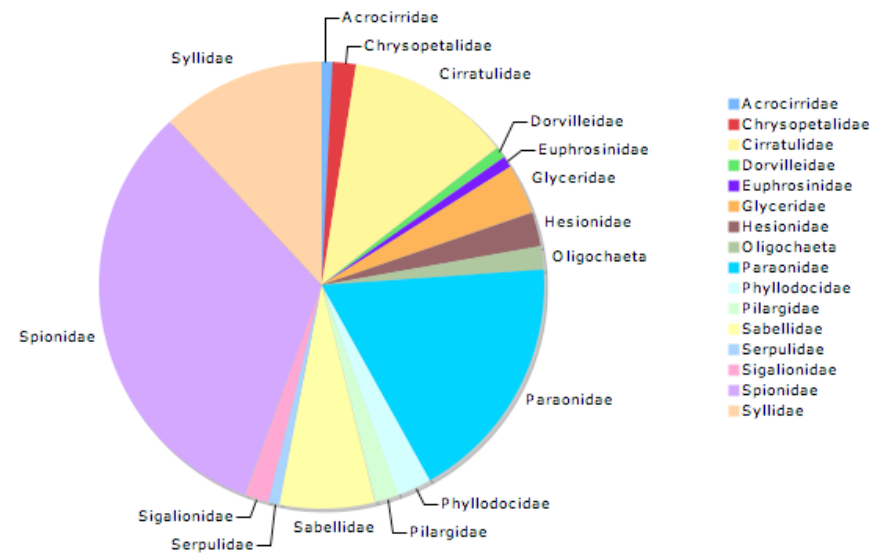


**Family composition of macrofaunal polychaetes from Kaplan Station E (Top) and Station C (Bottom).**

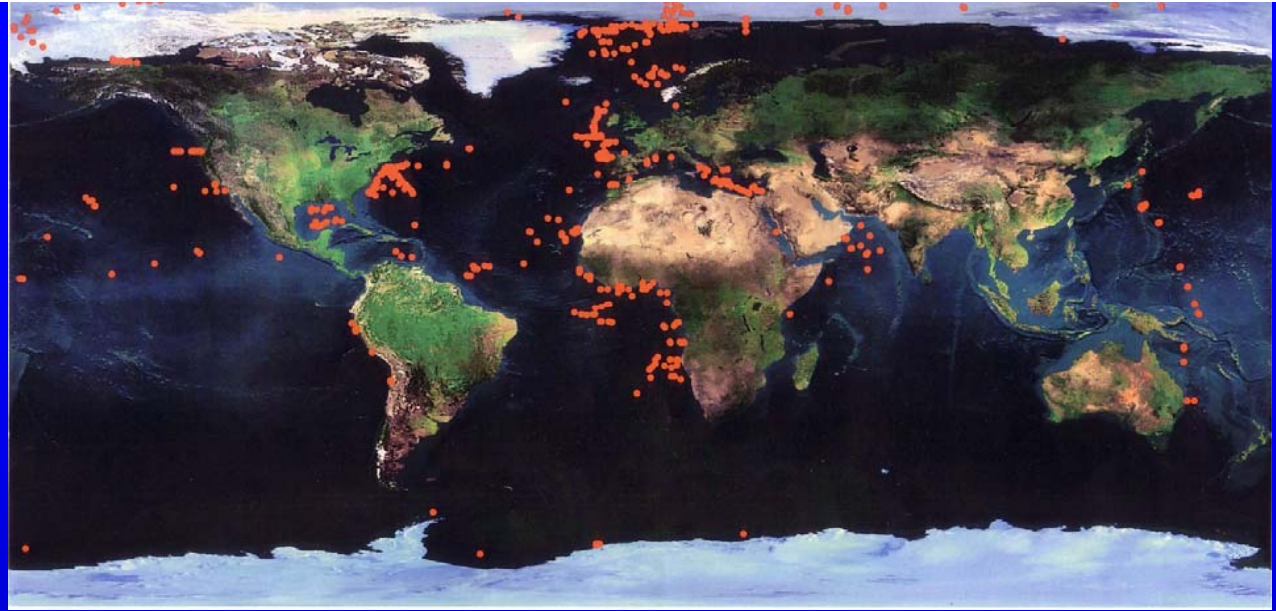
**Site E**



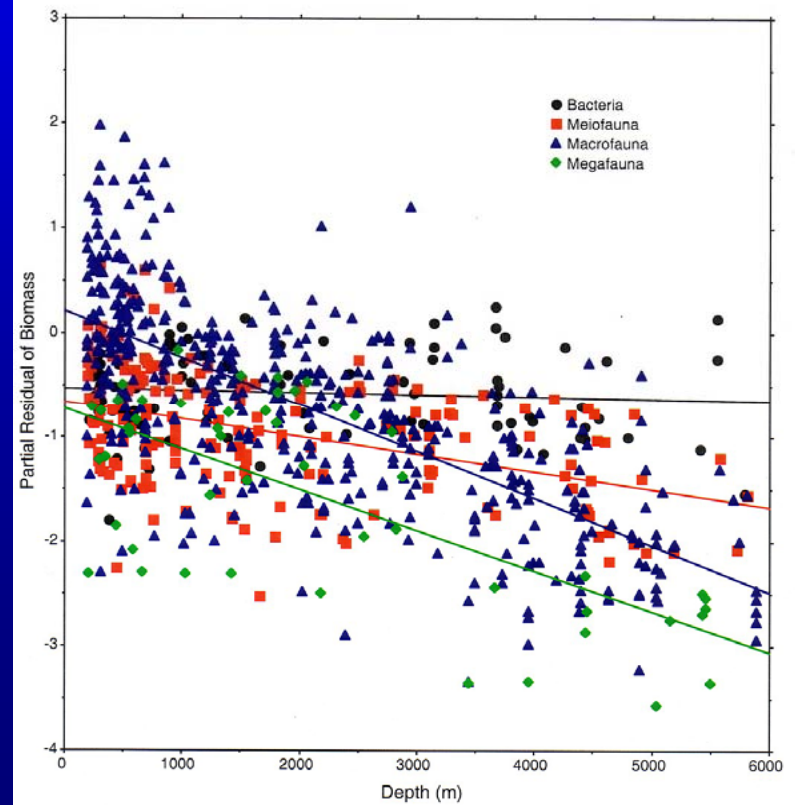
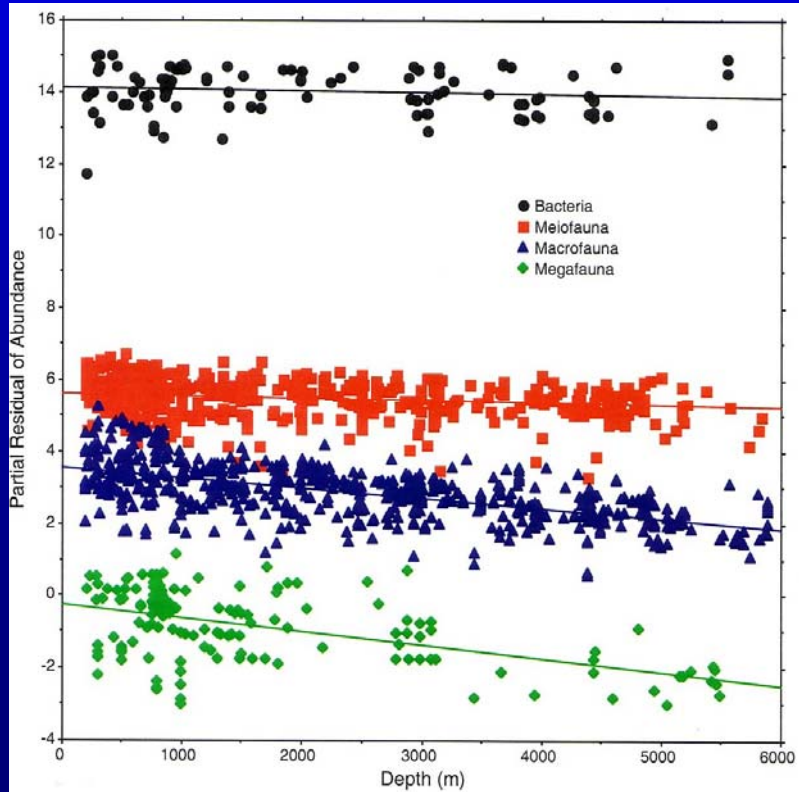
**Site C**



Rex et al., in press.  
Global bathymetric  
pattern of standing  
stock and body size in  
the deep-sea benthos.



Standing stock corrected for  
latitude and longitude  
(n=2310 from a total of 128  
studies)



## THE DEEP PACIFIC OCEAN FLOOR

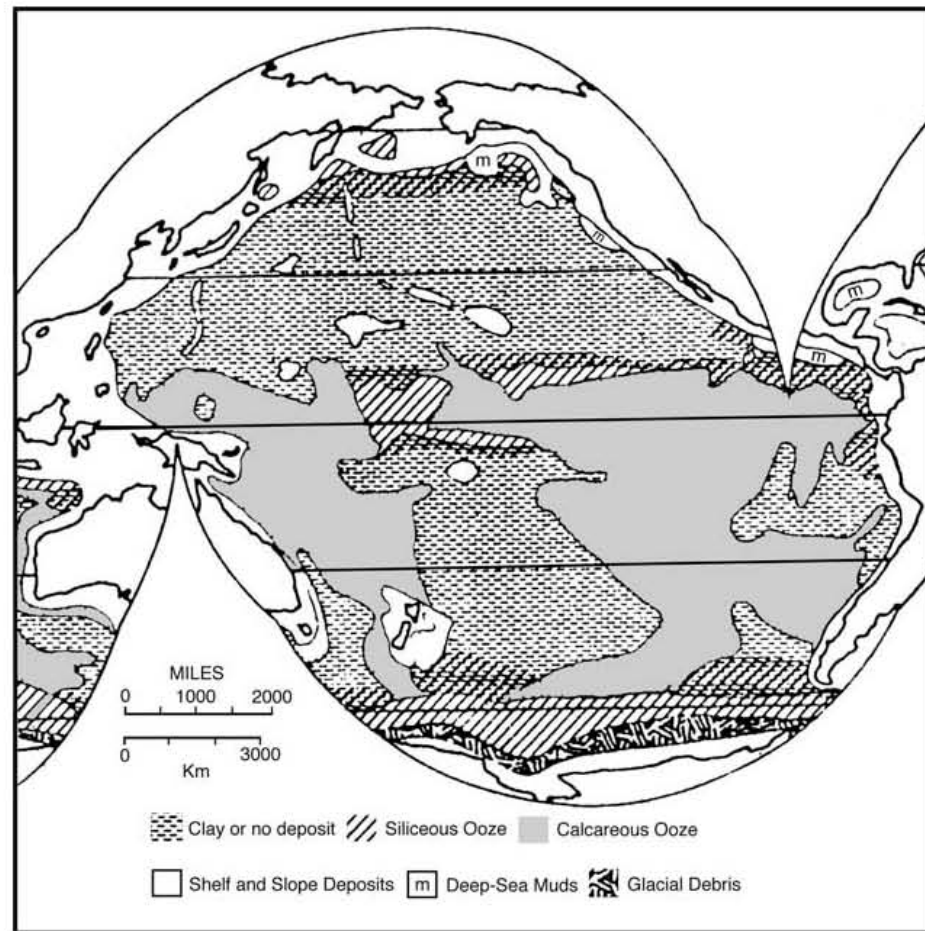
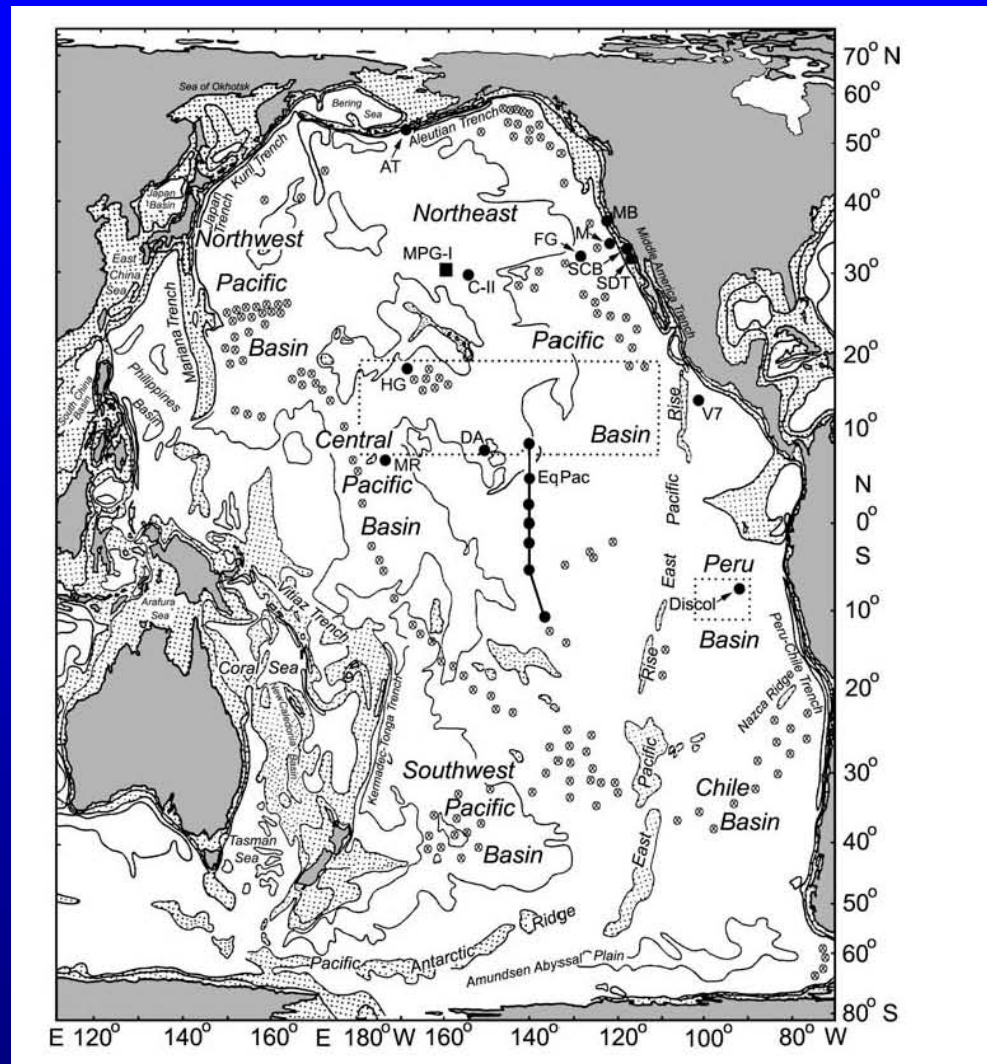
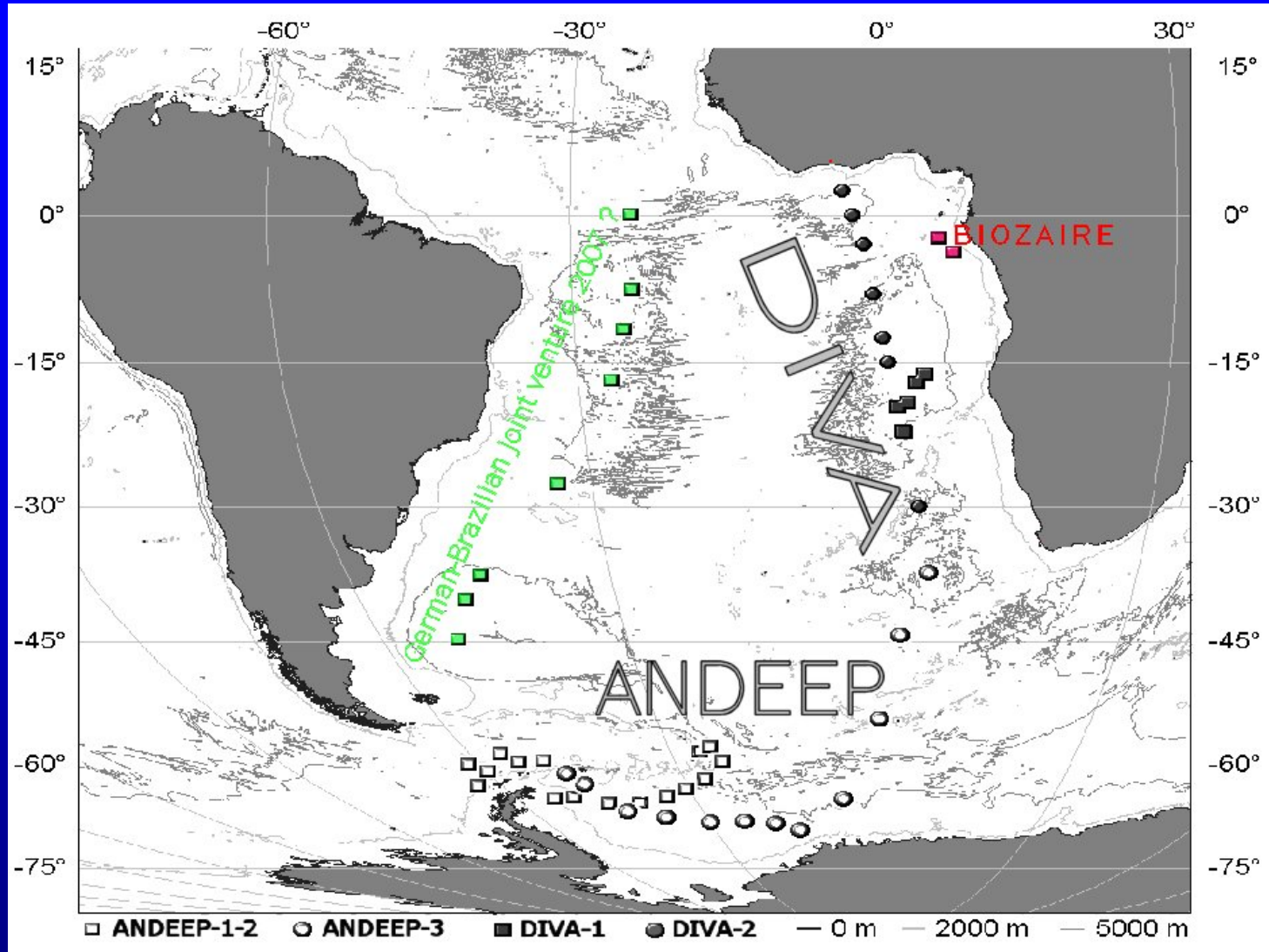


Fig. 6.3. Distribution of surface-sediment types in the deep Pacific Ocean. Modified from Berger





Location of the stations of the projects DIVA, ANDEEP, BIOZAIRE and the planned German-Brazilian cooperation.

roughly 100 and 1000 m (Wisner et al., 1990), and along the Peru–Chile margin at depths of tens to hundreds of meters (Diaz and Rosenberg, 1995). Partially enclosed basins may also contain bottom water with little or no oxygen at depths far below the oxygen-minimum zone if the deepest point of entry into the basin (i.e., its sill depth) falls within this zone; this is because the densest water entering the basin comes from the sill depth, and thus fills all deeper levels. Several such low-oxygen basins (e.g., the Santa Barbara, Santa Monica and San Pedro Basins) occur in the borderland region off southern California (Emery, 1960).

### Sinking flux of particulate organic carbon

The primary source of food material for deep-sea communities, excluding hydrothermal vents and cold seeps, appears to be the rain of organic particles, ranging from individual phytoplankton cells to dead whales, sinking from the euphotic zone (Chapter 2). The organic matter in the smaller of these particles degrades and is consumed by midwater animals during transit through the water column, generally yielding a very low flux of food to the deep-sea floor. Consequently, benthic assemblages of the abyss are among those with the poorest supply of food and the smallest biomass on the Earth's solid surface. As might be expected in an energy-poor ecosystem, the total biomass in many size-classes of benthos (e.g., the meiofauna, macrofauna and megafauna) on the deep-sea floor often is correlated with the annual rate of the rain of particulate organic carbon (Fig. 6.4; Rowe et al., 1991; C.R. Smith et al., 1997). In fact, it has been suggested that the biomass in certain benthic size classes, in particular the macrofauna, might be useful as an index of the annual flux of labile particulate organic carbon to the deep-sea floor (C.R. Smith et al., 1997); time series monitoring of abyssal benthic biomass might be employed, for example, to elucidate changes in the deep flux of particulate organic carbon (and the oceanic carbon cycle) in response to global climate change.

Two factors exert primary control on the sinking flux of particulate organic carbon to the ocean floor

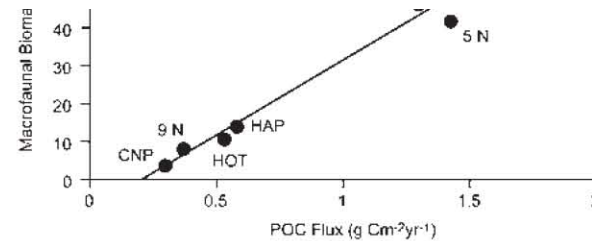


Fig. 6.4. Macrofaunal biomass (wet weight) in underlying sediments plotted against the annual flux of particulate organic carbon to sediment traps moored 600–800 m above the seafloor. Data come from: (1) the equatorial Pacific along the 140°W meridian at 0°, 2°, 5° and 9°N (C.R. Smith and R. Miller, unpublished data); (2) the Hawaii Ocean Time-Series (HOT) Station just north of Oahu, Hawaii (C.R. Smith and R. Miller, unpublished data); (3) the oligotrophic Central North Pacific (CNP) at 31°N, 159°W (K.L. Smith, 1992); and (4) the Hatteras Abyssal Plain (HAP) in the North Atlantic (Rowe et al., 1991), included to illustrate that the biomass versus flux pattern is likely to be a general oceanic deep-sea phenomenon. Only stations more than 1000 km from the nearest continent are included, to minimize the influence of downslope transport of organic matter produced in the coastal zone.

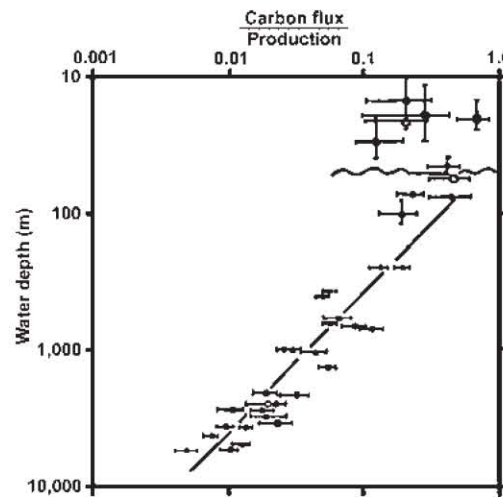


Fig. 6.5. Ratio of the sinking flux of particulate organic carbon to primary production in the euphotic zone (above the wavy line) as related to water-column depth, based on sediment-trap studies in the world ocean (data points). (Figure modified from Suess, 1980.)

(Fig. 6.5); these are the annual primary productivity in the overlying euphotic zone and, less importantly, the depth of the water column (Suess, 1980; Smith and Hinga, 1983; Jahnke, 1996). Thus, along continental slopes where coastal productivity is high and the water

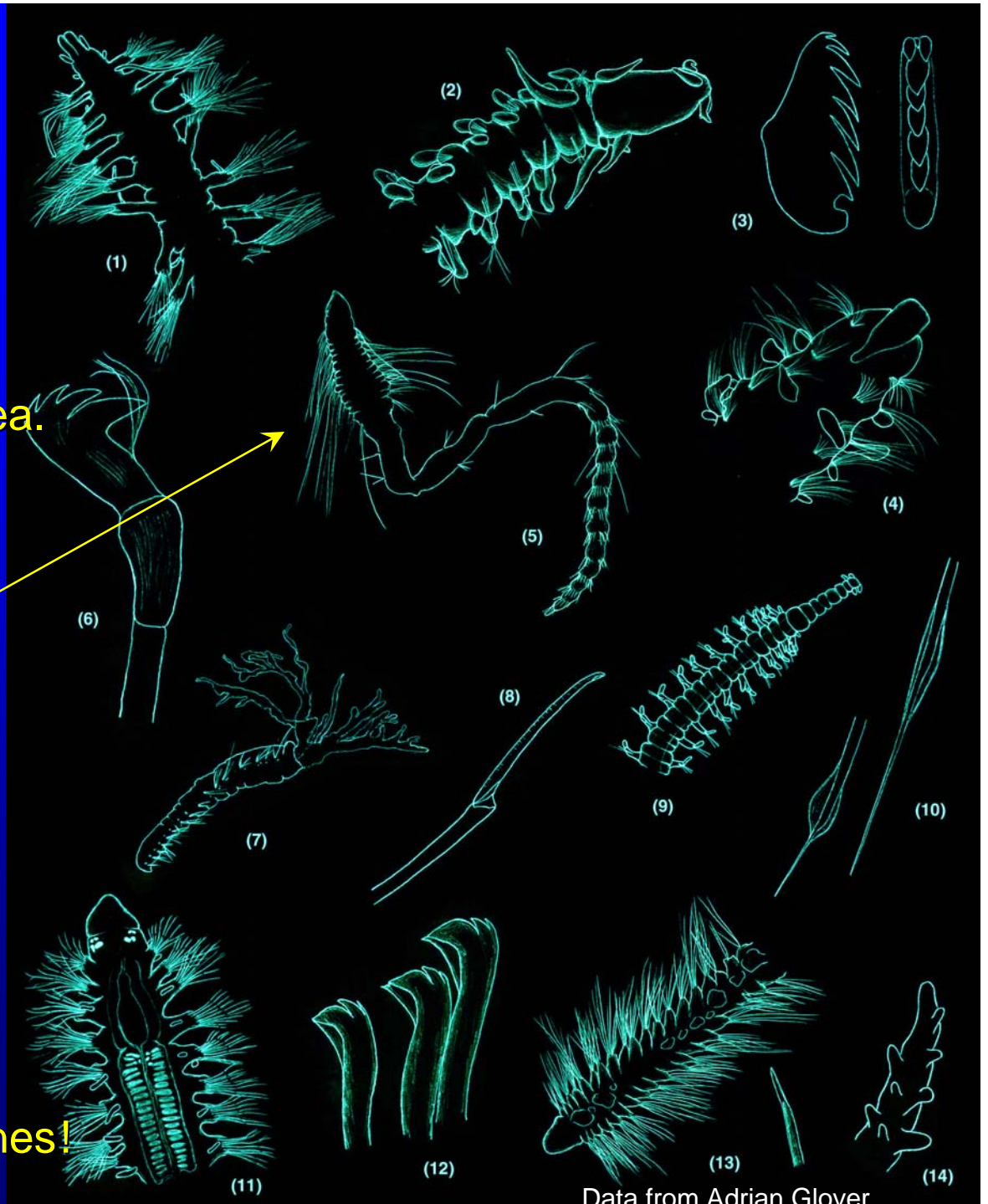
### 3) Taxonomy based only on morphological analyses

-Recent DNA-based analyses suggest many cryptic species in deep sea.

E.g., based on morph. *Chaetozone setosa* is cosmopolitan.

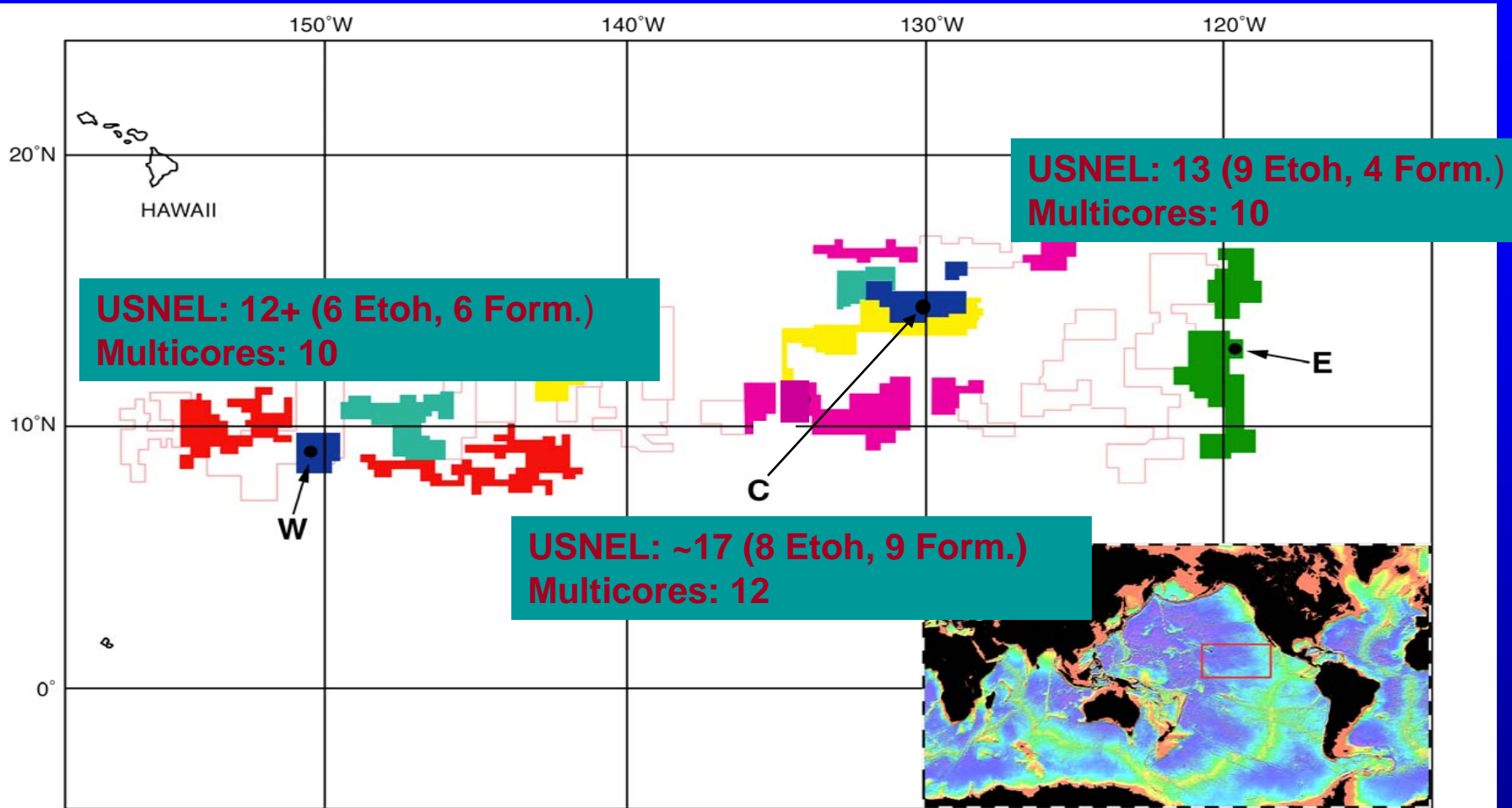
Common in -

- CCZ,
- Cal. Slope,
- NE USA & European coastal zones!



Data from Adrian Glover

# Kaplan Project Sampling to Date (85 days at sea)



PIONEER INVESTORS ALLOCATED AREAS FOR EXPLORATION OF  
POLYMETALLIC NODULES IN THE PACIFIC OCEAN

- |   |  |   |
|---|--|---|
|  COMRA (China)   |  DORD (Japan)  |  IFREMER/AFRENOD (France)  |
|  YUZHGEOLGEOLOGIA (Russia Fed.)                        |  KORDI (Korea) |  INTEROCEANMETAL<br>(Bulgaria, Cuba, Czech Rep.,<br>Russian Fed., Slovak Rep., Poland) |
|  RESERVED AREAS FOR THE INTERNATIONAL SEABED AUTHORITY |  |   |