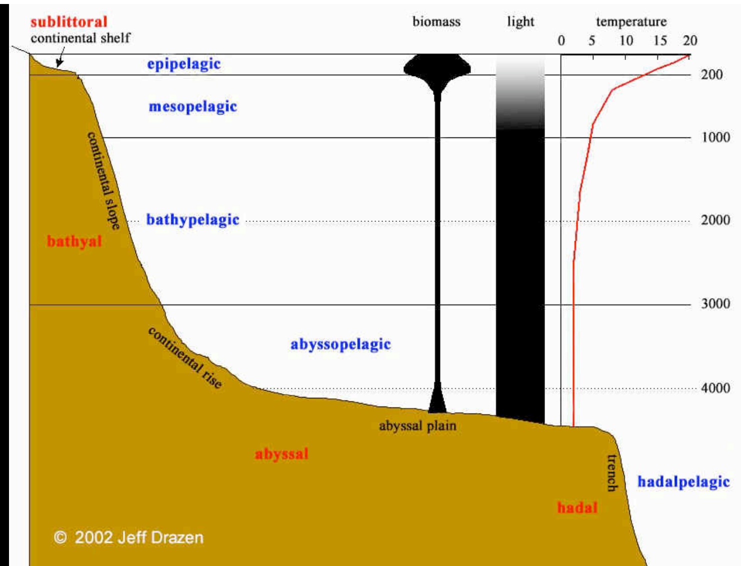
The Hadal Zone
Deep-sea Trenches



- Hadal - Ocean habitats deeper than 6,000m
- Deep-sea trenches comprise the overwhelming majority of these habitats
- *Deepest: Mariana Trench – 10,998 m*

The Hadal Zone Map > 6000 m (Not only trenches!)

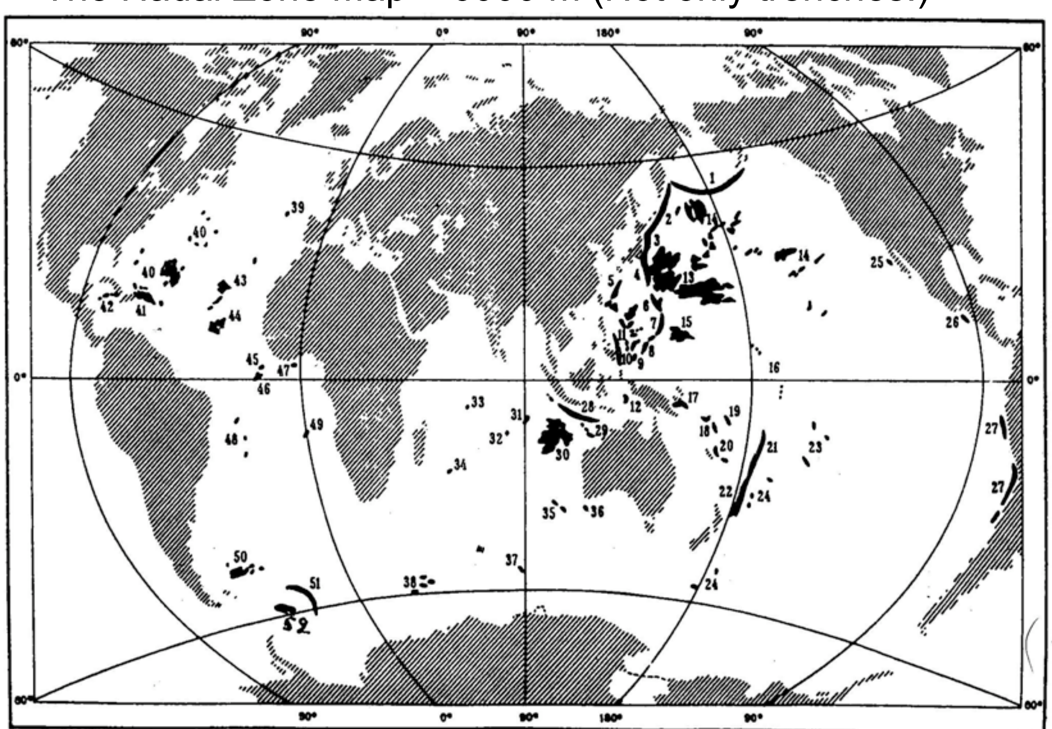
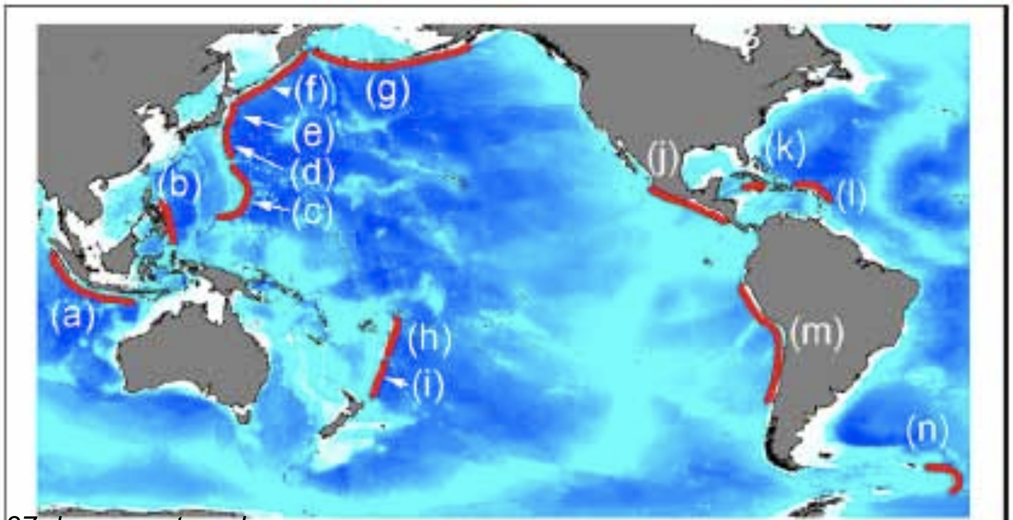


FIGURE 1. Schematic map showing the distribution of depths greater than 6,000 m in the oceans



37 deep-sea trenches
Most in the Pacific, deepest 9 in the Pacific

TRENDS in Ecology & Evolution

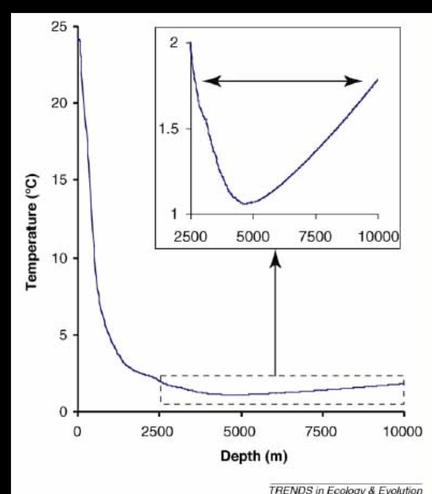
Figure 1. Major hadal trenches of the World. **(a)** Sunda (Java) Trench, 7450 m, **(b)** Philippine Trench, 10 540 m, **(c)** Marianas Trench, 10 989 m, **(d)** Izu-Bonin (Izu-Ogasawara) Trench, 9810 m, **(e)** Japan Trench, 8412 m, **(f)** Kurile-Kamchatka Trench, 10 542 m, **(g)** Aleutian Trench, 7820 m, **(h)** Tonga Trench, 10 800 m, **(i)** Kermadec Trench, 10 047 m, **(j)** Middle America Trench, 6662 m, **(k)** Cayman Trench, 7093 m, **(l)** Puerto Rico Trench, 8385 m, **(m)** Peru–Chile Trench, 8055 m, and **(n)** South Sandwich Trench, 8428 m.

Trench Environment

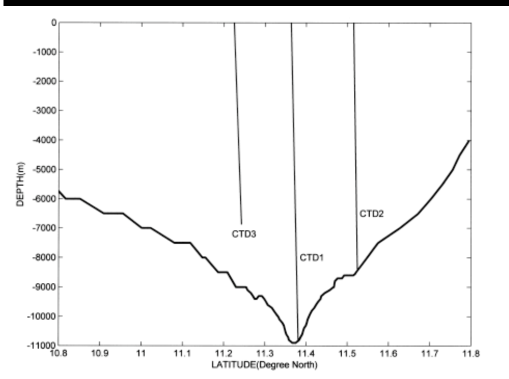
Temperature: 1.0-2.5^{o}C
Temperature increases below 4000 m due to adiabatic heating

South Pacific trench temperatures increase from 1.16 to 1.91^{o}C between 6000 and 10000 m (40%)
North Pacific trench temperatures rise from 1.67 to 2.40 ^{o}C between 6000 and 10000 m. (30%)

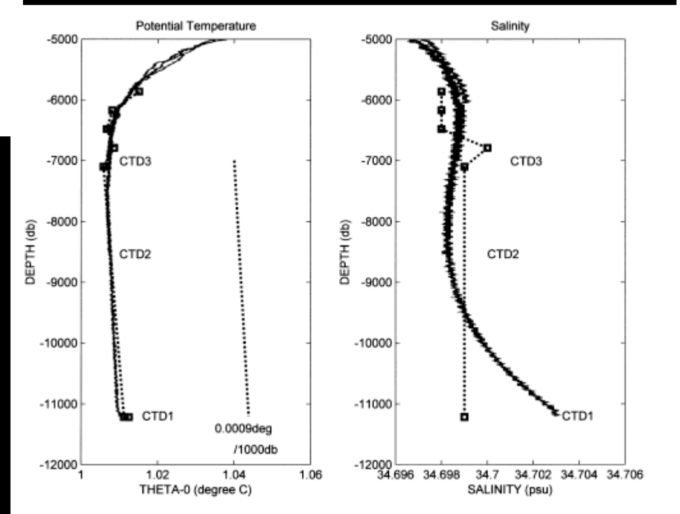
Temperatures in trenches are comparable to 3000 m cont. margin



Tonga Trench Temperature
(Jamieson et al. 2009 TREE)



Challenger Deep Cross Section
CTD Casts Temperature and Salinity
Taira et al. 2005
J. Of Oceanography



Flow regime: Deep currents ventilate trenches with values up to 8.1 cm/sec in the Challenger Deep
Up to 32 cm/s in other trenches

Currents exhibit lunar and semi-lunar tidal cycles

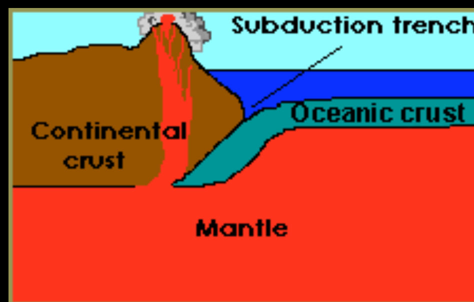
Mean **oxygen** in N. Pacific trenches 3.43 ml L^{-1}

Why is the Mariana Trench so deep?

1. Plate configuration – Pacific plate is old and cold and plunging beneath the Philippine plate.

The Philippine plate is young and soft and is carried downward with the Pacific plate.

2. Remoteness from sediment sources – it doesn't fill up over time!



Trench Biology – Historical

(courtesy of L. Blankenship)

- Challenger – sounding to 8200 m (no fauna)
- Incidental collection of arenaceous foraminiferan at 7228 m Japan Trench (Brady 1984 – 14 spp.)
- In 1899, the "Albatross" trawled the Tonga Trench deeper waters for the first time.
- All that was caught was fragments of a siliceous sponge (whose origin could not be determined)
- In 1901, "Princess Alice" successfully trawled a deep-sea basin at a depth of 6,035m
- Generally regarded as first authentic samples from depths greater than 6,000m

- 1948 – Swedish deep-sea expedition on the "Albatross II" landed 2 Polychaetes, 1 Isopod and 1 holothurian from 7.7 km (Japan Trench)

- 1949 – Soviets on the Vityaz obtain "rich collection of benthic invertebrates" from Kurile-Kamchatka Trench (8100m)
- Identified 20 species in 10 classes!!

Jan. 23,1960- *Trieste* (bathyscape) dive confirms life at 10.9km in the Marianas Trench

Jacques Piccard
Donald Walsh

4h 48 min descent
20 min on bottom
3 h 17min ascent

'red shrimp' observed ?
No fish?

Photo # NH 96801 Trieste hoisted out of water, circa 1958-59

Are hadal depths really a separate zone?

- 1953- Initially named “super-ocean”
- 1954 -“Ultra-abyss” proposed by Russians
- 1955-“Hadal” used outside USSR
- *Hadal originates from “Haides” or kingdom of the dead.*
- 1967- “Trench floor fauna” used but quickly squashed by opponents

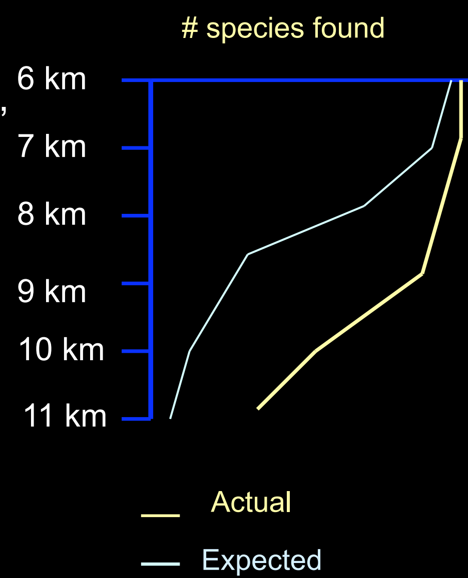
The case for the Hadal zone as distinct from the abyssal zone

- Physical Properties
  - Hydrostatic pressure
  - Temperature
  - Sediments
- Animal samples
  - An analysis in 1964 showed that 2/3 of all hadal animals are endemic to the hadal zone

= Ecological Isolation from abyssal zone (Wolff, 1964)

Early observations about hadal fauna

- In 1960, Wolff stated that 58% of species endemic to hadal zone using 6km boundary
- If boundary extended to 6.8-7km, then 74% of species endemic
- Species list at 85 (from 8 trenches) More than expected
- Benthic species richness and biomass directly correlates with overlying water production



Wolff 1971. The hadal fauna relative to the abyssal zone

(a) higher percentage of species of amphipods, polychaetes, bivalves, echiurids and holothurians than in abyss

(b) a lower percentage of species of asteroids, echinoids, sipunculids, and ophiuroids than in abyss

(c) the insignificance of several groups, including--in addition to the four latter groups---coelenterates (except actinians and scyphozoans), bryozoans, cumaceans and fishes

(d) the total lack of decapod crustaceans

Barophilic bacteria in the Trench – MT 41 from amphipod (*Hirondellea gigas)* guts – Yayanos et al. 1981

Optimal growth at pressure less than site of origin

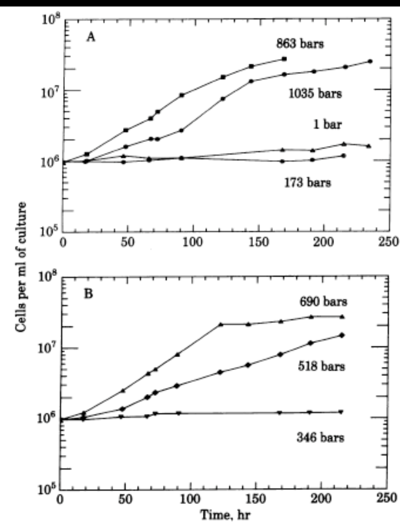
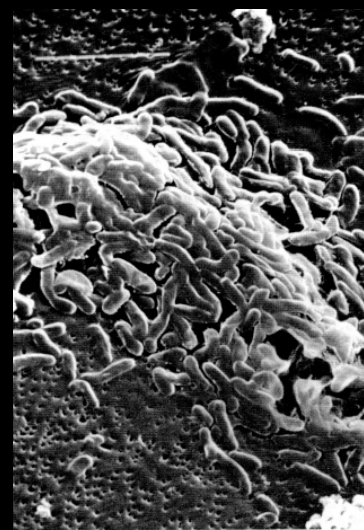


FIG. 1. Reproduction of MT-41 at 2°C. Strain MT-41 was incubated at seven different pressures at 2°C in nutrient medium. Growth was not observed at the three lowest pressures (1, 173, and 346 bars) but was clearly observed at higher pressures and even at 1,035 bars,



Adaptations to high P, low T

- Use of intracellular protein-stabilizing osmolytes (TMAO). Increases cell volume to counteract the effects of pressure.
- Increased use of unsaturated fatty acids in cell membrane phospholipids to maintain fluidity and cell function
- Reduced metabolic rate ? Not directly linked to pressure. Note – an animal going from 6k to 10K m only experiences a doubling in pressure (but animals on abyssal plains may be stenobathic).
- Wax esters for storage in animals (between bouts of feeding) - also act to maintain neutral buoyancy

Absence of calcareous & siliceous structures ?

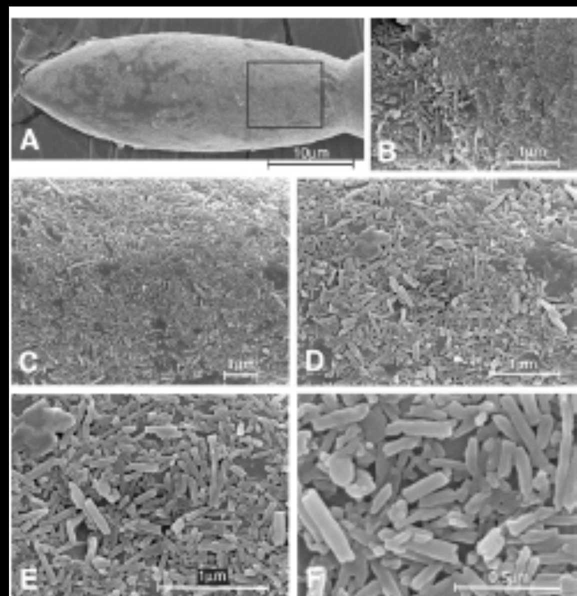
- Calcium compensation depth of 4000-5000 m & opal undersaturation leads to:
  - Organic-walled, soft-bodies foraminifera
  - Soft bodied holothurians

Challenger Deep Foraminifera

Photos by A. Gooday

Agglutinated surfaces on at least parts of *Nodellum*

(Gooday et al. 2008)



Metazoan Meiofauna in Trenches

Atacama Trench (N. Chile) Danovaro et al. 2002 DSR

- Trench sediments have TOC, chloroplastic equivalents to bathyal depths; 50% chlor a/ High OM quality

- Meiofauna contribution to total biomass (microbial + metazoan meiofauna)
  - 50% at bathyal depths, 70% at 7800 m
  - More food channeled to higher trophic levels

- Composition: Nematodes – 80% density, 50% biomass at 7800 m
  - Also copepods, polychaetes, kinorhynchs

- Meiofaunal dwarfism (30-40% body size reduction)

NOT OLIGOTROPHY! Alternatives:
More juveniles, selective predation on lg animals,
barophily associated with small size.

abundant
91-97% nematodes and harpacticoids
17,000 ind. /m2 at 8560-8580 m in Brownson Deep
George and Higgins 1979

Eutrophic setting
Lots of plant debris
anthozoans, pogonophorans, gastropods

Isopods, amphipods, cumaceans at 7600 m

RICHARDSON et al. 1995 DSR
Depauperate meio and macrofauna!
Refractory OM and turbidite flows.

Macrofauna in Trenches

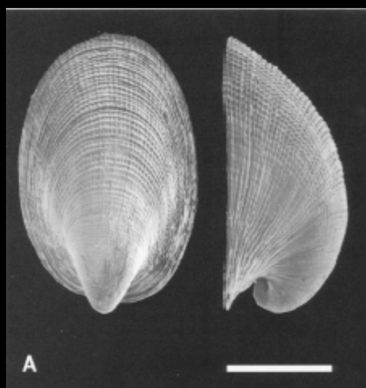
- Macrofauna were studied from the Aleutian Trench by Belyaev (1966) (2 cores) and
- Jumars and Hessler (1976) (1 core) between 6460 m and 7298 m - Density high (1272 ind. m^{-2}) but less than abyssal samples (2000-3800 ind. m^{-2} – in Rathburn et al. 2009)
- One box core at 7460 m in Japan Trench
- > 3,000 ind/m2 (Shin 1984)

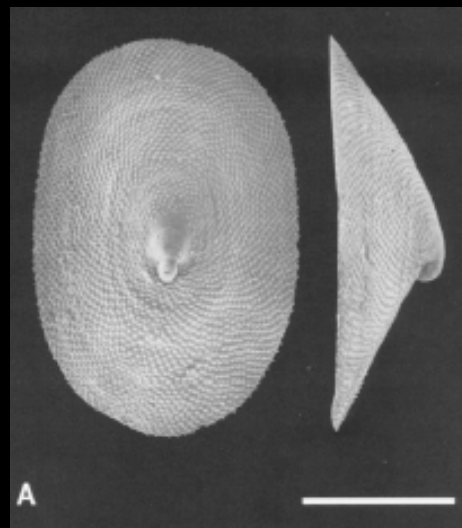
Hadal Limpets!

Cocculinidae and Pseudococculinidae in the Cayman and Puerto Rico Trenches (6740-7247 m) on wood and turtle grass

José H. Leal and M. G. Harasewych 1999 Invert. Biol.

- *Fedikovella caymanensis*





Caymanabyssia spina

Lots of Scavenging Amphipods

- http://planetearth.nerc.ac.uk/blogs/post.aspx?id=

Uristes sp.

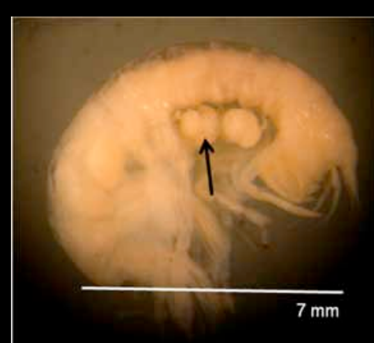
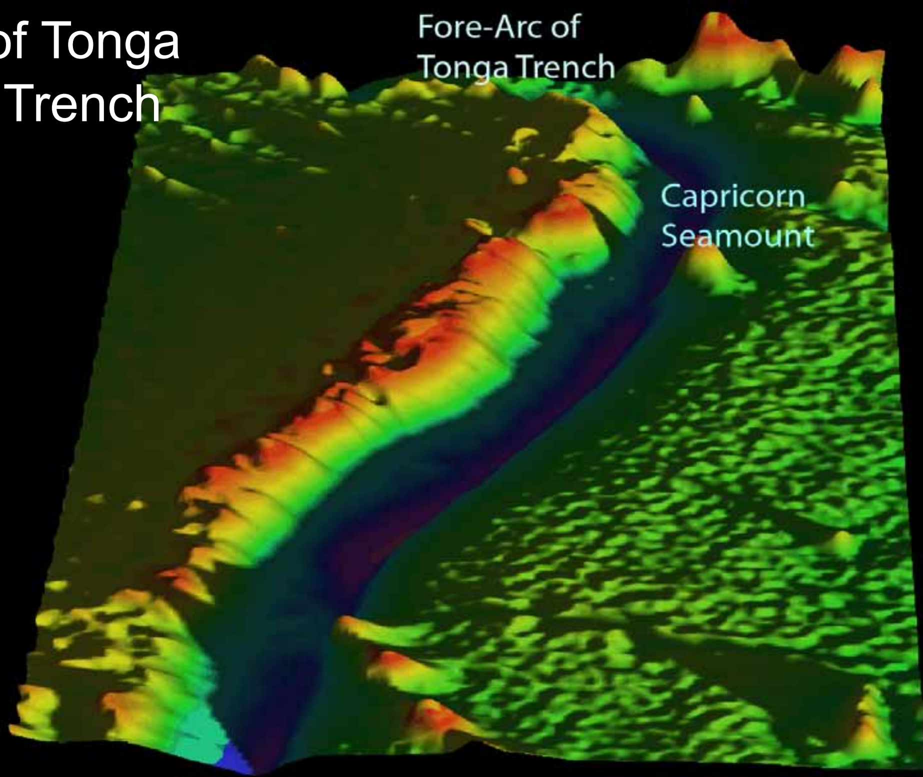


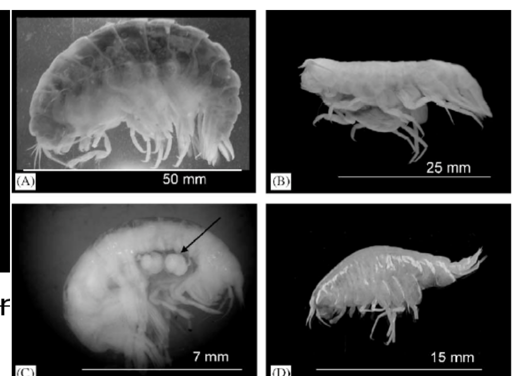
Photo by L. Blankenship

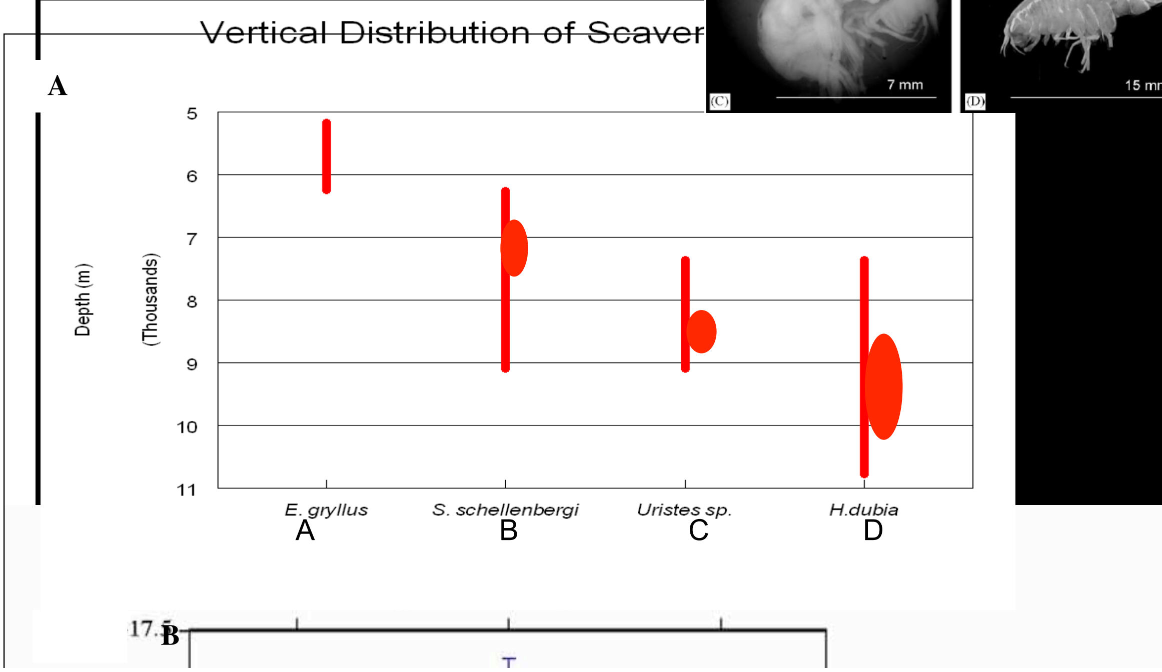
3D model of Tonga Trench

Blankenship papers: Amphipod structure and diet



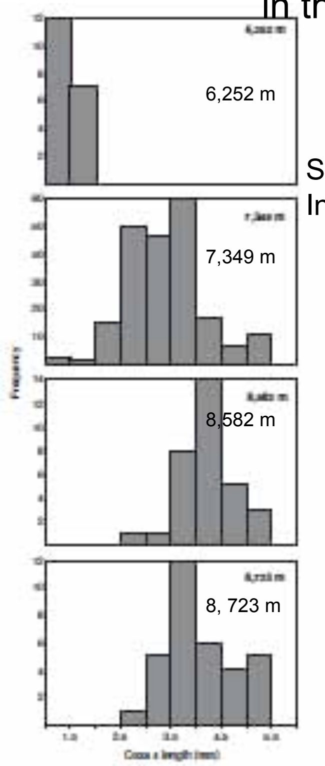
Zonation below the Abyss? Vertical zone partitioning by amphipods in Tonga/Kermadec Trenches- 13 traps; 5155-10786 m





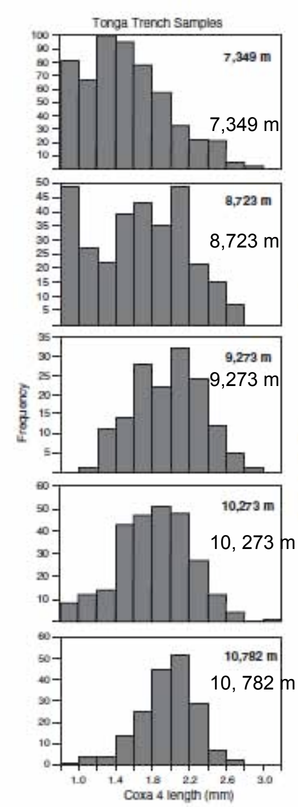
Scopelocheirus schellenbergi

Ontogenetic vertical partitioning in the Tonga Trench



Hirondellia dubia

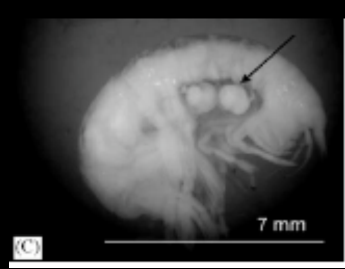
Smallest instars are found only
In shallow waters
physiological advantage?
nutritional advantage?



Brooding amphipods do not attend bait

Blankenship et al. 2006

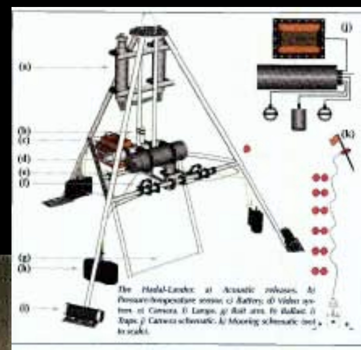
"There is a correlation between the extent to which a gut distends and the reproductive stage of females that will attend baited traps. In lysianassoid amphipods where the midgut and brood occur in the same position along the body axis (e.g. *Eurythenes, Scopelocheirus and Hirondellea*; Dahl, 1979), gluttonous forging would greatly expand the midgut. The developing brood would either be forcefully expelled or possibly crushed."



Uristes sp.

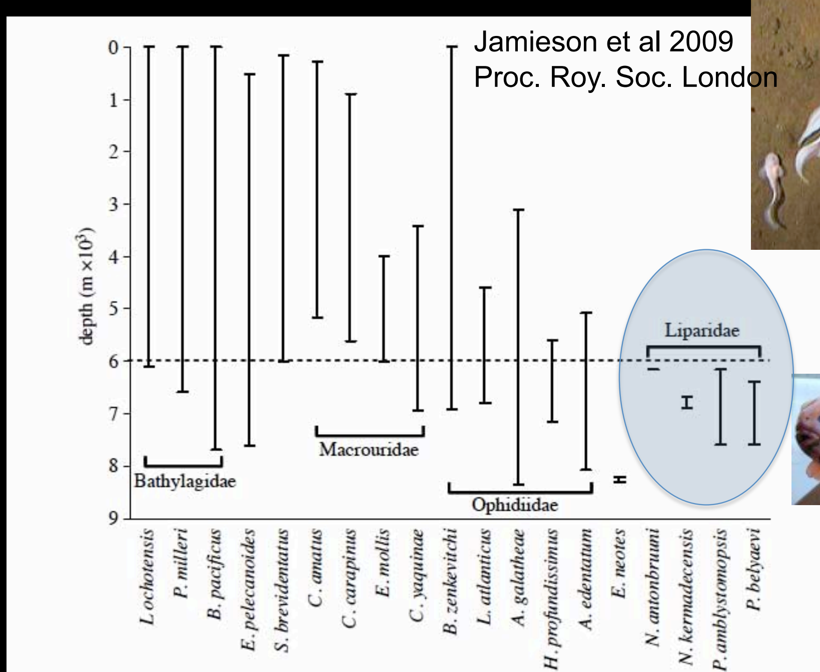
No fish or decapods in trenches?

Liparidae at 7500 m

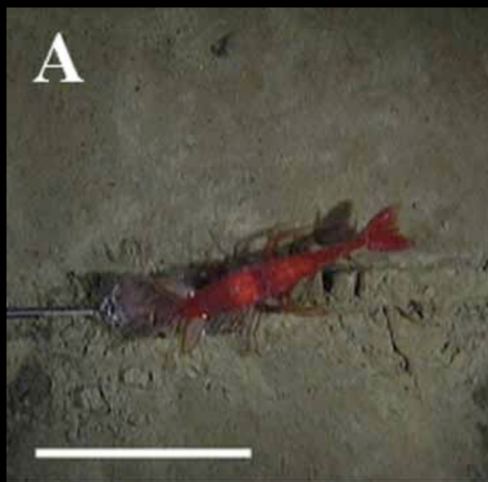


Trench endemic fishes are Liparidae (Snailfish)

Jamieson et al 2009
Proc. Roy. Soc. London

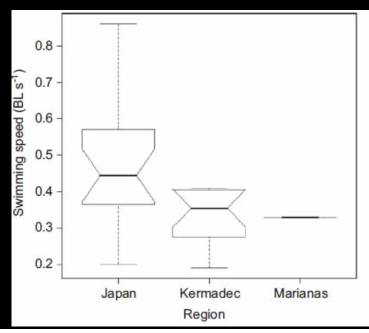


Decapods – 7700 m limit?

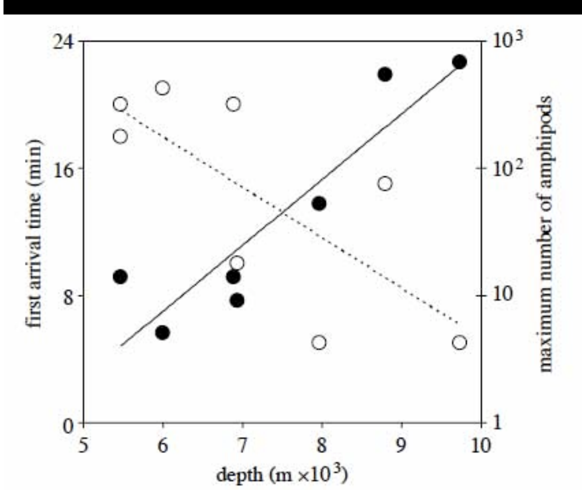


Decapods observed on video to consume scavenging amphipods

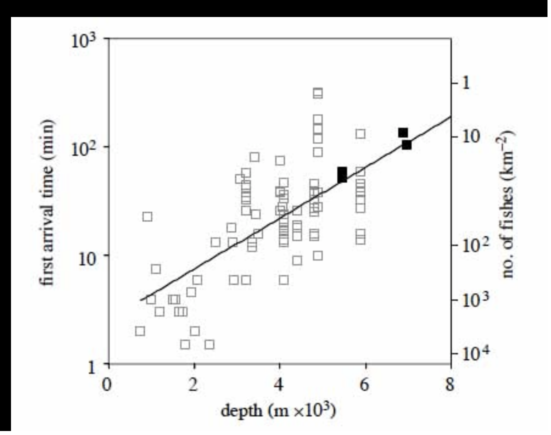
Jamieson et al. 2009 Deep-sea Research



Arrival time reveals densities



Jamieson et al. 2009 P.Roy. Soc. B



How important is primary productivity of overlying waters?

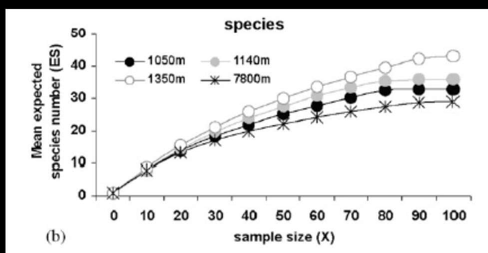
Atacama Trench – over 8000 m, beneath upwelling in N. Chile (9.9 g C/m2/da, 80 km from shore!

Meiofauna 10x higher than at bathyal depths

(Danovaro et al. 2002 DSR)

Nematode diversity low, body size low

(Gambi et al. 2003, DSR)



Blankenship et al. 2006

Tonga trench – oligotrophic

Female *H. dubia* have greater size at maturity

Kermadec trench – more productive

Annual spring bloom (higher latitude)

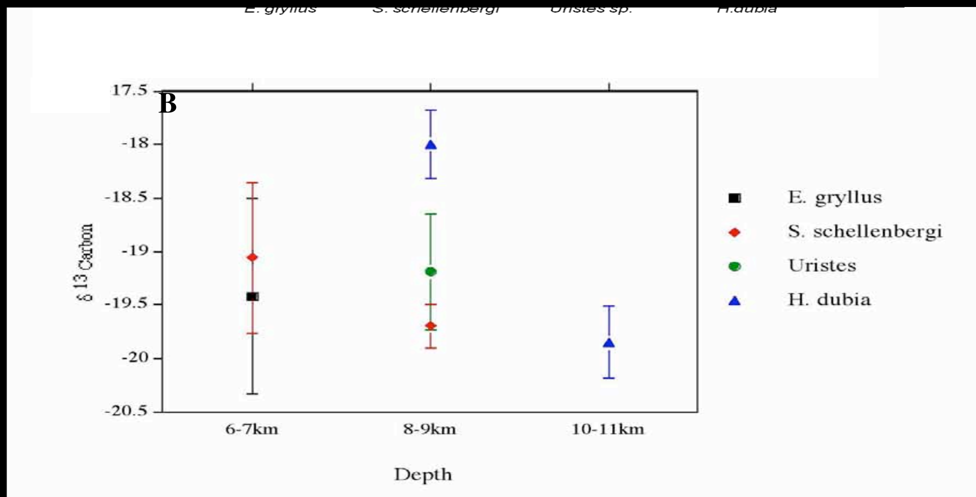
Female *H. dubia* have lower size at maturity, greater abundance

Diets of hadal fauna

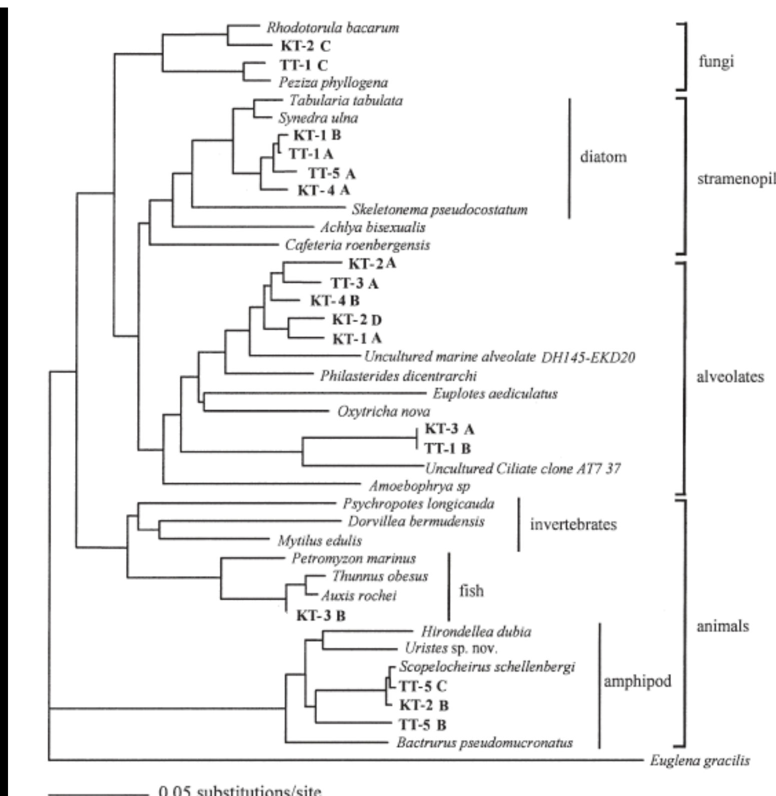
- Old ideas – scavengers consume carrion
- New ideas –
  - Surface derived POM (phytodetritus)
  - Chemosynthetic bacteria/inverts associated with seepage
  - Other invertebrates – especially scavenging amphipods
  - Sediments & phytoplankton!

Carnivory, Cannibalism, Carrion feeding

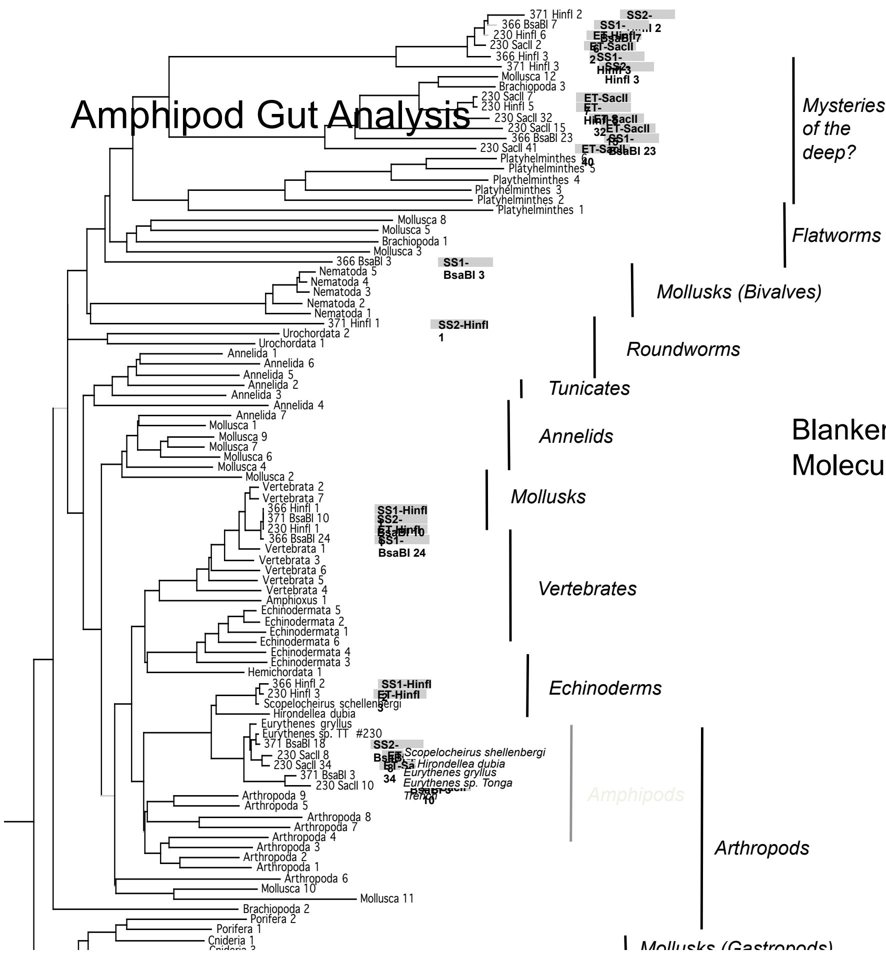
Diet partitioning among amphipod species
-within and between depths
Blankenship and Levin 2007 L & O



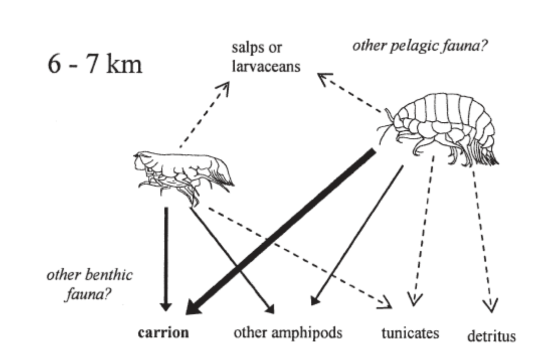
Hirondellia gut contents



Amphipod Gut Analysis

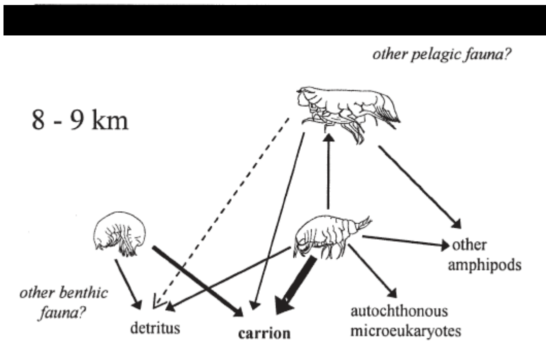


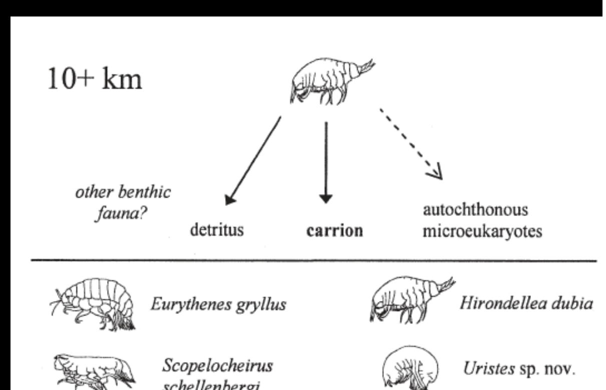
Blankenship et al. 2005
Molecular Ecology



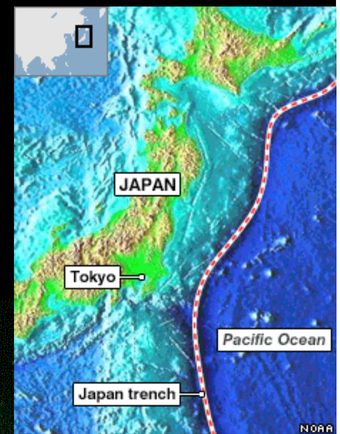
Diets of trench amphipods as determined by DNA sequencing of guts and stable isotope analyses

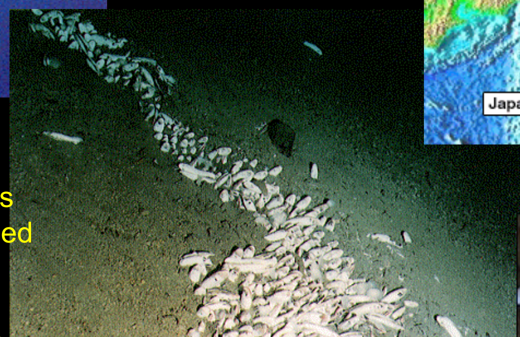
Blankenship and Levin 2007





Chemosynthetic communities Japan Trench 6370 m





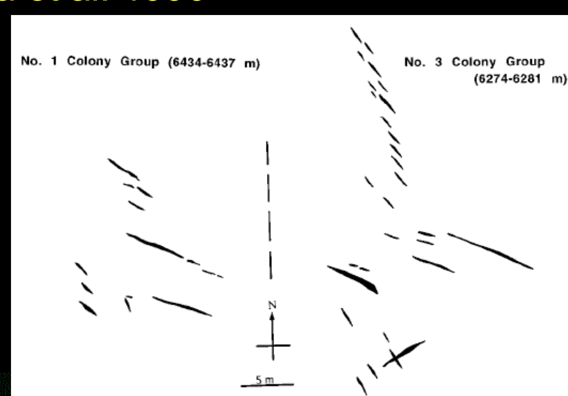
9 agglutinating and 3 calcareous Foraminiferal taxa in the clam bed
Kazumi and Chiaki 1999

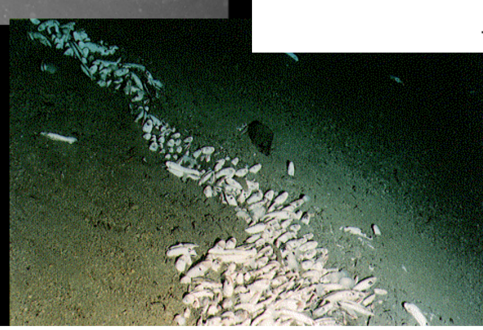
Calcareous forams (*Cibicides* & *Melonis* persist below the CCD!

Calyptogena phaseoliformis
Track faults/ fluid flow

Geometry of the clam colonies has the potential to provide sensitive kinematic indicators of plate movements

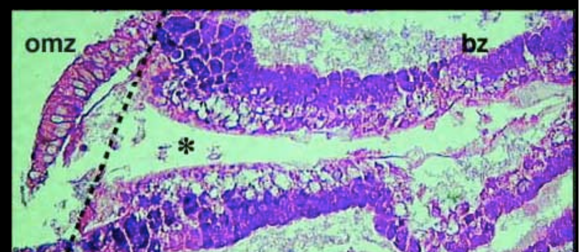
Ogawa et al. 1996





Maorithyas hadalis (Thyasiridae)
Japan Trench 7326 m
Fujikura et al. 1999;
Fujiwara et al. 2001 MEPS

- Dual symbiosis, spatially segregated
- (1) gamma Proteobacteria (thiotroph)
- (2) gamma Proteobacteria
- (unknown metabolism.. Related to free living thiotrophs and H oxidizers)
- Distinctive features –
  - Intracellular symbionts
  - Spatial segregation of bacteria



Endemism of hadal fauna

- Species list over 700 (Belyaev, 1989) and most trenches have been sampled at least once
- 56.4% of species endemic to hadal zone (using 6 km threshold)
- Of these, 47% found in single trench
- Only 3% found in geographically separated trenches
- = Hadal fauna as a whole are distinct from abyssal fauna but each trench harbors its own distinct community
- = Similarities in community structure across trenches?

-Vinogradova, 1997

Sources of Biodiversity

- "The complex bathymetry of deep-sea trenches results in sedimentation rates differing from place to place, and different substrates ranging from fine muds to hard outcrops, which create a variety of ecological niches for benthos."
- "While high pressure restricts diversity of inhabitants of the ultra-abyssal zone, suitable conditions are available in many deep-sea trenches for abundant quantitative development for animals which have adapted to extremely high pressure"

-Belyaev, 1967

- In 1966, number of benthic invertebrates known from abyssal zone is 58
- Number of hadal species at 254
- Since there is an estimated 67X more abyss than hadal, Belyaev calculated that ….
- #species/area is 15X greater in hadal environment than abyssal environment!
- He attributes this phenomenon to the "more favorable environmental conditions" found in the hadal zone, including varied substrate.

-Belyaev, 1966

* Note: this is prior to Sanders & Hessler "high diversity in deep-sea" paper

The Origin of Hadal fauna

INFLUENCES:

- Trenches are relatively new and during the last ice age (which was very rapid) the deep oceans cooled 10ºC to stay under 4ºC
- Trenches can be colder (1-2ºC) than abyssal oceans though the water heats slightly towards the bottom due to pressure
- Physiological studies stress that pressure is the limiting factor for hadal access…but the role of temperature should not be discounted

History of the Relevant Ideas

1955 – Zenkevich and Birshtein suggest that hadal fauna is ancient

1960- Wolff suggests that the hadal fauna might have two origins.

(1) preglacial hadal fauna that survived the massive temperature decrease

(2) continual invasion of post-glacial abyssal species adapted to cold water

1966- Belyaev suggests that fauna are relatively new

1990s- Temperature may be more of a factor…many authors note apparent connection of hadal fauna with Arctic or Antarctic fauna

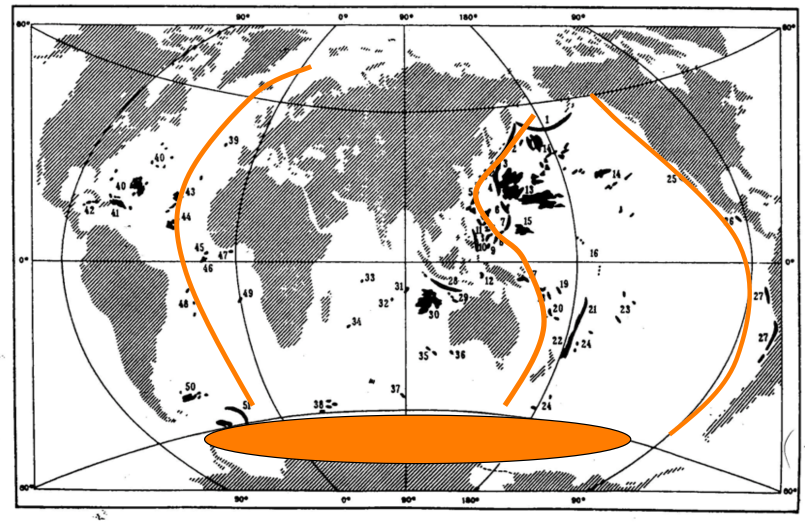


FIGURE 1. Schematic map showing the distribution of depths greater than 6,000 m in the oceans

Antarctic Bottom Water Flow

Future questions in hadal biology

- Why is biodiversity low? What is the role of sedimentation versus high pressure vs isolation?
- What are the key features structuring hadal community abundance, composition and diversity?
- Are trench populations connected through gene flow?
- Geographically limited trenches are analogous to inverted deep-sea islands: what can we learn about gene flow in the deep sea?
- Why are some species so successful under hadal conditions?
- How do calcareous species persist below the CCD?

http://www.youtube.com/watch?v=0mKotQs93Dc&feature=player_embedded#