Potential Mining Impacts

[Review of current exploration activity within contract areas and distribution of resources along the northern MAR.]

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Mining Operations

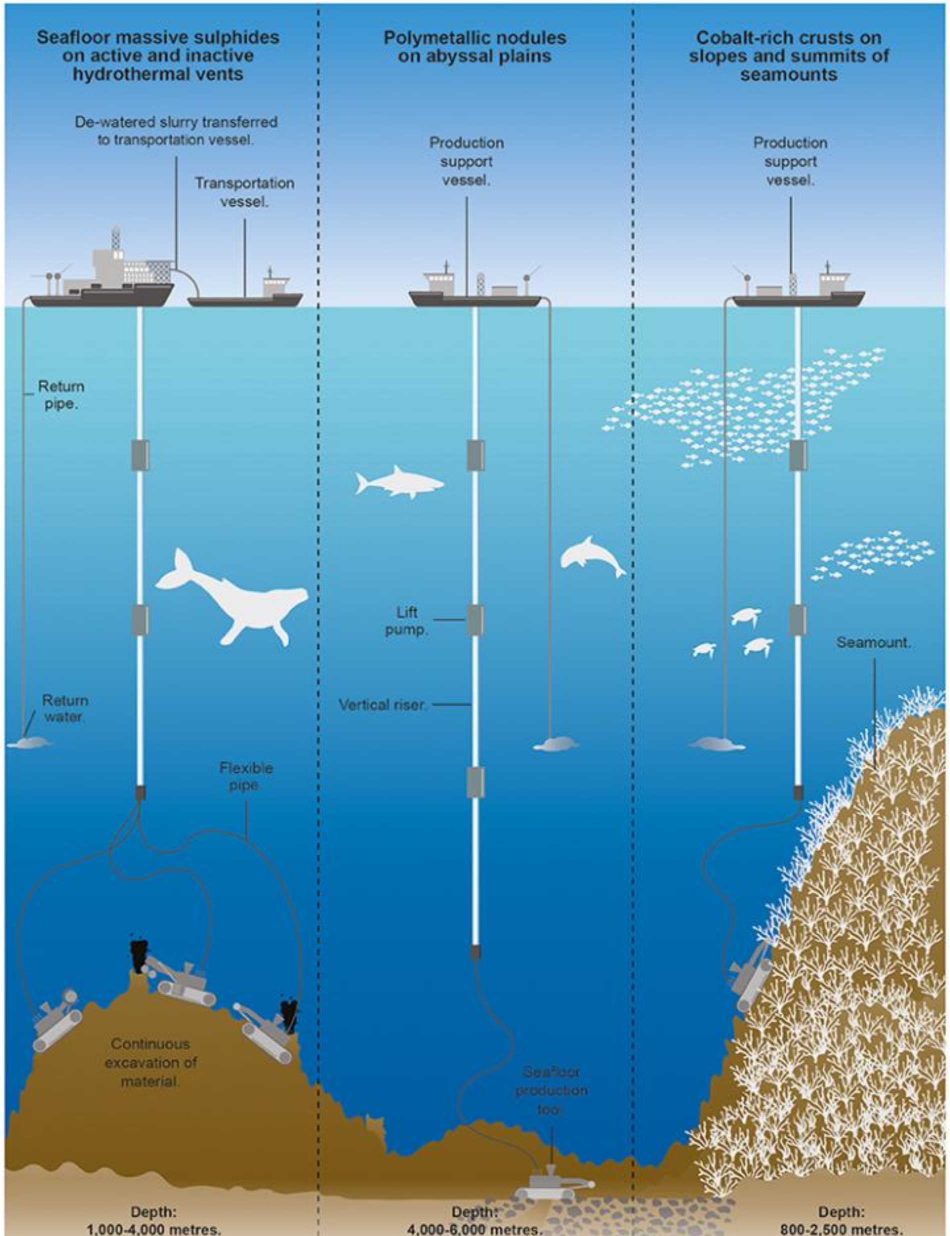


Image: Design Studio, University of Exeter

Mining Impacts Overview

Habitat alteration (Benthos). Open pit mining $\Rightarrow$ quasi-permanent destruction of hard substrate; local changes in benthic currents possible

Sediment plumes (water column). Dense (heavy) sediment particles sink while being dispersed (advected by mean flows and spread by eddy diffusion) by ocean currents $\Rightarrow$ dispersal potential limited by time scale of sinking

Dissolved plumes (water column). Conservative dissolved chemicals have "infinite" time scale $\Rightarrow$ potentially global dispersal potential; dissolved chemicals can be released together with particles (e.g. tailings) or separately; additional input from particle dissolution

Nutrient enrichment (near surface). Injection of deep water into euphotic zone causes nutrient enrichment, affecting biology

Noise and light (Benthos and upper ocean). Noise and light pollution associated with mining operations

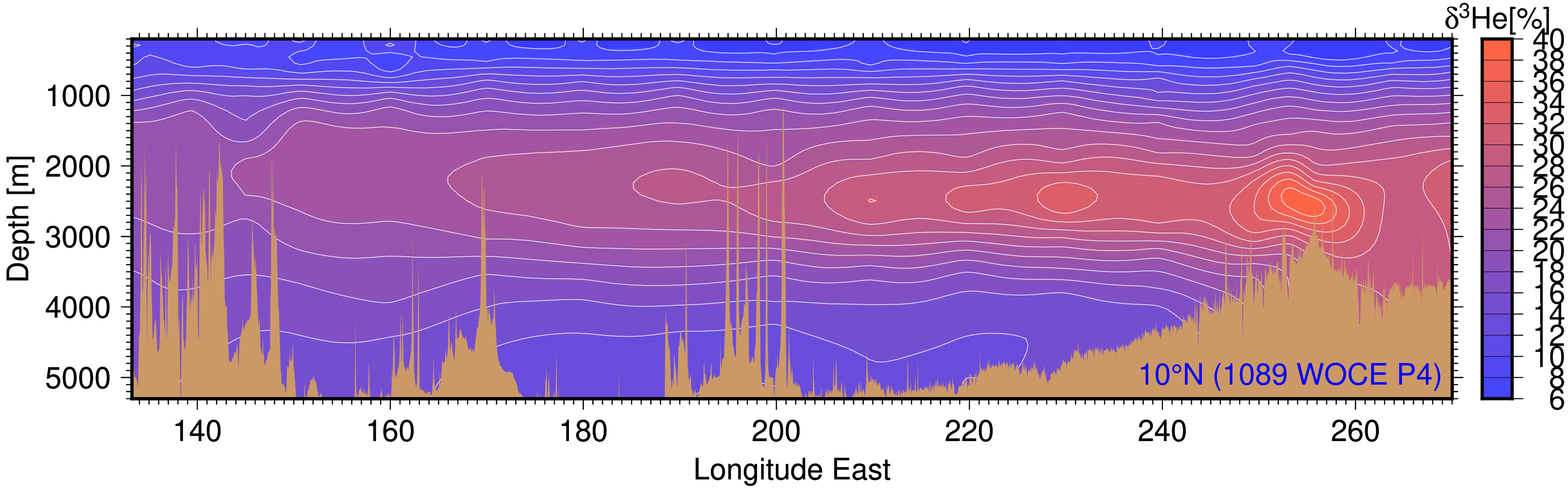
Buoyant and Non-Buoyant Plumes

- volcanic eruption plumes can serve as a useful analog
- plumes have two distinct regions: i) vertical motion in buoyant plume "stem" (plume source fluid is usually less dense or denser than surrounding); ii) horizontal spreading in neutrally buoyant plume "cap" (background density stratification)
- ash fallout underneath the spreading plume $\Rightarrow$ impacted region

Simplistic Plume Impact Assessment

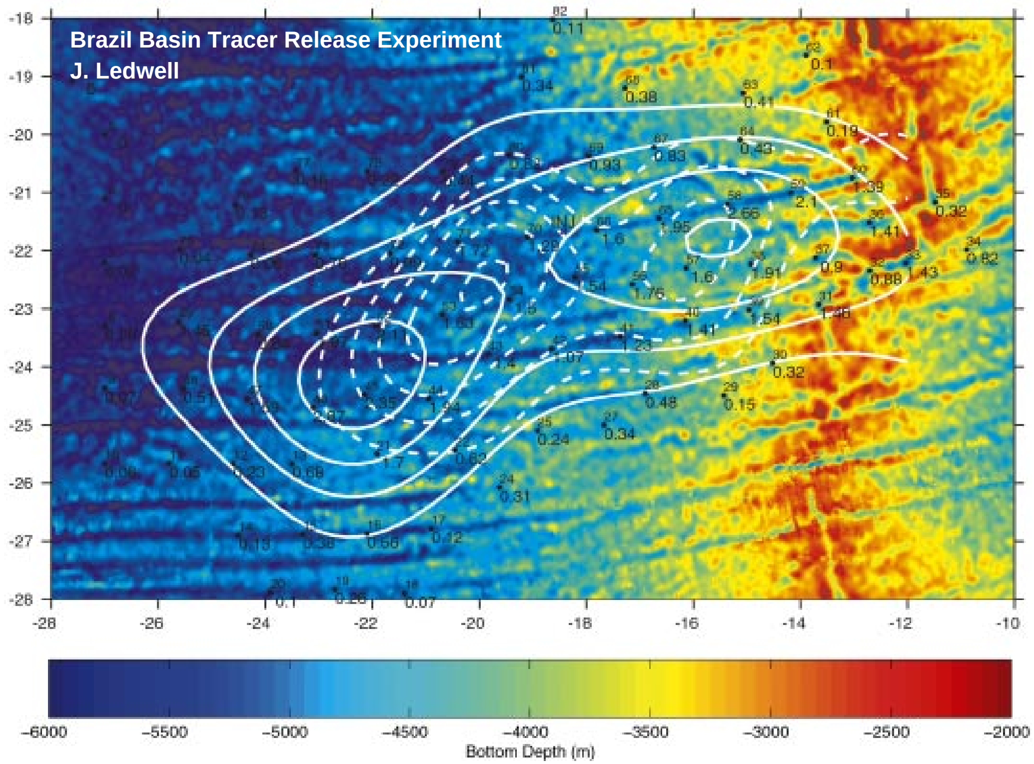
- estimate time scale for plume from rise height and particle settling velocity, and use long-term velocity measurements to assess dispersal potential over this timescale (e.g. environmental assessment for Solwara 1)
- Problem #1: material deposited on the seafloor cannot be assumed to remain immobile, as sediment resuspension by strong currents ("benthic storms") is well known

Problem #2: Time Scale Limit



- mining plumes will likely contain dissolved chemicals with potentially very large dispersal potential
- similar problem in volcanic eruption context: “How particles scatter after an eruption is incredibly complex and chaotic because of the different behavior of particles of different size and the uncertain distribution of particles at the source. Some particles can linger in the air for just a few minutes, whereas others can remain airborne for years, traveling thousands of miles around the world.” (Yan, EOS 2006)

Problem #3: Eddy Diffusion



- advection by the mean flow causes the center of mass of the western tracer patch to drift southwestward along the MAR flank
- simultaneously, eddy diffusion causes both tracer clouds to spread horizontally

$\Rightarrow$ tracer disperses in all directions, even against the mean flow!

Potential Mining Sites

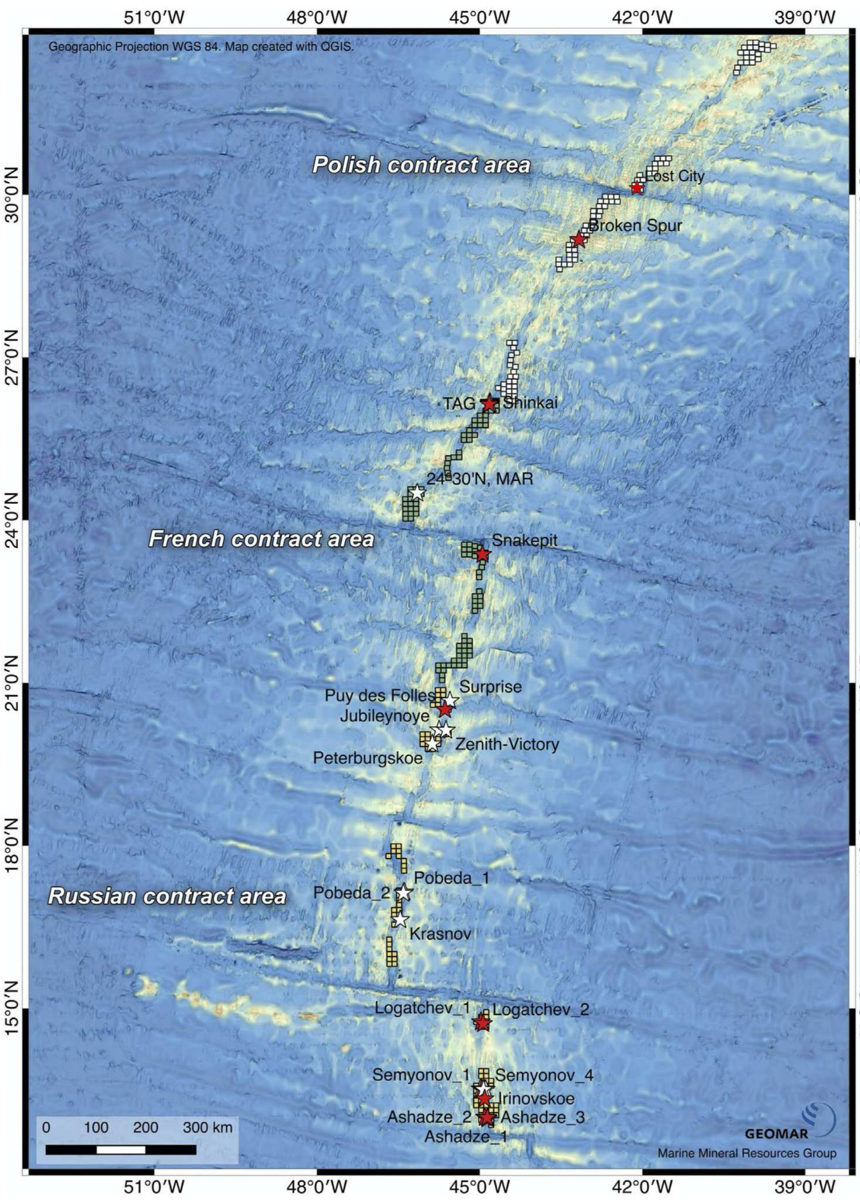
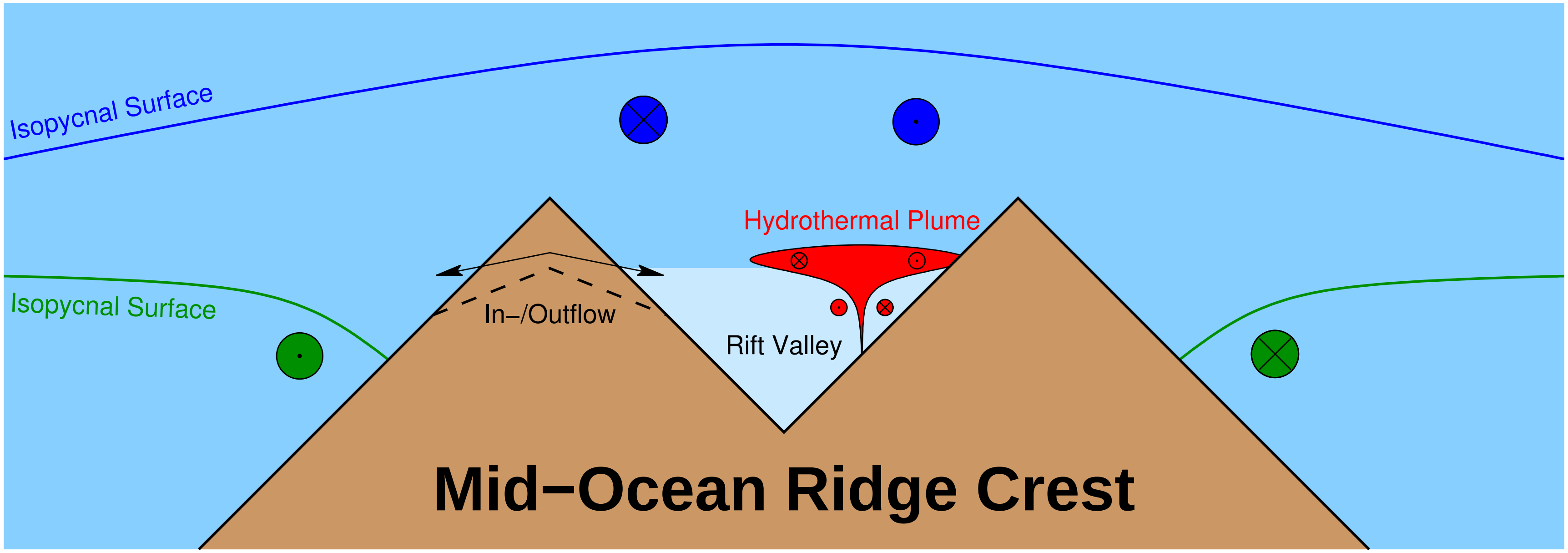


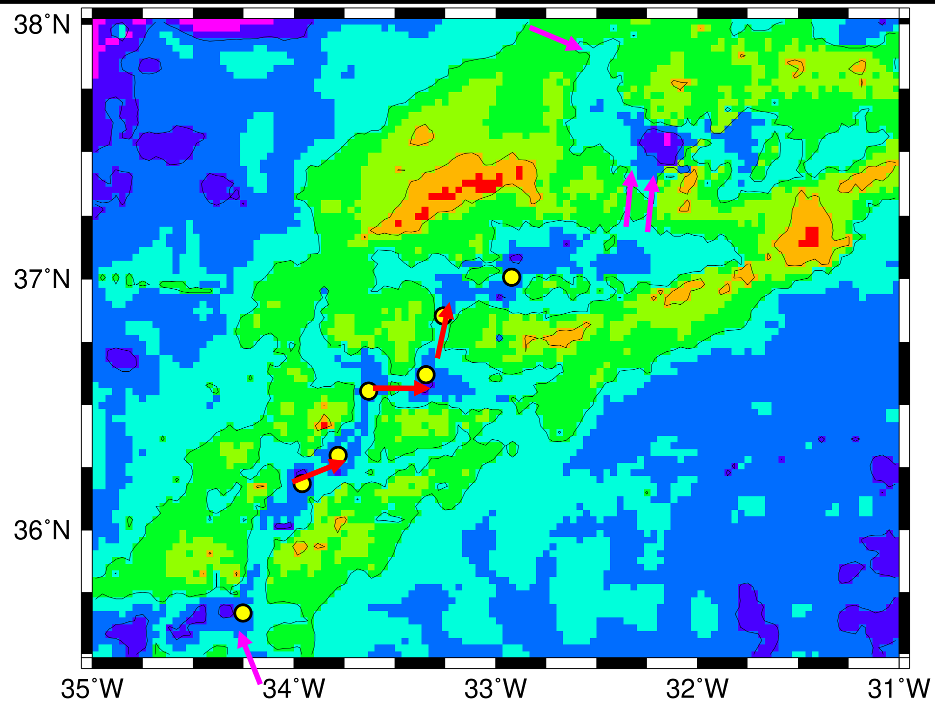
Fig. 2. Polymetallic sulfide blocks (each block is ≤ 10 km × 10 km) approved for exploration by the International Seabed Authority (ISA) in the north Atlantic (yellow blocks: Russian Federation, green blocks: France) or pending approval by the ISA (white blocks: Poland) and the locations of known active vent ecosystems (red stars) and inactive sulfide mounds (white stars). The size and distribution of blocks is prescribed by Regulation 12 (International Seabed Authority 2010): maximum exploration area per contract is 10,000 km^2, maximum area after all required relinquishment during the 15-year exploration contract is ≤ 2500 km^2; blocks must be arranged into ≥ 5 clusters, with each cluster containing ≥ 5 contiguous blocks, all within a rectangle not exceeding 300,000 km^2, with the longest dimension ≤ 1000 km. Additional requirements may apply (see Regulation 12). Background topography is the GEBCO 30 arc-second interval grid (www.gebco.net). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

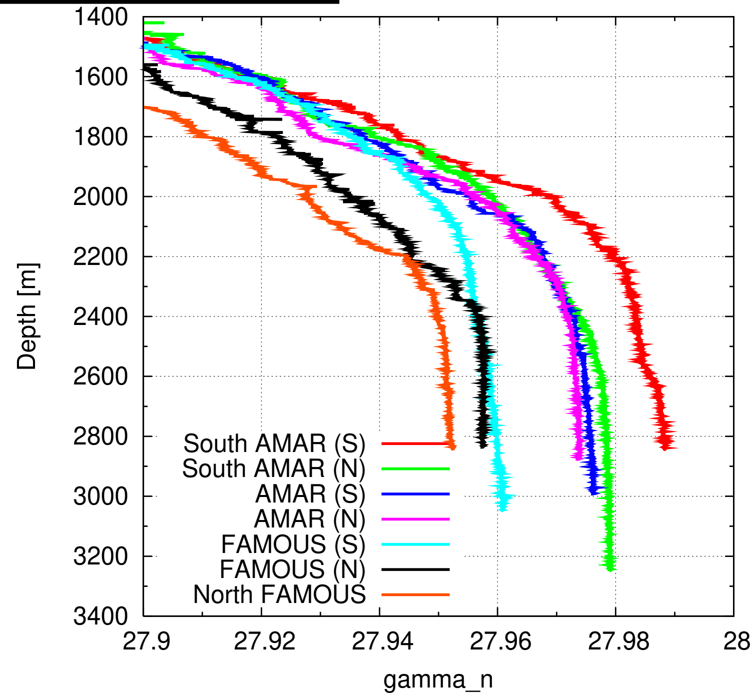
Rift-Valley Setting



- rift-valley water is topographically isolated from surroundings, with exchange taking place across saddles on the valley walls
- natural confinement of deep plumes inside the rift valley likely includes mining plumes from the excavators and from sufficiently deep tailings discharges
- topography "organizes" the circulation (valley flows, boundary currents, ridge-crest domes, etc.) and, thus, dispersal

Rift-Valley Circulation





- deep dispersal restricted to along-valley direction (but note transform faults)
- long, sloping rift valley segments host persistent along-valley currents, while the currents in shorter segments are more variable
- very high resolution numerical models are capable of simulating rift valley currents to a high degree of accuracy (Lahaye et al., 2019)

Main Points

- deep-sea mining has the potential of causing contaminant plumes throughout the entire water column
- convective plumes will first rise or descend to their “natural equilibrium level” where they are dispersed by oceanic mean currents and eddies (both important)
- particles settling from the spreading plumes cause sedimentation in the vicinity of the plume sources, with the smallest particles being carried the farthest
- solute plumes can have very long time scales
- advection-only assessments of mining-plume impacts based on time scales estimated from the properties of the dominant sinking particles are likely to underestimate the spatial extent of mining effects
- personally, it is not clear to me how realistic assessment of the potential impacts of mining plumes is possible without Lagrangian experiments

Supplemental Slides

Dispersal in the Ocean

- in order to assess dispersal, relevant time and space scales must be known; upper limits determined by:

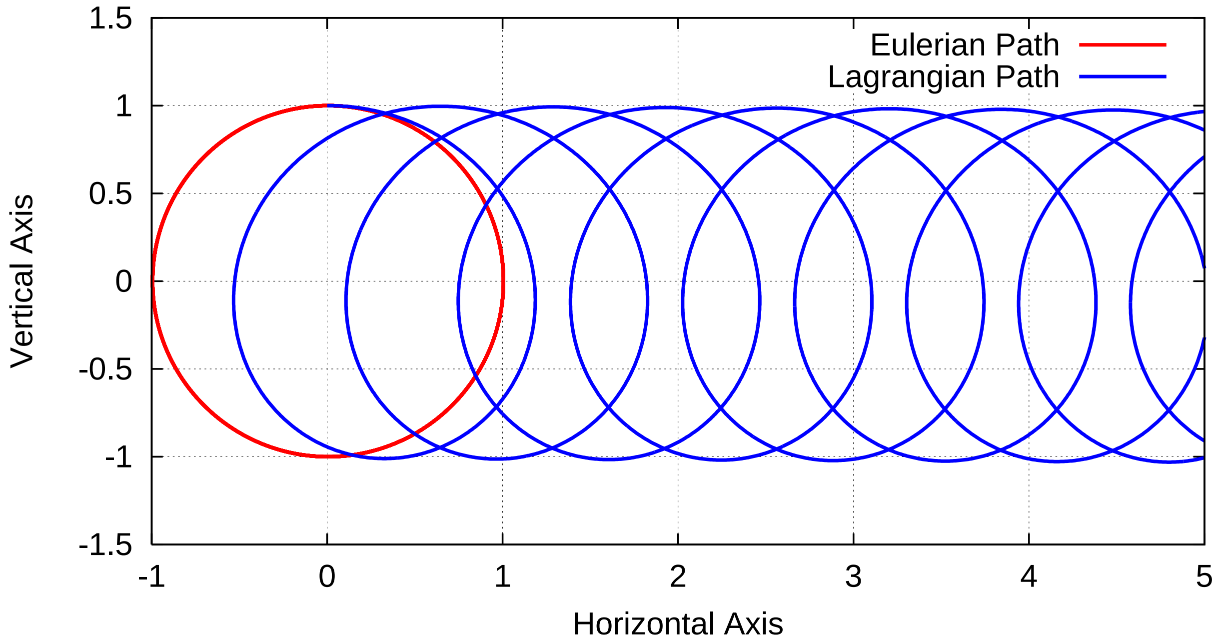
  dissolved substances: concentration limits, reactivity;

  suspended substances: settling velocities;

- near topography, tides (in particular M_2) and/or near-inertial oscillations are often dominant $\Rightarrow$ on time-scales of minutes to hours, dispersal is often omni-directional; (typical tidal dispersal distances are several $100\,\mathrm{m}$);
- the temporally & spatially varying flow field in the ocean causes diffusive dispersal along isopycnal surfaces on time scales longer than *Lagrangian integral time scale,* which is typically of order 10 days in the deep ocean.

Eulerian vs. Lagrangian Views

- **Eulerian:** fixed in space, e.g. moored current meters;
- **Lagrangian:** flow-following, e.g. floats, dye;
- dispersal is inherently Lagrangian, but Eulerian measurements are easier to carry out;
- in the spatially variable oceanic flow field the two views are not the same, as illustrated for idealized surface waves:



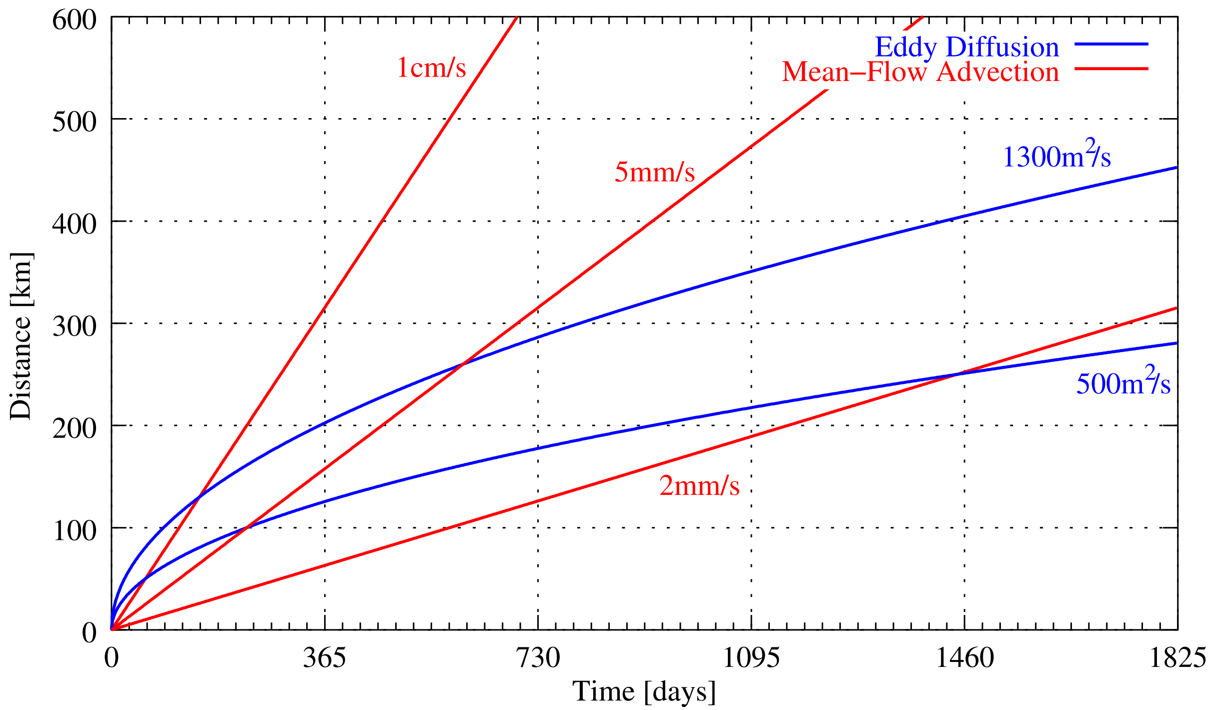
Advection vs. Eddy Diffusion

- dispersal is combination of two effects:

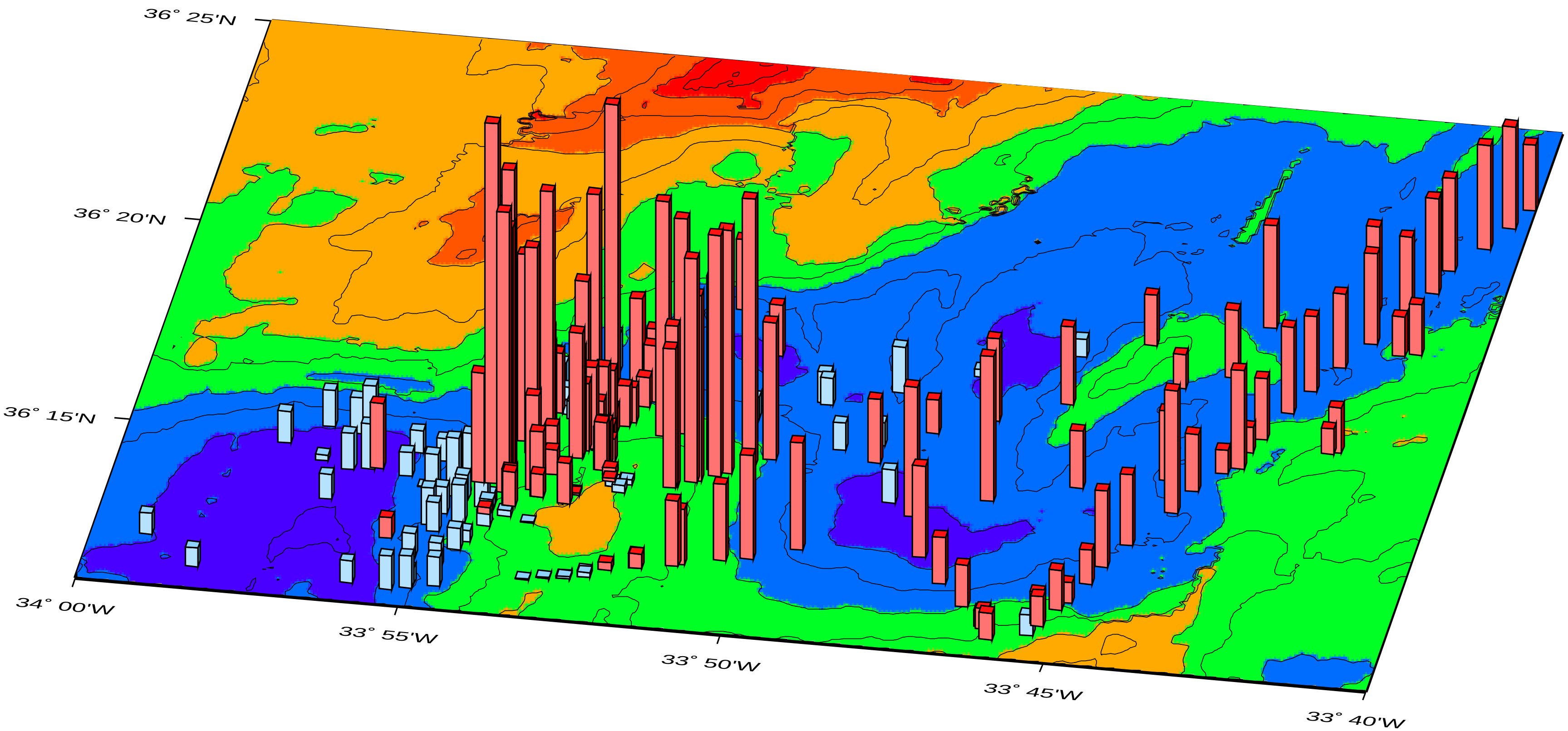
  advection by low-frequency (mean) flow: $\text{dispersal} \propto \text{time}$;

  eddy diffusion: $\text{dispersal} \propto \sqrt{\text{time}}$;

- in typical deep-ocean settings, dispersal is often diffusion dominated ($\Leftrightarrow$ in dispersal studies diffusion is often ignored):

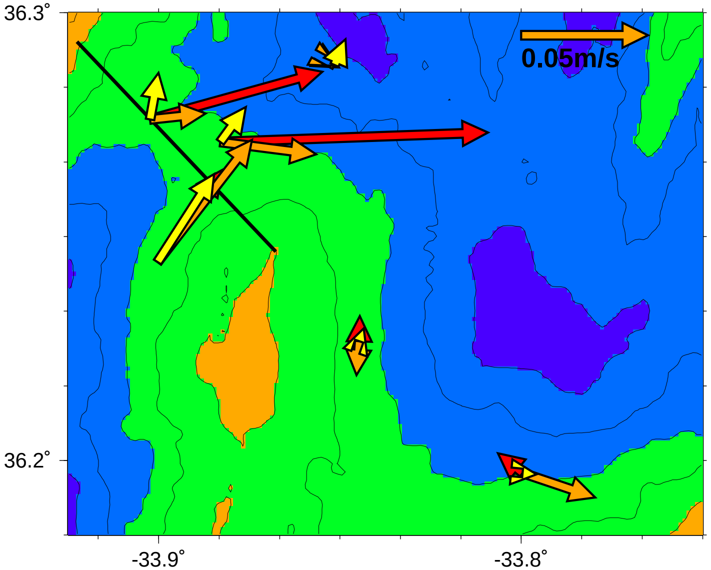


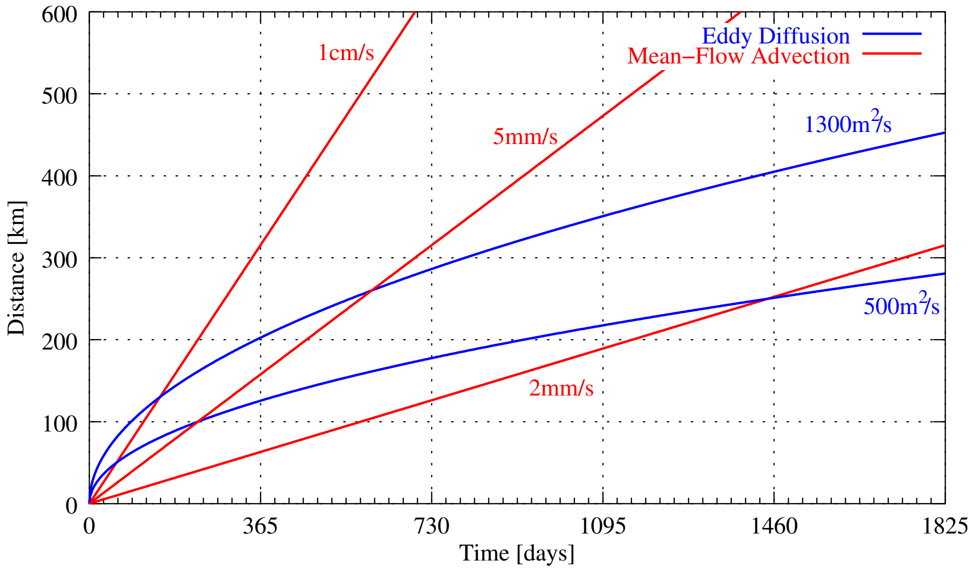
Hydrothermal Plume Dispersal



- hydrothermal particle plumes as easily observable natural Lagrangian tracer;
- *Rainbow* particle plume disperses unidirectionally along MAR rift valley ⇒ dispersal is advection dominated.

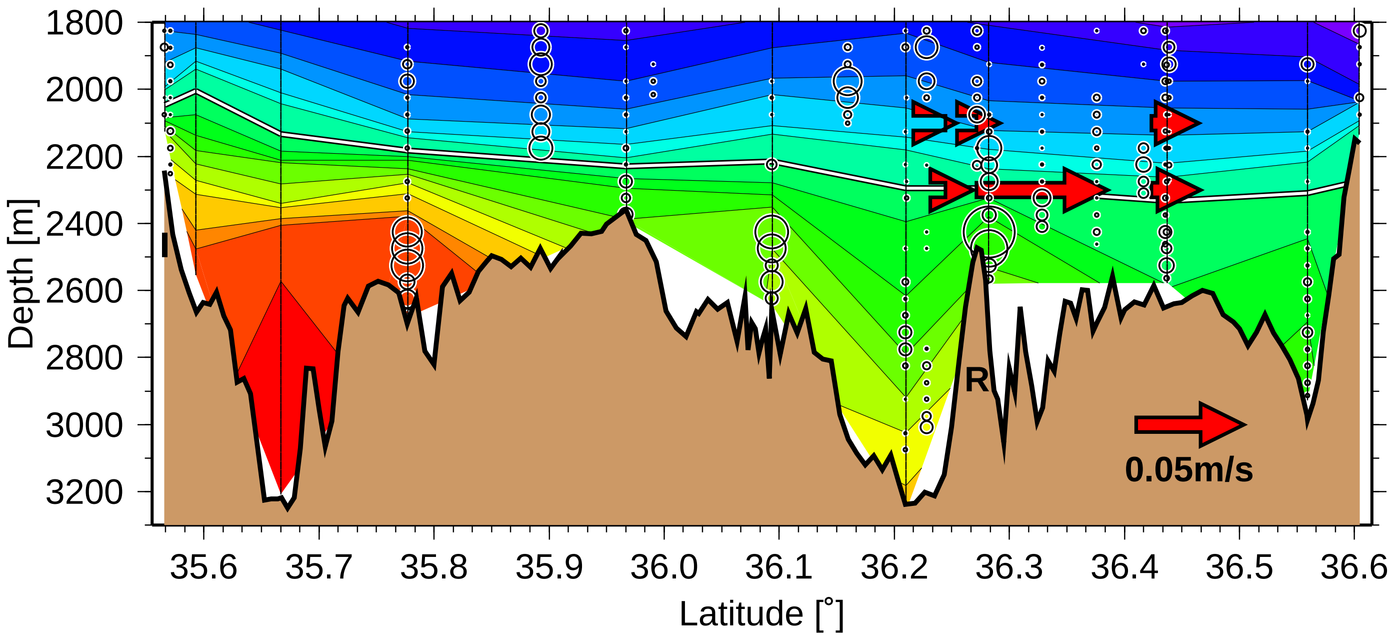
Rift-Valley Current-Meter Data





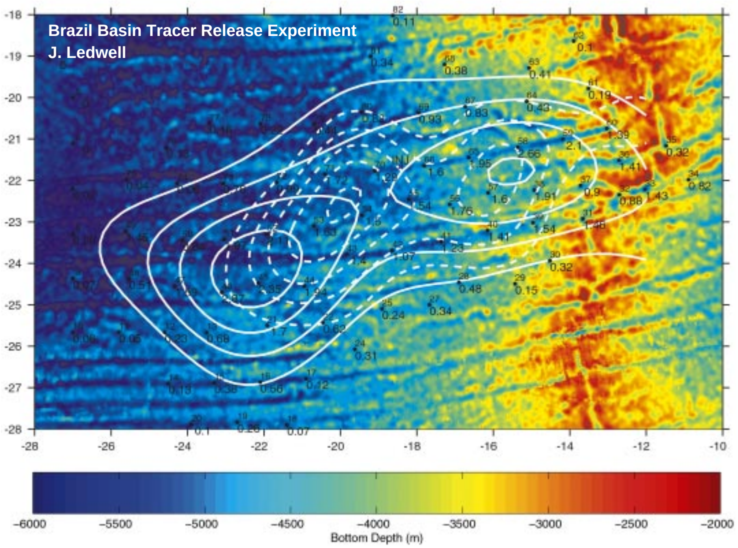
- plume-dispersal observations are entirely qualitative;
- 1-year-long current-meter data indicate persistent, strong, unidirectional velocities of $\approx 5\,\mathrm{cm\cdot s^{-1}}$ near vent field;
- using a “typical” deep-ocean eddy diffusivity of $10^3\,\mathrm{m^2\cdot s^{-1}}$, dispersal is advection dominated on all time scales (time of equal importance of advection and diffusion $<$ Lagrangian integral time scale).

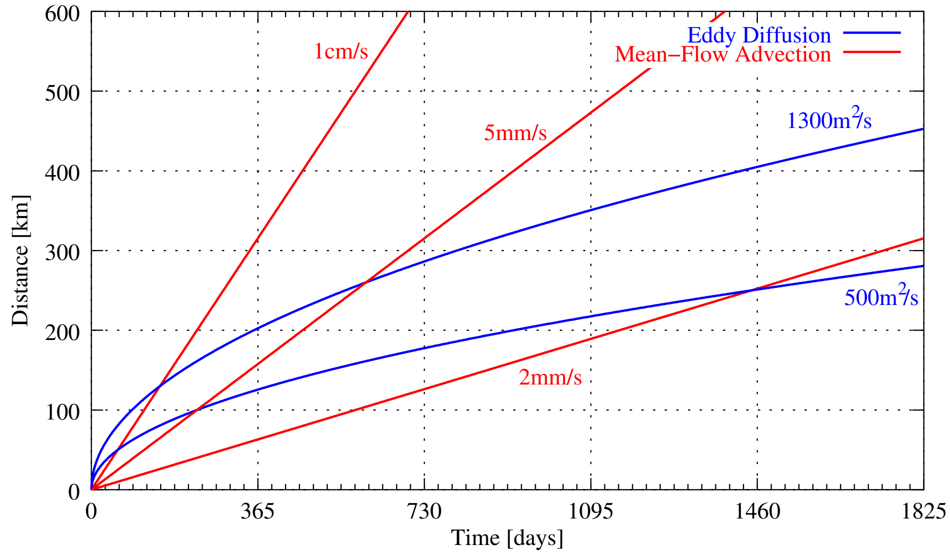
Valley Flows



- atypically (for deep ocean away from topography) large persistent velocities near *Rainbow* hydrothermal site are part of a dynamical situation involving a balance between advection and mixing that's only possible in deep submarine valleys;
- recent hydrographic evidence suggests that such "valley flows" occur everywhere on the flanks of slow-spreading mid-ocean ridges.

Ridge-Flank Dispersal





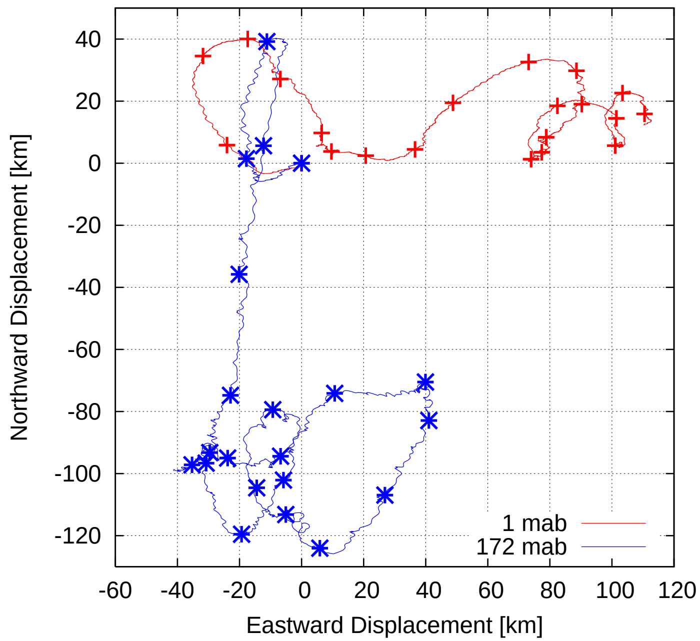
- 2-year dispersal on ridge flank is more typical (figure courtesy J. Ledwell):
  - C/M data indicate $0.5 \pm 1.1\,\mathrm{cm{\cdot}s^{-1}}$ to the north;
  - center of tracer patch implies $0.4\,\mathrm{cm{\cdot}s^{-1}}$ SW-ward;
  - tracer spreading is strong enough to overcome mean flow;

⇒ both advection and eddy diffusion are important for dispersal, which cannot be assessed from C/M data alone!

Ridge-Crest C/M Data

- 5-month-long C/M records from 2 levels above the EPR crest near $9°\mathrm{N}$ indicate mean velocities of $1 \pm 1\,\mathrm{cm}{\cdot}\mathrm{s}^{-1}$ to the E and to the SSW;

$\Rightarrow$ dispersal *might* be advection dominated, but there is a different problem:



- integration of Eulerian measurements to yield quasi-Lagrangian trajectories ignores any horizontal variability;
- flow $200\,\mathrm{m}$ above crest is significantly different from flow near topography $\Rightarrow$ it appears unlikely that flow over flanks (i.e. even higher above sea bed) is similar;

$\Rightarrow$ dispersal inferences from these data are unlikely to be valid.