Dispersal Near Topography

(The Physical Environment of Polymetallic Sulphides Deposits, The Potential Impact of Exploration and Mining on This Environment, And Data Required to Establish Environmental Baselines in Exploration Areas).

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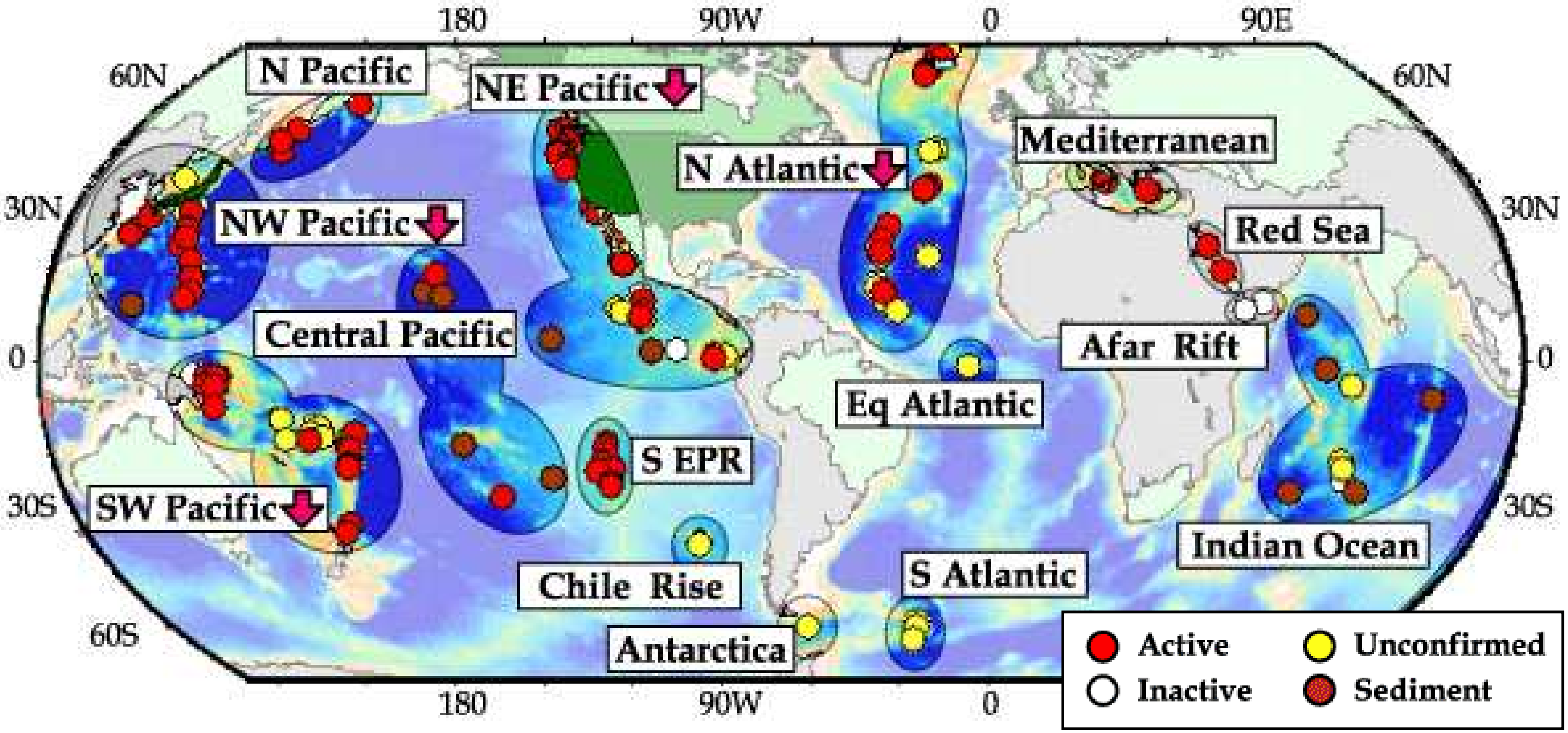
Polymetallic Sulphides Deposits

- polymetallic sulphides are deposited on the sea floor by high-temperature hydrothermal circulation;
- currently known vent fields (from `www.interridge.org`):



Setting of Active Vent Fields

Mid-Ocean Ridge Crest:

- predominantly deep (below $1000\,\mathrm{m}$);
- complex topography;

Backarc Basin Rift Zones:

- always(?) deep (below $1000\,\mathrm{m}$);
- complex topography;

Island-Arc Volcano:

- any depth possible;
- complex topography;

$\Rightarrow$ topography plays a dominant role.

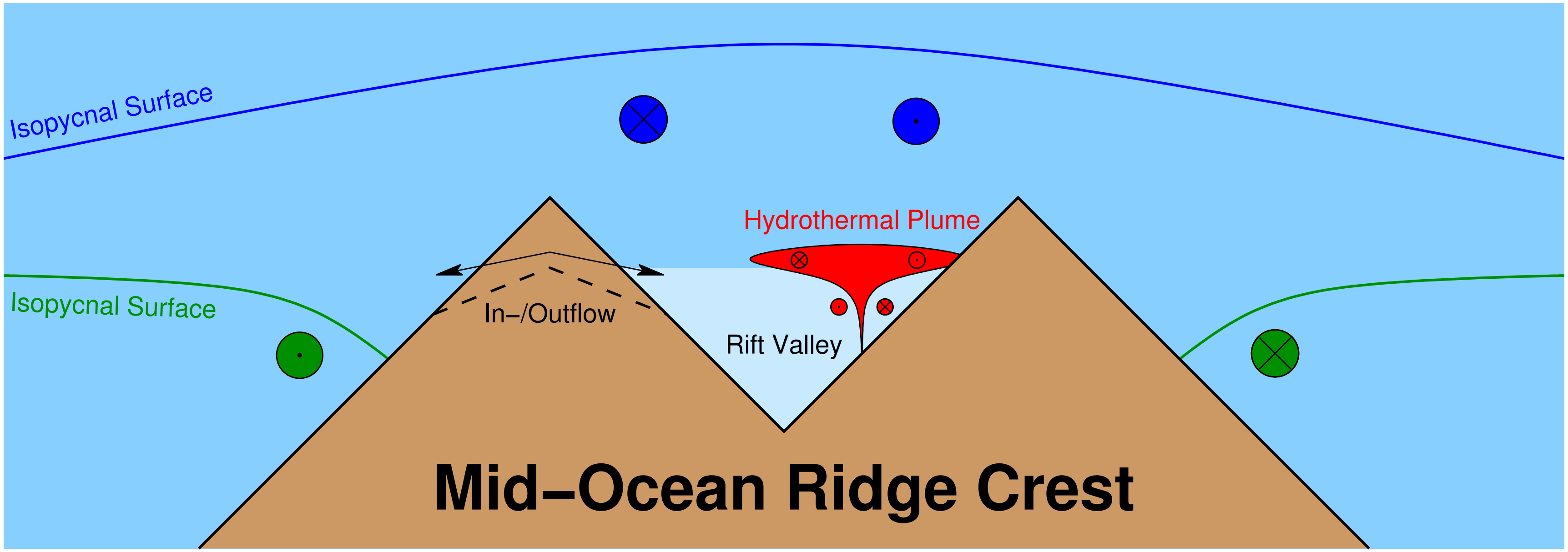
Talk Outline

1. Physical environment
2. Dispersal near complex topography
3. Examples:
    - rift-valley of slow-spreading ridge
    - ridge flank
    - crest-site of fast-spreading ridge
    - back-arc basins
4. Conclusions

Physical Environment

- typical deep-ocean environment: dark, cold, high pressure, instantaneous/mean flow velocities of order $\mathrm{cm{\cdot}s^{-1}}$/ $\mathrm{mm{\cdot}s^{-1}}$;
- mining operations are not expected to significantly affect physical environment on scales beyond physical scales of mining, . . .
- *. . . except if blasting techniques are used (underwater explosions are not covered in this presentation);*
- indirect large-scale effects are possible if mining introduces density anomalies at depth (e.g. heating, freshwater input, &c);
- dispersal of dissolved and suspended mining products by background flow field implies that physical environment on scales larger than mining scales is important, however.

Topographic Effects

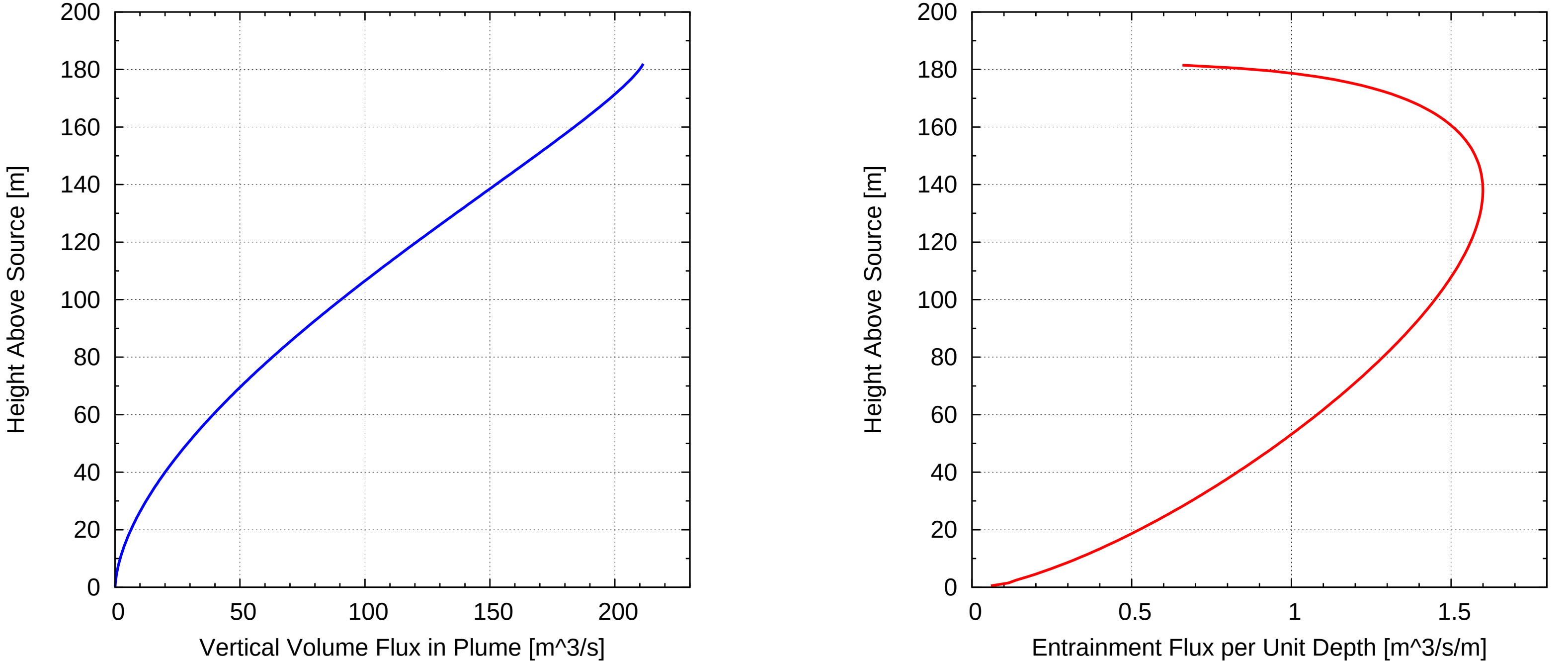


- topography influences deep ocean environment in many ways;
- every setting in complex topography is different . . .
- . . . , but the important processes are similar: *diapycnal mixing, blocking and hydraulics, background-flow amplification, wave trapping and flow rectification, vorticity effects.*

Hydrothermal Plumes (Near Field)

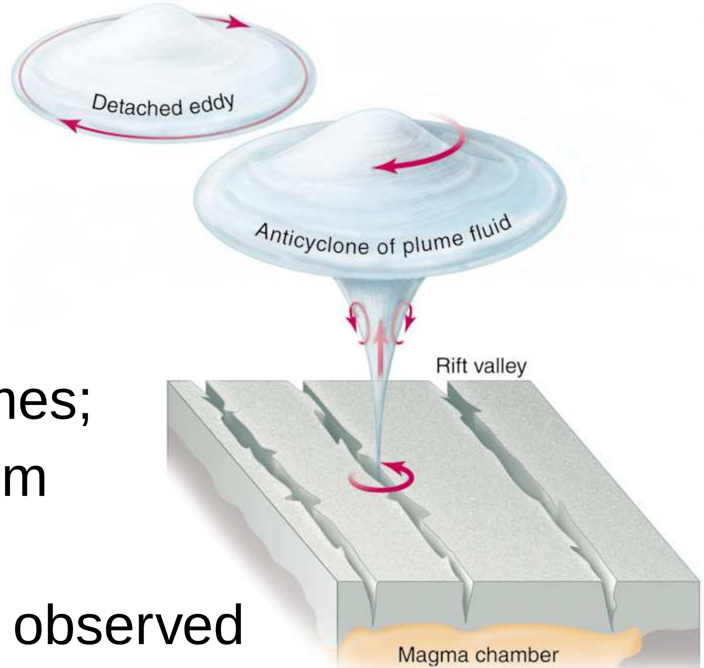
- high source temperatures ($300°$–$400°\mathrm{C}$); large vertical velocities ($\approx 1\,\mathrm{m}\cdot\mathrm{s}^{-1}$);
- entrainment $\Rightarrow$ sulphides and oxides precipitate;
- plumes rise to equilibrium height (50–$400\,\mathrm{m}$);
- equation of state for brines is highly non-linear $\Rightarrow$ buoyancy reversal and brine pools are possible, but there are few observations;
- double-diffusive effects make brine pools extremely stable $\Rightarrow$ potentially important for sulphides deposits.

Hydrothermal Plume Fluxes



- observations: $5\,\mathrm{m}$ above high-temperature source, temperature anomalies $<1^{\circ}\mathrm{C}$; entrainment velocities $\ll$ tidal velocities;
- the smallness of the physical effects is due to the small source volume fluxes ($<0.1\,\mathrm{m}^3{\cdot}\mathrm{s}^{-1}$ per “virtual source”);
- total dilution $\approx 10^4 \Rightarrow$ entrainment volume flux is small, too.

Hydrothermal Plumes (Far Field)



- theory suggests existence of coherent vortices around hydrothermal plumes (Speer, GRL, 1989):
  - velocities of several $\mathrm{cm}\cdot\mathrm{s}^{-1}$;
  - cyclonic around buoyant plumes;
  - anticyclonic around equilibrium plumes;
- but: such vortices have not been observed in the ocean, except in eruption-related “megaplumes”;
- on even larger scales: integrated effects of hydrothermal plumes have been hypothesized to drive basin-scale circulation (Stommel, EPSL, 1982); inferred velocities are only of order $\mathrm{mm}\cdot\mathrm{s}^{-1}$, however;

$\Rightarrow$ active hydrothermal circulation is largely insignificant in context of dispersal of mining products.

Dispersal

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

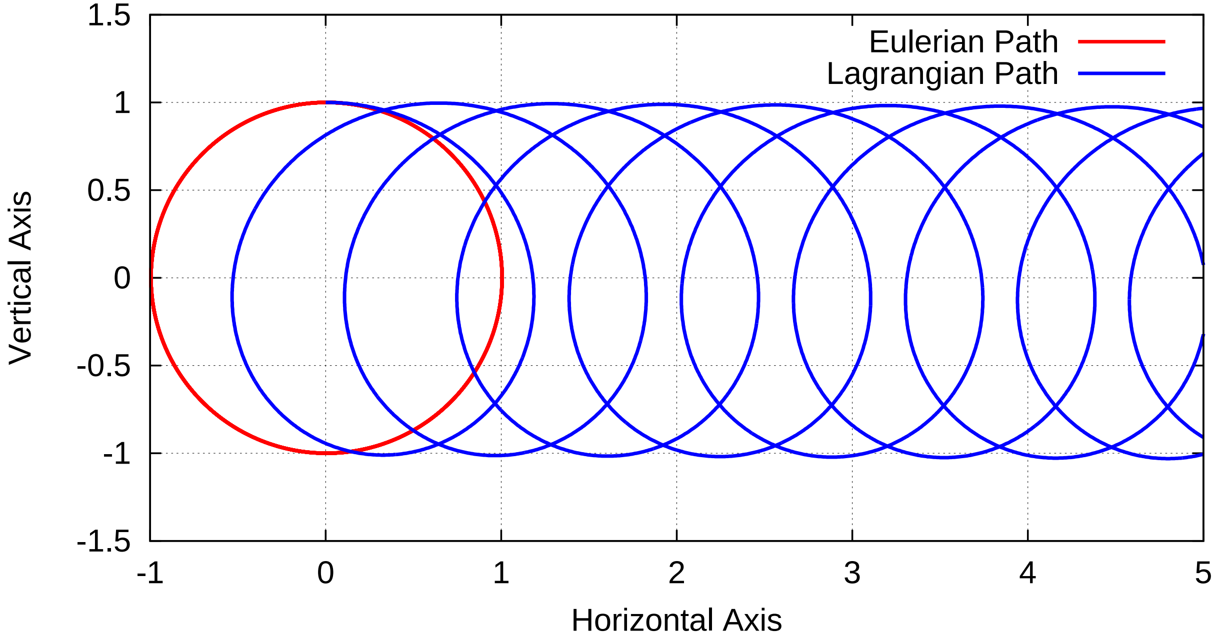
  dissolved substances: concentration limits, reactivity;

  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 omnidirectional; (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:



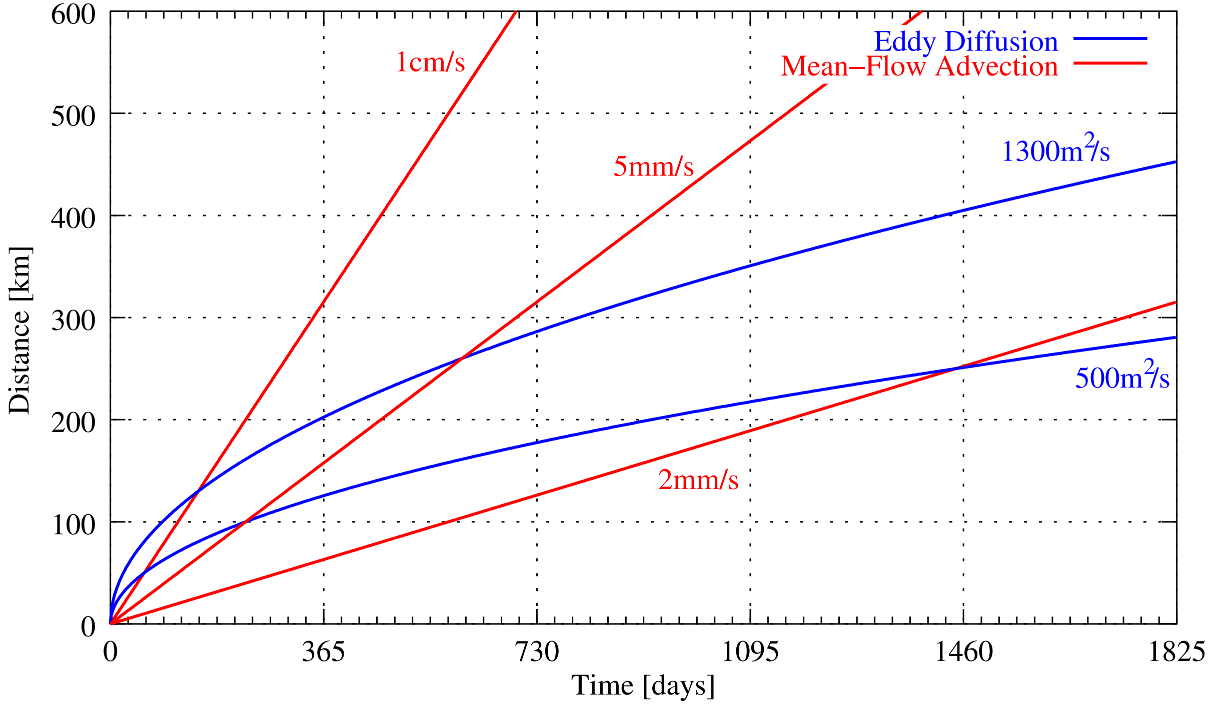
Advection vs. Eddy Diffusion

- dispersal is combination of two effects:

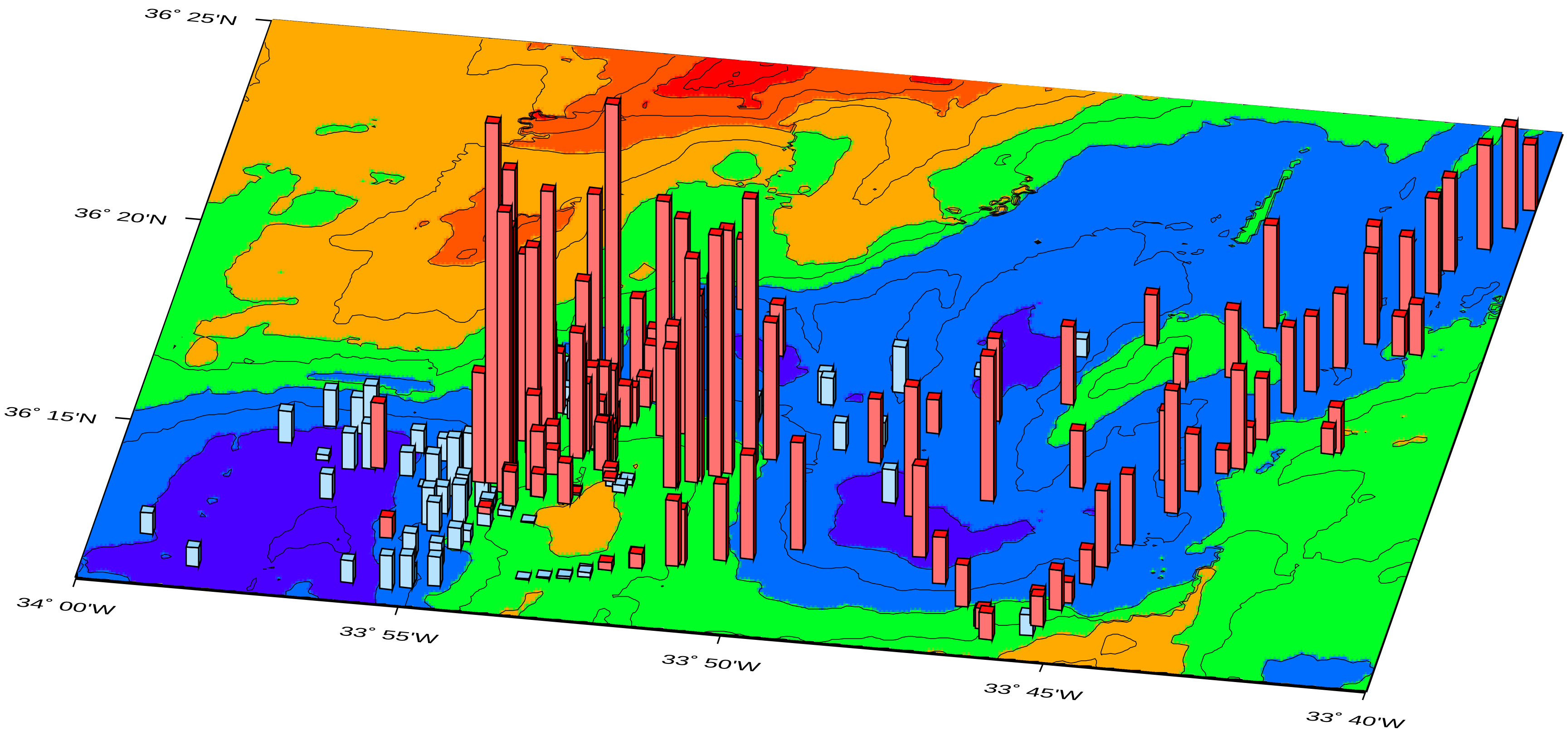
  advection by low-frequency (mean) flow: $\mathrm{dispersal} \propto \mathrm{time}$;

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

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

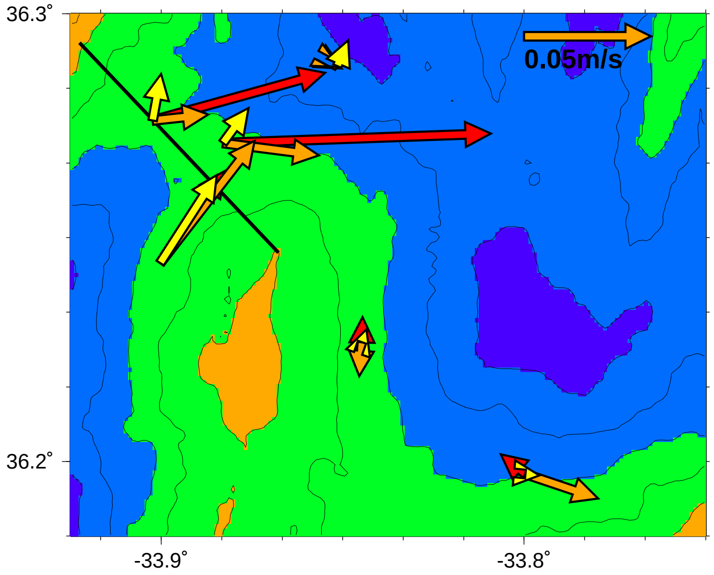


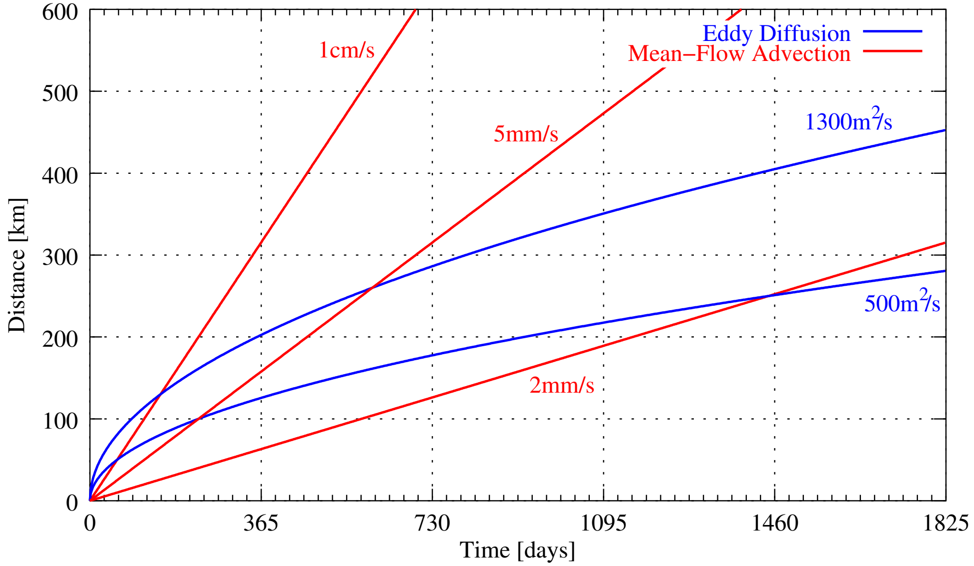
Hydrothermal Plume Dispersal



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

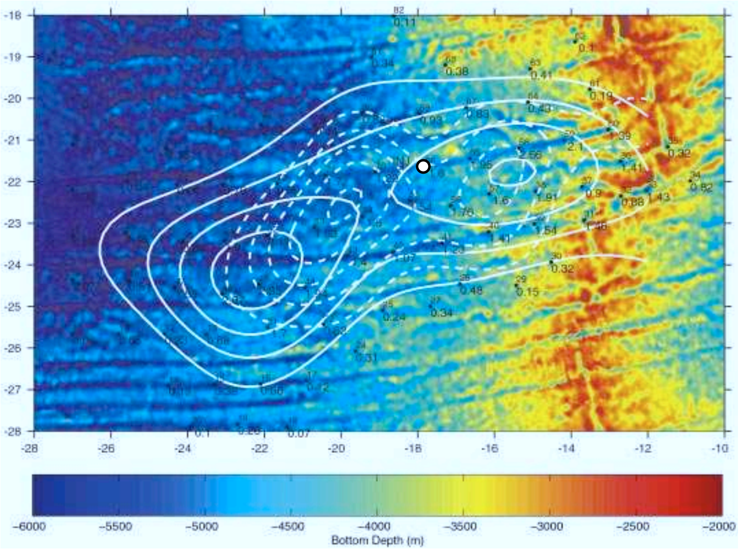
Rift-Valley Current-Meter Data

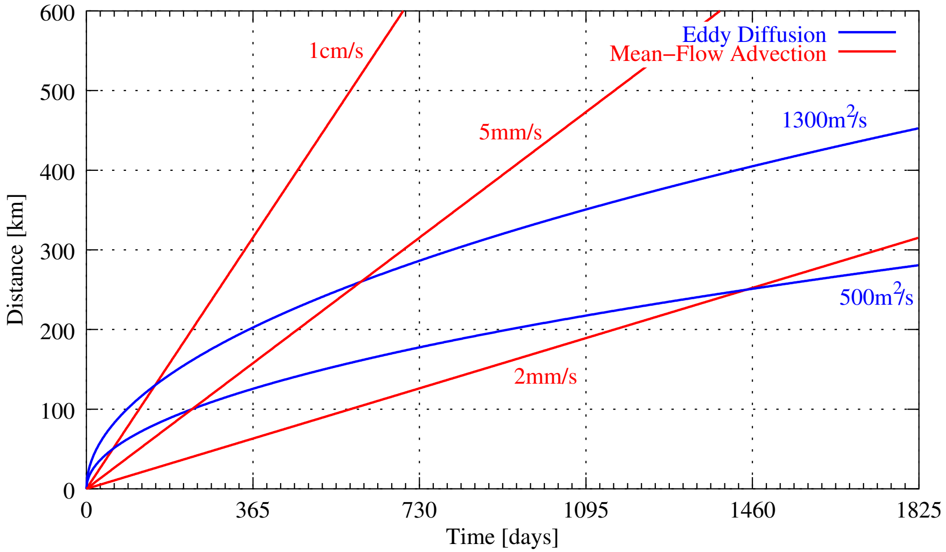




- plume-dispersal observations are entirely qualitative;
- 1-year-long current-meter data indicate persistent, strong, unidirectional velocities of $\approx 5\,\mathrm{cm}\cdot\mathrm{s}^{-1}$ near vent field;
- using a “typical” deep-ocean eddy diffusivity of $10^3\,\mathrm{m}^2\cdot\mathrm{s}^{-1}$,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

Ridge-Flank Dispersal





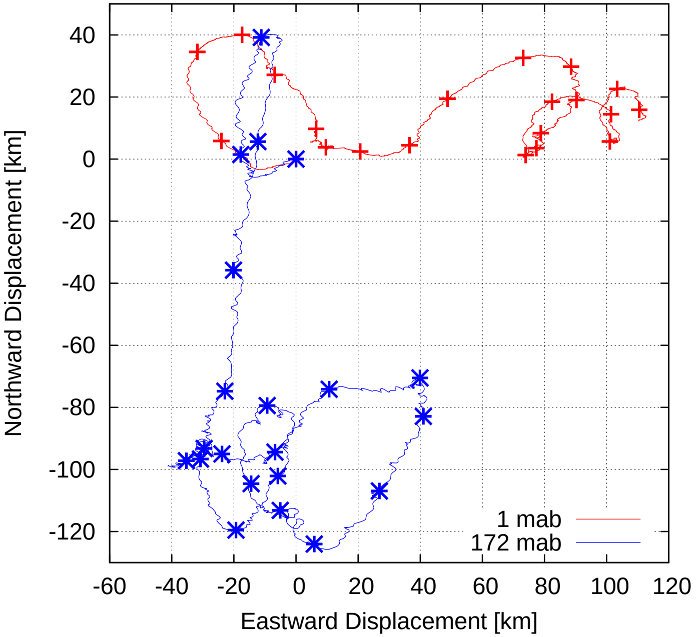
- 2-year dispersal on ridge flank is more typical (figure courtesy J. Ledwell):
  - C/M data indicate $0.5 \pm 1.1\,\mathrm{cm}\cdot\mathrm{s}^{-1}$ to the north;
  - center of tracer patch implies $0.4\,\mathrm{cm}\cdot\mathrm{s}^{-1}$ SW-ward;
  - tracer spreading is strong enough to overcome mean 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 $9^\circ\mathrm{N}$ indicate mean velocities of $1 \pm 1\,\mathrm{cm\cdot s^{-1}}$ to the E and to the SSW;

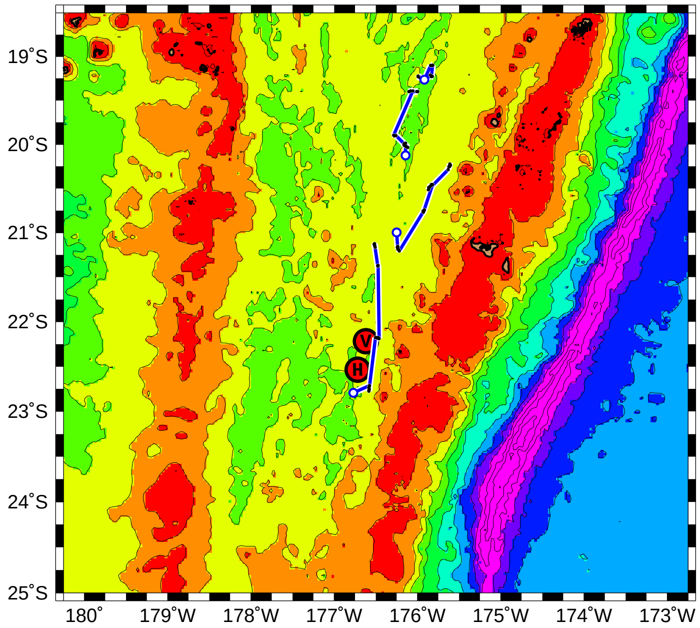
⇒ dispersal *might* be advection dominated, but there is a different problem:



- 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 ⇒ it appears unlikely that flow over flanks (i.e. even higher above sea bed) is similar;

⇒ dispersal inferences from these data are unlikely to be valid.

Backarc-Basin Float Data



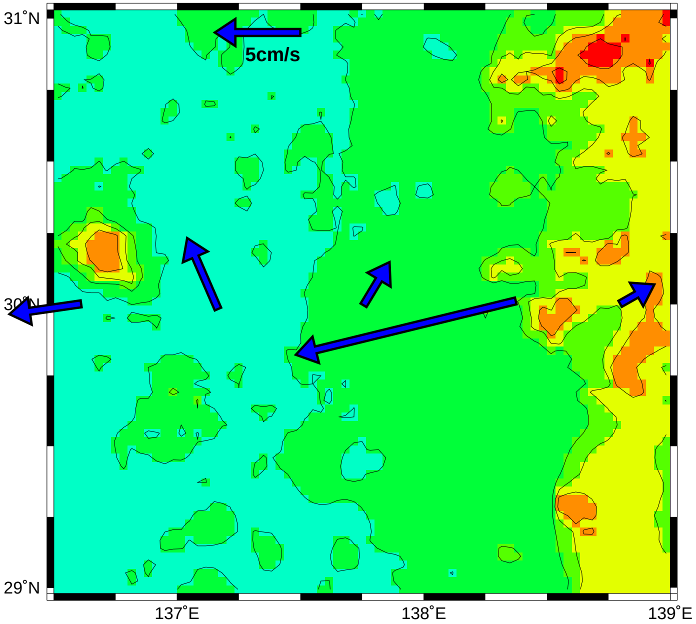
- off-the-shelf floats provide a cost-effective way for assessing dispersal (in the example, in the Lau Backarc Basin) using Lagrangian techniques;
- these particular floats drift at $1700\,\mathrm{m}$ and return to the surface every 4 weeks;

$\Rightarrow$ position and auxiliary data are available to the user in near-real time ($\Leftrightarrow$ current meters have to be recovered in order to gain access to the data);

- after 4 1-month cycles the floats suggest consistently northward flow of $1\text{–}2\,\mathrm{cm\cdot s^{-1}}$ in the eastern Lau Basin $\Rightarrow$ on longer time scales dispersal there is most likely dominated by advection.

Shikoku Basin LADCP Data

- during a recent (July 2004) hydrographic cruise, near-bottom velocities exceeding $15\,\mathrm{cm\cdot s^{-1}}$ were observed on a steep slope in the Shikoku Basin;
- the other near-bottom velocities of 2–$3\,\mathrm{cm\cdot s^{-1}}$ are likely of tidal origin;



⇒ unless the flow field is very well sampled (perhaps only possible with dye-release experiments) narrow, swift boundary currents can easily be missed.

Conclusions

- the physical environment near polymetallic sulphides deposits is highly complex, primarily because of topographic effects;
- while being spectacular, the effects of high-temperature hydrothermal circulation are unlikely to be significant for dispersal of mining products (mining in active hydrothermal vent fields may be inadvisable for other reasons);
- in many settings, both advection and eddy diffusion are important for dispersal on time scales of months to years;
- because of the spatial variability of the oceanic velocity field, it is not generally useful to assess dispersal with data from current-meter records alone (unless very large arrays are used);
- Lagrangian techniques, in particular floats, are a readily available and cost-effective method for assessing dispersal near topography.