# Week 3 – Intro to Hydrothermal Activity and Event Plumes (aka Megaplumes) from Submarine Eruptions

**Hydrothermal Processes overview**

- **General comments**
- **vent types: Focused flow, diffuse flow**
- **chronic plumes over actively venting areas**

**Event Plumes**

- **what are they?**
- **association with eruptions**

**Note: hydrothermal effluent chemistry also changes in response to eruptions but this is not part of today's discussion**

## Effects of hydrothermal activity on the ocean

- Source of heat
- Source of new dissolved chemicals
- Source of gasses
- Source of particles
- Source of microbes
- Supports chemosynthetic communities
- Helps to disperse organisms
- Metal rich sediments
- Other chemicals are lost from sea water in the reaction zone of hydrothermal systems.

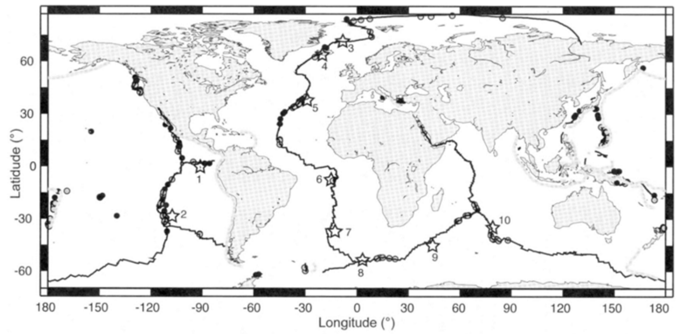



**Figure 1a.** Distribution of 144 known (black dots) and 133 inferred (gray dots) hydrothermal fields. Some individual fields contain several closely spaced (~100 m) "sites" distinctly named in the literature. Solid black lines are the midocean ridge and transform faults, gray lines are subduction zones. Hotspots (open stars) on or near (<500 km) the midocean ridge include 1, Galápagos; 2, Easter; 3, Jan Mayen; 4, Iceland; 5 Azores; 6, Ascension; 7, Tristan de Cunha; 8, Bouvet; 9 Crozet; and 10, Amsterdam–St. Paul.

**Remember from lecture 2**

**Global distribution of submarine hydrothermal vent sites (above) and areas of survey coverage (right), Baker and German, 2004.**

**Many of these sites are known from water chemistry in hydrothermal plumes above the sea floor rather than observations on the vents themselves**

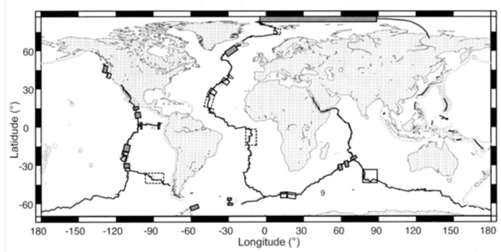
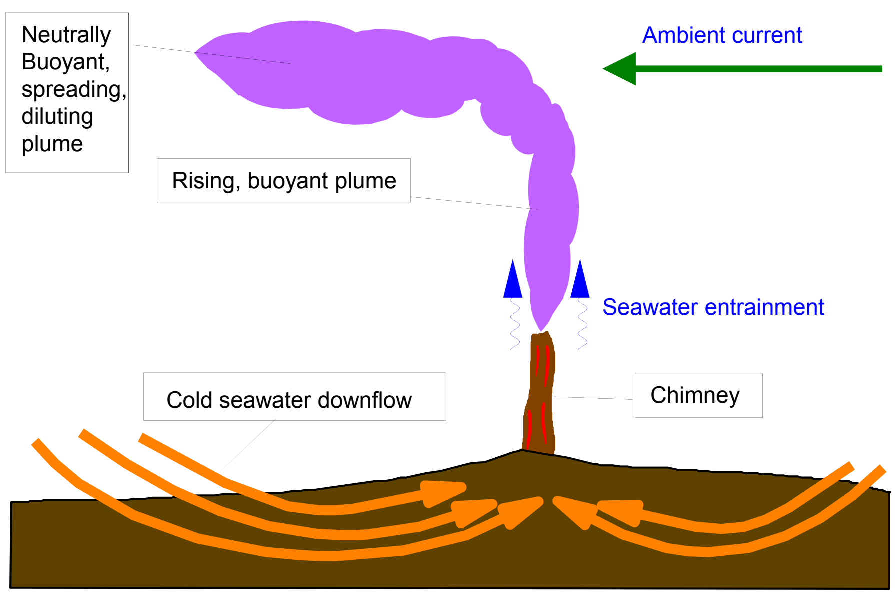
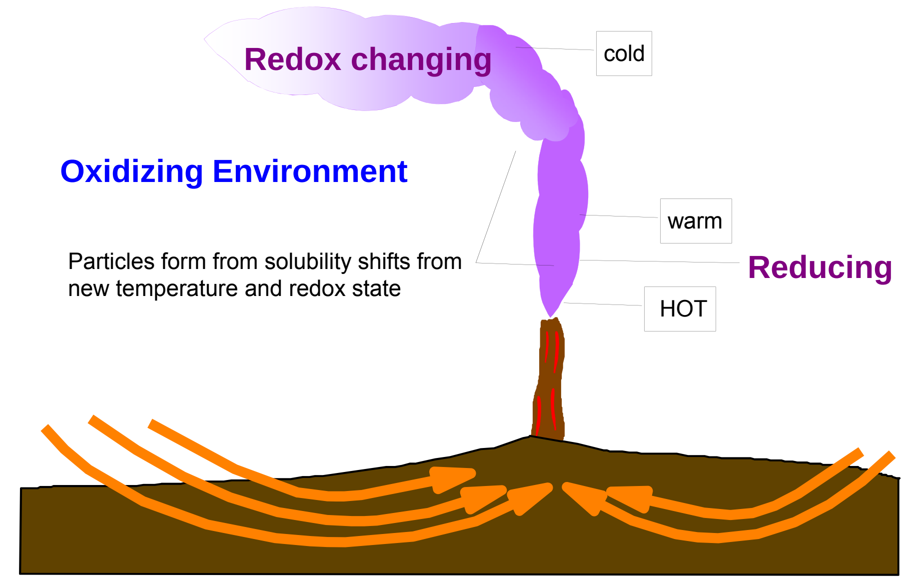



**Figure 1b.** Vent site distribution overlain with boxes indicating the quality of existing survey data along oceanic spreading ridges: densely surveyed (solid boxes), moderately well surveyed (open boxes), or sparsely surveyed (dotted line boxes).




Deep heat source temporally stable for years to decades or more

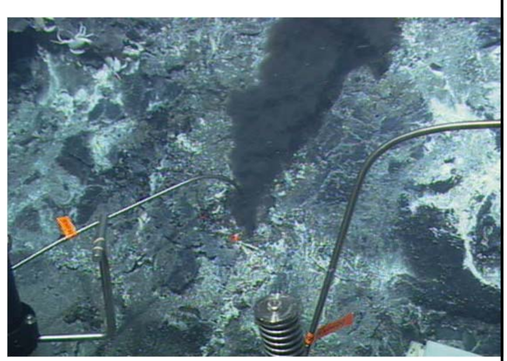


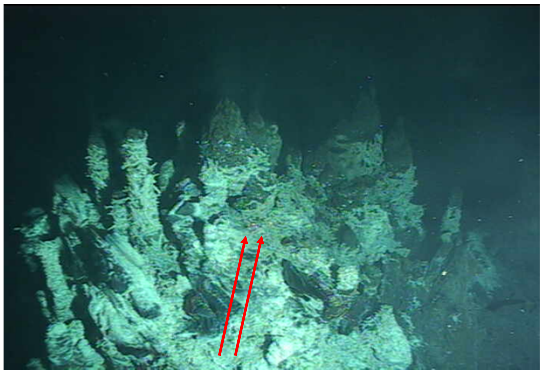

**Reducing Environment** Deep heat source temporally stable for years to decades or more; *but, punctuated during and just after eruptions*

nascent chimney systems

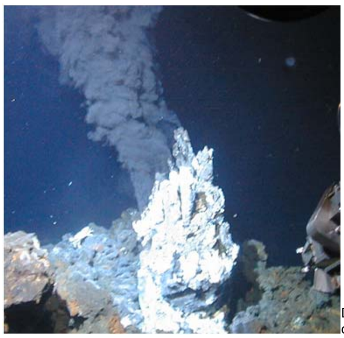
black smoker a few months after eruption – intense focused flow but no edifice (EPR 1991)

Immature black smoker chimney with little colonization (years old?) – SEPR 1999





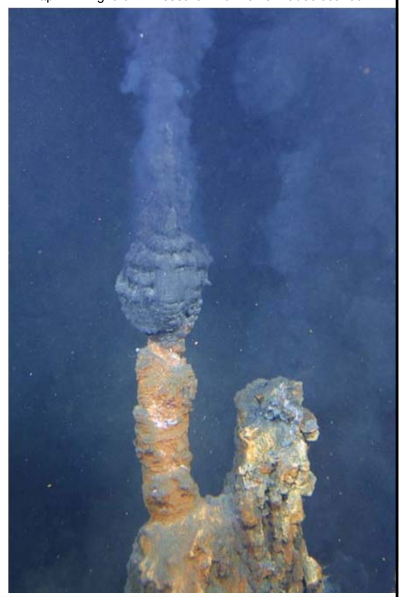
Dive 4206, N-EPR 2006, courtesy reset06 science party



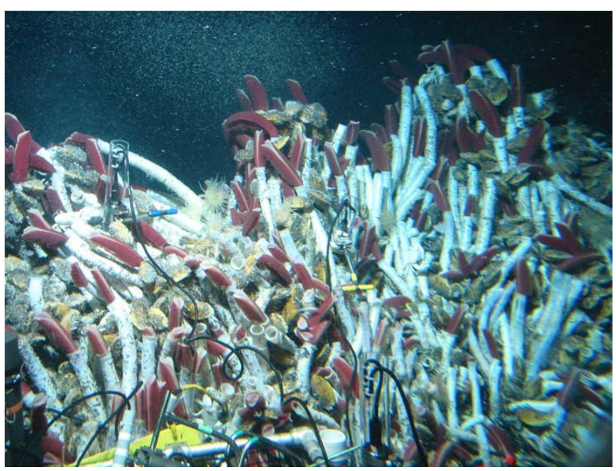
Dive 3350, S-EPR 2006, courtesy stowa science party

established chimney systems

http://www.gns.cri.nz/research/marine/kermadec/seafloor/

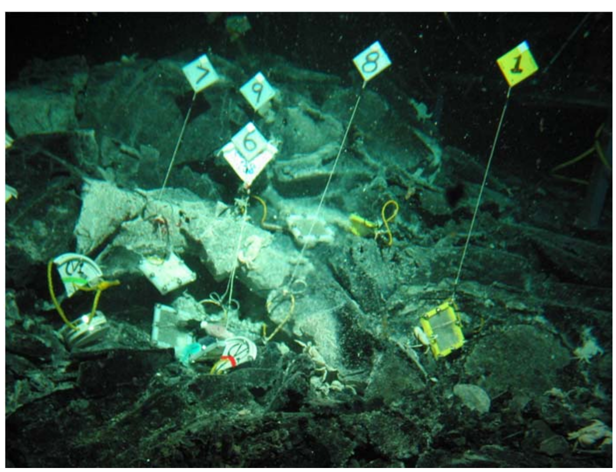


Riftia tubeworms at an established chimney system



Extinct chimney with new lava around it and a previously deployed temperature probe (9 50N EPR, 2006).

diffuse flow



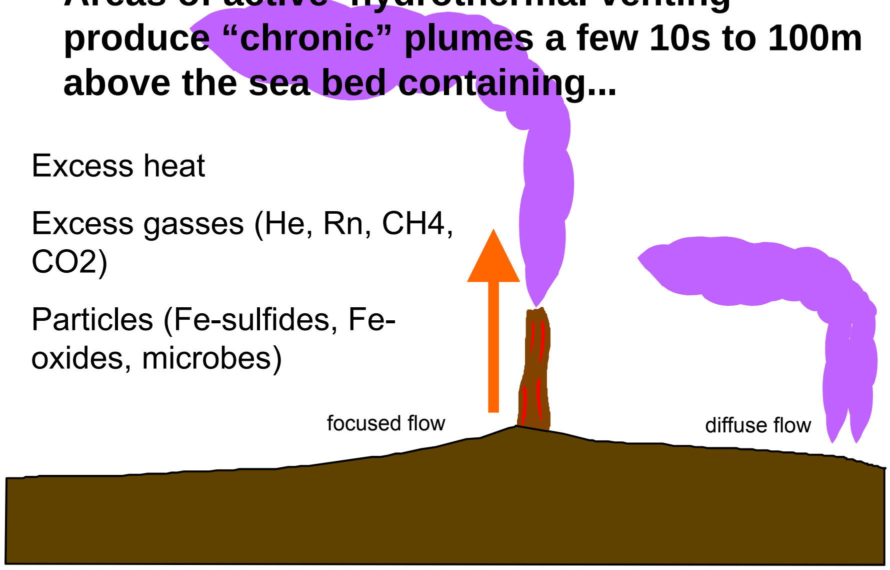
Colonization experiments at a diffuse flow vent site (N-EPR)

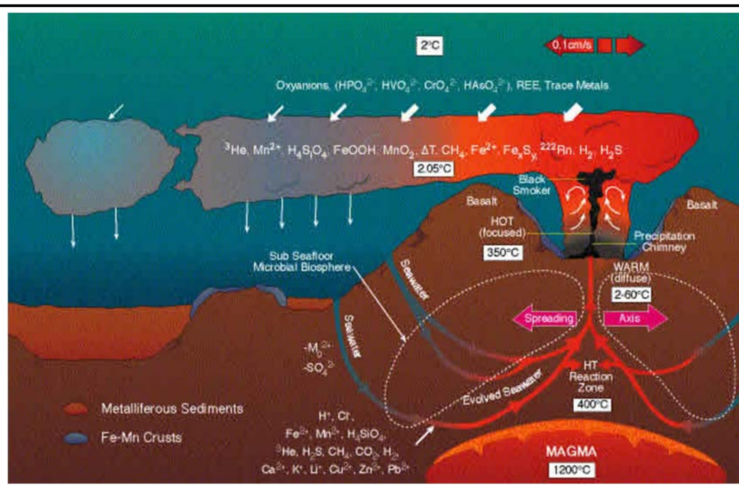
**Areas of active hydrothermal venting produce "chronic" plumes a few 10s to 100m above the sea bed containing...**

Excess heat

Excess gasses (He, Rn, CH4, CO2)

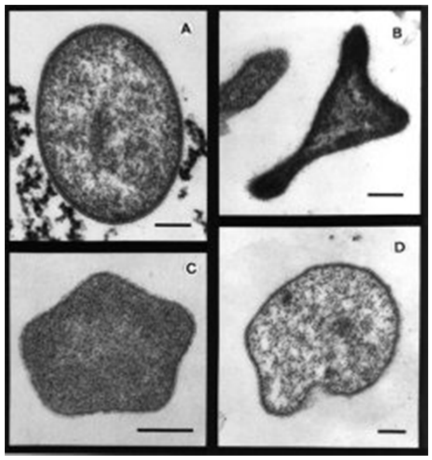
Particles (Fe-sulfides, Fe-oxides, microbes)




Hydrothermal fluids mix rapidly with seawater. Entrainment of ambient seawater dilutes the rising plume and causes temperatures and particle concentrations within the plume to decrease within a short distance from a vent orifice. Hydrothermal plumes continue to rise through seawater as long as plume fluids are less dense (more buoyant) than the surrounding seawater. Once the density of the hydrothermal plume matches the density of the ambient seawater, the hydrothermal plume stops rising and begins to disperse laterally. This "neutrally buoyant plume" gets distributed by being "blown" by ocean currents at that density level.
Source: NOAA Vents website

hydrothermal plumes are likely to be very important for the transport and distribution of marine organisms, especially thermophile or hyperthermophile bacteria that live under the seafloor and have been released into the ocean in plumes resulting from recent volcanic events such as at CoAxial Segment, Axial Volcano and the Gorda Ridge




## Transient chemical effects in plumes

•Dilution of conservative constituents from dispersal (e.g., salinity, He)

(*conservative means no chemical reactions during mixing)*

•cooling from seawater entrainment

•Reactive particle formation (especially Fe-rich)

•Scavenging of particle reactive metals and oxyanions from sea water

•Microbial oxidation of reduced gasses (e.g., CH4, H2)

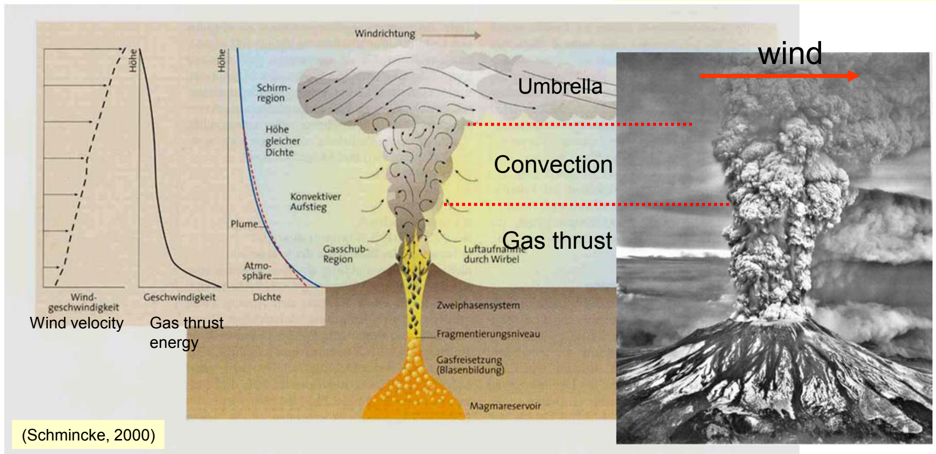
•Organic matter transformations

•Some tracers change at different rates and some roughly track each other (like 3He/heat)

I can suggest references if you are interested in this topic.

## Plume Physics - The analogy to processes in subaerial volcanic eruption columns is useful to consider

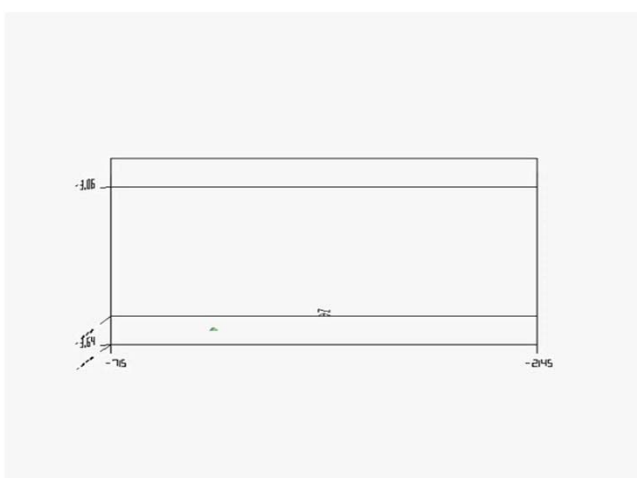
(this slide borrowed and rearranged from I. Skilling, Penn State)




**Some hydrothermal plume observations and model simulations**

**3-d rendering of the TAG hudrothermal mound (MAR)**

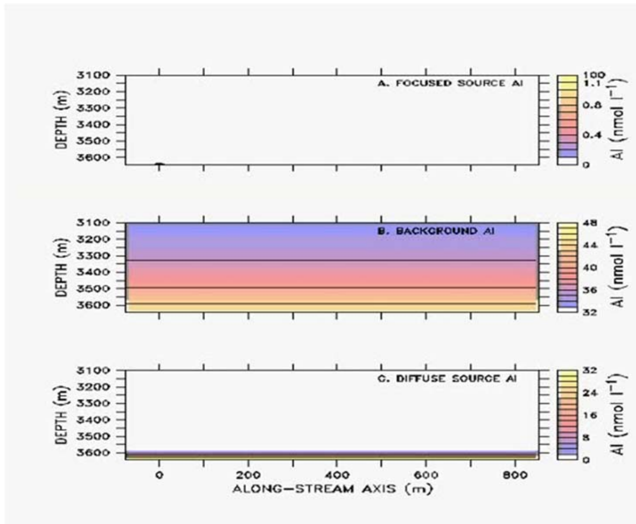
**http://www.pmel.noaa.gov/vents/modeling/**



Usually seval tens of ms to perhaps a couple of hundred m above the sea bed

**Some hydrothermal plume observations and model simulations**

**Vertical Geochemical Transport**




http://www.pmel.noaa.gov/vents/modeling/

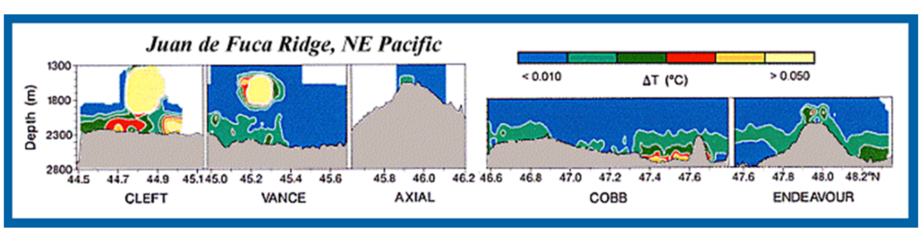
# Event Plumes, aka Megaplumes

Larger, transient features formed in response to eruptions and perhaps other catastrophic events at one place or another on the sea floor.

2 diagnostic features: lots of particles and larger temperature anomalies than chronic plumes. **Can rise to 1km above the sea floor.**

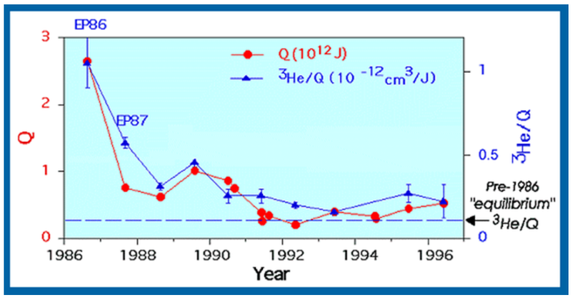
Mid-ocean ridge plumes typically have maximum anomalies of 0.02-0.1°C, although event plume anomalies of up to 0.3°C have been observed (e.g., Baker et al. 1987).

Seamounts can have anomalies in excess of 0.5°C



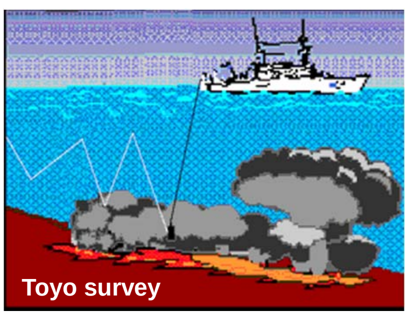

http://www.pmel.noaa.gov/vents/PlumeStudies/

Integrated 3He and heat (Q) output from a ridge segment in the years after an eruption




By calculating the hydrothermal heat inventory (Q) for a 1-meter wide transect along the North Cleft segment from 1986 to 1997 we get another measure of the evolution of this hydrothermal system with time after the volcanic eruption. We see that the largest heat inventory was in 1986, followed by a sharp decline in 1987/88, a secondary peak in 1989/90, and continued relatively low levels through 1997.

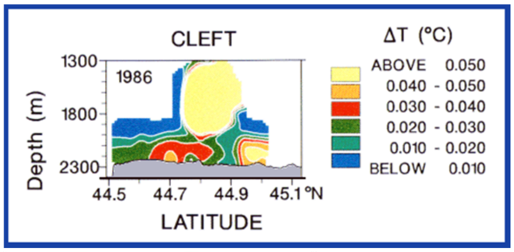
# Surveying for Chronic Plumes and Megaplumes




The CTD is towed behind the ship while being cycled through the bottom 200 meters or so of water where the hydrothermal plumes are located.

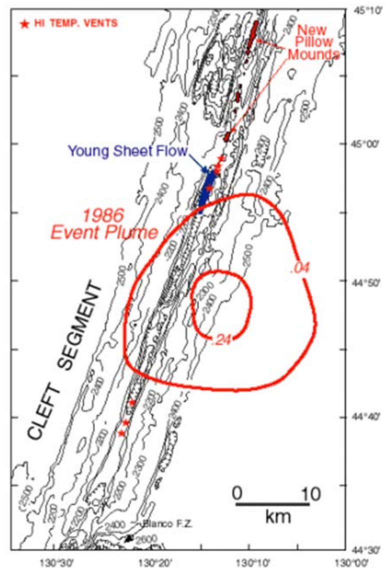
In 1986, a large plume of hot, particle laden water approximately one million cubic meters in volume was discovered over the North Cleft segment of the Juan de Fuca Ridge.

This plume was unique in its shape (horizontally and vertically symmetric), size (100 km$^3$) and rise height (~1km), indicating that an enormous volume of hot water had been released in a relatively short period of time.

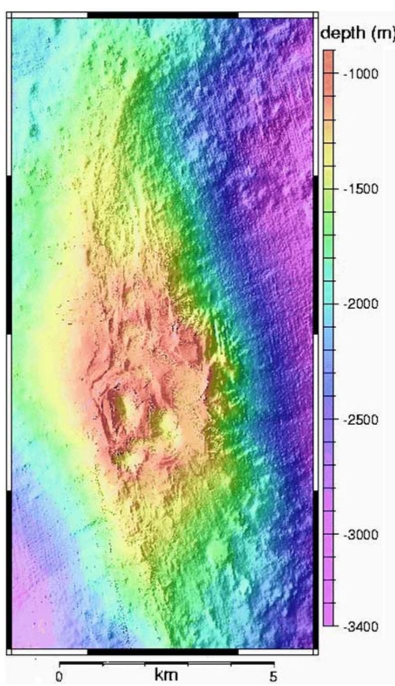



JdFR 1986

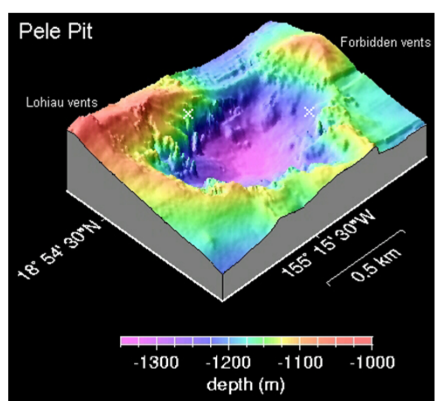
Fresh looking pillow lavas discovered after the megaplume

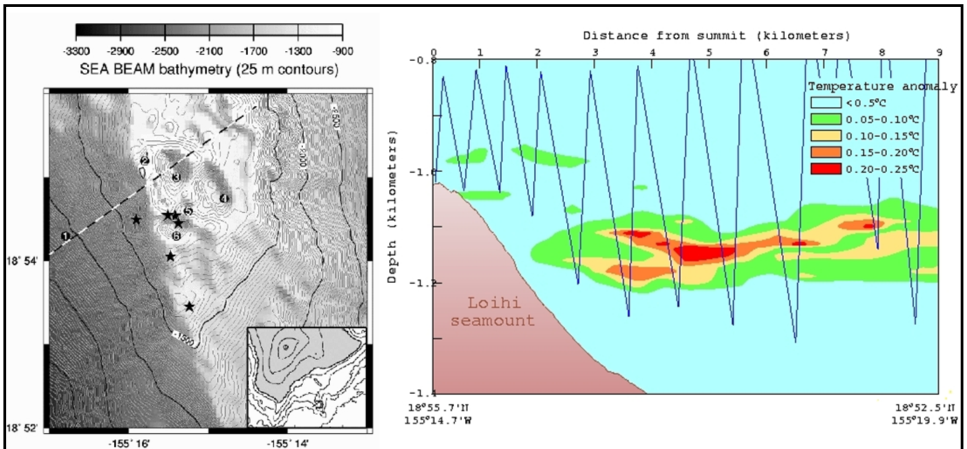



http://www.pmel.noaa.gov/vents/PlumeStudies/



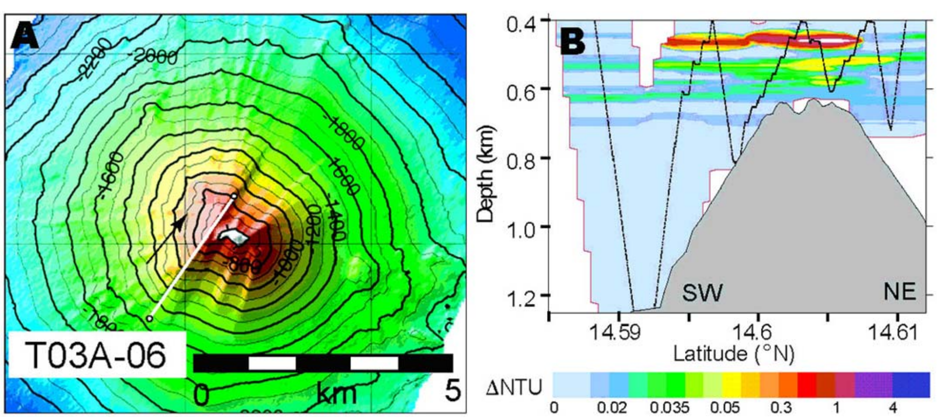

Loihi 1996






Intense hydrothermal plumes from the 1996 Loihi seismic event had temperature anomalies of 0.5°C during the rapid response cruise around the summit at depths of 1050-1250m, with anomalies of 0.1°C at distances >8 km.

One surprise was the observation of a very intense plume at 1600-1800 m depth at a “background” station 50 km NNE of Loihi. A marked decrease in pH (0.2 units) and a remarkable 3He enrichment (150%) were measured, suggesting an injection of magmatic gasses to the water column during a large short-lived, but rapidly cooled, volcanic episode well below the summit of Loihi during the early stages of the seismic event. Source: HCV website




NW Rota #1 (Marianas)

Towed hydrocast (tow-yo) at NW Rota #1 Submarine Volcano (14° 36' N) on February 12, 2003. **A)** Bathymetric map with tow line of hydrocast in white. **B.** Hydrothermal plume above volcano as delineated by optical backscatter. The black saw tooth pattern is the track of the CTD-rosette package as it passed over the volcano. The stair step features in the track are the locations where samples were taken. ΔNTU= nepelometric turbidity units above ambient seawater.

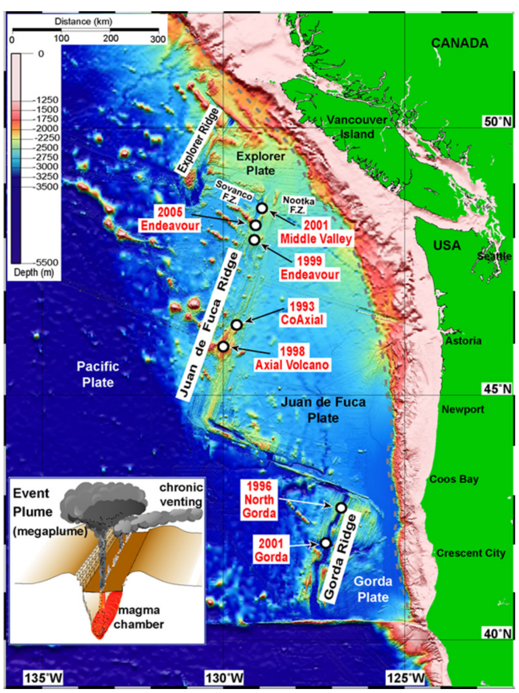
http://www.oceanexplorer.noaa.gov/explorations/06fire/background/plumes/plumes.html

**Some hydrothermal plume model simulations**

**1996 Gorda event plume**

**http://www.pmel.noaa.gov/vents/modeling/**

Usually hundreds of m above the sea bed but can be a km

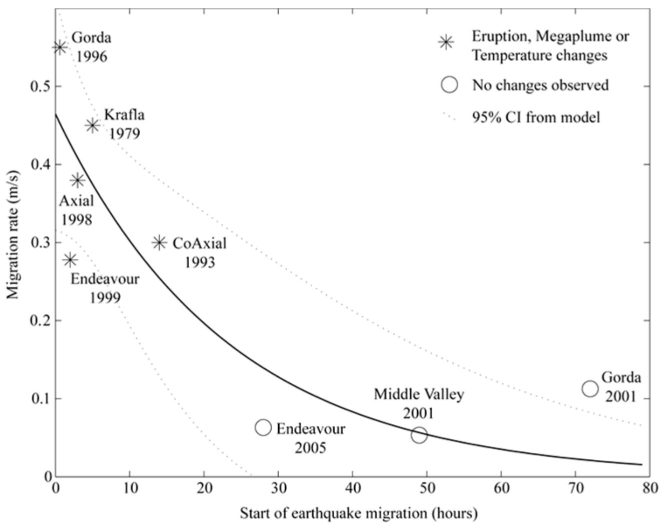



## Megaplume-eruption linkage

Dziak et al, 2007

Juan de Fuca and Gorda Ridge map showing location and date of significant earthquake swarms (seafloor spreading events) detected by the SOSUS system.

All swarms had either a response cruise that investigated the site or pre-swarm *in-situ* instrumentation. Inset diagram shows cartoon of event and chronic plumes released from a mid-ocean ridge.



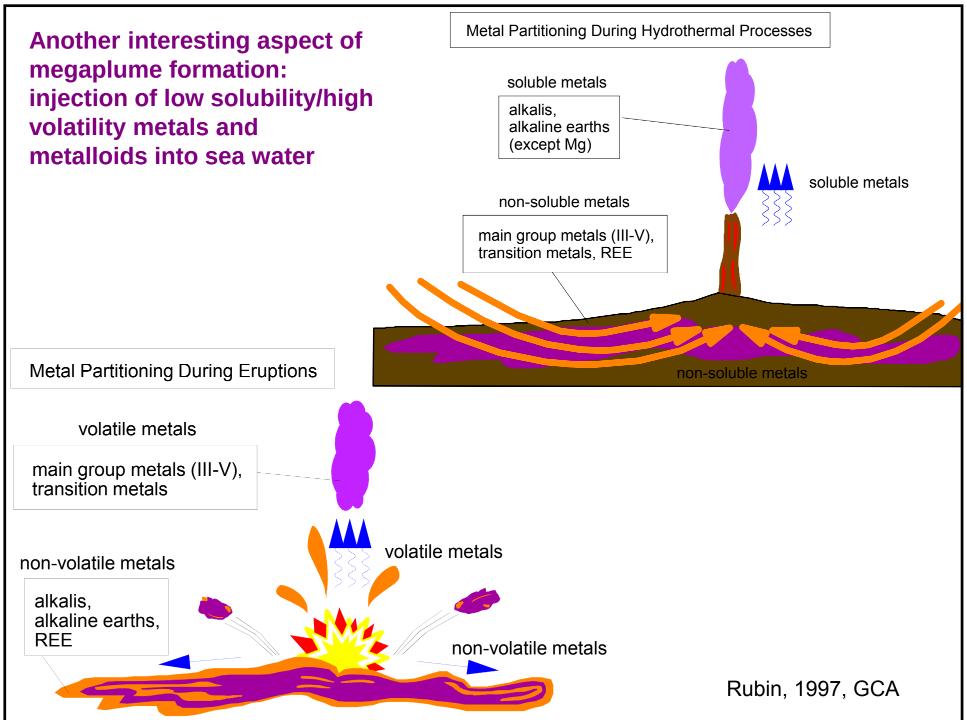

Relationship of earthquake migration rate (m-s-1) to onset of migration (hours after beginning of swarm) .

Logarithmic decay curve illustrates apparent non-linear relationship, dashed line shows 95% confidence interval derived from the model. The subaerial 1979 Krafla (Iceland) dike injection event (*23*) added for comparison.

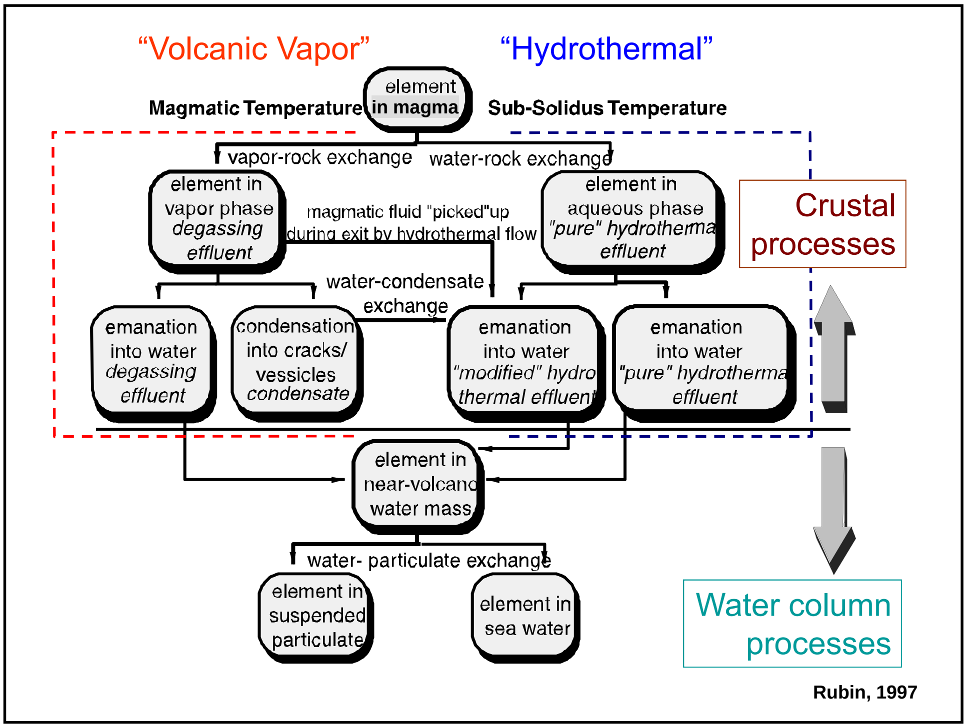
Dziak et al., 2007

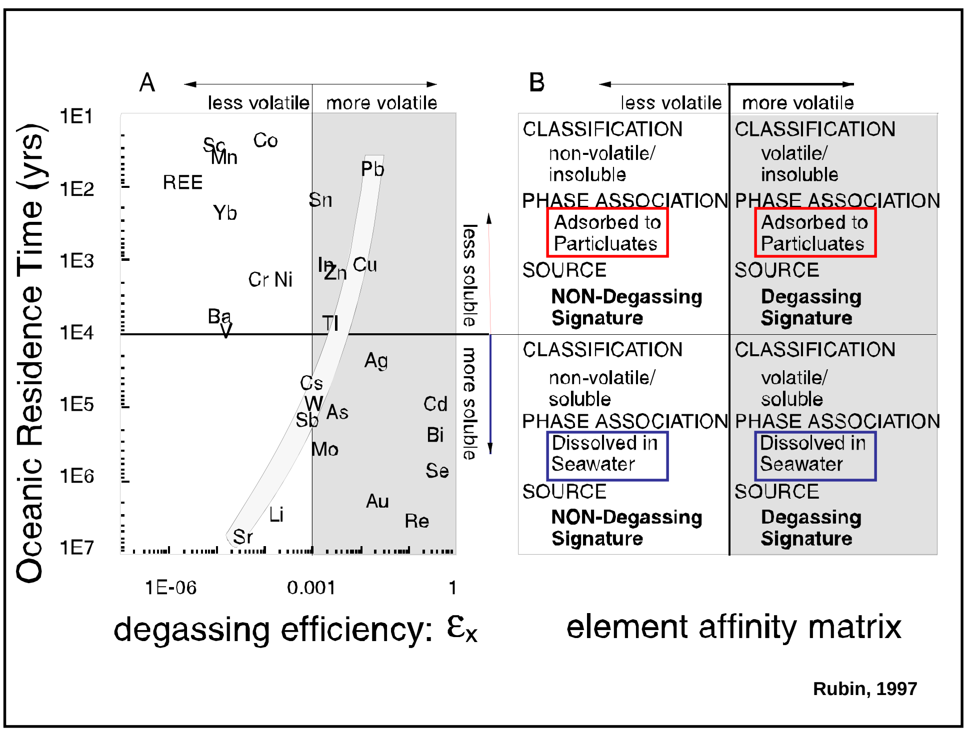
Earthquake swarms associated with seafloor eruptions, fluid-temperature changes, or megaplume events are shown as stars; swarms with no clear magmatic activity or megaplumes are circles.

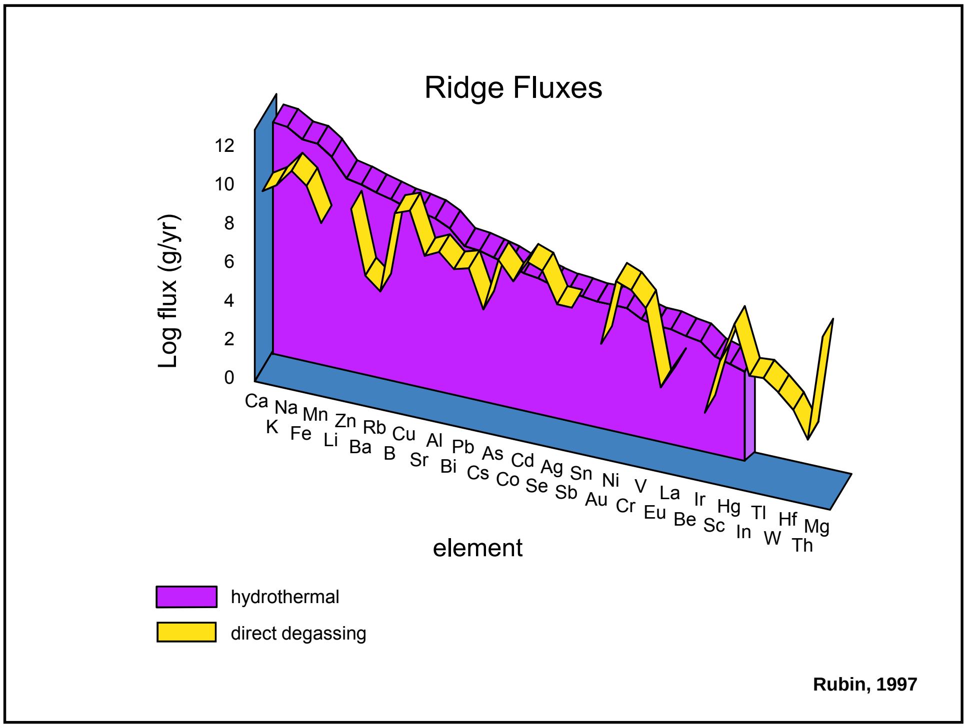
**Another interesting aspect of megaplume formation: injection of low solubility/high volatility metals and metalloids into sea water**




Rubin, 1997, GCA


"Volcanic Vapor"
"Hydrothermal"
element in magma
Magmatic Temperature
Sub-Solidus Temperature
vapor-rock exchange
water-rock exchange
element in vapor phase degassing effluent
magmatic fluid "picked"up during exit by hydrothermal flow
element in aqueous phase "pure" hydrotherma effluent
Crustal processes
water-condensate exchange
emanation into water degassing effluent
condensation into cracks/ vessicles condensate
emanation into water "modified" hydro thermal effluent
emanation into water "pure" hydrotherma effluent
element in near-volcano water mass
water- particulate exchange
element in suspended particulate
element in sea water
Water column processes
Rubin, 1997


A
less volatile
more volatile
Oceanic Residence Time (yrs)
1E1
1E2
1E3
1E4
1E5
1E6
1E7
Sc Mn Co REE Yb Pb Sn Cr Ni In Zn Cu Ba V Tl Ag Cs W Sb As Cd Bi Mo Se Au Re Li Sr
less soluble
more soluble
1E-06
0.001
1
degassing efficiency: $\varepsilon_x$
B
less volatile
more volatile
CLASSIFICATION non-volatile/ insoluble
PHASE ASSOCIATION Adsorbed to Particulates
SOURCE NON-Degassing Signature
CLASSIFICATION volatile/ insoluble
PHASE ASSOCIATION Adsorbed to Particulates
SOURCE Degassing Signature
CLASSIFICATION non-volatile/ soluble
PHASE ASSOCIATION Dissolved in Seawater
SOURCE NON-Degassing Signature
CLASSIFICATION volatile/ soluble
PHASE ASSOCIATION Dissolved in Seawater
SOURCE Degassing Signature
element affinity matrix
Rubin, 1997


Ridge Fluxes
Log flux (g/yr)
0
2
4
6
8
10
12
Ca Na Mn Zn Rb Cu Al Pb As Cd Ag Sn Ni V La Ir Hg Tl Hf Mg
K Fe Li Ba B Sr Bi Cs Co Se Sb Au Cr Eu Be Sc In W Th
element
hydrothermal
direct degassing
Rubin, 1997