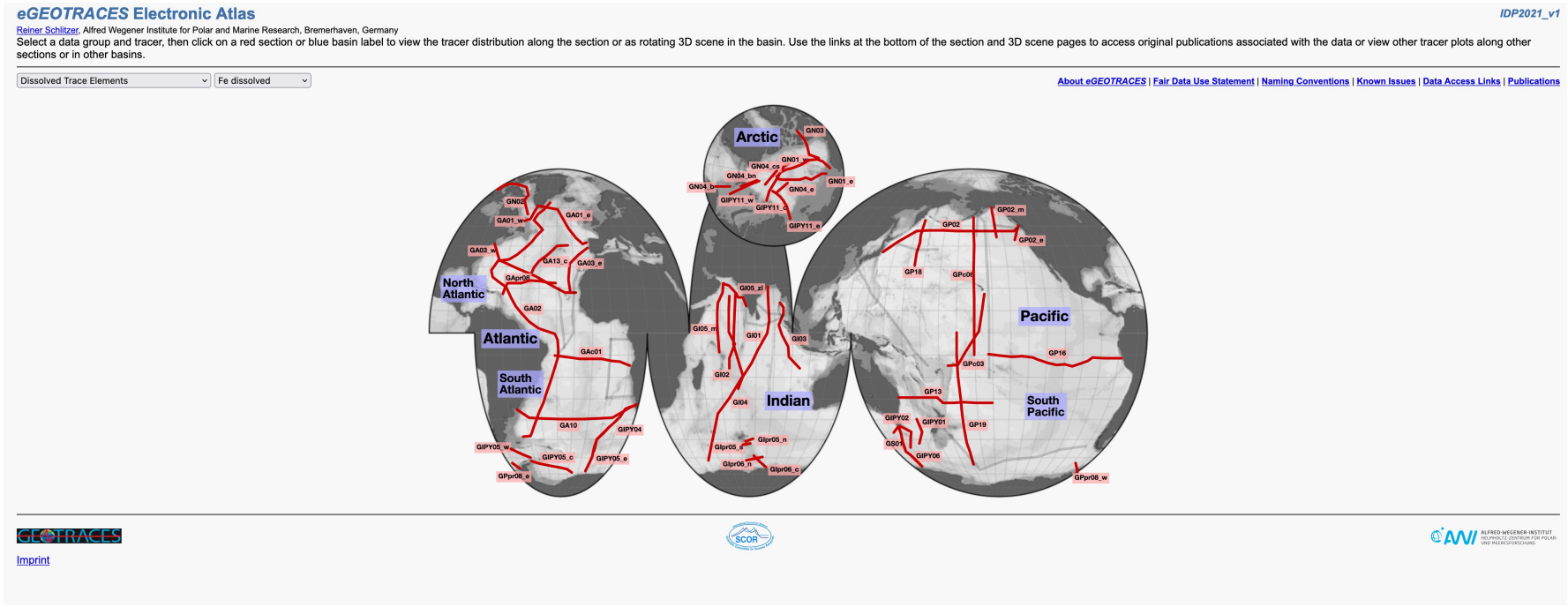
Hydrothermal systems

- Where hydrothermal vent systems exist
- How fluid flows through vents
- Reactions that take place during hydrothermal activity
- Tracing hydrothermal activity using He

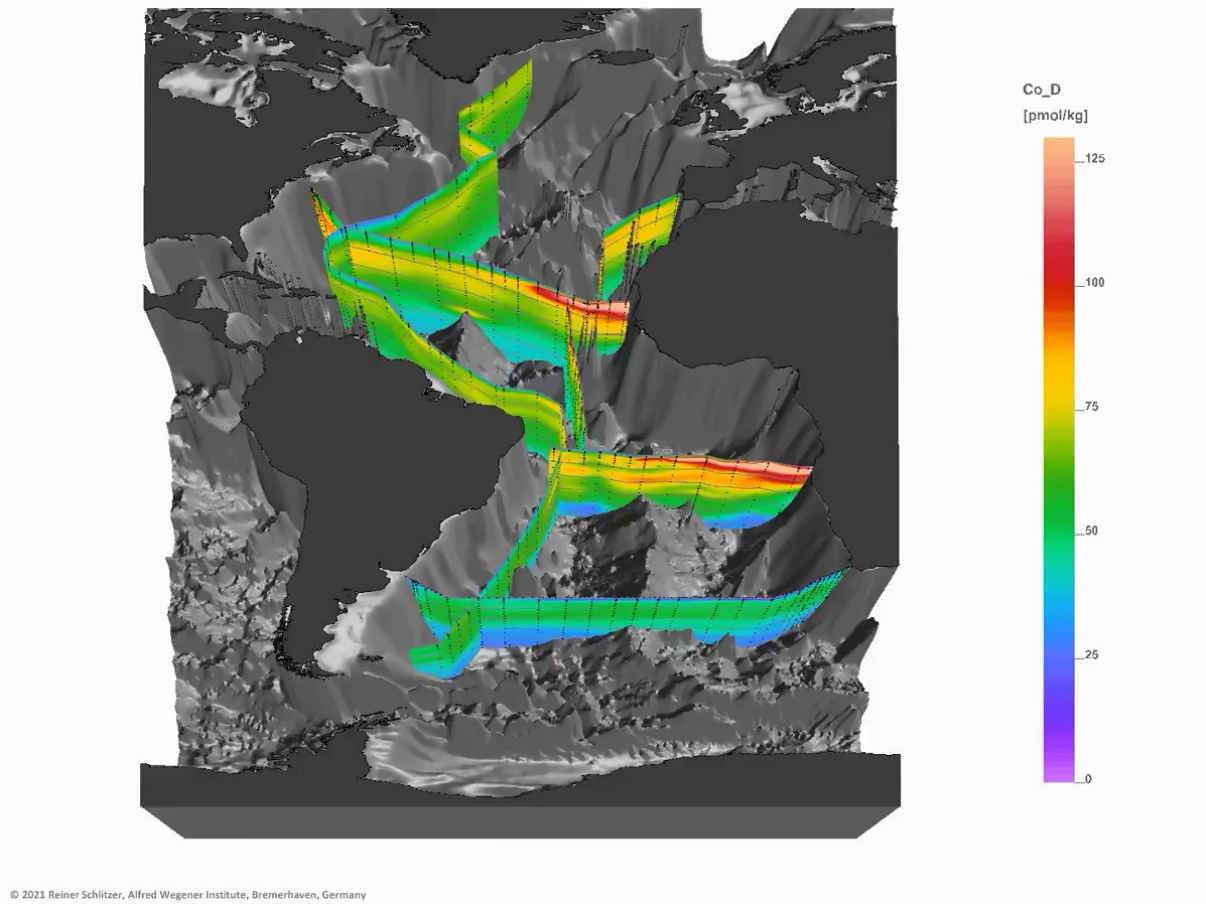
Trace element resource - eGeotraces



- https://www.egeotraces.org/

Dissolved Cobalt, Atlantic cruises

Basin-scale videos available at website, or individual section plots / data



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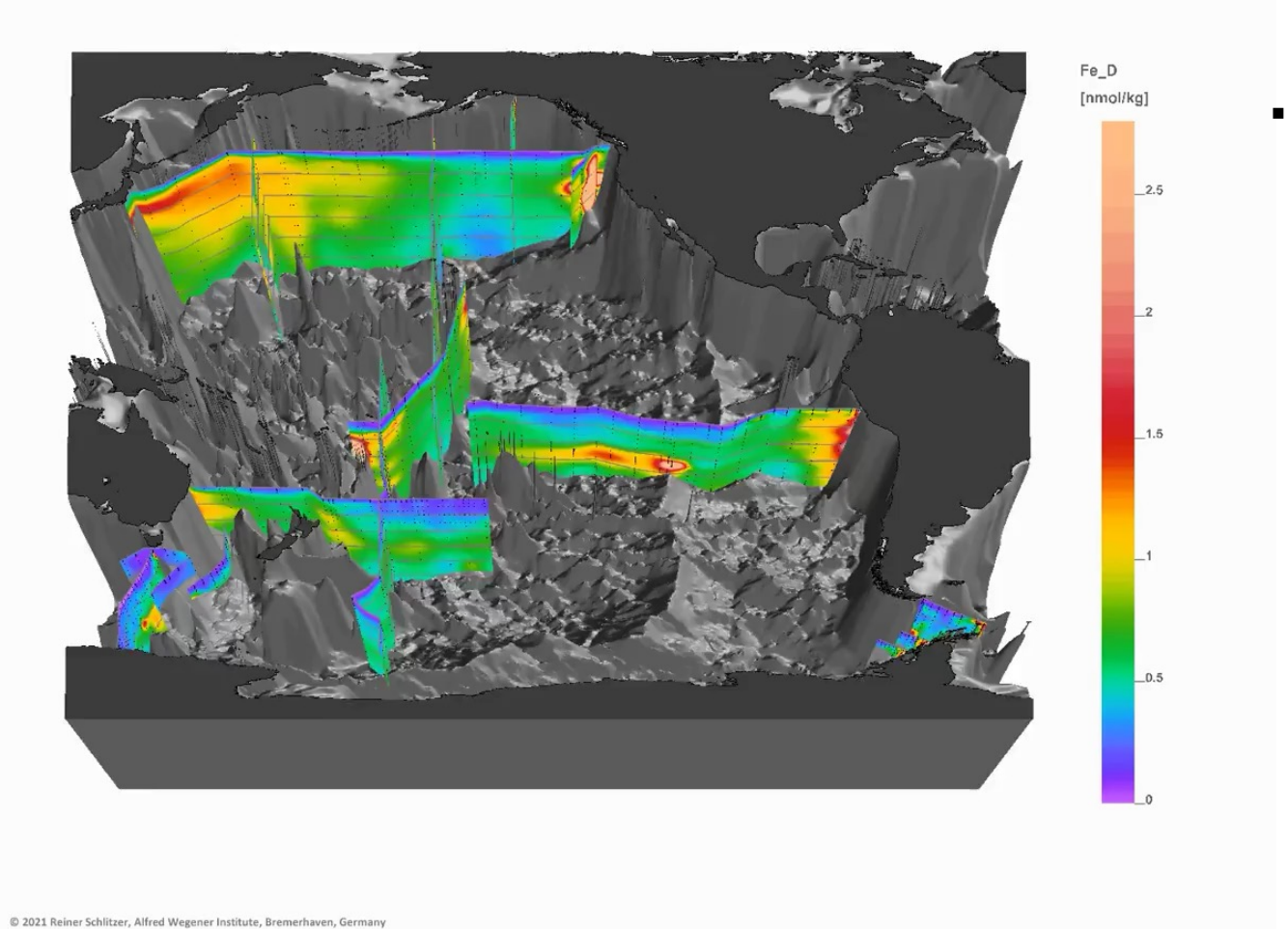
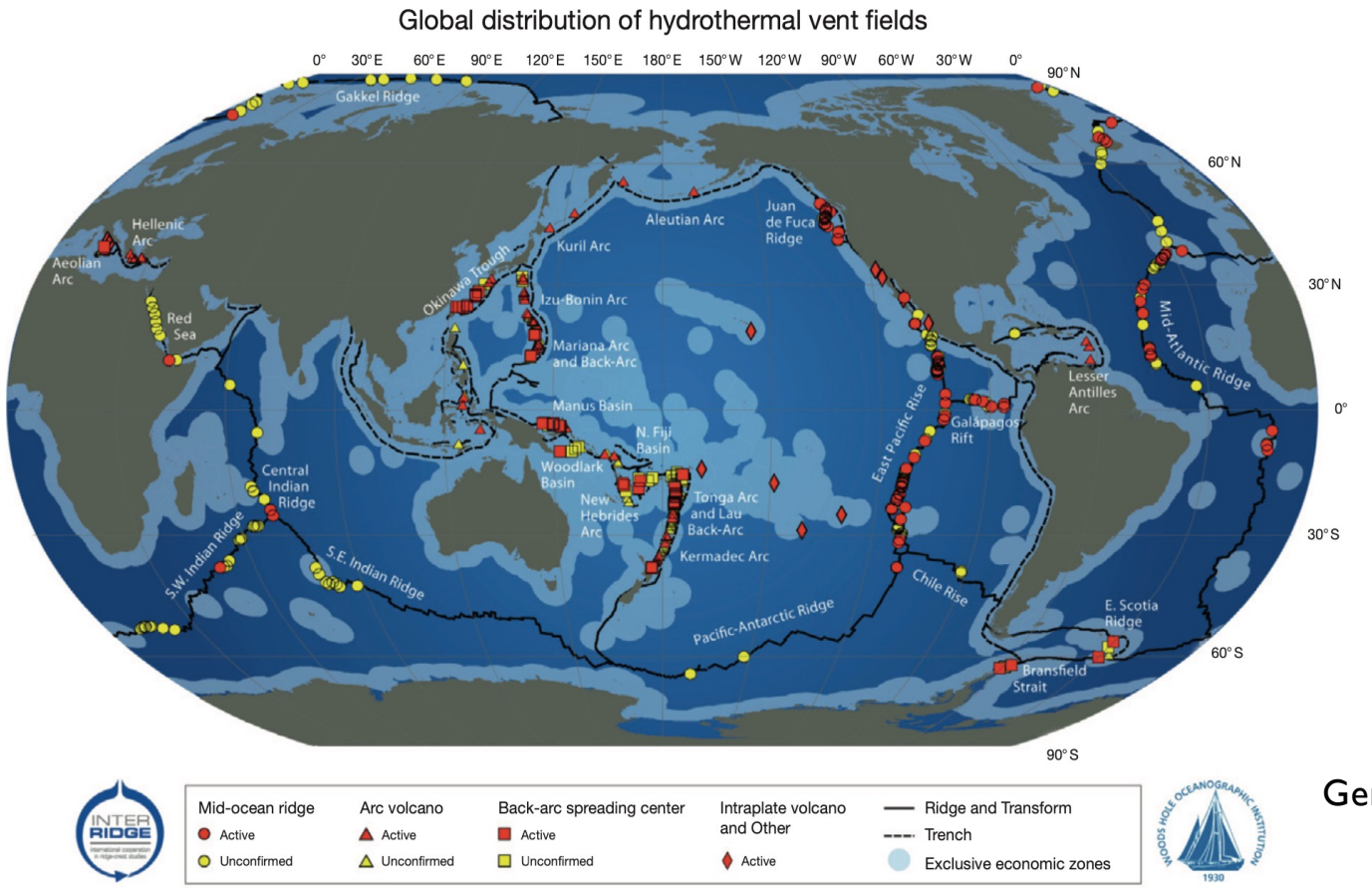
Dissolved Fe, Pacific



- What sources do you notice?

Ridge Crest / arc systems and (known) hydrothermal vents



German & Seyfried, 2014

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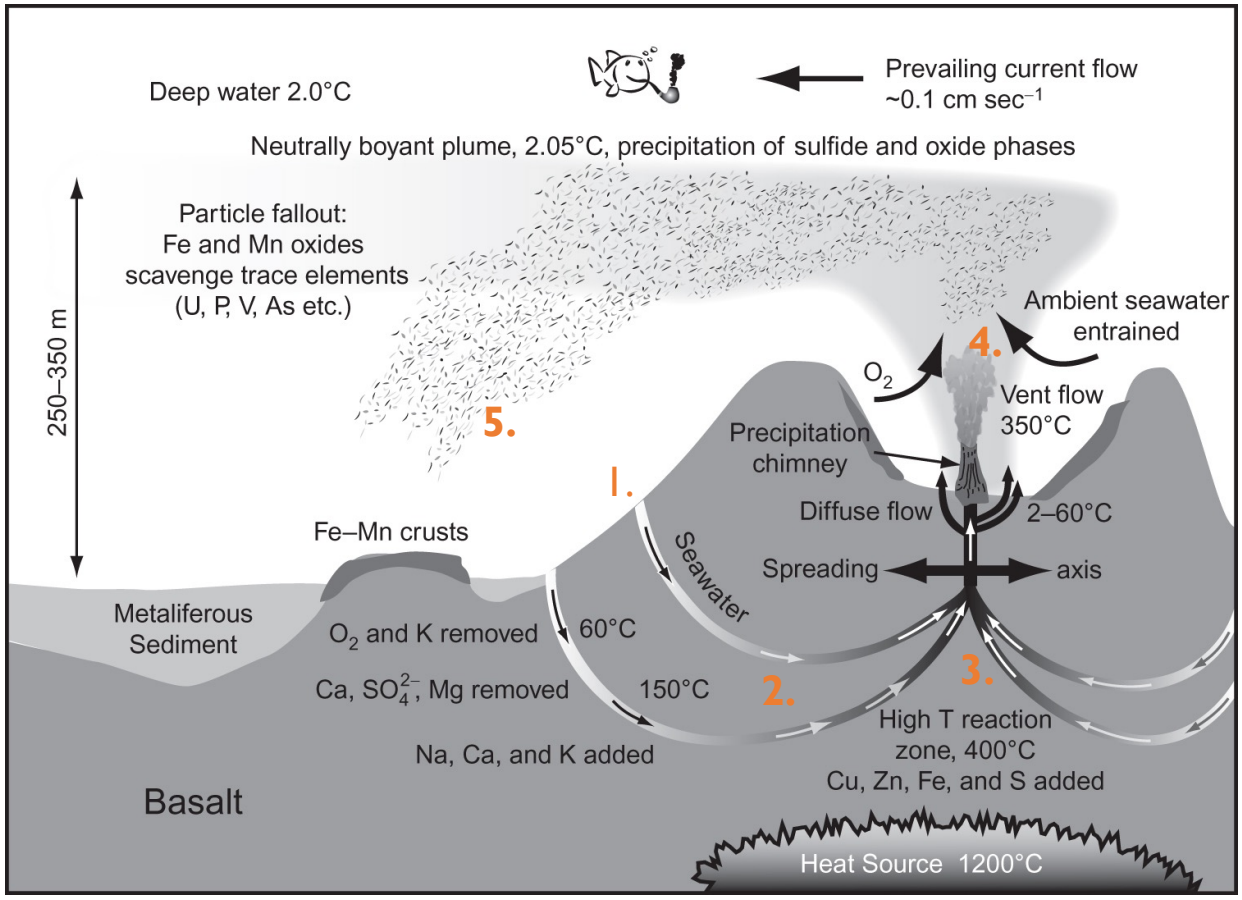
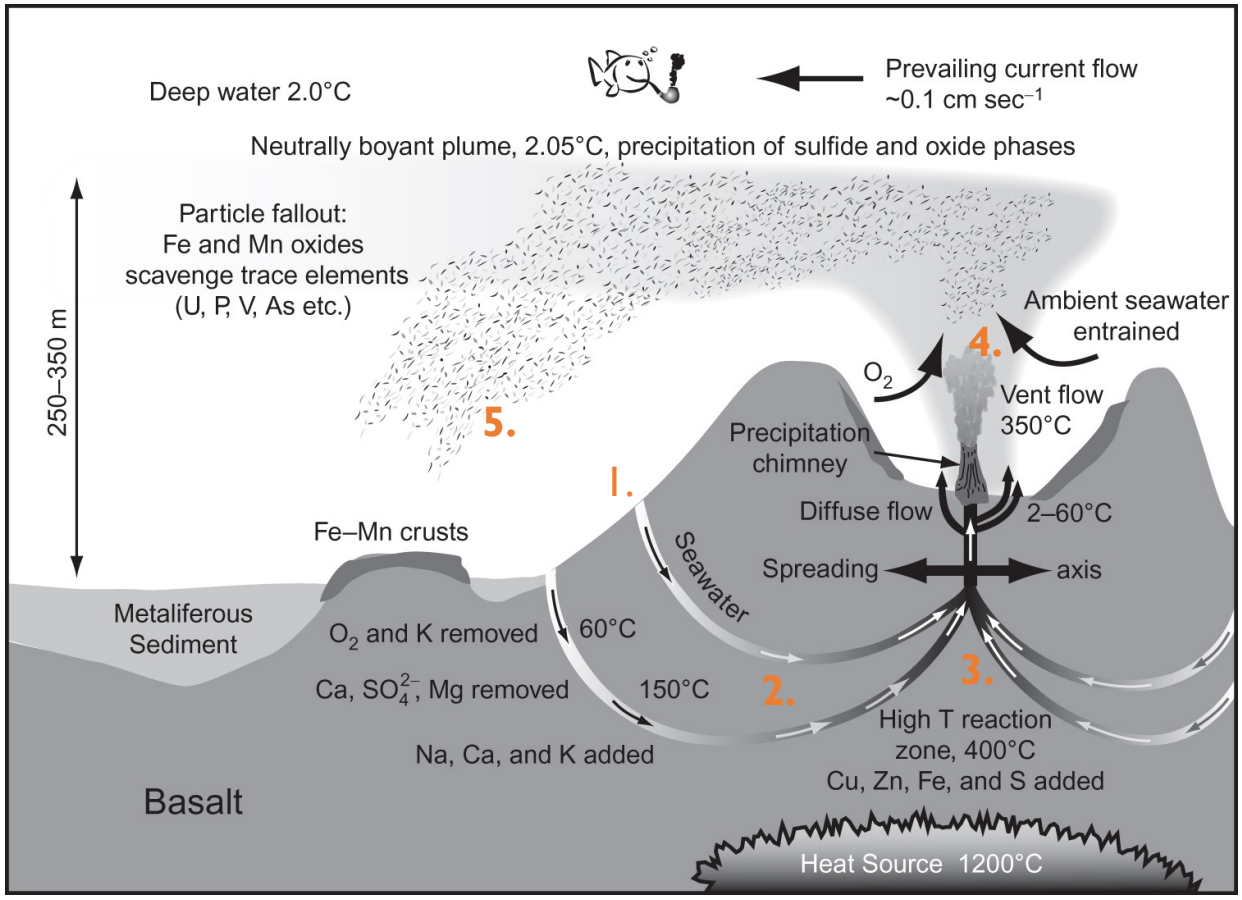
Hydrothermal schematic



1. Seawater flows into fractured basalt
   - 2C, oxygenated

Hydrothermal schematic



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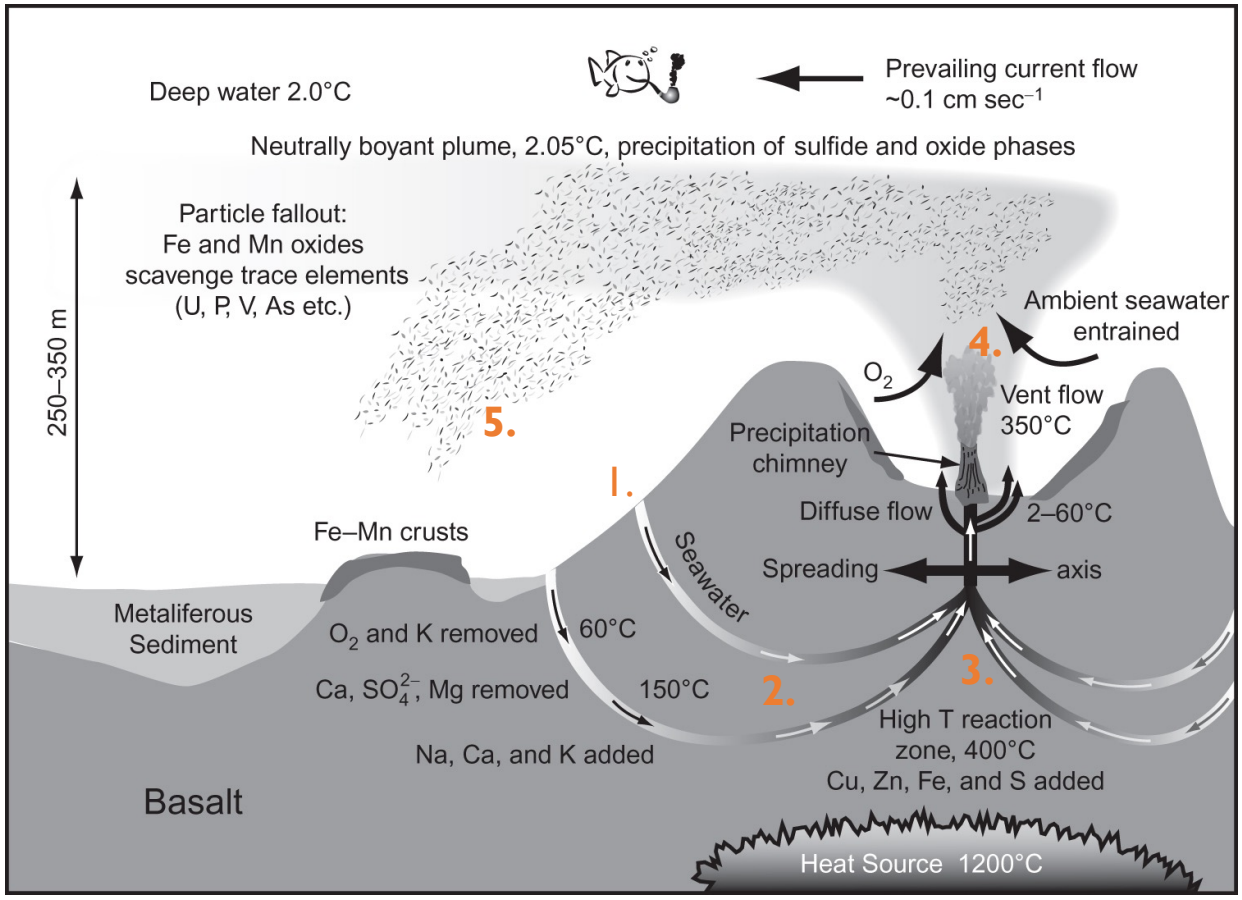
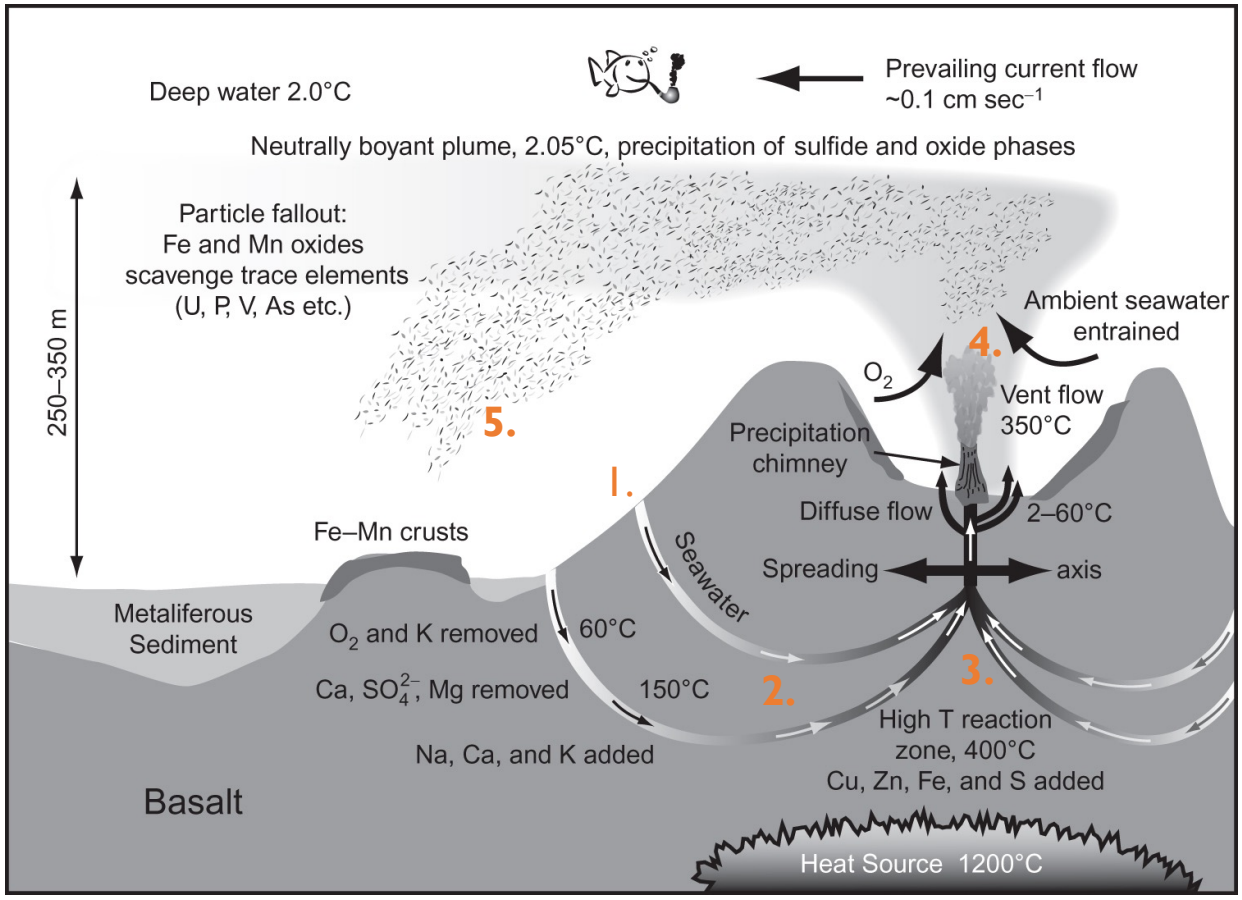


1. Seawater flows into fractured basalt
   - 2C, oxygenated
2. Water percolates into crust, some heating
3. Strong heating, dissolving of volatiles
   - SO_2 (will combine with water to make H_2SO_4), HCl, HF - all strong acids, CO_2 (H_2CO_3)
     - Will mobilize rock material (metal concentrations increase)
   - O_2 decreases to anoxia (reduced material comes out and oxidized ($Fe^{2+} + O_2 \rightarrow Fe^{3+}$)

Hydrothermal schematic



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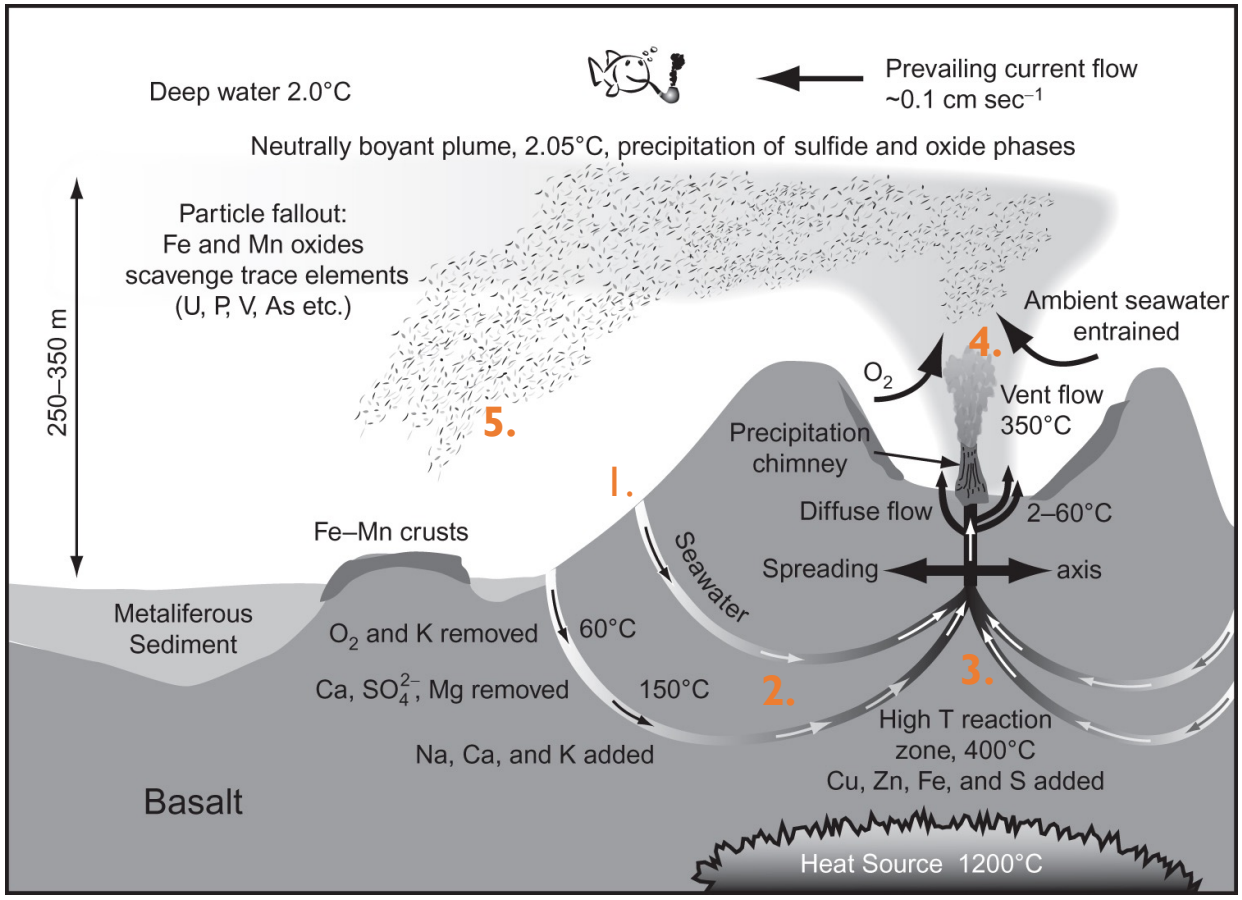
   - Rapid entrainment / dilution until neutrally buoyant
   - Huge redox gradients

Hydrothermal schematic



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   - Huge redox gradients
5. Precipitation of metaliferous sediments

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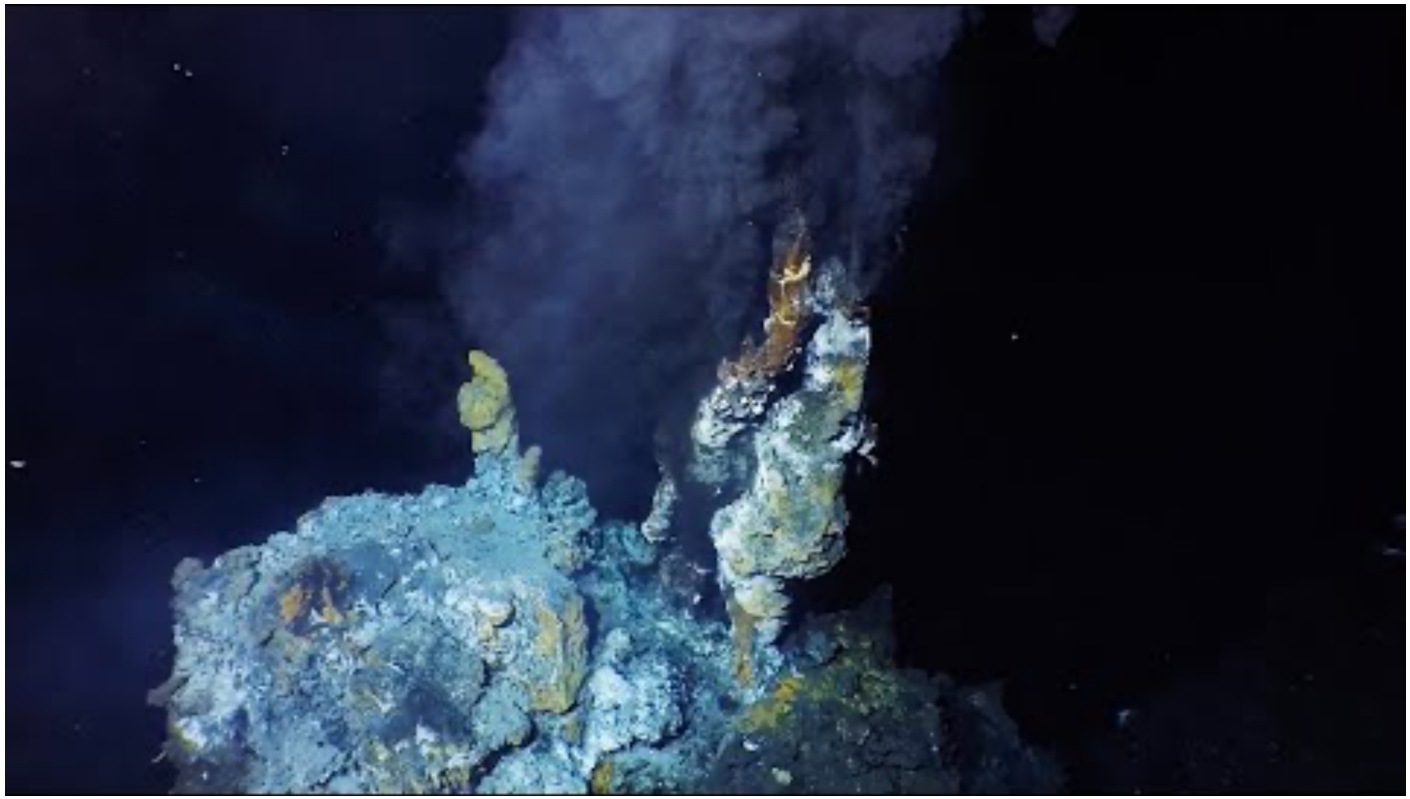
Hydrothermal vent, East Pacific Rise



Black smoker reactions

- High temperature reactions:

  $Mg^{2+} + SO_4^{2-} \rightarrow MgSO_{4(s)}$

  (53mM) (28 mM) – sulfate runs out first

  ~25mM Mg^{2+} left

  $Mg^{2+} + CaSiO_3 \rightarrow Ca^{2+} + MgSiO_{3(s)}$

  Mg^{2+} consumed to ~ 0 mM

  $2K^+ + CaSiO_3 \rightarrow Ca^{2+} + K_2SiO_{3(s)}$

  Both of these salts are normally very stable, so these are major sinks of these ions in seawater. Also major source of Ca^{2+}

- Production of H^+ can also create acidic waters

Mackenzie and Garrels 1966 … from Day 2

Major ion		SO_4^{2-}	Ca^{2+}	Cl^-	Na^+	Mg^{2+}	K^+	H_4SiO_4	HCO_3^-
Mass removed in 10^8 *y* (10^{18} *mol*)		429	1238	821	861	477	143	589	3573
Mineral formed	Moles Removed	*Amount of ion remaining after reaction*							
Pyrite, FeS_2	215[a]	214	1238	821	861	477	143	589	3573
Anhydrite, $CaSO_4$	214[a]	0	1024	821	861	477	143	589	3573
Calcium Carb., $CaCO_3$	1024		0	821	861	477	143	589	1525
Sodium Chloride, NaCl	821			0	40	477	143	589	1525
Opal, SiO_2	630[b]				40	477	143	0	1525

[a] Assume half of the SO_4 is removed by pyrite formation and half by $CaSO_4$ formation
[b] The biogenic opal (SiO_2) burial is taken from Tregeur and DeLaRocha, 2013

(b) Formation reactions:

Pyrite: $SO_4^{2-} + 2CH_2O(s) \rightleftarrows S^{2-} + 2CO_2 + H_2O$ followed by $Fe^{2+} + S^{2-} + S^0 \rightleftarrows FeS_2$

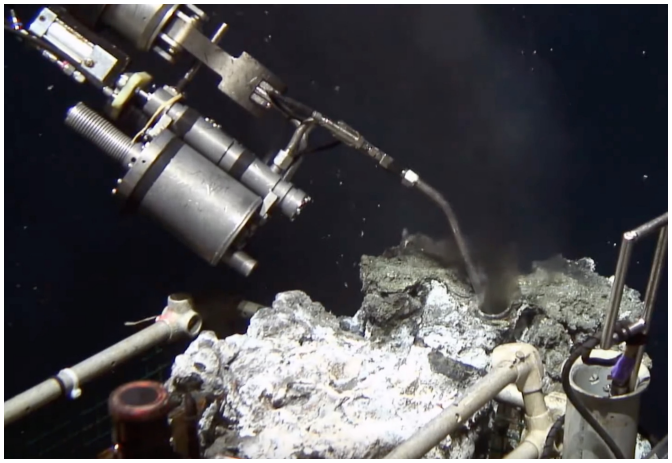
Anhydrite: $Ca^{2+} + SO_4^{2-} \rightleftarrows CaSO_4(s)$

Calcium Carbonate: $Ca^{2+} + 2HCO_3^- \rightleftarrows CaCO_3(s) + CO_2 + H_2O$

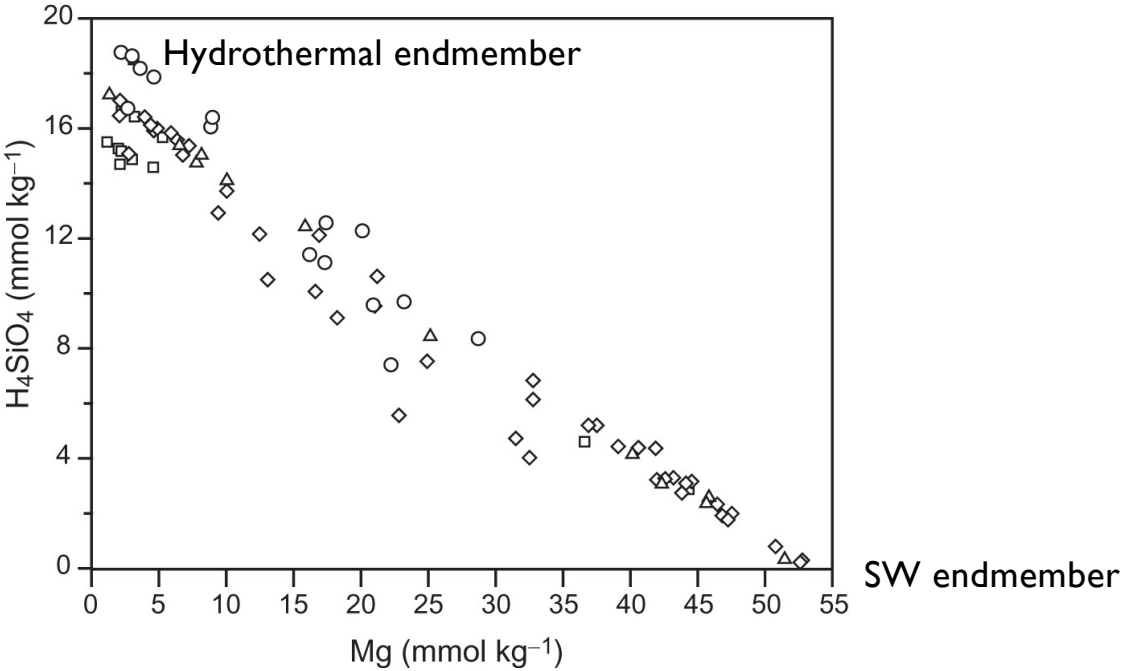
Sodium Chloride: $Na^+ + Cl^- \rightleftarrows NaCl(s)$

Opal: $H_4SiO_4 \rightleftarrows SiO_2(s) + 2H_2O$

How do you sample hydrothermal waters?



- How do you know if you're actually measuring the correct water?



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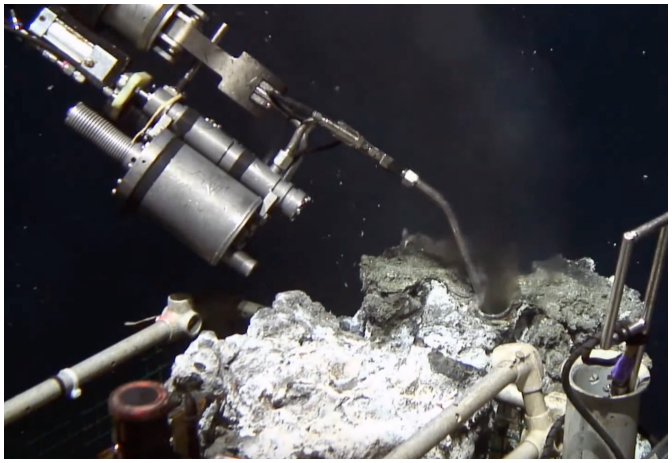
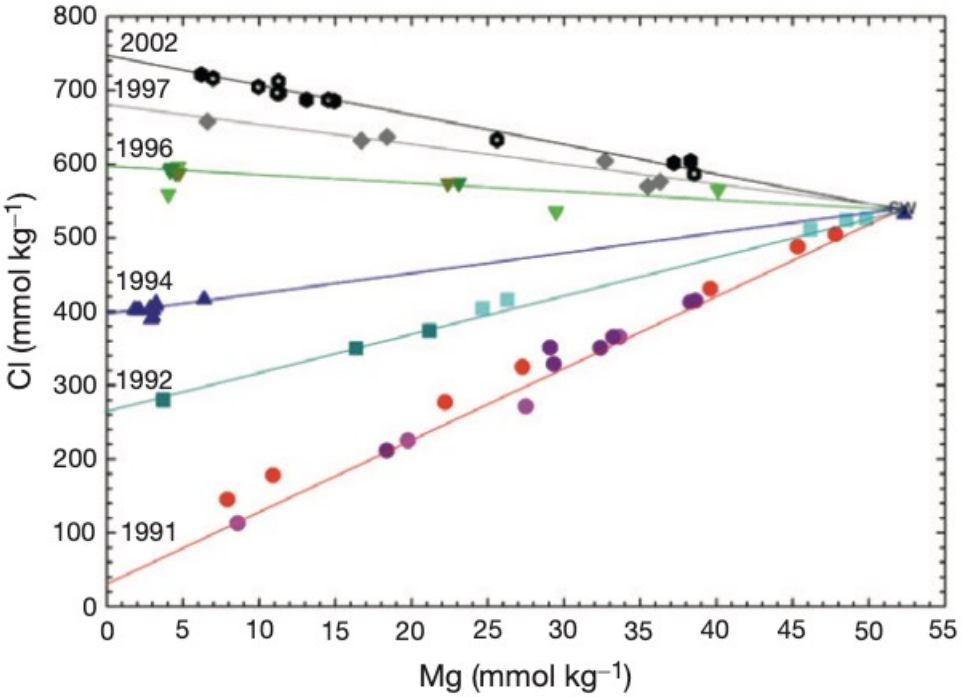
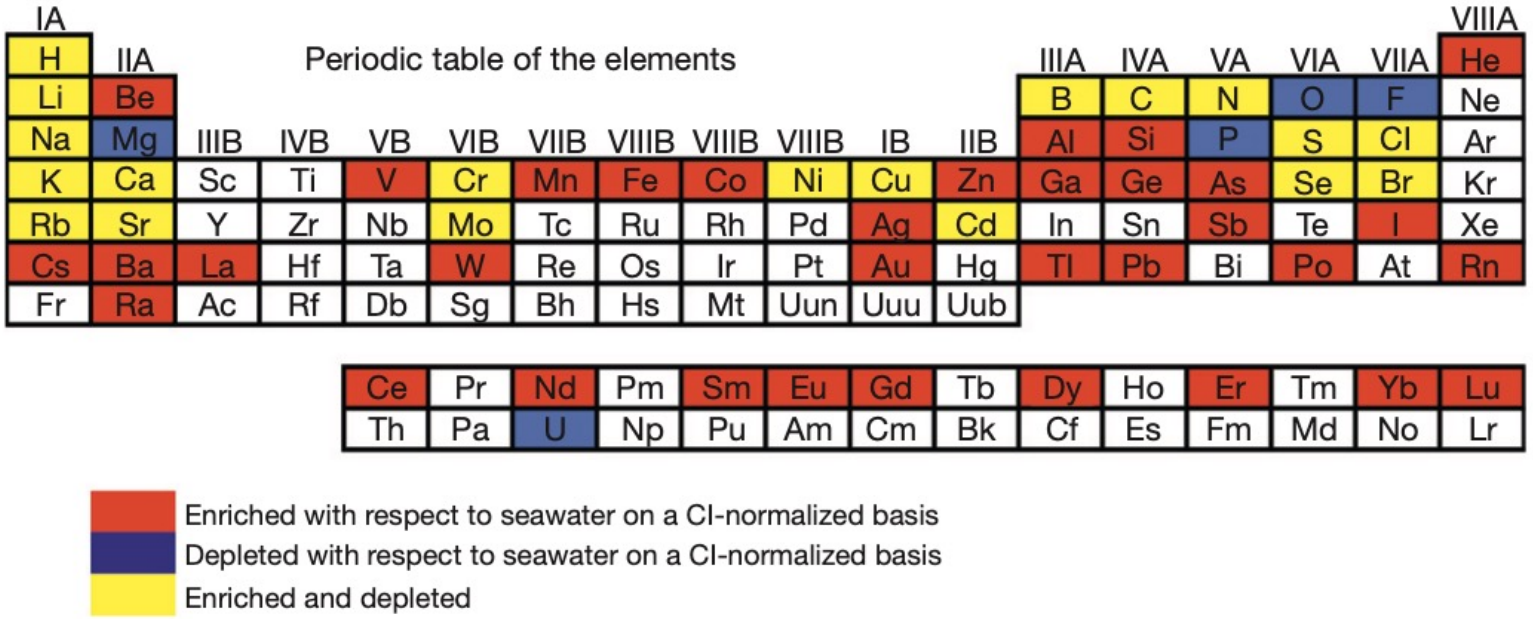


- Vent composition / flow can change over time



Von Damm (2000) and German & Seyfried, 2014

Elemental impacts from hydrothermal vents



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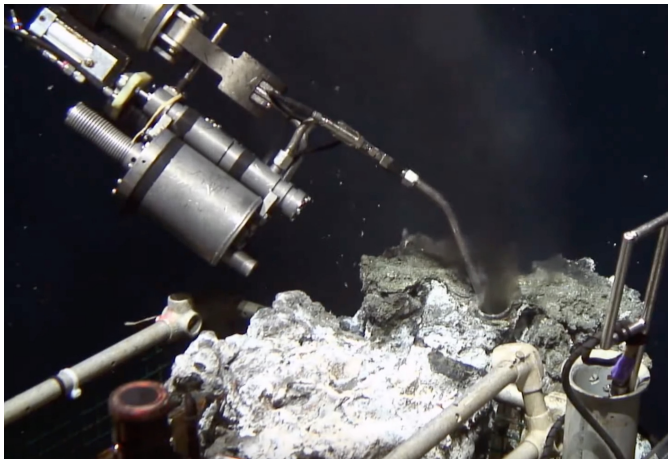

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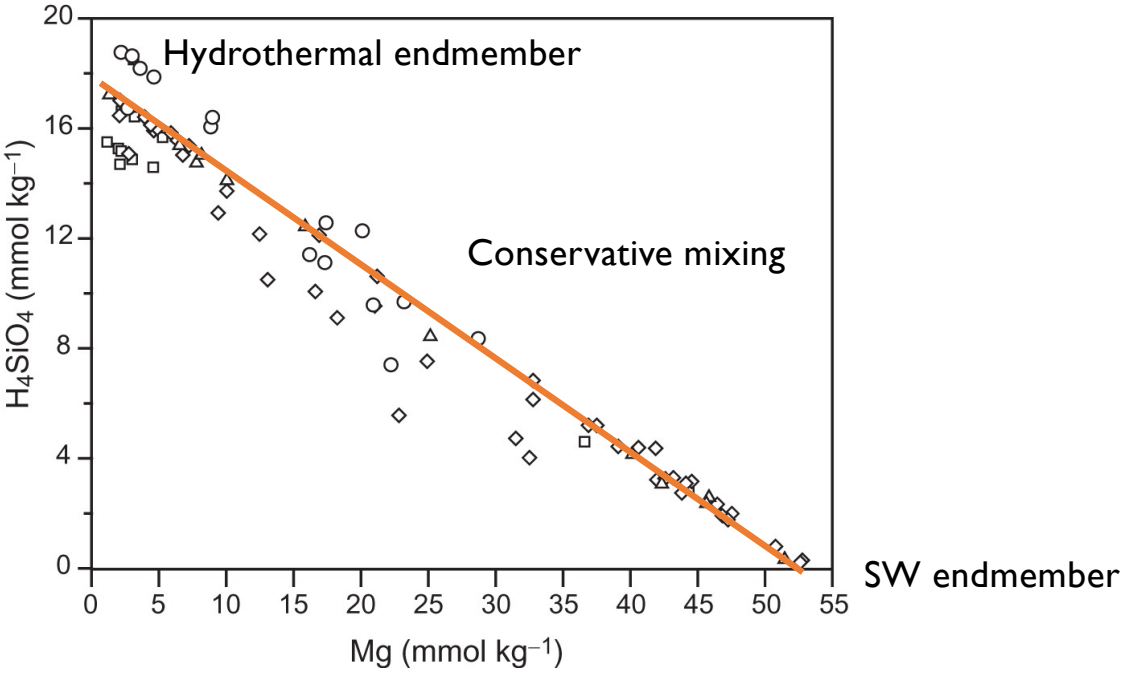
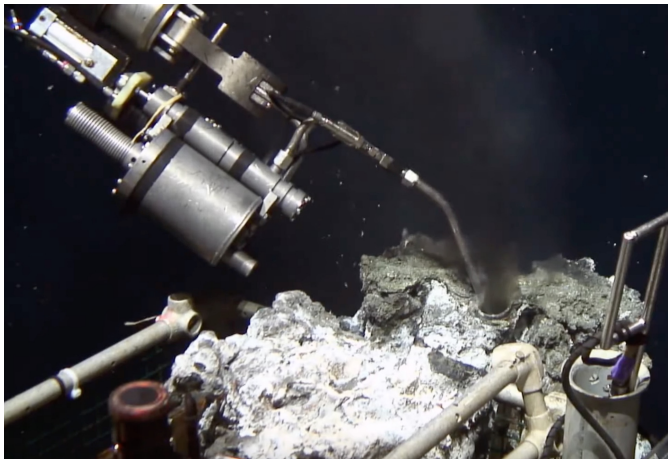
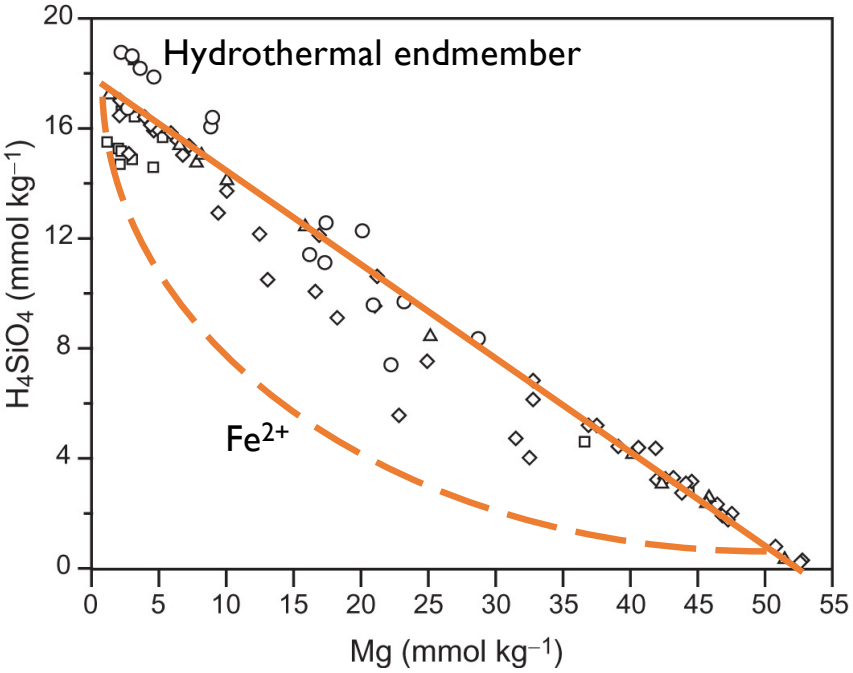


Reactions as hydrothermal waters mix



- What if your measurements follow a different shape?



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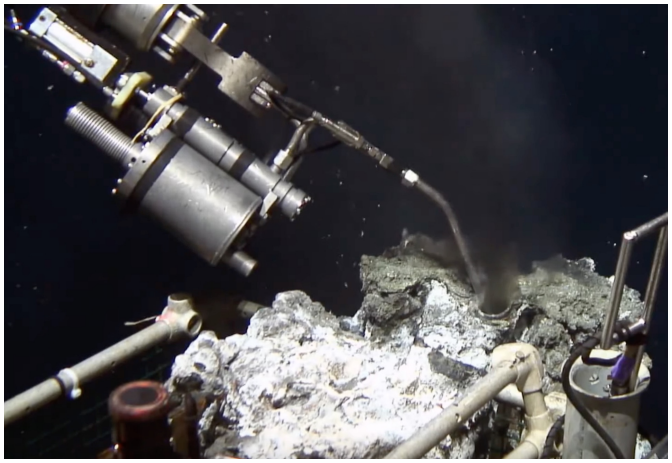

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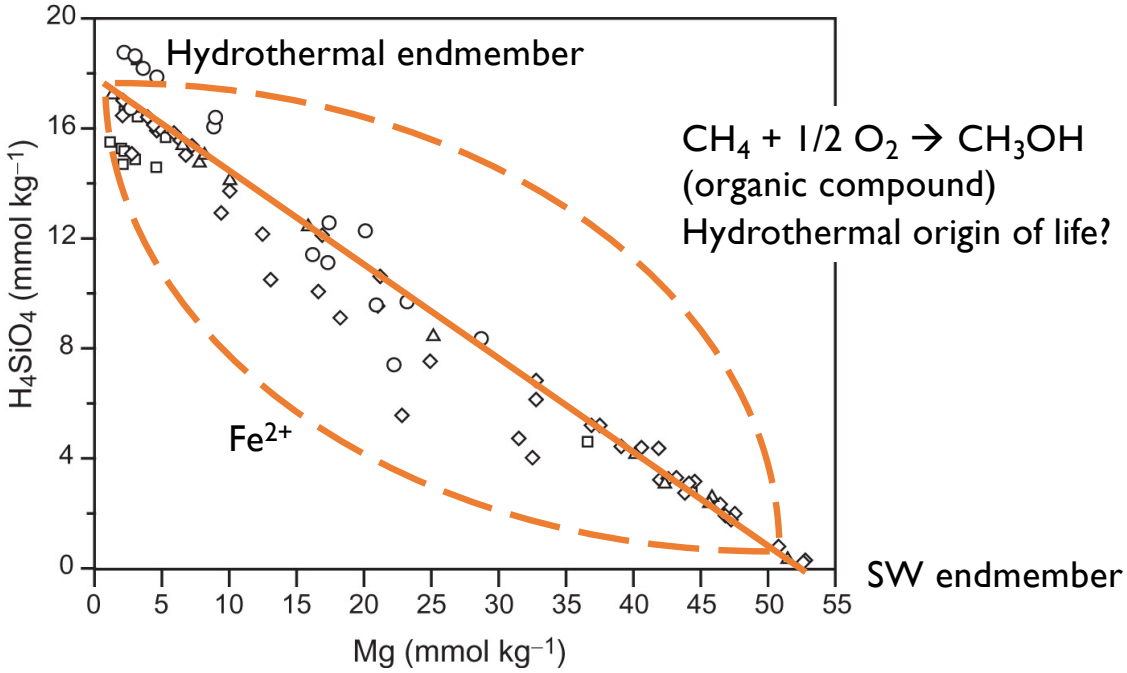
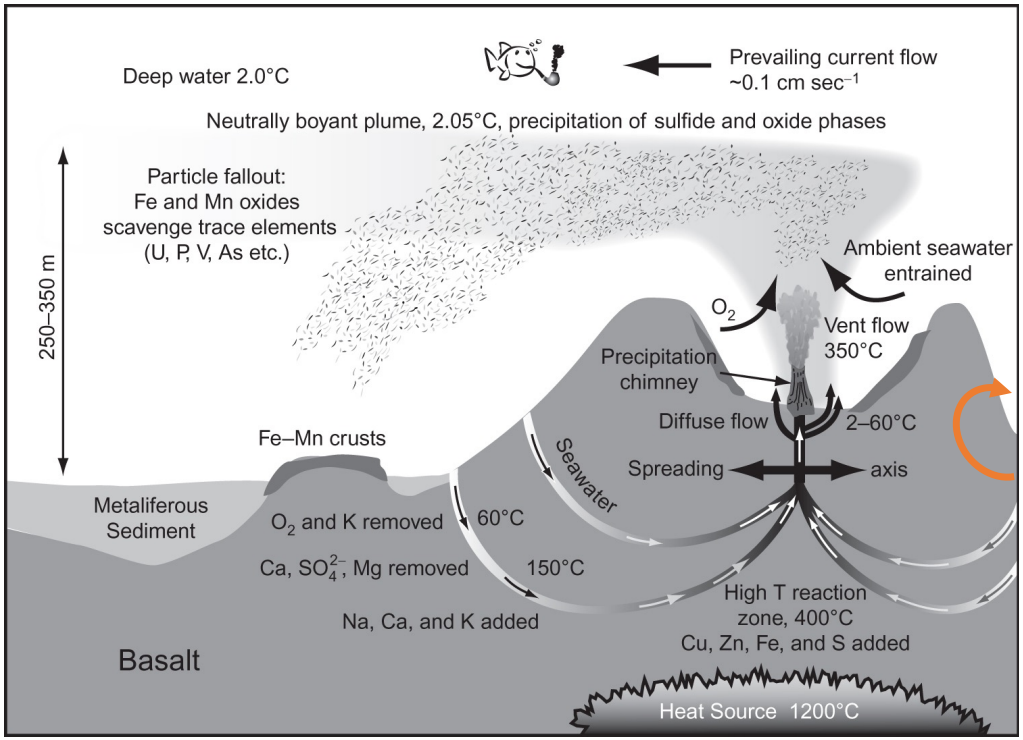


White smokers: Off axis



- If you are too far from the magma source, may still have high heat but no volatiles
- $H_2O + H^+ + MgSilicates\ or\ FeSilicates\ (olivine)$
  - Consumes acid, so pH rises (becomes more basic)
  - Can form Silicate, $CaSO_4$, or $CaCO_3$
    - Remember that when the pH is very high, most of DIC is CO_3^{2-} → so Carbonates can precipitate

White smokers: Off axis

Lost City

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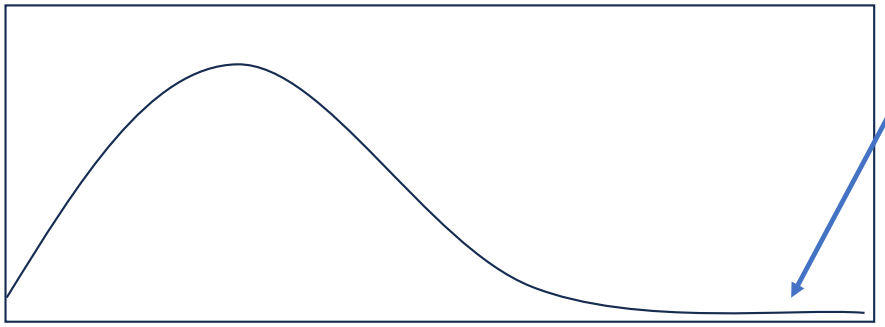
How do we know where hydrothermal vents exist?

- Helium in the atmosphere – 5 ppm
  - Two isotopes ^{3}He & ^{4}He



Some small fraction reaches escape velocity, leaves the atmosphere

- ^{4}He generated through radioactive decay in the crust
  - $^{238}U \rightarrow {}^{206}Pb + 8x\ {}^{4}He$
- ^{3}He released from hydrothermal vents – not generated by anything on earth (all ^{3}He from formation of earth)

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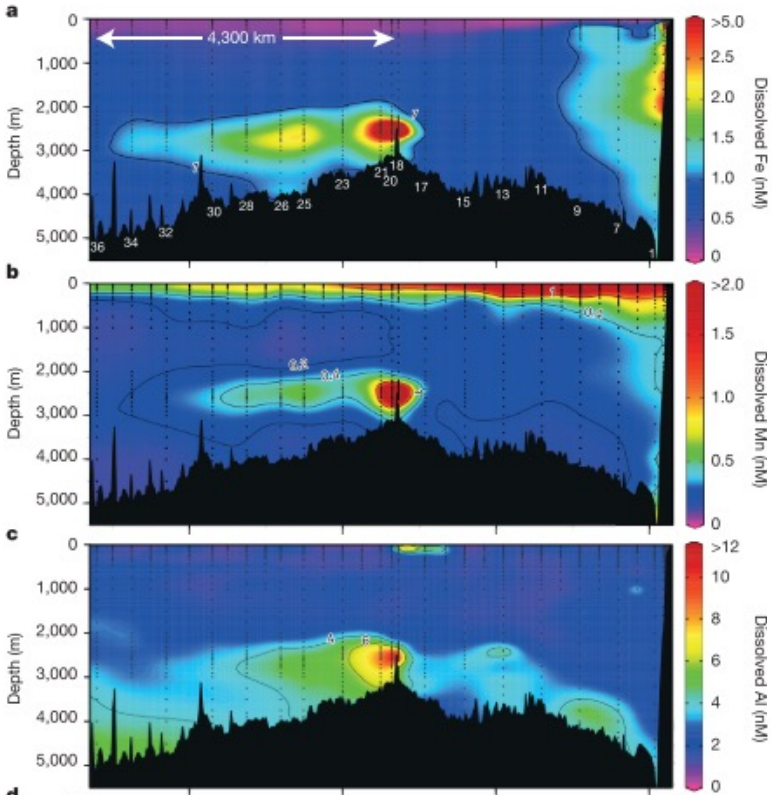
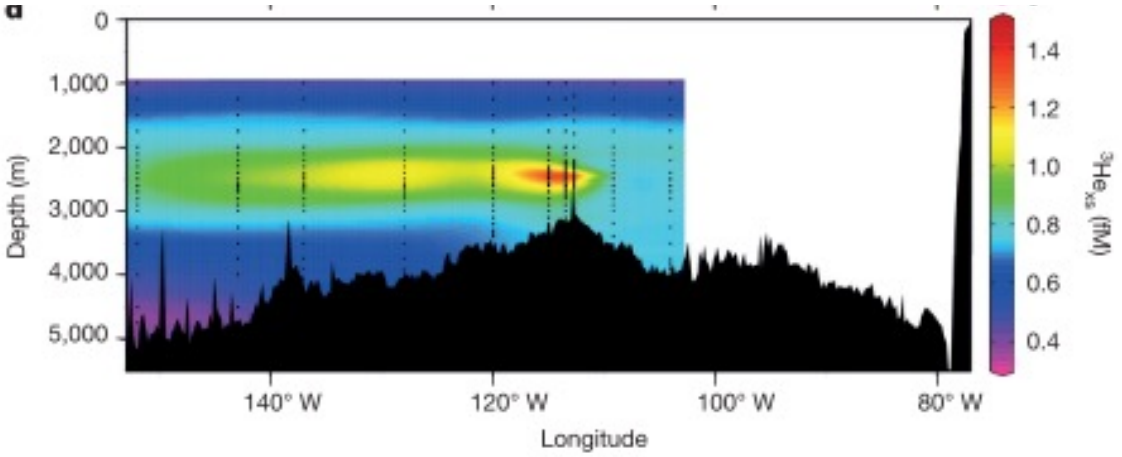
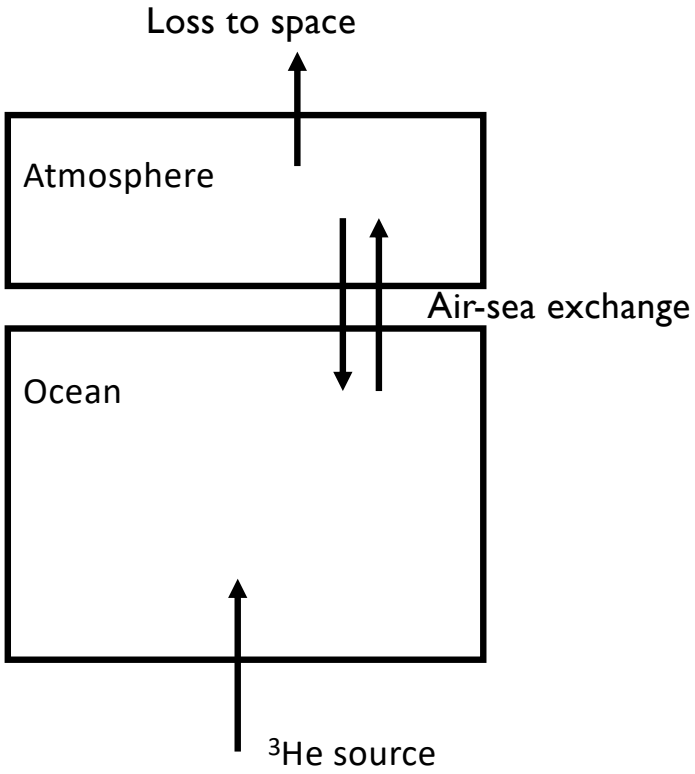


- ^{3}He released from hydrothermal vents – acts as a tracer of hydrothermal release



How much hydrothermal venting is occurring?



- Calculate an inventory of ^{3}He in an ocean basin
- Ocean overturning (~1000 years)

$\frac{\sum {}^3He}{\tau_{ocean}}$ = venting supply

~500-1000 mol ^{3}He/yr

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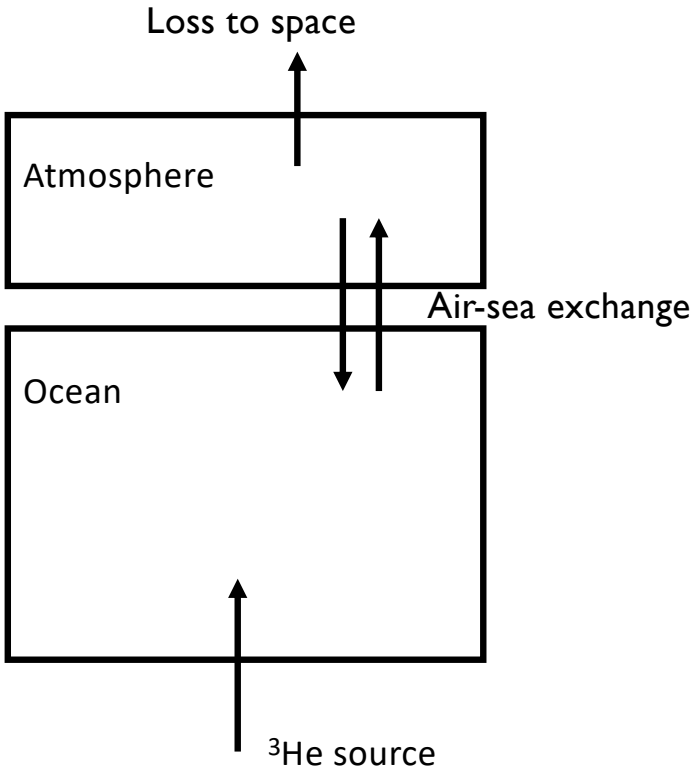

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Can use ^{3}He to then scale other non-conservative tracers

Ex. Hydrothermal Fe flux (J_{Fe})

$J_{Fe,HT} = J_{3He} * Fe/^3He$