Distribution of SMS deposits

Presentation to the

International Workshop for Students "Seafloor Mineral Resources: scientific, environmental, and societal issues"

Helmholtz-Zentrum fur Ozeanforschung Kiel (GEOMAR)

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by

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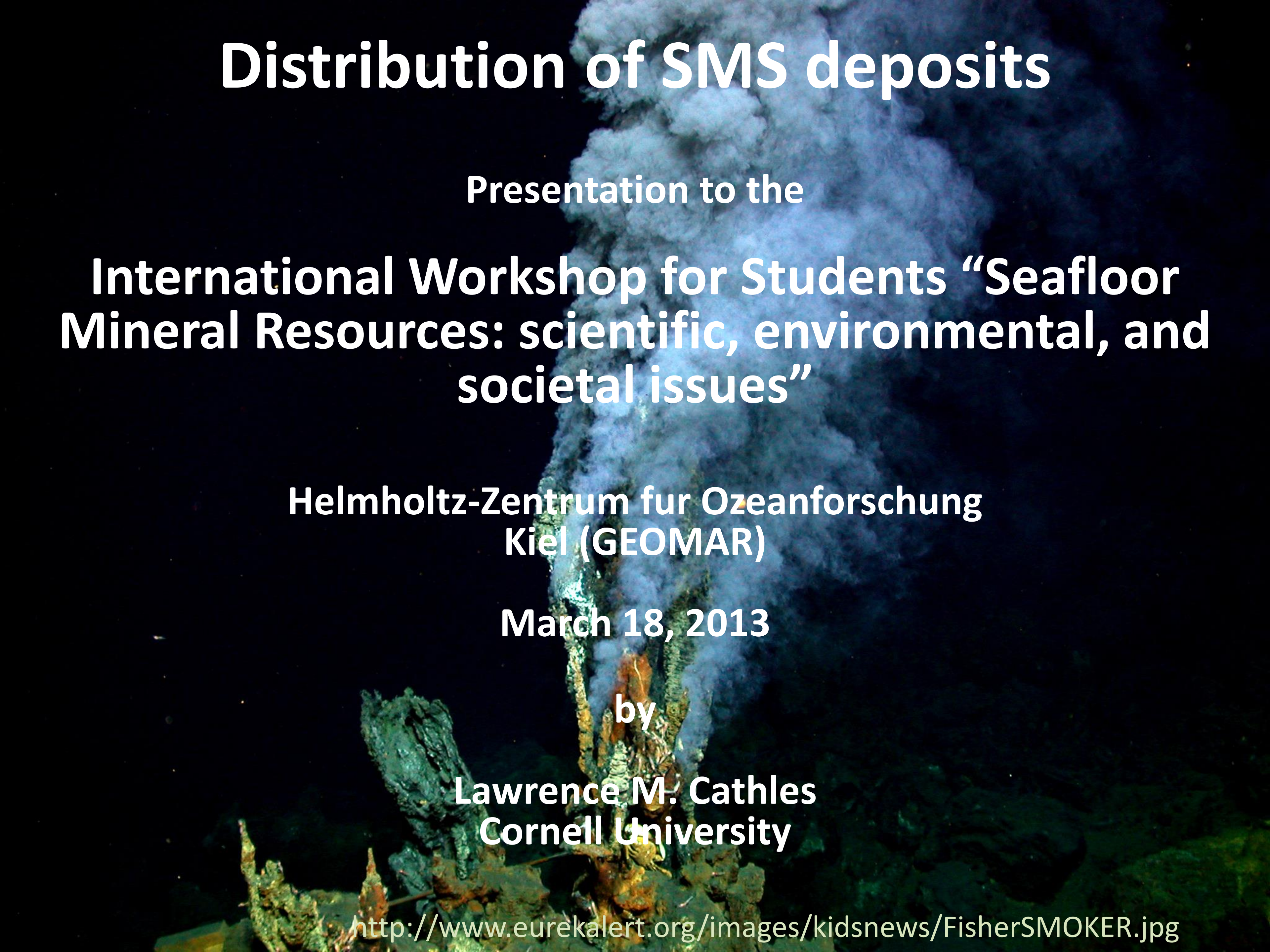
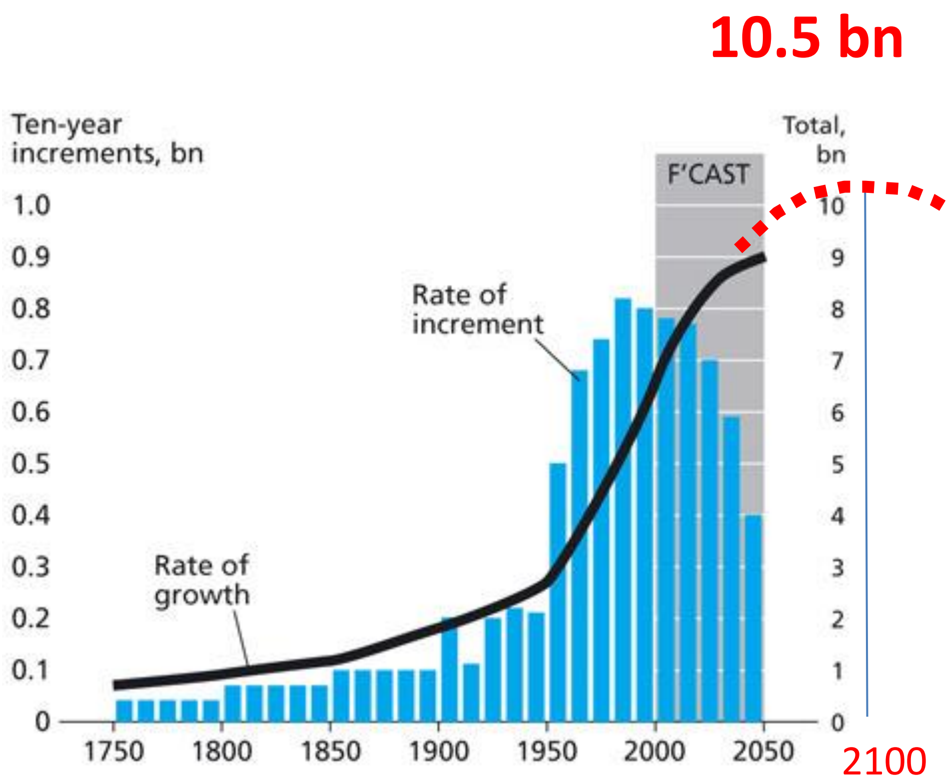


http://www.eurekalert.org/images/kidsnews/FisherSMOKER.jpg

The Grand Challenge:

To supply, indefinitely, the resources to bring 10.5 bn to an EU standard

in and environmentally acceptable fashion



UN Population Division

If not:

- Large fraction of humanity has no future
- No common future
- Fighting over resources

The ocean is the key

Outline

The context

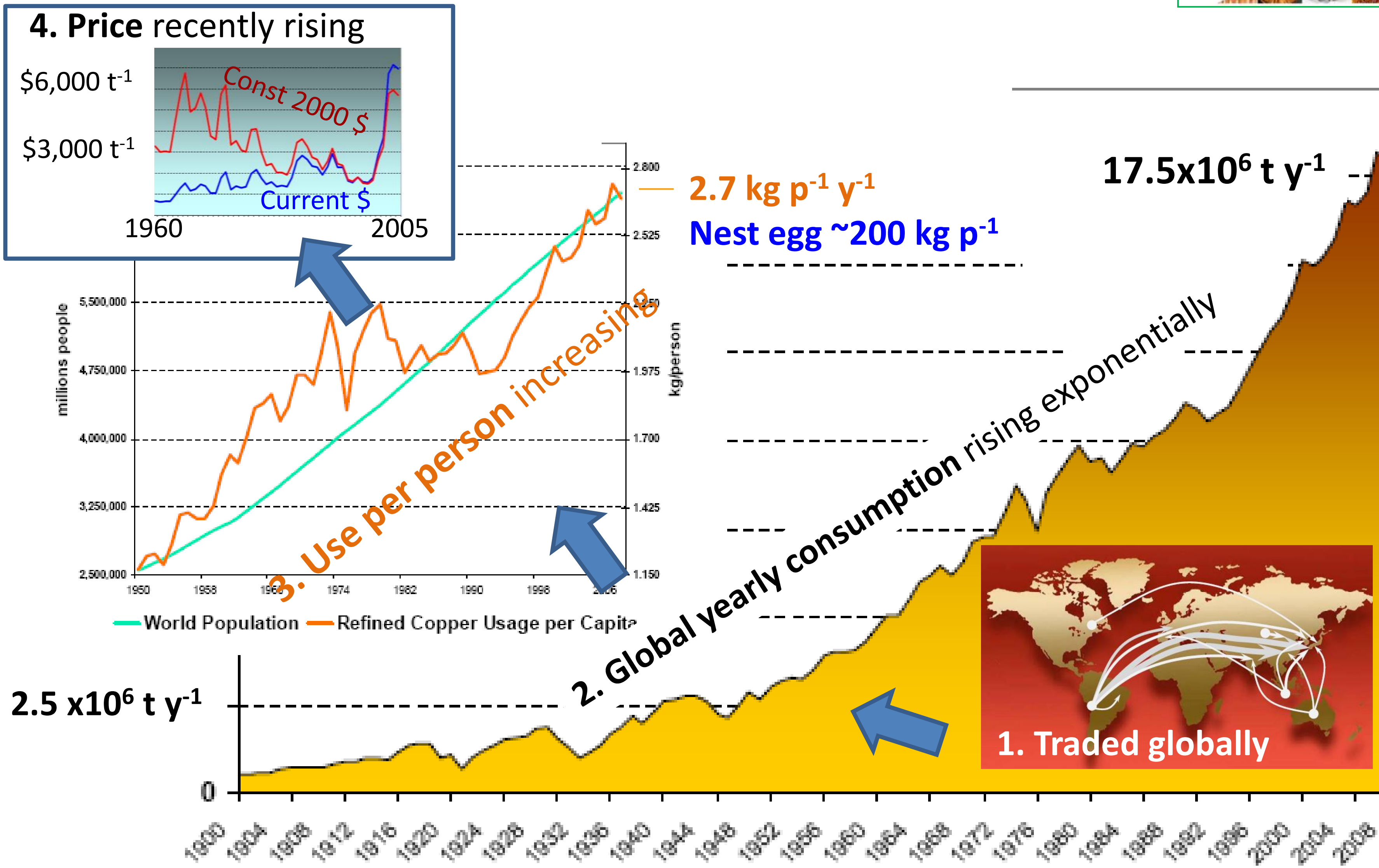
- Resources needed
- Resources available
- Why ocean special for resources
- How to assess resources in long term

Size and distribution of the SMS resource

Conclusions

- SMS only one example (U, Li, …)
- Must look to oceans and be positive and courageous

Copper resources needed



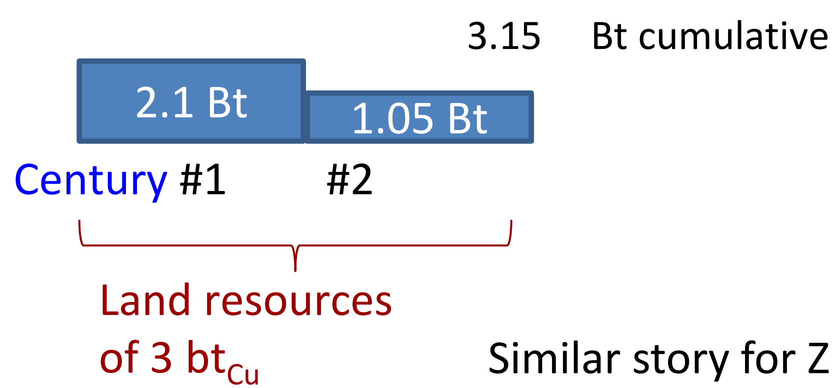
Land Resources of 3 bt_{Cu}

Each person needs nest egg of 0.2 t_{CU}

To bring 10.5 bn to EU standard of living in 100 years Requires: $(10.5\ \text{billion p})(0.2\ t_{Cu}\ p^{-1}) = 2.1\ bt_{Cu}$

To maintain against 50% loss per century requires 1.05 bt_{Cu} every 100 years thereafter

Land resources
will last ~ 200 yrs

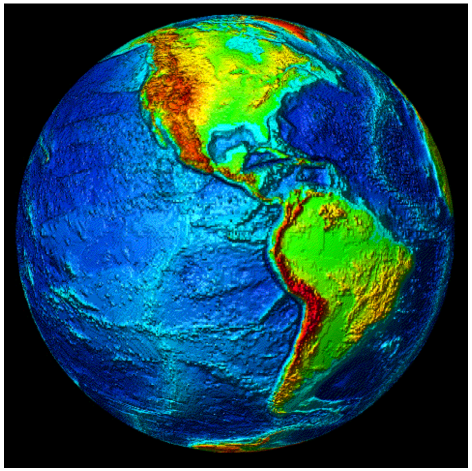


Similar story for Zn

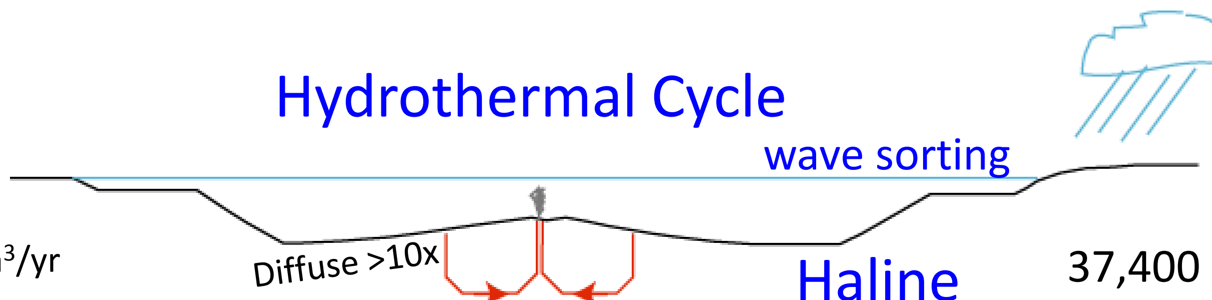
Gordon et al. (2005)

The ocean has 3 Planetary-scale Wagon Trains

+ a gold panning operation



Hydrologic Cycle



Mississippi = 550 km^3/yr
~US water use

500 km^3/yr
(cycle ocean in 2.6 Ma)

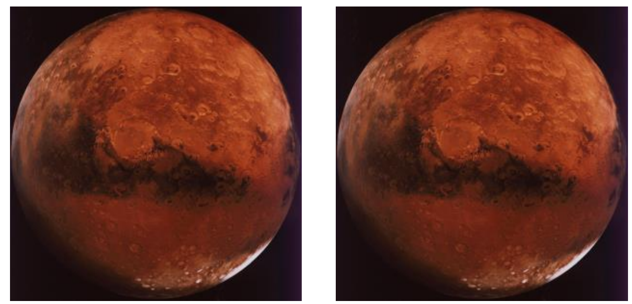
40 Sv*
1,260,000 km^3/yr

37,400 km^3/yr
w/ dissolved
& particulates

*$Sv=10^6\ m^3/s$

The area of the ocean is huge
The ocean is by far our biggest VMS district

Area of ocean =



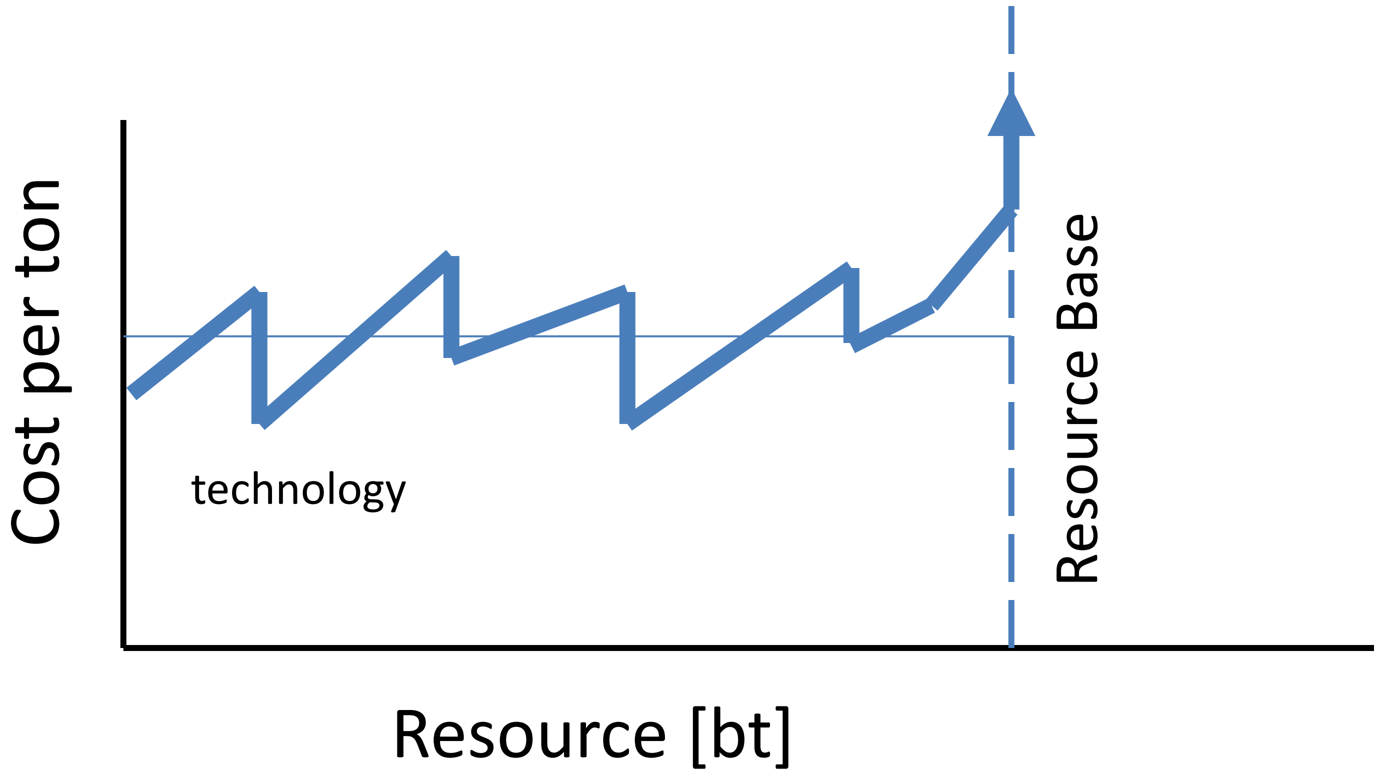
Mars

Moon

The ocean is special in terms of resources

Steve Scott

How do you look at resources long term?

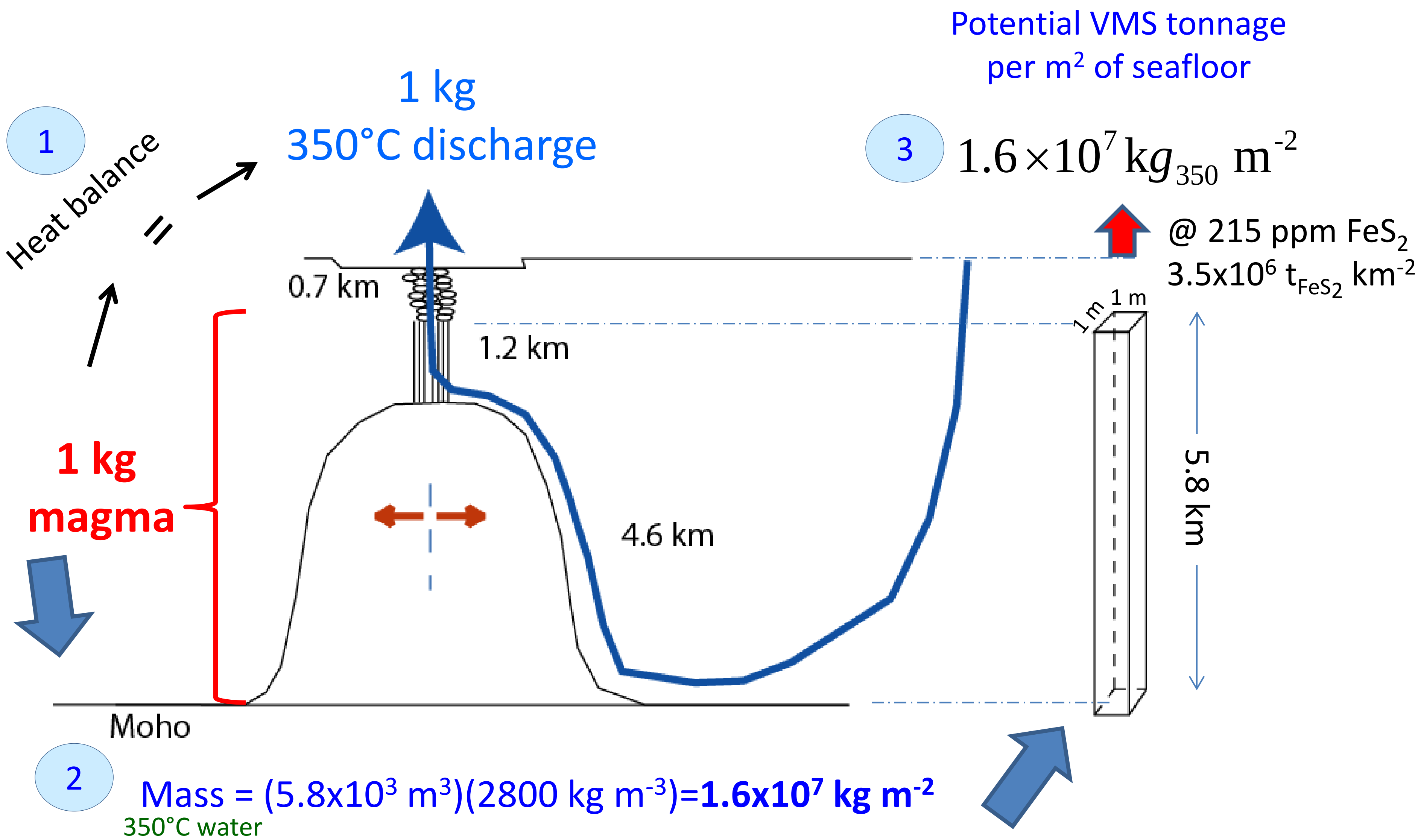


Technology keeps price ~constant until resource base exhausted

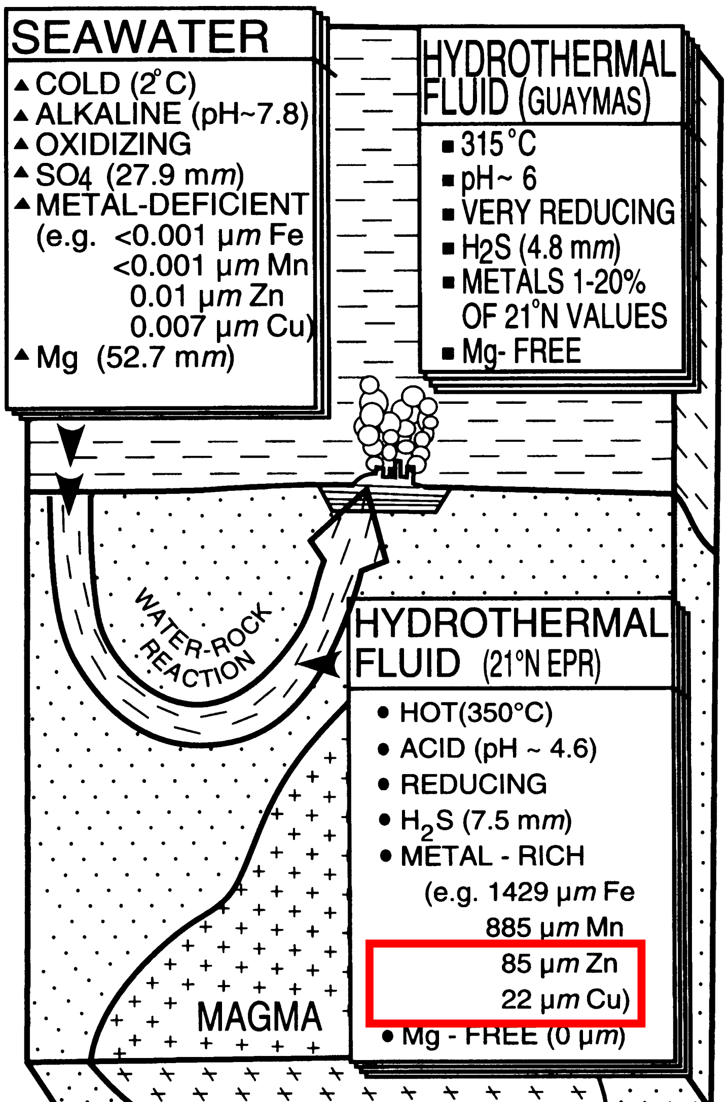
Resource base = what can be conceivably produced

Rognar (1997)

Estimating the SMS Cu Resource



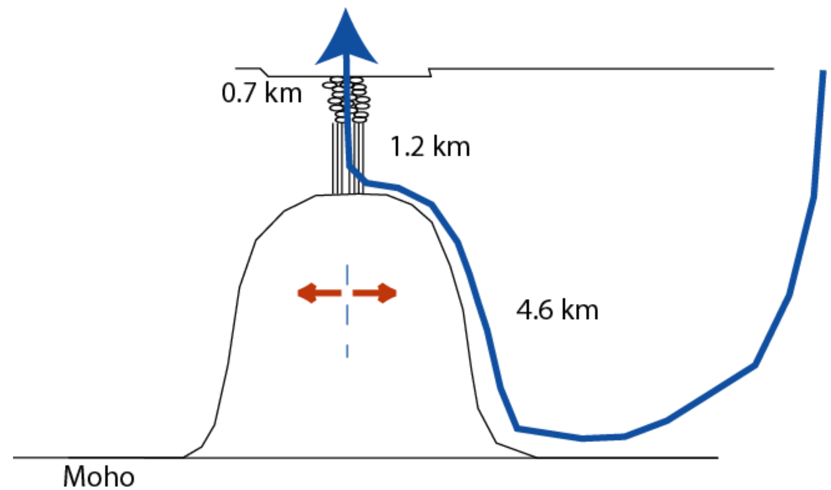
The ocean VMS resource



Scott (1997)

$$\underbrace{\left(1.6\times10^{7}\right)}_{\mathrm{kg}_{350}\,\mathrm{m}^{-2}}\begin{pmatrix}\underbrace{(85)}_{\mu m_{Me}}\underbrace{(0.0650)}_{\mathrm{kg\,mol}^{-1}}\\(22)(0.0635)\end{pmatrix}\underbrace{(0.03)}_{\text{accum. eff.}}=\underbrace{\begin{pmatrix}2.65\\0.67\end{pmatrix}}_{\mathrm{kg}_{Me}\,\mathrm{m}^{-2}}\begin{matrix}\mathrm{Zn}\\\mathrm{Cu}\end{matrix}$$

Zn+Cu =3.32 kg m^{-2}



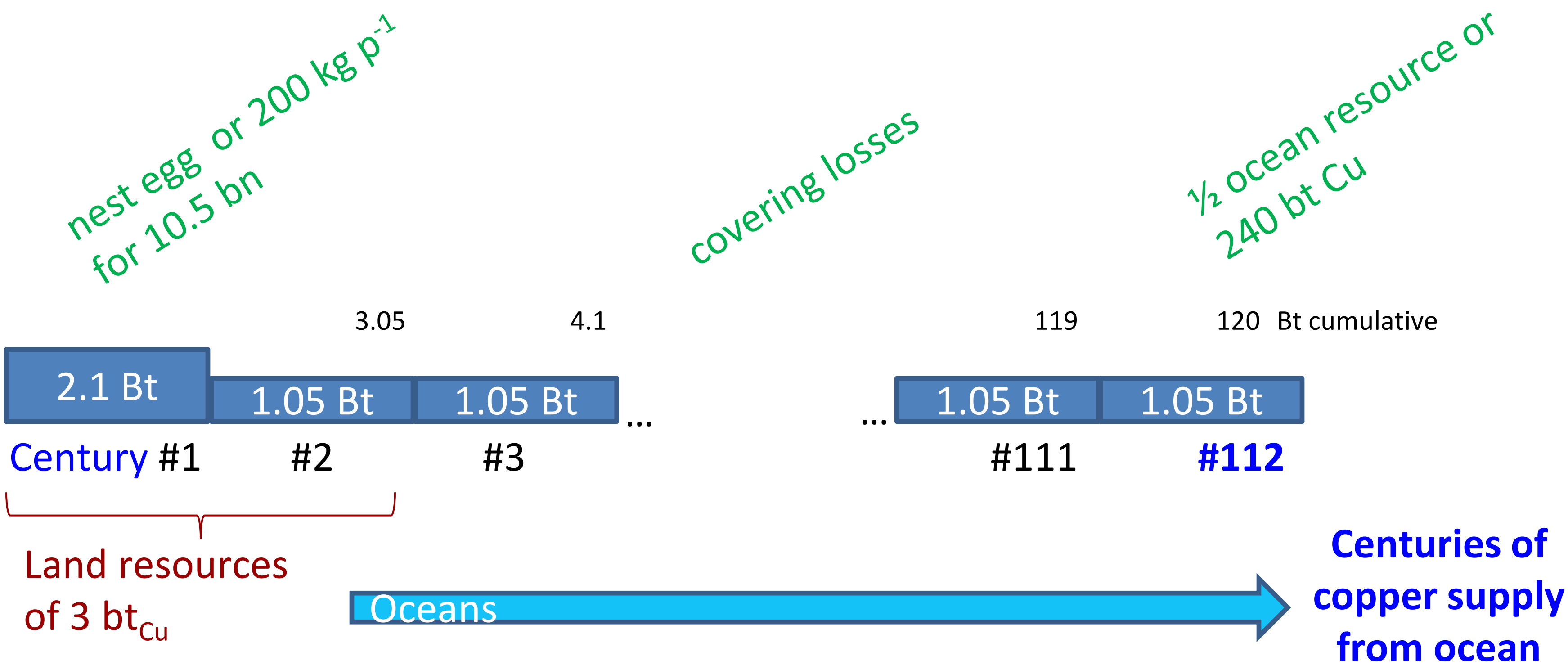
$A_{ocean} = 3.6\text{x}10^{8}\ km^{2}$

Ocean Resource =

$$\begin{matrix} Zn & & 954\,\mathrm{bt}_{Zn} \\ Cu & = & 241\,\mathrm{bt}_{Cu} \\ Zn+Cu & & 1200\,\mathrm{bt}_{Cu+Zn} \end{matrix}$$

~10 x land Cu resource of 3 mt

½ SMS Cu Resource Sustains 10.5 bn for 112 centuries at EU standard

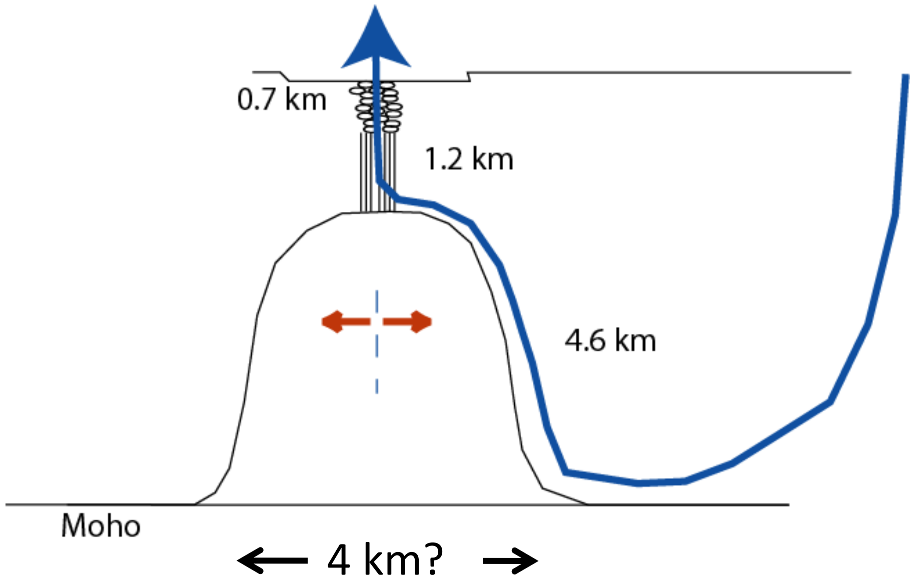


Same for Zn

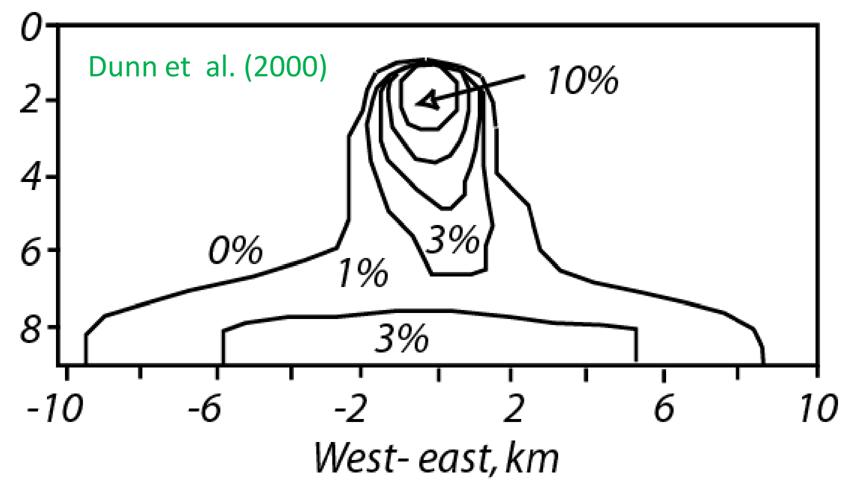
… much longer if losses decreased

A path forward, SEG Newsletter #83, 2010

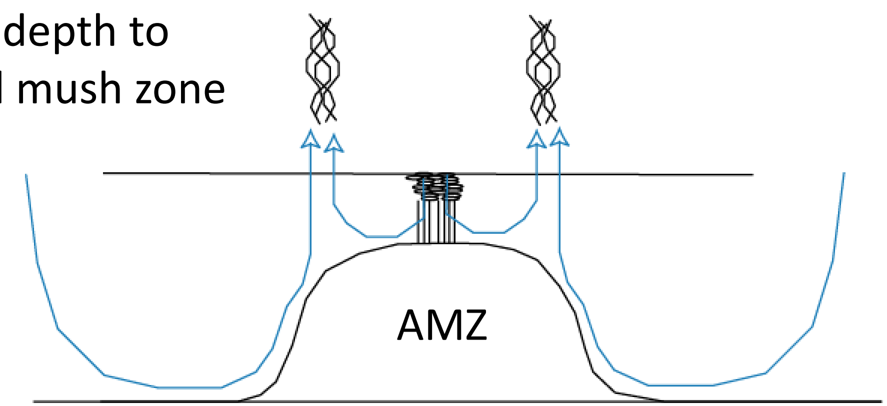
Confirmation of Narrow Melt Zone



Seismic tomography at 9°30'N EPR



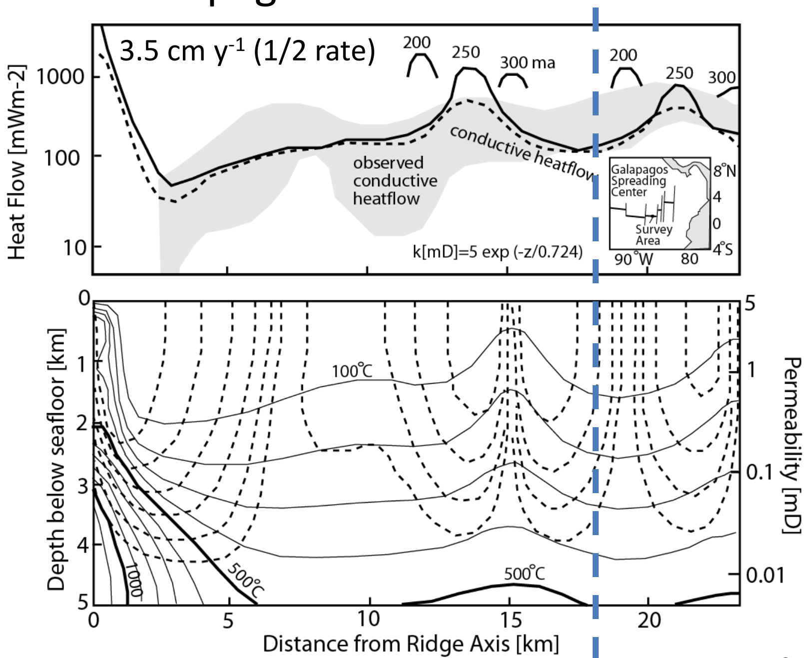
Off-axis smokers if width > 2x depth to top of axial mush zone



Mineralium Deposita DOI 10.1007/s00126-010-0292-9

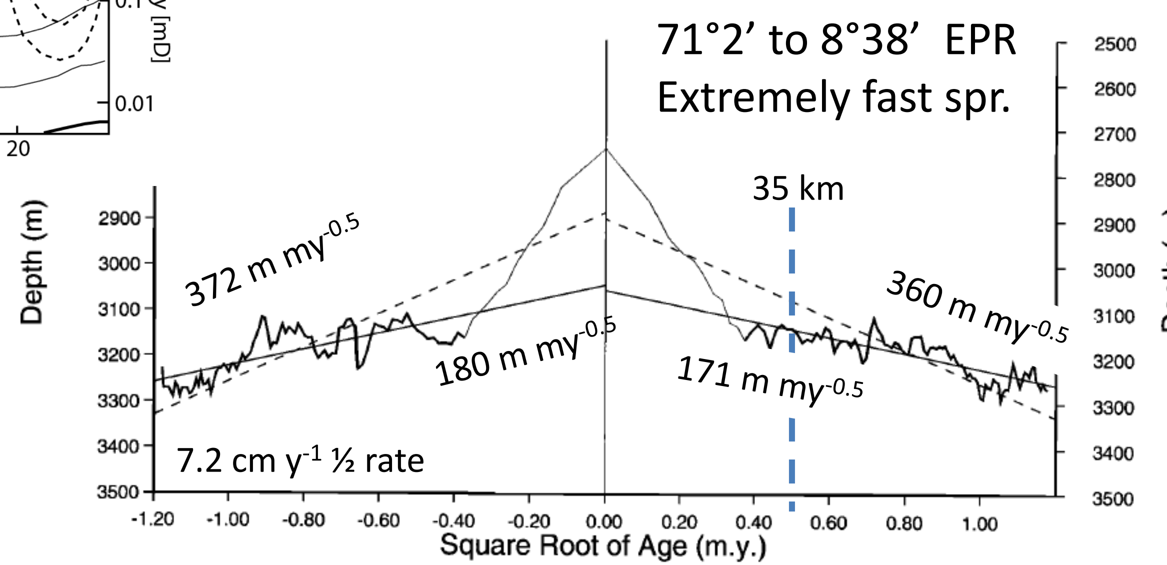
Confirmation of complete crustal cooling near ridge

Galapagos



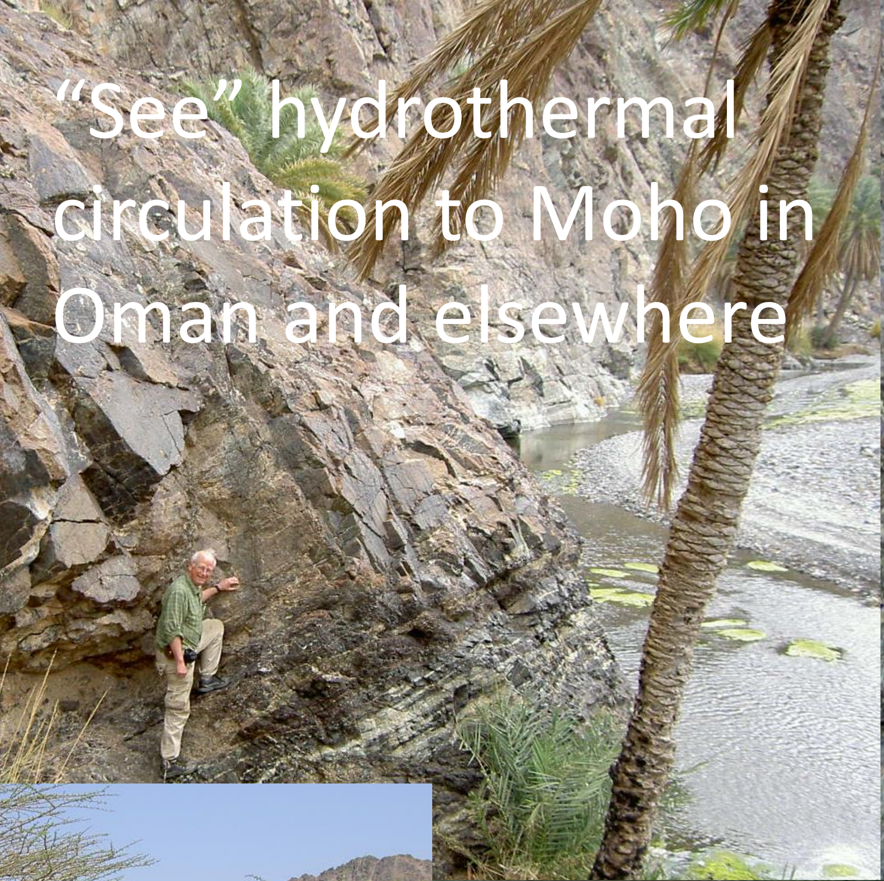
0.5 ma

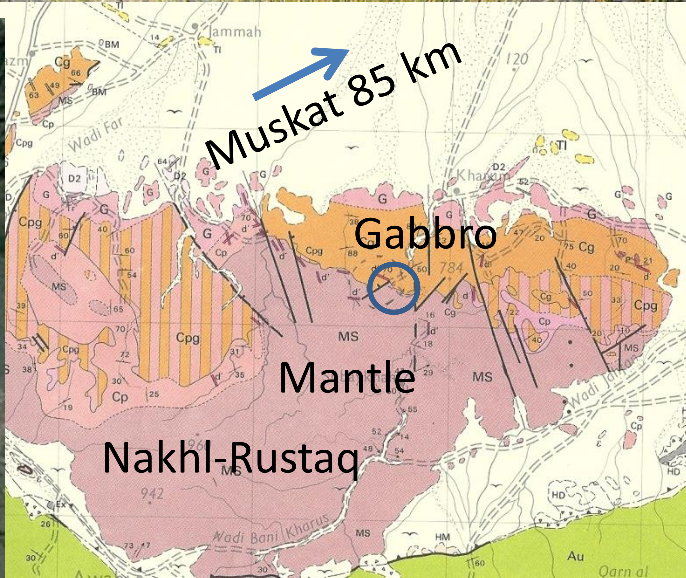
Retarded subsidence indicates cooling at ridge axis followed by re-heating at intermediate-, fast-, and extremely fast-spreading ridge segments



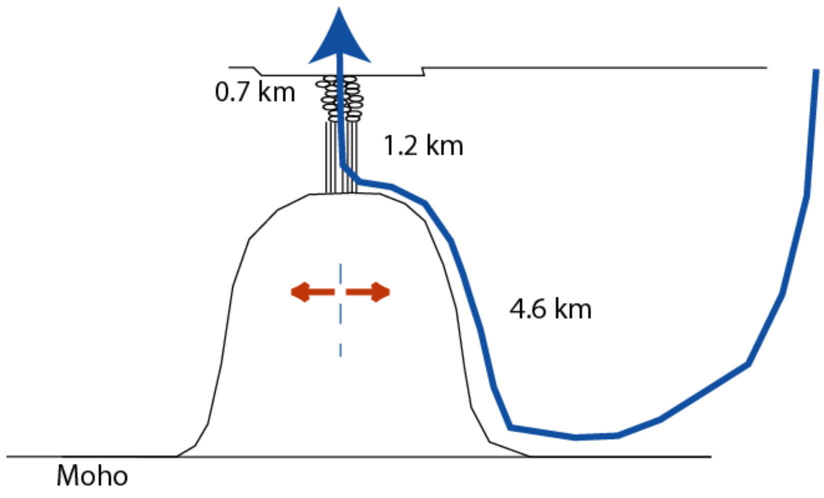
Cochran and Buck (2001)

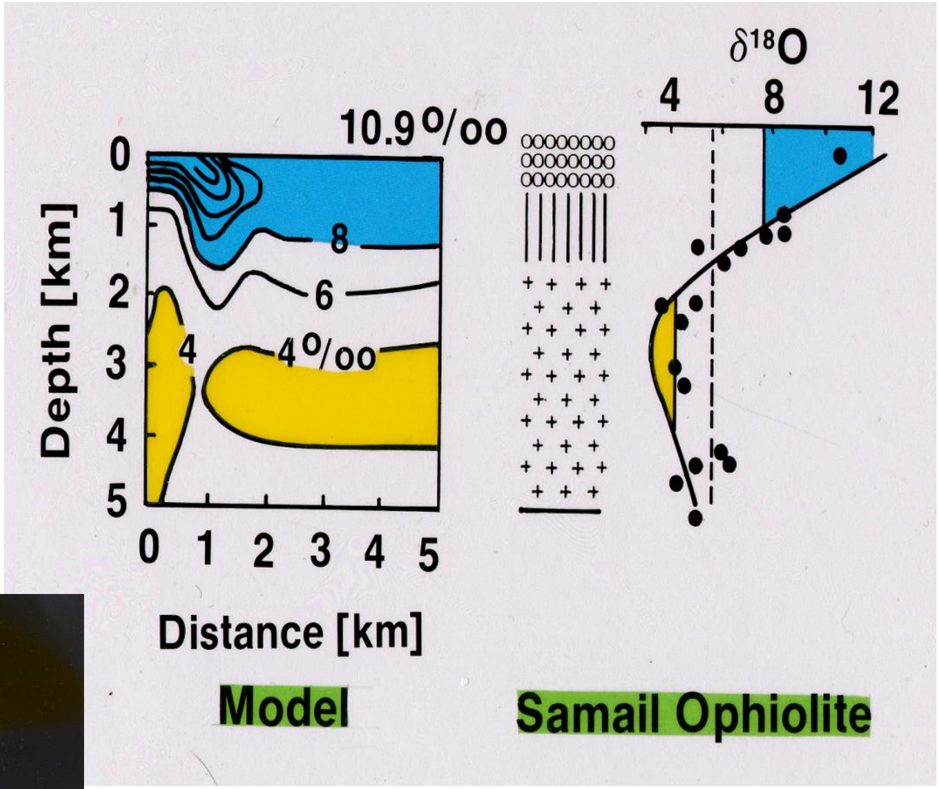
"See" hydrothermal circulation to Moho in Oman and elsewhere



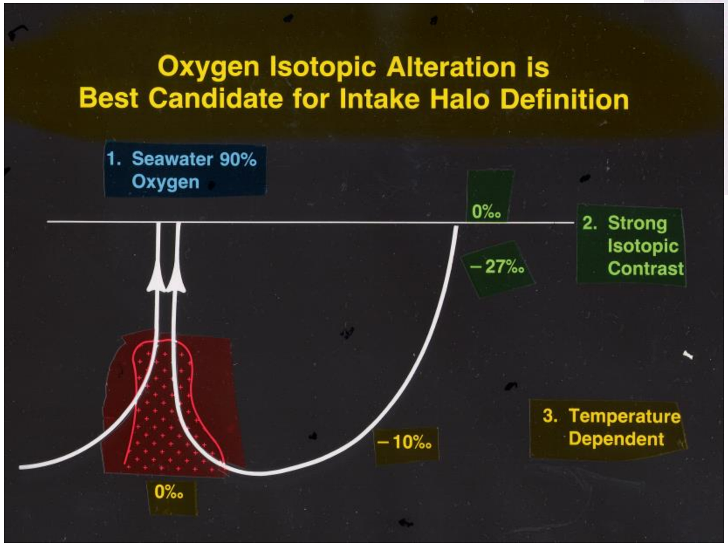


^{18}O Profile reflects circulation to Moho





Cathles (1993)



Accumulation factor

- 3% at 21N on EPR (Converse et al., 1984)
- Compatible with mined VMS districts (Sangster, 1980)
- Gives observed deposit sizes at Matagami (Carr et al., 2009)
- Probably biologically controlled and increasing with time
- Slow, diffuse venting increases
- Silicate replacement extreme example (Galley et al, 1985)

… there is a lot of uncertainly in this parameter

The magmatic curve ball

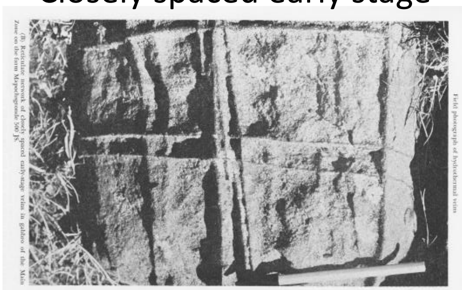
Hydrothermal and magmatic systems intermingled

Magmatic fluids could source metals

Back-arcs could be special

Ribbing

Closely spaced early stage

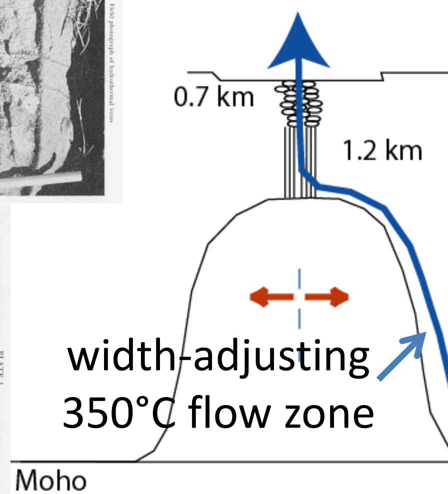


Early/no halo

>600ºC Ca-amphib w/ 5wt% Cl

0.5-5cm wide, 10 m long

0.2 TO 2 m^{-1} frequency

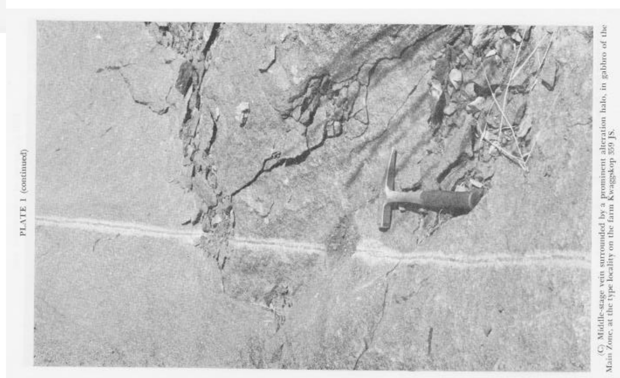


Late stage

<300ºC pren-pump-qtz

1 mm wide with wide alt halos

<10 to >100 m^{-1} frequency

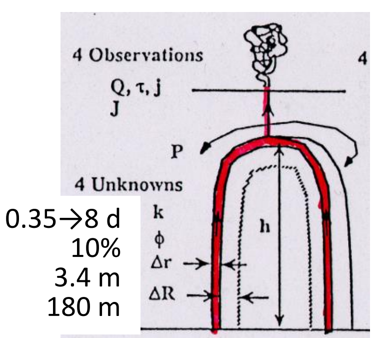


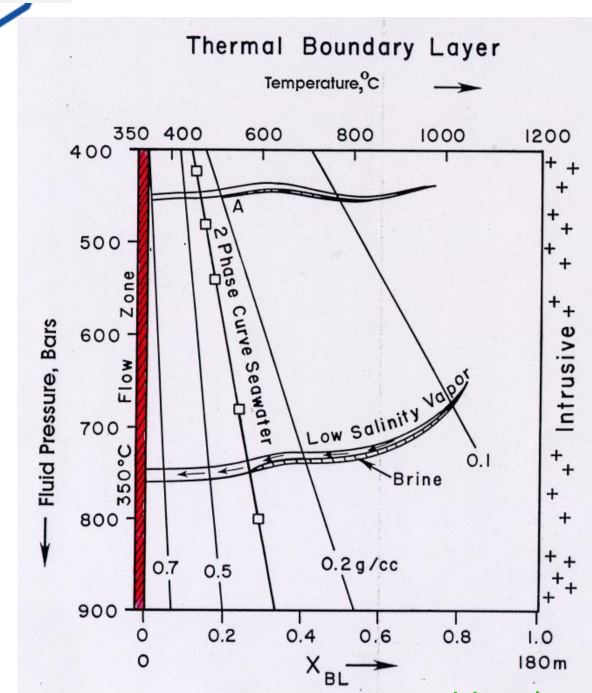
Middle/small halo

600-300ºC hydroth cpx

0.5-5cm wide, 20 m long

0.2 to 2 m^{-1} frequency

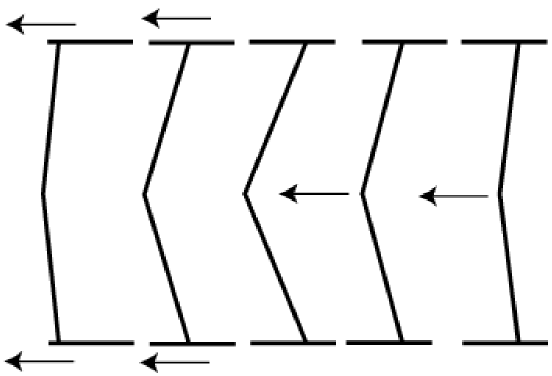




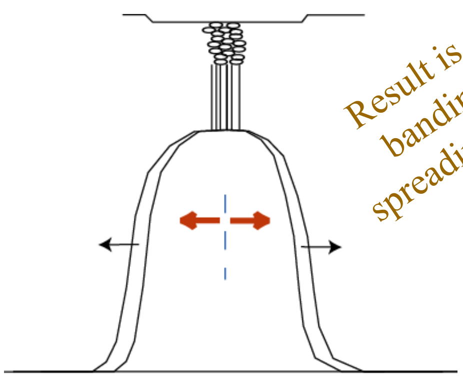
Cathles (1993)

SMS distribution and size

Spreading episodicity:
flapping of butterfly wing



Hydrothermal consequences of spreading pulse reach seafloor well after extrusive magmas

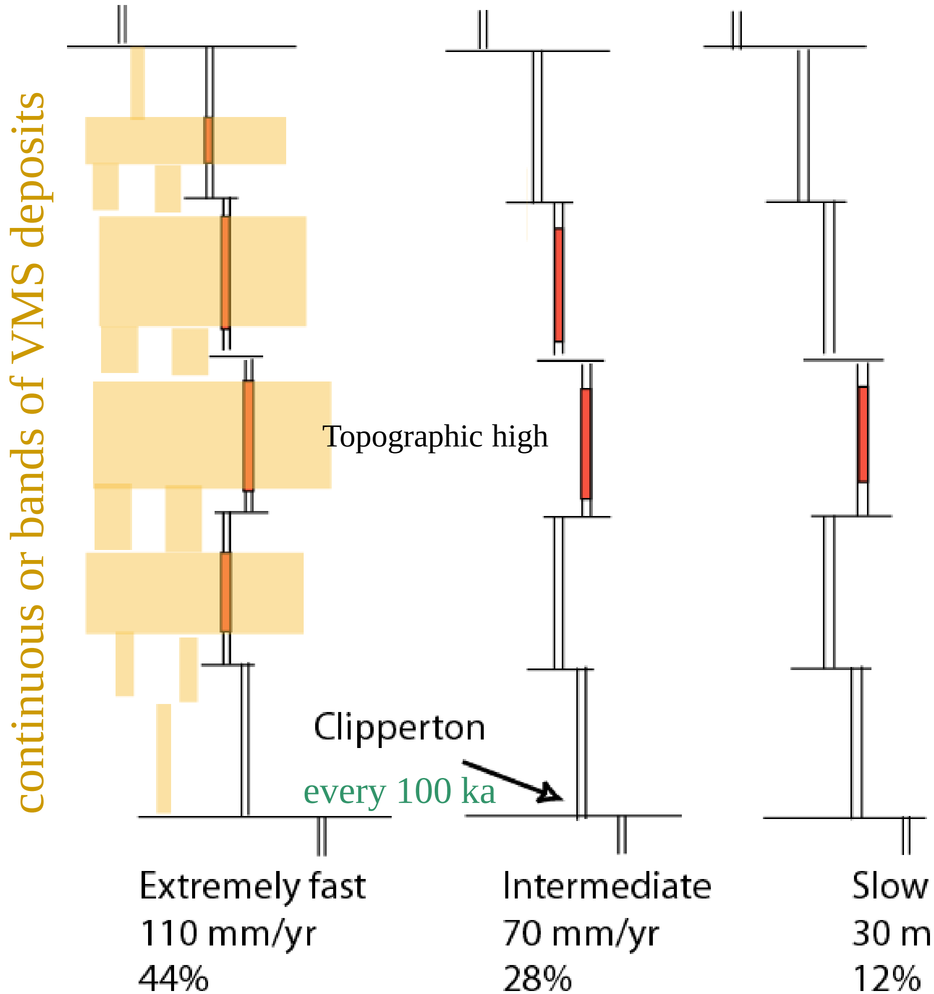


Result is deposit banding where spreading is episodic

A question of distribution and size but not amount

% black smokers = 0.004 (full spr rate [mm y^{-1}])

Baker et al. (1996)



* (One 20 km transf spr event / 89,000 km ridge) 30 yrs = 130,000 yrs

Less Environmental Impact

- Mobile infrastructure
- Surgically mine smaller deposits
- Greater safety
- Less environmental damage
- More equitable access

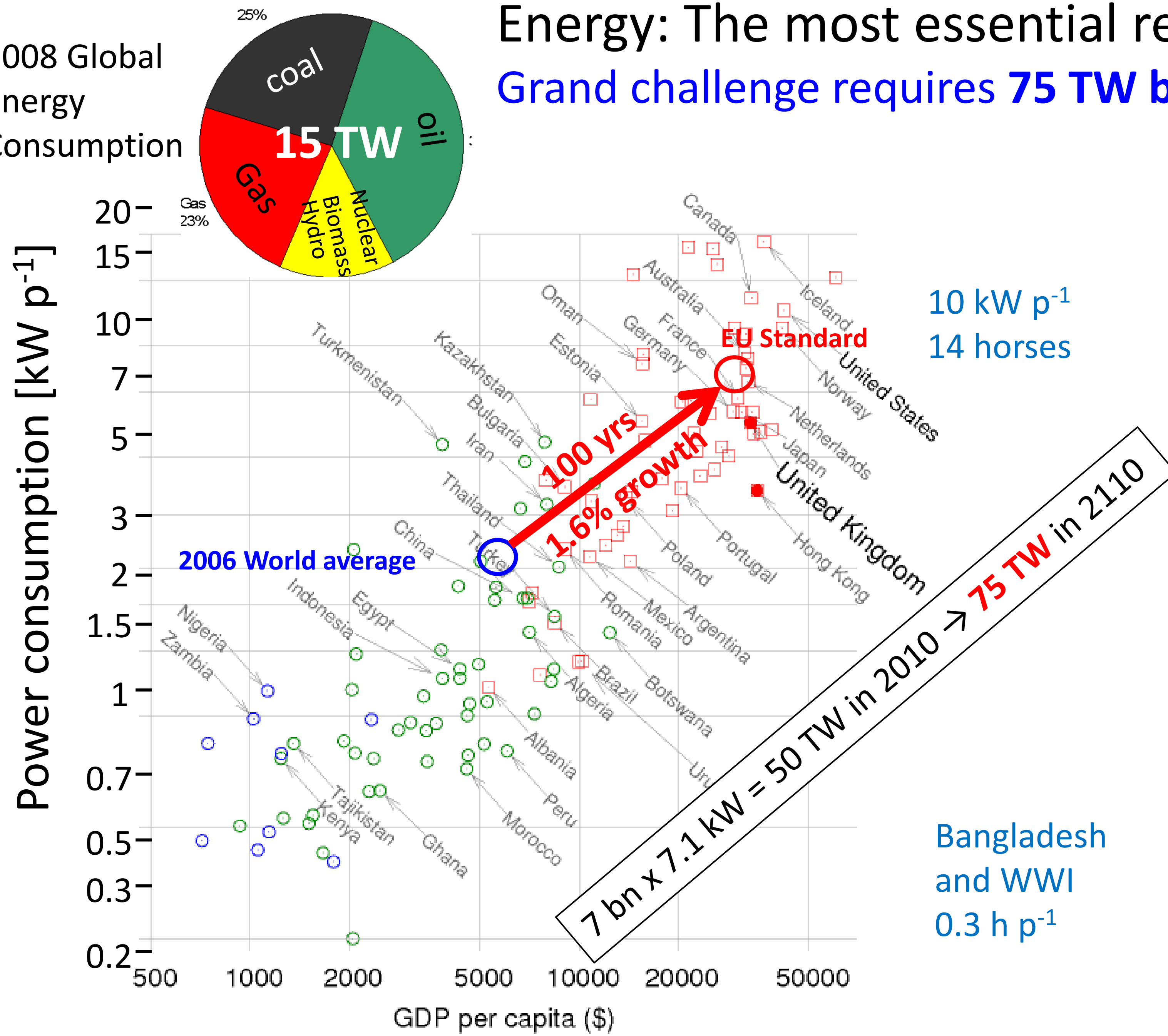
No acid mine drainage, tailings, old underground workings, surface disruption…

Nautilus Minerals (Smith presentations)

Energy: The most essential resource

Grand challenge requires **75 TW by 2100**

2008 Global Energy Consumption



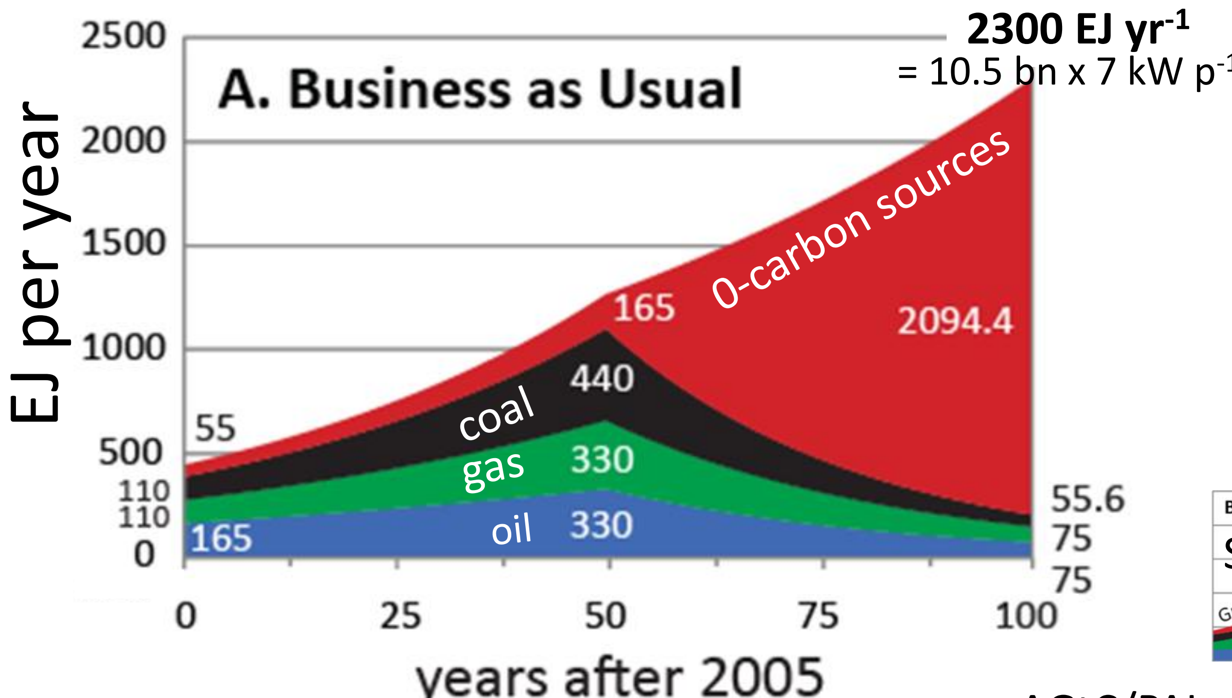
10 kW p^{-1}
14 horses

Bangladesh and WWI
0.3 h p^{-1}

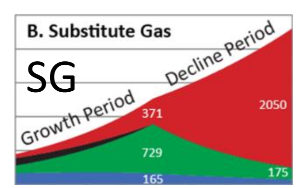
B as U consumes ~50% of O&G resource base

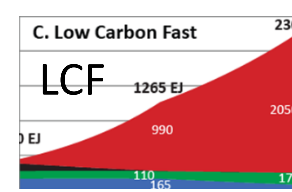
Rogner's Resource Base

Commodity	Resource Base (PAL = 595 GtC)		
	Conventional Units	Gtoe	GtC/PAL
Gas	33,852 tcf	870	0.9
Oil	6066 Gboil	814	1.2
Coal	5041 metric tons	3400	6.6
TOTAL		5209	8.8



Fuel	%RB
Gas [tcf]	50%
Oil [Gbbl]	59%
Coal [Gt]	15%
GtC/PAL	2.13





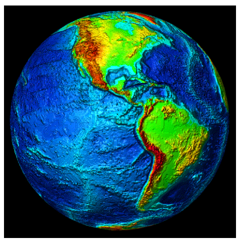
ΔGtC/PAL **-0.56** -1.22

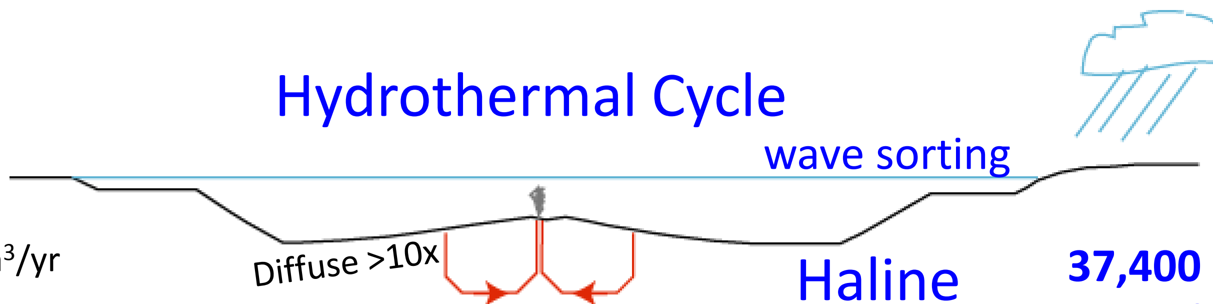
SG = 46% LCF

GtC = 10^9 tons carbon
EJ = 10^{18} joules
PAL = pre-industrial atmos level of C

⇨ Must move to low-C sources

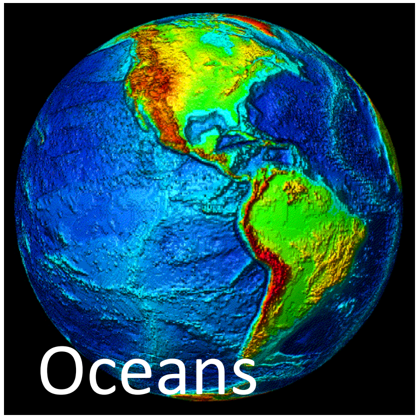
Nuclear the best low-C option
Ocean has needed U resources





The hydrologic cycle has accumulated a huge U resource in the oceans

	U_3O_8 (10^6 t)	U (10^6 t)
Reserves	4.7	3.9
Resources	35	28.7
Dissolved in Ocean (3.3 ppb)		4600



50% ocean resource

$$\left(2.3\times10^{9}\,t_{U}\right)\left(0.0071\,t_{^{235}U}\;t_{U}^{-1}\right)\left(0.25\,\text{conv. to ele}\right)\left(2/3\right)\left(81.7\times10^{15}\;J\,t_{^{235}U}^{-1}\right)=2.2\times10^{23}\;J$$

burned in reactor

$$\text{supply}=\frac{2.2\times10^{23}\;J}{75\times10^{12}\;J\,s^{-1}}=94\text{ yrs}$$

Need breeder reactors

$$\text{breeder}=94\text{ yrs}\times100=94\text{ centuries}$$

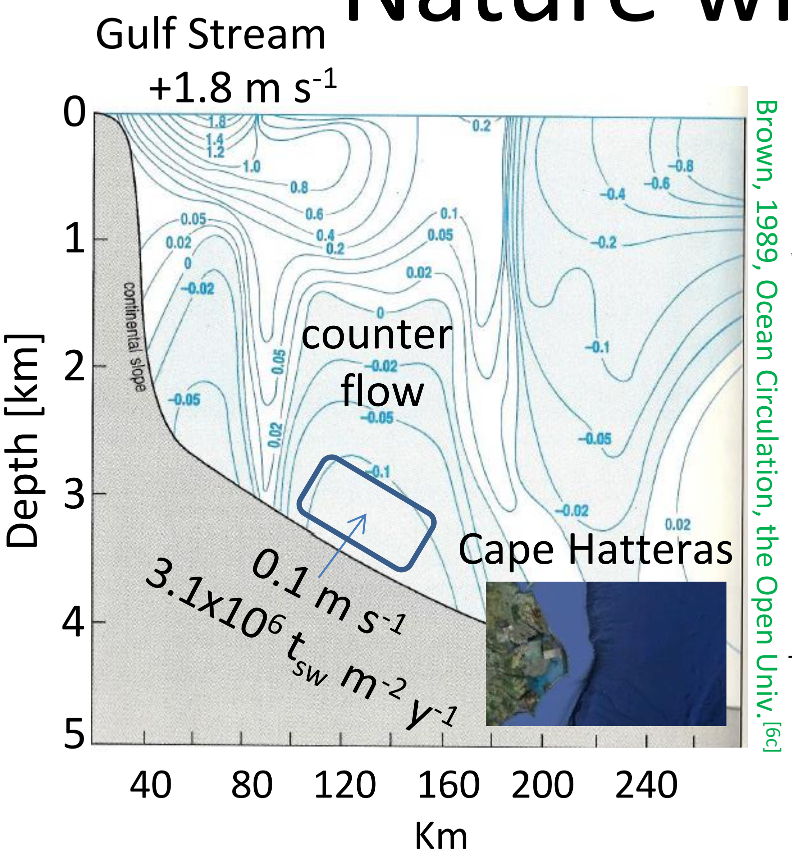
⟵ Assuming population steady at 10.5 bn

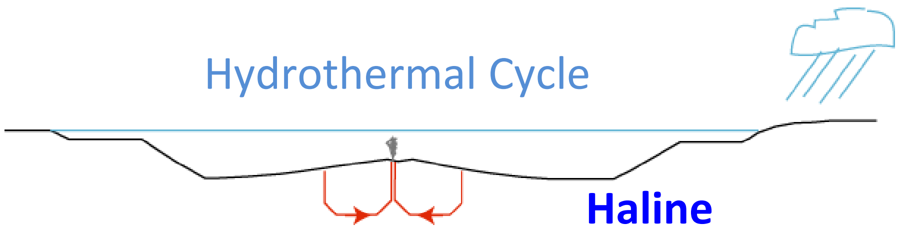
Does not count Th reactors

Or that in a few centuries we will have fusion power

Fuel is in oceans

Nature will extract it for us





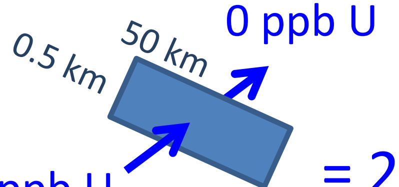
To supply 10.5 bn at 7 kW p^{-1} (EU std)

75 TW, seconds per yr

$$\frac{(75\times10^{12})(3.15\times10^{7})}{(0.0071)(0.166)(81.7\times10^{15})(100)} = 2.4\times10^{5}\ t_U\ y^{-1}$$

$^{235}U/U$ conv to ele J/tonne ^{135}U breeder

Can extract



= $2.5\times10^5\ t_U\ y^{-1}$

$(3.1\times10^6)(3.3\times10^{-9})$
$= 0.01\ t_U\ m^{-2}\ y^{-1}$

Extraction piloted already

3.3 ppb U in seawater

Current price **\$130/kg**
\$52/lb U_3O_8

0.35 t fabic recovered 1 kg U in 240d submersion (Seko et al., 2003) at **\$240/kg U** (IAEA, Uranium 2003)[8]

Ocean resources

Dissolved

Salt

Br

Mg

U (3 ppb)

Li (170 ppb)

Placer

Sand and gravel

Diamonds

Ti, Sn, Au, lime

largest marine mining (Indonesia)

Precipitated

Phosphate

Ferromanganese Crusts

Mn Nodules

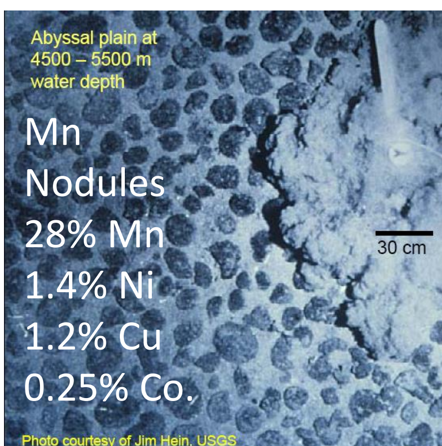
SMS

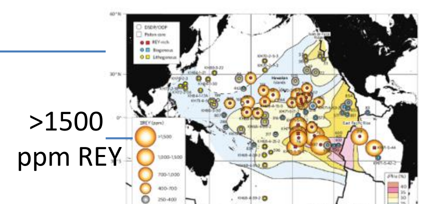
REE

Oil, Gas Hydrates

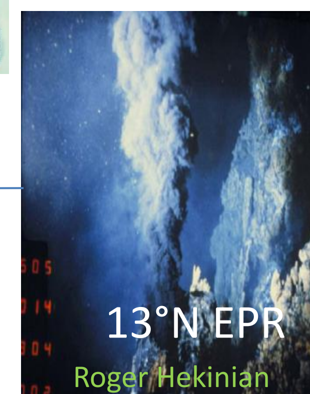
Mn crusts, Jim Hein USGS

1% Co, Ni, Cu, Mo, PGE, REE, Zr,Te



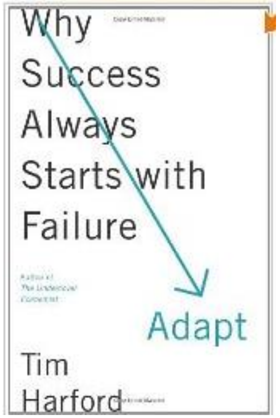


MOR oxyhydroxide sediments



Mero (1969)

Must look to the oceans



Accept grand challenge of 10.5 at EU std

Prepare to tap oceans wisely

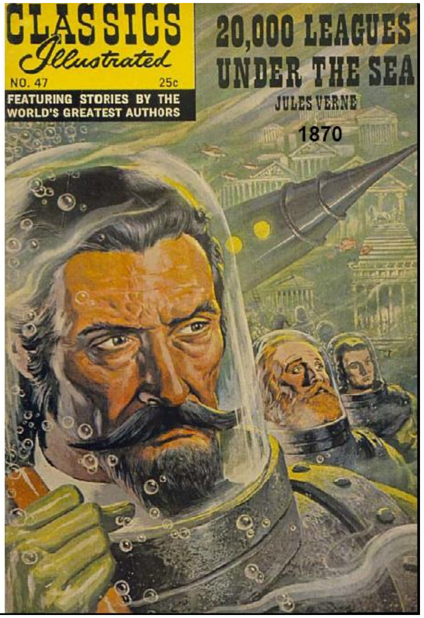
Accept risks and manage them

Solve problems don't just raise them

If we do this the future will be very bright indeed
… and we will learn a lot

=

"… in the ocean depths, there are mines of zinc, iron, silver and gold that would be quite easy to exploit"



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