Finding Real Magma

and real peace through tsunamis and eruptions

John Eichelberger
Dean of the Graduate School, University of Alaska Fairbanks
Vice President Academic, University of the Arctic

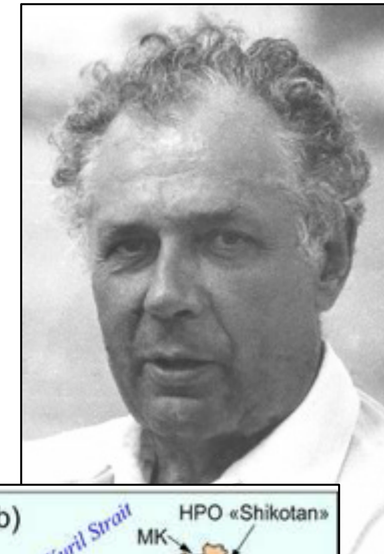
A personal note

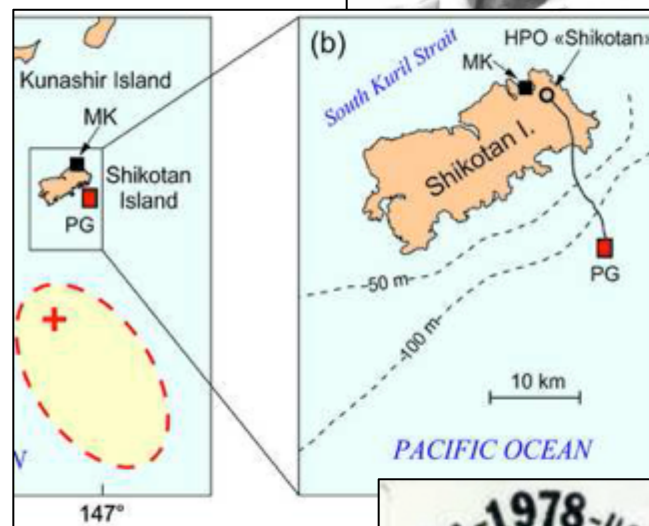
This unexpected award caused me to look into the career of Sergey Soloviev.

- He was at the forefront on the theory, risk assessment, and direct monitoring of tsunamis.
- He was a champion of international collaboration.

Following his lead:

- I will talk about the need for direct monitoring of magma and the continued importance of Russia – United States collaboration.





About magma and kinds of knowledge

- In evaluating volcano hazards and forecasting eruptions, what if we knew the location and conditions of storage of magma?
- There is a big difference between consensus – we agree where magma is - and real knowledge – we know where magma is.

Analogies

Seismic inference vs. seafloor pressure detection of tsunami wave.

Seismic inference vs. drilling confirmation of oil & gas reservoir.

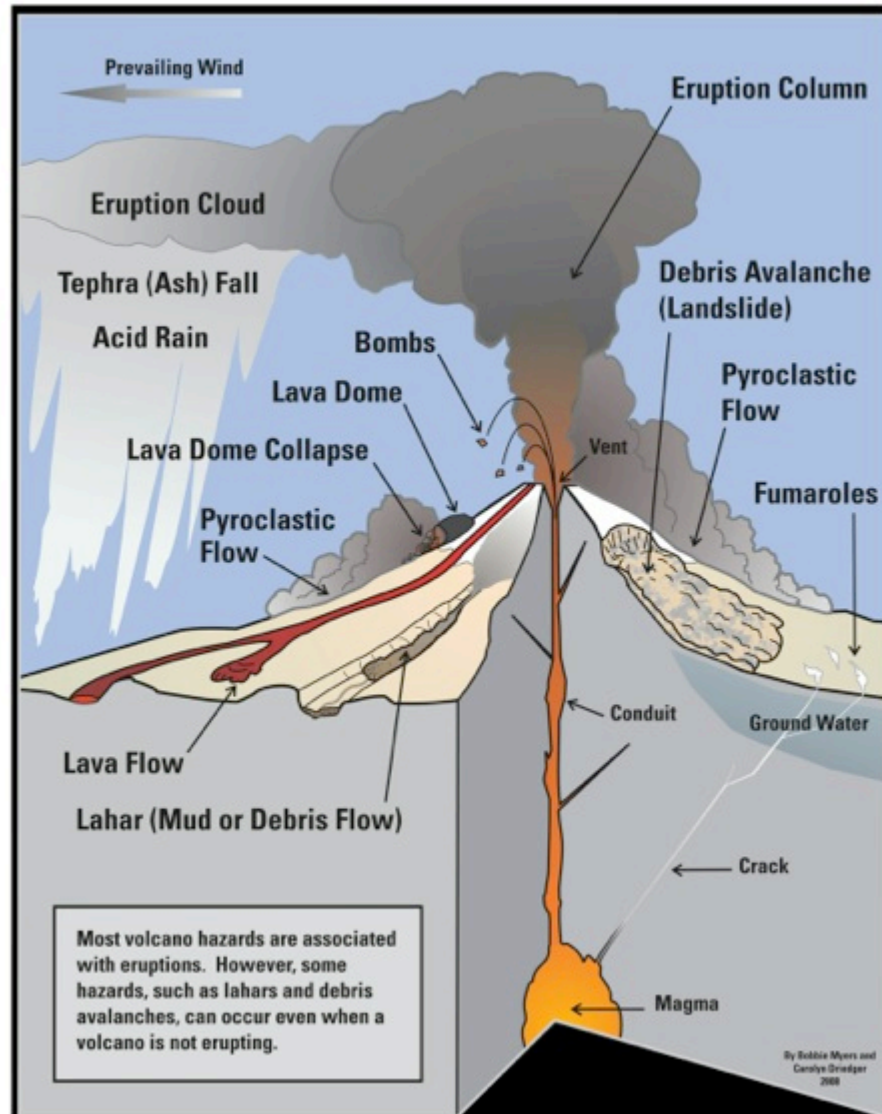
Importance

When huge assets are at risk, money or human life, real knowledge is required.

What if we knew where magma is located under a volcano and its current state?

- Such information would transform volcanology.

USGS



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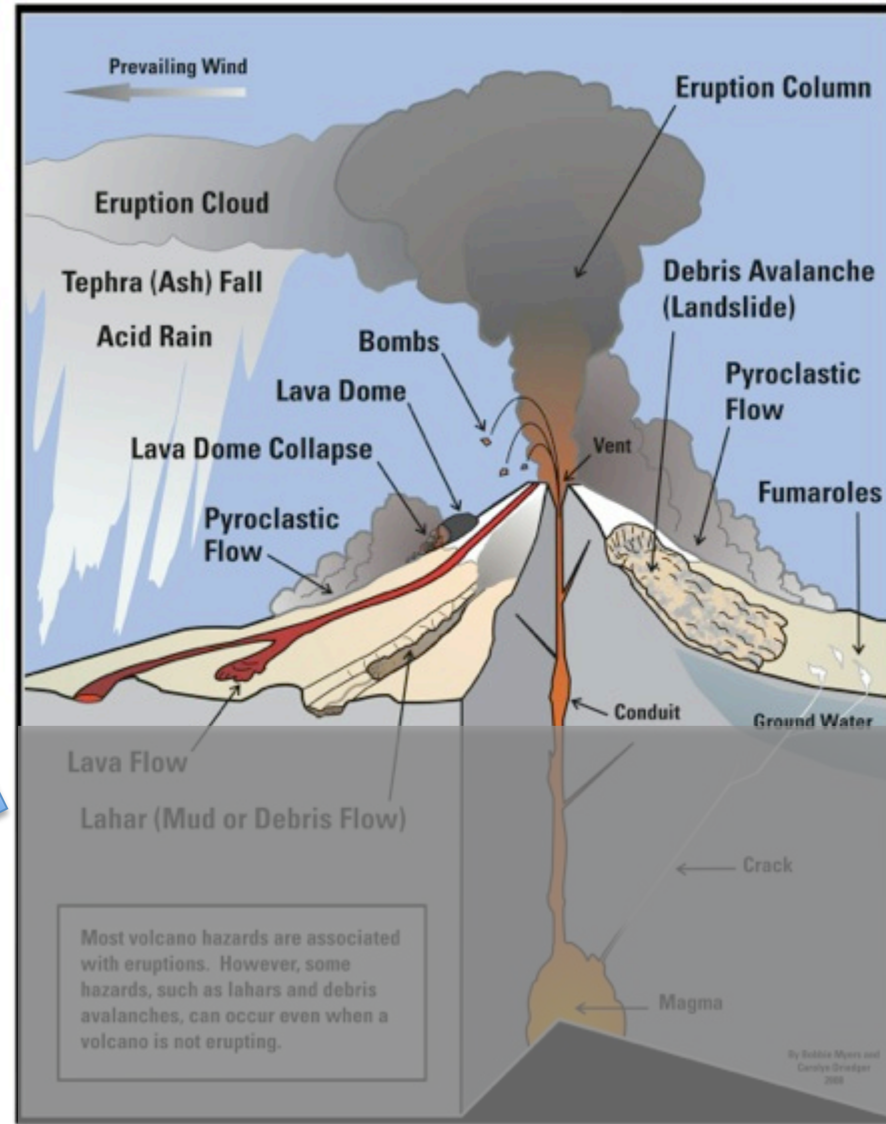
We don't know this



USGS

What we "know" now

- Seismic anomalies (velocity, attenuation, reflections, shadowing, microseismicity): can be aqueous fluids, partial melt, non-magmatic discontinuities
- E&M anomalies: can be hydrothermal alteration, hydrothermal fluids, certain rock types
- Gravity anomalies: magma and other rock bodies can be either positive or negative anomalies
- Deformation: non-unique; can also be caused by fluids
- Petrology: large error bars on phase-equilibrium geobarometry and geothermometry; melt inclusion data noisy – they may not trap representative melt and can leak; what is erupted may not be representative of what is in the subsurface

Real knowledge about magma

- Drilling technology has advanced to the point that we can, and have, drilled into magma.

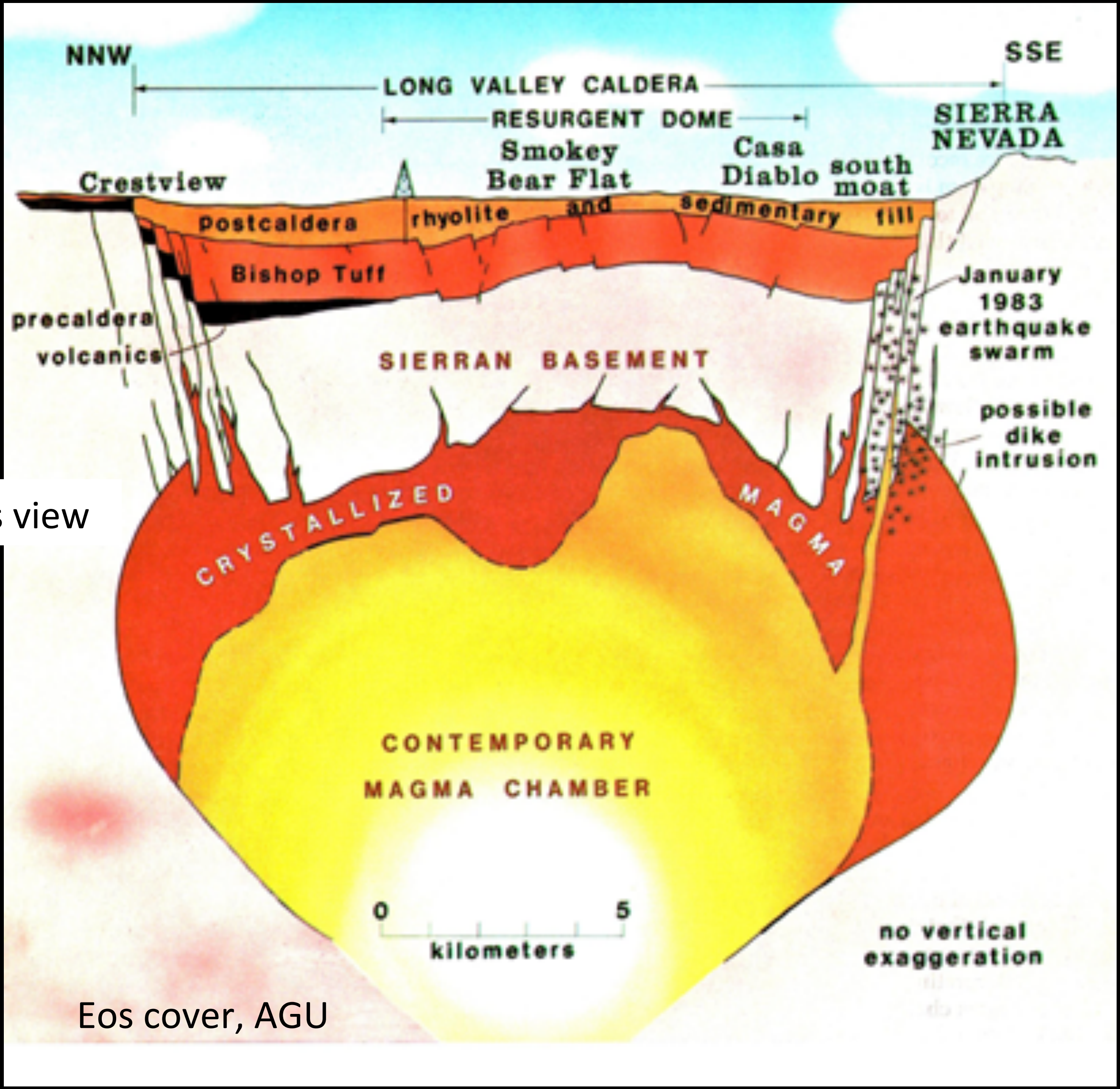
- It is demonstrated that we can core magma and thinkable that we can measure intensive parameters within magma *in situ*.

Why have volcanologists not already done more?

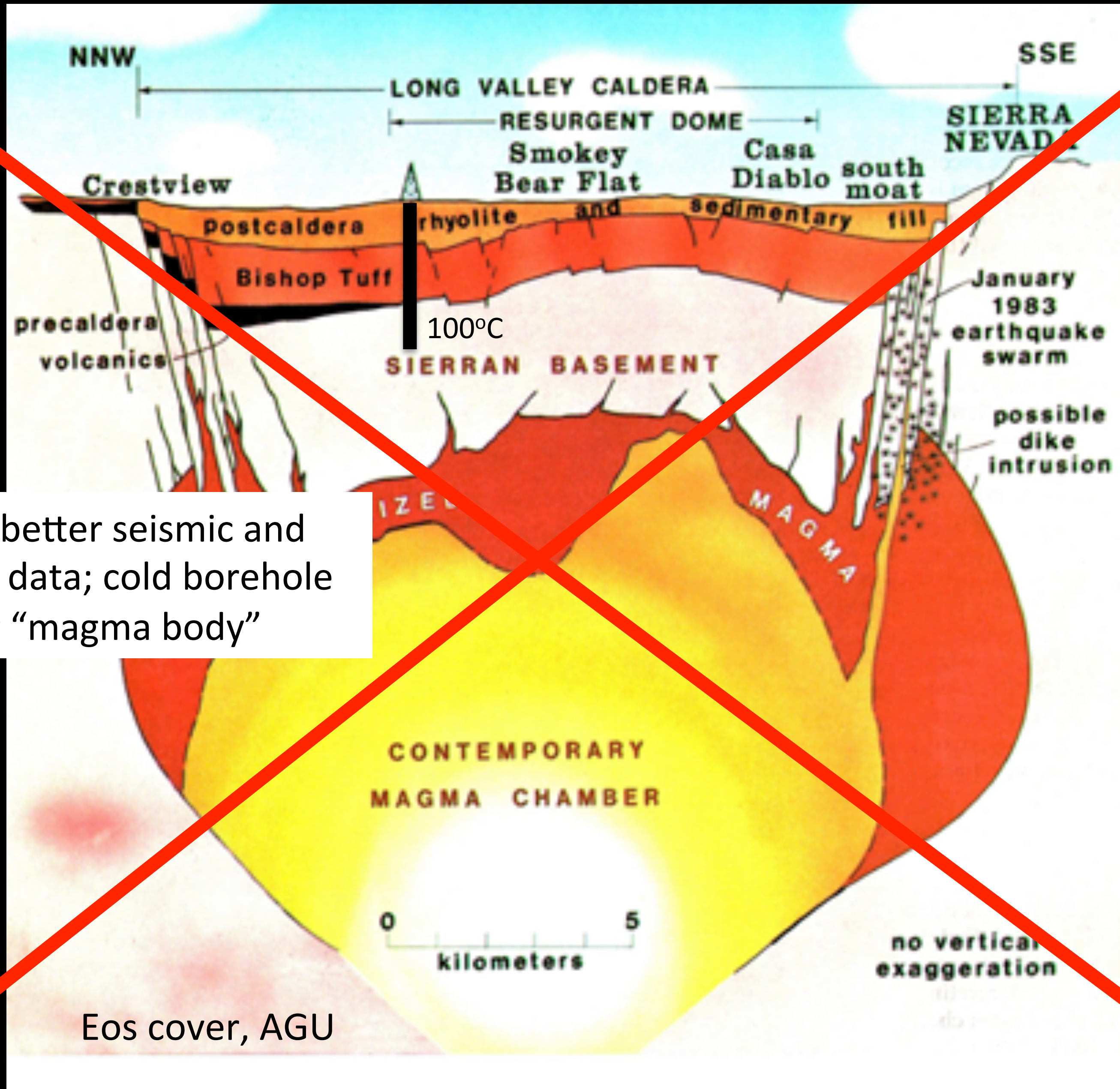
- Because we are accustomed to accepting inference as knowledge.
- Because real knowledge about magma requires a project scale unprecedented in volcano hazards science, with no guarantee of success.

Perhaps it was the same for tsunami hazard science in the ‘70s?

'70s – '80s view



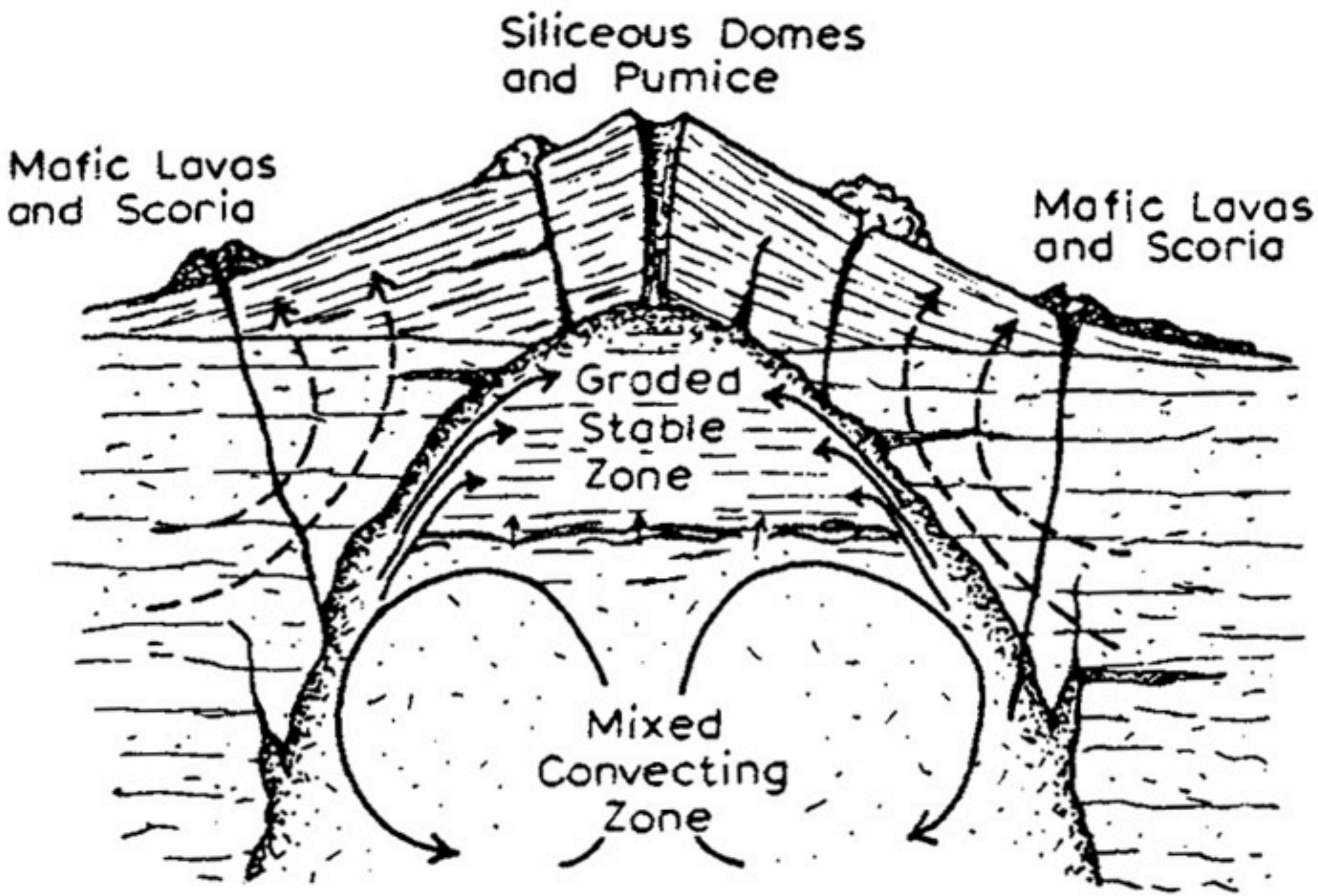
Eos cover, AGU



Eos cover, AGU

≥ '90s: better seismic and geodetic data; cold borehole over "magma body"

McBirney, 1980



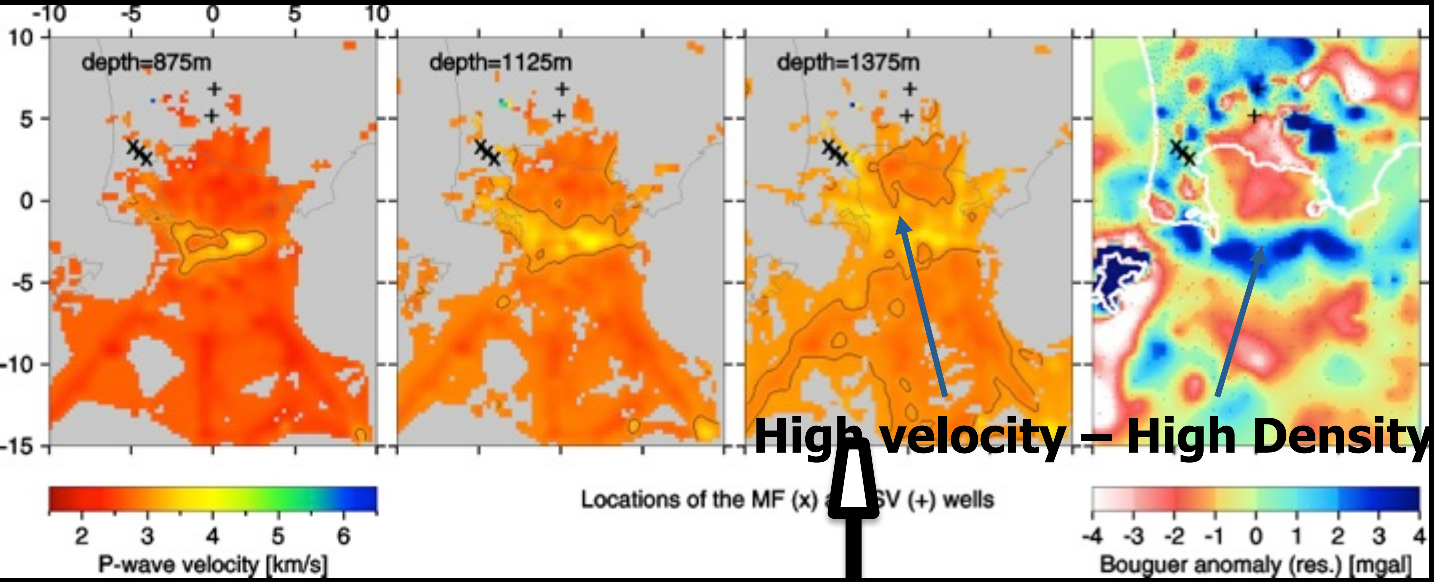
A vision not publishable now

Campi Flegrei Caldera, Italy:

Why magma chambers matter to people

INGV

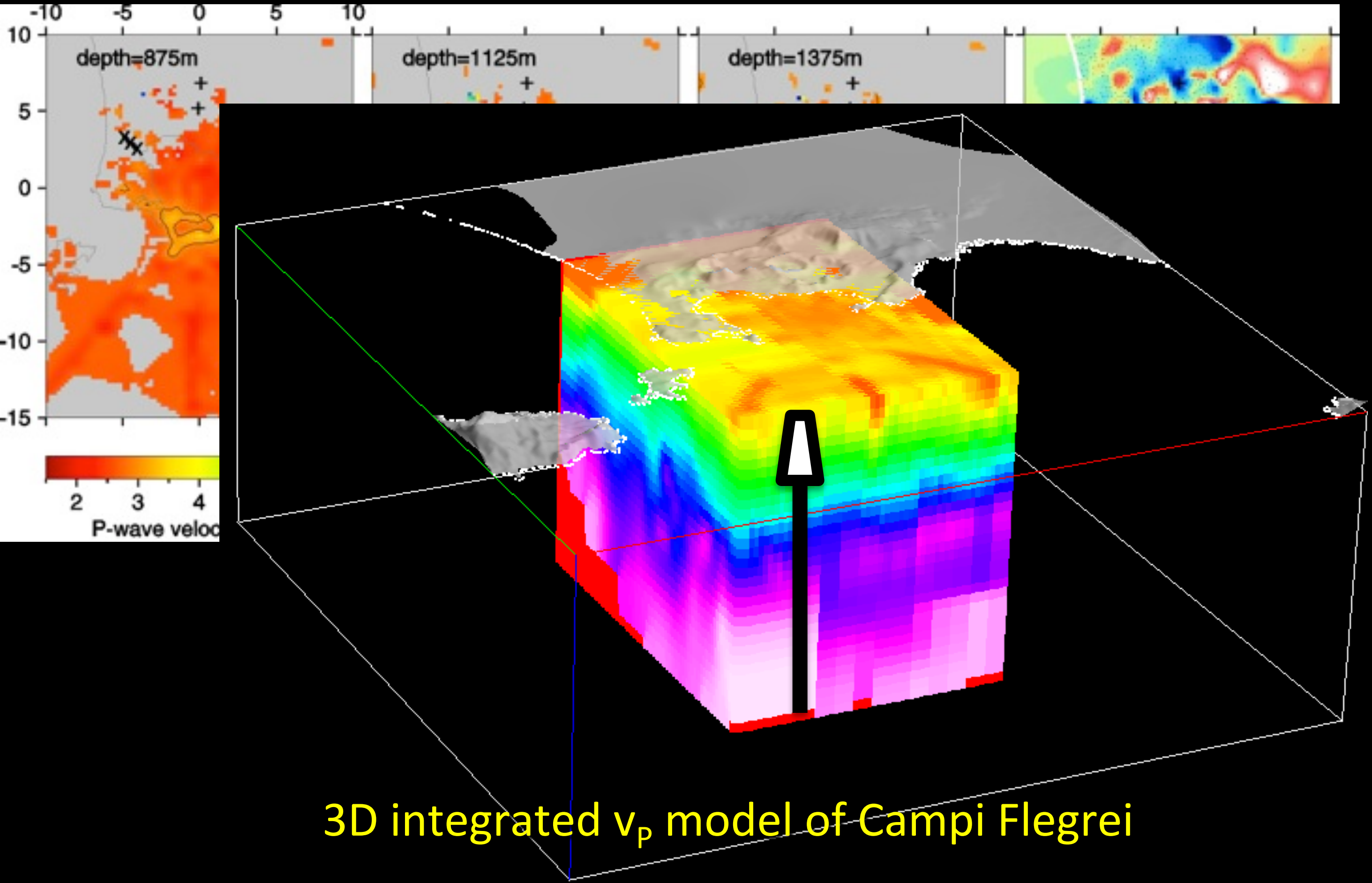
Inversion of P-wave velocity and gravity at Campi Flegrei



From A. Zollo and co-workers

Inversion of P-wave velocity and gravity at Campi Flegrei

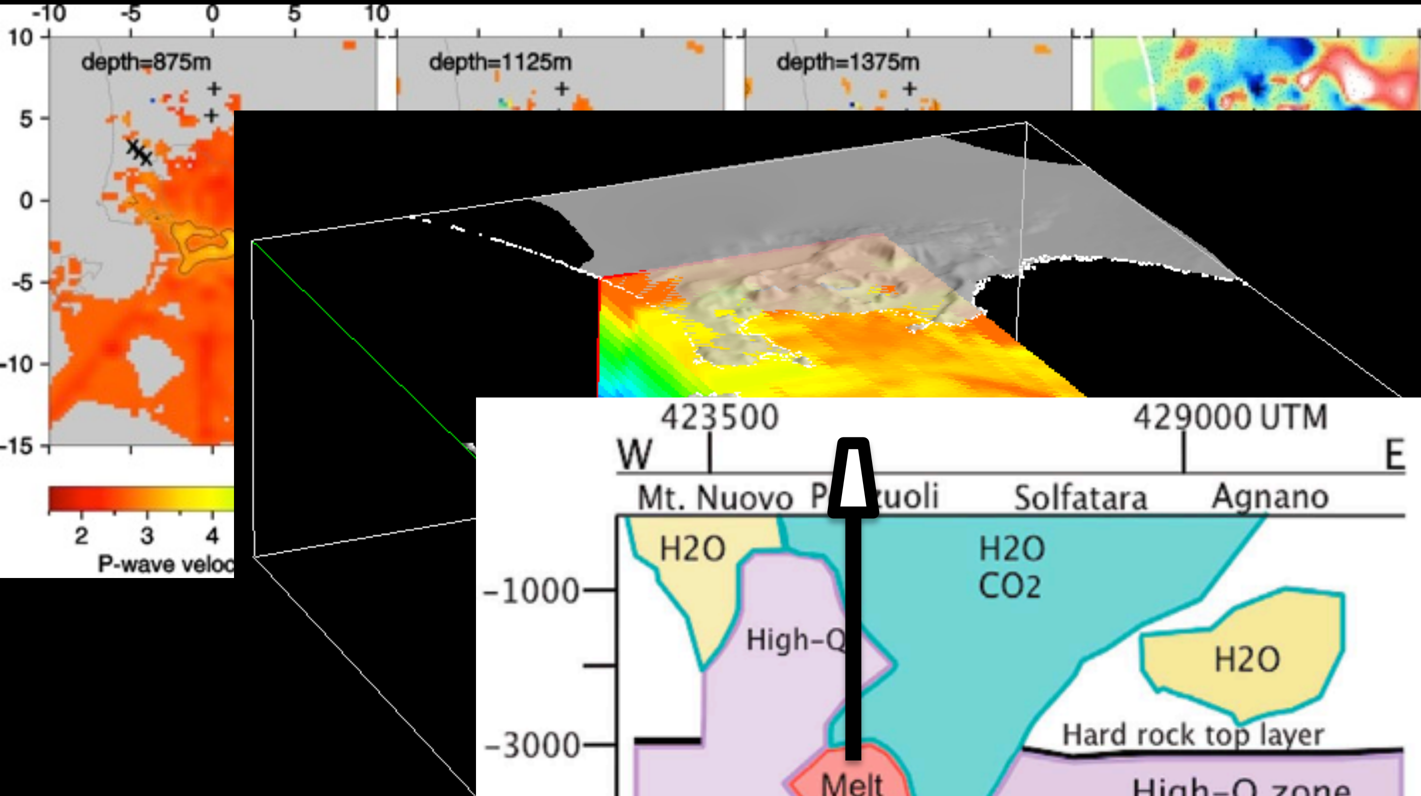
From A. Zollo and co-workers



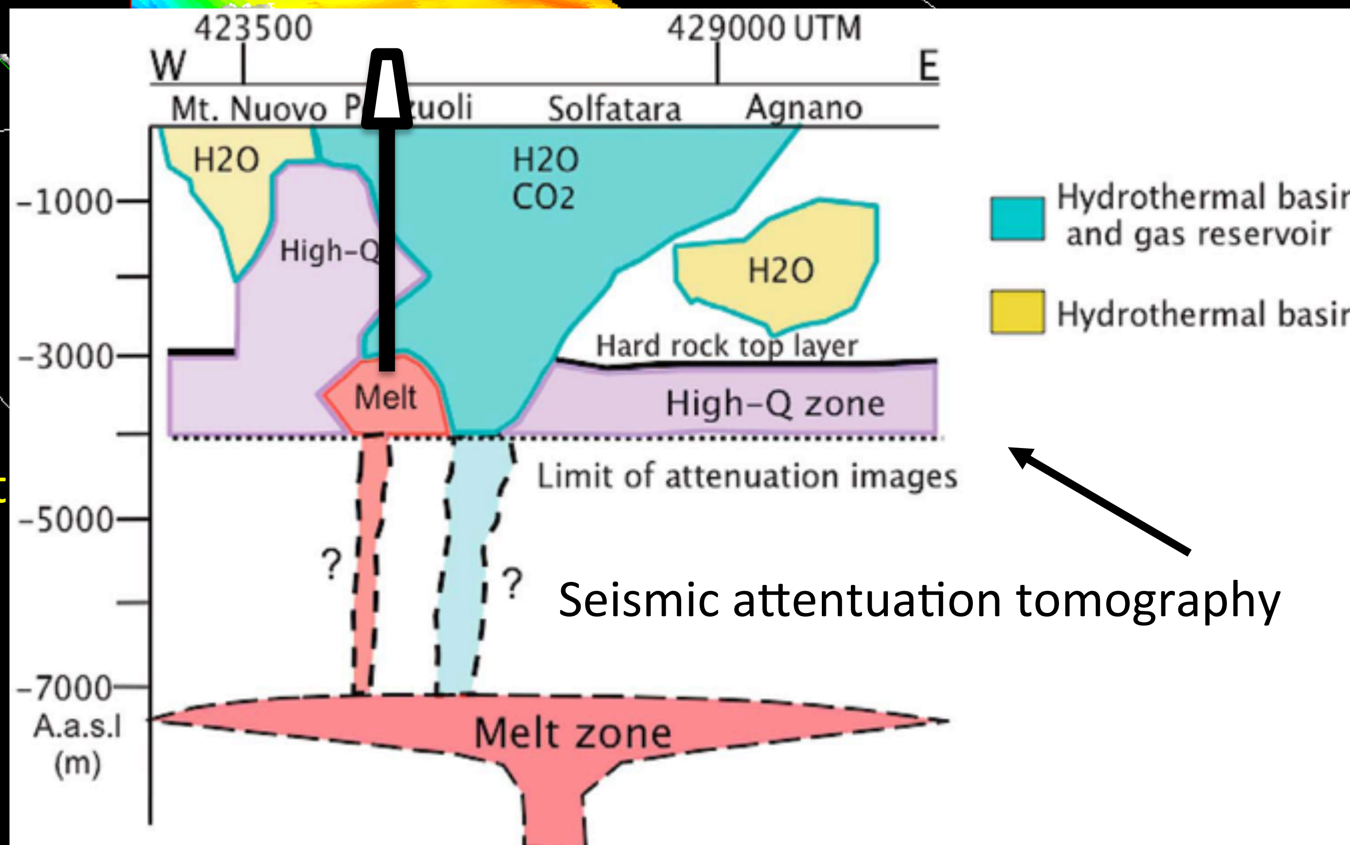
3D integrated v_P model of Campi Flegrei

Inversion of P-wave velocity and gravity at Campi Flegrei

From A. Zollo and co-workers

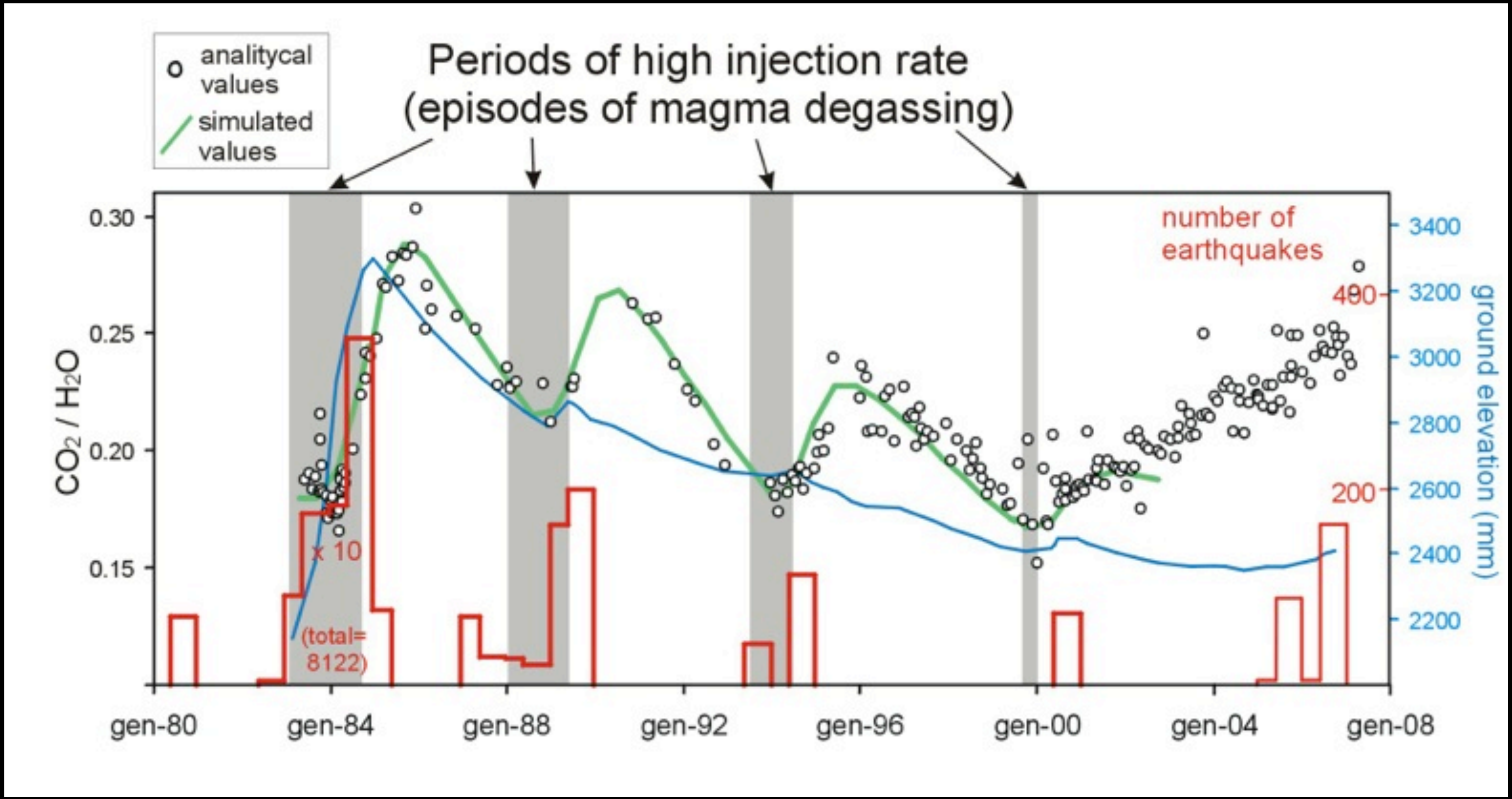


3D int



Seismic attentuation tomography

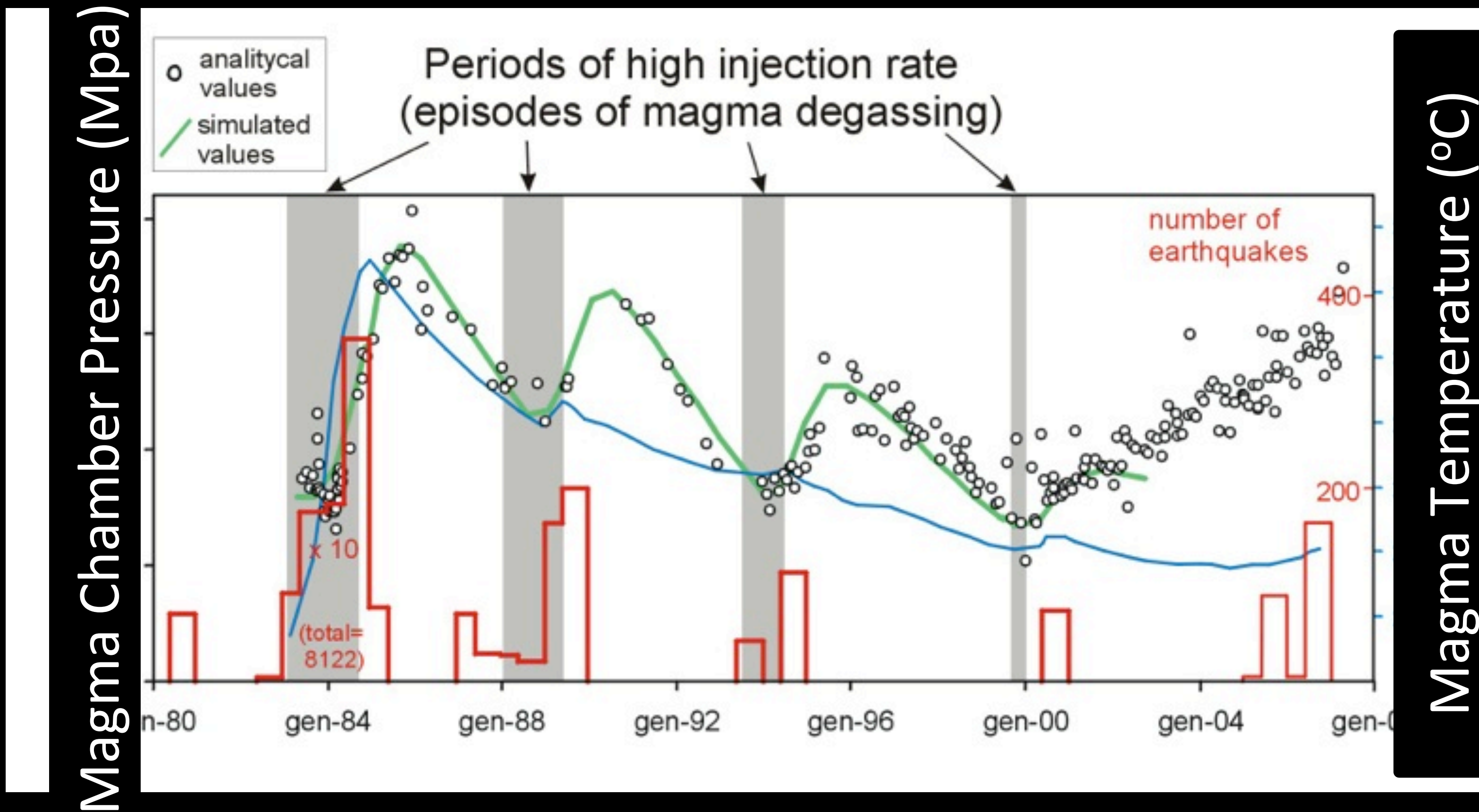
From De Siena et al., 2010



Campi Flegrei, Italy, 1980-2008

From: *Chiodini et al., 2008.*

With a million people at risk, we need to know more than we get from surface proxies of magma behavior



Campi Flegrei, Italy, 1980-2008

From: *Chiodini et al., 2008.*

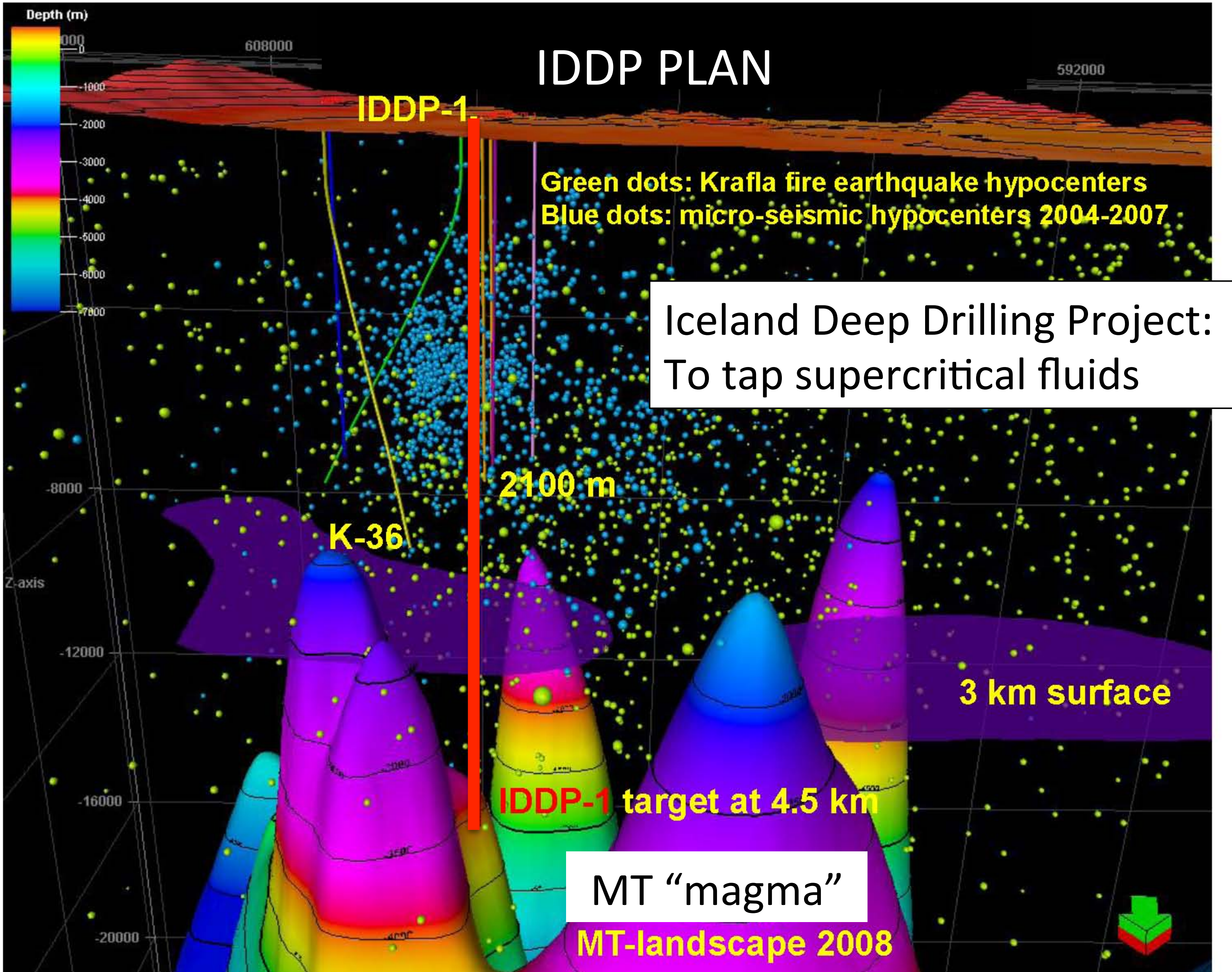
Suppose we could put sensors in magma chambers?

Krafla Caldera:
Where magma has been drilled

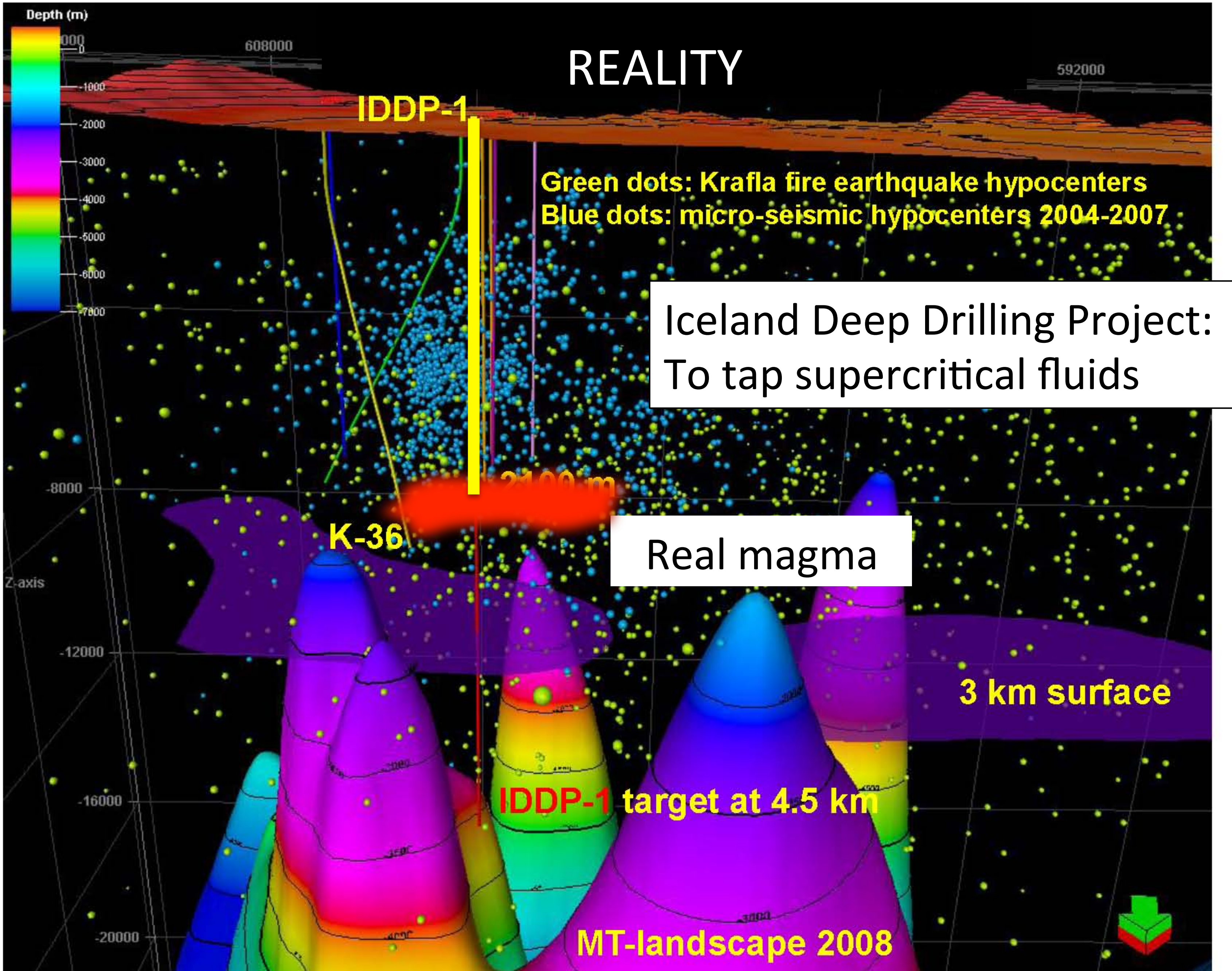
Perspective is NE towards ocean

Approximate caldera outline

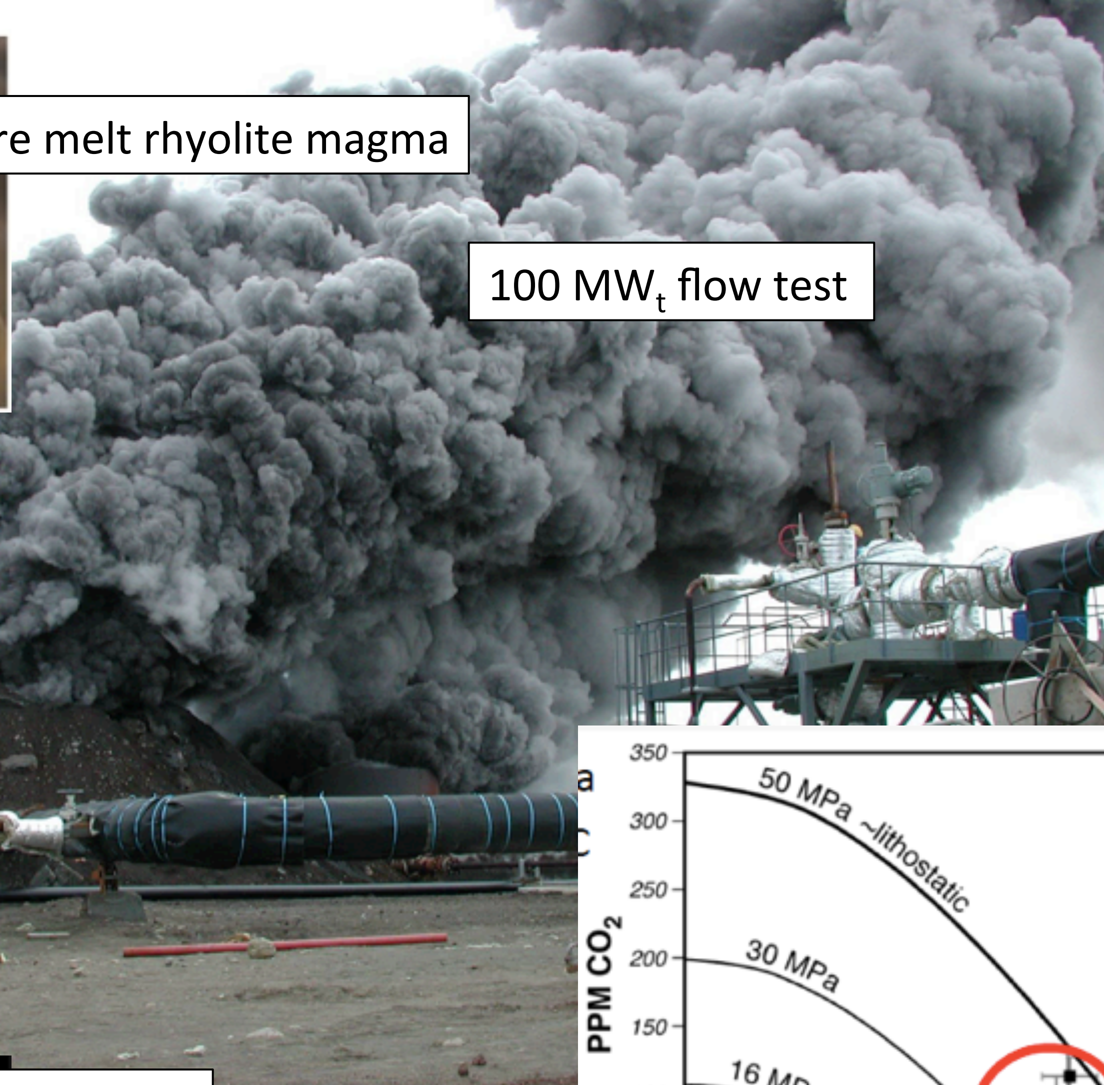
IDDP PLAN



WGC-2010-GÓF et al. paper 3902

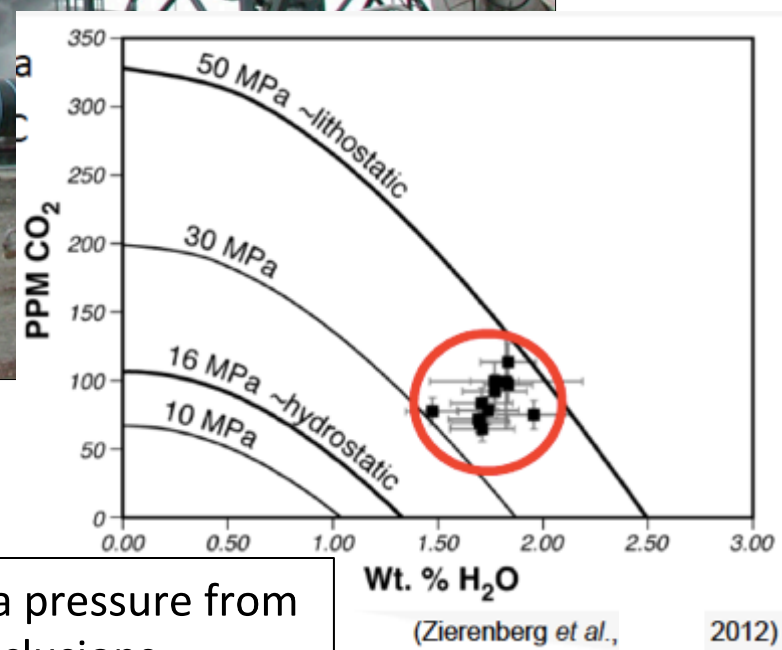

REALITY
Depth (m)
608000
592000
IDDP-1
Green dots: Krafla fire earthquake hypocenters
Blue dots: micro-seismic hypocenters 2004-2007
Iceland Deep Drilling Project:
To tap supercritical fluids
2100 m
K-36
Real magma
Z-axis
-8000
-12000
-16000
-20000
3 km surface
IDDP-1 target at 4.5 km
MT-landscape 2008

Pure melt rhyolite magma



$100\ MW_t$ flow test

Partially melted microgranite

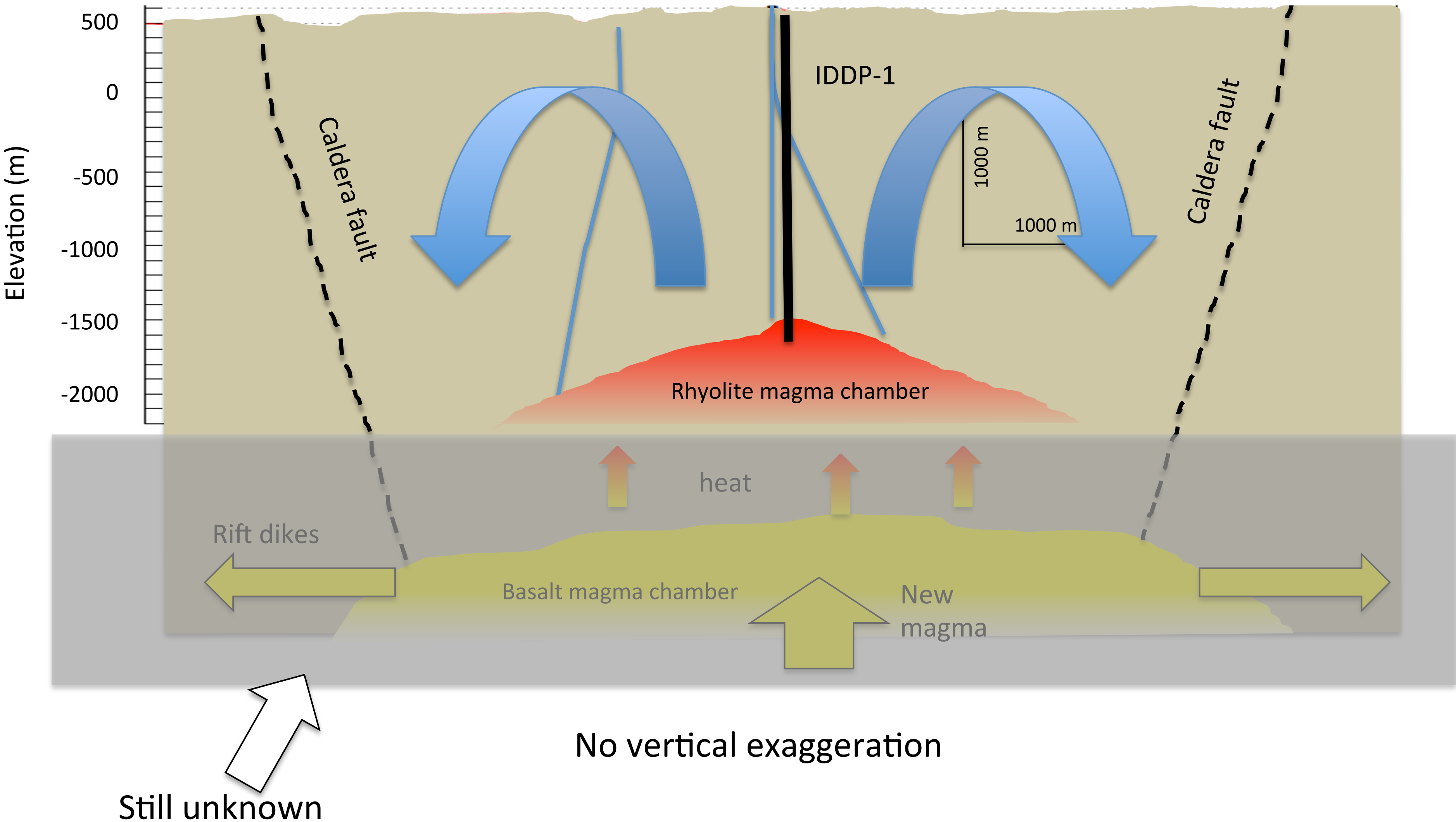


Magma pressure from melt inclusions

Surprises concerning Krafla magma

- Not detected by geophysical techniques
- No possibility it was recently intruded despite low crystallinity
- Rhyolite, but rhyolite has not been erupted in the last 9000 years
- High permeability of margin, despite T >> brittle/ductile transition

Location of magma body



No vertical exaggeration

Possible origins of magma body

Origin	comment
Emplaced before 1975-1984 Krafla Fires	Possible; Why did it not erupt? Why still at liquidus? See Askja
Emplaced after Krafla Fires	Not possible: Precluded by geodetic and gravity data
Differentiation *in situ*	Remarkable, but consistent with no geodetic or gravity signal

H. SIGURDSSON AND R. S. J. SPARKS, 1981

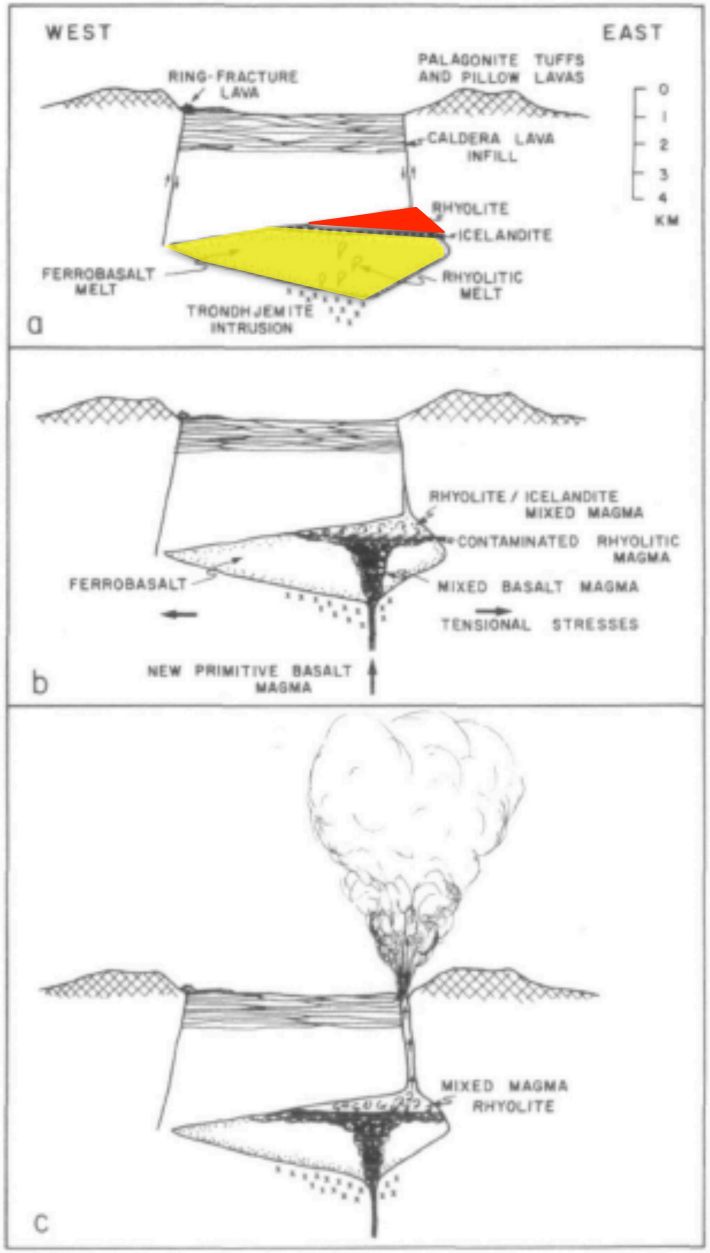


FIG. 16. A model of the Askja magma chamber before and during the 1875 eruption.

Askja Caldera analogy

A similar shallow body of rhyolitic magma apparently accumulated for thousands of years, undisturbed by basaltic eruptions until 1875.

A 30-m thick mystery zone spanning the solidus

P. Schiffman et al. / Geothermics 49 (2014) 42–48

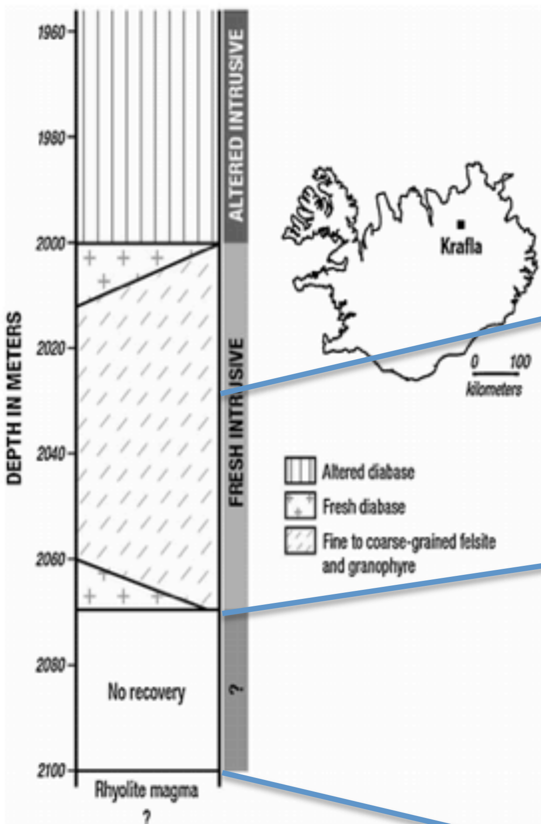
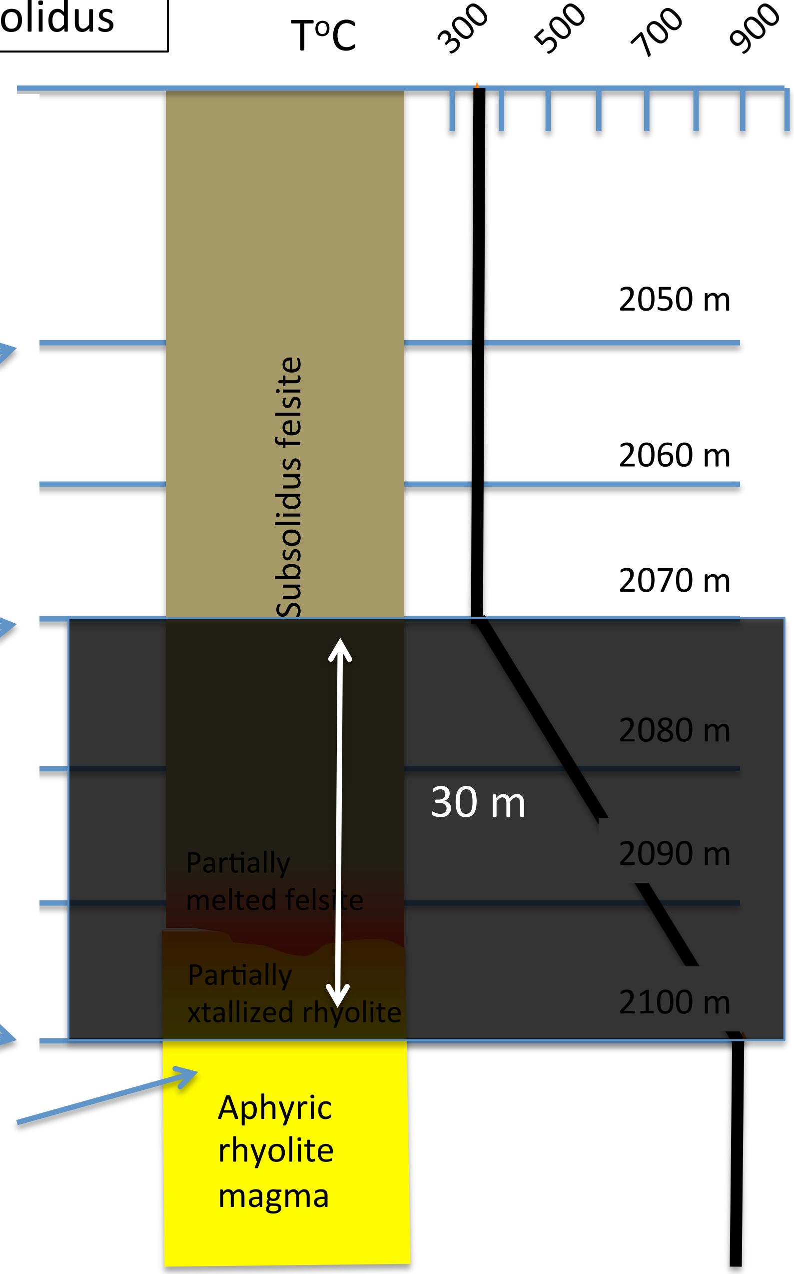
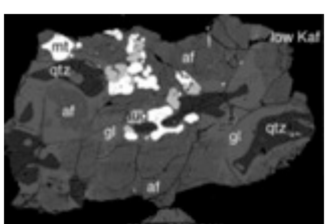


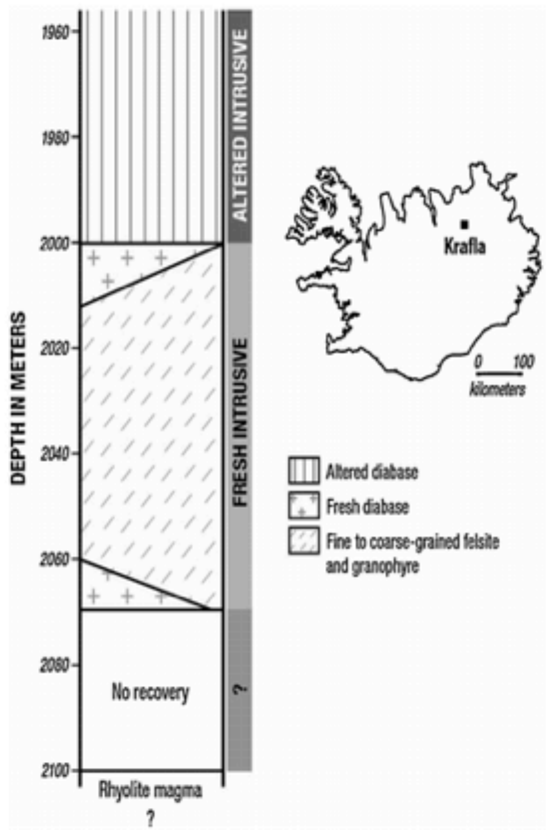
Fig. 1. Location map of the Krafla geothermal area and schematic lithologic column of the IDDP-1 borehole below 1960 m. The relationship between mafic and felsic intrusive lithologies between 2000 and 2070 m is not well constrained.



Chips:



P. Schiffman et al. / Geothermics 49 (2014) 42–48



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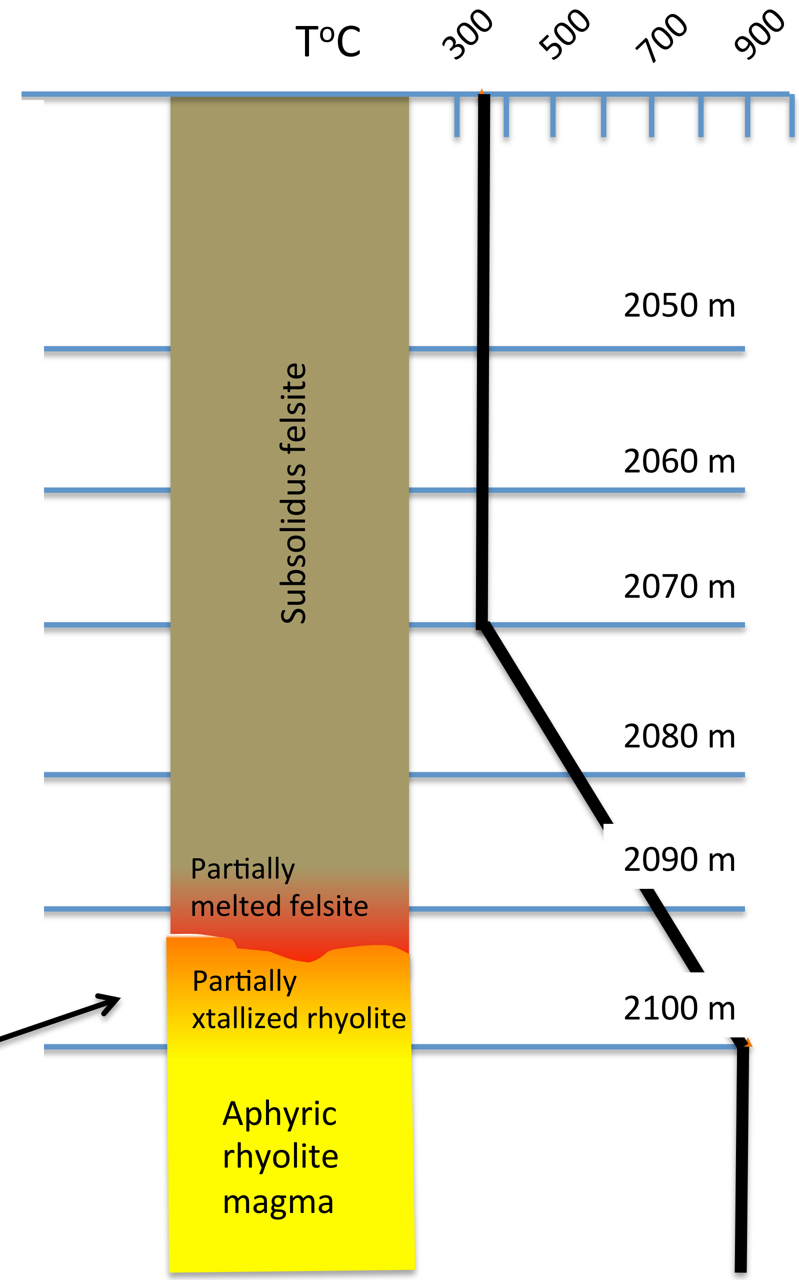
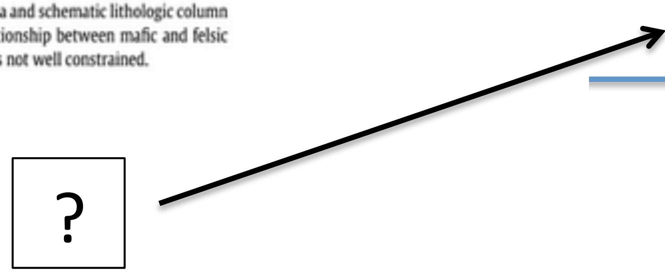
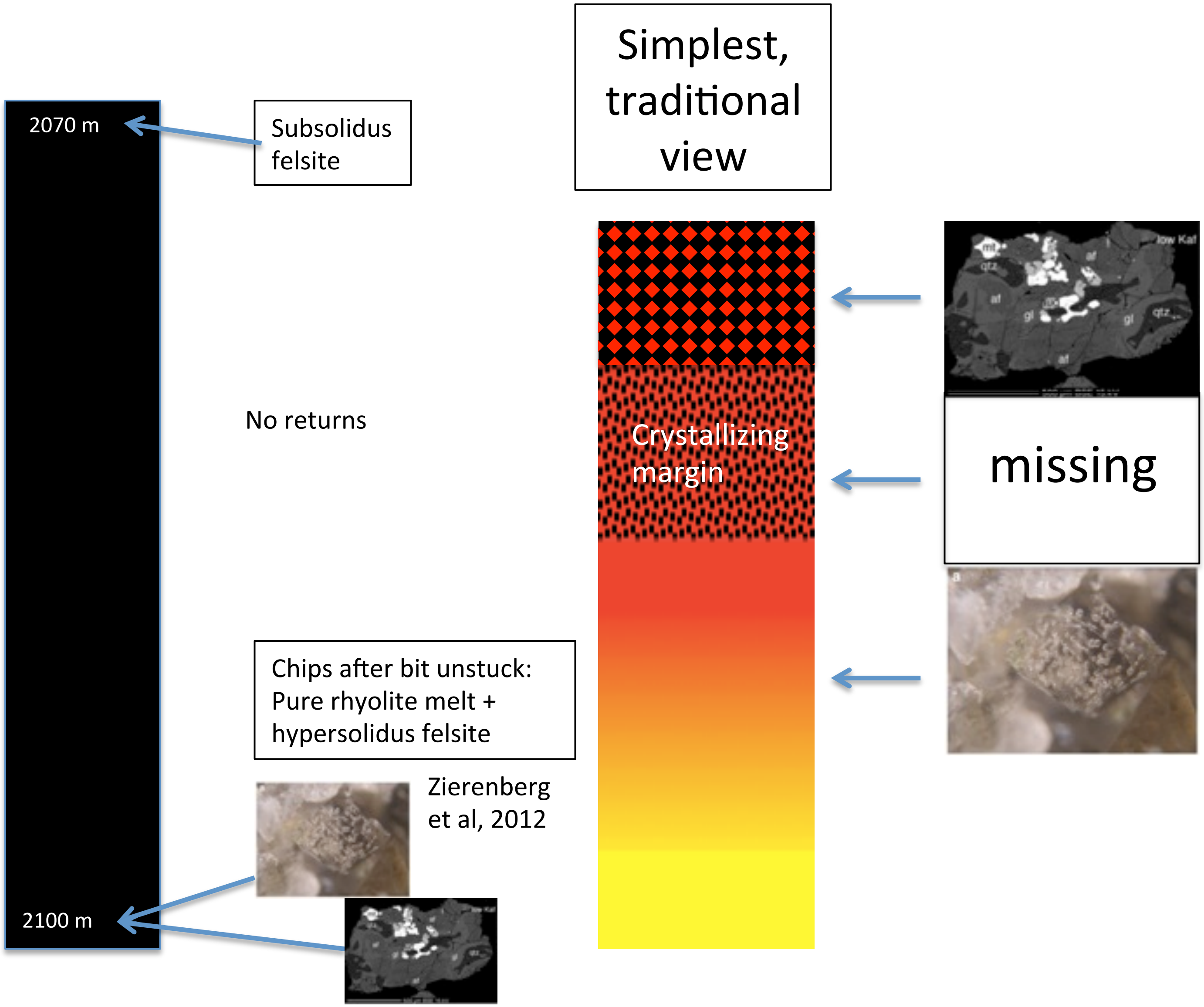




Petrology of magma margin



Petrology of magma margin

IDDP-1 team view

2070 m

Subsolidus felsite

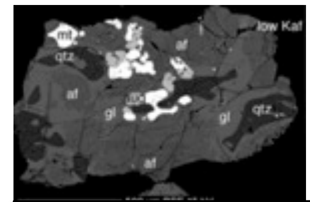
No returns

Chips after bit unstuck: Pure rhyolite melt + hypersolidus felsite

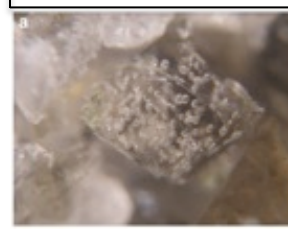
Zierenberg et al, 2012

2100 m

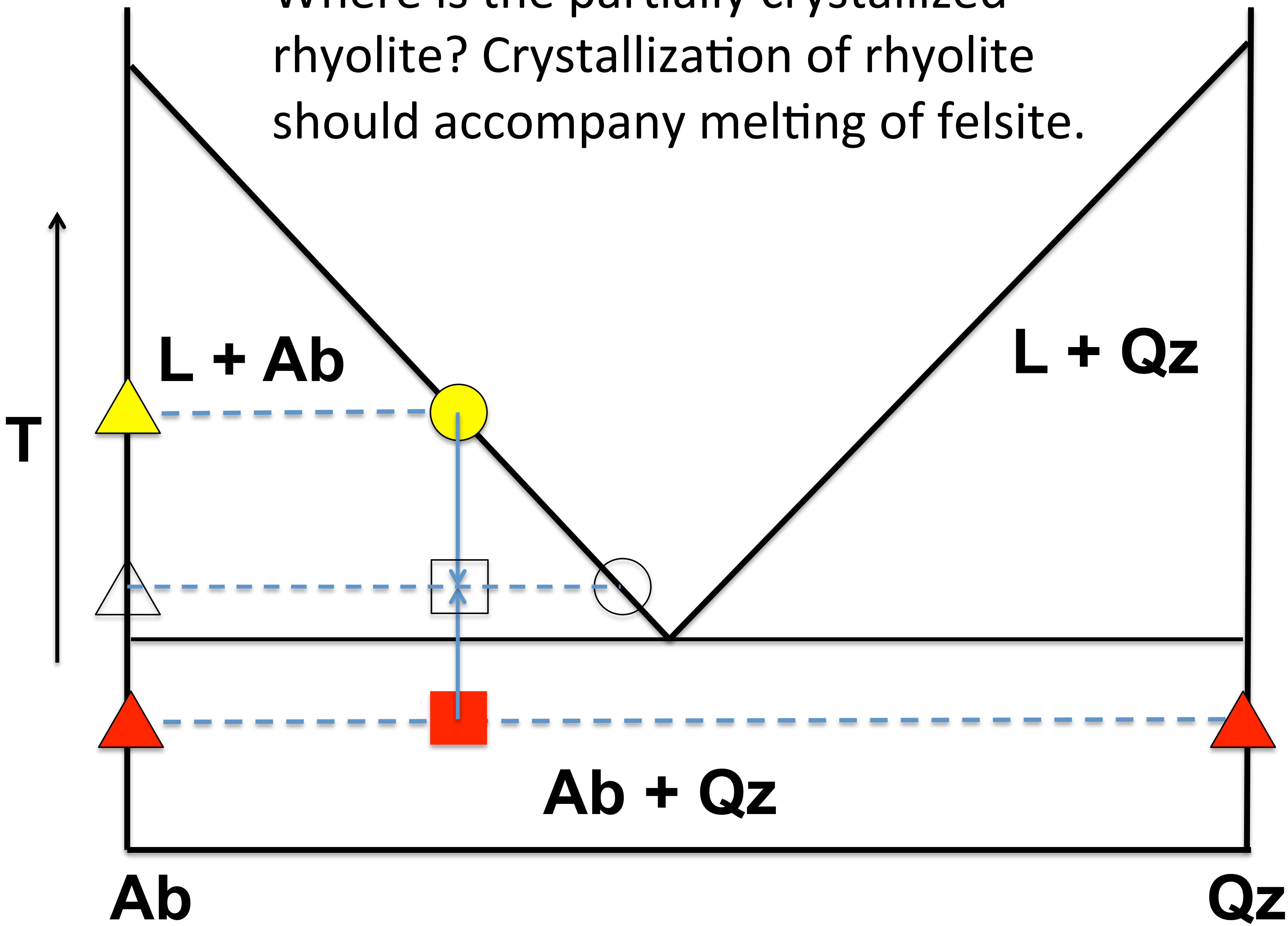
New liquidus rhyolite melting older felsite



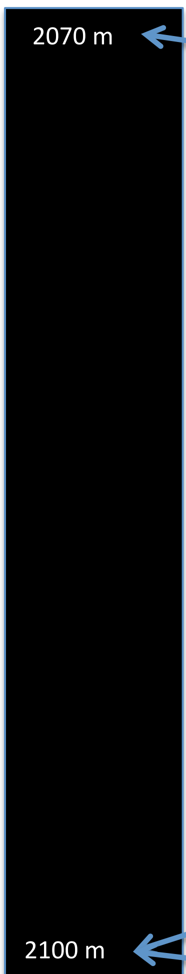
Absence of crystallizing rhyolite requires magma to be superheated



Where is the partially crystallized rhyolite? Crystallization of rhyolite should accompany melting of felsite.



Another possible magma margin



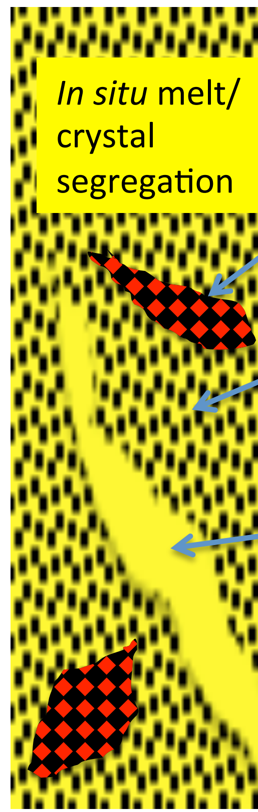
Subsolidus felsite

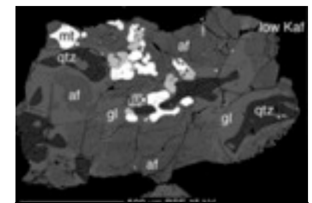
No returns

Chips after bit unstuck:
Pure rhyolite melt +
hypersolidus felsite

Zierenberg et al, 2012

Melt segregation from mush





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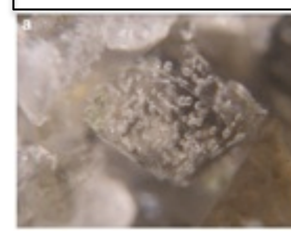
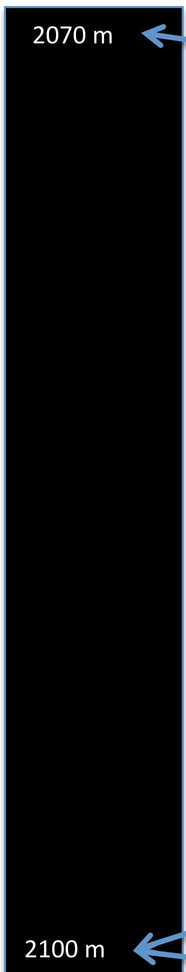


And another magma margin



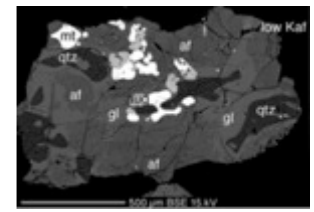
Subsolidus felsite

No returns

Chips after bit unstuck:
Pure rhyolite melt +
hypersolidus felsite

Zierenberg et al, 2012

Ooze from mush



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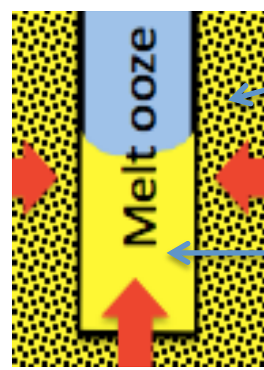
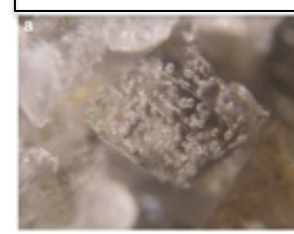


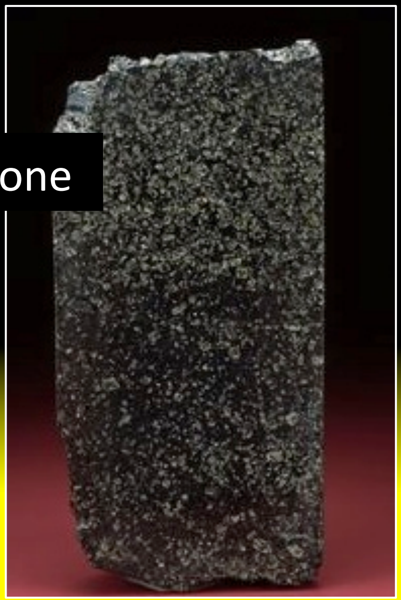


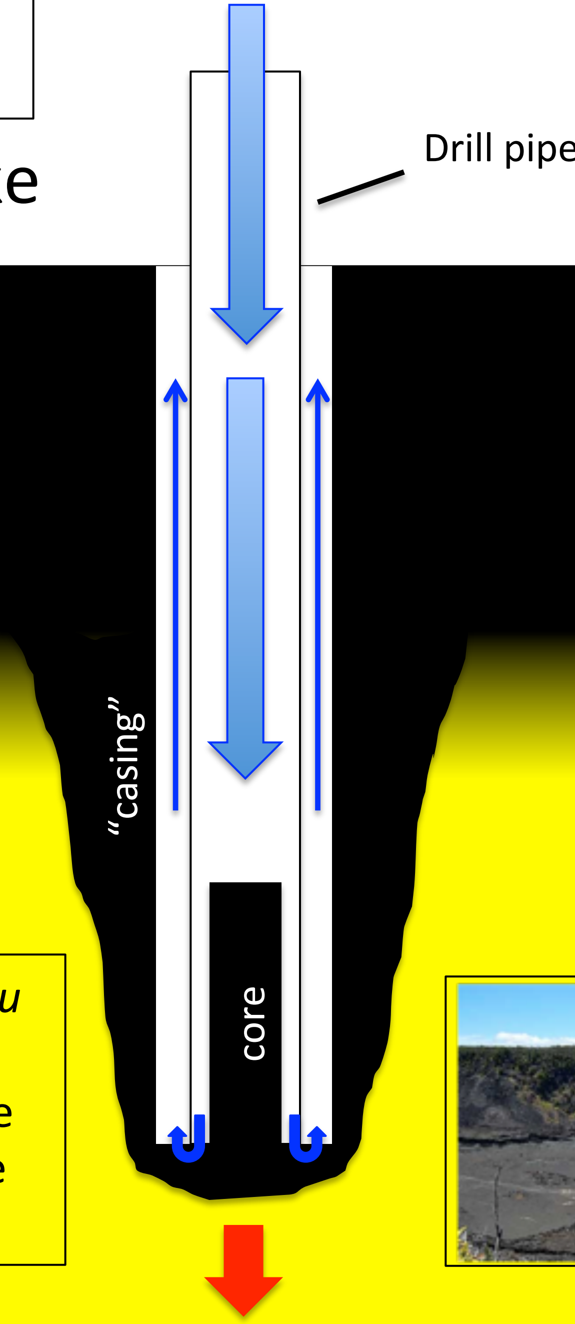
We need core!

Kilauea Iki Lava Lake

$$\frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial x^2}$$

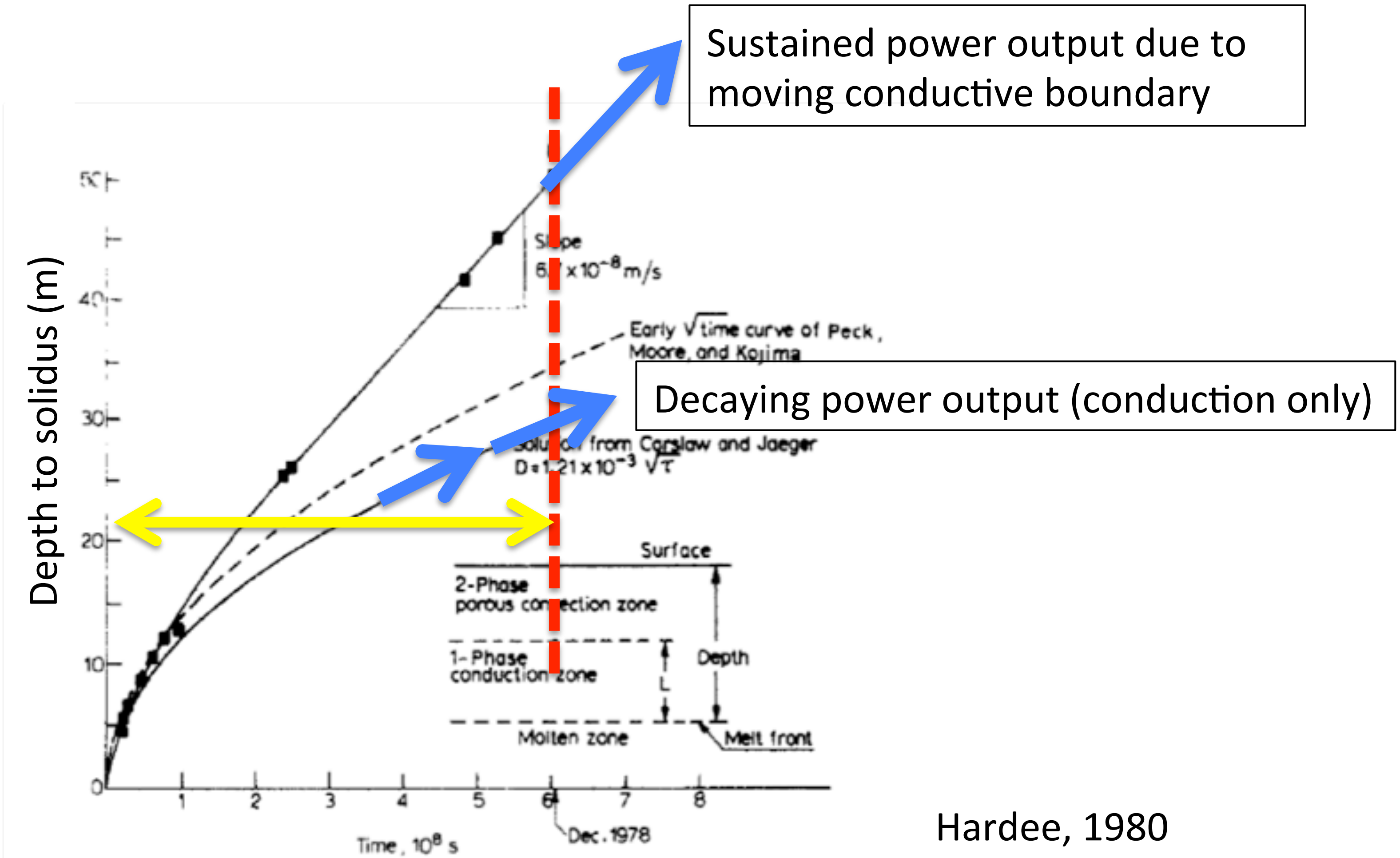
To get gradients and relationships





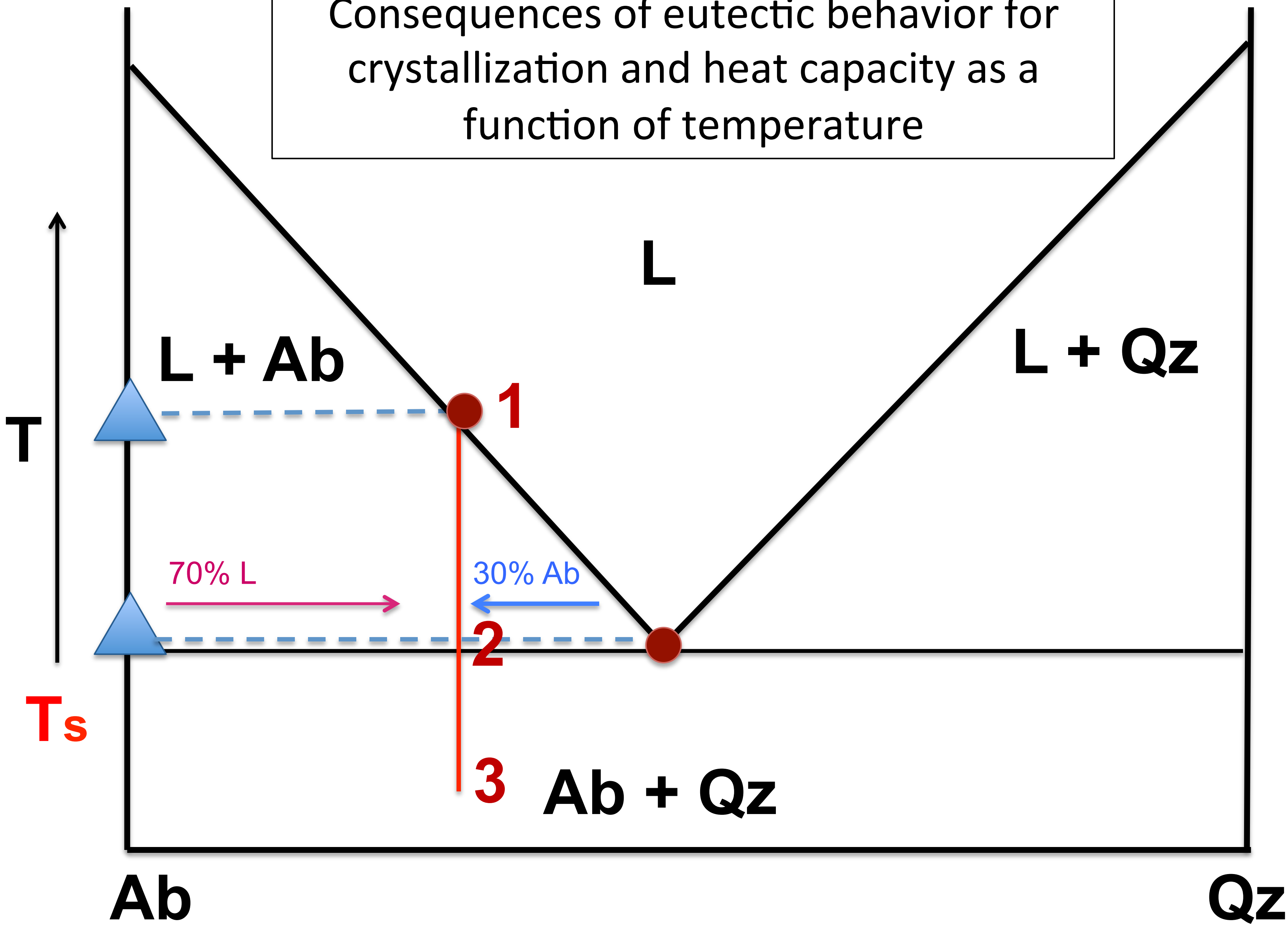
Magma quenched *in situ* and then sampled preserves original phase assemblage and volatile content.

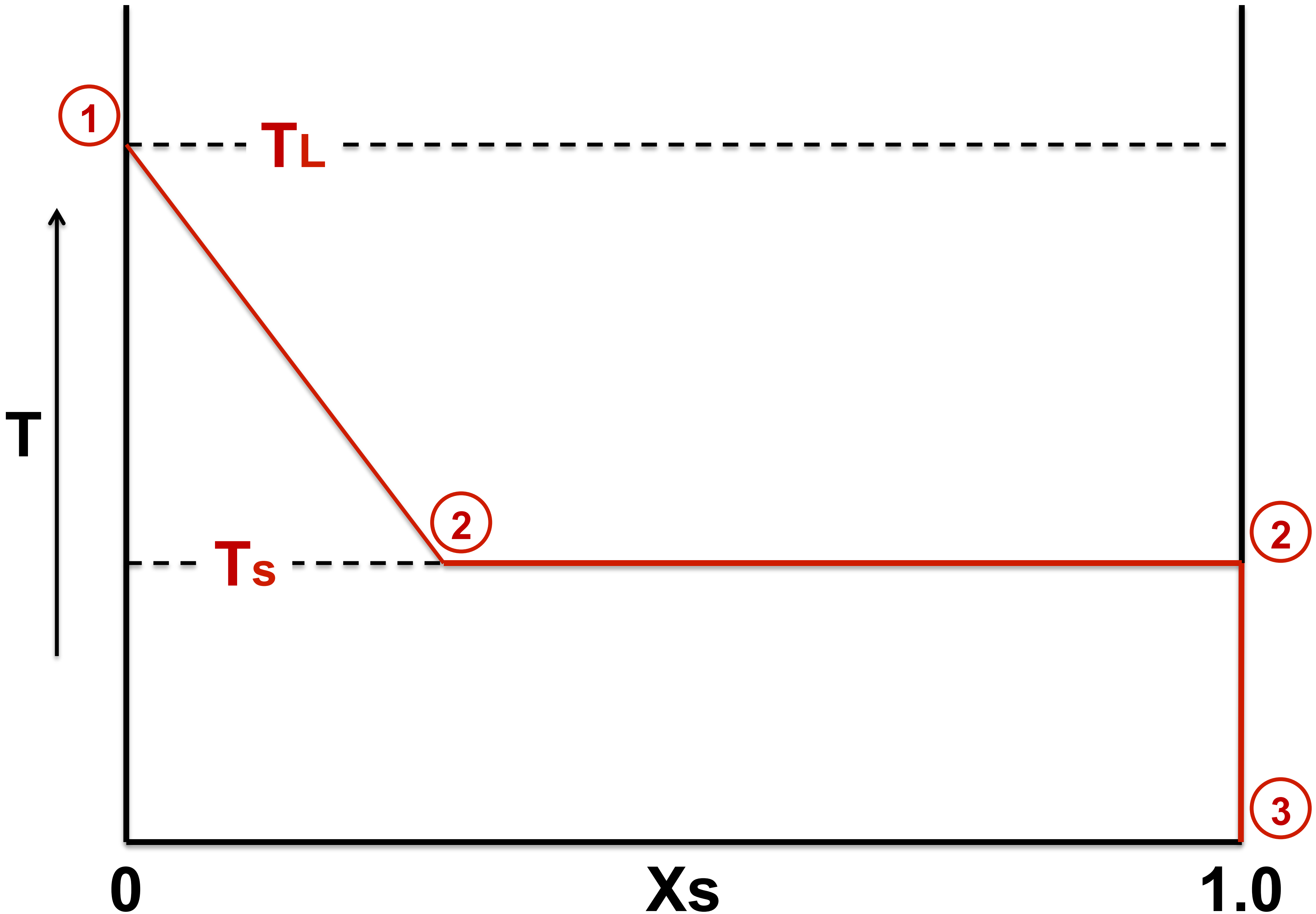
Mass/heat transfer from/to magma body



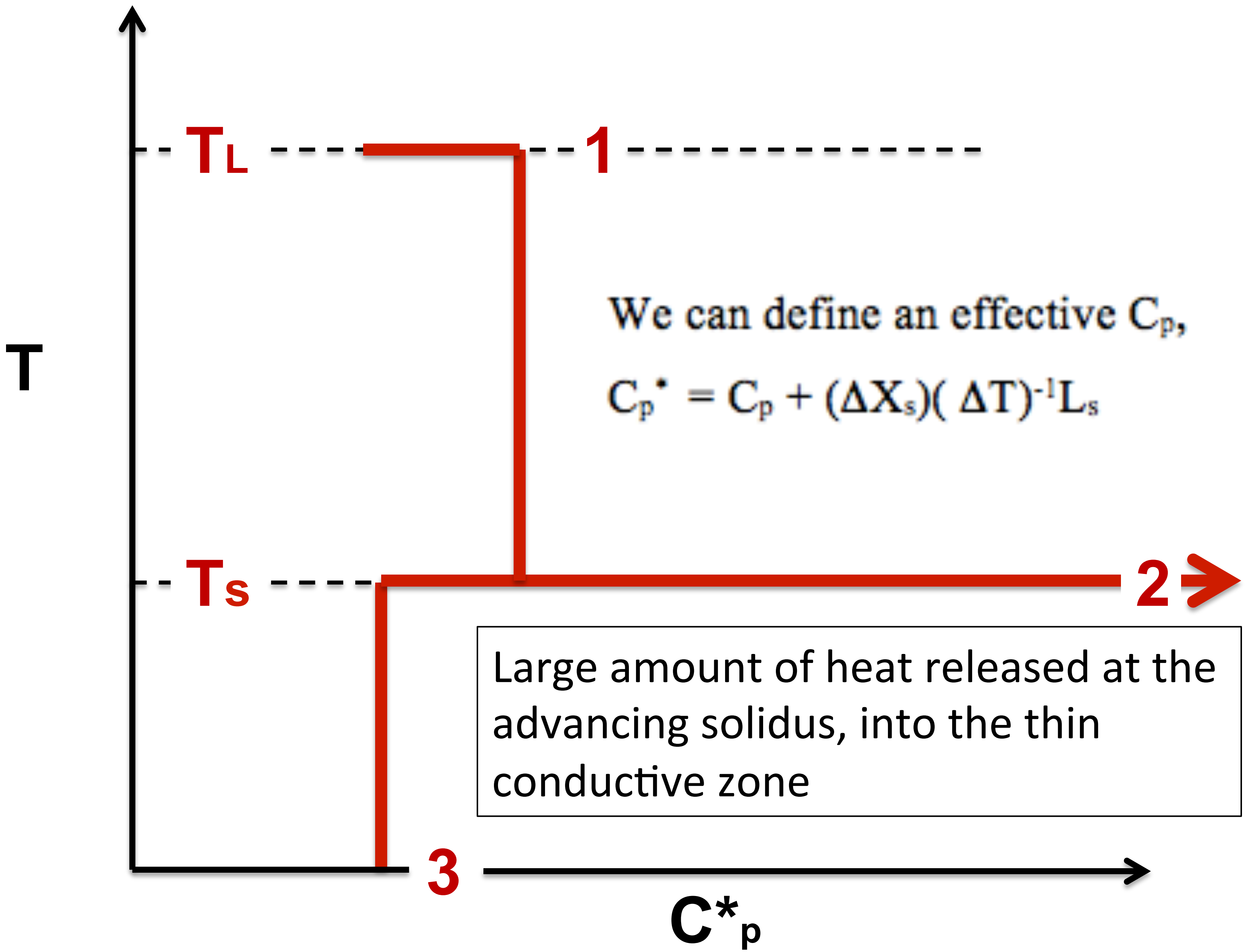
Hardee, 1980

Consequences of eutectic behavior for crystallization and heat capacity as a function of temperature



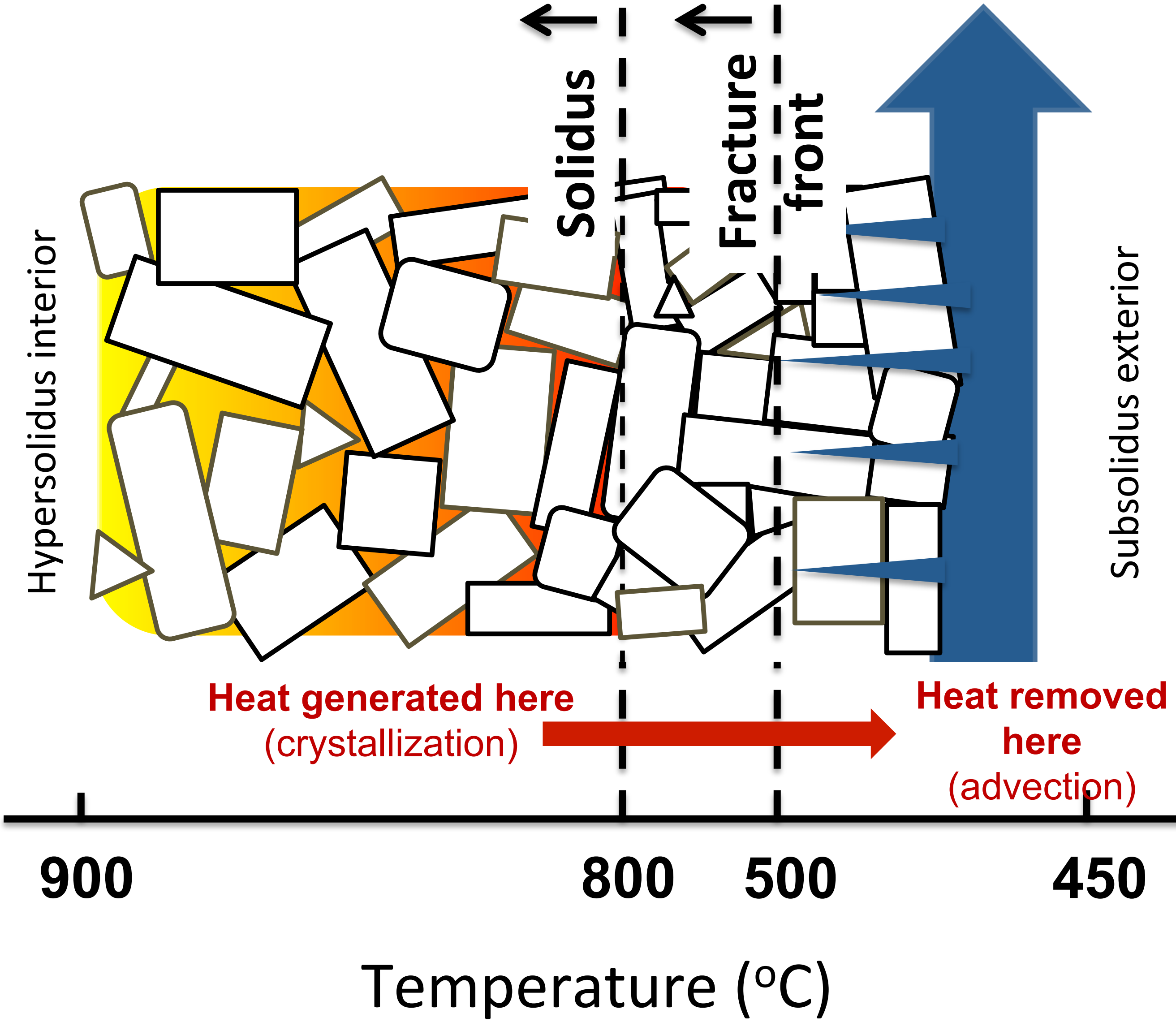


1
TL
T
2
Ts
2
3
0
Xs
1.0



T
T_L
1
We can define an effective C_p,
$C_p^* = C_p + (\Delta X_s)(\Delta T)^{-1} L_s$
T_s
2
Large amount of heat released at the advancing solidus, into the thin conductive zone
3
C^*_p

Moving conductive boundary



Steps in developing scientific drilling project: Krafla Magma Drilling Project

11/13 — Concept

1/14 — Pre-proposal; ask $ for workshop

9/14 — International workshop; agree on objectives; form science team

1/15 — Write proposal; submit to ICDP and other sponsors

now — Pre-paratory work; plan revisions

2016 — Project: drilling; borehole experiments; sample analysis; publications

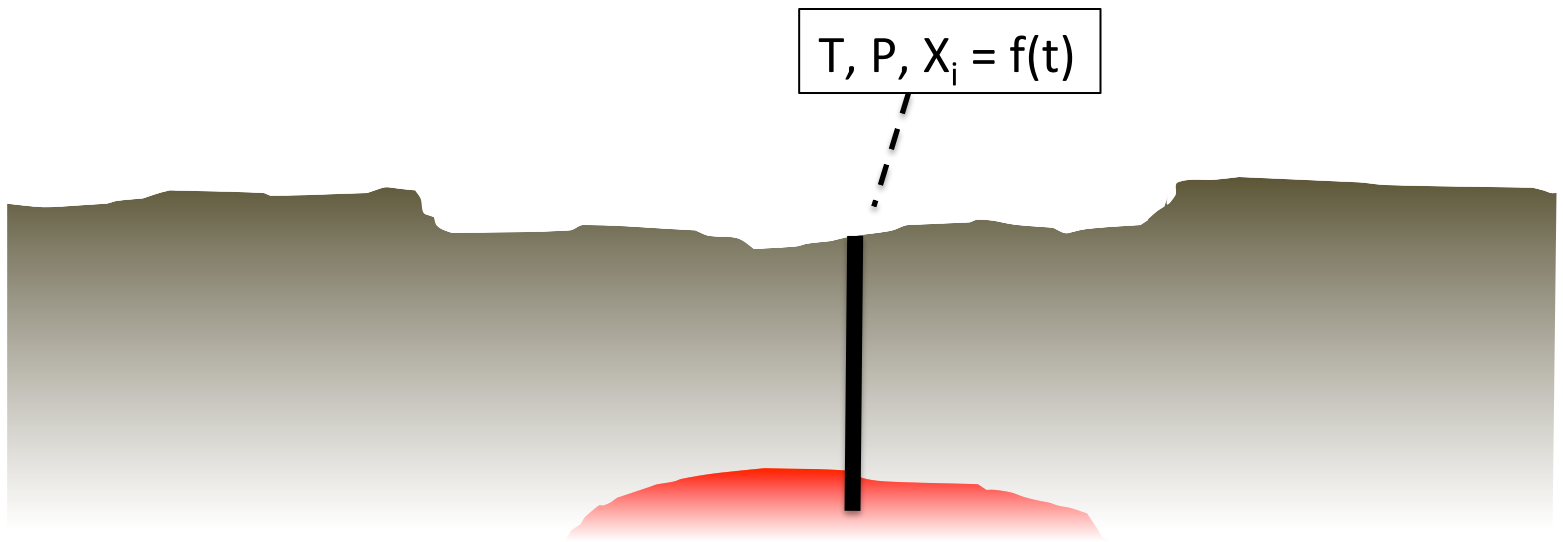
We are here

icdp

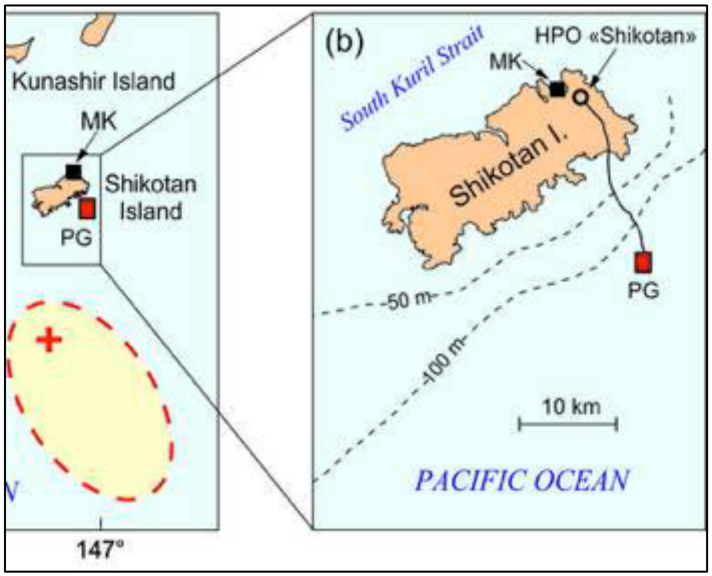
Landsvirkjun
National Power Company of Iceland

For the long-term future:

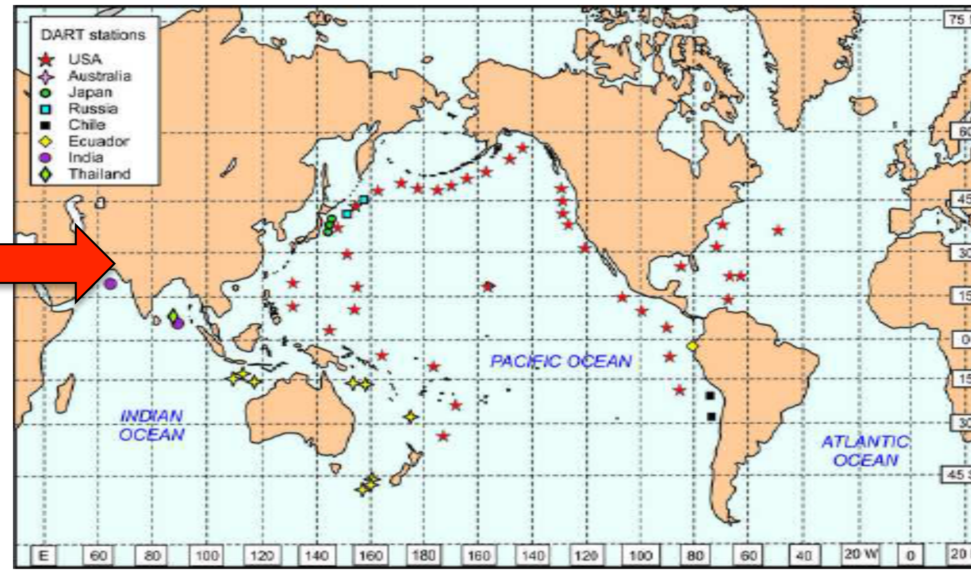
International Magma Laboratory



Decades of progress: from Soloviev's experiment to global application



Early seafloor pressure measurements



DART buoys today

KMDP team

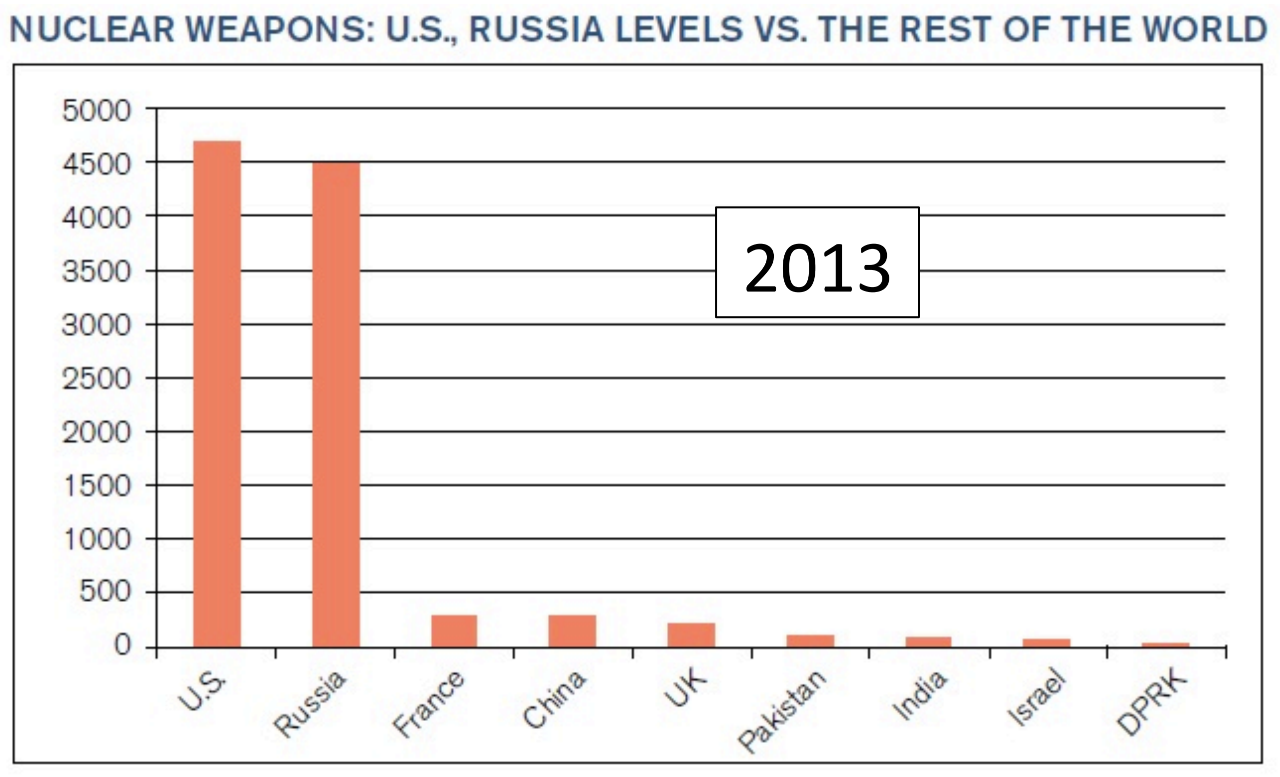
Why is international cooperation important in natural hazards science and risk management (besides $)?

- Because extreme events are rare events, we must draw on the broadest experience possible.
- Because natural hazard events transcend borders.
- Because we can use multiple approaches to advance the science faster and identify best practices in management

Also: The issue is humanitarian and apolitical.

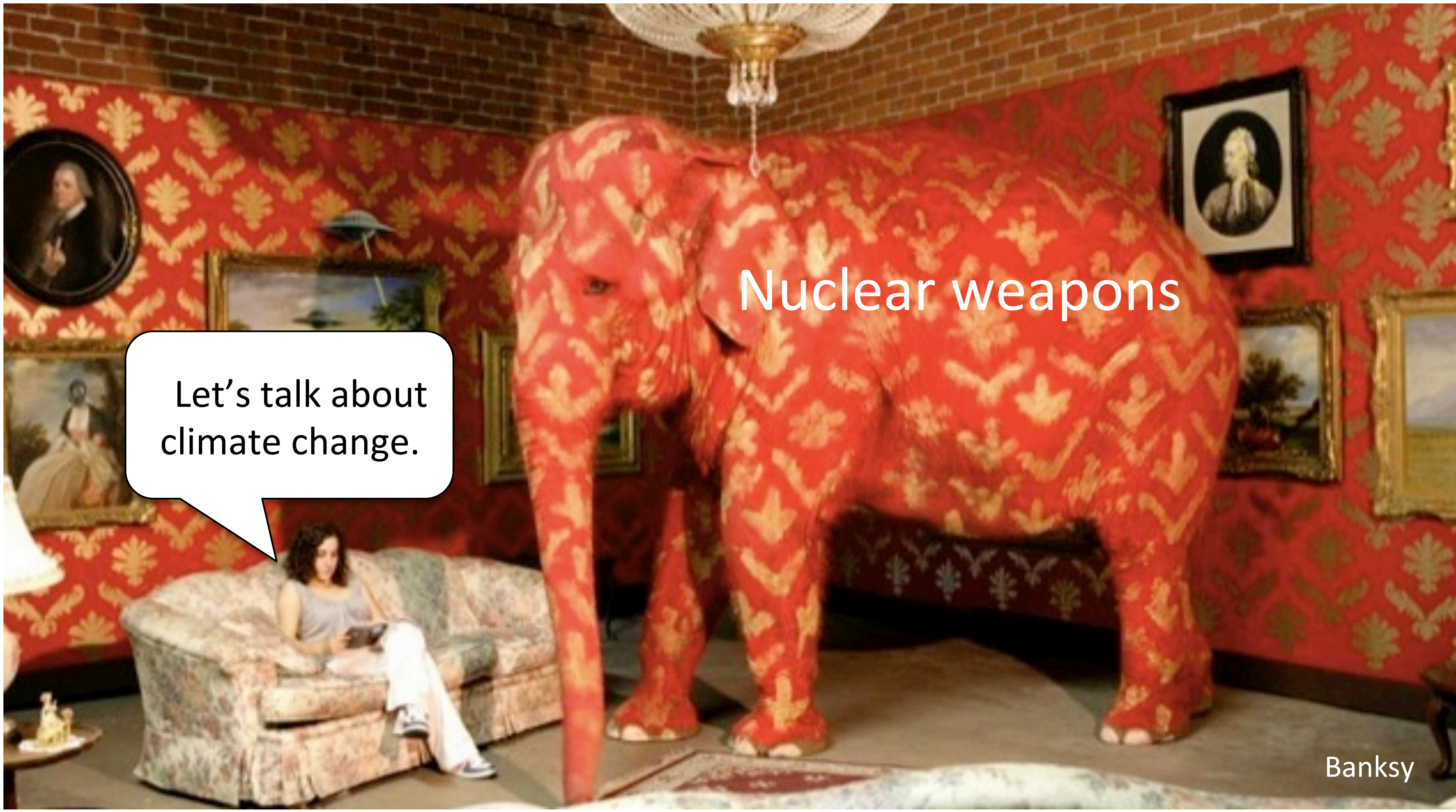
Why is cooperation between Russia and the US especially important?

- Because friends don't bomb friends



Federation of American Scientists

The post-bipolar world



Can we maintain a discussion about more than one dire threat to humanity?

USA-1978-USSR
TSUNAMI
СССР-1978-США

U.S.~RUSSIA
BILATERAL PRESIDENTIAL COMMISSION
2012 Joint Report

?

The line of cooperation has broken.

Joint monitoring of volcanic ash clouds

International Volcanological Field School

Kamchatka

Alaska

Partners in International Volcanological Research and Education (PIRE)

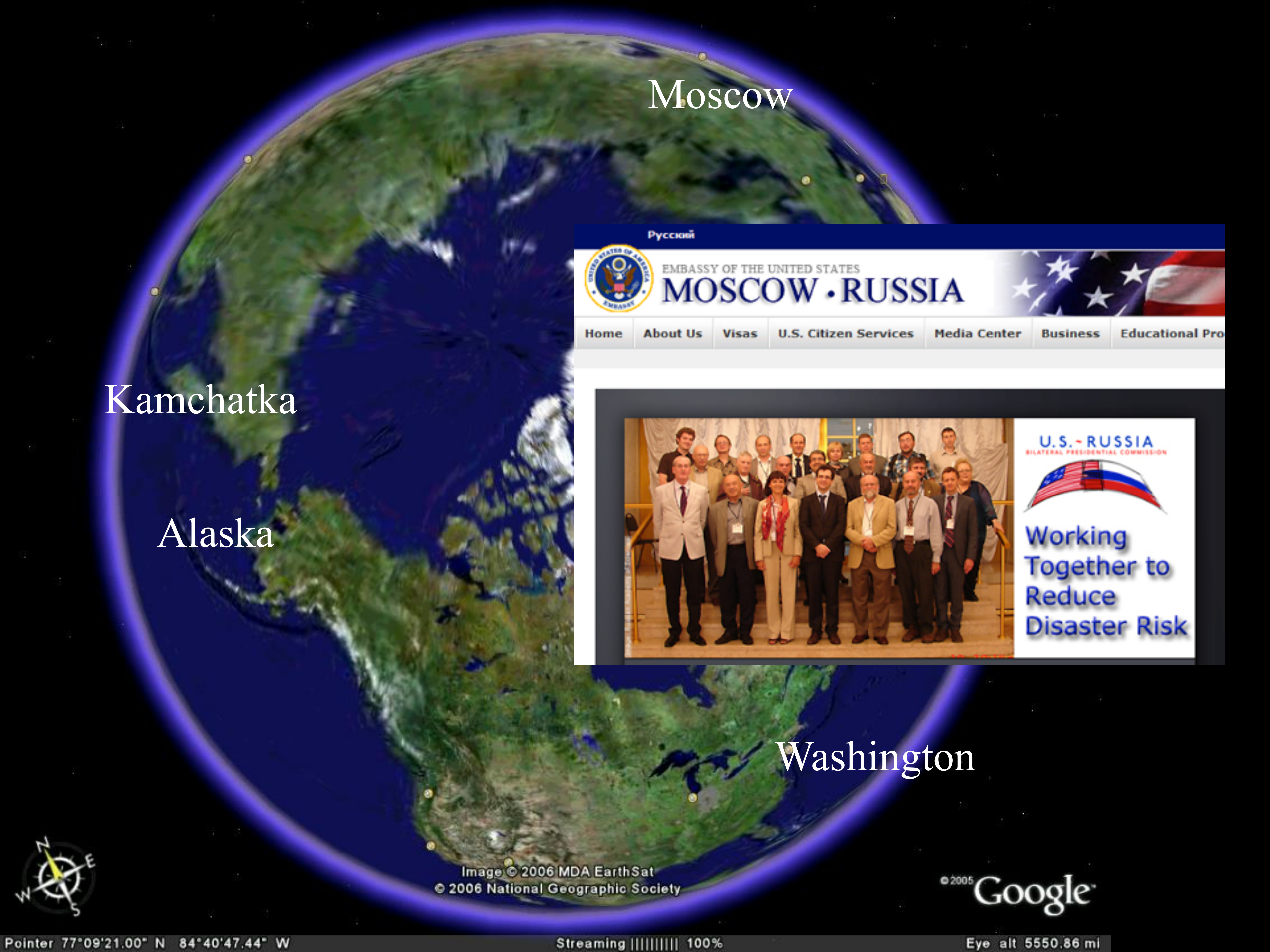
Bezymianny

Mount St Helens

How can we do better at mitigating risk and enhancing resilience?

Petropavlovsk-Kamchatsky

Galena, Alaska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Media Center
Business
Educational Pro
U.S. - RUSSIA
BILATERAL PRESIDENTIAL COMMISSION
Working Together to Reduce Disaster Risk
Image © 2006 MDA EarthSat
© 2006 National Geographic Society
© 2005 Google
Pointer 77°09'21.00" N 84°40'47.44" W
Streaming ||||||||| 100%
Eye alt 5550.86 mi

Working groups most relevant to natural hazards

Natural Hazards Science Subworking Group (including volcanoes, earthquakes. tsunamis. floods and wildfires)

Science and Technology

The Science and Technology Working Group agreed to develop cooperation in nanotechnology, IT, and climate monitoring as well as discuss obstacles to science cooperation, including tax, customs, and visa issues.

Agencies and institutions who were involved in the natural hazards initiative

United States

- USGS
- FEMA
- NOAA
- NASA
- Universities

Russia

- MES
- EMERCOM
- RAS
- RosHydroMet
- Universities

Agencies and institutions who are involved in the natural hazards initiative

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Russia

- MES
- EMERCOM
- RAS
- RosHydroMet
- Universities

We need to put the partnership back together!

Conclusions

- We should be bold about pioneering new measurements, especially where human life is involved.

- We should be bold about forging international partnerships, especially where human life is involved.