HLWYM HEmails

From: John Trapp [JST@nrc.gov]
Sent: Wednesday, March 21, 2007 11:26 AM
To: Debashis Basu; Donald Hooper; Brittain Hill; James Rubenstone; nadams@swri.org
Subject: Fwd: EPRI slides
Attachments: ACNWM1Mar07.pdf

>>> Neil Coleman 03/21/2007 10:28 AM >>>
Here are Meghan Morrissey's slides. The ppt file was too big to email so I converted a pdf for you (a few slides have multiple layers that won't show in pdf).
Regards,
Neil

Hearing Identifier: HLW_YuccaMountain_Hold_EX
Email Number: 1335

Mail Envelope Properties (s601166d.095)

Subject: Fwd: EPRI slides
Sent Date: 3/21/2007 11:26:14 AM
Received Date: 3/21/2007 11:27:19 AM
From: John Trapp

Created By: JST@nrc.gov

Recipients:
"Debashis Basu" <dbasu@cnwra.swri.edu>
Tracking Status: None
"Donald Hooper" <dhooper@cnwra.swri.edu>
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"Brittain Hill" <Brittain.Hill@nrc.gov>
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"James Rubenstone" <James.Rubenstone@nrc.gov>
Tracking Status: None
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Updated EPRI Response on Potential Igneous Events at Yucca Mountain

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Presented to the Advisory Committee on Nuclear Waste, March 21, 2007

Acknowledgements

Contributors to EPRI's Igneous-Event Analyses

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- Marcus Bursick Ph.D., SUNY-Buffalo
- Randy James Ph.D., ANATECH Co.
- John Kemeny Ph.D., University of Arizona
- John Kessler Ph.D., EPRI
- Matt Kozak Ph.D., Monitor Scientific LLC
- Fraser King Ph.D., Integrity Corrosion Consulting, Ltd.
- Meghan Morrissey Ph.D., Colorado School of Mines
- Alan Ross Ph.D., Alan M. Ross & Associates
- Ben Ross Ph.D., Disposal Safety, Inc.
- Frank Schwartz Ph.D., The Ohio State University
- Mike Sheridan Ph.D., SUNY-Buffalo
- Graham Smith Ph.D., Enviros Ltd.
- Wei Zhou Ph.D., Monitor Scientific LLC

Outline of Presentation

Nature of Magma in the Drift

- Magma solubility
- Gas escape
- State of magma upon intersection with a drift

Heat Loss

- Development of a chilled layer
- Magma solidification
- In-drift thermal calculation

Magma Dynamics

- Multiphase flow and initial conditions
- Nozzle geometry

Nature of Magma in Drift

NRC Reviewers:

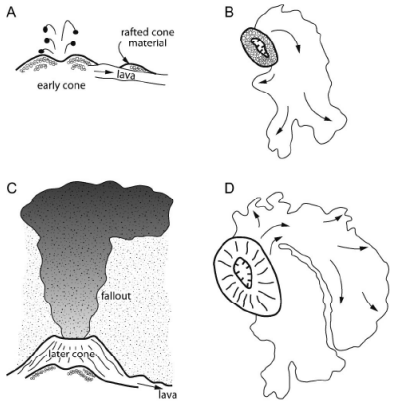
"EPRI asserts that the magma at the tip of an ascending column just prior to and at the point of intersection with a drift will be degassed".

"EPRI concludes that the intruding magma will have a relatively low temperature (975-1010°C), high viscosity 10^5-10^7 Pa-s, and rheology characteristic of an *aa* flow".

"These suppositions appear to be inconsistent with the fundamental physics of volatile-rich magma ascent …"

Nature of Magma in Drift

'Reasonably Expected' Volcanic Scenario for YMR (EPRI, 2004):



(Valentine et al., 2005)

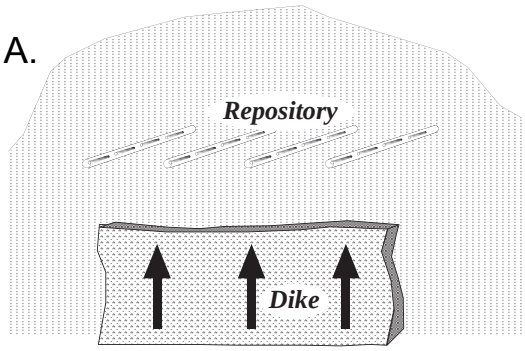
Lathrop Wells basalt center-best analog for future volcanism.

A. Lava fountains and Strombolian eruptions - early cone building phase.
B. <u>Northern aa lava flows</u>
C. Tephra ejection - late cone building stage
D. <u>Southern aa lava</u> flows

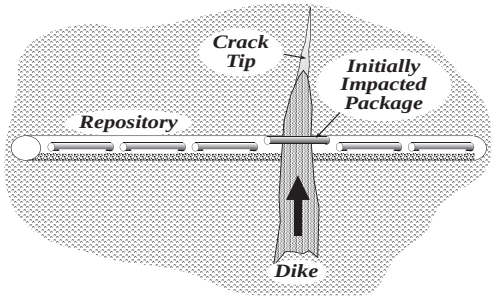
Nature of Magma in Drift

- Dike propagation and interaction with repository

A.

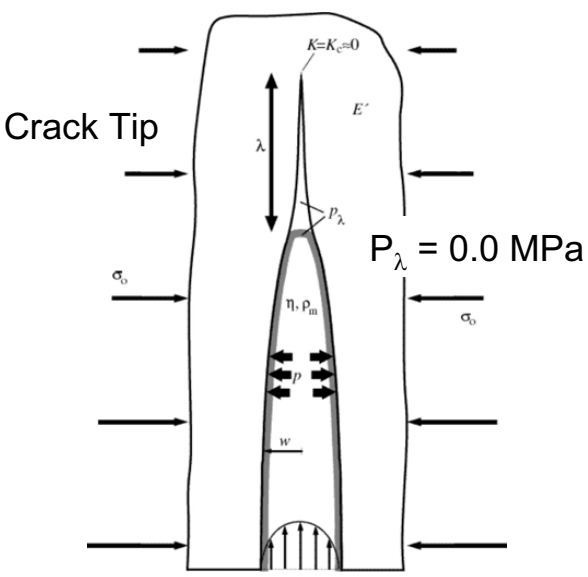


B.



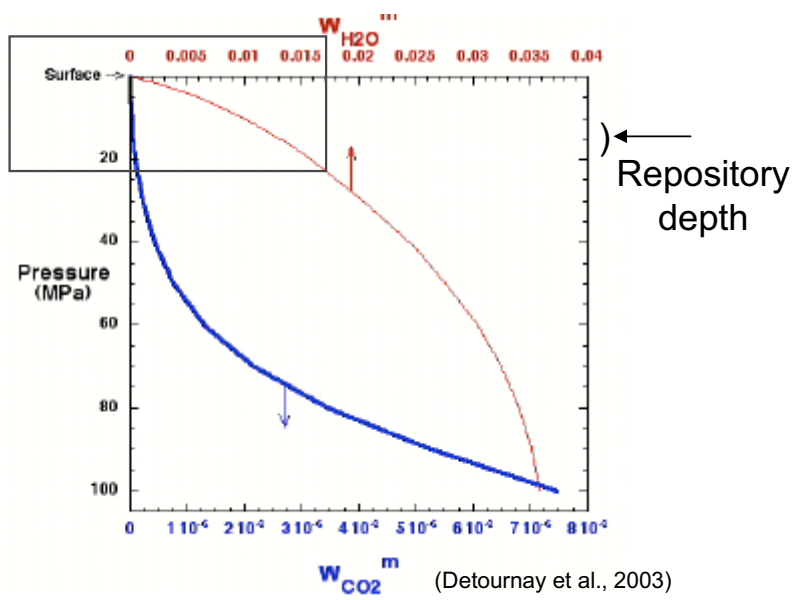
Nature of Magma in Drift

- Dike propagation and interaction with repository



(Lister and Kerr, 1991; Rubin, 1995; Detournay et al., 2003)

Wt% H_2O in magma as a function of pressure

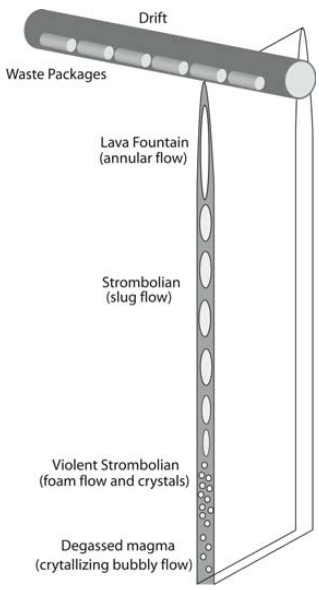


(Detournay et al., 2003)

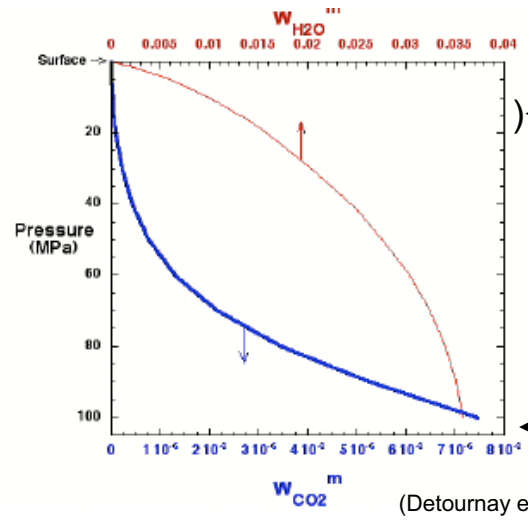
✓ *Near crack tip (P=0 MPa) magma will contain very little H_2O*

Nature of Magma in Drift

- Conceptual model of flow regimes prior to intersection with a drift. White areas denote gas phase and grey denotes liquid magma.



(EPRI,2004; 2006 - not to scale)



Repository depth

✓*As magma migrates toward the surface it will exsolve gases.*

4-5 km

(Detournay et al., 2003)

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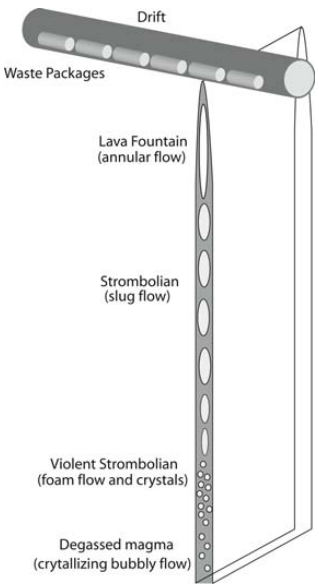
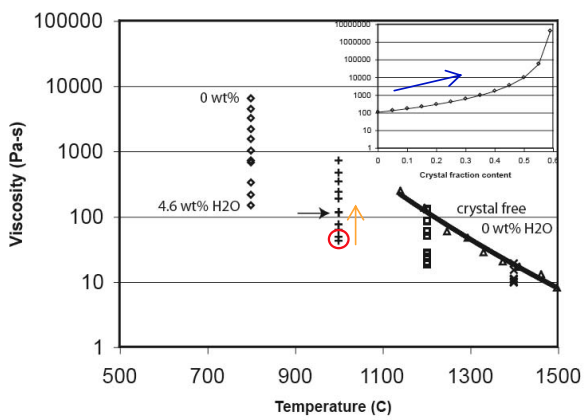
Nature of Magma in Drift

- Flow regimes require bubbles to nucleate, grow and coalesce.



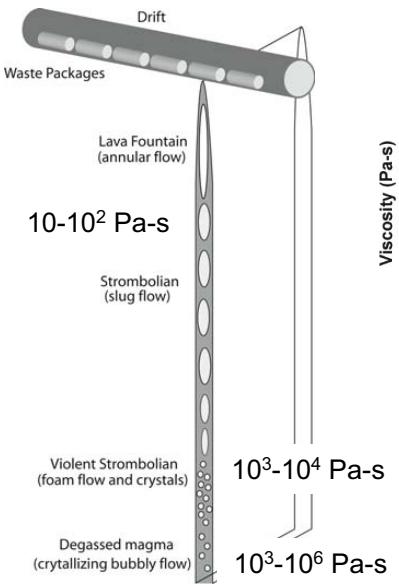


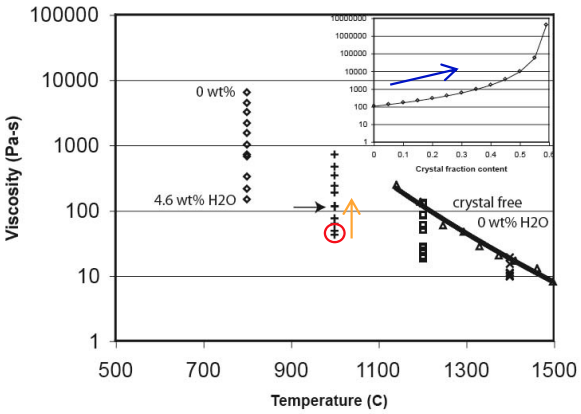
(EPRI, 2006)

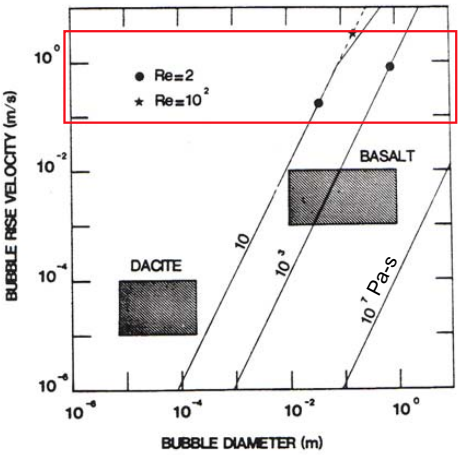
Magma viscosity as a function of H_2O and crystal content. Many small bubbles may increase viscosity by an order of magnitude.

Nature of Magma in Drift

- Flow regimes require bubbles to nucleate, grow and coalesce.







(Vergniolle and Jaupart, 1986)

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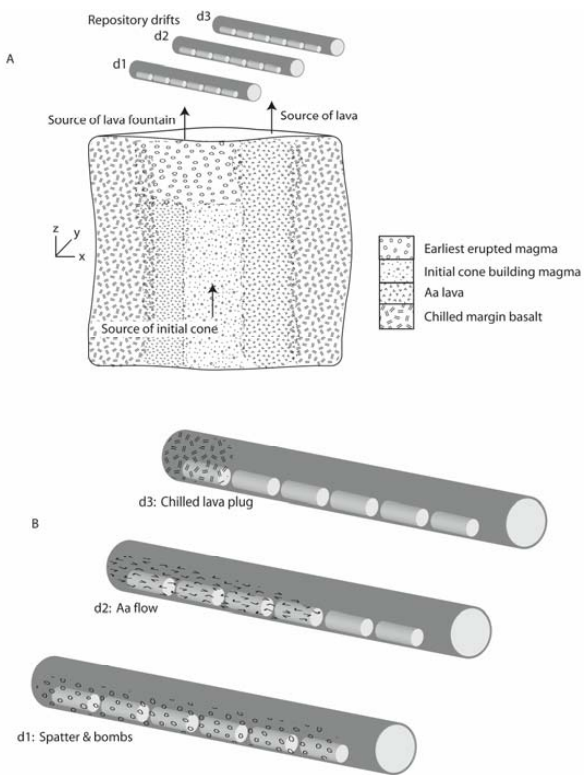
Nature of Magma in Drift

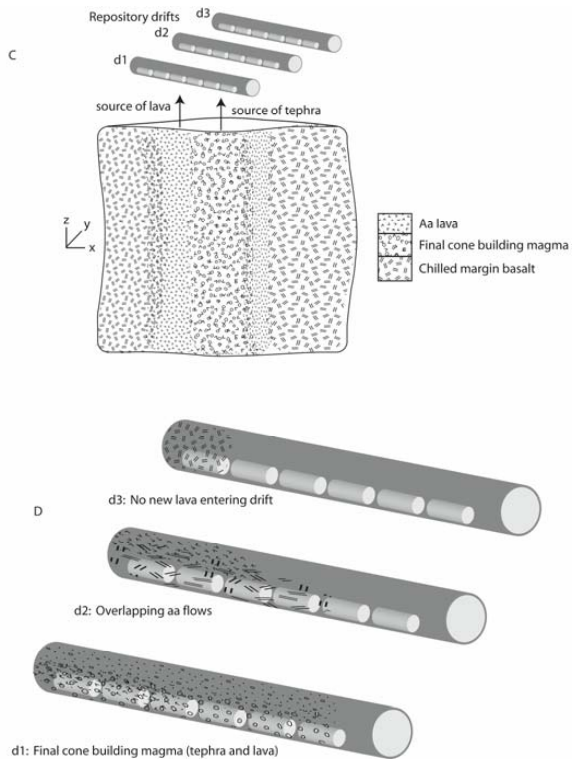


(from EPRI, 2006)

Three possible scenarios of initial magma-drift interaction:

1. (d1) spatter and bombs coat waste packages and pooling of magmatic material on drift floor.
2. (d2) aa lava flow entering drift entombing waste packages.
3. (d3) slow moving crystallizing lava from margin on dike forming plug sealing drift from dike.

Nature of Magma in Drift



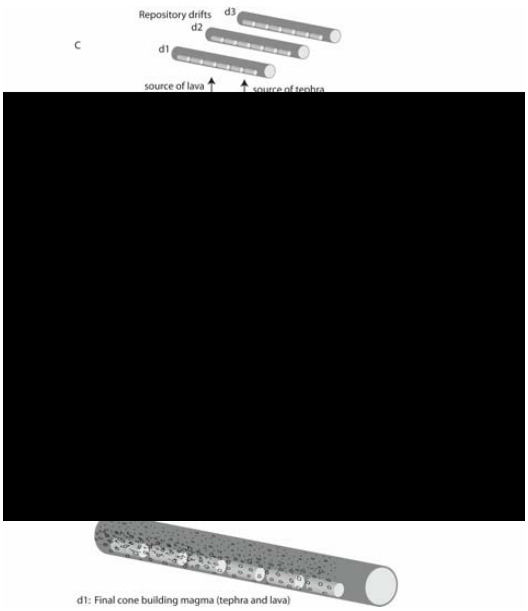
(from EPRI, 2006)

Three possible scenarios of late stage magma-drift interaction:

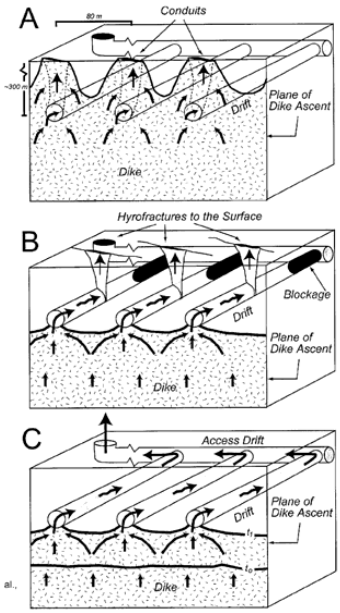
1. (d1) pyroclastic material entering drift containing spatter covered waste packages.
2. (d2) more lava entering drift already partially filled with lava.
3. (d3) no additional material - sealed drift.

Nature of Magma in Drift

- ✓ EPRI's conceptual model is consistent with fundamental physics of volatile-rich magma ascent. EPRI believes this model to be more realistic than that proposed by Woods and others (2002) whose model assumes magma enters the drifts with a constant viscosity of 10^2 Pa-s.



(from EPRI, 2006)



(from Woods and all, 2002)

Heat Loss

NRC Reviewers:

"EPRI concludes that the physical property of the magma entering the drift is similar to a lava erupted at the surface".

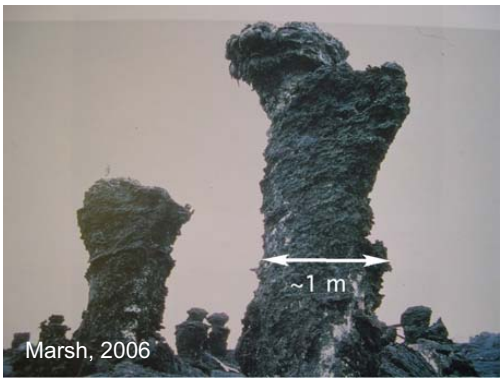
"EPRI's conceptual model entering a drift is derived from inappropriate analogy to the cooling of degassed basalt lava flows at the Earth's surface".

Examples of NRC asserted inappropriate analogies:

- EPRI cites descriptions of intact cars, gas tanks, and water tanks entrained in lava flows from ICRP" (in reality NRC should recheck p. 70, Detournay and others, 2003; Mastin 2002; 2007 personal communication).
- EPRI cites Lore and others (2000) as a basis for their assertion that radiative cooling dominates at the surface of the magma flow *into the drift* and conductive heating at its base" (in reality EPRI stated that EPRI (2004, p. 5-1; 2005, p. 17) used the basal temperature curve for conductive cooling that EPRI asserts will be one of the dominant modes of heat transfer).

Heat Loss

Chilled lava engulfing cars, trees, metal objects, …. EPRI believes that lava entering a drift will create a protective chilled contact crust.



Heat Loss

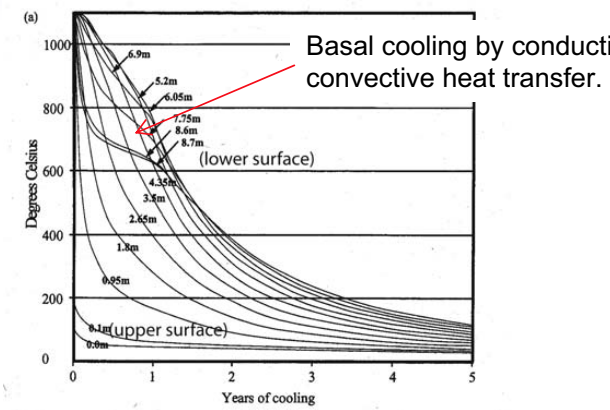
- Aa lava characterize flows observed in Yucca Mtn .
- Small volume, short in length (< 1-2 km) .

Figure 48. As flowing aa lava cools, degases, and becomes more viscous, the hardened crust on the flow surface breaks up into rubble and gives the flow a rough, clinkery appearance. The flow shown is about 8 feet high.
Photo by G. W. Tribble, U.S. Geological Survey

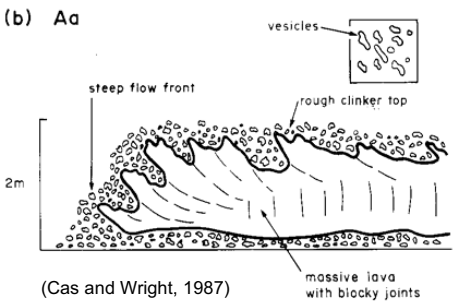
Table 4.1 ACNW, pg 60

Volcano	Age, Ma	Rock Type[a]	Volume, km^3	Fissure Length, km	Lava Flow Length, km	Maximum Lava Effusion Rate,[b] m^3/s	Brief description
Thirsty Mountain	4.63 ± 0.02[c]	Basaltic trachyandesite	2.28	5[d]	6	80	Broad shield volcano consisting of stacked lava flows and a central remnant of pyroclastic (near vent) deposits.[c]
Pliocene Crater Flat (aka Southeast Crater Flat)	3.73 ± 0.02[c]	Basalt	0.56	3.6	4	40	Low shield volcano, now broken by normal faults and partially buried by alluvium, with multiple lavas and pyroclastic vent facies exposed.
Buckboard Mesa	2.87 ± 0.06[c]	Basaltic trachyandesite	0.84	2.5	7.3	100	Large lava field with remnant of a main pyroclastic cone in northern part, fissure inferred from ridge of lava and pyroclastics that extends SE from main cone.
Black Cone	0.986 ± 0.047[e]	Trachybasalt	0.06[e]	0.6 (1.8)[f]	1	0.9	Pyroclastic cone remnant preserving Strombolian and violent Strombolian facies, and two lava fields that vented from the base of the cone.[e]
Red Cone	0.977 ± 0.027[e]	Trachybasalt	0.06[e]	0.5 (1.6)[f]	1.4	3	Pyroclastic cone remnant preserving Strombolian and violent Strombolian facies, and two lava fields that vented from the base of the cone.[e]
SW Little Cone	1.042 ± 0.045[e]	Trachybasalt	0.03	0.3 (0.8)[f]	0.7	0.4	Pyroclastic cone remnant, open to the south, with single lava field mainly buried by alluvium.[e]
NE Little Cone	1.042 ± 0.045[e]	Trachybasalt	Included with SW Little Cone	0.2 (1.8)[f]	1.8	4	Pyroclastic cone remnant, open to the south, with single lava field mainly buried by alluvium.[e]
Makani volcano (aka Northernmost)	1.076 ± 0.026[e]	Trachybasalt	0.002[e]	0.4	0.4	0.1–0.2	Small lava mesa with pyroclastic deposits marking location of short fissure.[e]
Little Black Peak	0.323 ± 0.027[c]	Basalt to trachybasalt	0.014	0.4 (1)[f]	1.3	2	Pyroclastic cone with lavas that extend from its base.
Hidden Cone	0.373 ± 0.042[b]	Basalt to trachybasalt	.03	0.3 (0.8)[f]	1.6	4	Pyroclastic cone on side of butte with two lava field extending from its base.
Lathrop Wells	0.076 ± 0.005[g]	Trachybasalt	0.09[h]	0.8 (1.8)[f]	1.6	4	Single pyroclastic cone with two lava flow fields that vented from the base of the cone.[h]

Heat Loss



✓ Temperature-time profiles calculated by a 2-dimensional viscoelastic stress model for cooling basalt with an initial temperature of 1100ºC (from Fig. 7A, Lore et al., 2000). (Fig. 7 EPRI 2005)



(Cas and Wright, 1987)

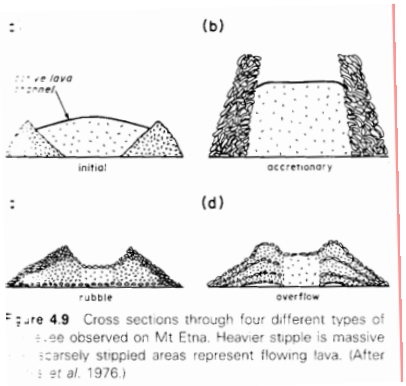


Figure 4.9 Cross sections through four different types of lava observed on Mt Etna. Heavier stipple is massive lava, coarsely stippled areas represent flowing lava. (After Lore et al. 1976.)

Characteristics of aa lava:

• Basal crusts form by the flow overrunning clinkers which have tumbled from the flow front rather than solely by conductive thickening. The main modes of heat transfer at the front and base are forced convection and conductive with contact temperatures at 700+/-200ºC. (Harris and Rowland, 2001).

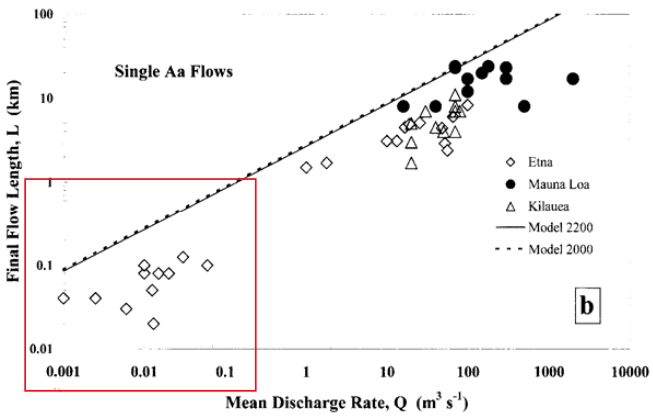
• The thickness of the basal layer of an *aa* flow is 10% the total thickness of the flow (Harris and Rowland, 2001).

• Degassing of the lava leads to considerable under cool, rapid growth of quenched crystallites, a rapid increase in the viscosity and the development of a high yield strength (Cas and Wright, 1987).

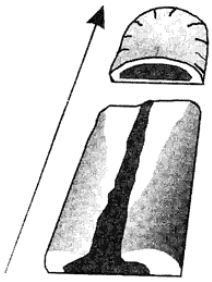
Heat Loss

What is the likelihood that a flow in the drift will melt existing chilled crust? NRC states it will melt because the flow rates will be sufficient to reheat and melt the material.

- Eruption discharge rate controls the flow length of small volume flows.



(Fig. 8b in Encyclopedia of Volcanoes, Kilburn, 2000)

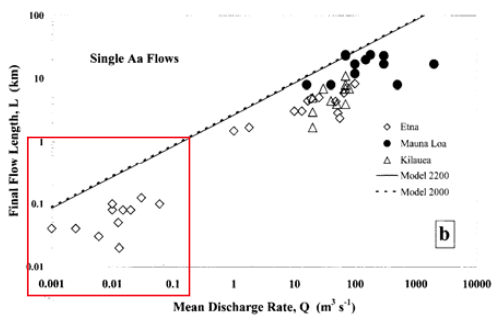


Crystallized margins forming clinkers

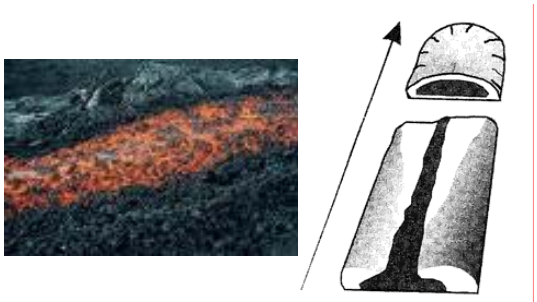
(Fig. 1 in Encyclopedia of Volcanoes, Kilburn, 2000)

Heat Loss

- Velocity of aa lava flows entering drift.



(Fig. 8b in Encyclopedia of Volcanoes, Kilburn, 2000)



Crystallized margins forming clinkers

(Fig. 1 in Encyclopedia of Volcanoes, Kilburn, 2000)

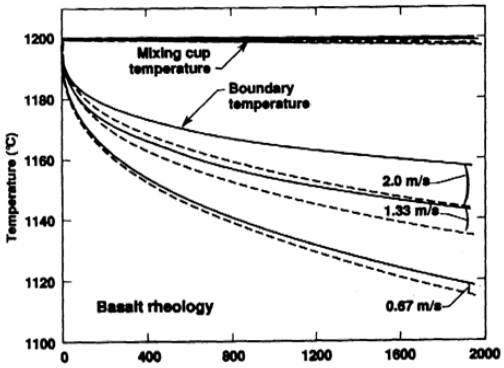
Velocity of lava entering a drift:

$Q = 0.001\text{-}0.1\ m^3/s$

Q = area * velocity

$Q = \pi r^2 * \text{velocity}$, r = radius of drift (-wp) (1.6 m)

Velocity = 0.00012 - 0.012 m/s



(From Carrigan et al. 1998).

(EPRI, 2004 p. 3-13)

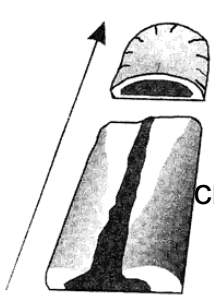
Heat Loss

- Aa lava flows entering drift.

✓ *Lava inside a drift will be slow moving (< 10 m/s), crystallizing flows.*

✓ *Additional flows entering a drift will not melt all chilled lava inside drift.*

✓ *Slower moving flows will lose heat faster thus viscosity will increase terminating the flow earlier than less viscous, more fluid lavas as expect by NRC.*



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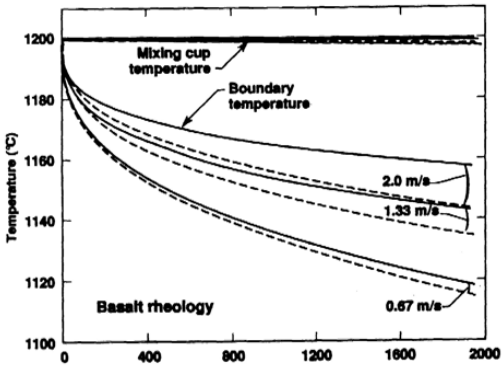
Velocity = 0.00012 - 0.012 m/s



(From Carrigan et al. 1998).

Heat Loss

- In Drift Thermal Calculation

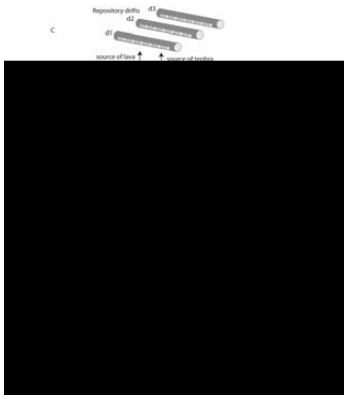
  NRC listed 8 deficiencies in EPRI's model approach including unsupported assertion that magma extends 20 m into drift; laminar/turbulent flow (magma or H_2O?); convective heat transfer viable mode (included in model); phase change or solidification (magma or hydrous phases?).

  Reason for EPRI's model approach:

  " EPRI has opted not to initiate an integrated analysis on the potential extent of magma intrusion into an emplacement drift. Instead, EPRI analysts have applied expert judgment to existing analyses by the DOE OCRWM (2003) and independent researchers. … EPRI believes that newer, more representative (updated) data for the basaltic magma … should be substituted for the more conservative data assumed in OCRWM (2003)". Pg. 19, EPRI 2005

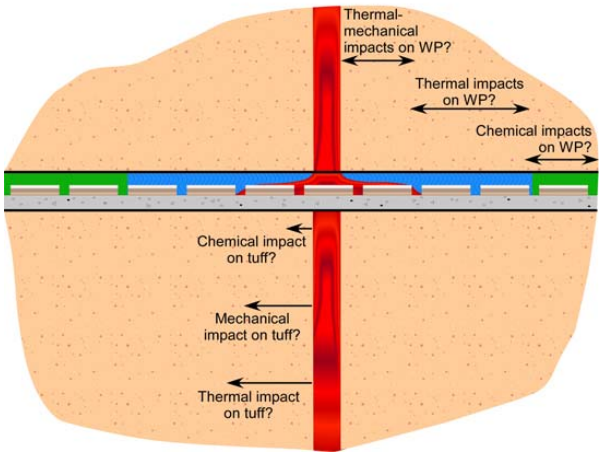
  In other words, the in-drift thermal calculation performed by EPRI analyzed the thermal effects on liquid water and vapor phase inside of drift ,on waste packages and in wall rock after the emplacement and solidification of magma inside a drift.

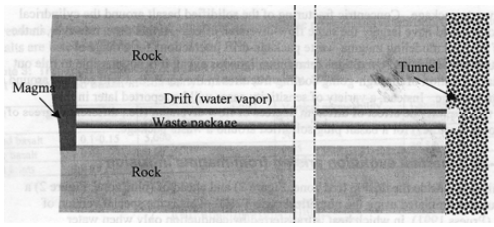
Heat Loss



In Drift Thermal Calculation

- T2HT, a version of TOUGH2.
- Convective and conductive heat transfer.
- Fracture network in solidified basalt.
- Temperature curve at the base of cooling lava (Lore et al., 2000).
- Considered reasonably realistic boundary and initial conditions.





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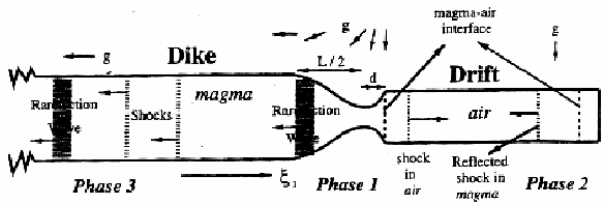
Magma Dynamics

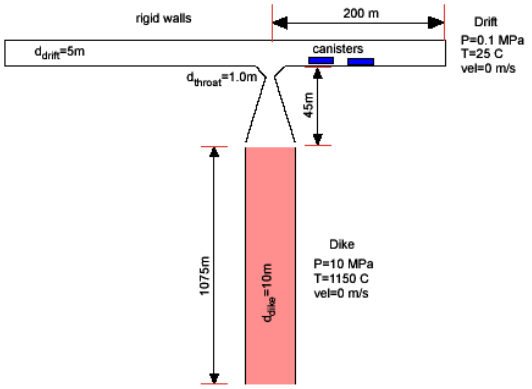
- Nozzle Geometry

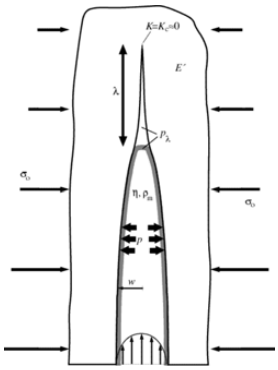
NRC states that "the geometric condition of the dike-drift cannot be adequately modeled as a nozzle flow problem. No rationale is provided to explain the significance of this divergence".



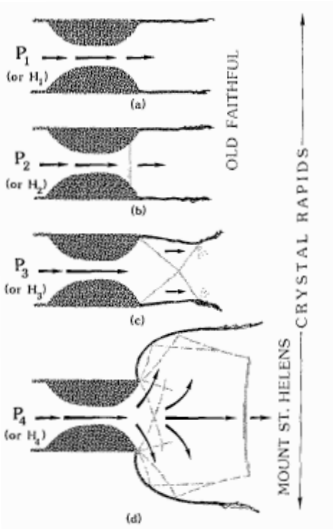
(from Figure 3 in Bokhove and Woods, 2002).

Examples:





(Detournay et al., 2003)

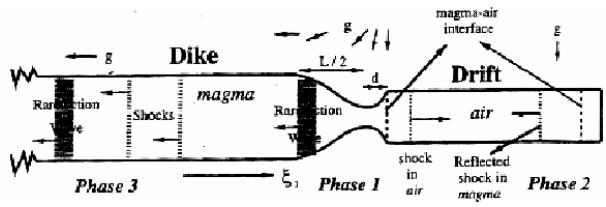


(Fig. 2 in Kieffer, 1988 Geologic Nozzles)

Magma Dynamics

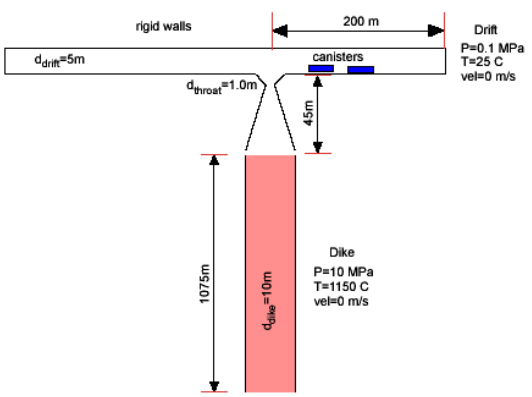
- Nozzle Geometry

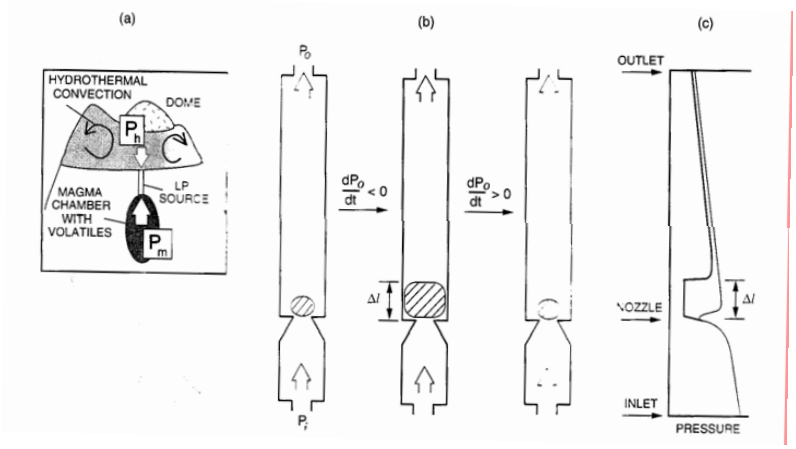
NRC states that “the geometric condition of the dike-drift cannot be adequately modeled as a nozzle flow problem. No rationale is provided to explain the significance of this divergence”.



(Fig 3 in Bokhove and Woods, 2002).

Examples:





(Fig. 3 in Morrissey and Chouet, 1997, DASH).

Magma Dynamics

• Multiphase flow and initial conditions

NRC: "EPRI's flow field does not appear to be consistent with fundamental physical and chemical processes of volcanic eruptions".

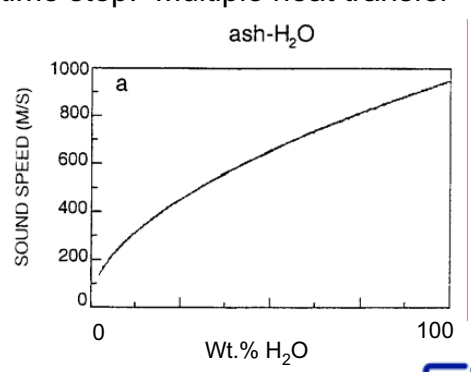
A fluid containing a high pressure gas is treated as compressible. The physics of a compressible fluid that is either a pure gas or a gas and particle (fragmented magma) mixture will behave similarly with differences in sound speed, rates of changes in flow properties and magnitude.

Woods et al. model: homogenous flow (magma, gas and bubbles move at same speed, bulk density term and solubility eqn; constant viscosity for magma (10 Pa-s)). Thermal eqm.

SAGE: multiphase compressible flow (steam, magma, air) viscosity and turbulence are not constant terms. These are calculated at every time step. Multiple heat transfer modes included.

$$\frac{p}{p_i} = (1 + \frac{\gamma - 1}{2} M^2)^{-\gamma/(\gamma-1)}$$

M = Velocity / sound speed



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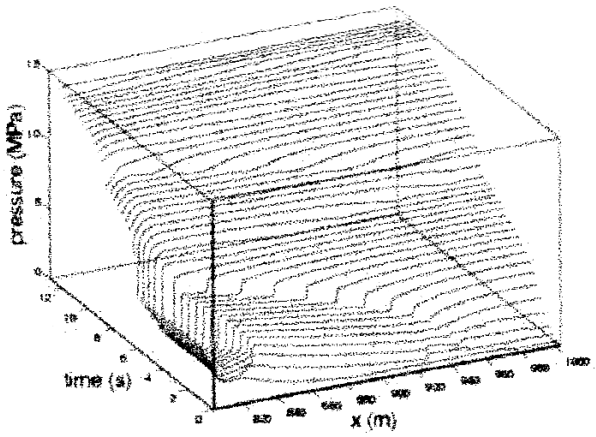
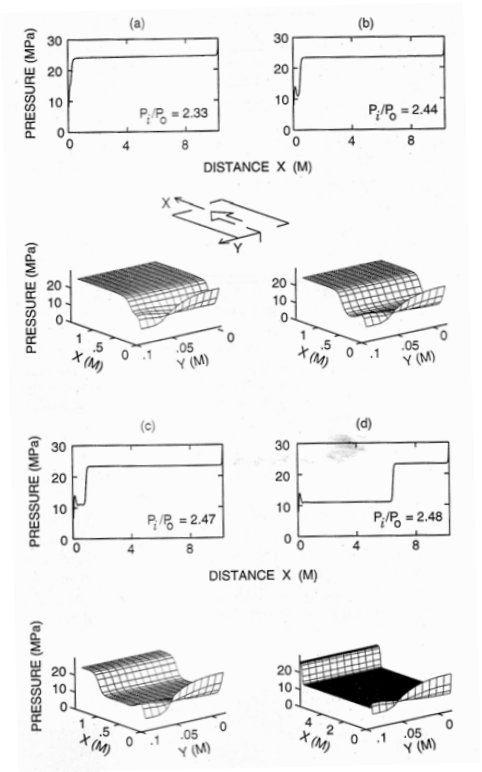
Magma Dynamics

- Multiphase flow - Compare homogeneous vs multiphase flow (SAGE, DASH)

✓ Very little difference in the fundamental physics



Homogenous flow
(Fig. 1, Woods et al., 2002)
1-D calculation



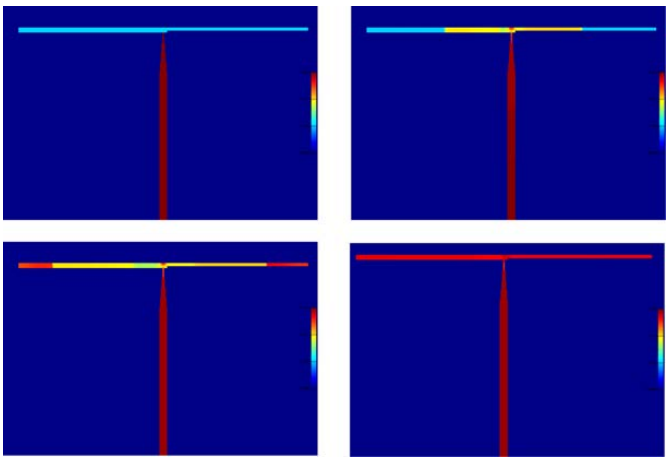
Single phase 2-D compressible flow (DASH)
(Fig. 7, Morrissey and Chouet, 1997)

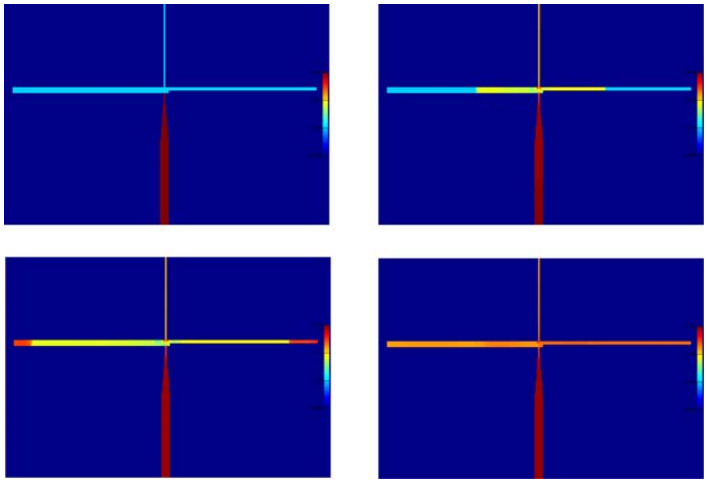
Magma Dynamics

- Snapshots of pressure inside drift (SAGE)

  Initial velocity = 0 m/s (dike ascent < 10 m/s)

  Initial pressure in dike 10 MPa; 0.1 MPa





Summary

EPRI believes that the conceptual model derived and analyses conducted by EPRI since 2004 are based on observations made routinely at volcanoes and on data from appropriate analogs of future Yucca Mountain volcanism. Contrary to the position put forward by the NRC and their consultants, EPRI's analyses are consistent with fundamental physical and chemical processes and EPRI's igneous consequences at Yucca Mountain are indeed technically defensible.