Review comments on ***Igneous Activity at Yucca Mountain: Technical Basis for Decision Making***, a draft report prepared by the Advisory Committee on Nuclear Waste, US NRC, December 2006.

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A. Comments on draft by William G. Melson, Senior Volcanologist Emeritus, Smithsonian Institution, and consultant to the Nuclear Waste Technical Review Board. Feb. 15, 2007

You ask that those cited in your report go over those citations for accuracy. Those on lines 5268-5276 are correct but need to be corrected as shown below.

Line 5272. The quote from my report to Leon Reiter reads not "in excess of 1200^{o} C" but "up to 1200^{o} C." (Melson, 2002 in your reference is correct (report in on the web at

http://www.nwtrb.gov/meetings/melson.pdf

Line 5275. My quote as to as dog-leg worst case scenario and my judgement, in accord with the igneous consequence panel's views, is in a report to the NWTRB dated February 28, 2003, not in the Sept. 2002 report. I have attached a complete copy of that report.

Editorial comments on other aspects of the report:

Overview comments

- Suggest start text on probability of disruption and move to consequences in the executive summary.

- Coverage of differing opinions on some of the technical issues is good. At the meeting of Feb 13-14, many comments and additions were mentioned by the DOE, NRC, EPRI and others that will be coming to authors before March 1, and will cover any suggested omissions or corrections in what appeared to be a comprehensive way.

- As far as readability, transitions between some of the sections and between change in authorship of the different sections may be helpful.

- This will be a valuable and so far as I know unique reasonably short document summarizing all the major aspects of volcanic hazard issues. As I'm sure the authors are aware, it is but a snapshot of a changing picture of many of the technical issues. In particular, the new estimates of the probability of disruption will not be finalized until June, 2008

Comments on some details referenced to line numbers:

241. Reminder: Temporal clustering may also lower probability of dike intersection because we're not sure if we're at the beginning or end of a cluster.

302. Duration as well as viscosity where duration = ƒ(volume) (and rate)

310. immobile once degassed (solidified)

338. Does this mean from the end vent (not tephra) or end of tephra sheet.

344. I believe one very heavy rainfall would remove nearly all of a few (2-3 cm) tephra fall and transport into drainage channel or cracks in ground. Steady state – usage may be miss-leading if it means uniform.

353-354. Transport by dust devils and windstorms can be very large as you know and not so easily ignored.

359. Arid terrain can erode very rapidly with storms so tephra apron can be short lived.

457. Clarify AMAD definition.

469. Cirque-like (?? for a desert landscape?)

480. remove electrochemical

490. wi-polished – wind-polished

987. About the starting quote: Chaos theory – popular in modern physics – negates this deterministic dream of Laplace, 1776. Suggest you remove it.

1014. In science I assume a "legitimate professional view" is a theory or model that is consistent with all known data, observations and other established theories.

1049. suggest you insert emplacement before solidification

1051. suggest you simplify this by saying because of density instead of "gravitational forces".

1052. from volcanoes or other volcanic deposits (i.e. lava sheets or ignimbrites)

1066-1068. Vague, Clarify or delete.

1067-68. "and precursor events...". This statement is not clear. Predicting an eruption or any scale is not "rudimentary" to my knowledge. Suggest you delete this sentence or clarify it, or did I miss the point?

1108-09. change to: " is based on an evaluation that is as quantitative as possible of the risk triplet...

1122. change to ..10,000 years following closure, the period of time...

1158-61. Redundant?? Suggest remove.

1173. Figure 1.2. The distinction between probabilistic and decision parameters is not immediately evident to me.

1311. Isn't the pre-closure estimate of activity indicated by PVHA-96 and so low as to not reasonably influence construction features of pre-closure structures?

1432. Insert paragraph break before ". The" paragraph is too long.

1563. This paragraph would benefit by being rewritten. A great deal of basaltic magma is in the low velocity zone or generated by thermal plumes. Although the latter is mentioned, the basaltic volcanism in the Great basin is not related to plate collisions, with which the paragraph begins.

1580. as = along

1591. Magmas may not be residual, but new magma produced in small volumes that has gone through some fractionation (and surely some contamination) on way to surface.

1623. include temperature.. "Magma composition, temperature, ...

1625. Suggest you delete "temperature is of minor importance." (it can be of major importance).

1627. water solubility is a function of water vapor pressure..even high magma total presssure cannot affect water content if there is no water present.

1629 at same water pressure...(strictly speaking we are speaking of the partial pressure of water). See consequence peer review panel section on magma properties by Frank Spera. It is one of the best exposition of magma properties that I've seen.

1649 I believe that intense Strombolian eruptions came very early in the eruptive sequence at Lathrop Wells as well.

1654 Presumably the missing 0.03 km^3 is as distant airfall. If it is, say so.

1656 Figurer 3.1 Vertical arrows in dikes are missleading..flow can be even horizontal. Might say "Only vertical component of flow is shown." Or, flow is assumed to be vertical only."

1668 "Nature's attempt" is a clumsy expression..state it as a physical process not as nature's attempt.

1672. Redundant..returning to water content.

1670-1677. Is this really necessary in speaking of what has occurred and what might occur in the future? Consider deleting?

1692 violent Strombolian... replace with Strombolian.

1699 Refer to opening phase of Paricutin?

1736 Again touches on being repetitive

1738 again, less on temperature.. specify what you mean by "quantitatively". A rapid drop in temperature, for example, in a narrow dike, can completely stop magma rise.

1754 delete "with the repository." Redundant.

1788-89 volcanic risk at the highest??? Reason. Not volcanic risk, but radioactivity maximum? Clarify.

1793 spelling "degas"..degass

1793-1804. Alas, Wood et al would not agree with this scenario.

1923-1969. How does this model approach differ from that now used by SW center and DOE??

1985. Wind velocity ranges tremendously... continuous means???

2039 "Inhalation"..remove capitalization

2162 replace heavily with deeply

2175 remove "was present"

2200 "heat energy" is a peculiar expression.. for volcanism volumes and rates are used. Suggest revise the sentence.

2297 This sentence ought to include the mean probability that any dike would intersect the repository.. standing alone without this explanation makes this an alarming sentence!

2203 This first sentence is not really about the topical matter of the paragraph. Suggest revise.

2544. Capitalize start of sentence – add period

2740 replace but by and

2768 best method *add:* in the repository.

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B. Comment from Leon Reiter, Feb. 15, 2007

There was a typo in the NWTRB's 2004 Report. We did not mean to urge the DOE to study "incompressible (as well as compressible) flow of magma into the repository." as you indicated on lines 5288-5299 of your white paper. It was a typo that slipped through the cracks. I suggest you end the sentence after (NWTRB, 2004) on line 5288 and leave out the part that follows.

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C. DOE Comments on Draft "Igneous Activity at Yucca Mountain: Technical Basis for Decision Making" 20 February 2007

Line in Draft	**Comment**
90-93	Report infers that thermal stresses could divert a dike around a repository during the thermal period (~2000 yrs). Dike-Drift Interaction (MDL-MGR-GS-00005 Rev01) reports model calculations of this effect and shows that while dike propagation would be temporarily slowed as a dike enters the thermally perturbed zone beneath the repository, it would not be deflected.
185-188	New work to be reported in ANL-MGR-GS-000002 Rev03 (under review) ties dike strike more closely to pre-existing faults, as supported by analog field data.
190-191	New work to be reported in ANL-MGR-GS-000002 Rev03 (under review) supersedes the DOE range of conduit diameters (at repository depth) with a lower mean value based upon recent analog studies.
193	Implies that a dike intersection always leads to an eruption. Current DOE eruption probability is less than the probability of intersection.
198-201	Currently, DOE allows for multiple conduits with a range of 1-3 and mean of 1.1.
203-205	Currently, DOE uses probability distribution function of dike length from PVH-96 ranging from 1 – 10 km with a mean of 4km. Recent analogue by DOE work indicates that this range and mean may over estimate this parameter.

210-211	DOE dike width distribution from PVHA-96 ranges from 0.5 - 5 m with a mean value of 1.5 m. Recent analogue work by DOE indicates that this range and mean may increase at repository depth; however, this is not a sensitive parameter in the DOE TSPA igneous consequences calculations.
260-261	ACNW report states that since 10 Myr basaltic volcanism has focused mainly in alluvial basins. Note that three of the eight Quaternary volcanoes erupted through structural blocks (Hidden Cone, Little Black Peak, and Lathrop Wells; reported in Valentine et al., 2007; Valentine and Keating, 2007).
279-283	Key to the assumptions about potential failure of waste packages in eruptive conduits is the fact that an event will last many months or a few years, with many complex dynamics.
308-313	The statement that the lavas are "relatively immobile" seems to overlook that fact that they typically flowed ~1 km on the Earth's surface where heat loss is likely to be faster than in an underground tunnel. The statement in the report does not mention the role of effusion rate and total volume on lava flow length.
326-335	Discussion of the hypothetical shock wave associated with initial dike-drift interaction. Note that DOE argues that even if shocks were to occur (which seems likely given the initial pressures and multiphase effects), their impact on waste packages would be minimal compared to the longer term interaction between multiphase magmatic flows and packages.
337-344	DOE model of tephra redistribution is being completely replaced with a process-based landscape model.
1512	"The caldera is no longer..." should be replaced with "The Crater Flat caldera is no longer ...."
1589-1593	This is an inference, but is stated more firmly.
1643-1644	Field data indicate that basaltic dikes in Yucca Mtn Region are typically several m wide (not "a meter or two"). They propagate perpendicular to the *least* (not maximum) compressive stress – *in the absence of pre-existing weaknesses*. See Valentine and Krogh (2006), Keating et al. (2007); Perry et al. (2006); Connor et al. (2000); and ANL-MGR-GS-000002 Rev03 (under review).
1683-1684	"Flow distance depends greatly on erupted volume and terrain slope" ignores the primary effect of effusion rate on flow length.
1697-1698	"..although polygenetic cinder cones are also not uncommon." None of the cinder cones in Yucca Mtn region are interpreted as polygenetic.

1730-1731	Dike-Drift Interaction AMR shows that topography of Yucca Mtn would have little effect on dike propagation, and Gaffney & Damjanac (2006) show a more detailed analysis of flow focusing given a dike ascending beneath variable topography.
1746-1749	This sequence of events for a scoria cone volcano overlooks the documented complexities, such as the fact that explosive activity commonly switches back and forth between Strombolian and violent Strombolian activity, and lavas can erupt throughout the activity, including contemporaneously with explosive activity (Valentine et al., 2006, 2007; Valentine and Keating, 2007)
1757-1758	Dike-Drift Interaction (MDL-MGR-GS-00005 Rev01) reports detailed calculations of the repository thermal effect and shows that while dike propagation would be temporarily slowed as a dike enters the thermally perturbed zone beneath the repository, it would not be deflected. The report also contains detailed calculations that indicate that an ascending dike would not be deflected around a repository by topography.
1886-1887	It is important to keep in mind the months-to-years duration of an igneous event when considering the response of waste packages in a conduit.
2046-2049	In the DOE biosphere work contaminated ash does not make its way into drinking water
2201-2202	Sentence should read: “Valentine et al. (2006, 2007) have concluded that the Pleistocene Crater Flat volcanoes are *each* derived from a single *conduit* (monogenetic) formed...” The field studies indicate that there were shallow breakouts from the individual conduits that fed lava (these vents are typically referred to as boccas), which some workers might consider to be “vents.”
2248-2249	Need to clarify that the DOE assumption is that any *event* that intrudes the repository will vent out to the surface. However, an event may consist of multiple dikes; only one of those dikes will feed eruptions, while the others might stall just below the surface. This is consistent with field analog studies (Valentine and Krogh, 2006; Keating et al. 2007) and is reported in ANL-MGR-GS000002 Rev03 (under review).
2328	Recent volume calculations for Grants Ridge place it at < 1 km^3 volume and is reported in ANL-MGR-GS000002 Rev03 (under review).
2336-2337	See above comment on new values for conduit diameter.

2481-2483	"DOE assumes a single eruption (monogenetic) volcanic event associated with each dike approaching the surface." Statement is not quite correct. Each event might have multiple dikes, and might have 1-3 conduits, but each conduit might have shallow breakout vents that feed lavas from the lower flanks of growing cones.
2486-2488	See comment above on dike lengths used in current DOE analyses.
2492-2493	See comment above on dike widths used in current DOE analyses.
2519-2520	10e-9 is 1 in 1 billion, not 1 in 100 million.
2520	Clarify that "10^{-6} to 10^{-9}" is the annual recurrence frequency, not the probability of an eruption ever happening.
2589-2590	The statement that lavas were formed after an earlier Strombolian cone building phase is not correct. Lavas were emplaced during a range of pyroclastic activity. See Valentine et al. (2007) and ANL-MGR-GS-000002 Rev03 (under review).
2628	Original data and age reference for anomaly B is Perry et al. 1998
2730-2733	Basalt of 23P is in fact associated with a magnetic anomaly, a normally magnetized, linear anomaly identified as "U" in Figure 5.4.
General	The 80 ka age of Lathrop Wells is mentioned numerous times, but never attributed to the work of Heizler et al. (1999), although Heizler is cited for other miscellaneous data.
2840-2846	Discussion on whether Lunar Crater and YMR volcanic systems are linked should also cite Farmer et al. 1989, DOE Characterize Framework for Igneous Activity at Yucca Mountain, Nevada, Rev. 02, and Perry et al. 2005, all of which contain discussion bearing directly on this issue.
2879, 2883	Phrase "active magma chamber" should instead allude to the presence of melt in the mantle source. "Magma chamber" traditionally refers to a crustal body.
2880-2881	Statement that "an active magma chamber.....is needed for basaltic igneous activity to occur" is incorrect.
2888-2896	Contrary to discussion, Biasi's data shows slow mantle beneath parts of Crater Flat that is separate from the fast root beneath the calderas. The position of the repository is in the diffuse boundary between these two areas (according to Biasi's interpretation). *Please contact Glen directly if more info required.*
P. 104, Fig 6.1	This simple sequence of events – explosive activity followed by lavas – is not consistent with field observations of the Quaternary volcanoes in the region, which show that the sequence of different styles is variable and that explosive and effusive activity can be interspersed with each other and probably coeval from a single eruptive center (Valentine et al., 2006, 2007; Valentine and Keating, 2007; ANL-MGR-GS-000002 Rev03 (under review)).

P.106	Note that groundmass volume fractions in pyroclastic materials at Lathrop Wells that have been quantified to date range from 20-30% (volume). Values of viscosity in ANL-MGR-GS-000002 Rev03 (under review) are reported clearly as values at the liquidus for appropriate temperatures and water contents, and are consistent with the plot (Figure 6.3) in the range of log(viscosity,poise) = ~2.7-1.9 for water contents of 0-4 wt%.
3949-3954	The sequence of flow regimes for magma encountering drifts is stated as beginning with slug flow and then transitioning to bubbly flow, but no basis or model calculation are shown to support this sequence of events (note that the slug flow regime is most consistent with relatively low viscosity melt, since it requires efficient segregation of bubbles into large pockets or slugs, and seems contradictory to later arguments that the magma viscosities are very high). The sequence discussed is one possibility, but there is no reason to weight it more than another scenario where the high water content has resulted in fragmentation beneath the repository (i.e., calculation assuming homogeneous flow allows for fragmentation at depths of ~4001200 m; ANL-MGR-GS-000002 Rev03 (under review)). Also note that during the months to years of dynamics associated with a typical monogenetic eruption, there is likely to be a very wide range of processes, and the time scale itself might be more important than the details of what might happen during the initial few minutes of an interaction.
4008-4009	This statement does not acknowledge the role of effusion rate and total volume in determining “mobility” (i.e. flow length) of lavas.
4058-4061	Statement is made that the “Icelandic magma was dry” but no reference is given (nor is it discussed in the original paper on the borehole eruption. The glass composition reported in Larsen et al 1979 is major element oxides only and totals to 98.5% leaving the possibility of dissolved water. In addition, the erupted clasts are described as “extremely vesicular”. Icelandic basalts have produced major explosive eruptions. In the case of the borehole eruption there is an additional uncertainty in the amount of geothermal water that mixed with magma in the borehole.). It is unclear what the statement “but lava never flowed out of this borehole” implies, since lava did erupt – explosively – from the borehole.

4213-4219	The pressure differences (between dike and drift, in initial interactions) are critiqued here but seem consistent with statements on p. 120 (lines 4475-4479) about initial magma pressures being 4.5-8 MPa. Note that the shock that occurs in the Dartevelle and Valentine (2005) calculations is considered to be of minor significance with respect to waste package effects, compared to the subsequent flow of pyroclasts and gas into a drift.
4230	"...significant conservatisms exist in the DOE and NRC analyses..." No calculations are provided to back this up, and only a very limited, inferred sequence of events and processes that are not consistent with field observations in the Yucca Mtn region. Also, the statement that the work is "conservative" carries an implication that the calculations were carried through full risk assessment and compared with "realistic" values.
4237-4238	"But repository drifts are small (~5.5 m diameter) and cool (100-300 C) and lava quenches and stagnates on all it touches." By comparison, lava tubes at Mt Etna have been reported to be in the ~2-3 m diameter range. Drift walls might initially be cool, but also have low thermal conductivity and their surfaces will receive thermal radiation from any magma in the drifts that could raise the "skin" temperature and reduce contact-cooling. The statement that lava quenches and stagnates on all it touches needs to be considered in light of the fact that the magmas are able to travel through tens of km of lithosphere and erupt onto the surface. Quenching is not a simple one-way process if there is also advection.
4249-4253	Not considered here is the importance of whether the flow is fragmented (see comment above) and the dynamics that might occur during a months to years long event.
4336-4338	It is inferred that a "small subsurface cinder cone" would form around the intersection of a dike with a drift. Scoria cones are formed by the accumulation of ballistic ejecta and fallout around a vent, and avalanching to maintain an angle of repose. The Lathrop Wells cone, for example, formed partly by fallout from sustained eruption columns that might have been several km high. It is difficult to envision how these processes would work within a 5.5 m confined height of a drift. No dynamical calculations are shown to back up this scenario in this report, while mulitphase flow simulations of Dartevelle and Valentine (2005) show that the dynamics of a fragmented mixture with a repository drift could be quite complex and transitory.
4350-4351	The discussion again attributes the limited extent of lavas at Lathrop Wells simply to an inferred high viscosity, and does not account for the primary influence of effusion rate and, to a lesser extent, total erupted volume, on flow length.

4362-4403	The underlying assumptions for this analysis of viscosity (i.e., radial spreading of a viscous fluid under gravity) are not consistent with the manner in which the lavas were emplaced. Valentine et al. (2006, 2007) provide much evidence for complex (and typical of basaltic lava fields) emplacement including stacking of flow units, migration of lava channels, breakouts from tube networks, and potential pulsing of lava effusion. The application of radially-spreading gravity current theory is not appropriate for these lavas, and therefore the viscosity estimate obtained through the theory is not useful.
4410-4411	Discussion of lava features at Lathrop Wells. It is true that the flows have steep fronts, but the heights of the flow fronts ranges from as low as ~1 m to several m, and there is evidence of internal flow and local breakouts from flow fronts. Rafting of scoria blocks from the cone does not simply imply high viscosity if the blocks have a lower density than the carrier lavas; note also that some of the rafts have squeeze-ups around them that might suggest a component of sinking of the rafts. The text refers to "the degassing sequence of extrusion" but it is not clear what this means – note again that lavas effused throughout the range of explosive activity.
4426-4437	The discussion of Woods et al (2002) seems to be mixing apples and oranges. The Woods et al analysis is for a fragmented mixture (dusty gas) and therefore the viscosities, flow speeds, and other properties are not comparable to non-fragmented lava flows as is implied in the discussion. And again, lava flow length is implied to depend primarily upon viscosity, when effusion rate is a major factor.
4439-4447	The points in this paragraph seem to be at odds with basic field characteristics of the volcanoes near Yucca Mtn. The statement is made that lava would flow no more than ~10 m into a drift. This is at odds with the fact that lavas flowed hundreds of m on the surface where the heat loss would have been much more rapid than in a relatively insulating drift. The 5.5 m diameter of a drift, even accounting for the presence of packages and drip shields, is consistent with lava tube sizes at other volcanoes with similar lava composition (e.g., Etna); these tubes are capable of *promoting* lava transport (by limiting heat loss) rather than reducing flow. The discussion of formation of a small scoria cone that would eventually plug a drift is speculative, and is not consistent with the energetics that can be inferred from field observations. No modeling is provided to back this up. Interestingly, the insulating properties of drift wall rocks are called upon in the discussion to prevent the cooling, and promote coalescence/welding, of pyroclastic debris, but are not acknowledged in the effects on slowing the cooling of lavas.

4464-4471	This process has been quantified in the Dike-Drift Interactions report (MDL-MGR-GS-00005 Rev01).
4496-4503	The tephra plug is inferred from a qualitative discussion in this report, but there are no quantitative calculations or observational data to back it up. Note that lavas can break through piles of variably welded pyroclastic debris to form lava boccas on the flanks of cones, carrying away chunks of pyroclastic deposits. This was a common occurrence in the Quaternary volcanoes near Yucca Mtn. This observation seems to contradict the inferences about resistance of the inferred pyroclastic plug.
4521-4528	It is important to keep in mind the range of dynamics in a conduit and the period of time (months to years) during which magma in various forms could interact with waste packages.
4809-4812	It is difficult to determine the significance of the xenolith size without knowing its original size where it was first entrained into the magma at depth.
4816-4820	DOE has now better constrained the conduit size at depth (see comment above) and agrees that the diameters are smaller than previously assumed.
4841-4846	Again, it is important to keep in mind the duration and dynamics of a monogenetic event. Can the arguments made here be quantified?
4852	A statement is made referring to the "relative pristine appearance of the million-year-old cones and flows in Crater Flat." Valentine et al. (2006) document that these cones are highly eroded – only remnants of the inward dipping beds of the inner cones are preserved at Red and Black cones, for example.
4856-4858	DOE agrees that fallout (inferred violent Strombolian eruptive style) accounts for a fraction of total products of an individual volcano. At Lathrop Wells the fallout volume is about 1.4 times the cone plus lava volumes. Current modeling is accounting for the relative fractions in terms of quantities of material available for violent Strombolian dispersal during a potential future eruption.
4863-4867	These qualitative arguments would need to be quantified and substantiated in order to move forward into critical review by the community.
5118-5144	The DOE approach to redistribution is being completely replaced with process-based landscape model of redistribution and sediment mixing.
5149-5150	Note that a significant portion of the proximal and medial tephra deposits from Lathrop Wells are *buried* by fluvial deposits, rather than eroded away (see Valentine et al. 2007).
5579-5584	Again, it is important to keep in mind the range of dynamics and the duration of an event.

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D. General comments regarding the ACNW white paper on volcanism.
From Professor Eugene Smith, University of Nevada at Las Vegas.
March 21, 2007

As I mentioned at the [ACNW] meeting, the white paper does not reference several key papers by our group at UNLV. The first paper is the basis for much of the probability work done by our group. The paper introduced the Area of Most Recent Volcanism as the area to be considered in any volcanic hazard analysis. The AMRV countered the Crater Flat zone proposed by DOE contractors and is currently being considered by the PVHA-U as a possible area of interest for probability studies. The paper also introduced the risk rectangle concept that suggests that future activity will occur either to the northeast or southwest of existing volcanoes. In other words, it relies heavily on the concept of volcanic chains and the northeast alignment of these chains. This idea is being revived by Chuck Connor in some of his recent models. The reference is:

Smith, E.I., Feuerbach, D.L., Naumann, T.R. and Faulds, J.E., 1990, The area of most recent volcanism about Yucca Mountain, Nevada: Implications for volcanic risk assessment: in Proceedings of the International Nuclear Waste Symposium, v. 1, American Nuclear Society and American Society of Civil Engineers, p. 90-97.

The second paper represents the first modern description of the Crater Flat cinder cones. It also provides chemistry and a petrogenetic model for Crater Flat magmas. The recent paper by Greg Valentine and others in GSA Bulletin references this paper many times. The Bradshaw paper is an important contribution and should be referenced:

Bradshaw, T.K., and Smith, E.I., 1994, Polygenetic Quaternary volcanism in Crater Flat, Nevada: Journal of Volcanology and Geothermal Research, v. 63, p. 165-182

The third reference is a map published by the Nevada Bureau of Mines and Geology and describes the geology of the eastern part of Crater Flat including the cinder cones and western sections of Yucca Mountain. The reference is:

Faulds, J.E., Bell, J.W., Feuerbach, D., and Ramelli, A.R., 1994, Geologic map of part of Crater Flat, southern Nevada: Nevada Bureau of Mines and Geology Map 101, 1:24,000

My last comment regards a better reference that argues against our deep melting models. Frank Perry wrote a discussion of our EOS paper and should be used.

The reference to Frank's paper is:

Perry, F. V., Cogbill, A.H., and Kelley, R.E., 2006, Uncovering buried volcanoes at Yucca Mountain: EOS, v. 86, no. 47, p. 485, 488.