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REVIEW OF:

Preliminary Draft: Status of Volcanic Hazard Studies for The Yucca Mountain Site Characterization Project, Dated February 1993

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REVIEW OF "*PRELIMINARY DRAFT*: STATUS OF VOLCANIC HAZARD STUDIES FOR THE YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT"
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1 INTRODUCTION

The report "Status of Volcanic Hazard Studies for the Yucca Mountain Site Characterization Project" (Crowe et al., 1993) provides a summary of U.S. Department of Energy (DOE) investigations of volcanism in the Yucca Mountain Region (YMR) through 1992 and conclusions about the geologic setting and possible impact of volcanism on the potential high-level nuclear waste (HLW) repository at Yucca Mountain. The status report, prepared for DOE by investigators at Los Alamos National Lab (LANL), also reviews work by other investigators and indicates areas of future investigation of volcanism issues as part of the ongoing research effort in site characterization by the DOE. In the introduction of the LANL status report, it is stated that the DOE presents this document, in part, to solicit response from the U.S. Nuclear Regulatory Commission (NRC) regarding the nature of the DOE's scientific approach to the volcanism issue and with regard to the validity of the conclusions drawn in the report.

Staff of the NRC will be required to review and evaluate the license application of the DOE for the proposed HLW repository at Yucca Mountain, Nevada. Requirements of post-closure performance are set forth by the Environmental Protection Agency (EPA) in 40 CFR Part 191 and by the NRC in 10 CFR Part 60. Because of the possible impact of volcanism on post-closure repository performance, two conditions related specifically to volcanism are included in siting criteria in 10 CFR Part 60.122(c)(3), potential for changes in regional groundwater flow as a result of volcanic activity, and Part 60.122(c)(15), evidence of igneous activity since the beginning of the Quaternary Period (i.e., within the last 1.6 m.y.).

The NRC intends to provide guidance to the DOE during pre-licensing activities so that technical issues in site characterization, such as those relating to volcanism, may be resolved in a timely and scientifically rigorous manner. The NRC Office of Nuclear Material Safety and Safeguards (NMSS) has requested that the Center for Nuclear Waste Regulatory Analyses (CNWRA) provide a comprehensive review of the LANL volcanism status report (Crowe et al., 1993). This review is structured to concentrate on technical aspects of the DOE status report. These aspects include review and critical analysis of:

- The logic and scientific validity of the DOE approach to resolving technical issues in volcanism
- The DOE's approach to the gathering, dissemination, and incorporation into models of data relevant to volcanism issues
- The DOE approach to model development and utilization in the investigation of volcanism in the YMR, particularly with regard to the probability of volcanic disruption of the potential repository.

In addition, NMSS has developed specific user needs, based on key technical uncertainties identified through its Systematic Regulatory Analysis, to guide research in volcanism and related issues. These user needs include the following.

- Mechanisms that control the location of igneous features
- Spatial and temporal patterns in igneous activity
- Effects of igneous activity on groundwater
- Theories of multiple igneous events
- Age determination techniques in volcanic terrain
- Coeval nature of basaltic volcanism and fault displacement in the Basin and Range.

These user needs have been established independently of DOE activities and will be addressed by CNWRA research programs in volcanology. Nonetheless, it is important to evaluate the effectiveness of DOE research with respect to these key technical uncertainties, as they must be resolved by scientific investigation in the pre-licensing stage.

It is notable that the document under review is considered preliminary by its authors. This is appropriate because formal, external review is part of the scientific process. It is the intent of the CNWRA to provide NMSS with a critical evaluation of the LANL status report, with the goal of furthering scientific investigation and evaluation of volcanic hazards in the YMR.

A total of eight CNWRA technical staff and consultants has reviewed sections of the LANL status report. Formal comments are presented following the organization of the LANL status report itself. Each comment is labelled by the section it refers to in the LANL status report. For example, comment 3.31 is the thirty-first comment in Section 3 of the LANL report. Each comment consists of: (i) a statement of concern that details the section, paragraph, or line in the LANL status report that is considered by the comment, (ii) a technical basis for the comment, which usually involves discussion of alternative models or additional data that should be considered, (iii) and a recommendation of how to resolve the concern. If additional references are cited beyond those provided in the status report or if the reference might be ambiguous, these are provided as part of each comment. Following these detailed comments, an overall summary is provided.

2 SPECIFIC COMMENTS

2.1 REVIEW OF SECTION 1: INTRODUCTION

COMMENT NO. 1.1

Statement of Concern: page 4, paragraphs 2 and 3. These paragraphs, especially the last few sentences in paragraph 3 "But the risks are small . . ." are misleading in several respects.

Basis: First, as the authors are aware, there is a range of explosivity in Basin and Range basaltic eruptions, from mildly effusive to extremely explosive. Ash column heights and ash dispersion from basaltic hydromagmatic eruptions can be quite substantial. These paragraphs imply that cinder cone and maar volcanism represent an end-member in eruption energetics. But there are numerous examples from recently active volcanoes of sub-plinian, plinian, "ultra-vulcanian" and "ultra-strombolian" small volume basaltic eruptions which have been accompanied by a cone building phase. Modern basaltic eruptions of magmas petrologically similar to those of the Yucca Mountain region and from cinder cones in a variety of tectonic settings *have been* accompanied by towering columns of ash, devastated surrounding areas, ruined property, and resulted in loss of life (e.g., Parícutin, Tolbachik, Cerro Negro, Tarawera)(Amos et al., 1983; Fedotov, 1983; Foshag and Gonzalez, 1956; GVN, 1992). Many Basin and Range eruptions likely had similar eruptive phases. To conclude at the outset of this report that Yucca Mountain region volcanism "has a limited capability to disperse radioactive waste at the surface of the earth" is tantamount to establishing this as a premise rather than a hypothesis to be tested by prudent scientific inquiry. At the least, it is currently unsupported by scientific data. In addition, of course, the risks are small compared to those associated with active arc composite volcanoes and calderas. However, this does not mean that they are not of significant regulatory concern.

Recommendation: In later sections it is stated that "quantifying magmatic radiological releases is not the subject of this volcanism report" (page 254, in bold), and that additional consequence studies will need to be made. Possibly this statement would be more appropriate for the introduction.

References:

Amos, R.C., S. Self, and B. Crowe. 1983. Pyroclastic activity at Sunset Crater: Evidence of a large magnitude, high dispersal strombolian eruption. Eos, Transactions of the American Geophysical Union 62: 1085.

Fedotov, S.A. 1983. Chronology and features of the southern breakout of the Great Tolbachik fissure eruption, 1975-1976. S.A. Fedotov and Ye. K. Markhnin, eds. The Great Tolbachik Fissure Eruption, Geological and Geophysical Data 1975-1976. Cambridge: Cambridge University Press: 11-26.

Foshag, W.F., and J. Gonzalez R. 1956. Birth and Development of Parícutin volcano, Mexico. U.S. Geological Survey Bulletin. 965-D: 355-489.

GVN. 1992. Violent strombolian activity at Cerro Negro. Bulletin of the Global Volcanism Network 17(3): 2-4.

COMMENT NO. 1.2

Statement of Concern: Page 6. "The small number of past events means the risk of future eruptions is low." This assertion is not justified by the material presented; it is too conclusionary, particularly so early in the report.

Basis: It is difficult to determine what is meant by "small" and "low" in a regulatory sense.

Recommendation: This type of statement should be deferred to later sections and presented after the basic arguments are made.

COMMENT NO. 1.3

Statement of Concern: page 6. "However, because of the small number of events, the uncertainty of calculating the risk is large." This illustrates reasonably well a significant problem in risk assessment. At what level of uncertainty does the risk estimate cease to be useful?

Basis: Discuss the basis of additional probability assessment given the paucity of events. Several statistical texts (e.g., Larsen and Marx, 1986) discuss the "power" of specific sample sizes in a formal sense.

Recommendation: Additional statistical tests can be applied and alternatives considered. Bound uncertainties using confidence intervals.

Reference:

Larsen, R.J., and M.L. Marx. 1986. An Introduction to Mathematical Statistics and Its Applications, New Jersey: Prentice-Hall: 630.

2.2 REVIEW OF SECTION 2: GEOLOGIC SETTING OF BASALTIC VOLCANISM

COMMENT 2.1

Statement of Concern: Many of the dates in this section are incorrectly reported or incorrectly cited. Numerous unpublished K-Ar dates are alluded to, but data are not presented. The main conclusions regarding geochronological hypotheses cannot be evaluated with the data provided.

Basis: p. 32: Age of Buckboard Mesa is incorrectly given as 2.9 Ma. The two dates from Crowe, Johnson and Beckman (1982) average 2.81 ± 0.11 Ma (i.e. 2.8 ± 0.1 Ma).

p. 32: Replicate K-Ar dates for the Little Cones are alluded to, but do not appear in the references cited. Crowe et al. (1982) report six dates for "Western Rift Crater Flat" units, but individual vents are not identified. These dates are, however, identical to those reported in Vaniman et al. (1982). Only one date is reported for "Little Cone SW," which is 1.11 ± 0.3 Ma. No other dates have been reported for either of the Little Cones. Other dates, which apparently range from 1.2 to 0.7 Ma for the

Little Cones, are unpublished data from the U.S. Geological Survey (USGS). Data and associated analytical uncertainties are not reported and cannot be evaluated.

p. 34: Dates for Red and Black Cones are alluded to as "unpublished data from the USGS." Data are not reported and cannot be evaluated. The reported age range of 0.8-1.5 Ma is not present in the references cited. The minimum age reported by Crowe et al. (1982), Vaniman et al. (1982; these are the same dates as in Crowe et al., 1982), Sinnock and Easterling (1983) and Ho et al. (1991) is 0.95 ± 0.08 Ma.

p. 34: What is the source of the 1.7 Ma date for Northern Cone? There are only two published dates for this center (Vaniman et al., 1982), which average 1.1 ± 0.3 Ma.

p. 34-35: The range of dates in the references cited are from 0.95 to 1.90 Ma, not 0.7 to 1.7 Ma.

p. 40: The range of K-Ar dates for Little Black Peak is 0.21 to 0.32 Ma with reported analytical uncertainties of 0.1 to 0.2 Ma (Crowe et al., 1982; Crowe and Perry, 1991), not 0.2 to 0.4 Ma as reported. Only one date of 0.32 ± 0.2 Ma has been presented for Hidden Cone (Crowe and Perry, 1991). This date is reported in Crowe and Perry (1991) as a personal communication to B. Crowe from B. Turrin in 1989, with no supporting analytical data.

p. 46-59: Turrin et al. (in press) is cited extensively in discussions of K-Ar dates. This document has apparently been "in press" for several years (e.g., reference 5 in Turrin and Champion, 1991). Hypotheses utilizing these dates cannot be evaluated unless individual analyses are provided.

p. 50, par. 3: What is the source for the ^{3}He dates? Assuming it is Crowe et al. (1992), the date for unit Ql_{4b} should be 48 ± 5 and not 4 ± 85 ka.

p. 50: Crowe et al. (1992a) only list 1 thermoluminescence date for the soil under Ql_3, which is reported as 24.5 ± 2.5 ka; a range of "25 to 30 ka" is not correct.

p. 51: Turrin et al. (1991) do not report (conventional) K-Ar dates; what is the source of the 116 ± 13 ka weighted mean? Also, Turrin et al. (1991) did not date by $^{40}Ar/^{39}Ar$ any samples from unit Qs_{2c}. Their sample 223-1 apparently was from unit Qs_{2b}. These four dates have a weighted mean of 0.175 ± 0.100 Ma, not 14 ± 945 ka as reported. Including the associated errors on these dates, the mean of these data is 0.139 ± 0.122 Ma with a standard deviation of 0.081 ± 0.140 Ma. The reported mean of 129 ± 77 ka for chronostratigraphic unit 2 incorrectly includes dates from unit Qs_5 (i.e., sample site 211-1 of Turrin et al., 1991).

p. 52: The ^{3}He dates reported by Crowe et al. (1992) are 23 ± 4, 28 ± 4, and 44 ± 5 ka, not 25, 25, and 45 ka as stated. In addition, Poths and Crowe (1992) report ^{3}He dates of unit S1 (scoria cone) of 22 ± 4, 28 ± 4, and 44 ± 6 ka. Which dates are correct? The additional date provided in the report (36 ka) does not show an analytical error and thus cannot be used to constrain the hypothesis that the cone age is "about 40 ka."

p. 58-65: Turrin and Champion (1991) do not provide any conventional K-Ar dates except to refer to their unpublished data. Turrin et al. (1991) also do not provide any conventional K-Ar dates except to refer to their unpublished data. Turrin et al. (in press) is not available. Turrin et al. (1991a) is not in the reference list. The hypotheses developed around the K-Ar dates cannot be evaluated without providing these unpublished analyses.

p. 68: The U-Th date of 140±40 ka is incorrectly reported for unit Ql_4. A date of 150±40 ka was reported for this unit in Crowe et al. (1992). The method used to calculate the uncertainty of the U-Th dates is not clear. Uncertainties are symmetrical for the 150±40 ka date, but unsymmetrical for the 135+35-25 ka date.

p. 68-69: Poths and Crowe (1992) report ^3He dates of 64±6 and 59±6, not 65±7 and 739 ka, for unit Ql_5. The dates for unit Ql_{4a} are 48±5 and >49 ka, not 4±85 and >49 ka. Unit Qs_{2a} has dates of 28±4, 22±4 and 44±6 ka in Poths and Crowe (1992), not 28±4, 23±4 and 44±5 ka.

Recommendation: Reported data should be checked with original references for accuracy, and referenced consistently throughout the report. Data contained in unpublished reports, meeting notes, or personal communications should either be reported in detail or omitted from the report. References should contain the data cited in the report.

COMMENT 2.2

Statement of Concern: Reported means and uncertainties do not adequately represent the analytical error associated with the data. Ages used in subsequent models do not reflect the large degree of error associated with the data, and do not adequately bound uncertainties in these models.

Basis: p. 46: As an example, this report cites a mean of 170±114 ka from Turrin et al. (1991) for eight $^{40}Ar/^{39}Ar$ dates from unit Ql_5. However, the reported uncertainty only represents 1 standard deviation of the absolute date population and does not reflect the large analytical errors (avg. 284 percent) associated with these data. Propagation of the reported errors during calculation of the mean value requires:

$$\bar{X} \pm \bar{x} = \frac{\sum X_i}{n} \pm \frac{\sqrt{(\sum x_i^2)}}{n}$$

and results in a mean of 170±121 ka. This uncertainty, however, does not indicate that 68 percent of the data fall within 121 ka of the mean, only that the mean has an uncertainty of 121 ka. Calculation of the standard deviation for this population requires:

$$Sdev = \sqrt{\frac{\sum (X_i \pm x_i - \bar{X} \pm \bar{x})^2}{n}}$$

resulting in 1 standard deviation of 106± 161 ka. Thus, 68 percent of these dates fall within the range of 170±388 (i.e., 121+106+161) ka. Although this range is large, it accurately reflects a data set of eight samples that have an average reported analytical error of 284 percent. Raw (i.e., nonaveraged) data must be presented in order to adequately evaluate the precision of both the K-Ar and $^{40}Ar/^{39}Ar$ dates, because the reported averages and associated uncertainties in this report and other radiometric dating reports (e.g., Turrin and Champion, 1991) do not necessarily reflect the large analytical errors associated with the data. The descriptive statistics reported in Table 2.1 of the LANL status report are essentially meaningless without a discussion of the errors associated with these dates. The significance of the probability and box plots (Figures 2.13-2.16 Crowe et al, 1993) is questionable when the reported one sigma errors for published $^{39}Ar/^{40}Ar$ dates are plotted on similar figures (Figure 2-1).

In addition, the statistical tests used to identify anomalously old dates produced by contamination fail to incorporate analytical uncertainties. The significance of the four contaminated $^{39}Ar/^{40}Ar$ dates of Turrin and Champion (1991) is questionable when these data are plotted with reported analytical errors (Figure 2-2). The sample at 0.95 Ma is significantly older than the rest of the population, but it is not at all clear how two samples at 0.45 ±0.09 Ma are distinctly contaminated yet samples at 0.39±0.22 and 0.39±0.64 Ma are not.

Recommendation: Statistical parameters must incorporate the error associated with the data to be meaningful. The reported precision of mean dates in this report does not reflect the large uncertainties associated with the original (i.e., nonaveraged) data.

COMMENT 2.3

Statement of Concern: Analytical information presented in this report and in original references is inadequate to evaluate the precision and accuracy of reported dates. Reported analytical data should be of sufficient detail to permit independent calculation of dates. Sample locations and descriptions are inadequate to independently determine accuracy of replicate analyses.

Basis: Insufficient analytical data are presented in this report and in all original references that would permit independent calculation of dates. For example, calculation of K-Ar dates requires, at a minimum, sample weight, K content of sample, percent $^{40}Ar_{rad}$ and mol/g $^{40}Ar_{rad}$. Similar data should be presented for all other geochronological techniques in this report.

Recommendation: Analytical data for all reported dates should be presented as an appendix to the report. Sample locations and descriptions also should be provided in either maps or tables.

COMMENT 2.4

Statement of Concern: The ages of the Quaternary Crater Flat volcanoes are insufficiently precise to permit the development of robust volcanological models. Probability calculations in this report do not accurately reflect the uncertainties associated with these dates.

Basis: Based on the data presented in this report, a reasonable estimate of the age of the Quaternary Crater Flat volcanoes is 1.2±0.4 Ma.

Northern Cone: There are only two published dates for this center, which average 1.1±0.3 Ma.

Black Cone: Two dates of 1.09±0.3 and 1.07±0.4 Ma are reported.

Red Cone: A total of 23 dates have been reported for Red Cone. A wide range of dates from 0.95±0.08 to 1.9±0.2 Ma is reported.

Little Cones: The only apparent date of 1.11±0.3 Ma is from a feeder dike exposed in a small scoria cone 0.5 km SE of the southern Little Cone. There are apparently no dates for the main cone of the southern Little Cone or for the amphibole-bearing northern Little Cone.

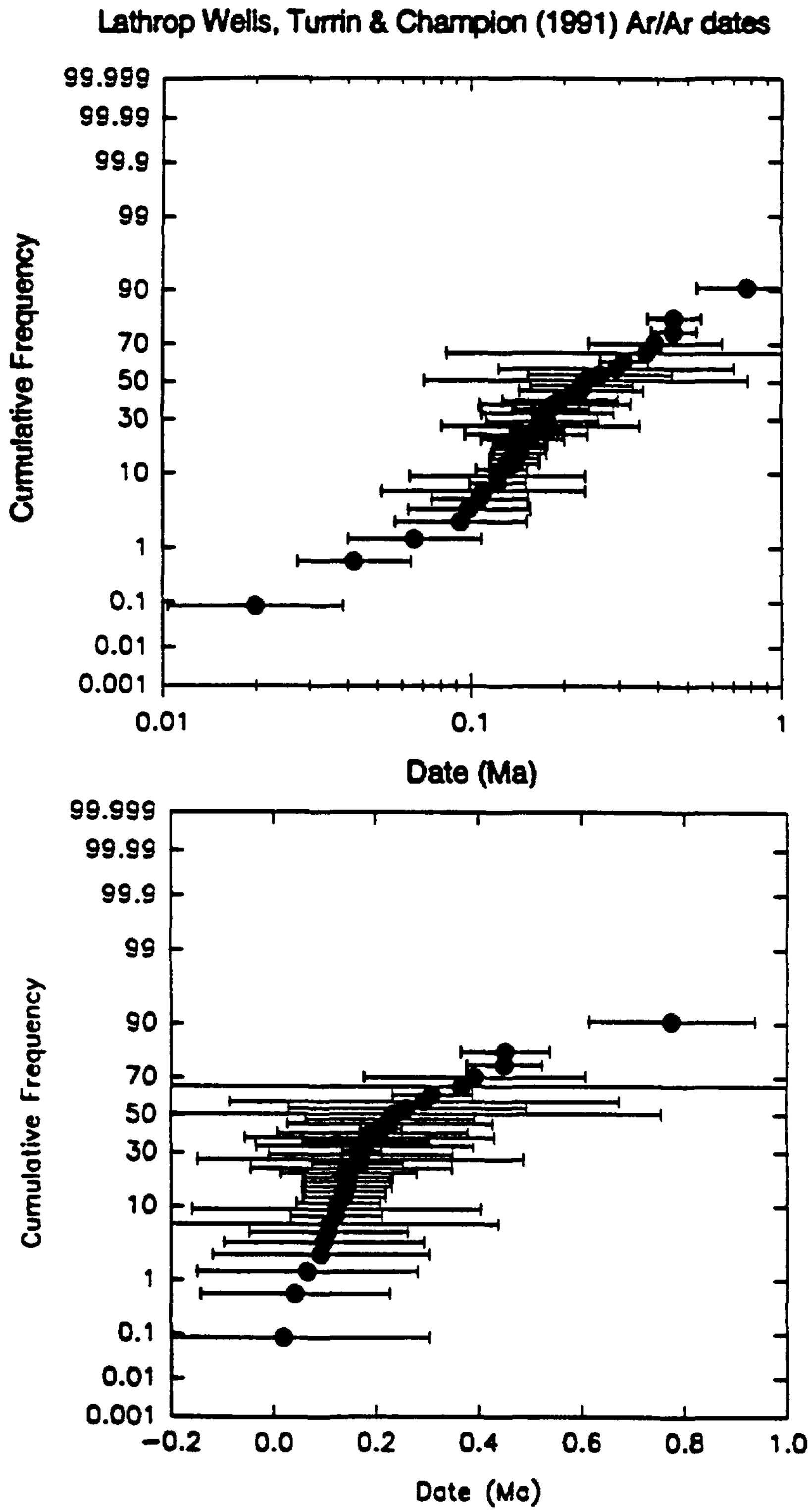


Figure 2-1. Lognormal (A) and normal (B) cumulative frequency plots of $^{40}Ar/^{39}Ar$ dates for Lathrop Wells by Turrin and Champion (1991). The large errors associated with these data preclude meaningful conclusions about the statistical distributions of this data set.

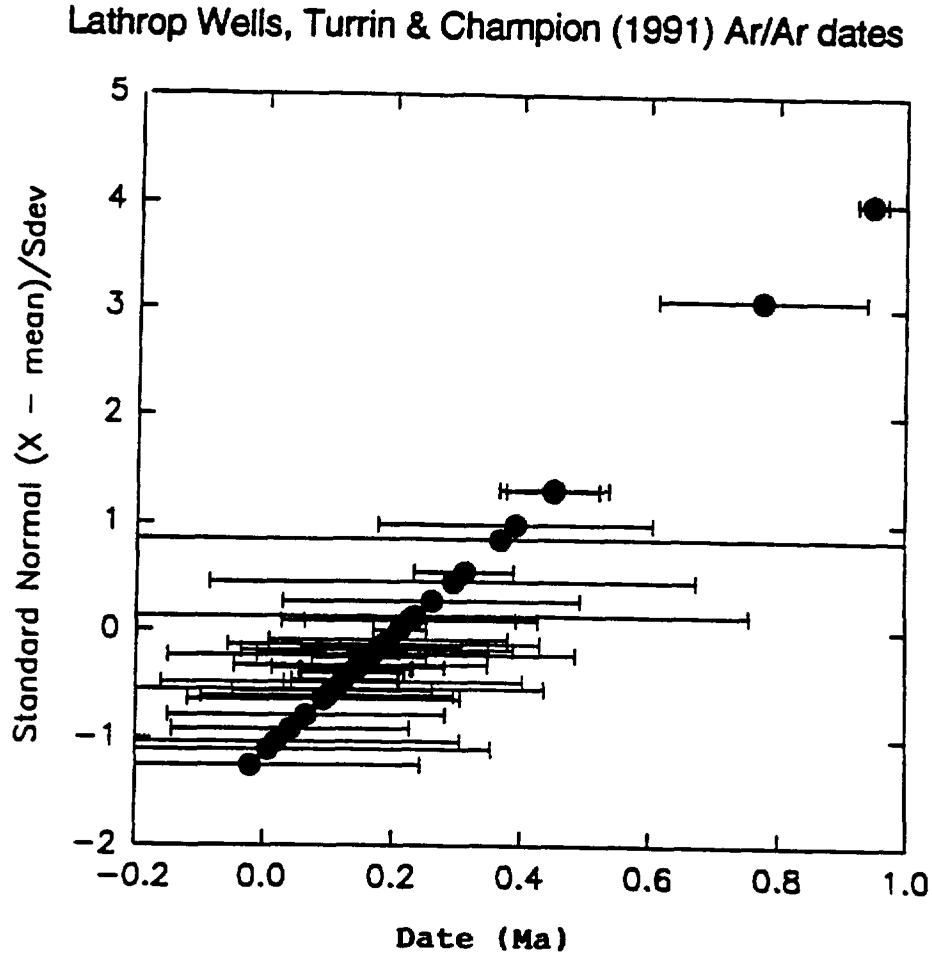


Figure 2-2. Transformation of Lathrop Wells $^{40}Ar/^{39}Ar$ dates by Turrin and Champion (1991) to a normal distribution shows that the dates are not normally distributed about the mean. Dates reported as contaminated are not significantly distinct from noncontaminated dates.

The Quaternary Crater Flat volcanoes may have erupted at resolvably different times. The development of distinct soil profiles between Red and Black cones (Wells et al., 1990) likely indicates that an age difference exists between these centers. Soil profiles apparently are similar for the Little Cones and Black Cone, which may indicate a similar age for these vents. Soil data are not presented for Northern Cone, but the relatively advanced degree of erosion at Northern Cone may indicate a relatively older age for this vent. In addition, it is not intuitive why the deep erosion of Northern Cone could be caused by it being a small volume center (third alternative on p. 34). Wells et al. (1990) do not make any conclusions relating the size of a cinder cone with the development of geomorphic characteristics.

Clearly, the hypothesis that the Quaternary Crater Flat volcanoes erupted at resolvably different times is valid and, more importantly, a testable hypothesis given the increase in analytical precision over the last decade. Similar evidence for a relatively long-lived volcanic alignment also exists at the Sleeping Butte volcanoes. Additional geochronology studies (Study Plan 8.3.1.8.5.1 activity 2) are critical to developing well-constrained eruption frequency rates used in probability calculations. Based on the limitations of the available data, the most accurate age of the Quaternary Crater Flat volcanoes is 1.2±0.4 Ma, not 1.2 Ma as reported.

This report concludes that possible age differences between Red and Black cones cannot be resolved using existing K-Ar dates. It is important to note that the majority of these dates were obtained over a decade ago. Analytical precision for young (<0.1 Ma), low potassium basalts has increased significantly in the last decade. Using the Critical Value (CV) formulation of Dalrymple and Lanphere (1969):

$$CV = 1.96 * \sqrt{\frac{\sigma^2}{n\ analyses}}$$

a resolution of about 50 ka should be achieved for 1 Ma basalt if analytical precision is roughly 5 percent and six dates are obtained for each unit.

It is also not clear how magnetic polarity directions were sampled for this system. The Crater Flat volcanoes are described as magnetically reversed, but the methods used to determine direction are not described. The procedure used to determine magnetic polarities (e.g., field flux-gate magnetometer) should be discussed, along with the sampling procedure used (e.g., how many samples per flow, where in the flow was sampled, how many samples per sample site). These data are critical to evaluating if these units formed in the Matuyama reversed magnetic polarity epoch and could not have been erupted during the 0.92 to 1.01 Ma Jaramillo event (Spell and McDougall, 1992).

Recommendation: Additional geochronology studies referred to in Study Plan 8.3.1.8.5.1 should be of sufficient detail to resolve potential age differences between the Quaternary Crater Flat volcanoes. Magnetic direction data also should be presented.

Reference:

Spell, T.L., and I. McDougall. 1992. Revisions to the age of the Brunhes-Matuyama boundary and the Pleistocene geomagnetic polarity timescale. *Journal of Geophysical Research* 19: 1,181-1,184.

COMMENT 2.5

Statement of Concern: The Little Cones are considered to be a single vent. Combining these centers results in an erroneously low vent count for the Crater Flat volcanic field.

Basis: Combining the Little Cones into a single vent is not supported by the available data. The Little Cones consist of two physically discrete cinder cones. The northern Little Cone (NLC) lacks an associated lava flow, but the southern Little Cone (SLC) apparently is associated with a buried flow that extends at least 0.5 km south of the cinder cone. The NLC contains phenocrysts of amphibole, but amphibole is apparently absent from the SLC (Vaniman and Crowe, 1981). The geochemical data from Vaniman and Crowe (1981) and Crowe et al. (1986) also show that the SLC and NLC have some compositional distinctions.

Recommendation: The Little Cones represent two discrete volcanic centers and should not be counted as one vent. The Quaternary Crater Flat volcanic field should contain five, not four, volcanic fields. Probability calculations utilizing cone/vent counts should be modified to reflect the presence of two discrete vents at the Little Cones.

COMMENT 2.6

Statement of Concern: The Sleeping Butte volcanoes may be contemporaneous with the Lathrop Wells volcano, based on data presented in this report.

Basis: The ages of the Sleeping Butte centers have not been determined with sufficient precision or accuracy to disprove the hypothesis that these centers are temporally equivalent with some of the eruptions at Lathrop Wells, when reported 1-sigma analytical uncertainties are rigorously considered. The average of five Little Black Peak K-Ar dates is 0.26±0.07 Ma with one standard deviation of 0.04±0.06 Ma (i.e., 0.26±0.17 Ma), and the only available date for Hidden Cone is 0.32±0.20 Ma. These Sleeping Butte dates are indistinguishable from an age of Lathrop Wells of around 0.10±0.05 Ma. The preliminary magnetic direction data presented by Champion (1991) and this report (p. 77) show that the Sleeping Butte and Lathrop Wells centers may preserve distinct paleomagnetic orientations, but there is some apparent overlap between these data. One possible explanation presented in this report for the relatively advanced degree of erosion at Northern Cone is the increased elevation of Northern Cone (3800 ft) relative to the other Crater Flat volcanoes (3000-3700 ft). Thus, differences in flow morphology between Lathrop Wells and the Sleeping Butte centers may be due to the differences in elevation (2800 ft and 4600-5000 ft, respectively) between these two perhaps contemporaneous centers.

Recommendation: The age of the Sleeping Butte volcanoes needs to be more precisely constrained in order to develop robust models of the latest volcanic episode(s) near Yucca Mountain.

COMMENT 2.7

Statement of Concern: The mineralogy of the younger post-caldera basalts is not adequately characterized to permit evaluation of the petrogenetic models proposed for this system. Phenocryst modes are uncertain or poorly constrained, and petrographic studies to date apparently are insufficient to determine the occurrence of amphibole in these units.

Basis: The basaltic andesite of Buckboard Mesa is reported as aphyric, yet the first sentence on p. 32 indicates the younger flow contains phenocrysts of amphibole. This is also the first mention of amphibole in the Buckboard Mesa flows aside from a brief mention in Table IV of Crowe et al., 1983. No analyses are presented to evaluate if the amphibole is kaersutite or possible compositional similarities to amphibole phenocrysts in the Crater Flat system. In addition, the presence of quartz xenocrysts(?) in the northern Buckboard Mesa flow may indicate that this unit was modified by crustal contamination, which could account for the relatively "saturated" composition of the unit.

There is no discussion of the mineralogy of the Quaternary basalts in this report, although phenocryst assemblages are listed for older units. It is important to note that phenocrysts of amphibole occur in the NE Little Cone scoria (Vaniman and Crowe, 1981), the Sleeping Butte cones (Crowe et al., 1983), and that at least some Red Cone units contain groundmass(?) amphibole and biotite (Vaniman and Crowe, 1981; Ho et al., 1991). The presence of amphibole phenocrysts has critical implications for eruption dynamics models, which are discussed in the review of Chapter 4.

The only detailed petrographic data reported for 3.7 Ma and younger basalts is by Vaniman and Crowe (1981). These data are inadequate to evaluate the mineralogy and phase relationships of these units. Petrographic data are presented without any description of the methods used to determine mineral abundances, nor are uncertainties in mineral abundances described. Detailed petrographic data have not been presented for Buckboard Mesa flows. Lathrop Wells petrographic data are reported as vesicle-free abundances, yet vesicle abundances are not listed (Vaniman and Crowe, 1981). Data presented in Chapters 2 and 4, and in Zreda et al. (1993), indicate that plagioclase is a phenocryst in Lathrop Wells unit Ql_6 and perhaps unit Ql_4, but plagioclase is not reported in Vaniman and Crowe (1981). The presence of plagioclase phenocrysts is critical to the arguments presented in Chapter 4 for increasing depth with time in the Crater Flat magma system.

In addition, the examination of thin-sections alone is inadequate to characterize the presence or absence of low abundance minerals in volcanic scoria (e.g., Chayes, 1956). Additional mineralogical analyses are not listed in Study Plan 8.3.1.8.5.1 part 3 (Field Geologic Studies) or part 4 (Geochemistry), with the exception of thin-section petrography. Unless detailed heavy-mineral separations are performed on these units, the presence of amphibole in some or all of the Quaternary cannot be discounted.

Recommendation: Detailed petrographic studies should be performed to more accurately and precisely determine the mineralogy of the younger post-caldera basalt suite, because the presence or absence of amphibole has important implications for the volatile content and, thus, explosivity of an eruption. Detailed heavy-mineral separations are required to determine the presence or absence of amphibole in these units. Additional matrix-mineral separations also are needed to determine the presence of plagioclase phenocrysts, which were not detected at Lathrop Wells in earlier studies.

Reference:

Chayes, F. 1956. *Petrographic modal analysis.* New York, NY: John Wiley & Sons.

COMMENT 2.8

Statement of Concern: There is no discussion in this report of the xenolith content of the Lathrop Wells cinder cone, nor are additional xenolith studies presented in Study Plans 8.3.1.8.1.1 or 8.3.1.8.5.1. The abundance, size distribution, morphology, and composition of xenoliths in the Lathrop Wells ejecta have critical implications for eruption consequence models, yet published data are inadequate to constrain those models.

Basis: Xenolith abundances directly reflect the ability of the fragmented magma to transport brecciated wall rock to the surface. Consequence models of potential volcanic eruptions through the Yucca Mountain repository horizon will need to constrain the ability of a basaltic dike to fragment and transport to the surface both wall rock and waste canisters. The abundances, origins, and size distributions of shallow (i.e., < 1 km) crustal xenoliths are thus critical to developing realistic consequence models.

Xenolith data for Lathrop Wells have been reported by Crowe et al. (1983) and Crowe et al. (1986). However, these data are inadequate to accurately characterize the process leading to xenolith formation and transport during this eruption. Crowe et al. (1983) state that thin-section examination of an unstated number of xenoliths shows that ". . . the fragments are probably derived entirely from the Tiva Canyon Member of the Paintbrush Tuff . . .," but the criteria used to make that determination are not described. In addition, the only reference to the size of the xenoliths at Lathrop Wells is that they have a median diameter of 4 mm (Crowe et al., 1983). Field examination of the Lathrop Wells cinder cone reveals that tuffaceous xenoliths much greater than 4 mm are extremely common, and tuffaceous xenoliths in the centimeter to decimeter range occur in unusual abundance relative to other Basin and Range cinder cones.

The only granulometric data that identifies clast composition in the Lathrop Wells cone is in Crowe et al. (1986). However, these data are only for clasts <0.7 mm, and xenolith composition is generally described as undifferentiated with only occasional identification of tuff or limestone clasts (Crowe et al., 1986, Appendix F). The bulk of the Tiva Canyon and Topopah Spring Members of the Paintbrush Tuff are compositionally zoned and sparsely phyric, containing very similar mineralogies (DOE SCP, p. 1-68). The only apparent distinction is that the Tiva Canyon contains trace phenocrysts of sphene, which are absent in the Topopah Spring (DOE SCP, p. 1-68). It is not at all clear how sub-millimeter, sparsely phyric tuff or undifferentiated xenoliths were uniquely assigned to the Tiva Canyon Member of the Paintbrush Tuff by Crowe et al. (1983). In addition, the occurrence of limestone xenoliths in the Lathrop Wells scoria (Crowe et al., 1983) clearly indicates that pre-tuff limestone units were entrained during the eruption.

Recommendation: Additional studies of the abundance, size distribution, morphology, and composition of xenoliths in the Lathrop Wells ejecta are needed in order to construct realistic models of fragmentation and transport of subsurface material.

COMMENT 2.9

Statement of Concern: The procedure used to calculate volumes of basalts is unclear. Models utilizing eruptive volumes cannot be evaluated unless the methods and assumptions used to calculate volumes are more completely described. How are eruptive volumes calculated and how are existing volumes calculated?

Basis: p. 52: What method is used by Crowe et al. (1983a) to calculate the volume of the cone? Assuming the cone represents a simple frustum with a basal diameter of 690 m, a crater diameter of 160 m, and a height of 140 m (Crowe et al., 1983a; Crowe and Perry, 1991), Lathrop Wells has a volume of 2.2×10^7 m^3. The volume reported by Crowe et al. (1983a) is 1.7×10^7 m^3, which apparently corresponds to the volume of a simple cone and underestimates the volume of the Lathrop Wells cone. In addition, Table 7.2 of this report lists the volume of Lathrop Wells as 1.4×10^8, but does not report separate cone and flow volumes.

p. 33: What is the basal diameter of Black Cone? Height is significantly different than reported in Crowe, Vaniman and Carr (1983) or Crowe et al. (1983), so is the basal diameter the same? If the morphometric parameters of Wells et al. (1990) are used at Red Cone, then shouldn't they be applied to the other cones as well?

There is no coherent description of how magmatic volumes were calculated. Vaniman and Crowe (1981) assume that magma density is 2.7 g/cm^3, but do not state the assumed lava flow densities. Fall-deposit densities also are not reported. Cone porosities are given as 25 percent, but clast densities are presumably taken from McGetchin et al. (1974), which gives a range of 1.2 to 2.8 g/cm^3 and a median of 1.5 g/cm^3. Distal scoria-fall deposits are assumed to have five times the volume of the cone, but no justification is presented for this relationship.

Recommendation: Provide a more complete description of parameters used to calculate eruption volumes and the assumptions used to convert volumes to dense rock equivalents.

Reference:

McGetchin, T.R., M. Settle, and B.A. Chouet. 1974. Cinder cone growth modeled after Northeast Crater, Mount Etna, Sicily. *Journal of Geophysical Research* 79: 3,257-3,272.

COMMENT 2.10

Statement of Concern: There are several inconsistencies in the geologic map and stratigraphic relationships at Lathrop Wells.

Basis: p. 45: Figure 2.9 needs a north arrow or other geographic coordinates. Site QE is mentioned in figure caption but does not appear on the map. Unit Qs_{4a} contains an internal contact by the dendritic lobes immediately up from the main Qs_{4a} scoria mounds.

p. 46: Champion (1991) does not provide sample numbers or sample sites. However, Figure 2 of Turrin and Champion (1991) shows samples NNTS #5-86 in unit Ql_5, B8203, 211-1 and B8191 in unit Qs_5. Unless sample locations and magnetic data are reported, there is no way to evaluate the lack of correlation between unit Ql_5-Qs_5 and the eastern fissure unit Qs_{2b}.

p. 47: Perry and Crowe (1992) also do not report sample locations. Although these geochemical data have apparently high precision, without knowing the number of samples and sample locations for these data, the analytical accuracy and, thus, stratigraphic correlations cannot be determined.

p. 50: Unit Qs_{2c} is supposedly exposed "north and northeast of the main cone," but there is no Qs_{2c} shown northeast of the cone on the map in Figure 2.9. Do the deposits "northeast of the main cone" refer to the surge deposits that underlie unit Ql_3 (i.e., to the northeast) and may be correlative with Qs_{2c}, or are there additional small exposures of unit Qs_{2c} that are not mapped? In contrast, the next paragraph states that subunit Qs_{2c} crops out extensively northwest and west of the main cone, which is apparently shown in Figure 2.9. The following paragraph states that "the thickest accumulations of the pyroclastic surge deposits occur north and northwest of the main cone."

p. 51: The pyroclastic surge unit (Qs_{2c}) overlying Ql_{4b} lava lacks carbonate coatings, which is inferred to indicate a time break between deposition of these units. Would carbonate coatings necessarily form at the same rate on these two units, given the differences in porosity, permeability, and composition? In addition, are carbonate coatings developed on any of the overlying unit 2 scoria deposits? This argument needs to be supported by data.

p. 53: No basis is provided for concluding that the erosional unconformity between units Qs_{4b} scoria and the main cone scoria represents "at least a few tens of thousands of years." The ^3He dates on the cone only yield a minimum age of the main cone of 44 ± 5-6 ka. The age of unit Qs_{4b} has not been determined directly but likely corresponds in age to unit Qs_{4a}, which has a preliminary U/Th date of 150 ± 40 ka. However, the ^3He dates on lava Ql_4 are 48 ± 5 and >49 ka (Crowe et al., 1992; Poths and Crowe, 1992) and are thus contemporaneous with the main cone. Poths and Crowe (1992) also conclude that the scoria cone might be as old as the lavas (units Ql_5, Ql_4, and Ql_3). These data do not support the conclusion that this unconformity represents "at least a few tens of thousands of years."

Recommendation: Correct minor errors on geologic map of Lathrop Wells. Clarify apparent stratigraphic discrepancies between map and text and discuss data used to quantify durations of erosional episodes.

COMMENT 2.11

Statement of Concern: The hypothesis that anomalously old K-Ar dates are due to excess Ar in the system has not been completely tested.

Basis: p. 65: Poths and Crowe (1992) report excess Ar in crushed olivine separates from Lathrop Wells units Ql_5 and Ql_3. There are several possible sources for excess Ar in these samples besides the presence of inherited radiogenic Ar. Poths and Crowe (1992) do not address the possibility that some of the excess Ar was produced by ^{40}K decay in quenched glass inclusions in the olivine. In addition, Poths and Crowe (1992) and Crowe et al. (1992) do not indicate if groundmass glass was completely removed from the olivine separates. Adhesion of glass to the olivine could also produce an anomalously high radiogenic Ar signal. Excess radiogenic Ar could well exist in the Lathrop Wells system. However, alternative hypotheses need to be explored before this possibility can be accepted as a significant source of error in the K-Ar system.

Recommendation: Describe methods used to minimize matrix adhesion during preparation of olivine separates. Constrain the amount of Ar that could be potentially contained in glass inclusions.

COMMENT 2.12

Statement of Concern: Criticism of the accuracy of ^{36}Cl dates by Zreda et al (1993) appears unwarranted.

Basis: p. 46: Zreda et al. (1993) clearly describe why a 30 percent correction for geometry should be applied to the background production rate of ^{36}Cl from thermal-neutron capture by ^{35}Cl when samples are collected from pressure ridges on lava flows. This is not an unknown factor and does not necessarily "overestimate" the exposure age. The basis for questioning the accuracy of the ^{36}Cl dates is not presented.

Recommendation: The ^{36}Cl dates of around 80 ka by Zreda et al. (1993) may accurately represent the age of the analyzed units at Lathrop Wells. The methods used appear well justified. These data should be discussed in detail, as should apparent discrepancies between the ^{36}Cl and ^{3}He dates.

COMMENT 2.13

Statement of Concern: Published U/Th dates related to the age of Lathrop Wells are not present in this report.

Basis: Carbonate coatings associated with Lathrop Wells units apparently are thick enough to date by the U/Th disequilibrium method. Szabo et al. (1981) report U/Th dates of 345+180-70 ka for stalactitic laminated calcrete in cavities between boulders immediately between a Lathrop Wells basalt flow. Szabo et al. (1981) also report a U/Th date of 25 ± 10 ka for caliche from the base of loess overlying the Lathrop Wells cinder cone. These data are not discussed in this report.

In addition, U/Th dates with a greater degree of precision and accuracy than Szabo et al. (1981) may be possible for carbonate coatings, using the technique for dating impure carbonate described by Luo and Ku (1991). Luo and Ku (1991) were able to date Quaternary units in trench CF-3 at 38 ± 3 and

17±3 ka. This technique may be directly applicable to determining the age of soil caliche and carbonate coatings on lavas and surge deposits at Lathrop Wells.

Recommendation: U/Th dates of carbonate coatings can be used to bound cosmogenic and other radiogenic dating techniques. In addition, the U/Th method can be used to verify the accuracy of thermoluminesence (TL) dates. This technique should be investigated in detail as part of planned geochronology studies in Study Plan 8.3.1.8.5.1 part 3.

References:

Luo, S., and T.-L Ku. 1991. U-series isochron dating: A generalized method employing total sample dissolution. *Geochimica et Cosmochimica Acta* 55: 555-564.

Szabo, B.J., W.J. Carr, W.C. Gottschall. 1981. Uranium-thorium dating of Quaternary carbonate accumulations in the Nevada Test Site region, southern Nevada. *U.S. Geological Survey Open-File Report.* 81-119.

COMMENT 2.14

Statement of Concern: Inadequate data are presented to validate the experimental U/Th disequilibrium dating technique. The reported information indicates that this technique may not accurately determine the age of the dated unit.

Basis: Insufficient analytical data are presented to independently evaluate analytical precision and accuracy for this technique. For example, ^{234}U and ^{230}Th abundances and associated analytical uncertainties should be reported in order to distinguish between the precision in counting statistics and the uncertainty of the reported date. These data are not presented in Crowe et al. (1992). In addition, the reported disequilibrium between different mineral size fractions demonstrates why it is critical for the authors to report all analytical data, so that an independent assessment of the data can be made.

A basic assumption in the U/Th technique is that the system has remained closed with respect to U and Th. The reported isotopic disequilibrium between different grain sizes of the same mineral may indicate that some part of the system was open for U or Th. In addition, the explanation provided for this apparent disequilibrium is that it may reflect ". . . alteration of the coarser-grained olivine and plagioclase grains by an uranium-rich fluid." (p. 68) indicates the investigators are aware of possible open-system behavior. It is also unclear why olivine "microphenocrysts microlites" will be probed to test for possible alteration, but that plagioclase will not be examined for alteration effects.

Recommendation: Until the accuracy of the U/Th technique is verified, the dates reported for Lathrop Wells should not be used in age-dependent hypotheses.

COMMENT 2.15

Statement of Concern: Reported uncertainties with the ^{3}He dates do not accurately represent the analytical uncertainties of this technique.

Basis: If the uncertainty in the calibration of the ^{3}He dates is estimated to be about 30 percent (Poths and Crowe, 1992; Crowe et al., 1992), then the ages of these units have at least a 30 percent uncertainty, regardless of presumed analytical precision. The minimum exposure age of Lathrop Wells (i.e., oldest date) is thus 44±13 ka, not 44±6 ka as reported.

Recommendation: The reported age of a unit should reflect the precision and accuracy of the analysis, not just the reported analytical uncertainty. If part of the analytical procedure has a 30 percent uncertainty, then the age of the unit should have a 30 percent uncertainty.

COMMENT 2.16

Statement of Concern: The accuracy of the thermoluminescence dates for the youngest soils at Lathrop Wells has not been determined in sufficient detail to support any conclusion regarding the age of these deposits.

Basis: Multiple analyses of nonbaked soil samples were presented in Crowe et al. (1992). The reproducibility of the dates demonstrates the precision of the technique used to obtain these values. However, there is no way to evaluate the accuracy of these dates, nor is it at all clear how the measured TL signal was acquired by the sample.

Details of the TL technique are presented in Study Plan 8.3.1.8.5.1 part 3.2.2.5. Crowe et al. (1992) and this report clearly states that this technique is preliminary and has not been applied to volcanic soils. However, even the limited data presented in this report seriously questions the accuracy of the dates produced through TL of unconsolidated soils.

A TL date of 24.5±2.5 ka is reported in Crowe et al. (1992) for baked soil under lava Ql_3. However, other dates for members of chronostratigraphic unit 3 are three to five times older than this date. The authors state that they ". . . currently have no reasonable explanation of the age discrepancy." (p. 70). A reasonable conclusion would be that although the TL technique yields fairly precise dates, the dates do not accurately reflect the age of the unit.

If the accuracy of a TL date on a baked soil is questionable, then the TL date of a nonbaked, nonconsolidated soil is even more questionable. It is practically impossible to evaluate the technique used for these TL dates, because hardly any analytical information is presented in this report or in the original data source (Crowe et al., 1992). Apparently, these samples were heated to only 100 °C to remove the least stable time signal (Crowe et al., 1992). However, it is recognized that electron traps below about 250-300°C are unsuitable for TL dating, and that different temperature traps have different mean lifetimes (e.g., Aitken, 1978; Geyh and Schleicher, 1990). The general application of the TL technique assumes that the mean lifetime of the trap should be ten times longer than the age to be determined. Thus, determination of a roughly 10 ka age requires measuring a deep TL trap, which exists at around 300 °C (Geyh and Schleicher, 1990, p. 258). Heating to only 100 °C is insufficient to determine a 10-100 ka age, because only shallow (i.e., short lifetime) traps are activated. The TL dates presented could thus reflect the roughly 10 k.y. stability of a low temperature trap and not reflect the age of the unit. Therefore, it is not at all clear, from the limited data presented, what the reported TL dates represent.

Recommendation: Complete analytical data, including calibration techniques and glow curves, must be presented before any of the reported TL dates can be taken as ages of the sampled units. Additional justification and explanation of the methodology used on the nonconsolidated soils also must be presented, because it is not clear what the reported numbers actually represent. Conclusions regarding the age of the youngest eruption at Lathrop Wells cannot be supported by these data.

References:

Aitken, M.J. 1978. Archaeological involvements of physics. *Physics Letters* C-40/5: 277-351.

Geyh, M.A., and H. Schleicher. 1990. *Absolute Age Determination*. New York, NY. Springer-Verlag.

COMMENT 2.17

Statement of Concern: The youngest eruption at Lathrop Wells (chronostratigraphic unit 1) apparently did not modify the morphology of the cone, yet, based on geomorphology, this unit is related to the approximately 20 ka Black Tank cone in the Cima volcanic field.

Basis: p. 70: The youngest eruption at Lathrop Wells is the tephra exposed in the quarry south of the main cone (this report, p. 55). This tephra apparently did not mantle the main Lathrop Wells cone and thus did not exert any geomorphic control on the main cone, in contrast to the apparently young mantling eruption at Hidden Cone. How can the geomorphology of the youngest Lathrop Wells eruption thus be compared with the geomorphology of the Black Tank cone?

Soil studies at the Black Tank cone do not demonstrate that chronostratigraphic unit 1 is appreciably younger (i.e., <20 ka) than the main cone at Lathrop Wells. On the bottom of p. 73 the authors conclude "... it is difficult and unwarranted to speculate on the extent of the time differences between the units," when referring to the different degrees of soil development between unit three and units two and one. It is not intuitive why pedogenic features would be too indistinct to estimate the age between unit 3 and overlying units, yet would be distinct enough to distinguish <20 ka differences.

Recommendation: The age of chronostratigraphic unit 1 needs to be determined by techniques other than geomorphology. Although the pedogenic features associated with unit 1 are similar to those at Black Tank cone, it has not been demonstrated that pedogenic character can resolve ages of 20-50 k.y. difference.

COMMENT 2.18

Statement of Concern: Geomorphic characteristics are used to conclude that the age of the main cone at Lathrop Wells is around 40 ka. Studies presented to date indicate that geomorphic characteristics may be incapable of resolving differences in age of 50-100 k.y. Geomorphic relationships further indicate that Lathrop Wells should be younger than the Black Tank cone, which is not supported by other geochronological data.

Basis: p. 53: The conclusion that the Lathrop Wells cone age is about 40 ka is not supported by the data in this report or Wells et al. (1990). A conclusion on page 69 is that ". . . the main cone (Qs_{2a}) can be no younger than 40 ka." does not support an age of "around" 40 ka. The ^{3}He dates report only minimum exposure ages and may not accurately reflect the absolute age of the rock. The apparent correlation between the cone exposure dates and the ^{3}He exposure dates for underlying lavas (Crowe et al., 1992; Poths and Crowe, 1992) also indicates that the ^{3}He dates provide only minimum estimates of a unit's age.

The geomorphic criteria presented by Wells et al. (1990) and Dohrenwend et al. (1986) are insufficiently precise to resolve approximately 50-100 k.y. differences in cone age. For example, variations in cone height to cone width are very similar for cones at Cima that range in age from 0.015 to at least 0.7 Ma. Ratios of crater width to cone height, apron height to cone height, apron slope length to cone slope length, and the tangent of mean maximum slope also can be very similar for cones produced over 0.2 m.y. intervals (Dohrenwend et al., 1986). The lack of a cone apron and incised drainages at Lathrop Wells likely indicates a relatively young age for this cone (Wells et al., 1990), given the amount of geomorphic modification that can occur over 100 ka intervals (Dohrenwend et al., 1986). But based on the reported geomorphic criteria, the Lathrop Wells cone should be younger than the Black Tank cone in the Cima volcanic field. However, the minimum age of Lathrop Wells ($>44\pm6$ ka) is significantly older than the age of the Black Tank cone (15 ± 5 to <30 ka, Wells et al., 1990). Thus, the geomorphic characteristics probably lack sufficient precision and accuracy to resolve differences in cone ages of around 50-100 ka.

Recommendation: The resolution of the geomorphic characteristics used to determine the age of Lathrop Wells and other Quaternary volcanoes needs to be more explicitly investigated. The apparent discrepancy between the geomorphically young character (i.e., <15 ka) and significantly older exposure dates (>40 ka) at Lathrop Wells needs to be resolved.

COMMENT 2.19

Statement of Concern: Some magnetic data presented in this report are missing from figures. Magnetic orientation data are not presented in sufficient detail to permit independent analysis of conclusions.

Basis: p. 76: The two sites for unit Ql_6 that give dispersed magnetic data are not shown in Figure 2.20 as referenced. In addition, what do the two dots near Dec. 0, Inc. 55 in Figure 2.20a-d represent?

The text states that at least one sample per site has been subjected to alternating field demagnetization, and that most samples yielded a univectoral decay as shown in Figure 2.19. The authors do not state how many samples did not show univectoral decay. Given the past controversies that have surrounded magnetization directions at Lathrop Wells, original data should be presented in tabular form to permit independent evaluation of the conclusions reached in this section.

Recommendation: Provide all the data collected, including a map of sample sites and anomalous orientation samples, so that independent conclusions can be derived.

COMMENT 2.20

Statement of Concern: Numerous citations in the text are not referenced, incompletely referenced, or incorrectly referenced.

Basis: p. 21: Noble et al., 1992, is not completely referenced.

p. 29: Champion, 1992, reference is not readily available and not included in the handouts prepared for this meeting.

p. 30: Turrin, 1992, is not in references.

p. 41: Which Crowe et al. (1992a) is referenced? There are two 1992a references in the list.

p. 46: (Zreda et al. 1993; p. 59): The only reference by Zreda et al. (1993) is an AGU abstract, p. 577.

p. 55: Whitney and Shroba (1991) is not in references.

p. 59: Turrin et al. (in press): Where is this in press? Is this the same as Turrin et al. ("1990") that was *in press* in a USGS Bulletin, referenced by Turrin and Champion (1991)?

p. 61: Wilkerson (1990) is not in the references.

p. 62: Turrin et al. (1991a) is not in the references.

p. 65: Turrin (1992, p. 226-235) is not in the references.

p. 81: What is meant by the Crowe et al. references with dates 1992a, 1992b and 1992b, 1992c? Why is reference 1992a identical to references 1992b,c?

p. 86: Valentine et al. (in press) was published in 1992, GSA Bulletin v. 104, #2, p. 154-165.

p. 86: Wells et al. (1988) — Which GSA Meeting? Not in annual meeting volume.

p. 87: Zreda et al. (1993) does not exist as referenced. Zreda et al. published some ^{36}Cl dates for Lathrop Wells in 1991, EOS v. 72, p. 577. Is this the correct reference? If so, then what is Zreda et al. (1993)? Geology, v. 21, p. 57-60 perhaps?

2.3 REVIEW OF SECTION 3: TECTONIC SETTING OF THE YUCCA MOUNTAIN REGION: RELATIONSHIP TO EPISODES OF BASALTIC VOLCANISM

COMMENT 3.1

Statement of Concern: p. 88, first paragraph, lines 21-23 — The statement is made that faults off-setting Miocene ignimbrites at Yucca Mountain are inferred to be related to the rifting process and are not detachment faults.

Basis: Faults related to rifting may also be detachment faults. The "rifting" process does not preclude a detachment style of faulting.

Recommendation: Consider inclusion of low-angle (detachment) fault systems as a potential fault type in both rift and pull-apart tectonic models.

COMMENT 3.2

Statement of Concern: p. 88, first paragraph, lines 6-7 — "Basin-range faults that cut the rocks of Yucca Mountain trend north and north-east." The concept of "basin and range faulting" is historically meaningful, and it is not clear exactly what is meant by "basin-range faults at Yucca Mountain" as used in this report.

Basis: While Yucca Mountain does lie within the Basin and Range physiographic province, faults at Yucca Mountain may be different from faults that bound large mountain ranges within the Great Basin north of Yucca Mountain. Reference to Yucca Mountain faults as "basin-range faults" may be construed to imply a style similar to the major range-bounding faults within the Great Basin. The structural style most typical of "basin-range faulting" is best developed within the northern Great Basin region of the Basin and Range province. Faults at Yucca Mountain generally have shorter trace lengths and smaller displacements, and may be substantially different in genesis, geometry, and mechanics from the major range-bounding faults of the Great Basin. This is a potentially important distinction that should be recognized.

Recommendation: When referring to particular models of faulting of the YMR, describe the pertinent fault geometry and slip (low-angle, high-angle, etc.).

COMMENT 3.3

Statement of Concern: p. 88, first paragraph, lines 7-9 — "The potential Yucca Mountain site is located at the north edge of a conspicuously amagmatic zone that exhibited no Cenozoic volcanism during episodes of extreme extension." The inference appears to be, because Yucca Mountain is adjacent to a Cenozoic amagmatic corridor, the likelihood of future volcanism in the Yucca Mountain area is somehow reduced.

Basis: The complete significance of this observation is not clear, since Yucca Mountain is also adjacent to what may be the largest Cenozoic caldera in the region.

Recommendation: Consider a more balanced approach. Describe the position of Yucca Mountain with respect to both magmatic and amagmatic domains.

COMMENT 3.4

Statement of Concern: p. 88, first paragraph, lines 14-15 — "However, there is a general consensus that the active faulting at Yucca Mountain, if related to detachment faulting, represents only the final stages of movement." The "general consensus" referred to is of interest. Displacements and deformation in this region are not currently resolved with sufficient certainty.

Basis: Yucca Mountain is directly adjacent to a continental-scale strike-slip fault system (Northern Death Valley-Furnace Creek), and to perhaps the most rapidly extending region (Death Valley) on the entire continent. Also, there is no clear stop-start boundary between detachment faulting and some other faulting style that may be interpreted to have replaced it. These systems may evolve continuously. In addition, there is Holocene slip on the Solitario Canyon fault (O'Neill et al., 1992), so either the long-lived system is active (likely) or a new system has formed coincident with it (less likely).

Recommendation: Consider other explanations for comparatively small extensional strains at Yucca Mountain. Finite strain may be related to structural position in the detachment system.

References:

O'Neill, J.M., J.W. Whitney, and M.R. Hudson. 1992. Photogeologic and kinematic analysis of lineaments at Yucca Mountain, Nevada: implications for strike-slip faulting and oroclinal bending. U.S. Geological Survey Open File Report 91-623.

COMMENT 3.5

Statement of Concern: p. 88, first paragraph, lines 18-21 — "An alternative tectonic model for the Yucca Mountain area is that it is in a N-NE trending, volcano-tectonic rift, the Kawich-Greenwater rift. The rift may be a pull-apart or right-stepped zone of rifting in the Walker Lane structural system." This statement does not seem consistent with the source paper (Carr, 1990).

Basis: Treatment of the Kawich-Greenwater rift as a pull-apart may not be what has been proposed by workers who suggested this structure.

Recommendation: Check the evidence for the Kawich-Greenwater structure being a pull-apart. This interpretation may not be what Carr (1990) meant.

COMMENT 3.6

Statement of Concern: p. 89, first paragraph — The "statistics" presented in this paragraph are not meaningful.

Basis: A glance at a geologic map shows the alignment discussed, but the interpretation is the important part. First, the alignment may not exist. The basalts of Thirsty Mesa and Sleeping Butte are not necessarily part of a common structural-conduit system with those in Crater Flat. If one removes Sleeping Butte, the regional Quaternary alignment disappears. It is basically a two-point alignment, and the alignment is the primary evidence of a deep structural trend. Furthermore, the interpretation of possible shallow orthogonal diversion of the dike/vent array from the deep northwest trend is not supported by mechanical/fluid dynamic arguments.

Recommendation: Do not depend on the inferred alignment for strong evidence for structural control on magma ascent.

COMMENT 3.7

Statement of Concern: Abstract, pages 89-90, paragraph split at bottom/top of referenced pages, first and last sentences — First sentence of paragraph states that Quaternary basalt sites do not appear to be controlled by structures; last sentence states that distribution of basalt centers can be related to possible structures.

Basis: These two sentences appear to present conflicting information and leave the reader uncertain about the position being taken in relation to structural control on volcanism in the Yucca Mountain area.

Recommendation: If the writers are trying to indicate that the exact model for relating volcanism with structures is uncertain at present, although structural control on the location of volcanic vents and dikes is possible or probable, then the sentences should be re-written to reflect that multiple models exist (and will be used) for assessment of structural control on volcanism in the Yucca Mountain area.

COMMENT 3.8

Statement of Concern: Abstract, pages 89-90, paragraph split at bottom/top of referenced pages, second sentence — This sentence states that the "best" spatial correlations of distribution of basalt centers and structures are with deep-seated structural features such as strike-slip (SS) faults and ring-fracture zones of calderas.

Basis: While the association of some basalts with ring-fracture zones of calderas does appear "proven" for the Yucca Mountain area, the association with deep-seated SS faults has not been proven. It appears the statement indicates the structural model preferred by the writers — apparently only one of the potential models to be used in assessment of structural control on volcanism, based on later discussions in the report. We know of no studies which have analyzed the proposed deep-seated SS faults thoroughly enough to ascertain the true association of volcanic centers with these structures, other than the proposed spatial correlation based on the orientation of the Crater Flat Volcanic Zone (CFVZ) (as defined by Crowe and Perry, 1989) being subparallel to the Walker Lane belt. In this model, NW-trending structures are considered to reflect the orientation of the regional controlling structure, while NE-trending structures are thought to exhibit only "local" control. On the other hand, however, Smith and others (1990) consider the NE-trending structures to be the regional controlling structures.

Recommendation: Since several structural models will apparently be used to assess structural control on volcanism and to compute associated risk of volcanic disruption of a repository (as indicated elsewhere in Section III), it may be better to state this up-front in the abstract rather than concentrating on the apparently preferred (by the writers) Crowe and Perry (1989) model. The abstract does not indicate, in fact, that alternative models will be used as the text specifies.

References:

Crowe, B.M., and F.V. Perry. 1989. *Volcanic probability calculations for the Yucca Mountain site: Estimation of volcanic rates. Proceedings for Focus '89, Nuclear Waste Isolation in the Unsaturated Zone.* La Grange, IL. American Nuclear Society: 326-334.

Smith, E.I., D.L. Feuerbach, T.R. Naumann, and J.E. Faulds. 1990. *The area of most recent volcanism near Yucca Mountain, Nevada: Implications for volcanic risk assessment. Proceedings for International Topical Meeting, High-level Radioactive Waste Management.* La Grange, IL. American Nuclear Society. 1: 81-90.

COMMENT 3.9

Statement of Concern: p. 91, first paragraph, lines 1-3 — "Miocene basaltic volcanism shows strong spatial associations with pre-existing structure (basin-range faults and ring-fracture zones of caldera complexes). No references or examples are given for association of Miocene basaltic volcanism with basin-range faults.

Basis: Caldera associations are obvious only for basalts of Rocket Wash (RW of Figure 3.10) and Pahute Mesa (PM of Figure 3.10). Are there other examples for Miocene basalts?

Recommendation: Give specific examples of basaltic centers associated with faults and offer a more thorough explanation of the association.

COMMENT 3.10

Statement of Concern: p. 92, third paragraph, last sentence — The statement is made that the fundamental tectonic setting of Yucca Mountain is unlikely to change in the next 10,000 years. Notwithstanding the fact that Yucca Mountain is located in an evolving and dynamic tectonic setting (where rates of extension have admittedly decreased), this statement is likely to be correct for the next 10,000-year frame.

Basis: This sentence may be construed to suggest that the key problem is being missed — that of analyzing and understanding the tectonic history well enough that tectonism/volcanism can be assessed and understood with some degree of certainty.

Recommendation: So as not to leave the reader with a false sense of security regarding what is known about the tectonic setting of Yucca Mountain, it may be useful to reiterate that understanding the tectonic setting and relating it to basaltic volcanism at this "local" scale is difficult and uncertainties exist relative to how well this can be achieved.

COMMENT 3.11

Statement of Concern: p. 93, second paragraph, lines 5-7 — The concept of eastward extension of the Garlock Fault is discussed. The eastward extension of the Garlock fault does not closely coincide with a boundary between the topographically high-standing Great Basin and the lower elevation southern Basin and Range region (Edwards and Batson, 1990).

Basis: It is not clear that there is adequate basis for extending the Garlock. If extended on the basis of geomorphic lineaments, both of the good alternatives are significantly south of the topographic boundary. There is no explanation of why this observation/interpretation is important. The geophysical trends indeed coincide roughly with the break in topography, but what role does the Garlock play?

Recommendation: Consider a more thorough explanation of the significance of this interpretation.

COMMENT 3.12

Statement of Concern: p. 93, third paragraph, lines 7-9 — "Many workers separate episodes of faulting into an earlier period of predominantly low-angle or detachment faulting followed by a younger period of high-angle normal faulting . . ." References are not provided.

Basis: No references are provided for the "many" workers alluded to in the sentence quoted.

Recommendation: Consider providing references to support the sentence quoted.

COMMENT 3.13

Statement of Concern: p. 99, third paragraph, lines 2-4 — "However, it has proven difficult to directly link extension with the development of the metamorphic complexes (Oldow et al., 1989)." This statement may not accurately represent Oldow et al. (1989).

Basis: Oldow et al. (1989) indicate that the difficulty is in linking core complexes with onset (Oligocene) of extension, not with finite Cenozoic extension. Metamorphic core complexes are clearly related to tectonic extension.

Recommendation: Examine the Oldow reference again and consider rephrasing this statement.

References:

Oldow, J.S., A.W. Bally, H.G. AveLallemant, and W.P. Leeman. 1989. Phanerozic evolution of the North American Cordillera, United States and Canada. A.W. Bally and A.R. Palmer, eds. *The Geology of North America: An Overview.* Boulder, Colorado: Geological Society of America: 139-232.

COMMENT 3.13

Statement of Concern: p. 99, third paragraph, lines 4-6 — "An alternative interpretation is the metamorphic complexes were reactivated during the period of subduction of the Farllon [sp] plate (40 to 20 Ma; Coney, 1978) and uplifted and exposed by later high-angle faulting." This statement may not accurately represent Coney (1978).

Basis: Coney does not propose uplift by high-angle faulting. High-angle faulting does not cause uplift. Uplift occurs isostatically after the upper crust is attenuated. High-angle faults do not accommodate strong extension. This is important because Yucca Mountain may have formed as part of a metamorphic core complex. Maldonado (1990) and Scott (1990) indicate that faults at Yucca Mountain may merge at depth with a regional low-angle detachment fault that is exposed in the Bullfrog Hills core complex.

Recommendation: Examine the Coney reference again. Offer an explanation for how high-angle faulting may be associated with uplift of an extending region.

References:

Coney, P.J. 1978. Mesozic-Cenozoic cordilleran plate tectonics. *Cenozoic Tectonics and Regional Geophysics of the Western Cordilleran.* R.B. Smith and G.P. Eaton, eds. Geological Society of America Memoir: 152: 33-49.

Maldonado, F. 1990. Structural Geology of the upper plate of the Bullfrog Hills detachment fault system, southern Nevada. *Geological Society of America Bulletin.* 102: 992-1006.

Scott, R.B. 1990. Tectonic setting of Yucca Mountain, southwestern Nevada. *Basin and Range Extensional Tectonics Near the Latitude of Las Vegas, Nevada.* B.P. Wernicke, ed. Geological Society of America Memoir: 176: 251-282.

COMMENT 3.14

Statement of Concern: p. 99, third paragraph, lines 10-11 — "The most active areas of volcanism and tectonism in the Great Basin are along its western and eastern margins." It is not clear what active volcanism is being referred to by the writers.

Basis: There is no active volcanism along the eastern flank of the Great Basin. There has been substantial Quaternary volcanism within the Snake River Plain along the northern flank. Most of the volcanism similar to Crater Flat Valley has been within the Mojave shear zone corridor, which is the regional tectonic setting of Yucca Mountain. As such, it is directly pertinent to assessment of volcanism at Yucca Mountain.

Recommendation: Review Luedke and Smith (1991) and re-examine the distribution of "active volcanism" in the region.

COMMENT 3.15

Statement of Concern: p. 104, third paragraph, lines 3-6 — The authors contend that strain rates have decreased since Miocene. So far, no mention is made of geodetic measurement of strain. Also, no mention is made of the potential influence of strain and/or strain rate on magmatism.

Basis: If Crater Flat Valley is interpreted as a pull-apart, intrusion/eruption processes may be directly influenced by the strain state. The contention that strain rates have decreased since the Miocene is probably true, but that inference is based on decreased average slip rates on the Yucca Mountain faults. Regional strains may still be significant, but slip may be localized on faults such as Death Valley-Furnace Creek, Bare Mountain, etc. The Crater Flat Valley pull-apart would still experience extension which may localize magmatism. The Little Skull Mountain earthquake is an indication that the area is still extending.

Recommendation: Describe how measurements of contemporary strain may be acquired and used to support this contention.

COMMENT 3.16

Statement of Concern: p. 105, third paragraph, lines 12-14 — "Thus most of the detachment deformation predated the episodes of extensional faulting that displaced the ignimbrite sheets of Yucca Mountain." It is probably more accurate to infer that most of the slip on the detachment system occurred west of Yucca Mountain, not necessarily before slip at Yucca Mountain.

Basis: The largest extensional strain accumulated in the Bullfrog Hills area (Maldonado, 1990). Alternatively, slip was accumulating on a different part of the system (i.e., Bullfrog Hills/Bare Mountain) and gradually broke into the footwall toward Yucca Mountain. Another reasonable alternative is that slip was roughly synchronous across the detachment surface, but the slip velocity field was not uniform.

Recommendation: Evidence is not sufficient to support this conclusion; further information should be obtained through appropriate Study Plans.

References:

Maldonado, F. 1990a. Structural geology of the upper plate of the Bullfrog Hills detachment fault system, southern Nevada. *Geological Society of America Bulletin* 102: 992-1006.

COMMENT 3.17

Statement of Concern: p. 106, first paragraph, lines 5-7 — "However, the important perspective for understanding the distribution of basaltic volcanism is the possible role of detachment faults in providing crustal pathways for ascent of basalt magma." This is a limited perspective on tectonic-magmatic processes.

Basis: First, an assumption is made that faults are conduits, or pathways, for magma transport. No explanation, mechanism or examples are given for this process. The important perspective, or at least a broader perspective, may be understanding the relative contribution of continuous (flow), discontinuous (faulting), and magmatic (dike intrusion) processes in accommodation of tectonic strain.

Recommendation: Offer a broader explanation of the roles of fault and dike intrusion as either complementary or exclusive mechanisms of extensional strain accommodation.

COMMENT 3.18

Statement of Concern: p. 115, last paragraph, lines 7-9 and 14-18; p. 116, Figure 3.10 — The statement is made that NW-trending boundaries between older post-caldera basalts (OPB) and younger post-caldera basalts (YPB) of Crowe and Perry (1989) are drawn assuming structural control by the Walker Lane belt, so that orientation of these boundary lines is based on both distribution of volcanic rock and structural features. Orientation of the NW-trending boundaries is based on the trend of one "set" of regional structures in the Yucca Mountain area (i.e., the NW set), but ignores the NE-trending structures which reflect the regional trend of many (Basin and Range) faults.

Basis: Clearly the assumption (as stated in the report) is that NW-trending structural features of the Walker Lane exercise control on basaltic volcanism — with the implication that this is the regional control at depth. The discussion fails to mention the work of Smith and others (1990), in which it is assumed there is regional and local control by NE-trending, normal (planar) faults — which the CFVZ model of Crowe and Perry (1989) considers to exercise only "surficial" control on vent location in Crater Flat.

Recommendation: Perhaps a discussion of alternative interpretations for structural control on volcanism in the Yucca Mountain area should be provided somewhere in the discussion of post-caldera basalts.

References:

Crowe, B.M., and F.V. Perry. 1989. *Volcanic probability calculations for the Yucca Mountain site: Estimation of volcanic rates. Proceedings for Focus '89, Nuclear Waste Isolation in the Unsaturated Zone*. La Grange, IL. American Nuclear Society: 326-334.

Smith, E.I., D.L. Feuerbach, T.R. Naumann, and J.E. Faulds. 1990. *The area of most recent volcanism near Yucca Mountain, Nevada: Implications for volcanic risk assessment. Proceedings for International Topical Meeting, High-level Radioactive Waste Management.* La Grange, IL. American Nuclear Society. 1: 81-90.

COMMENT 3.19

Statement of Concern: p. 119, first paragraph, lines 10 and 22-24, page 118, Figure 3.12 — The statement is made that distribution centroids of the two cycles of post-caldera basalts (i.e., OPB and YPB) are spatially distinct, vent distributions are distinctly different, and data support southwest stepping of volcanism with time.

Basis: Do these data provide a suggestion that the events are non-random at this scale, and argue against representing the events as a homogeneous Poisson distribution model in the analyses of probability as the report maintains?

Recommendation: Consider commenting on whether this "regional" distribution of post-caldera basalts suggests a homogeneous Poisson distribution model is inaccurate for probabilistic analyses for volcanism.

COMMENT 3.20

Statement of Concern: pages 119-120, third paragraph, lines 3-4 (page 119) and 5 (page 120) — This sentence refers to dikes of OPB at Pauite Ridge, which both follow NW-trending faults and are cut by NW-trending faults, being evidence that basaltic magmatism accompanied extensional faulting.

Basis: The point of confusion in this statement is that both the dikes and the faults which cut them appear to have the same trend (i.e., northwest), since no specific orientations are provided to show any distinction in the two northwest trends.

Recommendation: Consider clarifying wording to convincingly state the known relative age relationships between extensional tectonism and magmatism to clarify the point on association of extensional faulting with volcanism.

COMMENT 3.21

Statement of Concern: p. 123, first paragraph, lines 4-5 — "This observation strongly supports the inference that the location of basalt centers is controlled by a NW-trending structure."

Basis: The inferred alignment seems to be the main line of evidence for the stated inference. The statistics here are not very useful. It's essentially a two-point correlation. The correlation depends on the assumption that the Little Black Peak center (LP of Figure 3.13) and Hidden Cone center (HC of Figure 3.13) vents are related to the Crater Flat vents by a common conduit system at depth.

Recommendation: This type of correlation does not offer strong support for structural control.

COMMENT 3.22

Statement of Concern: p. 123, second and third paragraphs — The case is made that, for basalts of the YPB in the CFVZ, NW-trending structures provided deep-seated structural control on magma pathways, and NE-trending structures provided "surficial" control on location of basaltic vents in response to the maximum principal compressive stress direction of the shallow stress field. This discussion is based on the model of Crowe and Perry (1989), and there is no discussion of alternative models that have NE-trending structures as the regional control on magma pathways such as proposed by Smith et al. (1990).

Basis: Based on the above information on "surficial" structural control on vent location, NE-trending structures must be considered in modeling with regard to probability of magmatic disruption of a repository since NE-trending structures both bound and cut the repository block. That is, control of dike orientation and location of surface vents is related to NE-trending features in this report, so worst-case scenarios for repository disruption must consider this concept even when the deep-seated controlling structure for magma pathways is oriented northwest.

Smith et al. (1990) have proposed a model incorporating the area of most recent volcanism (AMRV) which has NE-trending structures as the regional and local control for volcanism, but this model is not mentioned for the Yucca Mountain area.

In addition, since the "secondary" structural control by the shallow stress field is called upon to explain the NNE alignment of cones in Crater Flat, what explanation exists for control of vents by northwest structures — a situation noted at Lathrop Wells and other locations? This observation, documented in this report, may indicate more complex structural controls on location of vents near Yucca Mountain that are not completely understood at present.

Recommendation: It appears that repository disruption scenarios should not eliminate the concept of surficial, NE-trending structural control on location of vents, so this should be treated in the final analyses of volcanic risk for the repository. This means both dike intrusion through a repository and formation of a vent at the location of the repository cannot be totally discounted, even if probabilities are low. Consider stating that alternative models (including that of Smith et al., 1990) will be used in assessment of structural control on volcanism. Consider discussing why NW-trending structures have locally controlled volcanic eruptions, in spite of the orientation of the maximum principal compressive stress which may enhance surficial structural control on vent location by NE-trending structures.

References:

Crowe, B.M., and F.V. Perry. 1989. *Volcanic probability calculations for the Yucca Mountain site: Estimation of volcanic rates. Proceedings for Focus '89, Nuclear Waste Isolation in the Unsaturated Zone.* La Grange, IL. American Nuclear Society: 326-334.

Smith, E.I., D.L. Feuerbach, T.R. Naumann, and J.E. Faulds. 1990. *The area of most recent volcanism near Yucca Mountain, Nevada: Implications for volcanic risk assessment. Proceedings for International Topical Meeting, High-level Radioactive Waste Management.* La Grange, IL. American Nuclear Society. 1: 81-90

COMMENT 3.23

Statement of Concern: Contentions about structural control of volcanism are generally contradictory. For example:

p. 123, second paragraph, lines 8-10 — "It is likely that the basalt dikes created their own fracture pathways to the surface because the location of basalt centers are largely independent of surface structures."

p. 123, fourth paragraph, lines 2-3 — "...The 3.7 Ma basalt centers of Crater Flat are aligned north-south parallel to the trend of faults cutting bedrock in Yucca Mountain..."

p. 127, second paragraph, line 1 — "By contrast, the Quaternary basalt centers show no clear relationship to bedrock faults."

p. 127, second paragraph, lines 7-10 "...The Lathrop Wells volcanic center occurs at the approximate intersection of the NE-trending Stagecoach Road fault, and NW-trending faults that may correlate with the Windy Wash fault (Crowe et al, 1992). These trends are paralleled by the trend of fissure vents in the center."

Basis: There are similar contradictions and inconsistencies throughout. In addition to the stated association of Lathrop Wells with the Stagecoach Road fault (which contradicts the opening sentence of the paragraph), the Crater Flat vents are clearly aligned parallel to and on direct trend with faults at Yucca Mountain.

Recommendation: Develop a clearer argument for the relationship between faults and vents.

COMMENT 3.24

Statement of Concern: p. 127, second paragraph, lines 1 and 6 — References are made to "no clear relationship to bedrock faults" and "obvious faults." These statements (and also in other parts of the report) seem to substitute for "mapped faults."

Basis: Field geologists may consider that an alignment of vents that parallels the regional structural grain of an area suggests structural control on location of vents, either by following existing faults or in response to the same stress field which generated the faults and thus bearing a relationship to faulting or stresses in that area.

Recommendation: Consider using the term "mapped faults," and indicating recognition of the possible structural/stress controls on volcanism when cones are aligned parallel to regional structural trends even if mapped faults do not occur.

COMMENT 3.25

Statement of Concern: Section VI-A, p. 127 — The statement "This net lowered the detection threshold and improved the accuracy of location of earthquakes near.....". What are the specifics about either the seismic event detection thresholds or the improved accuracy?

Basis: Seismometer passbands, sensitivities, detection thresholds, and noise levels profoundly affect the utility and accuracy of seismic data. The authors should convey the limitations of the data. Furthermore, because survey design always affects resolution, it is important in this section to discuss the optimal design for detecting intrusives or related igneous features.

Recommendation: More specific discussions of (1) the network and instrumentation, including a description of frequency passband, amplification, detection threshold, etc.; (2) the data characteristics including background noise, typical passband, etc.; and (3) the setting, including known and assumed seismic velocity structure, attenuation, etc. are needed to bring credibility to the statement cited above and this section, in general.

COMMENT 3.26

Statement of Concern: Section VI-A, p. 128 — The statement is made about a "A seismicity minimum may be observed . . ."

Basis: Statement as it stands is ambiguous. Is the minimum an energy release minimum, a seismic moment minimum, an event population or population density minimum, or something else?

Recommendation: Specify the nature of the minimum.

COMMENT 3.27

Statement of Concern: Section VI-A, p. 128 — Under item 6 the statement is made that "Rogers et al. (1987) summarized several lines of evidence supporting seismic uncoupling but noted that other interpretations are possible."

Basis: The summary statement above conveys too little information to be useful to the reader. The "summarized several lines of evidence" and the "other interpretations" should be specifically given. If Rogers et al. do not give the "other interpretations" this should be noted.

Recommendation: Please clarify statements such as "lines of evidence" and "other interpretations" so that the reader may evaluate the importance of alternative interpretations.

COMMENT 3.28

Statement of Concern: Section VI-A, p. 128 — Statement is made about the "correlation between recorded seismicity and the distribution of Quaternary basaltic centers in the Yucca Mountain area." Data may not be sufficient for conclusive correlation.

Basis: What is the time window of the observations of this seismicity? Are there reasons or evidence, as in analog studies of comparable geophysical provinces, for example, to believe that the seismicity is geographically stabilized enough to make such a statement about correlation. Meaning, is the time window sufficient to make a complete seismic location map? If so, why? Also, is the correlation of the cited statement hypocentral or epicentral?

Recommendation: Specify the time window and foundation of the belief in spatial location stability of the event source locations.

COMMENT 3.29

Statement of Concern: Section VI-A, page 128 — Statement is made that "basalt magma probably ascends rapidly through the crust..and the pathways need not necessarily be correlated with areas of historic seismicity."

Basis: This is a very important statement to this study, no foundation is given. Since it is a probabilistic statement, it requires substantiation and, possibly, negation of data or information to the contrary.

Recommendation: References and/or short summaries of the works that substantiate this statement are needed.

COMMENT 3.30

Statement of Concern: Section VI-A, page 128 — Statement is made regarding Gomberg (1991a) having ". . . derived a spatially varying model of the detection/location capabilities of the network based on empirical relations and statistics" and that she ". . . used several validation test for the model . . ."

Basis: The statements are too vague and give no concrete information by which Gomberg's work can be accepted or rejected. What is the basis of the model, the empirical relations, and the validation tests?

Recommendation: More specific and more detailed description of Gomberg's work is needed.

COMMENT 3.31

Statement of Concern: Section VI-A, page 129 — The statement is made that ". . . the simple shear model also showed a rotational component of the regional deformation field, possibly compatible with paleomagnetic studies . . ." Simple shear deformation may not be compatible with vertical-axis rotation.

Basis: Insufficient information is given to substantiate the compatibility of the model and the paleomagnetics.

Recommendation: Give a more complete accounting of the paleomagnetic studies and relationship to stress model.

COMMENT 3.32

Statement of Concern: Section VI-A, page 129 — Statement is made that Hansen and Bufe (1992) ". . . . discussed the difficulties of obtaining accurate data for earthquake hypocenters and the ambiguity this creates for focal mechanism solutions." The discussion of this important work is insufficient.

Basis: What are the difficulties and ambiguities? How do these affect the statements made in this section of this report?

Recommendation: Give a more complete discussion of the difficulties and ambiguities.

COMMENT 3.33

Statement of Concern: Section VI-A, Seismic Studies, pages 127-130 — Although there are a number of minor, simple-statement citings, the section seems to center completely around only three references, Rogers et al. (1987), and the two Gomberg articles (1991a and 1991b).

Basis: The regional seismic network has been in place since 1979 and that there are only three references, two in peer-review literature (Gomberg's) and one USGS open-file report, available and germane to this study. It may be that a thorough literature review of germane and useful local earthquake seismicity needs to be made. There is also concern that Gomberg recently published an article noting corrections to one of here 1991 articles cited in a recent (i.e. 1993) JGR and it is not cited here.

Recommendation: The authors need to address the concern noted above.

COMMENT 3.34

Statement of Concern: page 127-130, all paragraphs — There is no mention of the Little Skull Mountain seismic event, the fact that it was apparently linked to the Landers event, or the implications of this event and the proposed Landers linkage for seismicity and tectonism in the Yucca Mountain area.

Basis: Exclusion of data on the most recent earthquake in the vicinity of Yucca Mountain seems to be an oversight. These data may be considered to enhance the point made in the report (page 128) that areas of seismicity and locations of Quaternary volcanic vents do not appear to be spatially related at Yucca Mountain.

Recommendation: Consider discussing the Little Skull Mountain seismic event to reinforce the point that areas of seismicity and locations of Quaternary volcanism show no obvious spatial correlation at Yucca Mountain.

COMMENT 3.35

Statement of Concern: Section VI-B, page 130 — The statement "Gravity investigations were begun in the Yucca Mountain as early as 1970." is made. Specific references are not given.

Basis: This statement needs a reference or references.

Recommendation: Give reference or references.

COMMENT 3.36

Statement of Concern: Section VI-B, Gravity Investigations, page 130-131 — This section discusses gravity measurements and some of the implications and interpretations of anomalies. The discussion in this section is very vague failing to give specifics of the cited studies.

Basis: For example, what were spatial separations of the lines that were measured and what is the anomaly resolution capability of field studies? The discussion also fails to address inversion limitations of gravity data since it is a potential field data set.

Recommendation: A more complete discussion of the gravity studies is warranted.

COMMENT 3.37

Statement of Concern: Section VI-C, page 132, first paragraph, lines 3-6 — The statement is made that ". . . we have a relatively high degree of confidence that all significant sites of possible buried basalt have been identified in the Yucca Mountain area." This statement is made without substantiation.

Basis: There is no discussion of the resolution or detection levels of the aeromagnetic data. What is the smallest anomaly that the aeromagnetics can reasonably detect given the spatial sampling of aeromagnetic measurements and the noise level? How do geometric shapes of intrusion affect detectability? Could dikes have been missed?

Since some of the anomalies have been drilled, have they been cored and the cores recovered? If so, have the magnetization of basalts from the anomalies been measured? If so, what is the variation in the magnetization level? Given the variation in magnetization or assuming a constant magnetization, what is the magnetic anomaly detection threshold as a function of range (i.e. distance), physical size, and physical shape? Based on local data or data from an analogous region, what is a reasonable variation in the physical shape of the buried basalts? It seems warranted to suggest that questions about the characteristics, variabilities, and detectability of magnetic anomalies be answered.

Recommendation: The question posed in the previous paragraph need to be answered. Also, easily implemented, numerical models of 2-D and 3-D magnetic bodies (i.e. anomalies) have been available for three decades. Sometimes they are called Talwani codes. Commercial packages of these models for low end computers, specifically PC's, are available. Modeling should be used to examine and answer the detection and resolution questions.

COMMENT 3.38

Statement of Concern: Section VI-C, page 132 — Statements "More detailed drape aeromagnetic data were obtained" and "Ground magnetic traverses were run . . ." This section needs more technical detail.

Basis: These statements are vague and do not give the reader sufficient quantitative information for evaluation.

Recommendation: More quantitative statements of these studies should be added.

COMMENT 3.39

Statement of Concern: Section VI-C, page 132 — The statement that "There is a sufficient amount of magnetic data to place a relatively high degree of confidence in the judgment that all sites of Quaternary volcanic activity have been identified in the Yucca Mountain region." This section needs more technical detail.

Basis: Based on the amount of quantitative information given in this section the statement is not substantiated.

Recommendation: More quantitative information needs to be added to this section to be able to make such a strong statement acceptable.

COMMENT 3.40

Statement of Concern: Section VI-C, pages 132-132 — The statement is made that the small intrusive body about 1 km northwest of USW H-3 would be further studied. Potential additional studies are not discussed.

Basis: Is there any intent to do any other additional ground-based magnetic studies? Is further resolution of other aeromagnetic anomalies warranted?

Recommendation: Discuss whether additional ground-based studies are warranted. If not, discuss in more quantitative detail why the resolution and detection capabilities of the aeromagnetics is sufficient.

COMMENT 3.41

Statement of Concern: Section VI-E, Seismic Investigations — Entire section. Throughout this entire section insufficient information is given to evaluate the conclusions drawn from seismic reflection and refraction studies.

Basis: What types of survey were used? 2-D lines, swath surveys, 3-D? What are the receiver station spacing? Where were the sources located? What are the source characteristic? What are the relevant frequencies? What type of processing of the data was done? Were static corrections done? What is the depth of the datum? What is the velocity structure that has been derived from these data. As with the local earthquake studies, what are the detection thresholds, the resolution limits, and sources and limitations produced by error, like timing error? These types of questions are relevant because survey design has an important impact on resolution. The seismic data cited in this section may be useless for the detection of dikes, for example, because the width of dikes ($\approx$ 1 m) is small compared to the frequency of most seismic waves. As a result, dikes will not be detected. It is not possible to use much of the seismic data to answer questions about intrusive volcanism. This should be clarified for the reader.

Recommendation: The section needs to be greatly expanded with more complete explanations, more quantitative discussions, and some statements as to the strengths and limitations of the conclusions.

COMMENT 3.42

Statement of Concern: Section VI-E, page 133 — The statements ". . . relied heavily on existing site models . . .," ". . . confirm a greater depth . . .," and "Shot point 3 . . ." The cited statements are made without giving the reader enough prior information.

Basis: The "existing site models" are from where? "a greater depth" than what? "Shot point 3" of what survey and where?

Recommendation: More thorough explanations are needed.

COMMENT 3.43

Statement of Concern: Section VI-E, subsection 2, page 134, Seismic Reflection — Entire section.

Basis: The section is difficult to follow. Discussions of reflectors at 100 to 200 meters depth are intermixed with discussions of mid-crustal reflectors.

Recommendation: A more thorough and expanded discussion is required.

COMMENT 3.44

Statement of Concern: Section VI-E, Seismic Investigations, pages 133-134 — Entire section. There is no discussion of additional or recommended further seismic exploration studies.

Basis: Is the reader to conclude that sufficient seismic studies have been performed? What about large-scale 3D surveys? None have been reported here. Are they warranted or needed?

Recommendation: Discuss the topic of additional seismic exploration studies.

COMMENT 3.45

Statement of Concern: Section VI-F, Teleseismic Studies, page 135 — Statement about "other interpretations" besides Evans and Smith's (1992) theory that ". . . the low velocity anomaly form a track subparallel to the hot-spot vector of the North American plate . . ." The "other interpretations" are not properly referenced.

Basis: What are the other interpretations?

Recommendation: Give alternate interpretations and bases of these.

COMMENT 3.46

Statement of Concern: Section VI-F, Teleseismic Studies, pages 134-136 — Entire section

Basis: The entire section seems to center predominantly on substantiating the work discussed on one publication, Evans and Smith (1992). Are there no other relevant studies?

Recommendation: Find and discuss other studies, perhaps of a large scale like Hearn et al. (1991). Or if there are not other relevant studies, so state.

Reference:

Hearn, T., N. Beghoul, and M. Barazangi. 1991. Tomography of the western United States from regional arrival times. *Journal of Geophysical Research* 96: 16,369-16,381.

COMMENT 3.47

Statement of Concern: page 137, third paragraph, lines 4-7 — The statement is made that there is "no consistent and predictable relationship between volcanic activity and structural features," although "the features provide pathways for ascent of magma from depth." The statements appear somewhat contradictory, since a consistent relationship of near-surface control of basaltic volcanism is reported by both Crowe and Perry (1989) and Smith et al. (1990).

Basis: Crowe and Perry (1989) consider that magma rises along deep-seated, NW-trending, SS faults with location of dikes and vents controlled by both NE and NW-trending fractures. Smith et al. (1990) consider that magma rises along NE-trending structures with dike and vent locations controlled by NE and NW-trending fractures. Therefore, both groups of researchers recognize upper level control by NE-trending fractures. Faults as magma pathways would seem to constitute a consistent, if not predictable, relationship between volcanism and tectonic features. The fact that a single model or interpretation does not exist does not mean no consistencies are identified.

Recommendation: Consider rewording this sentence to capture the concept of where the consistencies do occur, in spite of the alternative models which exist for structural control of volcanism in the Yucca Mountain area.

References:

Crowe, B.M., and F.V. Perry. 1989. *Volcanic probability calculations for the Yucca Mountain site: Estimation of volcanic rates. Proceedings for Focus '89, Nuclear Waste Isolation in the Unsaturated Zone.* American Nuclear Society: 326-334.

Smith, E.I., D.L. Feuerbach, T.R. Naumann, and J.E. Faulds. 1990. *The area of most recent volcanism near Yucca Mountain, Nevada: Implications for volcanic risk assessment. Proceedings for International Topical Meeting, High-level Radioactive Waste Management.* American Nuclear Society. 1: 81-90.

COMMENT 3.48

Statement of Concern: page 138, first paragraph, last sentence — The statement is made that controls of occurrence of basalt are probably provided by structures which promote ascent of magma. This statement may be considered to leave out a part of the story, which is included in other parts of this report.

Basis: Magma may ascend from depth along one set of structures, and be localized at the surface by structures of a different orientation according to the model of Crowe and Perry (1989).

Recommendation: Consider rephrasing this sentence to capture concepts of magma ascent, orientation of developing dikes, and localization of surface vents. A suggestion for this wording is as follows: "We suggest . . . controls on the ascent of basaltic magma, orientation of feeder dikes, and localization of surface vents . . . are probably provided by . . . both deep-seated structures which promote ascent of magma and shallower structures which affect orientation of feeder dikes and location of vents at the surface." Alternative models could be presented, considering specific orientations of structures at Yucca Mountain which may control volcanism at the surface as interpreted by Crowe and Perry (1989) and Smith and others (1990).

References:

Crowe, B.M., and F.V. Perry. 1989. *Volcanic probability calculations for the Yucca Mountain site: Estimation of volcanic rates. Proceedings for Focus '89, Nuclear Waste Isolation in the Unsaturated Zone.* American Nuclear Society: 326-334.

Smith, E.I., D.L. Feuerbach, T.R. Naumann, and J.E. Faulds. 1990. *The area of most recent volcanism near Yucca Mountain, Nevada: Implications for volcanic risk assessment. Proceedings for International Topical Meeting, High-level Radioactive Waste Management.* American Nuclear Society. 1: 81-90.

COMMENT 3.49

Statement of Concern: page 138, second paragraph, lines 2-7 — The statement is made that Quaternary basalt sites "do not appear to be controlled by or follow prevailing surface structural features," although structures that penetrate deepest into the crust (i.e., NW and NE-trending structures) show correlations with sites of Quaternary basaltic centers.

Basis: The statements appear to be in conflict, presenting two different concepts about structural control on volcanism in nearly the same breath. Even though specific faults may not have been mapped, it does appear that orientations of prevailing regional structures are reflected in locations and alignments of cones in the volcanic field.

Recommendation: Consider rewording the referenced sentences to capture the concept that prevailing regional trends are reflected in locations and alignment of cones, even though surface faults have not been mapped. The wording modification should also remove the seemingly contradictory statements regarding structural control on volcanism.

COMMENT 3.50

Statement of Concern: page 138, second paragraph, line 1 and lines 9-17 — Line 1 indicates two generalizations are stated, but there are four included in this paragraph. The third, addressed in lines 9-17, causes some confusion because it is stated that "no direct relationship exists between structures and basaltic sites" even though structural features and basalt sites are associated. The statement is made that "structures may be preferential sites for ascent of basaltic magma," although there is no causative relationship between volcanism and structure. Furthermore, "structures may be required to promote ascent of basaltic magma."

Basis: It appears there is confusion between the concept of "no direct relationship between structure and basaltic volcanism" and "causative relationships" between structure and volcanism. The argument appears to be that faults are only conduits for magma ascent, and this process does not constitute a causative relationship between faulting and volcanic events. If structures provide deep-seated pathways for magma ascent, enhance localization of dikes in the shallow subsurface, and control location of vents at the surface (all points raised in the report), then the relationship would appear to be direct even if it is not totally understood or is not causative. Have structures ever been known to be the cause of volcanism, other than as controls on magma pathways, dike orientations, and vent locations? That is, has faulting at the scale we observe at Yucca Mountain ever been required to "cause" volcanism, or are more regional tectonovolcanic considerations the factors which cause volcanism?

Recommendation: Consider rewording the referenced sentences to clarify the concepts presented, clearly stating the differences between control on magma pathways, dike orientations, and vent locations (still a direct relationship) and causative factors of volcanism.

Clearly magma did ascend through the crust in the Quaternary, so perhaps there should be some discussion related to the point that not enough is understood about the regional tectonic framework, local geological structure, or subsurface magmatic processes (if this is the underlying point of the referenced sentences) to fully explain how/why magma rose and was controlled by NE- and NW-trending structures near the surface — even if the tectonic setting is not expected to change in the next 10,000 years. It is obvious that relationships between tectonics and magmatism are not understood in this region, and in particular the influence of faults on localization of volcanic vents is not concisely established for the Yucca Mountain area.

COMMENT 3.51

Statement of Concern: page 139, second paragraph under Subsection "A" — Detachment fault systems are judged to be unimportant for structural control of basaltic volcanism in the Yucca Mountain area.

Basis: The question may arise as to whether regional detachment faults in the Yucca Mountain area could provide a link between shallow normal faults (either NE-trending, listric normal faults such as those interpreted to exist at Yucca Mountain by Scott (1990) based on field data, or shallow planar normal faults which may control orientation of dikes and location of surface vents) and deep-seated, steeply-dipping, planar (normal) faults or SS faults which provide pathways for ascent of magma from depth. Intersection of the detachment surface with the deep-seated faults could potentially provide the link between structures controlling deep magma pathways and shallower structures controlling the orientations of dikes and locations of surface vents. Scott (1990) believes the detachment system is intersected by a steep normal fault on the east side of Bare Mountain (i.e., the Bare Mountain fault), and Reheis (1986) cites field evidence of Quaternary movement on the Bare Mountain Fault.

In addition, other alternative models may be proposed which potentially involve detachment faulting influencing magmatism. In a model which considers slip on an extant detachment system to indicate localized accumulation of extensional strain (leading to development of a pull-apart basin), magmatism may also be localized. Therefore, pull-apart systems involving low-angle faults may influence volcanism, perhaps without requiring specific fault conduits.

Recommendation: Consider adding some discussion of the possibility that a detachment fault surface could provide a link between the deep structures providing magmatic pathways and the shallower structures which may influence the orientation of dikes and control the locations of surface vents. Also consider alternative models wherein pull-apart basins and associated detachment faults may localize magmatism without the requirement for specific fault conduits.

References:

Reheis, M.C. 1986. Preliminary study of Quaternary faulting on the east side of Bare Mountain, Nye County, Nevada. *USGS Open-File Report*. 86-576: 13.

Scott, R.B. 1990. Tectonic setting of Yucca Mountain, southwest Nevada. Wernicke, B.P., Ed; Basin and Range extensional tectonics near the latitude of Las Vegas, Nevada: *GSA Memoir*. 176: 251-282.

COMMENT 3.52

Statement of Concern: page 140, paragraph under Subsection "D" — Pull-apart basins, associated with areas of strike-slip faulting or en echelon arrays of strike-slip faults, are recognized as exercising possible structural control on basaltic volcanism.

Basis: The possible association of pull-apart basins with detachment faulting in areas of strike-slip faulting is not discussed by the writers, although evolution of pull-apart basins may involve detachment faulting. Consider that pull-aparts are loci of large strains and probably high strain rates. High-angle normal faults cannot accommodate large horizontal strains (e.g., Christi-Blick and Biddle, 1985). Therefore, pull-aparts must involve low-angle fault systems (detachments).

Recommendation: Pull-apart and detachment models can be considered together. Consider not restricting models of faulting and volcanism strictly to concepts which require specific fault conduits for passage of magma. That is, consider areas of high strain rates and large strains for magma conduits as well.

Reference:

Christi-Blick, N. and K. Biddle. 1985. Deformation and basin formation along strike-slip faults. K. Biddle and M. Christi-Blick, eds. Strike Slip Deformation, Basin Formation, and Sedimentation. Society of Economics Paleontologists and Mineralogists Special Publication No. 37: 1-34. Tulsa.

COMMENT 3.53

Statement of Concern: Section VII, TECTONIC MODELS OF BASALTIC VOLCANISM IN THE YUCCA MOUNTAIN REGION, pages 136-140 — Entire section. Throughout the entire section many blanket statements are made that call for substantiation with a reference or references.

Basis: For example, the last paragraph on page 137 stating the quantitative volumes of erupted basaltic magma, the first paragraph on page 138 stating "There is widespread evidence . . .," first paragraph on page 139 stating "A wealth of geologic information . . .," and the third paragraph on page 139 stating "Debate continues . . . ."

Recommendation: More thorough attention to references is needed in this section.

COMMENT 3.54

Statement of Concern: page 141, paragraph under Subsection "F" — A statement is made regarding the intent to incorporate structural control by NNE-trending structures into tectonic models for assessment of volcanic risk at Yucca Mountain.

Basis: NE-trending normal faults in the vicinity of Yucca Mountain may have developed as steeply-dipping planar structures or as listric faults above a detachment fault. Smith and others (1989) interpret these faults as planar, while Scott (1990) cites field evidence that the structures are listric normal faults. Cross-section balancing efforts (Young and others, 1993) suggest that a listric origin associated with detachment faulting is feasible for structures of this orientation at Yucca Mountain. Deep-seated planar faults do occur in the area, however, including the Bare Mountain fault based on interpretations of field evidence (Reheis, 1986; Scott, 1990). Considering that detachment faulting may link deep structures with shallow structures in the vicinity of Yucca Mountain (See Comment 3.51), it may be useful to consider a tectonic model of the NNE-trending structures which treats them as part of a detachment fault system for assessment of volcanic risk.

Recommendation: Consider whether modeling should include treatment of the NNE-trending normal faults as both planar and listric for assessment of volcanic risk.

References:

Reheis, M.C. 1986. Preliminary study of Quaternary faulting on the east side of Bare Mountain, Nye County, Nevada. USGS Open-File Report 86-576: 13.

Scott, R.B. 1990. Tectonic setting of Yucca Mountain, southwest Nevada. Wernicke, B.P., Ed; *Basin and Range extensional tectonics near the latitude of Las Vegas, Nevada.* Geologic Society of American Memoir 176: 251-282.

Smith, E.I., D.L. Feuerbach, T.R. Naumann, and J.E. Faulds. 1990. *The area of most recent volcanism near Yucca Mountain, Nevada: Implications for volcanic risk assessment. Proceedings for International Topical Meeting, High-level Radioactive Waste Management.* American Nuclear Society. 1: 81-90.

Young, S.R., A.P. Morris, and G.L. Stirewalt. 1993. *Geometric analyses of alternative models of faulting at Yucca Mountain, Nevad. Proceedings of the Fourth Annual International High-Level Radioactive Waste Management Conference.* American Nuclear Society.

COMMENT 3.55

Statement of Concern: page 316, paragraph under Subsection "D," lines 7-8 — The statement is made that efforts will continue in development of structural models. Additional detail is required on future model development.

Basis: It is not clear whether this statement refers to development of new models or refinement of existing models as new data become available - or both.

Recommendation: Consider providing more detail on continuation of development of structural models.

COMMENT 3.56

Statement of Concern: page 115, third paragraph: ". . . in contrast, YPB occur west and southwest of Yucca Mountain." The phrasing is confusing and perhaps inaccurate.

Basis: This statement is misleading because Sleeping Butte centers are located NNW of Yucca Mtn. and AV site is located nearly due south.

Recommendation: Reword.

COMMENT 3.57

Statement of Concern: page 115; third paragraph: The reference to Figure 3.13 may be in error.

Basis: Figure 3.13 has nothing to do with the boundaries between basalt cycles, but is referenced in the text in this regard.

Recommendation: Correct figure or text.

COMMENT 3.58

Statement of Concern: page 115, paragraph 3: discussion of the south-stepping nature of volcanism. The spatial scale of the trend is not clear.

Basis: When discussing the south-stepping nature of basaltic volcanism in the YMR it is important to emphasize that this is a very regional trend. In detail, of course, there are many exceptions to the south-stepping rule - both within the YPB and the OPB.

Recommendation: Discuss the details.

COMMENT 3.59

Statement of Concern: page 118, Figure 3.12: This figure is quite confusing.

Basis: It would help to reorient the figure so that north is up on the page. Also, not every vent is mapped in the same place on this figure compared with Figure 3.11. For example, one of the AV centers appears to be mapped too far north and east. This inconsistency should be discussed because it could effect centroid location. Also, it is really best to use UTM coordinates in this kind of analysis because UTM coordinates are equal area and Lat./Long. are not. Overall, a table showing vent locations in UTM and Lat./Long and other relevant information would be extremely helpful.

Recommendation: Plot maps to scale and in a consistent manner.

COMMENT 3.60

Statement of Concern: page 119, Paragraph 1: What is the significance of vent centroid calculations?

Basis: The centroid method is an ineffective way of describing vent distribution, other than to say there is a general shift from NE to SW in the area. Papers in which the centroid calculations have been used (e.g., Tanaka et al., 1986; Condit et al., 1989) simply use the calculation to show very broad trends probably related to plate movements. Relating the centroid shape to rotation is much more difficult to support. The envelope simply means that the true centroid is located somewhere in the ellipse with 90 percent confidence. Most workers in the area believe that rotation took place prior to 4 my ago. Did 30° of rotation take place in the 2 million years between the eruption of the Nye Canyon and Thirsty Mesa basalts? In detail, there seem to be problems with the interpretation of centroid locations.

Recommendation: Discuss other evidence for rotation in detail or delete.

References:

Condit, C.D., L.S. Crumpler, J.C. Aubele, and W.E. Elston. 1989. Patterns of volcanism along the southern margin of the Colorado Plateau: The Springerville field. *Journal of Geophysical Research* 94: 7,975-7,986.

Tanaka, K.L., E.M. Shoemaker, G.E. Ulrich, and E.W. Wolfe. 1986. Migration of volcanism in the San Francisco volcanic field, Arizona. *Geological Society of America*, Bulletin 97: 129-141.

COMMENT 3.61

Statement of Concern: page 120; paragraph 2 and 3 (and page 123) The least squares regression is not an appropriate way to look for trends in this data set.

Basis: Tim Lutz in his 1986 paper on point pattern analysis in geology (Lutz, 1986) discusses the adverse effects of clustering on alignment analysis, specifically stating that alignments occur spuriously when data are strongly clustered. This problem has been discussed at length by Wadge and Cross (1988) in their article on the Michoacan volcanic field and elsewhere in the cinder cone literature. In this case, the position of the fit line is controlled by two - three groups of points (vents), Crater Flat vents, the Sleeping Buttes vents and Lathrop Wells (if it is considered to be distinct from the Crater Flat group). The distance between Sleeping Buttes and the rest of these volcanoes is about 40 km. This large gap heavily weights the orientation of the fit line. In statistics, this is sometimes known as the "King Kong effect," because outliers (like very large gorillas) adversely effect statistical analyses by creating spurious trends (e.g., Makridakis et al., 1983). Plotting Latitude and Longitude at the same scale in these figures would better illustrate this phenomenon. Really, a trend to two - three clusters occurs in the Crater Flat Valley. Little significance should be given to this trend unless other evidence (geophysical/ structural) can be found to support its significance.

Recommendation: Apply techniques that are commonly used to search for vent patterns to the Yucca Mountain region volcanoes (Lutz, 1986; Wadge and Cross, 1989; Connor, 1990; Connor et al., 1992).

References:

Connor, C.B. 1990. Cinder cone clustering in the TransMexican volcanic belt: structural and petrologic implication. *Journal of Geophysical Research* 95: 19,395-19,405.

Connor, C.B., C.D. Condit, L.S. Crumpler, and J.C. Aubele. 1992. Evidence of regional structural controls on vent distribution: Springerville volcanic field, Arizona. *Journal of Geophysical Research*. 97: 12,349-12,359.

Makridakis, S., S.C. Wheelwright, and V. E. McGee. 1983. *Forecasting Methods and Applications*, Second Edition. John Wiley and Sons: New York: 921.

Lutz, T.M. 1986. An analysis of the orientations of large scale crustal structures: a statistical approach based on the areal distribution of point-like features. *Journal of Geophysical Research* 91: 421-434.

Wadge, G., and A. Cross. 1988. Quantitative methods for detecting aligned points: an application to volcanic vents in the Michoacán-Guanajuato volcanic field, Mexico. *Geology*. 16: 848-851.

COMMENT 3.62

Statement of Concern: pages 123-125: Identification of trends in vent volumes should include all mappable centers.

Basis: Two - three groups of vents occur and one or two larger volume cones are found within each of these groups. There is little evidence of a statistically significant trend in these data, especially if the voluminous Buckboard Mesa is included in the analysis. Buckboard Mesa should be included in the analysis since it is a Plio-Quaternary vent, Buckboard Mesa is closer to Sleeping Buttes than the Crater Flat volcanoes are, and Buckboard is closer to the repository site than Sleeping Buttes.

Recommendation: Incorporate Buckboard Mesa into any analysis.

COMMENT 3.63

Statement of Concern: page 123 last paragraph to page 127, first paragraph: Additional information is required about additional structural trends.

Basis: The introduction of several additional structural directions here (N-S alignment of 3.7 m.y. old basalts and the NW trend of structures at Buckboard Mesa need to be supported by data. This is especially true for Buckboard Mesa because other workers have discussed NE trends in this region (Smith et al., 1990).

Recommendations: Provide maps of these areas.

References:

Smith, E.I., D.L. Feuerbach, T.R. Naumann, and J.E. Faulds. 1990. *The area of most recent volcanism near Yucca Mountain, Nevada: implications for volcano risk assessment. High-Level Radioactive Waste Management Proceedings of the International Topical Meeting, La Grange, Illinois.* American Nuclear Society 1: 81-90.

COMMENT 3.64

Statement of Concern: page 127; second paragraph: Are the trends in scoria mounds mappable?

Basis: Structural alignments in scoria mounds at Lathrop Wells (and probably elsewhere) should be discussed with reference to a map of these features.

Recommendation: Include a map of these features.

2.4 REVIEW OF SECTION 4: GEOLOGIC SETTING OF BASALTIC VOLCANISM

COMMENT 4.1

Statement of Concern: Volumetric relationships presented in Figure 4.2 compare vastly different volcanic systems in the western North America and do not accurately reflect the apparent similarities between the Crater Flat system and other Western Great Basin mafic volcanic systems.

Basis: The source of the data presented in Figure 4.2 is not referenced in the text (p. 160) or in the figure caption. The volumes of the 4.5 Ma Thirsty Mesa, 4.4 Ma Amargosa Valley and presumedly the 2.8 Ma Buckboard Mesa eruptions apparently are not included in this figure. Magma systems along the Colorado Plateau transition area certainly have higher eruption rates than Western Great Basin (WGB) systems, but it is not clear how analogous these two areas are. They have very different tectonic environments and histories, along with distinct petrogenetic trends (e.g., Fitton et al., 1991). Crater Flat is a small volume system, yet there are numerous other late Cenozoic, small-volume Basin and Range-WGB systems such as the Death Valley, Mono Lake, Seven Troughs, Winnemucca, Battle Mountain, Table Mountain, Monarch Divide, Candellaria, Kern, Greenwater, Fallon, Tahoe, and Saline Range, (Smith and Luedke, 1984) that are not on this figure. Although volumetric data are not readily available for most of these areas, that does not mean that these areas should be excluded from discussions in this report. The Crater Flat system certainly is small relative to Colorado Plateau transition systems, yet it many not be anomalously small relative to other WGB systems.

Recommendation: Hypotheses regarding volumetric relationships in the Crater Flat system need to explore potential relationships with poorly studied yet highly analogous WGB mafic volcanic systems.

Reference:

Smith, R.L., Luedke, R.G. 1984. Potentially active volcanic lineaments and loci in the western conterminous United States. *Reviews in Geophysics*: Washington, DC. National Academy Press: 47-66.

COMMENT 4.2

Statement of Concern: Regional petrogenetic models incorrectly combine Western Great Basin (WGB) systems with central Basin and Range (BR) systems. BR regional interpretations are misapplied to WGB systems.

Basis: Fitton et al. (1991) is extensively referenced to support the hypothesis that Basin & Range basaltic magmas shift to more Si-undersaturated compositions at about 5 Ma. However, Fitton et al. (1991) make a clear distinction between the Basin & Range (BR) and the WGB provinces. The WGB has been recognized as a distinct tectonic and magmatic sub-province of the Basin & Range in many studies (e.g., Leeman, 1970; Smith and Luedke, 1984; Farmer et al., 1989; Kempton et al., 1991). The WGB includes the Yucca Mountain area volcanoes, along with Coso, Death Valley, Mono Lake, Big Pine and Fallon volcanic fields (Fitton et al., 1991). Rocks in the WGB do not show a distinct shift to more undersaturated compositions at about 5 Ma (Fitton et al., 1991). Grouping the WGB and BR provinces together as the "Great Basin" in this report obscures many important spatial, temporal, and compositional distinctions and trends between these two provinces.

Recommendation: Regional petrogenetic models should incorporate the widely recognized distinction between BR and WGB volcanic systems.

References:

Leeman, W.P. 1970. The isotopic composition of strontium in late-Cenozoic basalts from the Basin-Range province, western United States. *Geochimica et Cosmochimica Acta* 34:857-872.

Smith, R.L., Luedke, R.G. 1984. Potentially active volcanic lineaments and loci in the western conterminous United States. *Reviews in Geophysics*: Washington, DC. National Academy Press: 47-66.

COMMENT 4.3

Statement of Concern: Models of temporal and spatial variations in parental basalt composition focus on changes in depth of the source, and fail to consider widely recognized compositional changes in the mantle. These models are used to erroneously conclude that the Crater Flat system is waning. Regional geochemical trends indicate that the WGB system may continue activity for several million years.

Basis: The conclusion that observed temporal trends in the Great Basin from tholeiitic to alkalic magmatism are produced exclusively by progressively lower degrees of mantle melting at "greater depths" is misleading, and ignores important differences in mantle composition that occur with this trend. The hypothesis that alkalic basalt can be derived through smaller degrees of mantle melting than occurs during the formation of tholeiitic magma has well-developed empirical (e.g., Gast, 1968) and experimental (e.g., Jakes and White, 1980) evidence. However, this argument is generally applied to systems such as Hawaii, where the mantle is of relatively uniform composition and has not been modified by metasomatic processes (e.g., Frey et al., 1978).

Isotopic and trace element studies (e.g., Perry et al., 1987; Farmer et al., 1989; Fitton et al., 1991; Kempton et al., 1991) have shown that asthenospherically derived melts in the Basin and Range have had variable amounts of interaction with metasomatized lithospheric mantle. The observed transition to more undersaturated compositions in the Basin and Range at about 5 Ma occurs with large geochemical and isotopic changes that clearly show different parental mantle compositions (i.e., less lithospheric character for <5 Ma basalts). Such changes are inconsistent with deriving these magmas from the same mantle source by simply varying the amount or depth of partial melting. Similar transitions from lithospheric to non-lithospheric character are less clearly developed for volcanic systems around the Colorado Plateau, such as the Springerville volcanic field (Fitton et al., 1991). Although Condit et al. (1989) hypothesize that smaller amounts of partial melting occurred during the late, alkalic stage of Springerville magmatism, they clearly state that this transition is accompanied by a shift from a lithospheric to an asthenospheric source for the magmas. Isotopic studies by Cooper and Hart (1990) also show a complex transition between lithospheric and asthenospheric mantle signatures in the Springerville system. Thus, even when a transition to more undersaturated compositions is observed, the mantle source changes from metasomatized lithosphere to OIB-type asthenosphere. These compositional changes in the mantle source need to be explicitly addressed in this report, instead of referring to a vague change in depth for the source.

In contrast to the main Basin and Range system, these temporal shifts to more undersaturated compositions at about 5 Ma are not observed in the Western Great Basin. Volcanic fields such as Crater Flat, Coso, Big Pine, Death Valley and Mono Lake clearly show a lithospheric source for both pre- and post-5 Ma rocks (Fitton et al., 1991; Farmer et al., 1989). This report combines the WGB with the main BR system, and thus makes erroneous conclusions regarding compositional shifts with time. This is important because the contention that alkaline magmatism in the WGB field indicates a waning system is not consistent with observed temporal trends throughout the central Basin & Range and Colorado Plateau margin systems. The WGB systems have yet to evolve from a lithospheric to an asthenospheric phase of activity. Cima and the Lunar Crater volcanic fields are non-WGB magma systems that show a transition from "lithospheric" Pliocene alkaline basalt to compositionally distinct "asthenospheric" Quaternary alkaline basalt (Crowe et al., 1986; Wilshire et al., 1991; Foland and Bergman, 1992; this report). This relationship shows that activity can continue for millions of years after inception of asthenospherically derived magmatism. The Crater Flat system has yet to reach an "asthenospheric stage" of magmatism (Vaniman et al., 1982; Farmer et al., 1989), and thus cannot be considered a waning magma system on the basis of regional petrogenetic trends.

Modification of WGB and other allied Basin and Range systems by crustal contamination is another possible hypothesis to explain regional petrogenetic trends. Glazner et al. (1991) presented data for the Amboy-Pisgah volcanic centers that contamination by mafic crust could produce some of the geochemical variability in the magma system. The hypothesis that crustal contamination could control some of the geochemical variation observed in the Crater Flat system has not been examined in detail by previous studies.

Recommendation: Changes in source composition need to be incorporated into regional petrogenetic models. Regional interpretations of "waning" magmatism need to be supported by comparison to analogous systems in the WGB, not to systems in the BR or BR-transition zone. Numerous alternative hypotheses besides waning magmatism are viable for WGB systems, and remain to be tested.

References:

Frey, F.A., D.H. Green, and S.D. Roy. 1978. Integrated models of basalt petrogenesis: a study of quartz tholeiites to olivine melilitites from southeastern Australia utilizing geochemical and experimental petrological data. *Journal of Petrology* 19: 463-513.

Gast, P.W. 1968. Trace element fractionation and the origin of tholeiitic and alkaline magma types. *Geochimica et Cosmochimica Acta* 32: 1057-1085.

Glazner, A.F., G.L. Farmer, W.T. Hughes, J.L. Wooden, and W. Pickthorn. 1991. Contamination of basaltic magma by mafic crust at Amboy and Pisgah Craters, Mojave Desert, California. *Journal of Geophysical Research* 96-B8: 13,673-13,691.

COMMENT 4.4

Statement of Concern: The argument that the Crater Flat magma system changed fractionation depth with time is not supported by the available data. The conclusion that petrogenetic trends indicate a waning magma system is not supported by the available data.

Basis: Several major problems exist for the petrogenetic models of the Crater Flat magma system used in this report to conclude that this system is waning.

1) Amphibole fractionation is critical to evolving most of the compositional differences observed in the Crater Flat system (Vaniman et al., 1982; this report, p. 165, paragraph 3) and amphibole phenocrysts have been observed in several Crater Flat and Sleeping Butte units (Vaniman and Crowe, 1981; Crowe et al., 1983), yet there is no mention of amphibole fractionation in Perry and Crowe (1992) and this report (p. 165, paragraph 4).

2) The experimental data of Mahood and Baker (1986) does not adequately represent the Crater Flat system. The experiments were essentially anhydrous (<0.07 wt percent H_2O), were only run at pressures of 1 atm. and 8 kbars., and used alkaline basalt compositions that are significantly less evolved than the Crater Flat alkaline basalts. Experimental phase relationships are strongly dependent on the composition of the starting material, pressure, and water content of the system (e.g., Holloway and Wood, 1988). Mahood and Baker (1986) also cite work by Yoder and Tilley (1962) and Eggler (1972) that demonstrates water contents >0.07 wt percent may have suppressed plagioclase crystallization, an effect that is not discussed by Perry and Crowe (1992) or this report.

3) The experiments of Knutson and Green (1975) used a starting composition that is very similar to Crater Flat alkaline basalts, were conducted between 5-10 kbars pressure (i.e., crustal depths) and ranged from anhydrous to 5 wt percent H_2O. Their experimental phase relationships show that plagioclase is a liquidus ($P < 7.5$ kbar) to near-liquidus ($P = 10$ kbar) phase in anhydrous systems. If the Crater Flat basalts were anhydrous, changes in pressure would have little effect on plagioclase stability (cf., Perry and Crowe, 1992). However, the presence of amphibole phenocrysts in some Crater Flat units (Vaniman and Crowe, 1981) and the necessity of extensive amphibole fractionation to produced observed geochemical trends (Vaniman et al., 1982) clearly shows that these magmas were not anhydrous. Amphibole was not a stable phenocryst in any of the Knutson and Green (1975) experiments with ≤ 2 wt percent H_2O, which ranged from 5-15 kbars and 1200°C and 1050°C. However, amphibole was present in all experiments with 5 wt percent H_2O, demonstrating that >2 wt percent H_2O is necessary for amphibole stability or fractionation. The addition of several percent H_2O to any mafic system will clearly affect the stability of plagioclase, generally suppressing plagioclase crystallization and resulting in more anorthitic plagioclase (e.g., Yoder and Tilley, 1962; Eggler 1972; Sekine et al., 1979; Grove and Baker, 1984).

An increase in the magmatic water content of the Crater Flat system since 3.7 Ma would produce the same effects that Perry and Crowe (1992) attribute to an increase in pressure. In addition, an increase in water content would stabilize amphibole, which is required to produce the observed geochemical trends (Vaniman and Crowe, 1981; Vaniman et al., 1982) and account for phenocrysts of amphibole in Buckboard Mesa, Little Cones, Red Cone, and Sleeping Butte cones (Vaniman and Crowe, 1981; Crowe et al., 1983). The conclusion in this paper and in Perry and Crowe (1992) that the Crater Flat system is changing depth with time is not supported by the available data, and does not support the argument that the magma system is waning. The presence of plagioclase phenocrysts in unit Ql_6 (this report, p. 168, par. 4) further undermines this hypothesis. Instead, the petrological and volcanological data support the hypothesis that water contents in this system are increasing with time, resulting in more explosive eruption with greater cone-to-flow ratios, less aerodynamically deformed ejecta, more frequent yet smaller-volume eruptions, a greater role of amphibole fractionation in the magma petrogenesis (i.e., Vaniman et al., 1982), and suppression of abundant plagioclase crystallization. Clearly, this testable hypothesis has serious implications for probability and consequence modeling, and is diametrically opposed to the conclusions in this paper and in Perry and Crowe (1992).

Recommendation: Petrogenetic models need to address the extensive and intensive variables that control the occurrence of amphibole. These models also need to consider how variations in water content, composition, and temperature could produce effects similar to those attributed exclusively to pressure by the authors.

References:

Eggler, D.H. 1972. Water-saturated and undersaturated melting relations in a Parícutin andesite and an estimate of water content in the natural magma. *Contributions to Mineralogy and Petrology* 34: 261-271.

Grove, T.L., and M.B. Baker. 1984. Phase equilibrium controls on the tholeiitic versus calc-alkaline differentiation trends. *Journal of Geophysical Research* 89(B5): 3,253-3,274.

Holloway, J.R., and B.J. Wood. 1988. *Simulating the earth: experimental geochemistry*. Winchester, MA: Unwin Hyman Inc.

Sekine, T., T. Katsura, and S. Aramaki. 1979. Water saturated phase relationships of some andesites with application to the estimation of the initial temperature and water pressure at the time of eruption. *Geochimica et Cosmochimica Acta* 43: 1,367-1,376.

Yoder, H.S., Jr., and C.E. Tilley. 1962. Origin of basaltic magmas: an experimental study of natural and synthetic rock systems. *Journal of Petrology* 3: 342-532.

COMMENT 4.5

Statement of Concern: The mineralogy of the Quaternary basaltic rocks in the Crater Flat area has not been examined sufficiently to permit the development of robust petrogenetic models.

Basis: The newly reported occurrence of plagioclase phenocrysts in Lathrop Wells unit Ql_6 and possibly Ql_4 convincingly demonstrates that the mineralogy of Crater Flat units has not been adequately investigated by previous studies. Plagioclase phenocrysts also are reported in Lathrop Wells units by Zreda et al. (1993). As stated in Comment 2.7, the presence or absence of amphibole and pyroxene phenocrysts has not been determined sufficiently for these units. Petrogenetic models for this system clearly cannot be evaluated or even adequately constrained until the mineralogy of these units is fully investigated through additional detailed (i.e., statistically significant) thin-section, mineral separation, and geochemical characterization studies.

Recommendation: Detailed thin-section, mineral separation, and geochemical characterization studies are required to support petrogenetic models and hypotheses.

COMMENT 4.6

Statement of Concern: Geochemical studies at Lathrop Wells are preliminary and have yet to consider intra-unit variations. Geochemical distinctions are not robust for some of the analyzed units. Some data apparently are missing from the figures in this report and Perry and Crowe (1992).

Basis: Over 100 geochemical samples have been collected by the authors at Lathrop Wells (p. 166), yet Figures 4.4 and 4.5 show only about 25 data points. Are the remaining 75 samples contained in the stippled fields, or yet to be analyzed? Using the analyses of "LW" samples provided in the Los Alamos Project Volcanism Print-Out Binder TWS-EES-13-LV-10-89-04 (Perry and Crowe, 1992), there appears to be data missing from Figures 4.4 and 4.5 of Crowe et al. (1993) and Perry Crowe, (1992); compare with Figure 4.1.

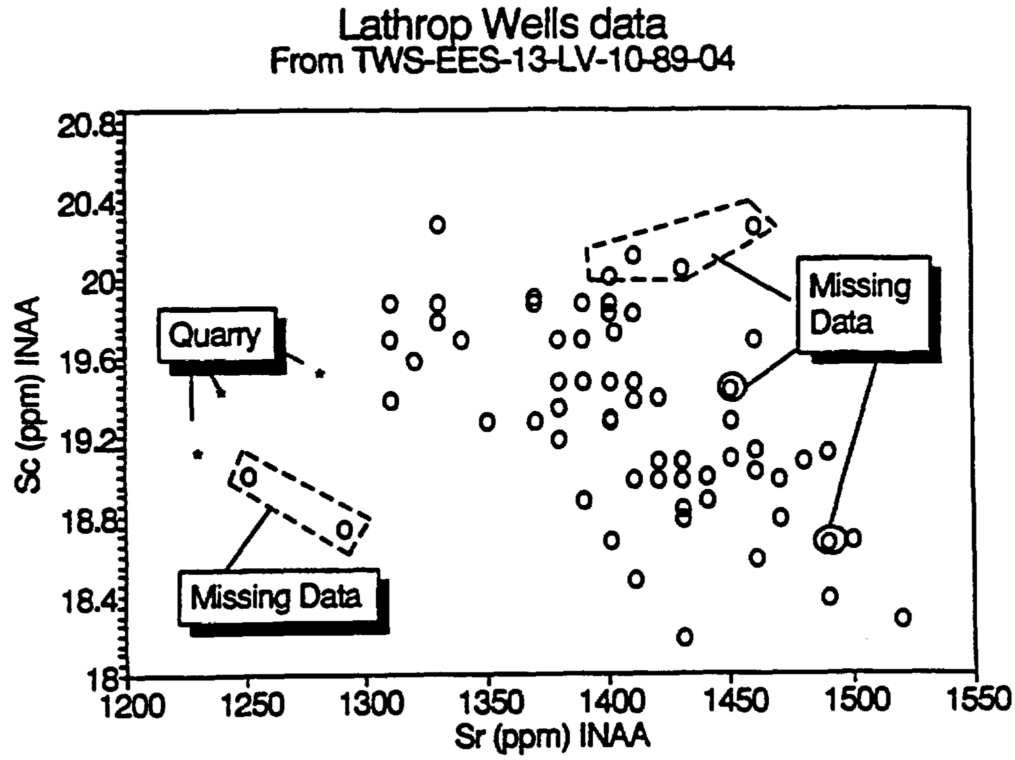
Perry and Crowe (1992) present preliminary data that shows some Lathrop Wells units may be compositionally distinct. Perry and Crowe (1992) and this report contend "that all the units cannot be derived from the same magma," and apparently test a closed-system fractionation hypothesis. With the exception of the Quarry unit, closed system fractionation is still a valid hypothesis for the trace element data presented. There is a small amount of variation within each unit, which is apparently related to small amounts analytical error. However, the scoria deposits for units Q_4 and Q_5 are at times compositionally distinct (i.e., beyond analytical error) from the associated lava flows. The magnitude of the presented interunit compositional distinctions is about the same as the magnitude of the presented intraunit compositional distinctions, with the exception of the Quarry unit. Within the range of analytical uncertainty reported in these figures, the removal of 3 percent plagioclase from these units would produce the observed compositional trends. Using the data presented, the Quarry unit may be the only Lathrop Wells unit that cannot be explained by a simple closed-system fractionation hypothesis.

However, in addition to the closed-system fractionation model of Perry and Crowe (1992), other hypotheses must be tested to constrain the origin of these petrogenetic distinctions before concluding that the distinctions represent spatially and temporally discrete magma "batches." Open system fractionation, which involves periodic recharge of a fractionating magma system that is open to mixing and small amounts of wall-rock contamination (e.g., O'Hara, 1977; DePaolo, 1981; Langmuir, 1989; Defant and Nielsen, 1990), can produce geochemical variations similar to those present at Lathrop Wells and could produce a complexly zoned but contiguous magma body. Open system modeling complements the geochemical modeling procedures proposed in Study Plan 8.3.1.8.5.1, activities 4 and 5. Eruptions in the Crater Flat system may have been produced by temporally and spatially discrete magma batches (i.e., Perry and Crowe, 1992), may have periodically tapped an open, long-lived, contiguous magma system, or could preserve the eruption of a single zoned magma body. Each of these hypotheses have different implications for the eruption dynamics of the Crater Flat system, and thus must be rigorously tested.

The variations in Figure 4.5 do not show that the quarry scoria is compositionally distinct from the main cone scoria, because two quarry scoria samples clearly plot within the main cone field. Rb is a highly mobile element under surficial conditions (e.g., Cousens et al., 1993), raising the possibility that the two anomalous samples may have undergone a small degree of surficial alteration.

The isotopic data in Figure 4.6 do not show that these units are all compositionally distinct. The variations in Nd are all within analytical error. The analytical error reported for Sr does not adequately reflect the uncertainty associated with the analysis, because the variation in Sr for the Ql_3 replicate analyses significantly exceeds the analytical error. If, however, these units are isotopically distinct as the authors propose, then how do small variations in the amount of mantle partial melting produce these isotopic distinctions?

Recommendation: No conclusions can be reached regarding the polygenetic origin of Lathrop Wells. One of several valid working hypotheses is that Lathrop Wells represents the polycyclic eruption of petrogenetically distinct batches of magma. However, it is equally valid to hypothesize that the Lathrop Wells eruptions tapped a single, long-lived, compositionally zoned magma system. Other valid petrogenetic hypotheses need to be tested besides closed-system fractionation. Models relating observed



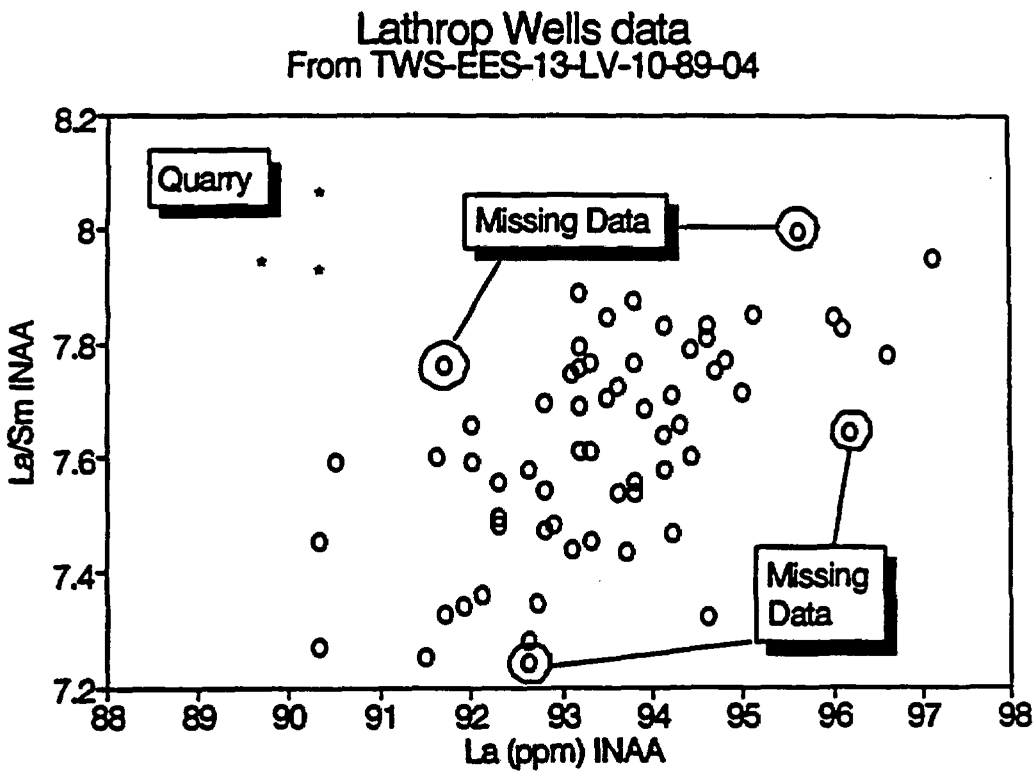


Figure 4-1. Some Lathrop Wells analyses in print-out binder TWS-EES-13-LV-10-89-04 apparently are missing from plots of these data in Crower et al. (1993) and Perry & Crowe (1992). No criteria are presented to distinguish missing data from plotted data.

geochemical variations to small variations in the amount of partial melting need to be quantified, and alternative models should be explored.

References:

Cousens, B.L., F.J. Spera, and P.F. Dobson. 1993. Post-eruptive alteration of silicic ignimbrites and lavas, Gran Canaria, Canary Islands: strontium, neodymium, lead, and oxygen isotopic evidence. *Geochimica et Cosmochimica Acta* 57: 631-660.

Defant, M.J., and R.L. Nielsen. 1990. Interpretation of open system petrogenetic processes: phase equilibria constraints on magma evolution. *Geochimica et Cosmochimica Acta* 54: 87-102.

DePaolo, D.J. 1981. Trace element and isotopic effects of combined wallrock assimilation and fractional crystallization. *Earth and Planetary Science Letters* 53: 189-202.

Langmuir, C.H. 1989. Geochemical consequences of in situ crystallization. *Nature* 340: 199-205.

O'Hara, M.J. 1977. Geochemical evolution during fractional crystallization of a periodically refilled magma chamber. *Nature* 266: 503-507.

COMMENT 4.7

Statement of Concern: Petrogenetic models apparently do not utilize accurate partition coefficients for minerals in alkaline basaltic systems.

Basis: Geochemical models involving fractional crystallization should use partition coefficients from more well-constrained sources than Philpotts (1990), which averages mineral/matrix partition coefficients from a variety of sources. Numerous well-constrained mineral/melt partition coefficients have been published in the last decade (e.g., Gallahan and Nielsen, 1991; Nielsen et al., 1992), which avoid equilibrium and inclusion contamination problems with mineral/matrix partition coefficients. Geochemical models do not report partition coefficients used and are thus extremely difficult to evaluate.

Recommendation: Geochemical models involving fractional crystallization should use partition coefficients from more well-constrained sources than Philpotts (1990). Partition coefficients used in geochemical models should be reported explicitly.

References:

Gallahan, W.E., and R.L. Nielsen. 1992. The partitioning of Sc, Y and the rare earth elements between high-Ca pyroxene and natural mafic to intermediate magmas. *Geochimica et Cosmochimica Acta* 56: 2,387-2,404.

Nielsen, R.L., W.E. Gallahan, and F. Newberger. 1992. Experimentally determined mineral-melt partition coefficients for Sc, Y, and REE in olivine, orthopyroxene, pigeonite, magnetite and ilmenite. *Contributions to Mineralogy and Petrology* 110: 488-499.

COMMENT 4.8

Statement of Concern: The authors do not to adequately consider the processes that result in fractional crystallization and the effects produced by the removal of minerals from a magma.

Basis: This report states that . . . "There is no mechanism recognized that can lead to changes in phenocryst assemblages without significantly changing the chemical composition of the magma (p. 168)." This is unsupported by the literature, even some very early works. Bowen (1928) succinctly summarized how changes in temperature will result in changes in the phenocryst assemblage of a system. If the phenocrysts remain in the system (i.e., are not removed), the bulk composition of the system remains the same. Changes in pressure will also result in changes in the phenocryst assemblage without changing bulk composition.

Plagioclase crystallization in unit Ql_6 could have resulted from a slightly lower temperature, slightly lower pressure, or slightly lower water content, relative to other Lathrop Wells units. Using the vectors in Figure 4.4, unit Ql_6 could well be parental to some other Lathrop Wells units through about 3 percent plagioclase fractionation, which would result in an increase in Sc from 18.4 to 19.0 ppm (D_{Sc}=0.01). The data presented in this report and Perry and Crowe (1992) are insufficiently precise to resolve whether or not small (1-5 percent ?) amounts of plagioclase were removed from post-Ql_6 units or accumulated in unit Ql_6.

Recommendation: Petrogenetic models should test the lower limits of detection for fractional crystallization and other geochemical effects. Models should also consider the effects of temperature, pressure, and water content on phenocryst assemblages.

Reference:

Bowen, N.L. 1928. *The Evolution of the Igneous Rocks*. Princeton, NJ: Princeton University Press.

COMMENT 4.9

Statement of Concern: The authors erroneously conclude that compositional distinctions cannot be preserved during the eruption of a zoned magma system.

Basis: The final paragraph states "It is unlikely that separate magma batches could form and ascend at or near the same time without mixing or homogenization of the magmas in some part of the magma plumbing system." The dynamics of magma withdrawal from compositionally zoned magma systems can be exceedingly complex, even for highly zoned, large, shallow magma chambers (e.g., Spera et al., 1986). Compositional distinctions that exceed those at Lathrop Wells by factors of 5-10 were preserved during the 10 year eruption of Parícutin (McBirney et al., 1987), and during the 1975 Tolbachik eruption magma composition at the Northern vent abruptly changed from Mg-rich alkaline basalt to Mg-poor subalkaline basalt (Fedotov et al., 1991). The Lathrop Wells eruptions could have come from a complexly zoned system, and would not necessarily have been homogenized as a direct result of the eruption process.

In addition, a petrogenetic mixing hypothesis has not been tested, and thus cannot be discounted. No data has been presented that directly addresses if the mineral assemblages present in these rocks are in equilibrium with the observed compositions. The rocks are sparsely phyric (<3 percent phenocrysts; Vaniman and Crowe, 1981). Mixing between compositionally distinct, sparsely phyric magmas may not result in obvious mineralogical or physical evidence of mixing, such as strongly zoned or resorbed phenocrysts, banded matrix textures, or nonequilibrium mineral assemblages. It is possible that eruptions of compositionally distinct magma at Lathrop Wells and Black Cone " . . . were separated by periods of at least several thousand years. (this report)." However, there are other viable hypotheses to these data, one of which is that the compositional distinctions could be preserved during a relatively continuous eruption from a zoned magma system.

Recommendation: Compositional heterogeneities have been be preserved at some historic basaltic eruptions. Conclusions requiring physically separate magma bodies to produce observed compositional distinctions at Lathrop Wells are not supported by the available data, and are at best one of several valid working hypotheses. Alternative hypotheses regarding the eruption of compositionally heterogeneous magma need to be considered.

References:

Fedotov, S.A., ed. 1991. *Active Volcanoes of Kamchatka.* Nauka Publishers, Moscow.

McBirney, A.R., H.P. Taylor, and R.L. Armstrong. 1987. Parícutin re-examined: A classic example of crustal assimilation in calc-alkaline magma. *Contributions to Mineralogy and Petrology* 95: 4-20.

Spera, F.J., D.A. Yuen, J.C. Greer, and G. Sewell. 1986. Dynamics of magma withdrawal from stratified magma chambers. *Geology* 14: 723-726.

2.5 REVIEW OF SECTION 5: SEGREGATION, TRANSPORT, AND LOCAL STORAGE OF BASALTIC MAGMA

COMMENT 5.1

Statement of Concern: page 185; paragraph 6: ". . . f_{ij} are a function of θ . . ." The meaning of this phrase is not clear. What is the physical meaning of this parameter?

Basis: Without further discussion it is difficult to evaluate the preceding equation.

Recommendation: Clarify the syntax and define f_{ij} explicitly.

COMMENT 5.2

Statement of Concern: page 186. paragraphs 2 and 3. What is the physical meaning of the geometric variables.

Basis: An illustration of the geometry of the fracture is important to interpret the physical meaning of the equations. For example, the meaning of the geometric variable *h* is never given in the text. What is the geometric relationship between h, l, and w(z)?

Recommendation: Define these variables explicitly, preferably with an illustration.

COMMENT 5.3

Statement of Concern: page 186, paragraph 3: What is the physical meaning of the variables $\Delta P_{o\text{-}f}$?

Basis: Lister and Kerr (1991) are careful to discuss the physical meaning of the ΔP parameters. It should be stated that ΔP_o is the effective overpressure, ΔP_i is the internal overpressure, ΔP_e is the elastic stress, ΔP_f is the internal pressure required for fracture propagation, ΔP_h is the hydrostatic pressure, and ΔP_v is the viscous pressure drop. Otherwise, it is impossible to evaluate the meaning of this and subsequent paragraphs. A schematic diagram illustrating the physical meaning of the parameters (c.f. Lister and Kerr, 1991) would be very helpful.

Recommendation: Define these variables explicitly and discuss the physical meaning of each.

References:

Lister, J.R., and R.C. Kerr. 1991. Fluid-mechanical models of crack propagation and their application to magma transport in dykes. *Journal of Geophysical Research* 96: 10049-10077.

COMMENT 5.4

Statement of Concern: page 186: Third equation. The parameter *m* is never defined.

Basis: The parameter *m* depends on the elastic properties of the country rock surrounding the dike.

Recommendation: It should at least be stated that *m* is related to the elastic properties of the country rock, etc.

COMMENT 5.5

Statement of Concern: page 186. Fourth equation. The variable $K(\pm h)$ is never defined.

Basis: The meaning of this equation is lost without definition of this variable.

Recommendation: Define this variable.

COMMENT 5.6

Statement of Concern: page 187, First equation. The unit *Mm*. What is a *Mm*?

Basis: This unit is not in common usage.

Recommendation: The ratio h^2/w should be restated in kilometers.

COMMENT 5.7

Statement of Concern: pg: 188, paragraph 2: The suggestion that the Crater Flat cones are related to a single, semi-continuous dike feeder system needs to be qualified by petrologic data.

Basis: The differences in petrology, geochemistry, etc., between Red Cone and Black Cone, and presumably Little Cone are discussed in Section II. Here, an attempt is made to relate these cones to a single batch of magma, which migrates laterally as a bladed dike for 6 km to the southwest and 6 km to the NE at some depth. With available data, this model is difficult to support, but may be testable.

Recommendation: Discuss the need to account for petrologic differences between the cones if this model is further developed.

COMMENT 5.8

Statement of Concern: pg. 192, paragraph 2-3: The hypothesis that there is structural control on magma migration at depth is difficult to support, in light of Lister and Kerr (1991).

Basis: Much of this chapter has been devoted to developing the ideas of Lister and Kerr (1991), to the point where parts of their paper are excerpted directly. One of the important points of their work is that there is little reason for propagating dikes to follow preexisting faults or joint sets, especially at depth, because the mechanical strength of the country rock is not an important constraint on dike propagation once ΔP_h (buoyancy force) is large enough for rise to be initiated.

Recommendation: Alternative models should be considered. Most of this chapter is devoted to largely theoretical models of dike propagation. The authors are taking a good approach in trying to link these theoretical models to field observations. Clearly, however, a gap remains between what is observed in the field and the state of development of the models. Why not state this at the outset?

References:

Lister, J.R., and R.C. Kerr. 1991. Fluid-mechanical models of crack propagation and their application to magma transport in dykes. *Journal of Geophysical Research* 96: 10049-10077.

COMMENT 5.9

Statement of Concern: pg. 192, paragraph 3 "A preferred model for dike emplacement in the Yucca Mountain Region is the ascent of pulses of magma at depth along NW-trending structures followed by . . . ." What data actually support this model and why is it preferred?

Basis: Little data appear to be available to support the idea that regional structures control the ascent of magma at depth. The data from cone distribution (sections II and III) are not convincing. Lutz (1986), for example, has discussed the relationship between clusters and alignments in some detail. Lutz (1986) found that alignments are frequently recognized spuriously when point clustering occurs. It seems more likely that there are 2 - 3 vent clusters in the YMR that may be interpreted to form a NNW trend. Even if this orientation is taken to be significant in a practical sense, alternatives to structural control on magma ascent need to be considered. For example, there may be an elongate zone of partial melting at mantle depths, and generation of magma within this zone results in a weakly developed pattern of vents at the surface. Alternatively, there may be two zones of partial melting at depth, one in the Amargosa-Lathrop-Crater Flat area, and a second at Sleeping Buttes-Rocket Wash-Thirsty Mesa. Structural control on magma migration is not required in these alternate hypotheses. Without other direct information (e.g., mappable structures, geophysical anomalies) it is difficult to chose between these models. Do the authors believe that structure is required for magma transport across the lithosphere? This is a tough problem.

Recommendation: Additional discussion of alternate hypotheses is required.

References:

Lutz, T.M. 1986. An analysis of the orientations of large scale crustal structures: a statistical approach based on the areal distribution of point like features. *Journal of Geophysical Research* 91: 421-434.

COMMENT 5.10

Statement of Concern: Compare statements on page 192, paragraph 3 with those made on page 119, paragraph 1: "Moreover, the variation in elongation of the centroids from west-northwest to north-northwest is consistent with clockwise rotation . . . ." (also see Figure 3.12). Are the arguments in section III consistent with structural control?

Basis: If one accepts the idea that elongate zones of Miocene to Pliocene and Pliocene to Quaternary age are significant (see, however, the discussion in the review of Section III), the rotation of these elongate zones through time, associated with rotation of the crust, implies that the elongate zones of vent distribution result from some sub-lithospheric process, such as partial melting, which is fixed in the asthenosphere and therefore does not rotate. This would argue against the need for structural control on magma migration through the crust. Alternatively, a second regional structure is required beneath the Miocene - Pliocene alignment. In that case the amount of rotation is unknown.

Recommendation: Attempt to reconcile these models or discuss the disparity between them.

2.6 REVIEW OF SECTION 6: HISTORY OF VOLCANISM STUDIES

COMMENT 6.1

Statement of Concern: page 206, paragraph 3, "There have been no valid published estimations of the probability of magmatic disruption of the potential Yucca Mountain site that fall outside this range . . ." This statement must be supported.

Basis: This statement is not unsupportable in light of the work of Ho (1992), who places the 90 percent confidence envelope of repository disruption at (1×10^{-3}, 6.7×10^{-3}) and Sheridan (1992), who gives worst case scenario values of between 0.001 and 0.01. C-H. Ho and his colleagues, in particular, have published several articles in peer reviewed journals and made a strong effort to compare their work to Crowe's results (Smith et al., 1990; Ho et al., 1991; Ho, 1992). It is inappropriate to dismiss this work as not valid, as this statement does. Furthermore, although the authors make it clear that they do not agree with Ho's models in subsequent paragraphs, the values obtained by Sheridan (1992) are apparently accepted (see page 231, paragraphs 1 and 2).

Recommendation: Delete this and similar comments.

References:

Ho, C-H., E.I. Smith, D.L. Feurbach, and T.R. Naumann. 1991. Eruptive probability calculation for the Yucca Mountain site, USA: statistical estimation of recurrence rates. *Bulletin of Volcanology* 54: 50-56.

Ho, C-H. 1992. Risk assessment for the Yucca Mountain high-level nuclear waste repository site: estimation of volcanic disruption. *Mathematical Geology* 24: 347-363.

Sheridan, M.F. 1992. A Monte-Carlo technique to estimate the probability of volcanic dikes. Third High-Level Radioactive Waste Management Conference, Las Vegas, Nevada: 2033-2038.

Smith, E.I., D.L. Feuerbach, T.R. Naumann, and J.E. Faulds. 1990. *The area of most recent volcanism near Yucca Mountain, Nevada: Implications for volcano risk assessment. High-Level Radioactive Waste Management Proceedings of the International Topical Meeting,* La Grange, IL: American Nuclear Society: 1: 81-90.

COMMENT 6.2

Statement of Concern: page 215: Crowe et al. (1989) is incorrectly referenced; the second author of Harrington is missing.

Basis: This paper is cited as presenting K-Ar dates for five sample sites at Lathrop Wells. Individual dates do not appear in this paper, only average values for 4 or 12 dates. This paper references Turrin, Crowe and Fleck (in prep) as the source of the original data. These dates have yet to be published as cited, and this reference does not appear in the Chapter II discussions of K-Ar dating. Are these some of the dates reported in Turrin, Champion and Fleck (1991)? In the geochronology sections of this report (primarily Chapter II), the K-Ar techniques is consistently subdivided into the "Conventional K-Ar" and "$^{40}Ar/^{39}Ar$" techniques. Which K-Ar technique are these dates?

Recommendation: Clarify.

COMMENT 6.3

Statement of Concern: page 217: Crowe and Perry (1989) use a decrease in magma volume with time at the Springerville Volcanic Field to support the hypothesis that the CFVZ is a waning system. There are two important considerations that are not discussed by Crowe and Perry (1989) and indicate that the Springerville system may not be truly analogous to the CFVZ.

Basis: The gradual change to smaller eruptive volumes in Springerville at about 1 Ma are accompanied by a change in magma composition from tholeiitic to alkalic (Condit et al., 1989; Cooper and Hart, 1990). This trend is thought to represent a shift from lithospheric to more asthenospheric mantle sources. Similar compositional trends are not observed in the CFVZ within the last 3.7 Ma (this report). The Springerville field erupted around 300 km^3 of mafic rock, but less than 1 km^3 has been erupted in the CFVZ since about 3.7 Ma (Crowe and Perry, 1989). The dynamics of magma generation, ascent, and eruption may be extraordinarily different for volcanic fields with such different magma fluxes.

Recommendation: Qualify the comparison by discussing the important differences between these fields or delete.

References:

Cooper, J.L., and W.K. Hart, 1990. Mantle sources in the Arizona transition zone and global mantle heterogeneity. *Geology* 18: 1146-1149

COMMENT 6.4

Statement of Concern: page 225, paragraph 4, "Their estimated values of the recurrence rate are bounded by the range . . ." But the recurrence rates of Ho et al. (1991) are not included in the range of likely values given in the probability section.

Basis: In the probability section, recurrence rates of up to about 4×10^{-6}/yr are considered. Ho et al. (1991) estimate 5×10^{-6}/yr to 6×10^{-6}/yr.

Recommendation: Incorporate the recurrence rate of Ho et al. (1991) into the probability calculation.

References:

Ho, C-H., E.I. Smith, D.L. Feurbach, and T.R. Naumann. 1991. Eruptive probability calculation for the Yucca Mountain site, USA: statistical estimation of recurrence rates. *Bulletin of Volcanology* 54: 50-56.

COMMENT 6.5

Statement of Concern: page 229, paragraph 1, "An item of continuing confusion . . . is the definition of a volcanic event." A tabular summary of volcanic events is required.

Basis: It is very difficult to discern in this report what the authors consider to be a volcanic event in the Yucca Mountain region. This is a source of confusion in and of itself.

Recommendation: A table, summarizing vent locations in the Yucca Mountain Region and volcanic events would be extremely appropriate.

COMMENT 6.6

Statement of Concern: page 222, paragraph 1, "There is 0 percent success rate using older sites of volcanic activity . . ." This statement misses the point of Smith et al. (1990).

Basis: The paper of Smith et al. (1990) represents an attempt to incorporate geological information into probability models. They have suggested that the probability of eruptions is greater in some parts of the region compared to others because of structural control and/or neotectonic stress pattern. This seems to be a reasonable idea that should be further considered by DOE.

Recommendation: Emphasize the point in Smith et al. (1990) that geologic information should be incorporated in probability models.

References:

Smith, E.I., D.L. Feuerbach, T.R. Naumann, and J.E. Faulds. 1990. *The area of most recent volcanism near Yucca Mountain, Nevada: implications for volcano risk assessment. High-Level Radioactive Waste Management Proceedings of the International Topical Meeting, La Grange, Illinois*. American Nuclear Society. 1: 81-90.

COMMENT 6.7

Statement of Concern: page 235, paragraph 3, "A more realistic calculation would be to chose an observation period equal to the duration of activity . . ." It is not clear why the DOE does not adopt this approach.

Basis: The most recent volcanic events in the Yucca Mountain region cluster in a time period between 1.2 ± 0.4 Ma and, essentially, the present. There have been seven to eight events during this period of most recent activity. That suggests that the late Quaternary recurrence rate could be as high as 7 to 8 $\times 10^{-6}$/yr in the Yucca Mountain region, which would be more conservative.

Recommendation: This problem needs to be clarified. Either the estimates of Ho (1992) using the Poisson-Weibull method are acceptable (in approach) or a high late-Quaternary rate needs to be assumed.

References:

Ho, C-H. 1992. Risk assessment for the Yucca Mountain high-level nuclear waste repository site: estimation of volcanic disruption. *Mathematical Geology* 24: 347-363.

2.7 REVIEW OF SECTION 7: VOLCANISM RISK ASSESSMENT

COMMENT 7.1

Statement of Concern: page 247, paragraph 1: The last sentence is easily misinterpreted and may need to be deleted.

Basis: The investigations should be seeking scientifically valid estimates, not just mean values.

Recommendation: Consider rewording.

COMMENT 7.2

Statement of Concern: page 248., paragraph 3. "The basalts are aphyric . . ." Not all basalts in Crater Flat valley are aphyric.

Basis: Several flows and scoria deposits in Crater Flat Valley are described as having phenocrysts in Section II of the Status Report.

Recommendation: Reword.

COMMENT 7.3

Statement of Concern: page 250. ". . ., *there is ample justification in both the seismic and volcanological literatures for application of a simple Poisson model (Crowe et al. 1992).*" The volcanological literature does not support the application of homogeneous Poisson models to vent distributions.

Basis: The articles cited in Crowe et al. (1992) are primarily for historically active stratovolcanic systems, which are often fed by periodically recharged, highly evolved crustal magma chambers. In addition, most of these studies examined eruption frequency on a single volcano and did not examine activity within volcanic fields over 1,000's of years.

The studies by Wickman (1966, 1976) were on historically active volcanoes, and examined repose times of months to tens of months between eruptions for single volcanic centers. Most of the studied volcanoes were arc stratovolcanoes, with exceptions being several Hawaiian and Icelandic centers. Of these studied volcanoes, only 5 out of 29 clearly show historically random eruptions. Others show activity that can be approximated by a Markovian model. This study did not examine recurrence rates in volcanic fields such as the Crater Flat Volcanic Field, and only examined volcanoes with periodically recharged, highly evolved magma chambers. Applying Wickman's studies, eruptions at single vents such as Lathrop Wells could well be described by a Poisson model. However, these models neither support or refute a Poisson model for volcanic fields that are active over > 1000 years.

Klein (1982) concluded that eruptions at Hawaiian volcanoes appear random because multiple processes occur simultaneously. Klein noted that statistical differences occur between the occurrence rates of summit and flank eruptions, large and small eruptions, and intrusive and extrusive events. These conclusions show that eruptions at historically active volcanoes such as Kilauea and Mauna Loa are not necessarily random events. Klein also concluded that long-term repose times at Kilauea and Mauna Loa are related, with periods of activity at one volcano coinciding with periods of general repose at the other. This study does not support the hypothesis that eruptions in the Yucca Mountain area are adequately described by a Poisson model.

Most of the other references cited in Crowe et al. (1992) to support a Poisson model (Scandone, 1983; Mulargia et al., 1985, 1986, 1987; Chester, 1986) also only addressed Poisson models of eruption recurrence for single, historically active volcanoes. It is not at all clear how eruption models at these volcanoes are related to eruption models in the Yucca Mountain mafic system. It is true that some early papers on cinder cone distribution suggested that a Poisson model is appropriate (e.g., Settle, 1979). However, there have been numerous papers that have stated that vent distributions are not Poisson, but are clustered and/or show regional pattern (e.g., Porter, 1972; Heming, 1980; Wadge and Cross, 1988; Connor, 1990; Connor et al., 1992). The concept of systematic shifts in vent locations through time (e.g., Tanaka et al., 1986; Condit et al., 1989; this status report) also suggest that vent distribution is not well described by homogeneous Poisson models. The studies by Bacon (1982) at Coso and Kuntz et al. (1986) at Craters of the Moon, Idaho, showed that eruptions in these Quaternary volcanic fields have a general time-predictable relationship, with long repose times after large-volume eruptions and shorter repose times after relatively smaller-volume eruptions. Similar relationships are also shown at some individual volcanoes (King, 1989). The conclusion in these studies that eruption frequency and volume is in part controlled by the frequency and volume of preceding eruptions does not support a homogeneous Poisson model.

Settle and McGetchin (1980) showed that the three vents in the 1971 summit of Stromboli volcano had individual eruption periods characterized by a Poisson process. However, activity at each vent could be correlated with the number of eruptions occurring at the other two vents, a non-Poissonian process. This study suggests that although individual vents may show random eruptions, eruptions for volcanoes supplied from the same magma system may show volume or time predictable eruption rates.

The implications for volume-predictable eruptions are that small-volume eruptions occur close in time, but large eruptions occur between longer periods of volcanic inactivity. The trend in the CFVZ since about 1 Ma has been a decrease in eruption volume coupled with an increase in eruption frequency. This relationship does not necessarily indicate that the system is waning. Rather, the tectonic and magmatic processes that control eruption dynamics are favoring smaller, more frequent eruption during Quaternary activity. The annual recurrence rate in the CFVZ is thus best represented by Quaternary activity: 8 events/$1.2 \pm 0.4 \times 10^6$ years = $7 \pm 2 \times 10^{-6}$ per year. We disagree with the conclusion that the Little Cones are a single event, because they are spatially, compositionally, and mineralogically distinct (Vaniman and Crowe, 1981). We also disagree that these events should be averaged over a duration of 1.8 m.y., which is presumed to represent the duration of the Quaternary period (cf. Palmer, 1983). The most meaningful period of time is the interval of small-volume eruptions, which began around 1.2 Ma. This recurrence rate is at least two times greater than the event rates listed in Table 7.3 (p. 267), and the likely recurrence rate used as E1 in the probability calculations.

Recommendation: Further justification needs to be made for the use of homogeneous Poisson models. Statistical tests for random distribution, both in time and space, should be applied. Alternatively, other statistical models should be applied.

References:

Bacon, C.R. 1982. Time predictable bimodal volcanism in the Coso Range, California. *Geology* 10: 65-69.

Chester, D.K. 1986. Comments on: A statistical analysis of flank eruptions on Etna volcano. *Journal of Volcanology and Geothermal Research* 23: 385-389.

Condit, C.D., L.S. Crumpler, J.C. Aubele, and W.E. Elston. 1989. Patterns of volcanism along the southern margin of the Colorado Plateau: The Springerville field. *Journal of Geophysical Research* 94: 7,975-7,986.

Connor, C.B. 1990. Cinder cone clustering in the TransMexican volcanic belt: Structural and petrologic implication. *Journal of Geophysical Research* 95: 19,395-19,405.

Connor, C.B., C.D. Condit, L.S. Crumpler, and J.C. Aubele. 1992. Evidence of regional structural controls on vent distribution: Springerville volcanic field, Arizona. *Journal of Geophysical Research* 97: 12,349-12,359.

Crowe, B.M., R. Picard, G. Valentine, and F.V. Perry. 1992. Recurrence models of volcanic events: Applications to volcanic risk assessment. *Third International Conference on High-Level Waste Management*. Las Vegas, Nevada: 2344-2354.

Heming, R.F. 1980. Patterns of Quaternary basaltic volcanism in the northern North Island of New Zealand. *New Zealand Journal of Geology and Geophysics* 23: 335-344.

King, C.Y. 1989. Volume predictability of historical eruptions at Kilauea and Mauna Loa volcanoes, *Journal of Volcanology and Geothermal Research* 38: 281-285.

Klein, F.W. 1982. Patterns of historical eruptions at Hawaiian volcanoes. *Journal of Volcanology and Geothermal Research* 12: 1-35.

Kuntz, M.A., D.E. Champion, E.C. Spiker, and R.H. LeFebure. 1986. Contrasting magma types and steady-state, volume predictable basaltic volcanism along the Great Rift, Idaho. *Geological Society of America, Bulletin* 97: 579-594.

Mulgaria, F., P. Gasparini, and E. Boschi. 1987. Identifying different regimes of eruptive activity: an application to Etna volcano. *Journal of Volcanology and Geothermal Research* 34: 89-106.

Mulargia, F., S. Tinti, and E. Boschi. 1986. A statistical analysis of flank eruptions on Etna volcano, reply to comments of D.K. Chester. *Journal of Volcanology and Geothermal Research* 28: 389-395.

Mulargia, F., S. Tinti, and E. Boschi. 1985. A statistical analysis of flank eruptions on Etna volcano. *Journal of Volcanology and Geothermal Research* 23: 263-273.

Palmer, A.R. 1983. The decade of North American geology 1983 geologic time scale. *Geology* 11: 503-504.

Porter, S.C. 1972. Distribution, morphology, and size frequency of cinder cones on Mauna Kea volcano, Hawaii. *Geological Society of America, Bulletin* 92: 448-456.

Scandone, R. 1983. Problems in the evaluation of volcanic risk. In: Tazieff, H. and Sabroux, J.C., eds., *Forecasting Volcanic Events*: Elsevier:New York: 57-67.

Settle, M. 1979. The structure and emplacement of cinder cone fields. *American Journal of Science* 279: 1089-1107.

Settle, M., McGetchin, T.R. 1980. Statistical analysis of persistent explosive activity at Stromboli, 1971: Implications for eruption prediction. *Journal of Volcanology and Geothermal Research* 8: 45-58.

Tanaka, K.L., E.M. Shoemaker, G.E. Ulrich, and E.W. Wolfe. 1986. Migration of volcanism in the San Francisco volcanic field, Arizona. *Geological Society of America, Bulletin* 97: 129-141.

Vaniman D., and B.M. Crowe. 1981. Geology and petrology of basalts of Crater Flat: applications to volcanic risk assessment for the Nevada nuclear waste storage investigations. LA-8845-MS. Los Alamos, NM: LANL.

Wadge, G., and A. Cross. 1988. Quantitative methods for detecting aligned points: an application to volcanic vents in the Michoacán-Guanajuato volcanic field, Mexico. *Geology* 16: 848-851.

Wickman, F.E. 1976. Markov models of repose patterns in volcanoes. In: *Random Processes in Geology*: Springer Verlag: 135-161.

Wickman, F.E. 1966. Repose-period patterns of volcanoes. V. General discussion and a tentative stochastic model. *Arkiv for Mineralogi och Geologi* 4: 351-367.

COMMENT 7.4

Statement of Concern: page 250, paragraph 2: Contrary to what is stated here, results of homogeneous Poisson models do differ significantly from the results of other models.

Basis: An additional justification for the use of the homogeneous Poisson model is that other results do not differ significantly from the results of other models. This statement is inconsistent with the results of Ho et al., 1991; Ho, 1992; and Sheridan, 1992. These studies suggest that the homogeneous Poisson tripartite approach underestimates the risk of volcanism. The authors must deal with this discrepancy in a systematic way in this section.

Recommendation: Discuss these alternative models in this section.

References:

Ho, C-H., E.I. Smith, D.L. Feurbach, and T.R. Naumann. 1991. Eruptive probability calculation for the Yucca Mountain site, USA: Statistical estimation of recurrence rates. *Bulletin of Volcanology* 54: 50-56.

Ho, C-H. 1992. Risk assessment for the Yucca Mountain high-level nuclear waste repository site: Estimation of volcanic disruption. *Mathematical Geology* 24: 347-363.

Sheridan, M.F. 1992. A Monte-Carlo technique to estimate the probability of volcanic dikes. *Third High-Level Radioactive Waste Management Conference.* Las Vegas, Nevada: 2033-2038.

COMMENT 7.5

Statement of Concern: page 251. Geophysical evidence is cited to infer that shallow intrusions do not occur without accompanying volcanic eruptions in the Quaternary. This does not seem justified, because of the low resolution of geophysical methods compared to dike size.

Basis: The idea that the aeromagnetics can identify all shallow intrusives above a depth of several kilometers is not supported by ample research and should not be incorporated into a conservative model.

Recommendation: Consider the resolution of geophysical methods and the possibility that subsurface intrusions have not been identified in many areas of the YMR.

COMMENT 7.6

Statement of Concern: page 254, second paragraph, and pg. 256, third paragraph. There are ideas in these two paragraphs that are contradictory.

Basis: It may be the case the magmas that reach repository depths will fragment — and, therefore, it is less likely that intrusives will be found at repository depths without fragmentation occurring. However, at the point fragmentation occurs, magma velocities will increase dramatically and Stokes settling will not be an important process. The argument that density contrasts been the magma and waste containers will effect transport is incorrect given the explosive nature of the magmas. Furthermore, the characterization of likely eruptions as Hawaiian or strombolian (mildly explosive) is without merit. Certainly many hydromagmatic phases of eruption at Lathrop Wells were considerably more energetic (e.g., Valentine et al., 1992) and, based on observations of modern cinder cone eruptions, other, magmatic phases of activity were likely explosive as well.

Recommendation: Delete the Stokes settling argument.

References:

Valentine, G.A., B.M. Crowe, and F.V. Perry. 1992. Physical processes and effects of magmatism in the Yucca Mountain region. Proceedings of the Third International Conference on High-Level Radioactive Waste Management. Las Vegas, NV: ANS and ASCE: 2014-2024.

COMMENT 7.7

Statement of Concern: The last sentence in paragraph three, page 256 is quite misleading.

Basis: Although the probability of release given disruption is likely to be less than 1, there is no evidence to support the idea that it will be less than 0.1, and to conclude this based on current models is not conservative.

Recommendation: Given the current stage of volcanism research in the YMR, the authors should maintain the position in the first paragraph of page 254, that magmatic radiological releases are not the subject of the report.

COMMENT 7.8

Statement of Concern: page 254, second paragraph, The statement that "current site data have not revealed any evidence in the Yucca Mountain region that an intrusive event has occurred at or near repository depths without an accompanying volcanic eruption" may be misleading.

Basis: Given the magnetic structure of Yucca Mountain (e.g., Schlinger et al., 1991) it seems likely that even detailed ground magnetic surveys can not possibly detect the presence of thin basaltic dikes at repository depths.

Recommendation: Some discussion of the resolution of these methods is warranted.

References:

Schlinger, C.M., D.R. Veblen, and J.G. Rosenbaum. 1991. Magnetism and magnetic mineralogy of ash flow tuffs from Yucca Mountain, Nevada. *Journal of Geophysical Research* 96: 6,035-6,052.

COMMENT 7.9

Statement of Concern: page 257, paragraph 2 and 3. What is the basis for defining volcanic events, particularly with reference to the Little Cones?

Basis: There are some critical assumptions in these paragraphs which need to be amplified, as they do not appear to be supported by observations. The idea that vents spaced closer than 5 km may be regarded as one event unless proven otherwise is not conservative. The average spacing of vents is much less than this in many of Earth's volcanic fields. The distances between near neighbor vents in the Crater Flat Valley is most often less than 5 km and these vents are often of greatly different age and petrology. Probably it would be better to identify individual volcanoes as separate events unless it can be proven otherwise. In the case of the Little Cones, the argument that the NE and SW cones are contemporaneous may be incorrect. No numerical dating of NE Little Cone has been done and the only published date on SW Little Cone actually comes from a sample collected on a scoria mound 0.5 km SW of SW Little Cone. Petrologically, there are significant trace element differences between NE and SW Little Cones. Samples from these two cones plot in different fields on Sr/Mg , Sr/Th, and La/Sm vs. Th plots. The differences between NE and SW Little Cones on this plots for example, are as large as the differences between 3.7 m.y. old Crater Flat lavas and Red and Black Cones. Also, amphibole is found at NE Cone and is largely absent in SW cone lavas.

Recommendation: If these differences are not significant enough to distinguish these cones as separate events, then a substantial justification will be necessary.

COMMENT 7.10

Statement of Concern: page 262: The terms cluster count and cluster length are introduced without any explanation. How are clusters identified? Are calculations involving clusters based on the probability of a new cluster forming?

Basis: Specific methods exist for cluster identification. These range from statistical testing to cluster analysis. If calculations involving clusters are based on the probability of a new cluster than the fact that Yucca Mountain is located close to a young, large cluster needs to be considered explicitly. Homogeneous models have difficulty evaluating this.

Recommendation: Define these terms in a rigorous way.

COMMENT 7.11

Statement of Concern: page 263: this table is very important. It is apparently switched with the next.

COMMENT 7.12

Statement of Concern: page 271, paragraphs four and five. The authors imply that recurrence rates in the Lunar Crater and Cima areas are "low." However, the recurrence rates in these areas are too high to qualify a repository.

Basis: The authors interpret Lunar Crater recurrence rates to be between 1.5×10^{-5}/ yr and 4.5×10^{-5}/yr, or on the order of ten times their estimated recurrence rate for the Yucca Mountain region.

Cima recurrence rates are about 1.4×10^{-5} /yr. The wording of the paragraph implies that these are low recurrence rates. Using a simple Poisson model, these recurrence rates imply that the probability of a volcanic eruption in these fields in the next 10,000 years is between 0.15 and 0.36. The statement that "if the repository were located in the center of any three of these volcanic fields, a future volcanic eruption would not be expected during the isolation period . . . ." is misleading. Incorporating an E2 term, the risk of "disruption" of an area of repository size at the center of these fields might be on the order of 10^{-6} or 10^{-7} /yr (c.f. Figure 7.16).

Recommendation: An important conclusion of the comparison seems to be that there are definitely areas in the western Great Basin where the repository could not be sited due to the risk of volcanism. It does not seem reasonable to argue that recurrence rates in the Cima and Lunar Crater areas are "low."

COMMENT 7.13

Statement of Concern: page 274, second paragraph, and page 277, last paragraph: The most likely recurrence rate, based on event counts is estimated to be 3.3×10^{-6} events / yr. The geometric mean recurrence rate based on volume estimated in this paragraph is 2.6×10^{-6}. This is reported to be a worst case recurrence rate for volcanism in the region. These numbers are small compared to estimates based on the number of events through time.

Basis: For example, based on Figure 3.10, there are at least 27 centers formed in the last 9 million years. Assuming that it is increasingly difficult to identify centers with increasing age (for example the Amargosa volcanics were identified through the application of geophysical methods), this must be a minimum estimate. This results in a Post-caldera basalt rate of 3 events/ one million years. The late Quaternary rate is on the order of 7-8 events is the last 1.2 ± 0.4 million years for the formation of new vents. Ho et al. (1991) present convincing arguments based on the maximum likelihood function and repose times that the Quaternary recurrence rate is between 5.0 and 6.0×10^{-6} events / yr. These higher recurrence rates are easily defendable both in a pragmatic sense (simply counting events through time over a period of recent activity) and using the statistical arguments developed by Ho et al. (1991).

Recommendation: If the authors reject these higher recurrence rates then they should support their position with arguments as compelling as those of Ho et al. (1991).

References:

Ho, C-H., E.I. Smith, D.L. Feurbach, and T.R. Naumann. 1991. Eruptive probability calculation for the Yucca Mountain site, USA: Statistical estimation of recurrence rates. *Bulletin of Volcanology* 54: 50-56.

COMMENT 7.14

Statement of Concern: pages 290-299: The bivariate Gaussian analysis done for Cima and Lunar Crater fields is not an appropriate use of the method.

Basis: No test is done to show that a bivariate Gaussian distribution is a good model of vent distribution in these fields. The fact that about 50 percent of the data fall within the 50th percentile does not represent a good test. It is not intuitive at all that a bivariate Gaussian model would be appropriate, especially after all of the discussion of homogeneous Poisson distributions and clustering. There is no reason to suspect that there is a normal distribution to geographic distributions of vents. Unlike analyses associated with errors in measurements, such as in the analysis of paleomagnetic data, there is no *(a priori)* reason to believe that a central tendency is present. Furthermore, the tails of distributions often deviate from perfectly Gaussian. This means that tests for the probability of volcanic eruptions, based on confidence intervals at 90 to 99 percent confidence levels, have no statistical validity.

Recommendation: A statement such as "The bivariate Gaussian distribution fits these data with (?) percent confidence" would make the analysis meaningful. Usually, Student-T tests are made to look for normal distributions in data.

COMMENT 7.15

Statement of Concern: page 251: The authors maintain that "any subsurface basaltic rocks of significant volume that are present above depths of several kilometers should be identifiable from aeromagnetic data.", and conclude that all Quaternary volcanic centers have been identified. The exposed Quaternary basaltic centers are of relatively small volume; do these volumes meet the test of "significant"? What resolution is present in the aeromagnetic data?

Basis: The only features that have been resolved by aeromagnetic studies are relatively large, buried flows. The comments of page 254 address the hypothesis that mafic dikes may be emplaced within the shallow crust (i.e., <300 m) and not erupt. Is the available geophysical data sufficient to resolve shallow, thin (1-10m) dikes?

Recommendation: Consider the problems with the geophysical data in more detail.

COMMENT 7.16

Statement of Concern: page 254: Undiscovered shallow intrusions in the YM area are discounted because "the volume expansion from volatile release provides a strong driving force to produce an eruption." Thus, any magma that reached repository depths (about 300m) is assumed to continue to the surface and erupt, and would not stagnate as a shallow intrusion. There is, however, evidence that shallow dikes can be emplaced very near surface without erupting.

Basis: At Craters of the Moon in Idaho, the Holocene vent field is cut by numerous NW-trending fissures, some of which terminate in cinder cones (Kuntz et al. 1986). Models of similar fissures associated with rhyolite domes at Medicine Lake Volcano by Fink and Pollard (1983) concluded the fissures were related to shallow (about 100 m) emplacement of dikes, only some of which are associated with an eruption. These rhyolite magmas were clearly oversaturated with volatiles, because the dome eruptions were preceded by small pyroclastic eruptions and the dome rhyolites contain extensive inflated zones (e.g., Fink and Manley, 1987). Rhyolite eruptions also generally have higher volatile abundances than basaltic eruptions. If volatile saturation is the driving force for shallow eruptions, a lower volatile content basalt could be emplaced at shallower depths than higher volatile content rhyolite.

Recommendation: The conclusion that all dikes which reached repository depths in the Yucca Mountain area resulted in an eruption and are thus identified needs to be re-examined. Numerous small (i.e., <1 km long) dikes may accompany a cinder cone eruption and not have any obvious surface manifestation, yet could be emplaced at or above repository depths. In addition, these studies indicate that it may be possible for a magmatic event to emplace dikes and sills at or above repository depths without any surficial eruption. Consider the implications of these other studies.

References:

Fink, J.H., D.D. Pollard, 1983. Structural evidence for dikes beneath silicic domes, Medicine Lake Highland Volcano, California. *Geology* 11: 458-461

Fink, J.H., C.R. Manley, 1987. Origin of pumiceous and glassy textures in rhyolite flows and domes. Fink, J.H., ed., *The Emplacement of Silicic Domes and Lava Flows*. Geological Society of America Special Paper 212: 77-88.

Kuntz, M.A., D.E. Champion, E.C. Spiker, and R.H. LeFebure. 1986. Contrasting magma types and steady-state, volume predictable basaltic volcanism along the Great Rift, Idaho. *Geological Society of America, Bulletin* 97: 579-594.

COMMENT 7.17

Statement of Concern: The random structural models assume an equal probability of future volcanic events throughout the area enclosing the distribution of previous volcanic events.

Basis: Structural features, such as the Ghost Dance fault may influence the likelihood of volcanism in particular areas. These factors need to be taken into account, or at least it should be stated that future models will take this into account, and that presently the influence of structures like the Ghost Dance fault on magma migration at shallow levels is poorly understood.

Recommendation: Place more emphasis on the need to incorporate geologic constraints in probability models.

2.8 REVIEW OF SECTION 8: STATUS AND IMPLICATIONS OF FUTURE STUDIES

Study Plan 8.3.1.8.1.2 is referenced throughout this report, yet there is no description of this unpublished plan. The major goals and approaches of this Study Plan should be outlined to give the reader some sense of how "Physical Processes of Magmatism and Effects on the Potential Repository" will be studied.

2.9 REVIEW OF SECTION 9: CONCLUSIONS

COMMENT 9.1

Statement of Concern: Conclusion A2. It is not clear why only four Pliocene centers are described, what is meant by "center," or that all Quaternary intrusions have been identified.

Basis: It is very important to identify "centers" in a consistent manner. For example, it is not clear from the data presented in this report that the two Little Cones should be considered as a single center. There are certainly eight Quaternary cinder cones in the region. Furthermore, the conclusion that there are four

Pliocene centers is in error. Numerous figures in Section III indicate that there are many more then four Pliocene centers. For example, about ten are shown on Figure 3.10. This is important because it has a direct effect on probability calculations, especially if an homogeneous Poisson model is used. If for example, the Amargosa Valley vents are considered to be one "center" as this conclusion implies, then the E2 term used in the probability calculation needs to be changed to reflect the large area of individual volcanic centers. This has not been done.

The conclusion that there are no unidentified Quaternary intrusions in the Yucca Mountain region is not supported. The geophysical methods described are not capable of detecting intrusions at repository depths over the area of interest.

Recommendation: A succinct review of vent and center locations is needed in the report. It is unlikely that a consensus between all scientists will develop on what constitutes an event. However, the DOE status report should summarize (in tabular form) the locations and timing of vent formation as well as possible. This table can be organized by center where applicable. At some point, probably in Section II, a comprehensive discussion of the categorization of particular vents needs to be made. It will be necessary to revise this conclusion with regard to Pliocene centers.

COMMENT 9.2

Statement of Concern: Conclusion A3. The ages represented for Crater Flat and Sleeping Butte have very large uncertainties.

Basis: Age differences are not slight in the Quaternary centers, and may be resolvable with currently available K-Ar dates. Lathrop Wells event 2 is not constrained at >40 ka. The age of the young event is not supported.

Recommendation: Additional work is required to resolve geochronological issues in the region. High-precision K-Ar methods have improved greatly and it is likely that application of these methods to Yucca Mountain region volcanoes can better constrain uncertainties in age for the Crater Flat volcanoes. Report uncertainty in the dates of all centers in a consistent manner. For example, from a statistical point of view, it is certain that the Crater Flat volcanoes are not 1.2 million years old. There are analytical uncertainties associated with these dates (0.4 million years) which must be reported.

COMMENT 9.3

Statement of Concern: Conclusion A4. This paragraph does not really constitute a conclusion in the scientific sense. The chronology of the youngest Quaternary basalt centers has not really been solved, even given the polycyclic nature of the volcanism.

Basis: Multiple dating techniques have only been applied at Lathrop Wells and large uncertainties in the dates persist for other cones. There is no evidence in this report of systematic geochronological studies at volcanoes other than Lathrop Wells.

Recommendation: A summary of the existing geochronological data (preferably in tabular form) would help greatly. Include the uncertainties in this table. Moreover, consider additional systematic sampling of Crater Flat vents.

COMMENT 9.4

Statement of Concern: Conclusion B1. The conclusion that basaltic volcanism is related to the waning stages of extensional faulting and volcanic activity is not supported.

Basis: The inference seems to be that basaltic volcanism is related to extensional strain and faulting; and further, that the strain rate in the area has decreased since the eruption of the Timber Mountain Caldera complex. The inferred conclusion is that since the rate of "extensional faulting" has decreased over some span of time, then the likelihood of associated small volume basaltic volcanism must have decreased over the same period. At the scale of the CFVZ (several tens of kilometers), finite strains, strain rates, and the direct relationship between strain and volcanism are not well enough established to support this conclusion. Scott (1990) calculates that the tectonic strain rate at Yucca Mountain has decreased from a maximum of about 10^{-14}/sec between 13 to 11.5 Ma to about 10^{-16}/sec over the last 11.5 million years. However, across the southern, most extended, part of Yucca Mountain, Scott (1990) estimates a maximum rate of 8.7×10^{-15}/sec. Across the NW part of the mountain, Scott (1990) estimates that rates decreased from 5.3×10^{-16}/sec to 2.1×10^{-16}/sec. There may be as much spatial as temporal variation in strain rate. Even though strain rate may have decreased overall at Yucca Mountain, extension has continued through the Holocene (O'Neill et al. 1992). Therefore, finite strain has increased across the YMR. Volcanism may be related to finite strain as well as strain rate. Decreased strain rate may not reliably indicate decreased likelihood of igneous activity. Causal mechanisms are not discussed in the DOE status report. Also, measurements of contemporary horizontal strain are not yet available at Yucca Mountain. Assessment of future volcanism related to tectonic strain should await acquisition and interpretation of these data.

Recommendation: Remove this statement or explain further.

References:

O'Neill, J.M., J.W. Whitney, and M.R. Hudson. 1992. *Photogeologic and kinematic analysis of lineaments at Yucca Mountain, Nevada: Implications for strike-slip faulting and oraclincal bending.* U.S. Geological Survey Open File Report: 91-623.

Scott, R.B. 1990. Tectonic setting of Yucca Mountain, southwest Nevada. Basin and Range Extensional Tectonics Near the Latitude of Las Vegas, Nevada. B.P Wernicke, ed. Geological Society of America Memoir 176: 251-282.

COMMENT 9.5

Statement of Concern: Conclusion B2, ". . . detachment that preceded eruption of most of the volcanic rocks . . . ."

Basis: A detachment fault system probably began to develop prior to the eruptions of the Timber Mountain Caldera complex. However, the Paintbrush Tuff is offset across faults that may be associated with continued slip along the detachment system. Slip on the detachment fault, and associated listric splays, did not exclusively precede eruptive activity. Indeed, the detachment system may have been active through the Holocene.

Recommendation: In the list of "important potential processes that shaped the structural framework of the Yucca Mountain area," consider that i) slip on a relatively low angle fault system (detachment) may have persisted through the Quaternary; and ii) detachment faults may play an important role in the structural evolution of pull-apart basins.

Basis: The "inferred formation of caldera(s) complexes associated with the development of the Crater Flat basin" is not supported in this report.

Recommendation: Elaborate on this in the text or delete this statement.

COMMENT 9.6

Statement of Concern: Conclusion B3. There is no justification presented to show that the basalt of the silicic episode (BSE) is any more or less localized along regional structural trends than the older or younger postcaldera basalts.

Basis: The CFVZ as defined in this report, is about 12 km wide and 70 km long. The repository site is located between 4 and 7 km NE of this zone, and 8-9 km from the nearest volcano within this zone. This type of statement is more supportable than the "the narrow Crater Flat volcano zone . . . does not intersect the repository site."

Recommendation: Rephrase this conclusion.

COMMENT 9.7

Statement of Concern: Conclusion B4. The statistical analysis of vent distribution in the CFVZ, and in the Yucca Mountain region in general, is misapplied and this conclusion is not supported by that analysis.

Basis: There are no known igneous features between Northern cone and the Sleeping Buttes-Thirsty Mesa area, a distance of about 35 km, or one-half the length of the zone. Linear regression is not an effective tool for alignment recognition and the outlying nature of Sleeping Buttes produces an artificially high correlation coefficient. Other techniques, such as Lutz's two-point azimuth method (Lutz, 1986) produce more interpretable results. Similarly, the analysis is not meaningful because Buckboard Mesa, a large volume center that is about 2.8 m.y. old, is not considered in the analysis. There is very limited evidence from vent distribution of a NW-trending concealed structure. Alternative explanations, such as the random distribution of clusters, or the presence of regional NE trends, are equally valid.

Recommendation: This conclusion is really a discussion of one model. It should either be deleted, or the alternative models should be discussed.

COMMENT 9.8

Statement of Concern: Conclusion B5. This report must present more of the data used to develop this conclusion.

Basis: There is a lack of discussion about the resolution of various geophysical data sets. For example, the statement that there is no correlation between gravity anomalies and small volume basaltic centers is only true at the wavelength of sampling considered. Aeromagnetic anomalies are relatively common in the alluvial areas (Crater Flat and Amargosa Valley), but this technique is probably inapplicable to detecting intrusives in the Yucca Mountain block because of the high magnetic susceptibility and remanent magnetizations of the silicic tuffs.

Recommendation: This conclusion needs to be qualified to state that "existing surveys of varying resolution indicate that . . . ." It would be appropriate, at this time, to conclude that additional geophysical work needs to be done to characterize the site. For example, in the discussion in Section V, it is mentioned that additional geophysical data is required to test models for the emplacement of Crater Flat volcanoes.

COMMENT 9.9

Statement of Concern: Conclusion B6. The statement that "Quaternary basalt centers . . . do not appear to be controlled by or follow shallow surface features" is not supported in the text by maps of the area, nor are geophysical data presented to support this conclusion.

Basis: No data are presented in this report to support this conclusion. As mentioned above, there is no evidence for regional, deeply penetrating structure controlling Crater Flat volcanism. The roughly 1.2 m.y. old cones of the Crater Flat valley align roughly parallel to faults at Yucca Mountain, in particular Fatigue Wash and Windy Wash (Frizzell and Shulters, 1990). Also, it is necessary to define what is meant by "shallow structure" when in fact there is little direct evidence of "depth of penetration" of faults at Yucca Mountain.

Recommendation: Presentation and/or acquisition of additional data is necessary to support this conclusion.

Reference:

Frizzell, V.A., Jr., and J. Shulters. 1990. Geologic map of the Nevada Test Site, southern Nevada. U.S. Geological Survey Miscellaneous Investigations Series Map I-2046.

COMMENT 9.10

Statement of Concern: Conclusion C1. The origin of the YM basalts has not been examined in detail, and multiple hypotheses have not been tested.

Basis: Pliocene and Quaternary basaltic magmas of the YM region are compositionally distinct from similar age Basin and Range basalts. For example, trace element patterns in the Yucca Mountain region are different from those of Lunar crater. In terms of volume, the Yucca Mountain region is similar to many fields in the western Great Basin.

Recommendation: Rephrase this conclusion.

COMMENT 9.11

Statement of Concern: Conclusion C2. Regional petrogenetic trends are incorrectly applied to the YM system to support a waning magmatism hypothesis.

Basis: Changes in petrogenesis observed in some central Basin and Range Volcanic Systems do not occur in the YM region. The source composition and degree of partial melting may have changed at about 5 Ma for some central Basin and Range systems, but such changes are not observed at YM or other western Great Basin systems. Central Basin and Range trends are incorrectly applied to the YM system to support the conclusion that magmatism is waning.

Recommendation: Reconsider this model in light of regional petrologic/petrogenetic information.

COMMENT 9.12

Statement of Concern: Conclusion C4. Arguments about magma flux through time are not well documented and are poorly supported.

Basis: The fields cited in this report are not in any part of Great Basin, and observed petrogenetic changes in those fields are not controlled simply by changes in depth and degree of partial mantle melting. The data presented do not demonstrate that Crater Flat basalt magma chambers have deepened through time or that any depth constraints can be placed on this system.

Recommendation: Presentation and/or acquisition of additional data is necessary to support this conclusion. In addition, alternative models should be considered.

COMMENT 9.13

Statement of Concern: Conclusion C5. Polycyclic volcanism is not required on petrogenetic grounds.

Basis: Little trace element data have been presented for Lathrop Wells and Black Cone. The data do not preclude derivation from a single magma batch, and the compositional differences in eruptive units are small relative to other historical, zoned mafic eruptions.

Recommendation: Presentation and/or acquisition of additional data is necessary to support this conclusion. Consider alternative models. For example, modern cinder cone eruptions have often shown a great deal of trace element variation.

COMMENT 9.14

Statement of Concern: Conclusions D1 and D2. These conclusions are actually a discussion of one largely theoretical model.

Basis: This conclusion is actually a discussion of one largely theoretical model. Why not say that magma ascent *can* be modeled this way?

Recommendation: Rephrase this conclusion.

COMMENT 9.15

Statement of Concern: Conclusion D3. The importance of the level of neutral buoyancy has not yet been assessed.

Basis: As with conclusions D1 and D2, little work appears to have yet been done to support or modify these conclusions.

Recommendation: State that these models are preliminary and need to be tested.

COMMENT 9.16

Statement of Concern: Conclusion F4. The DOE has apparently not attempted to test this model.

Basis: Homogeneous Poisson models can be tested using a variety of methods. For example, the Clark-Evans test (Clark and Evans, 1955) can be applied to these data to indicate whether an homogeneous Poisson model is applicable. Furthermore, the hypothesis of waning magmatism is not supported by available data. An equally if not more valid interpretation is that magmatism is waxing in all respects except eruptive volume. Eruptive volume has remained relatively constant since about 1 Ma, which does not support a waning hypothesis.

Recommendation: Test the homogeneous Poisson model and consider viable alternatives.

References:

Clark, P.J., and F.C. Evans. 1955. On some aspects of spatial pattern in biological populations. *Science* 121: 397-398.

COMMENT 9.17

Statement of Concern: Conclusion F6. A low recurrence rate is chosen with respect to the late Quaternary recurrence rate.

Basis: The maximum, and probably the most defensible, event rate for the late Quaternary Crater Flat systems may be $7 \pm 2 \times 10^{-6}$ events yr^{-1}. The published literature (e.g., Ho et al. 1991) provides a strong argument for recurrence rates of 5 to 6×10^{-6} events yr^{-1}. Furthermore, averaging the eight most recent events over an arbitrary period of time, such as the Quaternary (1.6 million years) gives a recurrence rate of 5×10^{-6} events yr^{-1}. The most likely value reported in the status report is 2.6×10^{-6} events yr^{-1}. This is roughly equivalent to the average rate since the Miocene (Figure 3.10 shows about 28 post-caldera vents). Use of a rate this low will require a great deal of justification.

Recommendation: Consider higher recurrence rates.

References:

Ho, C-H., E.I. Smith, D.L. Feurbach, and T.R. Naumann. 1991. Eruptive probability calculation for the Yucca Mountain site, USA: Statistical estimation of recurrence rates. *Bulletin of Volcanology*: 54: 50-56.

COMMENT 9.18

Statement of Concern: Conclusion F8. Is the 6 km^2 figure justified in this case?

Basis: The random models for estimation of E2 use a repository area of 6 km^2. Maps of Lathrop Wells, Red Cone, and Black Cone, for example, indicate that vents are distributed over a substantial area. Therefore, an event outside the repository perimeter can still lead to disruption, not even considering the effect of a dike, which may be long relative to the volcanic edifice. Also, some discussion is warranted about the effect of an increased repository area on the probability estimates because larger areas have been discussed in the past.

Recommendation: Revise the E2 term to reflect the area of volcanic disruption in some consistent way.

COMMENT 9.19

Statement of Concern: Conclusion F8. The most likely value of magmatic disruption (6.5×10^{-9}) uses the geometric mean recurrence rate, not the most likely recurrence rate given in F6.

Basis: Using the most likely recurrence rate results in an annual probability of 8.3×10^{-9}. Using a recurrence rate of $7 \pm 2 \times 10^{-6}$ events yr^{-1} gives an annual probability of $1.8 \pm 0.5 \times 10^{-8}$. The conclusion that repository disruption is less than 1 in 10,000 for 10,000 years is not supported by the data and models presented in this study. In addition, a systematic study of alternative models is needed.

It is concluded in F8 that the probability of an eruption in the YMR is about 8.8×10^{-7} yr^{-1}, or 0.008 in 10,000 years using a homogeneous model. This corresponds to a recurrence rate of less than 1 volcano/million years and is too low. Using 7 volcanoes/million years, the probability of a new volcano forming in the region in 10,000 years is 0.07, using a homogeneous Poisson model.

Recommendation: Consider a broader range of recurrence rates, other models, and correct the wording in this conclusion.

3 SUMMARY AND GENERAL COMMENTS

3.1 QUALITY OF WRITING AND ORGANIZATION

Numerous difficulties exist in the current version of the LANL status report which can be resolved either by rewriting certain sections or by changing the organization of the report. Although the report is largely organized in an appropriate fashion, the History of Volcanism Studies section (Section VI) is not. It is difficult to evaluate many statements made in the History of Volcanism Studies section without referring to other sections. It would be better to discuss basic contributions within the sections dealing with specific volcanism issues. This is particularly true of the probability section. The work of Smith (1990), Ho et al. (1991), Ho (1992), and Sheridan (1992) should be discussed in detail in the probability section (Section VII), rather than in the History of Volcanism Studies Section.

3.2 DATA PRESENTATION

There is a great need to present the data used in support of the conclusions of this report. The lack of critical data provided within the report itself makes it quite difficult to verify models in several sections. Three data sets, which should be presented in tabular form, are:

(i) Vent locations in the YMR

(ii) YMR geochronological data collected by all groups, when available

(iii) Petrological and geochemical data collected in the YMR.

It is important to present vent locations in tabular form, with accepted geographic names, UTM coordinates, and relevant morphological information, such as cone volume, flow volume, elevation, and similar information. This will clearly delineate the data set the DOE is using in its probability models and related investigations. A great deal of interpretation relies on these data and they must be presented in a systematic fashion.

Similarly, it is critical to present all numeric geochronological data in tabular form, clearly stating the geographic location of the sample, the unit the sample was collected from, the method used to date the sample, the analytical uncertainty of the result, and the QA conditions under which the sample was dated. It is often unclear what geochronological data actually exist for specific volcanoes. The case of the ages of the Little Cones seems to be typical. Apparently, the only geochronological data on the Little Cones volcanoes is a date from a feeder dike exposed in a small scoria cone 0.5 km SE of the southern Little Cone. There are apparently no dates for the main cone of the southern Little Cone, nor for the amphibole-bearing northern Little Cone. Replicate K-Ar dates are alluded to, but do not appear in the references cited. Crowe et al. (1982) report six dates for "Western Rift Crater Flat" units, but the vents are not identified. These dates are, however, identical to those reported in Vaniman et al. (1982). Only one date is reported for "Little Cone SW," which is 1.11 ± 0.3 Ma. No other dates have been reported for either of the Little Cones. Other dates, which apparently range from 1.2 to 0.7 Ma for the Little Cones, are unpublished data from the USGS. Data and associated analytical uncertainties are not reported and, consequently, cannot be evaluated. This report is an ideal vehicle for the publication of a summary of these data. A simple table could alleviate much confusion and point to areas where additional geochronological work will be necessary. Furthermore, within the DOE status report, ages of specific units, such as the Sleeping Buttes volcanoes, vary. A table will help lend consistency to the reported values in various sections of the document.

A table of geochronological data will help identify uncertainties in ages. For example, it appears that, based on uncertainties, some Sleeping Buttes and Lathrop Wells eruptions could be contemporaneous. This kind of comparison is currently difficult to make but would be clear if data were presented in tabular form, following common methods in the geochronological literature. A summary of the Lathrop Wells data would clearly be very useful in evaluating the controversy. Again, this table could incorporate analytical uncertainties and report the QA conditions under which samples were gathered. This would provide a vehicle for presentation of all geochronological data collected, clearly differentiating data collected under accepted QA conditions, and those which were not.

Presentation of geochemical and petrologic data in a tabular form is also sorely needed. This is a widely accepted method of data presentation in petrology. Many of the arguments in Section II and Section IV rely on the interpretation of petrologic data. Yet there is no single location where the DOE has summarized the data they are currently using to develop and support models of the petrologic evolution of the YMR. This is a problem because it is clear that not all samples analyzed in the past are currently utilized in the interpretation. Again, such a table could indicate which data were collected under a QA program and which data were not.

3.3 EXPLORATION OF ALTERNATIVE HYPOTHESES

Probably one of the most difficult tasks for the DOE is to incorporate and review the existing literature in an effective manner. Naturally, DOE scientists will not agree with every position and some "scientific studies" will lack the data and/or rigorous interpretation required before a thorough assessment of their validity can be made. However, a number of studies are discussed in the LANL status report, many of which reach conclusions that are different than those reached by the DOE. Although the LANL report brings up important points about these studies, their approach needs to be evaluated more thoroughly. For example, Smith et al. (1990) have proposed a basic model in which the probability of disruption is enhanced by the presence of NE-trends. Certainly there are difficulties with their model. However, it does represent an attempt to incorporate basic structural information into the probability calculation. This approach is defensible and should be explored further. Other probability models, such as nonhomogeneous Poisson, hierarchical cluster, and Markovian models should be explored before definitive statements are made about probability of repository disruption. No probability model yet proposed incorporates geological information at an appropriate level.

As a related issue, there is also clearly a problem with estimating an appropriate recurrence rate, primarily because the late Quaternary recurrence rate is high relative to Post-Caldera Basalt, or Young Post-Caldera Basalt recurrence rates. Justification for using longer-term averages than the late Quaternary, or justification for rejecting the Poisson-Weibull or temporally nonhomogeneous models, will need to be made by the DOE.

This need to test alternative hypotheses is clear in other facets of the study as well. Petrologic modeling of the area is clearly in its early stages. However, it is apparent from the report that models are focusing on the concept that small volume basaltic magmatism in the region is waning. Alternative models need to be stated explicitly and explored. For instance, changes in crustal assimilation and/or magmatic volatile content can account for the observed petrologic and geochemical variation as easily as increased depth of partial melting.

In addition, although it is clear that consequence modeling is in its early stages (Valentine et al. 1992), there is a tendency in the LANL status report to indicate that eruptions are not particularly energetic. This tendency is especially clear in Sections I and VII. It is important for the DOE to examine a range of eruptive styles, from effusive to explosive/hydromagmatic, to discuss the conditions under which these eruptions occur, and to evaluate their likely impact on the repository.

3.4 VALIDITY OF THE HOMOGENEOUS POISSON PROBABILITY MODEL

It is critical that the DOE place additional emphasis on model testing. It is suggested in the LANL status report, for example, that it is difficult to test for randomness in vent distribution data because few events have occurred. It is possible to test the validity of the homogeneous Poisson distribution using several approaches. Connor and Hill (1993) applied two different statistical tests to evaluate the null hypothesis that vents in the YMR are well described by spatially homogeneous Poisson models. One such test is the Clark-Evans test (Clark and Evans, 1955), which compares the mean distance between nearest-neighbor observations, d for n vents within an area, A, against the mean distance expected from randomly distributed points, δ, within the same area:

$$CE = \frac{\bar{d}-\bar{\delta}}{S_e}$$

Assuming an homogeneous Poisson distribution (Ripley, 1981):

$$\bar{\delta} = 0.5\sqrt{A/n}$$

and

$$s_e = \sqrt{\frac{0.0683A}{n^2}}$$

Applying the Clark-Evans test using all vents within the AMRV rejects the null hypothesis at the 90 percent confidence level. Applying the test to only Quaternary vents (eight) in the AMRV rejects the null hypothesis if a lower confidence level of 84 percent is accepted. Diggle (1977; 1978), Ripley (1977), and Hines and Hines (1979) have noted that the Clark-Evans test is not robust because of edge effects. In the Yucca Mountain region, for example, the ability to distinguish vent clusters from a homogeneous Poisson vent distribution is strongly dependent on the size and shape of the area considered. The AMRV is a minimum area bounding all vents less than approximately 3 m.y. old, hence, the ability to resolve clusters within this area using the Clark-Evans test is limited.

More recently, several near-neighbor statistics have been developed to test for homogeneous Poisson distributions in point patterns. Aherne and Diggle (1978) define two measures of intensity (expected number of vents/unit area):

$$\hat{\lambda}_p = \frac{m}{\sum_{i=1}^{m} u_i}$$

$$\hat{\lambda}_v = \frac{m}{\sum_{i=1}^{m} v_i}$$

where u_i and v_i are areas of circles whose radii are the distance from the i^{th} randomly chosen point to the nearest vent, and the i^{th} vent to its nearest neighbor, respectively; m is the number of near neighbors; λ_p is the intensity estimated from m point-to-vent measurements; and λ_v is the intensity estimated from m vent-to-vent measurements. For a homogeneous Poisson distribution, λ_p and λ_v should be approximately equal. In clustered distributions, λ_v tends to measure the intensity within clusters, and λ_p is a measure of cluster intensity. The Hopkins F-test provides a method of testing for randomness in the vent pattern given these two measures of intensity:

$$Hop_F = \frac{\hat{\lambda}_p}{\hat{\lambda}_v}$$

The Hopkins F-test has a $F(2m,2m)$ distribution (Byth and Ripley, 1980). Emulating the procedures of Aherne and Diggle (1978), random points within the AMRV are used to calculate λ_p. If all vents in the AMRV are considered: $\lambda_v = 3.85 \times 10^{-3}$ vents/km^2, $\lambda_p = 9.31 \times 10^{-3}$ vents/km^2, and $Hop_F = 2.42$. If only Quaternary vents are used to estimate intensities, $Hop_F = 3.14$. In either case, the null hypothesis that vents are randomly distributed in the AMRV is rejected with greater than 99 percent confidence. Even in areas as narrowly defined as the CFVZ (e.g., Figure 3.10), the Hopkins F-test demonstrates that vent distribution is not appropriately modeled as a homogeneous Poisson distribution.

Probability models based on a homogeneous Poisson density distribution will overestimate the likelihood of future igneous activity in parts of the AMRV far from Quaternary centers and underestimate the likelihood of future igneous activity within and close to Quaternary vent clusters. This has a profound influence on probability calculations for future igneous activity near the proposed repository, because the site is located comparatively close to Crater Flat, the largest and youngest vent cluster in the YMR.

<u>References</u>:

Aherne, W.A., and P.J. Diggle. 1978. The estimation of neuronal population density by a robust distance method. *Journal of Microscopy* 114: 285-293.

Byth, K., and B.D. Ripley. 1980. On sampling spatial patterns by distance methods. *Biometrics* 36: 279-284.

Clark, P.J., and F.C. Evans. 1955. On some aspects of spatial pattern in biological populations. *Science* 121: 397-398.

Connor, C.B., and B.E. Hill. 1993. Volcanism Research. *NRC High-Level Radioactive Waste Research at CNWRA, July 1 — December 31 1992.* 10.1-10.31.

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Ripley, B.D. 1977. Modelling spatial patterns. *Journal of the Royal Statistical Society* B39: 172-212.

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3.5 VALIDITY OF CONCLUSIONS

In light of these comments, it is apparent that many of the conclusions of the DOE status report (Section IX) are not supported. The DOE status report presents interpretations based on a tremendous amount of research conducted over more than a decade. Nonetheless, substantial uncertainty remains about the probability and consequences of volcanism in the YMR.