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U.S. Nuclear Regulatory Commission
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Subject: Submittal of Poster—Quantifying Hazards from Basaltic Tephra-Fall Eruptions

Dear Mrs. DeMarco:

Enclosed is a poster for presentation at the Cities on Volcanoes meeting. This poster is based on work done by Brittain Hill, Charles Connor, James Weldy, and Nathan Franklin of the CNWRA. The poster describes the application and status of CNWRA's volcanic hazards assessment work.

The abstract for this poster, Quantifying Hazards from Basaltic Tephra-Fall Eruptions, was accepted by the NRC in an e-mail from J. Trapp dated September 18, 2000. This poster will be presented at the Cities on Volcanoes meeting in Auckland, New Zealand, in February of 2001.

If you have any questions please contact Dr. Brittain Hill at (210) 522-8067 or me at (210) 522-5252.

Sincerely,

Budhi Sagar
Technical Director

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Enclosure

cc (w/o encl.):	J. Linehan	B. Meehan	T. Essig	B. Hill
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	B. Leslie	J. Holonich	W. Patrick	J. Weldy
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Quantifying Hazards from Basaltic Tephra-Fall Eruptions

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In Vulcan Veritas

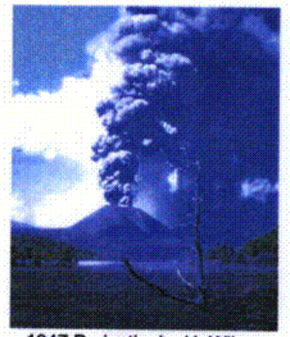
Introduction

1975 Tolbachik Cone 2, by Yu. Doubik

Basaltic cinder cone fields located in populated areas (e.g., Auckland, Mexico City) can adversely impact public health and safety by depositing centimeters or more of tephra. Some critical facilities such as nuclear power plants or waste repositories are located where future eruptions may directly disrupt facility operations.

Risks from future eruptions should be quantified to make informed decisions regarding the siting of critical facilities or potential mitigation strategies. Few tephra deposits, however, are preserved at most cinder cones older than 1,000 yr, making hazards difficult to quantify.

Hazards from future eruptions can be evaluated quantitatively using models that sample a range of eruption parameters stochastically. Here, we present several key components in quantifying hazard and risk from basaltic cinder cone eruptions.

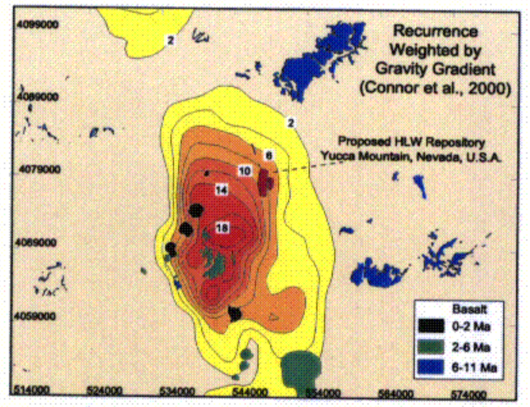


1947 Paricutin, by H. Wilcox

(1) What Are The Odds?

- Spatio-temporal patterns of past volcanism
- Geologic structure combined with statistical models

The timing and location of past eruptions can be used to develop spatio-temporal probability models (Connor et al., 2000). For the Yucca Mountain Region, Nevada, U.S.A., the past 11 m.y. of distributed basaltic volcanism is used to model variations in spatial recurrence rate. Here, spatial recurrence rate (volcanoes/km^2) is shown using a modified Gaussian kernel function that incorporates tectonic control on the recurrence rate. Note a proposed high-level radioactive waste repository site is located on a recurrence gradient, which corresponds to a probability of 1:1,000 to 1:10,000 of a new volcano forming at the site in the next 10,000 yr.



(2) What Type of Eruption?

- Basaltic cinder cones can disperse tephra 10's of km
- DRE Fall volumes are ≈ DRE Cone volumes

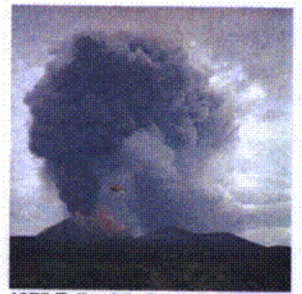
Observed cinder cone eruptions often produce 2-6 km high tephra columns that rise convectively and disperse tens to hundreds of km down wind. This violent Strombolian style is much more dispersive than classic Strombolian eruptions.

Tephra deposits >1 ka are poorly preserved, making dispersivity characteristics difficult to interpret. Although highly fragmented cone deposits strongly suggest a violent Strombolian eruption (i.e., dispersive), poorly fragmented and agglutinated deposits also can occur on violent Strombolian cones.

For example, 1975 Tolbachik Cone 2 is moderately agglutinated with abundant rheomorphic bombs, and a steep, armored crater that is breached by a large-volume lava flow. This features might suggest a low dispersivity, Strombolian eruption.

Cone 2, however, sustained 2-5 km high eruption columns with 22% of the erupted volume (DRE) as tephra falls, which is typical of violent Strombolian eruptions.

1995 Cerro Negro, 2.5-km-high



1975 Tolbachik Cone 1, 6-km-high

1975 Tolbachik Cone 2, 4-km-high column

80 ka Lathrop Wells volcano, Nevada. Likely 4-km column, 0.03 km^3 falls (1.4x cone)

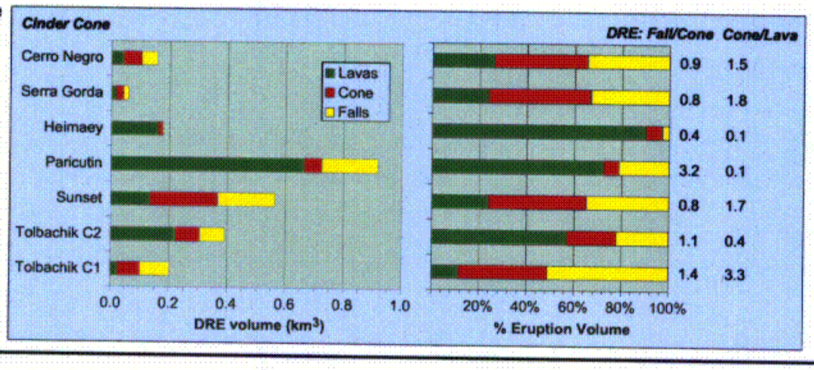
Using data from historically active analog volcanoes, we estimate these characteristics for Quaternary Yucca Mountain basaltic cinder cone volcanoes, which have Cone/Lava = 0.1 to 1.9

Estimated YMR volcano characteristics:
DRE Fall/Cone = 0.5 to 1.4

DRE Volume of Tephra = 1x10^6 to 5x10^7 m^3
DRE Total Volume of Eruption = 2x10^7 to 2x10^8 m^3

Column Heights = 2 to 6 km
Eruption Duration = 50 to 360 hr

Average Particle Diameter = 1 mm



(4) Hazards from Ash

- Basaltic ash can disrupt facility operations & collapse roofs
- Minor acute health effects, unlikely to cause long-term effects
- Radioactive particles in ash present significant health risks

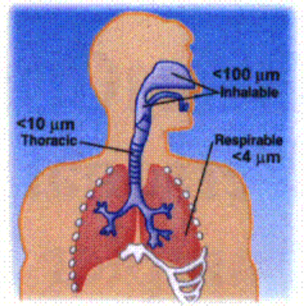
Fresh tephra-fall deposits from 1995 Cerro Negro have *in situ* densities of around 1200 kg/m^3 at 1-5 km from the vent, which decrease to around 600 kg/m^3 at 20 km. In 1992, 4-5 cm of tephra collapsed poorly framed buildings and clogged the water supply to 300,000 people in Leon, Nicaragua. Structural failures and electrical conduction also increase with rainfall.

After the 1992 Cerro Negro eruption, acute respiratory illnesses increased 5x and acute diarrhea increased 6x for several months (Malilay et al., 1997). Infants and people with preexisting respiratory ailments were most sensitive to ash-related illnesses.

Basaltic falls do not contain measurable crystalline silica and thus are unlikely to present significant long-term health effects (e.g., Baxter et al., 1999).

In the unlikely event a volcano erupts through a nuclear facility, radionuclides from nuclear facilities could be incorporated into the basaltic ash. Inhalation of contaminated ash can result in significant adverse health effects, through absorption of nuclides in the naso-thoracic region and respiration into the alveolar region of the respiratory system. Inhaled ash ≤100 μm must be evaluated in dosimetry calculations.

1992 Cerro Negro, Nicaragua. 5 cm tephra at about 20 km from vent



10 km from Cerro Negro February 1999

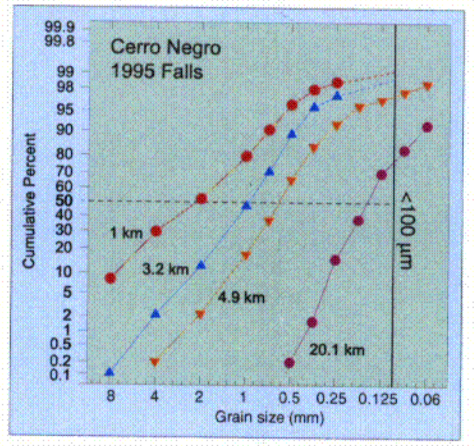
(5) Deposit Characteristics

- Falls contain 1-20% suspendable ash (<100 μm)
- Airborne particle concentrations in literature are rarely analogous

Basaltic tephra falls are rarely analogous to soils commonly monitored for airborne particle concentrations. Relative to soils, falls are very poorly sorted, nonvegetated, and lack clays or cementation.

Airborne particle concentrations were measured for 8 days in February 1999 over tephra-fall deposits from the December 1995 Cerro Negro eruption. Fall deposits collected immediately after the eruption contain 1-3 wt% of suspendable ash (i.e., ≤100 μm) within 5 km of the vent. Suspendable ash increases to 25 wt% at 20 km from the vent.

This area receives about 1 m of rainfall annually, with at least 2 m rainfall from Hurricane Mitch in November 1999. Although overland flow was not established on these highly permeable deposits, fine ash was visibly depleted from the surface layer by rainfall infiltration. Initial airborne particle concentrations likely were higher than measured after washing the deposit with about 6 m of rainfall.



(6) Sampling Methods

- Direct measurements must be made in the breathing zone
- Appreciable weighing errors even with a microbalance

Resuspended ash concentrations were measured primarily with Respicon virtual impactors, which use calibrated airflow velocities to deposit aerodynamically sorted particles onto preweighed filters. In addition, total suspended particulates (TSP) were measured using IOM filters attached to calibrated air pumps.

Filters were desiccated and weighed on a microbalance before and after sampling. Uncertainties are calculated based on weighing errors and flow-rate variations, and reported at 1 standard deviation.

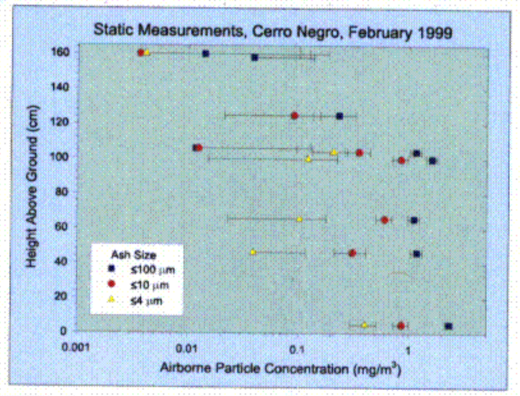
Respicon particle sampler with personal air pump

Concentrations of 10-100 μm ash are sensitive to distance above the ground surface, due to relatively high gravitational settling rates after eolian entrainment. Ash ≤10 μm is much less sensitive to settling effects. Note the roughly exponential trend of decreasing ash concentration with increasing height.

Because 10-100 μm ash is important for radiological studies, the height of airborne particle concentration measurements must be known.

The breathing zone extends about 50 cm around the nose and mouth. Measurements over disturbed deposits were conducted with filters 10-20 cm from the nose, within the breathing zone.

Wind speed and direction were measured during particle sampling. Daily wind speeds averaged 4±2 m/s and were directed across the 1995 fall deposits.



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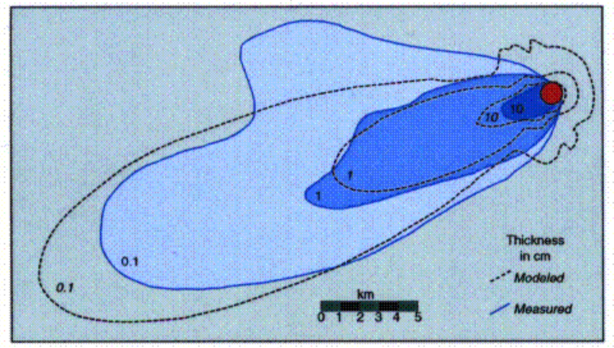
(3) Tephra Dispersal Modeling

- Tested, empirical model for tephra-fall dispersal and deposition
- Stratified wind field gives 3D hazard maps
- Parallelized code allows statistically significant number of realizations

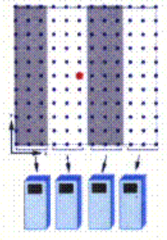
The modified Suzuki (1983, *Arc Volcanism*) model ASHPLUME is used to calculate fall-deposit thicknesses. This is a 2D advective diffusion model, suitable for continuous release eruptions with particle sizes >15 µm.

- Empirical; most parameters measured from eruptions and deposits:
  - Wind Speed - Wind Direction - Column Height
  - Tephra Volume - Eruption Duration - Column Shape
  - Clast Diameter - Clast Sorting - Clast Density

- ASHPLUME model reasonably calculates tephra-fall thicknesses from basaltic eruptions, as shown by comparison with 1995 Cerro Negro eruption (Hill et al., 1998, *Geol. Soc. Am. Bull.*).



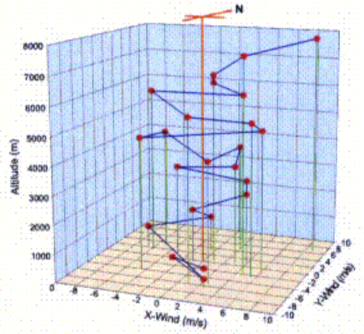
Comparison of 1995 Cerro Negro tephra-fall isopachs with isopachs calculated using the modified Suzuki (1983) model ASHPLUME.



Grid-based parallel processing

ASHPLUME is readily parallelized using Parallel Virtual Machine software running under LINUX (Connor et al., 2001, *Nat. Haz. Rev.*). We constructed a Beowulf cluster using ten 200 MHz Pentium II computers with a 400 MHz PII master node. Processing times for ASHPLUME on the cluster are comparable to a SUN 4-processor Enterprise 3500 server, or roughly 10x faster than a single 200 MHz PC.

For each model realization, ASHPLUME samples eruption and atmospheric parameters stochastically. A daily wind profile is randomly selected from a file of 14,000 radiosonde measurements for the Yucca Mountain area. Each measurement records wind speed and direction for 20-25 atmospheric levels between 0-10,000 m above ground level.

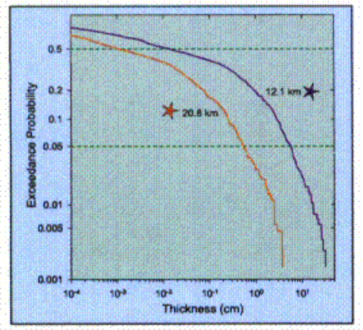


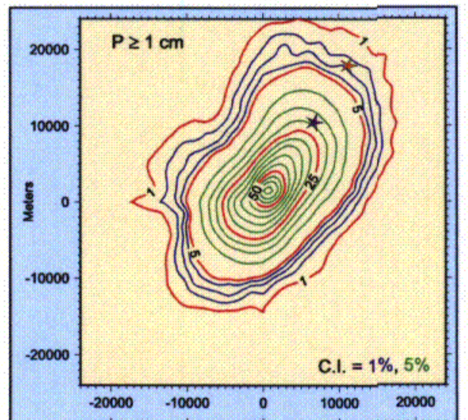
Representative daily wind field for Yucca Mtn area. The interval-weighted average of the velocity and direction vectors is used to model particle fall.

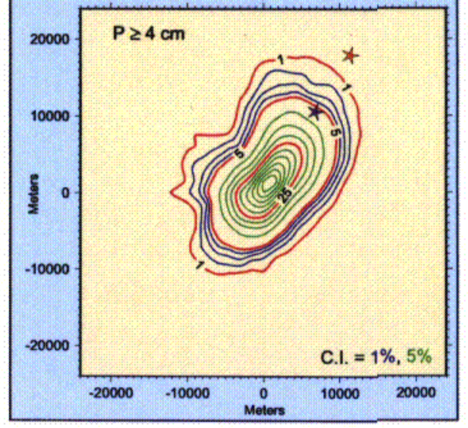
Deposit thickness is calculated 1,000 times for each 1-km point on a 50x50 km grid, sampling eruption and atmospheric parameters stochastically.

Results for each point are ordered and statistics calculated. The complementary cumulative distribution functions (right) show likelihoods of tephra exceeding specific thickness at starred points, given that an eruption occurs.

For example, at point ✶12.1 km NE of the volcano, tephra thickness should be <0.2 mm 50% of the time, and <6 cm 95% of the time, for eruptions using June-September winds patterns above Yucca Mountain, Nevada, U.S.A.







Results can be displayed to communicate different types of hazard information.

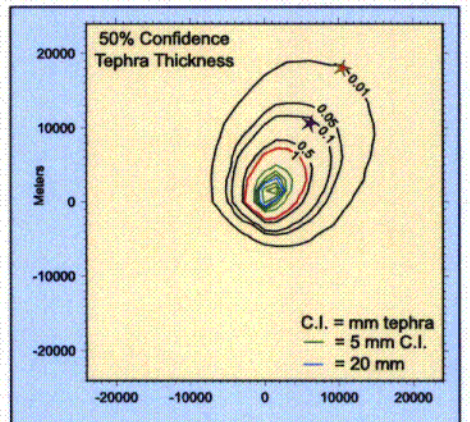
Probabilities of exceed specific hazard levels are often used in quantitative risk assessments.

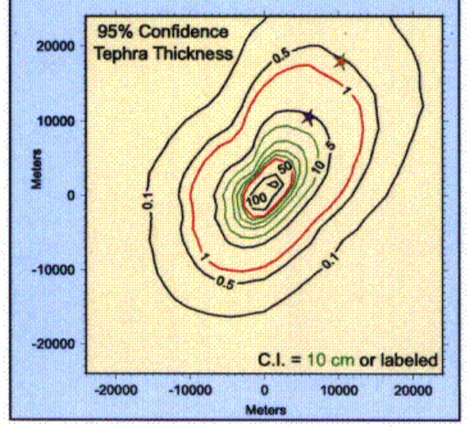
On the left, the probabilities of exceeding specific fall thicknesses are contoured. If 1 cm of fall is hazardous to people or systems, then this plot shows likelihood of exceeding 1 cm at any given location if an eruption occurs.

Other times, people may want to know what modeled deposit thicknesses are at given confidence levels.

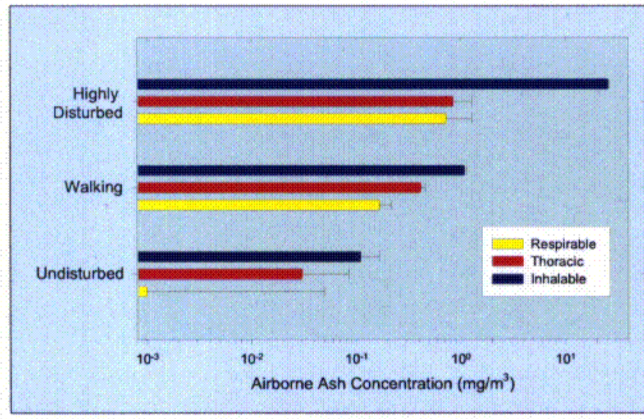
On the right, deposit thickness is contoured at 50% and 95% confidence levels, using the calculated distributions for each grid point.

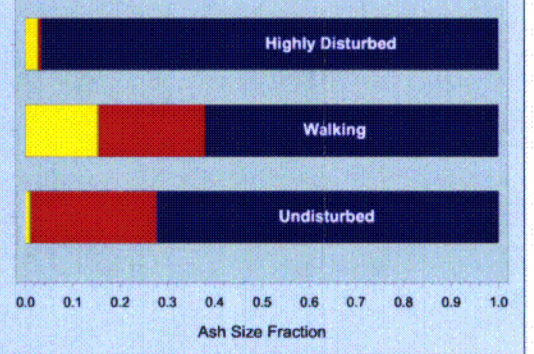
This approach allows decision makers to define a confidence level for mitigation/evacuation decisions, then see how deposit thickness can vary within that modeled confidence level.





(7) Airborne Ash Concentrations





Average airborne ash concentrations and 1σ uncertainties are shown for breathing zones located above:

- Highly Disturbed deposits driven over by a pickup truck or with digging
- Lightly distrubed deposits walked over by an individual
- Undistubed static deposits with a 4±2 m/s wind blowing across the tephra deposits toward the sample site

Ash <4 µm, like all fine particulates, may affect deep respiration processes. Respirable ash, however, represents a minor fraction of the total suspended ash above basaltic tephra fall deposits.

(8) Conclusions

- Tephra-fall hazards can extend for tens of kilometers from many basaltic cinder cone volcanoes
- Although eruption style is difficult to determine without tephra deposits, dispersive (i.e., violent Strombolian) eruptions can produce steep, agglutinated cones with significant lava flows, as well as fragmented cones with equivalent-volume flows.
- Well preserved cinder cones <5 ka have DRE volumes of Fall/Cone = 0.4-3.2 and Cone/Lava = 0.1-3.3 These volumetric relationships can be used to constrain likely tephra volumes for poorly preserved cinder cones.
- Quantitative tephra-fall hazard maps can be produced using a modified convective-dispersive model of Suzuki (1983), with stochastic sampling of volcanic parameters and stratified wind fields.
- Results of tephra dispersal models can be displayed as exceedance probabilities for specific fall-thickness hazards, as deposit thickness based on fixed confidence level, or in format needed to communicate hazard clearly.
- Highly disturbed basaltic tephra falls can produce airborne concentrations of 1-100 µm ash around 10 mg/m^3. Concentrations above lightly disturbed deposits are around 1 mg/m^3, and decrease to around 0.1 mg/m^3 for static, nondisturbed deposits.
- Respirable basaltic ash is generally <10% of the total suspended ash, and lacks silicate minerals linked to long-term respiratory illnesses.
- The primary hazard from basaltic tephra falls is collapse of buildings and damage to infrastructure from abrasive, conductive ash, with some short-lived health effects. Stochastic process models and data shown herein allow rigorous quantification of tephra-fall hazards. These results can be used for long-term risk mitigation or near-real time hazards assessment.

1 ka Sunset Crater, Arizona, U.S.A.

1975 Tolbachik Cone 1, by Yu. Doubik

Yerevan Nuclear Power Plant, Armenia

We thank Brandi Winfrey, Ron Martin, Mark Jarzemba, Jose De La Espriella, and Laura Connor for their computational assistance. Field assistance at Cerro Negro volcano by Wilfried Strauch, Marta Navarro, and Graciella Davoli of the Instituto Nicaragüense de la Estudios Territoriales, and Peter La Femina and Mike Conway, is gratefully acknowledged. Discussion with Peter Baxter, Chris McKenney, Steve Sparks, Andy Woods, and Yuri Doubik have helped clarify many aspects of basaltic volcanic hazards.

Baxter, P.J., C. Bonadonna, R. Dupree, V.L. Hards, S.C. Kohn, M.D. Murphy, A. Nichols, R.A. Nicholson, G. Norton, A. Searl, R.S.J. Sparks, and B.P. Vickers. 1999. Cristobalite in volcanic ash of the Soufriere Hills volcano, Montserrat: hazards implications. *Science* 283: 1142–1145.

Connor, C.B., B.E. Hill, B. Winfrey, N.M. Franklin, and P.C. La Femina. 2001. Estimation of Volcanic Hazards Related to Tephra Fallout. *Natural Hazards Review*, in press.

Connor, C.B., J.A. Stamatakos, D.A. Ferrill, B.E. Hill, G. Ofoegbu, F.M. Conway, B. Sagar, and J.S. Trapp. 2000. Geologic factors controlling patterns of small-volume basaltic volcanism: Application to a volcanic hazards assessment at Yucca Mountain, Nevada. *Journal of Geophysical Research* 105: 417–432.

Hill, B.E., C.B. Connor, M.S. Jarzemba, P.C. La Femina, M. Navarro, and W. Strauch. 1998. 1995 eruptions of Cerro Negro volcano, Nicaragua, and risk assessment for future eruptions. *Geological Society of America Bulletin*, 10: 1231–1241.

Malilay, J., M.G. Real, A.R. Vanegas, E. Noji, and T. Sinks. 1997. Vigilancia de la salud pública despuis de una erupción volcánica: lecciones aprendidas en Cerro Negro, Nicaragua, 1992. *Revista Panamericana de Salud Pública* 1(3): 213–219.

Suzuki, T. 1983. A theoretical model for the dispersion of tephra. Shimozuru, D. and I. Yokiyama, eds. *Arc Volcanism: Physics and Tectonics*. Tokyo, Terra Scientific Publishing, p. 95-113.

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