Geomorphologic Evolution of the Tephra Deposit from Parícutin Volcano, Mexico

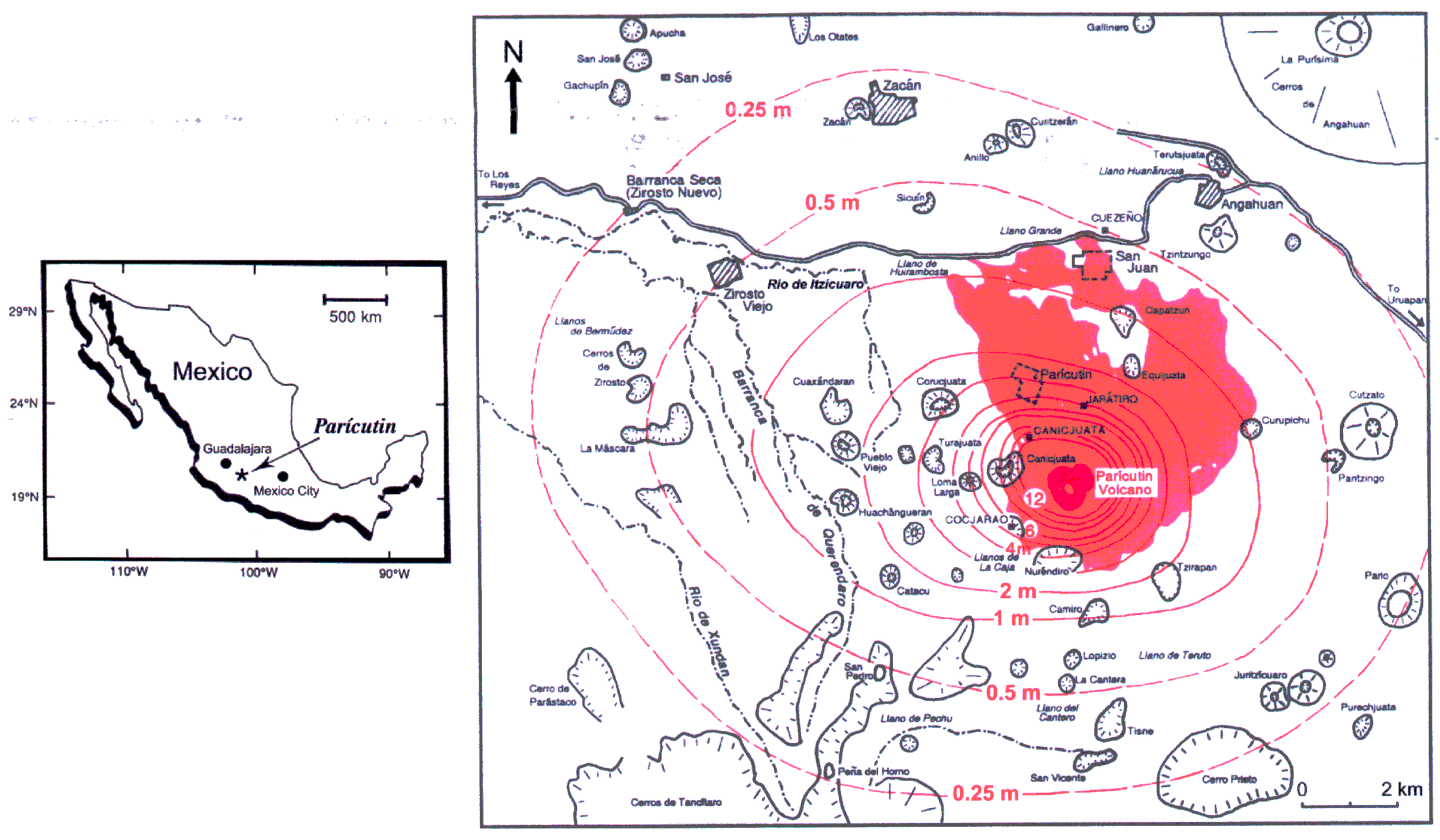
Donald M. Hooper and Brittain E. Hill

Center for Nuclear Waste Regulatory Analyses, Southwest Research Institute
San Antonio, Texas 78238-5166 U.S.A.
E-mail: DHooper@swri.org

CNWRA
A center of excellence in earth sciences and engineering ™

ABSTRACT

The 1943–1952 eruption of Parícutin scoria cone, Mexico, produced a tephra-fall deposit with a reported volume of 1.3 km^3. Emplacement of pyroclastic deposits results in accelerated erosion and increased sediment yield in affected drainages. Published data for Parícutin show that the erosion rate peaked in 1944, with a relative sediment yield seven times greater than the average pre-eruption rate. Extrapolation of these data using a logarithmic curve fit indicates that the Parícutin area should have returned to a pre-eruption sediment yield by 1972. A sediment budget was devised for Parícutin fall deposits to demonstrate the mass-flux relationships for abstracted processes of annual sediment production, transport rate, tephra remobilization and dilution, and associated changes in sediment storage capacity. For this first-order approach, all erosive processes are combined into an annual measure of sediment production. Using this sediment budget technique with an erosion rate of 10 $m^3 km^{-2} yr^{-1}$ and a deposit area of 58,682 km^2 [22,657 mi^2], less than 4% of the Parícutin tephra-fall deposit was eroded and redistributed between 1943–1972. Assuming a constant erosion rate, this model suggests at least 2,200 years of additional erosion is needed to remove the Parícutin fall deposit. This modeling approach has additional applications, including remobilization of possibly contaminated tephra from the potential high-level waste repository at Yucca Mountain, Nevada (USA).



Tephra thickness (to October 1946), cone (dark red), lava field (light red), drainages, and local names [modified from Segerstrom (1950) and Luhr and Simkin (1993)].

EROSION OF TEPHRA-FALL DEPOSITS

A process-level model is being developed to evaluate the long-term redistribution of tephra following a scoria-cone (violent strombolian) eruption. Initial modeling efforts focus on the deposits from three scoria cones with different sediment yields:

1. Parícutin (Michoacán, Mexico) with a high sediment yield of 100 $m^3 km^{-2} yr^{-1}$.

2. Sunset Crater (Arizona, U.S.A.) with an intermediate sediment yield of 50 $m^3 km^{-2} yr^{-1}$.

3. Lathrop Wells near Yucca Mountain (Nevada, U.S.A.) with a low sediment yield of 15 $m^3 km^{-2} yr^{-1}$.

Patterns of degradation at volcanoes such as Mount St. Helens and Mount Pinatubo typically show a peak in the erosion rate within 2 to 3 years after the eruption, and then rapidly decline. This decline is caused by:

- recovery of vegetation

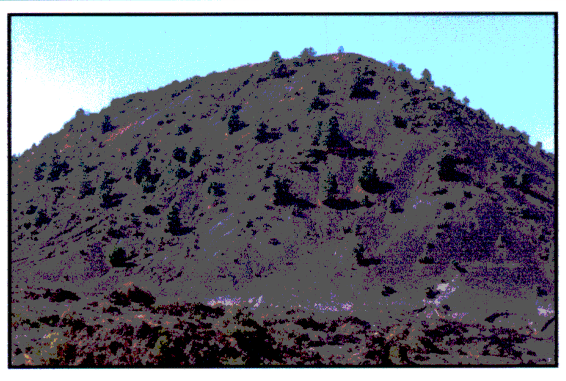
- decreased erodibility because of changes in the infiltration capacity of the tephra layer

- exposure of less erodible substrates

- development of a stable rill network.

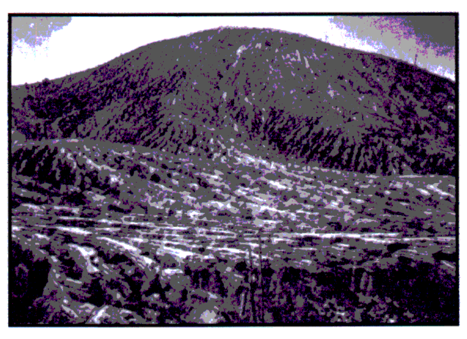
APPROACH

A simplifield mass-balance methodology is used to evaluate the geomorphologic evolution of a tephra-fall deposit following an eruption. Mass-flux is expressed in a sediment budget, which is a quantitative relationship that links erosion and sediment production, transport processes, storage and remobilization, and discharge from an eroding drainage basin.



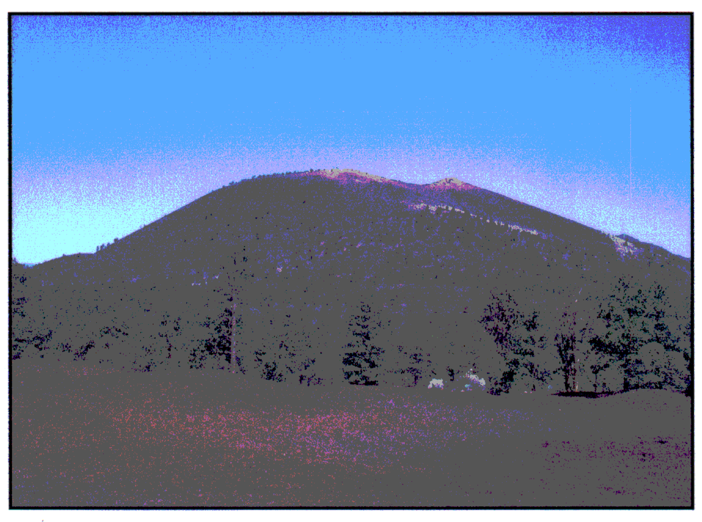
Rilling and gullying in the Paricutin tephra deposit, January 1997.

Parícutin volcano (Mexico) erupted from 1943 to 1952. The eruption produced a scoria (or "cinder") cone with an average height of 220 m and an average width of 950 m. Initial studies estimated a tephra-fall deposit volume of 1.3 km^3 (Fries, 1953), but more recent reports suggest a tephra deposit volume of 0.4 km^3 (e.g., NRC, 1999). The area encompassed by the 1 cm isopach is 6,000 km^2. Segerstrom (1950, 1960, 1961, and 1966) provided a thorough documentation of subsequent erosion.

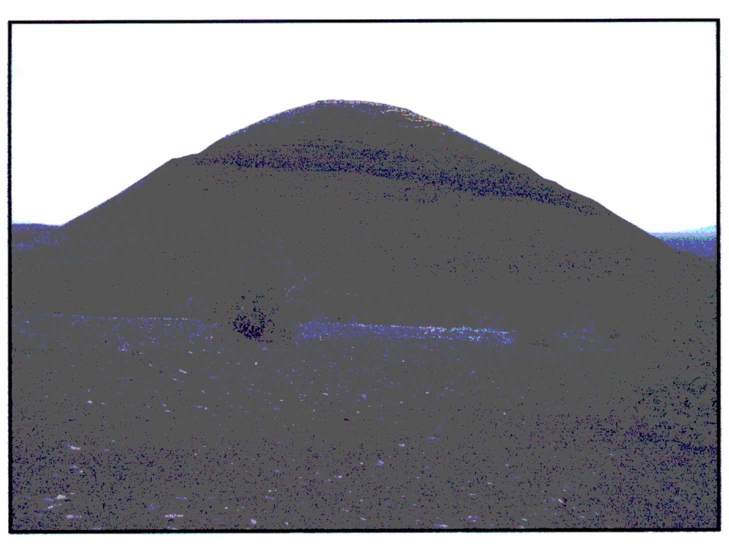


The Parícutin tephra deposit in February 1957, five years from the end of the eruption, displays extensive rilling and gullying (from Segerstrom, 1960). The deposit here is several meters thick and is fine grained. Rainfall averages 1,800 mm on this high-plateau region of Mexico. The underlying older cone and lavas are relatively impermeable, which influences the geomorphologic character of this deposit.

Near the base of the Parícutin cone, small rock-capped pedestals left after raindrops have splashed away the ash around their bases show the extent of erosion effected by raindrop impact. Sheet wash, rilling, and shallow landslides are the dominant surface processes eroding tephra-fall deposits from scoria cones, rather than lahars and large landslides.



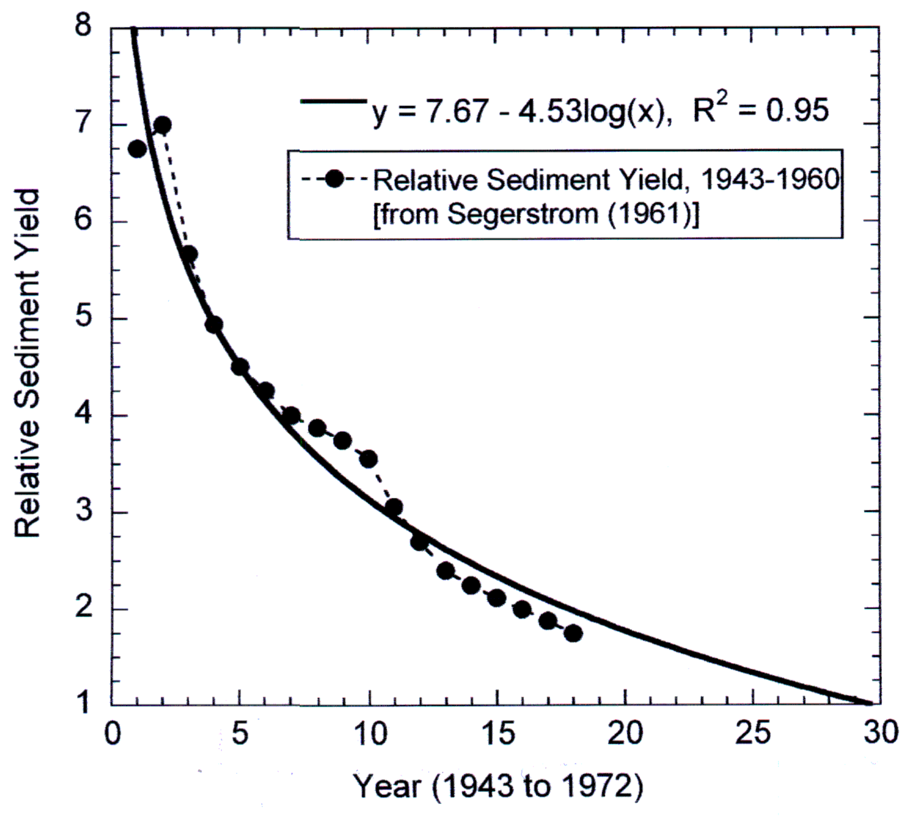
Sunset Crater volcano in the San Francisco volcanic field of northern Arizona (U.S.A.) erupted about 1100 A.D. The cone is 314 m in height and the calculated volume of the tephra-fall deposit is 0.75 km^3 (Amos, 1986). The area encompassed by the 1 mm isopach is 2,800 km^2. Precipitation averages 435 mm/yr in this region of Arizona. The tephra here is also several meters thick, but there is less gullying and overland flow than at Parícutin due to a more permeable deposit and substrate.



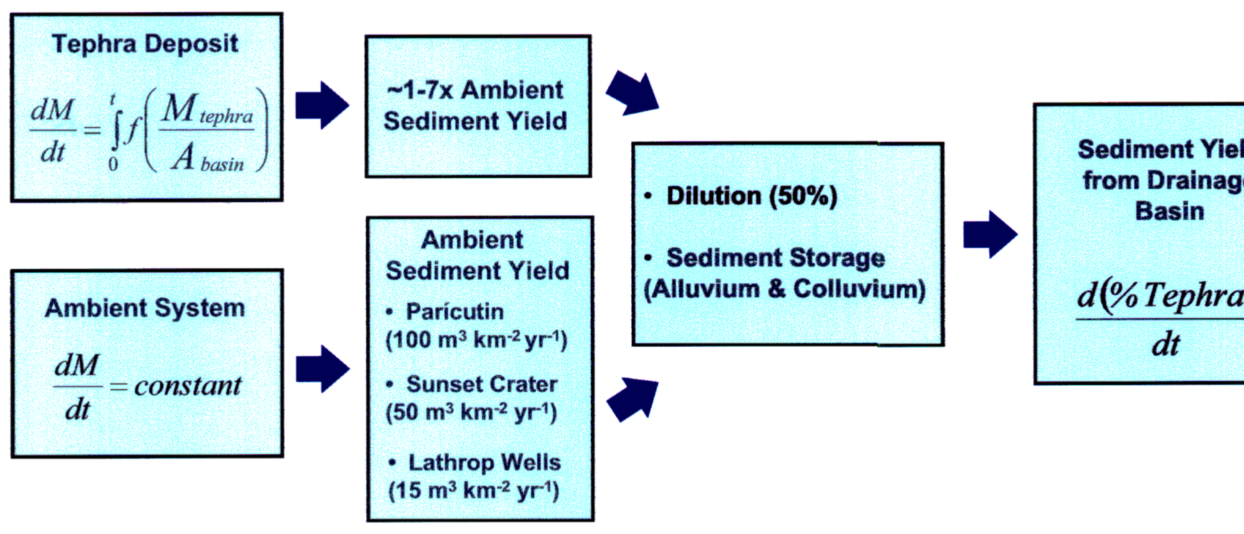
Lathrop Wells cone in the Crater Flat-Yucca Mountain region of southern Nevada (U.S.A.) has a present height of about 140 m (there is active quarrying along the south margin). Almost the entire 80,000-year-old tephra deposit has been eroded away, but the initial volume has been estimated to be 0.04 km^3 (NRC, 1999; BSC, 2003). The BSC (2003) study estimates an area of 182 km^2 encompassed by the 1 cm isopach. This is an arid region of Nevada with an ephemeral drainage system that receives an annual rainfall of 150 mm. In a desert soil, the progressive enrichment of clay and carbonates in the subsoil slowly restricts the depth of water penetration and increases surface runoff. Therefore, the extent and character of erosion is a complex function of site-specific processes and characteristics.

DECLINE IN EROSION AT PARÍCUTIN VOLCANO

Emplacement of pyroclastic deposits results in accelerated erosion and increased sediment yield in affected drainages. Published data (Segerstrom, 1961) for Parícutin show that the erosion rate peaked in 1944, with a relative sediment yield seven times greater than the average pre-eruption rate. Extrapolation of these data using a logarithmic curve fit indicates that the Parícutin area should have returned to a pre-eruption sediment yield by 1972 (after 30 years). This is in contrast to Inbar et al. (1994), who estimate that the declining trend will continue for several decades (after 1990) until it reaches pre-eruption erosion values.



SEDIMENT BUDGET AND CONCEPTUAL MODEL

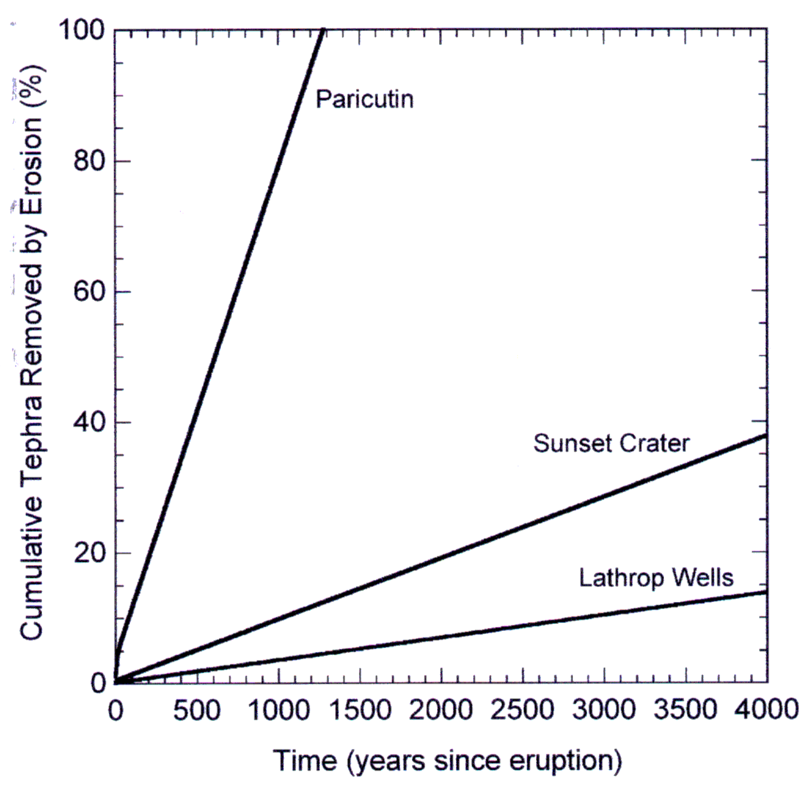


APPLICATION OF MODEL

Using the calculation that sediment yield recovers in about 30 years at Parícutin, a simple model for change in sediment yield through time is applied. We assume for this first-order conceptual model that other scoria-cone volcanoes would show a similar increase in sediment yield of 1-7x following an eruption.

RESULTS

The model is applied using data in the adjoining table and a 50% tephra dilution rate. Note that basin area and yield are revised from the abstract data. For Parícutin, the model results (y=3.9+0.075x) show that the cumulative volume of tephra removed by erosion should reach 100% after 1,280 years from the time of the eruption. About 8.5% of the tephra deposit has eroded by year 2004 (62 years since the eruption started). For Sunset Crater, the model results (y=0.5+0.0093x) show that the cumulative volume of tephra removed by erosion should reach 100% after 10,700 years from the time of the eruption. About 9.5% of the tephra has been eroded since deposition approximately 900 years ago. For Lathrop Wells (y=0.18+0.0034x), the results indicate that 100% of the deposit was eroded after 29,000 years (only minimal remnants of tephra remain at present).



Comparison of Scoria Cone Data

Volcano	Parícutin	Sunset Crater	Lathrop Wells
Location	Michoacán, Mexico	Arizona, U.S.A.	Nevada, U.S.A.
Volume of Tephra (km^3)	0.4	0.75	0.04
Tephra Area (km^2)	6,000	2,800	182
Sediment Yield ($m^3 km^{-2} yr^{-1}$)	100	50	15
Annual Precipitation (mm)	~1,800	435	150

Sources: Segerstrom (1950), Milliman and Meade (1983), Amos (1986), Graf (1988), Yucca Mountain Site Characterization Project (1993), NRC (1999), and BSC (2003).

CONCLUSIONS

- A simplified mass-balance approach using a sediment budget can evaluate tephra redistribution (geomorphologic evolution) following an eruption.

- At Parícutin, up to a 7x increase in sediment yield occurred immediately following the eruption, declining to ambient yields in about 30 years.

- Stated as a general understanding, sediment yields increase by 1-7x for some time after an eruption, but duration critically depends on the nature of the deposit, local substrate characteristics, vegetation, and rainfall.

- Scoria cones such as Sunset Crater show that substantial tephra deposits can persist for 1,000 years, even with periods of accelerated sediment yield.

- Application of this first-order model indicates that ~8.5% of the Parícutin tephra deposit has eroded in the 62 years since the eruption started, and ~9.5% of the Sunset Crater tephra deposit has eroded in the approximately 900 years since that eruption began. For Lathrop Wells, results indicate that 100% of the deposit was eroded after 29,000 years.

- A sediment budget is a quantitative relationship that links sediment sources, transport processes, storage and remobilization, and basin discharge. It provides a predictive tool for estimating sediment redistribution and developing landscape management strategies.

ACKNOWLEDGEMENTS

This poster was prepared to document work performed by the Center for Nuclear Waste Regulatory Analyses (CNWRA) for the U.S. Nuclear Regulatory Commission (NRC) under contract NRC–02–02–012. This poster is an independent product of the CNWRA and does not necessarily reflect the views or regulatory position of the NRC.

Presented at the IAVCEI (International Association of Volcanology and Chemistry of the Earth's Interior) General Assembly 2004, Pucón, Chile.

REFERENCES

Amos, R.C. "Sunset Crater, Arizona: Evidence for a large magnitude strombolian eruption." Master's thesis. Arizona State University. Tempe, Arizona: 1986.

BSC (Bechtel SAIC Company, LLC). *Characterize Eruptive Processes at Yucca Mountain, Nevada.* ANL-MGR-GS-000002, Rev 01. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2003.

Fries, C. "Volumes and Weights of Pyroclastic Material, Lava, and Water Erupted by Parícutin Volcano, Michoacan, Mexico." Transactions, American Geophysical Union. Vol. 34 No. 4, pp. 603–616. 1953.

Graf, W.L. *Fluvial Processes in Dryland Rivers.* Caldwell, New Jersey: The Blackburn Press. 1988.

Inbar, M., J.L Hubp, and L.V. Ruiz. "The Geomorphological Evolution of the Parícutin Cone and Lava Flows, Mexico, 1943-1990." Geomorphology. Vol. 9. pp. 57–76. 1994.

Luhr, J., and T. Simkin. *Parícutin: The Volcano Born in a Mexican Cornfield.* Phoenix, Arizona: Geoscience Press/Smithsonian Institution. 1993.

Milliman, J., and R. Meade. "World-wide Delivery of River Sediment to the Oceans." Journal of Geology. Vol. 91. pp. 1–21. 1983.

NRC (U.S. Nuclear Regulatory Commission). *Issue Resolution Status Report Key Technical Issue: Igneous Activity. Rev. 2.* Washington, D.C.: U.S. Nuclear Regulatory Commission. 1999.

Segerstrom, K. "Erosion studies at Parícutin, state of Michoacán, Mexico." U.S. Geological Survey Bulletin 965-A. p. 164. 1950.

Segerstrom, K. "Erosion and related phenomena at Parícutin in 1957." U.S. Geological Survey Bulletin 1104-A: pp. 1–18. 1960.

Segerstrom, K. "Deceleration of erosion at Parícutin, Mexico." U.S. Geological Survey Professional Paper 424–D. pp. D-225 to D-227. 1961.

Segerstrom, K. "Parícutin, 1965-Aftermath of Eruption." U.S. Geological Survey Professional Paper 550–C. pp. C93–C101. 1966.

Yucca Mountain Site Characterization Project. *Evaluation of the Potentially Adverse Condition "Evidence of Extreme Erosion During the Quaternary Period" at Yucca Mountain, Nevada.* Topical Report YMP/92-41-TPR. Las Vegas, Nevada: Yucca Mountain Site Characterization Office. 1993.

D-02