ECOLOGY

25 Years of Ecological Change at Mount St. Helens

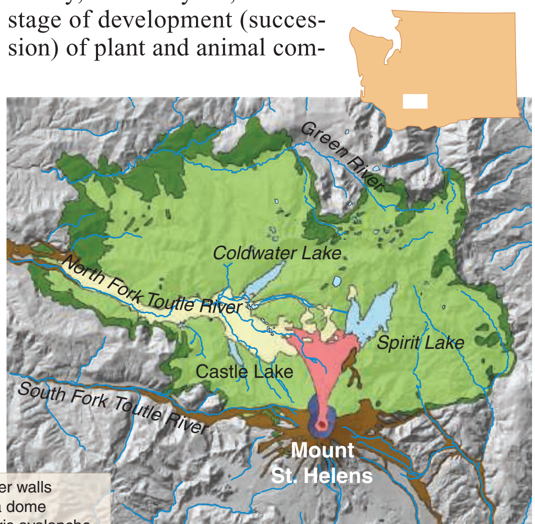
V. H. Dale, C. M. Crisafulli, F. J. Swanson

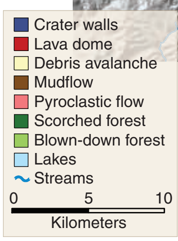
18 May 2005 marks the 25th anniversary of the massive eruption of Mount St. Helens. This eruption involved diverse geological processes (*1*) that disturbed forests, meadows, lakes, and rivers (*2*) (see the figure). A huge landslide and searing flows of hot gases and pumice fragments (pyroclastic flows) inundated 60 km^2 of land, obliterating preexisting ecosystems and landforms. A steam-driven blast left blown-down forest and scorched standing forest over more than 500 km^2, but deposited generally <1 m of new material. A gentle rain of tephra (airborne volcanic rock fragments) fell from the sky and blanketed >1000 km^2 of live forest and aquatic systems with >5 cm of deposits (*2*). The initial impression of a lifeless landscape quickly changed as surviving plants and animals reemerged.

Survival of organisms was strongly influenced by characteristics of disturbance processes, local site conditions, and biological factors (*2*). In areas of pyroclastic flow and avalanche debris, almost no organisms survived; but elsewhere, diverse refuges facilitated survival. In the blast area, survivors included plants with underground buds, burrowing animals, and organisms protected by snow, topography, or other features (*2*). In the area of thin tephra fall, organisms that were able to stand above or penetrate the deposits had a greater potential for survival. Certain life-history attributes also favored survival; for example, some anadromous fish (which return from the sea to rivers to reproduce) and migratory bird populations were not present during the eruption. Organism size also proved important: Large species and individuals suffered greater mortality than did small ones. Surviving organisms included all of the primary trophic groups—herbivores, predators, scavengers, and decomposers. Thus, complex foodwebs quickly developed in the emerging ecosystems. Surviving species provided source populations, ameliorated site conditions, processed dead biological legacies (such as toppled trees) of the pre-eruption system, and established ecological interactions.

The timing of the eruption—that is, time of day, time of year, and the stage of development (succession) of plant and animal communities—strongly influenced patterns of survival and succession (*2*). The early morning eruption allowed nocturnal animals to be protected in their subterranean retreats. The early spring eruption meant that snow and ice created refuges and that plants had not yet broken winter dormancy at high elevations. The early successional stage of many recently harvested forest sites led to a profusion of wind-dispersed seeds of pioneer plant species. The importance of timing underscores the significance of chance in survival and successional pathways.

Key successional processes after any major disturbance include dispersal, site amelioration, establishment of organisms, species accrual, biotic interactions, and changing community structure (*2*). Dispersal pattern and rate were influenced by distance from source populations, wind patterns, landscape permeability, and mobility of seeds, spores, and organisms. Site amelioration was critical: The new volcanic substrates had low nutrient status, little moisture holding capacity, and limited shade, but differed from lava flow substrates common in other volcanic terranes in that they were readily penetrated by plants and animals. Site amelioration occurred via weathering, decomposition, addition of nutrients to soils, microbial activity, mixing of soils by animals, and clearing of suspended particulates from lakes. Over time, community structure increased across all disturbance zones as species accrued, individuals and populations grew and spread, and interactions developed.





The diversity of geophysical disturbances. Views north from the summit of Mount St. Helens across Spirit Lake to Mount Rainier before (**top**) and after (**bottom**) the eruption of Mount St. Helens on 18 May 1980. (**Left**) This eruption involved several landscape-modifying processes: a massive landslide (debris avalanche), a lateral blast that blew down forest and scorched standing forest, pyroclastic flows, and mudflows down rivers that drained the volcano.

The rate of ecological response varied greatly among the different environments. In the quarter century since the 1980 eruption, lakes and most streams have largely returned to ecological conditions typical of forested areas of the region. Throughout the vast blast area, the terrestrial landscape has transformed from barren gray to mostly green with vegetation dominated by herbs, shrubs, and small patches of surviving trees. On the debris-avalanche and pyroclastic-flow deposits, vegetation is lush around ponds and wetlands, but sparse herb and shrub cover characterizes uplands and actively eroding sites. The number of verte-

V. H. Dale is at the Oak Ridge National Laboratory, Oak Ridge, TN 37831–6036, USA. C. M. Crisafulli is with the U.S. Department of Agriculture (USDA) Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, Olympia, WA 98512, USA. F. J. Swanson is at the USDA Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, Corvallis, OR 97331, USA. E-mail: dalevh@ornl.gov

Published by AAAS

brate species and their population sizes have increased dramatically since 1980. Birds have colonized in lock-step with increased habitat structure, but assemblages remain limited by the lack of forest structure. Yet even in the most disturbed areas, nearly all species of small mammals associated with undisturbed forests have returned. Secondary disturbances have modified pathways of succession. Shifting river channels, small landslides, and mudflows have repeatedly reset succession, enhancing the heterogeneity of vegetation patterns over the volcanic landscape.

Human activities have greatly altered natural ecological processes in many areas affected by the eruption. However, the U.S. Congress established a 43,300-ha National Volcanic Monument where natural processes can proceed unimpeded. Environmental scientists have provided advice concerning protection of natural features; management of erosion, floods, and natural resources; and development of interpretive programs and educational opportunities. During the decision-making process, potential risks to human life or property often outweighed ecological concerns.

A quarter century of ecological studies at Mount St. Helens has produced important lessons. First, living and dead biological legacies (for example, dead trees and rotten logs) are integral to the ecological response, even after severe disturbances. Second, ecological succession is very complex, proceeding at varying paces along diverse paths, and with periodic setbacks through secondary disturbances. Consequently, no single, overarching succession theory provides an adequate framework to explain ecological change. Third, chance factors, such as timing of the disturbance at various scales, can strongly influence survival and the course of succession. Finally, environmental scientists have provided a long-term and broad-scale view of how human actions can affect ecological systems, a requisite but not always integral component of decision-making.

The future at Mount St. Helens will be one of continuing change. The pace of ecological change will be determined by complex processes of ecological succession influenced by landscape position, topography, climate, and further biotic, human, and geophysical forces. The current volcanic activity at Mount St. Helens attests to its dynamic character (*3*). Even so, many biotic, landform, and soil legacies of the 1980 eruption will influence ecological processes for centuries to come.

References and Notes

1. P. W. Lipman, D. R. Mullineaux, Eds., *U.S. Geol. Surv. Prof. Pap.* **1250**, 844 (1981).
2. V. H. Dale, F. J. Swanson, C. M. Crisafulli, Eds., *Ecological Responses to the 1980 Eruption of Mount St. Helens* (Springer, New York, 2005).
3. D. Dzurisin *et al.*, *Eos* **86**, 25 (2005).

4. We thank J. Antos, D. Druckenbrod, J. Franklin, R. Parmenter, and A. Wallace for helpful comments. Support was provided by the USDA Forest Service, Pacific Northwest Research Station; Gifford Pinchot National Forest, Mount St. Helens National Volcanic Monument; National Geographic Society; EarthWatch; and Oak Ridge National Laboratory, which is managed by the University of Tennessee–Battelle for the U.S. Department of Energy under contract DE-AC05-00OR22725.

10.1126/science.1109684

ATMOSPHERIC SCIENCE

Rethinking Earth's Early Atmosphere

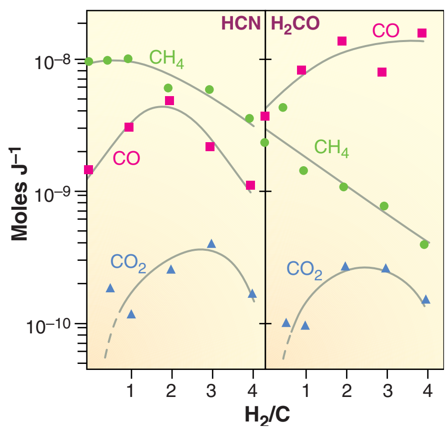
Christopher F. Chyba

In 1952, Stanley Miller, working with Harold Urey, simulated the atmosphere of early Earth with a gas mixture of methane (CH_4), ammonia (NH_3), molecular hydrogen (H_2), and water. When he introduced an electrical spark to represent lightning, he observed the formation of amino acids, the building blocks of proteins (*1*). Miller later showed that the amino acids were the result of reactions in liquid water (representing Earth's ocean) of simple organic molecules such as hydrogen cyanide (HCN) and formaldehyde (H_2CO) formed in the gas mixture (*2*). His experiment turned the study of the origin of life into an experimental science.

However, by the 1960s, the validity of hydrogen-rich (and hence reducing) model atmospheres for early Earth, such as the CH_4-NH_3 atmosphere used by Miller and Urey, was under attack (*3*). Since the 1970s, carbon dioxide (CO_2)–rich atmospheres have been favored (*4*). Miller has shown that the production of amino acids and other organic molecules is orders of magnitude less efficient in such atmospheres (*5*). For this and other reasons, the Miller-Urey approach to the origin of life has fallen out of favor with many researchers. But on page 1014 of this issue, Tian *et al.* (*6*) argue that the early-Earth atmosphere might have been hydrogen-rich after all.

In early models of Earth's evolution, the planet's iron-rich core was assumed to have formed slowly over hundreds of millions of years. Prior to core formation, metallic iron would have been abundant in Earth's mantle, in effect providing a huge oxygen sink. As a result, carbon and nitrogen compounds emitted ("outgassed") into the atmosphere—for example, in volcanic eruptions—would have been saturated with hydrogen (CH_4 and NH_3). Early life would have used the abundant organic molecules produced by Miller-Urey synthesis for energy and raw materials. Core formation would have freed the oxygen, leading to outgassing of CO_2 rather than CH_4 (*7*). Abiotic organic production would have plummeted, whereupon life would have evolved to cope with this change. It was an elegant picture—but probably largely wrong.

The author is at the SETI Institute, Mountain View, CA 94043, and in the Department of Geological and Environmental Sciences, Stanford University, Stanford, CA 94305, USA. E-mail: chyba@seti.org



Hydrogen lends a helping hand. Yields (in moles produced per joule of input spark discharge energy) of organic molecules thought to be key for the origin of life are lower in CO_2-rich atmospheres than in CH_4-rich ones, although H_2/C ratios >1 maximize organic production in the former case. [Adapted from (*5*)]

It now appears that Earth was hot at the time of its formation, because it accreted from fast-colliding planetesimals. It seems unavoidable that the core formed virtually simultaneously with Earth itself. If the iron was largely sequestered in the core from the start, then there never was a Miller-Urey atmosphere. Even if there ever had been such an atmosphere, modeling suggested that it would be quickly destroyed by solar ultraviolet light. However, this problem would be circumvented by the formation of a high-altitude organic haze, similar to that in the atmosphere of Saturn's moon Titan (*8*). Thus, if Earth ever had a Miller-Urey atmosphere, it could be sus-