# CHAPTER 1

## The Tephra Fall Zone

*Silver firs near the edge of the blast zone; needles were coated by ash that fell as mud during the first eruption (July 26, 1980).*

### Introduction

Magma blasts from a volcano inject vast quantities of new material into the atmosphere during what are called *Plinian* eruptions. Global effects, including significant temporary cooling often follow. This ejected rock eventually falls to earth and spreads widely to form a gradually thinning mantle downwind. Coarse, heavy material falls to earth first leaving fine dust to settle well away from the cone. These air-fall deposits are often called ash, but they are correctly termed tephra. Only fine-textured, powdery deposits are properly called ash. Tephra usually is rocky, frothy pumice, but it can also be formed by denser rock. It can be transported long distances, ultimately being deposited where dictated by the height of the plume, wind direction and velocity during the eruption. Young tephra deposits can enrich the soil, but often desert-like conditions can develop, especially when the tephra was part of a pyroclastic flow (see Ch. 5). Deep tephra layers eventually become compacted to form a soft, porous rock called tufa that was favored by Romans for several centuries starting in 200 B.C. to cover brick and concrete surfaces.

Ash may circle the globe before settling to earth and during this time, it can have significant effects on the weather. Eruptions 200 million years ago may have caused massive extinctions that allowed dinosaurs to develop and dominate the earth during the Jurassic and Cretaceous geological periods. Pleistocene eruptions probably altered the course of human evolution, and historical eruptions often cooled the planet for several years and may have triggered the European Dark Ages and the Little Ice Age.

### Past important tephra impacts

The climatic effects of tephra-fall have been studied intensively, while tephra deposits can be used to date soil layers and lake sediments. However, its broad impact on terrestrial ecosystems has been largely neglected by ecologists, at least until Mount St. Helens came under scrutiny and the importance of tephra to human history has only recently become widely appreciated.

Thick ancient ash layers periodically covered entire landscapes throughout the Cretaceous. Sometimes, they "froze" a community in time, preserving a vivid picture of what had been growing there. A remarkable case of this preservation comes from the late Cretaceous in Wyoming, when the first flowering plants were becoming common in the fossil record. Thick tuffs (geologically compressed fine tephra ash) preserved vegetation in place, allowing paleobotanist Caroline Strőmberg and others to reconstruct the vegetation, not just the flora (Wing et al. 2012).

Huge eruptions have repeatedly injected so much ash, carbon dioxide and sulfur dioxide into the atmosphere as to affect climate, not just weather. Just when humans were becoming distinctly modern, our ancestors had to cope with global-scale effects of volcanism, particularly of tephra, in addition to a highly variable climate. Around 70,000 years ago, in what is today Sumatra (Indonesia), a volcano called Toba produced a mega-colossal eruption, probably the largest on the planet in 25 million years. Pyroclastic flows and the associated tephra covered over 20,000 km$^2$ (roughly the size of New Jersey) to depths exceeding 500 m. About 800 km$^3$ of material became tephra (while Mount St. Helens contributed only 1.2 km$^3$ of tephra, making Toba about 700 times bigger by this measure). This event set off global cooling for at least a millennium and began with several very cold years with temperatures depressed by about 3°C. This climatic catastrophe is believed to have reduced humans to very small numbers, causing a "bottleneck" in human evolution, followed by rapid population differentiation. Our species remains genetically relatively homogeneous.

Until Mount St. Helens erupted, the best-known eruption in the Pacific Northwest occurred about 7,700 years ago when Mount Mazama produced an epic eruption. In the aftermath, Crater Lake was formed. The huge tephra cloud covered nearly all of what would become Oregon and much of the surrounding states and Canada. The global climate cooled slightly and then continued to rebound from glacial times. The resulting deposits from Mazama form an important tool in dating post-glacial events in this region. Associated pyroclastic flows covered the landscape as far as 60 km away. It is likely that human populations suffered tremendously from the combined effects. Lakes were clogged with tephra, wildlife was decimated and the vegetation withered. While the climate effects of the Mazama eruption are conjectural, they are supported in the pollen and limnological records that suggest profound effects lasted for decades.

European interest in volcanic eruptions seems to have begun in August 79 A.D. It was then that Pliny the Elder, Roman admiral and deeply inquisitive naturalist, was the first to describe tephra-falls up close. Unfortunately, his dedication led to his death when he was smothered by pumice falling from Vesuvius. We commemorate his valor by calling similar eruptions *Plinian*. The 1980 eruption of Mount St. Helens is but one of many major eruptions of this type to occur in the last 2000 years.

We now believe that in A. D. 535 a huge eruption caused catastrophic global cooling that caused the Dark Ages in Europe and certainly altered human history. Mongol tribes fled horrible weather and invaded south-central Europe, becoming today's Serbs and Croats. Crops failed from China to Ireland, famine was rampant and the Black Death raged from southern Asia to the Baltic. The darkened sun was recorded in Constantinople and by Chinese court reporters. Droughts severely affected the Peruvian Moche people. Ice cores in Greenland and Antarctica provide evidence for acidic dust and suggest an equatorial volcano. The guilty one has yet to be identified with certainty, although Rabaul (Papua New Guinea), Krakatau (Indonesia) and the Ilopanco caldera (El Salvador) are candidates. The eruption was at least 40% larger than that of Tambora, the reigning champion for documented historic eruptions.

Northern Europe recovered somewhat after 800 and even had a warm spell called the Medieval Warm Period that allowed Vikings to colonize Iceland, Greenland and Vineland. These halcyon days of Nordic colonization soon unraveled when a distinct cooling trend occurred. This is related to a huge eruption now dated to 1257 and associated with the Indonesian volcano Rinjani. Horrible winters and widespread famine recurred throughout northern latitudes from 1315 to 1320. This volcanic event sparked the start of the European Little Ice Age that lasted until about 1850 and certainly altered the course of European history.

To grasp what might be involved when volcanoes alter the climate, we can look at similar more recent events. Iceland's Laki fissure erupted in 1783 - 1784 to become the first definitely recorded weather-altering volcanic eruption. The local populations suffered most from tephra. About half of the livestock and 25% of the population perished in the ensuing famine. Solid sod-roofed, sunken dwellings called turf houses, that had survived centuries of smaller eruptions, were crushed or buried, killing both the human and animal inhabitants. Europe began to suffer appalling weather, a result of the sulfur cloud that covered northern latitudes. Nobody could even imagine that a distant eruption was the cause, although Ben Franklin (living in Paris at the time) did suggest that it might be due to an Icelandic volcano. The climatic consequences in Europe were staggering because the ensuing haze blocked solar radiation and lowered temperatures. Widespread famine became the new normal and direct poisoning from water polluted by sulfur deposits continued for years. Extreme winter storms killed many more people and livestock than normal; spring floods devastated swaths of fertile land. Europe reeled from drought, frigid winters, violent hailstorms and floods. Laki almost surely triggered the French Revolution, which was, after all, more about poverty and famine than about the rights of man. Undeniably, the effects transcended Europe. Droughts developed in India and Africa causing intense, extensive famines. Even deep in the balmy American South, plantation owners could ice-skate in Charleston Harbor, while food was scarce for most others during that protracted, cold winter of 1784. These catastrophes resulted from just one modest, distant eruption.

Perhaps stimulated by the Laki eruptions and spurred by global scientific explorations (e.g., Vancouver from 1791 to 1796 and Fitzroy with Darwin from 1831 to 1836), the relationship between volcanic eruptions and climate became well established. First the Indonesian volcano Tambora exploded in 1815 with the largest historic eruption; again Europe's weather cooled, slowing the recovery from the Napoleonic wars. Then the 1883 Krakatau eruption, which rivaled that of Tambora, cooled the planet. This event was so widely described and reported that there was no question as to the cause of subsequent adverse weather. Finally, Katmai (1912) produced mammoth eruptions that were followed by cold summers and harsh winters. Associated with this expanding understanding of causality were scientific developments such as using barometric pressure and maps of atmospheric conditions to predict the weather. Incidentally, both were due primarily to Robert Fitzroy, who did much more in his tormented life than cart around Charles Darwin. Global communications, notably the telegraph and underwater communication cables, allowed weather-altering events (e.g., the eruption of Krakatau) to be reported as they happened. That tephra was a major component of these impacts was verified by repeated descriptions of beautiful red sunsets.

In modern times, tephra eruptions have directly affected commerce and well-being. In 1980, first eastern Washington and then Portland were cloaked with fine tephra from eruptions of Mount St. Helens. The first eruption caused major problems for transportation and for sewage and water treatment throughout the inland empire of Washington. Just removing the ash was problematic.

Deep deposits of coarse tephra also have significant local effects. Deposits of more than 30 cm usually kill plants (Tsuyuzaki & del Moral 1994, Tsuyuzaki & Goto 2001), thus initiating primary succession. In March 1907, Mt. Ksudach near the southern tip of Kamchatka (Russia) erupted in a classic Plinian way. Because strong southerly winds prevailed, the plume spread for over 200 km and coated the only port city, Petropavlovsk. The birch forest was eliminated across a narrow swath that extended for over 30 km, but the tephra deposit thinned rapidly east and west of the main axis of deposition. Studies of this tephra deposit allowed detailed assessments of selective effects along a depth gradient (Grishin et al. 1996). Rhizomatous species were able to penetrate deposits less than 40 cm deep but otherwise perished. Ground layer species were killed by thinner deposits.

While dust clouds can be a serious inconvenience and large eruptions have severely affected many societies, today even moderate tephra events can upset technological societies. The 1991 mega-eruption of Volcan Hudson (Chile) dumped ash across Patagonia and even the Falkland Islands, disrupting the lives of thousands throughout the region. Large numbers of livestock starved, irrigation was disrupted and farms were abandoned. This eruption combined with the Mt. Pinatubo eruption of the same year to cool the planet significantly and to deplete ozone over Antarctica further. On Pinatubo, heavy clouds of tephra, deposited wet by torrential typhoon rains, crushed homes and were responsible for most of the casualties (Marler and del Moral 2011).

In 2010, the small, but tephra-rich eruption of Eyjafjallajökull, a volcano that emerged from beneath an Icelandic glacier, disrupted air traffic throughout Europe for several days. Planes were grounded because there was a great fear that jet engines would be destroyed by sucking in a tephra cloud, which in several cases have nearly brought down passenger planes. Tephra can sand blast windows, causing pilots to fly blind, and landing lights, making approaches dangerous. Various sensors become useless, eliminating any knowledge about air speed. A similar volcanic eruption occurred in the Chilean Puyehue-Cordón Caulle Volcano in June 2011. Tephra buried many towns and closed airports throughout the southern hemisphere, including Buenos Aires, Cape Town and Melbourne. Argentine tourism was curtailed, and has yet to recover fully.

Tephra alone rarely causes huge human casualties directly, but longer-term health effects can be severe. Respiratory problems can be widespread, particularly affecting those with asthma or other breathing difficulties. Tephra is abrasive, so eye-irritation is a common problem (as I can attest). Tephra-coated grasses can poison livestock, particularly if fluoride is concentrated. Tephra falling into lakes can kill fish and other aquatic life. After the Mount St. Helens eruptions, public health officials were particularly concerned about silicosis. We wore industrial breathing masks when dust was severe. All of these episodic events are, in the larger scheme of things, transient, but they cause billions of dollars in damage and disrupt lives.

These examples suggest that tephra can produce effects that escape the attention of most people unless they are directly downwind. These often-subtle effects, however, may be the most important of volcanic effects for humans because they can disrupt agriculture and commerce over wide areas.

Tephra clouds and deposits continue to cause huge problems at a global scale, and the potential for truly stunning events remains. However, deposits of thin layers of tephra can be beneficial to vegetation. In semi-arid lands, fine-textured tephra coats the soil and when wet it seals the surface, reducing evaporation. Plants benefit from reduced drought stress. The dusty pumice can abrade the exoskeletons of most insects caught in the ash-fall so that they quickly desiccate and die. The resultant lack of herbivores can allow crops to thrive. In natural vegetation, moderate tephra deposits kill selectively. Small plants incapable of growing through the deposit perish, while larger plants, especially ones with rhizomes can grow to the light and survive. Regions with intense volcanism may be disproportionately represented by species with underground parts capable of rapidly regenerating aboveground structures, and lacking in species with poor ability to sprout from buried tissue. In regions of with chronic eruptions, such as Patagonia and the Pacific Northwest, repeated tephra deposits may have selected for plant characteristics fostering rapid recovery.

***Side Bar 1.1.*** *The building lava dome sends us a gentle reminder*

During the mid-1980s, we usually were flown into Butte Camp. Lawrence Bliss had led the installation of a relatively comfortable base camp, sheltered by trees from wind and sun. It consisted of two large tents securely fastened to a wooden floor. Each tent was designed to catch rainwater and store it in a 50-gallon tank. August 4, 1983 was a mostly overcast day. The task for that day was to monitor the permanent plots arrayed on tephra and scoured sites on the slope above us. Jo Ellen van der Mark, Dave Wood and I, intent on the ground layer vegetation when we were not trudging up the steep slope, were oblivious to the subtle change in what we were breathing…from the morning mist to a fine ash suspension. Soon Jo Ellen, who was recording the data, asked me why the data form was so gritty. Looking up, we saw the ash-steam cloud emerging above the cone). A quick call via radio to the circling observer plane confirmed that a dome-building eruption had started. In a bit of a panic, we returned to the base camp, seeking refuge under the all-to-flimsy tents. Fortunately, it was a small, almost momentary belch and the observers overhead assured us that Vancouver (now the Cascade Volcano Observatory) saw no immediate danger. As the ash fall subsided, the clouds cleared and we resumed our tasks, albeit in a rather heightened state of awareness. While there have been many much more boisterous eruptions in the following years, this one, which I experienced, up-front and personal, remains etched indelibly in my memory.

## Tephra deposits on Mount St. Helens

The many layers of tephra on or immediately adjacent to Mount St. Helens attest to its recent volatile activity. Near

Lava Canyon, exposed by the Muddy River Lahar, a steep bank reveals 13,000 years of eruptive history of Mount St. Helens. Surrounding this volcano, geologists have identified strata marking at least 37,000 years of activity divided into several eruptive episodes (Mullineaux 1996). Pyroclastic flows, lahars and tephra deposits are inter-bedded, further testimony to the power of volcanoes to build and mold landscapes. In 1480 and 1482, separate events killed forests over 100 km$^2$ to the north. In 1800, tephra associated with lava eruptions killed forests to the northwest of the crater. Tephra from the 1842 eruption blew south towards The Dalles. This layer was covered by blocky lava northeast of the cone, probably in 1854. Earlier eruptions must have caused comparable damage, so that the landscape found in 1979 was a product of volcanism as well as of clear-cut logging. Timberline was about 600 m lower than the climate might allow, strong evidence that trees had not yet advanced up the cone. The 1980 eruption produced a cloud of ash that circled the earth, but its climate effects were minor. By chance, winds were flowing from the southwest, so most tephra fell to the northeast in an attenuating plume. The ecological effects of these deposits were significant, but minor compared to impacts associated with forceful events close to the mountain.

The texture of the tephra deposits became increasingly fine with distance and its harmful effects attenuated.

**Fig. 1.1.** *Air-fall tephra coats the landscape north of Mount St. Helens: Tephra covers the forest and filters down to cover the ground layer (September 8, 1980).*

Wheat farmers in eastern Washington ultimately benefited from the ash cloud that descended on their crops. As it settled to earth, it sealed in moisture so that soils could support greater yields. The ash also abraded the exoskeletons of the many crop pest insects, causing them to desiccate. There was very little insect damage to crops in 1980.

The May 18, 1980 tephra events extended far to the east-northeast, causing widespread havoc in eastern Washington. It is estimated that 1.2 km$^3$ of tephra was ejected from the crater. This volume was spread over 100 km$^2$ to depths of at least 5 cm (Major 2009; Fig. 1.1). To the north, fine textured tephra fell as ash through forest canopies and onto snow to form layers several to many cm deep over many km$^2$. On the south slope, pebble-sized chunks of pumice formed layers 20 to 30 cm deep over 16 km$^2$ (Fig. 1.2). North and east of the crater, the ash covered a landscape marked by wide swaths of clear cuts.

Tephra deposits were studied intensively in the ash-fall zone north and east of the crater. Here, the focus was on the biology of recovering understory species within relatively unscathed forests (Antos & Zobel 2005). On the south slope of the cone, where tephra fall was deeper and coarser in texture, the focus was on meadow community change in time.

**Fig. 1.2.** *Mosaic of clear cuts of several ages north of the crater (September 11, 1980).*

On and near the cone, there are substantial areas where very course tephra was the only significant impact. Because winds were blowing from the north, during the eruptions of May 25 and 26, 1980 it was the south slopes that were covered. At higher elevations, tephra fell on snow and on steeper slopes. The subsequent melt of snowfields removed much of this deposit and concentrated it in places to depths that smothered vegetation. As a result, although these eruptions produced deposits that ranged from six to 15 cm in depth, impacts were minor in most places and vegetation appeared to have recovered within two to four years. Level sites were disproportionately affected because tephra was not removed and because re-deposited tephra washed down to add 15 to 20 cm to the burden. Because these deposits were on the crater, the fallout consisted of the heavier materials, so that it was composed of coarse sand. Trees below the open meadows of the south side, in contrast to those beyond the blow-down zone to the north, suffered little because the tephra quickly fell through the canopy to the ground.

## Impacts of tephra deposits

*Coating of trees*. Tephra itself, based on work in several laboratories, was not toxic. Over the first decade, sulfates were leached from the material and soil pH became less acid. However, there were significant, if relatively transient, effects on trees.

Because the eruption created thunderstorms, much of the ash fell as mud, coating leaves (Fig. 1.3) before reaching the ground. These leaves, still alive, could no longer *transpire*. Transpiration, the loss of water through *stomata*, and airflow across leaves are crucial cooling mechanisms. Virginia Seymour with Tom Hinckley and others (1983) measured needle temperatures of firs and found that coated leaves were 10°C warmer, but had suffered no mechanical or chemical damage. Soon, coated leaves died. Most coated trees survived because they retained uncoated leaves, but the effects of tephra coating could be seen in the suppressed growth rings for several years. Segura and others (1995) used tree-ring and canopy analyses of silver fir trees to document that long-term effect of tephra on reduced crown size and tree ring growth.

**Fig. 1.3.** *Air-fall tephra coats the landscape north of Mount St. Helens: Tephra covers the forest and filters down to cover the ground layer (September 8, 1980).*

*Snow effects*. The presence or absence of a covering of snow proved to be crucial to understory species when tephra fell. However, the effects were complex and affected different kinds of species in different ways. In general, snow protected herbs because as it melted, tephra tended to crack and erode, so that its impact was reduced. Also, such suffrutescent species as false hellebore, protected by snow, quickly penetrated deep tephra deposits y following cracks. However, shrubs buried in snow were usually prostrate and, when snows melted, they became covered in mud, which nearly obliterated shrubs and small trees from areas with snow during the eruption. The effects of snow were better demonstrated in blown down areas.

*Deposit depths*. The differential effects of fine textured tephra deposits on the forest understory are well known and consistent in temperate and boreal regions. At Mount St. Helens, as little as 5 cm of tephra killed most mosses, but scattered survivors contributed to recovery of moss layers. Mosses survived in thin deposits, on logs or where protected by rocks or downed trees. While most herbs could grow through less than 5 cm of tephra, they were often killed by deposits thicker than 15 cm. Local microsites and cracking of the tephra crust was important to herb survival. On steeper slopes, gravity and rain often washed away tephra so that in some spots there was little effect by 1981. This favorable erosive effect was more common in open areas and meadows than below dense tree canopies. However, tephra could also be re-deposited to cause local mortality (Fig. 1.4). Because these deposits were sterile, dry and unstable, plants had difficulty establishing and barren spots persisted.

*Survival mechanisms*. Joe Antos and Don Zobel (2005; Zobel & Antos 1991, 1997) studied the effects of tephra in forests for more than 30 years. These studies have provided keen insights into how species survived the impact and regained dominance. They noted that even thin deposits were a major barrier to slow growing, mat-forming species like the alpine wintergreen. Even bear grass, a widespread, robust evergreen member of the lily family, cannot penetrate moderately deep or compacted tephra. This species is common in the Cascades, but is relatively sparse near Mount St. Helens. perhaps due to the periodic tephra deposits. Species that do survive do so in many ways. Plants that were dormant beneath the surface could grow through relatively shallow tephra. Often, plants produced new dormant buds in the tephra layer, minimizing the distance required for regrowth. Many woody species put out *adventitious* roots from buried stems, thus contributing to the conversion of tephra into soil. Some species, including thin-leaf huckleberry, survived burial for several years. This tolerance to burial enhances the chance that erosion will ultimately uncover the plant. Erosion of tephra was important in the forest zone, as it proved to be elsewhere.

*Long-term changes*. Compared to the impacts of the blast zone, those of the tephra-fall zone were subtle. However, they were real and important to understanding successional processes. Predictably, the smallest plants suffered the most. Bryophytes (mosses) sustained major damage, but had regained their original abundance by 2005. However, species composition was substantially different because once rare species had colonized tephra sites. Herbs were significantly reduced by deep tephra, but recovery was substantial and often dominated by species with strong aboveground growth (e.g., dwarf bramble and twinflower). Erosion hastened recovery significantly. As described above, shrub survival was related to snow pack during the eruption, and recovery has been slow on deep tephra. The combination of thick tephra deposits and snow proved too much for small trees, most of which perished.

***Fig. 1.4****. Silver fir needles coated with dense mud, formed by the thunderstorm spawned by the May 18 eruption. Coating killed some trees, but most survived, marked by several years of limited growth (July 26, 1980).*

*Lessons about tephra*. The detailed studies of tephra-fall in forests by Antos & Zobel (2005) and Zobel & Antos (2007, 2009) yielded several messages, some learned in other habitats as well. Deep tephra eliminated the understory and survivors directed the subsequent development of the ground layer. Recovery was slow for several reasons. These included little flowering, poor seed production, limited dispersal ability, slow vegetative growth, low light conditions that suppress weedy colonizing species, short growing seasons and inhospitable surfaces.

Patterns of recovery varied greatly over the landscape, so generalizations were difficult to make. Only the long-term nature of the Zobel-Antos study made it possible to find general patterns. The timing of the eruption dictated much of the recovery by determining the presence and depth of the snow pack. Erosion was crucial to the survival of most groups of species. Variation in tephra initial depth produced variations in flowering abundance both within and between species. Many species have traits that suggest adaptation to frequent volcanic events. These include the ability to form adventitious roots and to penetrate tephra deposits. Survivors (*legacies*) proved to be crucial, as elsewhere on the mountain.

Today, over most tephra-impacted forested areas, the recovery to an apparently normal understory is nearly complete. Understory species show few signs of having been buried by tephra (Fig. 1.5a, b). The actions of small mammals, soil invertebrates, plants, fungi and many other organisms have blended tephra into the soil. Subtle differences remain, but the tephra deposits from 1980 can be viewed as another in a series of disturbances that have selected for species recover quickly.

## Impacts of coarse tephra deposits

I studied recovery of meadow vegetation on the south slope of Mount St. Helens from 1980 to 2009 (see Sidebar 1.1). Others have studied plant physiology, climate, insects and rodent behavior to allow an understanding of how minor disturbances can have long-term consequences. The southwest slopes differed dramatically from the forests studied north of the crater. Here, the tree line had been suppressed by recent previous eruptions. Insufficient time for forests to reclaim their subalpine habitats had elapsed, so vegetation above about 1400 m was dominated by mixtures of meadow species and some forest understory species.

*Tephra impacts*. One week after the main eruption, a second, vertical eruption occurred that sent a tephra plume towards Portland. About 15 cm of coarse tephra was deposited on the south and western sides of the volcano without significant lasting effect (Fig. 1.6). While many plants were smothered by the tephra, others survived and sprouted through deposits even up to 30 cm in depth. This deposit was eroded from the steeper slopes and deposited on the level meadow areas. The resultant meadow communities were variable in species composition depending on slope features and the degree of erosion. The tephra was infertile, lacked organic matter and blanketed an immature, infertile soil that was covered by open meadow vegetation. The deposit had two major effects. It was sufficiently thick that soil moisture was

***Fig. 1.5.*** *Typical understory species in tephra affected sites: Above: twinflower (2006); Below, yellow wood violet (2009).*

locked into the soil. This, in turn, hastened the decomposition of plants that perished by burial. However, few, if any, species were eliminated and the number of species observed quickly reached a plateau. Studies by Bill Pfitsch and Larry Bliss (1988) showed that tephra had little effect on community structure or production, but that experimental addition of tephra reduced species richness, cover, diversity and productivity dramatically. However, few seedlings could germinate and grow in even shallow tephra, so they predicted that species richness would decline over many years. This will increase the annual variability in community productivity related to weather variation because there will be reduced compensatory behavior with fewer species.

This tephra was acidic and deficient in carbon, nitrogen, phosphorus and potassium. However, this infertility and acidity was like that of the resident soil and did not inhibit recovering plants as shown in greenhouse trials (del Moral & Clampitt 1985). Tolerant species included lupines and numerous persistent species that were common survivors, but not bent grasses, which eventually dominated these sites. Over the first four years, growth improved for most species as weathering and import of organic matter by the wind improved the substrate.

Pocket gophers have appeared in many videos and retrospective television programs. They represent survivorship and have an important role in facilitating succession by returning buried, more fertile soil, to the new surface. Many populations of gophers survived beneath the snow even in the blown-down zone and on the cone. As they continued to burrow, they brought old soil to the surface, disrupted tephra layers and exposed mycorrhizae to the surface (Fig. 1.7). Each of these activities allowed seedlings to establish and thrive.

***Fig. 1.6.*** *Lush recovery of meadows above the South Fork of the Toutle River. This is the only location where yellow penstemon occurs on the mountain (September 11, 1980).*

***Fig. 1.7.*** *When gophers back-fill their runways between the snow and the soil surface, these castings remain after snow melts. Their soil churning improves fertility and aeration in the newly deposited tephra material (September 4, 1981).*

Pocket gophers have appeared in many videos and retrospective television programs. They are survivors and

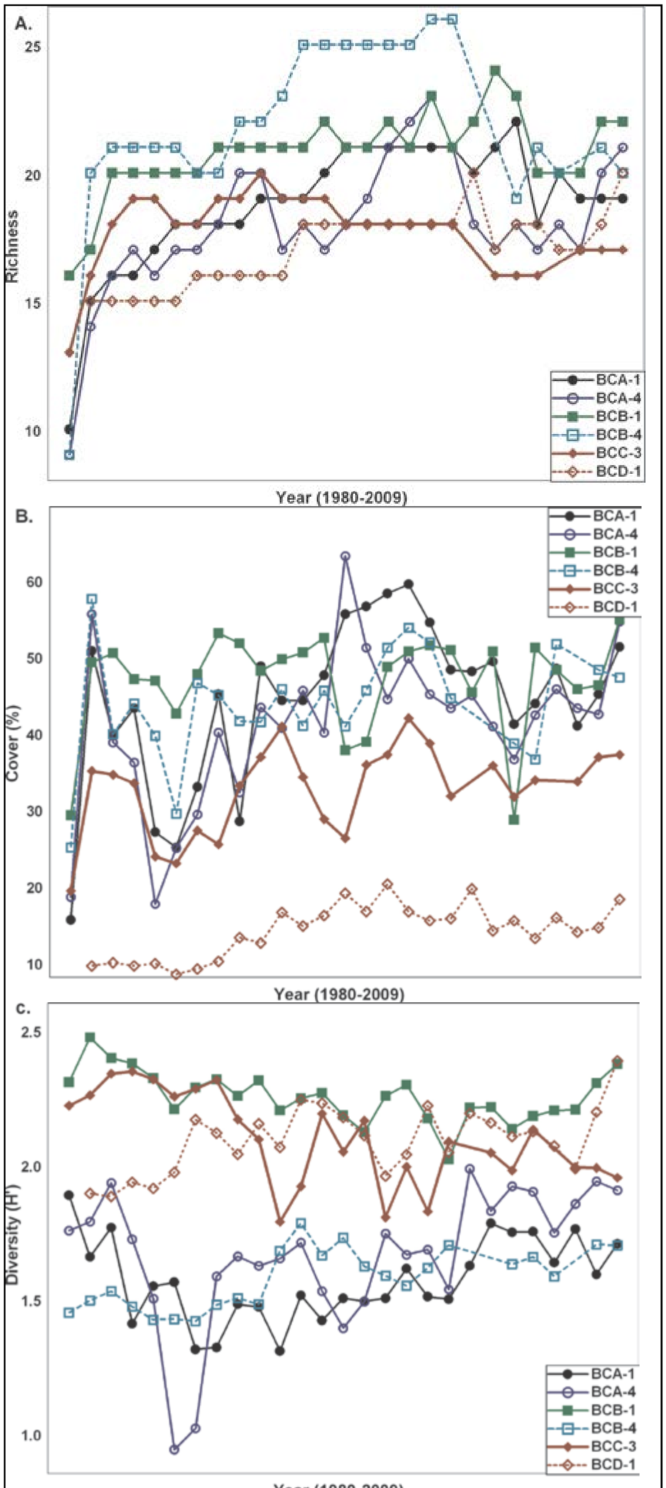

***Fig. 1.8.*** *Vegetation structure (1980-2009) in five representative tephra plots: A. Species richness (number of species in plot); B. Total cover of species in plot; C. Shannon diversity calculated from richness and relative cover in plots.).*

have an important role in facilitating succession by returning buried, more fertile soil, to the new surface. Many populations of gophers survived beneath the snow even in the blown-down zone and on the cone. As they continued to burrow, they brought old soil to the surface, disrupted tephra layers and exposed mycorrhizae to the surface (Fig. 1.7). Each of these activities allowed seedlings to establish and thrive.

*Monitoring methods for permanent plots.* Throughout the higher elevation regions that I have studied, permanent plots were established to document recovery. These plots will be discussed in the following chapters. Each was a permanently marked circle with a radius of 9 m (250 m$^2$). Each was sampled annually (usually) with 24 sub-plots (i.e., quadrats) 0.25 m$^2$ in area. In each quadrat, I estimated the vertical projection of each species to determine its percent cover. From these data, I determined several aspects of vegetation structure. Richness is the number of species in the plot. The average cover is total cover divided by the number of quadrats. The relative abundance is described by a diversity index called H', which is determined from the information theory statistic ($H' = [-\Sigma\ p_i \ln p_i]$). The equation determines the proportion of the total abundance represented by each species, $p_i$ and the natural logarithm of this value; it then multiplies the two values and sums the totals for all species. The index increases as the number of species increases, but of more interest is its behavior with respect to relative abundance. For any value of richness, the index decreases as one or a few species are strongly dominant. This monitoring method was used in plots distributed in a variety of habitats on the mountain. The number, exact location and years of initiation and termination varied. The data for permanent plots discussed in this book are in the archives of the journal *Ecology* (del Moral 2010).

*Recovery patterns.* Permanent plots that I established on the south-facing slopes and benches affected by tephra allowed me to test the prediction that richness should decline over the years as dominance was reestablished (del Moral 1983). In fact, the pattern of richness development was complex (Fig. 1.8A). At lower elevations, richness increased quickly and then stabilized. Only towards the end of monitoring, did species richness decline in a few plots (e.g., BCB-4). In other, higher elevation, tephra plots, richness quickly stabilized, but did not decline.

Cover percentage increased dramatically from 1980 to 1981 in most plots, and then declined quickly. The spike was probably due to release of nutrients from decomposing plants. Thereafter, cover varied widely from year to year, but values during the last few years were similar to those of the middle years (Fig. 1.8B). Cover in BCD-1 was less than half of the other plots. This plot, though little disturbed, occupied a site in which snow accumulated during the winter, and thus experienced a limited growing season.

Richness and cover varied significantly among years and these changes combined to affect diversity (Fig. 1.8C). This variation related primarily to annual differences in the conditions of the growing season, and demonstrated the rapid recovery of this vegetation. After Year 1, in which cover values were depressed, there was an increase in species diversity, indicating a reduction in dominance, because richness stayed about the same or declined slightly. Diversity can increase both as the number of species increases and as the species become more evenly abundant. If richness remains constant, diversity decreases if a few species come to dominate the site. In addition, gophers were extremely active in bringing up old soil to the surface, which further increased nutrient availability (Allen et al. 2005). Diversity of BCA-1 declined sharply as grasses dominated the community, and then gradually increased as cover became more evenly distributed. BCA-4 experienced a period of strong bentgrass dominance and hence low diversity, but as mosses increased in abundance, diversity gradually increased. BCB-1 remained stable throughout the study and BCB-4 slowly increased as a few new species entered the plot. Diversity of BCC-3 declined as grasses and mosses became more dominant. The diversity of BCD-1 increased along with both cover and richness. This plot remained quite open, so that competition did not seem to alter community structure (Sidebar 1.2).

*Succession*. Changes in floristic composition, more so than changes in vegetation structure, define succession. Floristic composition over time can be evaluated by several statistical methods (Walker and del Moral 2003). One relatively simple method is called detrended correspondence analysis (DCA; Hill and Gauch 1980). This robust ordination method places vegetation samples in an order based on their species composition. When it is applied to repeat sampling of the same plots, it can be used to assess such processes as the rate of vegetation change.

Successional trajectories indicate the direction of species composition change over time. Trajectories are often messy because the method is sensitive to such factors as weather differences between years, local disturbances and sampling errors. Trajectories are reported here (and in later chapters) as arrows that summarize the degree and direction of compositional change in a space defined by all permanent plots over all years of the study. This allows direct comparisons to be made among impact types.

The tephra plots changed relatively little after 1982 (Fig. 1.9). All the trajectories are relatively short. The arrows indicate the overall changes based on average position in the first and last three years. The value in parenthesis is the Euclidean distance between starting and finishing points, scaled in DCA units. One hundred units of change indicate about a 50% floristic change. The three lower transect plots (BCA-1, 3 and 4) changed significantly after the initial impact, and have tended to become more similar to each other. After the first response, they changed less than 0.5 HC (half-change = 100 units) over the 30 years. The four BCB plots are separated by a deep canyon. BCB-1 and 2 are on flat surfaces and they changed even less, while they also became more similar over time. BCB-3 is on a slope and composition has changed more than the other plots, but still only about 0.5; it has become more similar to BCD-1, which is located above it. BCB-4 changed less than 0.10 HC, suggesting very little directional change. It became more similar to BCD-2, which is also located above it in similar topography. BCC-3 is dominated by oat grass; however, it did change less than 0.4 HC. The two BCD plots also changed little during this study. These low values of change form a baseline for comparison to plots suffering much greater disturbance, which are described in subsequent chapters.

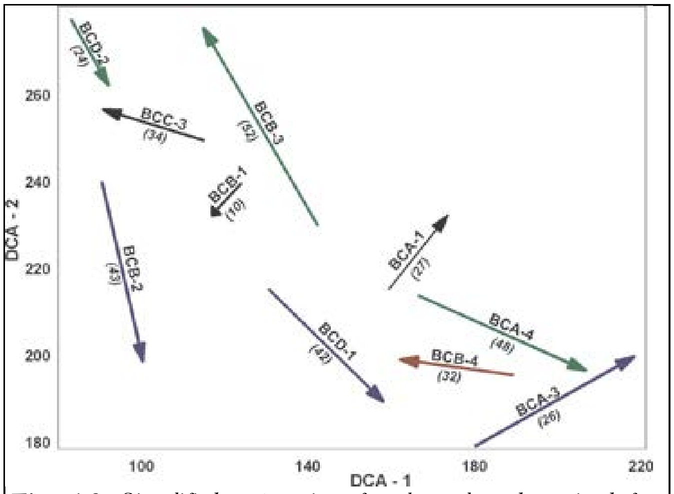

**Fig. 1.9.** *Simplified trajectories of tephra plots determined from detrended correspondence analysis of all plots in the study. Arrows indicate the direction and degree of floristic change (1980-2009). Two plots (or the same plot at different times) separated by 100 units indicates that they are about 50% similar. Numbers in parentheses indicate Euclidean distance traveled by plots in floristic space determined using DCA. .*

These changes may be understood better by looking at the species composition. The lower transect (BCA) changed little. Grasses remained essentially constant, while species common to open habitats declined. These included alpine buckwheat, prairie lupine and lomatium. In contrast, mosses invaded and became quite important, and lodgepole pine established a few saplings.

Plots of transect BCB located on gentle slopes at higher elevations increased in cover, but changed little in composition. Grasses and mosses increased, as did persistent evergreens including red heather and partridge foot. Other plots of this transect changed little, with two exceptions. In BCB-3, located by chance in a patch of juniper, the cover of this species increased dramatically. The tephra had devastated this large clone, but it recovered to its former size by 1990. Prairie lupine developed rapidly in the plot, but the recovery of juniper reduced the lupine to a minor role.

The sole tephra plot on transect BCC changed little. Oat grass became dominant at the expense of other grasses, and the prairie lupine declined. Mosses did not develop significantly in this plot. The higher elevation plots on transect BCD also changed little in composition. Grasses and mosses increased slightly. Overall, the composition of these plots changed only in minor ways. Mosses became established and in low elevation plots, pines invaded from nearby forests.

**Sidebar 1.2.** *Waiting at the Cougar Inn*

Harry Truman somehow became a minor legend in the weeks leading up to the May 18, 1980 eruption. Caretaker of the Mount St. Helens Lodge once located on the south shore of Spirit Lake, the 83 year old was interviewed repeatedly during the two months between the first warning earthquakes and the pyroclastic flow that engulfed the lodge. Despite the proximity (about 1 mile from the crater), he said that “the mountain ain’t gonna hurt me, boy”. Harry, his 16 cats and the lodge were buried under about 50 m of pyroclastic material, and the site is now beneath the bed of the new Spirit Lake.

Truman was venerated in the Cougar Inn, a truck-tourist stop in the town of Cougar. The walls were covered with photos of Harry (complete with detailed captions), the available Harry Truman Poster, eruption photos and several painted crosscut saws commemorating the eruption, wildlife and Harry. During those days, much of the morning clientele were logging truck drivers, motorcycle riders and tourists from the flat lands. The last group took a lot of interest in the “Harry-anna”, but after the first couple of long waits, my research team had lost interest.

Cougar was the jumping off point for the south and east side of the mountain, in the days we had to fly in to our study sites. Cougar is in a deep valley of the Lewis River, near the Swift Reservoir, and routinely has dense fog. So, choppers could not take off until this fog deck cleared. Usually it was not until late morning, and we had to be collected well before dark, so workdays were often short. Sitting in the Cougar Inn, drinking coffee and watching the clock tick (at $100 per hour for the chopper), was frustrating. After the first year, the frustration level was even greater because we knew that the weather was perfect up on the mountain…the cloud deck usually was only about 1200 m, well below our study areas. Our pilots, eager to get on with their other assignments, often pushed the window, searching for small holes in the clouds. That was more exciting than drinking coffee in the Inn.

## Where to see tephra-impacted forests

The best places to see forest tephra sites are from trails leading away from the Bear Meadows parking area. As always, you should use a recent map to the National Volcanic Monument and check on-line for current road and trail conditions. Locations are listed in Appendix 2 by impact type. See the location map, Fig. I-1.

Good locations for the tephra zone include these: 1. Bear Meadow: FS-99, about 7 km west of its junction with FS-25 and 18 km from the crater. On clear days, views are spectacular. Trails lead into the forest from this parking area. To the southwest, less than a km distant, the scorch zone starts.

2. FS-26: various turnouts along this secondary road and along Quartz Creek.

3. Red Rock Pass: along FS-81. Trail #238 gives access to an old lava flow, old growth forests, coarse tephra sites and to Butte Camp. The trail becomes Trail #238A. After a steep climb, the trail reaches a spring (Butte Camp). To reach the tephra sites described in this chapter, ascend several switchbacks that take you through a mature silver fir forest. You continue to ascend through open terrain and reach Trail #216 (Loowit Trail). Tephra, lava and lahar habitats are within easy reach of this location.

## Summary of tephra effects

Tephra is the most extensive of all volcanic ejecta. It can create problems for plants and animals at great distances, but lethal effects are usually confined to sites near the volcano where deposits can be thick. The main tephra deposits on Mount St. Helens were to the northeast. Close to the mountain, tephra damage was obscured by the direct effects of the blast. At a distance, fine ash coated vegetation and had more subtle and variable effects. Subsequent smaller eruptions deposited coarse tephra on the south side of the cone, with variable results.

Tephra effects demonstrated the importance of event timing because the presence of snow significantly altered subsequent development. Small differences in deposit depth allowed different species to survive and recover. Snowpack variations, surface tephra crusts and subsequent erosion created differential survival and intensified understory variation. Protected microsites provided important refuges for smaller species. In many places, even these effects were eventually overcome and species composition changes over the 30 years of the study were minor. In other places, changes in the understory appear to have persisted, adding to the complexity of forest understory vegetation. This was especially true of mosses, which often recovered to form assemblages that different greatly from undisturbed areas. Deep tephra suppressed the understory, but allowed a dense layer of tree saplings to develop, thus altering the trajectory of forest development.