AN ABSTRACT OF THE THESIS OF

Robyn A. Green for the degree of Master of Arts in Interdisciplinary Studies in Geology, Botany and Plant Pathology, and Anthropology presented on June 3, 1998. Title: Mount Mazama and Crater Lake: A Study of the Botanical and Human Responses to a Geologic Event

Abstract approved: ______________________
Robert J. Lillie

Crater Lake, located in the southern Cascade mountains of Oregon, is the seventh deepest lake in the world. Unlike a majority of the deepest lakes in the world, found in continental rift valleys, Crater Lake is in the caldera of a volcano. For the young at heart and mind, those willing to descend (and ascend) about 700 feet to Cleetwood Cove can undertake a boat tour of Crater Lake. From the boat, Crater Lake is more than just a beautiful blue lake; it becomes the inside of a volcano, where the response of people and plants to a geologic event can be investigated.

The catastrophic eruption of Mount Mazama 7,700 years ago affected both plant and human populations. Before pumice and ash from the volcano blanketed the landscape like freshly fallen snow, the forests to the east of Mount Mazama were dominated by ponderosa and lodgepole pine. Within the immediate vicinity of the volcano all life was obliterated; the force of the eruptive material toppled vegetation and buried it with ash and pumice.

Through the recovery process of succession, life has slowly returned to Crater Lake. Forests surrounding the lake are now dominated by mountain hemlock, whitebark pine, and lodgepole pine. These plants not only depict the process of succession, but also of adaptation to a volcanic environment.

Factors restricting establishment and growth of plants are controlled by the non-living environment. Climate, geologic activities, elevation, and time all contribute to the availability of water, soil, nutrients, and sunlight, which directly affect plant growth.

Heavy winter snows, which linger until July, and very little summer rain, control soil moisture and the length of the growing season at Crater Lake. Volcanic activity dictates the parent material, which with time breaks down forming soil. The properties of the soil determine its ability to hold water and the concentrations and availability of nutrients. Pumice soils provide developing plants with low nutrient supplies and affect the growth of plants with extreme surface temperature fluctuations. Volcanic cinder has a very low capacity to hold water and nutrients, thus restricting plant growth.

People have lived in the Pacific Northwest for at least the last 10,000 years. Direct archaeological evidence of life near Mount Mazama is scarce. Those occupation sites closest to the volcano were covered with pumice and ash from the climactic eruptions. Sites protected from the eruptive material and sites farther away provide archaeologists a glimpse into the cultures of the Basin and Range Province. People living around Mount Mazama were predominantly nomadic; their survival depended on available resources. The catastrophic eruption of Mount Mazama and the subsequent devastation of the land disrupted their lives. As the environment recovered from the eruption, the people also recovered. They were forced to find alternative food sources, fuels, and shelters.
The indigenous people's perceptions of this natural disaster are understood indirectly through the use of archaeological data and folklore. Their stories tell of angry gods and stalwart ancestors. Llao, the God of the underworld, and Skell, the God of light, were often at war, Llao from Mount Mazama and Skell from Mount Shasta. Although the origins of such legends are difficult to trace, they emphasize the perceptions of those who lived in the shadow of this mystical volcano. People's limited understanding of the volcano thus triggered their reverence for the place.

Mount Mazama and Crater Lake: A Study of the Botanical and Human Responses to a Geologic Event

by

Robyn A. Green

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Dean of Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Robyn A. Green, Author

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Preface

This thesis integrates the natural and social aspects of Crater Lake. It was written to facilitate ranger-led programs at Crater Lake National Park and eventually as a supplementary guide for visitors to the park. The thesis is intended as a source of information, as well as a foundation for further study. The focus is on the Geology, Botany, and Anthropology and their inter-relationships. This holistic approach gives insight beyond the listing of facts.

The writing follows the path of a boat tour commonly presented by Park Rangers at Crater Lake National Park. It provides, however, far more information than is necessary or appropriate when presenting any lake tour. Park Rangers can use the document for facts and insight, particularly into the interdisciplinary aspect, when designing their own boat tours.

The account begins at the Cleetwood Cove boat dock and moves counterclockwise around the lake. Each of the stops corresponds to a geologic feature. A majority of the botany and anthropology is not specific to the lake, but to the park and surrounding area. Therefore, unless specific to a stop, the botany, anthropology, and to some extent the geology, may be discussed at other times on a tour. Some features may be discussed from more than one vantage point; for example, the shape of the glacial valleys is best observed from the opposite side of the lake, but from immediately below, comparison is useful when discussing the lava filled glacial valley. Illustrations and photographs are included to define the locations discussed and to augment the descriptions of technical concepts.

Mount Mazama and Crater Lake: A Study of the Botanical and Human Responses to a Geologic Event

Introduction

Crater Lake and its surrounding area create a unique microcosm, a product of the eruptive history of Mount Mazama, and the physical and social histories of the Cascade mountains. The climactic eruptions of Mount Mazama occurred approximately 7,700 years ago (Bacon, 1996; Mastrogiuseppe and Mark, 1992). This impressive composite volcano, towering some 10,000 to 12,000 feet (3 to 4 km) above sea level (Harris, 1988), was reduced in height by almost a mile (1.5 km) in a matter of days. The eruptions culminated with the collapse of Mount Mazama and the subsequent filling of the basin to form Crater Lake, the seventh deepest lake in the world at 1,932 feet (589 meters).

The geology and botany of Crater Lake relate directly to the local and global geologic systems operating in the Pacific Northwest. Those systems dictate the topography and the substrate, and modify the climate, of the area. The climate developed as the Cascade mountains formed. Human activity in the Pacific Northwest shifted in response to catastrophic geologic events and a shifting climate. The climactic eruption and collapse of Mount Mazama, for example, devastated the landscape, covering it with thick deposits of pumice and ash, changing the topography and controlling the soil substrate.

Objectives of this thesis include analyzing both plant successional patterns and human adaptations to changing flora as a result of the climactic eruptions of Mount Mazama. Ultimately, this document could be used as part of a training manual for Crater Lake National Park, providing Park Rangers with facts and insight concerning the physical and anthropological aspects of the park.

Background Information

Geology of the Pacific Northwest

The story of Mount Mazama begins more than 600,000 years ago as a volcanic complex emerged in what is now southern Oregon (Harris, 1988). Mount Mazama is a relatively young feature in the Cascade Mountain Range, a row of volcanoes extending from southern British Columbia through northern California (Fig. 1). The Cascades result from the interaction between two large fragments of Earth's outer shell, the North American and the Juan de Fuca plates.

The interior of the Earth is differentiated into layers according to chemical composition and density (Fig. 2). The classic model of the earth partitions it into three concentric layers of different chemistry - crust, mantle, and core. Less dense minerals, rich in silica (silicon and oxygen) comprise the *crust.* The *mantle* has less silica and more heavy minerals rich in iron and magnesium, making it more dense. Heavier elements, predominantly iron and nickel, have settled toward the center of the Earth, forming the *core* (Lillie, 1999).

More recently the model of the interior of the Earth was modified according to the physical state of the materials comprising each layer. The *lithosphere* (Greek *lithos* = hard rock) is the solid outer shell of the Earth; it is made up of the thin crust and the outermost portion of the mantle. Earth's outer shell resembles a large jigsaw puzzle, broken into rigid plates of lithosphere (Fig. 3). At about 60 miles (100 km) depth, the mantle material is in a soft solid state, analogous to the creamy filling of an Oreo cookie; this softer zone is called the *asthenosphere* (Greek *asthenos* = weak). The flow (or "convection") of heat (Fig. 4) within the asthenosphere causes very slow movement of the overlying lithospheric plates, producing *tectonic* (Greek *tecton* = builder or architect) settings of mountains and valleys. The rate of plate motion is about 0.5 to 4 inches/year (1 to 10 cm/year), or

Fig 1. The Cascade Mountain Range extends from southern British Columbia through northern California.

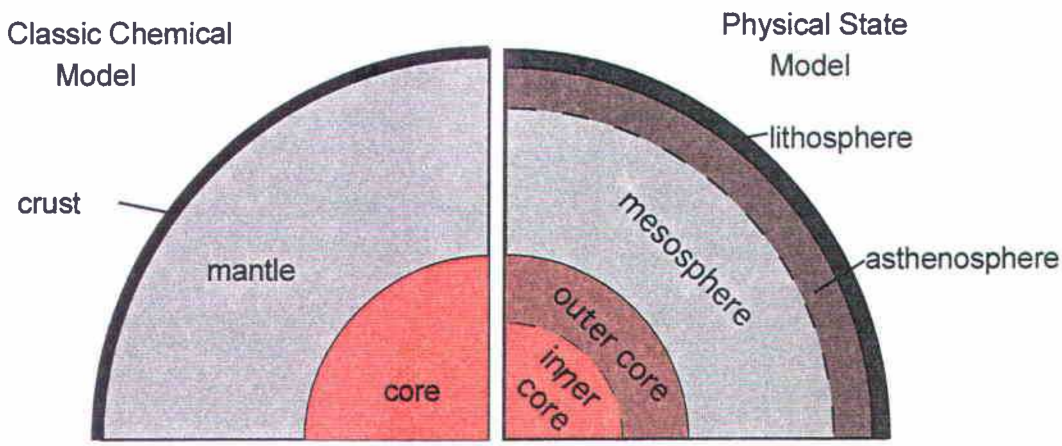


Fig. 2. The Earth is separated into concentric layers according to composition and density (left) and the physical state of the materials comprising each layer (right).

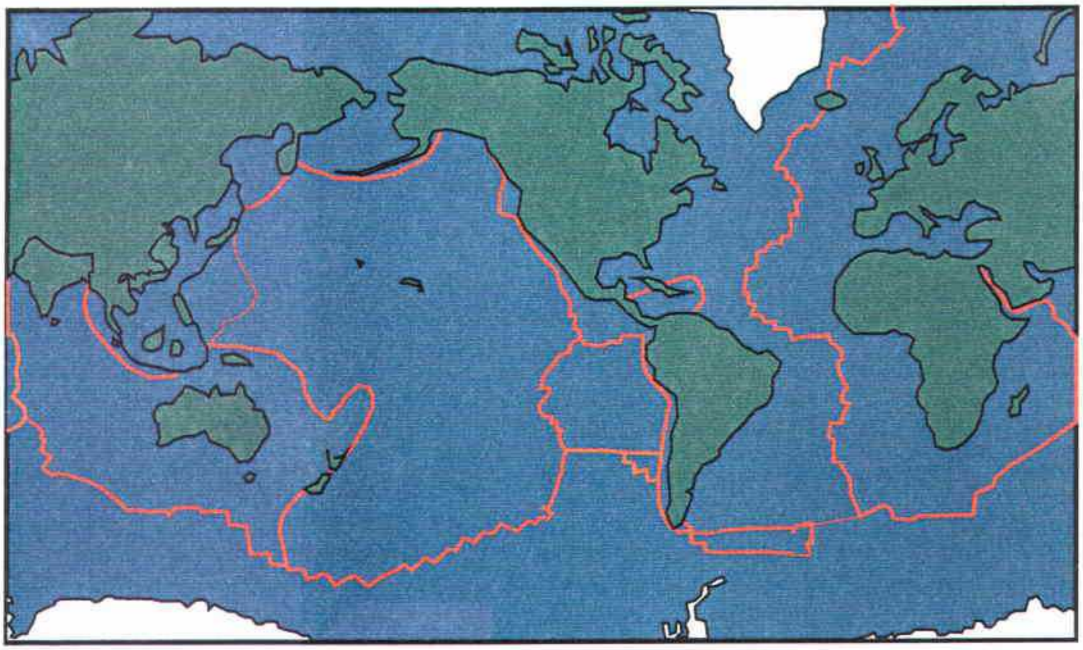


Fig. 3. The Earth's outer shell is broken into rigid plates of lithosphere, comprising seven major and several minor plates (adapted from Lillie, 1999).

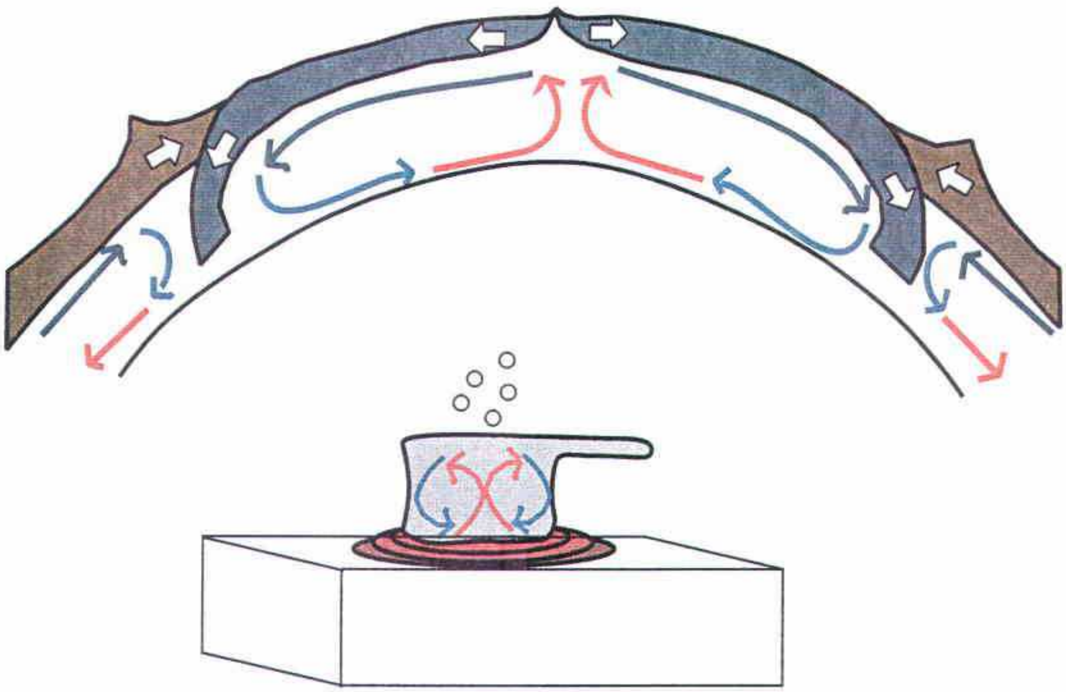


Fig. 4. Like a pot of boiling water, convection within the asthenosphere causes the lithospheric plates to move slowly. Red arrows indicate hot, buoyant material that rises, blue arrows cold, dense material that sinks.

roughly the speed a fingernail grows. It is this motion and interaction of the plates that results in earthquakes, volcanoes, and the formation of mountains. Kurt Vonnegut described the situation poetically:

> *Earth scientists had just discovered something fascinating about the continent Patty Keene was standing on, incidentally. It was riding on a slab about forty miles thick, and the slab was drifting around on molten glurp. And all the other continents had slabs of their own. When one slab crashed into another one, mountains were made.*
> (Breakfast of Champions, 1973)

The Pacific Northwest lies along the boundary of the Juan de Fuca and the North American lithospheric plates. The North American plate extends from the middle of the Atlantic Ocean across the continent to the Pacific Ocean. *Continental crust* is thick and buoyant compared to oceanic crust. The Juan de Fuca plate, capped by thin *oceanic crust*, is therefore more dense than the North American plate. As the two plates converge, the Juan de Fuca plate extends (or "subducts") beneath the more buoyant North American plate (Fig. 5). Earthquakes, volcanic eruptions, and parallel mountain ranges commonly result from plate interaction along such *subduction zones*.

Where the Juan de Fuca plate reaches depths of about 60 miles (100 km), it becomes so hot that it "sweats" fluids from its oceanic crust. The fluids rise and eat through the North American plate, forming pools of magma in the crust. Pressure builds as steam and other gases are trapped within the magma chamber. Like a pressure cooker or a soda pop can, when the pressure within the chamber is no longer containable, the material breaks through the crust, erupting onto the surface. Numerous eruptions have thus formed a volcanic mountain range, the Cascades.

Closer to the plate boundary, the subducting Juan de Fuca plate is shallow and therefore too cold to sweat off fluids. As the plate descends, oceanic materials (sediments and hard crust) are scraped off and added to the North American plate, forming the Coastal Ranges of Washington, Oregon, and northern California. Separating the volcanic mountains (Cascades) from the structural mountains (Coastal Ranges) are the lowlands of

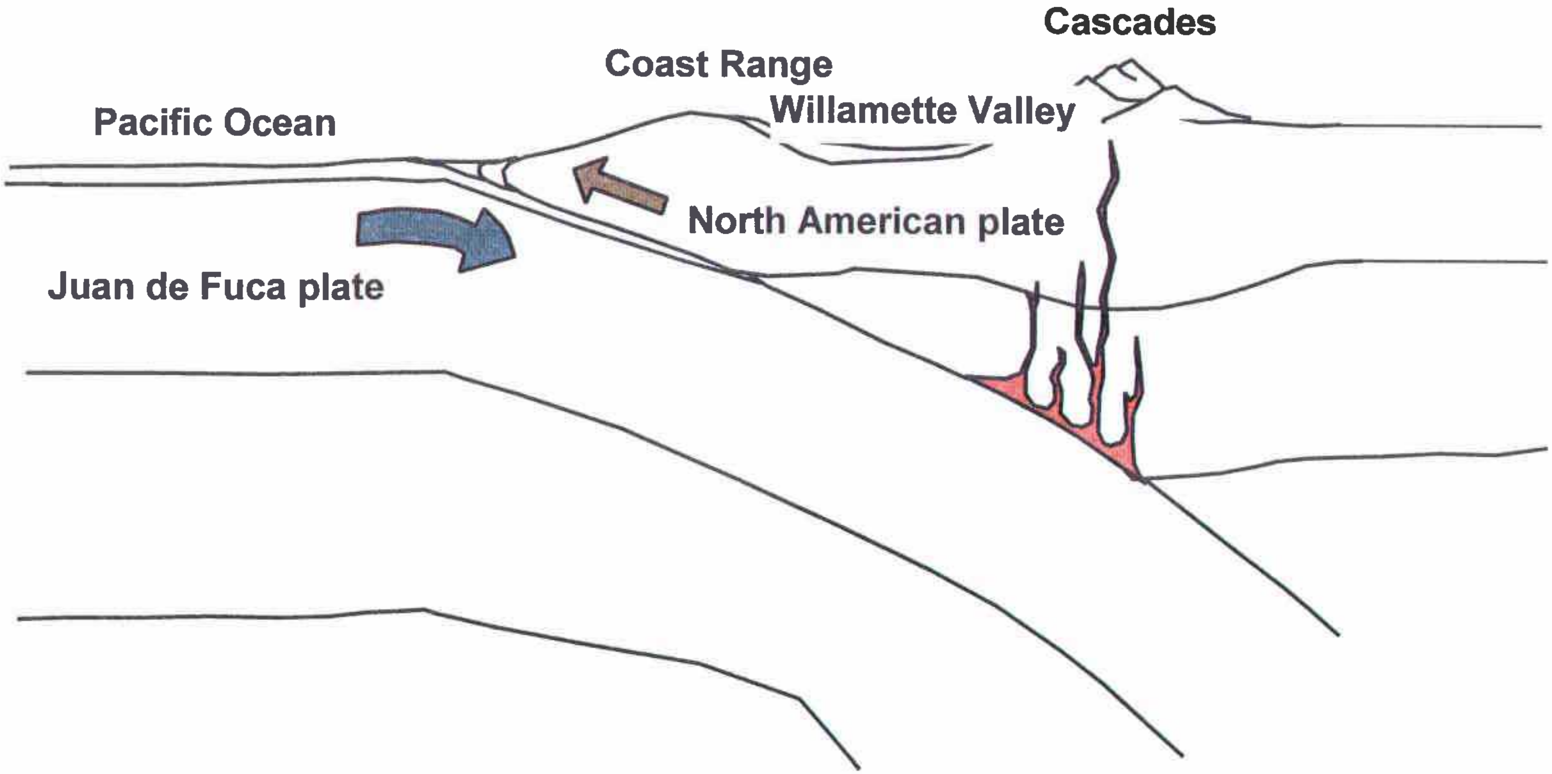


Fig. 5. The Juan de Fuca plate slowly subducts beneath the North American plate. Two parallel mountain ranges, one structural (Coast Range) and one volcanic (Cascades), form in the process.

Puget Sound in Washington, the Willamette Valley in Oregon, and the Great Valley of California.

The types of lava flows, eruptions, and resulting volcanoes depend on the chemical composition of the magma. *Viscosity* defines the fluidity of the material. A liquid with high viscosity is very "pasty" and does not flow easily, whereas a liquid with low viscosity is runny and can flow for long distances. Viscosity in magma depends on the silica content; the more silica in the magma the higher the viscosity. Silica (the elements silicon and oxygen) is a thickening agent, like adding flour to pancake batter. Low-silica (or "basaltic") magmas thus produce thin "runny" lavas that flow for long distances. Viewed from the air, the resulting volcanoes are very broad with gentle slopes, resembling warriors shields, hence the name *shield volcano* (Fig. 6). The Hawaiian volcanoes formed from such a series of gentle, flowing eruptions. High - silica ("andesitic" or "rhyolitic") magmas are thick and pasty, trapping gasses under pressure. The resulting eruptions are often violent, spewing hot solid materials and sticky (viscous) flows. The sticky lavas result in volcanoes with steep sides; such volcanoes often have lava flows interstratified with mud flows, ash, pumice, and other materials, and are hence called *strato* or *composite* volcanoes (Fig. 7). The eruption on May 18, 1980, of Mount St. Helens, a composite volcano, was a violent explosion that expelled pumice and ash, and triggered mudflows and debris avalanches.

Initially, the top portion of a subducting lithospheric plate is cold and brittle. As it subducts deeper within the Earth it heats. It is within the cold zone where most large earthquakes occur. In the Pacific Northwest, seismic activity is unusually low compared with other subduction zones (Goldfinger et al., 1992). It is thought that the last big earthquake in this region occurred about 300 years ago; the two plates have been locked together since then, building stress as they continue to converge. The next big earthquake could occur soon, when the stress becomes so great that the plates suddenly unlock.

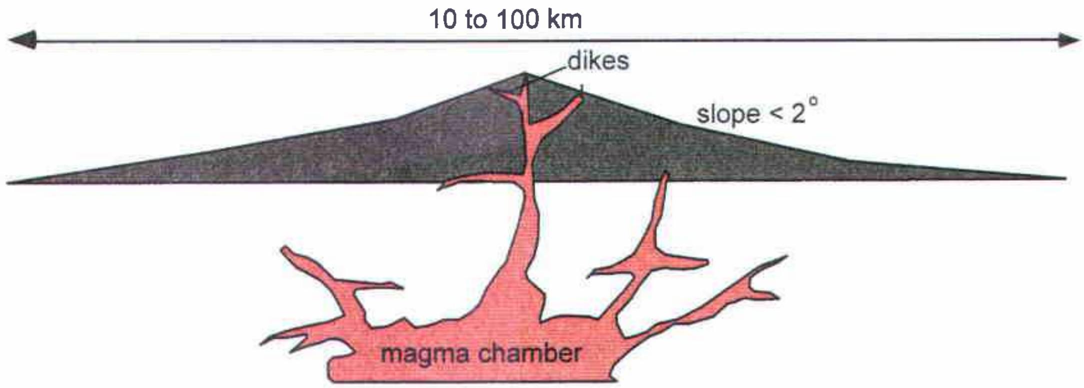


Fig. 6. Thin lavas build to form broad shield volcanoes.

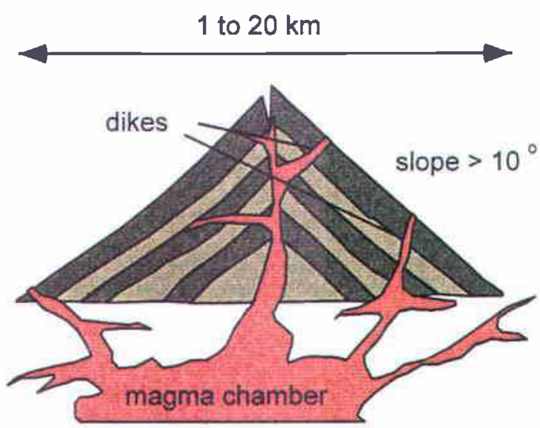


Fig. 7. Composite (or "strato") volcanoes produce layered, steep-sided mountains.

East of the Cascades, another tectonic setting, the Basin and Range Province, dominates. In this region, between the Cascades and the Rocky Mountains, the North American lithospheric plate is thinner and slowly pulling apart. The area is characterized by fault-block mountain ranges (German word: "horsts") and valleys (German: "grabens"); the faulting is due to the crust extending or "rifting" apart. This *continental rift zone* is called the "Basin and Range Province" because of the long, north-south trending valleys and intervening mountain ranges (Fig. 8). The Basin and Range Province bulges in the center, elevated by the hot, buoyant asthenosphere, and is depressed on the east and west by the basins of large ice-age, rain filled lakes, Lake Lahontan and Lake Bonneville. Associated with the Basin and Range Province, several fault zones, including the one responsible for the 1993 earthquake on the west side of the Klamath Basin, extend into Crater Lake National Park (Bacon, 1996).

Botany of the Pacific Northwest

Today Crater Lake National Park supports a diverse plant community that has adapted to the conditions of the High Cascades and to the most recent volcanic activity of Mount Mazama. Volcanic activity in the Pacific Northwest has repeatedly disturbed the landscape (Mullineaux, 1986). The vegetation east of the Cascades reflects the frequency of volcanic activity and its influence on the soil and microhabitats. Disturbance, such as volcanic activity, triggers change in an ecosystem. Interaction between the disturbance and the existing plant and animal life is often complex; it depends on the community structure and growth form, as well as the intensity and frequency of the disturbance event. The subsequent destruction tends to decrease with distance from the source. Unlike other disturbances, volcanic activity is relatively unpredictable and the consequent destruction of the landscape can be widespread and uniform (Zobel and Antos, 1997). When Mount Mazama erupted 7,700 years ago, it left a landscape covered in thick layers of pumice and ash. The vegetation currently growing in and around the large crater (or *caldera*)

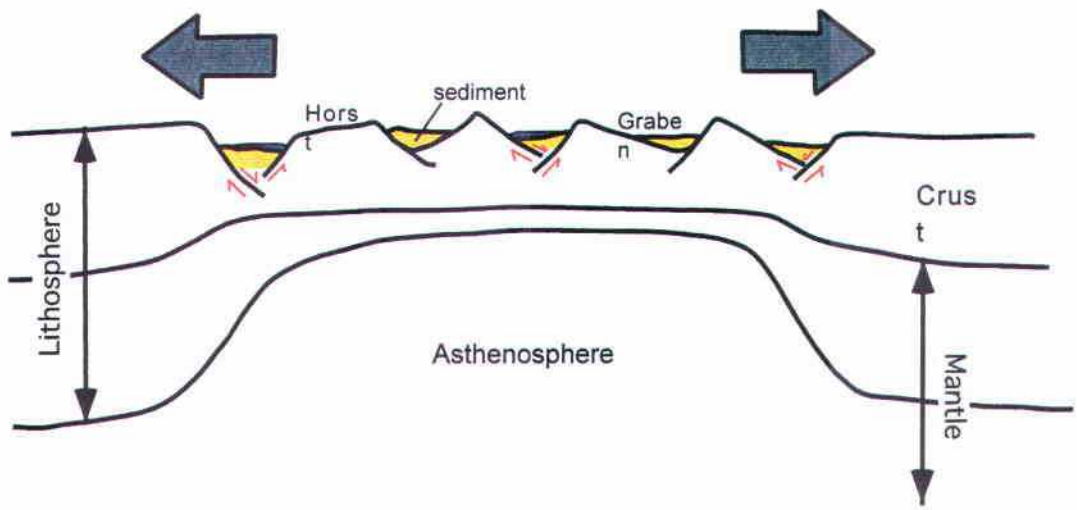


Fig. 8. A cross section of the Basin and Range Province, showing faulted "horsts" (mountain ranges) and adjoining "grabens" (valleys, filled with sediments and lakes).

represents the botanical response to volcanic activity. That response occurred gradually. A model of initial recovery can be developed through comparison to other volcanic systems and observations of current vegetation patterns.

The area surrounding the volcano is slowly recovering. *Succession* (the "vegetation" or "ecosystem" recovery process) occurs as plants and animals gradually return to the disturbed ecosystem. This may progress in developmental stages from mosses, algae and small plants to shrubs and trees; or as a more complex mosaic pattern, including both survivors and invaders. The plants that cover the volcanoes of the Pacific Northwest are adapting to an environment controlled by abiotic factors. *Abiotic* refers to the non-living environment versus the living, or *biotic* environment. The abiotic constraints that restrict the plant communities of Crater Lake include *climate*, underlying soil and rock or volcanic ejecta (or *substrate*), and *topography*. Plants require moisture, nutrients, light, and heat; those potentially limiting factors control an environment's ability to support plants and animals. These factors are controlled by the underlying geologic forces of the Pacific Northwest, in particular volcanic activity.

Topography and elevation are directly linked to the volcanoes. The volcanoes built in violent pulses of activity, accentuated by dormant intervals. A series of eruptions builds a volcano; the eruptive material covers the landscape, becoming the new substrate in which plants grow. As the Cascade Mountain Range rose, the climatic pattern changed. Galactic forces, such as changes in solar radiation and gravitational pull, and the byproducts of plate tectonics, such as volcanic dust and gases and the redistribution of continents and oceans, influence global climate. Local climates of the Pacific Northwest respond to the combined influence of the Pacific Ocean, prevailing westerly winds, and the height of the Cascades.

Globally, plants are distributed in general, recognizable patterns. Those patterns are based on species composition and physiognomy (or structural characteristics; for example, forest, grassland, desert). The patterns recognized on a global scale are further divided and subdivided into regional and local units. Vegetation patterns generally result from climatic regimes, as modified by elevation. Climate is the major force dictating the distribution of vegetation on the Earth (Daubenmire, 1978). Near the equator, high-angle sunlight and high moisture levels allow for dense forests with high species diversity. North and south of the equator, the angle of the sun decreases, thus decreasing the effective heat and shortening the growing season, which restricts species diversity (Fig. 9). Diversity is also limited by the movement of air in the Earth's atmosphere. The pattern of rising and sinking air above and below the equator influences precipitation (Ahrens, 1991). Near the equator, the air is directly heated by the sun and rises. As the air cools, it sinks, causing convection cells to form. In general, precipitation is greatest where the air is rising and least where the air is sinking. The Earth's deserts are concentrated in strips above and below the equator, where the air is sinking and thus, is hot and dry.

Local variance in topography, substrate, and microclimate dictate vegetation patterns on a smaller scale. The mesic temperate zones of the world include the forests of the Pacific Northwest. *Mesic* refers to the high level of moisture in the environment and *temperate* refers to the moderate temperatures. Both factors result from proximity to the Pacific Ocean and latitude, which regulates the climate in the region.

A simple transect through western Oregon across the Cascade Mountain Range represents a classic traverse of vegetational change dictated by climate and elevation (Fig. 10). The distribution of vegetation is controlled by the physical regime. Shifts in elevation and the corresponding shifts in temperature and precipitation control the distribution of vegetation. Typically, the temperature decreases with elevation and the precipitation increases with elevation, but decreases from west to east (Fig. 11). The precipitation ranges from 100 inches (250 cm) on the western slopes of the Cascades to less than 20 inches (50 cm) on the eastern slopes (Taylor, 1993). The elevation ranges

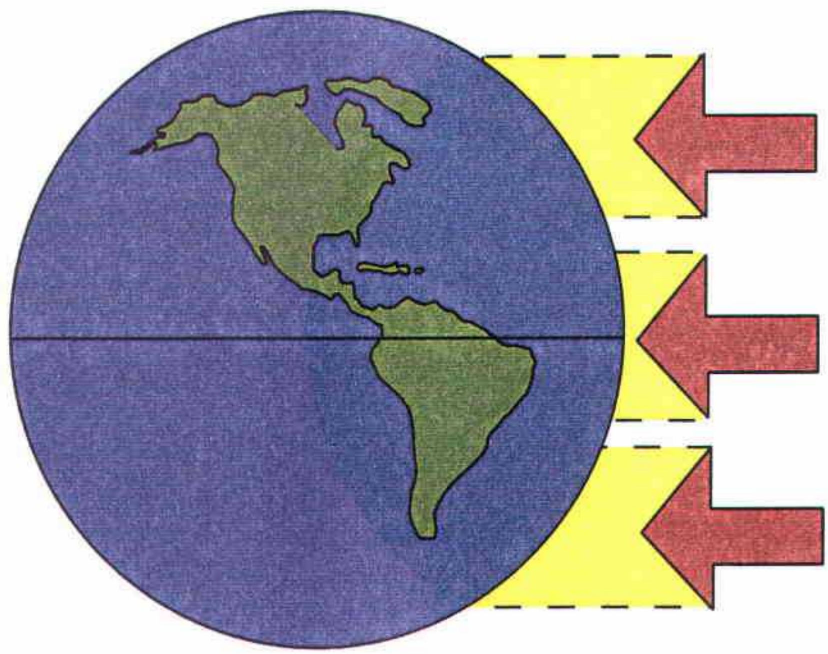


Fig. 9. The Earth's latitude plays a significant role in the amount of direct sunlight a particular location receives. Near the equator sunlight is more intense because the ratio of sunlight to area is greater than near the poles, where sunlight is dispersed over a greater area.

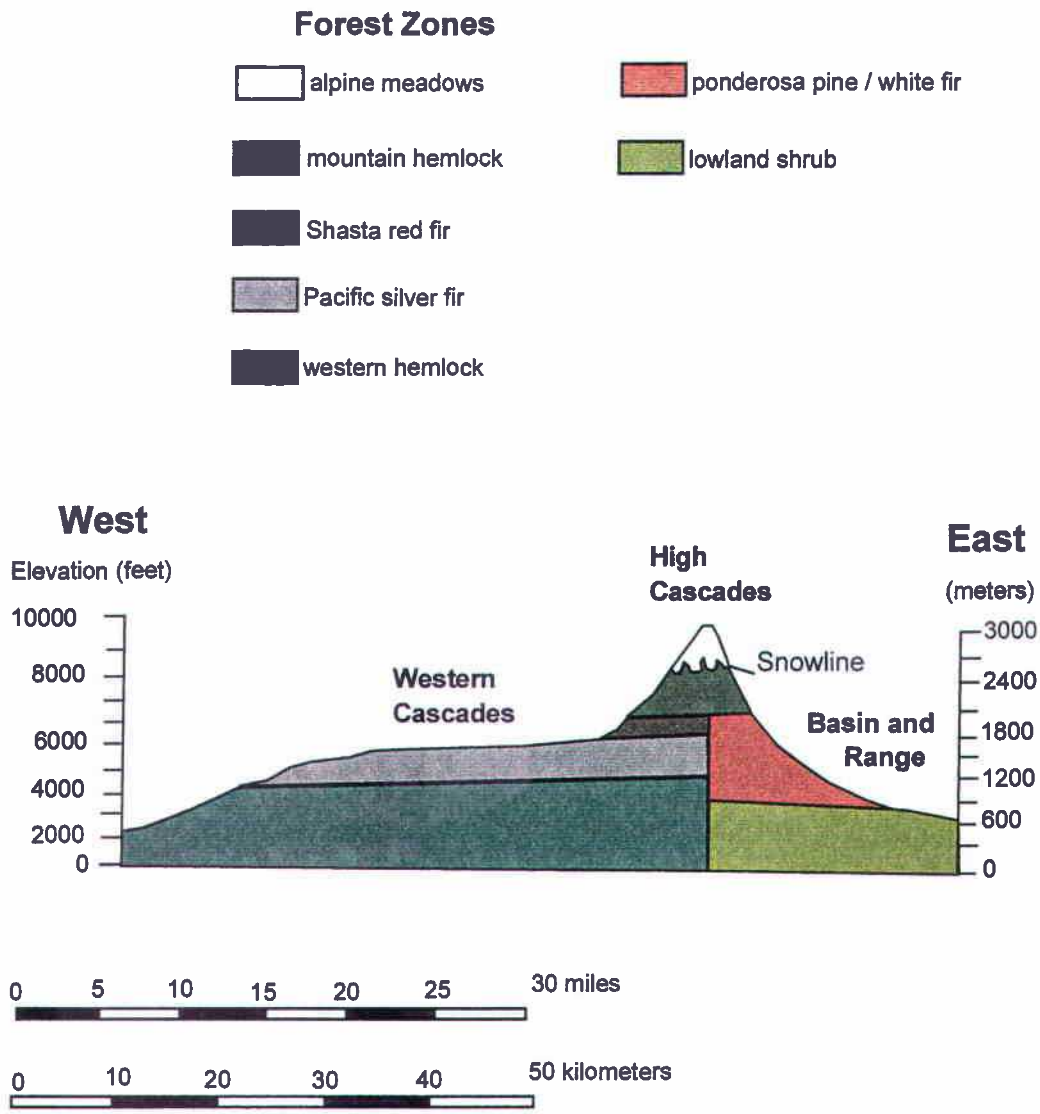


Fig. 10. A schematic model of western Oregon depicting general vegetation zones from the Willamette Valley on the west, across the Cascade Mountains and into the desert of the Basin and Range Province on the east.

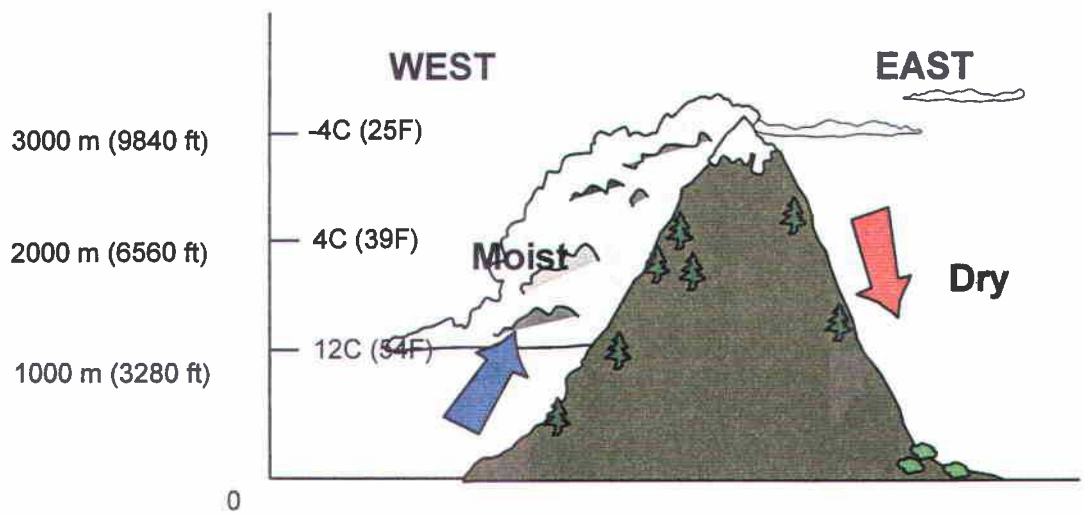


Fig. 11. As air rises over the Cascade Mountain Range the air expands and cools, and looses its ability to hold moisture. As the drier air descends on the eastern slopes, it warms and compresses, increasing its ability to hold moisture (adapted from Ahrens, 1991).

from near sea level to about 6500 feet (2 km) in the Cascades, with the large volcanoes rising to about 10,000 feet (3 km).

Oaks (*Quercus kelloggii* and *Q. garryana*) dominate the western foothills of the southern Oregon Cascades and extend into the interior valleys, where the warmest, driest conditions west of the Cascades prevail. Within this zone, elevation ranges from 200 feet (60 m) in the Willamette Valley to 1300 feet (400 m) in the Rogue River Valley. The vegetational composition of the oak woodlands encompasses both open savannah and dense stands mixed with conifers (Franklin and Dyrness, 1988).

The western hemlock *(Tsuga heterophylla)* zone is the most extensive forest zone in western Oregon (Franklin and Dyrness, 1988). Found in both the Coast Range and in the western Cascades, it surrounds the interior valleys of Washington and Oregon. Because the western Cascades are the older, inactive portion of the Cascades, they are more eroded, have steeper slopes and the soil contains more detritus (organic matter) and less ash. The build-up of detritus is a product of high precipitation and long term forest development. Douglas fir (*Pseudotsuga menziesii*) and western hemlock dominate the tree canopy and moss, ferns, and young western hemlock (which suggest a future forest dominated by hemlock) occupy the understory (Fig. 12).

As the elevation increases (and the overall temperature decreases), the precipitation reaches its peak and the type of vegetation changes from the western hemlock zone to the Pacific silver fir *(Abies amabilis*) zone. With elevation the soils are generally younger (the volcanic activity is more recent) and the percentage of ash increases. The soil is therefore drier, because moisture moves more easily through ash than through detritus. Noble fir *(Abies procera)*, Douglas fir, and western hemlock dominate the canopy (Fig. 13). Pacific silver fir is the main tree that can reproduce.

In the High Cascades approximately 6,000 - 10,000 feet (2-3 km) above sea level, the vegetation changes again (Franklin and Dyrness, 1988). The soil contains more ash because the zone lies within the young, active volcanic mountains. The High Cascades

Fig. 12. A typical Douglas fir dominated forest of the Pacific Northwest.
(Photograph courtesy of D. B. Zobel)

Fig. 13. A typical Pacific silver fir-zone forest with silver fir reproduction.
(Photograph courtesy of D.B. Zobel)

experience an average of 75 inches (190 cm) of annual precipitation, predominately as winter snowfall. Snow covers the ground for several months and the frost-free period is generally less than 50 days (USDA, 1986). Crater Lake National Park averages 65 inches (165 cm) of annual precipitation, including 50 feet (15 m) of snow, making the park one of the snowiest places on the North American continent. This zone, dominated by mountain hemlock (*Tsuga mertensiana),* is characterized by trees with stunted growth from long winters and short, dry growing seasons. Cold reduces the rate of organic matter decay. However, little summer precipitation also prevents a rapid buildup of organic soils. The soils are characteristically thin with very little horizon (vertical stratification) development. The understory is dominated by herbs and grasses and the canopy contains mountain hemlock (Fig. 14), subalpine fir *(Abies lasiocarpa),* and lodgepole pine (*Pinus contorta*).

The vegetation zones on the eastern slopes of the Cascades lie in the rain shadow of the Cascade mountains. The precipitation dramatically decreases from 80 inches (200 cm) to approximately 12 inches (30 cm). As the air sinks down the eastern slopes it becomes warmer and drier and consequently precipitation declines. Extreme fluctuations in temperature occur as heat from the sun is absorbed by barren soil and lost at night. Nighttime heat lose on pumice soils restricts plant growth. In certain areas only lodgepole pine seedlings are able to survive nighttime frost (Cochran et al., 1967). Fire suppression has altered the vegetational composition in this zone. Ponderosa pine forests have developed below the transitional zone; there the soils are dry and unconsolidated with little organic matter (Fig. 15). Ponderosa pine can be the climax species where the precipitation cannot support a dense canopy.

Fig. 14. A typical mountain hemlock dominated forest. (Photograph courtesy of D. B. Zobel)

Fig. 15. A typical ponderosa pine dominated forest (Photograph courtesy of D. B. Zobel)

Pre - history of the Pacific Northwest

Archaeology in eastern Oregon has been limited by volcanic activity, which covers the landscape with thick layers of pumice, ash, and other materials. Sheltered sites in caves and sites younger than the last volcanic eruptions comprise the knowledge of prehistoric populations in central and eastern Oregon. Limited data from central Oregon have led archaeologists to borrow from other areas, less affected by volcanic ejecta (Aikens, 1993; Clark, 1996). Therefore, what is known of the people who made this area their home is primarily speculative and derived from information on other sites some distance from the eruptive region and from ethnographic records collected after the arrival of American settlers.

A more exact history of the area began with the advent of European gold diggers and farmers. Dates and time were of more importance to the western world. History tells the chronological story of a people, whereas anthropology is a study of culture. The story of Crater Lake includes both the anthropology of prehistoric populations and the history of Crater Lake National Park.

People have lived in the Pacific Northwest for at least 10,000 years. The human history of North America is closely linked to the geologic events of the Quaternary Period, especially the Pleistocene Epoch, which ended approximately 10,000 years ago. During the Pleistocene, global cooling resulted in four episodic glacial events known collectively as the Ice Age. These events covered large areas of the Northern Hemisphere with massive sheets of ice. The Cordilleran ice sheet extended from the Rocky Mountains of British Columbia to the Pacific Ocean and down into central Washington. The Wisconsin episode, from at least 65,000 to about 10,000 years ago (Nilsson, 1983), marked the last glacial advance on the North American continent. During glacial periods, large volumes of water were trapped in the continental ice sheets, resulting in a global drop in sea level, and the exposure of Beringia.

Beringia refers to the very shallow-water continental shelf separating Siberia from Alaska. When sea level dropped, during periods of extensive ice, a land bridge between Asia and North America was exposed (Fig. 16). The last interval of glaciation peaked about 18,000 to 20,000 years ago (Nilsson, 1983). It is speculated that the first humans migrated to this continent between 12,000 and 35,000 years ago across the Beringia land bridge (Nilsson, 1983). Evidence of the human presence has been found in Oregon cave sites dating over 13,000 years ago and more dubious dates of about 25,000 years ago for occupation sites in Mexico. Early populations, small mobile groups of hunters, probably followed the large game animals across Beringia. The game animals dispersed over much of southwestern North America, as adequate habitat extended into modern arid landscapes

Immediately south of the ice sheets, the land resembled arctic tundra with lowland vegetation dominating the landscape (Barnosky et al., 1987). The Columbia Plateau and the Basin and Range Provinces were wetter than today and were covered with lush grasslands. Extensive pluvial (rain filled) lakes dotted the landscape. Large Pleistocene game animals, including mammoth, bison, and mastodon, roamed the grass prairies. People soon settled around the lakes, where abundant water supported a rich diversity of plants and animal.

As the glaciers receded, the climate in the Basin and Range Province shifted from wet and cool to hot and dry. By about 10,000 years ago, the climate had stabilized and, with only minor fluctuations, has remained relatively constant to the present (Ranere, 1970; Mehringer, 1986). Increased aridity caused the pluvial lakes to shrink slowly and forced vegetation zones to shift to higher elevations. At about this same time, many animals associated with Pleistocene glaciation began dying off. By about 8,000 years ago, many big game species were extinct (Diamond, 1987).

Increasing aridity and the extinction of large game animals marks a general cultural shift from big game hunting to more generalized hunting and gathering among prehistoric people of North America, particularly groups living in the western Intermountain region.

Fig. 16. Beringia was most recently exposed during the Wisconsin glacial episode from about 35,000 to 12,000 years ago. It is speculated that people followed the large game animals across this land bridge, eventually dispersing through the Americas.

The climatic trend towards aridity spanned thousands of years; thus, the recession of basin lakes and the migration of vegetation to higher elevations occurred at an almost imperceptible pace. This allowed Great Basin populations to adapt and evolve with the changing environment. As a result multiple cultures developed. Populations along the eastern boundary of the Great Basin migrated with the shifting vegetation zones, adjusting to a sagebrush-grass association. Others concentrated around the shrinking lake shores of Lake Bonneville and Lake Lahontan, and the remaining populations took advantage of relic ecosystems scattered throughout the desert (Ranere, 1970). The third group defined as the *Desert Culture* was thought to be the dominant lifeway of the Intermountain area from southern British Columbia to Mexico (Cressman, 1956).

The Desert Culture was defined as a traditional hunter-gatherer society (Steward, 1955). Small, mobile groups of people generally revolved around an economically self-sufficient family unit. Dependent on the environment, these people subsisted predominantly on gathered resources. There was, however, regional variability associated with climate and geography.

The grassland and lake-shore cultural patterns represent a continuity of culture established soon after populations migrated to the Great Basin; whereas the Desert Culture represents the cultural adaptation to an increasingly arid landscape. All three cultures were present prior to contact with European settlers. The cultures most affected by contact were concentrated around the waterways - rivers and lakes. For this reason the settlers' first impression of the native populations was of an impoverished, destitute people eking out an existence in an arid landscape.

Several lists have been compiled of artifacts associated with the cultures of the Basin and Range Province. The lists include such items as sandals, basketry, small projectile points, atlatls, scraper and chopper tools, and digging sticks (Jennings and Norbeck, 1964). The culture was characterized by intense seasonal exploitation of resources - seed grasses and small game.

By the middle Archaic, from about 4,000 to 2,000 years ago (Aikens, 1993), seasonal patterns of resource exploitation were well developed. A mountain-valley theme prevailed. During the summer months, small family units gathered and hunted, wandering through arid valleys. The movement depended on the resource availability. Larger groups wintered near juniper-pinyon woodlands, where pinyon nuts were gathered in late fall (Steward, 1955). Pinyon pine is the most important nut pine (Fowler, 1986). Today, this pine does not extend into Oregon; other pines, such as ponderosa pine, however, are found in the region. Pinyon pine nuts were found in charcoal deposits dating about 11,000 years ago in Fort Rock Basin. This indicates that either warmer temperatures temporarily increased the distribution of pinyon pine into the northern Great Basin or pinyon nuts were used as a trade commodity. In southeastern Oregon the seasonal pattern centered around marsh and lacustrine lowland resources and upland root resources.

There are four major physiographic provinces surrounding Crater Lake - the Cascade Range, the Klamath Mountains on the west and the Klamath Highland on the southeast, and the Northern Great Basin to the east. Corresponding to those physiographic regions were three dominant cultural groups - the Molala, the Klamath and Modoc, and the Northern Pauite (Fig. 17) (Cressman, 1981).

Although no cultural group used the Crater Lake region exclusively, the Klamath and Modoc territory overlap more than any other cultural group in the area (Winthrop, 1994). Their traditional lands lie on the western periphery of the Basin and Range Province; thus their culture was an adaptation of the hunter-gatherer culture. Unlike the Northern Pauite, the Klamath and Modoc had access to water resources year round. The Klamath and Modoc evolved from the conventional nomadic hunter-gatherer society into a riverine/lacustrine-dependent society. They maintained the seasonal round of summer foraging and winter fishing, although their habits were more sedentary than the habits of the Northern Pauite (Cressman, 1981). Year round, fish and waterfowl were the main sources of protein, supplemented by plant foods. The Klamath lived in large substantial

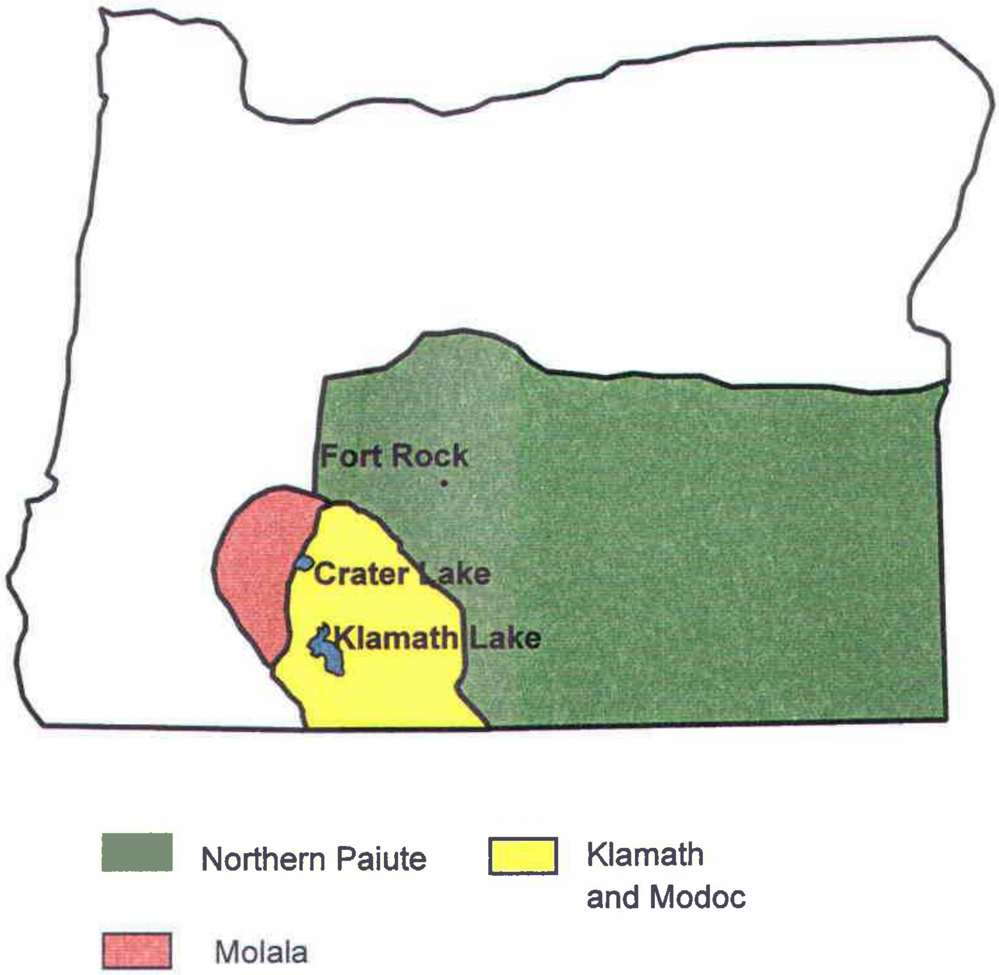


Fig. 17. A map of the cultural groups that surround Crater Lake (adapted from Cressman, 1981).

winter settlements and smaller, less permanent settlements during the summer months. The winter village was located where fish, waterfowl, drinking water, and other water resources were available and in areas protected from winter storms.

The Molala occupied the territory west of Crater Lake. They also followed a seasonal round, exploiting upland large game animals during the summer months and wintering along streams at lower elevations. They were dependent on hunting in the upland Cascades. Fish and some plant foods supplemented their diet (Winthrop, 1994).

Northeast of Crater Lake, in the Fort Rock Basin, charcoal from the Fort Rock Cave indicate human presence in the basin for at least the last 13,200 years. Occupation sites have been found in the wave-cut caves along the remnant shoreline of Fort Rock Lake, an ice-age fresh water lake (Cressman, 1981; Prouty, 1995). The Basin and Range Province provided no consistent food or water source for its inhabitants. Thus the Northern Pauite developed a nomadic lifestyle dictated by the extreme environment (Cressman, 1981). Settlements and foraging groups were small, limited by the resources available and the ability to store resources during the winter. The summer months were spent gathering plant foods and hunting mainly small game animals. If lucky, they sheltered in wave-cut caves along rain-filled lakes and marshes or wherever there was a source of water and game during the winter months. There is little archaeologic evidence of most occupation sites, since most were temporary and usually only consisted of a fire pit and miscellaneous debris. Caves and overhangs were favorite occupation sites, often used for thousands of years (Jennings and Norbeck, 1964). These sites were more easily preserved, therefore, cave sites can reveal a local chronology dating thousands of years. It is possible that both the Klamath and the Northern Paiutes of the Basin and Range Province lived in the shadow of "Llaoyeina" (Mount Mazama), which now holds Crater Lake.

A Boat Tour Around Crater Lake

In the heart of the Cascade Range is a little sheet of water which is destined to take a high rank among the wonders of the world. It is a unique phenomenon, taken as a whole, though some of its component features taken singly, may not be unexampled...To the geologist this remarkable feature is not less impressive than it is to the lover of the beautiful. Captain Clarence Dutton, 1886 (Unrau, 1988)

A boat tour on Crater Lake offers a unique experience (Fig. 18). There are very few places in the world where the general public can observe a volcano *from the inside looking out.* The tour stops at major geologic features, from which the story of Mount Mazama and Crater Lake unfold (Fig. 19). A volcano does not erupt in a vacuum. The eruption and the eruptive material affect life around the volcano. The geology of Mount Mazama and of Crater Lake impact the botany and anthropology of the area. Throughout the tour both rocks and plants provide the evidence of Crater Lake's dramatic past, tranquil present, and uncertain future.

Crater Lake is the deepest lake in the United States, the second deepest on the North American continent, and the seventh deepest lake in the world (Table 1). The lake spans approximately six miles by four miles (10 km by 6.5 km) and reaches a depth of 1,932 feet (589 m). The steep walls above the water line continue to great depths below the water. Llao Rock (1,870 feet above the lake), Hillman Peak (1,980 feet above) and Garfield Peak (1,884 feet above) all approximately mirror the depth of Crater Lake.

Compared to other deep lakes of the world, Crater Lake's total surface area is small. Crater Lake covers 21 square miles (54 square kilometers), minuscule when compared to the 12,162 square miles (31,500 square kilometers) of Lake Baikal (the deepest lake in the world) or the 143,244 square miles (371,000 square kilometers) of the Caspian Sea (the third deepest lake in the world) (The World Almanac, 1997) (Fig. 20). The formation of Crater Lake is also unique. Of the eleven deepest lakes in the world, Crater Lake is the only one in the throat of an ancient volcano (Table 1). Several of the

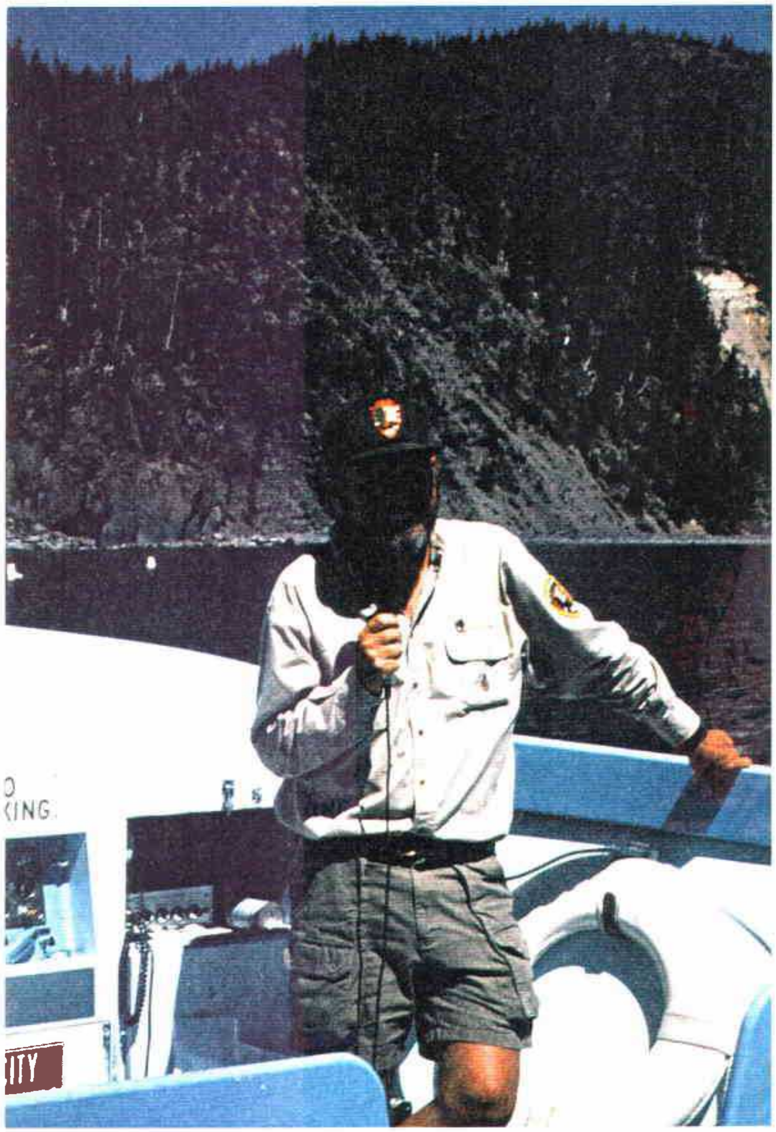
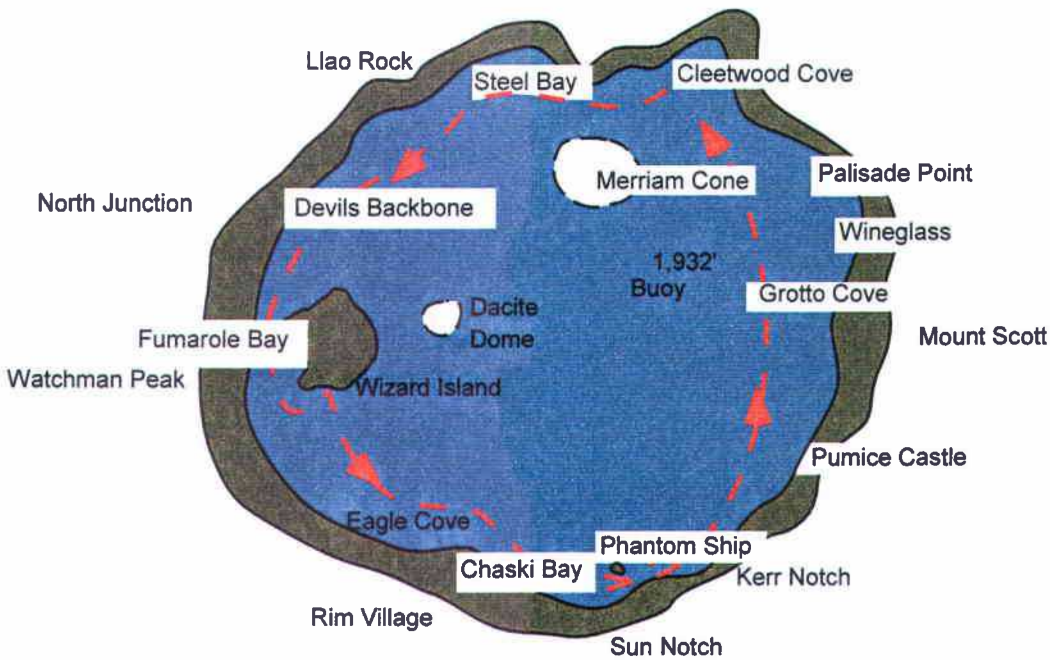


Fig.18. A boat tour on Crater Lake with Ranger Lillie.
(Photograph courtesy of R. J. Lillie)



The Crater Lake Boat Tour

Fig. 19. The Crater Lake Boat Tour makes a counter-clockwise circle around the lake, stoping at various geologic features. The outside contour represents the top of the steep wall of the caldera, an average of 7000 feet (2100 m) above sea level. The inside contour is the lake shoreline, an average of 5000 feet (1500 m) elevation.

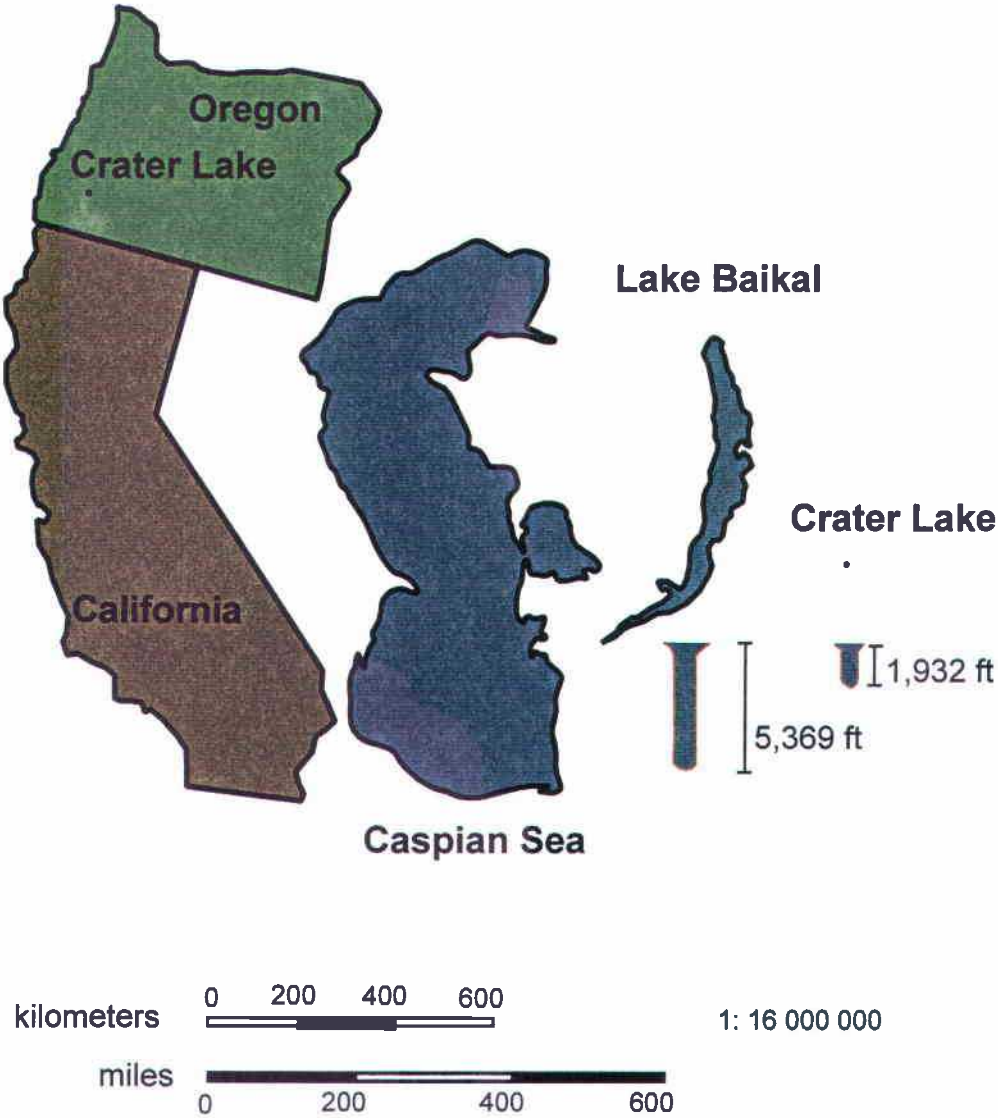


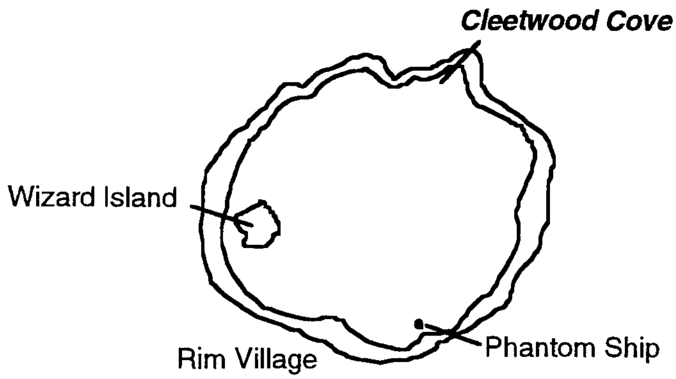
Fig. 20. Compared to other deep lakes in the world, Crater Lake's 21 square miles (54 square kilometers) is small. The Caspian Sea (the third deepest lake in the world) has an area of 143,244 square miles (371,000 square kilometers). Lake Baikal (the deepest lake in the world) has an area of 12,162 square miles (31,500 square kilometers) and the state of California has a total area of 163,707 square miles (424,000 square kilometers). The Lake Baikal and Crater Lake depths are compared in lower right.

deep lakes are found in continental rift valleys, a product of crustal extension; other deep lakes occur in flooded glacial valleys.

Table 1. A list of the 11 deepest lakes in the world and their origins.

Lake	Location	Depth feet (meters)	Origin
1.Baikal	Siberia, Russia	5,369 (1,637)	continental rift valley
2. Tanganyika	Africa (Tanzania, Zaire, & Zambia)	4,708 (1,435)	continental rift valley
3. Caspian Sea	Iran and Russia	3,104 (946)	remnant of an ancient sea
4. Malawi	Africa (Mozambique, Tanzania & Malawi)	2,316 (706)	continental rift valley
5. Issyk Kul	Kyrgizstan, Central Asia	2,297 (700)	continental rift valley
6. Great Slave	Northwest Territories, Canada	2,015 (614)	glacial valley
7. Crater Lake	Oregon, USA	1,932 (589)	volcanic caldera
8. Lake Tahoe	California & Nevada, USA	1,685 (514)	continental rift valley
9. Lake Chelan	Washington, USA	1,419 (433)	glacial valley
10. Great Bear	Northwest Territories, Canada	1,356 (413)	glacial valley
11. Lake Superior	Canada/USA	1,333 (406)	glacial valley

Cleetwood Cove



Geology of Mount Mazama

Where the pristine Crater Lake now sits, a volcano once stood. Part of the Cascade volcanic chain, Mount Mazama originated around 600,000 years ago. It began as a shield volcano (Fig. 21), and eventually shifted to a composite volcano (Fig. 22). During its history, Mount Mazama had several summits. The oldest summit is near what is now Mount Scott. The mountain building activity moved in a general westerly direction. The youngest mountain building events to survive the collapse are Llao Rock, the Cleetwood backflow, and Skell Head, discussed in the boat tour.

Botany

The vegetation surrounding Crater Lake depicts a typical pattern of forest cover on Cascade volcanoes - forests dominated by high elevation plants able to withstand extreme environmental factors, predominantly climate and topography, and the young undeveloped soils of a recently active volcanic complex (Fig. 23). Whitebark pine (*Pinus albicaulis*) and some other minor tree species, such as subalpine fir (*Abies lasiocarpa*), are found along the caldera rim and on the peaks surrounding the lake, where extreme high elevation

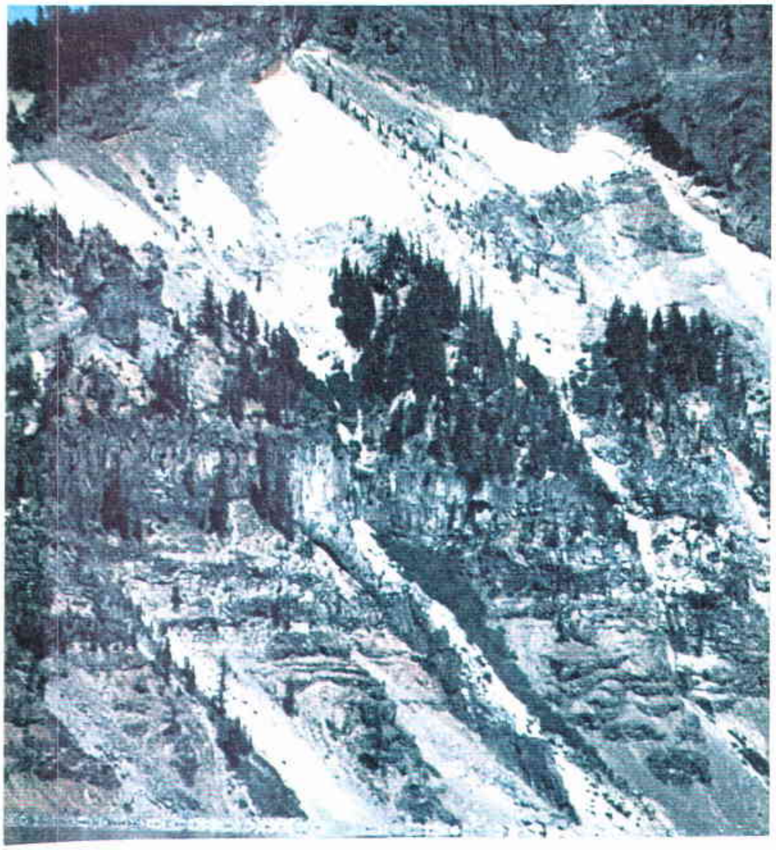


Fig. 21. In Steel Bay the layaering of thin, basaltic lavas suggests Mount Mazama began as a shield volcano (Photograph courtesy of R. J. Lillie

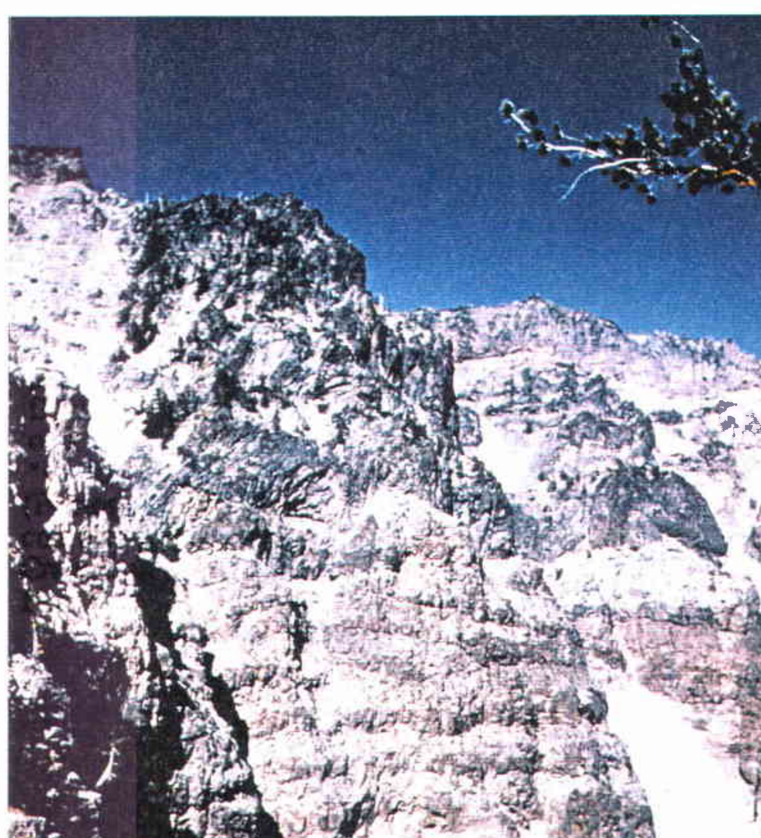


Fig. 22.The cross section of Dutton Cliff depicts alternating layers of ash cinders, pumice, and lava flows characteristic of a "composite" or "strato" volcano (Photograph courtesy of Crater Lake National Park archives)

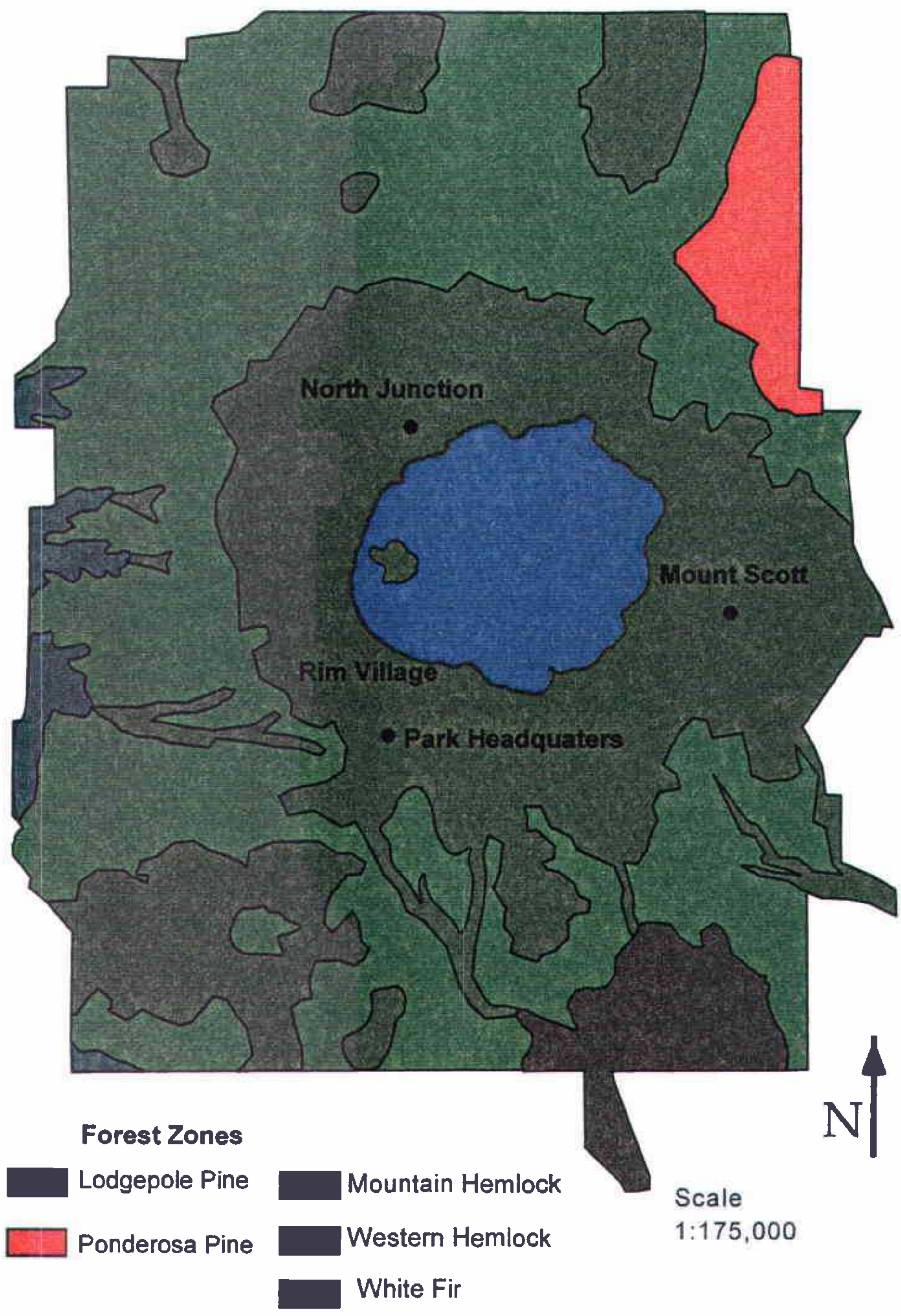


Fig. 23. A general map of the forest vegetation of Crater Lake National Park. (adapted from map in Crater Lake National Park Archives)

conditions prevail. On the slopes of Mount Mazama, mountain hemlock and Shasta red fir (*Abies magnifica* var. *shastensis*) dominate the tree canopy. Lodgepole pine (*Pinus contorta*) forests are scattered within and surround the mountain hemlock zone, especially in areas with thick pumice soils and in areas previously destroyed by fire. The lodgepole pine is an important tree species in volcanic systems, able to endure low nutrient soils and high soil surface temperatures (Zeigler, 1978). Interspersed with the lodgepole pine forests are Shasta red fir. Both the lodgepole pine and the Shasta red fir zones are transitional and usually mixed with mountain hemlock. On the fringes of the park are three minor tree zones. On the western, low elevation slopes of Mount Mazama grow western hemlock forests; ponderosa pine and white fir forests grow on the eastern slopes.

History of Crater Lake

Although the Native Americans were aware of the lake, it was not regularly visited (Winthrop, 1994). Many groups believed the lake was inhabited by powerful spirits, which restricted usage. Only shamans (religious leaders), an occasional chief or a brave young warrior on a vision quest would venture to the lake. Crater Lake was first "discovered" by Europeans in 1853. John Hillman and a party of gold prospectors stumbled upon the lake and called it "Deep Blue Lake". Hillman and his party were so disoriented that they were unable to describe its location and Crater Lake was lost. In 1865 Captain Franklin Sprague from Fort Klamath organized an expedition to rediscover the lake. He was the first to recognize the lake's volcanic origins. From "Deep Blue Lake" to "Blue Lake" and"Lake Majesty", the lake eventually became known as Crater Lake in 1869, perhaps because of the small crater on Wizard Island (Smith and Smith, 1997).

The story of Crater Lake National Park really began in Kansas in 1870. There, as a young boy, William Steel first learned of Crater Lake from a story on a scrap of newspaper wrapped around his lunch. He did not see the lake until 1885, but from that moment he was devoted to the preservation and promotion of Crater Lake (Fig. 24). He later said "an overmastering conviction came to me that this wonderful spot must be saved, wild and beautiful, just as it was, for all generations..." (Steel, 1886 in Greene, 1984). Steel's legacy, Crater Lake National Park, became the seventh national park in 1902. Today, Crater Lake National Park is ranked as the sixth oldest national park; Mackinac Island was returned to the state of Michigan in 1895.

Among other accomplishments, William Steel led the scientific expeditions of 1885 and 1886 on Crater Lake. Cleetwood Cove was named after the Cleetwood, one of three canvas-bottomed boats used on that expedition. The boats were carefully lowered down into the lake on snow, still remaining in ravines below what is now Rim Village. The expedition determined the lake was 1,996 feet (608 m) deep (Warfield, 1985). They used triangulations from Watchman Peak and Sentinel Rock to locate their positions, and a weight lowered down on piano wire to calculate water depths. Later in 1959, with more accurate equipment, research teams determined Crater Lake was 1,932 feet (589 m) deep (Warfield, 1985). William Steel and his crew were only 64 feet (19 m) off!

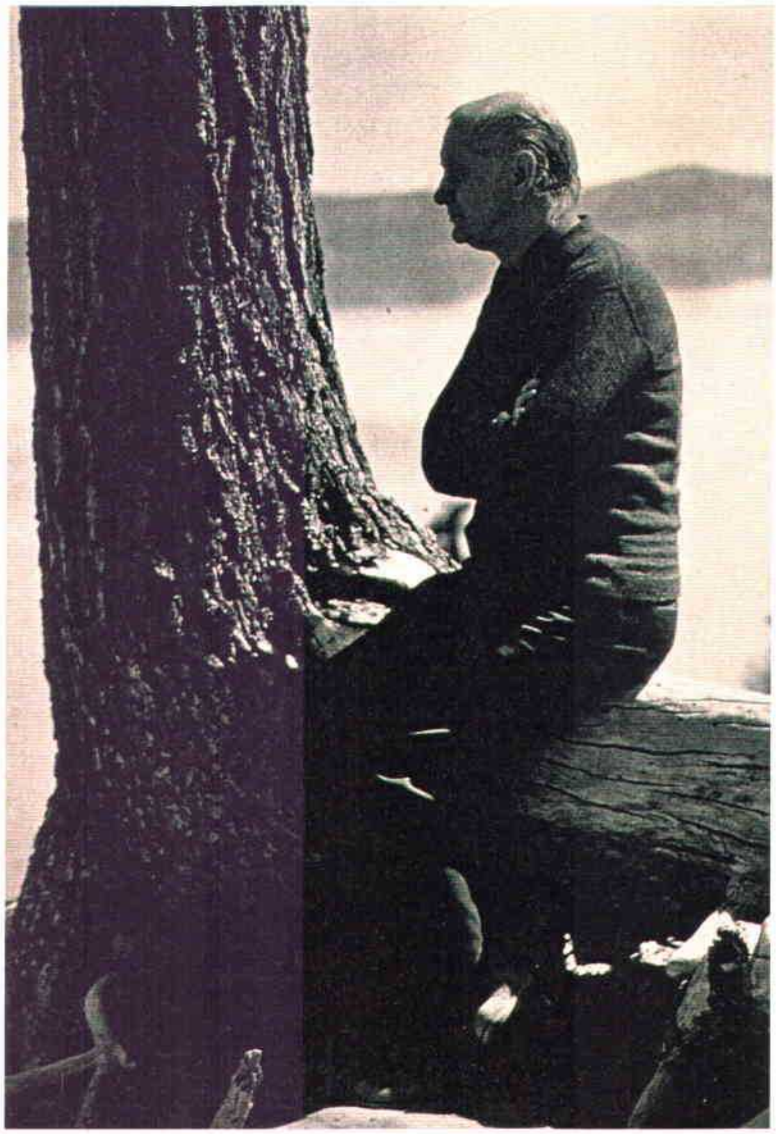
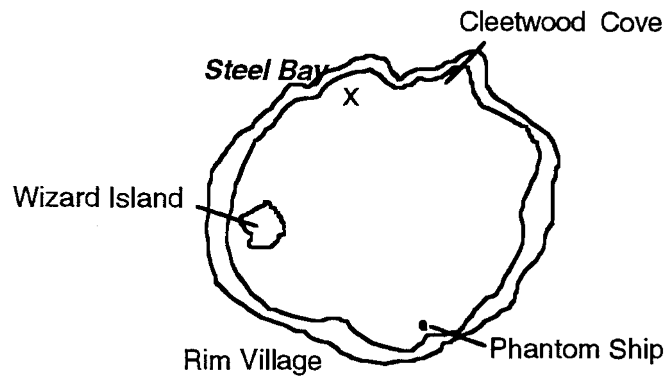


Fig.24. William Steel is considered the Father of Crater Lake National Park. (Photograph courtesy of Crater Lake National Park archives)

Steel Bay: *Pre- Eruption Landscape*



Geology: *Reconstruction of Mount Mazama*

The walls of Crater Lake reveal the history of Mount Mazama's formation. Before the climactic eruptions, Mount Mazama was perhaps similar in stature to Mount Adams in Washington state (refer to Fig. 1). It towered some 10,000 to 12,000 feet (3,600 m) above sea level. The walls of the volcano are layered, like a stack of pancakes. Those layers slope gently away from the lake; projecting the sloping layers upward can be used to envision the height of Mount Mazama (Fig. 25). The mountain peak had permanent ice fields, which extended down the mountain, forming valley glaciers. The extensive glaciation is evident from U-shaped valleys along the caldera flanks (Fig. 26). These beheaded glacial valleys can also be projected to imagine the summit of Mount Mazama.

The eruptive behavior of a composite volcano may include both quiet and violent eruptions. Below Llao Rock and in Steel Bay both types of eruptions are apparent by the alternating layers of ash and lava flows (Fig. 27). At the base of the wall there are dark layers of basalt representing the first stage of mountain building. *Basalt* forms from a fluid (low viscosity) magma, low in silica but rich in iron and magnesium. Like many of the volcanoes of the Cascades, Mount Mazama thus began as a shield volcano.

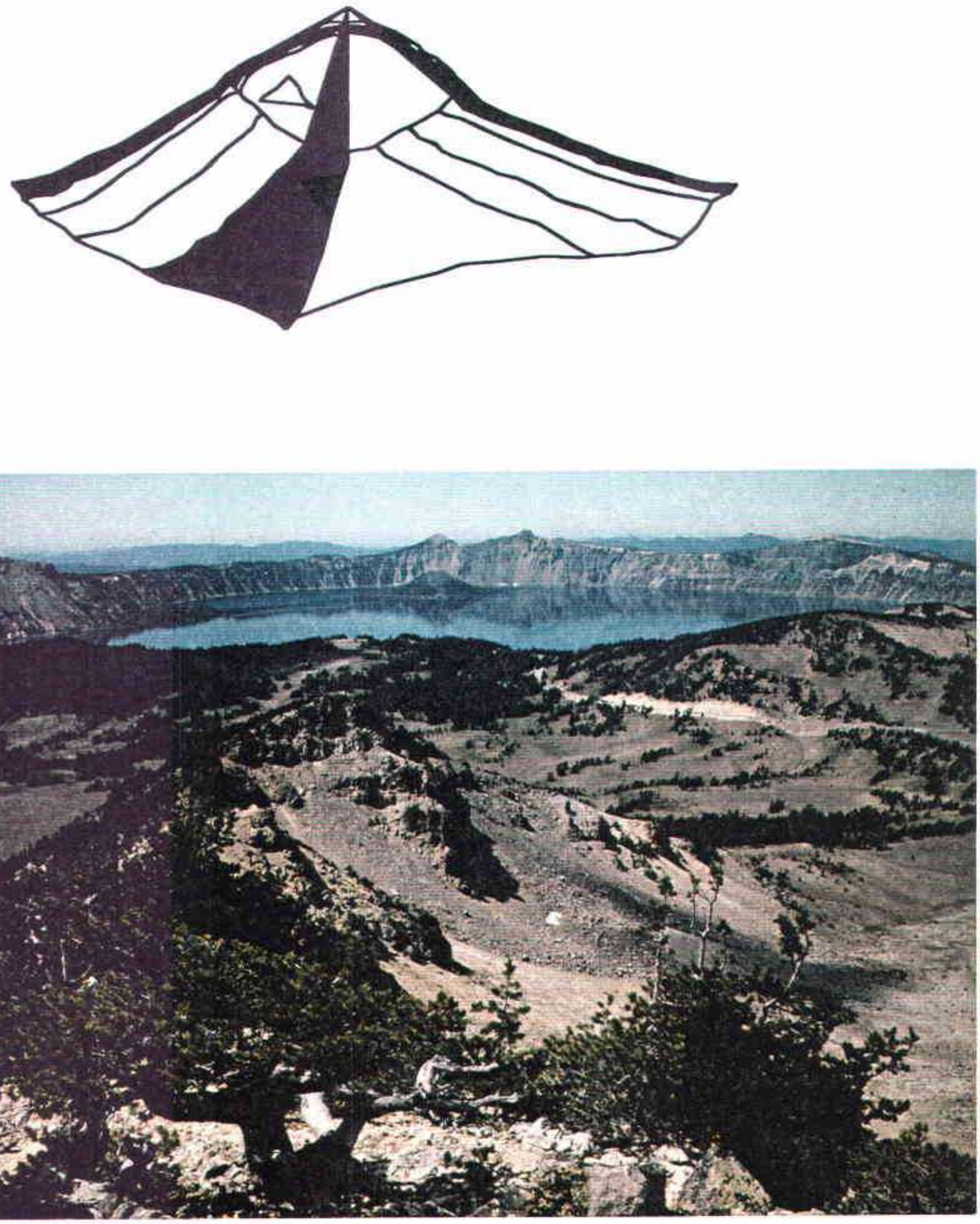


Fig.25. The height of Mount Mazama can be envisioned by projecting the dipping layers upwards. (Photograph courtesy of R. J. Lillie)

Fig. 26. Sun Notch and Kerr Notch are beheaded glacial valleys. The upper regions of the valleys were obliterated during the eruption and collapes of Mount Mazama.(Photograph courtesy of R.J. Lillie)

Fig. 27. Llao rock is the bird-like feature seen from the boat. (Photograph courtesy of R. J. Lilliel)

Mount Mazama shifted from a shield volcano to a composite volcano about 200,000 years ago (Bacon, 1983). The alternating lighter layers below Llao Rock and extending into Steel Bay are from the violent, explosive eruptions. The lighter layers consist primarily of *ash* (pulverized rock) and *pumice* (a light frothy rock). Ash and pumice form a solid eruptive (high viscosity) material, high in silica and low in iron and magnesium. Continental crust consists of high amounts of silica. As the fluid from the subducting Juan de Fuca plate rises, it eats through the North American plate, melting minerals rich in silica. A thick, pasty liquid thus accumulates within the magma chamber of a composite volcano. The gas-pressure builds within the chamber as a mixture of steam, other gases, and solid materials accumulate. The release of pressure within a volcano is similar to shaking a soda can. Gases build pressure within the can and those gases are violently released when the can is opened.

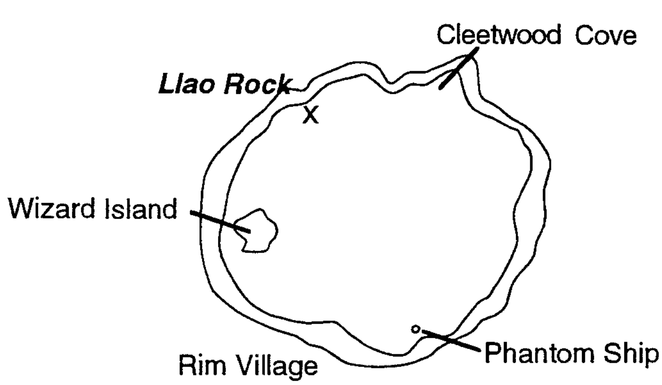
Botany : *Reconstruction of pre-climactic vegetation*

Mount Mazama and the surrounding landscape were the product of volcanism. The vegetation growing in the region has adapted to this harsh, unstable environment. Thus before the climactic eruption, and after a long period of recovery, vegetation patterns are likely similar. Pollen records suggest that, by 10,000 years ago, forests in this region resembled the present forests (Mehringer, 1985). Howell Williams (1942) collected fragments of charcoal from deposits of Mazama ash, which yielded samples of white pine, sugar pine, whitebark pine, lodgepole pine, white fir, and Douglas fir, all of which are found in the present forests surrounding Crater Lake. Through pollen analysis, Henry Hansen (1942) found that post-Pleistocene forests of central Oregon were populated with lodgepole pine, ponderosa pine, and white pine. Pumice from eruptive events associated with Mount Mazama affected dominance among the tree species. Lodgepole pine is a pioneer species found mainly on coarse pumice soils and able to withstand nutrient deficiency and moderate drought stress (Russell, 1986). Pollen analysis suggests that after each eruption lodgepole pine increased in relative importance, whereas ponderosa pine was adversely affected by the eruptions and never fully recovered.

Anthropology: *Usage of Llaoyeina (Mount Mazama)*

Archaeological studies in the area suggest that the Llaoyeina (Mount Mazama) region was used periodically as a summer, uplands hunting grounds and as a spirit quest destination; but no group lived exclusively in the region. The area provided an inadequate source of resources and the climate precluded year round usage (Winthrop, 1994). Most activities were done in the shadow of Llaoyeina along the river valleys and in the valley basins. High places were considered sacred, inhabited by the Gods; and, while the Gods would sometimes walk and talk among the people, it was not wise to anger them by treading on their sacred places (Winthrop, 1994; Clark, 1963).

Llao Rock: *The Eruption*



Geology of Mount Mazama

From trees buried in Mazama ash, the climactic eruptions have been radio-carbon dated to 7,700 years ago. The eruptions that ultimately resulted in the collapse of the mountain were triggered by increased activity approximately 8,000 years ago. The eruption that formed Llao Rock (probably similar to the eruption of Mount St. Helens in 1980) thus occurred just before the climactic eruptions.

Before the eruption of Mount St. Helens, increased earthquake activity and a growing bulge on the side of the mountain indicated volcanic activity was eminent. An earthquake on May 18, 1980, triggered a landslide of ice and rock down the north flank of the volcano. Removing this material from the bulge allowed built-up pressure to be suddenly, and violently, released. The resulting lateral blast breached the north flank of the volcano, removing approximately 1300 feet (400 m) from the top of the mountain (Decker and Decker, 1989; Harris, 1988). A 600°F (300°C) mixture of steam, explosive gases, and pulverized rock material escaped from the volcano, obliterating the vegetation within a 6 mile (10 km) radius north of the mountain and blanketing the landscape with up to 7 feet (2 m) of ash and rock debris (Rosenfeld, 1980). The eruption produced a horseshoe-shaped crater almost 2300 feet (700 m) deep. Within the crater a thick, sticky (high silica) lava oozed to form a dome 800 feet (250 m) high.

On a slightly smaller scale, the eruption producing Llao Rock resembled the Mount St. Helens eruption. A lateral blast resulted in an explosion crater on the north flank of Mount Mazama. The initial eruption produced pumice and fine air fall material, which left a thin veneer on the bottom of the crater and extended east of the vent (Bacon, 1983). A pasty lava oozed from the vent and domed over the side of the mountain, too sticky and sluggish to flow for more than 2 miles (3 km) (Unrau, 1988). The flow has a maximum vertical thickness of 1200 feet (360 m) and forms the bird-like feature seen from the boat (Fig. 27).

From the boat one has a short glimpse of the climactic, eruptive material on top of Llao Rock. The climactic eruptions, perhaps the most violent eruptions on Earth since the Ice Age - greater even than the historic eruptions of Tambora and Krakatau (Decker and Decker, 1989) - occurred in two phases (Bacon, 1983) (Fig.

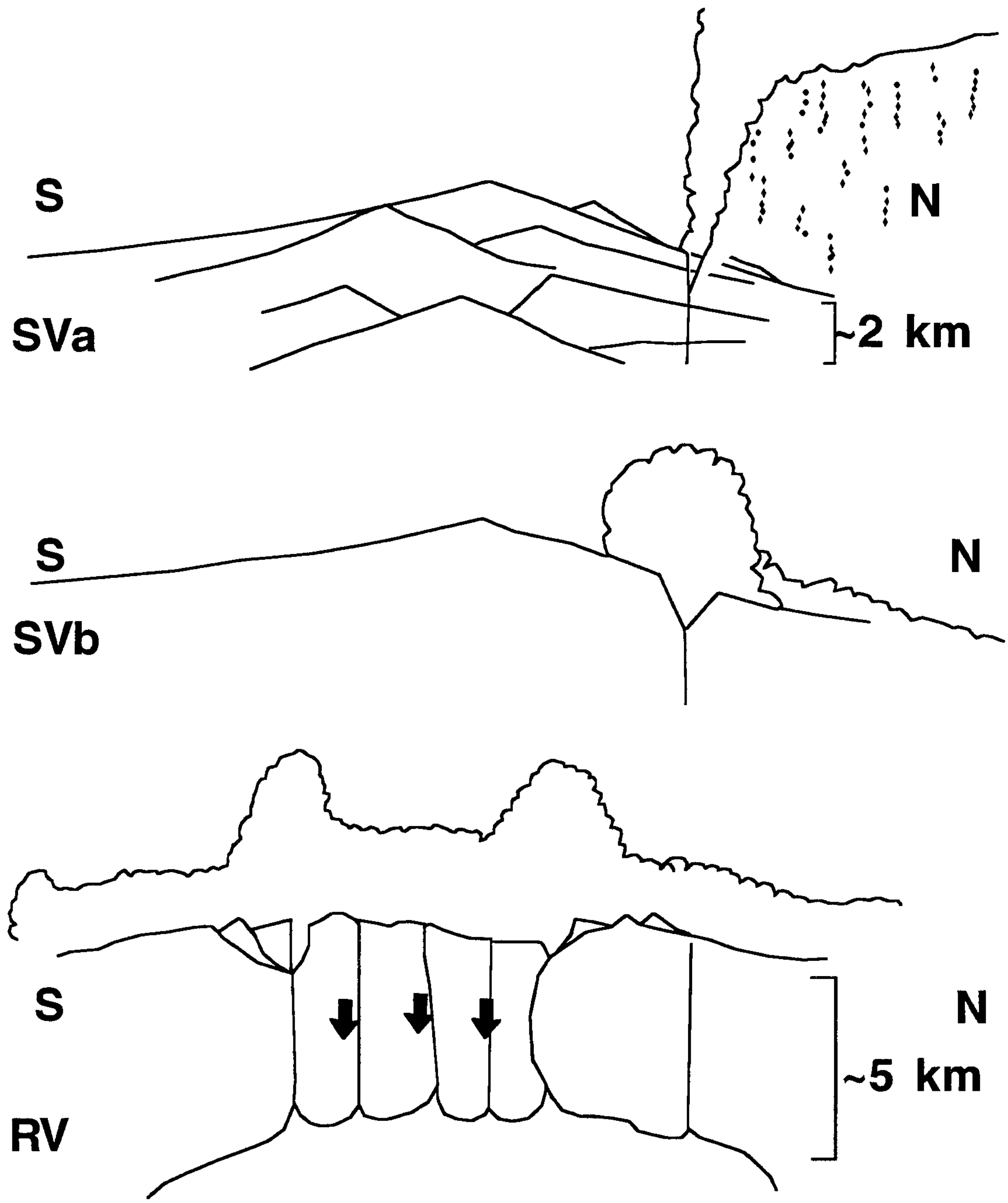


Fig. 28. A schematic model (cross sectional view) of the stages of the climactic eruption. First, during the single vent phase (SVa) a high column of pumice and ash erupted north of the glaciated summit . As the magma chamber erupted the high column collapsed and the vent expanded (SVb). Finally, the mountain top began to collapse and the single vent enlarged to form a ring vent (RV). (Adapted from Suzuki-Kamata, et al., 1993).

28). During the *single vent phase* a high column of air fall pumice erupted from an off center vent. The pumice conformed to the topography of the land with depths of 30 feet (10 m) near the rim and depths decreasing to less than 20 inches (50 cm), 60 miles (100 km) from the vent (Nelson et al., 1988), eventually covering over 500,000 square miles (1.3 million square kilometers) (Harris, 1988). The expulsion of so much material weakened the volcano and it began to collapse inward, thus opening a series of vents which formed a ring around the top of the volcano. As the initial vent expanded to include multiple vents, the eruption shifted from the single vent phase to the ring vent phase.

> *Fearsome as the first weeks of activity had been, they were only a prelude to the more violent eruptions that followed. The climax came with startling rapidity. There were no loud explosions to herald its approach. At first, a puff of steam rose from the summit of the mountain. Quickly it developed into an enormous cloud like a cluster of rapidly expanding balloons. It was composed of countless seething convulsions and was illuminated from below with a ruddy glare. Suddenly there was an ear-splitting roar; the cloud spread like a mushroom and settled over the summit in billowing folds. It rolled and surged down the mountainsides with ever increasing speed...* (Howell Williams, 1941)

The *ring vent phase* was characterized by highly mobile, gaseous flows of pumice and ash capable of moving at speeds over 100 mph (160 kph) (Harris, 1988). These flows covered the mountain at least 9 miles (14 km) from the vent and continued down into the valleys 37 miles (60 km), depositing as much as 300 feet (100 m) of pumiceous welded tuff (fused volcanic fragments) (Nelson et al., 1988). The single vent eruptions deposited 8 cubic miles (34 cubic kilometers) of pumice and the ring vent eruptions deposited 3 cubic miles (13 cubic kilometers) of ash-flow materials (Bacon, 1983). Prevailing winds projected a majority of the ash north and northeast of the volcano (Fig. 29). More than 20 inches (50 cm) of ash was deposited at Newberry Volcano, 70 miles (110 km) from Mount Mazama and more than 0.4 inches (1 cm) of ash fell in southwestern Saskatchewan, 750 miles (1200 km) from the source (Bacon, 1983).

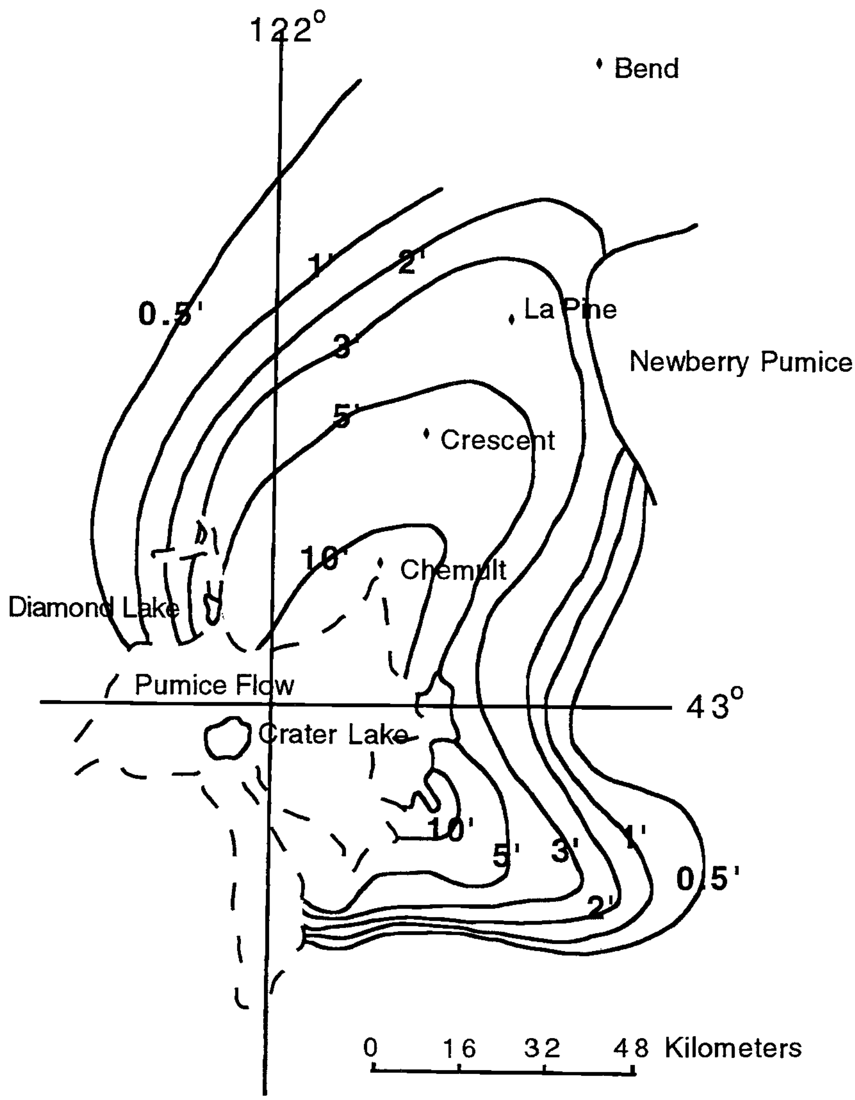


Fig. 29. The general pattern of tephra deposition radiating from Mount Mazama. The contours show thickness of air-fall material in feet (1foot = 0.305 m) (adapted from Matz, 1991).

The climactic eruptions produced so much material that a lack of pressure within the magma chamber supporting the volcano resulted in the collapse of the mountain. The huge basin created by the collapse is called a *caldera* (Spanish *caldron* = large kettle). Crater Lake sits in the caldera of Mount Mazama.

Botany : *Mount St. Helens as a small-scale model of the post - climactic eruption landscape surrounding Mount Mazama*

In the spring of 1980, Mount St. Helens awoke from 120 years of dormancy (Harris, 1988). Earthquake activity and the lateral blast on May 18, 1980, created a dramatically altered landscape. Volcanic activity impacts the distribution of local vegetation by destroying and damaging vegetation, producing new substrates, and affecting the local microclimatic regimes. The vegetation was affected in radiating zones away from the volcano, primarily to the northeast. Within the inner zone or blast zone, vegetation was completely obliterated, covered in thick deposits of ash and avalanche debris (Fig. 30). Beyond the blast zone, vegetation was blown down by the force of the eruption and then showered with hot ash and pumice (Fig. 31). On the fringes, vegetation was burnt and singed from the lateral blast. Within all three zones mudflows triggered from rapidly melting snow and secondary flooding from clogged waterways further complicated the subsequent recovery process. The Mount St. Helens eruption offered scientists an opportunity to observe and measure these effects. The recency of volcanic activity, the concentration of data concerning ecosystem recovery, and the location of Mount St. Helens made it a feasible model of recovery for the eruption of Mount Mazama.

Llao Rock is covered in pumice from the climactic eruptions. A similar environment to Pumice Plains, below Mount St. Helens, is found to the north of Llao Rock in the Pumice Desert. High reflection of light and extreme daily surface heating and night cooling make pumice a difficult substrate to colonize. Heat and moisture stress

Fig. 30. Pumice Plains below Mount St. Helens represents the area completely destroyed by the eruption of 1980. (Photograph courtesy of Crater Lake National Park archives)

Fig. 31. Within the blowdown zone of Mount St. Helens, trees were felled by the force of the eruption. (Photograph courtesy of D. B. Zobel)

control successional re-establishment on pumice soils (Reynolds and Bliss, 1986). Deficient nutrient supply also restricts colonization. Early pioneer species at Mount St. Helens included red alder, Douglas fir and lodgepole pine (Adams and Dale, 1987). The lodgepole pine had the highest germination success, but did not grow as rapidly as red alder and Douglas fir (Adams and Dale, 1987). Red alder is a nitrogen fixing species able to tolerate low nutrient soils. Lodgepole pine, found mainly on coarse soils, is also tolerant of low nutrient soils and is moderately drought resistant (Russell, 1986).

Anthropology

Native Americans lived in harmony with their surroundings, according to the dictates of their religion. They communed with their brothers and sisters which included the beast, fowl, and the physical elements of the earth. Chief Lalek said "*A long time ago, the spirits that live in the mountains, and in the water, in the earth and in the sky used to come and talk with the Klamath people*" (Clark, 1963). William Ritchie, an archaeologist in New York said "*We may say, in sharp contrast to the white man's way, that the Indian trod lightly through his natural environment, merging himself sympathetically into the world of living and even non-living things*." (Martin, 1978) It is hard to say how much of the natural world they understood. Throughout history, stories have been used to explain natural phenomena, to relate past events, and to entertain. The oral traditions describe a world dominated by supernatural beings and forces. However, the relationship people have with their environment and how they perceive geologic events can be explored (with some trepidation) through folklore. People have lived near Crater Lake, especially to the east and southeast, for thousands of years. The Northern Paiute extended into the Basin and Range Province of southern Oregon; the Modoc and earlier Makalak people lived around Klamath Lake. Their legends try to explain natural phenomena.

In the early days gods and human beings interacted all the time. It was normal for the gods to walk among the people. So every once in awhile, Llao would tire of his underworld and come up to the surface to mingle with the people. One day Llao was visiting a neighboring village when he met a very beautiful young woman. Llao immediately fell in love and asked her to join him in the underworld. Unfortunately for the people of her village, she refused. This made Llao very angry and he vowed revenge. So when he returned to his home, Llao began to spit fire and ash from the mouth of the mountain (Warfield, 1985; Greene, 1984; Clark, 1963).

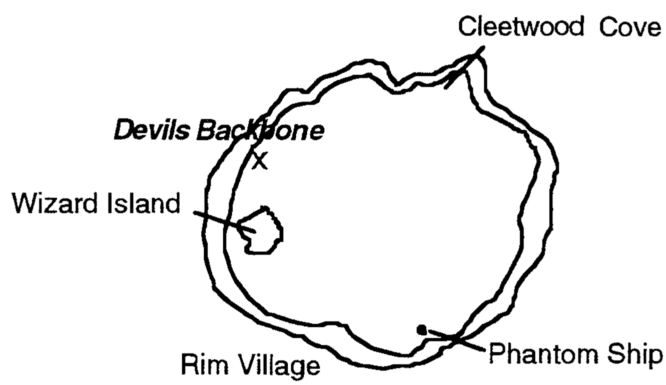
> *Mountains shook and crumbled. Red hot rocks as large as hills hurtled through the skies. Burning ashes fell like rain. The Chief of the Below World spewed fire from his mouth. Like an ocean of flame it devoured the forests on the mountains and in the valleys. On and on the Curse of Fire swept until it reached the homes of the people* (Clark, 1963).

This lasted for quite awhile. Llao's anger frightened the people. They decided the only way to appease Llao would be to sacrifice two elders' lives. So two went to the mouth of the mountain and jumped into the fiery pit. Skell witnessed this act of bravery and decided to intervene. A fierce battle ensued between Llao and Skell. Finally, Skell caused the mountain to collapse trapping Llao in his underworld kingdom. In gratitude the people gathered around the remains of the mountain and in relief and in tribute to the elders and Skell they began to cry. Their tears filled the basin forming Crater Lake. Rain slowly filled the basin in another version of the legend. "And then came the Spirit of storms. Rains that fell for many years wiped out the fires and partly filled the hole that was made when the mountain top collapsed." (Clark, 1963)

The legend explains the collapse of Llaoyeina (Mount Mazama was the name later given to the mountain by a hiking club from Portland in the late 1800s) and the formation of the lake. Other myths also attempt to explain the eruption and collapse of a great mountain. The stories all incorporate mortals interacting with the Gods. One legend describes a battle waged between the Klamath people; one faction prayed to the Gods for help and the Gods responded by causing the mountain to sink engulfing the rebellious warriors.

Although entertaining, these legends probably did not originate from the people who actually lived near Mount Mazama 7,700 years ago. The probability that stories passed through the generations by oral tradition would survive over 7,000 years is slim. And assuming the stories did survive, it would be difficult to trace legends shared by nomadic people.

Devils Backbone



Geology: *Plumbing system*

An extensive plumbing network radiates through the interior layers of a volcano (Fig. 7). The magma is forced through weak spots, by pressure building in the magma chamber. Tubular fingers of magma eat their way outward and squeeze through cracks and crevices within the volcano. These tubular intrusions of magma feed lava flows on the earth's surface. An elongate finger of magma eventually cools to form a *dike*, a somewhat vertical wall of solidified magma.

Several dikes survived the collapse of Mount Mazama; as the walls of the caldera slowly erode away, these dikes are further exposed. Dikes are made of essentially the same chemical composition as lava flows, but the cooling process makes a dike more resistant to erosion. There are two types of *igneous* (originally molten) rock - intrusive and extrusive. *Intrusive* (or "plutonic") igneous rock never reaches the Earth's surface; the magma cools and solidifies underground. Dikes are thus, intrusive igneous bodies. *Extrusive* (or "volcanic") igneous rocks form from magma that reaches the Earth's surface and cools as lava flows. Extrusive rock cools rapidly as it reacts with the atmosphere, whereas intrusive rock cools more slowly deep within the Earth. Intrusive rock has time to develop large crystals and form strong molecular bonds. Intrusive rocks are thus, harder and more resistant to erosion than finer grained, extrusive rocks.

The Devils Backbone is a textbook example of a dike (Fig. 32). The average width of this dike is 50 feet (the length of a Crater Lake tour boat is 40 feet) (15 and 12 m, respectively). The Devils Backbone is the only dike at Crater Lake that extends from the lake to the rim (1,300 feet or 400 m). According to Bacon (1983) the lava flows fed by the Devils Backbone were removed by the last glacial advance.

Below Llao Rock and to the northeast in Steel Bay are several other dikes (Fig. 33). The dike that feeds the Watchman Peak flow can be observed from the boat at Skell Channel. A dike in Cloudcap Bay will be discussed in more detail later.

Botany: *What controls plant distribution?*

First, plants have basic needs for healthy growth. Those needs are often limiting or lacking in volcanic environments. All plants need water, carbon dioxide, soil, light, and heat. From those fundamental requirements plants extract the nutrients and energy needed to grow. Plants require a continuous supply of water. Water sustains life and also supports microbial life, and makes nutrients available to plants through transport and solution. A plant's roots absorb most of the needed water from soil moisture.

Soil is essential for plant growth. Soil acts as a support system for a plant's underground parts and supplies the plant with most of the required nutrients and water.

Fig. 32. The Devils Baackbone is a dike, which extends from the lake to the rim. (Photograph courtesy of Crater LakeNational Park archives)

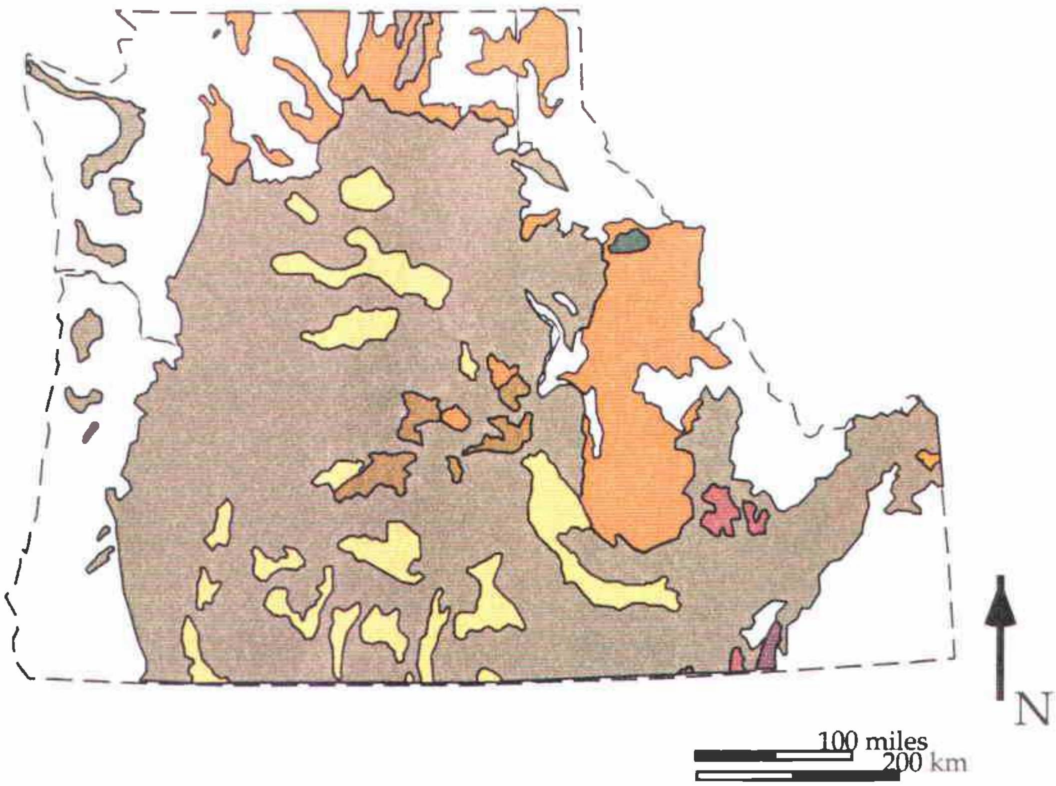
Fig. 33. Several dikes are found below Llao Rock Photograph Courtesy of Crater Lake National Park archives)

Soil provides the link between living and non-living entities on planet earth. The soils of the High Cascades are a product of volcanism, climate, organisms, and time.

Biotic activity in and around the soil indicates a healthy environment. The density and diversity of the soil microbial populations are a function of soil health. At low elevations under moderate climatic conditions, biotic activity is constant for most of the year. At higher elevations, microbial activity is dormant while snows cover the ground and only active during the short growing season (Killman, 1994). Since microbes aid in the decomposition of plant litter, the decomposition rate at high elevations is slower than at lower elevations. Generally, in alpine provinces the soils are thin with thick litter layers from slow decomposition rates.

Most of the Pacific Northwest is covered with volcanic material (Fig. 34). That material becomes the substrate (underlying soil) in which plants grow. In general, the soils of the High Cascades are categorized as inceptisols (weakly developed soils). They are further defined as Udic cryic soils (Latin *udus* = humid; Greek *kryos* = icy cold). The Lapine soil series, a coarse loamy sand, is derived from Mount Mazama tephra-fall (Youngberg and Dyrness, 1964). Crater Lake soils are young, excessively drained, coarse sands with very little horizon development. These soils develop in cinder, ash, and pumice. The character of soils prior to the climactic eruptions was probably typical of older volcanic mountain soils, which form on glacial till.

The third factor controlling plant growth is sunlight. For most organisms, light is the most important source of energy (Barbour et al., 1987). Through photosynthesis, plants convert light into energy. Heat, a product of sunlight, triggers plant growth. In volcanic systems plants must adapt to both heat and cold. After a volcanic eruption the landscape is left barren and void of life. That environment, where temperatures are extreme, is not conducive to plant growth. Barren volcanic landscapes absorb heat from the sun during the day and quickly loose heat at night. It is difficult for plants to establish under such extreme conditions. The Summer-dry climatic regime also produces moisture



Sedimentary Rocks

Upper Tertiary
(~24 million years ago (Ma) to 1.6 Ma)
Pliocene and Miocene including Recent and Pleistocene

Lower Tertiary
(~65 Ma to 24 Ma)
Oligocene, Eocene, and Paleocene

Jurassic and Triassic
(~250 Ma to 150 Ma)

Upper Paleozoic
(~275 Ma to 250 Ma)
Permian, Pennsylvannia, and Mississippian, parts of Rocky Mountains - middle and lower Paleozoic

Igneous and Metamorphic Rocks

Quaternary and Tertiary
(~65 Ma to present)
Includes small areas of intrusive rocks

Lower Tertiary and Mesozoic
(~245 Ma to 24 Ma)
Chiefly granitic rocks

Younger Precambrian
(~2.5 billion years ago to 570 Ma)

Older Precambrian
(> 2.5 billion years ago)
Metamorphic and igneous rocks

Figure 34. A general geologic map of the Pacific Northwest depicting the predominance of volcanic rock (adapted from Jackson and Kimerling, 1993).

stress in plants. At high elevations, the climate is characterized by long winters with heavy snowfall and short, relatively dry Summers. At Crater Lake snow blankets the ground from October to June (Fig. 35). Plants covered by snow are insulated from desiccating winter winds and cold temperatures, but the short summers, with less than 50 frost free days, severely restrict plant growth. All plants require a certain amount of heat to complete their growth cycle.

Topography regulates precipitation, sunlight, and plant activity on a local level. Soil moisture differs on north versus south facing slopes, valleys, floodplains, and mountains. An area that receives more direct sunlight, such as a southern facing slope, is drier and only supports plants adapted to drier conditions (Fig. 36). Conversely, valleys and floodplains are often wetter than the surrounding slopes as water drains to a local base level (Fig. 37).

Anthropology

Ethnobotany is the study of plants and people. "The two major parts of ethnobotany are encapsulated in the word itself: 'ethno', the study of people, and 'botany', the study of plants" (Balick and Cox, 1996). By studying this relationship, ethnobotanists are able to define the evolution of cultural boundaries. In the cosmopolitan centers of 1998, the link between plant and man has been obscured by technology, but in a hunter-gatherer society plants play an integral role in man's life. Activities associated with daily life and with ceremonies focus on plant use. In the Great Basin, the hunter-gatherer culture relied heavily on plants. This culture developed after the retreat of Pleistocene glacial ice and as aridity increased in the region. Survival in this harsh environment required an intimate knowledge of surroundings. Seasonal and communal activities centered around the availability of plant and animal resources. There were extensive ethnographic records of the subsistence habits of the Northern Paiute, Klamath and Modoc

Fig. 35. At Crater Lake, snow blankets the ground from October to June. (Photograph courtesy of Crater Lake National Park archives)

Fig. 37. Vegetation grows well in the exposed soils of Annie Creek valley after water cut through the thick ash deposits left by the climactic eruptions of Mount Mazama. (Photograph courtesy of Crater Lake National Park archives)

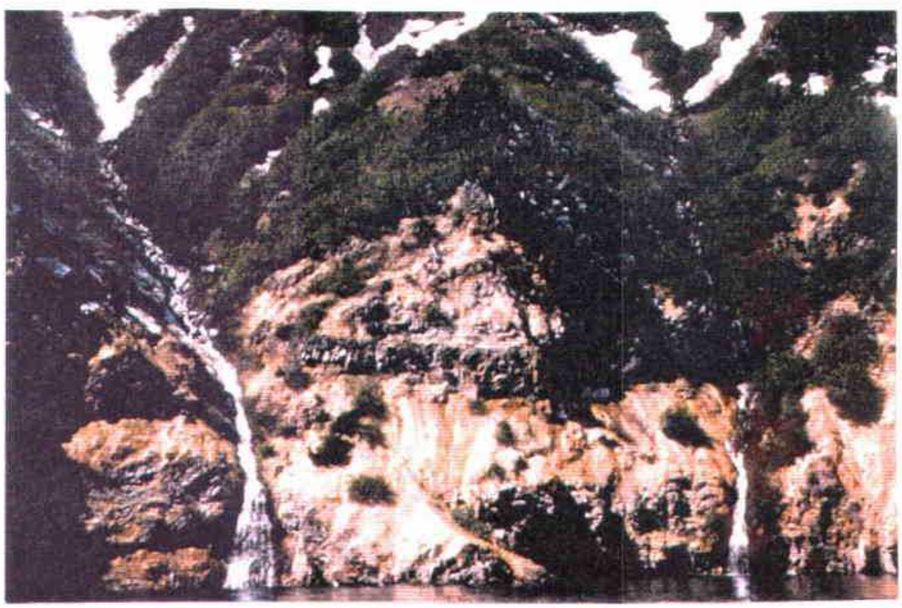
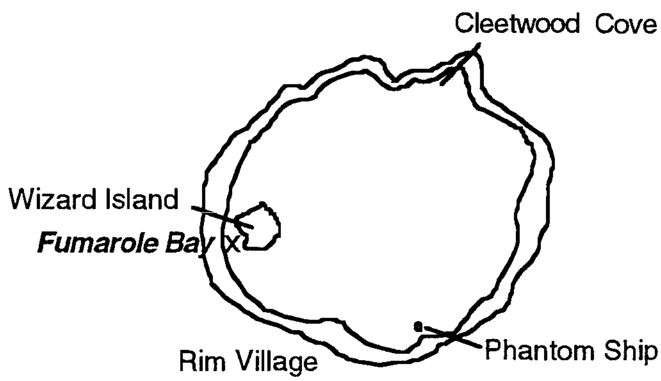


Fig. 36. The vegetation on dry slopes differs from the vegetation on wet slopes within the caldera. (Photograph courtesy of Crater Lake National Park archives)

made by Colville (1897) and others, soon after the arrival of American settlers. Archaeological data have supplemented the ethnographical records.

The seasonal round of the Northern Paiute included digging for roots and seed collection from mid-Spring through the end of Fall. Paleobotanical samples found in ancient fire-hearths and storage pits indicate the Northern Paiute used a variety of plants including chenopodium, grasses, sedges, rushes, and such upland plants as chokecherries (*Prunus* sp.), service berries (*Amelanchier* sp.), and biscuit root (*Lomatium* sp.) (Jenkins, 1996). Beginning in late Summer, the collection of berries and ponderosa pine nuts occurred (Prouty, 1995). There is evidence that people in the northern Great Basin were gathering seeds and possibly pinyon nuts before increasing temperatures and the eruption of Mount Mazama altered the local landscape, ultimately forcing people to move to more favorable sites (Cressman, 1986). Although questioned by Mehringer, pine nuts identified as either *Pinus edulis* or *Pinus monophylla* were found in charcoal deposits dating about 11,000 years ago in the Fort Rock Basin (Cressman, 1986). The Klamath and Modoc to the south, collected roots from cat-tails (*Typha* spp.), reeds, and camas (*Camassia* spp.), currant berries (*Ribes* spp.), and fruit from chenopodium, buckwheat, and grasses from mid-Spring through Fall (Colville, 1897). Beginning in late Summer they also collected water lilies (*Nymphaea polysepalum)* known as wokas, a major food staple, seeds, and nuts (Prouty, 1995).

<u>**Fumarole Bay:** *Recovery*</u>



Geology of Wizard Island

After the collapse of Mount Mazama, volcanic activity occurred only within the caldera. Three post caldera events occurred along the ring vent, the hypothesized vent complex during phase II of the climactic eruptions. Wizard Island developed soon after the collapse of Mount Mazama, as the caldera filled with water (Nelson et al., 1994). Wizard Island is the only caldera floor volcanism that is now above the water line, reaching 763 feet (233 m) above lake level (Fig. 38). Despite traditional myths Wizard Island is not Llao's head or the top of Mount Mazama. Wizard Island is actually a cinder cone volcano, within a volcano. Cinder cones are usually produced by one time events that erupt tephra (a collective term for solid material ejected from the volcano) from a central vent and lava from the base of the cone. The events occur over a variable amount of time, but are commonly fast. For example, Paricutin cinder cone grew out of a Mexican cornfield, reaching 1350 feet (400 m) in only nine years (Decker and Decker, 1989).

Cinder cones form as solid material shoots from a central vent. The shape of the cone forms much like the formation of the sand pyramid in an hourglass. Cinder falls directly down, piling up around the vent. The slope of Wizard Island represents the *angle*

Fig. 38. Wizard Island is a cinder cone that extends more than 750 feet above the lake. (Photograph courtesy of Crater Lake National Park archives)

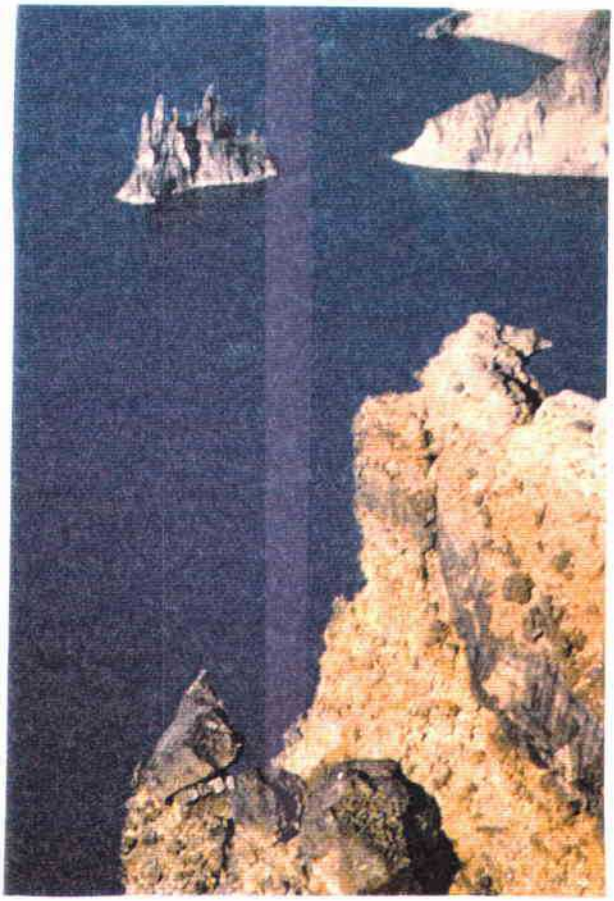


Fig. 39. Ancient examples of flow top breccia at Dutton Cliff and Garfield Peak. (Photograph courtesy of R. J. Lillie)

of repose, the maximum angle to which loose rock will remain stable. Wizard Island is a particularly symmetrical cone because the walls of the caldera prevented wind from manipulating the shape during the eruption. From the base of the Wizard Island cinder cone oozed andesitic (intermediate silica content) lava, which was too dense to rise through the central vent. As lava flows, the outer surface exposed to the atmosphere cools more rapidly than the interior. As the outer surface solidifies, the interior (insulated by the hardening outer crust) continues to flow, thus breaking up the solidified surface into sharp, angular blocks. This rubble called "flow top breccia" dominates the landscape at the base of Wizard Island. Ancient examples of flow top breccia are found within the layers of Dutton Cliff and around Sentinel Point (Fig. 39).

Botany of Wizard Island

Factors determining plant distribution on Wizard Island epitomize the restricted growth of plants in volcanic systems. The primary controlling factors are *slope instability, insufficient nutrient supply*, and *moisture stress* (Jackson and Faller, 1973). The slopes of the cinder cone are steep and unstable. The island is literally a pile of loose rubble that has very little capacity to hold water. This makes it difficult for plants to establish; thus most vegetation on the island is concentrated at the base. Plants have only recently (in geologic time) established on the island; thus, there is very little organic matter build-up and the soils are young and thin. The oldest trees on the island are approximately 800 years old (Schaffer, 1983). There are four vegetation zones on Wizard Island: the top of the cone, the north slope, the lower cone, and the lava flows.

The top of the cone is haunted by whitebark pine skeletons, which were heavily parasitized by leafless mistletoe (Jackson and Faller, 1973). Jackson and Faller (1973) predict that lodgepole pine and mountain hemlock will increase in importance as the whitebark pine populations will slowly decline along the rim of the cone. The soils of the upper cone are entirely mineral with very little organic matter. Moisture and organic matter are rapidly transported downslope.

The lower cone and the north slope are dominated by Shasta red fir, mountain hemlock and white pine. The staghorn lichen growing on the trees is a general indicator of snow depth on the island, since the lichen will not grow beneath the snowline. The understory, including pinemat manzanita and a few flowering plants such as penstemon, Newberry knotweed (*Polygonum newberryi*), bleeding heart and pumice paintbrush, is sparse. On the north slope where snow lingers longer there is greater plant diversity and quantity. The canopy is dominated by mountain hemlock and the groundcover is more abundant than at other locations on the island.

Plant life on the lava flows is restricted to low recesses where moisture and soil collect. Lichens grow on the barren rock in open spaces and in more protected sites other plants, such as manzanita (*Arctostaphylos nevadensis*), mountain hemlock and mountain elder (*Sambucus microbotrys*) are able to grow.

The loose rubble on Wizard Island is the soil, parent material. Along with microbial activity and climate, the parent material determines the rate of soil development, or the break down of rock into soil, and the movement of water through the medium. Water is an important erosional agent, breaking down the rock; however, vegetation growing on Wizard Island is restricted by moisture stress. The soils on the island are not well developed; thus most of the nutrients are still trapped in the rock. The few nutrients available in the soil are leached out by the rocks inability too hold water. Water movement through the rock or permeability is predominantly a product of particle size and the adhesive properties of the particles (Fig. 40). The larger the particles, the greater the pore space. Pore space in sandy soils (with an average particle size between 1/16 mm and 2 mm or 1/400 in and 1/13 in) is greater than pore space in clay soils (with an average particle size less than 1/16 mm or 1/400 in); thus, water moves easily through coarse sand and with more difficulty through fine clay soils. Because of the size and the chemical

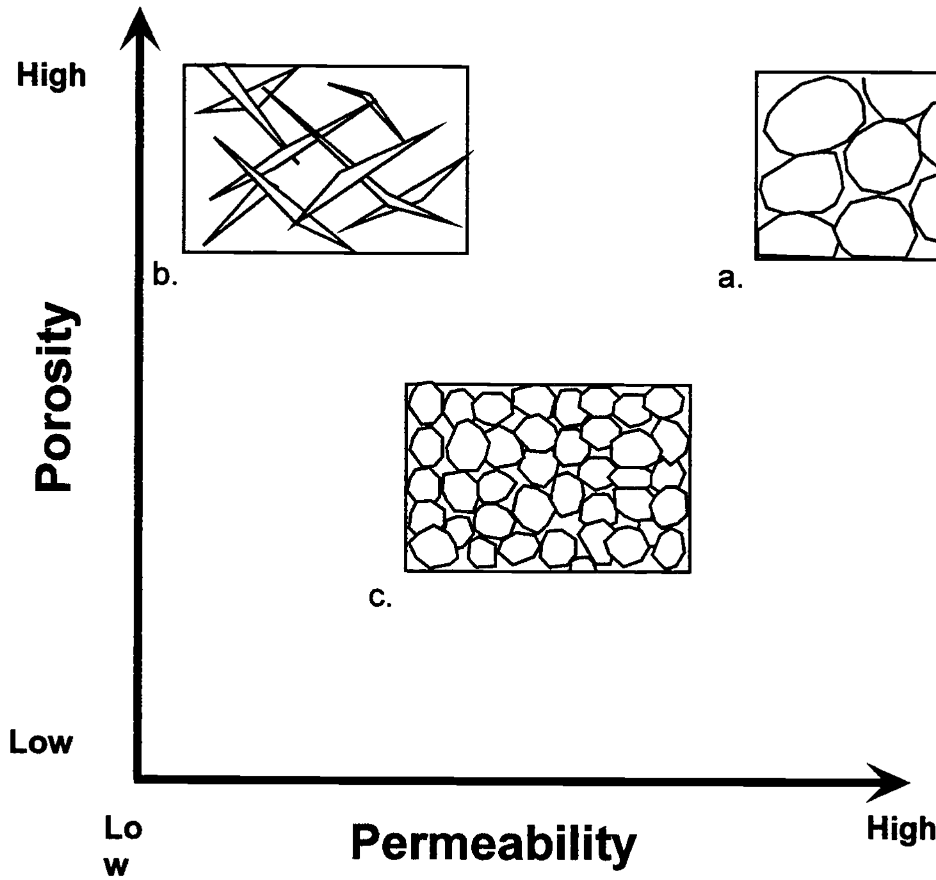


Fig. 40. The ability of water to move through a medium depends on the porosity and the permeability of the medium. In box (a) the combination of high porosity and high permeability allows fluid to flow easily through the medium. In box (b) fractures (cracks) in the rock provides high porosity (or storage space for fluid), but the fractures are not linked; thus the medium has low permeablity and fluid will not flow easily through it. In box (c) the grains are small and evenly sized; thus they are packed tightly allowing fluid to move with less ease through the medium.

composition of clay soils, water molecules are strongly attracted to the clay surface; thus the pore spaces are not well interconnected, and clay soils are less permeable than sands. The three dominant surficial volcanic rocks at Crater Lake National Park, ash, pumice and cinder, represent the spectrum of permeability from low to high.

Pumice is a light, frothy volcanic rock with many air pockets ("vesicles"). Despite the vesicular nature of pumice, studies have indicated that moisture stress is not a limiting factor in established vegetation on pumice soils (Youngberg and Dyrness, 1964) (Fig. 41). Large void spaces in pumice rock deter upward capillary movement and unsaturated flow is extremely slow. Thus, pumice has low permeability. Moisture stress does occur in *volcanic ash* soils with high concentrations of clay. Water strongly adheres to the clay particles, making the water unavailable for plant use. Extreme moisture stress occurs in *volcanic cinder*, the predominant rock type on Wizard Island (Fig. 42). Cinder is highly permeable, with less capacity to store water than coarse sand.

Water, plant growth and microbial activity all help to break down rock into soil. Vegetation growing on Wizard Island is restricted by moisture stress. The soils on the island are not well developed, thus most of the nutrients are still trapped in the rock. The few nutrients available in the soil are leached out by the rocks inability to hold water.

Anthropology

Another Klamath legend explains the presence of the island. *There were two gods who lived in this area. Llao, god of the underworld, lived here with his followers in Llaoyeina. Skell, the god of the above world, lived near by (in one account he lived with his followers at Mount Shasta, south of Mount Mazama). Llao and Skell were constantly at war. During one battle, Llao managed to capture Skell. He and his followers held a big feast; for the festivity they cut out Skell's heart to use as a soccer ball. Skell's followers tricked Llao and were able to steal back Skell and his heart. Once Skell's followers had retrieved Skell, they returned his heart and Skell returned to life. In revenge Skell*

Fig. 41. During the climatic eruptions over 200 feet of pumice and ash filled a valley, forming the Pumice Desert. Very little vegetation grows on the Pumice Desert; however, lodgepole pines along the periphery are slowly encroaching. (Photograph courtesy of Crater LakeNational Park archives)

Fig. 42. Vegetaion growing on Wizard Island is restricted by steep, unstable slopes and extremely dry conditions. (Photograph Courtesy of Crater Lake National Park archives)

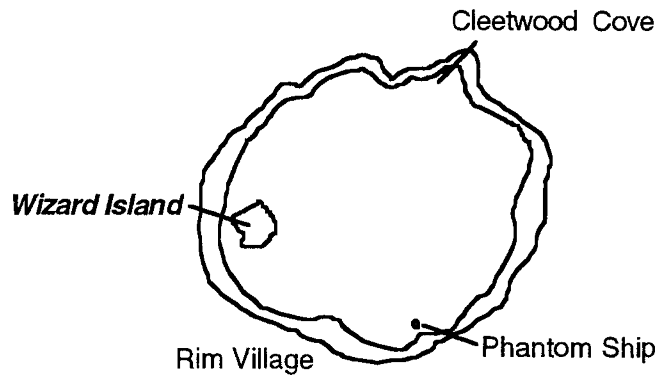
captured Llao and cut him into many little pieces. These pieces were thrown into the lake where a giant crawfish (one of Llao's subjects) lived. The crawfish ate the pieces as they were thrown into the lake, unaware that he was eating Llao. This continued until Skell threw in the head. Crawfish realized what he was eating and left the head. The head remains in the lake to this day...we know it as Wizard Island.

History

Look carefully at the shape of the island - with a little imagination one may see Merlin's hat. Wizard Island was named for its shape and "its weird appearance", which to William Steel resembled a wizard's pointed cap (Smith and Smith, 1997). Early exploration of the island dates to the late 1800s. In 1869 The Oregon Sentinel published a report on an expedition to Crater Lake. Among the party was James Sutton, who named the lake Crater Lake (Greene, 1984; Smith and Smith, 1997). On that trip, they carried a boat down to the lake and rowed to the island. They claim to be the first to stand on the island. In 1873 Judge Watson and his party reached the island and later in 1886 the Cleetwood expedition explored the island (Smith and Smith, 1997).

By 1907 motor boats and row boats were available for public use (Smith and Smith, 1997). Fishing, swimming , and hiking on Wizard Island were all popular activities. In the late summer of 1923, park service personnel transported explosives and red-fire to the island for an "eruption" (Smith and Smith, 1997). Earlier visitors had been warned (incorrectly) that Wizard Island was showing signs of erupting. To this day the rangers' prank is remembered by old-timers as an actual eruption. Today, the island is used as a popular day trip destination. It also houses the lake research equipment and during the long winter the tourist boats are dry docked in the sheds in Governor's Bay.

Wizard Island (the dock)



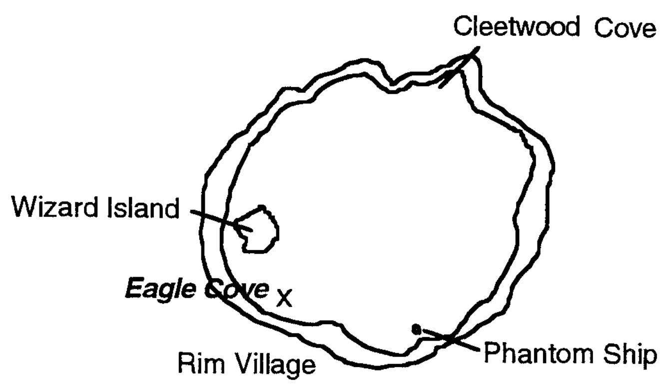
Currently Crater Lake National Park is working on a new fire policy program, but for most of this century fire suppression has dictated forest development in the park. In 1931 and again in 1997 small fires broke out on Wizard Island. Both fires were caused by careless smokers. A general sense of panic eminated from Rim Village as visitors watched the fires in horror. It appeared the island was erupting. Fire and volcanic activity actually produce similar landscape patterns.

Both fire and hot volcanic materials damage and destroy living plant tissue (Fig. 43). The damage produced by fire depends on the intensity and frequency of the disturbance event. The Native Americans were aware that low intensity fire actually stimulates the growth of groundcover plants and shrubs. A surface fire is characteristically a low intensity (cool, fast moving) fire (Fig. 44). The fire only destroys the underbrush, the soils are only surficially damaged and any trees are only scarred. In woodlands, fire helps to distribute the nutrients and allows grasses and small shrubs to dominate the undergrowth. If the fire manages to climb into the canopy, the intensity of the fire increases. This type of fire is called a crown fire. It is a very hot fire and if combined with a ground fire can devastate the entire area, killing trees and shrubs.

Fig. 43. Both fire and hot volcanic materials damage and destroy living plant tissue. (Photograph courtesy of Crater LakeNational Park archives)

Fig. 44. A surface fire is characteristically a low intensity fire. (Photograph Courtesy of Crater Lake National Park archives)

Eagle Cove



Geology

The collapse of Mount Mazama left a huge gaping hole about 4,000 feet (1220 m) deep. After the collapse, the caldera floor was covered with a thick layer of wall-collapse debris. The volcano was still temporarily active after the collapse. As water seeped through the hot rubble, it reacted with remnant magma causing *phreatic explosions* (violent eruptions associated with water and steam). These phreatic explosions formed craters on the caldera floor. Over the rubble and craters a low viscosity lava seeped from cracks and covered the caldera floor. Mixed with the lava were debris flow deposits as the caldera walls continued to stabilize. The sheetwash (lava) flows and debris flows sealed the basin forming a large bathtub with no apparent drain.

It is speculated that it took 300 years to fill the caldera to its present depth (Nelson et al., 1994). The depth of the lake has not varied much since its formation about 6,000 years ago. There is no evidence of any developed shorelines above or below the present shoreline. Crater Lake sits in a closed basin, thus no streams enter or exit from the lake. All water in the basin comes from rain and snowmelt, directly and indirectly as spring water. Spring water, water temporarily stored in the rock, provides a small, insignificant amount of water. The water in the lake is in equilibrium: input (rain and snowmelt) into the system is balanced by output (loss by evaporation and seepage).

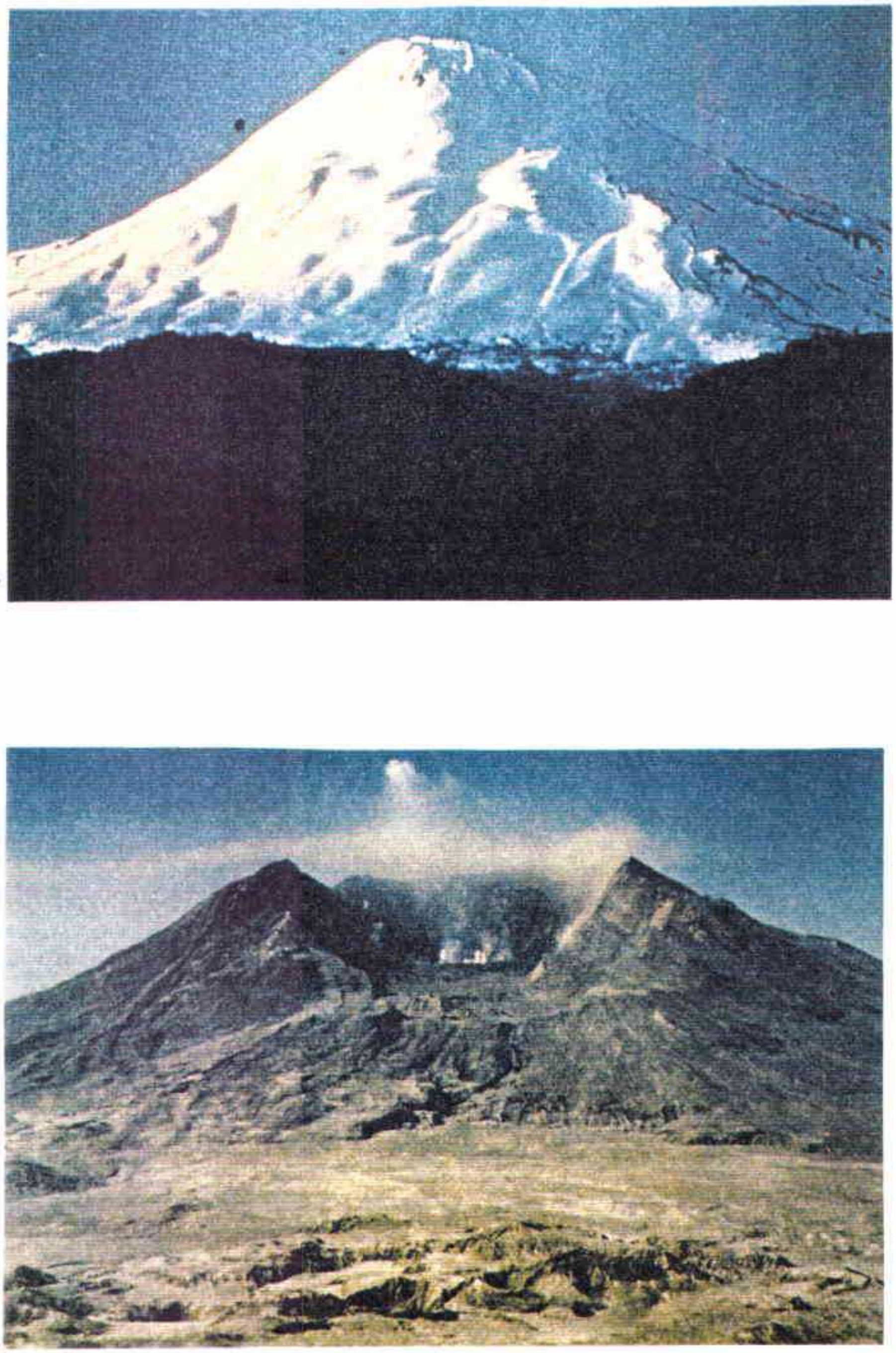
The water level has been recorded since August 1896 when the first water gage was installed (Smith and Smith, 1997). Measurements were not consistently recorded until 1961 when the water gage at Cleetwood Cove was installed; earlier measurements were randomly recorded by visitors who happened to stumble upon a water gage below the Rim Village or on Wizard Island. Since a majority of the annual precipitation occurs during the winter months, the lake level fluctuates with the seasons. As the snow melts in the late Spring the water level rises and then, as the Summer progresses, the water level declines. The total water input includes precipitation falling directly into the lake and runoff from the drainage basin. The High Cascades receives an average of 75 inches (190 cm) of annual precipitation. Water lost through evaporation amounts to about 47 inches per year (120 cm/yr), and the amount of water lost from seepage amounts to about 50 inches per year (125 cm/yr) (Redmond, 1990). In order to counterbalance the average loss of 97 inches (245 cm), runoff would need to account for about 22 inches (55 cm).

Botany: *Vegetation Recovery: Mount St. Helens as a model*

Traditionally succession has been defined as the sequence of stages of vegetation development that ultimately may lead to a climax community, or a community where the plant species regenerate in the presence of mature plants of the same species. Primary succession begins in substrate void of any biotic activity. Secondary succession is triggered by a disturbance. The frequency and intensity of the disturbance dictate the degree of damage to existing organisms and the subsequent recovery of the ecosystem. To say an ecosystem "has recovered" implies the secondary successional process has reproduced the pre-disturbance community. A volcanic eruption does not exclusively

The successional patterns observed at Mount St. Helens since 1980 are in response to both past and present volcanism (Fig. 45). No consistent or typical successional sequence occurred. Instead, a mosaic of new and relic communities emerged. Vegetation recovery has been a function of the intensity of the event, the season, the survivorship of intact adults and buried vegetative organs, and the re-establishment of vegetation on immature soils (del Moral and Wood, 1988). The time of the eruption is a significant factor in the survival of vegetation. The eruption of Mount St. Helens occurred in early spring (May). The tephra from the Mount St. Helens eruption was primarily distributed to the north and northeast, similar to the distribution pattern of Mount Mazama ash. Assuming the mode climate established about 10,000 years ago (see page 23), it is possible the eruption of Mount Mazama also occurred in the early Spring. From fig. 29 the direction of pumice fall implies a southwesterly wind, the general wind pattern of the southern Cascades during the winter months. The effects of volcanic ash are directly related to the depth of the deposit. With deposits in excess of 7 inches (18 cm), most herbaceous vegetation did not survive burial (Zobel and Antos, 1986). Most plants and shrubs survived burial in 1.5 inches (4 cm) (Zobel and Antos, 1997). Trees survived in up to 40 inches (1 m) of ash (Zobel, 1998). Snowpack complicated the survival pattern of both herbaceous vegetation and trees.

Dormant herbaceous plants were insulated by snow cover, whereas snowpack tended to decrease the survival of woody plants (Antos and Zobel, 1987; Zobel and Antos, 1997). The wet, heavy snow pressed shrubs and small trees to the ground. Even a light ash-fall deposit was more likely to completely cover and kill a prostrate plant after the underlying snow melted. In communities where the tree canopy escaped destruction and the ash layer did not exceed 2 inches (5 cm), and snowpack protected dormant vegetation, the shrub component was reduced, but the herbaceous component remained constant.



a.

b.

Fig. 45. Before the 1980 eruption Mount St. Helens was a stereotypical composite volcano-a snow covered peak surrounded by forest (a). After the eruption the volcano and surrounding landscape were drastically altered (b). (Photograph courtesy of Crater Lake National Park archives)

Herbaceous diversity tended to be higher at sites protected by snow (Hemstrom and Emmingham, 1987).

After one growing season, adaptations were observed in vegetation that had survived the initial burial. Some conifers, such as the Pacific silver-fir and the mountain hemlock, were able to produce adventitious roots into the ash (Zobel and Antos, 1982). Other plants were able to resume growth after erosion removed overlying ash deposits. In a wet climate, ash is easily eroded away by runoff, leaving the original soil along drainage basins. In Japan, following the eruption of Mount Usu in 1977-78, the seed bank of the original topsoil became an important factor in vegetation re-establishment (Tsuyuzaki, 1994). The seed bank was less significant at Mount St. Helens (Tsuyuzaki, 1994). The survival of intact vegetation and the regeneration of buried vegetative organs played a larger role in vegetation recovery at Mount St. Helens. Some herbs, shrubs and mosses survived burial for eight years and recovered after the tephra was removed (Zobel and Antos, 1992).

The vegetation surrounding Crater Lake represents a landscape in transition. The landscape patterns are a result of past volcanic activity. Early landscape recovery around Mount Mazama may have resembled the patterns observed at Mount St. Helens and other volcanoes in the Pacific Northwest. There are, however, several notable differences between the eruptions of Mount St. Helens and Mount Mazama. During the Holocene, Mount St. Helens has erupted more frequently than any other volcano in the 48 conterminous United States (Harris, 1988). In contrast, Mount Mazama last erupted more than 5,000 years ago. The magnitude and the intensity of Mount Mazama's climactic eruptions were much greater than the Mount St. Helens eruption of 1980. During the climactic eruptions Mount Mazama produced 50 times more material than Mount St. Helens. Therefore, the depth of air-fall tephra around Mount Mazama was much greater than around Mount St. Helens. Another significant difference between the two eruptions was the nature of the eruption material. At Mount St. Helens, the majority of deposit materials were air-fall tephra, with the exception of the Pumice Plains, where glowing avalanche deposits covered the area, whereas at Mount Mazama, the surrounding area is covered mainly with glowing avalanche deposits, associated with the ring vent phase of the eruption, which produced very deep deposits without surviving organisms.

Recovery was further hindered in central Oregon by climate. Mount St. Helens has a wetter climate. The annual precipitation of Mount St. Helens is 2,500 mm (Franklin et al., 1985). Winter snowpack accounts for a majority of the precipitation. During July and August severe moisture stress can develop (Reynolds and Bliss, 1986). The flora prior to the eruption of 1980 was atypical and depauperate compared to other Cascade volcanoes (Kruckeberg, 1987). This may be a function of unstable, dry pumice soils, deficient in nutrients, and the relatively youthful age of the volcano (del Moral and Wood, 1988). It was noted in 1938 that the timberline was at a much lower elevation than the timberline found on other Pacific Northwest volcanoes (Lawrence, 1938). In 1987 Kruckeberg described the timberline area as irregular and poorly developed, with a mixture of low and high elevation species (lodgepole pine, whitebark pine, noble fir, black cottonwood (*Populus trichocarpa*) and Sitka alder (*Alnus sinuata*)), at least 800 m below the timberline of neighboring volcanoes.

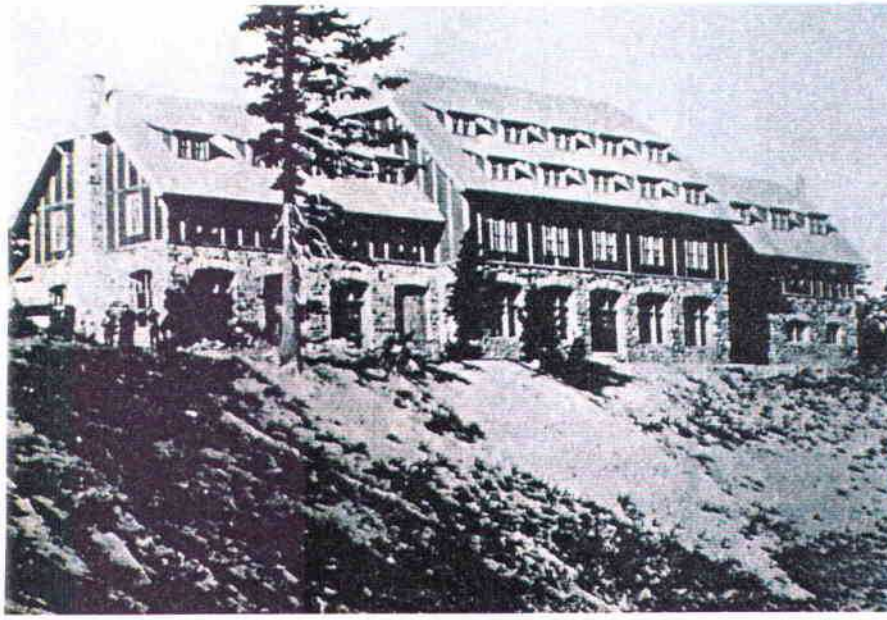
History of The Crater Lake Lodge

William Steel was a visionary. He envisioned a grand summer resort at Crater Lake where visitors could drive down to the lake and enjoy fishing and boating. He imagined a rustic lodge, where guests could dine on trout caught in the lake, while mesmerized by the enchanting views of Crater Lake. William Steel and the Crater Lake Improvement Association, founded by Steel, intended to "erect an elevator down the precipice leading to the water's edge, so that tourists can avoid the 1,500-foot climb from the water to the hotel" (Juillerat, 1995). Fortunately, not all of these grandiose dreams were realized. Perhaps the rehabilitated lodge, open today, may have fulfilled at least his dreams of a majestic hotel overlooking the natural beauty of Crater Lake (Fig. 46).

Since the construction of roads as early as 1865, Rim Village provided visitors with an excellent view of the lake and of Wizard Island. This area soon became an informal campground (refer to Fig. 49). Development around the lake began in earnest with the construction of the Crater Lake Lodge. The constructionof the lodge commenced during the summer of 1909 and it first opened in 1915. Crater Lake Lodge, however, was never fully completed. A short summer season and a lack of funds thwarted the efforts of concessionaires and park officials.

In 1915, for $3.50 a guest received meals and a room for the night and for $0.50 more a room with hot and cold water. Complaints soon began about the service, the food, inadequate water supplies, no central heating and fire safety. Visitors were not impressed with the small rooms partitioned by paper thin walls or the doorless lavatories (Juillerat, 1995). During the early 1920's, eighty rooms were added to the building, but the exterior remained incomplete. The structure had not been designed to withstand heavy accumulation of snow and there were no designated parking areas. Visitors parked anywhere they liked, causing environmental mayhem. The public facilities available did not meet the requirements of increased visitation during the early part of this century. In an attempt to regain control of the parking, the Park Service rerouted the road to its current location around the rim of the caldera and provided designated parking areas in the 1930's. A revegetation project was also instigated to hide and minimize human impact.

From poor construction and disrepair, the lodge slowly deteriorated until in 1989 it was deemed a safety hazard. The Park Service suggested removing the structure and building new accommodations away from the rim, but public outcry led to a $15 million rehabilitation of Crater Lake Lodge. Only about 10% of the original building was salvageable - the stone work and some of the wood decorative features (Juillerat, 1995). Today the restored lodge represents a nostalgic attempt to create William Steel's vision.



a.

b.

Fig. 46. The Crater Lake Lodge first opened in 1915 (a, photograph courtesy of Crater Lake National Park archives. Today the restored lodge represents a nostalgic attempt to create William Steel's vision (b. Photograph courtesy of R.J.Lillie)

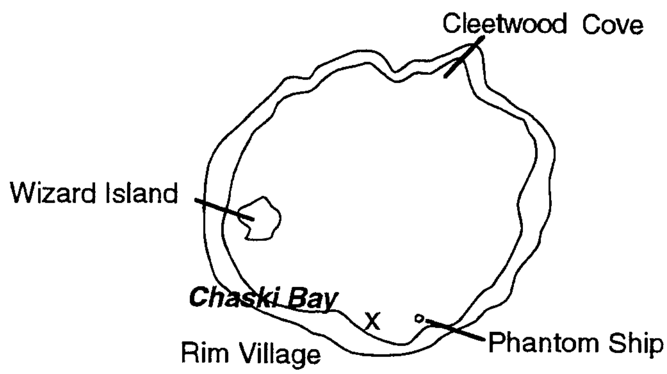
William Steel and others dreamed of a rustic "ornamental" lodge reminiscent of the manor houses of Europe. From the luxury of a verandah lounge chair, nature is comfortably viewed. The manor house was not designed to blend with its surroundings. Instead, it was meant to stand juxtaposed against the untamed surroundings, giving order to chaos. The building does have rustic charm - the green roof and brown walls create the park-like quality of groomed trees. The location of the lodge on the edge of the caldera rim provides a spectacular view of the lake and Klamath basin from the comfort of the dining room.

As early park visitors cautiously drove up the old road to the lake, the first object they saw was the lodge in all its grandeur. It was not until later that the emphasis of Crater Lake National Park returned to the natural beauty of the lake and surrounding country. In the 1930's, the concept of a National Park evolved from an obtrusive human presence to a more subtle presence. The architecture was no longer designed to stand apart from the scenery, but to blend and become a part of the scenery. Built in 1931, the Sinnott Memorial Overlook epitomizes the Rustic design concept. This observation structure was built in honor of Congressman Sinnott, who worked in behalf of the National Park Service. Inspired by this new unobtrusive concept, the architecture disappears into the caldera (Fig. 47). Whereas the lodge is easily recognizable from the water, it is difficult to find the overlook.

Fig. 47. Inspired by the Rustic design concept, the architecture of the Sinnott Memorial Overlook disappears into the caldera. (Photograph courtesy of R. J. Lillie)

Fig. 48. The Chaski Bay landslide probably occurred soon after the initial collapse of Mount Mazama. (Photograph courtesy of Crater Lake National Park archives)

Chaski Bay: *The Collapse of Mount Mazama and the beginning of Modern Dynamics*



Geology

It is speculated that the collapse of Mount Mazama was much like the depression of a piston, leaving very steep, almost vertical walls. Huge landslides occurred simultaneously or soon after the initial collapse, stabilizing the walls. Evidence for these landslides is seen on maps and aerial views of the Crater Lake caldera. The margins of the lake are scalloped. The landslides left broad bays separated by sharp ridges. Although scientists debate the actual timing, the Chaski Bay landslide probably took place soon after the collapse (Bacon, 1996; Nelson et al., 1988) (Fig. 48). It would appear that the Chaski slide occurred as a wedge-shaped block slid from higher on the wall. Bacon (1996), however, found no resemblance to the rock associated with the slide and any rock higher on the wall. He maintains the rock at the water level was highly altered by hydrothermal activity. The material from this slide extends northward into the lake about 1 mile (1.6 km) (Nelson et al., 1988). Often in the early morning and in the late afternoon deer and other animals are found browsing on the slide platform above the bay. Water percolates through the loose debris above the platform and pools in the slide materials, allowing for greater plant diversity and abundance. The water here seeps through the debris, feeding some of the most continuous waterfalls within the caldera.

Near the shoreline in Chaski Bay the caldera floor shallows. This is seen as a change in water color. Crater Lake is world known for the intensity of the "Crater Lake Blue" (refer to figure 58). This color is a function of water clarity and sunlight. Sunlight can be broken into various wavelengths, including visible wavelengths. The visible wavelength can be further divided into the colors of the rainbow (red, orange, yellow, green, blue, violet). Each of these colors has a specific wavelength. From the reds through the greens, the long wavelengths are almost immediately absorbed by water molecules, thus heating the lake. The blues and violets are shorter, more energetic wavelengths that can penetrate to greater depths within the lake, eventually scattering off the water molecules and returning to the surface. Thus, where the water is very deep, the color that is not absorbed and returns to the eye is deep blue. This lake has very little sediment suspended in the water column, which would reflect the longer wavelengths, interfering with the blue; thus clarity maintains the deep-blue color of the lake. Around the margins of the lake, the color appears green, then yellow, then red; as the water shallows, those wavelengths of light reflect off the caldera floor.

Botany: *Post - collapse vegetation recovery around Mount Mazama*

Figure 29 illustrates the general pattern of tephra (pumice and ash) depth radiating from Mount Mazama. Within a 100 km radius, particularly to the northeast of Mount Mazama, the effects of the climactic eruptions were probably the most destructive. The re-establishment of vegetation on tephra deeper than 12 - 16 inches (30 to 40 cm), would have followed a pattern of primary succession. However, as was noted with the re-establishment of vegetation at Mount St. Helens, all succession probably did not occur in completely sterile substrates. In ravines, such as Annie Creek, south of Crater Lake, runoff would have quickly eroded through the pumice and ash layers, allowing buried vegetation to regenerate above ground biomass. The ash-fall deposits conformed to the landscape; thus the deposits were probably not of uniform thickness. This would have allowed larger woody plants and other plants in protected sites to survive burial. The invasion of pioneering species across barren pumice flats would have resembled the current invasion of lodgepole pine into the Pumice Desert north of Crater Lake. At the Pumice Desert, microclimate produced by more than 200 feet of pumice filling an old valley restricts vegetation establishment, yet lodgepole pine is slowly encroaching 7,700 years later (Horn, 1968).

The revegetation program at Crater Lake National Park mentioned earlier (see page 78) was also inspired by the Rustic design concept. Until the 1930's there was no attempt to control vehicular or pedestrian traffic. The resultant landscape was barren. "Trees were used as bumpers for automobiles; vegetation was practically non-existent from trampling by visitors and/or their cars; and the nature of the site's soil combined with the prevailing winds, often created an unbearable dusty and dirty environment" (Gilbert and Luxenberg, 1990). The landscape architects improved this desolate site by blending function with aesthetics to recreate the natural scene. Beginning in the late 1920's, their plan involved planting native trees, shrubs, and groundcover to reduce soil erosion and add an aesthetically pleasing backdrop to the lake and to develop a system of paths and parking linking the Rim Village facilities with views of Crater Lake (Gilbert and Luxenberg, 1990) (Fig. 49). Some of the common plants found along the Rim Village promenade are mountain hemlock and whitebark pine, the Sitka mountain ash, Crater Lake currant, pearly everlasting, false hellebore, and other groundcover species.

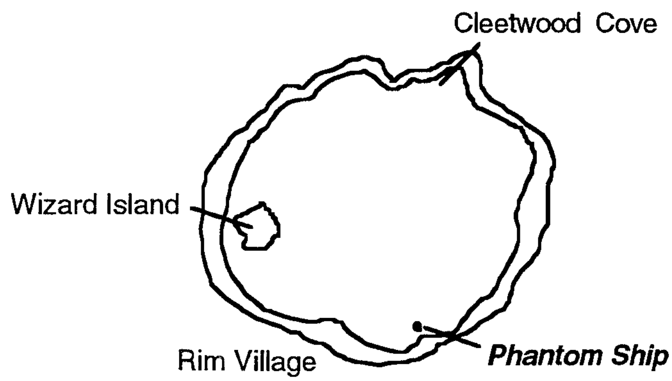
Anthropology

It is difficult to separate the human response to the eruption of Mount Mazama and the concurrent major fluctuations in climate. The eruption probably devastated plant populations and influenced animal and human populations in the northern Great Basin. How much the eruption of Mount Mazama actually affected local populations is a controversial issue. Malde (1964) suggested the eruption was catastrophic to people.

Fig. 49.The Rim Village has benefited by the efforts of revegetation crews. (Photograph courtesy of Crater Lake NationalPark archives.

"Besides damaging plants and foraging animals, the ash that washed into rivers and lakes probably exterminated most of the fish. The major rivers would have been roily with ash year after year, as the ash was progressively washed from the uplands. With food supplies dwindling, the Indians probably had to move elsewhere" (Malde, 1964, page 11). Fort Rock Cave, about 60 miles (100 km) northeast of Crater Lake National Park, was abandoned soon after the eruption of Mount Mazama; occupation of the cave did not resume for approximately 4,000 years (Cressman, 1986). The area was, however, not completely abandoned; its usage declined significantly. Since the altithermal, a period of increased aridity, was simultaneously occurring, abandonment can not be completely attributed to increased volcanic activity or warming climatic trends only. From mainly charred animal bone fragments found in fire-hearths in the Fort Rock region, it appears that the paleo-environment was not greatly affected by the eruption of Mount Mazama. A general decline in moisture was more influential (Grayson, 1979). The eruption was not induced by climatic variation, but the adaptation response appears to be intimately linked to climatic fluctuation, especially to the altithermal period.

Phantom Ship/ Dutton Cliff: *Island Ecology*



Geology: *Dating Methods*

The Phantom Ship stands as a beacon to visitors of Crater Lake National Park, representing both the inspirational beauty of the lake and the dynamics of the lake's past and present (Fig. 50). This small island is an erosional remnant of a ridge that once connected Dutton Cliff to the island. The Phantom Ship and the cliff behind it represent the oldest rock within the caldera.

There are different methods of dating rock and other materials. Most methods rely on the instability of individual chemical elements, such as carbon or potassium. Radiocarbon dating, possibly the most widely known dating method, is used in dating organic, or once living, objects. Carbon is a building block of life; when an organism dies the carbon begins to decay. The radiocarbon dating method thus traces the amount of original carbon isotope (C14), compared to the amount of its decay product (C12). The radiocarbon method is used primarily among archaeologists because the method is only reliable in dating within the past 30,000 years or so.

The sagebrush sandals found in Fort Rock Cave in the 1930s were dated with the radiocarbon dating method (Cressman, 1981). The climactic eruptions of Mount Mazama were also dated using this method. Fragments of charred wood found in the eruptive deposits were dated. This accounts for the discrepancy between dates. Many of the

Fig. 50. The Phantom Ship is located below Dutton Cliff.
(Photograph courtesy of Crater Lake National
Park archives)

information stations along the rim drive give an eruption date of 6,845 years ago. This is the radiocarbon date; the date 7,700 years ago is the actual calendar date, after systematic errors recognized in the radiocarbon method have been corrected (Mastrogiuseppe and Mark, 1992).

Rocks and other materials older than 30,000 years are dated using other methods, including the potassium to argon (K-Ar) method and relative dating. The radioactive element, potassium (K40), slowly decays into a more stable element, argon (Ar40). The K-Ar method traces the ratio of potassium to argon; the higher the K-Ar ratio, the younger the rock; the lower the K-Ar ratio, the older the rock. The rocks of Mount Mazama have been dated using this method.

The oldest rocks within the Crater Lake caldera are around 400,000 years old, as determined by K-Ar dating. These rocks make up the erosional remnants of the Phantom Cone in the southeast corner of the caldera. Mount Mazama was actually the agglomerate of several composite volcanoes such as Mount Scott, the Phantom Cone, and Hillman Peak, all fed by the same magma chamber that eventually coalesced to create one massive structure.

Although a less precise method, relative dating is also useful in sequencing past events. This method relies on several assumptions, including the *law of superposition*. That is, any formation below another formation must be older; the layers making up the walls of the Crater Lake caldera thus reveal the story of Mount Mazama's formation. The ash from Mount Mazama is a significant marker bed for geologists and archaeologists in sequencing events away from Crater Lake as well. Layers below the ash indicate events older than 7,700 years, layers above the ash are younger than 7,700 years.

Botany

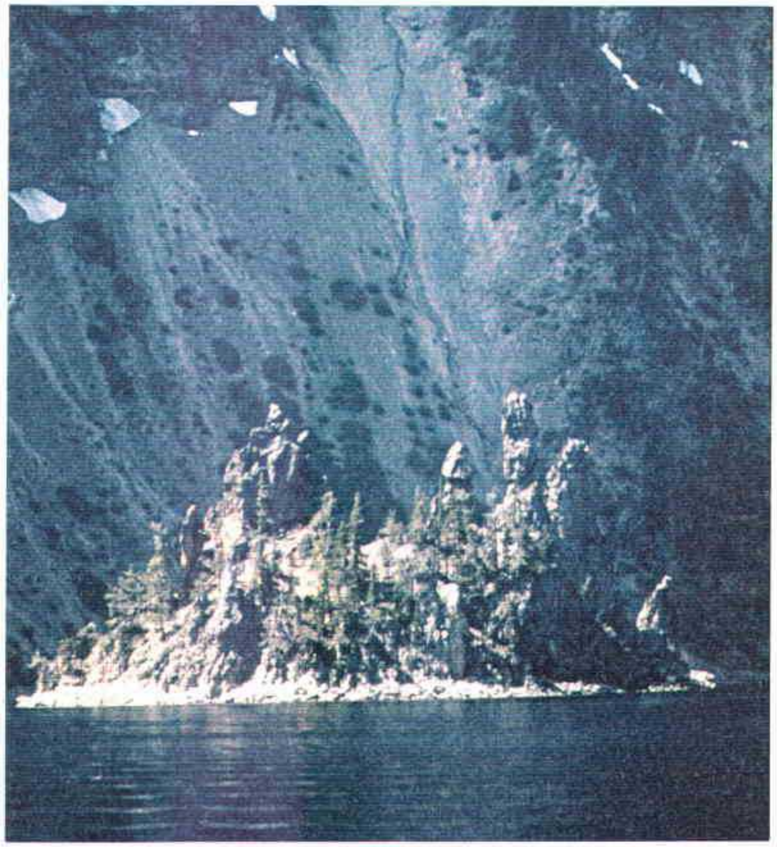
Plants growing around Mount St. Helens after the eruption fall under two major categories - survivors and invaders. Recovery occurred more rapidly where plants survived or where seed sources were close by (del Moral and Wood, 1988). Survivors were found in areas sheltered from the eruption, in areas where the ash eroded away exposing the pre-eruption soils, and in some cases, seeds and vegetative parts grew through the veneer of ash. Micro-topographic areas protected from the eruption included root mounds (the roots of previously blown over trees), and other features with steep sided surfaces that avoided deep deposits of hot ash and blast debris (Veirs, 1987). Lupine (a flowering plant) were an important native plant growing in the pumice deposits. Lupine is a nitrogen fixing plant. Bacteria growing on the roots of lupine are able to capture atmospheric nitrogen; thus lupine helps prepare the environment for the colonization of other plants by increasing the amount of available nitrogen in the soil.

Invaders or "colonists" are also influential in landscape recovery. Colonists include weedy opportunists such as pearly everlasting (*Anaphalis margaritacea*), Canada thistle (*Cirsium arvense*) and fire weed (*Epilobium angustifolium*). These plants produce many small seeds that are carried long distances by wind; they are thus able to establish in barren landscapes by the sheer number of seeds distributed. The small seeds of weedy colonists are not as hardy as other seeds. This is compensated for by the copious production of seeds. Early colonists are not as competitive as later colonists and tend to be less prominent as succession progresses.

Plants spread over the landscape through seed dispersal. Seeds are carried by wind, water, and animals and, if the conditions are favorable, the seed will germinate and the plants they produce will eventually mature and produce more seeds, thus perpetuating dispersal. Island ecosystems are eventually colonized in this manner. Surtsey, a small volcanic island off the coast of Iceland, which appeared in 1963, has provided scientists with a field laboratory (Thorarinsson, 1966; Lasky, 1992). Wind, birds and even fish carried seeds to the island. A continental volcanic system could be considered an island, isolated by such factors as volcanic materials that cover the landscape, the frequency of volcanic activity, and the height of the volcano. Only plants adapted to this environment or plants able to take advantage of the lack of competition are seen growing near volcanoes.

The Crater Lake ecosystem is a series of islands within islands. The slopes of Mount Mazama are covered in thick deposits of pumice and ash, which act as a barrier to most plants. Plants particularly adapted to the volcanic landscape are lodgepole pine, Newberry knotweed (*Polygonum newberryi*), and some lupine spp. The rim and peaks surrounding Crater Lake are islands isolated by climate. Trees must endure a very short growing season and harsh winter winds and heavy snows, which all restrict plant growth. Only quickly growing plants are found in the alpine meadows. Within the lake are two true islands, Wizard Island and Phantom Ship. The vegetation on Wizard Island is limited by moisture stress, slope instability, and insufficient nutrients.

The Phantom Ship has provided an unique environment for plant growth. Almost every tree species growing in the park grows on Phantom Ship. Mountain hemlock, Shasta red fir, white fir, and lodgepole pine grow on the north side of the island and on the south side, ponderosa pine and whitebark pine (Fig. 51). Flowering plants growing on the island include fire weed, penstemon, and paintbrush. The cliffs are painted with the bright orange and yellow colors of lichen (a mutually beneficial relationship between a fungus and an alga). Lichens grow on the rock, slowly breaking it down into its nutrient components; thus lichen acts as an erosional agent. Moss and algae are often important first colonizers, creating the first soil for plants to invade later. Lichens also indicate the health of an ecosystem. They are sensitive to poor air quality and unable to grow in heavily polluted areas. The air around Crater Lake is not affected by urban pollution, since there are no major sources of industrial pollution for hundreds of miles; thus the air is very clean and the lichens thrive.



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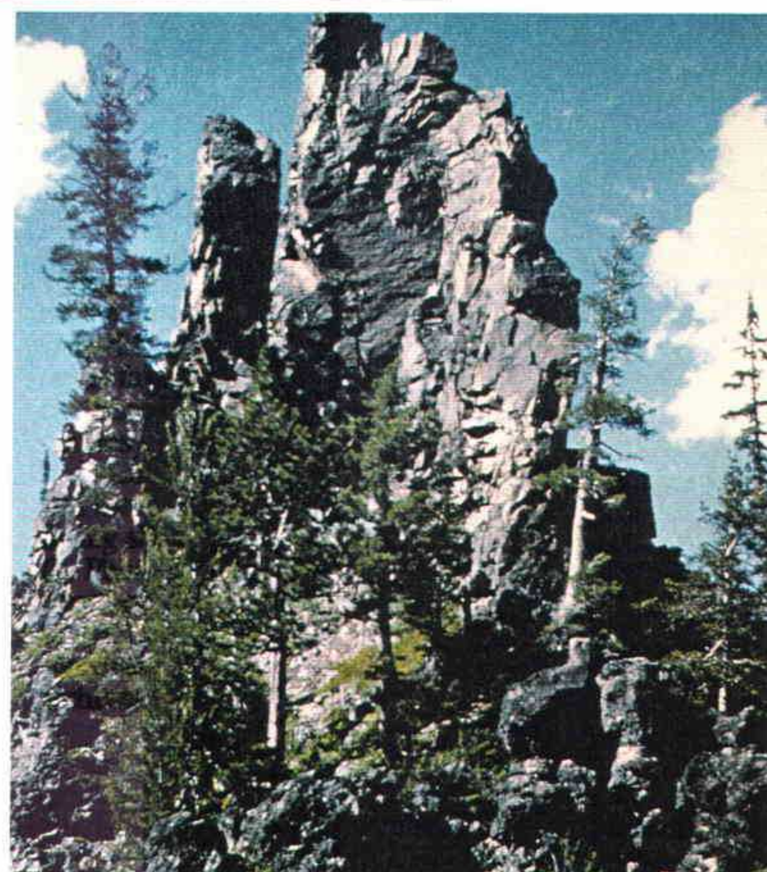


Fig. 51. Vegetation growing on the Phantom Ship differs on the north-facing slope (a. Photograph courtesy of R. J. Lillie) and the south-facing slope (b. Photograph courtesy of Crater Lake National Park archives)

b.

History

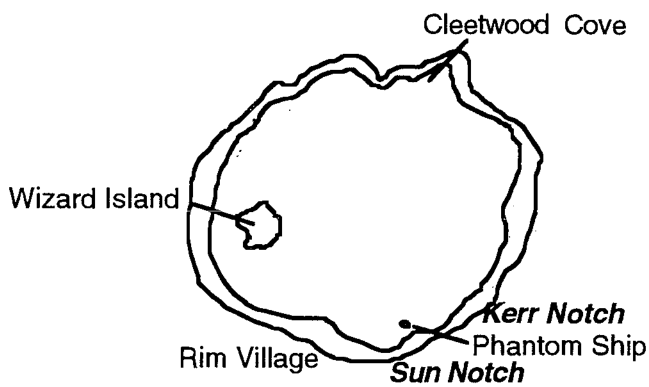
The Phantom Ship was named for its ship-like appearance, with masts that rise about 150 feet (50 m) above the water. The island appears to disappear from different vantage points and with shifting shadows as it blends into the caldera wall. Through the years the Phantom Ship has epitomized the mystic charm of Crater Lake. In 1930 a man from Illinois applied for the position of captain of the Phantom Ship (Smith and Smith, 1997). For many, it symbolizes both the past as the oldest rock in the caldera and the dynamic present of Crater Lake, as water and lichen slowly eat at the rock.

For some 6,000 years Crater Lake existed outside the realms of human impact. Within the last century, the human presence has increased from 1200 visitors in 1903 to over 500,000 per year. In order to accommodate the growing number of visitors and in an attempt to minimize the inevitable human impact on the lake and its surroundings, structures, roads and trails, and parking lots have been built. The structures house park employees and equipment and provide lodging and other facilities for visitors. The roads, trails and parking lots control pedestrian and vehicular traffic, minimizing compaction of soils and erosion along the rim. The tour boats also contribute to the pollution of Crater Lake; however the greatest contribution remains vehicular traffic along the rim road. Hydrocarbons (oil and gasoline) spilled on the roads eventually wash down into the lake.

Another concern involves the introduction of nitrates into the lake. Sewage and fertilizers are some of the major sources of nitrates. A nitrogen influx can harm a lake ecosystem, causing algal blooms, which in turn decrease oxygen concentrations and ultimately lake clarity. Fertilizers and human build-up around Lake Tahoe have affected that lake's clarity as algae choke the shoreline.

Crater Lake National Park has not avoided such problems. The park temporarily closed in the summer of 1975, when both staff and visitors were plagued by sickness. The Munson Valley spring, which supplied the park's drinking water, was contaminated by sewage. Unable to meet the increasing demand, the sewage lines had ruptured, affecting the ground water supply. The park treated the spring water with chlorine. Now the park's water comes from Annie Spring. Springs entering Crater Lake introduce nitrogen into the lake. The springs below Rim Village always have the highest concentrations of nitrogen (Gregory et al., 1990).

Kerr Notch / Sun Notch



Geology: *Sculpting Mount Mazama*

A glacier forms as snow and ice accumulate and begin to flow from the pressure of their own weight. This thick flowing ice sheet carves the landscape through abrasion. The ice flows through valleys already carved by running water. As running water cuts through the bedrock towards sea level or towards a local base level, it forms a characteristic "V-shaped" valley (Fig. 52). As the ice flows, it picks up rock and debris, which is slowly pulverized by tumbling through the ice flow and grinding against other rock. Massive quantities of flowing ice modify the landscape, leaving characteristic landforms. Deep U-shaped or trough-shaped valleys and less blatant features, such as grooves and scratches on the rock and rubble bulldozed by the nose and sides of the glacier, are all evidence of past glaciation. Kerr Notch and Sun Notch are dramatic examples of such U-shaped valleys (Fig. 26).

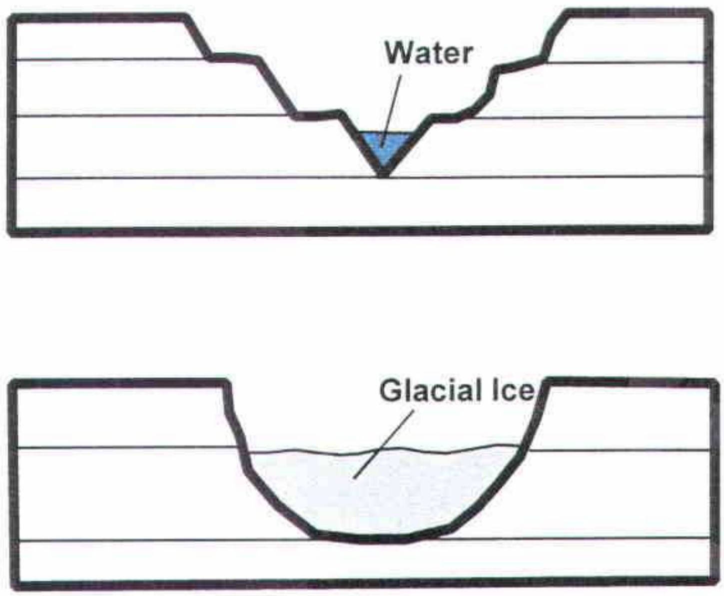


Fig. 52. A schematic model of a V-shaped (river-cut) valley and a U-shaped (glacier-cut) valley.

During the late Pleistocene, global cooling resulted in the most recent Ice Age, a period when massive ice sheets covered large areas of the Northern Hemisphere. On the North American continent, two ice sheets covered most of Canada and extended down into the United States. Fingers of these ice sheets extended farther south down the backbone of the Rocky Mountains and the Cascade Mountain Range. The Cascades were enshrouded with alpine glaciers. Mount Mazama was no exception. Glaciers filled Sun Notch, Kerr Notch and Munson valley. Some remnant glaciers remain on the high volcanic peaks of the Cascades, such as on Mt. Hood and Mt. Shasta, but the warming temperatures about 10,000 years ago caused most glaciers to recede into oblivion. By the time Mount Mazama erupted 7,700 years ago, the glaciers in Sun Notch, Kerr Notch and Munson valley had receded into ice fields at the peak.

Lake Ecology

Crater Lake is in a closed basin; thus there are no consistent natural sources of nutrients entering the lake. Sediment in the lake originates from loose rock falling into the lake and organic byproducts from organisms in and around the lake. Crater Lake is one of the most nutrient-poor or *oligotrophic* lakes in the world (Gregory et al., 1990). An oligotrophic lake supports very little life. Plant (phyto-) and animal (zoo-) plankton (mainly passively floating microscopic plant and animal life), fish, and crayfish grow in Crater Lake. Before the 20th century the lake supported no fish or crayfish. Of the six fish species originally stocked from 1888 to 1941, two species - kokanee salmon and rainbow trout - still maintain viable populations (Buktenica and Larson, 1990). The fish populations fluctuate with the abundance of plankton. Rainbow trout are found predominately along the shores, feeding on aquatic and terrestrial organisms, and the kokanee salmon are found in deeper waters, feeding on aquatic organisms.

Because Crater Lake is nutrient poor, the food web within the lake is relatively simple. Microscopic organisms including both plant plankton (such as algae) and animal plankton are found mainly within the upper 650 ft (200 m) of the water column (Larson, 1996). The lack of sediment suspended within the water column allows light to penetrate deeply; thus aquatic plants are able to grow at greater depths in Crater Lake than in other deep lakes. Around the hydrothermal vents on the lake floor, bacterial mats thrive. These mats receive their energy from iron-rich waters from the hydrothermal vents, not from sunlight. Kokanee salmon, rainbow trout, and crayfish feed on the plankton.

From on-going research at the lake, it appears that the introduction of fish may be the greatest human induced threat to the lake's natural food web and to lake clarity (Larson, 1996). Fish alter the native plant and animal populations, thus altering the chemical and physical balances within the lake. There has been no formal attempt to eliminate fish from this ecosystem; however, fishing in the lake is permitted.

History

Before "white man" discovered the lake, very few people used the area. There were no fish in the lake and the area was only accessible for a short time (only 1-3 months) during the summer. The lake was thus used primarily for spirit quests. "Gaining a vision of the supernatural beings residing in the lake was a major goal of that quest. The seeker would often swim at night, underwater to encounter the spirits lurking in the depths" (Winthrop et al., 1994). There are stories of chiefs proving their ability to lead and others desiring to be medicine men who would swim underwater to demonstrate their courage and strength. Others obtained visions by climbing to high places such as Dutton Cliff and other precipices along the caldera wall.

When European Americans found Crater Lake, the spiritual aspects of the lake were overshadowed by the recreational potential of the lake. People were drawn to the lake for the adventure and relatively inaccessible beauty of the area. The shoreline seemed unobtainable, guarded by steep, unstable slopes. It became a race to reach the shoreline. On October 9, 1865, Annie Gains (later Annie Creek was named in her honor), with Mrs O.T. Brown close behind, were the first white women to reach the lake shore (Fig. 53). They scrambled down below Kerr Notch. William Steel later envisioned tunneling through Kerr Notch, allowing vehicular access to the lake.

Early visitors often spent several days traveling to the lake. It was not until 1912 that the automobile made Crater Lake a day-use park (Smith and Smith, 1997). Before 1912 traveling required effort; thus once visitors arrived they would often spend several days to weeks at Crater Lake. The time passed fishing, boating, swimming, and hiking (Fig. 54). The Smith Brothers (1997) recorded several accounts of women swimming in Crater Lake. In 1925, a 15 year old girl claims she swam from the Lake Trail below Rim Village to Wizard Island with her sister rowing beside her. In 1929, Mrs. Lee Fourrier, a champion swimmer, was the first person to swim 6.25 miles (10 km) from the Wineglass across the lake.

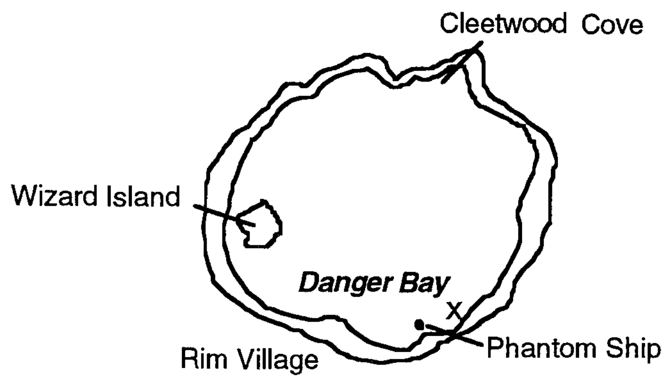
After William Steel introduced fish to the lake and surrounding streams, fishing became a popular pastime. The chef at the lodge dining room would even prepare the fish caught and serve it to the proud fisherman for dinner. At night, lodge guests were entertained by the lodge staff (Juillerat, 1995). Often staff and guests gathered around the piano, singing such songs as "The Crater Lake Waltz" written by Victor A. Tengwald. Today, for the half-million visitors a year, the lake still holds a spiritual quality. One is drawn to the mysterious and sometimes tranquil beauty. At times the intense blue mirrors the steep green and rocky cliffs above, and at other times the sheer power of nature is reflected in the turbulent dark waters.

Fig. 53. Annie Gaines was the first white woman to reach the lake shore. (Photograph courtesy of Crater Lake National Park archives.

Fig. 54. Visitors to Crater Lake enjoyed fishing, boating, swimming and hiking. (Photograph courtesy of Crater Lake National Park archives)

Fig. 55. The smiling rock to the left of Kerr Notch indicates the scouring of past glaciers. Below the filled in glacier is a hanging garden, where water seeps through the glaacial till. (Photograph Courtesy of R.A. Green)

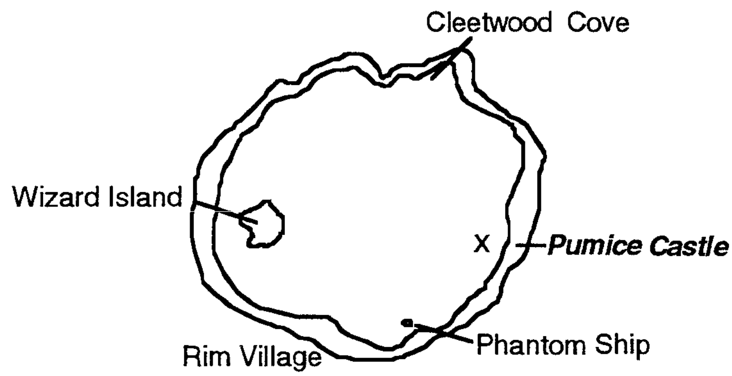
Danger Bay



The last Ice Age was not the only time Mount Mazama was covered in ice. The caldera walls reveal evidence of prior glacial episodes. The smiling rock to the left of Kerr Notch indicates the scouring of past glaciers. This "U-shaped" valley was subsequently filled with several lava flows. The lava flows were cut by the subsequent glaciation in Kerr Notch; thus these flows pre-date the Pleistocene Ice Age.

There are approximately 40 springs that enter Crater Lake (Gregory et al., 1990). The most continuous springs are found along the north-facing slopes of the caldera near Chaski Bay. As water filters through the pumice soils on the rim, it is sometimes trapped by a less permeable rock layer, forming a perched water table. Melting snow and perched groundwater feed the springs entering the lake. The diversity of vegetation surrounding these springs is greater than at other locations within the caldera, because the water source is more consistent. Water slowly seeps from the glacial valley rubble in Danger Bay, forming a lush hanging garden below (Fig. 55). The seepage reveals another secret of Mount Mazama's past. It hints that this valley dips toward the lake, not away from the lake like Kerr and Sun Notches, suggesting that at the time of glaciation the volcanic summit was somewhere near Mount Scott.

Pumice Castle / Redcloud Cliff



Geology

As the boat rounds Sentinel Rock, one of the first features seen on the caldera wall is what may at first appear to be a patch of snow. This white scar extending part way up the wall is a serpentine and kaolinite dike. Serpentine and kaolinite are metamorphic rocks (a rock altered by heat and pressure). They form under conditions of high heat and low pressure and are often a product of hydrothermal activity. After Mount Mazama collapsed, hydrothermal activity altered the caldera walls (see Palisades geology).

Above the dike, the Pumice Castle is the orange-pink tower on the caldera wall (Fig. 56). It stands about 100 ft (30 m) (McDonough, 1996) tall (approximately the same height as the Phantom Ship). It is composed of layers of welded and unwelded tuff (a generic term for volcanic material), and sits on a base of resistant dacitic (relatively high silica content) lava. From an eruptive vent near this site, hot pumice and ash spewed. Compaction of the bottom layers occurred as this hot material accumulated around the vent. Heat and pressure caused the material to fuse or weld together forming a rock more resistant to erosion. With time the softer (nonwelded) pumice and ash eroded away leaving the "Castle"

Fig. 56. The Pumice Castle, the orange-pink flower, stands below the red cliffs of Redcloud Cliff. (Photograph courtesy of Crater Lake National Park archives)

Fig. 57. The Oregon grapefern grows only in the fine pumice of Llao Rock. (Photograph courtesy of Crater Lake National Park archives)

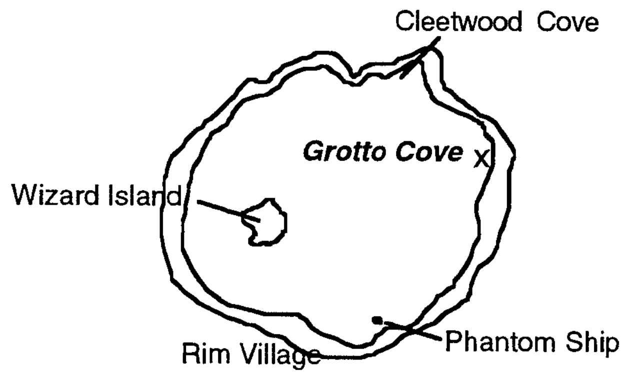
Above Pumice Castle is Redcloud cliff, which has the same bird-like appearance as Llao Rock. The Redcloud flow was the first of three precursor eruptions (Redcloud, Llao Rock, and the Cleetwood flow) to the climactic eruptions. This eruption was similar to the eruption that formed Llao Rock.

The last precursor eruption near Cleetwood Cove convinced Bacon (1983) and others that the climactic eruption and collapse occurred one after the other. When Mount Mazama collapsed, the Cleetwood flow was still warm enough to ooze down the newly formed caldera walls. This implies all three events (the Cleetwood flow, the climactic eruption, and the collapse) occurred within a short period. The Wineglass welded tuff deposits, made during the last stage of the single vent phase, left other clues on the timing of collapse. This deposit was relatively thin and had begun to cool when the collapse occurred, indicated by jointed fractures. However, where thicker, the deposit was still warm enough to slump into the caldera before completely cooling (Bacon, 1983).

Botany

Plants and animals have adapted to the unique "island" of Crater Lake National Park. Some plants grow only in a very small area. They may require a specialized growing environment or they may be unable to disperse because of a physical barrier such as a body of water (Moore, 1991). These plants, isolated either by some physical barrier or evolutionary trend, are called *endemic species*. Growing in the pumice on top of Llao Rock is such a plant. The Oregon grapefern (*Botrychium pumicola*), a small, delicate plant, grows exclusively in the fine pumice gravel on Llao Rock (Fig. 57). Animals can also be endemic to an area. The Crater Lake (Mazama) newt is found only at Crater Lake. This is a well documented case of subspeciation, since that particular newt did not exist before the lake formed (Smith and Smith, 1997).

Grotto Cove



Geology

Crater Lake represents a dynamic system, constantly changing. Today wind and water slowly wear away at the rock. During the winter months, storms generate waves which move predominantly to the northeast. Waves crashing against the cliffs has sculpted Grotto Cove, forming shallow grotto-like caves. As the rock in the caldera wears away it flakes or peals off like the skin of an onion. This process, called *exfoliation* , produces thin, slate-like flakes of rock.

Lake Ecology

Crater Lake is one of the clearest lakes in the world (Fig. 58). Lake clarity is measured by lowering a Secchi disk into the water, noting the deepest depth to where the disk is visible to the naked eye. A Secchi disk is a round flat object with an 8 in (20 cm) diameter. In 1969 a Secchi disk measured water clarity to approximately 140 ft (44 m), a world record (Dahm et al., 1990). Visibility is a function of the ability of light to infiltrate the water. Light is able to penetrate more than 650 ft (200 m) in Crater Lake, indicated by the presence of phytoplankton at this depth. Clarity is determined by water temperature and sediment concentration.

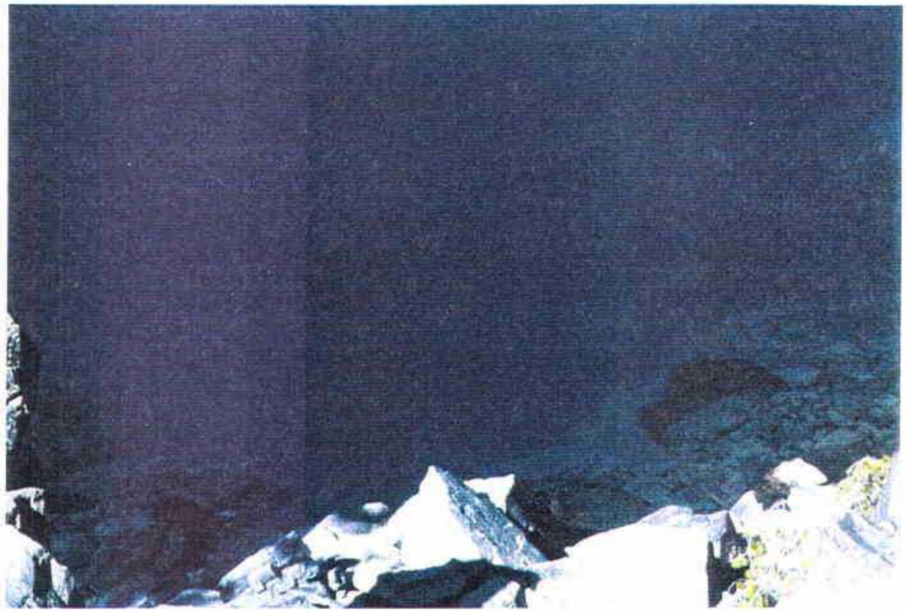


Fig. 58. Crater Lake is one of the clearest lakes in the world.
(Photograph courtesy of R.J. Lillie)

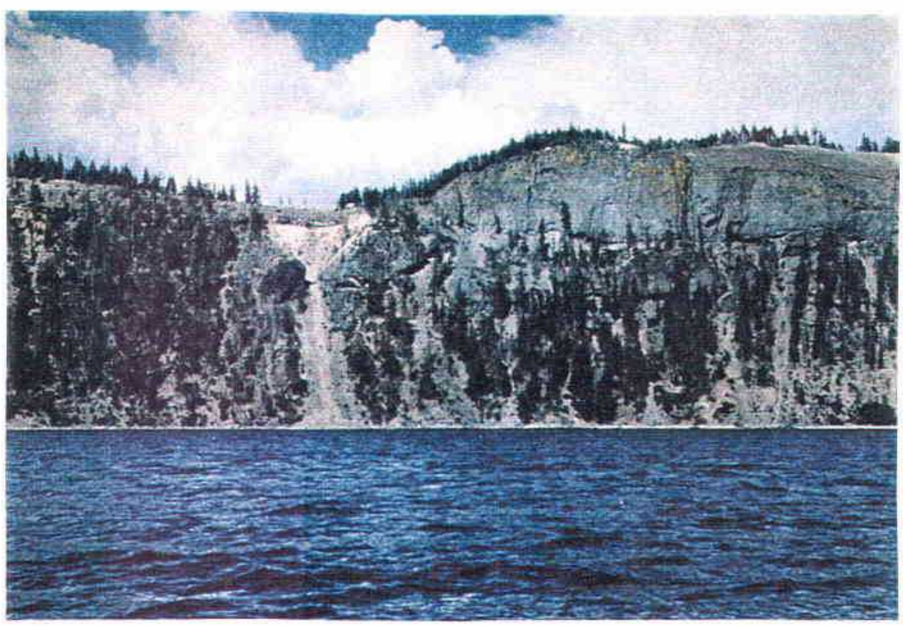
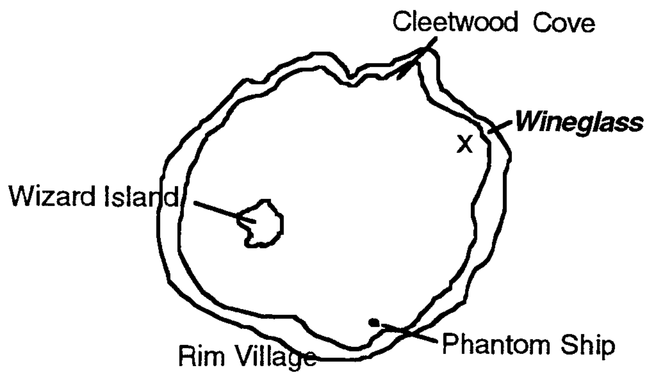


Fig. 59. The Wineglass is the type locality for the Wineglass formation, the resistant lava flow that follows the rim just above the glass.
(Photograph courtesy of Crater Lake National Park archives)

The average water temperature in Crater Lake is 38°F (3°C); thus the lake rarely freezes. The last time the lake surface froze completely was in 1949. Despite its depth, Crater Lake is well mixed. Hydrothermal venting on the lake floor and wind both contribute to water circulation within the lake. During the winter, deep, mineral-rich waters circulate with surface waters. Cold surface waters sink, forcing the deep, mineral-rich waters to the surface. During the summer the surface waters are warmed by the sun and a stratified water column forms.

In the 1980's it appeared the clarity of Crater Lake was declining. This motivated a comprehensive study of lake dynamics to understand the system better. Researchers found that clarity fluctuates seasonally and as aquatic populations fluctuate (Larson, 1996). Clarity is lowest in winter and spring from increased avalanche and snow melt debris and greatest in late summer when most of the sediment and pollen influx has settled.

Wineglass



Geology

The first phase of the climactic eruption occurred in two stages. First, a high column of pumice and ash resulted in a widespread distribution of pumice fall deposits. Places as far away as southwestern Saskatchewan have trace amounts of ash from the early stages of the climactic eruption. The high column stage forced so much material from beneath the mountain that a void formed where there was once magma. This resulted in the enlargement of the single vent and eventually the collapse of the mountain top. As the vent expanded, the eruptive material changed from air-fall pumice to ash flow tuff (a generic term for volcanic material). The chemical characteristics of the material were almost identical; the nature of the distribution was all that changed (Bacon, 1983). The air-fall pumice was distributed for hundreds of miles, whereas the ash flow material moved low to the ground, quickly conforming to the topography. It was still hot when deposited; thus most of the material is welded. The ash-flow material became the distinctive "peanut marshmallow candy" colored band of welded tuff which extends from Redcloud Cliff to Llao Rock (Bacon, 1996). This formation was named after a feature on the caldera wall which resembles a wineglass with a long (fluted) stem of loose rocks extending down from the "cup", an exposed section of the ash flow deposit (Fig. 59).

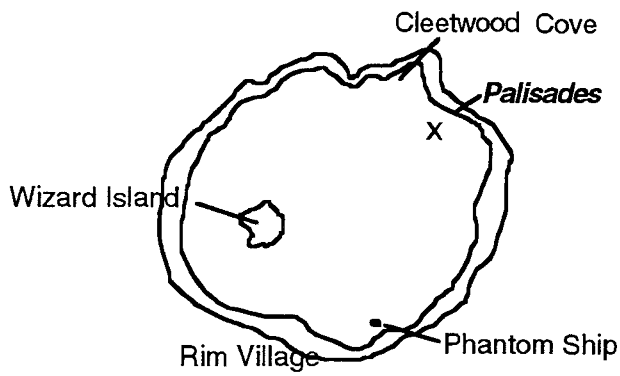
Botany

In general, the south-facing slopes of the caldera are less vegetated than the north-facing slopes. This is a function of sun exposure. In the northern hemisphere, south-facing slopes receive more direct sunlight than north-facing slopes. Snow lingers longer on slopes protected from direct sunlight and wind; thus, the slopes provide a moist microclimate for plants and animals. Steep unstable slopes with very little moisture or soil development create an unfavorable environment for most plants.

History

Before it became illegal to scramble down to the shore at any location other than the designated trail, the base of the Wineglass was a popular destination for fisherman. By 1974 the park service had removed all private boats from the lake and made the Cleetwood Cove trail the only legal descent to the lake. There were several practical reasons for closing all lake trails but the Cleetwood Cove Trail in 1959. The descent below Rim Village drops some 900 ft (270 m) and the drop at Cleetwood Cove is only about 700 ft (210 m). The south-facing slope is usually snow-free by late June, whereas snow will linger sometimes into August on the north-facing slope and the park managers felt the steeper slope below Rim Village was more prone to erosion and landsliding. Most of the caldera walls are steep and covered in loose rock. Over the years many adventuresome visitors have attempted to reach the lake by scrambling down the loose rock. A majority of those attempts ended in expensive rescue missions. By restricting descent to one designated trail, the Park Service hoped to eliminate or at least reduce the number of rescue missions. The rim above the Wineglass was also the site of the proposed second luxury rim lodge.

Palisades



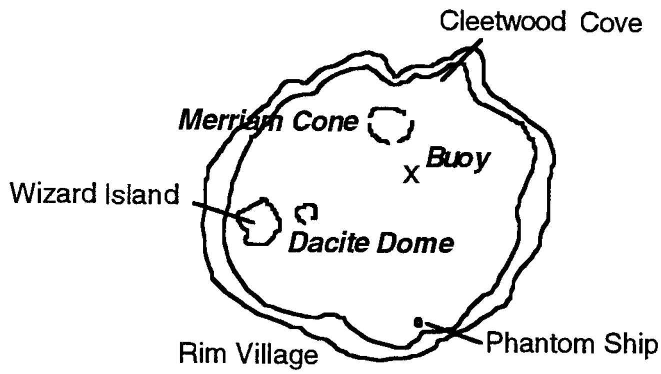
Permeability of rock or the ability of fluids to move through the rock is affected by the density of the rock and by the presence of fractures and joints in the rock. Despite the dense nature of some volcanic rock, as it cools it contracts, forming fractures and joints, thus making the rock more permeable. The flow top breccia (the top unconsolidated rubble of a lava flow) is probably even more permeable. This suggests that if water were held in the Crater Lake basin it would at least fluctuate drastically from season to season and from year to year. However, records show that the water level fluctuates very little, generally within a few feet each year.

In the late stages of the climactic eruption, after the collapse of Mount Mazama, the rubble was still very hot. Water filtering through the hot basin rubble resulted in hydrothermal activity, which altered the rock of the caldera walls, filling in the cracks and sealing the basin. The only possible point of leakage is below the Palisades, where the altered zone extends below the water line (Fig. 60).

Fig. 60. A log is seen floating below the Palisades (Photograph courtesy of R. J. Lillie)

Fig. 61. The Deep Rover was used to explore the depths of Crater Lake. (Photograph courtesy of Crater Lake National Park archives)

Buoy: *Past, Present and Future*



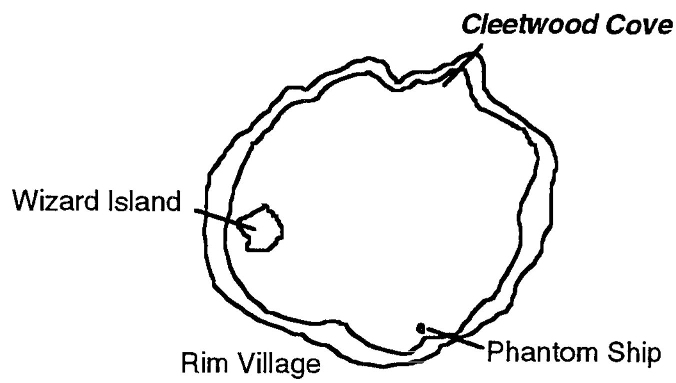
Geology

The last volcanic activity associated with the Mount Mazama magma chamber occurred within the caldera around the ring vent (a product of the final phase of the climactic eruption). Merriam Cone along the north margin of the caldera and the most recent dome forming activity northeast of Wizard Island, occurred entirely below the water surface. Wizard Island began erupting as the water rose; thus some of the cone formation occurred below and some above the water surface. Hydrothermal venting on the lake floor implies the magma chamber still maintains residual heat and suggests Mount Mazama is merely dormant, not extinct.

History: *Lake Research*

Lake studies were conducted from 1896 to 1969, but comprehensive data were not collected until 1982 when Congress passed a mandated ten-year limnological study with long term monitoring be conducted at Crater Lake. The goal was to understand better the physical, chemical, and natural parameters of the lake. The project included studies in lake level fluctuation, clarity, color, hydrothermal processes, and aquatic organisms. The question emphasized during the project was (and remains) - Has the lake changed? As part of the Congressionally-mandated study, a one man submersible, the Deep Rover, was employed to explore the depths of Crater Lake (Fig. 61). The expeditions focused primarily on hydrothermal venting on the lake floor (Larson, 1990). The submersible dives in 1989 noted measurable differences in water temperature around saline water sources on the lake floor, which were distinguishable by extensive bacterial mat colonies (Collier et al., 1990).

Return to Cleetwood Cove



For now Mount Mazama is sleeping; the Gods are momentarily appeased. The last volcanic activity occurred over 5,000 years ago, which may provide a false sense of security. Mount Mazama is a dormant volcano. One day it will possibly erupt again with all the fury of the climactic eruptions. This future eruption may surpass the past activity in violence as it must erupt through the water column, causing a tremendous explosion. Scientists continue to monitor seismic (earthquake) activity and other signs such as increased heat flow and bulging, which would indicate Mount Mazama is once again awakening. For now, visitors are attracted to the serenity of Crater Lake. There is a spiritual attraction to the lake and its surroundings that is difficult to describe.

Crater Lake offers us a chance to reflect on its turbulent past, dynamic present,anduncertain future. It remains one of the most pristine areas in the world. It is our responsibility to continue to learn about this ecosystem and the precarious balance between the human presence and natural processes. Ultimately, however, the human and natural landscape is controlled by the underlying forces of geology. When Mount Mazama erupts again, the cycle of adaptation and recovery will continue.

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