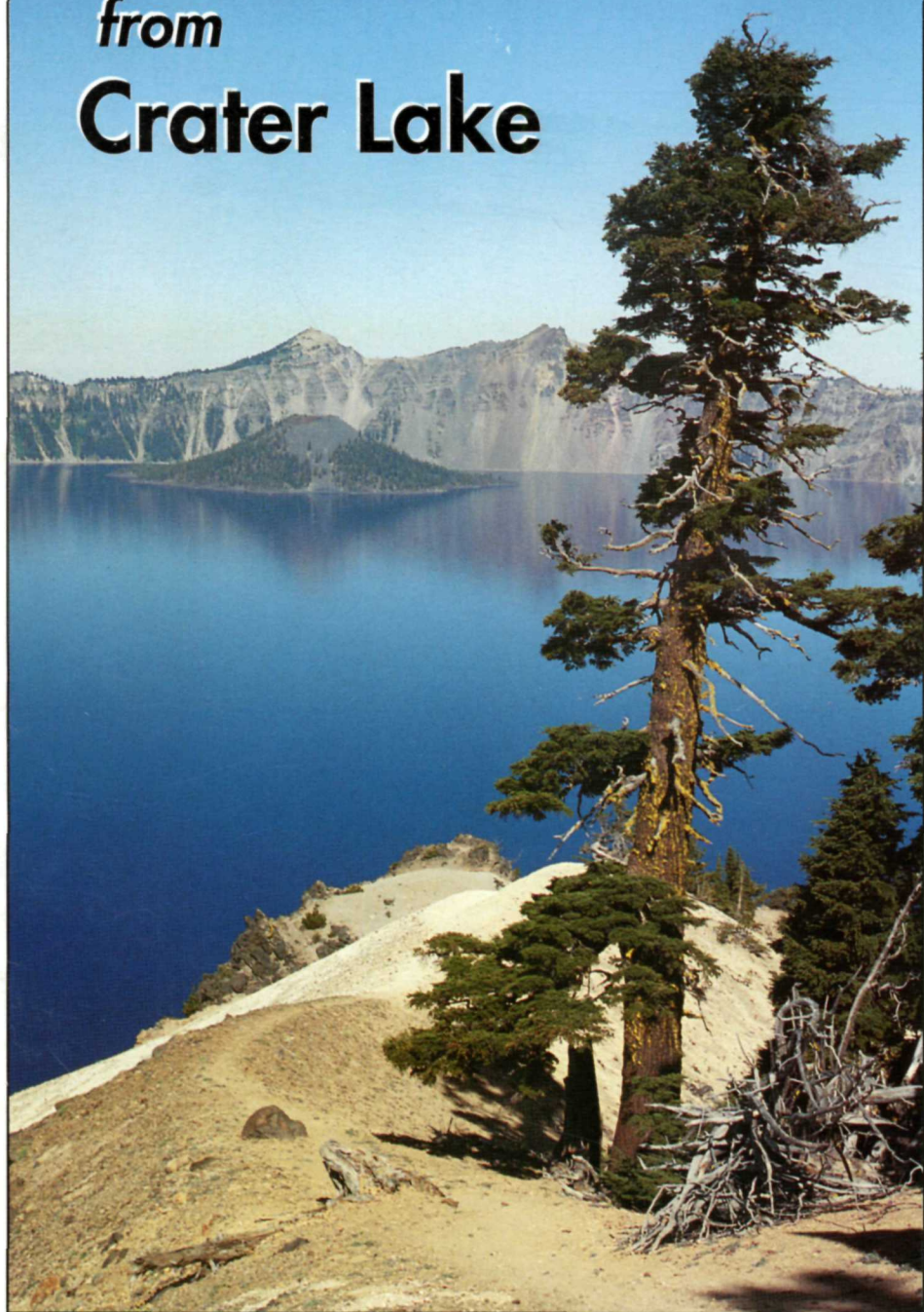


Nature Notes *from* Crater Lake





"Feeding Attitudes of Citellus lateralis (Mantled Ground Squirrel)"
by Kenneth Gordon, 1943

*Front Cover: Crater Lake and Wizard Island from Victor View,
National Park Service photo by Steve Mark.*

NATURE NOTES FROM CRATER LAKE

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Presented by

National Park Service
Crater Lake National Park



Crater Lake Natural
History Association





*"Theodore Roosevelt" and companions,
date unknown.*



The real Theodore Roosevelt in 1902.

NATURE NOTES FROM CRATER LAKE

Volume XXXI – 2000

National Park Service
Crater Lake National Park

Crater Lake Natural
History Association

Not Your Average Visitor

Some months ago a story about Theodore Roosevelt began circulating in the local area. According to sources in Klamath Falls, Roosevelt signed legislation establishing Crater Lake National Park on May 22, 1902 in the lobby of the Baldwin Hotel. His published correspondence, however, showed the President to have been either in the White House or New York City during that week. Other problems plagued the story, too. One concerned the lack of contemporary publicity accompanying such a momentous visit, especially when Roosevelt's western swing in 1903 was widely covered by local and regional news accounts. Access presented another difficulty, since passenger rail lines did not reach Klamath Falls until several years after the park's establishment.

Not to be deterred, some residents pointed to a photo taken within the first decade of the park's establishment. It showed a rotund man reputed to be Roosevelt and three companions sitting along the edge of the caldera with Garfield Peak as a backdrop. Their belief about the photo was publicized in a local newspaper article once doubt had been cast on the original story about signing legislation at the Baldwin Hotel. When the Associated Press gave the photo national publicity, representatives of the Theodore Roosevelt Association in New York challenged the notion about the central figure being Roosevelt and cited a number of reasons based on his known physical characteristics.

As good as any story about TR sounds at first blush, the only evidence for any Roosevelt to have visited Crater Lake comes from 1934. On the evening of July 31 Eleanor Roosevelt came to the park unannounced and stayed overnight in the Crater Lake Lodge. She wanted to enjoy a naturalist-led boat tour on Crater Lake the following day and did so. Her visit has so far constituted the only occasion when the Chief Executive or his wife visited the park while in office. Since that time, the only ex-President and First Lady to arrive at Crater Lake were Jimmy and Rosalyn Carter. They made a brief visit on a sunny September day in 1991.

It is worth noting that the Carters, not Mrs. Roosevelt, corresponded more closely to the average park visitor's profile. In this respect, Mr. and Mrs. Carter came as a single "family" where two people (not counting the Secret Service agents) comprise the most common group of visitors. Single families far outnumber the visitors traveling alone or larger groups such as bus tours. Like the majority of summer visitors, Mr. and Mrs. Carter had never seen Crater Lake previously and their midday stop in the park lasted less than four hours. They, like so many other people who come here, did not see it as a destination. Mr. and Mrs. Carter visited Crater Lake en route to the North Umpqua River, where they wanted to go fishing.

Most visitors do not encounter National Park Service staff during the course of their stay, but the Carters found employees willing to assist them because they made the effort to stop at Park Headquarters before proceeding to the rim. The ex-President and his wife even heard an interpretive talk, thereby joining the minority of the park's half million visitors each year who experience a portion of our educational program. Only one in five visitors



*Eleanor Roosevelt
enjoying a boat tour, 1934.*

find their way to a contact station such as the Kiser Studio in Rim Village or the Steel Information Center at Park Headquarters, yet those who do receive assistance on how to better enjoy their time in the park. These contact stations contain an impressive array of items offered for sale by the Crater Lake Natural History Association, and among them are fewer than 500 hundred copies of this publication. So few are printed because the average visitor chooses not to take a boat tour, hike a trail, nor even travel the full 33 miles of Rim Drive. Gentle reader, *Nature Notes from Crater Lake* is produced in the hope that you might take time to experience more of what this park has to offer.

Stephen R. Mark
Editor

Not So Static a Scene

By Tom McDonough

The famous pioneer artist and photographer Peter Britt first captured the unusual beauty of Crater Lake on a glass plate negative in 1874. Even in black and white, the magnificence of the scenery was clearly visible. Some 126 years later you can walk to the spot where Britt took his photographs and discover that the view of the lake has not noticeably changed. One might ask how it is possible that this deepest lake in the United States, the result of one of the largest volcanic eruptions in North America, has found some special state of tranquility?

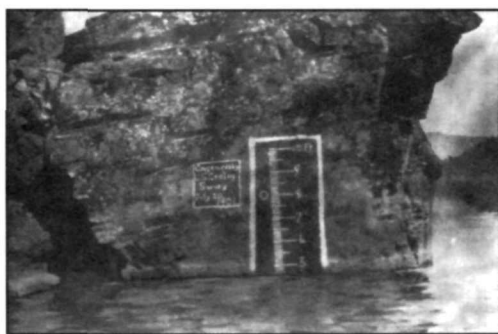
Crater Lake's physical setting is certainly unusual. The lake sits within a basin called a caldera, created when Mount Mazama exploded and collapsed here some 7,700 years ago. Within a few centuries, a lake appeared with a depth of nearly 2,000 feet. At the



Peter Britt took this photo of Crater Lake in 1874.

present time, the total volume of water located beneath its surface comes close to 4.5 trillion gallons. That is enough lake water to provide 750 gallons to each man, woman, and child on earth. Since the lake occupies a caldera, the surface area is restricted to about 21 square miles, with the widest point being a little more than 6 miles. Towering rocky walls loom above the entire shoreline with some rising to nearly 2,000 feet. These slopes stop the flow of streams originating from outside the caldera.

Given the physical restrictions nature has imposed upon this lake, how is it that this apparently stagnant pool of water can remain so blue and clear for so long? What prevents the lake from becoming salty to the extreme? To try to answer these fundamental questions about Crater Lake, scientists began examining the physical and chemical properties of Crater Lake as early as 1883. One survey party in 1886, for instance, made the first successful soundings of the lake and recorded depths ranging between 93 and 2,008 feet. Research continues to the present, not only to refine past data, but is also aimed at tackling as yet unanswered questions.



An early attempt to gauge changes in lake level.

Warm and sunny summer days at Crater Lake are too soon followed by months of cool and wet weather. Park Headquarters, with an elevation 6,500 feet above mean sea level, usually receives 533 inches of snow during a weather year (July though June). This precipitation annually provides the lake, on aver-

age, with 34 billion gallons of water. Some 27 billion gallons falls directly onto the surface of the lake, with the remaining 7 billion gallons entering as run-off from inside the caldera. Some minerals are introduced to the water as a result of this inflow, but the concentrations are minor. The principal sources for the minerals dissolved in the lake are the dozens of springs located within the caldera. When compared to other volcanic lakes, however, these sources are very limited. Within every gallon of water from Crater Lake, for example, there is about 1/100th of an ounce of dissolved salt. Public drinking water, by comparison, usually has considerably more. The mineral content would be much greater were the rock walls surrounding the lake absent and if creeks or streams originating from outside the caldera were permitted to discharge into the lake their load of dissolved solids.

A major reason why Crater Lake appears static is that the lake level seems fixed. In actual fact, however, the level can rise and fall as much as 16 feet with varying snowfall amounts from year to year. What happens to the snow that falls into the lake each winter? If the lake level changes only slightly from year to year water must be exiting in some fashion. Both evaporation and seepage are responsible; water evaporates at the lake surface, but exactly where water leaks away is still a mystery. There could be several places where seepage occurs, since the caldera is composed of fractured lava flows, unconsolidated avalanche debris, and glacial till. One likely spot for seepage is the north wall of the caldera where a glacial valley disappears beneath the shoreline. The fact that the lake level is no higher than this major discontinuity has led some observers to believe that here is a major hole in the side of the caldera, analogous to a leaky rain barrow.

To keep the lake level static, 17 billion gallons of water must seep out each year. We know this is the case because when Crater Lake last froze over (in 1949), the lake level continued to drop by a rate that, over a year's time, would add up to this amount. Evaporation removes only fresh water, but seepage removes the denser, salty water deep in the water column.

Scientists figure that a drop of water can expect to remain in the lake for at least 150 years before it either seeps out or evaporates away. A new lake is thus re-created every few centuries. This is another reason why Crater Lake remains fresh and pure.

The surface area of Crater Lake is limited, but wind from above still pushes the water around to produce ripples and waves. Under stormy conditions, the waves grow large enough to produce a display of foamy tops or white caps. Water is mostly pushed eastward according to the prevailing wind direction. In winter, when the water is uniformly cold, surface winds can push large volumes of water downward into the lake. Descending water currents transport large amounts of dissolved oxygen absorbed at the surface. For this reason, the upper 650 feet of lake water is well oxygenated. The vertical mixing of water in such a deep lake is, however, normally restricted. The upper layers are usually warmer and less dense than the colder water beneath. Some deep mixing may occur in January when winds are the strongest and when the vertical temperature structure of the lake is most uniform. Even then, the water at the lake basin is only incompletely exchanged with the oxygen-rich surface water and it appears that several winters are necessary for its complete replacement. Without such exchanges with surface water, decomposing organic materials on the bottom would eventually use up all available oxygen.

Another reason why the vertical movement of lake water is important relates to upwelling. As descending plumbs of oxygen-rich water reach the bottom, they displace upward some nutrient-rich bottom water. In this way, organisms occupying the upper part of the lake receive necessary chemical enrichment. There are 157 species of microscopic plants, called phytoplankton, that drift in the upper 600 feet of lake water. These plants are at the bottom of the lake's food chain and are preyed upon by a variety of animals, including the zooplankton. Ninety percent of the nitrogen needed by aquatic organisms must come from upwelling, nutrient-rich bottom water. Since the annual turnover of lake is incomplete, it is not yet known how this limited circulation pattern affects the overall biology or clarity of the lake from year to year.

The clarity of water in Crater Lake also varies seasonally and annually. In summer, as the surface of the lake



Winters with a higher than average snowfall will produce a corresponding rise in lake level.

heats, the less dense warm upper layers do not mix downward very well into the cooler, denser waters below. Floating particles remain in suspension until a strong wind forces the water to mechanically overturn. Under warm surface conditions, the clarity of Crater Lake usually decreases. No two years, however, are identical. There have been summers when clarity dropped for extended periods of time. Could it be that a successful winter turnover has redistributed large amounts of nutrient from far below the lake's surface? This might raise the concentration of phytoplankton in the water column above what is normally observed and contribute to the drop in clarity. Or could it be that an unusually large population of fish has consumed all the zooplankton? Since the zooplankton normally preys upon the phytoplankton, the phytoplankton populations might then soar. High concentrations of phytoplankton may thus restrict the lake's clarity.

It is worth remembering that Crater Lake is never truly the same from day to day. The lake is constantly in flux as water both enters and leaves the caldera. Wind currents move over the surface and push the water in several directions, yet from the rim this is impossible to discern except on very windy days. From this distance, the lake generally appears static. Given enough time, however, more obvious changes will occur. No lake can last forever, especially a volcanic one. The fires beneath Mount Mazama will warm some day and increased hydrothermal activity will alter the chemistry of Crater Lake, so that the clear blue lake will be no more. What we see as static is an illusion created by a faulty sense of time.



*Crater lake frozen over in 1949.
Taken from same site as Britt's photo of 1874.*

Studying the Denizens of Tomsandi

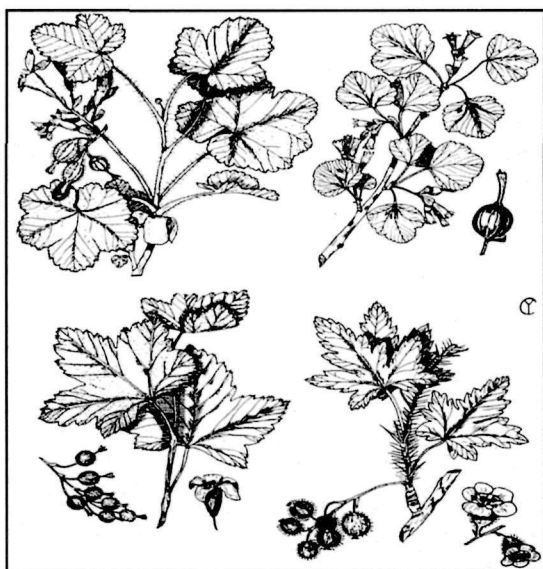
By Susie Donahue

In the summer of 1999 I had the opportunity to thoroughly explore large whitebark pine stands in the vicinity of Mount Scott. Aiming my map and compass toward random coordinates led me through drainages, up slopes, and into tree stands that I would have never seen by hiking the trails. The fieldwork for my senior capstone project at Southern Oregon University involved establishing and taking data in permanent plots for monitoring whitebark pine health. Specifically, I was looking for a tree disease called white pine blister rust. Blister rust is caused by the fungus *Cronartium ribicola* which invades the bark and stem tissues of five-needle pines including whitebark pine (*Pinus albicaulis*), sugar pine (*P. lambertiana*), and western white pine (*P. monticola*). Eventually the fungus girdles and kills infected branches and stems and is responsible for the decline of white pines in British Columbia and throughout the United States.

In the late 1800's expanded commercial cutting of white pines increased the demand for seedlings to be planted, but American nurseries could not profitably meet this demand. A high tariff, which had previously limited importation, was removed and large numbers of seedlings were imported from Europe between 1907 and 1909. Species native to North America were grown in the European nurseries and often shipped back infected with blister rust. The fungus is native to Asia and most North American white pine species are highly susceptible even though some natural



Mount Scott with whitebark pines in the foreground.



*Common species of native currants (Ribes)
that occur in Crater Lake National Park.*

genetic resistance exists. Blister rust was first found on the East Coast in eastern white pines as early as 1909. It spread quickly because infected seedlings from Germany had been planted throughout the Northeast. This allowed the fungus to spread from the New England states toward Minnesota, and as far down as North Carolina. Discovery of blister rust in western North America came in 1921, but the origin of con-

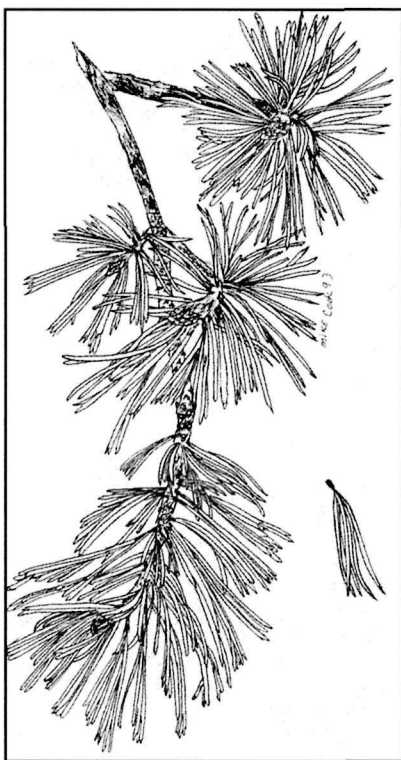
taminated seedlings could be traced to a shipment from a French nursery 11 years previously that arrived in Vancouver, British Columbia. Since then, the disease has spread throughout the range of western white pine in California, Oregon, Washington, northern Idaho, western Montana, and northwestern Wyoming.

The fungus has a complex life cycle that includes two hosts, five spore stages, along with strict moisture and temperature requirements. The alternate host requirement means that *Cronartium ribicola* infects two very different plants. Part of its life cycle depends upon five needle white pines; the other part infects currants and gooseberries of the genus *Ribes*. Of the five spore stages, two are of major concern in the spread of blister rust. One stage of the life cycle produces aeciospores that develop on pines, are long lived, and can travel considerable distances to infect only *Ribes* bushes. Amazingly, these types of spores have been known infect *Ribes* after traveling by wind for over 300 miles. Another stage produces sporidia that develop on *Ribes*, are short lived, and sensitive to sunlight and moisture conditions. Sporidia can only infect white pines and are capable of spreading infection within a radius of about 900 feet under normal conditions. A period of 48 hours with a maximum temperature of 68 degrees Fahrenheit and moisture-saturated air are necessary for sporidia from the *Ribes* host to develop, spread to, and infect white pines.

Current research has identified blister rust to be the major cause of whitebark pine decline in western North America. A recent study in the

Mount Thielson Wilderness approximately 15 miles north of Crater Lake unfortunately substantiated this finding. Forest Service researchers surveyed a section of the Pacific Crest Trail between 5200 and 7800 feet in elevation, where whitebark pines grow on rocky ridgetops and openings in mountain hemlock forest created by laminated root rot. The study found 46 percent of living whitebark pines were infected with blister rust, and 92 percent of these infected trees had “lethal” cankers on the trunk or on branches within six inches of the trunk. This symptom means that cankers will eventually girdle and kill the infected parts of the tree. In 42 percent of the infected trees, blister rust had already killed more than one third of the branches that make up the tree’s crown. Ten percent of the whitebark pines surveyed were dead, and 84 percent of these individuals showed evidence of blister rust infection. Oddly enough, no *Ribes* bushes were found along survey transects. The lack of gooseberries or currants in the survey area supports the idea that basidiospores from infected *Ribes* bushes at lower elevations can be carried in fog and clouds to spread blister rust infections.

According to a symposium paper presented in 1989 by research ecologists Katherine Kendall and Stephen Arno, there is a close correlation between the size of whitebark pine cone crops and human encounters with grizzly bears (*Ursus arctos*) at Yellowstone National Park. In years of large cone crops, grizzlies spend the fall raiding squirrel middens in the subalpine forests. When smaller cone crops occur, the bears must wander in search of food and cause conflict with park visitors or staff. Since the mortality and reproductive rates of grizzly bears at Yellowstone are closely correlated with the size of whitebark pine crops, maintaining healthy stands of *P. albicaulis* is essential for maintaining the park’s population of grizzly bears. Although grizzlies have been absent for more than a century at Crater Lake, local populations of black bears (*Ursus americanus*) are sometimes forced to depend on whitebark pine nuts in order to survive the snowy winters.



Detail of Whitebark pine.

I confirmed this upon seeing the footprints of a black bear while collecting data from plots on Scott Bluffs. The bear scat found near the prints appeared to entirely consist of whitebark pine cones.

Katherine Kendall writes that because whitebark pine occurs at high elevation within the western United States, most of the responsibility for preserving this species falls on the managers of public land—namely the National Park Service and U.S. Forest Service. Fifteen units of the National Park System are known to include stands of whitebark pine, yet the small amount of information available concerning blister rust presence, mortality, and the extent of living whitebark pine is too often derived from casual observations or assumptions based on extrapolated evidence.

Since current research indicates that whitebark pines are declining due to blister rust and no published information was available about blister rust at Crater Lake, park managers wanted to conduct a systematic study to evaluate the health of our whitebark pines. The first set of plots sampled the pure and extensive stands of whitebark pines on Mount Scott, Cloudcap, Anderson Bluffs, and Scott Bluffs. After taking baseline data at each study plot, these points can be checked later to track the health of these trees. The study found a low rate of whitebark pine mortality (only 4 percent) and no blister rust. This is good news for Clark's nutcrackers (*Nucifraga columbiana*) and other wildlife that depend on whitebark pine nuts. Other whitebark pine stands will be sampled in the future to develop a clearer picture of blister rust distribution in the park.

Like any good study, this one raises more questions than it answers. Why is blister rust present in other white pines of the Cascade Range but not on Mount Scott? Does the geographic position of Crater Lake National Park play a role in inhibiting the spread of blister rust? Are harsh conditions on Mount Scott preventing the fungus from successful reproduction? Could it be that measures to control *Ribes* during the late 1940s and in the 1950s are still having an effect? Further study will shed some light on some or perhaps all of these questions. Until then, we may continue to enjoy the beauty of whitebark pines around the rim of Crater Lake and in the vicinity of a peak the Klamath Indians called *Tomsandi*, known to newcomers as Mount Scott.

Reference

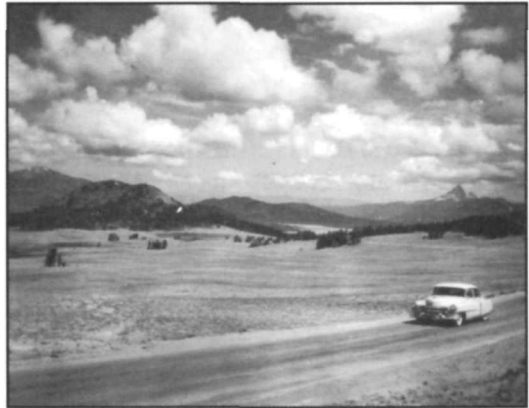
J.S. Boyce, *Forest Pathology*. New York: McGraw-Hill, 1961.

Research Natural Areas

By Steve Mark

As Aldo Leopold wrote, the first rule of intelligent tinkering is to save all the pieces. That thought is the rationale behind designation of research natural areas (RNAs) on selected federal lands in the United States. RNAs are administratively chosen (rather than legally created by Congress or a state legislature) to promote scientific research. They serve a threefold purpose: 1) as examples of significant ecosystems in a relatively undisturbed condition for comparison with those influenced by human activities; 2) as sites for scientific research as part of ecological and environmental studies; 3) as a reservoir of gene pools typical of endangered plants and animals.

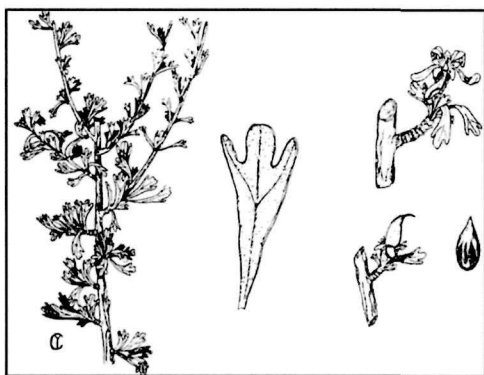
RNAs in Oregon fill one or more “cells,” a construct used to inventory, classify, and evaluate natural areas. Cells are described in a natural heritage plan for the state and contain one or more of the following ecosystem elements: plant communities, special animal or plant species, aquatic types, other natural features. As part of a statewide conservation strategy, 93 RNAs have been designated in Oregon as of 1998. Four of those



View of the Pumice Desert RNA.

are located in Crater Lake National Park, where a nomination process initiated by the Nature Conservancy in 1986 eventually resulted in formal designation with concurrence from the National Park Service.

The largest RNA within the park consists of 3,055 acres and encompasses much of the Pumice Desert. All of this RNA lies west of the road connecting Rim Drive with the North Entrance, but is readily accessible to those visitors who stop at the pullout containing a wayside exhibit. Anyone who makes a short walk will find a largely barren area, one where infertile soil and severe temperature extremes restrict the number of plant and animal species residing in the Pumice Desert. This RNA nevertheless represents Oregon's best example of two natural area cells, one being a lodgepole pine/Brewer's sedge (*Pinus contorta*/*Carex breweri*) forest. The other is



Bitterbrush found in Desert Creek RNA.

subalpine pumice and ash fields, created by Mount Mazama's climactic eruption that covered a former glacial valley some 7,700 years ago.

Only 14 plant species have been recorded in the Pumice Desert, so botanists are justified in describing its flora as depauperate.

Among the forbs, mountain buckwheat (*Eriogonum marifolium*) and pussypaws

(*Spraguea umbellata*) dominate, though the comparatively rare Brewer's sedge is abundant in small pockets. Despite the sparse vegetation, the Pumice Desert has attracted scientists interested in studying physiological adaptations by plants to harsh conditions. Another topic worth of further study is ecological succession in the area, one illustrated by the slow encroachment of lodgepole pine from the fringes of this seemingly desolate site.

If pumice and ash are defining characteristics of the Pumice Desert, they are also abundant in the park's second largest RNA. It is an area of 1,869 acres, extending some two miles north and west of Sharp Peak. The closest vehicle access to the Desert Creek RNA is by way of road #2308 on the Winema National Forest, a route that approaches the so-called "golf course" from the north. Hikers can proceed up the usually dry watercourse of Desert Creek once they cross a fence whose purpose is to discourage cattle from grazing in the park.

The few people who venture to Desert Creek are attracted by the prospect of seeing a remnant plant community dominated by bitterbrush (*Purshia tridentata*), a shrub favored by the occasional pronghorn antelope (*Antilocarpa americana*). The presence of bitterbrush constitutes the main reason for this RNA because livestock grazing elsewhere has so decimated these shrubs. Old growth ponderosa pine (*Pinus ponderosa*) can be seen in the upland part of this RNA, mainly because national park status for Crater Lake allowed these stands to escape the almost universal practice of selective logging east of the Cascades.

Llao Rock RNA not only lacks ponderosa pine, it contains hardly any shrubs or wood rush. Thick pumice deposits limit most of the understory to sedges in this area of 435 acres. Pumice does support tree islands or "atolls," ones composed chiefly of mountain hemlock (*Tsuga mertensiana*) and whitebark pine (*Pinus albicaulis*). The latter can be found lining ridges or perched precariously near the caldera's edge. Whitebark pine also represents

the cell filled by this RNA within the larger statewide plan, even if this tree species is hardly unique to Llao Rock.

The RNA on Llao Rock was nominated primarily to protect known populations of two rare plants. Botanists once feared that the Crater Lake rock cress (*Arabis suffrutescens* var. *horizontalis*) might be extinct, but the Nature Conservancy relocated these wildflowers while conducting its survey of potential RNAs in 1986. The other plant is known as the pumice grapefern (*Botrychium pumicola*) or Oregon moonwort, and can be found on level patches of course or “popcorn” pumice in two locations on Llao Rock. As a tiny green plant growing so close to the ground that it can be very difficult to see, the pumice grape fern is vulnerable to trampling. Hiking in this RNA is not prohibited, but *please be careful where you step!*

Access to the Llao Rock RNA is provided by Rim Drive, with several pullouts located just east of North Junction. Skiers will probably have an easier time of reaching the top than hikers who have to contend with uneven footing due to holes created by Mazama pocket gophers (*Thomomys mazama*). Wildflowers are relatively few, though colorful; similar habitats such as Cloud Cap or Grotto Cove offer easier access by vehicle.

The wildflowers present in the park’s fourth RNA, 180 acres in vicinity of Sphagnum Bog, contrast markedly from those found in areas dominated by dry pumice. Carnivorous sundews and bladderworts most readily come to mind when pondering a visit to the bog, but there is also a small population of the rare Mount Mazama collomia (*Collomia mazama*) within this RNA. More noticeable to the untrained eye are the pink and yellow monkeyflowers (*Mimulus lewisii* and *M. primuloides*) or the alpine shooting stars (*Dodecatheon alpinum*) that flower around Crater Springs. In all, approximately one quarter of the 150 plant species counted within the Sphagnum Bog RNA could be classed as wildflowers—a number far exceeding the combined total of wildflower species for Pumice Desert, Desert Creek, and Llao Rock.



Pumice grape fern.

What makes Sphagnum Bog exceptional, however, is the diversity among its plant communities. In this respect it outpaces other bogs or mires in the Oregon Cascades. Sphagnum Bog not only contains eight plant communities, but the RNA also includes another three communities delineated by forest type. Aquatic communities are present at the springs, along streams, and in pooled water that is isolated but sometimes deep. The mix of communities in this RNA allows it to fill six cells identified by the Oregon’s

natural heritage plan as needs in the west slope of the Cascade Range. These cells include flowing and pooled springs, Sitka sedge (*Carex sitchensis*) fen, Few flowered spikerush (*Eleocharis pauciflora*)/brown moss fen, Bog laurel (*Kalmia microphylla*) shrub swamp, Mountain alder (*Alnus incana*)/sedge community, and Bog blueberry (*Vaccinium occidentale*) shrub swamp.



Sphagnum Bog.

Although it is a wetland and therefore fragile, Sphagnum Bog makes an interesting destination for a hike. Several trails go there from locations inside the park, but the shortest way is to take state highway 230 and turn east at the sign for National Creek Falls. Use Rogue River National Forest road 6536 to go east, then spur road 660 to find the trailhead that is only one quarter mile from the park boundary. Anyone familiar with extended walking in dry subalpine forest or through open pumice will appreciate the contrast Sphagnum Bog offers.

The RNA designation is not aimed at enhancing recreational experience, but the casual visitor can nevertheless gain some appreciation for how each of these areas might contribute to current and future scientific study. Other localities in the park have been focal points for notable botanical and ecological investigations in the past, though areas like the Panhandle and Wizard Island did not score as well in the Nature Conservancy's evaluation process. Each place has its own peculiar characteristics, with some so distinctive that they can serve as the standard from which to compare various kinds and levels of tinkering.

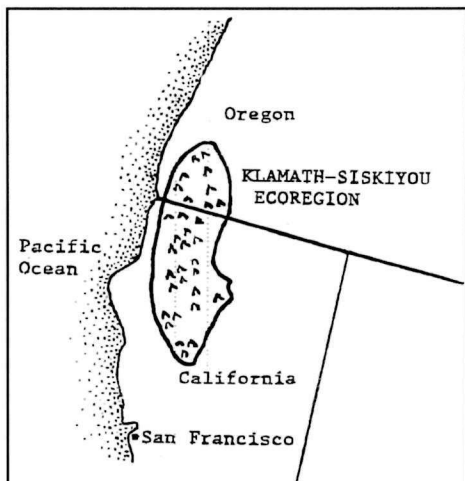
Why So Many Siskiyou Plants?

By John Roth

The Klamath-Siskiyou Ecoregion, hereafter KSE, is an oblong area that extends from Roseburg in southwestern Oregon to the Yolla Bolly range in northwestern California. The varied geology, location, and microclimates of the KSE accelerated plant evolution and migration but slowed extinction. At least 3,000 types of plants and all the major forest types in western North America occur here. More than 200 of these plants are KSE endemics, the name for a species found only in a particular area. Oregon Caves National Monument, as a small but important zone of transition in the KSE, illustrates this floral diversity by boasting almost one plant species per acre.¹

Geologic controls

Ocean basins were spread apart or squeezed for more than half a billion years while molten magma crystallized into rocks as different as basalt and granite. Erosion and metamorphism created another range of strata as well: sandstone, marble, pebbly conglomerate, glacial silt, and “baked” muds. Faults uplifted and split rock masses apart, changing what once were islands and ocean basins into a complex rock mosaic. This fragmentation of habitat favors small populations on each type of soil or rock, a situation in which mutations that give rise to new species are not diluted out of existence by interbreeding with large populations.



Peridotites are rocks with potent quantities of minerals like iron and magnesium that change to metal-rich serpentine when hot water is added. Since most life is not adapted to metals normally found deep in the earth, these metals disrupt photosynthesis and inhibit microbes. The most toxic may be nickel, chromium, and cobalt —though plant distribution in the KSE seems to be governed by the occurrence of magnesium. Little soil forms because clays need aluminum, an element lacking in serpentine. This and the toxicity of metals in serpentine



*A stand of Port Orford-Cedar
near Oregon Caves.*

will not allow clay, organics, or soil clumps to hold water. The cycle snowballs and becomes a situation where thin soils are often dry, hot, and nutrient-poor. This provides open habitat, increases population turnover, and thus encourages the evolution of new species. Because their populations are smaller, species that are rare usually evolve faster than common and/or widespread plants. Of the 200 endemic plant types in the KSE, 141 are either rare or uncommon, a very high ratio for endemics.

The low productivity of serpentine soils limits the dispersal of endemics to new areas because of fewer pollen grains, seeds, or tall plants.

Seeds in serpentine tend to be larger because of being in such stressful habitat, so as to give seedlings a head start on life. This characteristic may also limit dispersal, thus increasing the number of endemics.

The most common response for most plants on serpentine is to keep nickel out of their cells. Even some mariposa lillies and wild buckwheats living on non-serpentine soils tolerate high amounts of normally toxic metals, so they appear better prepared for evolving new species on serpentine soils. Some KSE plants have found other ways to avoid serpentine toxicity. In an endemic pennycress mustard and jewel flower, the plant stores nickel within its cell tissue. Another jewel flower (*Streptanthus tortuosus*) has developed a race of serpentine-tolerant plants and so may be on its way to becoming a new species.

Rapid evolution is also indicated by the fact that roughly two-thirds of KSE endemics are varieties or subspecies that likely are on their way to becoming full species. The crowding of habitats in the KSE results in many hybrids, some of which have given rise to new species.

An avenue for plant migration

The KSE is unusual in that it has more serpentine than any other ecoregion. The serpentine masses and size of the KSE helps plant migrants find suitable habitats more easily but are big enough to keep extinction rates low. Serpentine in the Illinois Valley, for example, is fragmented and

possesses different chemistries—an ideal situation for rapidly evolving small populations. The effects of fire or other disturbances may be so long lasting that plant populations are separated sufficiently and can evolve into new species. By the same token, disturbances in the KSE are not so large and competition among plants is not intense enough for extinction rates to increase. Varied rainfall amounts, frequent burns, and areas that serve as barriers (riparian zones, serpentine, cliffs, north slopes) tend to limit fires to patches of moderate size and intensity. Consequently, no one successional stage dominates with its restricted number of species.



Imperial Lewisia

Another reason for the relatively high species diversity in the KSE is because it contains the only mountains linking coastal ranges in California and Oregon with the Cascade-Sierra cordillera. Plants more easily cross over east-west oriented mountains, unlike north-south ranges where plants must migrate along lines of longitude if they cannot cross high elevations. Migration can promote speciation because it produces numerous small and isolated populations near the range limit of a species, a situation common in the KSE. Proximity to the endemic-rich Cascades, Sierra, and the coast ranges of northern California has increased plant diversity as the KSE shares over 200 endemics with these physiographic regions. At least half of those plants probably originated in the KSE.



*Vollmers
Tiger Lilly*

Extinction is low among shrubs and trees generally, furnishing an important reason why they comprise many of the paleoendemics, or “living fossils.” If you live a long time, you have more chance of reproducing at least once successfully. Even serpentine herbs tend to be long-lived, a trait indicative of harsh environments, and one that likely increases the number of endemics. During the great climate changes over the last few million years, the closely packed habitats of

the KSE allowed plants to grow in adjacent habitats that increased the chances for survival when the climatic regimes shifted. Some habitats shrank considerably, but paleoendemics in them continued to thrive. Port Orford-cedar and Brewer (or weeping) spruce are examples of paleoendemics that once had more extensive ranges.

Another type of endemic commonly found in the KSE is the edaphic endemic or geoendemics—those species mostly restricted to one soil type or topographic situation. Neoendemics (plants with no nearby relatives) in the

KSE also appear to be more common near the north end of their range at high elevations, perhaps because they are also glacial relicts that found suitable cool and open habitats to colonize. Among the endemic plants in the KSE, 80 types are found only on serpentine, while seven are confined to granite, four on marble, and three on volcanic rock.

Other factors promoting diversity

A lack of nutrients and water (up to a point) encourage greater diversity because plants then spend more of their energy surviving such conditions rather than competing with other plants and causing them to become extinct. The leaching of soil nutrients through high temperatures and rainfall lowers the productivity of soils and may increase the diversity of herb. Since the KSE is characterized by low rainfall during the growing season for herbs, habitat diversity is heightened because there are marked differences in slope and aspect that control evapotranspiration and the water retention capacity of soils.

More nutrients and water allow certain plants to dominate and thus reduce plant diversity, the so-called paradox of enrichment. The KSE is an area of climatic extremes, with annual rainfall amounts ranging from 100 inches near the ocean to 15 inches further inland. The differences in rainfall gives rise to a patchy distribution of plants, with the many subspecies and varieties of certain plants indicate rapid speciation—especially in their adaptation to dry soils of serpentine, marble, and granite. For example, dwarf ocean spray, myrtle, buckthorn, and tanoak stay small in stature even if grown in gardens with lots of water. Drought adaptations in endemic plant species include large tubers (as in lillies and toothworts), woodiness (as in pussytoes and pincushion), and waxy, hairy or divided leaves. Storing carbon dioxide at night so that water is not lost through leaf pores by day has favored many endemic sedums and lewisias.

The varied habitats and climate change over thousands or millions of years resulted in 50 or more disjunct species, plants whose brothers or population centers are hundreds of miles distant. Mutations are favored in such situations because of their small populations and the need for new adaptations to survive in a less than ideal habitat. The KSE also hosts at least 100 plant species at the edge of their range, where speciation most likely occurs due to isolated populations undergoing rapid change. Being at the right location between northern and southern plant communities, the KSE is situated so as to have a high number of disjunct species as well as plants at their geographic limit.

As a refuge for plants that once ranged from Japan to Georgia, the KSE provides rare habitat in the western United States. Many of the plant relicts are members of old families: heathers, orchids, honeysuckles, birthworts, and lillies. Plants such as fairybells, woodland stars, dogwoods, rhododendrons, redwoods, trilliums, gaultheria, and coralroots have their

greatest diversity of species in the northwest and southeast United States, as well as in eastern Asia. Paleoendemics evolved once tectonic forces and climate changes cut the connections to other landmasses. Trees such as Port Orford-cedar and Baker cypress, for example, have “twin” species in Asia. Likewise, cousins of plants in the KSE such as vanilla leaf, tanoak, Oregon grape, redwood, and skunk cabbage grow in eastern Asia.

Conclusion

The KSE enjoys the best of diversity among plants; it contains older flat areas where the lack of major disturbances has allowed paleoendemics to survive, but also provides newer habitats like cliffs and cirque lakes where new species can evolve due to isolation and a lack of competition. Northern Florida may possess more paleoendemics and Hawaii has greater numbers of neoendemics than the KSE. Parts of Nevada and Arizona display more edaphic endemics, but the distinctiveness of the KSE lies in its mix of all three types of endemic plants—more profuse than anywhere north of Mexico. In few other places will the location, size, varying ages and geodiversity of mountains with their varied climates combine to produce so many relicts, disjuncts, endemics, varieties, hybrids, and plants near their geographic limit. The Illinois Valley is a botanist’s delight each spring, while Oregon Caves constitutes a representative slice of the fascinating floral diversity found throughout the KSE.

¹The monument list contains some 400 plant species in only 480 acres, whereas Crater Lake National Park boasts fewer than 700 in 183,220 acres.



California Lady Slipper

Where Art Imitates Nature

By Steve Mark

What we see as architectural heritage (that is, worth keeping) is often formal, ornate, and part of commemorating a significant event or person. There are buildings, however, that are preserved for other reasons. Some simply continue to serve an important function for their users, whereas just a few bear testimony to how designers allow occupants to feel integrated with their surroundings. One can argue that nature is something that people construct for themselves, but seeing it with a painter's eye has a long European pedigree.

Situated only 25 yards or so from the cave entrance, the six story Oregon Caves Chateau spans a small gorge so that much of its mass seems hidden below the roadway. The size of this hotel is further downplayed by extensive landscaping with native vegetation and rock from the surrounding area. A steep gable roof with intersecting parts and dormers makes each side of the building appear different from the others. This reflects the variety found in nature, as do windows and doors configured to fit the scene. An exterior sheathing of Port Orford-cedar bark is a distinctive feature and brings about unity with other structures at Oregon Caves National Monument.

Visitors entering the Chateau's main doors next to the road will see a lobby evocative of the time in which this structure was built. One concessioner began operations at the monument as soon as the Oregon Caves Highway opened in 1922, but could provide only some tents for overnight accommodation. The following year a group of Grants Pass businessmen formed the Oregon Caves Company and announced plans for a resort at the monument. It took, however, the impetus provided by government funding for improving the highway, installing electric lights in the cave, and then blasting an exit tunnel, for the company to consider building a hotel.

The monument's rugged and oversteepened topography dictated that a large structure could be sited in only one place if it were to be located close to the cave entrance. That meant the hotel had to be built within a "gulch" next to where Cave Creek spills out from the Marble Halls of Oregon. This architectural challenge fell to Gust Lium, brother in law of a businessmen who helped to form the company. A man who spoke with a strong Norwegian accent, but was born in North Dakota, Lium designed and built many residences and commercial structures around Grants Pass beginning in the early 1920s. He enjoyed a solid reputation, and worked by the "measure twice, cut once" philosophy.

Lium's crew never numbered more than 20 at any one time once he

started construction in 1931. The bottom of the Great Depression brought some delays because money was tight, but the project finished on time in 1934. That spring a rail car load of furniture arrived from California, some of which can be seen in the hotel lobby. Perhaps more evident, at least to those who enter for the first time, is a massive freestanding double fireplace made of native marble. Adding to the ambiance are the massive logs that serve as beams and posts. These appear to be hand joined by wooden pegs, but this detail is only decorative. Wrought iron sconces are attached to the posts and are augmented with lights shaded by laced parchment that hang from the ceiling. Handcolored historic photographs of various tourist destinations in the region add interest to several walls in this room, enticing many visitors to explore the Chateau further.

The main staircase is one of the more ingenious pieces of construction in the entire building. It is open and contains rectangular oak planks for treads notched into peeled log stringers. The balustrades are madrone and support handrails made of lodgepole pine. This staircase can lead one up to guestrooms on the floors above, each level faintly imitating the maze of a cavern where oddly shaped chambers have windows with which to survey the sylvan scene outside. Those not staying overnight might wish to use the staircase for descending to the dining room and coffeeshop. The dining room is known for diverting part of Cave Creek through it by means of a conduit, in addition to a superb view down the drainage. A flood in December 1964 necessitated extensive repairs to the coffeeshop, but it retains some redwood wainscoting, as well as birch and maple counters that complement the soda fountain.



Oregon Caves Chateau in 1940.



Cave entrance from the future site of Oregon Caves Chateau, about 1912.

During business hours patrons can exit from either the dining room or the coffeeshop through the courtyard. A pool built by the Civilian Conservation Corps in 1935 constitutes its central feature and is fed by an eight foot waterfall. The pool, waterfall, drywall masonry, and plantings of fern, shrubs, and specimen trees demonstrate how landscape architects hired by the National Park Service worked with the CCC to create what really is a garden. A conspicuous lack of formality in the courtyard and in other landscaping around the Chalet makes the composition “naturalistic.” In this type of design, emphasis is placed upon using vegetation and materials native to the area and then arranging the most pleasing forms to meld development with the setting.

Naturalistic design has its origin in the history of private estates, at a time when the owners wished to extend the garden outward and surround the house to create various scenes or one “landscape.” Imitating the variety found in nature, yet providing order and unity for what could not occur of its own accord, drove development in public parks through much of the 19th century. Many of these parks were established in cities and adapted from private estates, so that the citizenry could enjoy the perceived benefits of the country. The “rustic architecture” of buildings that fit their natural surroundings became models for developing facilities in parks established to conserve features that displayed the nation’s heritage. The Oregon Caves Chateau is a National Historic Landmark because it demonstrates how rustic architecture and naturalistic design adapted to a new setting and embellished one of America’s oldest national monuments.

Raven's Call

By Ron Mastrogiuseppe

Leftovers from last evening's picnic just became a meal for ravens. They busily share with each other and fly to nearby trees to cache portions of food. Why would the first raven on the scene call others to share the find? They even allow a curious doe to approach and inspect the table, perhaps knowing that she will not be interested in chicken parts! The raven hops sedately but gives cautious, sideways jumps approaching the food. Their wings are half spread, poised for immediate takeoff. Only now do I remember that during the cold days of winter, a few opportunistic ravens are among the few commonly seen wildlife species in Rim Village, where they observe human visitors at lunch and play.

Ravens (*Corvus corax*) are the largest members of the crow family. This family also includes the smaller crows, as well as the more brightly colored nutcrackers, jays, and magpies. All are known for their learning abilities, especially in retrieving food caches. More than a hundred species are grouped into the family, one whose scientific name is *Corvidae*. Ravens are recognized by their large size—nearly twice that of the American crow. Whereas crows have square-shaped tails as well as blunt and splayed wings, ravens possess long and wedge-shaped tails, along with pointed wings which span up to four feet. There are no color differences with respect to gender among ravens, though males are slightly larger than females.

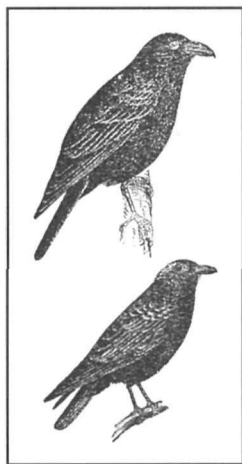
These birds historically followed the migrations of large game animals and tended to associate with predators such as bears, wolves, coyotes, and humans. Large predators not only killed game such as deer, elk, and caribou, but also were necessary to open or tear apart carcasses. Where humans subsisted as hunters, ravens frequented villages and played the role of scavengers. Ravens have disappeared from large areas of western and central Europe due to persistent persecution by farmers and gamekeepers. In contrast to crows, the raven has not adapted to urban areas and tends to be seen in the wilder portions of its former range. It still enjoys a wide geographical and ecological distribution (something that extends from the Arctic Circle to mountainous regions of Central America), however, and associates with humans in places where ravens have not been mistreated or continually harassed.

The raven occupies a prominent place in the lore of many cultures. To some Indian tribes of the Pacific Northwest, the raven is responsible for the creation of the earth, its moon, along with the sun and stars. Other groups have believed that ravens controlled or affected the weather. Associating ravens with death on the battlefield probably led to the assumption that these birds were somehow harbingers of doom. This comes through in western literature, where the hoarse croaking of ravens is often symbolic of evil and

impending destruction. In William Shakespeare's *Macbeth*, for example, the raven is the one who "croaks the evil entrance." Edgar Allen Poe's description of the raven is also ominous:

"Ghastly grim and ancient Raven wandering from the Nightly shore—
Tell me what thy lordly name is on the Night's Plutonian shore!" Quoth the Raven, "Nevermore."

Next time you are on the rim and have the feeling you are being watched, you probably are. Ravens have prospered because they are excep-



*Size comparison
between the raven (top)
and crow (bottom).*

tional observers with remarkable memories. They can successfully collate and retrieve information, while recognizing cause and effect sequences. Such ability assists the ravens in acquiring sustenance and allows them to feast on an amazing array of foods. It may be well to remember as we bear witness to ravens observing human activities in picnic areas, this is opportunistic behavior predating (by millennia) the sign reading, "Do not feed the wildlife." This National Park Service policy nevertheless makes sense in light of human visitation to parks being comparatively heavy, and wildlife numbers relatively few, such that the potential exists for creating dependence on humans for food.

It is nearly 6 a.m. and from my viewpoint at Crater Lake Lodge, I see the sun rising above the northern edge of Cloud Cap. During the past hour prior to sunrise, the high ceiling of clouds remaining from yesterday's lightning storm has been aglow with orange hues reflecting the lake's quiet waters. Mirrored images of the inner caldera walls and Wizard Island appear as perfect, while the shoreline seemingly dissolves. Volcanic rocks below the west rim—the Watchman, Hillman Peak, Llao Rock—are awash with early sunlight that constantly changes the display. The few human visitors, so ephemeral amid this scene, try to record through cameras yet another sunrise on the edge of what was once called the Sea of Silence. It is now one month since summer solstice, when the sun shone at its northernmost point just to the east of Wineglass slide.

Just as I began to think about shorter days, my attention suddenly turned to the Rim Picnic Area where three ravens were loudly squawking. Their bold black forms dove and swirled amid the dark green foliage of the old mountain hemlocks. This time they seemed to be at play, indulging in aerial acrobatics. Their antics include nose-diving with wings closed, turning, tumbling, and even somersaulting, then gliding upside down. With voices deep and penetrating, the ravens command immediate notice and respect. A guttural croaking echoes through the light breeze this peaceful morning. What are they saying to one another? I believe these birds have the answers, but they are not talking to us!

Small Shards of Stone

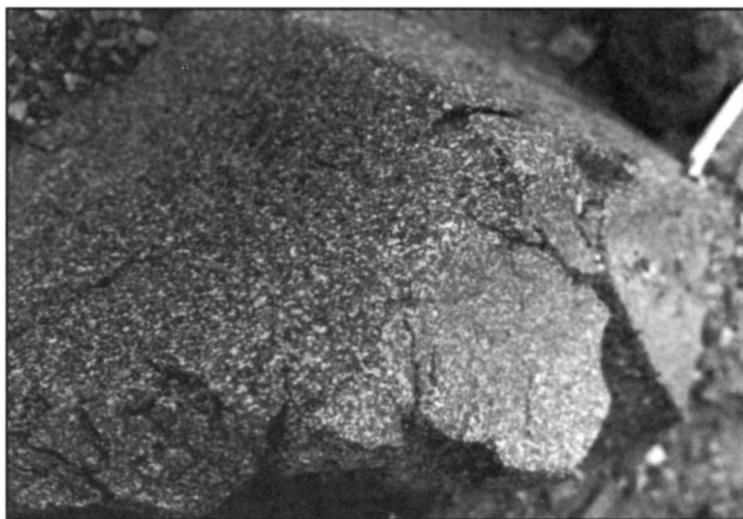
By Steve Mark

Nascent geologists quickly learn that there are three basic rock types: sedimentary, metamorphic, and igneous. Crater Lake National Park lacks both the sedimentary (rock fragments or natural cements under conditions found near the earth's surface) and metamorphic (rocks transformed in appearance or mineral composition through intense heat and pressure, but without melting), yet is abundantly blessed with igneous rocks. The latter are those rocks formed from molten rock or magma, and can be further divided into volcanic or plutonic rocks. *Volcanic igneous* rocks form when magma erupts and reaches the earth's surface, then hardens. *Plutonic igneous* rocks form when magma cools slowly underground, as in the case of granite. Plutons can sometimes be exposed at the surface through the process of erosion, uplift, or even by catastrophic geological events.

Volcanic rocks are divided into categories ranging from rhyolite to basalt, depending upon how much silica they contain. In ascending order, the spectrum at Crater Lake includes basalt, basaltic andesite, andesite, dacite, rhyodacite, and rhyolite. Lots of other terms refer to the texture and form these rocks assume after a volcanic eruption. Although a wide range of volcanic rocks can be found in the park, the only fairly common plutonic rock found here is granodiorite. It occurs in all deposits associated with Mount Mazama's climactic eruption, but is most abundant in late-erupted volcanic



Plutonic rock at Rim Village



*Plutonic rock close up.
Speckled appearance indicates crystalization.*

material. This material is very often ignimbrite, a “tuff” of welded crystal and rock fragments within a matrix of glass shards. These formed as a deposit from a rapidly moving, turbulent, and ignited cloud of gas flowing from a violent volcanic eruption. Granodiorite fragments found around the caldera came from the walls of the magma chamber that produced the climactic eruption. Being somewhat similar in appearance to granite, they are easy to distinguish at close range since the generally grey-black rock contains whitish crystalline specks.

A nice example of a granodiorite fragment can be seen at Rim Village. It is roughly the size of a dishwasher or a little larger, and sits on a bank near the lodge parking lot not far from the road junction to the concessioner’s dormitory. On one side of this plutonic rock is a carving that detracts from its appearance, but the fragment still has much to convey about Mount Mazama’s climactic eruption. The granodiorite crystallized 110,000 years ago in the same location where a large magma body later accumulated, one that eventually powered a violent series of climactic eruptions. In all probability the pluton made an impermeable barrier for the newer magma chamber, one whose rigid container also facilitated a progressively explosive accumulation of magmatic vapors. Much like an over primed bottle of beer, where the ever-expanding pressure of its contents ultimately leads to an explosion, Mount Mazama gave way some 7,700 years ago.

Reference

C.R. Bacon, et al., *Late Pleistocene granodiorite beneath Crater Lake caldera, Oregon, dated by ion microprobe*, *Geology* 28:5 (May 2000), pp. 467-470.

Other Crater Lakes

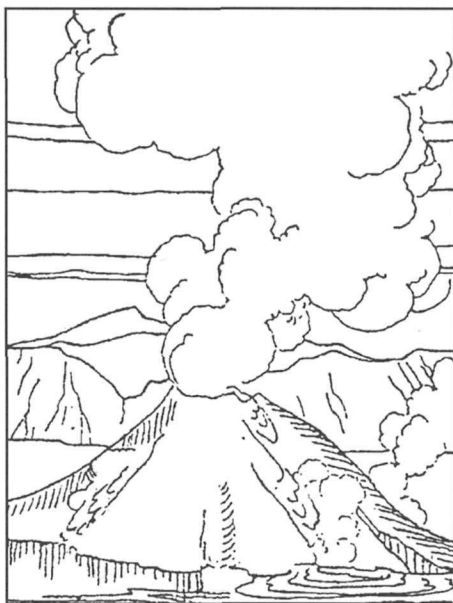
By Tom McDonough

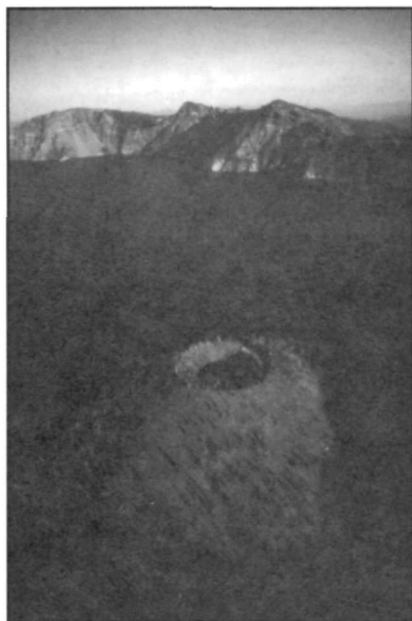
The unusual setting of Crater Lake may suggest to observers that volcanic forces in the Pacific Northwest have created a unique landscape that is rarely, if at all, duplicated elsewhere. Without regard to the special beauty attributed to Crater Lake, there are many other examples of volcanic lakes around the world (some in the Northwest) which, like Crater Lake, have unusual physical and chemical properties that set them apart from other bodies of water.

Crater and Caldera Lakes

Volcanic lakes are relatively common. About 12 percent of the world's Holocene-age volcanoes (those active over the past 10,000 years) have such lakes. Considering that stable volcanic lakes are often found in either very old or extinct craters (created more than 10,000 years ago), the total number of these types of lakes around the world must number in the hundreds. Within the immediate region surrounding Crater Lake, there are three volcanic lakes: Paulina and East Lake in Newberry Crater National Monument near La Pine, Oregon, as well as Medicine Lake, due south of Lava Beds National Monument in northern California. The distinction between lakes located in calderas as opposed to those found in true craters relates only to the size and depth of the resulting lake. Large volume volcanic lakes, with large quantities of water usually are more stable and survive longer.

Water will gather within a volcanic depression if the walls have become impermeable. This is often accomplished by the decomposition of fine volcanic materials (ash) which have been hydrochemically altered into clay. Fine particles, such as clay, can be effective in sealing the openings that appear between rocky layers. This process may begin long before a lake appears and while the parent volcano is still releasing lava. Once a depression forms, it may fill with water





Top of Wizard Island.

from a variety of sources. The water usually comes from the atmosphere (precipitation), but it can also be generated through hydrothermal activity or from groundwater that draws upon the local water table.

Many craters are dry. The depression atop Wizard Island (the Witches Caldron) is an example. It is filled with snow all winter but the melt simply drains through the unconsolidated ejecta of this cinder cone. Other craters, initially filled with water, may lose it in a variety of ways. Repeated volcanic eruptions might eject the trapped lake water, or perhaps the water might eventually leak or boil away. Most lakes considered in this article are located in the wet tropics where precipitation levels are naturally

high—so if the lake loses its water, it will eventually return.

Volcanic lakes vary in diameter (most are circular or elliptical), depth, temperature, color, chemistry (salinity and pH), and in their concentration of dissolved gasses (oxygen, carbon dioxide, and sulfur dioxide). These physical and chemical properties are directly related to the volcanic input supplied to the lake by fumerolic and hydrothermal activity. The stability of the lake, through time, is governed by the volcanic potential posed by the magma chamber, and the volume of water resting directly above these hot fluids.

Volcanic Lake Dynamics

For a body of water to remain inside the walls of a crater for some length of time, it must come into equilibrium with the volcanic forces that produced the depression. Energy is supplied to volcanic lakes by hydrothermal springs and fumerolic gas vents. The heat energy entering the lake from below must be effectively radiated away from the water surface without raising the temperature of the water beyond approximately 45°C (113°F). Smaller bodies of water having lower heat capacities are thus more easily boiled away, with time. Larger volcanic lakes can more easily absorb heat energy delivered from below and radiate it away over a bigger surface area.

No matter what volume of water accumulates within a crater, no lake can survive a major volcanic eruption. Vast amounts of water can be ejected

during a volcanic vent. The presence of lake water may additionally heighten the explosive nature of the eruption. Measured over thousands of years, the vast majority of crater lakes around the world display a life-cycle which starts with water accumulation followed by period of quiet. Eruptive episodes, however, shatter these quiet times with at least the partial evacuation of water from the crater.

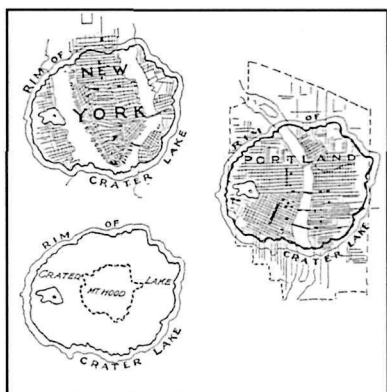
The chemistry of volcanic lakes can vary between pure, oxygen rich water and water that may be highly saline, acidic or alkaline, and gas rich. The latter can consist of oxygen and sulfur dioxide, or conversely, carbon dioxide. Much depends upon the nature of the hydrothermal springs and fumarolic vents feeding the lake. Recent work has permitted volcanic lakes to be classified into several distinctive groups that are based upon the degree of activity associated with the discharges occurring at the lake bottom.

Peak-Activity Volcanic Lakes

These lakes cannot reach a level of equilibrium, so they soon disappear. Peak-activity lakes tend to be small, hot, saline, and form corrosive pools that continuously steam and boil. Temperatures in these types of lakes are raised beyond 45°C by the injection of hot fumarolic gases somewhere at the basin. Their mass is eventually either ejected or simply just boils away. A good example of a peak activity lake is Laguna Calientes at Poas Volcano in Costa Rica. Poas has erupted 39 times since 1828 and is in a state of continuous mild activity. Between 1984 and 1990, this 140 meter lake had a temperature that fluctuated between 38°C and 96°C (100°F-205°F). Mineral concentration rose from 6 percent (by volume) to 35 percent and acidity decreases slightly from 0.26 to -0.87. During eruptions, water from the lake was ejected 500 meters into the air. In many photographs of Laguna Calientes, steam can be seen rising from the surface. The lake finally drained away in 1989 leaving an exposed pool of liquid sulfur, the first ever observed on earth.



Volcanic activity at Crater Lake is so miniscule that park naturalists have been giving boat tours since 1931.



*Early 20th century comparisons
with Crater Lake.*

High-Activity Volcanic Lakes

These lakes possess relatively high salt and strong acid content. Unlike peak-activity volcanic lakes, high-activity lakes are stable with temperature less than 45°C. Those with temperatures greater than 35°C are considered hot acid-brine lakes, while those less than 35°C are labeled as cool acid-brine lakes. Yagama Lake in Japan fits both categories. Between eruptions it is a cool acid-brine lake but warms up before and after events. A shallow hot acid-brine

lake has formed inside the new caldera at El Chichon, Mexico, following the 1982 eruption. The lake is blue-green in color, a consequence of its high salinity and large load of suspended ash.

The Keli Mutu volcanic lake, named “TiN” by western scientists, is an example of a cool acid-brine lake. It is one of three lakes located atop a degassing stratovolcano that straddles the equator. Located on the island of Flores, which is part of the Lesser Sunda chain of Indonesia. Year-round temperatures average about 27°C (80°F) and annual rainfall amounts approach three meters. “TiN” has a diameter of 311 meters and a depth of 67 meters. Its temperature varies slightly between 28° C and 33°C (82°F-91°F), just below the limiting value for hot acid-brine lakes. A large plume located in the center of the lake raises a fresh supply of sulfur to the surface. Input by fumaroles may inject as much as 85 tons of sulfur dioxide into the lake every day.

Medium-Activity Volcanic Lakes

With a temperature structure similar to the previous category, medium-activity lakes are less affected by venting at the bottom. Fumaroles release into the lake salts and acids, but buoyant plumes are unable to reach the surface. Total dissolved solids range between 1 and 4 percent and pH values vary between 1 and 3. A good example of a medium activity lake is one named “TAP” by western scientists. It is another lake on Keli Mutu, on the island of Flores. This lake’s temperature is 20°C (69°F), and it has 1.7 percent total dissolved solids in it. The water is very acidic with a pH of 1.8. Most of the year the lake has a dark green color due to the presence of barium, copper, and arsenic precipitates. When oxygen rich rainwater enters the lake, the lake color changes to blood red because ferric oxide precipitates are produced.

Low-Activity Volcanic Lakes

These lakes tend to be larger bodies of water with low heat flow into their basin. Heat may enter a low-activity lake through vents or sediments.

Some warm salty water may circulate up and into the lake's top layers that are thermally stratified. Low-activity lakes are capable of accumulating large amounts of carbon dioxide, a substance released during overturning events. A good example of such lakes is Lake Nyos in Cameroon, where a large volume of carbon dioxide ($\sim 1 \text{ km}^3$) was released in 1986, killing 1700 people living down slope. The source of the gas was (and still is) hot magma beneath the lake. The gas slowly accumulated on the lake bottom and was released once the stable layers of lake water overturned. It is worth asking whether an event like this could occur at Crater Lake. Carbon dioxide enters the bottom of Crater Lake, but in the form of carbonic acid (H_2CO_3). The acid ionizes once in lake water and remains in an ionic form of hydrogen (H^+) and bicarbonate (HCO_3^-). The slow process of turnover at Crater Lake appears rapid enough to prevent a build up of dissolved carbon dioxide at the bottom.

A new low-activity crater lake can be found at a national park in the Alaska Peninsula. At the summit of the collapsed Mount Katmai is a lake, 250 meters deep, one whose level is still rising. It is surrounded by a 9 km wide caldera with steep walls which measure 500-1000 meters high. This stratovolcano collapsed in 1912 when its magma chamber was drained by the eruption of nearby Novarupta. The lake is a blue-green color, but yellow-green plumes are still visible in the water.

No-Activity Volcanic Lakes

Many stable volcanic lakes display little or no activity. Crater Lake, the lakes in Newberry Crater, and Medicine Lake are of this type. The lake water is relatively pure and the color from a distance is perfectly blue. The chemical content of Crater Lake is 80 mg/liter or .008 percent by volume. These figures contrast sharply with all active systems having chemistry greater than 1 percent by volume. There are active hydrothermal springs on the bottom of Crater Lake, but the flow rate is minimal and the released minerals are greatly diluted by more than four trillion gallons of water. This warm hydrothermal spring water is, however, an important factor in the slow mixing process occurring within the lake.

Newberry Crater is located 30 km southeast of Bend, Oregon. This is one of the largest volcanoes in the Cascades and has been active for about 500,000 years. At the summit of this shield volcano is a caldera that measures 3 km by 7 km, and it appears to be the most recent of a series of overlapping depressions that have formed over time. The last caldera forming eruption occurred about 200,000 years ago and since then debris from other eruptions has filled the basin of the caldera. There may have been only one lake here in the past and its depth may have been close to the depth of Crater Lake. Two lakes now occupy the caldera separated by a narrow strip of pyroclastic material (airfall debris), with Paulina Lake being deeper of the two lakes. It is 76 meters deep and has a surface area of 1531 acres, about

one tenth the size of Crater Lake. Hot springs and vents feed this lake on its northeast side. East Lake is roughly two-thirds the size of Paulina Lake. Its surface rests 15 meters higher than Paulina Lake, but its depth is about half. There are no surface inlets for either lake, but Paulina Creek drains Paulina Lake.

Medicine Lake is located atop the largest shield volcano in the Cascade Range, the Medicine Lake volcano. It is located 50 km northeast of Mount Shasta and began forming less than a million years ago. Resting in the summit is a caldera, measuring 7 km by 12 km, which may have formed when a series of smaller craters circling the summit collapsed. The lake has a depth of 46 meters and is oblong in shape. Although it is nowhere near as deep as Crater Lake (at 1882 meters), the surface of Medicine Lake is higher above sea level—at 2036 meters.

Each of these low-activity lakes is relatively stable since the potential of a volcanic eruption in the near future is minimal. This does not mean, however, that any of these volcanic systems are extinct. They still produce enough heat for some engineers to consider each of the volcanoes as a potentially safe source of geothermal energy.

A Final Word

Volcanic lakes appear in a variety of forms around the world. Those located in the Pacific Northwest, specifically Crater Lake, are examples of inactive systems where the water is clear and blue amid a placid setting. These lakes are volcanically stable and tend to be older bodies of water. The more recent volcanic lakes are temporary features since they sit atop active magma bodies. During eruptive events, their water content may be ejected or will simply boil away at high temperatures. Nevertheless, no lake, whether volcanic or not, will last forever. Seismic activity, volcanic blasts, or the forces of erosion will eventually alter the appearance of every volcanic lake. Even Crater Lake, given enough time, will be replaced by other volcanic systems.

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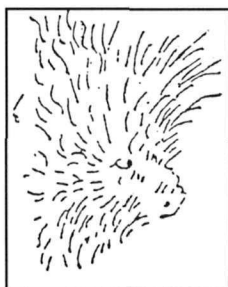
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About the Authors

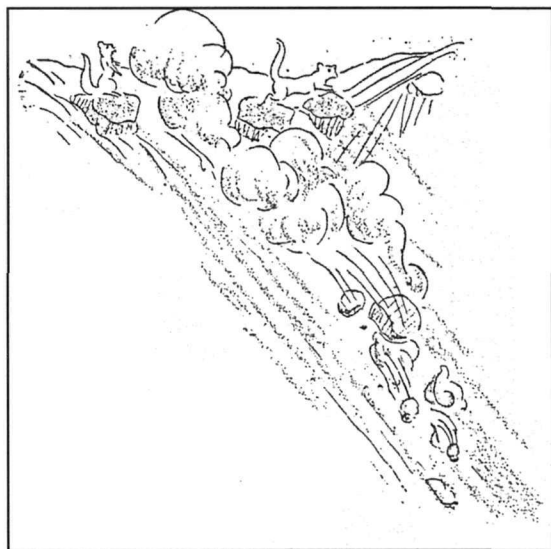
Susie Donahue currently resides in New Mexico but worked seasonally at Crater Lake beginning in 1993.

Tom McDonough teaches at Chemeketa Community College in Salem, Oregon, while also pursuing his scientific interests each summer at Crater Lake.

Steve Mark is a National Park Service historian who has served as editor of *Nature Notes* since its revival in 1992.

Ron Mastrogiuseppe has listened to the birds at Crater Lake National Park since his first visit almost three decades ago.

John Roth became fascinated with the plants of southwestern Oregon upon arriving at Oregon Caves National Monument in 1988.





*View of Phantom ship from Kerr Notch.
Oregon State Highway Commission photo, 1950.*



Sundew in Sphagnum Bog. Photo by Willis Keithley, 1957.