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Campground talk and slide show on volcanoes for Chiricahua National Monument

By

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Abstract and overview

The slides and the accompanying script presented here are based on a campground presentation at Chiricahua National Monument in 1994. Examples of eruptions at active volcanoes are used to help the audience visualize events that took place in the National Monument 27 million years ago. This presentation stresses the following themes: 1) The National Monument lies on the flank of an ancient volcano known as the Turkey Creek caldera. 2) This volcano produced **giant** explosive eruptions, much larger than any in the 20th century. Similar volcanoes that are still capable of producing giant eruptions exist today, and include examples in the United States. 3) We can learn how these giant volcanoes operate and what their typical "life histories" are by examining ancient analogues such as the Turkey Creek caldera that have been dissected by erosion. Studies of ancient volcanoes provide the conceptual framework for evaluating hazards at active volcanoes. 4) Large eruptions of the type that occurred in the Chiricahua Mountains are highly explosive. As a result, the molten rock, or magma, that feeds such eruptions is "blown to bits", producing volcanic ash and pumice instead of lava flows. 5) The volcanic history of Chiricahua National Monument can be reconstructed by geologic mapping and by "reading" the record of past eruptions from the layers of rock that were deposited by the volcano.

The slides and script follow the format of the 1994 campground presentation. Slides are keyed to the script by number. Italic print is used to identify the subject and source of each slide, and to provide additional background information. This document is intended to be used by interpreters at the National Monument for presentations on geology. It may be used as a complete "packaged" talk or as background material for customized presentations. Additional information for the non-specialist on the geology of Chiricahua National Monument is available in a separate report (Pallister and others, 1993).

Script

Chiricahua National Monument is on the flank of a giant volcano known as the Turkey Creek caldera. This volcano erupted 27 million years ago and produced the Rhyolite Canyon Tuff, the rock that forms the fantastic columns for which the Monument is best known. The Rhyolite Canyon Tuff is a vast layer of welded ash and pumice that is found throughout the Chiricahua Mountains. It was produced during a series of giant volcanic eruptions, any one of which was larger than any that have taken place in our lifetimes. These ancient eruptions make the great explosion of Katmai in 1883 and the eruptions of Mount St. Helens in 1980 and Mt. Pinatubo in 1991 look small by comparison. Other giant volcanoes like the Turkey Creek caldera are present in many parts of the world, including the western United States (e.g., the Valles caldera, near Los Alamos, New Mexico, the Long Valley caldera, near Mammoth Mountain in east-central California, and calderas in Yellowstone National Park), and Alaska (e.g., Katmai National Park). Many of these calderas are still active. Luckily, they erupt infrequently; giant eruptions are typically separated by tens of thousands to hundreds of thousands of years. Yet, another caldera-forming eruption would devestate a very large area (hundreds to thousands of square miles) and would have national or even global impacts on transportation, communication, local and national economies, and possibly even weather patterns. Therefore, it is important to understand how these large volcanoes work and what the signs of an impending large eruption might be. For this reason, the U.S. Geological Survey (USGS) monitors active volcanoes for signs of unrest, and studies both active and ancient volcanoes to better understand their internal structure and the kinds of events that might lead to future large eruptions.

In the following slides we will look at modern volcanic analogues in order to understand some of the processes that led to the development of the Turkey Creek caldera and the surrounding landscape.

1. *July 22, 1980 eruption of Mount St. Helens view from the south. Photo by R.L. Christiansen (USGS). Main eruption was May, 18, 1980.* In spite of the great impression that the 1980 eruption of Mount St. Helens made on the public, it was relatively small. The 1980 eruption produced only about 0.1 cubic mile of molten rock (magma). For comparison, an eruption 500 years ago at Mount St. Helens was ten times bigger, and the eruption here at Turkey Creek was 1000 times the size of the 1980 Mount St. Helens eruption.

   When most people think of volcanic eruptions, they have a "Hollywood" concept of rivers of lava flowing down from the top of a volcano. Although this does take place during relatively non-explosive eruptions, such as seen on the big island of Hawaii, explosive eruptions produce more ash and pumice than lava. Ash is simply lava that is "blown to bits" by an explosive eruption, and pumice represents blocks of lava that is "puffed up" like styrofoam with bubbles of volcanic gas.

2. *North slope of Mount St. Helens, showing the 1980 pumice and ash-fall deposit (grey to white material in foreground). Photo by J.S. Pallister (USGS).* One type of deposit from explosive eruptions is made up of pumice and ash fragments that were blasted into the sky and then fall, and accumulate, on the ground surface. Larger fragments fall to the ground close to the volcano but small ash particles may drift downwind for thousands of miles, forming ash clouds that intefere with airline travel. *{Sidebar: ~50 people killed, one main eruption on May 18, 1980 produced about 0.1 cubic mile of magma; smaller eruptions continued intermittantly till 1986 and accompanied growth of a lava dome in the crater that resulted from the 1980 eruption}.*

3. *Eruption column of Mount Pinatubo, Philippines, June 12, 1991, photo by Karin Jackson (USAF) from Clark Airbase, about 15 miles east of the volcano).* We are now stepping up an order of magnitude in size. The June 12-15 eruptions of Mount Pinatubo, in the Philippines produced a bit more than one cubic mile of magma, virtually all of which was blasted into ash and pumice. This was one of the largest eruptions of the 20th century. *{Sidebar: 200-300 people killed, despite large population living near, or on, the volcano. Probably the most successful volcano hazards mitigations efforts ever, with at least 60,000 people evacuated and many lives saved, and millions of dollars of military equipment transferred out of Clark Airbase prior to the eruption. Credit largely due to*

USGS and it's counterpart in the Philippines (Philippine Institute of Volcanology and Seismology)}.

4. *Clark Airbase, shortly after the June 15, 1991 eruption of Pinatubo volcano. Photo by Robert S. Culbreth (USAF).* The area surrounding Pinatubo volcano was blanketed by a thick cloud of ash and pumice that fell from the eruptive column.

5. *World Airways DC-10 parked on ramp at Cubie Naval Air Station, 25 miles south of the volcano. Photo by R.L. Rieger (USN).* The ash and pumice accumulated on everything, and because it fell during a typhoon, it became saturated with rainwater and took on the consistency and weight of wet cement. This explains why the DC-10 is acting like a "taildragger" here, the weight of the ash on the tail has lifted the nose off the ground. Most casualties from the eruption resulted from roofs collapsing under the weight of the wet ash. The ash column rose into the stratosphere and drifted downwind where it damaged 20 commercial jetliners in flight, most at distances of more than 400 miles from the volcano. *{Sidebar: A serious hazards of explosive eruptions, even those in remote locations, is the impact of the ash cloud on civil and military aviation. Numerous jet aircraft have been damaged by ash clouds. Ash that is injested by jet engines abrades and coats compressor blades, and can result in the engines flaming out. The airborne ash problem is being addressed in a joint effort by USGS, FAA, NOAA, and the commercial airlines to track ash clouds and issue warnings regarding volcanic activity and ash cloud hazards}.*

6. *Ash and pumice fall deposit from Pinatubo volcano, on cars at Clark Airbase. Photo by R.P. Hoblitt (USGS).* The ash and pumice accumulated to a thickness of up to three feet or more near the volcano, and covered an area of more than 1,500 square miles with ash at least two inches deep.

7. *Ash and pumice fall deposit about 20 miles southwest of Pinatubo volcano. Photo by J.S. Pallister (USGS).* Similar deposits that originated from clouds of ash are found here at Chiricahua National Monument. You may have already seen them as the white layers in the cliffs above the campground. We will talk about these deposits in more detail later, but suffice it to say that clouds of ash blanketed the countryside here 27 million years ago... and as at Pinatubo, we even see evidence that some of the ash fell to the ground during rainstorms.

8. *Composite map showing global distribution of sulfur dioxide cloud from the 1991 eruption of Pinatubo volcano (Image from Jet Propulsion Laboratory).* Explosive volcanic eruptions are really giant steam explosions, driven by the expansion of water when it is converted to steam. Deep beneath the surface of the earth, and at high pressure, molten rock may contain up to about five percent dissolved water. When that magma rises to the surface the confining pressure decreases and the dissolved water flashes to steam and expands up to fifty times in volume, propelling magma from the earth in an explosive eruption. In addition to water vapor, carbon dioxide and sulfur dioxide are injected into the atmosphere

during eruptions. This image shows the sulfur dioxide cloud from the 1991 eruption of Pinatubo volcano. Sulfur dioxide combines with water vapor in the atmosphere to make sulfuric acid droplets. The cloud of sulfuric acid from Pinatubo has been circulating the globe and slowly dissipating for the past several years. The cloud has affected global climate by filtering sunlight and lowering the global average temperature.

9. *Eruptive column from Mount Pinatubo. Photo by R.S. Culbreth (USAF).* So far we have only talked about ash and pumice fall deposits. Another type of deposit produced by explosive volcanoes is known as an **ash flow** deposit. This results when part of the billowing ash column, like you see here, collapses under its own weight, and flows downslope to scour and fill valleys with ash and pumice. In contrast to the ash and pumice fall deposits, which are relatively cool, ash flow deposits are hot; they have emplacement temperatures of more than 1,000°F.

    This is what happened in Chiricahua National Monument. Imagine a giant cloud of hot ash rising to more than 100,000 feet altitude, and billowing from the rim of a large volcano only six miles south of here. The cloud rises like a thunderhead, because it is hot and buoyant, until parts of the column of hot ash and pumice become too dense to rise further. Parts of the cloud collapse to form ash flows that rush down the slopes of the volcano at as much as 100 mph. The ash flows burn and sandblast everything in their paths. Ash flows of incandescent ash and pumice filled a broad valley in the Monument area to a depth of 1,500 feet.

10. *Ash flow deposits filling a rugged valley system on the west flank of Pinatubo volcano. Photo by R.P. Hoblitt (USGS).* These are examples of ash flow deposits from Pinatubo volcano. The tan material was deposited by ash flows that scoured and then then filled this formerly rugged valley system on the west slope of the volcano to a depth of up to 500 feet with hot ash and pumice. A similar event occurred here in the National Monument 27 million years ago; the eruption responsible for the ash flow deposits at the Monument was much larger and the resulting deposit is three times as thick.

11. *Aerial view of Pinatubo volcano after the June 15, 1991 eruption. Photo by R. Batalon (USAF).* An important question to ask is: what happens to the volcano when so much material is erupted? Often, a large hole or depression is left behind. After large eruptions we often discover that the central depression is not just a crater that was blasted out. When we compare the volume of the hole at Pinatubo to the volume of old rocks that were blasted out of the volcano, we find that the hole is too big. Therefore, in simple terms, the top of the volcano collapsed. This happens when a large eruption withdraws magma from a chamber beneath the volcano more rapidly than the chamber can be refilled from below. When this takes place, we refer to the resulting hole in the volcano's top as a collapse **caldera** instead of a crater.

12. *This diagram (adapted from A.R. McBirney, 1984) shows a simplified model of a volcano.* We can use this diagram to illustrate how a small caldera might form. Imagine that in a single eruption, all of the molten rock in the magma chamber colored yellow is erupted. As magma is withdrawn, the central part of the roof collapses producing a broad depression or caldera over the magma chamber.

    This is probably what happened at Mount Pinatubo. For larger eruptions like those in the Chiricahuas, or at Crater Lake National Park in Oregon, we find that the magma chamber formed beneath a much larger region. When these chambers erupted, a much larger area, encompassing several older volcanoes, collapsed to form a broad central depression that was several miles or more across.

13. *Aerial view of Crater Lake caldera, Oregon. Photo by J.S. Pallister (USGS).* Crater Lake volcano is an example of another relatively small caldera; it is five miles in diameter. From a geologic point of view, Crater Lake should really be named "Caldera Lake" because it is really a collapse caldera that formed about 6,800 years ago during eruption of twelve cubic miles of magma as ash and pumice.

14. *Aerial view of the wall of the Crater Lake caldera. Photo by J.S. Pallister (USGS).* This photo of the wall of Crater Lake caldera shows a thick lava flow from an older volcano that was cut in half by caldera collapse. The thin blanket of white ash atop the cliff is the "feather edge" of the ash deposit that resulted from the eruption 6,800 years ago. The deposit thickens away from the caldera rim, it forms the tan slopes in the background where it fills in old valleys.

15. *View of the Mazama ash flow deposit from the eruption of Crater lake volcano. Photo by J.S. Pallister (USGS).* Here you see an eroded cross-section through the ash flow deposit from the Crater Lake caldera.. The ash flow deposit filled valleys on the volcano's flank. It has been eroded through by a stream during the 6,800 years since the eruption.

16. *Cross-section model showing how many large calderas develop. Derived from studies of numerous ancient and variably eroded calderas by Lipman(1984).* So far, we have examined only relatively small volcanic eruptions; remember that the 1980 eruption of Mount St. Helens produced only about 0.1 cubic miles of magma, the 1991 eruption of Pinatubo produced only about 1 cubic mile of magma, and the eruption of Crater Lake produced 12 cubic miles of magma. To understand larger eruptions, like that of the Turkey Creek caldera, which erupted more than 100 cubic miles of magma, we must expand our perspective to incorporate entire mountain ranges. That is what is illustrated here. A very large magma chamber grows slowly in the Earth's crust beneath an entire volcanic mountain range (upper panel). Then in a catastrophic event, tens to hundreds of cubic miles of ash and pumice are erupted and the roof of the magma chamber collapses (middle panel). The result is a large caldera that may be tens of miles in diameter. Some time after the eruption, new magma may lift up the central part

of the caldera depression, forming a resurgent dome (lower panel). This is the sequence of events that took place in the Chiricahua Mountains.

17. *Simplified geologic map of the Chiricahua Mountains (adapted from Marjaniemi, 1969, and from work by the authors).* To comprehend the size of the Turkey Creek volcano, you must examine it using a geologic map of the entire mountain range, as shown here. Chiricahua National Monument is located in the northwest part of the 35 by 25 mile map. The caldera is outlined by the red circle and is 12 miles in diameter. On a geologic map, such as this, each color represents a different rock type. On this map, the rocks shown in green are older than the caldera, and are not important for our discussion. The Rhyolite Canyon Tuff, the ash flow deposit from the caldera-forming eruption is shown in blue. This is the principal rock type exposed in the National Monument, as well as within and south of the caldera. The pink color represents the crystallized top of the magma chamber that pushed up the central part of the caldera into a resurgent dome; this same magma also leaked out along the northeast edge to form lava flows that are also shown in pink. And finally, the rocks colored yellow are lava flows that were erupted last and filled in the area between the resurgent dome and the caldera wall.

    We name volcanic rocks according to what kind of deposits they form. For example you all know what **lava** is. **Tuff** (as in Rhyolite Canyon Tuff) is a rock that is composed mainly of ash and pumice. We also name rocks according to their chemical composition. The Rhyolite Canyon Tuff is a rhyolite, a volcanic rock with more than 70% silicon dioxide (or silica, for short). The last lava flows from the caldera, shown in yellow on the map, are also rhyolite. In contrast, the rocks colored pink on the map are dacite, a volcanic rock with about about 60 to 70% silica. In a general way, the greater the silica in a rock, the more viscous (or sticky) it is when molten, and the more likely it is to be erupted in an explosive fashion to form ash and pumice deposits. *(Explosivity is also a function of the amount of dissolved water, carbon dioxide, and other volatile components in the magma. This may explain why rhyolite was erupted explosively at first to form the Rhyolite Canyon Tuff, then later more rhyolite (with about the same amount of silica, but presumably less dissolved water) was erupted in a non-explosive manner to form lava flows).*

18. *View of Sugarloaf Mountain, Chiricahua National Monument (looking northeast from Rhyolite Canyon trail). Photo by J.S. Pallister (USGS).* The prominent cliffs are the Rhyolite Canyon Tuff that was produced by ash flows during the caldera-forming eruption. The break in slope between the cliffs is a layer made of white ash. There are three main sets of cliffs within the Rhyolite Canyon Tuff, each set of cliffs represents a peak in eruptive activity during which ash flow deposits accumulated in the Monument. The first series of ash flows poured into Rhyolite Canyon and filled the lowlands with a relatively dense deposit of hot ash and pumice. These flows generated their own clouds of ash, which filled the air. The cloud of ash settled atop the first steaming ash flow deposit, forming the white deposits seen in this photograph at the break in slope. Within a few weeks

another series of ash flows flooded the Monument, buried the first deposits, and formed the second set of cliffs in the photograph.

19. *Accretionary lapilli (volcanic hailstones) from Hailstone Trail. Photograph by J.S. Pallister (USGS).* Rainstorms took place as the ash cloud settled atop the early ash flow deposits. We know this because we find accretionary lapilli (volcanic hailstones) that formed as the dust-like volcanic ash stuck to small rain droplets or to wet crystal fragments, eventually forming marble-size balls of ash such as seen here along Hailstone Trail. *Remember when exploring the National Monument that you are free to examine these and other features of the rocks, but you are not allowed to deface rock exposures, and you may not collect samples without a permit from the National Park Service.*

20. *Balanced rock, Heart of Rocks area. Photo by J.S. Pallister (USGS).* As you marvel at the balanced rocks in the Monument, look closely and you will see additional evidence of their volcanic heritage. Small crystals of quartz and feldspar are present throughout the Rhyolite Canyon Tuff. These crystals grew in the magma before it was erupted. The horizontal partings in the rocks are a result of "welding" of the pumice and ash. When the ash flows came to rest they were still hot. In fact, they were at a temperature near the melting point of the rock itself. Therefore, as the deposit accumulated it also fused together, or welded, under the influence its own weight. As the deposit cooled, additional and much smaller crystals of quartz and feldspar grew within the pumice and ash. These processes of welding and crystallization formed a hard dense rock from what would otherwise be soft ash and pumice.

21. *Pumice fiame in Rhyolite Canyon Tuff. Photo by J.S. Pallister (USGS).* Look closely at the rocks and you will see white streaks, known as fiame (Italian for "flame"). These are are the flattened remains of pumice blocks that were deflated while still hot by the great weight of the overlying deposit.

22. *Pumice fiame in Rhyolite Canyon Tuff. Viewed perpendicular to the plane of flattening. Photo by J.S. Pallister (USGS).* If you find a boulder of the tuff on which several sides are exposed, you will find that the pumice fiame are actually flat plates. They appear to be thin in cross-section but are much larger when viewed perpendicular to the plane of flattening, as seen here.

23. *Thin welded ash flow deposit exposed in roadcut along Bonita Canyon. Photo by J.S. Pallister (USGS).* This is an unusual feature exposed only in a few areas of the Monument. It is a thin (less than 3-feet-thick) welded ash flow deposit with flattened pumice fiame. It is a geologic novelty, because thin ash flows such as this do not usually contain sufficient heat, nor do they weigh enough to weld. In this case, the deposit was compressed and welded by the weight of the much thicker overlying ash flows, which were deposited immediately after the thin deposit. *Notice the welded pumice fiame in the dark base of the unit, as well as the white ash-rich top that was deposited from its ash cloud. Note also the soft*

white ash at the bottom of the photograph; this is a deposit from the ash cloud that of the underlying ash flow deposit.

24. *"Boiling pot" of fossil fumarole near Sugarloaf trail. Photo by J.S. Pallister (USGS).* Another unusual feature that is preserved in the National Monument are fossil fumaroles. These are places where water boiled and steam jetted out of the ash flow deposit as it cooled. This photograph shows an example of the "boiling pot" of a fumarole. The concentric layers are Liesegang bands where small amounts of impurities in the boiling water were left behind. The Liesegang bands are similar to the mineral deposits that build up in your teapot.

25. *Fossil fumarole pipe near Sugarloaf trail. Photo by J.S. Pallister (USGS).* If you look carefully in the cliffs above the Sugarloaf trail, you will see hackly-weathering pipe-like trails that extend vertically through the rock. These are fumarole pipes through which steam jetted to the surface. As the steam jetted out it carried fine particles of ash with it, leaving coarse crystals behind, much as the wind removes fine dust and sand from desert pavements.

26. *Columnar jointing in Rhyolite Canyon Tuff, north of Little Pickett Canyon. Photo by J.S. Pallister (USGS).* Recent studies by geologists from the University of Arizona indicate that the spectacular rock columns of the National Monument are mainly the result of columnar jointing. This is a process by which the rock breaks into columns as a result of shrinkage upon cooling. Many examples of this phenomenon are seen in volcanic rocks, such as those at Devil's Postpile National Monument in California and in lava flows along the Columbia River gorge near the Washington-Oregon border. Columnar joints originated as a layer of close-packed columns within the Rhyolite Canyon Tuff such as you see in the photograph. Given enough time, and the proper setting, the freeze-thaw cycle of water and abrasion by wind-blown sand and dust erode away some of the tuff, and leave a forest of odd shaped columns.

27. *View of Sugarloaf Mountain from the south. Photo by J.S. Pallister (USGS).* Another chapter of the volcanic history of the Monument and the Turkey Creek caldera is found at the top of Sugarloaf Mountain. The uppermost layer on the mountain is a dacite lava flow that was erupted from near the caldera margin, six miles to the south. The lava flowed down the flank of the volcano, following the same broad valley to the National Monument that had already been partly filled with ash flow deposits. It may be difficult to imagine how the top of a mountain could have previously been the bottom of a valley, but his happens frequently with the passage of geologic time. In this case, the densely welded Rhyolite Canyon Tuff and the overlying lava flow that filled the valley are both very hard rocks that are not easily eroded. In contrast, the older rocks that formed the valley walls were composed of soft sedimentary rocks. So, during the 27 million years following the eruption these soft rocks were preferentially eroded and carried away by streams, leaving the thickest accumulations of the hard volcanic rocks standing high atop mountains.

28. *Aerial view of Rhyolite Canyon and Sugarloaf Mountain, looking west-northwest. Photo by J.S. Pallister (USGS).* Sometimes it is easier to get the geologic "big picture" from an airplane. Here you see the thick layers of Rhyolite Canyon Tuff, and the erosional remnant of the dacite lava flow atop Sugarloaf Mountain. Imagine what this area would have looked like before these volcanic rocks were deposited. The Monument must have been a large valley or basin in which these deposits accumulated.

29. *View looking south of the eastern margin of Chiricahua National Monument from near Timber Mountain, at the northern Monument boundary. Photo by J.S. Pallister. Sugarloaf Mountain is the small hilltop at right center.* Here is a view of the National Monument that few see. It is taken from the southeast spur of Timber Mountain, near the northern Monument boundary and illustrates how the rocks in the Monument are related to the Turkey Creek caldera. The caldera lies within the high terrane on the skyline, about six miles south of the Monument. From this perspective one can better imagine how the ash flows and lava from the caldera flowed downhill to the National Monument and how erosion stripped away the softer sedimentary rocks to form the present valley along the eastern margin of the Monument (left side of photograph).

30. *Wizard island, a post-caldera cinder cone that grew within the Crater Lake volcano. Photo by J.S. Pallister (USGS).* The final stage in the history of the Turkey Creek caldera took place when lava flows were erupted inside the caldera. This is to be expected when new magma pushes up through the collapsed floor of the caldera. Wizard Island, within Crater Lake caldera is a graphic example of late-stage volcanism within a caldera.

31. *Aerial photograph of Newberry caldera, Oregon. Photo by J.S. Pallister (USGS).* Another modern example of late-stage volcanism is seen here in Newberry caldera, Oregon, where 1,300 years ago, Big Obsidian Lava Flow, seen in the middle ground, was erupted within the caldera depression.

32. *Aerial photograph of Big Obsidian Lava Flow, Newberry Caldera, Oregon. Photo by J.S. Pallister (USGS).* In this photograph of Big Obsidian Lava Flow, you can see how this was an extremely viscous lava that piled up on itself like cold molasses. When rhyolite magma contains little dissolved water it is less likely to be "blown to bits" to form ash and pumice in explosive eruptions, rather it is extruded onto the surface to form slow moving lava flows. When cooled rapidly, this type of lava produces black volcanic glass, or obsidian.

33. *Simplified geologic map of the Chiricahua Mountains (adapted from Marjaniemi, 1969, and from work by the authors).* The post-caldera lavas of the Turkey Creek caldera, colored yellow on this map, are much like Big Obsidian Lava Flow. As you can see, they are found primarily within the caldera, where they accumulated

in an arcuate area between the central resurgent dome and the caldera wall, a region known as the caldera moat.

34. *Outcrop photograph of rhyolite lava within the Turkey Creek Caldera; outcrop just east of Dawings Pass summit, south of Pinery Canyon. Photo by J.S. Pallister (USGS).* Like Big Obsidian flow, the rhyolite lava flows that filled the moat of the Turkey Creek caldera were extremely viscous . This fact is obvious from the intricate flow bands visible in this outcrop. The rhyolite cooled rapidly at first to form obsidian. However as it continued to cool more slowly, microscopic crystals grew and converted most of the lava to a light grey color. As a consequence, there is little obsidian of the type used to make arrow points in the Chiricahua Mountains.

35. *Close-up photograph of rhyolite lava within the Turkey Creek Caldera, outcrop just east of Dawings Pass summit, south of Pinery Canyon. Photo by J.S. Pallister (USGS).* The flow bands seen here represent shear planes that developed within the pasty lava flow as it moved. The lava folded over on itself producing complex internal structures that are preserved in the flow banded outcrops.

36. *Upper part of Rucker Canyon, above Rucker Lake, southern Chiricahua Mountains. Highpoint is Raspberry Peak at 9420' elevation, bottom of Rucker Canyon is about 6,000' elevation. Photo by J.S. Pallister (USGS).* The Turkey Creek caldera is a good place to learn about the internal "plumbing" of a volcano because of the depth of natural exposures. During the past 27 million years, geologic faulting sliced through the volcano and erosion has cut deep river channels into its core, such that it hardly looks like a volcano at all today. For example, this is an area in the southern Chiricahua Mountains where you can descend for more than 3,000 feet from late-stage lava flows at the top of Raspberry Peak through welded tuff within the caldera and into the resurgent intrusion at the floor of Rucker Canyon. Such a 3-dimensional view is possible only at an ancient eroded volcano, and provides insight that is not possible to attain at an active volcano where only see the outermost surface is exposed.

37. *Geologic map of the edge of the caldera near Barfoot and Ida Peaks, about six miles south of the National Monument.* Here is an example of how we use topographic relief to our advantage to sort out the internal structure of the volcano. This is a geologic map of the edge of the caldera, about six miles south of the National Monument. Again, the green color represents rocks that were already here before the caldera formed. The blue color corresponds to Rhyolite Canyon Tuff, within the caldera. The pink, orange, and pink colors represent dacite lava like that atop Sugarloaf Mountain. The yellow colors represent the pasty rhyolite lava flows that were erupted last. In the next slide, we will look at a cross-section along line A-A'. Imagine that you cut a slice out of the mountain and turned it on edge, so you can see what lies beneath the surface.

38. *Cross-section of the edge of the caldera near Barfoot and Ida Peaks.* The blue line represents the present ground surface. We have reconstructed what the area might have looked like before erosion. Notice that the pasty rhyolite lavas overlie all of the older rocks and are therefore the youngest rocks here. Notice also that the pink and orange colored rocks are shown as lava flows at the surface, but as a cross-cutting, or intrusive, mass at depth. We believe that they are fed by the resurgent intrusion. In other words, the top of the magma chamber pushed up into the overlying rocks. Upon reaching the surface, pressure was released and the uppermost part of the magma was blown out explosively to form Rhyolite Canyon Tuff. Then the lower part of the magma chamber oozed out to form the lava flows that are color coded pink and orange here. One of these lava flows followed a valley to what is now Sugarloaf Mountain. Finally, a new batch of rhyolite magma, shown in yellow, was erupted to form the youngest lava flows in the caldera.

39. *Cross sections showing the geologic history of the Turkey Creek caldera (part 1).* This diagram summarizes the first part of the history of the Turkey Creek volcano. Only half of the circular caldera is shown here, and again we are looking at cross-sections cut through the middle of the volcano. Working from the bottom-up in a time sequence, a magma chamber formed within the older rocks, shown in green (Panel 1). The magma chamber contained rhyolite (blue) that was rich in water and other volatiles at the top and dacite (pink) at the base. So, the first eruptions were explosive and produced Rhyolite Canyon Tuff, which flowed down the slopes of the volcano and accumulated in the area of the National Monument (Panel 2). As these eruptions continued, more ash flows of Rhyolite Canyon Tuff rushed down the flanks of the volcano into the Monument, and as magma was withdrawn from the top of the chamber, the roof began to subside, forming the caldera depression. This depression also filled with Rhyolite Canyon Tuff (Panel 3). When most of the rhyolite magma was withdrawn from the chamber, dacite magma rose into the vents and was erupted as lava flows (Panel 4).

40. *Cross sections showing the geologic history of the Turkey Creek caldera (part 2).* The final two panels (Panels 5 and 6) show a new batch of rhyolite magma rising into the now-cooled magma chamber, causing uplift of the central region, and erupting to form lava flows in the caldera moat.

41. *Cross section of Long Valley caldera, California.* So, why should one investigate the history and internal structure of an ancient volcano? In addition to the academic interests, and the desire to inform you, the public, about the geology of public lands, there is a more applied interest. At the beginning of this talk, I mentioned that there are a number of active calderas in the United States and throughout the world. One example is the Long Valley caldera, in east-central California, which formed 730,000 years ago when about 12 cubic miles of magma was erupted to form the Bishop Tuff. Although 730,000 years seems like a long time, it is only an instant in the geologic time scale, and the Long Valley

caldera continues to show signs of unrest to the present. The cross section you see here is based not only on studies at Long Valley itself, but on what we know about the internal structure of a number of more ancient and eroded calderas like Turkey Creek. This kind of geologic framework is necessary to understand "how volcanoes work" and therefore to better predict the kinds of events we should expect at active volcanoes like Long Valley.

42. Finally, as a reminder of the large size and potential consequences of caldera-forming eruptions, this slide shows the area affected by ashfall from the Long Valley eruption, and eruption about the same size as the one responsible for the Turkey Creek caldera.

References cited and suggested reading

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N. Slope of Mount St. Helens

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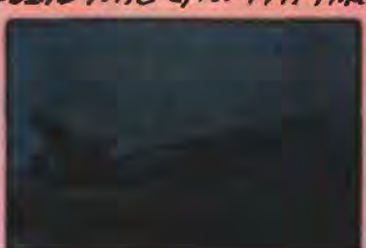
Erupt. column of Mt. Pinatubo June 12, 1991

USGS OF 94-232 4.

Clark Airbase, after June 15, 1991 eruption of Pinatubo

USGS OF 94-232 5.

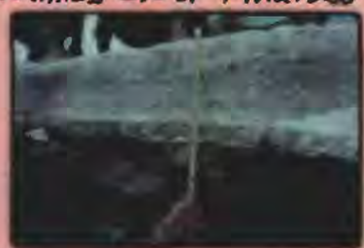
World Airways DC-10 at Cubi NAS after 1991 Pinatubo



Clark airbase 6

USGS OF 94-232 7.

Ash and Pumice fall deposit, ~20 miles SW of Pinatubo



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Composite map of SO_2 from Pinatubo volcano

Eruptive column, Mt. Pinatubo

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USGS OF 94-232 10.

Ash flow deposits, Pinatubo

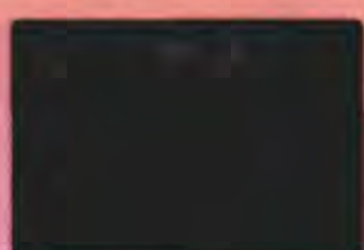

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Diagram of volcano, from A.R. McBirney

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Aerial view, Crater Lake Caldera, Oregon

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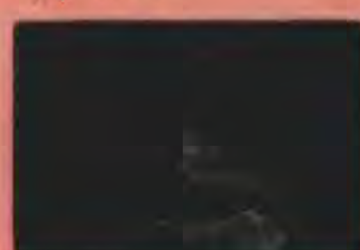
Aerial view, Crater Lake Caldera wall, ORE.



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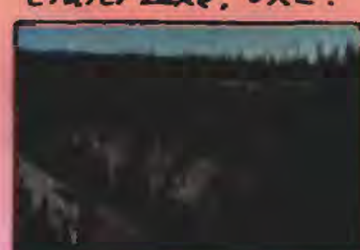
Mazama ashflow deposit, Crater Lake, ORE.



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Geol. Map, Chiricahua Mts.

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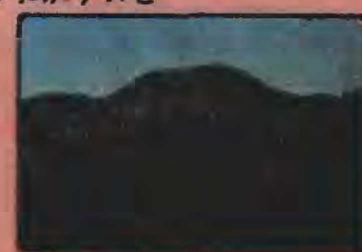
Sugarloaf Mtn. Chiricahua Natl. Mon., AZ



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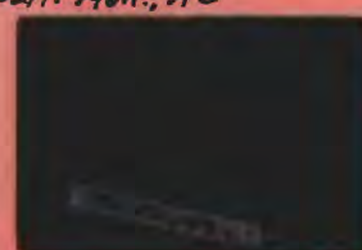
Accretionary lapilli, Chiricahua Natl. Mon., AZ



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Balanced Rock, Chiricahua Natl. Mon. AZ

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tuff., Chiricahua Natl. Mon., AZ

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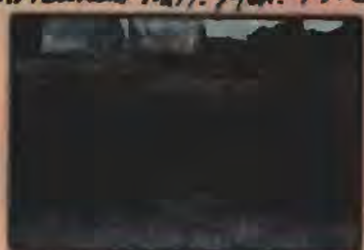
Pumice fiame, Rhyolite Cyn. Tuff. Chiricahua Natl. Mon., AZ

USGS OF 94-232 23.



Thin welded ash flow deposit, Chiricahua Natl. Mon., AZ

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Boiling pot of foss. fumarole. CNM, AZ.

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Fossil fumerole pipe, Chiricahua Natl. Mon., AZ.

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AZ.

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Sugarloaf Mtn, from the South Chiricahua Natl. Mon., AZ

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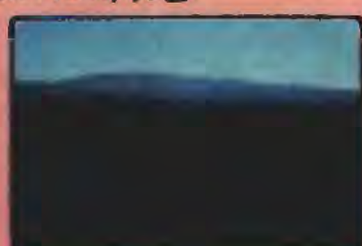
Aerial view of Chiricahua Natl. Mon. AZ.

USGS OF 94-232 29



View to S. of E-edge of Chiricahua Natl. Mon., AZ

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Wizard Island, Crater Lake, ORE

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Aerial view: Big Obsidian Lava Flow, Newberry Caldera ORE.

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Geol. Map, Chiricahua Mts.

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Rhyolite lava, Turkey Creek caldera, AZ

USGS OF 94-232 35.

close-up, Rhyolite lava, Turkey Cr. Caldera AZ

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AZ

USGS OF 94-232 37

Geol. Map, edge of Turkey Creek Caldera, AZ

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Cross-section, edge of Turkey Cr. Caldera, AZ

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Cross-section - geol. history of Turkey calder

USGS OF 94-232 40

Cross-section - Geol. history of Turk Cr. Cal part

41.

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Map showing distribution of Bishop Ash.