Geologic Resources Inventory Scoping Summary
Capulin Volcano National Monument
New Mexico

Prepared by Katie KellerLynn
August 31, 2011

Geologic Resources Division
National Park Service
U.S. Department of the Interior

The Geologic Resources Inventory (GRI) Program, administered by the Geologic Resources Division, provides each of 270 identified natural area National Park System units with a geologic scoping meeting, a scoping summary, a digital geologic map, and a geologic resources inventory report. Geologic scoping meetings generate an evaluation of the adequacy of existing geologic maps for resource management, provide an opportunity to discuss park-specific geologic management issues and, if possible, include a site visit with local experts. The purpose of these meetings is to identify geologic mapping coverage and needs, distinctive geologic features and processes, resource management issues, and potential monitoring and research needs.

The National Park Service (NPS) Geologic Resources Division held a GRI scoping meeting for Capulin Volcano National Monument on May 10, 2011, at the headquarters/visitor center, which is located 48 km (30 mi) east of Raton, New Mexico. Participants at the meeting included NPS employees from the national monument, Geologic Resources Division, Bent's Old Fort National Historic Site, Sand Creek Massacre National Historic Site, and the Southern Plains Network; and cooperators from Colorado State University and the New Mexico Bureau of Geology and Mineral Resources (see table 1, p. 15). Superintendent Peter Armato welcomed the group and expressed his support of the Geologic Resources Inventory. Although Armato had only been at the national monument for a month, he was thrilled to be in a "geologic park." Armato's many academic degrees are in geologic disciplines.

As part of the scoping meeting, Bill McIntosh (New Mexico Bureau of Geology and Mineral Resources) presented a geologic overview of the national monument, which placed Capulin Volcano in the regional context of volcanism in New Mexico (see "Park Setting"). Tim Connors (Geologic Resources Division) facilitated the group's assessment of the digital geologic map for Capulin Volcano National Monument (see "Geologic Mapping for Capulin Volcano National Monument"), and Bruce Heise (Geologic Resources Division) led the discussion of geologic features, processes, and issues (see "Geologic Features, Processes, and Issues").

During the site visit, participants drove up the Volcano Road, which provides access to the crater rim and summit, making a stop at a pullout to look at the layers of cinders that compose the volcano (fig. 1). Bill McIntosh and Nelia Dunbar (New Mexico Bureau of Geology and Mineral Resources) pointed out many features of the pyroclastic material, including primary layering, welding, "fresh" vs. chemically altered cinders, the difference between bombs and blocks, and pyroclastic "ghosts." Additionally, participants discussed and saw evidence of the cinders' natural tendency to form gullies. Participants also walked the Crater Rim Trail, taking in the view and the volcanic features surrounding the volcano, including Mud Hill and Baby Capulin (fig. 2). While at the summit, participants hiked into the volcano on the Crater Vent Trail. The crater is about 137 m (450 ft) below the highest point on the rim. Additionally, participants hiked to a collapsed lava tube on the Boca Trail (fig. 3).

Figure 1. Inclined beds of volcanic rock. Layers of primarily cinders but also bombs line the road to the summit of Capulin Volcano. Layers of ash separate the layers of cinders. Photo by Katie KellerLynn.

Figure 2. Volcanic features near Capulin Volcano. In the middle ground of the photo, Mud Hill is covered with trees. Baby Capulin is to the upper right of Mud Hill. Both are prominent volcanic features in the viewshed of Capulin Volcano National Monument. Photo by Katie KellerLynn.

Figure 3. Collapsed lava tube. On May 10, 2011, scoping participants hiked to a collapsed lava tube on the Boca Trail. Photo by Katie KellerLynn.

Park Setting

At 2,494 m (8,182 ft) above sea level, Capulin Volcano stands 305 m (1,000 ft) above the surrounding prairie. Not surprisingly, Capulin Volcano served as a landmark along the Santa Fe Trail. The Cimarron Route of the Santa Fe Trail runs to the south of the national monument, and the Mountain Route runs to the west. Originally established in 1916 as "Capulin Mountain National Monument," the name was changed to "Capulin Volcano National Monument" in 1987. The name change highlights the significance of volcanism for the national monument and the state of New Mexico. Since the beginning of the Cenozoic Era (the last 65.5 million years), volcanism in New Mexico has occurred mainly along the Rio Grande Rift and the Jemez lineament (fig. 4). The Rio Grande Rift runs north to south across the state and represents an ongoing episode of east-west crustal extension. Volcanism associated with this extension brings deeper mantle materials and processes closer to the surface. The Jemez lineament is another area of crustal weakness, which runs east-west across the northern part of the state. The lineament hosts numerous volcanic fields, which are aligned but represent no trend in age. The Valles caldera is at the intersection of the Rio Grande Rift and the Jemez lineament. East of the Valles caldera are the Ocaté and Raton-Clayton volcanic fields (fig. 4). Capulin Volcano is part of the 20,720 km^2 (8,000 mi^2) Raton-Clayton field.

The entire landscape surrounding Capulin Volcano is composed of volcanic rock. Basalt covers the area between Capulin Volcano and the village of Capulin. According to Bill McIntosh (New Mexico Bureau of Geology and Mineral Resources), Capulin is at the low end of "explosivity," as compared to Bandelier, for example, and would have had a relatively minor impact on the surrounding landscape at the time of eruption. A series of four lava flows emanated from the vents in Capulin Volcano's boca ("mouth") at the base of the crater. The first flow spread eastward from the base of the cinder cone. The second, third, and fourth flows spread south, southwest, and north respectively (fig. 5). These flows are part of the Capulin phase of eruptions of the Raton-Clayton field. The Capulin phase is the most recent phase, erupting between 1.4 million to 13,000 years ago. Elsewhere in the region, eruptions occurred during the Clayton (2.4 million to 2.3 million years ago) and the Raton (9 million to 3.6 million years ago) phases.

Initial relative dating with alluvium indicated that Capulin Volcano erupted contemporaneously with local inhabitation by Folsom Man (10,000 years before present) (Baldwin and Muehlberger 1959). However, in 1995, cosmogenic-helium dating revealed the error of this date, pushing back the timing of the eruption to 59,100 ± 6,000 years ago (Sayre et al. 1995). In 1997, argon-argon dating of Capulin's rocks provided additional credence for the volcano's age (Stroud 1997). Unfortunately, the 10,000-year-old date still persists in popular literature.

The "best age date" for the Capulin phase is from the fourth flow, and yielded an age of 56,000 ± 8,000 years ago (Bill McIntosh, volcanologist, New Mexico Bureau of Geology and Mineral Resources, scoping presentation, May 10, 2011). Interestingly, the first two flows may predate the formation of the cinder cone. However, argon-argon dating, or other dating technique, needs to confirm this interpretation.

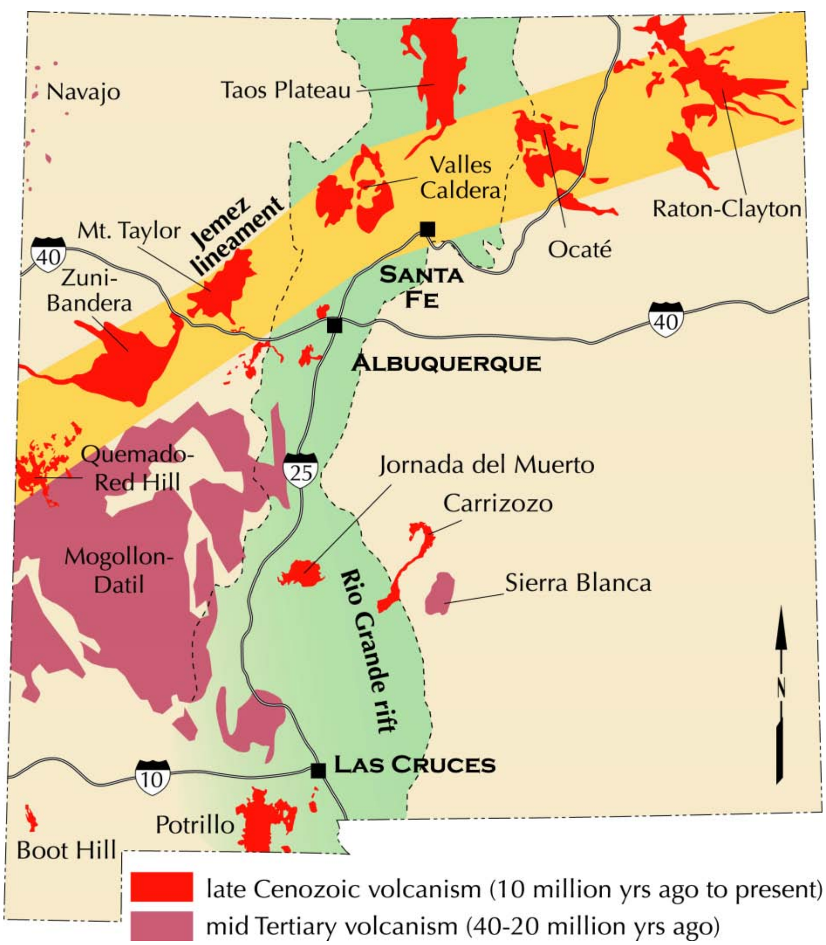

Figure 4. Major volcanic fields in New Mexico. Capulin Volcano is part of the Raton-Clayton volcanic field in the northeast corner of the state. Graphic by New Mexico Bureau of Geology and Mineral Resources, extracted from Bill McIntosh's GRI scoping presentation (May 10, 2011).

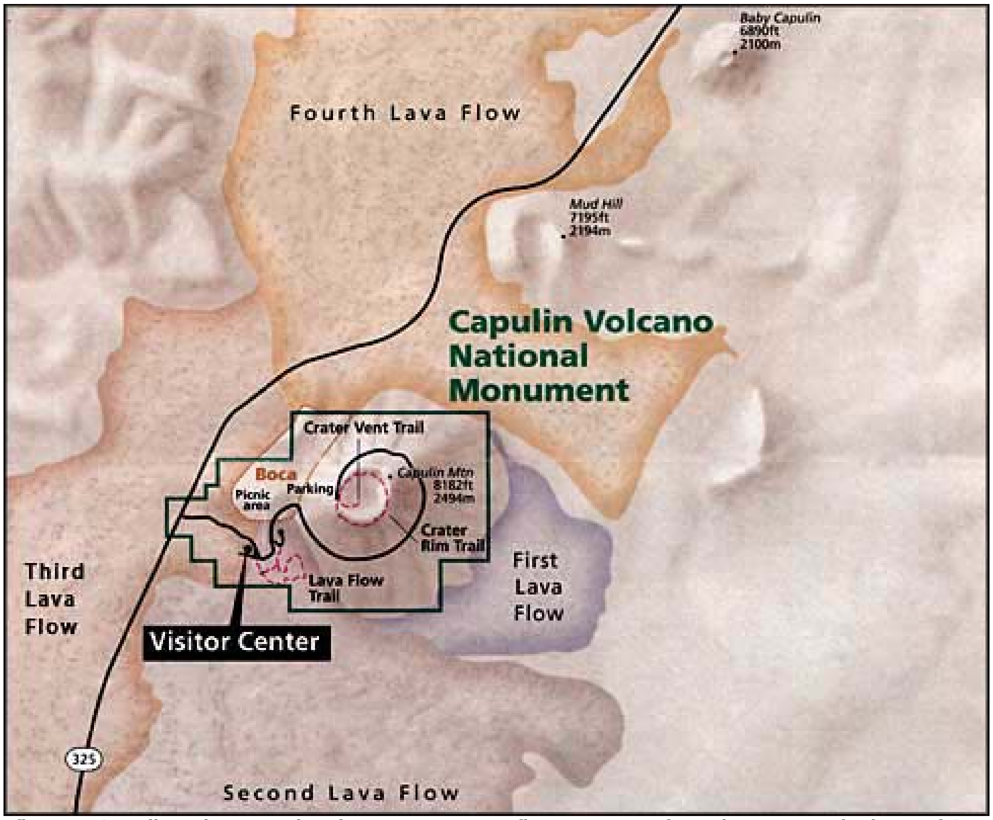

Figure 5. Lava flows at Capulin Volcano National Monument. Four flows emanate from the vents at the base of Capulin Volcano. National Park Service graphic.

Geologic Mapping for Capulin Volcano National Monument

During the scoping meeting, Tim Connors (Geologic Resources Division) presented some of the main features of the GRI Program's digital geologic maps, which reproduce all aspects of paper maps, including notes, legend, and cross sections, with the added benefit of being GIS compatible. The NPS GRI Geology–GIS Geodatabase Data Model incorporates the standards of digital map creation for the GRI Program and allows for rigorous quality control. Staff members digitize maps or convert digital data to the GRI digital geologic map model using ESRI ArcGIS software. Final digital geologic map products include data in geodatabase and shapefile format, layer files complete with feature symbology, Federal Geographic Data Committee (FGDC)–compliant metadata, a help file that captures ancillary map data, and a map document that displays the map and provides a tool to directly access the help file. Final GRI products are available through the GRI publications webpage at http://www.nature.nps.gov/geology/inventory/gre_publications.cfm (accessed May 25, 2011).

When possible, the GRI Program provides large-scale (1:24,000) digital geologic map coverage for each unit's area of interest, which is generally composed of the 7.5' quadrangles that contain NPS-managed lands. Maps of this scale (and larger) are useful to resource managers because they capture most of the geologic features of interest and are spatially accurate within 12 m (40 ft). In 2010, a Student Conservation Association (SCA) intern, Rebecca Richman, compiled digital geologic data for Capulin Volcano National Monument. Her work was based on previous studies by Sayre et al. (1995) and Sayre and Ort (1999). GRI Program staff converted Richman's data to the NPS data model. Richman's report, which provides descriptions of volcanic features, accompanies the GIS data. These data are available through the GRI publications webpage and include the lava flows and volcanic features (Richman 2010) (fig. 6).

During the scoping meeting, participants evaluated this digital product and determined that the data are useful both for resource management and interpretation at the national monument. However, participants suggested enhancements to the product, namely age dates to verify the geochronology of the flows and the ages of surrounding volcanic features. Specifically, staff from the New Mexico Bureau of Geology and Mineral Resources suggested that Mud Hill and Baby Capulin be dated. Age dates would help to answer the question whether Capulin's eruption was "one big event," that is, from a monogenic vent. Furthermore, Nelia Dunbar (New Mexico Bureau of Geology and Mineral Resources) proposed that the report and map by Sayre and Ort (1999), which was unpublished at the time of the scoping meeting, be published as an open-file report by the bureau. This report and map are now available as Open-File Report 541 (Sayre and Ort 2011) from the New Mexico Bureau of Geology and Mineral Resources (Nelia Dunbar, geologist, New Mexico Bureau of Geology and Mineral Resources, written communication, August 4, 2011).

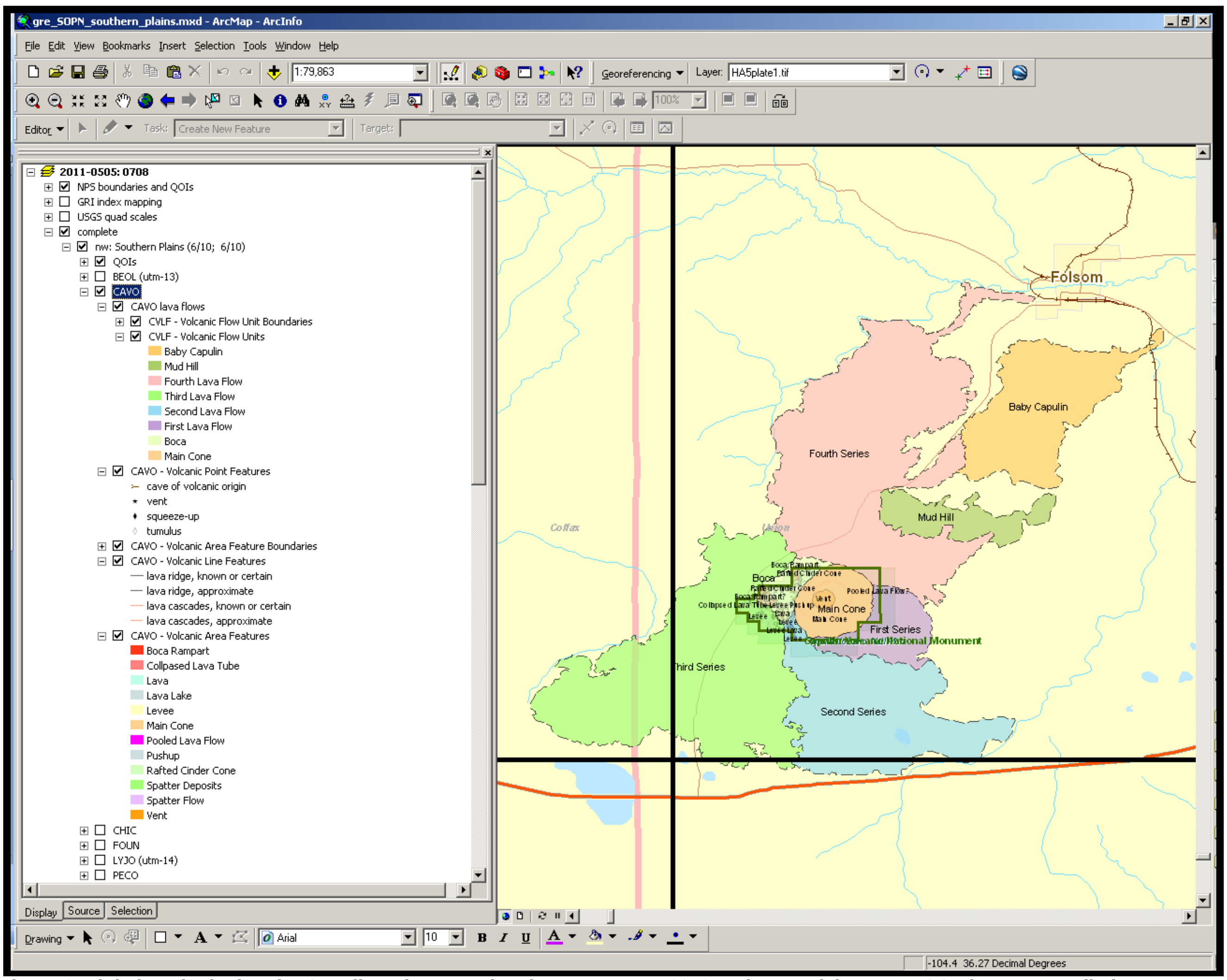

Figure 6. Digital geologic data for Capulin Volcano National Monument. In 2010, Rebecca Richman, an SCA intern, compiled digital data for Capulin Volcano National Monument. The GRI Program converted these data to the NPS data model. Screen capture of National Park Service data.

Geologic Features, Processes, and Issues

The scoping meeting for Capulin Volcano National Monument provided an opportunity to discuss geologic features and processes, many of which have associated issues of management concern. The highest priority issue related to the geologic features and processes at the national monument is the stability of Volcano Road and the impacts the road has on the cinder cone. This issue is discussed first followed by other features and processes at the national monument.

Volcano Road and Mass Wasting

A 3-km (2-mi) road spirals up Capulin Volcano and leads to a parking lot and two trailheads: the Crater Rim Trail and the Crater Vent Trail. The road incorporates several pullouts, which allow examination of various sites of geologic interest, in particular, exposures of the inclined layers of cinders (fig. 1). The road has been referred to as "Mountain Road," "Capulin Volcano Road," and in a 2005 Federal Highway Administration report, "Volcano Road." As "Volcano Road" is consistent with the national monument's mailing address (46 Volcano Road), Peter Armato suggested that "this may be the best way to [refer to the road]" (Peter Armato, superintendent, Capulin Volcano National Monument, e-mail communication, May 20, 2011).

Although the exact date of when the road was cut into the volcano is not known, some accounts suggest that initial road construction began in 1926 (Peter Armato, superintendent, Capulin Volcano National Monument, e-mail communication, May 20, 2011). A local farmer used a mule-drawn plow to grade a road to the rim (Muehlberger et al. 2005). As a part of a 1986 reconstruction project, the National Park Service paved the original road with bituminous concrete pavement, 5 cm (2 in) thick.

Volcano Road is a distinctive feature at the national monument and provides for the enjoyment of visitors. The road facilitates access to summit views, which are quite spectacular and filled with volcanic features. The viewshed incorporates a panorama of four states (New Mexico, Colorado, Utah, and Texas). Below the parking lot at the summit, visitors can see the boca ("mouth") from which lava flowed. To the other side of the parking lot, visitors can look (and walk) into the volcano's crater.

While providing access, construction of the road also created a dilemma for the National Park Service's mission: *to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations*. In short, the road, which provides access and enjoyment, is causing localized but significant erosion of the cinder cone. According to Greco (2001), the road and upslope retaining walls have impeded natural drainages. Many of these drainages are headcutting, especially in the areas above the retaining walls. During construction, the slopes were excavated to an angle that is steeper than the natural slope. In addition, the existing road-drainage structures are inadequate for conveying intense storm-related runoff. Bruce Heise (Geologic Resources Division) described the erosion of cinders during storm events as akin to hydraulic mining: cinders repeatedly clog culverts, but when an unclogged culvert is reached, a strong jet of storm water and cinders blast out of the culvert (Dave Steensen, chief, Geologic Resources Division, personal communication to Bruce Heise, April 2011).

As Nelia Dunbar and Bill McIntosh (New Mexico Bureau of Geology and Mineral Resources) pointed out during the site visit, the natural tendency for cinders is to develop into gullies. This type of erosion has been operating since the cinder cone formed, and paleo-slopes of the volcano record past mass wasting (gravity-driven processes and features). Various investigators have studied the progression of erosion on cinder cones. Scoping participants thought that a study by Claire Renault on the Cima volcanic field in the eastern Mojave Desert of California would be applicable to Capulin Volcano. Renault (1989) studied four basaltic cinder cones of the Cima field in an attempt to understand the geomorphic and volcanic processes involved in the constructional and degradational evolution of late Quaternary cinder cones in arid climates. In addition, several other recent papers, including Fornaciai et al. (2010), Bemis et al. (2011), Doniz et al. (2011), and Inbar et al. (2011) and the references therein, provide information about the morphological evolution of cinder cones through time (Nelia Dunbar, geologist, New Mexico Bureau of Geology and Mineral Resources, written communication, August 4, 2011).

Mass wasting is ongoing at Capulin Volcano and causes cinders to slide, debris flows to form, and entire sections of slopes to fail. Mass wasting is a particular concern at the national monument where it impacts infrastructure. The primary concern is Volcano Road, where deposits of cinders 1.5 m (5 ft) thick have covered sections of road up to 60 m (200 ft) in length. Rockfall, such as cinders sliding onto the road, is continuous, but larger scale mass-wasting events seem to be associated with storms and higher than average annual precipitation. However, the actual triggers and timing of debris-flow events are not well documented. Most recently, in 2010, a "wet year," a cinder slide flowed across the road, inhibiting access and trapping visitors (in cars) at the summit. Precipitation in 2010 was 76 cm (30 in). By comparison, the annual average is 38 cm (15 in). Using long-term weather data and historical photographs retained by the national monument, a Geoscientist-in-the-Parks (GIP) participant would likely be able to make correlations and provide documentation of the link between storms and mass-wasting events. Lisa Norby (Geologic Resources Division) is the contact for the GIP Program (lisa_norby@nps.gov or 303-969-2318).

In the natural resource condition assessment for Capulin Volcano National Monument, which the Southern Plains Network is currently drafting, a significant portion of the "Geologic Resources" section addresses the threat of erosion, particularly as it relates to Volcano Road. The assessment will include results from preliminary monitoring of areas of severe erosion below culverts.

In August 2011, the Federal Highway Administration will begin work on Volcano Road. The primary purpose of the project is to rehabilitate drainage and shoulder conditions (Federal Highway Administration 2010). The project will focus on outlet erosion (down slope from culverts); sheet flow, which is causing pavement raveling and erosion on the outside road edge in various sections; and the capacity of culverts (Federal Highway Administration 2010).

Volcanic Features and Processes

Richman (2010)—the digital geologic map for Capulin Volcano National Monument—documented the following volcanic features: two boca ramparts, 16 lava cascades, 19 lava lakes, 15 lava levees, 18 lava ridges, three lava tubes/caves, six collapsed lava tubes, one main cone, one pooled lava flow, one pushup, two rafted cinder cones, 24 spatter deposits, one spatter flow, 23 squeeze-ups, and 18 tumuli. The final GRI report will highlight each of these features, providing details and characteristics and explaining the mode of formation. Richman (2010) provided descriptions, and *Encyclopedia of Volcanoes* (Sigurdsson et al. 2000) may supply additional information of interest about the volcanic features at the national monument.

During the scoping meeting the two participating volcanologists were asked, “What’s special about the volcanic features at the national monument?” Nelia Dunbar replied, “The crater is really nice.” This off-the-cuff reply succinctly encapsulates the significance of the volcanic features at the national monument. The beauty of the archetypal cinder cone of Capulin Volcano is the reason for inclusion in the National Park System. Dunbar and McIntosh described the cinder cone as “well preserved,” “big,” and “relatively young.” Because the flows erupted from the boca at the base of the volcano and the cone was never breached, the classic shape was preserved. Visitors can walk around the entire crater rim, circumnavigating the volcano and getting a 360° view of the surrounding landscape. According to monument staff, visitors are as interested, or perhaps more interested, in the surrounding viewshed and outlying volcanic landscape as they are in the volcano itself. The view seems to be the reason for return visits.

Capulin Volcano provides a vantage point from which to view other volcanic features, including Baby Capulin, which is the youngest of the volcanoes in the region, and Mud Hill, which in contrast to Capulin Volcano, has a “missing” side, indicating a violent eruption in the past. Both Capulin Volcano and Baby Capulin formed during the Capulin phase of the Raton-Clayton volcanic field. Baby Capulin is interpreted as being younger than Capulin Volcano because its lava flows override flows from Capulin. Mud Hill is also from the Capulin phase, but is older than Capulin Volcano. In the distance Sierra Grande looms 2,658 m (8,720 ft) above sea level. It is the largest volcano in northeastern New Mexico. Sierra Grande dates from the Clayton phase (approximately 2.67 million years ago) (Muehlberger et al. 2010). Unlike Capulin Volcano, which is composed of basalt, Sierra Grande is an andesite volcano. However, it is neither a true shield volcano nor a true composite volcano. Also from the summit of Capulin Volcano, visitors can see prominent pressures ridges in the lava flows. These features formed when the upper surface of the flow cooled and stiffened while liquid lava kept moving below the surface, in the process folding the upper-surface crust into ridges. Also on the landscape are topographic humps, which indicate the location of vents. Additionally, squeeze-ups appear as large round balls. Squeeze-ups formed when the top of the lava flow solidified and cracked, allowing the still-molten lava below to “squeeze up” through the cracks.

Ash, cinders, and bombs, and cross-sectional exposures of these deposits along Volcano Road are also notable features. Cinders and bombs rained down, building up the cone. Bombs were ejected up to 1 km (0.6 mi) from the vent. The pullout on Volcano Road is an excellent place to see bombs that landed on cinder beds. Each layer of pyroclastic material represents an episode of the eruption. Distinct layers indicate primary bedding, while disrupted layers or an absence of layers represent reworked material, most likely down-slope movement after initial deposition. Closer to the rim and vents, the pyroclastic materials are commonly welded. Interpreters at the national monument use these volcanic materials and a “rock box” as tangible tools for educating visitors about volcanism in general and Capulin Volcano in particular.

Another interesting feature related to volcanism is “inverse topography;” that is, cliffs and mesas, such as Robinson Peak and José Butte in the area, represent former river valleys. During eruptions, lava flowed into and filled these ancient drainages. Subsequently, the surrounding uplands eroded away, leaving the former topographic "lows" as present-day "highs."

Eolian Features and Processes

The wind is a primary geologic agent at Capulin Volcano National Monument (Pete Biggam, soil scientist, Geologic Resources Division, personal communication to Rob Bennetts, network coordinator, Southern Plains Network, November 2010). The wind continuously blows cinders onto Volcano Road, which is a concern for maintenance and safety. Dust storms are notable at the national monument, primarily during March and April. Scoping participants felt the effects of the wind in May as they walked around the crater rim, as well as at lower elevations as they held onto their hats and lunches at the picnic table outside of the visitor center. Commonly, grazing is a factor in the amount of dust available for eolian transport, but grazing within the boundaries of the national monument ended in the late 1970s. However, present-day construction activities can denude vegetation, making sediment available for dust storms.

Significant eolian features and processes at the national monument include windblown silt that fills the vesicles and cracks on the tops of lava flows. Windblown silt can also fill caves (lava tubes) in the flows. In the 1970s, a local Boy Scout troop cleared silt from one of the caves as a service project. Unfortunately, the effort most likely resulted in the unintentional destruction of valuable cultural resources (see "Cave and Karst Features and Processes"). Rain events also help transport sediment onto the flows. Water generally flows through (rather than over) the lava flows until silt has filled most depressions.

Based on the amount of silt infilling, geologists can estimate the age of a flow: a clean, silt-free surface indicates young age, depressions filled with silt indicate moderate age, and removal of topographic highs by silt indicates old age. As a lava flow fills in and attains a smooth surface, vegetation augments sedimentation by influencing moisture content and trapping sediment. Bauman (1999)—"Spatial Variability of Desert Loess on the Carrizozo Lava Flow, South-Central New Mexico"—studied the influences of climate, provenance (source of sediment), and surface cover types on soil formation within the Carrizozo lava flow in central New Mexico (see fig. 4). A significant finding from this M.S. thesis was that the soils on the Carrizozo flow are of eolian origin and not basalt weathering products. The sources of the loess were gypsum sand from White Sands National Monument and dolomitic rocks from the San Andres Mountains. Methods used in this study may be applicable to future research of the lava flows at Capulin Volcano National Monument.

Another significant eolian feature is the asymmetry of the crater rim. The rim of Capulin Volcano is higher on the northeast side because that was the downwind side at the time of the eruption. The prevailing southwesterly winds caused the cinders to accumulate on the opposite flank of the cone.

Because cinder cones do not produce a great amount of ash, this is not a significant eolian feature at Capulin Volcano. Unlike the ashes from the Yellowstone crater, which completely covered New Mexico and surrounding states (see Izett and Wilcox 1982), the ash from Capulin's eruption likely covered only a 1-km (0.6-mi) area around the volcano (Bill McIntosh and Nelia Dunbar, New Mexico Bureau of Geology and Mineral Resources, personal communication during scoping, May 10, 2011).

Energy Development

Although wind is a significant geologic agent at the national monument, the development of wind energy in the vicinity is possible but not probable. The winds in the Capulin area are neither consistent nor sustainable enough to allow for large-scale development. Nevertheless, because scenic views are such an important resource for the national monument, the Intermountain Region has a plan to study visitor attitudes of wind farms within Capulin's viewshed.

Cave and Karst Features and Processes

Caves and karst features are typically associated with dissolution of carbonate rocks such as limestone. Nevertheless, there are caves in the basalt at Capulin Volcano National Monument. This particular type of cave is referred to as a "lava tube." Richman (2010) documented three lava tubes and six collapsed lava tubes in the Capulin flows. Scoping participants visited one of the collapsed lava tubes along the Boca Trail during the site visit (fig. 3).

The lava tubes are significant archaeological resources and host cultural artifacts. Both out of concern for potential theft of artifacts and for the safety of visitors, monument staff would like to keep the locations of the caves proprietary. Therefore, the locations of caves will not be part of the publicly available GIS data delivered by the Geologic Resources Inventory (GRI) Program.

Scoping participants believed that information about these cave resources was retained in the resource files at the national monument, and that Adrienne Anderson, a recently retired archaeologist with the NPS Intermountain Region, completed a comprehensive survey of the caves. However, post-scoping research/correspondence with staff at the Technical Information Center in Denver, Colorado; the Southern Plains Network, namely data manager Heidi Sosinski; and the national monument neither resulted in tracking down the survey nor discovered information about the caves. The author sent a message to Adrienne Anderson's personal e-mail address on August 10, 2011, which has gone unanswered to date. Locating information and conducting a geologic survey of the lava tubes at the national monument may be a potential project for a Geoscientist-in-the-Parks (GIP) participant. Lisa Norby (Geologic Resources Division) is the contact for the GIP Program (lisa_norby@nps.gov or 303-969-2318).

Mining and Disturbed Lands

Mines, Mills and Quarries in New Mexico by Pfeil et al. (2001) listed two scoria mines in Union County, New Mexico, the county where Capulin Volcano is situated. Both are in Des Moines, east of the national monument. Scoria (volcanic cinders) is mined for landscaping, railroad ballast, and road base. Baldwin and Muehlberger (1959) noted that cinder cones in the Folsom area, including Capulin Volcano, have been prospected for sources of cinders. Three test pits for cinders occur within the boundaries of the national monument, but at the time of the scoping meeting, monument staff did not deem any in need of restoration. The Geologic Resources Division has expertise to assist with restoration projects, if needed in the future.

Surface Water Features and Processes

Although ephemeral streams flow as a result of storm runoff, there are no perennial streams and no riparian corridor within the national monument. Moreover, there are no lakes or ponds. However, playa lakes are part of the monument's viewshed to the south and east. Playa lakes are shallow, ephemeral lakes in arid or semiarid regions that appear in the wet season and subsequently dry up.

Baldwin and Muehlberger (1959) highlighted the ephemeral lakes of Union County. Most of these “dry lakes” probably formed as a result of wind erosion (Baldwin and Muehlberger 1959). The playas in the viewshed of the national monument are likely wind-scoured depressions in the Dakota sandstone (Baldwin and Muehlberger 1959). However, some ephemeral lakes represent areas where the crust of a lava flow has collapsed. Examples of lakes of this type are in the town of Clayton, southeast of Capulin Volcano National Monument (Baldwin and Muehlberger 1959).

Geothermal Features and Processes

Staff at the national monument has anecdotal evidence for a “hot vent” near the maintenance building. However, nothing is documented about this vent, and national monument staff at the GRI scoping meeting could not provide any details. The former chief of Maintenance, Jay Ellis, may have information about the vent. According to scoping participants, Ellis still lives in the area.

Paleontological Features and Processes

Apart from occasional tree molds, fossils are rare in igneous deposits (Koch and Santucci 2003), including, for example, the basalt flows at Capulin Volcano National Monument. Tree molds form when fluid lava engulfs a tree, which is later incinerated or decays away, leaving a cylindrical hollow. Tree molds may preserve an impression of a tree’s original bark.

According to “Paleontological Resource Inventory and Monitoring, Southern Plains Network” (Koch and Santucci 2003), which includes a summary for Capulin Volcano National Monument, no investigations have noted that the lava flows or cinder cone at the national monument host paleontological resources. The inventory goes on to say that such resources are likely not preserved.

Seismic Features and Processes

Capulin Volcano National Monument is not within a seismically active area, and there are no seismic stations monitoring earthquake activity in the vicinity. The one connection to seismic features and processes at the national monument is that the youngest vents are aligned, suggesting that faults or fractures controlled their locations.

Unique Geologic Features

“Unique geologic features” for Capulin Volcano include age dates from the lava flows. Stroud (1997) documented five samples that yielded argon-argon dates of approximately 56,000 years ago for the age of the volcano. This dating technique showed good agreement with helium-3 dates by Sayre et al. (1995).

Xenoliths are another unique feature contained within the lava of Capulin Volcano. Xenoliths appear as inclusions in volcanic rocks, and are fragments of distinctively different rocks from their host rocks. Xenoliths may have come from the sides of a magma chamber, walls of an erupting lava conduit, or the base of a lava flow. Some xenoliths provide important information about the composition of the Earth’s mantle, which is generally inaccessible. However, the xenoliths at Capulin are from the upper crust.

Another unique geologic feature for Capulin Volcano National Monument is the nearby “K/T boundary,” short for Cretaceous/Tertiary boundary, which records a major worldwide extinction in the fossil record. Although the boundary does not occur within the national monument, an exposure is very accessible near Goat Hill in Raton, New Mexico. The proximity to the national monument may be of interest to visitors. The K/T boundary often captures the public's imagination because it resulted in a world without dinosaurs. The actual, physical boundary is a thin layer of clay rich in iridium that was the result of an asteroid impact 65.5 million years ago. At the exposure near Goat Hill, a sign "iridium layer" indicates the boundary's location (fig. 7).

Figure 7. Cretaceous/Tertiary (K/T) boundary. The K/T boundary is exposed in the Raton Formation in an outcrop near Goat Hill in Raton, New Mexico. This important exposure is accessible by car. Muehlberger et al. (2005) provided directions to the site. Photo by Katie KellerLynn.

Literature Cited

Baldwin, B., and W. R. Muehlberger. 1959 (reprinted 1981). Geologic studies of Union County, New Mexico. Bulletin 63. New Mexico Bureau of Geology and Mineral Resources, Socorro, New Mexico, USA.

Bauman, S. L. 1999. Spatial variability of desert loess on the Carrizozo lava flow, south-central New Mexico. Thesis. New Mexico Institute of Mining and Technology, Socorro, New Mexico, USA.

Bemis, K., J. Walker, A. Borgia, B. Turrin, M. Neri, and C. Swisher. 2011. The growth and erosion of cinder cones in Guatemala and El Salvador: models and statistics. Journal of Volcanology and Geothermal Research 201:39–52.

Doniz, J., C. Romero, I. Carmona, and A. Garcia. 2011. Erosion of cinder cones in Tenerife by gully formation, Canary Islands, Spain. Physical Geography 32:139–160.

Federal Highway Administration. 2010. Improve Volcano Road, Capulin Volcano National Monument (CAVO). Project agreement (July 28, 2010). Project Management Information System (PMIS) 90821 / FHWA Project NM PRA CAVO 10(2). Federal Highway Administration, Central Federal Lands, Lakewood, Colorado, USA.

Fornaciai, A., B. Behncke, M. Favalli, M. Neri, S. Tarquini, and E. Boschi. 2010. Detecting short-term evolution of Etnean scoria cones: a LiDAR-based approach. Bulletin of Volcanology 72:1209–1222.

Greco, D. 2001. Findings and recommendations: Reconnaissance-level site investigation of erosional problems associated with social trails and disturbed areas contributing to the road-related erosion at CAVO. Memorandum to superintendent, Capulin Volcano National Monument (March 12, 2001). National Park Service, Geologic Resources Division, Lakewood, Colorado, USA.

Inbar, M., M. Gilichinsky, I. Melekestsev, D. Melnikov, and N. Zaretskaya. 2011. Morphometric and morphological development of Holocene cinder cones: a field and remote sensing study in the Tolbachik volcanic field, Kamchatka. Journal of Volcanology and Geothermal Research 201:301–311.

Izett, G. A. and Wilcox, R. E. 1982. Map showing localities and inferred distributions of the Huckleberry Ridge, Mesa Falls, and Lava Creek ash beds (Pearlette family ash beds) of Pliocene and Pleistocene age in the western United States and southern Canada (scale 1:4,000,000). Miscellaneous Investigations Series Map I-1325. U.S. Geological Survey, Washington, D.C., USA. http://ngmdb.usgs.gov/ngmsvr2/ILimagery/imagery/8000_9999/9153_1.sid (accessed May 23, 2011).

Koch, A. L., and V. L. Santucci. 2003. Paleontological resource inventory and monitoring, Southern Plains Network. Technical Information Center (TIC) number D-107. National Park Service, Fossil Butte National Monument, Kemmerer, Wyoming, USA.

Muehlberger, W. R., S. J. Muehlberger, and L. G. Price. 2005. High Plains of northeastern New Mexico: A guide to geology and culture. Scenic Trip Series 19. New Mexico Bureau of Geology and Mineral Resources, Socorro, New Mexico, USA.

Muehlberger, W. R., S. J. Muehlberger, and L. G. Price. 2010. Capulin Volcano National Monument, National Park Service. Pages 313–318 *in* L. G. Price, editor. The Geology of Northern New Mexico's Parks, Monument, and Public Lands. New Mexico Bureau of Geology and Mineral Resources, Socorro, New Mexico, USA.

Pfeil, J. J., A. J. Leavitt, M. E. Wilks, S. Azevedo, L. Hemenway, K. Glesener, J. M. Barker, G. E. Miera, P. Kozushko, and P. Kolbenschlag. 2001. Mines, mills and quarries in New Mexico. New Mexico Energy, Minerals, and Natural Resources Department, Mining and Mineral Division; New Mexico Bureau of Mines Inspection; and New Mexico Bureau of Geology and Mineral Resources; Santa Fe and Socorro, New Mexico, USA.

Renault, C. E. 1989. Hillslope processes on late Quaternary cinder cones of Cima volcanic field, eastern Mojave Desert, California. Thesis. University of New Mexico, Albuquerque, New Mexico, USA.

Richman, R. 2010. Digital data of the geologic map of Capulin Volcano National Monument, including report on the creation of geologic inventory map for Capulin Volcano National Monument (scale 1:24,000). Prepared for Capulin Volcano National Monument, Capulin, New Mexico, USA. Student Conservation Association (SCA), Charlestown, New Hampshire, USA.

Sayre, W. O., and M. H. Ort. 1999. A geologic study of Capulin Volcano National Monument and surrounding areas. Final Report. Cooperative Agreement CA7029-1-0017 (December 4, 1999). Prepared for Capulin Volcano National Monument, Capulin, New Mexico, USA. College of Santa Fe, and Northern Arizona University, Santa Fe, New Mexico, and Flagstaff, Arizona, USA.

Sayre, W. O., and M. H. Ort. 2011. A geologic study of Capulin Volcano National Monument and surrounding areas, Union and Colfax counties, New Mexico. Open-File Report 541. New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico, USA. http://geoinfo.nmt.edu/publications/openfile/details.cfml?Volume=541 (accessed August 30, 2011).

Sayre, W. O., M. H. Ort, and D. Graham. 1995. Capulin Volcano is approximately 59,100 years old: Cosmogenic helium aging technique key to clearing up age old question. Park Science 15(2):10–11.

Sigurdsson, H., B. F. Houghton, H. Rymer, J. Stix, and R. D. Ballard. 2000. Encyclopedia of volcanoes. Academic Press, San Diego, California, USA.

Stroud, J. R. 1997. The geochronology of the Raton-Clayton volcanic field, with implications for volcanic history and landscape evolution. Thesis. New Mexico Institute of Mining and Technology, Socorro, New Mexico, USA.

Table 1. Scoping Meeting Participants

Name	Affiliation	Title	Phone	E-mail
Peter Armato	Capulin Volcano National Monument	Superintendent	575-278-2201 x210	peter_armato@nps.gov
Rob Bennetts	Southern Plains Network	Network Coordinator	719-846-4663	robert_bennetts@nps.gov
Lynn Cartmell	Capulin Volcano National Monument	Lead Park Ranger	575-279-2201 x231	lynn_cartmell@nps.gov
Tim Connors	Geologic Resources Division	Geologist	303-969-2093	tim_connors@nps.gov
Nelia Dunbar	New Mexico Bureau of Geology and Mineral Resources	Geologist	505-835-5783	nelia@nmbg.nmt.edu
Bruce Heise	Geologic Resources Division	Geologist/Program Coordinator	303-969-2017	bruce_heise@nps.gov
Adam Heberlie	Bent's Old Fort National Historic Site	Biological Sciences Technician	719-383-5014	adam_heberlie@nps.gov
Katie KellerLynn	Colorado State University	Research Associate		
Bill McIntosh	New Mexico Bureau of Geology and Mineral Resources	Volcanologist	575-418-8803	mcintosh@nmt.edu
Fran Pannebaker	Bent's Old Fort National Historic Site	Chief of Resources	719-383-5016	fran_pannebaker@nps.gov
Phil Reiker	Geologic Resources Division	Geologist/Writer-Editor	303-969-2171	philip_reiker@nps.gov
Karl Zimmerman	Sand Creek Massacre National Historic Site	Chief of Resources and Operations	719-469-7728	karl_zimmermann@nps.gov