National Park Service
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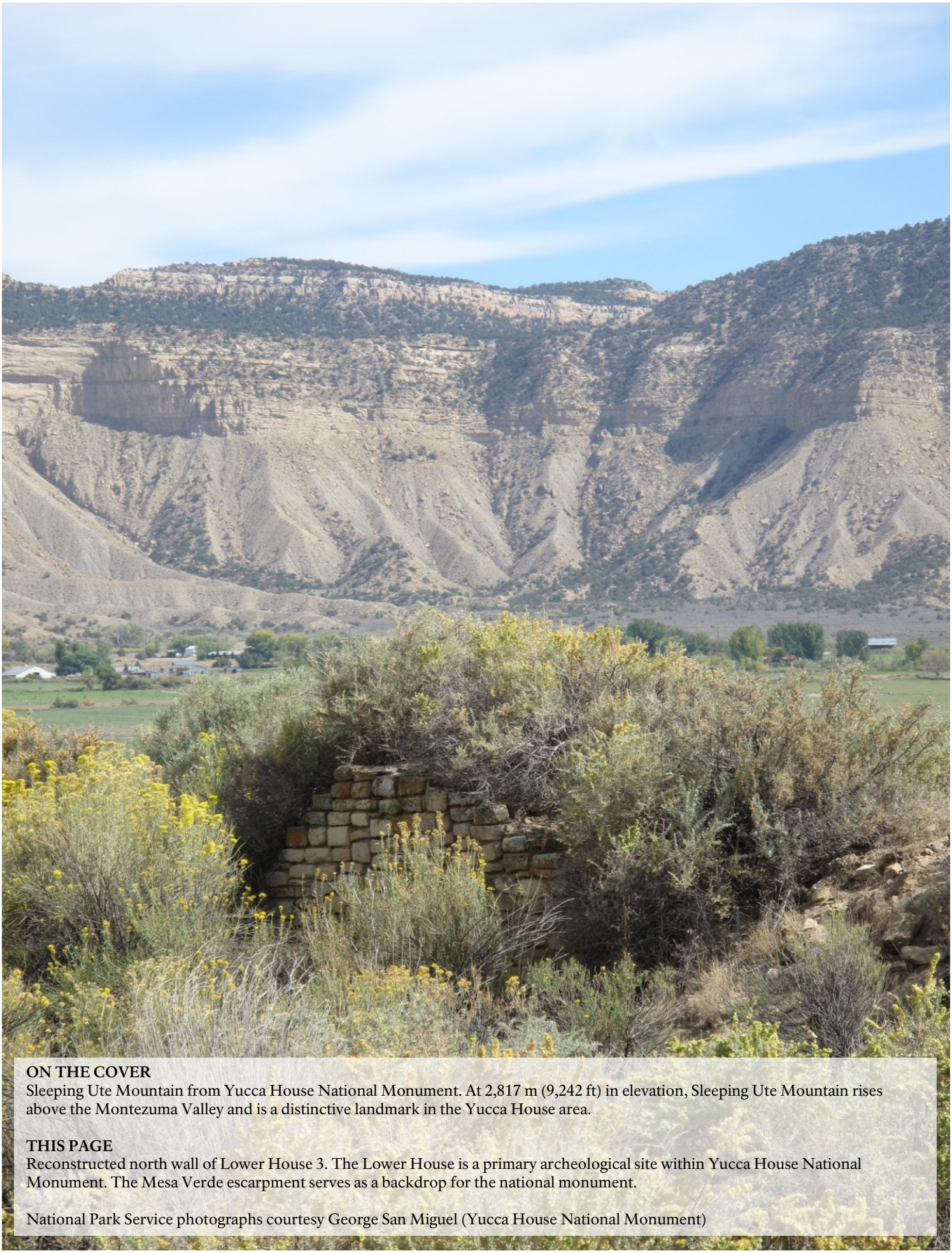
Natural Resource Stewardship and Science

Yucca House National Monument

Geologic Resources Inventory Report

Natural Resource Report NPS/NRSS/GRD/NRR—2013/705



ON THE COVER
Sleeping Ute Mountain from Yucca House National Monument. At 2,817 m (9,242 ft) in elevation, Sleeping Ute Mountain rises above the Montezuma Valley and is a distinctive landmark in the Yucca House area.

THIS PAGE
Reconstructed north wall of Lower House 3. The Lower House is a primary archeological site within Yucca House National Monument. The Mesa Verde escarpment serves as a backdrop for the national monument.

National Park Service photographs courtesy George San Miguel (Yucca House National Monument)

Yucca House National Monument

Geologic Resources Inventory Report

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National Park Service
Geologic Resources Division
PO Box 25287
Denver, CO 80225

August 2013

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Executive Summary

The Geologic Resources Inventory (GRI) is one of 12 inventories funded by the National Park Service Inventory and Monitoring Program. The Geologic Resources Division held a Geologic Resources Inventory (GRI) scoping meetings for Yucca House National Monument in Colorado on 17 July 1998 and 24–27 May 1999, in conjunction with meetings for Mesa Verde National Park and Hovenweep National Monument, to discuss geologic resources, the status of geologic mapping, and resource management issues and needs. A follow-up conference call occurred on 13 June 2012. This report synthesizes those discussions and is a companion document to the previously completed GRI digital geologic map data.

Yucca House National Monument encompasses a cluster of unexcavated mounds in the midst of a gently sloping landscape in southwestern Colorado. Leaving the ruins in situ, beneath the mounds at Yucca House National Monument, is intentional to preserve them for future research and to demonstrate how ancestral Puebloan sites appear prior to excavation. The abandoned ruins provide testament for a prolific ancient society. The monument preserves one of the few main settlements of the ancestral Puebloan people, often called Anasazi. The site, which has survived without major damage and large-scale excavation, surrounds a permanent spring that focused ancestral Puebloan activity. Local, fossiliferous limestone from the Juana Lopez Member of the Mancos Shale (map unit Kmj) provided building stone for ancient structures.

Together with Mesa Verde National Park, Hovenweep National Monument, and the other cultural sites throughout the Four Corners area, Yucca House National Monument tells the story of the delicate balance between human society and the environment—an environment shaped by dynamic geologic processes. As preserved, Yucca House National Monument remains a unique Montezuma Valley ancestral Puebloan site with archeological treasures for future generations of scientists and visitors to study and enjoy. According to the statement for management (National Park Service 1989), the monument offers "unparalleled potential to add significant information to the understanding of the interactions between two major groups of the Anasazi culture—the Chaco Branch and the Mesa Verde Branch."

This Geologic Resources Inventory (GRI) report was written for resource managers at Yucca House National Monument to assist in science-based decision making, but it may also be useful for interpretation. The report was prepared using available geologic information. The Geologic Resources Division did not conduct any new fieldwork in association with this report. The report discusses geologic issues facing resource managers at Yucca House National Monument, distinctive geologic features and processes within the national monument, and the geologic history leading to the monument's present-day landscape. It also provides information about the GRI geologic map data produced for the monument. A geologic map graphic (in pocket) illustrates these geologic data. The Map Unit Properties Table (in pocket) summarizes report content for each map unit. This report also contains a glossary and a geologic time scale.

Geology provides the foundation of every park ecosystem. The geology at Yucca House prompted the ancestral Puebloan people to create a settlement here. The slopes of Sleeping Ute Mountain are mantled by unconsolidated sediments. Annual precipitation moves easily through the unconsolidated material, fueling a prolific spring at Yucca House. This spring was the primary contributor to the success of an ancient culture trying to establish itself in a semi-arid climate.

Bedrock units in the vicinity of Yucca House National Monument are predominantly Jurassic sandstones and Cretaceous shales and sandstones (approximately 200 million–66 million years old). The oldest Jurassic sandstones developed in a great sand desert on the edge of a slowly forming sea that would become the expansive Western Interior Seaway. The Cretaceous rocks were primarily deposited in the Western Interior Seaway as it advanced and retreated over the Four Corners area. Bedrock underlying the national monument is the Upper Cretaceous Juana Lopez Member of the Mancos Shale (Kmj), which was originally deposited in the seaway, far from shore. The Mancos Shale is exposed across Montezuma Valley and forms the base of the steep slopes of Mesa Verde National Park, 25 km (15 mi) northeast of Yucca House. It formed in a variety of offshore, nearshore, and terrestrial depositional environments.

The subsequent 80 or 90 million years of Earth history are missing from the geologic record in the Yucca House area. The time between deposition of the Mancos Shale and of recent, unconsolidated deposits such as slope wash, block rubble, talus, and alluvium is not recorded in the rocks. Sedimentary deposits that once spread across this area were subsequently eroded away in the Tertiary Period during regional uplift of the Colorado Plateau.

Geologic processes provided the resources used by the ancestral Puebloan people and continue to shape the landscape today. An understanding of the geologic resources at Yucca House National Monument will help

managers make informed decisions pertaining to future scientific research projects, future development, interpretive needs, and mineral and energy resources associated with the Yucca House National Monument area. Geologic features and processes of particular significance for resource management include the following:

- Connections between Geology and Park Stories. The monument demonstrates the strong connections that the ancestral Puebloan people had with their natural surroundings, and their ability to use the natural resources at hand to thrive in an environment that could at times be challenging. The initial description of the Yucca House mounds by William H. Holmes was part of the historically significant Hayden Survey. Groundwater quality and soil salinity at some areas of the national monument may limit the types of vegetation that can thrive there; changes to these factors, either from anthropogenic or natural causes, likely affected ancestral Puebloan occupation.
- Paleontological resources. The bedrock within the national monument contains fossils. The building material used by the ancestral Puebloan people contains Cretaceous sea life, including mollusks, ammonites, bivalves, and gastropods, which are now fossilized in the Juana Lopez Member of the Mancos Shale (Kmj).

Geologic issues of particular significance for resource management identified during the GRI scoping meetings and follow-up conference call include the following:

- Disturbed Land Restoration. The monument has very little infrastructure; however, adjacent land use including road clearing, fencing, and farming have created scars on the landscape that impact scenic views and vistas from the monument. Within the monument, disturbed areas are difficult to restore because native vegetation does not easily proliferate, even when aided by human efforts.
- Springs and Seeps. The springs in the monument form where surface topography intersects groundwater flowing from the slopes of Sleeping Ute Mountain. Spring flow and position have changed over time. Today, flow from Aztec Spring (also known as "Yucca House Spring") could not support a community as large as that of the ancestral Puebloan people in the 10th and 11th centuries.
- Swelling Clays. The Mancos Shale contains layers of bentonite, a type of clay that will swell when wetted and shrink while drying. This volume change can cause maintenance problems for roads and structures built on bentonite.
- Surficial Features and Processes. Slope wash (Qsw) mantles the eastern half of Yucca House National Monument. Less vegetated areas in the national monument may be subject to erosion associated with slope wash. Small gullies and larger alluvial channels (Qal), created by intermittent channelized flow, cut the surface of the national monument. Map unit Qpg marks a pediment (erosion) surface that covers much of the western half of the national monument.
- Slope Movements. Muted topography within the national monument precludes slope movements. However, talus, landslide deposits, and block rubble occur in the vicinity of the national monument and are part of the GRI data set for Yucca House National Monument. Pediment deposits (Qpg) contain gravel, cobbles, and boulders, in part from slope movements.
- Aeolian Features and Processes. The dry, arid climate of southwestern Colorado lends itself to wind erosion and deposition. Aeolian erosion may hinder restoration projects, and aeolian silt and sand may cover valued resources such as biological soil crusts.
- Seismic Activity. Changes in groundwater flow paths and ground shaking during earthquakes could impact buried archeological resources.
- Future Park Development. Potential boundary expansion may result in new resource management issues, including mitigation of gullying, consideration of flash flood potential, planning public access, and situating visitor-use facilities.
- Energy Development. Private landholdings surround the monument and include solar energy facilities. Shale gas and coal-bed gas developments occur regionally.

Although access is limited and Yucca House National Monument presently contains no visitor facilities, in situ preservation of the ruins will contribute to the long-term study of ancestral Puebloan society, as well as the reasons for settling in, and later migrating from, what is now southwestern Colorado.

Acknowledgements

The GRI is administered by the Geologic Resources Division of the Natural Resource Stewardship and Science Directorate.

The Geologic Resources Division relies on partnerships with institutions such as Colorado State University, the US Geological Survey, state geological surveys, local museums, and universities to develop GRI products.

The GRI team would like to acknowledge Mary Griffitts' long-term dedication to studying the geology of the Four Corners area, particularly Yucca House National Monument and Mesa Verde National Park. Pete Biggam (NPS Geologic Resources Division) reviewed the soils information. Steve Monroe (NPS Southern Colorado Plateau Inventory and Monitoring Network) provided information regarding springs in Yucca House National Monument and the surrounding area. Marilyn Colyer (Mesa Verde National Park, retired) provided information regarding exposures of the Juana Lopez Member. George San Miguel (Mesa Verde National Park and Yucca House National Monument) provided many of the photographs used in this report.

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Introduction

This section briefly describes the National Park Service Geologic Resources Inventory Program and the regional geologic setting and history of Yucca House National Monument.

Geologic Resources Inventory Program

The Geologic Resources Inventory (GRI) is one of 12 baseline natural resource inventories funded by the National Park Service (NPS) Inventory and Monitoring Program. The Geologic Resources Division of the NPS Natural Resource Stewardship and Science Directorate administers the GRI.

The objectives of the GRI are to provide geologic map data and pertinent geologic information to support resource management and science-based decision making in more than 270 natural resource parks throughout the National Park System. To realize these objectives, the GRI team undertakes three tasks for each natural resource park: 1) conduct a scoping meeting and provide a scoping summary, 2) provide digital geologic map data in a geographic information system (GIS) format, and 3) provide a GRI report. These products are designed and written for nongeoscientists. Scoping meetings bring together park staff and geologic experts to review available geologic maps, develop a geologic mapping plan, and discuss geologic issues, features, and processes that should be included in the GRI report. Following the scoping meeting, the GRI map team converts the geologic maps identified in the mapping plan to digital geologic map data in accordance with their data model. Refer to the "Geologic Map Data" section for additional map information. After the map is completed, the GRI report team uses these data, as well as the scoping summary and additional research, to prepare the geologic report. This geologic report assists park managers in the use of the map and provides an overview of the park's geology, including geologic resource management issues, geologic features and process, and the geologic history leading to the park's present-day landscape.

The compilation and use of natural resource information by park managers is called for in the 1998 National Parks Omnibus Management Act (section 204), *Management Policies 2006*, and the Natural Resources Inventory and Monitoring Guideline (NPS-75). Refer to the "Additional References" section for links to these and other resource management documents.

For additional information regarding the GRI, including contact information, please refer to the GRI website (http://www.nature.nps.gov/geology/inventory/). The current status and projected completion dates of GRI products are available on the GRI status website (http://www.nature.nps.gov/geology/GRI_DB/Scoping/Quick_Status.aspx).

Park Setting

Although dry and sparsely populated today, around 500 CE (common era) the Yucca House National Monument area was filled with the voices of more than 2,500 ancestral Puebloan people. A national monument was designated in 1919 in recognition of the archeological potential for the preservation of antiquities and insight into the ancestral Puebloan culture. The monument is located approximately 25 km (15 mi) west–southwest of Mesa Verde National Park and 34 km (21 mi) southeast of Hovenweep National Monument. Geologic Resources Inventory (GRI) reports, previously called Geologic Resources Evaluation (GRE) reports, for Hovenweep and Mesa Verde were completed by Thornberry-Ehrlich (2004) and Graham (2006).

What began as 4-ha (9-ac) Yucca House National Monument in 1919 was expanded in 1990 to approximately 14 ha (34 ac) in order to protect a large ancestral Puebloan surface site that may have been a major trade center of the pre-Columbian Indians. Two major archeological complexes are situated in the central part of the monument: The Lower House contains a rectangular room block, walls, plaza, and a great kiva. The Upper House—a prominent rubble mound (fig. 1)—is part of the West Complex, which is a pueblo consisting of room blocks, kivas, a great kiva, and a bi-wall structure (Glowacki 2001).

Despite early interest in the site, a lack of funding, low public support, and limited accessibility prevented archaeologists from excavating the ruins at Yucca House. Now, the unexcavated nature of the ruins provides a rare opportunity to view an ancestral Puebloan site in a manner similar to 19th century archeologists. The undeveloped monument also has the long-term potential to reveal tremendous archeological data and information concerning the Mesa Verde Branch of the ancestral Puebloan people, as well as to show how they incorporated their environment into their daily lives.

Yucca House National Monument is located in southwestern Colorado on the gently sloping eastern flank of Sleeping Ute Mountain, near the margin of the Montezuma Valley west of the Mesa Verde scarp (fig. 2). This area is part of a much larger geologic province, the Colorado Plateau, which covers parts of Colorado, Utah, Arizona, and New Mexico (fig. 3). The Colorado Plateau is a region of high plateaus, laterally extensive monoclines (local steepening), and broad, rounded uplands separated by vast rangelands. Large elliptical basins underlie the rangelands. The pattern of gently warped and deeply eroded sedimentary rocks of the Colorado Plateau contrasts sharply with the intense

Figure 1. Upper House mound. "Upper House," the highest portion of the West Complex, rises 5 to 6 m (15 to 20 ft) above the nearby architecture, dominating the surrounding landscape. It was most likely an impressive building. National Park Service photograph by George San Miguel (Yucca House National Monument, taken October 2012).

Figure 2. Mesa Verde. Mesa Verde (Spanish for green table) covers approximately 21,000 ha (52,000 ac) of the Colorado Plateau. The correct geological term for the area is "cuesta," which is similar to a mesa, but instead of being relatively flat, gently dips in one direction. Mesa Verde is inclined slightly to the south at about a 7° angle and has been highly dissected by wind and water erosion into a series of canyons and "mesas." Elevations range from about 1,830 m (6,000 ft) in the canyon bottoms near the southern park boundary to 2,613 m (8,572 ft) at Park Point, about 16 km (10 mi) north. View is from the northwestern corner of Yucca House National Monument looking east. National Park Service photograph by George San Miguel (Yucca House National Monument, taken October 2012).

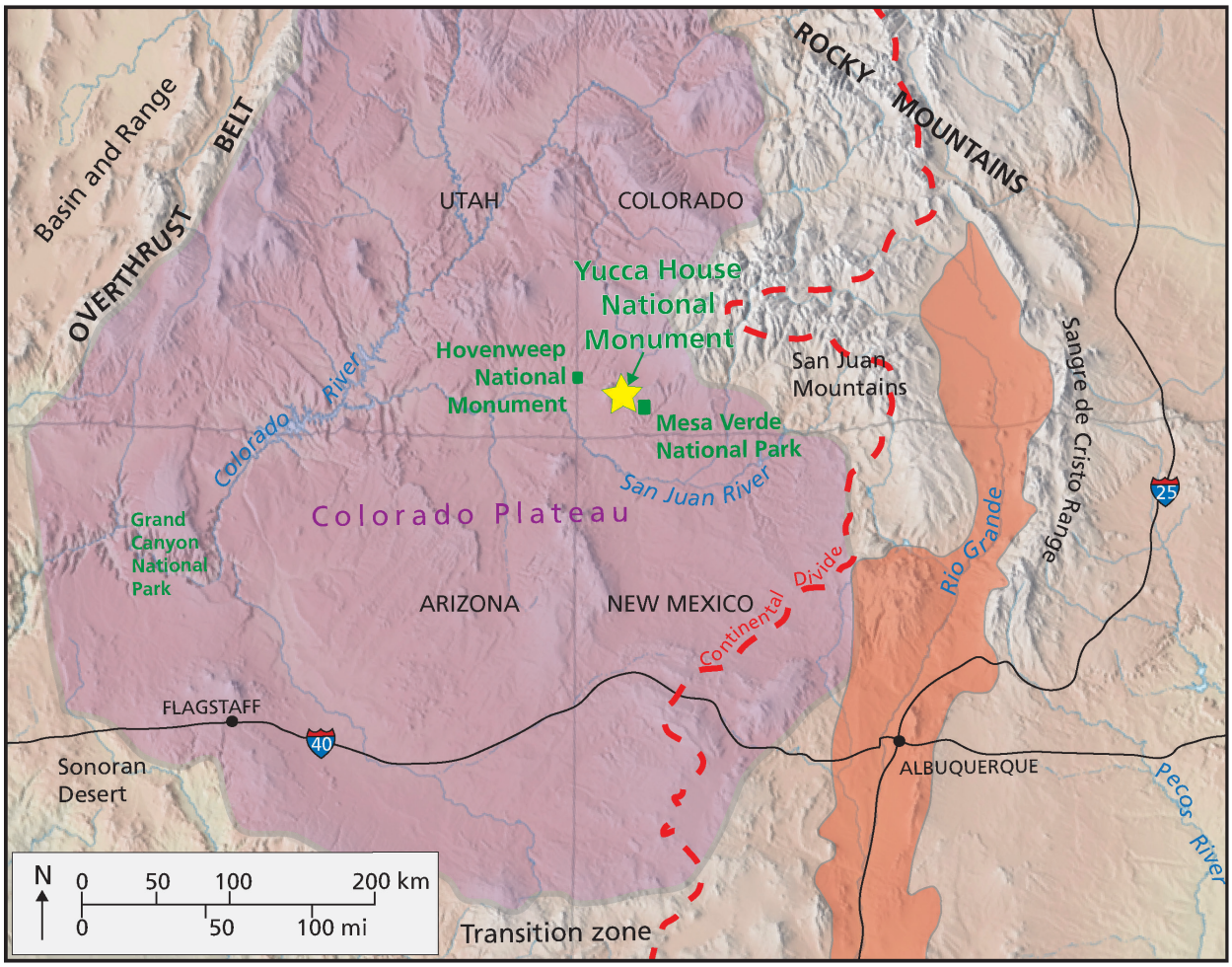


Figure 3. Shaded relief map of the Four Corners area. The Colorado Plateau (purple area) is a region of relatively undeformed, but highly eroded, landscapes. It is surrounded by areas with much more deformed rocks and landscapes, including the Rocky Mountains, Rio Grande rift, and Basin and Range. Note the locations of the Rio Grande rift (orange area), Mesa Verde National Park, and the San Juan Mountains. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University). Base map by Tom Patterson (National Park Service), available online: http://www.shadedrelief.com/physical/index.html (accessed 26 August 2013).

deformation and faulting of the surrounding provinces—the Rocky Mountains and Basin and Range, including the Rio Grande rift. Northeast and east of the Colorado Plateau are the jagged peaks of the Rocky Mountains. A Mesozoic-age overthrust belt (an elongated area where thick rock layers have been pushed over one another by compressional forces) marks the western–northwestern edge of the Colorado Plateau. The extensional, normal-faulted Basin and Range province that rifted apart the overthrust belt borders the Colorado Plateau on the west and south. The Rio Grande rift, which forms an elongate basin in the landscape, borders the plateau on the southeast. Surrounded by major overthrusting and uplifting, the Colorado Plateau remains somewhat of a tectonic enigma, as it has undergone relatively little geologic deformation compared to adjacent provinces.

Ancient volcanoes and shallow intrusions of molten rock that did not reach the surface created the surrounding landscape: on the northeast, the rugged La Plata and Rico mountains; to the east, the San Juan Mountains; and to the west, the Navajo volcanic field, including Ship Rock and dikes within or near Mesa Verde, and Sleeping Ute Mountain, along with the Carrizo, La Sal, Abajo, Navajo, and Henry mountains. Igneous activity occurred during two distinct periods separated by a hiatus. The La Plata, Rico, Sleeping Ute, and Carrizo mountains date to the latest Cretaceous Period and Paleocene Epoch, approximately 65 million–55 million years ago (fig. 4), whereas the Henry, La Sal, Abajo, and San Juan mountains, as well as the Navajo volcanic field, date to the Oligocene and Miocene epochs, mostly 34 million–22 million years ago, with minor Miocene activity as late as 14 million–5 million years ago (Cunningham et al. 1977; Semken 2003; M. Gillam, geologist, written communication, 14 May 2013). Other features present today on the Colorado Plateau, including rugged canyon lands and mesas, formed as a result of relentless erosion accelerated by Cenozoic uplift of the plateau.

Within the boundaries of Yucca House National Monument, elevation ranges from 1,788 to 1,807 m (5,865 to 5,930 ft) above sea level. In addition to the historic Aztec Spring (also known as "Yucca House

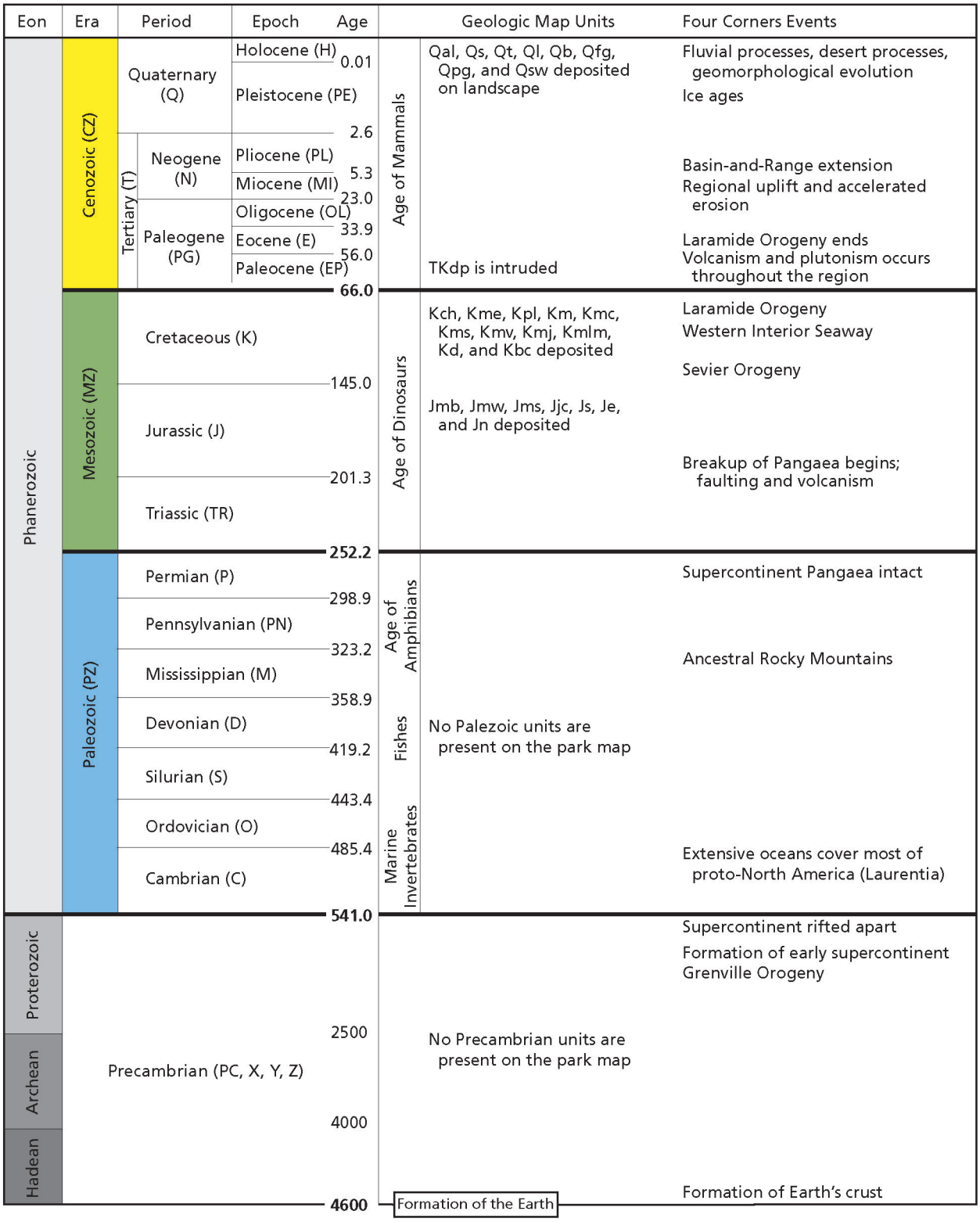


Figure 4. Geologic time scale. The divisions of the geologic time scale are organized stratigraphically, with the oldest at the bottom and youngest at the top. GRI map abbreviations for each geologic time division are in parentheses. Boundary ages are in millions of years ago. Major life history and tectonic events affecting the monument area are included. The geologic map units for Yucca House National Monument are also listed stratigraphically. Bold horizontal lines indicate major boundaries between eras. Graphic by Trista Thornberry-Ehrlich (Colorado State University) and Rebecca Port (NPS Geologic Resources Division). Ages are from the International Commission on Stratigraphy (http://www.stratigraphy.org/index.php/ics-chart-timescale; accessed 23 August 2013).

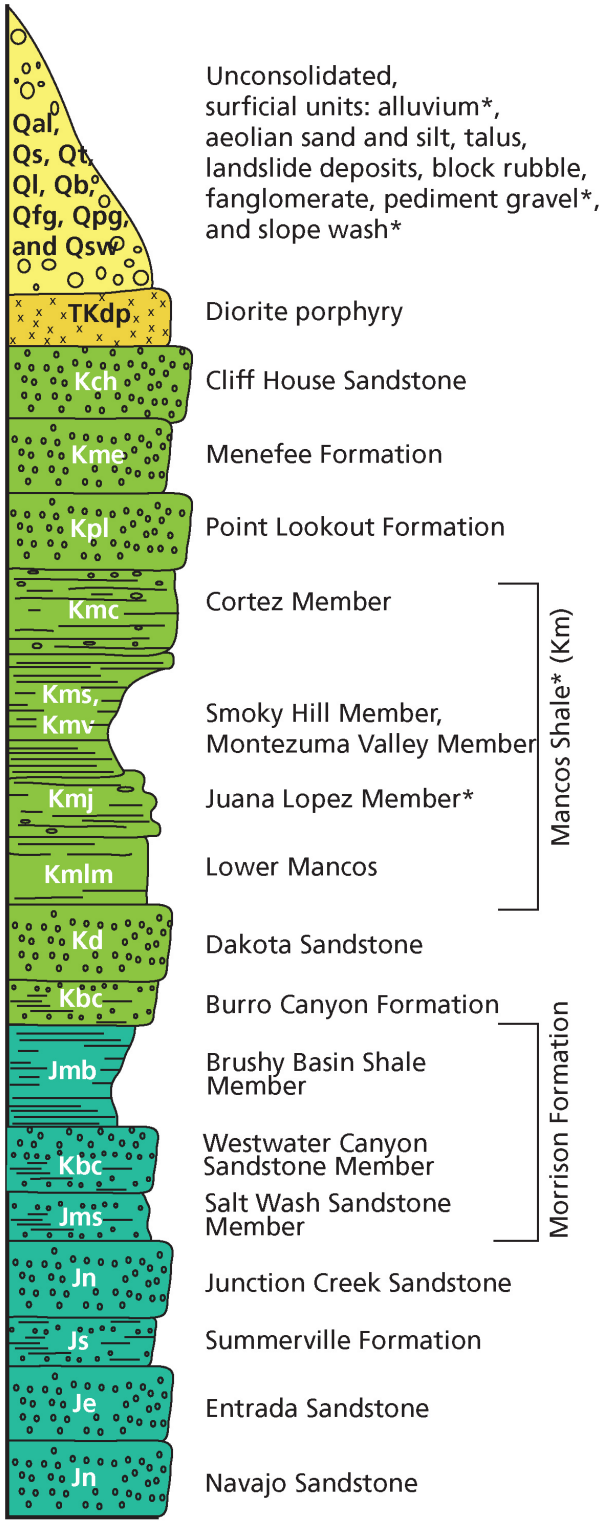


Figure 5. Stratigraphic column for Yucca House National Monument. This stratigraphic column shows the rock units present in the GRI digital geologic map data. Only geologic map units Qal, Qpg, Qsw, and Kmj occur within the national monument as denoted by an asterisk. Unit thicknesses are not to scale. Relative weathering profiles are indicated by indentations on the right side of each rock unit. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

Spring"), which was once the focal point of the ancestral Puebloan settlement, a few minor, dry channels mark where water flowed. Bedrock within the monument is limited to the Juana Lopez Member of the Cretaceous Mancos Shale (map unit Kmj) (figs. 4–6). This fossiliferous, calcium carbonate–rich unit has dense layers of rock that naturally break into blocks along bedding planes and joints. The ancestral Puebloan people used these blocks in the construction of Yucca House. Unconsolidated, younger surficial geologic units in the monument include slope wash, pediment deposits, and alluvium (Qsw, Qpg, and Qal, respectively). These attest to continuing geomorphological changes on the landscape as bedrock and surficial deposits are weathered by wind and water.

Figure 6. Exposure of Mancos Shale within Yucca House National Monument. The Juana Lopez Member of the Mancos Shale (map unit Kmj) was deposited far from shore in a marine basin 90 million years ago. Now, it is exposed at the surface of Yucca House National Monument. National Park Service photograph by George San Miguel (Yucca House National Monument, taken October 2012).

Hayden Survey Discovery of Yucca House

The Hayden Survey first visited the Yucca House area in 1874. Then, William H. Jackson recorded the earliest description of the mounds. William H. Holmes first visited the site in 1875 and published maps and descriptions of the area for the US Geological Survey in 1878. As a geologist and artist with the government–sponsored Ferdinand V. Hayden surveys of the western United States, Holmes was the first artist to capture the reality of the landscape. His drawings and sketches are in each of the Hayden Survey *Annual Reports* from 1872 to 1878. By 1874, Hayden had made Holmes an assistant geologist, and by 1875 Hayden put him in charge of an expedition that explored the little-known San Juan region (Stegner 1954). Holmes' sketches of the cliff dwellings at Mesa Verde National Park supplement William H. Jackson's well-known photographs.

Holmes became a geologist who was able to capture the beauty of geology in his art. Of all the artists of the time, Holmes "clarified the West more than any of them. A Holmes panorama cuts through the haze, it is clear to the farthest distance as no photograph ever is. By almost imperceptible tricks of contrast it emphasizes lines of stratification and profiles of erosional forms. More impressively than any Western artist, even Moran, he captured the plastic qualities of rock" (Stegner 1954, p. 188).

Geologic Features and Processes

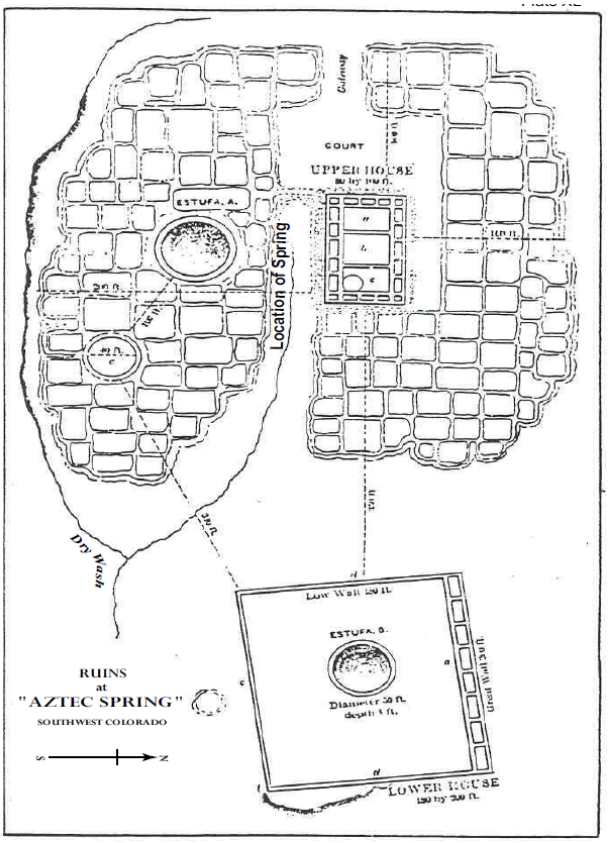
Geologic resources underlie park ecosystems and geologic processes shape the landscape of every park. This section describes the most prominent and distinctive geologic features and processes in Yucca House National Monument.

During the 1998 and 1999 scoping meetings and the 2012 conference call, the following geologic features and processes were identified:

- Connections between Geology and Park Stories
- Paleontological Resources

Connections between Geology and Park Stories

At Yucca House National Monument, park stories are reflected in a landscape that developed over the last 100 million years. The National Park Service chose "Yucca House" for the monument's name, recognizing the Ute name for Sleeping Ute Mountain, which was "mountain with lots of yucca growing on it." It was also known as "Yucca Mountain" by the Tewa (Puebloan) Indians. The mountains remain a sacred place to the Weeminuche Ute Band. This setting yields a rich and wide range of habitats from the floor of Montezuma Valley up the slopes of Sleeping Ute Mountain. The yucca plant is an ethnobotanically significant species for the ancestral Puebloan culture, serving many uses. Only a few yucca plants grow in the monument today (G. San Miguel, natural resource manager, Yucca House National Monument, conference call, 13 June 2012).



Yucca House Pueblo

The location of Aztec Spring was likely the basis for ancestral Puebloan construction of the Yucca House settlement. Geologic features and groundwater processes controlled the location of the spring. Unconsolidated gravels and coarse sediments—map units Qt, Ql, Qb, Qfg, Qpg, and Qsw—cover a gently sloping pediment (erosional surface or plain) on the flanks of Sleeping Ute Mountain. Precipitation higher on the mountain slopes percolates through these porous, unconsolidated deposits. At the contact with the less porous Mancos Shale bedrock (Km), the groundwater flows laterally through the subsurface. Spring water discharges where surface topography intersects groundwater flow. More than 900 years ago, Aztec Spring was flowing sufficiently to support the establishment of the Yucca House community (fig. 7). The exact timing of the beginning of occupation cannot be determined given the unexcavated nature of the site. However, tree ring dates from the southeastern corner of the Upper House in the West Complex go back to 1163 CE, and some archeologists surmise the first structures date to the Chaco Period (1050 to 1150 CE) (Glowacki 2001; G. San Miguel, written communication, 27 June 2012).

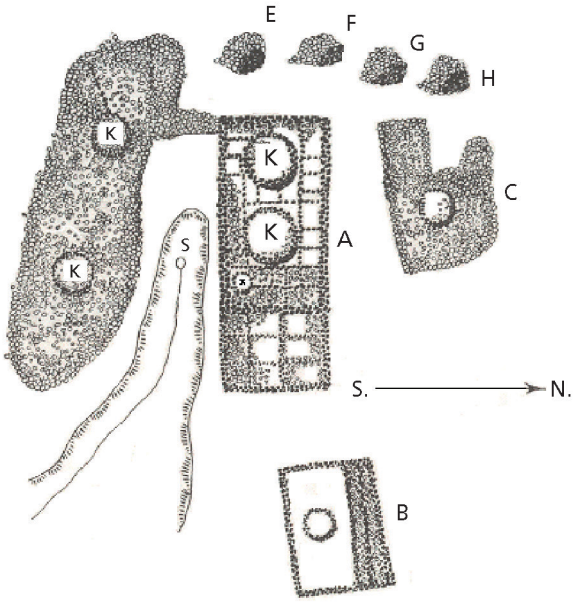


Figure 7. Sketches of Yucca House ruins. In 1874, W. H. Holmes wrote about and produced the first map of Yucca House (left). Holmes described a prolific spring surrounded by rubble on three sides. Sketch by W. H. Holmes in Wright (2006, figure 2). Fewkes (1919) later reworked Holmes' map into the ground plan on the right. S = Aztec Spring. A = Upper House. B = Lower House. C and E–H = remains of other pueblos. K = kiva. No scale given. Sketch by Fewkes (1919). Sketch and labels rotated to match orientation of Holmes' sketch.

The pueblo, or communal dwelling, constructed at Aztec Spring (named by the Hayden Survey in 1874), was likely at least three stories high (Wiese 2000; G. San Miguel, written communication 27 June 2012). Accompanying the pueblo was a kiva, a ceremonial chamber dug into the earth (Wiese 2000). The ancestral Puebloan people used natural fossiliferous calcarenite (limestone from map unit Kmj) for building blocks as well as sandstone boulders from Quaternary terrace gravels, pediment deposits (Qpg), and alluvium (Qal) (fig. 8) (Ekren and Houser 1965; Glowacki 2001; Griffitts 2001). Igneous cobbles (diorite) used in construction were eroded from Sleeping Ute Mountain (Ekren and Houser 1965; Glowacki 2001). From surficial surveys, it appears the pueblo was constructed with approximately 42% Juana Lopez calcarenite (Kmj), 39% sandstone, and 19% diorite (i.e., TKdp) (Glowacki 2001). Further excavation may reveal whether blocks of Dakota Sandstone (Kd) or sandstone from the Point Lookout Formation (Kpl), both of which are more than 5 km (3 mi) away, were used as building materials (Glowacki 2001; Griffitts 2001). Adobe construction with mud and jacal (similar to wattle and daub) was used at Yucca House. This method may be an indication of available resources or the influence of groups from other regions (Glowacki 2001). The structure wrapped around Aztec Spring creating a pool there. Today, the pool is a wetland (G. San Miguel, and M. Gillam, geologist, conference call, 13 June 2012). The former spring must have been much larger than today's trickle to support a thriving community at Yucca House (Wright 2006).

Figure 8. Building stone used at Yucca House. Local geologic resources provided the building blocks for ancient structures at Yucca House National Monument. Clockwise from top left, calcarenite, igneous rock, building block rubble, and building block rubble strewn atop a mound. National Park Service photographs by George San Miguel (Yucca House National Monument, taken October 2012).

Abandonment of Yucca House

For reasons that are still not fully understood, the ancestral Puebloan people migrated away from their settlements throughout the Four Corners area by the end of the 13th century. Exact dates of occupation at Yucca House are difficult to discern because the site is not excavated, but surface artifacts indicate that people inhabited the settlement until around 1280 CE (Glowacki 2001; G. San Miguel, written communication, 27 June 2012). Many other ancestral Puebloan sites, including Hovenweep and Mesa Verde, were abandoned around this same time and possibly correspond to a significant change in climate, deforestation, depletion of soils, social factors, or overpopulation (Wright 2006). According to tree-ring studies, drought conditions existed between 1125–1175 CE and 1276–1300 CE (Van West and Dean 2000; G. San Miguel, written communication, 2 October 2012).

After abandonment, the pueblo eventually collapsed into a cluster of mounds (fig. 9) scattered around Aztec Spring. In 1877–1878, William H. Holmes, part of the Hayden Survey, wrote about and produced the first map of the mounds, which was later reworked by Fewkes (fig. 7). Holmes designated the two more conspicuous mounds as "Upper House" and "Lower House." The Upper House is the most prominent of the mounds, rising 5 to 6 m (15 to 20 ft) above its foundation. The Lower House is an isolated collection of ruins located about 100 m (330 yds) from the Upper House.

Figure 9. Lower House mound. Lower House was an L-shaped pueblo with at least eight first-story rooms. A low wall enclosed the plaza with a great kiva at its center. National Park Service photographs by George San Miguel (Yucca House National Monument, taken October 2012).

Modern Ecosystem

The bedrock of the monument area is the Cretaceous Mancos Shale (see geologic map graphic, in pocket), which consists of many different minerals and compounds such as quartz, calcium carbonate, dolomite, volcanic ash, traces of pyrite, organic matter, fossils, and abundant trace elements (Griffitts 2001; Wright 2006). Trace elements include chromium, iron, manganese, nickel, selenium, uranium, vanadium, and zinc (Wright 2006). The Mancos Shale weathers to produce a clay-rich regolith (fig. 10), reflecting its heterogeneous composition.

Groundwater from sources on Sleeping Ute Mountain flows through alluvium and colluvium and has a calcium bicarbonate signature. The farther away groundwater flows from these sources, the more chemical interactions it has with the bedrock. When sulfide minerals such as

Figure 10. Clay-rich soil developed from Mancos Shale. Millions of years ago, erupting volcanoes provided volcanic ash that became clay in present-day soils. National Park Service photograph by George San Miguel (Yucca House National Monument, taken October 2012).

pyrite (present in the Mancos Shale) break down, sulfate and iron are released into solution. In some cases, the dissolved sulfate combines with calcium, magnesium, and sodium ions and precipitates as efflorescent salts. These soluble salts appear on the surface in the Yucca House area. They dissolve readily in rainfall runoff and can lead to high mineral content of surface water (Wright 2006). The sulfate concentrations at Aztec Spring, Gate Marsh Spring, and Navajo Wash exceed drinking water standards set by the Environmental Protection Agency and the Colorado Department of Public Health and Environment. Standards are available at http://www.colorado.gov/cs/Satellite/CDPHE-Main/CBON/1251595703337 (accessed 11 July 2013).

The NPS Soil Resources Inventory Program identified one soil unit at Yucca House National Monument with a moderately saline horizon within 75 cm (30 in) of the surface (P. Biggam, soil scientist, NPS Geologic Resources Division, written communication, 20 August 2012). Soils that have the highest available water holding capacities also have higher salinity and sodium than other soils in the monument. As salinity increases in the soil, it becomes more difficult for plants to extract water. This aggravates water stress conditions, which is already an issue in semi-arid to arid climate. Plants growing in highly saline soils may be stunted with dark green leaves, and may experience defoliation and decreased yields (Wright 2006). Native plant species have adapted to grow on these saline sites such as the Salt Meadow ecological site (P. Biggam, written communication, 20 August 2012). These natural salts could have affected the crops that the ancestral Puebloan people may have grown, such as beans and corn. However, by irrigating these crops, the ancestral Puebloans may have literally diluted some of the potential soil issues of pH and salinity (P. Biggam, written communication, 20 August 2012).

The generalized plant cover in the monument is Desert Shrub (Colyer 2000). Sheets of blowing sand (Qs) have the potential to bury vegetation. However, this is not yet an issue at Yucca House National Monument (G. San Miguel, written communication, 2 October 2012).

Paleontological Resources

Paleontological resources (fossils) have been documented within Yucca House National Monument and summarized by Tweet et al. (2009). The Juana Lopez Member of the Mancos Shale (Kmj) is the only bedrock present within the monument. It was deposited approximately 95 million–80 million years ago in a transgressive–regressive (sea level rise / shoreline retreat–sea level fall/shoreline advance) episode within the Western Interior Seaway (see "Geologic History" section). This fossiliferous shale also contains some sandy, silty, and carbonate-rich layers. The ledge-forming layers of the calcium carbonate–rich rock, calcarenite, naturally weather into blocks (Griffitts 2001). The ancestral Puebloan people took advantage of this local, fossiliferous natural resource in the construction of their structures. Fossils contained within the Juana Lopez Member include mollusks, ammonites, bivalves, gastropods, chondrichthyans, skate teeth, fish bones and scales, and a toothed bird (*Ichthyornis*) (Ekren and Houser 1965; Griffitts 2001; Scott et al. 2001; Lucas and Johnson 2003; Tweet et al. 2009). Many of the fossils now curated at Mesa Verde National Park were collected from the Juana Lopez Member of the Mancos Shale at Yucca House National Monument (Griffitts 2001). Most frequently, these fossils appear in calcarenite slabs that have broken from an outcrop (fig. 11).

Tweet et al. (2009) documented the discovery of two vertebrae from a plesiosaur (marine reptile) in a spoil pile associated with a Bureau of Reclamation ditch adjacent to the monument. The Museum of Western Colorado in Grand Junction retains these specimens. The discovery of these plesiosaur remains inspired some interest in further paleontological resource surveys. Because the remains were part of a spoil pile, determining their original location and stratigraphic position would be difficult, although they must have come from the Mancos Shale (map unit Km).

The surficial geologic units at Yucca House National Monument also may contain fossils such as pollen, packrat middens, and macrofossils. Remains of muskox, canids, weasels, rodents, rabbits, deer, elk, antelope, sheep, and insects are associated with archeological sites throughout the Four Corners area, though none are known to exist within the monument (Lyman 1983; McDonald et al. 1987; Tweet et al. 2009). Because the Yucca House ruins are unexcavated, these types of cultural–natural resource connections may be buried, yet to be discovered, in the mounds.

Currently NPS staff members are not monitoring paleontological resources at Yucca House National Monument, but a long-term goal for resource managers is to identify and map the paleontological resources, classify resource condition, correct any problems, and ensure that future plans and visitor activities do not pose a risk to the fossils (Wiese 2000). Santucci et al. (2009)—the paleontological resources chapter in *Geological*

Monitoring—described five methods and vital signs for monitoring in situ paleontological resources: (1) erosion (geologic factors), (2) erosion (climatic factors), (3) catastrophic geohazards, (4) hydrology/bathymetry, and (5) human access/public use. Tweet et al. (2009) provided details about the paleontological resources at Yucca House National Monument, and presented recommendations for future paleontological work.

Figure 11. Fossiliferous building blocks at Yucca House National Monument. The remains of past sea life became incorporated into the ancient Puebloan structures of Yucca House. National Park Service photographs by George San Miguel (Yucca House National Monument, taken October 2012).

Geologic Issues

Geologic issues described in this section may impact park resources or visitor safety and could require attention from resource managers. Contact the Geologic Resources Division for technical assistance.

During the 1998 and 1999 scoping meetings and 2012 conference call, participants (see Appendix A) identified the following geologic resource management issues at Yucca House National Monument:

- Disturbed Land Restoration
- Springs and Seeps
- Swelling Clays
- Surficial Features and Processes
- Slope Movements
- Aeolian Features and Processes
- Seismic Activity
- Future Park Development
- Energy Development

Yucca House National Monument remains undeveloped and currently has no visitor-use infrastructure. Public access to the monument involves crossing and parking on adjacent private ranch property. Monument staff wishes to preserve this courtesy until a better alternative may be developed on NPS property (G. San Miguel, written communication, 15 May 2013).

Resource managers may find *Geological Monitoring* (Young and Norby 2009) useful for addressing these geologic resource management issues. The manual provides guidance for monitoring vital signs—measurable parameters of the overall condition of natural resources. Each chapter of *Geological Monitoring* covers a different geologic resource and includes detailed recommendations for resource managers and suggested methods of monitoring.

Disturbed Land Restoration

A sand and gravel pit (possibly in map unit Qpg) is located next to the southwestern corner of Yucca House National Monument. This quarry operation is no longer active, although a two-track access road still exists (fig. 12). In 2008, in order to access farm land on the western side of the national monument, adjacent landowners used this road, and in the process widened it. The resultant road scar cut into national monument property; a 0.2-km- (0.1-mi-) long unvegetated strip now exists (fig. 13). Natural resource staff has attempted to revegetate this area, but thus far, efforts have been unsuccessful. The arid climate of the area makes revegetation difficult and time-consuming. In a self-perpetuating situation, a lack of stabilizing vegetation exacerbates erosion, which in turn removes regolith needed to support plant life. Moreover, the site has a salt-rich substrate, and Russian knapweed has invaded.

Figure 12. Abandoned access road within Yucca House National Monument. Road was toward a sand and gravel operation west of the national monument. Restoration efforts have not yet been successful. National Park Service photograph by George San Miguel (Yucca House National Monument, taken October 2012).

Figure 13. Revegetation efforts of abandoned access road. In 2008, adjacent landowners utilized a previously-abandoned access road (fig. 12) to reach farm land. The incident exacerbated the disturbance, and revegetation attempts by the National Park Service have thus far proved unsuccessful. National Park Service photograph by George San Miguel (Yucca House National Monument, taken October 2012).

Also, a notable gully is forming (G. San Miguel, natural resource manager, Yucca House National Monument, and M. Gillam, geologist, conference call, 13 June 2012; G. San Miguel, written communication, 2 October 2012). A new access road was constructed immediately west of of the southernmost part of the national monument (G. San Miguel, written communication, 2 October 2012).

Surrounding land-use activities could potentially impact the monument's viewshed (scenic views and vistas) and increase local traffic. Several gravel pits are located to the

south and west of the monument on the Ute Mountain Ute Reservation. A tribally owned construction company is investigating the possibility of developing quarries for aeolian soils for brick production. The proposed location is 4.0 km (2.5 mi) away from the monument (M. Gillam, geologist, conference call, 13 June 2012).

In addition to disturbed areas associated with local gravel pits, grazing has led to disturbed areas within the national monument. Prior to the late 1990s, the monument was inadequately fenced and goats and sheep from adjacent ranches were able to graze within the monument. Grazing resulted in trampling and significant damage to vegetation. Current fencing is stronger and completely surrounds NPS property, keeping out cattle and horses (G. San Miguel, conference call, 13 June 2012).

An area on the eastern side of the national monument was particularly impacted by grazing. A historic cabin just outside of the eastern boundary was used by previous landowners as a livestock barn for cattle and goats (fig. 14). A decade or so ago (approximately 1999–2000), some of the animals were actually fenced within the monument, just west of the cabin. The animals denuded native vegetation and invasive plants spread. Natural resource staff is still attempting to revegetate the site (G. San Miguel, conference call, 13 June 2012). As an interesting aside that illustrates the challenges of revegetating the site, metal fence posts used to corral the animals corroded away due to the high alkaline content of the substrate and a higher amount of precipitation than current levels (G. San Miguel, conference call, 13 June 2012).

Figure 14. Historic cabin east of Yucca House National Monument. Note the social trail in the foreground leading up from the gate. Vegetation damaged from grazing in this area has yet to recover. National Park Service photograph by George San Miguel (Yucca House National Monument, taken October 2012).

Springs and Seeps

Unconsolidated gravels, cobbles, and boulders make up the alluvial fan piedmont (base of slope) that forms the east–northeastern flank of Sleeping Ute Mountain. Within Yucca House National Monument, piedmont slope deposits include Qal, Qsw, and Qpg (fig. 15). Fanglomerate (Qfg; an alluvial fan cemented into solid rock) is also part of the piedmont, but crops out beyond park boundaries (Ekren and Hauser 1959). The vertical flow of precipitation percolating through these gravels is directed downslope at the contact with the much less permeable Mancos Shale bedrock (Wright 2006). Springs result where surface topography intersects groundwater flow. As described in the "Geologic Features and Processes" section, this process influenced the siting of Yucca House by the ancestral Puebloans. In general, surface water and groundwater flow to the southeast, from Yucca House National Monument to Navajo Wash in Montezuma Valley.

The mounds at Yucca House National Monument surround an area historically known as Aztec Spring (figs. 7 and 16), now called Yucca House (National Park Service 1989). Discharge at springs and seeps throughout the area fluctuates over time and space as groundwater flow responds to increasing or decreasing precipitation and/or extraction by plants and humans. The trend over the past decade (from 2000 to 2012) has been toward dryer, more arid conditions, resulting in lower groundwater levels (Wright 2006; G. San Miguel, conference call, 13 June 2012; National Oceanographic and Atmospheric Administration 2012). As a consequence, seeps and springs are drying up. Under wetter conditions, many local seeps had wetland plants such as cattails and sedge, but increased aridity limits water available for such hydrophilic species, and they no longer grow in many areas (G. San Miguel and M. Gillam, conference call, 13 June 2012).

Aztec Spring is a culturally and naturally significant feature at Yucca House National Monument. At present, this spring is a trickle within a small wetland. Discharge varies seasonally. Flow has decreased noticeably over the past decade (G. San Miguel, conference call, 13 June 2012). In fall 2012, investigators measured discharge at the spring using a portable flume. Recorded rates were 84.95 cm^3/sec (0.003 ft^3/sec) or 4.9 L/min (1.3 gal/min). The flume measured nearly all the flow that now occurs in a single narrow channel (Steve Monroe, hydrologist, NPS Southern Colorado Plateau Network, written communication, 9 November 2012). In 1989, discharge at Aztec Spring was about 15 L/min (4 gal/min) (National Park Service 1989).

In 1995, the National Park Service surveyed the water resources at Yucca House National Monument at the behest of Hallie Ismay, the monument's former caretaker who had noticed that the springs had changed their location and flow (Ismay 1995). The following sites were surveyed: (1) Ismay (main) Spring on Ismay land (now Box Bar Ranch) north of the monument; (2) north spring

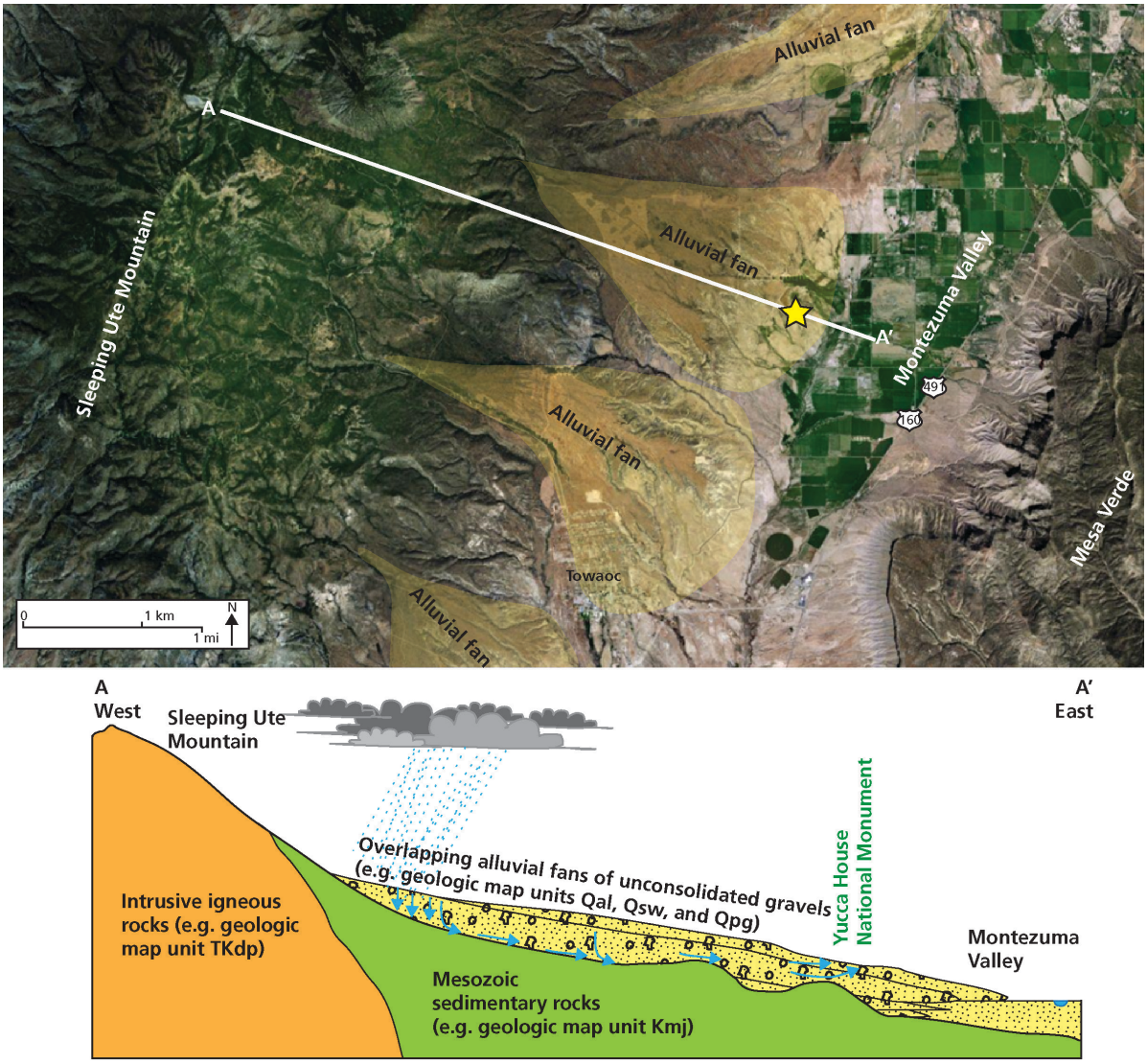


Figure 15. Alluvial fans mantling the slopes of Sleeping Ute Mountain. Cross section A–A' shows a conceptual subsurface through Yucca House National Monument (yellow star) with groundwater flow paths through the unconsolidated gravel emerging as springs downslope. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University), with aerial imagery from ESRI ArcGIS base layer imagery.

Figure 16. Aztec Spring marsh. Archeological mounds surround the spring site and reflect the spring's importance to the ancestral Puebloans. National Park Service photograph by George San Miguel (Yucca House National Monument, taken October 2012).

in the northeastern corner of the monument; (3) middle spring (Aztec Spring) east of the kiva area in the monument; (4) south spring along the southern fence line in the monument; (5) West Pond 100 m (330 ft) west of the monument; (6) a small drainage south of West Pond; and (7) a seepy, grassy slope east of the 1990 acquisition. On 21 September 1995, the only springs that contained flowing water were the Ismay Spring and Aztec Spring (fig. 17).

A 2006 hydrologic study of the monument and surrounding area by Wright (2006) detailed the flow and quality of selected ponds and springs including Ismay Spring, Gate Marsh Spring, Aztec Spring (therein referred to as Yucca House Spring), West Pond, and South Sunfish Pond (fig. 17). Aztec Spring and a portion of the West Pond wetland, as indicated by wetland vegetation, are within Yucca House National Monument. Aztec Spring's water is currently mixing with irrigation runoff as evidenced by elevated nitrate content and thus cannot be a proxy for ancestral Puebloan

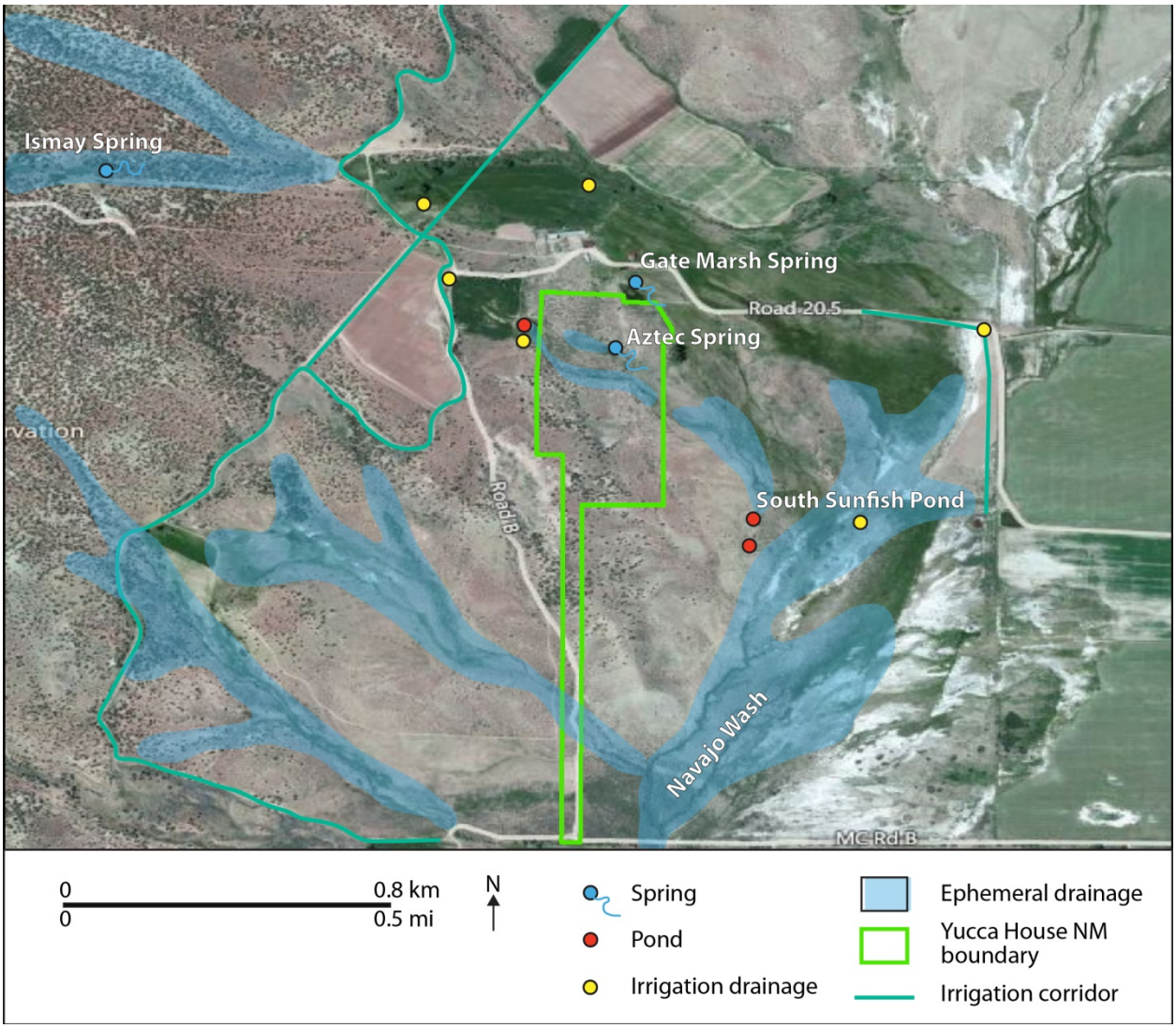


Figure 17. Locations of springs, ponds, and other water features in the Yucca House National Monument area. The national monument's boundary is bright green line. Note the locations of Ismay Spring, Navajo Wash, Gate Marsh Spring, Aztec Spring (also known as "Yucca House Spring"), and South Sunfish Pond. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University), based on Wright (2006, figure 8).

conditions. Minerals precipitate out of spring water and groundwater and create mineral cements, which seal fractures and flow paths causing the location of springs and seeps to change over time. For example, the groundwater flow paths discharging at Gate Marsh Spring and South Sunfish Pond may have previously discharged from Aztec Spring (Wright 2006). Because of its location, hypothesized flow path, and geochemistry, Gate Marsh Spring may be an analog for Aztec Spring during the occupation period. Its present flow is undiluted from irrigation water sources. After percolating through the local bedrock, the spring's water is highly mineralized and not particularly palatable or potable. In contrast, water flowing from Ismay Spring is only in contact with surficial alluvium and colluvium (such as map units Qal and Qt), and thus, is not highly mineralized.

Given the historical significance of springs and seeps to the ancestral Puebloans and the documented variance of springs in modern times, past hydrologic studies at Yucca House National Monument typically have recommended that monitoring be conducted as often as three times each year. The NPS Southern Colorado Plateau Inventory and Monitoring Network is developing a monitoring program for Aztec Spring. Additional information that would support increased understanding of the hydrologic systems within the monument includes detailed, groundwater and surface water flow maps. Potential action items regarding springs and seeps at Yucca House National Monument include (1) installing wells for testing and potential potable water development, and (2) excavating the ancient spring site to determine seasonal dependence on the water source and its possible effect on local ancient agricultural practices.

Swelling Clays

Some clays have the capacity to absorb water into their crystalline structure. When saturated with water, these clays expand. Upon drying, they shrink. Smectite and bentonite are examples of clays that change volume with water content. The NPS Soil Resources Inventory product for Yucca House National Monument identified smectite as a component in the soil clay mineralogy (P. Biggam, soil scientist, NPS Geologic Resources Division, written communication, 20 August 2012). Bentonite, a clay derived from altered volcanic ash deposits, is responsible for road damage at neighboring Mesa Verde National Park. Both smectite and bentonite are components of Mancos Shale (map units Km, Kmc, Kms, Kmv, Kmj, and Kmlm).

Because swelling clays can cause the ground surface to heave and buckle, they have the potential to impact future visitor-use facilities and natural resources at Yucca House National Monument. Issues related to shrink-and-swell clays occur because of improper drainage and accumulation of water, for example at downspouts near foundations (P. Biggam, written communication, 20 August 2012). In areas that are drained properly, however, the semi-arid environment at Yucca House National Monument would preclude much of the shrink-and-swell issue.

The Soil Resources Inventory Program product for Yucca House National Monument has detailed information on the potential for shrink-and-swell issues. This product (National Park Service 2006) is available at the NPS Integrated Resource Management Applications (IRMA) website, or by contacting Pete Biggam (Soil Resources Inventory program manager, NPS Geologic Resources Division).

Surficial Features and Processes

Broad, continuous sheets of water moving across a sloping surface remove thin layers of material and produce slope wash (Qsw) deposits. Such deposits occur on the eastern side of the national monument and bisect the vegetated central mound area. Archeological mounds in the northern area of the monument are less vegetated and could be subject to slope wash (G. San Miguel and M. Gillam, conference call, 13 June 2012).

Intermittent surface water may become channelized. For example, two incised alluvial channels, mapped as unit Qal (see geologic map graphic, in pocket), cut southeast across the surface of the national monument. On a smaller scale, intermittent flow may create gullies (fig. 18). Although gully erosion is a natural process, it may be complicated by anthropogenic modifications to surface water flow. Gully erosion depends on external influences such as land use and climatic conditions, and internal adjustments in surface hydrology, stream morphology, changes in sediment availability and type, and biological response of native and invasive plant species (Love and Gellis 2008).

Figure 18. Gully formation at a drainage culvert. Erosive flows are bypassing the culvert forming a gully around it. National Park Service photograph by George San Miguel (Yucca House National Monument, taken October 2012).

In addition to slope wash (Qsw) and alluvium (Qal), the pediment surface, mapped as unit Qpg (see geologic map graphic, in pocket), is a significant feature at Yucca House National Monument. The pediment is a broad, gently sloping erosion surface that formed at the base of the mountain front. It covers much of the western half of the national monument. Like slope wash (Qsw), unit Qpg contains material transported and deposited by unconfined, overland flow, but it also contains material transported downslope via gravity-driven processes (see "Slope Movements" section).

Slope Movements

Surficial units mapped outside Yucca House National Monument include talus (Qt), landslide deposits (Ql), and block rubble (Qb), which are the result of mass-wasting processes as material moves downslope under the force of gravity. The source of slope-movement deposits are bedrock units such as sandstones, calcarenites, and conglomerates—map units Kch, Kpl, Kms, Kmj, Kd, Kbc, Jmw, Jjc, Js, Je, and Jn—which crop out on slopes or form ledges prone to slope movements such as rockfall. Of these sources, only Kmj is mapped within the monument, but the muted topography of the monument's landscape precludes slope movements. However, slope-movement debris (gravel, cobbles, and boulders) may be strewn across pediment surfaces (Qpg) and in washes.

Wieczorek and Snyder (2009)—the chapter in *Geological Monitoring* about mass wasting—described five vital signs for understanding and monitoring slope movements: (1) types of landslides; (2) landslide causes and triggers; (3) geologic materials in landslides; (4) measurement of landslide movement; and (5) assessing landslide hazards and risks.

Aeolian Features and Processes

Wind is a major force that can redistribute soil and soil resources in the Four Corners area. The National Park Service describes soils as the unconsolidated portion of Earth's crust modified (not static) through physical, chemical, and biotic processes into a medium capable of supporting plant growth (see http://nature.nps.gov/geology/soils/index.cfm). Windblown components of soil may include rock fragments, soil litter, organic matter, evaporated salts, and nutrients. Geomorphologists have documented loess (windblown silt) deposits forming on the upper surfaces of alluvial deposits shed from Sleeping Ute Mountain and adjacent ridgeline. These deposits are not particularly mobile, but are accumulating (M. Gillam, geologist, conference call, 13 June 2012). Though not mapped within Yucca House National Monument, aeolian sand and silt (map unit Qs) has been deposited along the flanks of the highlands north and northwest of Yucca House (see GRI digital geologic map data).

Increased losses of soil and soil resources by wind erosion can indicate degradation of arid-land ecosystems. Wind erosion and sediment transport may be influenced by overgrazing or other vegetation-denuding activities outside the monument. Aeolian sand from unvegetated surfaces may saltate (process by which particles are moved in short leaps or jumps) onto undisturbed ground, burying vegetation and/or biological soil crusts, or breaking biological soil crusts to expose more soil to erosion.

Lancaster (2009)—the chapter in *Geological Monitoring* about aeolian features and processes—described the following methods and vital signs for monitoring aeolian resources: (1) frequency and magnitude of dust storms; (2) rate of dust deposition; (3) rate of sand transport; (4) wind erosion rate; (5) changes in total area occupied by sand dunes; (6) area of stabilized and active dunes; (7) dune morphology and morphometry; (8) dune field sediment state (supply, availability, mobility); (9) rates of dune migration; and (10) erosion and deposition patterns on dunes.

Seismic Activity

The Colorado Plateau interior has low-level seismic hazards (Wong et al. 1996). A seismograph at nearby Mesa Verde National Park records seismic activity, which is frequent but very small magnitude (G. San Miguel and M. Gillam, conference call, 13 June 2012). Ground shaking from earthquakes may cause surficial damage to the mounds that cover the ancient structures at Yucca House National Monument, but probably does not damage unexcavated artifacts. If the structures were ever to be excavated, they would be subject to potential damage from seismic activity.

Braile (2009)—the chapter in *Geological Monitoring* about earthquakes and seismic activity—described the following methods and vital signs for understanding earthquakes and monitoring seismic activity: (1) monitoring earthquakes; (2) analysis and statistics of earthquake activity; (3) analysis of historical and prehistoric earthquake activity; (4) earthquake risk estimation; (5) geodetic monitoring and ground deformation; and (6) geomorphic and geologic indications of active tectonics.

Future Park Development

The act of leaving the ruins in situ, as mounds, was originally due to lack of support for excavations. Now, the unexcavated nature of the site is an intentional management practice to preserve the ruins for future research and to show what ancient Puebloan sites look like before excavation and/or reconstruction (G. San Miguel, conference call, 13 June 2012). Detailed archeological mapping by Glowacki (2001) established the spatial relationships among the different architectural features at Yucca House National Monument. Glowacki's report forms an important baseline assessment of the ruins for current and future management.

In 1919, little was known about the extent and distribution of archeological resources surrounding Yucca House National Monument. The monument was originally only 4 ha (9 ac), but was expanded to 14 ha (34 ac) in 1996 to include additional resources. Currently, many more ancestral Puebloan sites, including the original building-stone quarry (or quarries) for Yucca House, are thought to exist beyond the monument's boundaries. The ancestral Puebloans probably utilized the closest local source of building materials. The nearest significant outcrops of the upper two units of the Juana Lopez Member (Kmj) calcarenite, which are potential quarry areas, are about 800 m (0.5 mi) west and southwest of the monument (fig. 19) (Griffitts 2001).

Figure 19. Outcrop of calcarenite beds of the Juana Lopez Member of the Mancos Shale. This exposure of Mancos Shale (Kmj) is about 800 m (0.5 mi) southwest of Yucca House National Monument. Such a location may have provided building materials for Yucca House. Photograph by Mary O. Griffitts (Griffitts 2001, figure 3).

Additional exposures occur in gullies in the northwestern corner of the monument and in a hillside east of Highway 491 (M. Colyer, retired biological technician, Mesa Verde National Park, written communication 28 June 2012). National monument staff is very interested in determining the exact location of the building stone quarry, though this activity may have been dispersed among several potential sites at bedrock outcrops (G. San Miguel, written communication, 2 October 2012).

The National Park Service is in the midst of negotiating the inclusion of an additional 32 ha (80 ac) of land to the southeast of the monument. In contrast to the gentle hill within the current boundaries, this new parcel is in a low-lying area within Navajo Wash (fig. 17). Previous landowners built a series of catch basins within this parcel that once hosted wetlands (cattail marshes). Due to rising local temperatures and decreasing precipitation, between approximately 2000 and 2012, these artificial wetland features have disappeared; evaporitic calcium salts now cover much of the land surface (G. San Miguel, conference call, 13 June 2012).

If this parcel is added to the national monument, new natural resource management issues would include monitoring gully formation and possible fluvial processes (flash floods) associated with Navajo Wash and tributary channels that occasionally experience brownish water flows through the parcel (G. San Miguel and M. Gillam, conference call, 13 June 2012).

Although limited water rights accompanied the original 1919 donation of land, Yucca House National Monument currently has no water rights (G. San Miguel, written communication, 2 October 2012). Water rights to Aztec Spring are still retained by the adjacent ranch (G. San Miguel, written communication, 15 May 2013), although the ranch's water supply comes primarily from the Dolores River. If the monument is developed for visitor use, the hydrology of the area will need to be investigated and water sources defined.

The monument is currently developing a new general management plan (GMP) that will address visitor access to the monument, interpretive signage, and infrastructure. Because the monument does not currently contain any designated trails, visitation into the monument has resulted in the development of unauthorized "social trails." One such trail crosses the flow path of Aztec Spring, dispersing it (S. Monroe, hydrologist, NPS Southern Colorado Plateau Network, written communication, 9 November 2012). Distinctive social trails occur around the gate and on some archeological mounds (fig. 20); otherwise, they are widely dispersed throughout the national monument (G. San Miguel, written communication, 2 October 2012).

The current boundary includes a long, thin strip originally intended to be an access road. However, this strip is too steep for such a road. If the 32-ha (80-ac) parcel is acquired, space would be available to design a parking facility. Building an access road from the east to a parking area at the middle point is preferred. Soil and substrate characteristics will factor strongly into any infrastructure development considerations (G. San Miguel, conference call, 13 June 2012). The Soils Resources Inventory map and report (National Park Service 2006) include infrastructure development considerations for Yucca House National Monument.

Figure 20. Social trail on the Upper House mound. Without a designated trail system, visitation to Yucca House National Monument has created social trails via repeated trampling. National Park Service photograph by George San Miguel (Yucca House National Monument, taken October 2012).

Energy Development

The Bureau of Land Management (BLM) is using GIS to determine locations for solar energy developments. In 2012, a suitable location within Montezuma County appeared to be 5 km (3 mi) north of Yucca House National Monument, on the other side of a view-blocking ridge, the Aztec Divide, which separates the McElmo drainage to the north and west from the Navajo drainage to the south (G. San Miguel, written communication, 2 October 2012). In 2013, however, this particular parcel was determined to be part of a protected landscape and not an option for energy development. As of May 2013, the closest BLM lands potentially available for development are several kilometers east of Cortez and not visible from Yucca House National Monument. However, they are visible from Mesa Verde National Park (G. San Miguel, written communication, 15 May 2013).

In northern Montezuma County, oil and gas operations currently tap into the Pennsylvanian-age Gothic Shale of

the Paradox Basin. The closest fields are west of Sleeping Ute Mountain some 50 km (30 mi) from the monument (Utah Geological Survey 2003). In the future, however, development of shale gas or coal-bed gas may be likely (G. San Miguel and M. Gillam, conference call, 13 June 2012). The Colorado Oil and Gas Conservation Commission (COGCC) maintains a website (http://cogcc.state.co.us/) that shows current well locations and pending well permits. Active drilling fields include Little Ute, Sleeping Ute, Sage, and McElmo (Colorado Oil and Gas Conservation Commission 2012). None of the bedrock geologic units associated with active drilling—including Kd, Kbc, Jmb, Jmw, Jms, Jjc, Js, Je, and Jn—occurs within the monument. In other parts of Colorado, these rocks are reservoir rocks (porous and permeable rock bodies that accumulate oil and gas), but near Yucca House National Monument, they are likely too close to the surface to have trapped and stored hydrocarbons produced from underlying geologic units.

All land within Yucca House National Monument is federally owned, so surface mineral rights are not a concern. However, land surrounding the national monument is privately owned, and tribal lands occur in Montezuma County.

Geologic History

This section describes the rocks and unconsolidated deposits that appear on the digital geologic map of Yucca House National Monument, the environment in which those units were deposited, and the timing of geologic events that formed the present landscape.

Yucca House National Monument is part of the Colorado Plateau, a physiographic province that includes parts of Colorado, Utah, Arizona, and New Mexico (fig. 3). The rocks on the Colorado Plateau and in the subsurface at the national monument record the episodic but persistent development of western North America. The geologic history of Yucca House National Monument includes long-standing sedimentary deposition in shallow seas, deformation by several orogenies (mountain-building events) that led to the formation of the Rocky Mountains, and uplift of the Colorado Plateau. Much younger, unconsolidated deposits mantle the monument's surface today. These record the relentless processes of weathering and erosion that shape the distinctive topography of the Four Corners area.

Mesozoic Era (251 million–65.5 million years ago): North America Separates from Pangaea and is Flooded by a Shallow Sea

The oldest rocks included as part of the GRI data set for Yucca House National Monument were mapped in the surrounding Mud Creek quadrangle (see "Geologic Map Data" section). These rocks are from the Jurassic Period (approximately 200 million–146 million years ago). During the Jurassic Period, the supercontinent Pangaea—which had formed earlier, at the end of the Paleozoic Era (fig. 4)—was rifting apart. Individual continents on tectonic plates broke away from the huge landmass and began to move toward their present-day positions. The oldest rock unit—Navajo Sandstone (Jn; fig. 5)—represents sand dunes deposited in an arid erg (sand dune "sea") on the western edge of what is now North America (fig. 21A). Atop the Navajo Sandstone, the Jurassic Entrada Sandstone (Je) represents a variety of depositional environments, including tidal mudflats, beaches, and sand ergs, that existed between 180 million and 140 million years ago (fig. 21B). Arid climates prevailed at this time, and Pangaea continued to rift apart as mud and rippled sands of the Summerville Formation (Js) formed in marginal marine and tidal environments of the Middle Jurassic, 161 million–155 million years ago (Wilcox 2007).

The Junction Creek Sandstone (Jjc), which grades up into the Morrison Formation (Jmb, Jmw, and Jms), reflects the formation of a highlands west of the Yucca House National Monument area. As those highlands eroded, sediment was deposited in surrounding lowlands that consisted of alluvial plains, fluvial channels, and floodplains. The units of the Morrison Formation formed in those lowland environments (fig. 21C) (University of Utah 2010). The Burro Canyon Formation (Kbc) consists of stream-laid pebble conglomerates and coarse-grained sandstone with some finer sandstone and shale layers (fig. 21D). These characteristics suggest transport by streams meandering across a broad alluvial plain at the shore of a shallow sea that would become the Western Interior Seaway (Hansen 1965).

Lithospheric plate collisions and mountain building on the western margin of North America caused the western interior of North America to flex into an elongate, north–south shallow basin in the Cretaceous Period. Marine water from the ancestral Gulf of Mexico and Arctic Ocean began to flood this shallow basin as Africa and South America rifted away from North America. Approximately 100 million years ago, during the Upper Cretaceous, deposition of the Dakota Sandstone (Kd) signaled a start of several cycles of marine transgression and regression in the Four Corners area (fig. 21E) (Aubrey 1991; Griffitts 2001). By late Cretaceous time, about 93 million years ago, the Western Interior Seaway (also known as the Cretaceous Interior Seaway) covered previously exposed, continental deposits throughout Colorado and across much of North America (fig. 22).

Throughout the Cretaceous Period, the Four Corners area was a shallow ocean basin, collecting both fine-grained terrestrial sediments and volcanic ash that drifted into the area from the west and southwest. The shoreline changed positions throughout the history of the Western Interior Seaway, either due to increased sedimentation into the basin coming off the highlands forming to the west or from tectonic response to collisions on the western continental margin during the Sevier Orogeny. The thick sequence of shale, siltstone, and limestone beds that make up the rock formation known as the Mancos Shale (Km, Kmc, Kms, Kmv, Kmj, and Kmlm) accumulated directly on the fluvial coastal plain and nearshore deposits of Dakota Sandstone (Kd) (Griffitts 2001). The Mancos Shale is the bedrock that underlies Yucca House National Monument.

At first glance, Mancos Shale appears as a thick section of monotonous black and gray rock, with a few fossil-rich beds. Yet, the history of the Mancos Shale reflects at least four major changes in depositional systems where shoreline and nearshore environments were inundated and new environments were created as sea level rose and fell (fig. 23A–C). The Juana Lopez Member of the Mancos Shale (Kmj), which underlies the monument, was deposited far from shore in a quiet marine environment that received little clastic sediment from land (fig. 21F) (Griffitts 2001). Additionally, fossil evidence suggests that ocean currents within the "Mancos Sea" were not homogeneous. At times, the currents circulated oxygenated water throughout the

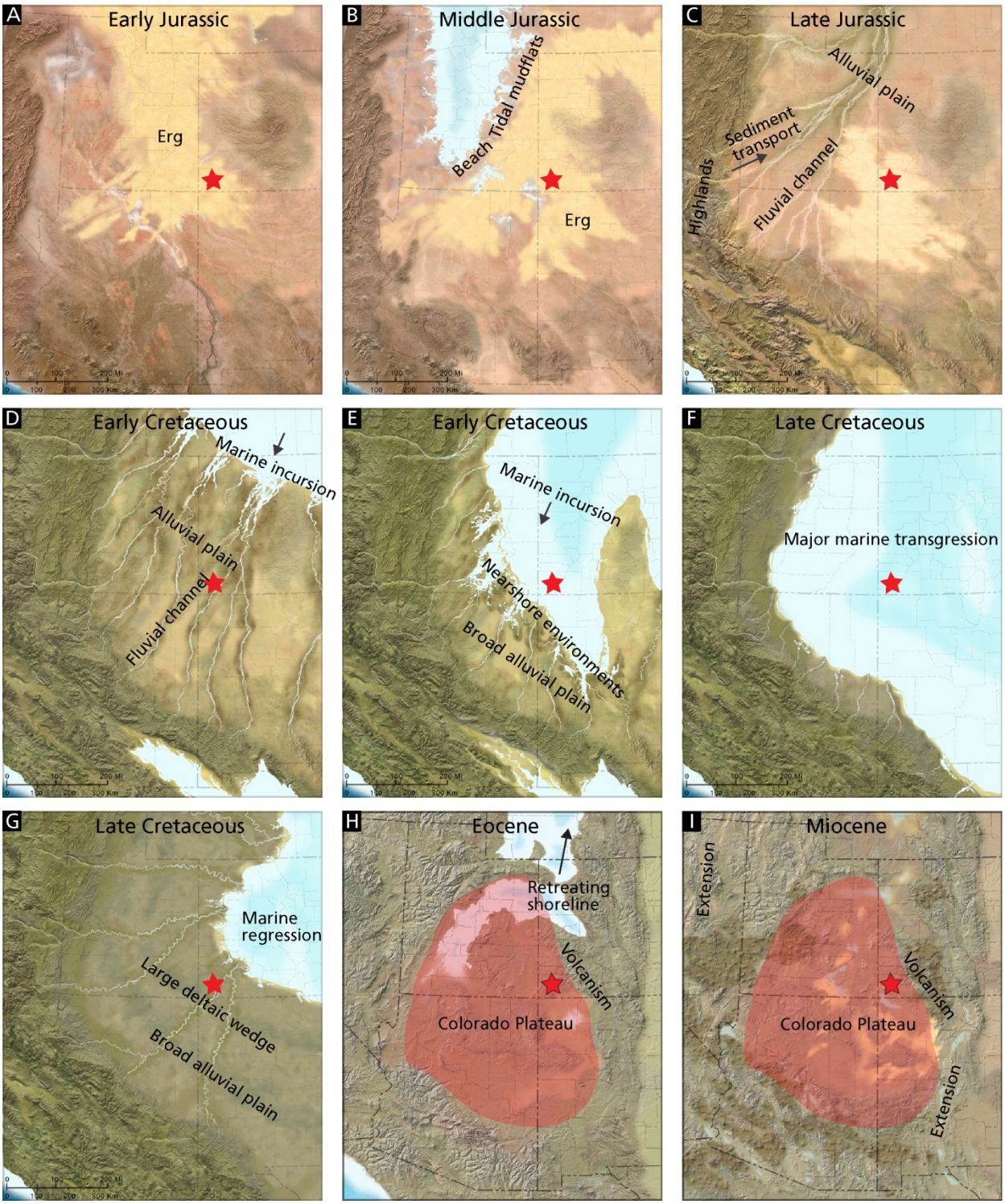


Figure 21. Paleogeographic maps of the Four Corners area. This series of graphics shows the early Jurassic Period through the Miocene Epoch, which is the age range of rocks within and surrounding Yucca House National Monument. The series depicts the changes in depositional environments, the inundation of the Western Interior Seaway, and the development of the Colorado Plateau. Red stars indicate the position of Yucca House National Monument. Paleogeography maps by Ron Blakey (Colorado Plateau Geosystems), available at http://cpgeosystems.com/ColoPlatPalgeog.html (accessed 11 July 2013), annotated by Trista L. Thornberry-Ehrlich (Colorado State University).

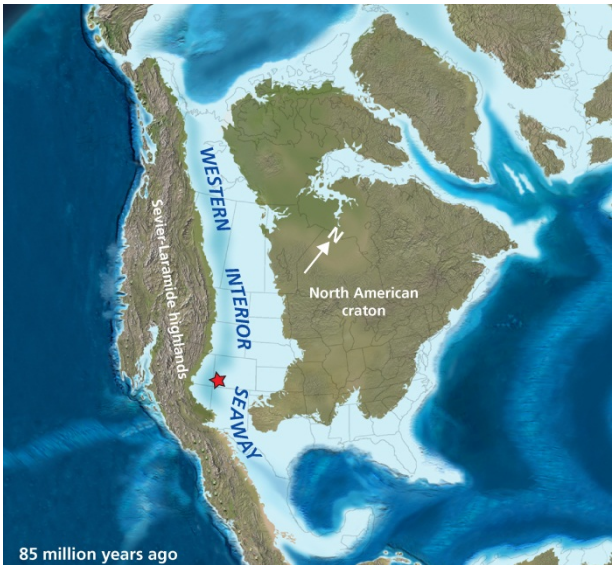


Figure 22. Paleogeographic map of the Western Interior Seaway. At approximately 85 million years ago, the seaway was near its greatest extent, and the Four Corners area was completely inundated. The red star indicates the position of Yucca House National Monument. Paleogeography map by Ron Blakey (Colorado Plateau Geosystems), available at http://cpgeosystems.com/paleomaps.html (accessed 12 July 2013), annotated by Trista L. Thornberry-Ehrlich (Colorado State University).

water column allowing life to prosper at all levels, including within the muddy sea bottom. During transgressions, however, the circulation in the seaway was restricted to the upper water layer, and black, organic-rich muds accumulated in the oxygen-poor sea bottom. In those environments, the fossil material includes very few, if any, bottom-dwelling fauna. As the organic-rich mud was buried, heat and pressure transformed the material to hydrocarbons. Millions of years later, those hydrocarbons would migrate upward through the rocks, out of the buried Mancos Shale and into overlying sandstones (reservoir rocks), where they would much later be the targets of oil and gas exploration.

Fluvial systems that drained the highlands adjacent to the interior seaway formed large deltas that flowed north, northwest, and west into the basin (fig. 23D) (Kent 1968; Cotter 1975; Hill 1982). At this time the Mesa Verde Group—composed of the Point Lookout Formation (Kpl), Menefee Formation (Kme), and Cliff House Sandstone (Kch)—was deposited atop the Mancos Shale as a large deltaic wedge pointing to the northeast (fig. 21G) (Aubrey 1991; Griffitts 2001). This is the youngest geologic map unit from the Mesozoic Era in the vicinity of Yucca House National Monument.

Cenozoic Era (65.5 million years ago to the Present): Uplift of the Colorado Plateau, Regional Erosion

Toward the end of the Cretaceous Period and into the Cenozoic Era, from about 70 million to 35 million years ago, subduction (one tectonic plate sliding beneath another) along the west coast of North America created compressive forces that fueled the Laramide Orogeny and formed much of the present-day Rocky Mountains. The Laramide Orogeny transformed the extensive basin that had housed the Western Interior Seaway into smaller basins, eventually draining the seaway (fig. 21H).

The Colorado Plateau was not folded and faulted in the same manner as the Rocky Mountains. Instead it bowed and flexed, but remained more or less intact with gently tilted sedimentary layers across the landscape (Wanek 1959; Levin 1999). The timing and mechanism of the uplift of the Colorado Plateau is the subject of much study and debate (e.g., Flowers 2010). Based on the presence of widespread marine sediments such as the Mancos Shale and younger Mesa Verde Group, the region was last known to be at sea level during the Upper Cretaceous Period (Ekren and Houser 1959; Griffitts 2001; Flowers 2010). Timing estimates for uplift vary from early, middle, and late Tertiary time (Haynes et al. 1972; Hintze 1988; Levin 1999; Fillmore 2000; Flowers 2010). Two recent studies by Liu and Gurnis (2010) and van Wijk et al. (2010) proposed uneven uplift migrating from southwest to northeast in Upper Cretaceous through mid-Cenozoic time, with a late Cenozoic uplift phase and the development of differential topography along the plateau edges (i.e. a higher plateau topography with sharp edges) (Flowers 2010). To explain the differential uplift, the first study employed a mantle flow and upwelling model to facilitate uplift (Liu and Gurnis 2010); the second study involved small-scale mantle convection along the plateau margins induced by differences in lithospheric thickness between the plateau and adjacent regions (van Wijk et al. 2010). A reasonable model for Colorado Plateau uplift must take into account differential uplift and widespread volcanism throughout the region at that time.

Igneous activity was locally associated with the Laramide Orogeny. Plutons were intruding in the Colorado Mineral Belt, a southwest–northeast-oriented feature of structural weakness and concentrated mineralization that extends from southwestern to north-central Colorado (Christiansen et al. 1994). The relatively shallow intrusions of molten material into sedimentary rocks, called laccoliths, also formed throughout the region. The laccoliths forming Sleeping Ute, Rico, and La Plata mountains were part of an igneous event during the latest Cretaceous Period into the Paleocene Epoch, approximately 65 million–55 million years ago (M. Gilliam, geologist, written communication, 14 May 2013). Near the end of the Laramide Orogeny, from about 35 million–26 million years ago, volcanic activity erupted across the Colorado Plateau, including the San Juan Mountains (Semken 2003). Plutonic rocks called diorite porphyry (map unit TKdp) were emplaced in laccoliths north and west of Yucca House (Mud Creek quadrangle; see "Geologic Map Data" section). Laccoliths that formed the Henry, La Sal, and Abajo mountains were emplaced during Oligocene to Miocene epochs (primarily 34 million–22 million years ago, with minor Miocene activity as late as 14 million–5 million years ago). At this time, volcanism also gave rise to the extensive San Juan volcanic field in southern Colorado east of Mesa Verde National Park (Cunningham et al. 1977; Condon 1991; Baars 2000; Fillmore 2000; Semken

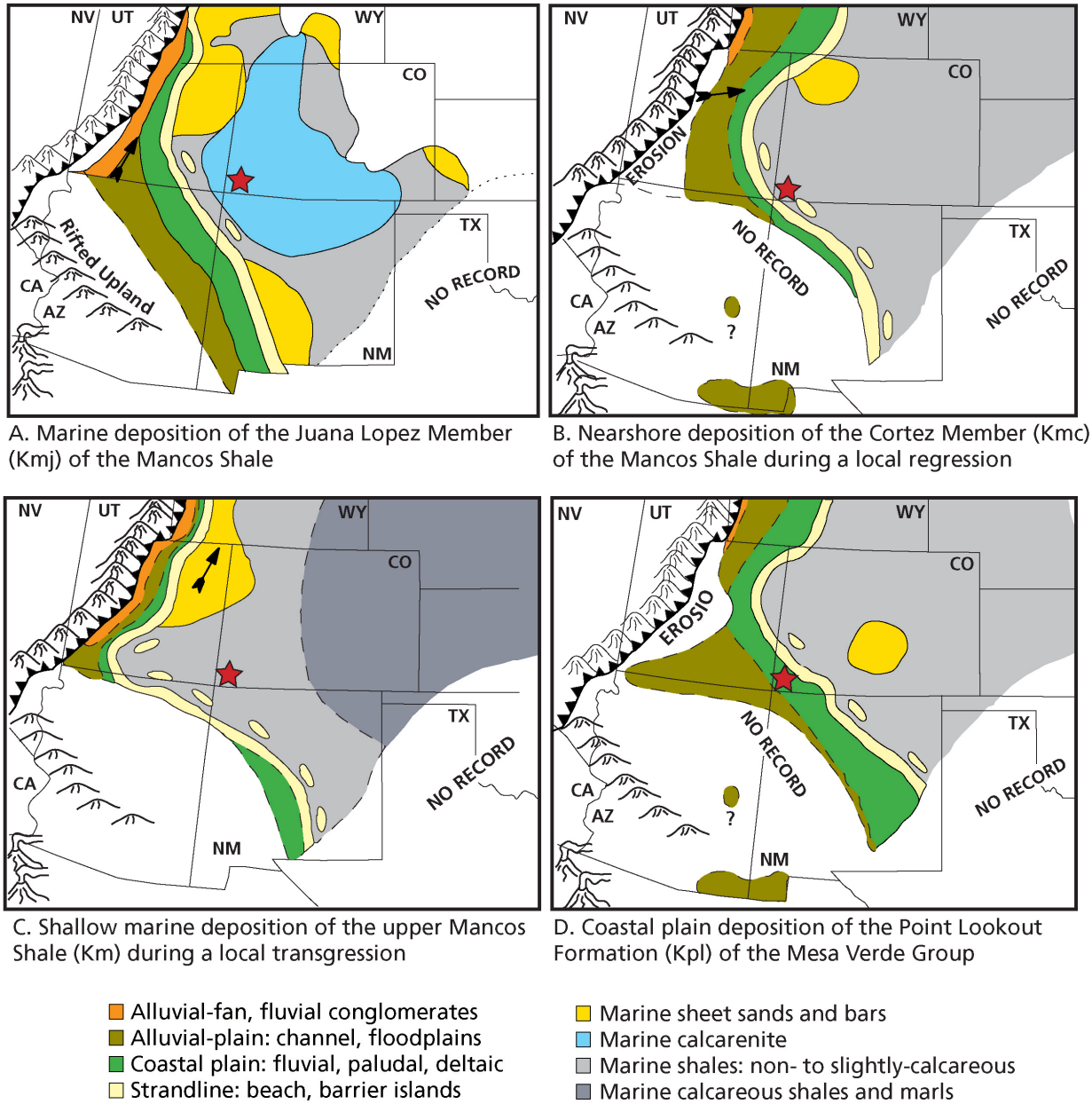


Figure 23. Paleogeographic map of Mancos Shale depositional environments. Graphics show undulating shorelines across the area as the Western Interior Seaway transgressed and regressed throughout the Upper Cretaceous Period. Red stars indicate the location of Yucca House National Monument. Large arrows indicate nearshore sediment transport direction. The chain of triangles marks the leading edge of thrust faulting with the triangles on the overriding plate. Graphic from Elder and Kirkland (1994), modified by Trista L. Thornberry-Ehrlich (Colorado State University).

2003; M. Gilliam, written communication, 14 May 2013). Volcanism and intrusion of igneous dikes locally formed Ship Rock, south of the national monument in New Mexico, approximately 27 million years ago (Delaney 1987). As the mountains rose, the processes of weathering and erosion began to bevel the mountain fronts. After the Western Interior Seaway drained from the continent, rivers carved into the underlying sediment and bedrock. Tertiary gravels eroded from the La Plata Mountains and Sleeping Ute Mountain choked the river channels in the Four Corners area.

A period of volcanic quiescence followed from about 19 million to 16 million years ago. During this time, the southwestern part of the North American continent underwent a tectonic transformation. The compressional regime that had dominated for hundreds of millions of years transitioned to an extensional regime in the southwest (fig. 21I). As Earth's crust pulled apart, the surface developed into the modern-day, basin-and-range, block-faulted topography of western Utah, Nevada, and the Rio Grande rift in New Mexico. Volcanism was concurrent with extension; basaltic lava flows formed resistant layers that cap some of the plateaus and mesas on the Colorado Plateau.

More or less concurrent with uplift of the Colorado Plateau was the entrenchment of the Colorado River and its tributaries (Fillmore 2000). Six million years ago, major drainage in the area that once flowed to the northwest began to flow to the southwest toward the Colorado River (Pederson et al. 2002; M. Gillam, written communication, 14 May 2013). Local drainages created a patchwork of local erosional and constructional (depositional) surfaces coalescing to form a discontinuous southward sloping piedmont, or plain, at the base of the mountains (M. Gillam, written communication, 14 May 2013).

Along with regional uplift in the Quaternary, streams meandering across the broad plain downcut and eroded the area. Deep valleys and river channels carved into the plain, forming the broad Montezuma Valley bordered by the topographically isolated Mesa Verde to the east and the sloping piedmont of the Sleeping Ute Mountain to the west. Flanking the mountain are deposits of sediment (Qt, Ql, Qb, and Qfg) shed from higher elevations. With wetter, cooler climate during the Pleistocene ice ages, streams were rejuvenated, and cut headward into canyons, developing present-day drainages (Harris et al. 1997). Sleeping Ute Mountain and the adjacent ridgeline were not glaciated, though likely were subjected to increased erosion rates under periglacial (beyond, but influenced by glacial activity) conditions associated with the colder climate (J. Johnson, retired geologist, Mesa State College, personal communication, 2001 in National Park Service 2005; M. Gillam, written communication, 14 May 2013). Meltwater, from alpine glaciers in the higher mountains to the north and northwest of Yucca House, transported more gravel deposits into the area. Rainwater, roots, organisms, and other physical and chemical processes weathered the bedrock. Wind blew loess (silt-size particles) into the area from the southwest. Soils began to thicken upon Pleistocene deposits, and a complex soil regime developed over time.

The ancestral Puebloan people made use of this soil system on nearby Mesa Verde by developing agriculture and building terraces on slopes with northeastern exposures (Erdman et al. 1969). In the immediate vicinity of Yucca House National Monument, gravel that eroded from Sleeping Ute Mountain formed an isolated area of unconsolidated sediment (Qal, Qpg, and Qsw) over the Juana Lopez Member of the Mancos Shale (Kmj) (Condon 1991). Finer alluvial deposits fill the axis of the valley. These and other unconsolidated deposits in the region (Qs, Qt, Ql, Qb, and Qfg) reflect the active geomorphological processes at work on the landscape since the Colorado Plateau rose. American Indians used jasper, quartzite, and flint from these alluvial deposits for tool making and other uses. They also utilized local bedrock sources such as the Morrison Formation (Jmb, Jmw, and Jms), Burrow Canyon Formation (Kbc), Mancos Shale (Km and Kmj), and shallow intrusive rocks (Arakawa and Miskell-Gerhardt 2009; M. Gillam, written communication, 14 May 2013).

The current semi-arid climate produces intermittent streams that continue to cut downwards. Alluvium (Qal) collects in small washes, and wind blows eolian silt and sand (Qs) across the landscape. Springs, such as Aztec Spring—integral to the Yucca House story—are fueled by water flowing along the contact between surficial deposits and bedrock.

Today, Yucca House is at an elevation of about 1,800 m (5,900 ft) above sea level, but it rests on 90-million-year-old sediment that was deposited at the bottom of the Western Interior Seaway. Taken together, the rocks mapped within and surrounding Yucca House National Monument represent a variety of environments, including expansive sand dunes, open and nearshore marine settings, lagoons and swamps, deltas, rivers, lakes, and alluvial fans. A long geologic history established these environments that became a foundation for occupation and a framework integral to the 900-year-old history of ancestral Puebloan occupation.

Geologic Map Data

This section summarizes the geologic map data available for Yucca House National Monument. A geologic map graphic (in pocket) displays the map data draped over imagery of the monument and surrounding area. The Map Unit Properties Table (in pocket) summarizes this report's content for each geologic map unit. Complete GIS data are included on the accompanying CD and are also available at the GRI publications website: http://go.nps.gov/gripubs.

Geologic Maps

Geologic maps facilitate an understanding of an area's geologic framework and the evolution of its present landscape. Using designated colors and symbols, these maps show the location, extent, and age of rocks and unconsolidated deposits. Geologic maps can be divided into two primary types: surficial and bedrock. Surficial geologic maps typically encompass deposits that are unconsolidated and formed during the past 2.6 million years (the Quaternary Period). Surficial map units are differentiated by geologic process or depositional environment. Bedrock geologic maps encompass older, typically more consolidated sedimentary, metamorphic, and/or igneous rocks. Bedrock map units are differentiated based on age and/or rock type. Bedrock and surficial geologic map data are provided in the GRI data set for Yucca House National Monument.

Geologic maps often depict geomorphic features, structural interpretations (such as faults or folds), and locations of past geologic hazards that may be prone to future activity. Anthropogenic features such as mines or quarries, as well as observation or collection locations, may be indicated on geologic maps.

Source Maps

The GRI team converts digital and/or paper geologic source maps to GIS formats that conform to the GRI GIS data model. The GRI digital geologic map product also includes essential elements of the source maps, including unit descriptions, map legend, map notes, references, and figures. The GRI team used the following source maps to produce the digital geologic data for Yucca House National Monument. These source maps also provided information for the "Geologic Features and Processes," "Geologic Issues," and "Geologic History" sections of this report.

Carrera, P. 2009. Yucca House geologic map (scale 1:12,000). Unpublished. US Geological Survey, Reston, Virginia, USA.

Ekren, E. B., and F. N. Houser. 1959. Preliminary geologic map of the Cortez SW quadrangle, Montezuma County, Colorado (scale 1:24,000). Miscellaneous field investigations map MF-217. US Geological Survey, Reston, Virginia, USA. http://pubs.er.usgs.gov/publication/mf217 (accessed 11 July 2013).

Griffitts, M. O. 2001. Bedrock geology and paleontology of Yucca House National Monument Area, Colorado (scale 1:62,500). Unpublished. National Park Service, Mesa Verde National Park, Cortez, Colorado, USA.

Griffitts, M. O. 1999. Mesa Verde National Park geology (scale 1:24,000). National Park Service, Mesa Verde National Park, Cortez, Colorado, USA.

Haynes, D. D., J. D. Vogel, and D. G. Wyant. 1972. Geology, structure, and uranium deposits of the Cortez quadrangle, Colorado and Utah (scale 1:250,000). Miscellaneous geologic investigations map I-629. US Geological Survey, Reston, Virginia, USA. http://pubs.er.usgs.gov/publication/i629 (accessed 11 July 2013).

Geologic GIS Data

The GRI team implements a GIS data model that standardizes map deliverables. The data model is included on the enclosed CD and is also available online (http://science.nature.nps.gov/im/inventory/geology/GeologyGISDataModel.cfm). This data model dictates GIS data structure, including layer architecture, feature attribution, and relationships within ESRI ArcGIS software. The GRI team digitized the data for Yucca House National Monument using data model version 2.1.

GRI digital geologic data are included on the attached CD and are available through the NPS Integrated Resource Management Applications (IRMA) portal (https://irma.nps.gov/App/Reference/Search?SearchType=Q). Enter "GRI" as the search text and select a park from the unit list.

The following components are part of the data set:

- Data in ESRI geodatabase and shapefile GIS formats
- Layer files with feature symbology (see table below)
- Federal Geographic Data Committee (FGDC)–compliant metadata
- An ancillary map information document (PDF) that contains other information captured from source maps such as map unit descriptions, geologic unit correlation tables, legends, cross-sections, and graphics

- An ESRI map document (.mxd) that displays the digital geologic data
- A KML/KMZ version of the data viewable in Google Earth (not all data layers are represented in the Google Earth data; see table)

Geology data layers in the Yucca House National Monument GIS data

Data Layer	Map	Data Layer Code	On Overview Graphic?	Google Earth Layer?
Surficial contacts	Surficial	yuhssura	Yes	Yes
Surficial units	Surficial	yuhssur	Yes	Yes
Fault map symbology	Bedrock	yuhosym	Yes	No
Faults	Bedrock	yuhoflt	Yes	Yes
Geologic contacts	Bedrock	yuhoglga	Yes	Yes
Geologic units	Bedrock	yuhoglg	Yes	Yes
Mine point features	Mud Creek quadrangle	mucrmin	No	No
Map symbology	Mud Creek quadrangle	mucrsym	No	No
Geologic measurement localities	Mud Creek quadrangle	mucrgml	No	No
Geologic attitude observation localities	Mud Creek quadrangle	mucratd	No	No
Structure contour lines (base of the Mancos Shale)	Mud Creek quadrangle	mucrcn1	No	No
Linear joints	Mud Creek quadrangle	mucrjln	No	No
Geologic cross section lines	Mud Creek quadrangle	mucrsec	No	No
Folds	Mud Creek quadrangle	mucrfld	No	No
Faults	Mud Creek quadrangle	mucrflt	No	No
Geologic contacts	Mud Creek quadrangle	mucrglga	No	No
Geologic units	Mud Creek quadrangle	mucrglg	No	No

Geologic Map Graphic

A geologic map graphic (in pocket) displays the GRI digital geologic data draped over a shaded relief image of the national monument and surrounding area. For graphic clarity, not all GIS feature classes are visible on the graphic (see table). Geographic information and selected park features have been added to the graphic. Digital elevation data and added geographic information, are not included with the GRI GIS data for the park, but are available online from a variety of sources.

Map Unit Properties Table

The Map Unit Properties Table lists the geologic time division, symbol, and a simplified description for each of the geologic map units in the GRI GIS data. Following the structure of the report, the table summarizes the geologic issues, features, processes, and history associated with each map unit.

Use Constraints

Graphic and written information provided in this report is not a substitute for site-specific investigations. Ground-disturbing activities should neither be permitted nor denied based upon the information provided here. Please contact GRI with any questions.

Graphic and written information provided in this section is not a substitute for site-specific investigations. Ground-disturbing activities should neither be permitted nor denied based upon the information provided here. Minor inaccuracies may exist regarding the location of geologic features relative to other geologic or geographic features on the overview graphic. Based on the source map scales (1:12,000, 1:24,000, 1:62,500, and 1:250,000) and US National Map Accuracy Standards, geologic features represented in the geologic map data are horizontally within 6 m (20 ft), 12 m (40 ft), 32 m (105 ft), and 127 m (417 ft), respectively, of their true location.

Glossary

This glossary contains brief definitions of selected geologic terms relevant to this report. Definitions are based on those in the American Geosciences Institute Glossary of Geology *(5th edition; 2005). Additional terms are defined at: http://geomaps.wr.usgs.gov/parks/misc/glossarya.html.*

aeolian. Describes materials formed, eroded, or deposited by or related to the action of the wind. Also spelled "aeolian."

alluvial fan. A fan-shaped deposit of sediment that accumulates where a hydraulically confined stream flows to a hydraulically unconfined area. Commonly out of a mountainous area into an area such as a valley or plain.

alluvium. Stream-deposited sediment.

amphibole. A common group of rock-forming silicate minerals. Hornblende is the most abundant type.

anticline. A convex-upward ("A" shaped) fold. Older rocks are found in the center.

arc. See "volcanic arc" and "magmatic arc."

argillaceous. Describes a sedimentary rock composed of a substantial amount of clay.

arroyo. A small, deep, flat-floored channel or gully of an ephemeral or intermittent stream in the arid and semiarid regions of the southwestern United States.

ash (volcanic). Fine material ejected from a volcano (also see "tuff").

axis (fold). A straight line approximation of the trend of a fold which divides the two limbs of the fold. "Hinge line" is a preferred term.

back arc. The region adjacent to a subduction-related volcanic arc, on the side of the arc opposite the trench and subducting plate.

bajada. Geomorphic feature formed from the coalescence of alluvial fans along a basin margin.

barrier island. A long, low, narrow island formed by a ridge of sand that parallels the coast.

basalt. A dark-colored, often low-viscosity, extrusive igneous rock.

base flow. Stream flow supported by groundwater; flow not attributed to direct runoff from precipitation or snow melt.

base level. The lowest level to which a stream can erode its channel. The ultimate base level for the land surface is sea level, but temporary base levels may exist locally.

basement. The undifferentiated rocks, commonly igneous and metamorphic, that underlie rocks exposed at the surface.

basin (structural). A doubly plunging syncline in which rocks dip inward from all sides.

basin (sedimentary). Any depression, from continental to local scales, into which sediments are deposited.

beach. A gently sloping shoreline covered with sediment, commonly formed by the action of waves and tides.

bed. The smallest sedimentary strata unit, commonly ranging in thickness from one centimeter to a meter or two and distinguishable from beds above and below.

bedding. Depositional layering or stratification of sediments.

bedrock. A general term for the rock that underlies soil or other unconsolidated, surficial material.

bentonite. A soft clay or greasy claystone composed largely of smectite. Formed by the chemical alteration of glassy volcanic ash in contact with water.

block (fault). A crustal unit bounded by faults, either completely or in part.

calcareous. Describes rock or sediment that contains the mineral calcium carbonate ($CaCO_3$).

calcarenite. A limestone consisting predominantly of sand-size carbonate grains; a consolidated calcareous sand.

calc-silicate rock. A metamorphic rock consisting mainly of calcium-bearing silicates and formed by metamorphism of impure limestone or dolomite.

calcite. A common rock-forming mineral: $CaCO_3$ (calcium carbonate).

carbonaceous. Describes a rock or sediment with considerable carbon content, especially organics, hydrocarbons, or coal.

carbonate. A mineral that has CO_3^{-2} as its essential component (e.g., calcite and aragonite).

carbonate rock. A rock consisting chiefly of carbonate minerals (e.g., limestone, dolomite, or carbonatite).

cementation. Chemical precipitation of material into pores between grains that bind the grains into rock.

chemical sediment. A sediment precipitated directly from solution (also called nonclastic).

chert. A extremely hard sedimentary rock with conchoidal (smooth curved surface) fracturing. It consists chiefly of interlocking crystals of quartz, also called "flint."

clast. An individual grain or rock fragment in a sedimentary rock, produced by the physical disintegration of a larger rock mass.

clastic. Describes rock or sediment made of fragments of pre-existing rocks (clasts).

clay. Can be used to refer to clay minerals or as a sedimentary fragment size classification (less than 1/256 mm [0.00015 in]).

claystone. Lithified clay having the texture and composition of shale but lacking shale's fine layering and fissility (characteristic splitting into thin layers).

cleavage. The tendency of a rock to split along parallel, closely spaced planar surfaces. It is independent of bedding.

colluvium. A general term for any loose, heterogeneous, and incoherent mass of soil material and/or rock fragments deposited through the action of surface

runoff (rainwash, sheetwash) or slow continuous downslope creep.

conglomerate. A coarse-grained, generally unsorted, sedimentary rock consisting of cemented, rounded clasts larger than 2 mm (0.08 in).

continental crust. Crustal rocks rich in silica and alumina that underlie the continents; ranging in thickness from 35 km (22 mi) to 60 km (37 mi) under mountain ranges.

creep. The slow, imperceptible downslope movement of mineral, rock, and soil particles under gravity.

cross-bedding. Uniform to highly varied sets of inclined sedimentary beds deposited by wind or water that indicate flow conditions such as water flow direction and depth.

cross section. A graphical interpretation of geology, structure, and/or stratigraphy in the third (vertical) dimension based on mapped and measured geological extents and attitudes depicted in a vertically oriented plane.

crust. Earth's outermost compositional shell, 10 to 40 km (6 to 25 mi) thick, consisting predominantly of relatively low-density silicate minerals (also see "oceanic crust" and "continental crust").

crystalline. Describes a regular, orderly, repeating geometric structural arrangement of atoms.

deformation. A general term for the processes of faulting, folding, and shearing of rocks as a result of various Earth forces such as compression (pushing together) and extension (pulling apart).

delta. A sediment wedge deposited where a stream flows into a lake or sea.

differential erosion. Erosion that occurs at irregular or varying rates, caused by differences in the resistance and hardness of surface material.

diorite. A type of plutonic igneous rock. It is the approximate intrusive equivalent of andesite.

dip. The angle between a bed or other geologic surface and horizontal.

dolomite. A carbonate sedimentary rock of which more than 50% by weight or by areal percentages under the microscope consists of the mineral dolomite (calcium-magnesium carbonate).

dolomitic. Describes a dolomite-bearing rock, or a rock containing dolomite.

downcutting. Stream erosion process in which the cutting is directed in primarily downward, as opposed to lateral erosion.

drainage basin. The total area from which a stream system receives or drains precipitation runoff.

dune. A low mound or ridge of sediment, usually sand, deposited by wind.

entrainment. The process of picking up and transporting sediment, commonly by wind or water.

ephemeral stream. A stream that flows briefly only in direct response to precipitation in the immediate locality and whose channel is at all times above the water table.

erg. An regionally extensive tract of sandy desert; a "sand sea."

escarpment. A steep cliff or topographic step resulting from vertical displacement on a fault or by mass movement. Also called a "scarp."

evaporite. A sedimentary rock composed primarily of minerals produced from a saline solution as a result of extensive or total evaporation of the solvent (usually water).

extension. A type of strain resulting from forces "pulling apart." Opposite of compression.

extrusive. Describes molten (igneous) material that has erupted onto Earth's surface.

fan delta. An alluvial fan that builds into a standing body of water. This landform differs from a delta in that a fan delta is next to a highland and typically forms at an active margin.

fanglomerate. A sedimentary rock of heterogeneous materials that were originally deposited in an alluvial fan and have since been cemented into solid rock.

fault. A break in rock along which relative movement has occurred between the two sides.

feldspar. A group of abundant (more than 60% of Earth's crust), light-colored to translucent silicate minerals found in all types of rocks. Usually white and gray to pink. May contain potassium, sodium, calcium, barium, rubidium, and strontium along with aluminum, silica, and oxygen.

fissile. Capable of being easily split along closely spaced planes.

flat slab subduction. Refers to a tectonic plate being subducted beneath another tectonic plate at a relatively shallow angle.

floodplain. The surface or strip of relatively smooth land adjacent to a river channel and formed by the river. Covered with water when the river overflows its banks.

fold. A curve or bend of an originally flat or planar structure such as rock strata, bedding planes, or foliation that is usually a product of deformation.

foliation. A preferred arrangement of crystal planes in minerals. In metamorphic rocks, the term commonly refers to a parallel orientation of planar minerals such as micas.

footwall. The mass of rock beneath a fault surface (also see "hanging wall").

formation. Fundamental rock-stratigraphic unit that is mappable, lithologically distinct from adjoining strata, and has definable upper and lower contacts.

fracture. Irregular breakage of a mineral. Any break in a rock (e.g., crack, joint, fault).

glauconite. A green mineral, closely related to the micas. It is an indicator of very slow sedimentation.

groundmass. The material between the large crystals in a porphyritic igneous rock. Can also refer to the matrix of a sedimentary rock.

gully. A small channel produced by running water in earth or unconsolidated material (e.g., soil or a bare slope).

hanging wall. The mass of rock above a fault surface (also see "footwall").

hydraulic conductivity. Measure of permeability coefficient.

hydrocarbon. Any organic compound gaseous, liquid, or solid consisting solely of carbon and hydrogen.

igneous. Refers to a rock or mineral that originated from molten material; one of the three main classes of rocks—igneous, metamorphic, and sedimentary.

incision. The process whereby a downward-eroding stream deepens its channel or produces a narrow, steep-walled valley.

intrusion. A body of igneous rock that invades (pushes into) older rock. The invading rock may be a plastic solid or magma.

island arc. A line or arc of volcanic islands formed over and parallel to a subduction zone.

joint. A break in rock without relative movement of rocks on either side of the fracture surface.

laccolith. A mushroom- or arcuate-shaped pluton that has intruded sedimentary strata and domed up the overlying sedimentary layers. Common on the Colorado Plateau.

lacustrine. Pertaining to, produced by, or inhabiting a lake or lakes.

lag gravel. An accumulation of coarse material remaining on a surface after the finer material has been blown away by winds.

lamination. Very thin, parallel layers.

landslide. Any process or landform resulting from rapid, gravity-driven mass movement.

lava. Still-molten or solidified magma that has been extruded onto Earth's surface though a volcano or fissure.

lens. A sedimentary deposit characterized by converging surfaces, thick in the middle and thinning out toward the edges, resembling a convex lens.

lenticular. Resembling in shape the cross section of a lens.

limb. Either side of a structural fold.

limestone. A sedimentary rock consisting chiefly of calcium carbonate, primarily in the form of the mineral calcite.

loess. Windblown silt-sized sediment, generally of glacial origin.

magma. Molten rock beneath Earth's surface capable of intrusion and extrusion.

mass wasting. A general term for the downslope movement of soil and rock material under the direct influence of gravity.

meander. Sinuous lateral curve or bend in a stream channel. An entrenched meander is incised, or carved downward into the surface of the valley in which a meander originally formed. The meander preserves its original pattern with little modification.

mechanical weathering. The physical breakup of rocks without change in composition. Synonymous with "physical weathering."

member. A lithostratigraphic unit with definable contacts; a member subdivides a formation.

mesa. A broad, flat-topped erosional hill or mountain bounded by steeply sloping sides or cliffs.

mica. A prominent rock-forming mineral of igneous and metamorphic rocks. It has perfect basal cleavage meaning that it forms flat sheets.

mineral. A naturally occurring, inorganic crystalline solid with a definite chemical composition or compositional range.

monocline. A one-limbed fold in strata that is otherwise flat-lying.

normal fault. A dip-slip fault in which the hanging wall moves down relative to the footwall.

oceanic crust. Earth's crust formed at spreading ridges that underlies the ocean basins. Oceanic crust is 6 to 7 km (3 to 4 miles) thick and generally of basaltic composition.

oil field. A geographic region rich in petroleum resources and containing one or more wells that produce, or have produced, oil and/or gas.

orogeny. A mountain-building event.

outcrop. Any part of a rock mass or formation that is exposed or "crops out" at Earth's surface.

paleogeography. The study, description, and reconstruction of the physical landscape from past geologic periods.

paleontology. The study of the life and chronology of Earth's geologic past based on the fossil record.

palynomorphs. A microscopic, resistant-walled organic body; can include pollen, spores, and colonial algae.

Pangaea. A theoretical, single supercontinent that existed during the Permian and Triassic periods.

parent material. The unconsolidated organic and mineral material in which soil forms.

parent rock. Rock from which soil, sediments, or other rocks are derived.

pebble. Generally, small rounded rock particles from 4 to 64 mm (0.16 to 2.52 in) in diameter.

pediment. A gently sloping, erosional bedrock surface at the foot of mountains or plateau escarpments.

permeability. A measure of the relative ease with which fluids move through the pore spaces of rocks or sediments.

phenocryst. A coarse (large) crystal in a porphyritic igneous rock.

plateau. A broad, flat-topped topographic high (terrestrial or marine) of great extent and elevation above the surrounding plains, canyons, or valleys.

pluton (plutonic). A body of intrusive igneous rock that crystallized at some depth beneath Earth's surface.

porosity. The proportion of void space (e.g., pores or voids) in a volume of rock or sediment deposit.

porphyry. An igneous rock consisting of abundant coarse crystals in a fine-grained matrix.

porphyritic. Describes an igneous rock wherein the rock contains conspicuously large crystals in a fine-grained groundmass.

porphyroclast. A partly-crushed, non-metamorphosed rock fragment within a finer-grained matrix in a metamorphic rock.

regolith. General term for the layer of rock debris, organic matter, and soil that commonly forms the land surface and overlies most bedrock.

regression. A long-term seaward retreat of the shoreline or relative fall of sea level.

rift. A region of crust where extension results in formation of many related normal faults, often associated with volcanic activity.

rift valley. A depression formed by grabens along the crest of an oceanic spreading ridge or in a continental rift zone.

ripple marks. The undulating, approximately parallel and usually small-scale ridge pattern formed on sediment by the flow of wind or water.

rock fall. Mass wasting process where rocks are dislodged and move downslope rapidly; it is the fastest mass wasting process.

sand. A clastic particle smaller than a granule and larger than a silt grain, having a diameter in the range of 1/16 mm (0.0025 in) to 2 mm (0.08 in).

sand sheet. A large irregularly shaped plain of aeolian sand, lacking the discernible slip faces that are common on dunes.

sandstone. Clastic sedimentary rock of predominantly sand-sized grains.

scarp. A steep cliff or topographic step resulting from displacement on a fault, or by mass movement, or erosion. Also called an "escarpment."

sediment. An eroded and deposited, unconsolidated accumulation of rock and mineral fragments.

sedimentary rock. A consolidated and lithified rock consisting of clastic and/or chemical sediment(s). One of the three main classes of rocks—igneous, metamorphic, and sedimentary.

sequence. A major informal rock-stratigraphic unit that is traceable over large areas and defined by a sediments associated with a major sea level transgression-regression.

shale. A clastic sedimentary rock made of clay-sized particles that exhibit parallel splitting properties.

sheet flow. An overland flow or downslope movement of water taking the form of a thin, continuous film over relatively smooth soil or rock surfaces and not concentrated into channels larger than rills.

sheetwash (sheet erosion). The removal of thin layers of surface material more or less evenly from an extensive area of gently sloping land by broad continuous sheets of running water rather than by streams flowing in well-defined channels.

silicate. A compound whose crystal structure contains the SiO_4 tetrahedra.

sill. An igneous intrusion that is of the same orientation as the surrounding rock.

silt. Clastic sedimentary material intermediate in size between fine-grained sand and coarse clay (1/256 to 1/16 mm [0.00015 to 0.002 in]).

siltstone. A variably lithified sedimentary rock composed of silt-sized grains.

slope. The inclined surface of any geomorphic feature or measurement thereof. Synonymous with "gradient."

slump. A generally large, coherent mass movement with a concave-up failure surface and subsequent backward rotation relative to the slope.

soil. Surface accumulation of weathered rock and organic matter capable of supporting plant growth and often overlying the parent material from which it formed.

spring. A site where water issues from the surface due to the intersection of the water table with the ground surface.

strand plain. A prograded shore built seaward by waves and currents, and continuous for some distance along the coast.

strata. Tabular or sheet-like masses or distinct layers of rock.

stratification. The accumulation, or layering of sedimentary rocks in strata. Tabular, or planar, stratification refers to essentially parallel surfaces. Cross-stratification refers to strata inclined at an angle to the main stratification.

stratigraphy. The geologic study of the origin, occurrence, distribution, classification, correlation, and age of rock layers, especially sedimentary rocks.

stream. Any body of water moving under gravity flow in a clearly confined channel.

stream channel. A long, narrow depression shaped by the concentrated flow of a stream and covered continuously or periodically by water.

stream terrace. A planar surface along the sides of a stream valley representing the remnants of an abandoned floodplain, stream bed, or valley floor produced during a former stage of erosion or deposition..

strike. The compass direction of the line of intersection of an inclined surface with a horizontal plane.

structure. The attitude and relative positions of the rock masses of an area resulting from such processes as faulting, folding, and igneous intrusions.

subaerial. Describes conditions and processes that exist or operate in the open air on or immediately adjacent to the land surface.

subduction zone. A convergent plate boundary where oceanic lithosphere descends beneath a continental or oceanic plate and is carried down into the mantle.

syncline. A downward curving (concave-up) fold with layers that dip inward; the core of the syncline contains the stratigraphically-younger rocks.

system (stratigraphy). The group of rocks formed during a period of geologic time.

talus. Rock fragments, usually coarse and angular, lying at the base of a cliff or steep slope from which they have been derived.

tectonic. Relating to large-scale movement and deformation of Earth's crust.

tectonics. The geologic study of the broad structural architecture and deformational processes of the lithosphere and asthenosphere.

terrace. A relatively level bench or step-like surface breaking the continuity of a slope (also see "stream terrace").

terrestrial. Relating to land, Earth, or its inhabitants.

thrust fault. A contractional dip-slip fault with a shallowly dipping fault surface (less than 45°) where the hanging wall moves up and over relative to the footwall.

topography. The general morphology of Earth's surface, including relief and locations of natural and anthropogenic features.

trace (fault). The exposed intersection of a fault with Earth's surface.

trace fossil. Tracks, trails, burrows, coprolites (dung), etc., that preserve evidence of organisms' life activities, rather than the organisms themselves.

transgression. Landward migration of the sea as a result of a relative rise in sea level.

trend. The direction or azimuth of elongation of a linear geologic feature.

type locality. The geographic location where a stratigraphic unit (or fossil) is well displayed, formally defined, and derives its name. The place of original description.

unconfined groundwater. Groundwater that has a water table; i.e., water not confined under pressure beneath a confining bed.

uplift. A structurally high area in the crust, produced by movement that raises the rocks.

volcanic. Describes anything related to volcanoes. Can refer to igneous rock crystallized at or near Earth's surface (e.g., lava).

volcanic arc. A commonly curved, linear, zone of volcanoes above a subduction zone.

wash. A term used especially in the southwestern United States for the broad, gravelly dry bed of an intermittent stream, generally in the bottom of a canyon; it is occasionally swept by a torrent of water.

water table. The upper surface of the saturated zone; the zone of rock in an aquifer saturated with water.

weathering. The physical, chemical, and biological processes by which rock is broken down.

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Additional References

This section lists additional references, resources, and websites that may be of use to resource managers. Web addresses are current as of August 2013. Refer to Appendix B for laws, regulations, and policies that apply to NPS geologic resources.

Geology of National Park Service Areas

NPS Geologic Resources Division (Lakewood, Colorado): http://nature.nps.gov/geology/

NPS Geologic Resources Inventory: http://www.nature.nps.gov/geology/inventory/index.cfm.

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NPS Geoscientist-in-the-parks internship and guest scientist program: http://www.nature.nps.gov/geology/gip/index.cfm

NPS Views program (geology-themed modules are available for Geologic Time, Paleontology, Glaciers, Caves and Karst, Coastal Geology, Volcanoes, and a variety of geologic parks): http://www.nature.nps.gov/views/layouts/Main.html#/Views/

NPS Resource Management Guidance and Documents

1998 National parks omnibus management act: http://www.gpo.gov/fdsys/pkg/PLAW-105publ391/pdf/PLAW-105publ391.pdf

Management Policies 2006 (Chapter 4: Natural resource management): http://www.nps.gov/policy/mp/policies.html#_Toc157232681

NPS-75: Natural resource inventory and monitoring guideline: http://www.nature.nps.gov/nps75/nps75.pdf

NPS Natural resource management reference manual #77: http://www.nature.nps.gov/Rm77/

Geologic monitoring manual:
Young, R., and L. Norby, editors. 2009. Geological monitoring. Geological Society of America, Boulder, Colorado, USA. http://nature.nps.gov/geology/monitoring/index.cfm

Geological Surveys and Societies

Colorado Geological Survey: http://geosurvey.state.co.us/

Arizona Geological Survey: http://www.azgs.az.gov/

Utah Geological Survey: http://geology.utah.gov/

New Mexico Bureau of Geology and Mineral Resources: http://geoinfo.nmt.edu/

US Geological Survey: http://www.usgs.gov/

Geological Society of America: http://www.geosociety.org/

American Geosciences Institute: http://www.agiweb.org/

Association of American State Geologists: http://www.stategeologists.org/

US Geological Survey Reference Tools

US Geological Survey national geologic map database (NGMDB): http://ngmdb.usgs.gov/

US Geological Survey geologic names lexicon (GEOLEX; geologic unit nomenclature and summary): http://ngmdb.usgs.gov/Geolex/geolex_home.html

US Geological Survey geographic names information system (GNIS; official listing of place names and geographic features): http://gnis.usgs.gov/

US Geological Survey geoPDFs (download searchable PDFs of any topographic map in the United States): http://store.usgs.gov (click on "Map Locator")

US Geological Survey publications warehouse (many publications available online): http://pubs.er.usgs.gov

US Geological Survey tapestry of time and terrain (descriptions of physiographic provinces): http://tapestry.usgs.gov/Default.html

Appendix A: Scoping Meeting Participants

The following people attended the GRI scoping meetings for Yucca House National Monument, held on 17 July 1998 and 24–27 May 1999, in conjunction with meetings for Mesa Verde National Park and Hovenweep National Monument, or the follow-up report writing conference call, held on 13 June 2012. Discussions during these meetings supplied a foundation for this GRI report. The scoping summary document is available on the GRI publications website: http://go.nps.gov/gripubs.

1998 Scoping Meeting Participants

Name	Affiliation	Position
Chris Carroll	Colorado Geological Survey	Geologist
Marilyn Colyer	Mesa Verde National Park	Natural Resources
Tim Connors	NPS Geologic Resources Division	Geologist, GRI Maps Coordinator
Jim Fassett	U.S. Geological Survey	Geologist
Gary Gasaway	Mesa Verde National Park	Maintenance
Mary Gillam	Mesa Verde National Park	VIP Geologist/Consultant
Joe Gregson	NPS NRID I&M	Geologist
Mary Griffitts	Mesa Verde National Park	VIP Geologist
Bruce Heise	NPS Geologic Resources Division	Geologist, GRI Program Coordinator
Allan Loy	Mesa Verde National Park	GIS Specialist
Will Morris	Mesa Verde National Park	Interpretation
Doug Ramsey	NRCS Soil Survey	Scientist
George San Miguel	Mesa Verde National Park	Natural Resources
Larry Wiese	Mesa Verde National Park	Superintendent
Chris Wilkins	Mesa Verde National Park	GIS Specialist

1999 Scoping Meeting Participants

Name	Affiliation	Position
Joe Gregson	NPS NRID I&M	Geologist
Tim Connors	NPS Geologic Resources Division	Geologist GRI Maps Coordinator
Bruce Heise	NPS Geologic Resources Division	Geologist GRI Program Coordinator
Christine Turner	U.S. Geological Survey	Geologist
Fred Peterson	U.S. Geological Survey	Geologist
Jack Stanesco	Red Rocks CC	
Craig Hauke	Canyonlands National Park	
Grant Willis	Utah Geological Survey	Geologist
George Billingsley	U.S. Geological Survey	Geologist
Vince Santucci	NPS Geologic Resources Division	Geologist/Paleontologist
Jim Dougan	Natural Bridges National Monument	
Al Echevarria	Red Rocks CC	
Dave Wood	Canyonlands National Park	
Traci Kolc	Canyonlands National Park	
Margaret Boettcher	NPS Arches National Park SCA	
Clay Parcels	Arches National Park	
Alicia Lafever	Arches National Park	
Adrienne Gaughan	Arches National Park	
Shawn Duffy	Arches National Park	
Murray Shoemaker	Arches National Park	
Helmut Doelling	Utah Geological Survey	Geologist
Doug Sprinkel	Utah Geological Survey/Utah Geological Association	Geologist
Jim Webster	Arches National Park	
Gery Wakefield	NPS SEUG	GIS coordinator
Phil Brueck	NPS SEUG	
Bruce Rodgers	NPS SEUG	
Diane Allen	Arches National Park	
Paul Henderson	NPS SEUG	

2012 Conference Call Participants

Name	Affiliation	Position
Jason Kenworthy	NPS Geologic Resources Division	Geologist, GRI Reports Coordinator
Mary Gillam		Geologist/Consultant
Rebecca Port	Colorado State University	Research Associate
George San Miguel	Yucca House National Monument	Natural Resource Manager
Trista Thornberry-Ehrlich	Colorado State University	Geologist

Appendix B: Geologic Resource Laws, Regulations, and Policies

The Geologic Resources Division developed this table to summarize laws, regulations, and policies that specifically apply to National Park Service minerals and geologic resources. The table does not include laws of general application (e.g., Endangered Species Act, Clean Water Act, Wilderness Act, National Environmental Policy Act, or National Historic Preservation Act). The table does include the NPS Organic Act when it serves as the main authority for protection of a particular resource or when other, more specific laws are not available. Information is current as of February 2013. Contact GRD for detailed guidance or a complete list of laws, regulations, and policies for all geologic resources. This appendix is abridged to those resources applicable to Yucca House National Monument.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Paleontology	**National Parks Omnibus Management Act of 1998, 16 USC. § 5937** protects the confidentiality of the nature and specific location of paleontological resources and objects. **Paleontological Resources Preservation Act of 2009**, **16 USC. § 470aaa *et seq.***, provides for the management and protection of paleontological resources on federal lands.	**36 C.F.R. § 2.1(a)(1)(iii)** prohibits destroying, injuring, defacing, removing, digging or disturbing paleontological specimens or parts thereof. **36 C.F.R. § 13.35** prohibition applies even in Alaska parks where the surface collection of other geologic resources is permitted. Regulations in association with 2009 PRPA are being finalized (February 2013).	**Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity. **Section 4.8.2.1** emphasizes I & M, encourages scientific research, directs parks to maintain confidentiality of paleontological information, and allows parks to buy fossils only in accordance with certain criteria.
Rocks and Minerals	**NPS Organic Act**, **16 USC. § 1 *et seq.*** directs the NPS to conserve all resources in parks (which includes rock and mineral resources) unless otherwise authorized by law. **Exception: 16 USC. § 445c (c) – Pipestone National Monument enabling statute**. Authorizes Native American collection of catlinite (red pipestone).	**36 C.F.R. § 2.1** prohibits possessing, destroying, disturbing mineral resources…in park units. **Exception: 36 C.F.R. § 7.91** allows limited gold panning in Whiskeytown. **Exception: 36 C.F.R. § 13.35** allows some surface collection of rocks and minerals in some Alaska parks (not Klondike Gold Rush, Sitka, Denali, Glacier Bay, and Katmai) by non-disturbing methods (e.g., no pickaxes), which can be stopped by superintendent if collection causes significant adverse effects on park resources and visitor enjoyment.	**Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity.
Mining Claims	**Mining in the Parks Act of 1976, 16 USC. § 1901 *et seq.*** authorizes NPS to regulate all activities resulting from exercise of mineral rights, on patented and unpatented mining claims in all areas of the System, in order to preserve and manage those areas. **General Mining Law of 1872, 30 USC. § 21 *et seq.*** Allows US citizens to locate mining claims on Federal lands. Imposes administrative and economic validity requirements for "unpatented" claims (the right to extract Federally-owned locatable minerals). Imposes additional requirements for the processing of "patenting" claims (claimant owns surface and subsurface). Use of patented mining claims may be limited in Wild and Scenic Rivers and OLYM, GLBA, CORO, ORPI, DEVA. **Surface Uses Resources Act of 1955, 30 USC § 612** restricts surface use of unpatented mining claims to mineral activities.	**36 C.F.R. § 5.14** prohibits prospecting, mining, and the location of mining claims under the general mining laws in park areas except as authorized by law. **36 C.F.R. Part 6** regulates solid waste disposal sites in park units. **36 C.F.R. Part 9, Subpart A** requires the owners/operators of mining claims to demonstrate bona fide title to mining claim; submit a plan of operations to NPS describing where, when, and how; prepare/submit a reclamation plan; and submit a bond to cover reclamation and potential liability. **43 C.F.R. Part 36** governs access to mining claims located in, or adjacent to, National Park System units in Alaska.	**Section 6.4.9** requires NPS to seek to remove or extinguish valid mining claims in wilderness through authorized processes, including purchasing valid rights. Where rights are left outstanding, NPS policy is to manage mineral-related activities in NPS wilderness in accordance with the regulations at 36 C.F.R. Parts 6 and 9A. **Section 8.7.1** prohibits location of new mining claims in parks; requires validity examination prior to operations on unpatented claims; and confines operations to claim boundaries.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Nonfederal Oil and Gas	**NPS Organic Act, 16 USC. § 1 *et seq.*** authorizes the NPS to promulgate regulations to protect park resources and values (from, for example, the exercise of mining and mineral rights). Individual Park Enabling Statutes: 16 USC. § 230a (Jean Lafitte NHP & Pres.) 16 USC. §450kk (Fort Union NM), 16 USC. § 459d-3 (Padre Island NS), 16 USC. § 459h-3 (Gulf Islands NS), 16 USC. § 460ee (Big South Fork NRRA), 16 USC. § 460cc-2(i) (Gateway NRA), 16 USC. § 460m (Ozark NSR), 16 USC.§698c (Big Thicket N Pres.), 16 USC. §698f (Big Cypress N Pres.)	**36 C.F.R. Part 6** regulates solid waste disposal sites in park units. **36 C.F.R. Part 9, Subpart B** requires the owners/operators of nonfederally owned oil and gas rights to: - Demonstrate bona fide title to mineral rights; - Submit a plan of operations to NPS describing where, when, how they intend to conduct operations; - Prepare/submit a reclamation plan; and - Submit a bond to cover reclamation and potential liability. **43 CFR Part 36** governs access to nonfederal oil and gas rights located in, or adjacent to, National Park System units in Alaska.	**Section 8.7.3** requires operators must comply with 9B regulations.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Federal Mineral Leasing (Oil and Gas, Salable Minerals, and Non-locatable Minerals)	**The Mineral Leasing Act, 30 USC. § 181 *et seq.***, and the **Mineral Leasing Act for Acquired Lands, 30 USC. § 351 *et seq.*** do not authorize the BLM to lease federally owned minerals in NPS units. **Exceptions**: Glen Canyon NRA (16 USC. § 460dd et seq.), Lake Mead NRA (16 USC. § 460n et seq.), and Whiskeytown-Shasta-Trinity NRA (16 USC. § 460q et seq.) authorizes the BLM to issue federal mineral leases in these units provided that the BLM obtains NPS consent. Such consent must be predicated on an NPS finding of no significant adverse effect on park resources and/or administration. **Exceptions**: Native American Lands Within NPS Boundaries Under the Indian Allottee Leasing Act of 1909, (25 USC. § 396), and the Indian Leasing Act of 1938 (25 USC. §§ 396a, 398 and 399) and Indian Mineral Development Act of 1982 (25 USC.S. §§ 2101-2108), all minerals are subject to lease and apply to Native American trust lands within NPS units. **Federal Coal Leasing Amendments Act of 1975, 30 USC. § 201** does not authorize the BLM to issue leases for coal mining on any area of the national park system.	**36 C.F.R. § 5.14** states prospecting, mining, and…leasing under the mineral leasing laws [is] prohibited in park areas except as authorized by law. **BLM regulations at 43 C.F.R. Parts 3100, 3400, and 3500** govern Federal mineral leasing. **Regulations re: Native American Lands within NPS Units:** 25 C.F.R. pt. 211 governs leasing of tribal lands for mineral development. 25 C.F.R. pt. 212 governs leasing of allotted lands for mineral development. 25 C.F.R. pt. 216 governs surface exploration, mining, and reclamation of lands during mineral development. 25 C.F.R. pt. 224 governs tribal energy resource agreements. 25 C.F.R. pt. 225 governs mineral agreements for the development of Indian-owned minerals entered into pursuant to the Indian Mineral Development Act of 1982, Pub. L. No. 97-382, 96 Stat. 1938 (codified at 25 USC.S. §§ 2101-2108). 30 C.F.R. §§ 1202.100-1202.101 governs royalties on oil produced from Indian leases. 30 C.F.R. §§ 1202.550-1202.558 governs royalties on gas production from Indian leases. 30 C.F.R. §§ 1206.50-1206.62 and §§ 1206.170-1206.176 governs product valuation for mineral resources produced from Indian oil and gas leases. 30 C.F.R. § 1206.450 governs the valuation coal from Indian Tribal and Allotted leases. 43 C.F.R. pt. 3160 governs onshore oil and gas operations, which are overseen by the Bureau of Land Management	**Section 8.7.2** states that all NPS units are closed to new federal mineral leasing except Glen Canyon, Lake Mead and Whiskeytown-Shasta-Trinity NRAs.
Nonfederal minerals other than oil and gas	**NPS Organic Act, 16 USC. §§ 1 and 3** **Surface Mining Control and Reclamation Act of 1977, 30 USC § 1201 *et. seq.*** prohibits surface coal mining operations on any lands within the boundaries of a NPS unit, subject to valid existing rights.	**NPS regulations at 36 C.F.R. Parts 1, 5, and 6** require the owners/operators of other types of mineral rights to obtain a special use permit from the NPS as a § 5.3 business operation, and § 5.7 – Construction of buildings or other facilities, and to comply with the solid waste regulations at Part 6. **SMCRA Regulations at 30 C.F.R. Chapter VII** govern surface mining operations on Federal lands and Indian lands by requiring permits, bonding, insurance, reclamation , and employee protection. Part 7 of the regulations states that National Park System lands are unsuitable for surface mining.	**Section 8.7.3** states that operators exercising rights in a park unit must comply with 36 CFR Parts 1 and 5.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Park Use of Sand and Gravel	**Materials Act of 1947, 30 USC. § 601** does not authorize the NPS to dispose of mineral materials outside of park units. **Exception:** 16 USC. §90c 1(b) the non-wilderness portion of Lake Chelan National Recreation Area, where sand, rock and gravel may be made available for sale to the residents of Stehekin for local use as long as such sale and disposal does not have significant adverse effects on the administration of the National Recreation Area.	None applicable.	**Section 9.1.3.3** clarifies that only the NPS or its agent can extract park-owned common variety minerals (e.g., sand and gravel), and: - Only for park administrative uses. - After compliance with NEPA and other federal, state, and local laws, and a finding of non-impairment. - After finding the use is park's most reasonable alternative based on environment and economics. - Parks should use existing pits and create new pits only in accordance with park-wide borrow management plan. - Spoil areas must comply with Part 6 standards - NPS must evaluate use of external quarries. Any deviations from this policy require written waiver from the Secretary, Assistant Secretary, or Director.
Upland and Fluvial Processes	**Rivers and Harbors Appropriation Act of 1899, 33 USC. § 403** prohibits the construction of any obstruction, on the waters of the united states, not authorized by congress or approved by the USACE. **Clean Water Act 33USC. § 1342** requires a permit from the USACE prior to any discharge of dredged or fill material into navigable waters (waters of the US (including streams)). **Executive Order 11988** requires federal agencies to avoid adverse impacts to floodplains. (see also D.O. 77-2) **Executive Order 11990** requires plans for potentially affected wetlands (including riparian wetlands). (see also D.O. 77-1)	None Applicable.	**Section 4.1** requires NPS to manage natural resources to preserve fundamental physical and biological processes, as well as individual species, features, and plant and animal communities; maintain all components and processes of naturally evolving park ecosystems. **Section 4.1.5** directs the NPS to re-establish natural functions and processes in human-disturbed components of natural systems in parks unless directed otherwise by Congress. **Section 4.4.2.4** directs the NPS to allow natural recovery of landscapes disturbed by natural phenomena, unless manipulation of the landscape is necessary to protect park development or human safety. **Section 4.6.4** directs the NPS to (1) manage for the preservation of floodplain values; [and] (2) minimize potentially hazardous conditions associated with flooding **Section 4.6.6** directs the NPS to manage watersheds as complete hydrologic systems and minimize human- caused disturbance to the natural upland processes that deliver water, sediment, and woody debris to streams **Section 4.8.1** directs the NPS to allow natural geologic processes to proceed unimpeded. Geologic processes…include…erosion and sedimentation…processes. **Section 4.8.2** directs the NPS to protect geologic features from the unacceptable impacts of human activity while allowing natural processes to continue.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Soils	**Soil and Water Resources Conservation Act, 16 USC. §§ 2011 – 2009** provides for the collection and analysis of soil and related resource data and the appraisal of the status, condition, and trends for these resources. **Farmland Protection Policy Act, 7 USC. § 4201 *et. seq.*** requires NPS to identify and take into account the adverse effects of Federal programs on the preservation of farmland; consider alternative actions, and assure that such Federal programs are compatible with State, unit of local government, and private programs and policies to protect farmland. NPS actions are subject to the FPPA if they may irreversibly convert farmland (directly or indirectly) to nonagricultural use and are completed by a Federal agency or with assistance from a Federal agency. Applicable projects require coordination with the Department of Agriculture's Natural Resources Conservation Service (NRCS).	**7 C.F.R. Parts 610 and 611**are the US Department of Agriculture regulations for the Natural Resources Conservation Service. Part 610 governs the NRCS technical assistance program, soil erosion predictions, and the conservation of private grazing land. Part 611 governs soil surveys and cartographic operations. The NRCS works with the NPS through cooperative arrangements.	**Section 4.8.2.4** requires NPS to: - Prevent unnatural erosion, removal, and contamination. - Conduct soil surveys. - Minimize unavoidable excavation. - Develop/follow written prescriptions (instructions).

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 318/122182, August 2013

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US Department of the Interior

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