National Park Service
U.S. Department of the Interior

Natural Resource Program Center

Mesa Verde National Park

Ancillary Map Information Document

Produced to accompany the Geologic Resources Inventory Digital Geologic Data for Mesa Verde National Park

meve_geology.pdf

Version: 2/4/2010

Geologic Resources Inventory Map Document for Mesa Verde National Park

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Geologic Resources Inventory Map Document

Mesa Verde National Park, Colorado

Document to Accompany Digital Geologic-GIS Data

meve_geology.pdf

Version: 2/4/2010

This document has been developed to accompany the digital geologic-GIS data developed by the Geologic Resources Inventory (GRI) program for Mesa Verde National Park, Colorado (MEVE)

Attempts have been made to reproduce all aspects of the original source products, including the geologic units and their descriptions, geologic cross sections, the geologic report, references and all other pertinent images and information contained in the original publication.

National Park Service (NPS) Geologic Resources Inventory (GRI) Program staff have assembled the digital geologic-GIS data that accompanies this document.

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About the NPS Geologic Resources Inventory Program

Background

Recognizing the interrelationships between the physical (geology, air, and water) and biological (plants and animals) components of the Earth is vital to understanding, managing, and protecting natural resources. The Geologic Resources Inventory (GRI) helps make this connection by providing information on the role of geology and geologic resource management in parks.

Geologic resources for management consideration include both the processes that act upon the Earth and the features formed as a result of these processes. Geologic processes include: erosion and sedimentation; seismic, volcanic, and geothermal activity; glaciation, rockfalls, landslides, and shoreline change. Geologic features include mountains, canyons, natural arches and bridges, minerals, rocks, fossils, cave and karst systems, beaches, dunes, glaciers, volcanoes, and faults.

The Geologic Resources Inventory aims to raise awareness of geology and the role it plays in the environment, and to provide natural resource managers and staff, park planners, interpreters, researchers, and other NPS personnel with information that can help them make informed management decisions.

The GRI team, working closely with the Colorado State University (CSU) Department of Geosciences and a variety of other partners, provides more than 270 parks with a geologic scoping meeting, digital geologic-GIS map data, and a park-specific geologic report.

Products

Scoping Meetings: These park-specific meetings bring together local geologic experts and park staff to inventory and review available geologic data and discuss geologic resource management issues. A summary document is prepared for each meeting that identifies a plan to provide digital map data for the park.

Digital Geologic Maps: Digital geologic maps reproduce all aspects of traditional paper maps, including notes, legend, and cross sections. Bedrock, surficial, and special purpose maps such as coastal or geologic hazard maps may be used by the GRI to create digital Geographic Information Systems (GIS) data and meet park needs. These digital GIS data allow geologic information to be easily viewed and analyzed in conjunction with a wide range of other resource management information data.

For detailed information regarding GIS parameters such as data attribute field definitions, attribute field codes, value definitions, and rules that govern relationships found in the data, refer to the NPS Geology-GIS Data Model document available at: http://science.nature.nps.gov/im/inventory/geology/GeologyGISDataModel.cfm

Geologic Reports: Park-specific geologic reports identify geologic resource management issues as well as features and processes that are important to park ecosystems. In addition, these reports present a brief geologic history of the park and address specific properties of geologic units present in the park.

For a complete listing of Geologic Resource Inventory products and direct links to the download site visit the GRI publications webpage http://www.nature.nps.gov/geology/inventory/gre_publications.cfm

GRI geologic-GIS data is also available online at the NPS Data Store site http://science.nature.nps.gov/nrdata/. To find GRI data select “geology” as a Category, and use “GRI” as a Word Search term.

For more information about the Geologic Resources Inventory Program visit the GRI webpage: http://www.nature.nps.gov/geology/inventory, or contact:

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The Geologic Resources Inventory (GRI) program is funded by the National Park Service (NPS) Inventory and Monitoring (I&M) program. For more information on the Inventory and Monitoring (I&M) program visit: http://science.nature.nps.gov/im/index.cfm

For more information on this and other Inventory and Monitoring (I&M) Natural Resource inventories visit: http://science.nature.nps.gov/im/inventory/index.cfm

Map Unit List

The geologic units present on digital geologic-GIS data produced for Mesa Verde National Park, Colorado (MEVE) are listed below. Units are listed with their assigned unit symbol and unit name (e.g., Qal - Alluvium). Units are listed from youngest to oldest. Information about each geologic unit is also presented in the Geologic Unit Information (UNIT) table included with the GRI geology-GIS data.

Geologic Map Units

Cenozoic Era

Quaternary Period

Qal Alluvium
Qls Colluvium - landslide deposits
Qtg High level terrace gravels
Qtgt High level terrace gravels with travertine cement
Qtr Travertine

Tertiary Period

Ti Minette

Mesozoic Era

Cretaceous Period

Kch Cliff House Formation
Kme Menefee Formation
Kpl Point Lookout Formation
Km Mancos Formation
Kms Mancos Formation, Smoky Hill oyster bench
Kmj Mancos Formation, Juana Lopez Member
Kmb Mancos Formation, Bridge Creek Member
Kd Dakota Sandstone

MAP UNIT DESCRIPTIONS

Descriptions of all geologic map units, generally listed from youngest to oldest, are presented below.

Qal - Alluvium (Quaternary)

Unconsolidated sands, silts, and gravels deposited mainly in stream beds and flood plains (Griffitts, 1999). (*GRI Source Map 978*)

Soil, sand, and gravel of alluvial origin (Wanek, 1954).

Qls - Colluvium - landslide deposits (Quaternary)

Qls - Landslide deposits (Holocene to middle Pleistocene)

Landslide deposit (Holocene to middle Pleistocene)—Unit consists of a heterogeneous mixture of unconsolidated surficial materials and rock fragments in a wide range of sizes. Size and lithology of rock fragments and grain size of matrix depend on various bedrock and surficial units involved in landslide. Unit includes rotational slides, translational slides, debris and rock avalanches, debris and earth flows, and complex landslides (Varnes, 1978). Some identified areas contain a complex of multiple landslide masses that may have moved at different times. Landslides in map area commonly display well-defined geomorphic features including: headwall scarp, hummocky topography, prominent toe, and deflection of drainage. Those landslides shown with a stippled pattern have occurred recently as evidenced by historical records (M. Colyer, written commun., 2006) and vegetation scars. Thickness of larger landslides may exceed 100 ft (SIM-3090). (*GRI Source Map 75204*)

Qls - Landslide deposits (Quaternary)

Unconsolidated and unsorted irregular deposits of boulders, gravel, sand, and silt derived mostly from talus and landslides (Griffitts, 1999). (*GRI Source Map 978*)

Heterogeneous rock detritus such as talus and landslide material (Wanek, 1954).

Qtg - High level terrace gravels (Quaternary)

Unconsolidated gravels on mesa tops in Mancos valley (Griffitts, 1999). (*GRI Source Map 978*)

Gravel and boulder deposits of alluvial origin on high surfaces (Wanek, 1954).

Qtgt - High level terrace gravels with travertine cement (Quaternary)

Poorly sorted gravel deposits (same as Qtg), locally cemented with very thick travertine (Griffitts, 1999). (*GRI Source Map 978*)

Qtr - Travertine (Pleistocene?)

Calcium carbonate deposits, often associated with major joints and faults. Possibly the result of hot spring activity. Age uncertain; as of yet no age-dating research has been done on these deposits (Griffitts, 1999). (*GRI Source Map 978*)

Ti - Minette (Oligocene, probably 32 to 36 Ma)

Igneous plugs and dikes, light gray to almost black biotite and olivine rich lamprophyric rocks containing abundant breccias and locally rounded cobbles of basement rocks (Griffitts, 1999). (*GRI Source Map 978*)

Basic igneous rocks in dikes and plugs (Wanek, 1954).

Kch - Cliff House Formation (Upper Cretaceous)

White to red-brown, fine to medium grained marine sandstones interbedded with sandy shales. Upper and lower units of massive sandstones separated by a unit of thinner bedded sandy shales. Thickness 200-300 feet. Part of “Mesaverde Group”, with Menefee and Point Lookout Formations (Griffitts, 1999). (*GRI Source Map 978*)

Massive cliff-forming pale to dark yellowish-orange cross-bedded marine sandstone, 400+/- feet thick; intertongues toward base with Menefee formation and includes locally an upper tongue, a middle tongue (Barker Dome tongue) and a lower tongue (Wanek, 1954).

See also the Geology section of (SIM-3090) map text for additional unit information.

Kme - Menefee Formation (Upper Cretaceous)

Dark gray and brown carbonaceous non-marine shales, thin siltstones and thin coal beds in upper and lower units separated by a middle sandy unit of poorly sorted, irregular bedded sandstones, sandy shales and bentonite beds. Thickness 400-800 feet. Part of “Mesaverde Group”, with Cliff House and Point Lookout Formations (Griffitts, 1999). (*GRI Source Map 978*)

Gray to grayish-orange lenticular cross-bedded sandstone and gray to brownish-gray and black carbonaceous shale and coal beds, 340-800 feet thick; includes locally an upper coal member, a middle barren member, and a lower coal member; intertongues toward top of Cliff House sandstone, and toward base with massive sandstone member of the Point Lookout sandstone (Wanek, 1954).

See also the Geology section of SIM-3090 map text for additional unit information.

Kpl - Point Lookout Formation (Upper Cretaceous)

White to yellow fine to medium grained marine sandstone with shaly sandstone breaks, highly cross-bedded. Thickness 360 feet. Part of “Mesaverde Group”, with Cliff House and Menefee Formations (Griffitts, 1999). (*GRI Source Map 978*)

Cliff-forming pale to yellowish-orange, cross-bedded marine sandstone; consists of an upper massive sandstone member 230-340 feet thick, and, at the base, an alternating sandstone and shale member 60-140 feet thick which intertongues with the upper massive sandstone member at the top and with the Mancos shale at the base (Wanek, 1954).

See also the Geology section of SIM-3090 map text for additional unit information.

Km - Mancos Formation (Upper Cretaceous)

Marine light to dark gray thin bedded shales and siltstones with well developed faunal zones. 2000 feet. Three faunal/lithologic units mapped where well exposed: Smoky Hill oyster bench, Juana Lopez Member, and Bridge Creek Member (Griffitts, 1999). (*GRI Source Map 978*)

Soft dark-gray to black marine shale containing thin lenses and concretions of sandy yellowish-orange limestone, 2000+/- feet thick; intertongues at top with the sandstone and shale member of the Point Lookout sandstone (Wanek, 1954).

See also the Geology section of SIM-3090 map text for additional unit information.

Kms - Mancos Formation, Smoky Hill oyster bench (Upper Cretaceous)

A prominent oyster (*Pseudoperna congesta*) bench about 900 feet above base of Mancos Formation (also referred to as 'Niobara' on map; (Griffitts, 1999). (*GRI Source Map 978*)

See also the Geology section of SIM-3090 map text for additional unit information.

Kmj - Mancos Formation, Juana Lopez Member (Upper Cretaceous)

About 500 feet above base of Mancos, 140 feet of highly fossiliferous dark silty shale with numerous beds of orange weathering calcarenite and thin bentonites (Griffitts, 1999). (*GRI Source Map 978*)

See also the Geology section of SIM-3090 map text for additional unit information.

Kmb - Mancos Formation, Bridge Creek Member (Upper Cretaceous)

50 feet of light gray limestone and calcareous shale about 80 feet above Dakota / Mancos contact (also referred to as 'Greenhorn Member' on map; Griffitts, 1999). (*GRI Source Map 978*)

See also the Geology section of SIM-3090 map text for additional unit information.

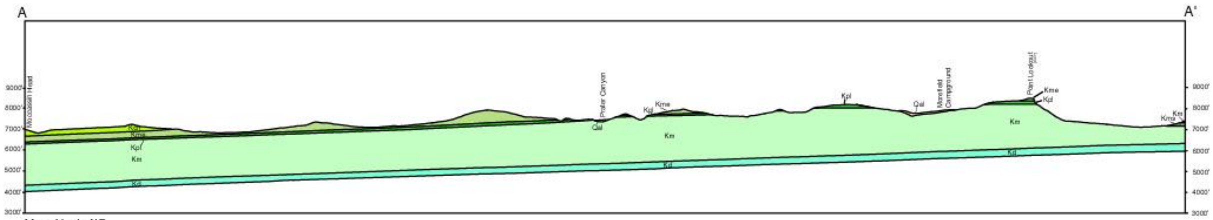
Kd - Dakota Sandstone (Upper Cretaceous)

Dark brown medium to coarse grained marine sandstone (Griffitts, 1999). (*GRI Source Map 978*)

Gray to dark yellowish-orange cross-bedded sandstone that contains shale lenses and beds of coal, 100+/- feet thick (Wanek, 1954).

Geologic Cross Section

The geologic cross section present in the GRI digital geologic-GIS data produced for Mesa Verde National Park, Colorado (MEVE) is presented below.



Mesa Verde NP
Geologic Cross Section A-A'
Geologic Map of Mesa Verde National Park, Colorado
By Mary Griffitts (cross section by Trista L. Thornberry)
unpublished, 2001

Cross section by Trista Thornberry (Colorado State University).

GRI Source Map Citations

The GRI digital geologic-GIS maps for Mesa Verde National Park, Colorado (MEVE) were produced from the following sources:

Griffitts, Mary O., 1999, Mesa Verde National Park Geology, National Park Service, unpublished map, 1:24,000 scale (Griffitts, 1999). (*GRI Source Map 978*)

Carrara, P.E., 2009, Preliminary Map of Landslide Deposits in the Mesa Verde National Park Area, Colorado, U.S. Geological Survey, Scientific Investigations Series Map SIM-3090, 1:24,000 scale (SIM-3090). (*GRI Source Map 75204*)

Additional information pertaining to each source map is also presented in the Source Map Information (MAP) table included with the GRI geology-GIS data.

Griffitts, Mary O., 1999

Griffitts, Mary O., 1999, Mesa Verde National Park Geology, National Park Service, unpublished map, 1:24,000 scale (*GRI Source Map 978*)

Map References

Condon, Steven M., 1991, Geologic and structure contour map of the Ute Mountain Ute Indian Reservation and adjacent areas, southwest Colorado and northwest New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-2083, scale 1:100,000.

Ekren, E.B. and Houser, F.N., 1965, Geology and petrology of the Ute Mountains area, Colorado: U.S. Geological Survey Professional Paper 481, scale 1:48,000.

Hayner, D.D., Vogel, J.D., and Wyant, D.G., 1972, Geology, structure and uranium deposits of the Cortez Quadrangle, Colorado and Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-629, scale 1:250,000.

Leckie, R. Mark, Kirkland, James I., and Elder, William P., 1997, Stratigraphic framework and correlation of a principal section of the Mancos Shale (Upper Cretaceous), Mesa Verde, Colorado: New Mexico Geological Society Guidebook, 48th Field Conference, Mesozoic Geology and Paleontology of the Four Corners Region.

Wanek, A.A., 1959, Geology and fuel resources of the Mesa Verde area, Montezuma and La Plata counties, Colorado: U.S. Geological Survey Bulletin 1072-M, scale 1:63,360.

Base maps from U.S. Geological Survey 7.5 minute series topographic quadrangle maps Cortez (1965, photorevised 1979), Point Lookout (1965, photorevised 1973), Mancos (1965), Wetherill Mesa (1966, photorevised 1975), Moccasin Mesa (1967, photorevised 1975), and Trail Canyon (1966), Colorado; also from 7.5 minute series orthophotoquads Cortez (1975), Point Lookout (1978), Mancos (1978), Wetherill Mesa (1975), Moccasin Mesa (1975), and Trail Canyon (1975), Colorado.

Additional References

Wanek, A.A., 1954, Geologic Map of the Mesa Verde Area, Montezuma County, Colorado, U.S. Geological Survey. Oil and Gas Investigations Map OM-152, 1:63,360 scale.

Griffitts, Mary O., 1990, Guide to the Geology of Mesa Verde National Park: Mesa Verde Museum Association, 88 p.

Cliff House Formation Photograph

Photograph by Anne Poole (NPS).

Mancos Shale Road Cut Photograph

Photograph by Anne Poole (NPS).

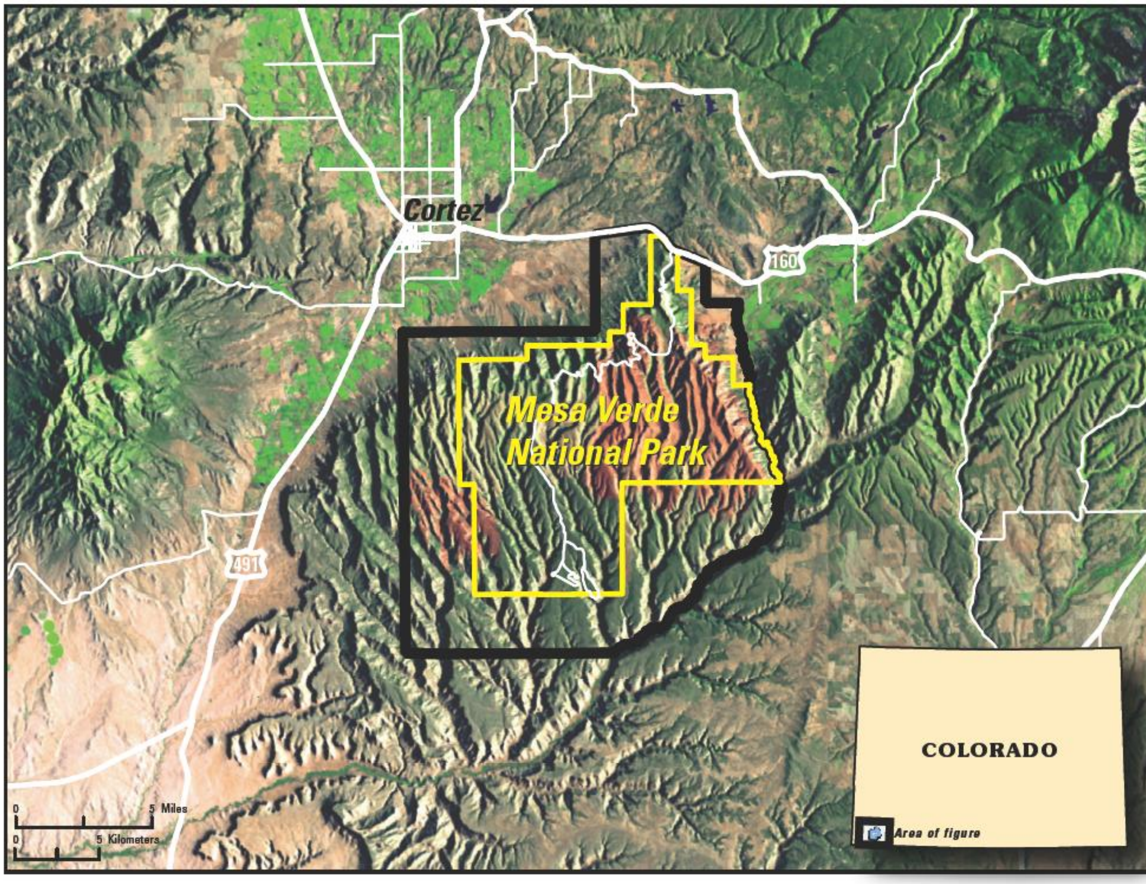
Point Lookout Photograph

Photograph by Anne Poole (NPS).

Carrara, P.E., 2009 (SIM-3090)

Carrara, P.E., 2009, Preliminary Map of Landslide Deposits in the Mesa Verde National Park Area, Colorado, U.S. Geological Survey, Scientific Investigations Series Map SIM-3090, 1:24,000 scale (*GRI Source Map 75204*)

Index Map



Index map. Map showing Mesa Verde National Park (yellow outline) located in the southwestern corner of Colorado. Mapping of Quaternary-age landslide deposits (Qls) was limited to within black boundary line.

Extracted from: (SIM-3090).

Figure 1. Stratigraphic Column

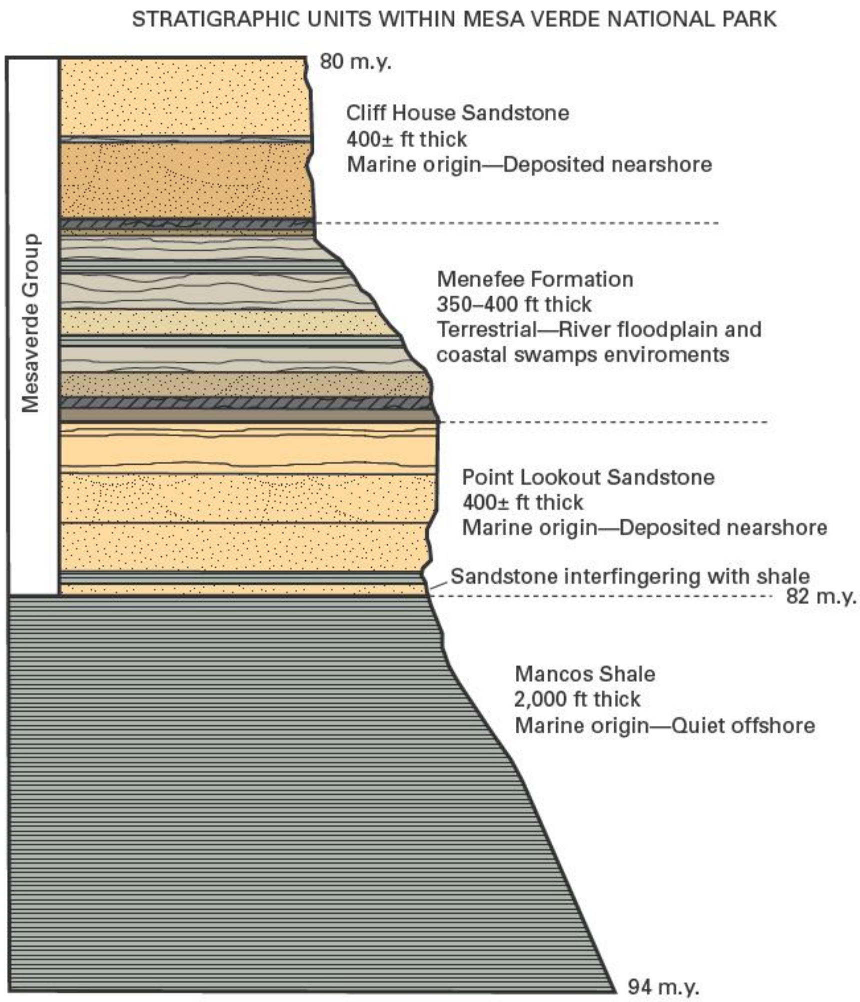


Figure 1. Stratigraphic section of Mesa Verde National Park (after Griffitts, 1990). Ages given are from Cobban and others (2006) and Cobban (personal commun., 2007).

Extracted from: (SIM-3090).

Figure 2. Photograph of landslides near the head of Morefield Canyon

Figure 2. Photograph of large landslide near the head of Morefield Canyon. Although the area is below the boundary between the Mancos Shale and overlying Point Lookout Sandstone, note the boulders of Point Lookout Sandstone in the foreground of the photograph.

Extracted from: (SIM-3090).

Figure 3. Photograph of hills capped by Point Lookout Sandstone rubble

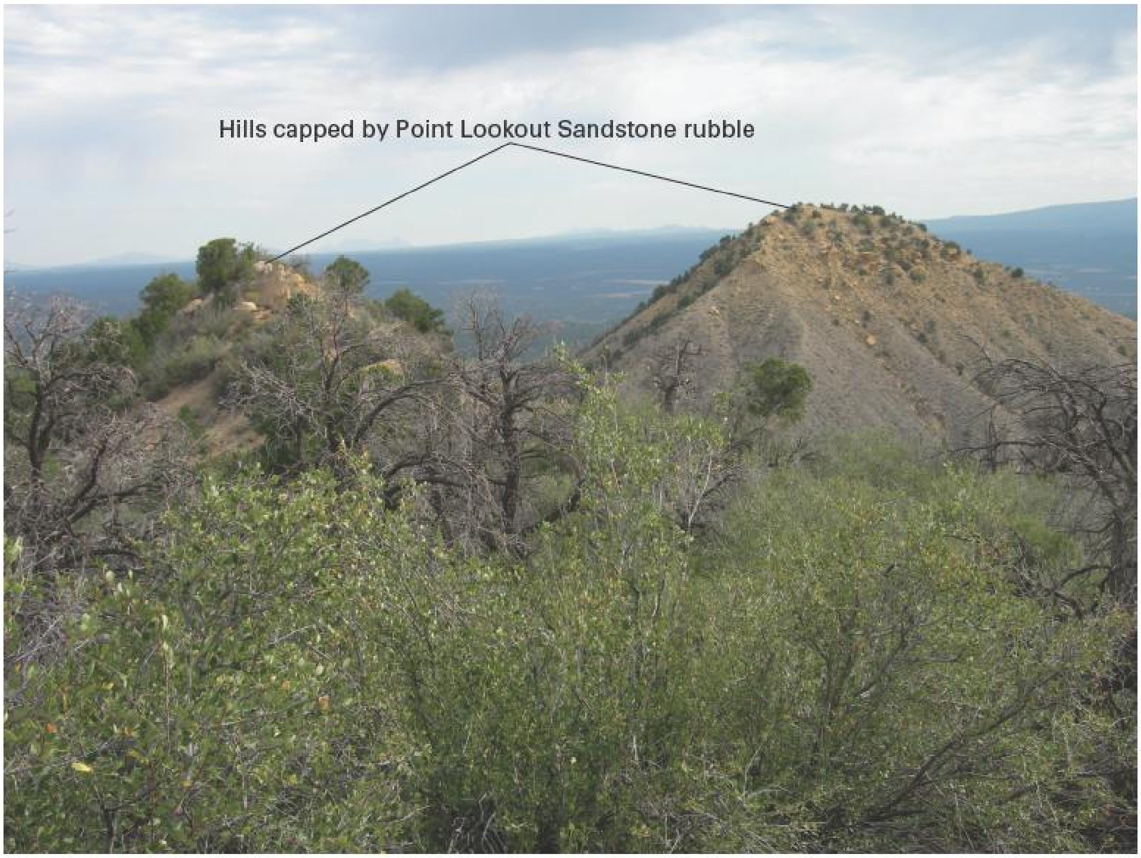


Figure 3. Photograph taken near mile two of the entrance road showing two small hills of Mancos Shale capped by Point Lookout Sandstone landslide rubble.

Extracted from: (SIM-3090).

Figure 4. Photograph of large landslide viewed from the Navajo Canyon Overlook

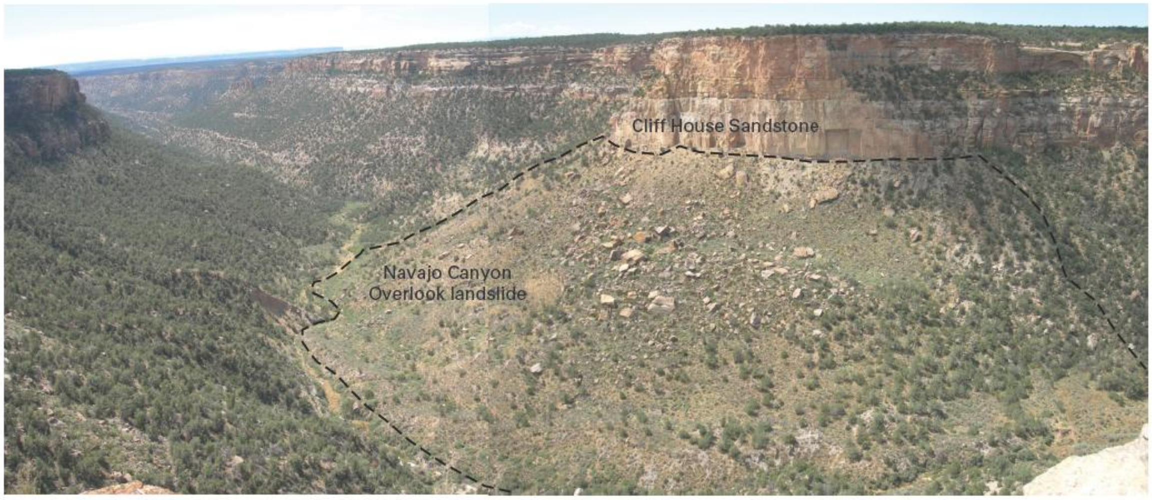


Figure 4. Photograph of large landslide viewed from the Navajo Canyon Overlook. Note that the landslide has pushed the ephemeral stream channel to the eastern side of the canyon. In addition, the landslide temporarily dammed the canyon, forming a flat valley floor of alluvium upstream (beyond the photo to the right).

Extracted from: (SIM-3090).

Figure 5. Photograph of tilted tree on the toe of a small landslide in Wickiup Canyon

Figure 5. Photograph of tilted tree on the toe of a small landslide in Wickiup Canyon. The tilted tree indicates landslide movement during its lifetime. Tree-ring analysis of increment cores taken from several of these trees indicates the landslide occurred in 1986.

Extracted from: (SIM-3090).

Introduction

Importance of Landslide Recognition

This report presents a preliminary map of landslide deposits in the Mesa Verde National Park area (see map sheet) at a compilation scale of 1:50,000. Landslide is a general term for landforms produced by a wide variety of gravity-driven mass movements, including various types of flows, slides, topples and falls, and combinations thereof produced by the slow to rapid downslope transport of surficial materials or bedrock. The map depicts more than 200 landslides ranging in size from small (0.01 sq mi) earthflows and rock slumps to large (greater than 0.50 sq mi) translational slides and complex landslides (Varnes, 1978).

This map has been prepared to provide a regional overview of the distribution of landslide deposits in the Mesa Verde area, and as such constitutes an inventory of landslides in the area. The map is suitable for regional planning to identify broad areas where landslide deposits and processes are concentrated. It should not be used as a substitute for detailed site investigations. Specific areas thought to be subject to landslide hazards should be carefully studied before development.

Many of the landslides depicted on this map are probably stable as they date to the Pleistocene (about 1.8-0.011 Ma) and hence formed under a different climate regime. However, the recognition of these landslides is important because natural and human-induced factors can alter stability. Reduction of lateral support (by excavations or roadcuts), removal of vegetation (by fire or development), or an increase in pore pressure (by heavy rains) may result in the reactivation of landslides or parts of landslides.

History and Geography

Mesa Verde National Park, in southwestern Colorado, was established in 1906 to preserve and protect the dwelling sites, including the famous cliff dwellings, of the Ancestral Puebloans, who lived in the area from about A.D. 550 to A.D. 1300. The geology of the park played a key role in the lives of these ancient people. For example, the numerous (approximately 600) cliff dwellings are closely associated with the Cliff House Sandstone of Late Cretaceous age, which weathers to form deep alcoves. In addition, the ancient people farmed the thick, red loess (wind-blown) deposits on the mesa tops, which because of its clay content has good moisture retention properties. The soil on this loess cover and the seasonal rains of the "Arizona monsoon" allowed these people to grow their crops (corn, beans, squash) on the broad mesa tops.

Today, geology is still an important concern in the Mesa Verde area as it is susceptible to various forms of mass movement (landslides, debris flows, rock falls), swelling soils, and flash floods that affect the park's archeological sites as well as its infrastructure (roads, septic systems, utilities, and building sites).

The map, which encompasses an area of about 140 sq mi, includes all of Mesa Verde National Park, part of the Ute Mountain Indian Reservation, which borders the park on its southern and western sides, and some Bureau of Land Management and privately owned land to the north and east.

Mesa Verde is essentially a broad upland surface sloping gently to the south and dissected by a series of generally north to south-trending, steep-walled canyons containing ephemeral streams that drain south to the Mancos River. The northern edge of the mesa, which contains Park Point, the highest point in the park at an elevation of 8,571 ft, drops abruptly more than 2,000 ft into Montezuma valley, containing the towns of Cortez and Mancos. The steep northern escarpment with its high erosion rate has cut headward back (south) into the rim of the northern escarpment such that upper parts of Morefield and Prater Canyons have been cut away and removed by erosion. These valleys are called "beheaded valleys" as the upper part of their drainage has been removed and their valley floors simply end abruptly at the escarpment. At the southern edge of the upland surface, approximately 9-10 miles distance from its northern edge, elevations range from about 6,700 to 6,900 ft and the canyons that have been incised into it are as much as 1,000 ft deep. Canyon cutting probably began in the early Pleistocene (about 1.8-0.78 Ma).

Climate

The climate of the Mesa Verde National Park region is typical of much of the semiarid southwest. Winters are generally mild, summers are warm, and precipitation is light. Climate records for Mesa Verde National Park, from February 1922 to December 2008, indicate a mean January temperature of 29.1 °F and a mean July temperature of 71.8 °F. The lowest temperature on record is -20 °F on January 13, 1963. The highest temperature on record is 102 °F on July 24, 1936. Mean annual precipitation in the park is 18.11 in. and is fairly evenly distributed throughout the year with 1.5 to 2 in. falling in most months except May (1.06 in.) and June (0.60 in.) when a dry period commonly occurs. After this dry period, the summer precipitation is usually in the form of intense thunderstorms often accompanied by hail. Average annual snowfall totals 80.6 in. (Western Regional Climate Center, unpub. data accessed August 5, 2009, on the World Wide Web at URL http://www.wrcc.dri.edu/summary/Climsmco.html. Thunderstorms occur about 40 days each year, mainly in July and August. The prevailing wind is from the south to southwest.

Vegetation

Several vegetation zones are present in the Mesa Verde National Park area because of its semiarid climate, moderate altitude and relief. The two most extensive vegetation types are the pinyon-juniper forests (Pinus edulis and Juniperus osteosperma), and Petran chaparral or Gambel oak-serviceberry shmbland (Quercus gambellii and Amelanchier utahensis). Pinyon pine and Utah juniper dominate the lower elevations (5,700 to about 7,400 ft) of the mesas and canyon slopes in the southern area of the park, although some Douglas fir and ponderosa pines may be found in well-shaded canyons. At the lower elevational boundary, the pinyon and junipers are small and widely spaced; with increasing elevation, they become larger and are closer together, forming dense woodlands. The ground under the pinyon-juniper forests is commonly bare and rocky, but may support a sparse cover of shrubs, such as big sagebrush (Artemisia tridentate) and bitterbrush (Purshia tridentat), and various grasses. Above about 7,400 ft, in the northern park area, the pinyon-juniper forest gives way to a chaparral dominated by Gambel oak and service-berry with mixed conifers, including ponderosa and pinyon pines, and Douglas fir. These two vegetation zones have similar floristic composition, but differ in appearance and species abundance. Hence, the chaparral may contain scattered pinyon or juniper trees, and many of the chaparral's shrub species grow in the understory of the woodlands (Floyd-Hanna and others, 1994).

Geology

Four geologic formations (fig. 1), all Late Cretaceous in age and dipping gently to the south, are exposed in the Mesa Verde area (Wanek, 1954, 1959; Hayes and others, 1972; Griffitts, 1990; Condon, 1991). The lowest formation is the Mancos Shale, a thick sequence of gray to black fissile shale containing siltstone, and fine-grained sandstone beds, generally less than a foot thick, deposited in a deep-water marine environment. Near the park's entrance, the Mancos Shale is about 2,000 ft thick (Wanek, 1959). This formation is prone to landsliding where exposed on steep slopes.

Overlying and gradational with the Mancos Shale is the Point Lookout Sandstone of the Mesaverde Group. The Point Lookout Sandstone was deposited as barrier beaches and near shore sands (Griffitts, 1990) as the Late Cretaceous sea regressed to the south. Its lower part is interbedded yellowish-gray and light-brown, fine-grained, crossbedded sandstone and olive-gray to gray, sandy, fossiliferous shale; its thickness ranges between 80 and 250 ft (Wanek, 1954, 1959; Condon, 1991). The upper part consists of yellowish-gray, pale-orange, and light-gray, fine- to medium-grained, crossbedded sandstone approximately 200-250 ft thick (Wanek, 1959). The Point Lookout Sandstone forms much of the cap rock in the northern park area.

The Menefee Formation conformably overlies the Point Lookout Sandstone and consists of gray to grayish-orange lenticular, crossbedded sandstone and gray to brownish-gray and black carbonaceous shale, coal beds, and bentonitic clay beds. This formation was deposited in a broad coastal plain environment (Condon, 1991), indicating further southward regression of the Late Cretaceous sea. In the Mesa Verde area, the Menefee Formation is about 350-400 ft thick (Wanek, 1959) and forms broad slopes within many of the park's canyons. The Menefee Formation is prone to failure on steep slopes.

Above the Menefee Formation is the Cliff House Sandstone, which intertongues toward its base with the Menefee Formation. The Cliff House Sandstone consists of a grayish-orange to pale-yellow, fine-grained, thick-bedded sandstone deposited in a shallow nearshore marine environment (Wanek, 1959), indicating a northward transgression of the Late Cretaceous sea. In the southern part of the park, the formation commonly consists of two massive, cliff-forming sandstone beds, each more than 100 ft thick, separated by a thin shale unit (Griffitts, 1990). The upper sandstone bed weathers to form deep alcoves in which many of the cliff dwellings have been built (Wanek, 1959; Griffitts, 1990).

Generally, this formation is stable although rockfalls sometimes occur from the ceilings in the alcoves.

Extracted from: (SIM-3090).

Landslides in the Mesa Verde Area

Landslide Recognition in the Map Area

Although there are several existing geologic maps that encompass the Mesa Verde National Park area (Wanek, 1954, 1959; Hayes and others, 1972; Colton and others, 1975; Condon, 1991; Griffitts, unpub. map, 1999) these maps either: (1) are at a small scale (1:100,000 to L250,000), (2) underrepresent the surficial geology, including landslide deposits, or (3) both. Hence, there is a lack of adequate surficial information for the Mesa Verde National Park area.

Landslides are a dominant surficial feature in the Mesa Verde area. More than 200 landslides, most previously unrecognized and unmapped, have been identified in the map area. These landslides range in size from small (0.01 sq mi) earthflows and rock slumps to large (greater than 0.50 sq mi) translational slides, debris avalanches, and complex landslides (Varnes, 1978), such as the large landslide near the head of Morefield Canyon (fig. 2). Landslide movement takes place on an inclined failure surface that separates the displaced material above from intact substrata below.

Landslide deposits shown on the map were identified and mapped by a variety of methods including: (1) compilation from existing geologic maps (Wanek, 1954, 1959; Hayes and others, 1972; Colton and others, 1975; Condon, 1991; Griffitts, unpub. map, 1999), (2) stereoscopic analysis of 1:12,000-scale color and 1:40,000-scale black-and-white aerial photographs, and (3) fieldwork. Low sun-angle in the early morning and late afternoon enhanced the subdued topography of many older landslide deposits and was a useful aid to their identification in the field.

Physical characteristics common to landslides that aided in their identification included: (1) headwall scarps, (2) hummocky topography, including closed depressions, (3) bulging landslide toes, (4) deflection of ephemeral stream channels by landslide toes, (5) bedrock blocks with anomalous strikes and dips, (6) displaced masses of geologic units downslope from their sources, and (7) vegetation scarring, especially along the northern escarpment. Landslide morphology and topographic relief between the head and toe suggest that some of the larger landslide deposits may be more than 100-feet thick.

Location of Landslides in the Map Area

Within the Mesa Verde National Park area many landslides occur in the Mancos Shale and Menefee Formation. Landslides are present both along the northern and eastern escarpments and within the canyons of the park. Along the steep slopes of the northern and eastern escarpments the Mancos Shale commonly falls as debris flows and rotational or translational landslides. On these escarpments many of the slopes underlain by Mancos Shale are bare of vegetation. indicating very high rates of erosion and ongoing mass-wasting processes.

In addition. the Mancos Shale may have moderate- to high-swelling potential due to the presence of expansive days, and may contain sulfate minerals that are corrosive to conventional concrete and metal pipes. When wet. the surface of the Mancos Shale becomes sticky and very slippery. Unimproved roads are virtually impassable when wet.

Prior to 1957 the entrance road into Mesa Verde National Park traversed the steep Mancos Shale slopes along the northern escarpment between the head of Morefield and Prater Canyons. This 1.5 mile section of road was known as the "Knife Edge." Landslide movement in the eastern part of the Knife Edge consisted of mostly large blocks of weathered shale. which disintegrated into debris slides and in wet weather into small mudflows as they moved downslope (Varnes, 1949). Movement in the western part was mainly by rockfall and, to a lesser extent, rockslides (Varnes, 19491 This section of road was eventually considered too treacherous to maintain by the National Park Service (Martin. 2005). In 1957 a 1,400-ft-long tunnel was constructed between Morefield and Prater Canyons (Dobrovollay and others. 1954: Bohman, 1958) resulting in the abandonment of the Knife Edge section. From the head of Morefield Canyon one can walk a mile section of this old road along the park's Knife Edge Trail. From the Montezuma Overlook, at the head of Prater Canyon, visitors can view the remains of this road as it traversed the steep Mancos Shale slope below the Knife Edge. By bypassing and abandoning the Knife Edge section of road, the present entrance road traverses only about 1.6 miles of steep Mancos Shale slopes along the eastern face of Point Lookout.

Mass-wasting of the underlying Mancos Shale along the northern and eastern escarpments undercuts the overlying Point Lookout Sandstone. which then fails as large rockfalls. rock avalanches. and (or) debris flows. This rubbly debris buries the shale, protecting it Porn erosion. Evidence of this process can be observed upon first entering the park, as along the entrance road several small hills and ridges of Mancos Shale are capped by a jumble of sandstone blocks derived from the Point Lookout Sandstone (fig. 3). These hills and ridges stand above the general terrain as the sandstone rubble, acting as a protective cap, shields the underlying Mancos Shale from erosion.

The Menefee Formation is also prone to failure on steep slopes and forms many large rotational or translational landslides within the canyons of the park. One of these large landslides can be observed from Navajo Canyon Overlook (fig. 4). Here, the landslide pushed the ephemeral stream channel to the eastern side of the canyon, temporarily damming the canyon and forming a flat-valley floor of alluvium on the upvalley side of the landslide.

Much of the road between Montezuma Overlook and the Park Point turnoff is in the Menefee Formation. Parts of this section of road have had to be rerouted because the soft organic-rich shales and thin-bedded, brittle coal layers of the formation are too unstable to allow the road to be maintained safely (Griffitts. 1990).

Age of Landslides

Landsliding in the Mesa Verde area was probably more active during the Pleistocene Epoch. which ended about 11,000 years ago, when the climate was wetter and cooler and canyon incision probably occurred at a faster rate than present. A deposit on a hill near the entrance station to Mesa Verde National Park demonstrates an ancient age for some of the landslide deposits shown on this map. The hill. at an elevation of 7,388 ft. is approximately 300 ft above the surrounding terrain and is capped by a thick (30 ft) blanket of Point Lookout Sandstone rubble. The rubble consists of sand-size particles to boulders as large as 10 ft in intermediate diameter and was emplaced by a large rockfall rock avalanche, or debris flow originating from the Point Lookout Sandstone. That this hill is now 300 ft above the surrounding terrain of Mancos Shale and the nearest outcrop of Point Lookout Sandstone is at Point Lookout, about 1.5 miles to the south, suggests that an extended period of erosion, possibly on the order of several hundreds of thousands of years. has occurred since the deposition of this deposit.

However, landsliding is still an ongoing process in Mesa Verde National Park. As the park has only one entrance road, which traverses a steep slope of Mancos Shale, a landslide along this slope has the potential to trap thousands of visitors inside the park. After an exceedingly wet fall in 1978, a series of landslide movements along the east side of Point Lookout occurred during the spring of 1979 (Plazak, 1989) and closed the entrance road for over a month (Smith, 2002). The first landslide occurred on April 28th, when 100,000 cu ft of material slumped onto a 200-ft section of the road. A second landslide on April 30th deposited about 600,000 cu ft of material onto the road north of the first slide, and on May 27th, a 250-ft section involving one lane of the road moved downslope, further delaying the reopening of Mesa Verde National Park (Smith, 2002). Over the years, millions of dollars have been spent keeping the park's road system open (G. San Miguel, written commun., 2005).

Further evidence of ongoing landslide activity is indicated by tilted pinyon and juniper trees on a small landslide near the lower end of Wickiup Canyon in the southwestern part of the park (fig. 5). The tilted trees indicate landslide movement during the lifetime of the trees. Tree-ring analysis of increment cores taken from several tilted trees indicated the landslide occurred in 1986. In addition, many small landslides in Mesa Verde National Park were recorded between 1974 and 2006 (M. Coyler, written commun., 2006) and other recent landslides are indicated by fresh scars in vegetation. These landslides are indicated by a stippled pattern on the map.

Limitations of Map

Landslide deposits shown on this map are thought to under represent the actual number and aerial extent of landslides present for several reasons: (1) many small landslide deposits (<0.01 sq mi) may not have been recognized because of the scale (1:12,000) of the air photographs used in this study, (2) extensive areas of shadows on some air photographs made interpretation difficult and some landslide deposits in these shadowed areas may not have been identified, (3) small or shallow landslide deposits in the higher parts of the map area, covered by thicker vegetation, may not have been recognized, and (4) older landslide deposits whose original topography has been extensively modified by erosion may not have been identified. Because of the scale of the map, small talus and debris flow deposits are not shown.

Extracted from: (SIM-3090).

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GRI Digital Data Credits

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The information contained here was compiled to accompany the digital geologic-GIS map(s) and other digital data for Mesa Verde National Park developed by Anne Poole and updated by Stephanie O'Meara. GRI digital geologic-GIS map development of the Carrara, P.E., 2009 map from U.S. Geological Survey digital data was done by Stephanie O"Meara.

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