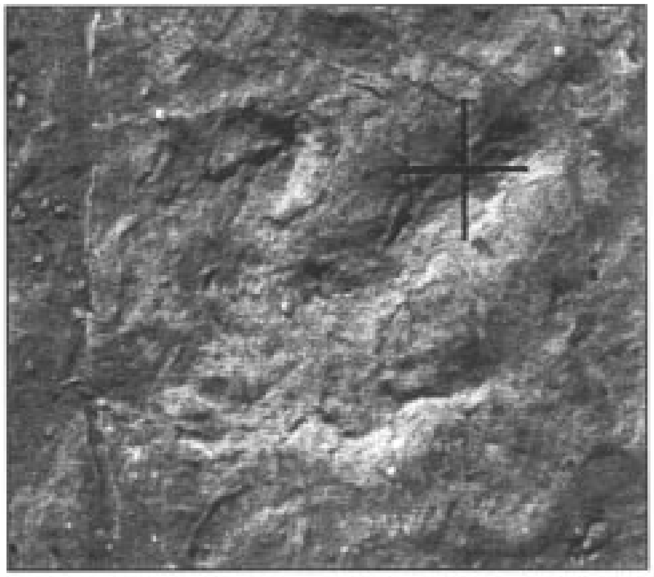
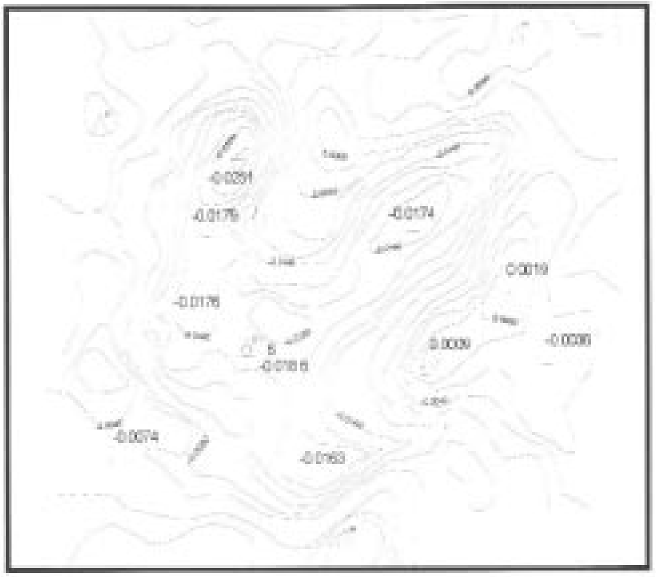
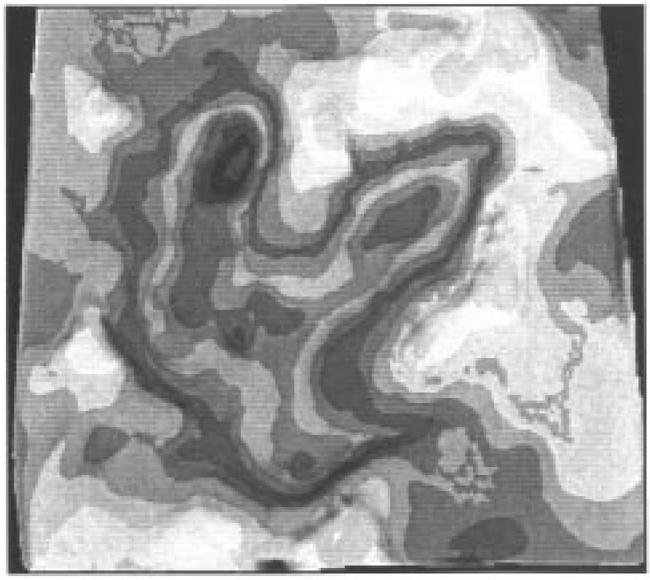
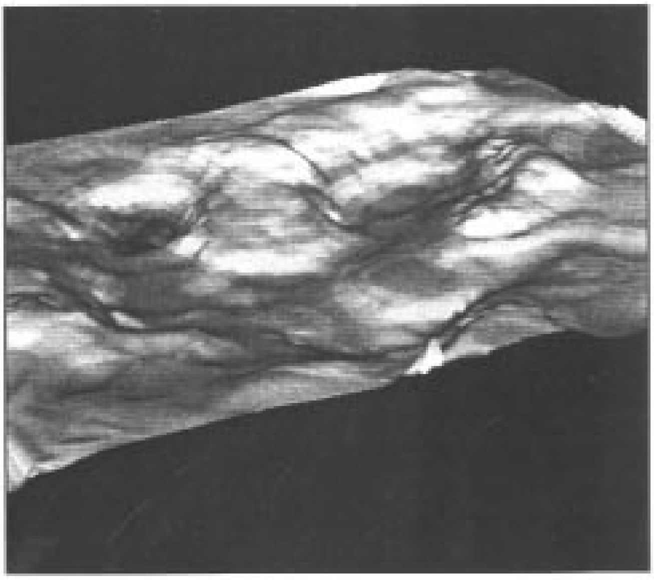
PROCEEDINGS OF THE 6TH FOSSIL RESOURCE CONFERENCE









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Geological Resources Division
12795 West Alameda Parkway
Academy Place, Room 480
Lakewood, CO 80227
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Cover Illustration
Photo of Red Gulch Dinosaur Tracksite footprint (upper left); digital contour of track (upper right); Digital Terrain Model of track, planar view (lower left); and Digital Terrain Model of track, oblique view (lower right).

2001

a fossil odyssey

PROCEEDINGS OF THE 6TH FOSSIL RESOURCE CONFERENCE

EDITED BY

Vincent L. Santucci
National Park Service
PO Box 592
Kemmerer, WY 83101

AND

Lindsay McClelland
National Park Service
Room 3223 - Main Interior
1849 C Street, N.W.
Washington, DC 20240-0001

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AN INVENTORY OF PALEONTOLOGICAL RESOURCES FROM THE NATIONAL PARKS AND MONUMENTS IN COLORADO

REBECCA SCOTT[1], VINCENT L. SANTUCCI[2], AND TIM CONNORS[3]

[1]Bodie State Historic Park, PO Box 515, Bridgeport, CA 93517;
[2]Fossil Butte National Monument, PO Box 592, Kemmerer, WY 83101;
[3]National Park Service, Geologic Resources Division, 12795 West Alameda Parkway, Academy Place, Room 480, Lakewood, CO 80227

ABSTRACT—The National Park Service (NPS) currently administers eleven park units within the state of Colorado. Most of these parks and monuments have been established and are recognized for their significant geologic features. Two monuments in Colorado, Dinosaur National Monument and Florissant Fossil Beds National Monument, were specifically established for their significant paleontological resources. Fossiliferous rocks of Paleozoic, Mesozoic, and/or Cenozoic age have been identified in all of the National Park System units in Colorado. In 2000, the first comprehensive inventory of paleontological resources in the national parks and monuments of Colorado was initiated. A wide diversity of fossilized plants, invertebrates, vertebrates, and trace fossils has been documented. Paleontological resources identified from within the parks and monuments have been assessed for their scientific significance, potential threats, and management as non-renewable resources. Baseline paleontological resource data obtained during this survey will assist National Park Service staff with management of the paleontological resources and protection of fossils within their park.

PALEONTOLOGICAL RESOURCE MANAGEMENT AND PROTECTION

The paleontological resources in the national parks and monuments of Colorado provide valuable information about ancient plants and animals and their environment. Fossils are recognized as non-renewable resources that possess both scientific and educational values. The NPS manages fossils along with other natural and cultural resources for the benefit of the public. All fossils from NPS areas are protected under federal law and their collection is prohibited except under the terms of a research permit.

Paleontological resources are exhibited in a number of national parks and monuments in Colorado. The Quarry Visitor Center at Dinosaur National Monument provides visitors with the opportunity to view the world famous dinosaur bone-bearing rock wall as an *in situ* exhibit. Several thousand macrofossils, representing 110 species, have been collected from Mesa Verde National Park and there are excellent displays of fossils at the park. Florissant Fossil Beds National Monument has an *in situ* exhibit of giant petrified stumps, *Sequoia affinis,* along an interpretive trail.

More comprehensive paleontological resource inventories are underway in a number of the NPS units in Colorado. These surveys are designed to identify the scope, significance, and distribution of the paleontological resources and to assess any natural or human-related threats to these ancient remains. Fossils reported from areas adjacent to the parks and monuments are also considered in this study in order to assess the potential for stratigraphically equivalent resources within park boundaries. Baseline paleontological resource data will enable park staff to enhance the management, protection, research and interpretation of park fossils.

Ongoing and future paleontological research in the various NPS units within the state of Colorado will expand our knowledge of the fossil record and the ancient environments in which these organisms lived.

BENT'S OLD FORT NATIONAL HISTORIC SITE

Bent's Old Fort National Historic Site (BEOL) was authorized on June 3, 1960 as a national historic site to preserve one of the important trading centers on the Sante Fe Trail. The site is one of the smaller NPS areas administered in Colorado. The fort is located on the flood plain of the Arkansas River in the southeastern part of the state.

Bedrock at Bent's Old Fort consists of Cretaceous rocks identified as the Bridge Creek Member of the Greenhorn Limestone Formation. The Greenhorn is overlain by approximately twelve feet (3.6 m) of Pleistocene (Wisconsinan) sands and gravel deposited between 11,000 and 8,000 years ago. This unit is overlain with clayey sand that is also of Wisconsin age (Moore, 1973).

Twenty-eight specimens of the rudist *Durania cornupastoris* were collected from the Bridge Creek Member of the Greenhorn Limestone just outside the park boundaries

(Cobban et al., 1985). Rudists are an extinct group of bivalved (pelecypod) mollusks. The rudist-producing bed in the Bridge Creek Member extends into the national historic site; thus, the potential for this resource in the park also exists.

A fragmentary mammoth tusk was discovered at Bent's Old Fort by Jackson Moore, a NPS archeologist. Tusk fragments were collected by Jackson between 1963 and 1966. The remains were found in a gravel bed overlying a white limestone unit at the historic site (Moore, 1973). The fragments have been tentatively identified as *Mammothus columbi* (personal communication, Nancy Russell, 2000). According to the park's museum records, an additional three mammoth tusk fragments were found in 1992 by archeologist Jerry Dawson.

BLACK CANYON OF THE GUNNISON NATIONAL PARK

Black Canyon of the Gunnison (BLCA) was originally proclaimed a national monument on March 2, 1933, to preserve a twelve mile stretch of river gorge carved by the Gunnison River in west-central Colorado. The Monument was given wilderness designation on October 20, 1976 and was later redesignated as a national park on October 21, 1999.

Hansen (1987) provides a comprehensive overview of the geology of Black Canyon of the Gunnison National Park. Hansen (1971) published a geologic map, which includes the national park. During 1999 and 2000, the National Park Service Geologic Resources Division produced a digital geologic map for BLCA, compiling maps by Hansen, at 1:24,000 scale.

The geologic setting of BLCA consists of a sequence of Precambrian rocks including arkosic sandstones, graywackes, and granite (Hansen, 1967). Renewed crustal movement in the area accompanied the intrusion of the Vernal Mesa and Curecanti plutons (Hansen, 1981). Most of the Paleozoic section in the park has been eroded away before or during the time of the Uncompahgre uplift. The only evidence of Paleozoic rocks in the canyon are diabase dikes dating to the Cambrian or Ordovician.

During the Jurassic, sediments accumulated on the older Precambrian rocks in the Black Canyon area. The Entrada, Wanakah, and Morrison formations preserve Jurassic paleoenvironments in the park, but these are poorly exposed within BLCA. Fiorillo (1996) reports on a Morrison Formation vertebrate locality within the boundaries of BLCA with the most significant fossil locality being a badly weathered sauropod bone impression found on the North Rim (Fiorillo, 2001, personal communication). One locality in the Salt Wash Member of the Morrison Formation, located just outside of the park, has yielded fragments of a theropod posterior caudal vertebra, a sauropod rib, and numerous other dinosaur bone fragments (Anonymous, 1990).

Overlying the Morrison Formation are the Cretaceous Burro Canyon Formation, Dakota Formation and Mancos Shale (Hansen, 1971). A few marine invertebrate fossils are known from the Mancos Shale in the park. A series of Tertiary volcanic eruptions covered the area with lava flows, breccias, and tuffaceous deposits including the West Elk Breccia (Fig. 1).

COLORADO NATIONAL MONUMENT

Colorado National Monument (COLM) was established by presidential proclamation on May 24, 1911. The Monument is located in the west-central portion of Colorado along the eastern margin of the Colorado Plateau and preserves scenic sheer-walled canyons and towering monoliths.

COLM contains rocks dating from the Precambrian to the Cretaceous. Basement rock consists of Precambrian schist and gneiss. During the Paleozoic, the area was uplifted forming the Uncompahgre Highlands. Precambrian rocks are overlain by Mesozoic sedimentary units including, from oldest to youngest, the Chinle Formation, Wingate Sandstone and Kayenta Formation. The Triassic Chinle Formation is the oldest sedimentary formation in the COLM and unconformably overlies Precambrian crystalline rocks, reflecting a major unconformity. All of the sedimentary units in the park are Mesozoic. A theropod track site was discovered in the Chinle Formation in 1990 (A. Hunt, personal communication, 1999). The *Grallator*-like track site is located near the east entrance to the Monument.

Where the Kayenta has been removed; the Wingate Sandstone weathers into rounded domes and forms most of the named features within the Monument (Dubiel, 1992). The Entrada Sandstone of the Jurassic San Rafael Group is usually salmon colored and crossbedded: it is topped by the Wanakah. The Entrada Sandstone of Rattlesnake Canyon has been referred to as the second largest concentration of arches in the world and is of a different origin than the arches at Arches National Park. The Morrison Formation overlies the San Rafael Group and is fossiliferous. The Morrision Formation consists of the Tidwell, Salt Wash and the Brushy Basin Member (Turner and Fishman, 1991). The Jurassic section is topped by the Cretaceous Burro Canyon Formation and Dakota Sandstone (Fig. 2).

In 1900, a famous dinosaur discovery was made in an area just outside of the current boundary of COLM. Elmer Riggs uncovered the forelimb of a sauropod dinosaur (*Camarasaurus grandis*) in the Brushy Basin Member of the Morrison Formation (Armstrong and Kihm, 1980). The site is marked today with an historic marker and is a local tourist stop known as Dinosaur Hill.

During 1977, an inventory of the Morrison Formation in COLM documented fourteen fossil localities (Callison, 1977). Fossils identified during the inventory included bivalves, gastropods, turtles, crocodilians, and dinosaurs, including an ischium of a dryosaur. Most of the specimens were found in the lower Salt Wash Member or Brushy Basin Member of the Morrison Formation. In 1985, many of these sites were resurveyed by George Engelmann yielding unionid bivalves, gastropods, and a sauropod caudal vertebra (Armstrong and Kihm, 1980). Engelmann and Fiorillo (2000) resurveyed these sites again in 1995 and reported several

FIGURE 1. Stratigraphy of Black Canyon of the Gunnison National Park and Curecanti National Recreation Area.

Stratigraphy of Black Canyon of the Gunnison National Park and Curecanti National Recreation Area, Colorado

Era	Period	Epoch	Formation	Member	Map Unit	Description
Cenozoic	Quaternary	Holocene	Alluvium, talus, landslides		Qab	succession of silty sands and gravels, mostly derived locally, underlain by well-rounded, well-sorted stream gravels derived largely from volcanic terraces in the San Juan Mountains.
Cenozoic	Tertiary	Miocene and Pliocene	Hinsdale		Th	Medium- to dark-gray aphanitic slightly vesicular to scoriaceous intermediate (dacite) flow remnants Maximum thickness about 150 feet.
Cenozoic	Tertiary	Oligocene	Carpenter Ridge Tuff		Tcr	Very light gray platy devitrified welded or partly welded tuff; at the base, dark-brown vitrophyre. Maximum thickness about 220 feet.
Cenozoic	Tertiary	Oligocene	Fish Canyon Tuff		Tfc	Light-gray crystal-rich (<45 percent) loosely welded tuff containing predominant fragmented crystals of plagioclase and subordinate sanidine, biotite, quartz, oxyhornblende, and sparse pale-green clinopyroxene.. Maximum thickness about 300 feet.
Cenozoic	Tertiary	Oligocene	Sapinero Mesa Tuff		Tsm	Mostly reddish-brown devitrified welded tuff grading upward into non-welded tuff. At the base, black vitrophyre 20-50 feet thick containing abundant reddish-brown spherulites, commonly underlain by gravel. Thickness commonly about 80-180 feet.
Cenozoic	Tertiary	Oligocene	Dillon Mesa Tuff		Tdm	Mostly light-brown slightly porphyritic moderately welded tuff, locally with 10-20 feet of dark-brown vitrophyre at base, commonly underlain by gravel. Generally less than 80 but locally as much as 180 feet thick.
Cenozoic	Tertiary	Oligocene	Blue Mesa Tuff		Tb	Reddish-brown devitrified densely-welded vitric lapilli ash tuff;
Cenozoic	Tertiary	Oligocene	West Elk Breccia		Twa	Ash-flow tuff lens, locally welded, as much as 200 feet thick.
Mesozoic	Cretaceous	Upper	Mancos Shale		Km	Dark-gray silty clay shale containing scattered lenses of friable gray sandstone and scattered calcareous siltstone concretions. Plastic when wet and susceptible to failure. Section incomplete but as much as 2,200 feet thick near axis of Montrose syncline and beneath Cathedral Peak.
Mesozoic	Cretaceous	Lower	Dakota Sandstone		Kdb	mostly light-gray fine to very fine grained platy sandstone, commonly quartzitic, and dark-gray papery carbonaceous shale; coalbeds near base; minor conglomeratic sandstone. Ripple marks common toward top. Forms dip slopes.
Mesozoic	Cretaceous	Lower	Burro Canyon		Kdb	chiefly very light gray cross-bedded cliff-forming conglomeratic sandstone and pebbly conglomerate. Discontinuous beds of light-gray shale.
Mesozoic	Jurassic	Upper	Morrison	Brushy Basin	Jm	chiefly varicolored red, lavender, green, and light-gray bentonitic mudstone and silty shale, gray to lavender massive siltstone, and fine-grained light-gray sandstone. Mudstone plastic when wet. Pebble conglomerate containing red and green chert pebbles, and locally dinosaur bone, about 140 feet below top. Member is about 315-360 feet thick.
Mesozoic	Jurassic	Upper	Morrison	Salt Wash	Jm	chiefly light-gray massive to cross-bedded fine-grained cliff-forming sandstone interbedded with red silty shale. Sandstone beds lenticular fill channels. Member is about 110-175 feet thick.
Mesozoic	Jurassic	Upper	Wanakah	Junction Creek Sandstone	Jj	Light-gray to light-brown, fine- to medium-grained, quartzose sandstone; massive, thick-bedded, weakly crossbedded; tightly cemented and quartzitic in upper part. Maximum thickness about 180 feet. (
Mesozoic	Jurassic	Upper	Wanakah	Pony Express Limestone	Jwj	discontinuous, locally brecciated fetid pellatal to aphanitic silty gray limestone 1-7 feet thick. Nonexistent east of Dead Horse Mesa.
Mesozoic	Jurassic	Upper	Entrada		Je	very fine grained friable indistinctly cross-bedded eolian sandstone. Basal conglomerate 1-5 feet thick contains abundant fragments of locally derived Precambrian rock
Precambrian	Proterozoic		Pegmatite		Pcp	Very coarse variably grained dikes and sills
Precambrian	Proterozoic		Curecanti Quartz Monzonite		pCc	Light-gray to orange-pink, medium-grained sodic quartz monzonite or granite.
Precambrian	Proterozoic		Vernal Mesa Quartz Monzonite		pCv	pinkish-gray very coarse grained porphyritic weakly to strongly foliated quartz monzonite near to granodiorite in composition.
Precambrian	Proterozoic		Pitts Meadow Granodiorite		pCpv	dark medium-grained variably foliated quartz diorite and diorite.
Precambrian	Proterozoic		Metamorphic rocks		pCa	Dark lineated medium-to coarse-grained schist

Summarized from "**Geologic Map of the Black Canyon of the Gunnison River and Vicinity, Western Colorado**" by Wallace R. Hansen, 1971; scale 1:31,680;USGS Miscellaneous Investigations Series Map I-584 ***NOTE: squiggly lines represent unconformities (major breaks in the geologic record)***

FIGURE 2. Stratigraphy of Colorado National Monument.

Bedrock Stratigraphy of Colorado National Monument, Colorado

Era	Period	Epoch	Formation / Member		Map Unit	Description
Mesozoic	Cretaceous	Upper	Mancos Shale		Km	medium-dark-gray, dark-gray, brownish-gray, and brownish-black fissile shale that forms gentle slopes, which are broken at wide intervals by thin, brownish-gray sandstone ledges and sparse, white bentonite beds. Only the lowermost Mancos Shale is exposed along the northern boundary of the map area near the Colorado River. This lowermost Mancos was deposited in a shallow marine subtidal setting, similar to the modern Texas Gulf Coast.
		Upper and Lower ?	Dakota		Kd	Sandstone and conglomerate forming prominent and resistant ledges and ridges, whereas mudstone and interbedded sandstone and shale generally form slopes. The Dakota Formation caps Black Ridge near the central western boundary of the map area and forms a series of low hogbacks in the Redlands area south of the Colorado River. Locally in the Redlands area, dinosaur tacks are preserved in sandstone beds.
		Lower	Burro Canyon		Kb	in most localities, the upper part is dominated by mudstone and forms slopes, whereas the lower third to two-thirds of the unit is dominated by sandstone and forms cliffs.
	Jurassic	Upper	Morrison	Brushy Basin	Jmb	multicolored mudstone forming gentle rounded slopes. The Brushy Basin Member was deposited in a mud flat to saline lacustrine setting (Turner and Fishman, 1991) characterized by associated highly sinuous fluvial systems. Volcanic basins in New Zealand are possible modern-day analogs.
				Saltwash	Jms	sandstone-rich cliff-forming unit sandwiched between the mudstone-rich, slope-forming Brushy Basin and Tidwell Members of the Morrison Formation. The Salt Wash Member was deposited in a fluvial setting including associated flood plains and shallow ponds. The architecture of the channel-form sandstone bodies suggests that the fluvial channels were relatively thin (1 to 7 m), narrow (5 to 30 m), and moderately sinuous. An analog for this depositional setting exists where rivers empty into the modern-day Texas Gulf Coast.
				Tidwell	Jmt	mudstone-rich; forms slopes that are broken by relatively thin ledges of sandstone and limestone; with rare exception, this is the only limestone in the map area. Within the Tidwell Member, the character and thickness of mudstone, sandstone, and limestone change significantly laterally.
		Middle	Wanakah		Jw	mudstone-rich, slope-forming; recognized easily by its distinctive green-over-red colors and by a noticeable reduction of vegetation. The depositional setting for the Wanakah is nonmarine mudflat and (or) shallow lacustrine environment.
			Entrada	"Board beds" unit	Jeb	interbedded resistant sandstone and less resistant mudstone form slabby exposures that resemble a stack of boards, giving the "board beds" unit its informal name. This unit was deposited in a wet sand flat environment in a coastal setting. The western coast of Baja California, Mexico, at Guerrero Negro, may be a possible modern-day analog (Fryberger and others, 1990).
				Slick Rock Member	Jes	forms a conspicuous pale-orange, ribbon-like cliff or rounded bench that is almost totally free of vegetation below its white cap of the "board beds" unit.
		Early	Kayenta		Jk	commonly forms resistant ledges above the cliff-forming Wingate Sandstone (Jwg) and also forms cliffs in several areas. Sandstone is present throughout the Kayenta, whereas conglomerate and mudstone are found mainly in the upper half.
			Wingate Sandstone		Jwg	forms the magnificent 100-m-high, orange cliffs that give the Colorado National Monument its most spectacular vistas.
	Triassic	Late	Chinle		TRc	distinct red slopes underlie the towering cliffs of the Wingate Sandstone (Jwg), and in turn, rest on the great angular unconformity on dark Proterozoic basement rocks.
Precambrian	Proterozoic	Early	Meta-igneous gneiss		Xi	metamorphosed granite that contains minor xenoliths of host rock and is exposed chiefly in the eastern part of Ute Canyon. Meta-igneous bodies in and near Ute, Red, Columbus, and Gold Star Canyons are probably part of a single pluton, here called the Ute Canyon stock.
			Migmatitic meta-sedimentary rocks		Xm	consist of a complexly folded mixture of dark schist and light migmatitic pegmatite found in the bottoms of most of the canyons at the Monument.

*Summarized from "**Geologic Map of Colorado National Monument and Adjacent Areas, Colorado**" by Robert Scott, 2001; scale 1:24,000;*
USGS Miscellaneous Investigations Series Map I-2740
NOTE: squiggly lines represent unconformities (major breaks in the geologic record)

new sites. Only one of the original sites inventoried in 1977, specifically the site adjacent to the Black Ridge Trail, appears to have been vandalized (Engelmann, personal communication, 2000).

A historic newspaper clipping in the COLM files indicates that a mastodon tooth was found in 1965 in Thoroughfare Canyon. The tooth was reportedly discovered by Dr. Jack Roadifer, a local geologist. The whereabouts of the specimen are currently unknown.

Ichnofossils in COLM, all of which occur in the Chinle Formation, include *Scoyenia gracilis, Koupichnium nopsca* and *Camborygma* (Hasiotis, 1997), crayfish burrows, and plant roots (rhizoliths. Horseshoe crab traces were discovered in the lower units of the Tidwell Member of the Morrison Formation (Hasiotis et al., 1996), representing the first report of these traces from Jurassic rocks.

CURECANTI NATIONAL RECREATIONAL AREA

Curecanti National Recreational Area (CURE) has been administered under a cooperative agreement between the Bureau of Reclamation and the NPS since February 11, 1965. The site contains three reservoirs: Morrow Point Lake, Crystal Lake, and Blue Mesa Lake. Blue Mesa Lake is the largest lake in Colorado with a surface area of 14 square miles.

The geologic setting is similar to that of the Black Canyon of the Gunnison. The park is recognized for having exposures of rocks that date to over 1.7 billion years in age, making these rocks among the oldest in western North America. (Fiorillo and Harris, 2000) (Fig. 1).

The Brushy Basin Member and the Salt Wash Member of the highly fossiliferous Upper Jurassic Morrison Formation are exposed at CURE. Trujillo (2000) prepared a detailed report documenting the paleontological field activities undertaken at the Dino Cove locality at CURE where the remains of two dinosaur taxa have been recovered from the Morrison Formation. The remains have been identified as a sauropod (cf. *Apatosaurus* sp.) and the theropod *Allosaurus* sp. (Fig. 3) (Fiorillo et al., 1995, 1996). There is a reptilian caudal vertebra in the park museum collection (Frank, personal communication, 2000). Conchostracans are very abundant in the Morrison at Curecanti, one location is Dino Cove (Fiorillo and May, 1996). There are several types of ichnofossils preserved within the Morrison Formation at CURE including crayfish burrows, termite nests, root casts and unionid clam burrows found near Red Creek (Fiorillo and Harris, 2000; Fiorillo, 1999; Fiorillo and McCarty, 1996). The invertebrate trace fossils predominantly occur in sandstone layers and suggest that during periods of non-deposition there were an abundance of small life forms (Fiorillo, 1999).

The first collection of Pleistocene (Rancholabrean) vertebrate remains from western Colorado come from Haystack Cave, located just outside of the CURE boundary. Specimens include remains identified as cf. *Miracinonyx trumani*, *Equus* sp. and *Phenacomys intermedius* (Emslie, 1986; Jefferson, personal communication, 2001; see Appendix A).

FIGURE 3. Dinosaur excavation at Curecanti National Recreation Area.

DINOSAUR NATIONAL MONUMENT

Dinosaur National Monument (DINO) was established by presidential proclamation on October 4, 1915. The site was originally established to protect the famous dinosaur quarry discovered in the Upper Jurassic Morrison Formation by Carnegie Museum paleontologist Earl Douglass. The Monument was enlarged in 1938 to include the spectacular canyons cut by the Green and Yampa Rivers.

Although the dinosaur-producing Morrison Formation has been the principal focus at DINO, the geologic record extends from the Precambrian through the Cretaceous. For more information on the geology of DINO, see Gregson and Chure (2000), Untermann and Untermann (1954, 1969), Hansen et al. (1983), and Hansen (1996).

The oldest sedimentary rocks within DINO are in the Precambrian Uinta Mountain Group. Hansen (1996) reported on fossilized algal globules *Chuaria* sp. from the Uinta Mountain Group near Manila, Utah, about 70 miles north of the Monument. Thus there is a potential for these fossils in the Monument.

The Upper Cambrian Lodore Formation consists of variegated, glauconitic shales and sandstones that contain marine invertebrates and trace fossils. Brachiopods, gastropods, and trilobites have been identified from the Lodore Formation in DINO (Herr, 1979; Herr et al., 1982; Hansen, 1996).

Corals, brachiopods, gastropods, and echinoderms are preserved, but rare, in the Lower Mississippian Madison Limestone (Hansen et al., 1983). Upper Mississippian brachiopods, fish, and coal beds are present in the Doughnut Formation (Hansen et al., 1983). The Lower Pennsylvanian Round Valley Limestone contains bryozoans, brachiopods, mollusks, and echinoderms (Hansen et al., 1983). Sponge spicules, corals, brachiopods, echinoid spines, crinoids, foraminifera, and conodonts are common in the marine facies of the Middle Pennsylvanian Morgan Formation (Driese, 1982).

The Permian Park City Formation (equivalent to the Phosphoria Formation farther north) consists of limestone, sandstone, and some chert layers (Fig. 4). Marine invertebrates including brachiopods, bivalves, cephalopods, gastropods, and other invertebrates have been found in this unit (Hansen et al., 1983).

Peabody (1948) studied some unusual reptile tracks in the Lower Triassic Moenkopi Formation in the vicinity of DINO. These include some swimming traces now in the collections of the Utah Field House Museum of Natural History in Vernal, Utah. *Scoyenia* traces have been reported from the Moenkopi at DINO (Lockley et al., 1990).

In the 1960's an important vertebrate tracksite was discovered just northeast of DINO. Today over two dozen tracksites have been identified within the Monument. Numerous tracksites have been discovered in the Upper Triassic Popo Agie and Chinle Formations. Fossil tracks are diverse and include those identified from dinosaurs, mammal-like reptiles, phytosaurs, aetosaurs, lepidosaurs, trilophosaurs, and tanystropheids (Lockley et al., 1990, 1992a, 1992b, 1992c; Hunt et al., 1993). Among these is a swimming trackway of *Gwyneddichnium* that shows webbing between the toes. In addition, there are examples of both walking and swimming types of these tracks. Horseshoe crab-like tracks and petrified wood are documented from the Chinle Formation at DINO.

Tridactyl theropod tracks and a rich *Otozoum* tracksite are known from the Lower Jurassic Glen Canyon Sandstone, which is equivalent to the Glen Canyon Group farther south and the Nugget Sandstone farther west and north (Lockley et al., 1992a; Santucci et al., 1998). The Middle Jurassic Carmel Formation is a shallow marine deposit that locally contains gypsiferous beds. Bivalves, gastropods, echinoderms, and a few rare tridactyl vertebrate tracks have been reported from the Carmel Formation near DINO.

Chure (1993) reported on three plesiosaur specimens that may have been collected from the Redwater Member of the Stump Formation (Middle to Upper Jurassic) near the western boundary of DINO. Belemnites, ammonites, gastropods, and bivalves occur in the Middle Jurassic Curtis Member of the Stump Formation in the DINO area.

The Upper Jurassic Morrison Formation is widely recognized as one of the most prolific dinosaur-bearing units in the world. In addition to dinosaurs, the Morrison Formation has produced important collections of Jurassic mammals and other vertebrates (Chure and Engelmann, 1989). The Morrison Formation at DINO contains four members including, from oldest to youngest, the Windy Hill, Tidwell, Salt Wash, and Brushy Basin Members (Turner and Peterson, 1999).

Utah's first theropod dinosaur (also recognized as the second dinosaur discovered in Utah) was found in 1870 near what is today DINO (Marsh, 1871; Bilbey and Hall, 1999). Earl Douglass made his famous discovery of the dinosaur bonebed in 1909. Under Douglass' direction the Carnegie Museum worked the site until 1922. During 1923, the U.S. National Museum (Smithsonian Institution) paleontologists collected a specimen of *Diplodocus,* which was mounted for display in that museum (Fig. 5). In 1924, the University of Utah collected a skeleton of *Allosaurus* from the quarry. Holland (1912, 1915, 1916, and 1924) and Gilmore (1924, 1925a, 1925b, 1926, 1932, 1936a, and 1936b) published extensively on the dinosaur discoveries from DINO.

FIGURE 5. Paleontologist Earl Douglass during the excavation of a Diplodocus skeleton in the Douglass Quarry at Dinosaur National Monument, circa 1923).

Theodore White was hired as the Monument's first paleontologist in 1953. White focused his attention on the preparation of the *in situ* bone-bearing layer and talking with the public about the world of dinosaurs. He hired and trained two maintenance men, Tobe Wilkins and Jim Adams, to expose in relief the bones on the Carnegie Quarry cliff face. White published both scientific and popular articles about the fossils at DINO (White, 1958, 1964). White liked to call himself the "Chief Ramrod of the Hammers and Chisels" until his retirement in 1973 (Ann Elder, written communication, 1999). Russ King, Dan Chure, Ann Elder, and Scott Madsen have recently worked as staff paleontologists at DINO (Chure, 1987, 1992; Chure and McIntosh, 1990). Elder (1999) provides an historical overview of the Carnegie Quarry at DINO.

Between 1989 and 1992, George Engelmann conducted a comprehensive paleontological survey of the Morrison Formation at DINO (Engelmann, 1992). More than 270 fossil sites were recorded during the survey. Most of the sites were dinosaur bone localities, but sites containing plant remains, invertebrates, and small vertebrates were also reported.

A number of new dinosaurs have been collected in recent years from DINO. In 1990, the first large carnivorous theropod dinosaur was collected from the Salt Wash Member of the Morrison Formation (Chure and Madsen, 1993; Chure et al., 1993). Chure (1994) reported on the oldest known troodontid dinosaur that was recovered from the Monument. A partial skeleton of a hatchling dinosaur, identified as *Camptosaurus*, was discovered at the Monument in 1991 (Chure et al., 1992) and represents the only hatchling of this genus known in the fossil record.

Chure et al (1989) reported on non-mammalian vertebrates collected from the Brushy Basin Member of the Morrison in DINO. Evans and Chure (1999) reported on lizards from the Morrison Formation that were collected in the Monument. The remains of the turtle *Glyptops* sp. and the crocodile *Goniopholis* sp. have been collected from the Monument. Several tiny frog skeletons and many isolated frog bones have been collected from a Brushy Basin microvertebrate locality in DINO. These amphibian remains

FIGURE 4. Stratigraphy of Dinosaur National Monument.

Stratigraphy of Dinosaur National Monument, Colorado and Utah

Era	Period	Epoch	Formation Member	Map Unit	Description
Cenozoic	Quaternary	Holocene	Alluvium	Qa	Poorly sorted gravel, sand, and silt of floodplain deposits, islands, and bars in river channels, bouldery debris fans and alluvial fans, and silty sandy gravel fills along minor tributaries.
			Eolian sand	Qe	Sand derived chiefly from Weber and Glen Canyon sandstones, and Browns Park Formation.
		Holocene and Pleistocene	Talus and colluvium	Qtc	Talus: accumulations of coarse angular rock fragments below cliffs and steep slopes. Colluvium: heterogeneous mixes of soil (engineering sense) and rock; grades into alluvium.
			Landslide deposits	Ql	Heterogeneous rock fragments and soil including blocks and (or) slabs of rock many meters long.
		Pleistocene	Older Alluvium	Qoa	Gravel and sand capping terraces and pediments of several different ages at varied heights above present drainage.
	Tertiary	Miocene	Browns Park	Tbp	Sandstone (predominant); limestone (subordinate); conglomerate (rare in map area)
		Oligocene	Bishop Conglomerate	Tb	Conglomerate and sandstone derived from Paleozoic limestones and Proterozoic Uinta Mountain Group. Pebble-size red chert common. Caps mesas and fills old valleys.
Mesozoic	Cretaceous	Upper	Mancos: Main Body	Kms	Dark gray, expansive, fossiliferous calcareous shale with minor siltstone, sandstone (in upper half) and layered bentonite (in lower half). A few thin beds of limestone in lower part. Forms slopes, valley bottoms, and badlands.
			Mancos: Frontier Sandstone	Kmf	Upper: calcareous, crossbedded, ripplemarked sandstone; marine fossils, coal; forms hogbacks and flatirons. Lower: Shale and siltstone, calcareous, silty, fossiliferous. Lower part forms slopes and saddles.
		Lower	Mancos: Mowry Shale	Kmm	Bentonitic, dark, siliceous, fissile Shale; abundant fish scales; weathers silvery gray. Forms slopes and strike valleys.
			Dakota Sandstone	Kd	Sandstone, light-gray to light-yellow, medium- to coarse-grained, pebbly, crossbedded, ripplemarked, fluviatile; subordinate chert-pebble conglomerate and dark-gray shale. Forms hogbacks and dipslopes.
			Cedar Mountain	KJcm	non-marine multicolored claystone, siltstone, and fluviatile sandstone. Lavender tints prevalent in Cedar Mountain; distinctive chert-pebble Buckhorn Conglomerate Member marks its base. Morrison contains fluviatile conglomeratic sandstone, including the renowned dinosaur-bearing beds at the fossil quarry, and fresh-water limestone. Claystone, siltstone, and shale are regarded as overbank floodplain deposits. Unit forms slopes and is slide prone.
	Jurassic	Upper	Morrison		
			Stump: Redwater	Jsr	Soft, marine, fissile, glauconitic green siltstone and shale, sparse interbeds of crossbedded glauconitic oolitic fossiliferous marine limestone and sandstone. Forms slopes.
		Middle	Stump: Curtis	Jsc	Sandstone, light-gray to light-greenish gray, crossbedded, locally ripplemarked, fossiliferous, marine. Forms ledges.
			Entrada	Je	Pink-gray sandstone, fine- to medium-grained, thick-bedded, crossbedded, eolian. Forms cliffs.
			Carmel	Jca	Shale, siltstone, and mudstone, dark-red, sandy, marine; some fine- to medium-grained sandstone; a few thin beds of marine limestone. Forms slopes and saddles.
		Lower	Glen Canyon Sandstone	JTRg	Fine-grained sandstone. Large-scale eolian cross bedding deposited by winds that blew from north and northeast (Poole, 1962). Forms large sculptured outcrops, occasional cliffs.
	Triassic	Upper	Chinle: Main Body	TRc	Siltstone, shale, sandstone, and conglomerate, vari-colored, fluviatile; lacustrine or paludal ocherous marlstone, sandstone, and conglomerate. Forms slopes.
			Chinle: Gartra Member	TRcg	Sandstone, pale-yellowish gray to tan to pink, coarse-grained to conglomeratic, generally thickly bedded crossbedded, fluviatile. Truncates and channels underlying Moenkopi Formation. Forms cliffs, benches, and rimrocks.
		Lower	Moenkopi	Trm	Siltstone and shale, vari-colored; gypsiferous toward base and in middle section; ripplemarks. Shoreward marine, possibly a tidal-flat deposit. Forms slopes, but a few resistant siltstone beds near middle form ledges or low cliffs.
Paleozoic	Permian		Park City: Upper	Ppu	Limestone, siltstone, sandstone, and dolomite, mostly nonresistant, thin-bedded, locally fossiliferous, marine. Ledge-forming phosphatic dolomite or limestone bed 3-10 m below top (Schell and Yochelson, 1966). Forms slopes.
			Park City: Lower	Ppl	Sandstone, dolomite, and limestone, cherty, locally phosphatic and fossiliferous, unevenly bedded, marine. Resistant, forms long dipslopes and caprocks on cliffs. In places sharply truncates cross bedding of underlying Weber Sandstone; in other places, contact is vague.
	Pennsylvanian	Middle	Weber Sandstone	PNw	very thickly bedded sandstone. Large-scale eolian crossbeds separated by diastems; deposited by winds that blew chiefly from the north (Fryberger, 1979). Rugged outcrops; the prime cliff-former in Dinosaur National Monument.
			Morgan: Upper	PNmu	crossbedded to planar bedded to massive, well-cemented Sandstone, and cherty fossiliferous marine limestone. Locally some sandstone is gray and Weber-like. Individual beds < 1 m to several meters thick.
			Morgan: Lower	PNml	Shale, siltstone, interbedded sandstone and fossiliferous limestone. Forms slopes mantled with colluvium; slide prone.
		Lower	Round Valley Limestone	PNrv	Limestone, thick-bedded, cherty, fossiliferous, marine, and thin partings of gray to red shale. Pink to red chert in nodules and irregular masses, occasionally replacing fossils. Forms cliffs, ledges, and long dipslopes.
	Mississippian	Upper	Doughnut Shale	Mdh	Shale; largely marine, but has non-marine deposits in adjacent areas. Poorly exposed; plastic when wet, slide prone.
			Humbug		Sandstone interbedded with marine limestone and shale. Forms ledgy slopes, but locally makes good cliff exposures.
		Lower	Madison Limestone	Mm	Limestone, thick-bedded and unevenly bedded; nodular gray chert; locally dolomitic, sparsely fossiliferous, marine. Forms massive cliffs, ledgy toward top, and dipslopes. Locally is cavernous.
	Lower Ordovician or Upper Cambrian		Dike	Ocd	Leucitite, aphanitic, slightly microporphyritic. Ground mass crowded with disseminated hematite, rutile, and anatase (George A. Desborough, U.S. Geol. Survey, written commun., 1979)
	Cambrian	Upper	Lodore	Cl	ledge-forming sandstone, underlain by glauconitic marine sandstone. Basal contact uneven, and in Whirlpool Canyon, boss-like masses (fossil sea stacks) of Uinta Mountain Group protrude up into the formation. upper shaly unit has been wholly or partly removed by pre-Mississippian erosion and the thickness of the formation varies accordingly.
Precambrian Proterozoic Y			Uinta Mountain Group	Yu	Sandstone, some quartz & metaquartzite pebble conglomerate; some silty shale and (or) siltstone with micaceous bedding planes. Forms cliffs and ledges. Shale with micaceous bedding planes, and (or) siltstone, interbedded with fine- to coarse-grained red sandstone.

Summarized from "**Geologic Map of Dinosaur National Monument and Vicinity, Utah and Colorado**" by Wallace R. Hansen, Peter D. Rowley, and Paul E. Carrara, 1983; scale 1:50,000;USGS Miscellaneous Investigations Series Map I-1407

NOTE: squiggly lines represent unconformities (major breaks in the geologic record)

represent at least four different species of frogs including *Comobatrachus* sp., *Eobatrachus* sp., and a new pipoid anuran (Henrici, 1992, 1993, 1998).

Engelmann et al (1989) reported on microvertebrates, including mammals that have been collected from quarries in DINO. The quarries are in the Brushy Basin Member of the Morrison and have yielded hundreds of isolated teeth and a few partial jaws. The skull of a new multituberculate, *Glirodon grandis,* was also found at the Monument (Engelmann and Callison, 1999). Other mammals identified include a triconodont, a symmetrodont, at least two species of dryolestids, and a paurodontid.

Yen and Reeside (1950) described freshwater mollusks from the Morrison Formation. Sohn and Peck (1963) identified the ostracode *Theriosynoecum wyomingense* as a guide fossil to the Salt Wash Member of the Morrison Formation.

Ash (1993, 1994) reported on an unusual leaf *Czechanowskia* sp. from the Brushy Basin Member of the Morrison Formation in the Monument. This plant is considered by some as an indicator of humid paleoclimates, but, the discovery of this plant in deposits of an alkaline-saline lake farther south brings this interpretation into question (Turner and Fishman, 1991). A gingko leaf locality occurs in the middle of the Brushy Basin Member . Tidwell (1990) reported on a plant locality in Orchid Draw in the western part of DINO. A palynological (fossil pollen) assessment of the Morrison Formation, including several sites within the Monument, was conducted by Litwin et al (1998).

Recent evidence shows that dermestid beetle larvae (Coleoptera: Dermestidae) borings (Fig. 6) are preserved in dinosaur bones collected from the Carnegie Quarry (Hasiotis, et al., 1999). These trace fossils suggest subaerial exposure of the dinosaur carcasses prior to burial and represent the earliest evidence of dermestids in the paleontological record.

Recent work in the Lower Cretaceous Cedar Mountain Formation has produced some spectacular fossil specimens. One site in particular, a river-deposited bonebed, has yielded a nearly complete articulated sauropod skull, elements of a second disarticulated sauropod skull, numerous sauropod post-cranial elements, and a few isolated theropod bones. Though only a preliminary analysis of these fossils has been completed, the cranial materials appear to be some of the most complete Cretaceous sauropod specimens found in North America (A. Elder, written communication, 1999).

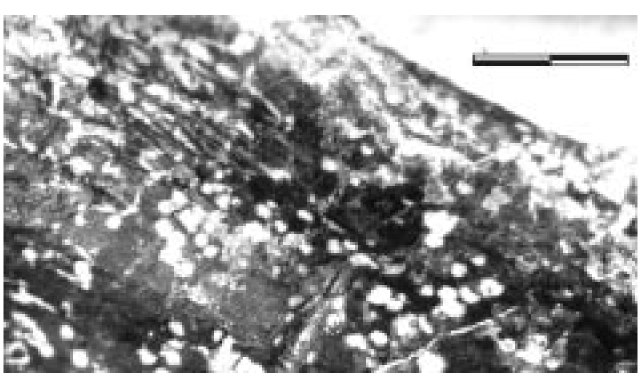

FIGURE 6. Small borings on the surface of dinosaur bone from Carnegie Quarry, Dinosaur National Monument.

The Dakota Formation of Late Early or Early Late Cretaceous age consists of shoreface and terrestrial strata deposited along the western margin of the western interior seaway. Petrified wood and fragmentary invertebrate remains have been found in the Dakota. Fish scales and bones are locally abundant in the Upper Cretaceous Mowry Shale, while bivalves, ammonites, and shark teeth are also known from this unit within DINO. The Upper Cretaceous Frontier Formation contains bivalves, gastropods, ammonites, petrified wood, and some thin coal beds. The Mancos Shale is not well exposed in the Monument, but locally this unit is very fossiliferous and preserves a high diversity of marine invertebrates. Ammonites are reported from the Mancos Shale at Ashley Creek and Brush Creek near the Monument (Kennedy and Cobban, 1991).

Sharpe (1991) reported on the Quaternary and Holocene flora in DINO that was collected to assess vegetational changes.

FLORISSANT FOSSIL BEDS NATIONAL MONUMENT

Florissant Fossil Beds National Monument (FLFO) was established by presidential proclamation on August 20, 1969 to preserve the unique fossil insects and plants found in the area. The Monument is located in central Colorado approximately 35 miles west of Colorado Springs near the town of Florissant.

The Florissant area is underlain by Precambrian Pike's Peak granite. This unit has a distinctive pink color and was formed more than one billion years ago. The massive granitic pluton was uplifted during the Late Cretaceous Laramide Orogeny (approximately 65-70 million years ago) (Meyer and Weber, 1995). Paleozoic and Mesozoic sediments were eroded away during the uplift, and a widespread erosion surface developed by Late Eocene time.

The Wall Mountain Tuff (36.6 million years old) unconformably overlies the Pike's Peak granite in the vicinity of Florissant and is exposed in isolated outcrops (Henry, et al., 1996). It is believed that the source of the Wall Mountain Tuff was the Mt. Princeton caldera (Wobus, personal communication, 2000). The Florissant Formation overlies the Wall Mountain Tuff and is composed of shales interbedded with volcaniclastic deposits (Fig. 7). Early eruptions from the Thirty-Nine Mile volcanic complex produced lahars (mudflows) that buried the giant redwoods and other trees with 13-16 feet of debris. An influx of silica-rich water saturated tree stumps and preserved them by permineralization, which accounts for the preservation of cellular structure in the stumps (Fig. 8). The lahar layer containing the petrified stumps is the lowest layer in the Florissant Formation. Subsequent volcanic eruptions, also from the Thirty-Nine Mile volcanic field, impounded the stream drainage to the south and formed ancient Lake Florissant. Plant debris and insects were trapped within the volcanic sediments that slowly washed into the lake. Diatoms flourished in the lake and contributed to the

FIGURE 7. Stratigraphy of Florissant Fossil Beds National Monument.

Stratigraphy of Florissant Fossil Beds National Monument, Colorado

Era	Period	Epoch	Formation	Member	Map Unit	Description
Cenozoic	Quaternary	Holocene	Alluvium		Qal	Brown unconsolidated humus-rich sands and gravelly sand occurring along streams.
			Colluvium		Qc	Thin gravels mantling slopes, composed of granular grus derived from the Pikes Peak Granite, rhyolitic gravel derived from the Wall Mountain Tuff, and shale, mudstone, sandstone, and silicified wood fragments derived from the Florissant Formation.
		Pleistocene	Pleistocene gravels		Qg	Thick gravels mainly composed of granular grus derived from the Pikes Peak Granite. Also includes scattered fragments of Wall Mountain Tuff and silicified wood. Vertebrate fossils rare, including a mammoth from the SW ¼, sec. 12, T. 13 S., R 71 W.
	Tertiary	Eocene	Florissant	Lacustrine / fluvial	Tf5	Pumice-rich white sandstones and conglomerates, structureless to locally trough crossbedded. Numerous pink pumice clasts near top. Near south entrance includes poorly sorted brown pumiceous sandstones interbedded with scattered lenticular mudstones and shales. Contains locally abundant fingernail clams, rare plant and lymnaeid snail fossils. Maximum measured thickness 22.8 m. Lacustrine at base, fluvial at top.
				Lacustrine	Tf4	Gray to greenish brown paper shales and blocky mudstones; interbedded with planar, thin yellow to white pumiceous sandstone beds. Near the south entrance this unit is represented by fossiliferous gray to yellowish brown sandstones interbedded with cherty stromatolites. Fossils include leaves, insects, ostracodes, fish scales, and fingernail clams. Maximum measured thickness 5.6 m in the northwest corner of the monument; unit thins to the south. Lacustrine.
				Volcanigenic Debris flow	Tf3	Yellowish-gray conglomerate with subangular to rounded clasts of tuff, quartz, and andesite. Locally contains blocks of andesite, pumiceous sandstones and blocky mudstone. Unit typically graded, otherwise structureless to crudely horizontally bedded. Fossils include scattered fingernail clams near top. Maximum thickness 7.9 m measured near Lodge stump (E of Scudder pit). Unit thins to the north and is not present in the northwest corner of the monument. Represents a volcanigenic debris-flow deposit.
				Lacustrine	Tf2	Interbedded brown paper shales, grayish brown blocky mudstones, thin yellowish pumiceous sandstones, and thin granular pumice conglomerates. Contains abundant plant fossils with less abundant insects and planorbid snails. Most of the fossil quarries in the monument occur in the this unit. Maximum thickness 9 m. Lacustrine.
				Fluvial / volcanigenic mudflow	Tf1	Tan to gray blocky tuffaceous mudstones interbedded with yellowish gray pumiceous sandstones and rare arkosic sandstone ribbons. The arkosic sandstones typically have abundant trough crossbedding. Fossil include stumps and logs of gymnosperms and angiosperms, scattered leaves and rare mammal bones. Bottom contact poorly exposed, with a maximum measured thickness of 10.4 m. Fluvial with a volcanigenic mudflow deposit at the top.
			Boulder Conglomerate		Tb	Lenticular boulder conglomerate composed primarily of large rounded blocks of Pikes Peak Granite, and secondarily of gneiss and rhyolite cobbles and boulders. Rhyolite clasts are rounded to subangular and were derived from the Wall Mountain Tuff. Contains scattered silicified wood fragments. Unit is interbedded with Tf1, and rests on surface cut into the Wall Mountain Tuff and the Pikes Peak Granite. Probable equivalent of the Tallahassee Creek Conglomerate exposed south of Wrights Reservoir (Wobus and Epis, 1978). Maximum thickness about 15 m. Fluvial and debris-flow deposit.
			Wall Mountain tuff		Twm	Rhyolitic welded tuff, brownish gray to dark gray. Contains abundant sanidine and less abundant biotite, argillized plagioclase, and magnetite. Weathers to large angular to subangular blocks. Mantles sides of the Florissant paleovalley, and is as thick as 15 m in lower exposures. Age of this tuff is 36.6 +/- 0.06 Ma based on 40Ar/39Ar dating
Precambrian	Proterozoic		Pikes Peak Granite		Pcg	Medium to coarsely crystalline reddish granite and quartz monzonite. Contains abundant perthitic microcline, quartz, and biotite. Weathers into rounded tors and boulders, and into granular grus. Age is 1041 +/- 13 Ma based on Rb/Sr isochron

Summarized from "**Surficial geologic map of Florissant Fossil Beds National Monument, Colorado**" by Evanoff, E., Brill, R.A., de Toledo, P.M., Murphey, P.C., and Cushman, R.A. Jr., 1992, , scale 1:10000. In Doi, K., and Evanoff, E., eds., 1992, The stratigraphy and paleontology of Florissant Fossil Beds National Monument: a progress report: University of Colorado Museum, 169 p.

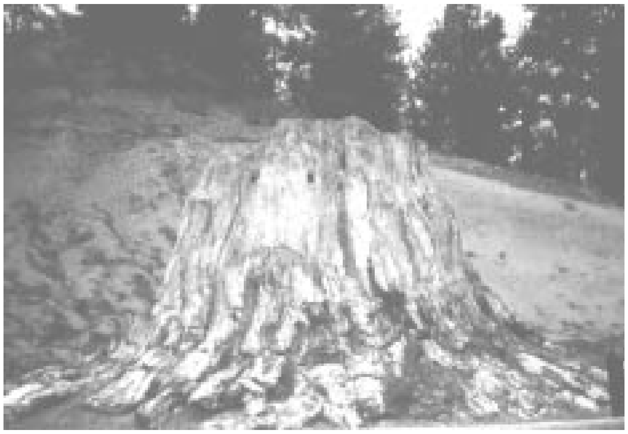

FIGURE 8. Petrified tree stump at Florissant Fossil Beds National Monument.

sedimentation processes by forming mats. These mats contributed to the preservation of the insect and plant fossils (Harding and Chart 2000). These sediments compacted over time forming fossiliferous "paper-shales".

Although the first official report of the fossil beds was published in 1874 by A.C. Peale of the Hayden Survey, the first known collection of the fossil deposits was made in 1871 by Theodore Meade (Meyer and Weber, 1995). Other research has been done by Shaler from Harvard and Cockerell from the University of Colorado To date, the Florissant Formation has yielded more that 50,000 specimens, representing approximately 140 species of plants and 1400-1500 species of insects. The world's most diverse collection of fossil butterflies has come from Florissant, representing 12 species (not including moths). The most common plants found at Florissant are *Fagopsis longifolia* and *Cedrelospermum lineatum* sp., extinct members of the Beech Family (Betulaceae) and Elm Family (Ulmaceae), respectively. The flora represents a much warmer temperate to nearly tropical climatic regime than what is found here today. Paleoclimates were calculated using floristic and physiognomic methods and different lapse rates. The Mean Annual Temperature (MAT) at Florissant during the Late Eocene has been estimated at approximately 10.7°-14°C (Meyer, 1986, 1992; Wolfe, 1992; Gregory and Chase, 1992) with an estimated paleoaltitude of 6230 - 10,500 feet (Meyer, 1992).

Figure 9. Petrified tree stump on display at Disneyland, California. The stump was collected by Walt Disney from Florissant prior to the site's establishment as a national monument.

One of the most famous of the Florissant fossils is no longer part of the park but is on display at Disneyland in California (Fig. 9). During the summer of 1956, Walt Disney visited the private Pike Petrified Forest (later to become Florissant Fossil Beds) and purchased a petrified tree stump. According to the plaque placed on the tree at Disneyland, the stump is seven feet six inches in diameter, weighs five tons and came from a tree whose original height was estimated at 200 feet (letter, Walt Disney Archives, 1999).

There are currently 59 fossil localities identified at Florissant Fossil Beds National Monument. The Monument's museum database contains historic information about each specimen, accompanied by a digital photo. A bibliographic database has also been developed by the paleontology staff at the Monument to include all publications related to the geology and paleontology of the Florissant area. A new database is being developed to compile all the most recent taxonomic designations for all plant and insect species.

GREAT SAND DUNES NATIONAL MONUMENT

Great Sand Dunes National Monument (GRSA) was established by presidential proclamation on March 17, 1932. The Monument received wilderness designation on October 20, 1976 and was upgraded to a national monument and preserve on November 22, 2000. It will become a national park as soon as a land purchase is completed. The Park is located in south central Colorado in the San Luis Valley and preserves the tallest sand dunes in North America. Individual dunes can reach 700 feet in height. The dunes cover approximately 39 square miles along the western edge of the Sangre de Cristo Range. The sand dunes were created by northeast winds transporting quartz sands and volcanic debris across this valley and depositing them at the base of the Sangre de Cristo Mountains.

The Great Sand Dunes area consists of thin layers of alluvium between layers of lava and tuff. These deposits are Miocene in age and are known as the Sante Fe Formation (Fig. 10). This unit is overlain by post-Miocene sands and clays of the Alamosa Formation (Merk, 1960). Johnson (1967) provides a more comprehensive overview of Great Sand Dunes geology. Bruce and Johnson (1991) published a geologic map that includes the Great Sand Dunes.

The Park museum collection contains some crinoid columnals and a rock specimen with the casts of three partial brachiopods. These brachiopod specimens were collected along the Mosca Pass Trail. A mammoth femur and bison phalange have also been collected in the park.

FIGURE 10. Stratigraphy of Great Sand Dunes National Park.

Stratigraphy of Great Sand Dunes National Park, Colorado

Era	Period	Epoch	Formation	Member	Map Unit	G_NOTE_TXT
Cenozoic	Quaternary	Holocene and Pleistocene	Alluvium		Qal	Sand, gravel, and clay deposited by streams. Includes Holocene stream deposits, Pleistocene glacial outwash, and, locally, colluvium; along east side of Sangre de Cristo Range, includes pediment deposits of Quaternary and possibly Tertiary age composed of deeply weathered detritus derived mostly from Precambrian and upper Paleozoic rocks.
		Holocene	Alluvial Fan Deposits		Qaf	Poorly sorted, coarse sand and gravel deposited by distributary stream systems along west side of Sangre de Cristo Range
			Eolian Sand		Qes	Surficial deposits of well-sorted sand; covered by sparse vegetation. Thin and discontinuous, interspersed with alluvial sand and clay north of Deadman Creek; dunes as high as 10 m south of Deadman Creek.
			Landslide Deposits		Ql	Deposits of angular rock debris of all sizes; typically hummocky topography
		Holocene and late Pleistocene	Rockfall Deposits		Qrf	Accumulations of talus below large outcrops
			Rock Glaciers		Qrg	Angular blocks at base of steep slopes and at floors of cirques. Lobate forms of deposits suggest formation by ice-cored flow.
	Tertiary	Pliocene and Miocene	Santa Fe Formation		Ts	Stratified sand and gravel derived mostly from Proterozoic and upper Paleozoic rocks. Overlain by deeply weathered pediment sloping away from mountains.
		Miocene	Andesite		Ta	Andesitic lahar, biotite latite, and dense hornblende-pyroxene
		Miocene?	Mafic Volcanic Rocks		Tmv	Black, vesicular, porphyritic olivine basalt; Composed of several flows probably erupted from a fissure as shown by flow foliation dipping into axis of elongate area of outcrop.
		Miocene or Oligocene	Felsic Dikes		Tf	Light-gray to white, fine-grained, felsite dikes as much as 3 m wide; porphyritic; nonfoliated.
		Miocene? or Oligocene?	Mafic Dikes		Tm	Dark-gray-green to black, aphanitic to medium-grained, holocrystalline dikes as much as 3 m wide;
Mesozoic	Jurassic	Late	Morrison Formation		Jm	interbedded gray and brown shale, gray to brown sandstone, and minor gray, fine-grained limestone; exposed in overturned syncline at Loco Hill; about 50-70 m thick
		Middle	Entrada Sandstone		Je	thin-bedded, white to tan, friable quartz sandstone; fine- to medium-grained, well-sorted, well-rounded, and frosted
Paleozoic	Permian and Pennsylvanian		Sangre de Cristo	Crestone Conglomerate Member	PPNsc	Red conglomerate, conglomeratic sandstone, and minor siltstone and shale. Exposed between Sand Creek thrust and Little Sand Creek thrust. Coarse conglomerate contains boulders and cobbles of Early Proterozoic gneiss (Xgn and Xlgn), syenite, and quartz monzonite (Xqm)
				diamictite	PPNscd	from Crestone Needle to Milwaukee Peak, in lower part of Crestone Conglomerate Member, marker bed of diamictite (d) as much as 40 m thick contains distinctive clasts of amphibolite and tourmaline pegmatite
				lower member	PPNsl	Red arkosic sandstone, conglomeratic sandstone, siltstone, and shale, arranged in fining- upward cycles, 2-40 m thick; contains crossbedding; siltstone and shale contain ripple marks, cross-lamination, and sparse mudcracks.
	Pennsylvanian	Middle	Minturn	crinoidal silty limestone	PNmcls	About 230 m below top, marker bed of crinoidal silty limestone (cls), 12-16 m thick, containing abundant crinoid columnals as much as 0.3 m long, brachiopods, sponge spicules, and bryozoans; shaly, carbonaceous, and radioactive in lower part
				oolite limestone	PNmols	About 900 m below top, marker bed of oolite limestone (ols), 4 m thick
				biohermal limestone unit	PNmbls	About 1,000 m below top, lenticular biohermal limestone units (bls), 300 m thick and extending 1,500 m along strike, containing abundant brachiopods, and other marine invertebrate fossils. Bioherms contain fusulinids of Desmoinesian age; and conodonts
	Mississippian	Lower	Leadville Limestone		MDOr	dark-gray, massive limestone, locally contains limestone breccia, 70 m thick
			Chaffee Group	Dyer Dolomite		yellow-gray, cherty dolomite, 30 m thick.
	Devonian			Parting Quartzite		gray, massive quartzite and dolomite, 15 m thick.
	Ordovician	Upper	Fremont Dolomite			dark-gray, coarsely crystalline dolomite, 70 m thick
		Middle	Harding Sandstone			pale-red, thin-bedded quartzite, 30 m thick.
		Lower	Manitou Limestone			dark-gray, fine-grained, cherty, dolomitic limestone, 60 m thick.
Precambrian Proterozoic		Middle-Early	numerous			igneous intrusions and metamorphic rocks

FIGURE 11. Stratigraphy of Hovenweep National Monument.

Stratigraphy of Hovenweep National Monument, Colorado and Utah

Era	Period	Epoch	Formation	Member		Map Unit	Description
Cenozoic	Quaternary	Holocene	Alluvium			Qa	Silt, sand, and gravel in stream valleys and flood plains; includes soil and locally some colluvial and eolian deposits.
			Eolian deposits			Qe	Reddish-brown loess on broad plains, mesas, and large benches; unconsolidated silt and sand banked against cliffs and mantling large areas of broad valleys.
			Colluvial deposits			Qc	Talus, slope wash, block rubble, rock glaciers, and in some high cirques in the San Miguel Mountains, young glacial till.
Mesozoic	Cretaceous	Upper	Mancos shale			Km	Gray to dark-gray soft fissile sparsely fossiliferous marine clay shale; a few thin distinctive calcareous sandstone and sandy clayey limestone ledges in lower 500 feet.
			Dakota sandstone			Kd	Dominantly yellowish-brown to gray quartzitic sandstone and conglomeratic sandstone in thick beds; subordinate thin lenticular beds of gray claystone, impure coal, carbonaceous papery shale, and gray friable carbonaceous sandstone; local coarse basal conglomerate. Marine near top; fluvial near base. Intertongues with Mancos Shale. A few tens of feet to 225 feet thick; averages about 100 feet thick.
		Lower	Burro Canyon			Kbc	Light-gray and light-brown fluvial quartzose sandstone and conglomerate in thick beds; lenticular greenish-gray, locally purplish, commonly non-bentonitic siltstone, shale, and mudstone; a few thin lenses of gray limestone and chert near top. Averages about 150 feet thick; thins southward to an irregular wedge edge near San Juan River south of which are only a few thin discontinuous conglomerate lenses. A few uranium deposits occur in some thick sandy conglomeratic beds and in some beds of gray shale.
	Jurassic	Upper	Morrison	Brushy Basin		Jmb	Variegated gray, pale-green, red-brown, or purple bentonitic mudstone; a few lenses of distinctive green and red chert-pebble conglomeratic sandstone, some of which contain uranium-vanadium deposits. Thickness ranges from about 150 to more than 700 feet.
				Westwater Canyon		Jmw	Mostly yellowish- and greenish-gray to pinkish-gray lenticular fine- to coarse-grained arkosic sandstone; some interbedded greenish-gray or grayish-red sandy shale and mudstone. About 180 feet thick in Bluff area; thins northeastward to a wedge edge between Blanding and Cortez.
				Recapture		Jmr	Reddish-gray, white, and brown fine- to medium-grained sandstone characterized by dark- and light-colored grains; interbedded reddish-gray siltstone and mudstone. About 200 feet thick in southwest corner of map; thins, intergrades, and intertongues northeastward with Salt Wash Member. Contains a few uranium deposits.
				Salt Wash		Jms	Pale-gray, grayish-orange, or moderate-reddish-brown fine- to medium-grained fluvial sandstone in thick discontinuous beds; interbedded greenish- and reddish-gray mudstone; thin beds of limestone locally near base. As much as 550 feet thick; more continuous sandstone beds contain numerous small and some large uranium deposits.
		Upper / Middle	San Rafael	Junction Creek Sandstone		Jj	Lateral equivalent of Bluff Sandstone. Pink or reddish-orange fine- to coarse-grained poorly sorted eolian crossbedded sandstone. Forms a rounded "slick rim." About 275 feet thick; merges northward with the upper part of Summerville Formation (a.k.a. Wanakah Formation); thins and becomes even bedded to the east and mapped with the Salt Wash Member of the Morrison Formation.
		Middle		Wanakah		Jw	25 to 100 feet thick; consists of 3 members (in descending order): marl member, greenish-gray to red-brown friable limy sandy siltstone; Bilk Creek Sandstone Member, light-colored friable fine-grained quartz sandstone in thin even beds with a distinctive red chalcedony zone at the top; Pony Express Limestone Member, dark-gray fetid bituminous thin-bedded limestone generally about 10 feet thick
				Entrada	Moab	Je	white medium-grained crossbedded or flat-bedded well sorted sandstone
					Slick Rock		white or reddish- or yellowish-orange thick massive fine- to medium-grained eolian crossbedded quartz sandstone that erodes to prominent rounded cliffs
					Dewey Bridge		reddish-brown flat-bedded locally contorted earthy siltstone and some flat-bedded white sandstone. In northeast part of map and on the southeast side of the La Plata Mountains, pale- to greenish-gray massive sandstone contains large low-grade vanadium-uranium deposits. Averages about 150 feet thick, but ranges in thickness from 70 to 440 feet.

Summarized from "*Geology, structure, and uranium deposits of the Cortez quadrangle, Colorado and Utah*" by **Haynes, D.D., Vogel, J.D., and Wyant, D.G.** 1972; scale 1:250,000;USGS Miscellaneous Investigations Series Map I-629

NOTE: squiggly lines represent unconformities (major breaks in the geologic record)

HOVENWEEP NATIONAL MONUMENT

Hovenweep National Monument (HOVE), in southwestern Colorado, was established by presidential proclamation on March 2, 1923. The site preserves a concentration of Pre-Columbian cliff dwellings, pueblos, and towers. The Upper Jurassic Morrison Formation is exposed along the south edge of Hovenweep National Monument. Locally the Burro Canyon Formation (Lower Cretaceous) and the Dakota Sandstone (Upper Cretaceous) cap the fluvial deposits of the Morrison Formation (Fig. 11).

The only report of paleontological resources from the Monument is an unidentified bone fragment found by Mike Hylland, a Utah Geological Survey geologist (M. Hayden, written communication, 1999). Although there are not many reports of fossils from within the Monument, judging from their nearby, invertebrate fossils most likely are present in HOVE (Santucci, 2000).

MESA VERDE NATIONAL PARK

Mesa Verde National Park (MEVE) was established by Congress on June 26, 1906 to preserve the famous Anasazi cliff dwellings and ruins of the southwestern Colorado high mesas. The park received wilderness designation on October 20, 1976 and World Heritage Site designation on September 6, 1978.

Mesa Verde National Park lies on a broad, flat-topped mesa with deeply cut and steep-walled canyons. The canyons are oriented north-south reflecting the regional dip of the rocks to the south. Wanek (1954 and 1959) provides a comprehensive overview of the geology of Mesa Verde National Park.

The oldest exposed geologic unit in the park is the Upper Cretaceous Mancos Shale (Fig. 12). The Dakota Sandstone directly underlies the Mancos Shale in southwest Colorado, but the Dakota is not exposed in the Park. A few fine specimens of *Tempskya* sp. were collected from the Dakota Sandstone adjacent to the park. These specimens were sent to Dr. Bill Tidwell who concluded that these specimens probably represent a new species and are younger than any other known specimens of this taxa.

The 2000-foot-thick Mancos Formation was deposited in a fluctuating inland sea, mostly far from shore. The type section of the Mancos is exposed below Point Lookout on the north side of Mesa Verde National Park. Pike (1947) originally identified five faunal zones in the 2191-foot section of Mancos Shale at the park. A detailed revision of the type section divided the formation into eight distinct faunal and lithologic units (Kirkland, et al., 1995; Leckie, et al., 1997).

The oldest member of the Mancos is the Graneros Shale Member, about 79 feet thick. The Graneros does not crop out within the park boundaries, but is found a short distance to the north. The lowest part of this bentonite-rich member has a very limited fauna, but in the upper part is an almost solid bed of small oysters, *Pycnodonte newberryi* (Stanton) (Hook and Cobban, 1977). These oysters indicate warm and shallow water conditions. Some cephalopods, gastropods, and shark teeth also occur in this oyster bed.

Above the Graneros Shale, about 45 feet of the Bridge Creek (Greenhorn) Limestone Member of the Mancos is found. The Bridge Creek Limestone crops out north of the Mesa Verde National Park capping small erosion remnants of the soft Graneros Shale. It contains a varied molluscan fauna including numerous inoceramids of the genus *Mytiloides*, and ammonites of the genera *Mammites, Watinoceras, Baculites, Kamerunoceras* and others (Leckie, et al, 1997, p. 171-173). The Bridge Creek Limestone does not contain many fossils in Mesa Verde National Park, but it has a very rich assemblage of fossils to the east near Pueblo, Colorado (Cobban and Scott, 1972). Pyritized clams are known from this unit in the park.

About 92 feet of light gray Fairport Shale overlies the Bridge Creek Limestone. The shales are soft and include many thin bentonite seams. The most common fossils are found in beds crowded with juvenile *Collignoniceras woollgari* (Mantell). No adult *C. woollgari* are found in these beds, but small oysters, fragmentary inoceramids, barnacle fragments and shark teeth occur in association with the ammonites.

Overlying the Fairport Member of the Mancos, is nearly 250 feet of dark gray, sparsely fossiliferous Blue Hill Shale. The Blue Hill does not crop out within the Mesa Verde Park boundaries and is not easily recognized topographically.

The Juana Lopez Member of the Mancos is the oldest part of the formation to crop out within the park. The widespread, highly fossiliferous Juana Lopez consists of approximately 140 feet of calcareous shale and beds of solid calcarenite. Calcarenite is composed of sand-sized grains of calcium carbonate, mostly broken fragments of mollusk shells and some recrystallized calcite. It is relatively resistant to erosion and caps many of the small buttes along the north edge of the park. The calcarenite is a dark solid rock in freshly broken specimens, but weathers a characteristic rusty color in most outcrops. The Juana Lopez is highly fossiliferous, especially in the calcarenite layers. Ammonites and bivalves are common and well preserved. The most common and stratigraphically useful ammonites are the several species of *Prionocyclus; P. macombi* Meek, *P. wyomingensis* Meek, *P. novimexicanus* (Marcou), and *P.quadratus* Cobban; the *Scaphites, S. warreni* Meek and Hayden, and *S. whitfieldi* Cobban, and the *Baculites, B. undulatus* d'Orbigny, *and B. yokoyami* Tokunaga and Shimizu. Four faunal zones within the Juana Lopez are based on these ammonites. Bivalves *Inoceramus dimidius* White, *Inoceramus perplexus* Whitfield, and *Nicaisolopha lugubris* (Conrad) are also useful guide fossils in this member of the Mancos Formation. Some silt, but no quartz sand, is present, as these sediments were laid down in quiet water far from a source of coarse clastics.

About 50 feet of calcareous shale named the Montezuma Valley Member overlie the Juana Lopez (Leckie, et al., 1997). Numerous prionocyclids, scaphites, baculites, bivalves, inoceramids, and oysters occur in this sequence of shales

FIGURE 12. Stratigraphy of Mesa Verde National Park.

Stratigraphy of Mesa Verde National Park, Colorado

Era	Period	Epoch	Formation	Member	Map Unit	Description
Cenozoic	Quaternary	Holocene	Alluvium		Qal	Unconsolidated sands, silts, and gravels deposited mainly in stream beds and flood plains.
			Colluvium		Qls	Unconsolidated and unsorted irregular deposits of boulders, gravel, sand, and silt derived mostly from talus and landslides.
			High level terrace gravels		Qtg	unconsolidated gravels on mesa tops in Mancos valley.
			High level terrace gravels with travertine cement		Qtgt	Poorly sorted gravel deposits (same as Qtg), locally cemented with very thick travertine.
		Pleistocene	Travertine		Qtr	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.
	Tertiary	Oligocene	Minette		Ti	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.
Mesozoic	Cretaceous	Upper	Cliff House		Kch	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.
			Menefee		Kme	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.
			Point Lookout		Kpl	White to yellow fine to medium grained marine sandstone with shaly sandstone breaks, highly cross-bedded. Thickness 360 feet.
			Mancos	Smoky Hill	Kms	A prominent oyster (Pseudoperna congesta) bench about 900 feet above base of Mancos Formation.
				Juana Lopez	Kmj	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.
				Bridge Creek	Kmb	50 feet of light gray limestone and calcareous shale about 80 feet above Dakota / Mancos contact. (Also referred to as 'Greenhorn Member' on map.)
			Dakota sandstone		Kd	Dark brown medium to coarse grained marine sandstone.

but not in the abundance of those found in the Juana Lopez.

Nearly 300 feet of limy shales and limestone overlie the Montezuma Valley Member of the Mancos. This unit is correlated with the Smoky Hill Member of the Niobrara Formation. The Smoky Hill forms prominent benches around the north edge of the Mesa Verde. The oyster *Pseudoperna congesta* (Conrad) encrusts very large *Inoceramus (Volviceramus) grandis* (Conrad) and form compact solid beds within the Smoky Hill, which makes an easily recognized stratigraphic horizon. *Scaphites depressus* (Reeside) and *Baculites codyensis* Reeside are found in the middle part of the Smoky Hill sequence, and in the upper part are inoceramids such as *Inoceramus (Platyceramus) platinus*(Logan, *I. (Endocostea) balticus* Boehm, *I. (Magadiceramus) subquadratus* Schluter and the ammonites *Desmoscaphites bassleri (*Reeside) and *Scaphites hippocrepis* (DeKay).

The uppermost portion of the Mancos Formation consists of almost 1300 feet of sandy shale and thin shaly sandstones, previously referred to as the Transitional Zone. Leckie (1997) has named it the Cortez Member. It represents the beginning of a regressive stage of deposition and consists of shallow water, near shore deposits. Within this thick sequence fossils are sparsely scattered, and include baculites, occasional scaphites, a *Placenticeras planum* Hyatt, and rarely the crinoid *Uintacrinus*.

FIGURE 13. Stratigraphy of Rocky Mountain National Park.

Stratigraphy of Rocky Mountain National Park, Colorado

Era	Period	Epoch	Formation	Map Unit	Description
Cenozoic	Quaternary	Holocene-Pleistocene	Numerous		Man-made fill, Roaring River alluvial fan deposits, Holzwarth debris flow deposits, snow and ice, alluvium, organic rich sediment, colluvium, landslide deposits, talus, rock glacier and till deposits
		Pleistocene	Till: Pinedale age	Qp	Subangular to subrounded boulders, cobbles, and pebbles set in a sandy silt to silty sand matrix. Pinedale glaciation probably began > 35,000 years ago, and occurred in several pulses. Last major advance approached its maximum ~ 22,000 years ago, and these glaciers began to recede from their terminal moraines between 13,000-15,000 yrs. ago. Most gone by 10,000-11,000 yrs. ago (age data from Madole and Shroba, 1979, p. 128-129).
			Till: Bull Lake age	Qb	Subangular to subrounded boulders, cobbles, and pebbles in a silty sand matrix. Till of Bull Lake age may have been deposited between about 130,000-150,000 years ago (Madole and Shroba, 1979, p. 130).
			Till: pre-Bull Lake age	Qpb	Boulders and cobbles in a silty sand matrix. Age very poorly known-possibly deposited between 400,000-550,000 years ago (Madole and Shroba, 1979, p. 133).
			Gravel deposits	Qg	Stratified deposits of rounded to subrounded cobbles, pebbles, and sand of pre-Bull Lake age.
	Neogene		Diamicton	QNd	Unsorted, unstratified deposits of boulders, cobbles, and pebbles in a silty sand matrix.
	Tertiary	Lower Miocene	Troublesome	Tt	Gray and orange-gray, tuffaceous mudstone and sandstone, volcanic ash beds, and minor clayey limestone and conglomerate; several interlayered basaltic lava flows
		Oligocene	Sedimentary rocks, undivided	Ts	Small exposures of sedimentary rocks that interfinger with or underlie Oligocene volcanic deposits south of Peterson Park, west of Long Draw Reservoir, between Thunder Mountain and Iron Mountain, and northeast of Specimen Mountain on the ridge between Willow Creek and the Cache la Poudre River.
		Eocene Paleocene	Coalmont Formation	Tc	Gray to brown, fine- to medium-grained, arkosic sandstone, dark-gray carbonaceous mudstone, and conglomerate containing clasts as large as 1.5 m..
Mesozoic	Cretaceous	Upper	Pierre Shale	Kp	Interbedded silty shale and sandstone overlying dark-gray to black shale. Lower 500 m. of formation, poorly exposed north of Porphyry Peaks, contains fossils identified as *Inoceramus subcompressus* Meek and Hayden, *Didymoceras* sp.., and *Baculites gilberti* Cobban (W.A. Cobban, written commun., 1974); lower formation, exposed southwest of site of Willey Lumber Camp on south side of Michigan River, contains *Baculites obtusus* Meek (O'Neill, 1976, p. 39). Adjacent to the Mount Richthofen stock, the Pierre has been thermally metamorphosed to dense, hard, medium- to dark-gray hornfels that weathers yellowish gray. O'Neill (1976, p. 39-40) correlated this hornfels at Nokhu Crags with the Terry and Hygiene Sandstone Members of the Pierre, and reported *Inoceramus barabini*, Morton from the upper and middle sections.
			Niobrara Formation	Kn	Light- to dark-gray calcareous shale.
			Benton Shale	Kb	topmost beds of fossiliferous limestone and underlying very fine grained sandstone (thickness about 12 m. total) contain fossils of Juana Lopez age (Late Cretaceous;
					middle unit is medium-gray calcareous shale (thickness about 60 m)
		Lower			lower unit is medium- to dark-gray non-calcareous shale (thickness about 46 m.).
			Dakota Formation	Kd	Light-gray to light-brown, very fine grained to fine-grained, ripple-marked, thin- to very thick bedded sandstone; locally conglomeratic; local trace fossils (tracks and burrows) in upper part; light-gray to light-brown lenticular conglomeratic sandstone and chert pebble conglomerate in lower part; thickness varies from about 25 to 75 m.
	Jurassic	Upper	Morrison Formation	Jm	Green, greenish-gray, and grayish-red silty claystone, light-gray sandstone, and a few thin, discontinuous beds of dense limestone; thickness about 90 m.
		Middle	Sundance Formation	Js	Buff very fine grained sandstone and laminated siltstone; about 40 m. thick.
	Triassic	Lower	Chugwater Formation	TrPc	Reddish-brown to orange-red shale, siltstone, and fine-grained sandstone; laminated to thin bedded; contains detrital mica; also Upper Permian in age
	Precambrian Proterozoic	Middle	Intrusive igneous		Gabbro of the iron dike, Silver Plume granite, garnet-sillimanite granite, leucogranite, granite aplite, intrusion breccia, granite of Hagues Peak, mafic dikes, biotite-muscovite granite, quartz diorite, Boulder Creek granodiorite, trondhjemite of Thompson Canyon, pegmatite
		Early	Metamorphic rocks		Biotite schist, microcline-biotite-quartz-plagioclase granofels, hornblende gneiss and amphibolite, calc-silicate gneiss, biotite schist and hornblende gneiss, granitic gneiss, leucocratic gneiss.

Summarized from **"Geologic Map of Rocky Mountain National Park and Vicinity, Colorado"** *by William A. Braddock and James C. Cole, scale 1:50,000;*
USGS Miscellaneous Investigations Series Map I-1973
NOTE: squiggly lines represent unconformities (major breaks in the geologic record)

Overlying more than 2000 feet of the Mancos Formation is the Mesaverde consisting of three formations from the oldest to the youngest: the Point Lookout, Menefee, and Cliff House.

The Point Lookout Formation consists of a series of about 300 feet of thick sandstones deposited in shallow water and along beaches of a regressing sea. The contact with the upper Cortez Member of the Mancos is gradational and difficult to place. The Point Lookout Sandstone is a cliff-forming unit, which makes the resistant cap rock around the rim of the Mesa Verde. There are few identifiable fossils in this formation, but trace fossils are common and a large *Baculites* cf *haresi*, some broken inoceramids, and drift wood are present.

The sea drained off to the northeast, and the area became a lowland, coastal plain. Thick deposits of the Menefee Formation totaling up to 800 feet in places, were laid down in swamps, lagoons, and along broad meandering streams and include woody shales, coal, dark carbonaceous shales, and discontinuous irregular stream sands. No invertebrate or vertebrate fossils have been found, but a rich paleobotanical record is present, especially in the sandstones of the middle part of the formation. Although plant fossils are common in this unit, identification has been difficult because of problems in preservation. Paleobotanists who have been helpful in making identifications of specimens brought to them from MEVE include Jack Wolfe (USGS retired), Gary Upchurch (formerly USGS), Kirk Johnson (DMNH), Elizabeth Wheeler (NC State University), Una Smith (Yale Univ). Petrified wood is common in the sandstone units and has been identified as conifer. A few pieces of wood, along with bark and twigs, have been identified as *Auricaria.* Palms identified as *Sabal* and *Sabalites* are quite common and well preserved in the sandstones and make a thick hash of broken fronds in one layer of the Menefee. Other paleontological material includes: grass blades, a crushed stem of *Calamites*, a twig of a probable *Sequoia*, an unknown fern, a monocot, *Brachyphyllum,* and leaves from *Sycamore, Theaceae, Laurel, Camelia,* and *Ficus* trees. Kirk Johnson identified a well-preserved flower bud as probably *Paleoaster iniqueriende*, but is much smaller than any other known specimen. Una Smith (Yale University) indicated that the specimen resembles a paleoaster, but cannot refer it to a known species (Griffitts, personal communication, 2001).

The youngest Mesozoic sediments on the Mesa Verde are the marine sandstones of the Upper Cretaceous Cliff House Formation deposited in a shallow transgressive sea. The formation consists of two massive sandstone beds separated by a shaly sandstone unit. The prehistoric Puebloan cliff dwellings were constructed in alcoves in the massive sandstones. Invertebrate, vertebrate, and trace fossils are found throughout the formation (Siemers and King, 1974). The ammonite *Baculites maclearni* Landes is common within the unit and more rare are fragments of a *Placenticeras sp.* Bivalves include *Ethmocardium whitei, Cymbophora, Modiolus, Dosinopsis,* and *Inoceramus.* Several echinoids have been found and an excellent sea star, probably representing a new species and possibly a genus, was also collected.

Fossil vertebrates from the Cliff House include jaw, fins and isolated teeth from the bony fish *Enchodus*, shark teeth, amphibians, and reptiles (mosasaurs, plesiosaurs, turtles). Trace fossils including the Crustacean burrows *Ophiomorpha* are abundant throughout the sandstones. In 1934, during the construction of an addition to the Mesa Verde park museum, many excellent upper Cliff House fossils were collected.

Holocene insect fossils have been reported from a number of the Anasazi archeological sites within the park (Graham, 1965). Analysis of fossil insect assemblages indicated that the synanthropic insect population remained virtually unchanged from the Basketmaker culture through the Pueblo culture (Elias, 1997). Insect fossils were found associated with human remains, coprolites, and in food storage containers.

ROCKY MOUNTAIN NATIONAL PARK

Rocky Mountain National Park (ROMO) was established as a national park on January 26, 1915. The park was designated a Biosphere Reserve in 1976 and given wilderness designation on December 22, 1980. Rocky Mountain National Park has the highest elevation of any of the NPS areas in Colorado and includes the highest peaks of the Front Range in the Rockies. This area is sometimes referred to as the “Roof of the Rockies” as the Continental Divide crosses through Rocky Mountain National Park. The park shows extensive evidence of several different glacial episodes. Glacial features including cirques, moraines, icefields, glacial lakes, striations, and glacial debris are evident within the park.

The oldest rocks in Rocky Mountain National Park consist of Precambrian gneisses and schists dated to approximately 1.8 billion years old (Fig. 13). These metamorphic rocks have been intruded by granite batholiths. During the Tertiary, the Laramide Orogeny caused regional uplift and increased volcanic activity. Glacial activity started during the Pleistocene Epoch around 1.5 million years ago, representing the Bull Lake glaciation and the Pinedale glaciation (Wisconsinan age). The last of the Pleistocene glaciers disappeared in the park region about 7500 years ago (Harris, 1977). There are still several small active glaciers within the park boundaries.

Paleontological resources known from Rocky Mountain National Park are limited to the Pleistocene and Holocene. Although the Mancos Formation is exposed in the park, there are no documented fossil specimens reported from this unit. There are a few enigmatic specimens in the museum collection at ROMO, including several pieces of petrified wood, *Stylommatophora,* several molluscan specimens as well as other marine fossils. Additional specimens in the park collection include teeth from *Ursus americanus, Equidae* sp. and *Bovidae* sp. and ten plant fossils from the Willow Creek Pass area just outside the park boundaries. There are 35 different Holocene insects identified from the Mount Ida

Ridge Pond (Elias, 1985), with additional specimens from the Roaring River and La Poudre Pass sites that are listed in Appendix B (Elias, 1996a, 1996b). Pollen samples were also collected from these localities.

YUCCA HOUSE NATIONAL MONUMENT

Yucca House National Monument (YUHO) was proclaimed a national monument on December 19, 1919 to preserve a complex of unexcavated prehistoric Native American pueblos. The site is administered through Mesa Verde National Park and is currently not open to the public. The monument located on the west side of the broad Montezuma Valley south of McElmo Creek consists of a group of unexcavated mounds outlining kivas and room blocks originally described and sketched by W.H. Holmes during his 1875-76 field excursions (1876).

The bedrock geology at Yucca House consists of the Upper Cretaceous Mancos Formation. The Mancos Formation has been divided into eight members at the type section at Mesa Verde National Park by R.M. Leckie (Leckie, et al., 1997). However, at Yucca House only the top four members are exposed within the monument boundaries. The lower four, the Graneros shale, the Bridge Creek (Greenhorn) Limestone, and the Fairport and Blue Hills Shales crop out to the west of the monument. The older Dakota Formation crops out about 2 ½ miles north and about 2 ½ miles west of the present boundaries of Yucca House.

The oldest sedimentary rock cropping out in the monument, the Juana Lopez Member of the Mancos, is most important to Yucca House both in paleontology and archeology. The low mesas just west of the monument boundary are capped by the rusty calcarenite of the Juana Lopez Member. The gullies between the small hills cut into this member. The Juana Lopez is a highly fossiliferous unit composed of dark soft calcareous shales and hard calcarenite layers. The calcarenite is a granular, solid rock that resembles a sandstone, but is almost entirely composed of calcium carbonate. It is dark gray, almost black in fresh specimens, but weathers to a rusty brown. Solution of pieces of this calcarenite in hydrochloric acid leaves only a very small residue of fine silt and clay. The Juana Lopez represents a period of quiet deposition far from shore, with little clastic material being brought into the area. Although the calcarenite is largely composed of bioclastic debris such as broken shell material, some probably represents a chemical recrystallization of calcium carbonate derived from the molluscan shells.

Much of this part of the Montezuma Valley is underlain by the Juana Lopez Member. The dip is gentle, rarely more than 3 degrees, so that a relatively thin formation, less than 140 feet thick, crops out over a large geographic area. Most of the valley is covered with alluvium and terrace and landslide deposits, so bed rock outcrops are not common. The area has been cultivated for generations and soil covers much of the flat area. Bedrock crops out west of Yucca House Monument in the low foothills below the Ute Mountain laccoliths.

The Juana Lopez calcarenites bear a rich fauna of ammonites and bivalves. *Prionocyclus wyomingensis* Meek and *P. novimexicanus* (Marcou), *Baculites undulatus* d'Orbigny and *B. yokoyami* Tokunaga and Shimizu,. and *Scaphites warreni* Meek and Hayden and *S. whitfieldi* Cobban are common ammonites. Common bivalves include *Nicaisolophalugubris* (Conrad), *Inoceramus dimidius* White, *I. perplexus* Whitfield and various small oysters. This member is so highly fossiliferous that almost every block of calcarenite shows at least fragments of molluscs. A collection of fossils from the monument are catalogued and stored at the Mesa Verde Museum.

The paleontologic record is especially important to the archeologist because many of the building blocks visible in the rubble mounds have well-preserved fossils of the above species (Fig. 14). The closest outcrop of this fossiliferous zone is about ½ mile to the west. Where the Juana Lopez is cut by gullies, ready-made building blocks, shaped by 3-6 inch bedding planes plus vertical jointing, are found. The layer that caps the low hills is usually thinner bedded and would not make good building material. Some of the building blocks are boulders from the terrace gravels and landslide debris, but a large part is the highly fossiliferous Juana Lopez calcarenite.

Two small outcrops of the Smoky Hill Member of the Mancos are found several miles to the east of Yucca House with typical bivalves, *Pseudoperna congesta* (Conrad) encrusting *Inoceramus (Volviceramus) grandis* (Conrad), and *Inoceramus (Platyceramus) platinus* Logan.

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FIGURE 14. Fossil bivalves in the building stones at an archeological site in Yucca House National Monument.

der and Scott Madsen from Dinosaur National Monument; Herb Meyer, A. Cook, and A. Kinchloe from Florissant Fossil Beds National Monument; Andrew Valdez and Sue Judis from Great Sand Dunes National Park; George San Miguel, Jack Muller, and M. Colyer (photographer) from Mesa Verde National Park; and Bill Butler from Rocky Mountain National Park.

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Appendix A: List of fossils from Haystack Cave Gunnison County, Colorado. Midwest Archaeological Center, National Parks Service Radiometric dates 14, 935± 610, 12,154± 1,700 yr BP ^{14}C

Taxa:
Bufo sp *B. boreras* or *B. woodhousei*
Sceloporus undulatus
Buteo sp.
Lagopus sp.
Sialia sp.
Ochotona princeps
Lepus sp.
Sylvilagus sp.
Marmota flaviventris
Spermophilus richardsoni
Thomomys talpoides
Thomomys sp.
Peromyscus maniculatus
Microtus longicaudus
Microtus sp.
Lagurus curtatus
Mustela frenata
Taxidea taxus
Spilogale putorius
Canis latrans
Vulpes vulpes
Vulpes sp. or *Urocyon* sp.
Ursus americanus
Acinonyx trumani
Felis colcolor
Equus sp.
Odocoileus hemionus
Antilocapra americana
Ovis canadensis
Bootherium sp.
Euceratherium sp.

Appendix B: Taxonomic list of fossil insects found in Rocky Mountain NP

Class	Order	Family	Genus and Species	Mount Ida Bog	Roaring River	La Poudre Pass
Insecta						
	COLEOPTERA					
		Carabidae				
			Agonum bembidioides		X	
			Agonum sp.		X	X
			Amara cf. apricaria	X		
			Bembidion cf. trasversale		X	
			Bembidion incertum		X	X
			Bembidion striola	X		
			Bembidion spp.		X	X
			Calathus advena		X	
			Carabus taedatus agassii		X	
			Discorderus sp.		X	
			Elaphrus cf. Clairvillei			X
			Metabletus americanus		X	
			Notiophilus directus		X	X
			Patrobus septentrionis	X		X
			Pterostichus sp.		X	
			Stenelophus conjunctus		X	
			Selenophorus gagatinus		X	
			Selenophorus planipennis	X		
			Trechus sp.		X	X
			Trichocellus mannerheimi		X	
		Dytiscidae				
			Agabus inscriptus			X
			Agabus sp.	X		X
			Enochrus sp.			X
			Hydrospous occidentalis			X
			Hydrospous sp.	X		
			Hydrospous spp.			X
			Genus indet.		X	
		Hydrophilidae				
			Cercyon sp.			X
			Helophorus linearoides			X
			Helophorus sempervarisns			X
			Helephorus sp.			X
			Hydrobius sp.			X
		Staphylinidae				
			Acidota quadrata	X	X	X
			Deinopsis sp.		X	
			Eucnecosum brunnescens	X	X	
			Eucnecosum tenue	X	X	X
			Eucnecosum spp.	X	X	X
			Geodromicus sp.	X	X	X
			Gymnusa atra			X
			Hapalarea sp.	X		
			Lathrobium spp.			X
			Lordithon sp.		X	
			Microedus sp.		X	
			Micropeplus laticollis		X	
			Mycetoporus sp.		X	
			Olophrum consimile	X	X	
			Olophrum rotundicolle	X	X	X
			Olophrum spp.	X	X	X
			Orobanus sp.		X	
			Oxytelus sp.		X	
			Quedius sp.	X	X	
			Philonthus spp.		X	X
			Phlaeopterus sp		X	

Appendix B: (continued)

Insecta			
COLEOPTERA			
Staphylinidae			
Stenus (Colonus) sp.	X		X
Stenus dissentiens	X		X
Stenus immarginatus or formicetorum		X	
Stenus leviceps		X	
Stenus spp.			X
Tachinus elongatus	X		
Tachinus frigidus		X	
Tachinus sp.		X	
Tachyporus sp.	X		
Unamis sp.		X	
Xantholinus sp.		X	
Genus indet.	X		
Histeridae			
Genus indet.		X	
Byrrhidae			
Genus indet.		X	
Elmidae			
Genus indet.		X	X
Elateridae			
Genus indet.		X	X
Cantharidae			
Podabrus sp		X	
Anobiidae			
Genus indet.		X	
Bostrichidae			
Stephanopachys sobrinus		X	
Scarabaedidae			
Aegialia lacustris		X	X
Aphodius sp.	X	X	X
Lathridiidae			
Genus indet.	X		
Nitidulidae			
cf.Epurea sp.		X	
Genus indet.			
Cucujidae			
Laemophloeus sp.	X		
Mycetophagidae			
Genus indet.		X	
Cerambycidae			
Genus indet.		X	
Chrysomelidae			
Altica spp.	X	X	X
Oedionbchis sp.		X	
Plateumaris flavipes	X		
Genus indet.	X		X
Curculionidae			
Apion sp.		X	X
Magdalis hispoides	X		
Rhynocolus marcops		X	
Genus indet.			X
Scolytidae			
Dendroctonus cf. brevicomis	X		
Dendroctonus rufipennis		X	X
Dendroctonus sp.	X		
Dryocoetes affaber	X	X	
Dryocoetes autographus		X	
Dryocoetes sp.		X	
Polygraphus rufipennis	X	X	X

Appendix B: (continued)

Insecta			
COLEOPTERA			
Phloeotribus lecontei		X	X
Pityokteines minutus	X		
Pityophthorus spp.		X	X
Scolytus piceae		X	
Genus indet	X		X
HETEROPTERA			
Lygaeidae	X		X
Genus indet			
TRICHOPTEREA			
Hydropsychidae			
Arctopsyche sp.		X	
Limnephilidae			
cf. Asynarchus sp.	X		
cf. Clistoronia sp.		X	
Dicosmoecuss sp.		X	
cf. Limnephilus sp.	X		
Genus indet	X	X	X
Rhyacophilidae			
Himalopsyche sp.		X	
Rhyacophila sp.		X	
HYMENOPTERA			
Formicidae			
Camponotus herculeanus		X	
Formica rufa cf. marcida		X	X
Leptothorax sp.	X	X	
Myrmica incompleta			X
Myrmica (incompleta) sp.		X	
Hymenoptera parasitica			
Genus indet	X		
ARACHNIDA			
Aranaeae			
Genus indet	X		
ARANEIDA			
Genus indet		X	X
ACARI			
Oribatidae			
Genus indet	X	X	X
CLADOCERA			
Daphniidae			
Daphnia spp.	X		