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Colorado National Monument

Paleontological Resource Inventory (Public Version)



A large tridactyl track cast attributable to *Hadrosauropodus leonardii,* an ornithopod ichnotaxon found in the Cretaceous Naturita Formation of Colorado National Monument.
NPS / AUSTIN SHAFFER

Colorado National Monument: Paleontological resource inventory (public version)

Science Report NPS/SR—2024/116

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Abstract

Colorado National Monument (COLM) in western Colorado was established on May 24, 1911 with the purpose of preserving, understanding, and enjoying the natural and cultural resources of the landscape, focusing on the history, erosional processes, and geology present. Although not explicitly mentioned in the monument's purpose statement, the paleontological resources of COLM are nevertheless important. Significant fossils have been known from the area since the late 19th and early 20th centuries, and from COLM specifically within a few decades of the monument's founding. The direct urban interface of COLM with Colorado's Grand Valley provides unique management concerns for fossils and other resources of the monument.

While COLM preserves a long geologic history (roughly 1.7 billion years ago to the present), the fossils preserved at the monument mostly come from sedimentary rocks of the Mesozoic Era. The paleontological resources of COLM include both body fossils and trace fossils of a wide variety of organisms (e.g., freshwater mussels, dinosaurs, plants) representing diverse paleoenvironments.

In order to assess the paleontological resources of COLM, a field inventory was conducted from April to November 2023, visiting all previously reported fossil sites and documenting new localities. A total of 226 paleontological localities were verified during this fieldwork, of which nearly two-thirds (146 sites) were newly documented. Two more were discovered in March 2024. These 228 localities are distributed throughout much of the monument and many of the geologic units, with higher concentrations present in certain units (e.g., the Morrison Formation). Fieldwork was supplemented by the review of published and gray literature and assessment of COLM paleontological collections.

A number of significant paleontological discoveries were made during this inventory, including the first documented fossils (dinosaur tracks, plant fossils, and dinosaur skin) from the Naturita Formation within COLM and multiple novel fossil occurrences (e.g., likely the oldest-known fish otoliths in North America and possibly one of the only Jurassic ankylosaur tracks known globally). When considered alongside previously identified significant fossil finds from COLM (e.g., one of only three known turtle tracksites in the Morrison Formation and potentially one of the only known lizard trackways in the same unit), the paleontological resources of the monument are of high scientific importance. Future research on the paleontological resources of COLM has a high potential for identifying important fossil specimens and/or describing new species.

This report provides foundational data on the scope, significance, and distribution of paleontological resources at COLM and provides recommendations to support the management, interpretation, and research of these resources.

List of Terms or Acronyms

Adhesive meniscate burrow: A fossil burrow containing millimeter-scale crescents representing compressed backfill.

Aeolian or **eolian:** Wind-blown transport or an environment where wind transport dominates.

Aetosaur: A representative of the order Aetosauria. A quadrupedal herbivorous armored reptile related to crocodylians. Known from the Late Triassic.

Alkaline: When applied to bodies of water, this refers to a pH greater than 7.0.

Alluvial (adjective), **alluvium** (noun)**:** a general term for unconsolidated terrestrial sediment moved by water and not attributed to a more specific process (i.e., not fluvial, glacial, or lacustrine).

Amphicoelous: A type of vertebral articulation in which the vertebral body has concave surfaces at both ends.

Angiosperm: A representative of the clade Angiospermae. Includes all flowering plants.

Ankylosaur: A representative of the suborder Ankylosauria, a group of heavily armored herbivorous dinosaurs. The armor of ankylosaurs varied, with large spines, shields, and tail clubs being seen in a number of species. Known from the Jurassic to the Cretaceous.

Annelid: A representative of the phylum Annelida. Also known as "segmented worms," annelids are known from the Cambrian to the present and are incredibly diverse in the modern day (common examples are earthworms and leeches).

Annular or **annual rings** (biology)**:** Circular, concentric growth rings indicating the growth of an organism (visible rings corresponding to changes in growth rate). These can be found in various taxa including trees, fish, and bivalves.

Anthozoan: A representative of the subphylum Anthozoa, a group of marine invertebrates including corals and sea anemones.

Archosaur: A representative of the clade Archosauria, which contains the most recent common ancestor of crocodylians and birds and all of its descendants. A diverse group containing crocodylians, birds, dinosaurs, pterosaurs, and many more unique reptile groups.

Archosauromorph: A representative of the Archosauromorpha, which includes archosaurs (crocodylians and birds) and all reptiles more closely related to them than to lepidosaurs (lizards, snakes, and rhynchocephalians).

Aridisol (geology)**:** A classification of paleosol characterized by shallow calcareous, gypsiferous, or salty horizons produced under arid to semi-arid conditions and a lack of rain. The depositional environment corresponds to deserts and xeric shrublands, with sparse xerophytic vegetation and low

concentrations of organic matter. Within the United States, modern aridisols are found in much of the Southwest.

ARPA: Archaeological Resources Protection Act.

Arthropod: A representative of the phylum Arthropoda, a diverse group of invertebrates with exoskeletons, segmented bodies, and jointed appendages. Insects, arachnids, and crustaceans are modern examples.

Artifact (archeology)**:** Objects made or modified by humans.

Azendohsaurid: A representative of the family Azendohsauridae. A close relative to trilophosaurids. A Middle to Late Triassic reptile resembling a large, long-necked lizard (sometimes with horns).

Basal (geology)**:** Located near or at the bottom of a specific geologic unit.

Basal (phylogeny)**:** A taxon closer to the base/root of a phylogenetic tree or cladogram.

Basement (geology)**:** Crystalline rocks that underlie all other rocks and sediment and are above the mantle.

Basin (geology)**:** A geologic downwarp formed by folding and faulting; geologic basins can often be identified by rock strata dipping to a central point, a bullseye pattern of rocks in a geologic map with the youngest rocks at the center, or an anomalous area of young rocks at the same elevation as older rocks in the vicinity. An eroded geologic basin does not necessarily form a depression.

Bedrock (geology)**:** A general term for the rock that underlies soil or other unconsolidated, surficial material.

Bench (geology)**:** A long, relatively narrow, shelflike strip of rock of shallow slope with much steeper slopes above and below.

Bennettitale or **cycadeoid:** A representative of the order Bennettitales. A plant clade known from the Permian to the Cretaceous, noted for combining cycad-like foliage with flower-like reproductive organs.

Bentonite: A clay produced by weathering of the volcanic glass particles that make up volcanic ash.

Biostratigraphy: Using fossils to identify the relative positions and relative ages of rocks.

Bioturbation: Disturbance of sediment by organisms to the extent that sedimentary features such as bedding and stratification are destroyed.

Bivalve: A representative of the class Bivalvia. A mollusk with two shells. Historically referred to as pelecypods. Examples include clams, oysters, mussels, and scallops.

BLM: Bureau of Land Management.

Body fossil: Fossilized remains of the body of past organisms, including bones, teeth, skin, shells, wood, and leaves.

Brachiopod: A representative of the phylum Brachiopoda. A marine filter-feeding animal with two shells, resembling bivalve mollusks but more closely related to bryozoans. Brachiopods are sometimes known as "lamp shells" due to the resemblance of some taxa to ancient oil lamps.

Bryozoan: A representative of the phylum Bryozoa. A filter-feeding aquatic colonial animal. Bryozoans are sometimes called "moss animals" because they often encrust objects.

Caecilian: A representative of the clade Gymnophiona. A limbless, worm-like or snake-like amphibian that lives in soil or streambeds.

Calcareous: Mostly or partly composed of calcium carbonate; lime-rich.

Calcisol (geology)**:** A classification of paleosol characterized by significant secondary accumulation of lime. Commonly occur in arid and semi-arid environments with highly calcareous parent materials and generally sparse vegetation. Within the United States, modern calcisols are found across the Southwest.

Calcite: A mineral made of calcium carbonate. Found in limestone and some fossils.

Calcium carbonate: $CaCO_3$, a mineral-forming compound. Calcite is a common form.

Cambrian: The first geologic period of the Phanerozoic Eon and the Paleozoic Era, noted for the diversification of complex, multicellular animal life. Lasted from approximately 539 to 487 Ma.

Carbonate (geology)**:** A general term for minerals containing carbonate ions (CO_3^{-2}), such as calcite, and rocks containing these minerals, such as limestone.

Carboniferous: Internationally, the fifth geologic period of the Paleozoic Era, often divided into the Mississippian and Pennsylvanian in North America. Lasted from approximately 359 to 299 Ma.

(Natural) Cast: In paleontology, sediment-filled external molds of an organism.

Cenozoic: A geologic era, dated approximately 66 Ma to the present, noted for the diversification of mammals. The term means "new life".

Charophyte: A representative of the clade Charophyta, a group of freshwater green algae from which terrestrial plants evolved.

Chert: A rock made of silica lacking obvious macroscopic crystals. Flint is a variety of chert found in chalk and limestone.

Choristodere: A representative of the order Choristodera, an enigmatic group of semiaquatic reptiles with crocodile-like, lizard-like, and long-necked forms. Known from the Jurassic to the Miocene.

Chronostratigraphy: A branch of stratigraphy that examines the relationship between strata and time. Isotope geology and geochronology are heavily utilized to determine the precise age of certain rocks.

Chronozone or **chron:** A unit in chronostratigraphy defined by the presence of certain fossil taxa (**biochronozone**) or geomagnetic reversal events (**magnetozones**).

Cladistics: A biological classification method grouping organisms in groups (**clades**) based on the proportion of shared measurable derived characteristics (**synapomorphies**). Cladistics is the most commonly utilized method for classifying organisms.

Cladogram: In cladistics, a diagram used to show the relationships of organisms.

Clast: A rock fragment of any size. A rock made up of clasts, such as sandstone or shale, is called clastic.

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

Coelacanth: A representative of the class Actinistia, a group of lobe-finned fish more closely related to tetrapods than to ray-finned fish. There are two extant coelacanth species.

Coelophysid: A representative of the family Coelophysidae. A relatively small, bipedal, carnivorous theropod dinosaur known from the Late Triassic to Early Jurassic. Coelophysids were quite slender and lightly built, allowing fast and agile running.

Coeval: Occurring or existing at the same time; contemporary.

Coleopteran: A representative of the order Coleoptera, a group of insects including the beetles.

Colluvial (adjective), **colluvium** (noun)**:** a general term for unconsolidated terrestrial sediment deposited at the base of a slope through various means (e.g., mass wasting).

COLM: Colorado National Monument.

Conchostracan: A representative of the paraphyletic clade Conchostraca. A bivalved crustacean, also known as “clam shrimp”.

Conformable (geology)**:** A successive, continuous sequence of strata deposited without interruption or disturbance.

Conglomeratic (adjective), **conglomerate** (noun)**:** A clastic sedimentary rock comprised of a significant proportion of gravel-sized clasts (>2 mm [0.08 in]) and a finer grained matrix.

Conifer: A representative of the division Pinophyta, including gymnosperm trees such as pines, firs, cypresses, cedars, hemlocks, larches, spruces, and more.

Consolidant (paleontology)**:** a dilute adhesive used to penetrate a fossil specimen and adhere internally in order to prevent damage.

Contact (geology)**:** The boundary that separates two bodies of rock; the horizon or plane where two formations meet.

Coprolite: Fossil feces.

Core (archeology)**:** A chunk of stone from which flakes have been removed.

Cretaceous: The third and last geologic period of the Mesozoic Era, noted for the rise of flowering plants and the extinction of many groups at the end of the period. Lasted from approximately 143 to 66 Ma.

Crinoid: A representative of the class Crinoidea. An echinoderm known as a sea lily, featuring a cup-like body with feathery tentacular arms, usually but not always attached to a surface with a stalk.

Crocodylomorph: A representative of the clade Crocodylomorpha, containing modern crocodylians and their extinct relatives. Early crocodylomorphs were small and active terrestrial hunters, with the modern crocodilian body-plan not appearing until the Jurassic.

Cross-bedding or **cross-stratification:** Uniform to highly varied sets of inclined sedimentary beds deposited by wind or water that indicate flow conditions such as deposition direction and depth/height.

Cyanobacteria: A representative of the phylum Cyanobacteria. Photosynthetic bacteria, also known informally as "blue-green algae."

Cycad: A representative of the division Cycadophyta. A seed plant with a stout, woody trunk and large, hard, evergreen leaves. Sometimes mistaken for palms or ferns.

Cynodont: A representative of the clade Cynodontia. All modern mammals fall within this clade, with early representatives from the late Permian to Early Jurassic being relatively small in size and exclusively egg-laying.

Czekanowskiale: A representative of the order Czekanowskiales, an extinct group of tree-/shrub-like seed plants with scale-like leaves. Known from the Permian to the Cretaceous.

Decapod: A representative of the order Decapoda, a group of crustaceans that includes prawns, shrimp, lobsters, crayfish, and crabs.

Dicynodont: A representative of the clade Dicynodontia. A tusked, beaked herbivore related to mammals. Known from the Middle Permian to Late Triassic. Dicynodonts ranged in size from rodent-like to elephant-like.

Dike (geology)**:** A large sheet of rock that forms within the fracture of an existing rock, either through intrusive (**magmatic dike**) or sedimentary (**clastic dike**) processes.

Dinosaur: A representative of the clade Dinosauria, a diverse group of reptiles that arose during the Triassic and continue to the present in birds. Dinosaurs have occupied a wide variety of different shapes, sizes, and niches over their evolutionary history.

Dinosauromorph: A representative of the clade Dinosauromorpha, which contains dinosaurs and all organisms more closely related to them than to pterosaurs. Some groups of dinosauromorphs may belong in Dinosauria proper (e.g., Herrerasauria, Silesauridae).

Disconformity: An unconformity where the strata above and below the geologic contact are parallel, but the contact itself shows evidence of erosion or nondeposition.

Distributive fluvial system (DFS): A fluvial system that disperses into a radial, distributive channel pattern upon entering a sedimentary basin. A large number of DFSs are known to occur worldwide in the present, with numerous examples in particular in Central Asia.

Docodont: A representative of the order Docodonta, a group of cynodonts closely related to modern mammals. A number of different forms were taken by docodonts, including mole-like, squirrel-like, and otter-like taxa. Known from the Jurassic to Cretaceous.

DOI: Department of the Interior or, in references, digital object identifier.

Doswelliid: A representative of the family Doswelliidae. A semiaquatic, armored archosauromorph reptile resembling a crocodilian, although distantly related. Known from the Middle to Late Triassic.

Drepanosaur: A representative of the clade Drepanosauromorpha. An enigmatic reptile resembling a chameleon with a bird-like head. Known from the Late Triassic. Different drepanosaurs display evidence of arboreal and burrowing lifestyles.

Echinoderm: A representative of the phylum Echinodermata. A group of invertebrates noted for their five-fold symmetry. Sea stars, sea urchins, sea lilies, and sea cucumbers are some examples.

Eocene: The second epoch of the Paleogene Period. Lasted from approximately 56 to 34 Ma.

Erg: A sand-covered desert at least 125 km^2 (48 mi^2) in area. May also be called a dune sea if dunes are abundant.

Eutriconodont: A representative of the clade Eutriconodonta. A group of early mammals that possessed a diverse variety of body plans and occupied various niches including small shrew-like insectivores, large badger-like carnivores, and even gliding flying squirrel-like taxa. Known from the Jurassic to the Cretaceous.

Extant: Still in existence, not extinct.

Facies: A body of rock that is distinct from the surrounding rock, due to specific aspects of deposition and setting. Facies are generally invoked when there are differences within a formation or member that are not suitable for mapping (i.e., not laterally persistent).

Fissile (geology)**:** A rock that has a tendency to split along flat planes of weakness.

Flake (archeology)**:** A lithic fragment broken from a larger stone during tool manufacturing.

Float (geology)**:** Eroded material resting on the surface, not attached to an outcrop.

Fluvial: Of or pertaining to a river or rivers.

Formation (geology)**:** Fundamental rock-stratigraphic unit that is mappable, lithologically distinct from adjoining strata, and has definable upper and lower contacts. The basic unit of stratigraphy.

Fossiliferous: A rock or deposit that yields fossils.

Ga: An abbreviation for "gigaannum" or "giga-annum" meaning "billion years."

Ganoid scales: A type of fish scale seen today in sturgeons, paddlefish, bichirs, bowfin, and gar, as well as in a number of extinct taxa. These thick, diamond-shaped scales provide exceptional protection against predators.

Geochronology: A branch of geology dedicated to determining the age of rocks, sediments, fossils, and geologic events. A number of different types of geochronology exist based on the use of varying dating methods.

Ginkgo: A representative of the genus *Ginkgo*; may be used to refer to stem relatives as well within the order Ginkgoales. The single extant species is a tree most closely related to cycads and possesses unique fan-shaped leaves. The order Ginkgoales are known since the Permian, while the genus *Ginkgo* is known from the Jurassic to the present.

Gneiss: A high-grade metamorphic rock characterized by banding of light-colored (quartz) and dark minerals.

Gnetophyte: A representative of the division Gnetophyta, a group of gymnosperm plants with a diverse fossil record yet only a handful of modern genera (including the widespread genus *Ephedra*). Known from the Jurassic to the present.

Goniopholidid: A representative of the family Goniopholididae, a group of semi-aquatic crocodyliforms that very closely resemble extant crocodylians. Known from the Jurassic to the Cretaceous.

Gradational (geology)**:** A conformable contact between rock layers in which the transition between depositional environments is prolonged.

Granite: An igneous rock formed at depth, composed primarily of light-colored quartz and feldspar minerals with small quantities of dark minerals.

GRD: Geologic Resources Division of the National Park Service.

GRI: Geologic Resources Inventory.

Group (geology)**:** A lithostratigraphic unit comprising several related formations classified together.

Gymnosperm: A representative of the clade Gymnospermae, a group of seed plants that includes conifers, cycads, gnetophytes, and ginkgophytes.

Gypsiferous: Containing gypsum.

Gypsum: A mineral made of calcium sulfate dihydrate, $CaSO_4\ 2H_2O$. Often deposited through evaporation of lake/sea water, as well as in veins.

Hemipteran: A representative of the order Hemiptera, a large and diverse group of insects commonly referred to as "true bugs" and including cicadas, aphids, bed bugs, water bugs, and many more.

Herrerasaur: A representative of the clade Herrerasauria (or Herrerasauridae), early bipedal carnivorous dinosaurs that superficially resemble theropods. Known from the Late Triassic.

Heterodontosaur: A representative of the family Heterodontosauridae, fox-sized herbivorous or omnivorous ornithischian dinosaurs with large tusks. Known from the Early Jurassic to the Early Cretaceous. Some recent research has recovered Heterodontosauridae as paraphyletic with respect to the Late Cretaceous dome-headed Pachycephalosauria.

Holocene: The second and most recent epoch of the Quaternary Period, following the Pleistocene and the last glacial maximum, beginning approximately 11.7 ka and continuing to the present.

Holotype: A specimen that serves as the basis for an organism's scientific name and is ideally representative of the given taxon, although this is not necessarily the case. Other "types" exist for specific situations, such as a paratype or a neotype.

Hymenopteran: A representative of the order Hymenoptera, a large and diverse group of insects including ants, wasps, and bees.

Ichnofossil or **trace fossil:** Fossilized remains of the biological activity of past organisms, including traces of burrows, tracks, root traces, feeding marks, fossilized dung, and layers produced by microbial mats.

Ichnogenus, ichnospecies, ichnofamily, ichnotaxon: A scientific name used for a trace fossil, existing in parallel to the names used for body fossils.

Ichnology: The study of traces or biological activity beyond an organism's remains. Sometimes divided into **paleoichnology** (the study of trace fossils or ichnofossils) and **neoichnology** (the study of modern traces).

Igneous: Refers to a rock or mineral that originated from molten material. One of the three main classes of rocks, alongside metamorphic and sedimentary.

In situ (geology)**:** When describing fossils, this means found in place at an outcrop.

Interbedding (geology)**:** Rock layers of a specific lithology lying between or alternating with those of a different lithology.

Interdune: A flat or gently sloping surface enclosed or partially enclosed by dunes, taking a variety of different forms (such as erosional, dry, damp/wet, evaporitic, and vegetated).

Interfingering, intertonguing, interdigitating, interlocking (geology)**:** A conformable contact between rock layers in which an alternating series of wedge-shaped "tongues" represent the fluctuating boundary between different contemporary depositional environments.

Intertidal: Within the range from low tide to high tide.

Intrusive (adjective), **intrusion** (noun)**:** In igneous rocks, refers to rocks that cooled from a molten state below the surface of the Earth.

Ischium: One of three bones of the hip (or regions, in animals where hip bones are fused), located below and posterior to the hip socket.

Jurassic: The second geologic period of the Mesozoic Era. Lasted from approximately 201 to 143 Ma.

Ka: An abbreviation for "kiloannum" or "kilo-annum" meaning "thousand years."

Lacustrine: A lake as a depositional environment or mode of transport.

Lagerpetid: A small, bipedal relative of pterosaurs, known from the Late Triassic.

Lepidosaur: A representative of the superorder Lepidosauria, a group including lizards, snakes, and rhynchocephalians.

Limestone: A sedimentary rock consisting mainly of calcium carbonate, primarily in the form of the mineral calcite.

Lithic (archeology)**:** A modified stone tool, often achieved through grinding or chipping.

Lithified: A sedimentary deposit that has become rock.

Lithology: The variety or varieties of rock in a formation, member, bed, or other division.

Locality: A distinct site, especially one known to field fossils or other unique features.

Lycopod: A representative of the class Lycopodiopsida, a group of plants containing clubmosses and firmosses, quillworts, and spikemosses. While modern examples are relatively small, giant lycopods were abundant during the Carboniferous.

Ma: An abbreviation for "megaannum" or "mega-annum" meaning "million years."

Magnetochronology: A type of geochronology based on reversals of geomagnetic polarity.

Mammaliamorph: A representative of Mammaliamorpha, a clade including tritylodontids, some other close relatives of mammals, and true mammals.

Manus (ichnology)**:** The forefoot track ("hand") of a tetrapod.

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

Matrix (geology)**:** A fine-grained mass of rock in which larger grains, clasts, crystals, and/or fossils are embedded.

Member (geology)**:** A lithostratigraphic unit with definable contacts; a subdivision of a formation.

Mesaxonic (adjective)**, mesaxony** (noun)**:** A foot structure in which an enlarged middle digit forms the axis of the foot.

Mesoproterozoic: The second geologic era of the Proterozoic Eon. Lasted from approximately 1.6 to 1.0 Ga.

Mesozoic: A geologic era, dated approximately 252 to 66 Ma, noted for the dominance of dinosaurs on land and the appearance of birds, mammals, and flowering plants. The term means "middle life."

Metamorphic: Refers to a rock that formed through metamorphism. One of the three main classes of rocks, alongside igneous and sedimentary.

Metamorphism (geology)**:** The transformation of an existing rock's composition/structure into a different form through heat, pressure, and/or chemical processes. The rock remains mostly solid throughout this transformation.

Metasedimentary: A variety of metamorphic rock in which the original material was sedimentary rock, produced through sedimentary processes.

Metavolcanic: A variety of metamorphic rock in which the original material was produced through volcanic processes.

Metoposaur: A representative of the family Metoposauridae. Triassic trematosaurian amphibians that reached 1.5 to 3 m (4.9 to 9.8 ft) in length.

Microconchid: A representative of the order Microconchida, a group of enigmatic extinct invertebrates known from small spiral-coiled shells resembling certain fossil "worm" tubes, found encrusting other fossils.

Microfossil: A fossil, typically of a millimeter (0.04 in) or less in size, that must be studied with a microscope.

Microvertebrate: A vertebrate microfossil, requiring a microscope for study.

(Packrat) Midden: A collection of debris by a packrat (*Neotoma* spp.) including a variety of material (such as plants, bones, rocks, artifacts, etc.) that can provide important ecological/environmental data. Middens may preserve debris from the late Pleistocene through the Holocene.

Miocene: The first epoch of the Neogene Period. Lasted from approximately 23 to 5.33 Ma.

(Natural) Mold: In paleontology, an internal or external impression of an organism left in sediment.

Mollusk: A representative of the phylum Mollusca, a diverse group of invertebrates noted for their combination of a muscular foot, a shell, and a mantle that covers the innards and secretes the shell. Examples include bivalves, cephalopods, and gastropods.

Monophyletic (adjective), **monophyly** (noun)**:** A taxon that includes a common ancestor and all of its descendants (e.g., mammals within Mammalia).

Multituberculate: A representative of the order Multituberculata, a diverse group of extinct mammals resembling rodents, ranging from burrowers, arboreal-dwellers, and hoppers, and coming in a variety of sizes from mouse-sized to beaver-sized.

Nematode: A representative of the phylum Nematoda, an abundant and diverse group of invertebrates often called "roundworms."

Neogene: The second geologic period of the Cenozoic Era. Lasted from approximately 23 to 2.58 Ma.

Neoproterozoic: The third and final geologic era of the Proterozoic Eon. Lasted from approximately 1.0 Ga to 539 Ma.

Nepomorph: A representative of the infraorder Nepomorpha, a group of insects including water bugs.

NPS: National Park Service.

Oligocene: The third and final epoch of the Paleogene Period. Lasted from approximately 34 to 23 Ma.

Oncoid: A concentrically laminated structure formed by microbes; rocks made of oncoids are called oncolites.

Organic: Made of organic compounds (i.e., molecules of carbon, hydrogen, nitrogen, and oxygen); pollen, spores, and cysts, all of which can be fossilized, have organic walls.

Ornithischian: A representative of the clade Ornithischia. A "bird-hipped" dinosaur, which despite the name was not closely related to birds. Ornithischians included the ankylosaurs, stegosaurs, pachycephalosaurs, ceratopsians, and ornithopods. All had a bony beak at the tip of the lower jaw.

Ornithomimosaur: A representative of the clade Ornithomimosauria. A fast-running, omnivorous/herbivorous theropod dinosaur resembling an ostrich.

Ornithopod: A representative of the clade Ornithopoda. A beaked herbivorous dinosaur, bipedal at small body weights but progressing toward quadrupedality when large. Hadrosaurs, or "duck-billed dinosaurs", are the best-known ornithopods.

Orogeny: A mountain-building event.

Orthopteran: A representative of the order Orthoptera, a group of insects containing grasshoppers, crickets, and locusts.

Ostracod: A representative of the class Ostracoda. A shelled crustacean that is generally microscopic. Known informally as "seed shrimp."

Paleocene: The first epoch of the Paleogene Period. Lasted from approximately 66 to 56 Ma.

Paleoclimatology: The study of ancient climates through the use of various proxies (e.g., rock/sediment, ice, tree rings, fossils, etc.).

Paleocurrent: The direction of flowing water at the time of sediment deposition, typically determined through the use of sedimentary structures and useful in reconstructing depositional environments.

Paleoecology: The study of interactions among organisms and between organisms and their environments on a geologic timescale.

Paleogene: The first geologic period of the Cenozoic Era. Lasted from approximately 66 to 23 Ma.

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

Paleoproterozoic: The first geologic era of the Proterozoic Eon. Lasted from approximately 2.5 to 1.6 Ga.

Paleosol (geology)**:** A preserved ancient soil buried and sometimes lithified. Can be useful for interpretation of the depositional environment and/or climate. Divided into distinct classes similar to those used in modern soil science.

Paleozoic: A geologic era, dated approximately 539 to 252 Ma, noted for the diversification of invertebrates and the appearance of vertebrates and land plants. The term means "early life".

Palynomorph: An organic-walled microfossil. Pollen and spores are common examples. Other types include tests (hard spherical shells) of some microorganisms and the jaw elements of worms.

Paralic (geology)**:** A system of interfingered marine and nonmarine sediments recording a mix of terrestrial/aquatic coastal environments and various marine transgressions/regressions.

Paraphyletic (adjective), **paraphyly** (noun)**:** A taxon that includes some descendants of a common ancestor but excludes others (e.g., Reptilia, which includes birds, is paraphyletic in a traditional sense).

Pegmatite: A coarse igneous rock with interlocking crystals generally between 1 cm (0.4 in) and several meters in length, with some individual crystal examples reaching upwards of 10 m (33 ft) long. Pegmatites are typically found in the form of dikes, sills, or veins related to large intrusions.

Permian: The seventh and last geologic period of the Paleozoic Era, ended by the largest mass extinction in Earth's history. Lasted from approximately 299 to 252 Ma.

Pes (ichnology)**:** A hindfoot track ("foot") of a tetrapod.

Phanerozoic: The fourth and final geologic eon of Earth's history, beginning approximately 539 Ma and continuing to the present.

Phylogenetics: The study of the evolutionary relationships and history of organisms, determined through a variety of methods (such as DNA sequences and morphology). A **phylogenetic tree** is utilized to show hypothesized relationships and the evolutionary history of a group of organisms.

Phytosaur: A representative of the order Phytosauria. A semi-aquatic carnivorous reptile known from the Triassic. Distantly related to modern crocodylians but evolved a crocodile-like appearance and lifestyle convergently.

Playa: A dry lakebed.

Pleistocene: The older of two epochs in the Quaternary, noted for extensive glaciation. Lasted from approximately 2.58 Ma to 11.7 ka.

Pliocene: The second and final epoch of the Neogene Period. Lasted from approximately 5.33 to 2.58 Ma.

Polyphyletic (adjective), **polyphyly** (noun)**:** A taxon that includes multiple distinct groups, but not a common ancestor or all of its descendants (e.g., algae).

Poposaurid: A representative of the family Poposauridae, a group of large carnivorous pseudosuchians that filled similar niches to theropod dinosaurs. Known from the Triassic.

Precambrian: Geologic time before the Cambrian, before approximately 539 Ma.

Procolophonid: A representative of the family Procolophonidae. A stocky lizard-like herbivorous or insectivorous parareptile with a large head. Known from the Permian to the Triassic.

Proterozoic: The third and final geologic eon of the Precambrian. Lasted from approximately 2.5 Ga to 539 Ma.

PRPA: Paleontological Resources Preservation Act (2009).

Pseudofossil: An object or feature that resembles a fossil but is not of organic origin.

Pseudosuchian: A representative of the clade Pseudosuchia. One of the major branches of Archosauria, containing all animals more closely related to crocodylians than to birds.

Pteridosperm: A representative of the polyphyletic clade Pteridospermatophyta. A seed-producing plant with fern-like fronds. Often used in an informal sense to classify or describe seed plants that are not cycads, cycadeoids, gingkoes, conifers, or angiosperms. Commonly referred to as seed ferns.

Pterosaur: A representative of the order Pterosauria, extinct flying reptiles known from the Triassic to the end of the Cretaceous.

Quartz: A common mineral composed of silica.

Quartzite: 1) Moderately metamorphosed quartz sandstone in which the quartz sand grains have recrystallized into an interlocking mosaic (also known as **metaquartzite**); 2) Unmetamorphosed quartz-cemented quartz sandstone (also known as **orthoquartzite**).

Quaternary: The most recent geologic period, third and last in the Cenozoic Era, noted for extensive glaciation and numerous glacial/interglacial periods, beginning approximately 2.58 Ma and continuing to the present.

Radiocarbon, carbon-14, ^{14}C: A radioactive isotope of carbon that forms the basis of the radiocarbon dating technique of radiometric dating.

Radiocarbon years (BP): Uncalibrated radiocarbon dates are presented as radiocarbon years before present (defined as 1950).

Radiometric dating: A geochronologic method in which the age of a given material can be determined through measuring a radioactive isotope's amount of decay. Different dating schemes may be employed given the age range of a sample (e.g., **radiocarbon (^{14}C) dating** is reliable for samples up to roughly 50 ka, whereas **uranium-lead (U-Pb) dating** is reliable for samples ranging from 1 Ma to upwards of 4.5 Ga).

Rauisuchid: A representative of the family Rauisuchidae, a group of large carnivorous pseudosuchians that filled similar niches to theropod dinosaurs. Known from the Triassic.

Recrystallization: Reorganization of a mineral's structure under the influence of temperature, pressure, and/or chemically active fluids.

(Marine) Regression (noun), **regressive** (adjective): A marine retreat, exposing land.

Reworked (geology)**:** A fossil or other object that has been eroded from an older rock unit and redeposited in a younger unit.

Rhizoconcretion: A concretion that formed around or in response to a root.

Rhizohalo: A zone of mottled strata representing mineral depletion developed around a root.

Rhizolith: A sedimentary structure formed by plant roots and found in paleosols; sometimes referred to as root traces.

Rhodophyte: A representative of the division Rhodophyta, a group of eukaryotic algae commonly known as red algae.

Rhynchocephalian: A representative of the order Rhynchocephalia, a group of lizard-like reptiles with a single living taxon, the tuatara. Rhynchocephalian diversity reached its height during the Triassic and Jurassic before being largely overtaken by lizards during the Cretaceous.

Riparian: Pertaining to a riverbank setting.

Sabkha: A salt flat above the level of tides.

Sacrum: Two or more fused vertebrae supporting the hip.

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

Sandstone: Clastic sedimentary rock of predominantly sand-sized grains.

Sauropod: A representative of the clade Sauropoda. A quadrupedal herbivorous dinosaur with a proportionally long neck and tail and a small head. Most known sauropods were at least 9 m (30 ft) long and weighed several tons.

Sauropodomorph: A representative of the clade Sauropodomorpha, the group of dinosaurs including sauropods and their close relatives (sometimes known informally as prosauropods). The earliest sauropodomorphs differed from the sauropods by being small and bipedal.

Schist: A coarser-grained metamorphic rock in which the mineral grains are oriented such that the rock can be easily split into irregular, thin flakes or plates. Typically formed in association with orogeny.

Screenwashing or **wet sieving:** A technique by which water is used in conjunction with screens of various sizes in order to separate fossils (particularly microfossils) from sediment and/or matrix.

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

Sedimentary: Refers to a consolidated and lithified rock consisting of clastic and/or chemical sediment(s). One of the three main classes of rocks, alongside igneous and metamorphic.

Shuvosaurid: A representative of the family Shuvosauridae, a group of toothless, herbivorous, theropod-like pseudosuchians with some taxa bearing a striking resemblance to the later ornithomimosaurs. Known from the Late Triassic.

Silesaurid: A representative of the possibly paraphyletic family Silesauridae. Quadrupedal reptiles from the Triassic that are traditionally considered one of the closest relatives of dinosaurs within Dinosauromorpha; however, recent research has suggested that they may be true dinosaurs and the ancestors of Ornithischia.

Silica: The compound SiO_2; it is the building block of the common mineral quartz.

Silicate mineral: A mineral with a framework of silica. Quartz and feldspar minerals are common silicates.

Silicification: The replacement of a non-silicate mineral with a silicate mineral.

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

Siltstone: A clastic sedimentary rock composed of silt-sized grains.

Sinuosity: In reference to water, the degree to which the shape of a stream curves and bends along its course (i.e., **meandering**).

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

Spicules: In sponges, the structural components of the skeleton, comprised of calcium carbonate or silica.

Stegosaur: A representative of the suborder Stegosauria, a group of herbivorous dinosaurs distinguished by large spikes, including at the end of their tail (**thagomizer**), and bony plates along their backs. Known from the Jurassic to the Cretaceous.

Stem group (phylogenetics)**:** A paraphyletic group of organisms basal to and lacking certain traits of a derived clade (e.g., dinosaurs and pterosaurs are stem-birds).

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

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

Stratum (singular), **strata** (plural)**:** A layer of rock/sediment distinguished by specific lithological characteristics.

Stromatolite: A layered microbial mat, typically of a column or dome structure.

Subtidal: Below low tide.

Supratidal: Above high tide.

Symmetrodont: A representative of the order Symmetrodonta, an extinct group of mammals resembling shrews. Known from the Cretaceous.

Synapsid: A representative of the clade Synapsida, the group containing mammals and all animals more closely related to them than to other vertebrates. Early members are sometimes informally known as "mammal-like reptiles."

Talus or **scree:** Broken rock shed from cliffs through rock falls.

Tanystropheid: A representative of the family Tanystropheidae. A long-necked piscivorous reptile known from the Triassic.

Taxonomy: The study of naming, defining, and classifying organisms into groups. Taxonomic groups or **taxa** (singular: **taxon**) are provided a taxonomic ranking (the main ranks utilized are **domain, kingdom, phylum/division, class, order, family, genus,** and **species**, although additional ranks exist).

Tectonics: The movements and interactions of Earth's plates.

Tetrapod: A representative of the superclass of Tetrapoda, meaning "four feet", although some members have lost some or all four limbs (e.g., snakes). Tetrapods include amphibians, reptiles, birds, and mammals.

Theropod: A representative of the clade Theropoda, bipedal dinosaurs that usually possessed a large head and three long functional toes per hind foot; generally carnivorous but sometimes omnivorous or herbivorous. Theropod dinosaurs include birds.

(Marine) Transgression (noun), **transgressive** (adjective)**:** A marine encroachment, submerging land.

Trematosaurian: A representative of the clade Trematosauria, a diverse extinct group of amphibians with many medium- to large-sized and semi-aquatic to aquatic taxa. Known from the Triassic to Cretaceous.

Triassic: The first geologic period of the Mesozoic Era. Lasted from approximately 252 to 201 Ma.

Tridactyl: A digit arrangement in which only three digits are present. In ichnology, a track bearing three toes.

Trilophosaurid: A representative of the family Trilophosauridae. An herbivorous archosauromorph reptile that resembled a large lizard. Known from the Late Triassic.

Tritylodontid: A representative of the family Tritylodontidae, a group of specialized cynodonts with rodent-like teeth. Known from the Triassic to the Cretaceous.

Type section: A geologic exposure that serves as the basis of definition for a stratigraphic unit.

Unconformity: A general term for any erosional or non-depositional surface between two rock units.

Unionid: A representative of the family Unionidae, a diverse group of freshwater bivalves sometimes referred to as “river mussels”. Known from the Jurassic to the present. Unionids possess a parasitic larval stage that relies on fish.

USGS: United States Geological Survey.

Vertisol (geology)**:** A classification of paleosol characterized by swelling smectitic clay. Depositional environment is typically wooded grassland with a seasonally humid climate or subject to erratic droughts and floods. Within the United States, modern vertisols can be found in southern and eastern Texas.

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

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

Worked (archeology)**:** Refers to a stone tool that exhibits evidence of human modification (i.e., flaking, lithic reduction).

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Many paleontologists provided invaluable input, information, and support over the course of this inventory. For this and everything else they contributed to this project—including assistance in the field—we extend our thanks. Thanks to ReBecca Hunt-Foster (Dinosaur National Monument), Jim Clark (George Washington University), Julia McHugh (Museums of Western Colorado), Don Brinkman (Royal Tyrell Museum of Palaeontology), Jim Gardner (Royal Tyrell Museum of Palaeontology), Werner Schwarzhans (University of Copenhagen), Kelli Trujillo (University of Wyoming), John Foster (Utah Field House of Natural History State Park Museum), Don DeBlieux (Utah Geological Survey), Jim Kirkland (Utah Geological Survey), Ryan King (Western Colorado University), and Josh Smith (Western Slope Paleontological Services).

A number of people, including some of those already listed, assisted in the fieldwork of this project, and in doing so enabled a much more thorough inventory to take place. Specific thanks to Daniel Arinze, Christa Cherava, Brandon Gottung, Tracey Hart, Bridget Hyde, Ryan King, Jessica Resnik, Olivia Ruiz, and Tom Shaffer for their efforts here.

We also want to thank the wide variety of individuals, many of whom are listed above, that participated in the scoping meeting for the project. Their discussions helped shape the project and drove its development into this report.

The assistance of Tim Connors, contributing relevant maps and coordinating peer review, is appreciated as is the support of other NPS Geologic Resource Division (GRD) staff. The support and opportunities provided by the Scientists in Parks (SIP) program, the NPS Youth Partnership Program, and partnerships with Conservation Legacy and the Geologic Society of America were invaluable to the completion of this project.

Finally, we thank John Foster, Ryan King, Ken Mabery, Julia McHugh, Kelli Trujillo, Jessica Resnik, Perrin Pring, Nathan Souder, and Kait Thomas for their reviews of this work. The useful feedback provided by these individuals helped to improve the final product.

Dedication

We dedicate this inventory report to paleontologist and geologist Ann Elder (*née* Schaffer). For many years, Ann combined her passions for geology and biology through paleontological work with the National Park Service.

Born in 1958, Ann spent her youth in Frederick, Maryland before attending Northland College in Wisconsin and the University of Vermont, where she received her bachelor's degree in geology in 1980. Ann married Tom Elder in 1989 and earned her master's degree in geology/paleontology from Utah State University in 1992.

She began her career at Fossil Butte National Monument before proceeding to Dinosaur National Monument where she worked primarily with the museum program. Here, Ann completely overhauled the collections, excavated fossils, preserved exhibits (including the famous dinosaur bone wall of Carnegie Quarry), and engaged with visitors. During this time, she also collaborated with other parks and museums through teaching, consulting, and assisting fieldwork.

Following budget cuts at Dinosaur National Monument in 2008, Ann transitioned to a position as the Chief of Resource Management at Colorado National Monument. Unfortunately, Ann passed away due to complications from surgery on March 31, 2009, at the age of 50. Her loss is still felt throughout the National Park Service and the field of paleontology as a whole. One can only imagine what the state of paleontology at Colorado National Monument could have been had Ann continued her work here. In 2018, the Morrison Formation dinosaur species *Dryosaurus elderae* was named in honor of Ann based on specimens found at Dinosaur National Monument, ensuring that her impact on science will not soon be forgotten.



Ann Elder (NPS / VINCENT SANTUCCI)

Introduction

Colorado National Monument (COLM) preserves 8,310.78 ha (20,536.39 acres; 32.09 mi^2) of semi-desert canyons, monoliths, and mesas along the northeastern edge of the Uncompahgre Plateau within the greater Colorado Plateau Province of the American Southwest (Figure 1). COLM is located in Mesa County, Colorado, forming a portion of the southern edge of the Grand Valley. The monument borders Bureau of Land Management (BLM) land to the west (McInnis Canyons National Conservation Area) and the southeast (Bangs Canyon Special Recreation Management Area), while a mix of BLM and private land abuts COLM along its current northeast and southwest borders. Fruita is just north of COLM, and Grand Junction is just east.

The monument was established by William Howard Taft's Presidential Proclamation 1126 on May 24, 1911, in order to protect the extraordinary erosional features found within (National Park Service 2015). Herbert Hoover's Presidential Proclamation 2037 on March 3, 1933 expanded the boundary to include adjoining land of historic/scientific interest, to protect Rim Rock Drive, and for administrative purposes. Certain lands were excluded by Dwight D. Eisenhower's Presidential Proclamation 3307 on August 7, 1959, lands which remained with the Department of Interior (currently administered by the BLM). The boundaries of COLM were expanded once more by Congress on October 21, 1976, in Section 302 of Public Law 94-578, authorizing the acquisition of areas of scenic, historic, and geologic significance in No Thoroughfare Canyon and Red Canyon, bringing COLM to its current boundaries as of the time of writing (National Park Service 2015). A significant amount of geologic and human history is protected by COLM, including substantial paleontological resources.

This report provides detailed information on the paleontological resources of COLM, including the history of paleontological work in the lands now within the monument, geologic units, taxonomic groups, localities, museum collections, research, interpretation, and management and protection. In addition to the main body of text, there are six appendices: Appendix A (tables of paleontological species arranged by stratigraphy); Appendix B (museum collections data); Appendix C (contact information for repositories); Appendix D (paleontological resource law and policy); Appendix E (paleontological locality data and monitoring recommendations); and Appendix F (a geologic time scale).

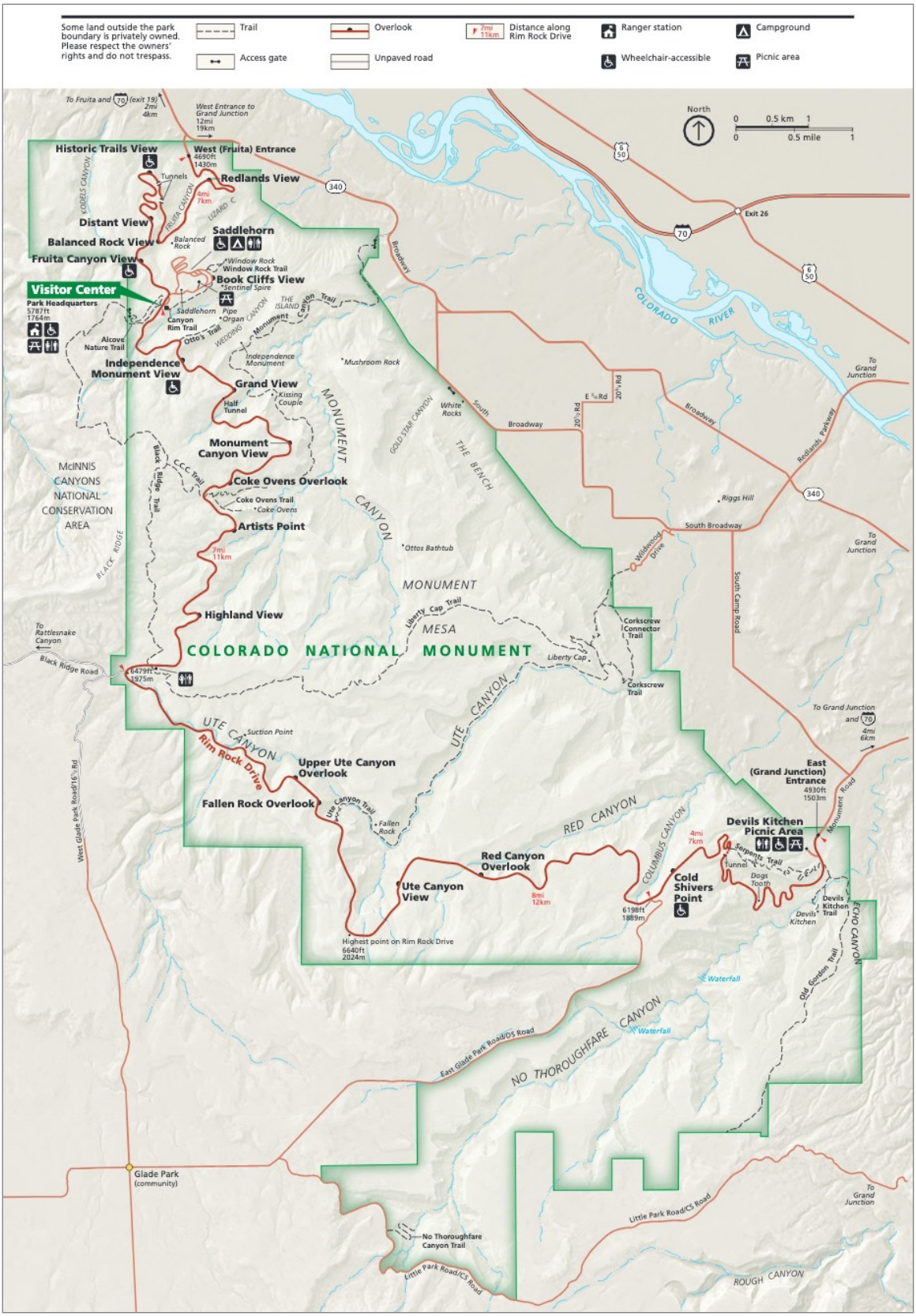


Figure 1. Park map of COLM (NPS).

Significance of Paleontological Resources at COLM

The geologic strata of Colorado National Monument span a significant span of time, with the corresponding fossil record contained within being rich and diverse. Paleontological resources have been reported from COLM in rocks dating from the Late Triassic (roughly 215 million years ago) to the middle Cretaceous (around 100 million years ago) as well as from deposits of the late Pleistocene and Holocene (126 thousand years ago to present). Such fossils document a range of different flora and fauna, representing numerous different ecosystems. This includes diverse trace fossils of the Wingate Sandstone (Late Triassic–Early Jurassic), an abundance of paleontological resources from the Morrison Formation (Late Jurassic), and fossils from a number of other geologic units within the monument. Despite the abundance of paleontological resources at COLM, only a handful of dedicated paleontological studies have taken place here. As such, a comprehensive paleontological resource inventory of COLM, consolidating and expanding upon this former work, will allow for a greater understanding of the paleontological resources present at COLM and support research, interpretation, and management of said resources.

Purpose and Need

The NPS is required to manage its lands and resources in accordance with federal laws, regulations, management policies, guidelines, and scientific principles. Those authorities and guidance directly applicable to paleontological resources are cited in Appendix D. Paleontological resource inventories have been developed by the NPS in order to compile information regarding the scope, significance, distribution, and management issues associated with fossil resources present within parks. This information is intended to increase awareness of park fossils and paleontological issues in order to inform management decisions and actions that comply with these laws, directives, and policies. Options for paleontological resource management are locality-specific and may include surveys, site monitoring, cyclic prospecting, stabilization and reburial, shelter construction, excavation, closure, patrols, alarm systems or electronic surveillance, and no action. See Appendix D for additional information on applicable laws and legislation.

Project Objectives

This park-focused paleontological resource inventory project was initiated to provide information to COLM staff for use in formulating management activities and procedures that would enable compliance with related laws, regulations, policy, and management guidelines. Additionally, this project will facilitate future research, proper curation of specimens, and resource management practices associated with the paleontological resources at COLM. Methods and tasks addressed in this inventory report include:

- Locating, identifying, and documenting paleontological resource localities through field reconnaissance and perusal of archives, photography use, GPS data, standardized forms, and cave surveyor reports.
- Relocating and assessing historic fossil localities.
- Assessing collections of COLM fossils maintained within monument collections and in outside repositories.
- Documenting current information on faunal assemblages and paleoecological reconstructions.

- Interviewing current and former monument staff to gather information on the current status of paleontological resources, to aid in formulating plans for management, ideas for interpretation, and recommendations.
- Conducting a thorough search for relevant publications, unpublished geologic notes, and outside fossil collections from COLM.

History of Paleontological Work at COLM

The paleontological resources of COLM have seen much less attention than other locations in the Grand Valley (e.g., Mygatt-Moore Quarry, Fruita Paleontological Area, Dinosaur Hill, Riggs Hill) as well as the region at large (e.g., Dinosaur National Monument, Jurassic National Monument, Mill Canyon Dinosaur Tracksite, Copper Ridge Dinosaur Trackway, etc.). There have been a handful of surveys of COLM paleontology in the past; however, many of these were of limited scope (e.g., focused on one topic such as Morrison Formation vertebrate body fossils) and most are unpublished. Relevant references include Riggs and Farrington (1901), Holt (1942), Peck (1957), Lohman (1965, 1981), Callison et al. (1977), Armstrong and Kihm (1980), Armstrong and McReynolds (1987a), Hasiotis and Demko (1996), Hasiotis (1997, 2004), Good (1998, 2004), Evanoff et al. (1998), Turner and Peterson (1998), Engelmann and Hasiotis (1999), Anderson et al. (2000), Scott et al. (2001a, 2001b, 2002), Demko et al. (2004), King et al. (2004), Trujillo et al. (2004), Bilbey et al. (2005), Imhof and Trujillo (2005), Trujillo et al. (2005), Foster and Lockley (2006), KellerLynn (2006), Lockley and Foster (2006), Lucas et al. (2006a, 2006b), Hunt and Lucas (2007), Lockley et al. (2008), Tweet et al. (2012a), Green (2014), Foster (2015a), Benck et al. (2016), and Hybels (2019).

Dinosaur bones have been known locally since at least the 1880s, with the earliest paleontological work in the Grand Valley conducted by Elmer S. Riggs in the early 1900s (Riggs and Farrington 1901). His work seems to have been largely, if not entirely, restricted to the outcrops outside of COLM, and included the discovery of multiple large dinosaurs from Morrison Formation exposures just beyond the modern monument boundary.

The first fossils reported from within COLM were unionid bivalves, gastropods, and charophytes from the Morrison Formation. These fossils included a bivalve specimen collected by Willis T. Lee and identified by John B. Reeside, Jr. in 1925 from Monument Canyon (J. B. Reeside, Jr., written comm. to W. T. Lee, November 25, 1925), other fossils collected from Monument Canyon in the same time frame (J. B. Reeside, Jr., written comm. to E. M. Spieker and J. B. Reeside, Jr., February 1, 1926), and work published by Edward L. Holt in 1942 and Raymond E. Peck in 1957. Fossils in COLM were also reported (and collected) by locals during the 1950s and 1960s. These fossils, which have since been lost, included purported metoposaur remains discovered in the Chinle Formation by an unknown individual around 1955 and a partial mammoth tooth from Quaternary valley-fill deposits collected by local geologist Jack Roadifer in 1965.

The first official survey of paleontological resources at COLM, focused on vertebrate remains from the Morrison Formation, was led by George Callison in 1977. Callison and the members of his field team, James M. Clark, Steven R. May, and Mark A. Norell, had been conducting work at the nearby Fruita Paleontological Area prior to their survey work at COLM. Members of this field team (Figure 2), identified 14 paleontological sites at COLM, representing the first official fossil localities documented for the monument; no specimens were reported to have been collected (Callison et al. 1977). A few years later, Harley J. Armstrong and Allen J. Kihm evaluated vertebrate fossil resources in the Grand Junction area of western Colorado and included a literature-based

examination of some of the sites discovered by Callison et al., with twelve of these sites included in their report (Armstrong and Kihm 1980).



Figure 2. Field crew of the 1977 paleontological survey of COLM conducting work in the Morrison Formation (NPS).

The first survey dedicated to the Quaternary paleontological resources at COLM, specifically packrat (*Neotoma* spp.) middens, took place in 1994–1995. This fieldwork, undertaken by Larry Agenbroad, Jim Mead, and R. Scott Anderson, was part of a larger inventory of Quaternary resources in Rocky Mountain Region NPS units on the Colorado Plateau. They identified and sampled a number of packrat middens at COLM, which were later dated to span much of the Holocene (Anderson et al. 2000). The contents of packrat middens are commonly used by Quaternary researchers for reconstructing recent paleoenvironments.

In the mid to late 1990s, a joint NPS–USGS interdisciplinary study known as the Morrison Extinct Ecosystems Project aimed to reconstruct the Late Jurassic ecosystem of the Morrison Formation across the Western Interior (Turner and Peterson 1998). The project involved more than a dozen NPS units across the Colorado Plateau and Rocky Mountain region, including COLM. A number of different researchers associated with this project conducted research at COLM during this time period, including George F. Engelmann, Stephen T. Hasiotis, and Tim M. Demko. Engelmann,

accompanied for some time by Lawrence Bradley and others, conducted fieldwork at COLM in the summer of 1995. As well as revisiting some of the localities discovered by Callison et al. in 1977, Engelmann and crew identified a number of new fossil sites with four documented collections taking place. Some of the discoveries made during this fieldwork were later mentioned in a publication by Engelmann and Hasiotis (1999). Work by Hasiotis and Demko also took place at COLM in the mid-1990s, identifying ichnofossil occurrences in the monument and looking at paleosols (Hasiotis and Demko 1996; Hasiotis 1997, 2004; Demko et al. 2004).

Proposals for a comprehensive paleontological resource inventory at COLM have existed since the 1990s (Figure 3). A number of surveys conducted during the 2000s and early 2010s laid the foundation for such an inventory to be conducted and began to demonstrate the paleontological potential of the rocks at COLM.

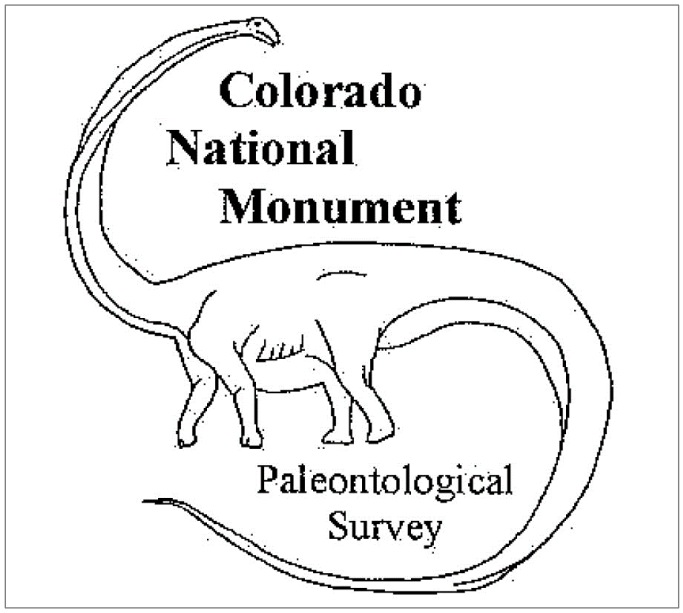


Figure 3. A logo depicting a diplodocoid sauropod, associated with a late-1990s proposal for a paleontological survey at COLM (NPS).

A 2001 publication summarizing the paleontological resources of the various national parks and monuments in the state of Colorado included COLM and thus represented the first summary of paleontological resources at the monument (Scott et al. 2001b). This was followed by a brief report in a Northern Colorado Plateau Inventory & Monitoring Network paleontological resources summary (Koch and Santucci 2002). Multiple surveys in the following few years discovered numerous additional localities and, as a result, a much better picture of the fossils present at COLM began to emerge.

A paleontological survey of COLM trails conducted by Rodney D. Scheetz in 2001 (Scheetz 2002) was the first to extensively look at the Mesozoic deposits of COLM beyond the Morrison Formation, although these Late Jurassic exposures were also assessed. Scheetz identified 31 new localities in this survey; no collections were reported. These localities, along with those recorded in other surveys,

were revisited a few years later by a team of researchers led by Kelli C. Trujillo. The report by Trujillo, Margaret Imhof, and Zachary Walke (2004) represented the most exhaustive assessment of COLM paleontology to date and was the first to incorporate both field and literature components for the survey. This team searched for new localities alongside relocating/assessing known localities, reporting two collections, identifying 19 new localities, and assessing 56 known localities. This survey was also the first to document new and known localities using GPS technology at COLM, and they produced the first GIS map of all known fossil localities within the monument.

Over several years in the early 2000s, occasional paleontological survey work expanded knowledge of certain Mesozoic formations at COLM. Investigations led by John Foster from 2001 to 2005—accompanied by Josh Smith, Ryan King, Ken Cart, and Robin Prunty—examined vertebrate fossils of the Chinle Formation, Wingate Sandstone, and Morrison Formation. A number of fossils were found, including numerous tracks from the Wingate Sandstone (King et al. 2004; Trujillo et al. 2004). In 2005 and 2006, an in-depth field survey of these Wingate Sandstone tracks was undertaken by Spencer Lucas (Lucas et al. 2006b).

The staff at COLM have collaborated with the Museums of Western Colorado (MWC) on occasion in order to handle significant paleontological discoveries within the monument. One notable instance of this occurred in 2010, when paleontologist John Foster, the curator of MWC at the time, assisted in the recovery of a fallen slab in the Morrison Formation containing rare turtle tracks (*Chelonipus* isp.) (Figure 4). This slab, initially discovered in 2005, was collected through the help of COLM maintenance staff and displayed at the COLM Visitor Center for the inaugural National Fossil Day in October 2010 before transitioning to exhibition at MWC's Dinosaur Journey museum in Fruita, Colorado. Around the same time in 2010, COLM maintenance staff also assisted with the relocation of roadside sauropod tracks to a location away from potential vandalism (Shaffer 2023).

The paleontological resources of COLM were summarized in a 2012 report which assessed the paleontology of parks within the Northern Colorado Plateau Inventory & Monitoring Network (Tweet et al. 2012a). This literature-based report provided an overview of prior paleontological resource work undertaken at COLM, synthesizing many of the various reports up to that point and acting as a foundation for subsequent studies.

The most recent survey to document new paleontological localities from COLM was that of Cyrus C. Green, conducted in 2013 (Green 2014). The report associated with that survey identified 23 new localities, examined 59 known sites, and reported one collection. In 2015, John R. Foster completed a survey of select existing localities, examining 20 known localities and reporting collection from five of these sites. In the time since the surveys of Green and Foster were conducted, there have been multiple new fossil occurrences reported by monument staff that remained undocumented until the present inventory.



Figure 4. Collection of *Chelonipus* isp. turtle track block from COLM in 2010 through collaboration between MWC and monument maintenance staff (NPS).

Summary of 2023 Paleontological Survey

Beginning in April 2023, Scientists in Parks intern Austin Shaffer (Figure 5) assembled all available information on fossil occurrences within COLM, including both official documentation (through prior surveys and published sources) and unofficial reports, with the goal of comprehensively documenting the paleontological resources of the monument. Austin proceeded to spend much of the subsequent six and a half months surveying potentially fossiliferous outcrops within the boundaries of COLM, attempting to locate each reported fossil find, searching for new fossil occurrences, and documenting any and all paleontological localities. COLM paleontological resources were documented through field notes, locality forms, photographs, and GPS. Various spreadsheets were used, alongside an ArcGIS Pro map, in order to consolidate and organize the data collected. Significant fossil finds and/or those of substantial management concern were collected with minimal ground disturbance under permit COLM-2023-SCI-0004.



Figure 5. Scientists in Parks intern Austin Shaffer at a novel fossil locality in the Morrison Formation of COLM (NPS / JESSICA RESNIK).

The productivity of a given week of fieldwork varied significantly over the course of the field season, with upwards of 38 localities found during certain weeks, while other weeks saw no new fossil localities documented (Figure 6). The bulk of COLM fossil localities were located/discovered from June to early September (Figure 7). A drop-off in the number of fossil localities visited occurred in late September when priority for the project shifted from survey work to writing of the report and documenting visited sites.

Documentation and report writing were assisted through continued examination of relevant published literature, allowing for tentative identification of fossil taxa and specimens. Spreadsheets and lists containing 2023 inventory data can be found in Appendices A, B, and E (COLM taxa, collections, and localities, respectively). Additional information (e.g., field notes, locality forms) may be accessed by qualified researchers through the NPS at COLM.

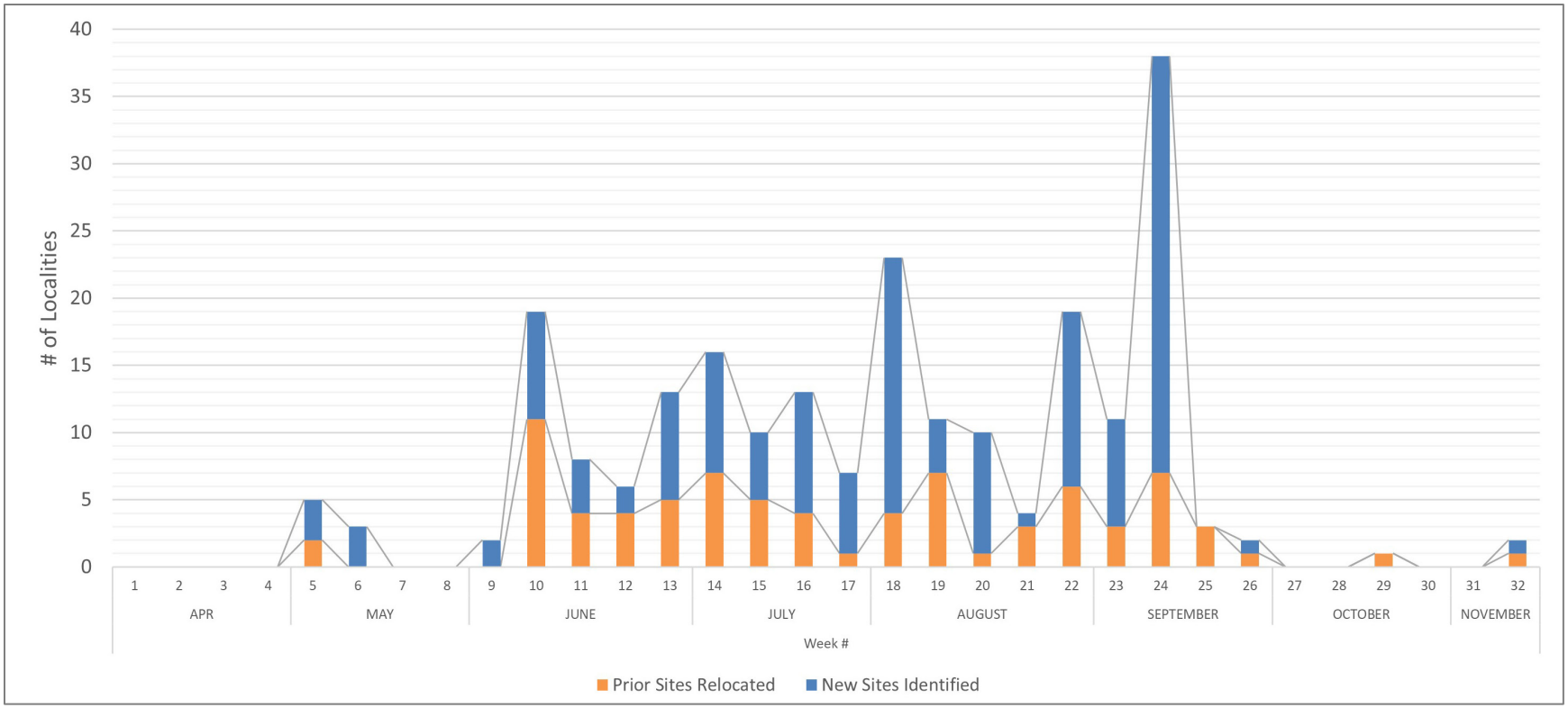


Figure 6. Number of localities visited (existing sites relocated and new localities identified) each week of the field season (April to mid-November) during the 2023 inventory (NPS / AUSTIN SHAFFER).

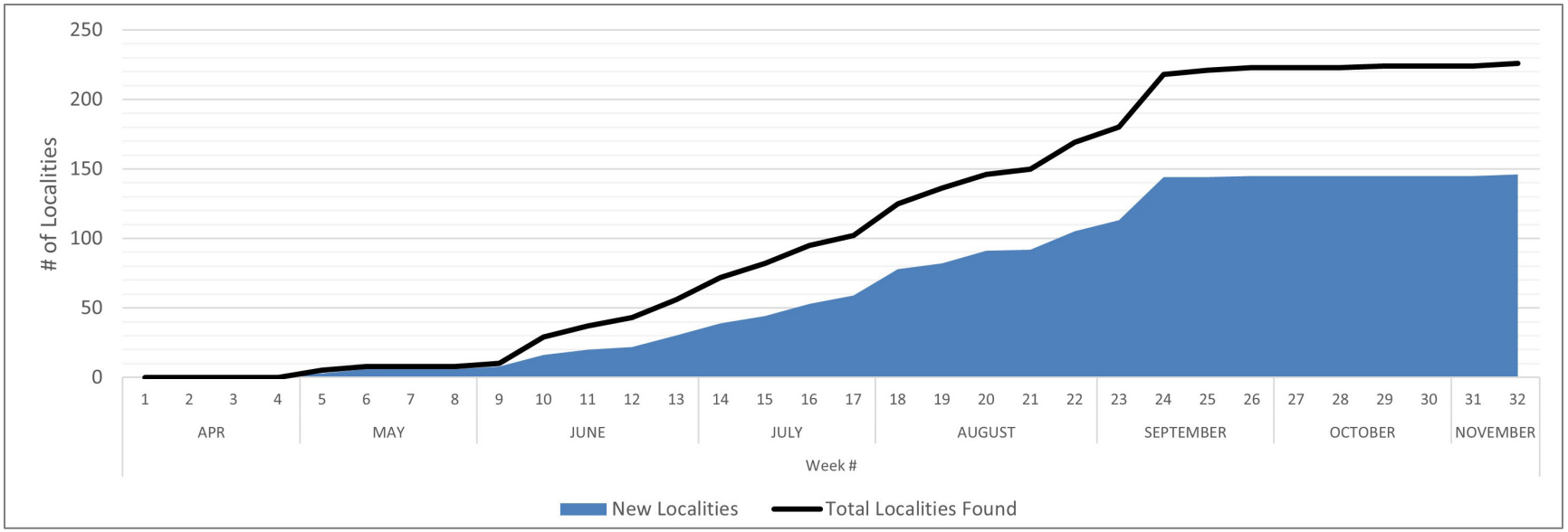


Figure 7. Cumulative total of localities visited throughout the field season (April to mid-November) and the proportion of that total comprised of new sites identified during the 2023 inventory (NPS / AUSTIN SHAFFER).

Geology

Geologic History

The rocks exposed at COLM span a large portion of geologic time, encompassing geologic units from the Precambrian to the Quaternary. There are significant gaps in this timespan, however, with the bulk of the preserved fossiliferous sedimentary rock formations within COLM dating to the Mesozoic (Late Triassic–middle Cretaceous). (Note that "early" and "late" refer to geochronological age, whereas "lower" and "upper" refer to stratigraphic position, and "middle" applies to either; these terms are capitalized if officially defined, lowercase if not, e.g., Upper Cretaceous, early Eocene. A glossary containing definitions for much of the terminology used in this report can be found near the beginning of this report.)

Underlying the Mesozoic rocks, the basement geology at COLM is comprised of Precambrian metasedimentary and metavolcanic rocks (often referred to locally as the "Black Canyon Group"). Metamorphism of the original sedimentary and volcanic rock is thought to have occurred around 1.7 Ga (billion years ago) in the Paleoproterozoic, subjecting the original rock to intense heat and pressure, recrystallizing it into the form seen today (Shoemaker 1956; Hedge et al. 1968; Mose and Bickford 1969; Hansen 1981; Hedlund and Olson 1981; Case 1991). In the Mesoproterozoic, a few hundred million years after the rocks were metamorphosed, magma intruded into fractures in the rock before cooling and crystallizing into an abundance of dikes; similar igneous intrusions are seen across the northern Colorado Plateau (Hedge et al. 1968; Mose and Bickford 1969; Hedlund and Olson 1981). The next-oldest rocks preserved at COLM are from the Late Triassic, some 1.1 billion years later. This immense gap in time is similar to that seen in the Great Unconformity first recognized at the Grand Canyon, but since found elsewhere across North America (including Black Canyon of the Gunnison National Park [BLCA]). However, the absence of any Paleozoic strata at COLM, unlike the Grand Canyon area where Paleozoic geologic units make up a large portion of the rocks, indicates that an additional/extended period dominated by erosion and/or lacking significant deposition occurred here before the Triassic rocks were eventually laid down (Campbell 1981; Dubiel and Hasiotis 2011). In fact, the only direct evidence from the Paleozoic at COLM comes in the form of fossil-bearing cobbles reworked into Lower Cretaceous rocks and originating from undetermined locations (fossils discovered during the 2023 inventory). The additional period of erosion prior to Late Triassic deposition was likely the result of the Uncompahgre Uplift associated with the orogeny of the Ancestral Rocky Mountains during the Pennsylvanian and Permian, roughly 300 Ma (million years ago) (White and Jacobson 1983; Kluth and DuChene 2009). This uplift produced a mountainous island rising from the shallow continental seas known as Uncompahgria (Mack and Rasmussen 1984). Erosion of this mountainous uplift continued throughout the Paleozoic and Early Triassic at COLM until the surrounding basins had been filled and the relief had been flattened enough that the fluvial systems of the Late Triassic Chinle Formation flowed over the region (Campbell 1981).

During the Late Triassic, the red mudstones of the Chinle Formation were deposited at COLM by valley fill gravels followed by sinuous fluvial systems, floodplains, ponds, and paleosols under tropical semi-arid conditions with substantial seasonal shifts in precipitation (Dubiel et al. 1992;

Tanner 2003; Dubiel and Hasiotis 2011). As the region moved northward, significantly drier conditions developed and the environment shifted to that of an expansive erg as seen in the Wingate Sandstone. The great aeolian sand dunes of this desert likely reached 30 to 45 m (98 to 148 ft) high during arid periods, between which were a number of wetter interdune environments (Scott et al. 2001a). The erg deposits of the Wingate Sandstone straddle the Triassic–Jurassic boundary, with the end-Triassic extinction event lying somewhere within its tall sandstone cliffs. After this, sometime in the Early Jurassic the region experienced a shift towards wetter conditions for a few million years during the deposition of the Kayenta Formation. The environment represented in these deposits corresponds to predominantly fluvial conditions, with a number of freshwater braided and meandering streams flowing across this still largely arid landscape (Parrish et al. 2019; Breeden et al. 2021). A subsequent return to drier overall conditions, seen elsewhere in the Navajo Sandstone and accompanying units, is not preserved at COLM. Rather, another hiatus of roughly 20 million years is present before the next rock unit is seen in the late Middle Jurassic.

The last major erg of the region is represented at COLM in the Entrada Sandstone cliffs, deposited around 165 Ma in the Middle Jurassic (Loope 2008; Dossett 2014). This hot, semi-arid to arid desert environment with sparse vegetation (Ekdale and Picard 1985), was located near the coast of the inland Curtis Sea, which supplied a good deal of moisture despite the overall aridity of the region at the time (Gross et al. 2022). The dunes in this erg were substantially smaller than those of the Wingate Sandstone, likely only reaching 10 to 20 m (33 to 67 ft) high (Scott et al. 2001a). The upper portion of the Entrada Sandstone, informally termed the “board beds member”, represents a shift towards a wet coastal sand flat, following the movement of the Curtis Sea. This sand flat environment shifted somewhat during deposition of the Wanakah Formation towards that of a supratidal sabkha. During the Late Jurassic, the retreat of marine influence northwards, in combination with sediment influx from western and southwestern volcanic highlands stretching from British Columbia to northern Mexico, contributed to the deposition of the overlying Morrison Formation (Turner and Peterson 2004; Tanner et al. 2014; Christiansen et al. 2015; Maidment and Muxworthy 2019).

The Morrison Formation crops out across much of the Western Interior of North America and is quite variable in its lithology and age depending on the location. This is due to the extensive number of environments encompassed by the unit over its time of deposition, ranging from approximately 157 to 149 Ma across its exposures (Trujillo and Kowallis 2015; Maidment and Muxworthy 2019; Carpenter 2022). At COLM, the basal deposits of the Tidwell Member, the lowest part of the Morrison Formation, were deposited initially by either a playa complex or extensive sand sheet (depending on location) followed by floodplains at the advancing edge of a large distributive fluvial system (DFS) (Chesley and Leier 2018; Carpenter 2022). This DFS, as seen in the overlying Salt Wash Member of the Morrison Formation, encompassed a variety of localized environments, including lakes, rivers, wetlands, and floodplains. The upper unit of the Morrison Formation at COLM, the Brushy Basin Member, likely saw a shift towards a landscape comprised of broad vegetated floodplains and isolated wetland/lacustrine systems, although other interpretations exist (Dunagan and Turner 2004; Turner and Peterson 2004; Tanner et al. 2014; Maidment and Muxworthy 2019; K. Trujillo, University of Wyoming, pers. comm., January 2024). Across this wide

variety of environments that made up the Morrison Formation, the climate was also varied—decreasing in humidity to the seasonally arid (monsoonal) south yet increasing in humidity over time (Tanner et al. 2014; Maidment and Muxworthy 2019). The region also seems to have been impacted by orbital variation during this time, alternating between semi-arid and sub-humid conditions in a similar fashion to that seen in northern Africa today (Tanner et al. 2014).

Another gap in time of roughly 20 to 30 million years is seen before the Early Cretaceous strata of the Burro Canyon Formation at COLM. The Burro Canyon Formation was deposited under a semi-arid climate (Craig 1981), the lower horizons representing incised valley fill deposited by a braided fluvial system while the upper portion corresponds to a meandering fluvial system with abundant floodplains and lakes (Scott et al. 2001a; Clark et al. 2018; Tellez Rodriguez et al. 2020). The fluvial systems of the formation were vegetated, of low sinuosity, and originated from sediment eroded in the south (Miller 2016; Clark et al. 2018; Tellez Rodriguez et al. 2020). In the early Late Cretaceous, the encroachment of the Western Interior Seaway saw the fluvial system transition to a paralic (estuarine) system as the shoreline advanced from the north, flooding the surface (Kirkland et al. 1997; Phillips et al. 2020). The estuarine deposits of the Naturita Formation (formerly referred to as the "Dakota Formation" in the region) reflect the shifting environments during this marine transgression, from valleys, channels, and floodplains to coastal plains, tidal bars, and marshes to barrier islands and coastal deposits (Kirkland et al. 1997; Phillips et al. 2020). Eventually, the seaway would fully cover the region; these marine deposits are not found at COLM but are present nearby.

In the Late Cretaceous, the area surrounding COLM became inundated by the Western Interior Seaway, represented by the marine deposits of the Mancos Shale. This unit—as well as the terrestrial Mesa Verde Group above it—is found throughout the Grand Valley but is absent from COLM. This is almost certainly due to erosion following the Laramide uplift of the Uncompahgre Plateau. The majority of the area covered by COLM lies on this plateau, which was uplifted from the Late Cretaceous through to the middle Eocene (75–40 Ma) in conjunction with the Laramide orogeny that created the modern Rocky Mountains (Rønnevik et al. 2017). A second period of regional uplift occurred in the last 5 to 10 million years, beginning during the Miocene and Pliocene; this uplift event is associated with tectonic uplift across the Colorado Plateau and saw substantial canyon incision occur (Rønnevik et al. 2017). These uplift events have led to a near-complete absence of Cenozoic deposits at COLM, save for recent sediments of the Pleistocene and Holocene.

In summary, the geologic formations present at COLM include (in ascending order of age, oldest to youngest) metasedimentary and metavolcanic rocks (at least Paleoproterozoic), magmatic intrusives (Mesoproterozoic), the Chinle Formation (Late Triassic), the Wingate Sandstone (Late Triassic–Early Jurassic), the Kayenta Formation (Early Jurassic), the Entrada Sandstone (Middle Jurassic), the Wanakah Formation (Middle–Late Jurassic), the Morrison Formation (Late Jurassic), the Burro Canyon Formation (Early Cretaceous), the Naturita Formation (Early–Late Cretaceous), and Quaternary sediments (Pleistocene–Holocene) (Figures 8 and 9). The ages, fossil content, and depositional environments of these units at COLM are summarized in Table 1.

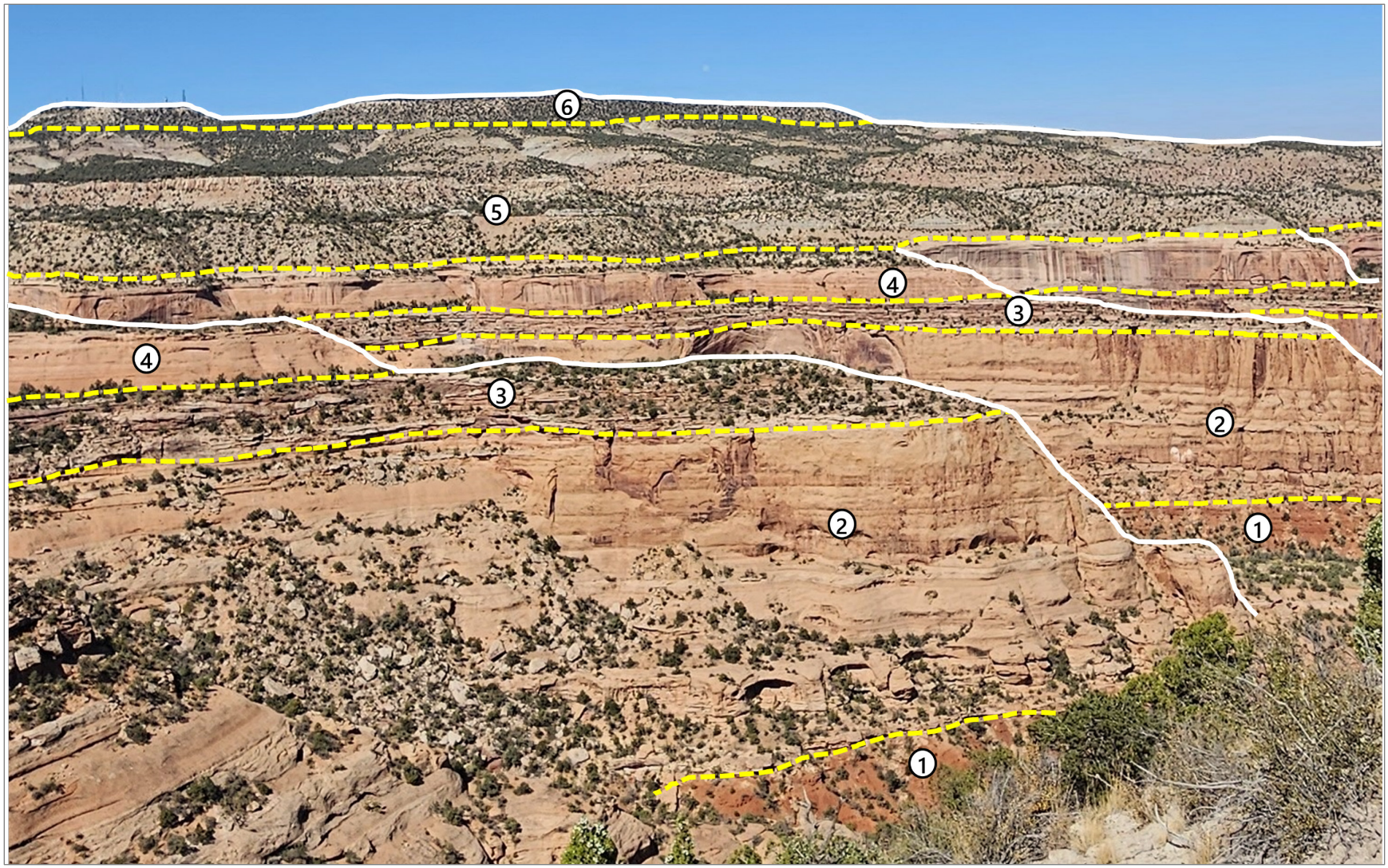


Figure 8. COLM landscape and geologic units as seen above Monument Canyon (looking west towards Black Ridge). All Mesozoic geologic units present at COLM are visible in this image. Geologic contacts between certain units are shown by dashed yellow lines and the units are numbered as follows: (1) Chinle Formation, (2) Wingate Sandstone, (3) Kayenta Formation, (4) Entrada Sandstone, (5) Wanakah and Morrison Formations, (6) Burro Canyon and Naturita Formations (NPS / AUSTIN SHAFFER).

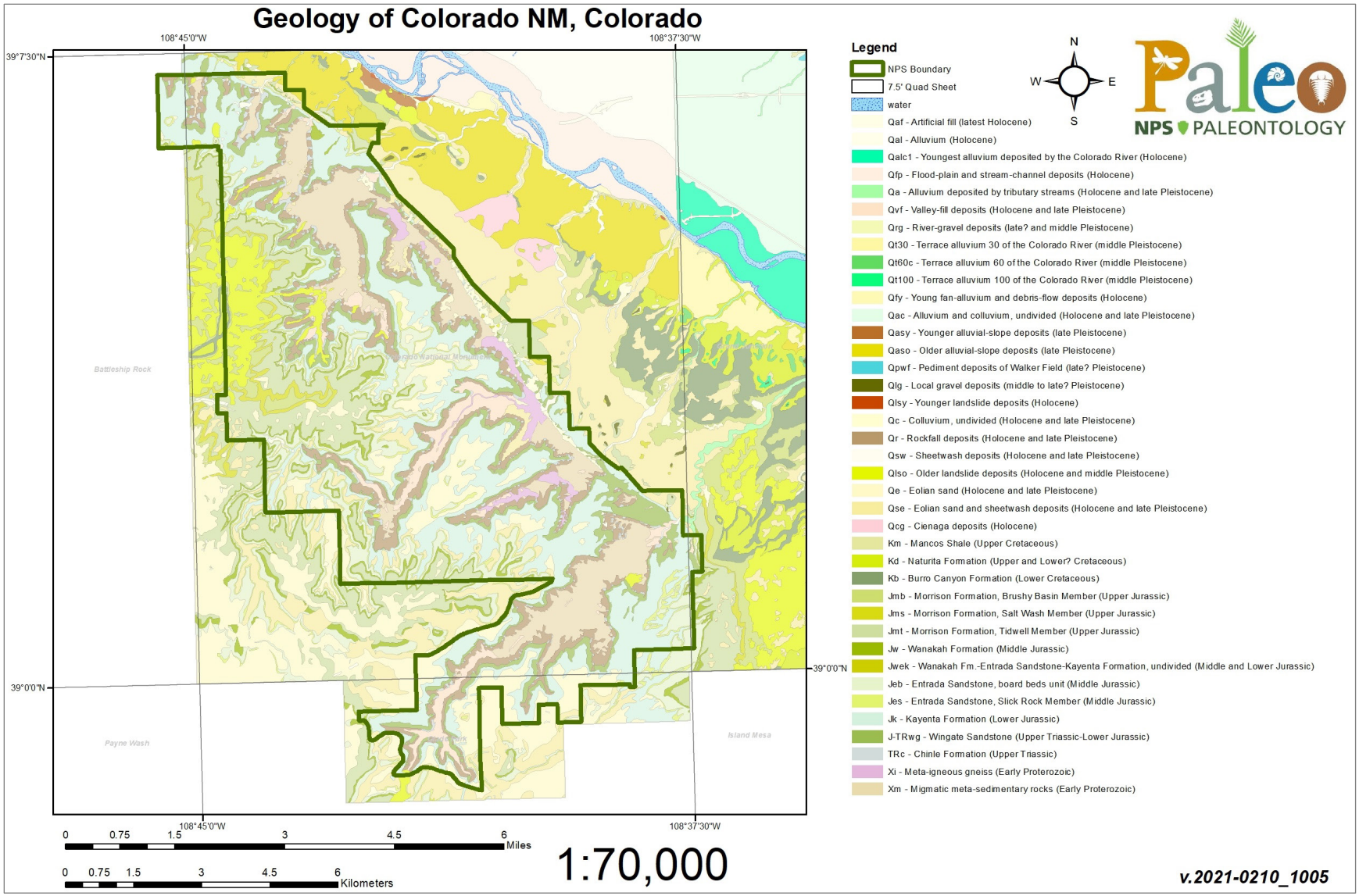


Figure 9. Geologic map of COLM, derived from digital geologic map data available at the following URL: https://irma.nps.gov/DataStore/Reference/Profile/1047632.

Table 1. Summary of COLM stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest.

Formation	Age	Fossils Within COLM	Depositional Environment
Quaternary sediments	Pleistocene–Holocene	Plant remains (conifers, gnetales, and angiosperms), insect material, a mammoth tooth, and bones of at least ten other lizard, bird, and mammal taxa, and packrat middens	Alluvial, aeolian, colluvial, and landslide deposits
Naturita Formation (=Dakota Formation)	Early–Late Cretaceous	Plant fossils, invertebrate traces, and dinosaur tracks and a skin impression	Tidal estuarine/fluvial system
Burro Canyon Formation	Early Cretaceous	Plant fossils (petrified wood, fern impressions, and undetermined material), invertebrate traces, dinosaur bones, and reworked Paleozoic marine invertebrates (bryozoans, brachiopods, and crinoids)	Braided/meandering fluvial system within incised valleys and floodplain-dominated environments
Morrison Formation	Late Jurassic	Plant fossils (charophytes, carbonized wood, and plant fragments), unionid bivalves, gastropods, fish otoliths, a lungfish tooth, bones (turtles, dinosaurs, and possible crocodylomorphs), oncoids/stromatolites, invertebrate traces, and vertebrate tracks (turtles, pterosaurs, dinosaurs, and possible lizards and crocodylomorphs)	(1) Playa complex and floodplains; (2) Distributive fluvial system with various localized environments (e.g., lacustrine, riverine, wetland, floodplain, etc.); (3) Broad vegetated floodplains with isolated wetland and lacustrine systems
Wanakah Formation	Middle–Late Jurassic	None verified during 2023 inventory	Supratidal sabkha
Entrada Sandstone	Middle Jurassic	Invertebrate traces	Marginal marine erg with interdune sabkhas
Kayenta Formation	Early Jurassic	Bone fragments, possible petrified wood, and a possible dinosaur track	Fluvial system among sand dunes
Wingate Sandstone	Late Triassic–Early Jurassic	Invertebrate traces and various tetrapod tracks (including dinosaurs, synapsids, and pseudosuchians)	Erg with interspersed fluvial activity

Table 1 (continued). Summary of COLM stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest.

Formation	Age	Fossils Within COLM	Depositional Environment
Chinle Formation	Late Triassic	Root traces (rhizohaloes/rhizoliths), invertebrate traces, possible dinosauromorph and pseudosuchian tracks, and rare bones (unverified report of metoposaur bones)	Vegetated fluvial-lacustrine complex alongside aeolian dune and sandflat environments
Magmatic intrusives	Mesoproterozoic	Unfossiliferous (intrusive igneous rocks)	Not applicable (igneous rocks that solidified at depth)
Metasedimentary and metavolcanic rocks	At least Paleoproterozoic	None to date; fossils are extremely unlikely because of lithology and metamorphism	Not applicable (igneous rocks that solidified at depth and strongly metamorphosed sedimentary rocks)

Geologic Formations

Metasedimentary and metavolcanic rocks (at least Paleoproterozoic)

Description: The dark-colored metasedimentary and metavolcanic rocks of COLM form the primary basement in the area. These rocks, comprised predominantly of gneiss and schist, are similar to those seen in other portions of western Colorado (e.g., BLCA and Unaweep Canyon). This group of similar rocks are sometimes referred to as the "Black Canyon Schist" or the "Black Canyon Group", however this name has little stratigraphic or lithologic significance (Shoemaker 1956; Hedge et al. 1968; Hansen 1981; Hedlund and Olson 1981; Case 1991). Across these similar metamorphic rocks, isotopic ages have placed the occurrence of metamorphism around 1.7 Ga, meaning the original sedimentary/volcanic rock dates at least to the Paleoproterozoic Era (Shoemaker 1956; Hedge et al. 1968; Mose and Bickford 1969; Hansen 1981; Hedlund and Olson 1981; Case 1991).

Fossils found within COLM: Unfossiliferous crystalline rocks; included for completeness.

Fossils found elsewhere: Unfossiliferous crystalline rocks; included for completeness.

Magmatic intrusives (Mesoproterozoic)

Description: Abundant igneous intrusions can be seen in the metasedimentary/metavolcanic rocks at COLM. Pegmatite dikes cut across the older schist and gneiss in a very similar fashion to that seen in other Precambrian exposures in the region (e.g., BLCA and Unaweep Canyon). Age analysis of the dikes across western Colorado indicates that intrusion and crystallization of this volcanic material predominantly took place between 1.4–1.3 Ga, a few hundred million years after the metamorphism of the host rock (Hedge et al. 1968; Mose and Bickford 1969; Hedlund and Olson 1981).

Fossils found within COLM: Unfossiliferous crystalline rocks; included for completeness.

Fossils found elsewhere: Unfossiliferous crystalline rocks; included for completeness.

Chinle Formation (Upper Triassic)

Description: The Late Triassic-age Chinle Formation is an important fossiliferous unit of the Colorado Plateau. It is a heterogeneous terrestrial unit largely deposited in various fluvial and lacustrine settings, divisible into several members depending on location. At COLM, only one member is present, the informally named "red siltstone member" (Stewart et al. 1972) (Figure 10). The formation has been elevated to geologic group status as the Chinle Group by some researchers, with the geologic members being elevated to formation rank themselves (Lucas et al. 1997). Following such stratigraphic classification, the rocks at COLM have been referred to the Rock Point Formation of the Chinle Group (Lucas et al. 1997; Tanner 2003; Tanner and Lucas 2006). However, this classification has not been universally adopted (e.g., Dubiel and Hasiotis 2011). While the deposits at COLM are likely age-equivalent to those attributed to the Rock Point Formation (Tanner and Lucas 2006), the traditional classification scheme is retained herein to maintain consistency with existing NPS Geologic Resources Inventory products. The Chinle Formation of COLM is mostly composed of lime-rich mudstone, generally reddish in color, with a variety of compositions ranging from silty claystone to sandy siltstone. Less than 10% of the formation is composed of reddish sandstone; lesser quantities of sandy conglomerate and limestone are also present. The formation

produces distinctive red slopes and benches beneath the cliffs of the Wingate Sandstone in the monument's canyon system (Scott et al. 2001a). The Chinle Formation is not especially thick at COLM; Stewart et al. (1972) found thicknesses of 29 m (95 ft) and 27 m (88 ft) at two locations bracketing the monument from north to south. The upper contact with the Wingate Sandstone is generally sharp in the area but appears to be conformable and locally gradational (Lohman 1965). The "red siltstone member" is also exposed in the Eagle Basin of Colorado (roughly 160 km or 100 mi northeast of COLM), where it can be divided into two distinct facies: lower coarser facies and upper finer facies. The transition between these facies resembles that of the Petrified Forest Member to the Owl Rock Member elsewhere in the Colorado Plateau (Martz and Small 2019). Further lithostratigraphic work is needed to determine the precise relationship between the "red siltstone member" and these upper Chinle Formation units.



Figure 10. An exposure of the "red siltstone member" of the Chinle Formation at COLM exhibiting both slope- and cliff-forming structure found in the monument (NPS / AUSTIN SHAFFER).

The Chinle Formation has been dated using various methods, including magnetochronology and U-Pb zircon geochronology, with dates ranging between ~224 to ~209 Ma from strata in Petrified Forest National Park (Kent et al. 2019; Gehrels et al. 2020; Rasmussen et al. 2020). This date range falls entirely within the Norian stage of the Late Triassic, although the deposition of the Chinle Formation almost certainly extends into the Rhaetian (Rasmussen et al. 2020). Evidence also supports the "red siltstone member" dating to these latest stages of the Triassic (middle Norian to Rhaetian) as fossil taxa known from the unit suggest that it falls within the Revueltian and Apachean estimated biochronozones (215–202 Ma) (Martz and Small 2019). Until the data necessary for definitive biostratigraphic/chronostratigraphic correlation are discovered within the "red siltstone member", this age remains tentative for COLM. Paleosols are abundant in the COLM Chinle Formation outcrops and have been identified as both vertisols and aridisols (calcisols) (Dubiel et al. 1992; Tanner 2003; Tanner and Lucas 2006; Dubiel and Hasiotis 2011). These paleosols and

associated root traces, along with the general lithology of the unit, seem to indicate a vegetated complex fluvial-lacustrine system deposited under tropical semi-arid conditions, with significant seasonal shifts in precipitation and increasing aridity over time (Dubiel et al. 1992; Tanner 2003; Dubiel and Hasiotis 2011). The uppermost portions of the Chinle Formation, such as those exposed at COLM, have regularly been attributed to aeolian dunes and sandflats as well (Dubiel and Hasiotis 2011).

Fossils found within COLM: In contrast to the Chinle Formation of New Mexico and Arizona, the deposits of the "red siltstone member," including those of COLM, are sparsely fossiliferous. The most frequently encountered fossils in the Chinle Formation at COLM are those of root traces (rhizoliths); these root traces are ubiquitous across the outcrops of COLM, being found nearly everywhere the mudstone has not yet eroded into slopes.

Besides these abundant root traces, there are a handful of vertebrate and invertebrate trace fossils observed at COLM, more or less relegated to the uppermost portion of the unit, near the contact with the Wingate Sandstone. Invertebrate traces are present in various forms, including horizontal traces akin to *Planolites* and adhesive meniscate burrows. It is also plausible that certain fossils attributed to the aforementioned root traces are instead crayfish (*Camborygma*) or lungfish burrows, as is seen elsewhere in the "red siltstone member" (Hasiotis and Mitchell 1993; Hasiotis et al. 1993; Fischer and Hasiotis 2018); however, no clear examples of such traces were observed during the 2023 inventory.

There are two instances of vertebrate ichnofossils in the Chinle Formation of COLM, representing possible dinosaur (cf. *Grallator* and cf. *Atreipus*) and pseudosuchian (cf. *Brachychirotherium*) tracks. There is also a report of metoposaur bone fragments and teeth collected from COLM around the mid-20th century. This material may have been reposited at the Museums of Western Colorado prior to 1993 but follow-up searches have been unable to locate the fossils (Trujillo et al. 2004; Tweet et al. 2012a).

Fossils found elsewhere: There are some fossil reports from similar rocks in the general vicinity of the monument. Notably, diverse and abundant tetrapod trace fossils are known from western Colorado and eastern Utah (specifically around Gateway, Colorado, and Moab, Utah), predominantly dinosaurs and other archosaurs (Lockley et al. 1996a, 2005; Lockley and Gierliński 2009; Foster and Lockley 2019). Additionally, invertebrate traces, lungfish burrows, and root traces are common throughout the region (Dubiel et al. 1992). Vertebrate body fossils are rare in the area surrounding COLM; however, roughly equivalent rocks near Bedrock, Colorado (75 km or 47 mi south-southwest of COLM) have yielded the skull of a coelacanth (Elliot 1987). Further away, in the Eagle Basin of Colorado, a number of additional finds have been made, including fish, a possible metoposaur, an enigmatic trematosaurian (previously identified as a stem-caecilian), therapsids, a number of small reptiles and parareptiles, aetosaurs, shuvosaurids, rauisuchids, basal crocodylomorphs, lagerpetids, and silesaurids (Small and Sedlmayr 1995; Sedlmayr and Small 1997; Small 2001; Martz and Small 2019; Kligman et al. 2023).

The various members of the Chinle Formation have similar general types of fossils, differing in the specific taxa present and which are most commonly found. Plants are represented by charophyte algae (Lucas and Kietzke 1993), diverse palynomorphs (Gottesfeld 1972; Fisher and Dunay 1984; Parker 2004), and leaves, wood, and other remains of lycopods, horsetails, ferns and fern-like plants, cycads, bennettitales, ginkgoes, conifers, and taxa of uncertain classifications (Ash 1972, 1989, 2003, 2005a; Stewart et al. 1972). Fungal remains are also present (Ash 1972; Stewart et al. 1972). Invertebrates are represented by microconchids (previously misidentified as shells of the worm *Spirorbis* [Ash 2005b]), bivalves, gastropods, ostracods, conchostracans (Breed 1972; Stewart et al. 1972), crabs (Rinehart et al. 2003), crayfish (Miller and Ash 1988), insects (Breed 1972; Stewart et al. 1972), and various trace fossils (Caster 1944; Breed 1972; Gillette et al. 2003; Demko et al. 2005), including borings in wood (Walker 1938; Tapanila and Roberts 2012) and a variety of feeding traces on plants (Ash 1996).

The Chinle Formation's vertebrate assemblage has been summarized in a number of papers, including Stewart et al. (1972), Colbert (1974), Parrish (1989), Long and Murry (1995), Heckert et al. (2005a, 2005b), Irmis (2005), Parker (2005), Lucas et al. (2007), Loughney et al. (2011), and Parker and Martz (2011). Vertebrates include: freshwater sharks; ray-finned fish; lungfish; coelacanths; several types of enigmatic tetrapods known from isolated bones and teeth; metoposaurs and other trematosaurians; a stem-caecilian, a stem-frog, procolophonids; rhynchocephalians; trilophosaurids; tanystropheids; the aquatic reptile *Vancleavea*; drepanosaurs; several phytosaurs; several aetosaurs; the aetosaur relative *Revueltosaurus*; various pseudosuchians including poposaurids, rauisuchids, shuvosaurids, and basal crocodylomorphs; lagerpetids and pterosaurs; dinosauromorphs and early dinosaurs including silesaurids, herrerasaurs, and coelophysids; a cynodont; and dicynodonts. Lungfish, metoposaurs, aetosaurs, and phytosaurs are the most common forms. Vertebrate trace fossils include coprolites (Hunt et al. 1998), swim traces, and footprints possibly attributable to crocodylomorphs, tanystropheids, phytosaurs, aetosaurs, carnivorous and herbivorous dinosaurs, and synapsids (Hunt and Lucas 2007). Recent discoveries have included a stem-caecilian, a stem-frog, and a number of new archosauromorphs (such as doswelliid, azendohsaurid, and pterosaur remains) (Whatley et al. 2013; Stocker et al. 2019; Parker et al. 2021; Marsh et al. 2022; Kligman et al. 2023).

Glen Canyon Group: Wingate Sandstone (Upper Triassic–Lower Jurassic)

Description: The Wingate Sandstone is an aeolian sandstone unit that spans the Triassic–Jurassic boundary (Lucas et al. 2006b). Limestone lenses are also present locally (Harshbarger et al. 1957). At COLM, this formation is responsible for much of the monument's striking scenery, forming 100 m (330 ft)-tall cliffs (Figure 11). The great majority is orange-tinted stratified lime-rich sandstone, with brown to reddish-brown siltstone intervals making up the rest. The siltstones represent interdune deposits among the great aeolian sand dunes, which are thought to have reached heights of 30 to 45 m (98 to 148 ft) during arid periods (Scott et al. 2001a). Winds blew material to the southeast (Lohman 1965). The Wingate Sandstone of the COLM area appears to have formed in a series of dune complexes over time (Scott et al. 2001a). This formation ranges from 95 to 110 m (310 to 360 ft) thick in the area, and in the monument a number of faults formed in it during the Laramide Orogeny (Jamison and Stearns 1982). The upper contact with the Kayenta Formation is sharp (Scott

et al. 2001a) to gradational (Lohman 1965). After much debate concerning the age of the Wingate Sandstone, it was thought that the unit was entirely Jurassic in age, but the discovery of a skull of the phytosaur *Redondasaurus* at the base of the formation in Lisbon Valley in Utah shows that at least some of the unit is Late Triassic in age (Lucas et al. 1997). Trace fossils showing affinity to Triassic taxa also suggest that the Triassic–Jurassic boundary is in the middle to upper 75 m (245 ft) of the formation (Lucas et al. 2006b).



Figure 11. A typical outcrop of the cliff-forming Wingate Sandstone at COLM (NPS / AUSTIN SHAFFER).

The Wingate Sandstone has a complicated history (Colbert and Mook 1951). It was originally defined to be much the same rocks as what was later named the Entrada Sandstone, but the Entrada Sandstone eventually took over most of these rocks, including the original type section for the Wingate Sandstone (at Fort Wingate, New Mexico). Furthermore, the Wingate Sandstone was later divided into the lower Rock Point Member and the upper Lukachukai Member, but where the Rock Point Member has been assigned to the Chinle Formation, the Lukachukai Member is abandoned as superfluous (Dubiel 1989).

Fossils found within COLM: A number of trace fossils are known from the Wingate Sandstone at COLM, both invertebrate and vertebrate. Invertebrate traces are known from a number of localities throughout the monument and come in varying forms. Vertebrate traces from COLM illustrate a diverse assemblage, including synapsids (cf. *Brasilichnium*), pseudosuchians (cf.

Brachychirotherium), and dinosaurs (e.g., “grallatorids”) (Figures 12 and 13). The ichnotaxa identified seem to have biostratigraphic associations with the Late Triassic and many of the tracks originate within the lower portions of the Wingate Sandstone near the contact with the Chinle Formation (often being found within fallen blocks from these lower horizons and/or in association with ripple marks). The ichnotaxonomic assemblage observed at COLM is similar to other Wingate Sandstone sites in western Colorado (Lucas et al. 2006b; Hunt and Lucas 2007; Lockley et al. 2011, 2023).



Figure 12. Assorted tridactyl (*Grallator* isp.) tracks as seen in a large fallen block of the Wingate Sandstone at COLM. Tracks are located high up on the block in an inconvenient location for a scale bar Estimated length of small track at bottom-center is 4 to 6 cm (1.6 to 2.4 in) (NPS / AUSTIN SHAFFER).



Figure 13. A tridactyl trackway alongside ripple marks found in a fallen block of the Wingate Sandstone at COLM (NPS / AUSTIN SHAFFER).

Fossils found elsewhere: In general, while body fossils are uncommon in the Wingate Sandstone, the phytosaur skull mentioned above being the only body fossil of note, an abundance of trace fossils are known from multiple levels in Utah, Arizona, and Colorado. Trace producers include invertebrates (Odier et al. 2004), synapsids, non-dinosaurian reptiles, theropod dinosaurs, and sauropodomorph dinosaurs (Odier et al. 2004; Lucas et al. 2006b, 2006c; Lockley et al. 2011). Synapsid traces are often found as isolated tracks (Odier et al. 2004). There may be distinct Late Triassic and Early Jurassic assemblages, with synapsid and aetosaur tracks limited to the Late Triassic (Lucas et al. 2006b, 2006c). Gateway, Colorado (Lockley et al. 1996a, 2005) and Bedrock, Colorado (Dubiel et al. 1989) also have track sites.

Glen Canyon Group: Kayenta Formation (Lower Jurassic)

Description: The Kayenta Formation is mostly made up of fine- to coarse-grained sandstone with some small amounts of interbedded shale and siltstone, and rare limestone and conglomerate (Vandiver 1936). At COLM, the Kayenta Formation forms ledges and cliffs (Scott et al. 2001a), often making a bench between the cliffs of the Wingate Sandstone and Entrada Sandstone. The

Kayenta Formation of the monument is composed of red and purple siltstone, shale, sandstone, and conglomerate (Lohman 1981) (Figure 14). It ranges from up to 24 m (80 ft) thick in the northern part of the monument to 14 m (47 ft) thick in the southeast, disappearing outside of the monument. It is more conglomeratic in the western part of the monument. The upper contact with the Entrada Sandstone is a disconformity (Lohman 1965). The age of the Kayenta Formation is generally thought to be middle Early Jurassic, between approximately 197 and 190 Ma (Lucas et al. 2005), with some evidence yielding younger dates of ~184 Ma (Breeden et al. 2021). However, recent ages recovered from the area around Moab, Utah (roughly 80 km or 50 mi southwest of COLM), suggest that the Chinle Formation, Wingate Sandstone, and Kayenta Formation in the region were deposited over about two to three million years at the end of the Late Triassic (Parrish et al. 2019); it remains to be seen whether the same is true of the strata at COLM. As such, the Kayenta Formation is herein retained as Early Jurassic in age. The Kayenta Formation was formed primarily by shifting freshwater braided and meandering streams (Colbert 1974); floodplain deposits are also known (Lucas et al. 2005). The primary depositional environment of the Kayenta Formation in the COLM area is interpreted as fluvial (Lohman 1965), with many channels present (Stearns and Jamison 1977).



Figure 14. An exposure of the Kayenta Formation at COLM showcasing the sandstone and conglomeratic mudstone lenses that are seen across the monument (NPS / AUSTIN SHAFFER).

Fossils found within COLM: Fossils in the Kayenta Formation are sparse within the monument, with only five scattered occurrences known. These include a possible piece of petrified wood, a possible tridactyl track, and three instances of bone fragments. The small and fragmentary nature of the bone fragments found at COLM makes taxonomic or anatomic identification difficult. The possible track is found within a sandstone streambed, while the other isolated fossils come from conglomeratic mudstone lenses that occur occasionally throughout the formation at COLM.

Fossils found elsewhere: In neighboring Utah, the formation is known for its dinosaur tracks (Santucci and Kirkland 2010). Vertebrate body fossils of the Kayenta Formation have been described in many publications, but most are from a silty facies found to the southwest in Arizona (see Lucas et al. [2005] for a partial list). Vertebrate body fossils of the sandy facies of the Kayenta Formation, which would be more typical of COLM, include fish scales, crocodylomorphs, and tritylodontid synapsids such as *Kayentatherium* (Clark and Fastovsky 1986). Kayenta Formation vertebrate trace fossils include coprolites (Luttrell and Morales 1993), therapsid tracks, lepidosaur tracks (Hamblin and Foster 2000), and dinosaur tracks such as *Grallator* and *Eubrontes* (Lucas and Tanner 2007). A summary for the Chinle Formation and Glen Canyon Group can be found in Lucas et al. (2006c). Kayenta Formation fossils that are not vertebrates or vertebrate traces include microbial limestone (Luttrell and Morales 1993), petrified wood (Jenkins and Shubin 1998), plant impressions (Rigby et al. 1971) freshwater bivalves and gastropods (Harshbarger et al. 1957), ostracods (Lucas and Tanner 2007), and invertebrate trails and burrows (Luttrell and Morales 1993).

San Rafael Group: Entrada Sandstone (Middle Jurassic)

Description: The Entrada Sandstone is the most prominent cliff-former at COLM after the Wingate Sandstone (Figure 15); in some places, the two form a combined cliff with the Kayenta Formation (Lohman 1965). The Entrada Sandstone is dominated by red sandstone, with some silt (Harshbarger et al. 1957). It is divided into multiple members depending on location. Historically, the Entrada Sandstone of COLM was divided into the Slick Rock Member and the Moab Member (or Tongue) (Lohman 1965), but recently the Moab Member terminology has been replaced by the informal "board beds member" (Cole et al. 1999; Scott et al. 2001a, 2002; Potter and Hayden 2006). The Moab Member was regarded by Kirkland et al. (2005) as pertaining to the Curtis Formation. The Slick Rock Member is around 34 m (110 ft) thick at COLM, and the "board beds member" is about 13 m (43 ft) thick (Scott et al. 2001a). The Slick Rock Member, almost entirely sandstone, is expressed as a pale orange thin cliff or bench (Scott et al. 2001a), while the "board beds member" is a series of white sandstone benches (Lohman 1965).



Figure 15. Orange sandstone cliff of the Entrada Sandstone at COLM (NPS / AUSTIN SHAFFER).

The upper contact with the Wanakah Formation is sharp (Lucas et al. 2006c). Analysis of tephra beds in central Utah suggests deposition of the Entrada Sandstone occurred largely during the Bathonian and Callovian stages of the Middle Jurassic (~168 to ~161 Ma) (Dossett 2014). The climate has been characterized as semi-arid to arid (Ekdale and Picard 1985) and hot, with sparse vegetation. Yet, due

to its proximity to the inland Curtis Sea, the aeolian system has been found to have been relatively wet, drying over time (Gross et al. 2022). The Entrada dunes made up the last major erg of the area and formed when southern Utah was about 22° N (Loope 2008). The Slick Rock Member is interpreted as a coastal dune field with dunes 10 to 20 m (33 to 67 ft) tall and wet interdunes. The "board beds member" is interpreted as representing a wet coastal sand flat. The Entrada Sandstone system is perhaps analogous to the Baja California coast at Guerrero Negro (Scott et al. 2001a). Probable pyrite pseudomorphs were observed during the 2023 fieldwork at COLM similar to those reported from elsewhere in the Entrada Sandstone (Rushton et al. 2020).

Fossils found within COLM: A single isolated fossil occurrence was observed for the Entrada Sandstone of COLM during the 2023 field inventory. This consists of a sandstone slab with invertebrate traces within monument collections. A bioturbated zone in this unit was reported during Scheetz's 2001 survey, but could not be verified during this inventory.

Fossils found elsewhere: Fossils are generally rare in the Entrada Sandstone. Many reports of fossils from the Entrada Sandstone are from the Moab Member, now regarded as part of the Curtis Formation (Kirkland et al. 2005; Doelling 2010). These include the well-known megatracksite of the Moab area (Lockley 1991; Lockley et al. 2007) and the crocodylomorph *Entradasuchus* (Hunt and Lockley 1995). Trace fossils have been reported from the Escalante Member in south-central Utah, including rare root traces, insect burrows (Loope 2008), vertebrate burrows, traces of sand-swimming vertebrates (Graversen et al. 2007), and theropod (large *Megalosauripus* and smaller *Therangospodus*) and sauropod (cf. *Brontopodus*) dinosaur tracks (Foster et al. 2000; Eves et al. 2012). Hoggan (1970) reported bivalves and crinoids in marine facies of the Entrada Sandstone in the Vernal area.

San Rafael Group: Wanakah Formation (Middle–Upper Jurassic)

Description: The Wanakah Formation and overlying Tidwell Member of the Morrison Formation represent the most problematic stratigraphic interval of COLM. Generally, older references use the Summerville Formation for the rocks between the Entrada Sandstone and Salt Wash Member of the Morrison Formation at COLM (Lohman 1960, 1965; Jamison and Stearns 1982). Scott et al. (2001a, 2002) used the Wanakah Formation and Tidwell Member instead, incorporating part of the Salt Wash Member into the Tidwell Member. Lucas et al. (2006a) produced a different interpretation, in which the Summerville Formation name is reintroduced, the Tidwell Member of the Morrison Formation becomes the Tidwell Member of the Summerville Formation, and the contact of the Tidwell and Salt Wash Members is returned to its previously recognized level. This is further complicated by Lucas et al. (2006a)'s contention that the Summerville and Wanakah formations are synonymous; other researchers, including Condon (1992), O'Sullivan (1992, 2004) and O'Sullivan et al. (2006), have found the Wanakah Formation to be older than the Summerville Formation. Recent work has reaffirmed the placement of the Tidwell Member as part of the Morrison Formation and the laterally equivalent nature of the Wanakah and Summerville Formations—being divided largely along the Utah–Colorado state boundary (Carpenter 2022). In-depth analysis of the Wanakah and Summerville Formations is necessary in order to resolve the relationship between the two. The Wanakah Formation is divided into three members, but only the uppermost, the Crooked Tree Member, is

lithologically present as far north as COLM; the other two (the Pony Express Limestone and Bilk Creek Sandstone Members) are only distinguishable at more southerly outcrops, grading into the "board beds member" of the Entrada Formation in the north (O'Sullivan 2004; Jones and Fenton 2022).

Scott et al. (2001a) described the Wanakah Formation of COLM as a red and green slope-forming mudstone unit with minor sandstone and limestone (Figure 16), about 9 m (30 ft) thick, with a disconformable upper contact with the Morrison Formation. The depositional environment of the Summerville and Wanakah Formations has been interpreted as tidal and supratidal sabkhas, respectively, with the former representing predominantly terrestrial deposits and the latter predominantly shallow marine deposits (Carpenter 2022). The regressive sequence that deposited the Wanakah Formation dates to the Middle–Late Jurassic (Callovian–early Oxfordian stages) (Scott et al. 2001a; Carpenter 2022), about 165 to 160 Ma.



Figure 16. A typical red and green mudstone-dominated slope of the Wanakah Formation at COLM (NPS / AUSTIN SHAFFER).

Fossils found within COLM: No fossils were verified in the Wanakah Formation of COLM during the 2023 inventory. There have been prior reports of fossils from this unit at COLM (Scott et al. 2001a; Trujillo et al. 2004), including possible pterosaur feeding traces, invertebrate traces, root traces, and bioturbation, but none of these could be verified during the 2023 field inventory. However, given these unverified reports, as well as occasional fossil finds in the surrounding area, it seems plausible that fossils will be found within this unit of COLM at some point.

Fossils found elsewhere: The Wanakah Formation is not known for its fossils; reports from areas outside of COLM of fossils in the upper section include microbial limestone (Hansen 1968), possible sponge spicules, bivalves, gastropods, ostracods, indeterminate fossils, and possible worm tubes and other trace fossils (O'Sullivan et al. 2006). However, Summerville Formation fossils include plant debris (Petersen and Pack 1982), a single sauropod tail vertebra (Lucas and Heckert 2000), invertebrate traces (Lockley and Wright 2003), and a variety of vertebrate traces including pterosaur tracks (Lockley et al. 1995; Lockley and Wright 2003; Mickelson et al. 2004), theropod tracks

(Lockley et al. 1996b), and sauropod tracks from near the top of the Summerville Formation in Moab, Utah (Lockley 1991).

Morrison Formation (Upper Jurassic)

Description: The Morrison Formation is a heterogeneous unit dated to the Late Jurassic that is exposed across much of the Western Interior of North America. On the Colorado Plateau, the formation is divisible into several members. From oldest to youngest, the Tidwell, Salt Wash, and Brushy Basin Members are reported from COLM. Extensive outcrops of all three members are found in the western part of the monument (Scott et al. 2001a). Overall, the formation is about 160 m (525 ft) thick at COLM, but this ranges widely (Scott et al. 2001a). Scott et al. (2001a) reported thicknesses of 38 m (125 ft), 31 m (102 ft), and 95 m (312 ft) for the Tidwell, Salt Wash, and Brushy Basin Members, respectively. These three members all appear to interfinger, with the contacts between each being difficult to place in some locations. At COLM, this has caused problems with distinguishing the members, leading to mapping issues—the consensus is that much of what is currently mapped as the Tidwell Member likely belongs in the Salt Wash Member (Lucas et al. 2006a; Foster 2015a, pers. comm., July 2023). The upper contact with the Burro Canyon Formation is arbitrarily defined (Scott et al. 2001a). Lohman (1965) reported having seen both potential intertonguing of the Brushy Basin Member and the Burro Canyon Formation, and apparent disconformable relationships at other sites in the COLM area. The Morrison Formation, as a whole, seems to range from ~157 to 149 Ma, with the age of the Tidwell Member reported as ~157–156 Ma, the Salt Wash Member reported as ~153–151 Ma, and the Brushy Basin Member reported as ~152–149 Ma, however, it is important to note that the dates recovered for the Morrison Formation and its constituent members vary (Trujillo and Kowallis 2015; Galli et al. 2018; Maidment and Muxworthy 2019). Significant volcanism originating from the highlands to the west and southwest contributed large amounts of volcanic ash across the Morrison depositional basin, with the largest amount being produced from 152 to 150 Ma, coinciding with the Brushy Basin Member at COLM (Christiansen et al. 2015).

The Tidwell Member of COLM is a slope-former comprising interbedded thin layers of sandstone, siltstone, mudstone, limestone, and dolomite overlying either a basal sandstone bed or a basal gypsum bed (Carpenter 2022) (Figure 17). The basal sandstone bed was likely deposited by an extensive sand sheet whereas the basal gypsum bed was likely deposited by a playa complex, both beds being covered by floodplain deposits—possibly from the distal portions of the Salt Wash fluvial system (Chesley and Leier 2018; Carpenter 2022).



Figure 17. An example of the interbedded layers of the Tidwell Member of the Morrison Formation at COLM (NPS / AUSTIN SHAFFER).

The Salt Wash Member forms both cliffs and slopes dominated by sandstone with significant portions of claystone, siltstone, and mudstone (Figure 18). It has been commonly characterized as representing a distributive fluvial system (DFS) with various localized environments (e.g., lacustrine, riverine, wetland, floodplain, etc.) (Chesley and Leier 2018), although there has been some opposition to the attribution of a DFS to these deposits (Carpenter 2022).



Figure 18. An exposure of the Salt Wash Member of the Morrison Formation at COLM showing the sandstone-dominated cliffs and mudstone-rich slopes that are typical of the unit (NPS / AUSTIN SHAFFER).

The Brushy Basin Member is a slope-former dominated by mudstone, with minor sandstone and limestone components (Figure 19). The interpretation of this member as broad vegetated floodplain deposits with isolated wetland/lacustrine environments is followed herein, although alternative hypotheses exist (Turner and Fishman 1991; Dunagan and Turner 2004; Turner and Peterson 2004; Tanner et al. 2014; Maidment and Muxworthy 2019; K. Trujillo, pers. comm., January 2024).

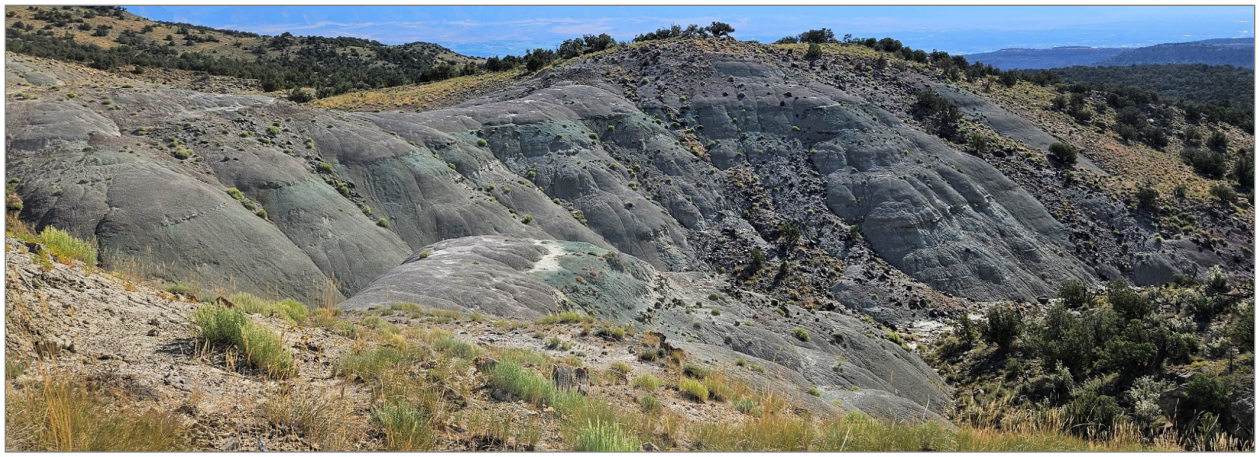


Figure 19. An outcrop exhibiting the typical slope-forming mudstones of the Brushy Basin Member of the Morrison Formation at COLM (NPS / AUSTIN SHAFFER).

The climate of the Morrison Formation is generally considered to have varied across its extent, being more humid in the north and seasonally arid (monsoonal) further south, increasing in humidity over time (Tanner et al. 2014; Maidment and Muxworthy 2019). This environment may have also been impacted by orbital variation, shifting between semi-arid and sub-humid conditions over tens of thousands of years, similar to that seen in northern Africa today (Tanner et al. 2014).

Fossils found within COLM: The strata of the Morrison Formation at COLM are among the most fossiliferous at the monument, preserving a diverse assemblage of taxa and fossils. In terms of body fossils, material of plants (e.g., carbonized wood, fragments, charophytes), invertebrates (e.g., unionid bivalves, gastropods), fish (e.g., lungfish, possible ray-finned fish), and saurians (e.g., turtle, possible crocodylomorph, dinosaurs) are found at COLM. Dinosaur fossil material at COLM consists of large amounts of bone fragments alongside isolated instances of more significant remains, such as a fragmented sauropod tooth, an ornithopod pelvic fragment, and an articulated sacrum and vertebral column possibly referrable to Sauropoda (Figure 20).

Ichnofossils found in the Morrison Formation at COLM are equally diverse, if not more so, than their body fossil counterparts. A large assortment of invertebrate ichnofossil morphotypes are observed alongside stromatolites/oncolites, tracks of dinosaurs (e.g., stegosaur, possible ankylosaur, small/medium/large ornithopods, small/medium/large theropods, sauropods), and non-dinosaurian saurian traces (e.g., possible lepidosaur, turtle, crocodylomorph, pterosaur). When the ichnofossil and body fossil material found at COLM are considered together, a significant diversity of different taxa from the Late Jurassic is demonstrated to have been present at what is now COLM.



Figure 20. An articulated dinosaur (cf. Sauropoda indet.) sacrum and vertebral column (exposed portions roughly outlined by dashed line) from the Salt Wash Member of the Morrison Formation at COLM (NPS / AUSTIN SHAFFER).

Fossils found elsewhere: The Grand Junction area is of historic and ongoing importance for the paleontology of the Morrison Formation. Turner and Peterson (1999) and Foster (2003, 2020) provided site-level inventories for vertebrate finds across the entire Morrison Formation and Armstrong and McReynolds (1987a) provided an overview of Grand Junction–Fruita sites and their geographic and stratigraphic positions. Additional information on specific Morrison Formation fossil sites of eastern Utah and western Colorado (Cleveland-Lloyd Quarry, Mygatt-Moore Quarry, Fruita Paleontological Area, etc.) can be found in Foster et al. (2016). Significant fossil sites in the

Morrison Formation of the Grand Valley include the sites excavated by Elmer Riggs and his crew in 1900 and 1901 (summaries in Chenoweth 1987, 1991), and the Fruita Paleontological Area (described in detail by Kirkland et al. 2005 and Kirkland 2006). The Riggs sites are known for providing the first described specimen of the giant sauropod *Brachiosaurus* and most of a skeleton of *Apatosaurus* (Chenoweth 1987). The Fruita Paleontological Area is particularly noted for its record of small vertebrates, including rhynchocephalians, lizards, dinosaurs, and mammals (Callison 1987; Kirkland 2006). Among the diminutive fossils are articulated specimens of lizards and rhynchocephalians (Kirkland 2006), the robust rhynchocephalian *Eilenodon* (Rasmussen and Callison 1981a), rare examples of unusual terrestrial crocodylomorphs (*Fruitachampsa* [Clark 2011]; *Macelognathus* [Göhlich et al. 2005]), the heterodontosaur *Fruitadens* (Callison and Quimby 1984; Callison 1987; Galton 2007; Butler et al. 2010, 2012), and early mammals (Rasmussen and Callison 1981b; Rougier et al. 1996), including the burrowing *Fruitafossor* (Luo and Wible 2005). Another Fruita Paleontological Area site provided a skull and skeleton of the horned theropod *Ceratosaurus* (Madsen and Welles 2000).

The Morrison Formation has one of the best terrestrial fossil records of the Mesozoic. There are several recent enumerations of its fossils: Chure et al. (2006) listed all taxa known to that time, Foster (2003, 2020) detailed the vertebrate assemblages, and Turner and Peterson (1999) and Foster (2003, 2020) included quarry-level lists of vertebrates. Microbial, fungal, or photosynthetic organisms and traces represented in the Morrison Formation include stromatolites, fungi (both body and traces), charophyte algae, bryophytes, horsetails, ferns, pteridosperms, cycads, bennettitales, ginkgoes, czekanowskiales, and conifers (Ash and Tidwell 1998; Chure et al. 2006), along with palynomorphs of rhodophytes, mosses, lycopods, ferns, cycads, bennettitales, conifers, gnetophytes, and unknown plants (Dodson et al. 1980; Tschudy et al. 1980, 1981, 1988a, 1988b; Chure et al. 2006), as well as a variety of plant debris, root casts, indeterminate wood, and seeds (Chure et al. 2006). Identified fossil trees from the Morrison Formation, include a relatively diverse number of different conifers (e.g., araucarians, pines, redwoods, etc.) (Chure et al. 2006).

Invertebrates represented by body fossils include sponges, gastropods, unionid bivalves, “conchostracans”, ostracods, crayfish, orthopterans, nepomorphs, and coleopterans (Chure et al. 2006; Smith et al. 2011; Lara et al. 2020, 2023). Many other invertebrates are known from traces, including numerous insect groups not yet known from body fossils. Invertebrate trace fossils have been attributed to anthozoans, brachiopods, gastropods, bivalves, nematodes, annelids, horseshoe crabs, mayflies, orthopterans, caddisflies, hemipterans, flies, beetles, hymenopterans, termites, decapod crustaceans, and echinoderms (Hasiotis 2004; Chure et al. 2006); however, some of the traces, such as those attributed to anthozoans, brachiopods, horseshoe crabs, and echinoderms are only known from marine-influenced units that are not found at COLM (Hasiotis 2004). Vertebrates known from body fossils in the Morrison Formation include several varieties of ray-finned fish, lungfish, frogs, salamanders, turtles, rhynchocephalians, lizards, possible snakes, the choristodere *Cteniogenys*, terrestrial and semiaquatic crocodylomorphs (such as the goniopholidid *Amphicotylus*), long-tailed and short-tailed pterosaurs, multiple large (such as *Allosaurus*, *Ceratosaurus*, and *Torvosaurus*) and small (such as *Ornitholestes*) theropods, diverse sauropods (generalized, stocky like *Camarasaurus*, elongate like *Diplodocus*, or long-limbed and long-necked like *Brachiosaurus*),

stegosaurs and ankylosaurs, ornithopods (such as *Camptosaurus* and *Dryosaurus*), and eutriconodont, docodont, multituberculate, and symmetrodont mammals (Foster 2003, 2020; Chure et al. 2006). Fossil tracks are known from most of these groups as well, as well as mammal burrows and coprolites of herbivorous dinosaurs (Chure et al. 2006). Finally, eggshells from the Morrison Formation have been attributed to turtles, crocodylomorphs, and dinosaurs (Hirsch 1994; Bray and Hirsch 1998; Chure et al. 2006).

Burro Canyon Formation (Lower Cretaceous)

Description: The Burro Canyon Formation of the COLM area is heterogeneous, with lithologies including shale, siltstone, sandstone, conglomerate, and limestone (Lohman 1965). It includes a lower sandstone-rich portion and upper siltstone/claystone-rich portion. The sandstone-rich portion is white to yellowish gray in color and occupies the lower third to two-thirds of the formation and forms cliffs, while the finer-grained upper portion forms pale red or greenish slopes. Within COLM, the formation is only found in place (Figure 21) on Black Ridge, a landform that encompasses much of the western monument boundary (Scott et al. 2001a), but blocks displaced by landslides are found over a wider area. On Black Ridge, the finer-grained portion is thicker, while east of the monument, near the mouth of No Thoroughfare Canyon, sandstone becomes more prominent. Overall, the lithology of the formation is quite variable (Lohman 1965). It is nearly 30 m (98 ft) thick on Black Ridge (Scott et al. 2001a) but is at least 37 m (120 ft) thick to the east (Lohman 1965). It is interpreted as mostly fluvial in origin in the area, with minor lacustrine deposition (Lohman 1965). The lower sandstone-rich and conglomeratic section seems to represent a low-sinuosity braided fluvial system deposited as an incised valley fill, while the upper finer-grained section represents a low-sinuosity meandering fluvial system dominated by floodplain and lacustrine settings (Scott et al. 2001a; Clark et al. 2018; Tellez Rodriguez et al. 2020). Sediments were deposited under a semi-arid climate, possibly reworking material from the Morrison Formation (Walters et al. 1987). The predominant paleocurrent was to the north (Craig 1981).

The age of the Burro Canyon Formation is uncertain. Scott et al. (2001a) proposed an Aptian–Albian age (approximately 125 to 100 Ma) for the Burro Canyon Formation at COLM. It is usually thought of as having been deposited between the Barremian stage of the Early Cretaceous (130 to 125 Ma) and the onset of Naturita Formation sedimentation around 100 Ma. Such an age has been supported by subsequent work on the Burro Canyon Formation more broadly, yet the precise age of the formation remains uncertain (Joeckel et al. 2019; Tellez Rodriguez et al. 2020). In fact, the base of the formation has been reported to intertongue with the Brushy Basin Member of the Morrison Formation in places, which would imply a Late Jurassic age for part of the formation (Ekren and Houser 1959; Dickinson and Gehrels 2008). It should be noted that the Burro Canyon Formation and Brushy Basin Member can be difficult to distinguish. The upper contact with the Naturita Formation is disconformable (Lohman 1965), but the Naturita Formation and the Burro Canyon Formation can also be difficult to distinguish; one difference is the relative abundance of plant fossils, which are common in the Naturita Formation and rare in the Burro Canyon Formation (Simmons 1957). The Burro Canyon Formation and Cedar Mountain Formation of Utah are lateral equivalents. Generally, the Burro Canyon Formation is present east of the Colorado River and the Cedar Mountain Formation is present west of it; however, this division is largely arbitrary and due to convention

(Dickinson and Gehrels 2008). Yet, the two formations were seemingly deposited by sediment from different fluvial sources—the Cedar Mountain Formation sediments coming from the west and the Burro Canyon Formation sediments coming from the south—as well as the two formations being deposited under different flow rates; this difference in paleocurrent produced different lithologies within the resultant deposits (Miller 2016). Considering these differences, it is reasonable to maintain the distinction between the two formations, but the true geographic boundary likely does not line up with the traditional separation along the Colorado River.



Figure 21. An outcrop of orthoquartzite and cross-bedded sandstone in the Burro Canyon Formation as seen at COLM (NPS / AUSTIN SHAFFER).

Fossils found within COLM: Burro Canyon Formation fossils are almost exclusively found within landslide material in COLM. Among these landslide deposits, invertebrate ichnofossils are often seen in orthoquartzite, while vertebrate body fossils are typically observed within conglomeratic sandstone. These vertebrate body fossils include a number of likely sauropod bones, such as vertebrae (Figure 22), pelvic material, limb portions, and more. Given the relative paucity of vertebrate material in the Burro Canyon Formation—particularly when compared to the coeval Cedar Mountain Formation—and the condition/amount of material at certain COLM sites, these fossils hold significance.



Figure 22. Conglomeratic sandstone containing a sauropod vertebra within the Burro Canyon Formation landslide material at COLM (NPS / AUSTIN SHAFFER).

Plant material has been documented within the Burro Canyon Formation rocks of COLM, with petrified wood, undiagnostic impressions and fragments, and fern fragments observed during the 2023 inventory.

In addition to fossils of organisms that lived at the time the Burro Canyon Formation was being deposited, the formation also contains older reworked fossils. Fossils of Paleozoic marine invertebrates (including bryozoans, a brachiopod, and crinoids) have been found in COLM within reworked clast fragments. This chert was eroded from older rocks, fluvially transported from an original location further to the south, and eventually incorporated into the Cretaceous conglomeratic sandstone at COLM. Similar Paleozoic marine fossils have been reported from Cretaceous conglomerates of the Front Range and North Park, Colorado (Chronic 1954), as well as more broadly across the United States (Merriam 2007). Identification and examination of such reworked fossils may shed light on the source area for the deposits at COLM.

Fossils found elsewhere: In general, the fossils of the Burro Canyon Formation are not well known at this time. The current fossil assemblage from the formation over its entire area of outcrops includes organic debris, lake-dwelling algae, palynomorphs including conifer and angiosperm pollen

(Tschudy et al. 1984), fern leaves (Simmons 1957), *Tempskya* (Dayvault and Hatch 2005), cycadeoids (Tidwell et al. 1976), conifers (Simmons 1957), early flowers (Fishell 1981; Armstrong and McReynolds 1987b), plant fragments (Stokes 1952), wood fragments (Tschudy et al. 1984); freshwater bivalves (Reeside 1957), gastropods, freshwater ostracods, ganoid fish scales (Simmons 1957), and dinosaur bones (Trujillo et al. 2005). Additionally, a site in Utah near the border with Colorado (the Hotel Mesa Quarry) has yielded fossils of sharks, bony fish, lungfish, various crocodylomorphs, theropods, the sauropod *Brontomerus*, and ornithopods (Taylor et al. 2011). It has been attributed to both the Burro Canyon Formation (Kirkland and Madsen 2007) and the Ruby Ranch Member of the Cedar Mountain Formation (Taylor et al. 2011); by geography, it is within the Burro Canyon Formation (Taylor et al. 2011). Furthermore, a diverse ichnofauna, the White Mesa tracksite, was recently described from the Burro Canyon Formation of southeastern Utah containing an assortment of theropod, sauropod, ornithopod, and ankylosaur tracks (Milàn et al. 2015).

Naturita Formation (=Dakota Formation) (Lower–Upper Cretaceous)

Description: The Naturita Formation, formerly referred to as the Dakota Formation or Dakota Sandstone, records the initial encroachment (transgression) of the Western Interior Seaway across western Colorado and Utah. In the COLM area, the Naturita Formation includes a basal conglomerate, followed by a grayish coaly mudstone interval, then a light-colored sandstone interval (Figure 23), and finally an interval of interbedded shale and sandstone that transitions into the overlying Mancos Shale (Scott et al. 2001a). With the exception of the upper interbedded interval, the conglomerate-coaly shale-sandstone sequence is common for the formation throughout the Colorado Plateau. These divisions reflect environments changing during the transgression of an estuarine system, from valleys, channels, and floodplains at the base to coastal plains, tidal bars, and marshes in the middle to barrier islands and coastal deposits at the top as the Western Interior Seaway approached from the north and east, flooding the surface (Kirkland et al. 1997; Phillips et al. 2020). The age of the formation decreases southward, following the movement of the shoreline during the transgression of the seaway. The age range of the Naturita Formation, based on analysis of ash beds, is roughly 104 Ma to 94 Ma, corresponding to the late Albian and Cenomanian stages of the Early to Late Cretaceous (Phillips et al. 2020; Lee 2021; informal “middle” Cretaceous). The Naturita Formation also appears to be contemporaneous/interfingering with the Mussentuchit Member of the Cedar Mountain Formation, representing more terrestrial deposits to the west (Phillips et al. 2021).



Figure 23. An exposure of yellow sandstone in the Naturita Formation at COLM (NPS / AUSTIN SHAFFER).

Fossils found within COLM: The 2023 inventory revealed fossils in the Naturita Formation at COLM, specifically plant remains and various ichnofossils. Plant remains from this unit include petrified wood material, coaly layers containing assorted plant fragments, and isolated leaves. The leaves likely represent multiple angiosperm taxa. Vertebrate traces were also seen, predominantly consisting of ornithopod and ankylosaur tracks with some isolated tracks of theropods. These tracks, as well as the relative percentages of the attributed taxa, are quite similar to other sites in western Colorado (Lockley et al. 2018a, 2021a). Some small invertebrate traces have also been observed. A dinosaur skin impression was discovered in March 2024.

Fossils found elsewhere: In recent years, a large number of trace fossils (encompassing a variety of dinosaur taxa and others) have been found in the Naturita Formation. These include traces associated with horseshoe crabs, turtles, neosuchian crocodylomorphs, pterosaurs, ankylosaurs, ornithopods, possible ornithomimosaurs, and large theropods (Lockley et al. 2014a, 2014b, 2015, 2016, 2018b, 2018c, 2021a, 2021b; Lockley 2018). The majority of sites and trackways in western Colorado are known from the Uncompahgre Valley southeast of COLM, specifically from Dominguez-Escalante National Conservation Area, Gunnison Gorge National Conservation Area, and other places near Delta, Colorado (Lockley et al. 2014a, 2014b, 2015, 2016, 2018b, 2021b; Noe et al. 2014). These sites also comprise the bulk of taxonomic diversity known from the region. However, a couple of track occurrences are known from the Grand Valley nearby COLM, representing ornithopods, ankylosaurs, theropods, and neosuchians (Lockley et al. 2018c, 2021a). A handful of tracksites are known from further west in Utah as well (such as the Muddy Creek and Cedar Canyon sites) with ankylosaur, ornithopod, theropod, pterosaur, and neosuchian tracks identified (Kirschbaum and Schenk 2011; Lockley 2018; Lockley et al. 2018a).

The tracks of western Colorado and Utah are similar in some ways to those found in rocks of the "Dakota Sandstone" on the other side of the continental divide in eastern Colorado and portions of New Mexico and Oklahoma; however, differences in terms of taxonomic composition persist between these two portions of what is referred to as the Dinosaur Freeway (Kukihara and Lockley 2012; Kukihara et al. 2010; Lockley et al. 1992, 2006a, 2010a, 2014b, 2015, 2018b). In terms of overall tracksite number between the eastern and western slope regions, Lockley (2018) reported 1,179 trackways for the eastern slope and 228 trackways for the western slope. This discrepancy—many more tracks known from the east than the west—was suggested to be due to differences in the exposure of rock surfaces and in the amount of study undertaken.

While vertebrate body fossils are historically rare in the Naturita Formation, some mammal and turtle remains have been attributed to the unit in southern Utah (Joyce et al. 2016; Carneiro 2018). A number of body fossils have also been reported from the coeval Mussentuchit Member of the Cedar Mountain Formation. This member has been deemed as laterally equivalent to portions of the Naturita Formation and in certain instances, specific localities have seen attribution to both the Mussentuchit Member and the Naturita Formation by different researchers (e.g., the holotypic quarry of the brachiosaurid sauropod, *Abydosaurus mcintoshi*, located in DINO; Holmes 2017; Phillips et al. 2021). Given this close relationship between the Naturita Formation and the Mussentuchit Member, it is important to mention that microfossils screenwashed from rocks attributed to the Mussentuchit Member have seen recent attention in Utah, with thousands of fossil specimens of fish, amphibians, turtles, crocodiles, various dinosaurs, birds, and mammals reported (Avrahami et al. 2018).

The fossil flora of the Naturita Formation is much better known than the unit's vertebrate fossil record, with sites such as the one near Westwater in eastern Utah preserving a diverse paleobotanical assemblage (Rushforth 1971). This assemblage contains a large number of ferns from the families Matoniaceae and Gleicheniaceae, alongside many other fossil plant taxa.

Quaternary sediments (Pleistocene–Holocene)

Description: The Quaternary deposits of COLM are a heterogeneous group of primarily surficial deposits left by water (alluvium) (Figure 24), wind (aeolian), and gravity (colluvium) movements scattered throughout the monument (Scott et al. 2001a; KellerLynn 2006; Tweet et al. 2012a; Benck et al. 2016).



Figure 24. Quaternary valley-fill deposits in No Thoroughfare Canyon at COLM (NPS / AUSTIN SHAFFER).

Fossils found within COLM: Quaternary fossils found at COLM are typical of those found across the Colorado Plateau, consisting of isolated animal bones (predominantly large mammals) and fossil material useful for paleoecological and paleoclimatological studies (such as pollen and packrat middens) (Tweet et al. 2012a). A mammoth tooth was reportedly found in COLM by local geologist Jack Roadifer in 1965, but the specimen has since been lost (Scott et al. 2001b; Trujillo et al. 2004) (Figure 25). Animal bones and plant remains were collected from a fissure exposed by rockfall in January 2000. At least ten vertebrate taxa were tentatively identified from this collected material, including lizard, eagle, rodent (two taxa), rabbit (two taxa), wolf, skunk, bighorn sheep, and bison material (Trujillo et al. 2004).



Figure 25. Image from a 1966 issue of *The Criterion* student newspaper showing a mammoth tooth from COLM (now lost) being observed by Grand Valley geology instructor Jack Roadifer and geology student Ron Harris (SPECIAL COLLECTIONS AND ARCHIVES DEPARTMENT, TOMLINSON LIBRARY, COLORADO MESA UNIVERSITY).

Packrat (*Neotoma* spp.) middens are known from COLM; however, these remain largely unpublished. Middens were observed, and in some cases collected, near Rim Rock Drive by Kirk Anderson of Northern Arizona University in 1994 (Trujillo et al. 2004). Anderson et al. (2000) mentioned the presence of an unspecified number of middens in the monument, from elevations ranging from 1,890 to 2,139 m (6,200 to 7,018 ft) and ranging in age from 8,500 calendar years before present to modern. Scott et al. (1999) noted the presence of numerous packrat middens under overhangs at COLM, and Trujillo et al. (2004) observed middens in several locations; these examples may be significantly older than those documented by Anderson et al. (Trujillo et al. 2004; Tweet et al. 2012a). Packrat middens were seen during the 2023 inventory but were not thoroughly investigated. For additional information on *Neotoma* middens in NPS units, see Tweet et al. (2012b).

Charcoal in valley fill within the monument has been dated to a range that includes most of the Holocene, from 9,190 ± 50 radiocarbon years before present (10,500–10,240 calendar years before present) to 1,280 ± 50 radiocarbon years before present (1,290–1,070 calendar years before present) (Scott et al. 1999, 2001a). Note that radiocarbon dates are not the same as calendar dates, and that

radiocarbon years require calibration to yield calendar years. Dates here were calibrated using Calib 8.2 (http://calib.org/calib/) where appropriate.

Fossils found elsewhere: Quaternary fossils are not common within about 100 km (60 mi) of COLM. The best-known site is Bison Alcove within Arches National Park (ARCH). Bison Alcove is an alcove site that has abundant packrat middens (Sharpe 1993), packrat droppings (Smith and Betancourt 1991), and remains of other mammals, including *Ovis* (bighorn sheep) and the namesake bison (Mead et al. 1991; Sharpe 1993). Most of the midden dates are from the latest Pleistocene, particularly from 22,000 to 14,000 radiocarbon years before present and 14,000 to 11,000 radiocarbon years before present, while the megafaunal remains are much younger, from 405 ± 60 radiocarbon years before present (530–310 calendar years before present) and 355 ± 60 radiocarbon years before present (510–300 calendar years before present) (Sharpe 1993). Humans also utilized the alcove, leaving behind an artifact composed of a horn sheath and twig joined by resin (Mead et al. 1991). The alcove has also been host to raptor roosts (Sharpe 1993). Of other fossils, there are isolated reports of mammoths from several locations: ARCH; Bartlett Wash, Utah about 92 km (57 mi) southwest of COLM; Fruita, Colorado; and Professor Valley, Utah about 61 km (38 mi) southwest of COLM (Agenbroad and Mead 1989). Isolated mammal bones have been found deep in the old river gravels of the Grand Junction area, including a horse metatarsal from Fruita and a bison radius from Grand Junction that were donated to the MWC (Tweet et al. 2012a). Peat records from as far back as the early Holocene are known from fens on Grand Mesa, but they are from high elevations (>3,100 m [10,170 ft]) (Sullivan and Gilmore 2006), much higher than COLM. Finally, at least one other ancient charcoal record is known from the vicinity, in Sieber Canyon, Colorado 19 km (12 mi) west of COLM; its record goes back to about the Pleistocene–Holocene boundary, 11,160 to 10,750 radiocarbon years before present (Aslan et al. 2004).

Taxonomy

A diverse array of fossil taxa has been documented from COLM, including various plants, invertebrates, and vertebrates. See Appendix A for full lists of taxa. Locality data for fossil sites can be found in Appendix E. A glossary containing definitions for much of the terminology can be found near the beginning of this report.

Body Fossils

Plants

Paleobotanical body fossils are known from many of the units at COLM, and in many forms.

Petrified and carbonized wood has been found in the Kayenta Formation, Morrison Formation, Burro Canyon Formation, and Naturita Formation (Figure 26) at COLM. While none of the petrified wood documented in this inventory has been identified to a specific taxon, the quality of preservation on certain specimens indicates that specific tree taxa could be identified through future analysis (e.g., morphological, cell structure, etc.). Such analysis could provide useful insight into the paleobotanical assemblages of the geologic units in question at COLM.

In addition to fossil wood, assorted plant fragments and three instances of leaves are known from the rocks at COLM. Specifically, two leaf occurrences were observed in the Naturita Formation, with certain specimens potentially representing angiosperm leaves of the family Magnoliaceae (Figure 27). Fern fragments were seen in sandstone of the Burro Canyon Formation (Figure 28), which are herein attributed to *Gleichenia* cf. *comptoniaefolia*, an extinct species of an extant genus of forked ferns, based on comparisons with similar fossils in Lower Cretaceous strata of the Colorado Plateau (Rushforth 1971). The Cretaceous fossil leaves of COLM are consistent with fossil floras of similar age seen elsewhere in Colorado and Utah (Brown 1949; Rushforth 1971; Tschudy et al. 1984; Tidwell and Hebbert 1992; Tidwell et al. 2007; Barclay et al. 2015).



Figure 26. A slope covered by petrified wood fragments from the Naturita Formation of COLM (NPS / AUSTIN SHAFFER).



Figure 27. An angiosperm (cf. Magnoliaceae indet.) leaf fossil seen in the Naturita Formation of COLM (NPS / AUSTIN SHAFFER).



Figure 28. A fern fragment (*Gleichenia* cf. *comptoniaefolia*) in sandstone from the Burro Canyon Formation of COLM (NPS / AUSTIN SHAFFER).

Charophytes (freshwater green algae) are also known from COLM, specifically from the Brushy Basin Member of the Morrison Formation. The charophytes confirmed during the 2023 inventory came in the form of agatized fragments (Figure 29), often associated with fossil gastropods.



Figure 29. Agatized algal fragments (Charophyta) in the Morrison Formation of COLM (NPS / AUSTIN SHAFFER).

A number of additional extant plant taxa have been reported from Quaternary midden material of COLM, including gymnosperms, monocots, and eudicots. Many of these taxa can still be observed within the boundaries of the monument. A full list of these taxa can be found in Appendix A.

Invertebrates

Phylum Mollusca: Class Bivalvia (clams, oysters, scallops, etc.)

Bivalve body fossils at COLM are represented by remains of the family Unionidae in the Late Jurassic Morrison Formation. The time in which the Morrison Formation was deposited was a time of relative prosperity for this group and numerous taxa are commonly found—generally attributed to

one of three genera: *Hadrodon*, *Vetulonaia*, or "*Unio*" (Evanoff et al. 1998; Good 1998, 2004; Watters 2001). Fragmentary remains of unionids are found throughout the Morrison Formation of COLM, particularly the Salt Wash Member, with one site containing notable instances of whole, articulated specimens (Figure 30). It is likely that the unionid remains found at COLM are attributable to multiple different taxa based on the variation in morphology observed during the 2023 inventory and the reports of multiple unionid genera from the monument made during prior surveys. However, the unionid fossils are retained as Unionidae indet. until a thorough assessment of the fossil mollusk diversity at COLM can occur.



Figure 30. Articulated unionid clams found among assorted fragments in the Salt Wash Member of the Morrison Formation at COLM; these specimens were collected during the 2023 fieldwork and await accession into monument collections (NPS / AUSTIN SHAFFER).

Phylum Mollusca: Class Gastropoda (snails)

Within the Morrison Formation of COLM, specifically the Salt Wash and Brushy Basin Members, a variety of different gastropod fossils can be found. These gastropods include freshwater taxa of prosobranchs (Caenogastropoda) and air-breathing pulmonates (Panpulmonata), similar to those seen

elsewhere in the Morrison Formation (Evanoff et al. 1998). A diversity in appearance among these taxa is observed, with various shapes and sizes as well as certain specimens being largely agatized (Figure 31). This diversity observed at COLM correlates well with that of western North America as a whole during the Late Jurassic, being a period of particularly high diversity and speciation among freshwater gastropods (Neubauer et al. 2022). Certain specific Morrison Formation gastropod taxa have been identified from the specimens at COLM (e.g., *Amplovalvata scabrida* [formerly *Valvata*]); however, similar to the situation with COLM Unionidae fossils, the majority of gastropods observed in the 2023 inventory are retained herein as Gastropoda indet. until a thorough assessment of fossil mollusk diversity at COLM can occur.



Figure 31. Agatized gastropods seen in the Brushy Basin Member of the Morrison Formation at COLM (NPS / AUSTIN SHAFFER).

Other Invertebrates

Paleozoic chert, reworked into clasts within conglomerates of the Cretaceous Burro Canyon Formation, has been found to contain late Paleozoic marine invertebrates. These invertebrate fossils include crinoids, a brachiopod (cf. Rhynchonellida) impression, and many bryozoans (of different varieties). Within the fragments of one clast, net-like fenestellid bryozoan (Fenestellidae) remains are particularly prevalent (Figure 32). The original provenance of the reworked clasts is not known and potentially includes more than one source formation, but taxonomic study of the fossils could provide useful biostratigraphic information (e.g., diagnostic for a specific time range). This could in turn constrain the source areas and formations, providing insights on the sedimentary source of the Burro Canyon Formation's conglomeratic sandstone at COLM. Similar reworked late Paleozoic chert material within Early Cretaceous conglomerates has been reported from western Kansas and elsewhere in Colorado, with the material from Colorado also preserving marine invertebrate fossils within the reworked pebbles (Chronic 1954; Merriam 2007). Similar taxa are seen therein, with bryozoans dominating certain pebbles. Further assessment of these Paleozoic invertebrate fossils may shed light not only on the Cretaceous system of uplift, erosion, and deposition, but also on the environment and ecosystem near COLM present during the late Paleozoic.



Figure 32. A chert clast fragment from the conglomeratic sandstone of the Burro Canyon Formation containing Paleozoic marine fossils (Bryozoa) (NPS / AUSTIN SHAFFER).

Insect remains have also been reported from Quaternary midden material of COLM. Such remains may correspond to extant taxa of the region, but none have been identified.

Vertebrates

Superclass Osteichthyes (bony fish)

Two fossil occurrences at COLM, both from the lower Morrison Formation, are representative of fish. The first is a lungfish (*Ceratodus*) tooth plate (Figure 33). While a number of lungfish taxa have been identified from the Morrison Formation, the specific identity of the COLM specimen is based on specific measurements (orientation angles of tooth ridge crests), herein interpreted as most similar to *C. frazieri* (Kirkland 1987, 1998; Parris et al. 2014; Frederickson and Cifelli 2017). Future analysis of this specimen (i.e., more detailed comparison with other Morrison Formation lungfish specimens) may challenge or support this identification.



Figure 33. A lungfish (*Ceratodus* cf. *frazieri*) tooth plate collected from the Morrison Formation at COLM in 2004 (NPS).

The other fish fossil occurrence at COLM comes in the form of two otoliths, mineralized components of the inner ear (Figure 34), from the Salt Wash Member of the Morrison Formation. While the otolith fossil record is heavily skewed towards teleosts and Cenozoic marine deposits, a number of diverse otolith-based ichthyofaunas are known from Jurassic and Cretaceous strata (Friedman 2022; Schwarzhans and Keupp 2022; Schwarzhans et al. 2022; Pindakiewicz et al. 2023). The fossils

discovered during the 2023 inventory appear to be the only known otoliths from the Morrison Formation and the Jurassic of North America as a whole; however, other fish remains are known from this time and place (Foster 2020). Prior to this discovery, the oldest published occurrence of otoliths in North America was an assemblage in the Late Cretaceous of Texas, roughly 50 Ma younger than the otoliths from COLM (Schwarzhans et al. 2022). The otoliths from COLM appear to be lapilli, a pair of otoliths in fish that are often difficult to relate to specific taxa (W. Schwarzhans, University of Copenhagen, pers. comm., January 2024). While closer analysis of this fossil material and comparison with other otoliths may produce additional information, this is unlikely without the discovery of additional material. Examination of the locality which produced these specimens for further microfossils may shed light on the Jurassic diversity of fish at COLM. It should also be noted that the preservation of annular rings in otoliths (as observed in the COLM specimens) can also provide useful ontogenetic information about the fish taxon in question as well as information about the environment at large (Friedman 2022).



Figure 34. Otoliths (lapilli) discovered in the Salt Wash Member of the Morrison Formation at COLM during 2023 fieldwork (note the annular rings visible in the two specimens) (NPS / AUSTIN SHAFFER).

Clade Batrachomorpha (frogs, salamanders, caecilians, etc.)

Amphibian fossils at COLM are limited to reports of metoposaurid teeth and bone fragments from the Chinle Formation. These fossils have since been lost and therefore could not be verified during the 2023 inventory.

Clade Sauria: Order Testudines (turtles)

Assorted bone fragments attributable to turtles can be observed in the Morrison Formation at COLM. However, none of this bone material is substantial enough to be diagnostic. Future discoveries may shed light on the diversity of Testudines in the Jurassic rocks of COLM.

Clade Sauria: Clade Pseudosuchia (crocodylians, aetosaurs, etc.)

Isolated bone fragments from the Morrison Formation of COLM may be referrable to crocodylomorphs (e.g., Goniopholididae). Some vertebral material from the Salt Wash Member is of appropriate size and amphicoelous morphology, suggesting potential attribution to a Jurassic crocodylomorph. Further assessment of the material in question is necessary to confirm or refute this.

Clade Sauria: Clade Dinosauria (dinosaurs)

Many body fossil occurrences in the rocks of COLM have been identified as being from dinosaurs. However, the vast majority of these are bone fragments only, lacking diagnostic features; a number of instances are of significant enough size to be attributed to Sauropoda indet., yet no further. A couple of sites in the Burro Canyon Formation and the Salt Wash Member of the Morrison Formation appear to yield enough bone material to support identification to a specific taxon, but the strongly consolidated sandstone matrix at these sites precludes taxonomic identification until intensive preparation can occur; the material at these sites is therefore retained as cf. Sauropoda indet. until future work can take place.

Only two fossils are attributed to more specific dinosaur taxa: a fragmented tooth resembling those of macronarian sauropods (e.g., *Camarasaurus* and *Brachiosaurus*) (Figure 35) and an ischium fragment attributed to cf. *Dryosaurus* sp. (Figure 36), both from the Brushy Basin Member of the Morrison Formation. The presence of bone fragments on the surface in units such as the Morrison Formation suggests that additional dinosaur taxa may be identified from COLM in the future, pending future finds and/or excavation at sites exposing bone material.



Figure 35. A fragmented probable macronarian sauropod tooth discovered in the Morrison Formation of COLM during 2023 fieldwork (NPS / AUSTIN SHAFFER).



Figure 36. An ornithopod (cf. *Dryosaurus*) ischium fragment collected from COLM in 1995 (NPS / AUSTIN SHAFFER).

Other Vertebrates

Body fossils of other vertebrates, sometimes of indeterminate taxonomic origin, have also been reported from COLM. One example of this is the bone fragments found in the Kayenta Formation. These bone fragments, discovered during fieldwork in 2002, 2004, and 2023, may be attributable to specific saurian taxa or otherwise. Unfortunately, the fragmentary nature of the specimens precludes any such attribution herein and therefore, the bone fragments are merely attributed to indeterminate Vertebrata.

Quaternary vertebrate remains from COLM include a now-lost mammoth tooth (Figure 25) and material recovered from a fissure. The mammoth tooth was found in Quaternary sediments of COLM in 1965, but has since been lost and was therefore unavailable for examination during the 2023 inventory. The taxa reported from the fissure include a number of mammals (large and small), as well as remains of squamates and a raptor (Accipitridae) that have yet to be provided specific identification. A full of list of Quaternary vertebrate taxa reported from COLM can be found in Appendix A.

Ichnofossils

Plants

Plant ichnofossils at COLM come in the form of root traces in the Chinle Formation (Figure 37). Such root traces vary in appearance (from rhizoliths to rhizohaloes to rhizoconcretions) and are commonly associated with paleosols (calcisols/aridisols). Similar paleosols and root traces are seen across similar deposits of the Colorado Plateau (Dubiel et al. 1992; Tanner 2003; Tanner and Lucas 2006; Dubiel and Hasiotis 2011).

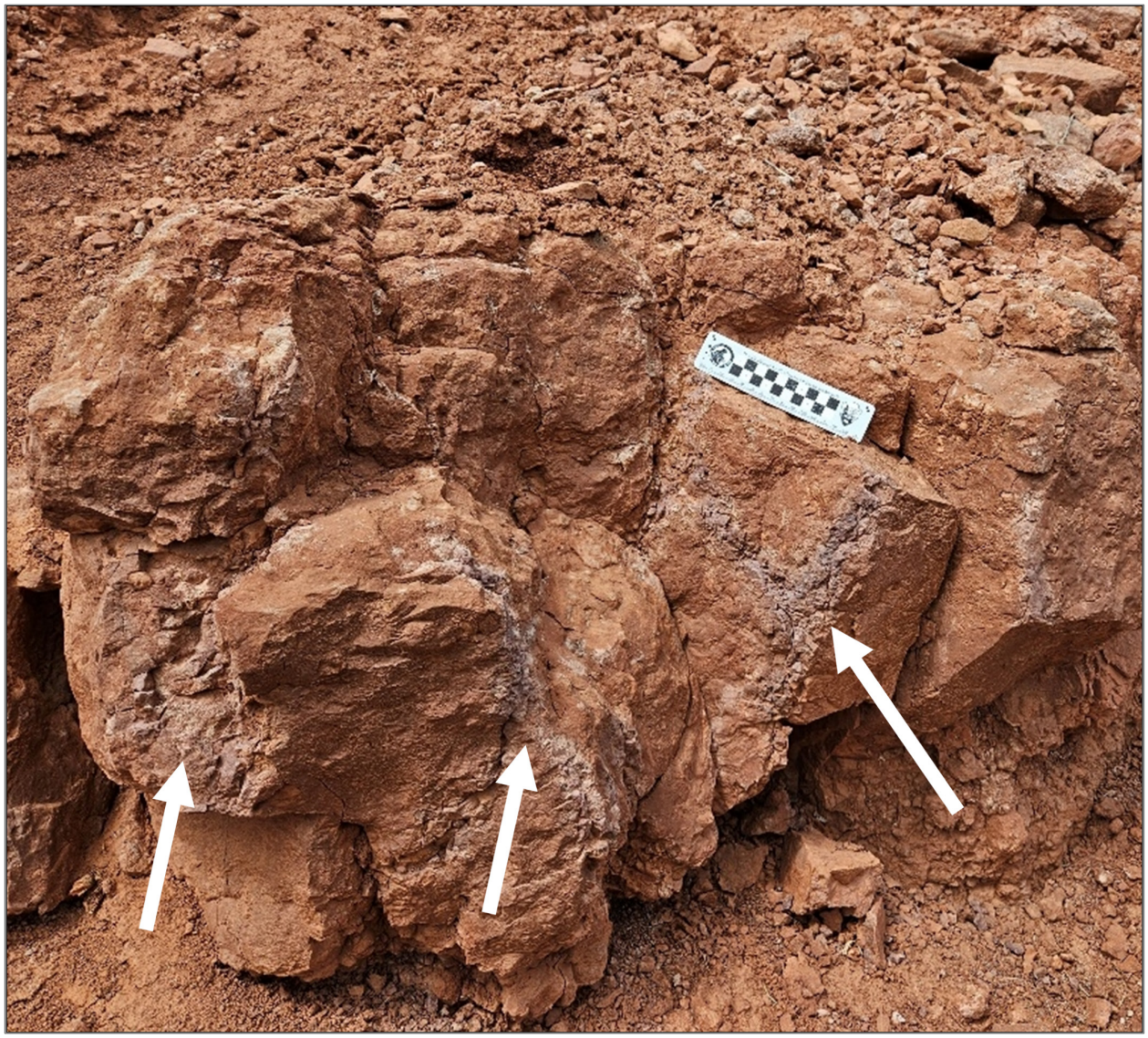


Figure 37. Root traces (rhizoliths) as seen abundantly in the Chinle Formation of COLM, indicated by arrows (NPS / AUSTIN SHAFFER).

Invertebrates

A substantial diversity of invertebrate ichnofossil morphotypes can be observed at COLM in several different geologic units, including the Chinle Formation, Wingate Sandstone, Entrada Sandstone, Morrison Formation, Burro Canyon Formation, and Naturita Formation. While some of these ichnofossils have been tentatively attributed to specific ichnotaxa (e.g., cf. *Planolites,* cf. *Thalassinoides,* cf. *Fuersichnus* [Figure 38], cf. *Lockeia*, etc.), the majority of invertebrate trace fossils observed during the 2023 inventory are herein retained as undetermined, pending thorough analysis of the morphotypes present at COLM. See Appendix A for a list of tentative ichnotaxa and the corresponding geologic units in which they were observed.



Figure 38. Channel sandstone block from the Salt Wash Member of the Morrison Formation containing abundant invertebrate ichnofossils (cf. *Fuersichnus* isp.) (NPS / AUSTIN SHAFFER).

Vertebrates

Clade Synapsida (mammals)

Tracks resembling the synapsid taxon *Brasilichnium* have been observed in the Wingate Sandstone of COLM (Figure 39). These tracks of cf. *Brasilichnium* isp. are likely representative of a small mammaliamorph trackmaker and are seen in the Triassic rocks of New Mexico and Colorado (Lockley 2011; Klein and Lucas 2021).



Figure 39. A small synapsid (cf. *Brasilichnium* isp.) track in a fallen block of Wingate Sandstone at COLM. No scale is provided because the track is located high up on a large block in an inconvenient place for a scale bar. Estimated track width is 1 to 3 cm (0.4 to 1.2 in) (NPS / AUSTIN SHAFFER).

Clade Sauria: Superorder Lepidosauria (lizards, snakes, rhynchocephalians)

One of the more significant fossil specimens collected from COLM (COLM 5172) consists of two thin limestone slabs previously collected from the Tidwell Member of the Morrison Formation bearing ripple marks and possible lepidosaur tracks. The tracks preserved here (Figure 40) closely resemble those of the largely Triassic ichnogenus *Rhynchosauroides*, and to a lesser extent the Cretaceous *Neosauroides* (Kim et al. 2017). While *Rhynchosauroides* is largely relegated to the early Mesozoic, a handful of similar occurrences do exist in Late Jurassic and Early Cretaceous strata of Europe and South America (Avanzini et al. 2010a; Buck et al. 2022). However, these tracks from COLM are some of the only such traces known from the Late Jurassic of North America, with one other possible lepidosaur track also reported from the lower Morrison Formation of the nearby Fruita Paleontological Area (Foster and Lockley 2006). Future assessment of COLM 5172 will ideally shed further light on the presence of this ichnotaxon in the Morrison Formation.



Figure 40. A close-up on possible lepidosaur (cf. *Rhynchosauroides* isp.) tracks collected from COLM. This specimen (COLM 5172) is currently housed at the Museums of Western Colorado (NPS / AUSTIN SHAFFER).

Clade Sauria: Order Testudines (turtles)

Only three tracksites of the turtle ichnotaxon *Chelonipus* have been identified from the Morrison Formation, two from eastern Utah and one from the Salt Wash Member at COLM (Lockley and Foster 2006; Lockley et al. 2018d). A collected slab from a well-preserved assemblage of turtle tracks at COLM (Figure 41) is exhibited at the Museums of Western Colorado (MWC)'s Dinosaur Journey at the time of writing. The rarity of *Chelonipus* tracks in the Morrison Formation likely does not represent low turtle abundance during the Late Jurassic; rather, this pattern is likely the result of such traces being previously overlooked based on a recent assessment of this ichnogenus within Cretaceous deposits of North America (Lockley et al. 2018e).

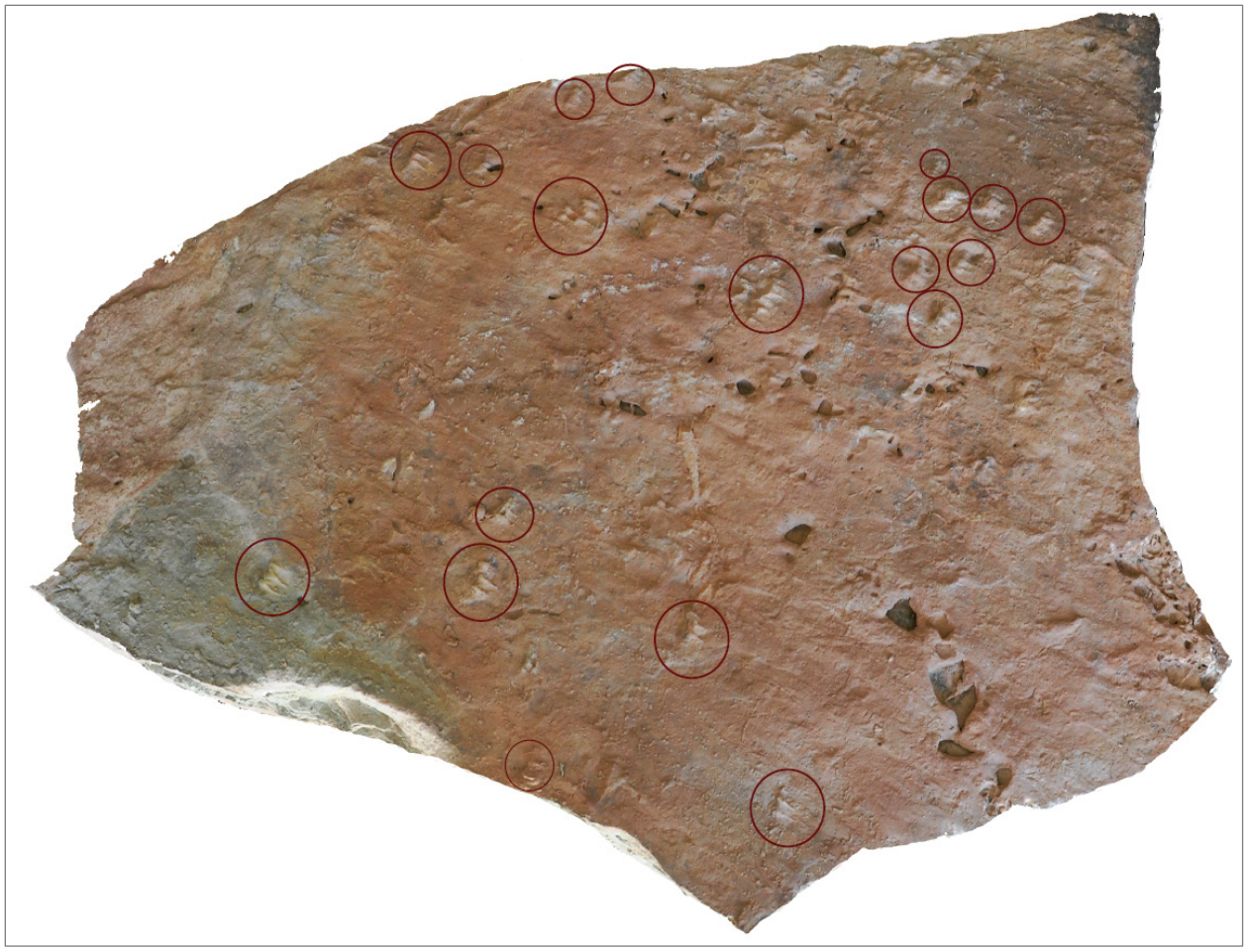


Figure 41. A sandstone slab containing turtle (*Chelonipus* isp.) tracks (highlighted by dark red circles) collected from the Morrison Formation of COLM. This specimen is currently on display at the Museums of Western Colorado (NPS).

Clade Sauria: Clade Pseudosuchia (crocodylians, aetosaurs, etc.)

Pseudosuchian traces at COLM occur in the Triassic rocks of the Chinle Formation and the Wingate Sandstone as well as in the Late Jurassic Morrison Formation. Tracks in the Triassic deposits correspond to Chirotheriidae, whereas the swim traces of the Late Jurassic strata likely correspond to neosuchian crocodyliforms (e.g., Goniopholididae).

A large diversity of tracks belonging to the ichnofamily Chirotheriidae are known from Triassic deposits worldwide, with the proposed trackmakers including a number of different pseudosuchian taxa, particularly aetosaurs (Klein et al. 2015; Hminna et al. 2019; Klein and Lucas 2021). From the Triassic deposits of COLM, a couple of different forms seem to be present; however, during the 2023 inventory, only those resembling *Brachychirotherium* have been identified beyond the family level. Tracks attributed to cf. *Brachychirotherium* isp. were observed at COLM within both the Chinle Formation (Figure 42) and Wingate Sandstone. Additional chirothere tracks not appearing to match the form of *Brachychirotherium* were also observed in the Wingate Sandstone (Figure 43), indicating

a degree of diversity among Triassic pseudosuchians within the erg environment that characterizes this unit.

The possible pseudosuchian traces of the Morrison Formation at COLM occur exclusively in the form of swim traces. Swim traces such as those observed at COLM (Figure 44) and seen in Late Jurassic and Cretaceous rocks around the world are generally attributed to aquatic neosuchian crocodyliforms (Avanzini et al. 2010b; Lockley et al. 2010a, 2010b, 2010c; Vila et al. 2015). Multiple such traces are known from the Morrison Formation of eastern Utah and have been named *Hatcherichnus sanjuanensis* (Foster and Lockley 1997; Lockley and Foster 2010). The ichnotaxonomic identity of crocodyliform swim traces is complicated without preservation of clear manus or pes structures. Due to their favorable comparison with traces of *Hatcherichnus* and possible poorly preserved manus/pes structures observed during 2023 field work, the swim traces at COLM are tentatively referred to cf. *Hatcherichnus* isp., although an alternative identification as *Characichnos* remains possible (Kukihara et al. 2010; Lee et al. 2019; Lockley et al. 2021c).



Figure 42. Chirothere (cf. *Brachychirotherium* isp.) track (white dashed outline) in the Chinle Formation at COLM (NPS / AUSTIN SHAFFER).



Figure 43. An undetermined chirothere track in the Wingate Sandstone of COLM (NPS / AUSTIN SHAFFER).



Figure 44. Swim traces (cf. *Hatcherichnus* isp.) in the lower Morrison Formation of COLM (NPS / AUSTIN SHAFFER).

Clade Sauria: Order Pterosauria (pterosaurs)

The only fossil evidence of pterosaurs documented at COLM comes in the form of trace fossils. Two tracks attributable to the taxon *Pteraichnus* (Figure 45) were observed in sandstones of the Morrison Formation (one example of which is currently housed in COLM collections). Similar tracks are seen across equivalent deposits of the Intermountain West. A possible pterosaur feeding trace was also reported by Scheetz (2002) from the Wanakah Formation, but has not been observed since.

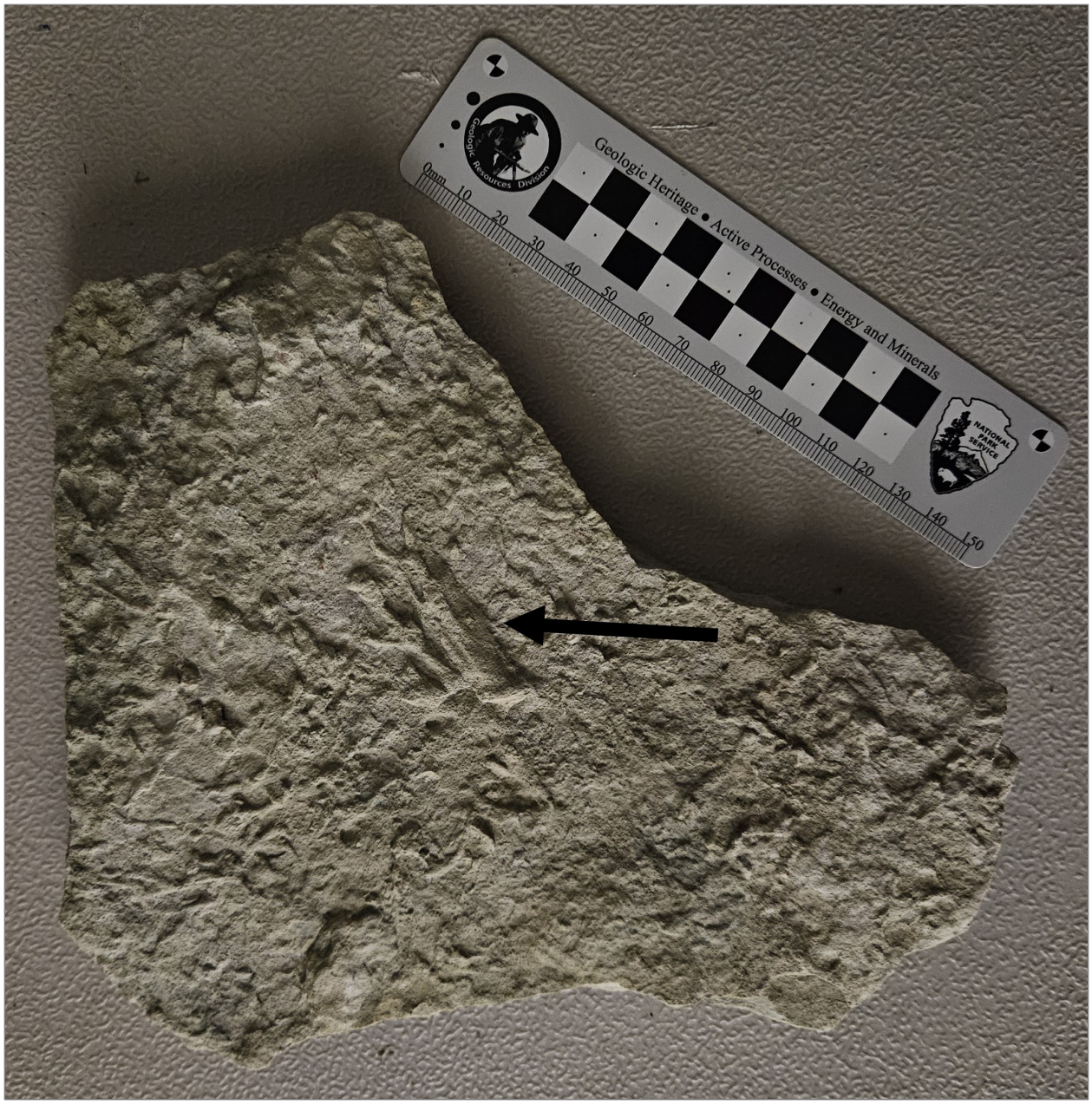


Figure 45. A sandstone slab from the Morrison Formation containing a pterosaur (*Pteraichnus* cf. *saltwashensis*) track (indicated by arrow), as observed within COLM collections (NPS / AUSTIN SHAFFER).

Clade Sauria: Clade Dinosauria: Clade Ornithischia ("bird-hipped" dinosaurs)

A large diversity of ichnofossils from the herbivorous ornithischian dinosaurs can be found at COLM. The representative ichnotaxa identified and/or verified during the 2023 inventory include stegosaurs, ankylosaurs, small and large ornithopods, and basal ornithischians.

A single ichnofossil occurrence in the Chinle Formation, seemingly attributable to cf. *Atreipus* isp., may be the oldest ornithischian track known from COLM. This ichnofossil (Figure 46) may include

both manus and pes natural casts (albeit somewhat poorly preserved), the characteristics of which are congruent with the "grallatorid" ichnogenus *Atreipus* (Klein and Lucas 2021). This ichnotaxon is often found in Triassic rocks of the Northern Hemisphere and has been attributed to basal ornithischians (Klein and Lucas 2021); such a trackmaker identification is particularly well supported when silesaurids are considered a paraphyletic group at the base of Ornithischia, as has been found by recent phylogenetic research (Norman et al. 2022). The possibility exists that the track identified herein as cf. *Atreipus* isp. instead represents a different "grallatorid" or a chirotheriid.



Figure 46. A probable tridactyl track (cf. *Atreipus* isp.) as seen in an exposed block of the Chinle Formation at COLM (NPS / AUSTIN SHAFFER).

Two possible instances of stegosaur tracks have been observed at COLM, matching similar tracks reported from nearby eastern Utah (Gierliński and Sabath 2008; Milàn and Chiappe 2009; Gierliński et al. 2010; Lockley et al. 2017, 2018d). The most distinct stegosaur tracks observed at COLM are in the form of loose manus and pes natural track casts from the Tidwell Member of the Morrison Formation (Figure 47). These tracks were initially identified as being from a small sauropod (due to the similar crescentic manus shape) before being revised to the current diagnosis as *Deltapodus* cf. *brodricki*. Such an identification appears well-founded morphologically, based on the modified diagnosis of the ichnotaxon provided by Guillaume et al. (2022). An additional set of tracks from the Brushy Basin Member of the Morrison Formation is identified as cf. *Stegopodus* isp.; however, these tracks are largely secluded from view on the underside of a sandstone bed and may instead represent

a different taxon (Gierliński and Sabath 2008). It should be noted that the similar structure of stegosaur and sauropod tracks (particularly with regards to the crescentic manus), alongside the documented instance of mistaken identity herein and similar cases described elsewhere (Guillaume et al. 2022), may indicate that a number of ichnofossils identified from COLM as sauropod tracks may instead represent stegosaur tracks.



Figure 47. A loose natural cast of a stegosaur (*Deltapodus* cf. *brodricki*) pes found at COLM (NPS / AUSTIN SHAFFER).

Tracks attributable to ankylosaurs are known from two units at COLM, the Naturita Formation and the Salt Wash Member of the Morrison Formation, occurring abundantly in the former and known from only a single possible occurrence in the latter.

Abundant tracks (both manus and pes) of *Tetrapodosaurus* isp. have been observed in the Naturita Formation of COLM. This is in accord with abundant tracks of the same ichnotaxon from the nearby

Dominguez-Escalante National Conservation Area (Lockley et al. 2021c). These ankylosaur tracks range in size and include incredibly large examples in some cases (Figure 48). The high proportion of ankylosaur tracks seen at COLM matches what is seen across the western slope of Colorado and Utah, more broadly (Lockley 2018).



Figure 48. A large ankylosaur (*Tetrapodosaurus* isp.) pes in the Naturita Formation of COLM (NPS / AUSTIN SHAFFER).

Within the Salt Wash Member of the Morrison Formation of COLM, a single track cast was found loose during the 2023 inventory (Figure 49). Initially thought to potentially represent a stegosaur, further assessment suggests that the track may tentatively be assigned to an ankylosaur. Ankylosaur tracks are rare in Jurassic deposits with only a handful of known instances worldwide (Francischini et al. 2017; Rodriguez-de la Rosa et al. 2018). Notably, one such instance is known from the Morrison Formation, a manus resembling that of *Tetrapodosaurus* found only a few km or mi from COLM in the Brushy Basin Member at Cactus Park, Colorado (Hups et al. 2008). The track found in the Salt Wash Member of COLM compares favorably with the pes tracks of *Metatetrapous valdensis* from the Berriasian (Early Cretaceous) of Germany (Hornung and Reich 2014). As such, the track is

herein referred to cf. *Metatetrapous* isp. pending a more in-depth analysis and comparison. If this track does indeed represent a Jurassic ankylosaur pes, its occurrence at COLM is not surprising given the proximity to the skeletal material of *Mymoorapelta maysi* (only a few km or mi to the west in Rabbit Valley, Colorado) (Kirkland and Carpenter 1994). In any case, this track could be extremely significant given the global rarity of ankylosaur tracks from this time.



Figure 49. A loose natural cast possibly from an ankylosaur (cf. *Metatetrapous* isp.) found in the Morrison Formation of COLM (NPS / AUSTIN SHAFFER).

Seven instances of small ornithopod tracks are known from sites in the Salt Wash Member of the Morrison Formation at COLM. These tracks have been attributed to cf. *Anomoepus* isp. and *Dinehichnus socialis*, with those identified as the latter representing some of the only instances of the ichnotaxon *Dinehichnus* from the Morrison Formation (Lockley and Foster 2006). Both of these small ornithopod ichnotaxa are represented by mesaxonic tridactyl tracks, with the medium-sized tracks of *Dinehichnus* typically significantly larger than those of cf. *Anomoepus* isp. The two are also distinguished on the basis of morphology (Castanera et al. 2020). One slab of small ornithopod track casts (cf. *Anomoepus* isp.) was recovered in 2003 and is currently housed in the collections of COLM (Figure 50).



Figure 50. Sandstone slab in COLM collections containing ornithopod (cf. *Anomoepus* isp.) trackway (NPS / AUSTIN SHAFFER).

A single track observed in the Salt Wash Member of the Morrison Formation at COLM during the 2023 inventory may represent a large ornithopod. This track (Figure 51) displays many of the diagnostic features of Iguanodontipodidae (mesaxonic, tridactyl, subsymmetrical pes tracks; one pad impression in each digit and one in the heel; digit pads longer than wide) as described by Díaz-Martínez et al. (2015). The ichnofamily Iguanodontipodidae is largely known from the Cretaceous, but a few isolated examples are known from the Late Jurassic of Europe and Asia (Díaz-Martínez et al. 2015). Such tracks may have been made by basal members of the clade Ankylopollexia—taxa from which body fossils are known in Late Jurassic deposits of Europe and North America, including the Morrison Formation. While the possibility exists that this track may instead represent a theropod, it is considered as cf. Iguanodontipodidae indet. herein. Future work comparing this track with other tridactyl tracks of similar geologic age may confirm or refute this identification.



Figure 51. A tridactyl track cast in a sandstone block of the Salt Wash Member of the Morrison Formation at COLM provisionally identified as cf. Iguanodontipodidae indet. (NPS / AUSTIN SHAFFER).

Alongside the abundant tracks of *Tetrapodosaurus* isp. seen in the Naturita Formation are many large ornithopod track casts attributable to *Hadrosauropodus leonardii*. Large tridactyl tracks attributed to ornithopods such as these (Figure 52) are common across the rocks of the Naturita Formation (Lockley 2018; Lockley et al. 2014a, 2018c, 2021a). The ichnotaxonomy of large ornithopod tracks has been a complicated issue for some time (Lockley et al. 2014c; Díaz-Martínez et al. 2015). While the large ornithopod tracks of the Naturita Formation and similar deposits in the "Dakota Group" have traditionally been referred to *Caririchnium* and the ichnospecies *C. leonardii*, we follow the most recent comprehensive review of such tracks in their referral of this ichnospecies to the ichnogenus *Hadrosauropodus* as *H. leonardii* (Díaz-Martínez et al. 2015). The tracks seen in the Naturita Formation of COLM can be attributed to this ichnotaxon with some confidence on the basis of multiple diagnostic characters (e.g., bilobed heel) provided in the emended diagnosis of *H. leonardii* (Díaz-Martínez et al. 2015). The trackmaker of *H. leonardii* is inferred to have been a hadrosauroid.



Figure 52. An ornithopod track (*Hadrosauropodus leonardii*) in the Naturita Formation of COLM (NPS / AUSTIN SHAFFER).

The Naturita Formation also produced a single dinosaur skin impression example at COLM in March 2024. This specimen (Figure 53) exhibits a number of polygonal scales, partially obscured by black lichen. Only a handful of such skin impressions have been reported from geologic units of this age

across the region, namely ornithopod and theropod tracks bearing scales from the South Platte Formation near Denver, Colorado and the Naturita Formation near Delta, Colorado, respectively (Currie et al. 1991; Noe et al. 2014). The rarity of skin traces in the Naturita Formation and its coeval units highlights the significance of this fossil.



Figure 53. Dinosaur skin impression in sandstone from the Naturita Formation of COLM (NPS / AUSTIN SHAFFER).

Clade Sauria: Clade Dinosauria: Clade Theropoda ("beast-footed" dinosaurs)

Theropod dinosaur tracks can be found at COLM in the same layers as their ornithischian counterparts: the Chinle Formation, Wingate Sandstone, Morrison Formation, and Naturita Formation. Several different taxa can be observed in these layers.

A number of early Mesozoic tridactyl tracks are found at COLM within the Chinle Formation and Wingate Sandstone, being most prevalent near the contact between these units. Many of these tracks fall under the usage of the term "grallatorid", which includes a complex of taxa, most of which are early representatives of Theropoda (Klein and Lucas 2021). The probable theropod tracks observed in the Chinle Formation of COLM are only tentatively referred to cf. *Grallator* isp. due to their relatively poor preservation. The tracks found in the Wingate Sandstone, on the other hand, show a much higher preservation quality, including distinct phalangeal pads ("toe pads") on certain specimens. These tracks from the Wingate Sandstone resemble those found across western Colorado and eastern Utah with forms attributable to *Grallator* isp. and cf. *Anchisauripus* isp. observed

(Lockley and Gierliński 2009; Klein and Lucas 2021; Lockley et al. 2023). These tracks come in a variety of sizes (Figure 54) and likely correspond to a number of distinct theropod species and ontogenetic stages.



Figure 54. A fallen block of Wingate Sandstone at COLM containing “grallatorid” theropod tracks (roughly outlined by dashed lines) of varying sizes (NPS / AUSTIN SHAFFER).

Theropod tracks in the Morrison Formation range widely in size, from small to large. The small tridactyl tracks attributed to cf. *Grallator* isp. from this geologic unit at COLM are few in number and often difficult to distinguish from the abundant small ornithopod tracks also found. However, upon reaching larger sizes, theropod tracks at COLM are more readily diagnosable.

A medium-sized theropod track found in the Tidwell Member of the Morrison Formation at COLM is attributable to the ichnotaxon *Therangospodus pandemicus* (Figure 55). This ichnotaxon was

named from the Late Jurassic Summerville Formation and can be distinguished by a variety of characters (Lockley et al. 1998a; Castanera et al. 2018), which correlate well with the track from COLM.



Figure 55. A medium-sized theropod (*Therangospodus pandemicus*) track from the Morrison Formation of COLM (NPS / AUSTIN SHAFFER).

The largest theropod track from COLM is one from the Tidwell Member of the Morrison Formation (Figure 56). Large theropod tracks of this time and place are often attributable to either *Megalosauripus* or *Hispanosauropus*, with the characteristics of the track found at COLM supporting referral to cf. *Megalosauripus* isp. (Lockley et al. 1998b; Foster 2015b; Razzolini et al. 2016, 2017;

Castanera et al. 2018; Belvedere et al. 2019; Lockley 2022). This ichnotaxon likely corresponds to an allosauroid or megalosauroid trackmaker.

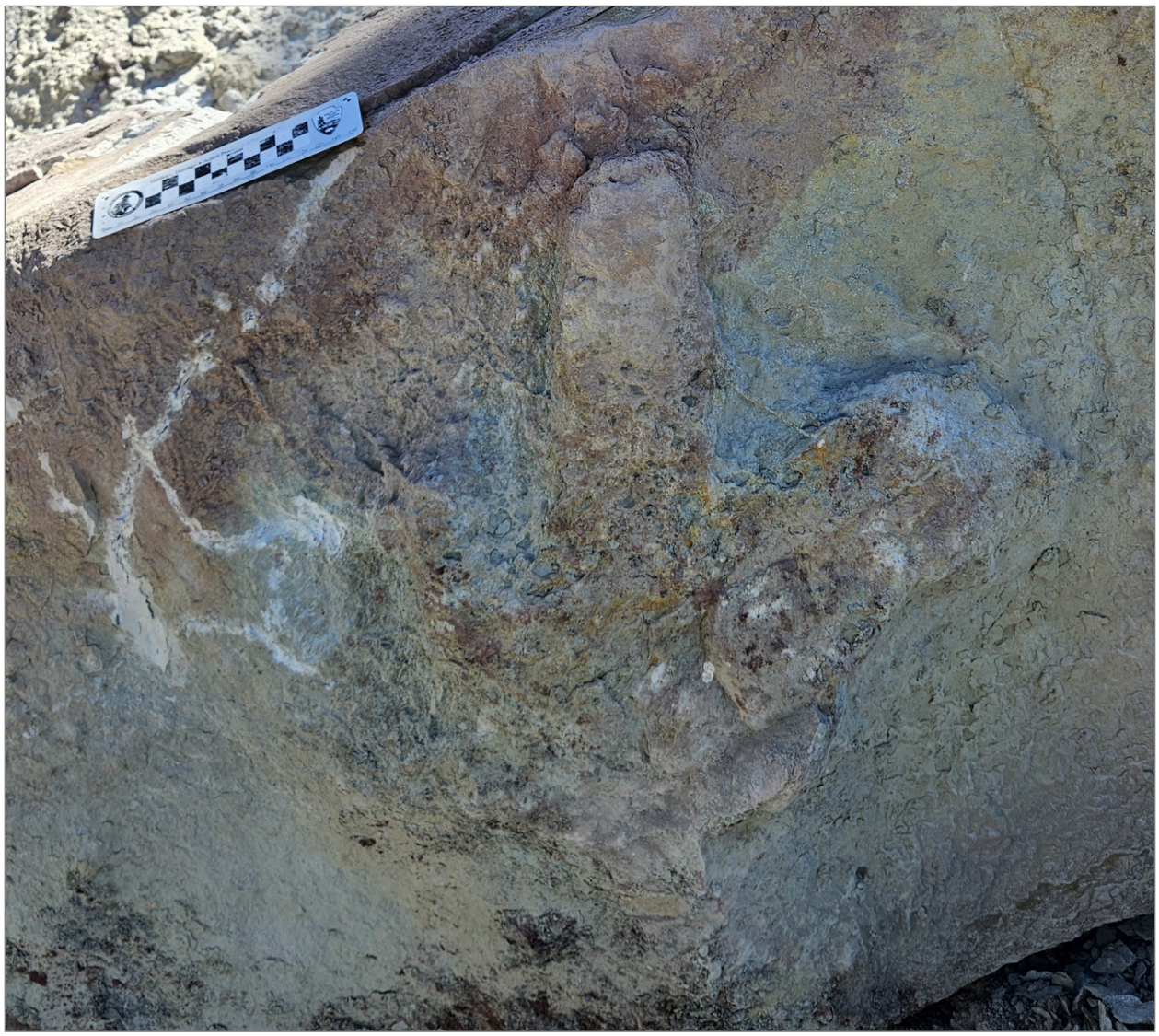


Figure 56. A tridactyl natural track cast (cf. *Megalosauripus* isp.) from the Morrison Formation of COLM (NPS / AUSTIN SHAFFER).

The Naturita Formation of COLM only records seven tracks provisionally attributable to the theropod ichnotaxon cf. *Magnoavipes* isp. (Figure 57), although none of these are very well preserved. Despite the quality of these tracks, they nevertheless resemble tracks of *Magnoavipes* seen in similar deposits across the region, tracks which exhibit similar abundance levels in relation to the tracks of ankylosaurs (*Tetrapodosaurus*) and ornithopods (*Hadrosauropodus*) (Kukihara and Lockley 2012; Noe et al. 2014; Lockley et al. 2014a, 2014b, 2015, 2018a, 2018c).

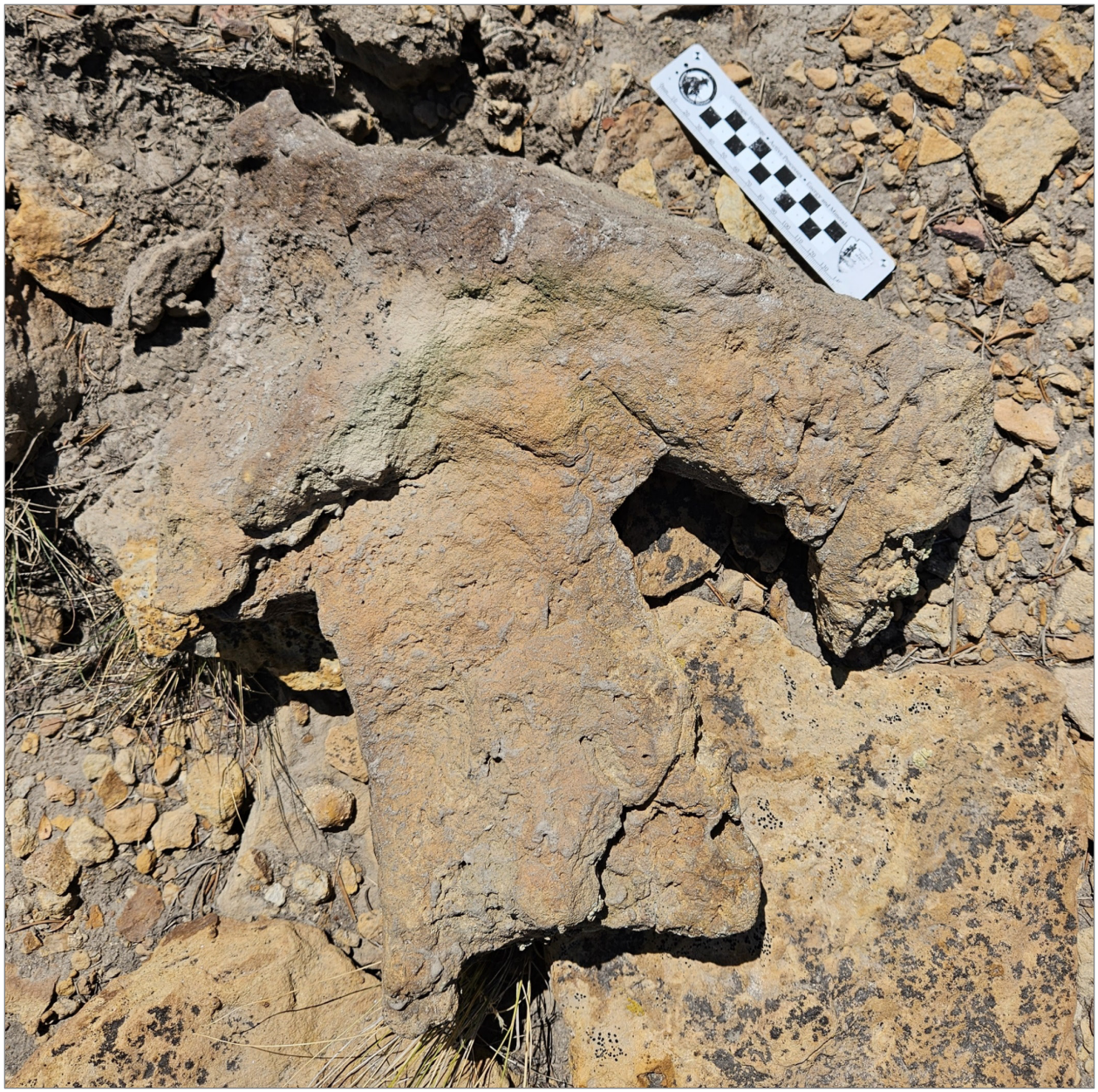


Figure 57. A theropod (cf. *Magnoavipes* isp.) track from the Naturita Formation at COLM (NPS / AUSTIN SHAFFER).

Clade Sauria: Clade Dinosauria: Clade Sauropodomorpha ("lizard-footed" dinosaurs)

Both early sauropodomorphs of the Triassic and large sauropods of the Late Jurassic are represented by tracks at COLM.

The Triassic rocks of the Wingate Sandstone at COLM preserve tracks of the early sauropodomorph *Eosauropus*. The ichnotaxon *Eosauropus cimarronensis* was named in 2006 on the basis of Triassic tracks from New Mexico, Utah, and western Colorado, with additional material attributed to the ichnogenus from Europe and Greenland (Lockley et al. 2006b; McClure et al. 2021). The tracks of this ichnotaxon are particularly abundant in eastern Utah and western Colorado (Lockley et al. 2011).

Tracks of *Eosauropus* cf. *cimarronensis* are observed in COLM in situ within a sandstone bed of the Wingate Sandstone (Figure 58) and as loose pes tracks eroded out from this bed (Figure 59).



Figure 58. A bed of *Eosauropus* tracks, as seen in the Wingate Sandstone of COLM (NPS / AUSTIN SHAFFER).



Figure 59. A loose pes track of *Eosauropus* cf. *cimarronensis* from the Wingate Sandstone of COLM (NPS / AUSTIN SHAFFER).

A number of sauropod tracks (both manus and pes) are found in the Morrison Formation at COLM. These tracks occur in both isolated instances as well as in extensive beds (Figure 60). A variety of track sizes can be observed at COLM, although as discussed elsewhere, some of these may represent other taxa (e.g., stegosaurs). One instance of possible juvenile sauropod tracks has been collected (currently housed at MWC); however, further analysis of this specimen and comparison with examples of small sauropod tracks reported from the Late Jurassic and Early Cretaceous of Europe and Asia is necessary to support or refute such an attribution (Xing et al. 2015; Demathieu et al. 2022).



Figure 60. A sandstone layer of the Morrison Formation containing multiple large sauropod track casts. Note the scale bar (=15 cm, or 6 in) below the track at left (NPS / AUSTIN SHAFFER).

Other Ichnofossils

Sedimentary structures produced by cyanobacteria are found at COLM, in the form of stromatolites and oncolites (Tucker and Wright 1990). Such microbial ichnofossils are restricted to the rocks of the Morrison Formation and are particularly abundant in certain horizons of the Salt Wash Member (Figure 61).



Figure 61. A chunk of oncolite from the Morrison Formation of COLM (NPS / AUSTIN SHAFFER).

Paleontological Localities

Paleontological Localities Within COLM

During the 2023 field inventory, a total of 226 paleontological localities were documented within the boundaries of COLM. These localities were confirmed to either possess paleontological resources currently or have produced fossil specimens currently within the collections at COLM. Of these 226 documented localities, approximately 35% (80 localities) represent prior COLM fossil localities which were relocated and whose fossil material was verified, while nearly two-thirds (~65%; 146 localities) of the fossil localities observed at COLM were newly identified/documented during the 2023 field inventory. Two additional localities were discovered in the Morrison and Naturita Formations in March 2024, as this report was being finalized, raising the total to 228 localities. They have not been incorporated into the following charts, but do not significantly change any of the numbers.

The fossil localities documented at COLM are overwhelmingly from certain geologic units (e.g., Wingate Sandstone, Morrison Formation, Burro Canyon Formation, Naturita Formation) (Figure 62). Other geologic units at COLM (e.g., Wanakah Formation, Quaternary sediments) have no sites where a fossil occurrence was verified during 2023 field survey; it is likely that these geologic units possess fossils that were simply not observed during the 2023 field inventory—particularly when considering unverified previous finds. The presence of fossils within these units may be verified/refuted through future field survey at COLM.

The fossils observed at COLM localities consist of numerous different fossil types (e.g., vertebrate trace/body fossils, invertebrate trace/body fossils, plant fossils, etc.). The relative number of localities containing these different fossil types varies between geologic unit. Vertebrate fossil localities make up more than half of the documented localities at COLM, with invertebrate fossil localities comprising roughly another quarter (Figure 63). A limited number of sites with fossil type co-occurrence were documented from COLM in 2023, with an overwhelming majority (92%) of sites containing only a single fossil type.

A breakdown of COLM paleontological localities and associated data can be found in Appendix E. Information regarding specimen collection from COLM paleontological localities can be found in Appendix B. Further details are available to qualified researchers. A glossary containing definitions for much of the terminology used can be found near the beginning of this report.

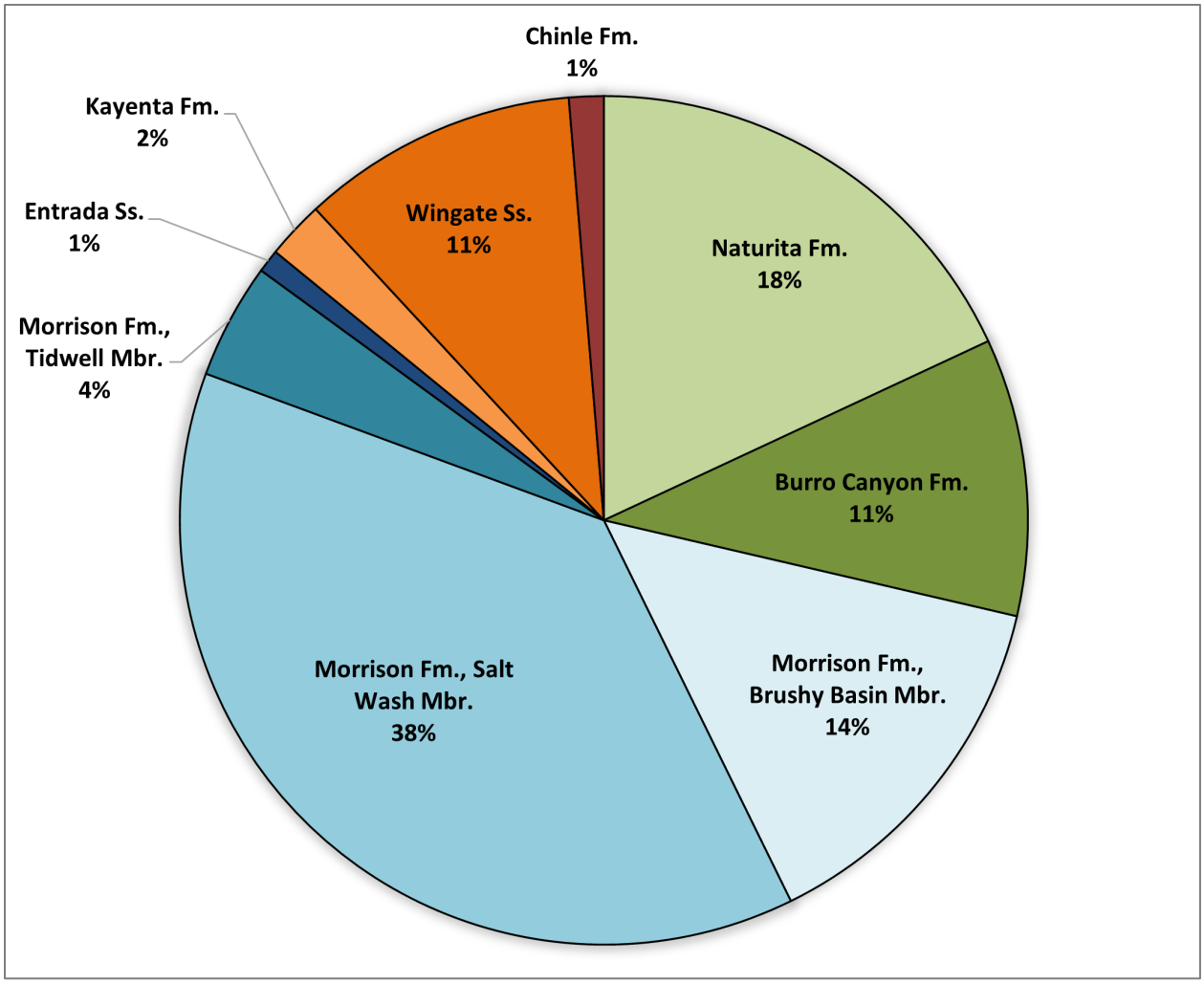


Figure 62. The relative percentages of fossil localities within the geologic units of COLM, both previously known and newly documented during the 2023 inventory (NPS / AUSTIN SHAFFER).

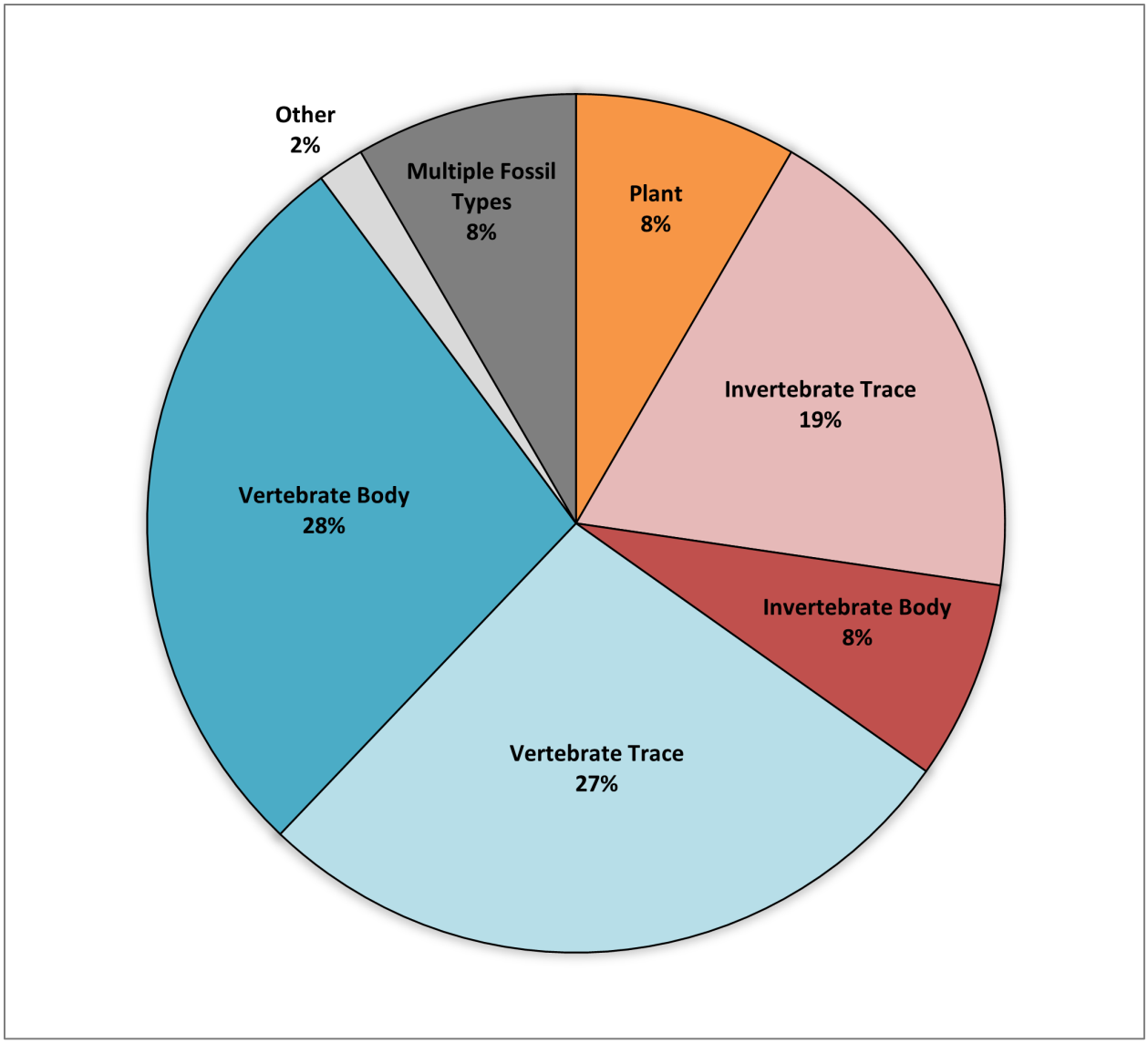


Figure 63. The relative percentages of COLM fossil localities containing different fossil types, both previously known and newly documented during the 2023 inventory (NPS / AUSTIN SHAFFER).

Paleontological Localities Near COLM

Many fossil sites can be found in the area surrounding COLM, many within the Morrison Formation of the Late Jurassic (e.g., Riggs Hill, Dinosaur Hill, Mygatt-Moore Quarry, Fruita Paleo Area), but including a wide range of geologic units and taxa. Relevant references with additional information on these nearby sites include Armstrong and McReynolds (1987b), Chenoweth (1987), Jensen and Padian (1989), Kirkland et al. (2005), Kirkland (2006), Foster et al. (2016, 2018), and Foster (2020). A significant number of these sites contain similar fossil occurrences to those of COLM, although many (such as the aforementioned examples from the Morrison Formation) contain unique taxa—with three taxa being named after the nearby town of Fruita, Colorado alone (*Fruitafossor*, *Fruitadens,* and *Fruitachampsa*). Paleontological localities near COLM can be found on land administered by the Bureau of Land Management and the U.S. Forest Service.

Cultural Resource Connections

There are many ways for paleontological resources to have connections to cultural resources. Examples of paleontological resources in cultural contexts include, but are not limited to: fossils used by people for various purposes, such as petrified wood used for tools, spear points, and other artifacts, or fossil shells picked up as charms or simply because they looked interesting; associations of prehistoric humans with paleontological resources, such as kill sites of mammoths, prehistoric bison, and other extinct animals; incorporation of fossils into cultural records, such as fossils in Native American lore, "tall tales" of mountain men, and emigrant journals; and fossils in building stone. Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

A notable instance of paleontological resources in a cultural context at COLM was discovered during the 2023 fieldwork. A number of clast fragments, eroded out from conglomeratic sandstone boulders of the Burro Canyon Formation, were found to be comprised of fossiliferous limestone/chert, containing an assortment of Paleozoic marine fossils (including bryozoans, crinoids, and a brachiopod). Examination of five chert fragments by COLM archeologists Adam Brinkman and Adam Grotjohn indicated evidence of human activity (pers. comm., August 2023). Three of the fragments represent angular lithic shatter—unintentional byproducts of human stone processing. However, the other two are more significant, being fragments of a "core tool". Past people worked the original cobble by removing flakes from it (seen in conchoidal flake scars), reached a certain point in the process, and decided to use an edge of the core as a tool. This edge was used in some unknown fashion, eventually becoming dull and then being re-sharpened by retouching the core along the distal end and one of the sides through the removal of microflakes.

The fossiliferous clast fragments were discovered within 40 m (130 ft) of a known archeological site (5ME23583). This site is a prehistoric open camp and lithic quarry area lacking any diagnostics or features that could provide an age of occupation (A. Brinkman, pers. comm., September 2023). The quarry area represents a location where people were collecting larger quartzite cobbles from the surface and reducing them to size for ease of transport off site. Evidence of tool manufacture and modification is also present, whereby people refined stone into more readily usable tools. Additionally, there may have been some degree of animal or other resource processing activities occurring at the site. This broadly fits with how the tools found would have been worked, with some initial flaking removed from the cobbles along with more refined flaking on some of the edges indicating their usage in some capacity. The fossiliferous cobble pieces specifically, while indeed showing evidence of being worked, do not correspond to any formal tool; however, they nevertheless were usable material for resource processing as evidenced by the modification seen (A. Brinkman, pers. comm., September 2023).

Museum Collections and Paleontological Archives

Museum Collections and Curation

Interior Collection Management System (ICMS) catalog data for COLM collections maintains 456 listings classed as paleontological specimens. However, these data are currently outdated; 110 of these 456 catalogued specimens were deaccessioned in 1989 having been deemed outside the scope of collections (three of these deaccessioned specimens remain in COLM collections despite this status). The remaining 346 catalogued specimens (alongside a number of uncatalogued specimens) are currently housed in COLM collections and other repositories.

Monument Collections

Thirty-nine fossil specimens are currently housed within COLM collections. Of these, 14 specimens possess associated ICMS catalog numbers, two specimens have been accessioned but not catalogued, and 23 specimens await accessioning and cataloguing. Fifteen of the 23 specimens that have yet to be accessioned/catalogued were recovered during fieldwork associated with the 2023 inventory. More than half (22) of the fossil specimens in COLM collections originate from the Morrison Formation; the remaining specimens come from the Wingate Sandstone, Kayenta Formation, Burro Canyon Formation, Naturita Formation, and undetermined or uncertain units. The earliest-catalogued specimens currently housed in COLM collections date back to the late 1940s, with the great majority of specimens having been recovered during later paleontological surveys of COLM (e.g., G. F. Engelmann in 1995, K. C. Trujillo in 2004, C. C. Green in 2013) or the work of John R. Foster in the 2000s and 2010s (Figure 70).

Two instances of fossils collected from COLM are not associated with any catalog numbers, nor are they present within the collections (having been lost): the metoposaur fragments from the Chinle Formation and a mammoth tooth from Quaternary sediments (Figure 25).

Collections in Other Repositories

Two repositories are known to currently house specimens from COLM: the Museum of Northern Arizona (MNA) and the Museums of Western Colorado (MWC). See Appendix C for contact information.

The MNA houses the bulk of COLM's current paleontological collection, comprising all catalogued (325) and uncatalogued (8) specimens from the monument's Quaternary sediments—a total of 333 specimens. The majority of these specimens (325) are from 13 packrat (*Neotoma* sp.) middens at COLM collected in the early 1990s. The specimens at MNA were originally housed at Northern Arizona University (NAU) before being transferred to MNA.

Dinosaur Journey, a component museum of MWC, currently maintains five COLM paleontological specimens, notably a specimen of possible lepidosaur (cf. *Rhynchosauroides* isp.) tracks and a slab of turtle (*Chelonipus* isp.) tracks currently on exhibit. One of the COLM specimens currently housed at Dinosaur Journey is a cast of a *Brachiosaurus* humerus specimen found in Potter Creek, Colorado; this specimen was formerly on display at the COLM Visitor Center (see below). The four fossil

specimens collected from COLM and housed at Dinosaur Journey were collected by the former curator of MWC, John R. Foster.

Finally, four other institutions may have specimens from COLM or information related to collecting or research activities at COLM:

Cincinnati Museum Center: The online database of this institution, as searched from iDigBio, includes IP26083, a specimen of the snail *Valvata scabrida* attributed to COLM, with no other information.

New Mexico Museum of Natural History and Science: Lucas et al. (2006b) recorded localities from COLM with numbers from this institution, but did not report collecting any specimens and the museum's database does not list any specimens from Mesa County, Colorado.

University of Colorado Museum: Casts of the dinosaur and turtle traces described by Lockley and Foster (2006) were reposited in the University of Colorado–Denver Dinosaur Tracks Museum and the Museums of Western Colorado (Lockley and Foster 2006). The University of Colorado–Denver casts would have since gone to the University of Colorado Museum.

National Museum of Natural History: It is possible that paratypes of *Vetulonaia faberi* (Holt 1942) from COLM are reposited here under USNM 103262.

Type Specimens

No fossil species have been described from COLM specimens to date.

Archives

NPS Paleontology Archives

All data, references, images, maps, and other information used in the development of this report are maintained in the NPS Paleontology Archives and Library. These records consist of both park-specific and servicewide information pertaining to paleontological resources documented throughout the NPS. If any resources are needed by NPS staff at COLM, or additional questions arise regarding paleontological resources, contact the NPS Senior Paleontologist & Paleontology Program Coordinator Vincent Santucci, vincent_santucci@nps.gov. Park staff are also encouraged to communicate new discoveries to the NPS Paleontology Program, not only when support is desired, but in general, so that this information can be incorporated into the archives. A description of the Archives and Library can be found in Santucci et al. (2018).

E&R Files

E&R files (from "Examination and Report on Referred Fossils") are unpublished internal USGS documents. For more than a century, USGS paleontologists identified and prepared informal reports on fossils sent to the agency by other geologists, for example to establish the relative age of a formation or to help correlate beds. The system was eventually formalized as a two-part process including a form sent by the transmitting geologist and a reply by the survey geologist. Sometimes the fossil identifications were incorporated into publications, but in many cases the information is unpublished. These E&R files include documentation of numerous fossil localities within current

NPS areas, usually predating the establishment of the NPS unit in question and frequently unpublished or previously unrecognized. Extensive access to the original files was granted to the NPS by the USGS beginning in 2014 (Santucci et al. 2014).

E&R files relevant for COLM include two reports by John B. Reeside, Jr. (J. B. Reeside, Jr., written comm. to W. T. Lee. November 25, 1925; J. B. Reeside, Jr., written comm. to E. M. Spieker and J. B. Reeside, Jr., February 1, 1926). These reports mention two localities that may correspond to the Morrison Formation where unionid bivalves and gastropods were identified (relatively common fossils in this geologic unit). These localities may be within the boundaries of COLM; however, the specific location of either locality could not be verified during the 2023 field inventory.

Park Paleontological Research

Current and Recent Research

Since the 1990s, 17 permits have been issued for projects at COLM that were either paleontological in focus, or a geological project with paleontological significance. They are listed below in chronological order by research permit number.

- COLM1994AKQX, principal investigator Larry Agenbroad of Northern Arizona University, project "Quaternary Paleoenvironments on the Colorado Plateau Rocky Mountain Region National Park Service Units: Inventory, Synthesis, Management and Curation", issued for 1994; this project was continued in 1995 under COLM1995AOKW.
- COLM-2001-SCI-0002, principal investigator John Foster of the Museums of Western Colorado, project "Early Mesozoic vertebrate paleoecology of western Colorado", issued for 2001–2002; this project was continued in 2003–2004 under COLM-2003-SCI-001 (cancelled) and COLM-2003-SCI-0002, 2004–2005 under COLM-2004-SCI-0005, and 2005–2007 under COLM-2005-SCI-0005.
- COLM-2001-SCI-0004, principal investigator Paula Valencik of the University of Massachusetts, project "Tidwell Member of the Morrison Formation in Western Colorado and Eastern Utah", issued for 2001.
- COLM-2002-SCI-0001, principal investigator Paula Valencik of the University of Massachusetts, project "Depositional Environments and Facies Relationships in the Tidwell and Salt Wash Members of the Late Jurassic Morrison Formation, Grand Junction Area, Colorado: A Sedimentological and Geochemical Approach", issued for 2002–2005.
- COLM-2004-SCI-0001, principal investigator Ranie Lynds of the University of Wyoming, project "Quantitatively integrating studies of modern braided streams with the rock record: an example from the Lower Jurassic Kayenta Formation of the Colorado Plateau", issued for 2004–2005.
- COLM-2004-SCI-0007, principal investigator Kelli Trujillo of the University of Wyoming, project "Paleontological Survey/Inventory and Management Plan for Colorado National Monument", issued for 2004.
- COLM-2005-SCI-0002, principal investigator Spencer Lucas of the New Mexico Museum of Natural History and Science, project "Footprints in the Wingate Sandstone", issued for 2005.
- COLM-2007-SCI-0003, principal investigator Deborah Kennard of Mesa State College, project "Determining Prehistoric Fire History of the Colorado National Monument, Colorado", issued for 2007; this project was continued in 2008–2009 under COLM-2008-SCI-0001, and 2010–2011 under COLM-2010-SCI-0001.
- COLM-2019-SCI-0002, principal investigator Lawrence Jones of Colorado Mesa University, project "Preliminary Correlation Study of the Jurassic Wanakah Formation in Southwestern Colorado", issued for 2019–2021.

- COLM-2023-SCI-0004, principal investigator Austin Shaffer of the Scientists-in-Parks Internship program, project "Colorado National Monument Paleontological Resource Inventory", issued for 2023–2024.

Paleontological Research Permits

See the National Park Service Natural Resource Management Reference Manual DO-77 section on Paleontological Resource Management, subsection on Scientific Research and Collection (https://irma.nps.gov/DataStore/Reference/Profile/572379). NPS Management Policies 2006, section 4.8.2.1 on Paleontological Resources, states that

> *The Service will encourage and help the academic community to conduct paleontological field research in accordance with the terms of a scientific research and collecting permit.*

Any collection of paleontological resources from an NPS area must be made under an approved research and collecting permit. The NPS maintains an online Research Permit and Reporting System (RPRS) database for researchers to submit applications for research in NPS areas. Applications are reviewed at the park level and either approved or rejected. Current and past paleontological research and collecting permits and the associated Investigator's Annual Reports (IARs) are available on the RPRS website (https://irma.nps.gov/rprs/). Additional information on NPS law and policy can be found in Appendix D.

Recommended Research

Numerous potential future research topics related to COLM paleontology have been identified during the 2023 inventory. These topics are listed below, separated into categories according to their likely scientific implications. Within each category, the research recommendations are listed in rough stratigraphic order from youngest to oldest. The research topics herein deemed to be of highest scientific priority are denoted using bold font and with a footnote at the end of the appropriate sentences.

Taxonomic Diversity:

- **Thorough survey of packrat midden sites and examination of midden contents with focus placed on possible early Holocene and Pleistocene examples**[1]
- Survey of Quaternary valley-fill sediments for Pleistocene fossil material
- **Determination of invertebrate ichnofossil diversity in the Mesozoic units of COLM through assessment of morphotypes present**[1]
- In-depth examination of the ichnofaunal assemblage present in the Naturita Formation at COLM
- Detailed assessment of the paleobotanical assemblage (e.g., petrified wood, leaves, etc.) present in the Naturita Formation at COLM

[1] This research topic was deemed to be of highest scientific priority.

Interpretation

At the time of writing, paleontology and fossils play a limited role in the interpretation and education programs at COLM. There is currently no interpretive media (websites, brochures, site bulletins, wayside exhibits, etc.) at COLM addressing paleontology. The fossiliferous nature of the Morrison Formation, in particular, is mentioned and ancient climates discussed as part of geology hikes and talks at COLM (K. Thomas, COLM, pers. comm., August 2023). While fossils and paleontology-related materials were exhibited at the COLM visitor center prior to 2012 exhibit renovations, there are no current exhibits of such resources. Similarly, COLM does not currently maintain an interpretive collection of fossils. Interest in developing interpretive media, exhibit(s), and/or an interpretive collection of fossils has been expressed by COLM staff (K. Thomas, pers. comm., August 2023). COLM has celebrated National Fossil Day on a handful of occasions, including the inaugural one in 2010 (Figure 64). For National Fossil Day in 2023, a small educational table was set up at the COLM visitor center with fossils and visual aids.



Figure 64. Turtle (*Chelonipus* isp.) track slab and other paleontological materials (e.g., a cast of a *Brachiosaurus* humerus from Potter Creek, Colorado in upper left) displayed at the COLM Visitor Center for the inaugural National Fossil Day in 2010. This trace fossil and display have since been transferred to the Museums of Western Colorado's Dinosaur Journey Museum in Fruita, Colorado (NPS).

Current Long-Range Interpretive Plan

A long-range interpretive plan was produced for COLM in 2002. Paleontological resources are mentioned within the document as "unknown" and in need of future study (K. Thomas, pers. comm., August 2023). The COLM foundation document (National Park Service 2015) addresses the presence of paleontological resources at COLM but does not discuss the interpretation thereof. Development

and use of at least one formal paleontological interpretive theme should occur in conjunction with the interpretive themes found in the COLM foundation document (National Park Service 2015).

Recommended Interpretive Topics

I. General Paleontological Information

All of the following interpretation topics include a section instructing visitors how to be paleontologically aware while in the monument. The ranger will provide the visitor with advice on why fossils are important, how paleontologists look for fossils, what to do if fossils are found, and reminders to be aware that fossils exist and should be respected within monument boundaries.

- Fossils are non-renewable resources that possess scientific and educational information and provide insight into what Earth was like thousands and even hundreds of millions of years ago.
- When paleontologists survey for paleontological resources, the most important tool for planning is a geologic map. Paleontological resources are more common in certain geologic units, so knowing where those units are exposed is important for a successful search. Other tools that a paleontologist takes into the field include a field notebook for recording data and observations, small picks and brushes, consolidants to stabilize fossils, GPS unit, camera, topographic maps, and appropriate First Aid and safety equipment. It might be helpful to provide examples of these items for visitors when giving an interpretive talk.
- If fossils are found in the monument by a visitor, the visitor should photograph it and notify a ranger of where the resource was found, but most importantly, they should leave the fossil where they found it. It is extremely important for scientific and resource management purposes for contextual information to be preserved. Visitors should be informed that monument fossils are protected by law.

II. Fossils of COLM

- Programs could be developed to educate the public on what types of fossils are present in COLM and what they tell scientists about Earth's dynamic history. The goal of these programs would be to increase visitors' understanding of local geology and paleontology. Therefore, information regarding fossils from the vicinity of COLM can be included. Programs should not include locations of sensitive fossil resources.

III. Further Interpretation Topics

Staff at COLM should promote their paleontological resources and provide additional opportunities or programs for visitors to learn about fossils on National Fossil Day, celebrated annually on Wednesday of the second full week in October (National Earth Science Week). For more information on this event visit: https://www.nps.gov/subjects/fossilday/index.htm. The NPS coordinates the National Fossil Day partnership and hosts fossil-focused events across the country. Conducting one or more paleontology-focused activities on this day would be a perfect opportunity to not only increase public awareness about paleontological resources in COLM, but also to connect with other parks and museums that are also participating in this national event. The NPS Geologic Resources Division can assist with planning for National Fossil Day activities and provide Junior Paleontologist

Program supplies including activity booklets, badges, posters and other fossil-related educational resources (https://www.nps.gov/subjects/fossils/junior-paleontologist.htm).

Other Recommendations for Interpretation and Education

Given the current lack of interpretive and educational materials/programs about paleontology at COLM, there exists a substantial opportunity to develop new content. This is in line with the desires of current Interpretation and Education staff at COLM, who would like to see fossils and paleontology play a greater role in their programs (K. Thomas, pers. comm., August 2023). However, in doing so, an emphasis must be placed upon maintaining a balance between sharing paleontological information with the public and protecting the resources of COLM.

Opportunities to develop paleontological interpretive and educational materials include:

- A paleontological field guide could be developed which highlights fossils that are commonly encountered at COLM. This could be useful for not only interpretive programs and visitors, but for the various other staff at COLM who might encounter paleontological resources during their daily activities (e.g., Facilities staff).
- While substantial information on geology is currently available on the COLM NPS website, little to no material covers the paleontology of the monument. The creation of a suitable webpage dedicated to paleontology would significantly increase the ability of the public to engage with these resources, particularly if photos from the inventory are incorporated to illustrate common/unique fossils of COLM. The current lack of paleontological educational materials could also be remedied through the development of bulletins and/or brochures on the subject. Such materials could be utilized in both a physical and a digital format to increase accessibility of information regarding COLM paleontology.
- The establishment of fossil wayside exhibits along certain trails (e.g., Alcove Nature Trail) at COLM could allow for important interaction between visitors, staff, and fossils without threatening sensitive localities and their resources. The various fossil blocks that have been recovered primarily from threatened locations on the roadside would be ideal for such an endeavor, allowing visitors direct interaction with COLM fossils such as dinosaur tracks and petrified wood.
- Development of an interpretive collection of fossil and geologic specimens would assist Interpretation and Education staff in the production of informative programs for monument visitors. Potential specimens should be assessed for scientific importance and usefulness in an interpretive context. An interpretive collection dedicated to paleontology could also utilize digital versions of specimens; for instance, photogrammetry and 3D printing could be used to share fossil specimens (e.g., blocks featuring tracks produced by dinosaurs/turtles) in a more easily accessible format without risking damage to the actual specimens and without necessitating travel over difficult terrain. Such digital fossil models could even be uploaded to the COLM NPS website, allowing remote engagement.
- Collaboration on paleontological programs with nearby institutions also provides useful opportunities for interpretation and education on fossils. This may include fossil-related

activities and events, such as National Fossil Day, hosted by Dinosaur Journey, the Bureau of Land Management, and Colorado Mesa University.

Paleontological Resource Management and Protection

Fossils have scientific, aesthetic, cultural, educational, and tourism value, and impacts to any of these values impairs their usefulness. Effective paleontological resource management protects fossil resources by implementing strategies that mitigate, reduce, or eliminate loss of fossilized materials and their relevant data. Because fossils are representatives of adaptation, evolution, and diversity of life through deep time, they have intrinsic scientific values beyond just the physical objects themselves. Their geological and geospatial contexts provide additional critical data concerning paleoenvironmental, paleogeographic, paleoecologic, and a number of other conditions that together allow for a more complete interpretation of the physical and biological history of the earth. Therefore, paleontological resource management must act to protect not only the fossils themselves, but to collect and maintain other contextual data as well.

In general, losses of paleontological resources result from naturally occurring physical processes, by direct or indirect human activities, or by a combination of both. These processes or activities influence the stability and condition of in situ paleontological resources (Santucci and Koch 2003; Santucci et al. 2009). The greatest loss of associated contextual data occurs when fossils are removed from their original geological context without appropriate documentation. Thus, when a fossil weathers and erodes from its surrounding sediments and geologic context, it begins to lose significant ancillary data until, at some point, it becomes more a scientific curiosity than a useful piece of scientific data. A piece of loose fossil "float" can still be of scientific value, as demonstrated by multiple recent paleoecological studies conducted at the nearby Mygatt-Moore Quarry (Drumheller et al. 2020; McHugh et al. 2020, 2023). However, when a fossil has been completely removed from its original context, such as an unlabeled personal souvenir or a specimen with no provenance information in a collection, it is of very limited scientific utility. Similarly, inadvertent exhumation of fossils during roadway construction or a building excavation may result in the loss or impairment of the scientific and educational values associated with those fossils. It is not necessary to list here all of the natural and anthropogenic factors that can lead to the loss of paleontological resources; rather it is sufficient to acknowledge that anything that disturbs native sediment or original bedrock has potential to result in the loss of the paleontological resources that occur there, or the loss of associated paleontological resource data.

National Park Service Laws, Regulations, and Policies

Paleontological resources are non-renewable remains of past life preserved in a geologic context. At present, there are 429 official units of the National Park System, plus national rivers, national trails, and affiliated units that are not included in the official number. Of these, 286 are known to have some form of paleontological resources, and paleontological resources are mentioned in the enabling legislation of 18 units. Fossils possess scientific and educational values and are of great interest to the public; therefore, it is exceedingly important that appropriate management attention be placed on protecting, monitoring, collecting, and curating these non-renewable paleontological specimens from federal lands. In March 2009, the Paleontological Resources Preservation Act (PRPA) was signed into law as part of the Omnibus Public Land Management Act of 2009. The new paleontology-focused legislation includes provisions related to inventory, monitoring, public education, research

and collecting permits, curation, and criminal/civil prosecution associated with fossils from designated Department of Interior (DOI) lands. More information on laws, policies, and authorities governing NPS management of paleontological resources is detailed in Appendix D. Paleontological resource protection training is available for NPS staff through the NPS Paleontology Program. The Paleontology Program is also available to provide support in investigations involving paleontological resource theft or vandalism.

Between 2009 and 2022 an interagency coordination team including representatives from the Bureau of Land Management (BLM), Bureau of Reclamation (BOR), National Park Service (NPS) and U.S. Fish & Wildlife Service (FWS) developed the DOI final regulations for PRPA. In 2022, the DOI Paleontological Resources Preservation Act final regulation was published in the Federal Register and was subsequently made available online: https://www.federalregister.gov/documents/2022/08/02/2022-16405/paleontological-resources-preservation. For more information regarding this act, visit https://www.nps.gov/subjects/fossils/fossil-protection.htm.

2006 National Park Service Management Policies (section 4.8.2.1) state

> *... Paleontological resources, including both organic and mineralized remains in body or trace form, will be protected, preserved, and managed for public education, interpretation, and scientific research. The Service will study and manage paleontological resources in their paleoecological context (that is, in terms of the geologic data associated with a particular fossil that provides information about the ancient environment).*
>
> *Superintendents will establish programs to inventory paleontological resources and systematically monitor for newly exposed fossils, especially in areas of rapid erosion. Scientifically significant resources will be protected by collection or by on-site protection and stabilization. The Service will encourage and help the academic community to conduct paleontological field research in accordance with the terms of a scientific research and collecting permit. Fossil localities and associated geologic data will be adequately documented when specimens are collected. Paleontological resources found in an archeological context are also subject to the policies for archeological resources. Paleontological specimens that are to be retained permanently are subject to the policies for museum objects.*
>
> *The Service will take appropriate action to prevent damage to and unauthorized collection of fossils. To protect paleontological resources from harm, theft, or destruction, the Service will ensure, where necessary, that information about the nature and specific location of these resources remains confidential, in accordance with the National Parks Omnibus Management Act of 1998.*
>
> *All NPS construction projects in areas with potential paleontological resources must be preceded by a preconstruction surface assessment prior to disturbance. For any occurrences noted, or when the site may yield paleontological resources, the site will be avoided or the*

resources will, if necessary, be collected and properly cared for before construction begins. Areas with potential paleontological resources must also be monitored during construction projects.

Paleontological Resource Management at COLM

The paleontological resources at COLM are vulnerable to unauthorized collection due to various factors, such as the close proximity of the monument to the Grand Junction metropolitan area, the presence of significant fossils along and near roads and trails, and the legality of collecting fossils in some nearby or adjacent federal lands. A variety of different terms are used to describe this practice, such as looting, theft, and poaching. Regardless of the term used, the unauthorized collection of fossils from federal lands is a historic problem in the Grand Valley of Colorado. Notable instances of fossil theft have been recorded at various sites just beyond the boundary of COLM, including Riggs Hill in Grand Junction, Dinosaur Hill in Fruita (Chenoweth 1987), and the BLM lands of McInnis Canyons National Conservation Area just to the west (U.S. Attorney's Office, District of Colorado 2018; J. McHugh, Museums of Western Colorado, pers. comm., May 2023; J. Kirkland, Utah Geological Survey, pers. comm., July 2023). While little evidence of unauthorized fossil collection is known from COLM, the extreme proximity of these other documented cases of fossil poaching to COLM suggests that the monument is at high risk for these activities and that they should be monitored for and protected against.

The direct interface between Facilities staff at COLM and the monument's paleontological resources, largely a result of extensive Morrison Formation exposures along Rim Rock Drive, leads to frequent encounters during road maintenance that demand management action. Fortunately, a number of documented instances at COLM over the last couple of decades have demonstrated how Facilities staff members can play an important role in the proper management and protection of fossils, be it through discovery, relocation, or recovery (Shaffer 2023). The possibility of finding fossils and the potential actions that can be taken should be considered when developing management strategies and plans for road maintenance.

An inventory of slope hazards at COLM in 2020 identified a number of areas where rockfall is common within the monument (Olsen 2020). Many of the fossil localities identified during the 2023 paleontological resource inventory were associated with rockfall, indicating that the locations where slope hazards were identified at COLM also present a likelihood for future paleontological resource exposure. Rockfall also presents management concerns for existing paleontological resources at these slope hazard locations.

A number of the paleontological localities identified during the 2023 fieldwork occur along or near the various trails or social trails of COLM (Landolt 2023). The proximity of such paleontological localities to these paths of human traffic places them in direct risk of vandalism/unauthorized collection and are therefore of management concern.

Management strategies to address any of these conditions and factors could also incorporate the assistance of qualified local specialists to collect and document resources rather than relying solely

on staff to accomplish such a large task at COLM. Active recruitment of paleontologists could therefore facilitate resource management.

Baseline Paleontology Resource Data Inventories

A baseline inventory of paleontological resources is critical for implementing effective management strategies, as it provides information for decision-making. This inventory report has compiled information on previous paleontological research done in and near COLM, taxonomic groups that have been reported within COLM boundaries, and localities that were previously reported. This report can serve as a baseline source of information for future research, inventory reports, monitoring, and paleontological decisions. The Paleontological Resource Inventory and Monitoring reports for the Northern Colorado Plateau I&M Network completed by Koch and Santucci (2002) and Tweet et al. (2012a) and the references cited within were important baseline paleontological resource data sources for this COLM-specific report.

Paleontological Resource Monitoring

Paleontological resource monitoring is a significant part of paleontological resource management, and one which usually requires little to implement beyond time and equipment already on hand, such as cameras and GPS units. Monitoring enables the evaluation of the condition and stability of in situ paleontological resources (Santucci and Koch 2003; Santucci et al. 2009). A monitoring program revolves around periodic site visits to assess conditions compared to a baseline for that site, with the periodicity depending on factors such as site productivity, accessibility, and significance of management issues. For example, a highly productive site that is strongly affected by erosion or unauthorized collection, and which can be easily visited by park staff, would be scheduled for more frequent visits than a less productive or less threatened site.

A monitoring program is generally implemented after an inventory has been prepared for a park and sites of concern have been identified, with additional sites added as necessary. Because each park is different, with different geology and paleontology among other factors, ideally each park which has in situ fossils or significant accumulations of reworked fossils would have its own monitoring protocol to define its monitoring program. Data accumulated via monitoring is used to inform further management decisions, such as the following questions: Is the site suitable for interpretation and education? Does the site require stabilization from the elements? Is collection warranted? Is there a need for some form of law enforcement presence?

Collection is recommended to be reserved for fossils possessing exceptional value (e.g., rare or high scientific significance) or at immediate risk of major degradation or destruction by human activity and natural processes. Therefore, paleontological resource monitoring is a more feasible potential management tool, informing when fossil collection is merited.

The first step in establishment of a monitoring program is identification of localities to be monitored, as discussed previously. Locality condition forms are then used to evaluate factors that could cause loss of paleontological resources, with various conditions at each locality rated as good, fair, or poor. Risks and conditions are categorized as Disturbance, Fragility, Abundance, and Site Access. “Disturbance” evaluates conditions that promote accelerated erosion or mass wasting resulting from

human activities. “Fragility” evaluates natural conditions that may influence the degree to which fossil transportation is occurring. Sites with elevated fragility exhibit inherently soft rapidly eroding sediment or mass wasting on steep hillsides. A bedrock outcrop that is strongly lithified has low fragility. “Abundance” judges both the natural condition and number of specimens preserved at the locality as well as the probability of being recognized as a fossil-rich area by non-paleontologists, which could lead to unpermitted collecting. “Site Access” assesses the risk of a locality being visited by large numbers of visitors or the potential for easy removal of large quantities of fossils or fossil-bearing sediments. A locality with high access would be in close proximity to public use areas or other access (along trails, at roadcuts, at beach or river access points, and so on).

Each of the factors noted above may be mitigated by management actions. Localities exhibiting a significant degree of disturbance may require either active intervention to slow accelerated erosion, periodic collection and documentation of fossil materials, or both. Localities developed on sediments of high fragility naturally erode at a relatively rapid rate and would require frequent visits to document and/or collect exposed fossils in order to prevent or reduce losses. Localities with abundant or rare fossils, or high rates of erosion, may be considered for periodic monitoring in order to assess the stability and condition of the locality and resources, in regard to both natural processes and human-related activities. Localities that are easily accessible by road or trail would benefit from the same management strategies as those with abundant fossils and by occasional visits from park staff, documentation of in situ specimens, and/or frequent law enforcement patrols. Further information on paleontological resource monitoring can be found in Santucci and Koch (2003) and Santucci et al. (2009). A comprehensive suite of management actions is described in NPS Management Policies 2006 and summarized in Appendix D.

Foundation Documents and Resource Stewardship Strategies

Foundation documents and Resource Stewardship Strategies are two types of park planning documents that may contain and reference paleontological resource information. A foundation document is intended to provide basic guidance about a park for planning and management. It briefly describes a given park and its purpose, significance, fundamental resources and values, other importance resources and values, and interpretive themes. Mandates and commitments are also identified, and the state of planning is assessed. Foundation documents may include paleontological information, and are also useful as a preliminary assessment of what a park’s staff know about their paleontological resources, the importance they place on these resources, and the present state of these non-renewable resources. A foundation document for COLM has been published (National Park Service 2015).

A Resource Stewardship Strategy (RSS) is a strategic plan intended to help park managers achieve and maintain desired resource conditions over time. It offers specific information on the current state of resources and planning, management priorities, and management goals over various time frames. An RSS for COLM has been published (National Park Service 2016) and includes paleontological resources.

Geologic Maps

A geologic map is the fundamental tool for depicting the geology of an area. Geologic maps are two-dimensional representations of the three-dimensional geometry of rock and sediment at or beneath the land surface (Evans 2016). Colors and symbols on geologic maps correspond to geologic map units. The unit symbols consist of an uppercase letter indicating the age and lowercase letters indicating the formation's name. The American Geosciences Institute website (https://www.americangeosciences.org/environment/publications/mapping) provides more information about geologic maps and their uses. The NPS Geologic Resources Inventory (GRI) has been digitizing existing maps of NPS units and making them available to parks for resource management.

Geologic maps are one of the foundational elements of a paleontological resource management program. Knowing which sedimentary rocks and deposits underlie a park and where they are exposed are essential for understanding the distribution of known or potential paleontological resources. The ideal scale for resource management in the 48 contiguous states is 1:24,000 (maps for areas in Alaska tend to be coarser). Whenever possible, page-sized geologic maps derived from GRI files are included in paleontological resource inventory reports for reference, but it is recommended that GRI source files be downloaded from IRMA for use. The source files can be explored in much greater detail and incorporated into the park GIS database. Links to the maps digitized by the GRI for COLM can be found in IRMA at https://irma.nps.gov/DataStore/Reference/Profile/1047632 and https://irma.nps.gov/DataStore/Reference/Profile/1047631. In addition to a digital GIS geologic map, the GRI program also produces a park-specific geologic resource evaluation report discussing the geologic setting, distinctive geologic features and processes within the park, highlighting geologic issues facing resource managers, and describing the geologic history leading to the present-day landscape of the park. The report for COLM is KellerLynn (2006).

Paleontological Resource Potential Maps

A paleontological resource potential map is included in this report (Figure 65). The map shows the distribution of geologic units within a park that are known to have yielded fossils within the park (green), have not yielded fossils within the park but are fossiliferous elsewhere (yellow), or have not yielded fossils (red). This map gives a quick indication of areas where fossils may be discovered, which in turn can provide suggestions for areas to survey or monitor, or areas where the discovery of fossils may be of concern during work that disturbs the ground (road work, building construction, etc.).

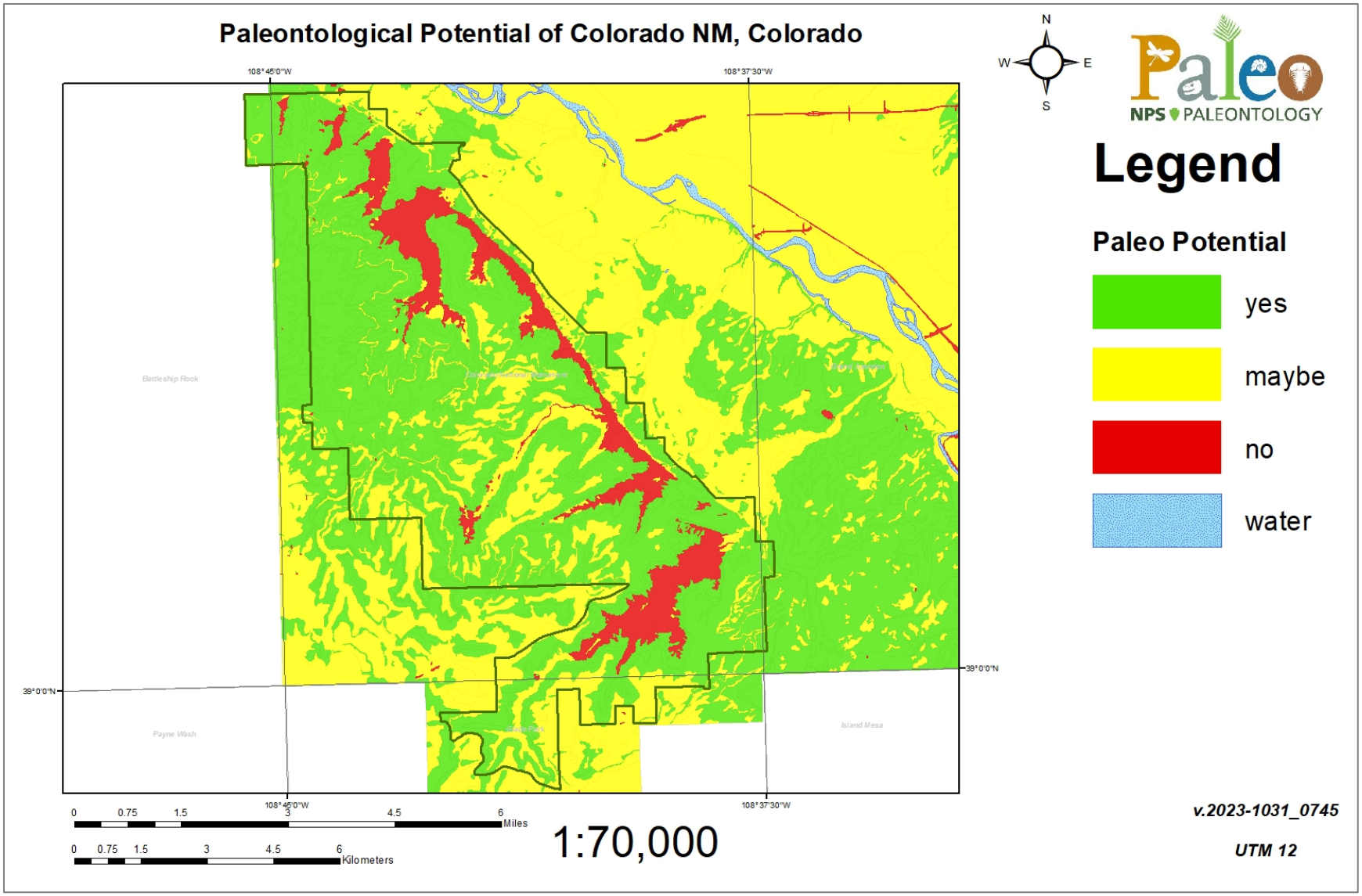


Figure 65. Map indicating paleontological potential of geologic map units in COLM (NPS / TIM CONNORS).

Paleontological Resource Management Recommendations

The paleontological resource inventory at COLM has documented rich and previously unrecognized paleontological resources. This report captures the scope, significance, and distribution of fossils at COLM as well as provides recommendations to support the management and protection of the monument's non-renewable paleontological resources.

- COLM staff should be encouraged to observe exposed rocks and sedimentary deposits for fossil material while conducting their usual duties. To promote this, staff should receive guidance regarding how to recognize common local fossils. For instance, when opportunities arise to observe paleontological resources in the field and take part in paleontological field studies with trained paleontologists, staff should take advantage of them, if funding and time permit. Paleontological resource guides (particularly COLM-specific) and virtual/in-person trainings can also assist in this.
- COLM staff should photo-document and monitor any occurrences of paleontological resources that may be observed in situ. Fossils and their associated geologic context (surrounding rock) should be documented, but left in place unless they are subject to imminent degradation. Paleontological resources at high risk of damage should be considered for collection. A Geologic Resource Monitoring Manual published by the Geological Society of America and NPS Geologic Resources Division (GRD) includes a chapter on paleontological resource monitoring (Santucci et al. 2009). Santucci and Koch (2003) also present information on paleontological resource monitoring.
- Fossil theft is one of the greatest threats to the preservation of paleontological resources and any methods to minimize these activities should be utilized by staff. Any occurrence of paleontological resource theft or vandalism should be investigated by a law enforcement ranger. When possible, incidents should be fully documented and the information submitted for inclusion in the annual law enforcement statistics.
- Fossils found in a cultural context should be documented like other fossils, but will also require the input of an archeologist or a cultural resource specialist. Any fossil which has a cultural context may be culturally sensitive as well (e.g., subject to NAGPRA) and should be regarded as such until otherwise established. The GRD can coordinate additional documentation/research of such material.
- The monument may fund and recruit paleontology interns as a cost-effective means of enabling some level of paleontological resource support. The Scientists in Parks Program is an established program for recruitment of geology and paleontology interns. Local partnerships (e.g., Dinosaur Journey, Colorado Mesa University, Bureau of Land Management) may also be established to support paleontological resource management at the monument.
- Contact the NPS Paleontology Program for technical assistance with paleontological resource management issues.

If fossil specimens are found by COLM staff, it is recommended they follow the steps outlined below to ensure proper paleontological resource management.

- Photo-document the specimen without moving it from its location if it is loose. Include a common item, such as a coin, pen, or pencil, for scale if a ruler or scale bar is not available.
- If a GPS unit is available, record the location of the specimen. If GPS is not available, record the general location within COLM and height within the outcrop, if applicable, as well as any notable landmarks. If possible, revisit the site when a GPS unit is available. Most smartphones also have the ability to record coordinates; if no GPS unit is available, attempt to record the coordinates with a phone.
- Write down associated data, such as rock type, general description of the fossil, type of fossil if identifiable, general location in COLM, sketch of the fossil, position within the outcrop or if it is loose on the ground, any associated fossils, and any other additional information.
- Do not remove the fossil unless it is loose in an area of heavy traffic, such as a public trail, and is at risk of being taken or destroyed. If the specimen is fragile, determine whether consolidant is needed to prevent damage and if removing the fossil will cause unnecessary damage. If the fossil is removed, be sure to wrap in soft material, such as tissue paper, and place in a labeled plastic bag with associated notes.

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Appendix A: Paleontological Taxa

Paleozoic Invertebrate Taxa

The following list documents the Paleozoic marine invertebrate taxa known from body fossils at COLM. These taxa are all known from reworked chert found in the Cretaceous Burro Canyon Formation.

Bryozoa

- Bryozoa indet.
- Fenestellidae indet.

Brachiopoda

- cf. Rhynchonellida indet.

Echinodermata

Crinoidea

- Crinoidea indet.

Mesozoic Taxa

The following tables (Tables 2–6, for plant fossils, invertebrate trace fossils, invertebrate body fossils, vertebrate trace fossils, and vertebrate body fossils, respectively) document the Mesozoic fossil taxa found at COLM in stratigraphic context, as verified by personal observation in comparison with published literature. Many of the taxonomic identifications listed below are provisional, pending in-depth assessment of the specimen(s) in question. The rows are organized systematically, placing taxa of the same taxonomic group together. The columns are organized by formation, which are presented in ascending order (oldest to youngest) left to right. If a taxon is present in a given formation at a locality that can be placed within COLM, that cell is marked "Y"; if there is some question about the formation, the cell is marked "?". A null record is marked "–".

"[Taxon] indet." refers to fossils that are taxonomically indeterminate at a high level; e.g., a fragment of a broadleaf may be classified as "Angiospermae indet." The abbreviations "sp." and "isp." mean "species" and "ichnospecies", respectively, and indicate a fossil has not been classified to a species or ichnospecies. The abbreviation "cf." comes from the Latin *confer* and, when placed before a taxonomic name, means the fossil is comparable to that taxon but the identification is not certain.

Stratigraphic abbreviations are as follows, in descending order (youngest to oldest). They follow the maps used for this report. In the interest of space, only units that have documented records of fossils at COLM are included.

- Kd = Naturita Formation
- Kb = Burro Canyon Formation
- Jmb = Morrison Formation, Brushy Basin Member
- Jms = Morrison Formation, Salt Wash Member

- Jmt = Morrison Formation, Tidwell Member
- Je = Entrada Sandstone
- Jk = Kayenta Formation
- J-TRwg = Wingate Sandstone
- TRc = Chinle Formation

Table 2. Mesozoic paleobotanical taxa from COLM in stratigraphic context.

Group	Taxon	TRc	Jk	Jmt	Jmb	Kb	Kd
Angiospermae	cf. Angiospermae indet.	–	–	–	–	–	Y
	cf. Magnoliaceae indet.	–	–	–	–	–	Y
Polypodiopsida	*Gleichenia* cf. *comptoniaefolia*	–	–	–	–	Y	–
Charophyta	Charophyta indet.	–	–	–	Y	–	–
Undetermined	Petrified wood	–	?	–	–	Y	Y
	Carbonized wood	–	–	Y	–	–	–
	Plant fragments	–	–	–	Y	Y	Y
	Plant impressions	–	–	Y	–	Y	–
	Root traces	Y	–	–	–	–	–

Table 3. Mesozoic invertebrate ichnotaxa from COLM in stratigraphic context.

Taxon	TRc	J-TRwg	Je	Jmt	Jms	Jmb	Kb	Kd
cf. *Beaconites* isp.	Y	–	–	–	Y	–	–	–
cf. *Celliforma* isp.	–	–	–	–	Y	–	–	–
Cochlichnus isp.	Y	–	–	–	Y	–	–	–
cf. *Cylindricum* isp.	–	–	–	–	Y	–	–	–
cf. *Fuersichnus* isp.	–	Y	–	–	Y	–	–	–
Lockeia isp.	–	–	–	Y	–	–	–	–
cf. *Planolites* isp.	Y	Y	–	–	Y	–	Y	–
cf. *Scoyenia* isp.	Y	–	–	–	–	–	–	–
Steinichnus isp.	–	–	–	–	Y	–	–	–
cf. *Taenidium* isp.	Y	–	–	–	Y	–	–	–
cf. *Thalassinoides* isp.	Y	Y	–	–	–	–	–	–
Undetermined burrows	Y	Y	Y	Y	Y	Y	Y	Y

Table 4. Mesozoic invertebrate taxa known from body fossils at COLM in stratigraphic context.

Group	Taxon	Jmt	Jms	Jmb
Mollusca: Bivalvia	Unionidae indet.	Y	Y	–
Mollusca: Gastropoda	Gastropoda indet.	–	Y	–
	cf. *Amplovalvata scabrida*	–	–	Y

Table 5. Mesozoic vertebrate ichnotaxa from COLM in stratigraphic context.

Group	Taxon	TRc	J-TRwg	Jk	Jmt	Jms	Jmb	Kd
Synapsida	cf. *Brasilichnium* isp.	–	Y	–	–	–	–	–
Sauria: Lepidosauria	cf. *Rhynchosauroides* isp.	–	–	–	Y	–	–	–
Sauria: Testudines	*Chelonipus* isp.	–	–	–	–	Y	–	–
Sauria: Pseudosuchia	Chirotheriidae indet.	–	Y	–	–	–	–	–
	cf. *Brachychirotherium* isp.	Y	Y	–	–	–	–	–
	cf. *Hatcherichnus* isp.	–	–	–	–	Y	–	–
Sauria: Pterosauria	*Pteraichnus* isp.	–	–	–	–	Y	–	–
Sauria: Dinosauria	Dinosauria indet.	–	–	?	–	Y	–	Y
	cf. *Atreipus* isp.	Y	–	–	–	–	–	–
Sauria: Dinosauria: Sauropoda	*Eosauropus* cf. *cimarronensis*	–	Y	–	–	–	–	–
	Sauropoda indet.	–	–	–	Y	Y	–	–
	cf. *Parabrontopodus* isp.	–	–	–	–	Y	–	–
Sauria: Dinosauria: Theropoda	cf. Theropoda indet.	–	–	–	–	Y	–	–
	cf. *Grallator* isp.	Y	–	–	–	Y	–	–
	Grallator isp.	–	Y	–	–	–	–	–
	cf. *Anchisauripus* isp.	–	Y	–	–	–	–	–
	Therangospodus pandemicus	–	–	–	–	Y	–	–
	cf. *Megalosauripus* isp.	–	–	–	Y	–	–	–
	Magnoavipes isp.	–	–	–	–	–	–	Y
Sauria: Dinosauria: Ornithopoda	cf. *Anomoepus* isp.	–	–	–	–	Y	–	–
	Dinehichnus socialis	–	–	–	–	Y	–	–

Table 5 (continued). Mesozoic vertebrate ichnotaxa from COLM in stratigraphic context.

Group	Taxon	TRc	J-TRwg	Jk	Jmt	Jms	Jmb	Kd
Sauria: Dinosauria: Ornithopoda (continued)	cf. Iguanodontipodidae indet.	–	–	–	–	Y	–	–
	Hadrosauropodus leonardii	–	–	–	–	–	–	Y
Sauria: Dinosauria: Thyreophora	cf. *Stegopodus* isp.	–	–	–	–	–	Y	–
	Deltapodus cf. *brodricki*	–	–	–	Y	–	–	–
	cf. *Metatetrapous* isp.	–	–	–	–	Y	–	–
	Tetrapodosaurus isp.	–	–	–	–	–	–	Y

Table 6. Mesozoic vertebrate taxa known from body fossils at COLM in stratigraphic context.

Group	Taxon	TRc	Jk	Jmt	Jms	Jmb	Kb
Vertebrata	Vertebrata indet.	–	Y	–	Y	–	–
Osteichthyes	Osteichthyes indet.	–	–	–	Y	–	–
	Ceratodus cf. *frazieri*	–	–	Y	–	–	–
Amphibia: Temnospondyli	Metoposauridae indet.	?	–	–	–	–	–
Sauria: Testudines	Testudines indet.	–	–	Y	–	Y	–
Sauria: Dinosauria	Dinosauria indet.	–	–	Y	Y	Y	Y
	cf. *Dryosaurus* sp.	–	–	–	–	Y	–
	Sauropoda indet.	–	–	–	Y	Y	Y
	Macronaria indet.	–	–	–	–	Y	–

Quaternary Taxa

The following lists document the Quaternary fossil taxa found at COLM, as reported in museum collections. Vernacular names are included in parentheses following the scientific name of certain taxa.

A number of Quaternary plant taxa have been identified, spanning gymnosperms (Acrogymnospermae) and two groups of angiosperms: monocots and eudicots.

Acrogymnospermae

Coniferae

Cupressales

- *Juniperus osteosperma* (Utah juniper)
- *Juniperus scopulorum* (Rocky Mountain juniper)

Pinales

- Pinaceae indet.
- *Pinus edulis* (Colorado pinyon)
- **Pinus* cf. *engelmannii* (Apache pine)
- *Pinus flexilis* (Limber pine)
- *Pinus ponderosa* (Ponderosa pine)
- **Pinus* cf. *strobiformis* (Southwestern White Pine)
- *Pseudotsuga menziesii* (Douglas fir)

Gnetales

- *Ephedra* sp.

Angiospermae

Monocots

- Poaceae indet.
- *Eriocoma hymenoides* (Indian ricegrass)
- *Yucca* sp.

Eudicots

Caryophyllales

- *Atriplex canescens* (Fourwing Saltbush)
- *Atriplex confertifolia* (Shadscale)
- *Krascheninnikovia lanata* (Winterfat)
- *Opuntia polyacantha* (Plains prickly pear)

Asterids

Asterales

- Asteraceae indet.
- *Ambrosia* sp. (Ragweed)
- *Cirsium* sp. (Plume Thistle)
- *Gutierrezia microcephala* (Threadleaf Snakeweed)
- *Tetradymia argyraea* (Spineless Horsebrush)

Boraginales

- Boraginaceae indet.
- *Phacelia* sp. (Scorpionweed)

Dipsacales

- *Symphoricarpos* sp. (Snowberry)

Ericales

- *Linanthus pungens* (Granite Gilia)

Lamiales

- cf. *Castilleja* sp. (Indian Paintbrush)
- cf. *Penstemon* sp. (Beardtongue)

Solanales

- *Physalis* sp. (Groundcherry)

Rosids

Brassicales

- Brassicaceae indet.
- *Lepidium* cf. *fremontii* (Desert Pepperweed)

Fabales

- *Astragalus* sp. (Vetch)

Fagales

- *Quercus gambelii* (Gambel Oak)
- *Quercus turbinella* (Shrub Live Oak)

Malpighiales

- *Populus* sp. (Cottonwood/Aspen)

Malvales

- Malvaceae indet.

Rosales

- Rosaceae indet.

- *Amelanchier alnifolia* (Western Serviceberry)
- *Amelanchier utahensis* (Utah Serviceberry)
- *Celtis reticulata* (Netleaf Hackberry)
- *Cercocarpus montanus* (Mountain Mahogany)
- cf. *Prunus* sp.
- *Purshia tridentata* (Antelope Bitterbrush)
- *Rosa* sp. (Rose)

Sapindales

- *Rhus trilobata* (Skunkbush Sumac)

***Note** that COLM is far outside of the modern ranges of *Pinus engelmannii* and *P. strobiformis*; it is possible that the remains identified as belonging to these taxa instead belong to other closely related *Pinus* species (e.g., *P. ponderosa* and *P. flexilis*, respectively).

A handful of animal taxa have also been identified from Quaternary deposits (midden, fissure-fill, and valley-fill) at COLM, predominantly mammals.

Arthropoda

Insecta

- Insecta indet.

Mammalia

- Mammalia indet.

Afrotheria

- cf. *Mammuthus* sp. (Mammoth)

Artiodactyla

- *Bison bison* (American bison)
- *Ovis canadensis* (Bighorn sheep)

Carnivora

- *Canis lupus* (Wolf)
- *Spilogale gracilis* (Spotted skunk)

Lagomorpha

- *Lepus* sp. (Jackrabbit)
- *Sylvilagus* sp. (Cottontail rabbit)

Rodentia

- *Neotoma* sp. (Packrat)
- *Otospermophilus variegatus* (Rock squirrel)

Sauria

Squamata

- Squamata indet.

Aves

- Accipitridae indet.

Appendix B: Museum Collections Data

The following tables, Tables 7 and 8, include information on the COLM fossil specimens housed in the collection at COLM (Table 7) and other repositories (Table 8). Geologic units have been abbreviated for space (Gp. = Group; Fm. = Formation; Mbr. = Member; Ss. = Sandstone). See the text and Appendix E for more locality information, and Appendix A for definitions of “cf.”, “indet.”, “isp.”, and “sp.”.

Table 7. Paleontological specimens currently housed within COLM collections. Some specimens (e.g., those lacking locality information) may have not come from within COLM boundaries.

Catalog #	Locality #	Geologic Unit	Taxa	Element(s)
COLM 398	UNKNOWN	UNKNOWN	Plantae indet.	petrified wood
COLM 399	UNKNOWN	UNKNOWN	Plantae indet.	petrified wood
COLM 448	UNKNOWN	UNKNOWN	Plantae indet.	petrified wood
COLM 477	UNKNOWN	UNKNOWN	Plantae indet.	leaf
COLM 514	UNKNOWN	Mesa Verde Gp.	Plantae indet.	palm-like leaves
COLM 515	UNKNOWN	Mesa Verde Gp.	Plantae indet.	palm-like leaves
COLM 2219	COLM-PAL-95-K	Morrison Fm., Salt Wash Mbr.	Sauropoda indet.	partial caudal vertebra
COLM 2220	COLM-PAL-95-L	Morrison Fm., Brushy Basin Mbr.	cf. *Dryosaurus* sp.	ischium fragment
COLM 2221	COLM-PAL-95-N	Morrison Fm., Salt Wash Mbr.	Unionidae indet.	clam fragments
COLM 2222	COLM-PAL-77-C	Morrison Fm., Brushy Basin Mbr.	Gastropoda indet., Charophyta indet.	agatized snail shells & algae
COLM 4029	COLM-PAL-04-S	Wingate Ss.	*Grallator* isp., cf. *Anchisauripus* isp.	tridactyl tracks
COLM 5072	COLM-PAL-13-B	Morrison Fm., Salt Wash Mbr.	*Pteraichnus* isp., cf. *Grallator* isp., Invertebrata indet.	pterosaur track, tridactyl track, invertebrate burrows
COLM 5092	COLM-PAL-02-I	Morrison Fm., Salt Wash Mbr.	*Anomoepus* isp.	tridactyl tracks
COLM 5093	COLM-PAL-04-T	Entrada Ss.	Invertebrata indet.	invertebrate burrows
n/a	COLM-PAL-04-P	Kayenta Fm.	Vertebrata indet.	bone fragments (?rib)
n/a	COLM-PAL-04-B	Morrison Fm., Tidwell Mbr.	*Ceratodus* cf. *frazieri*	tooth
n/a	COLM-PAL-77-H	Morrison Fm., Salt Wash Mbr.	Sauropoda indet.	partial caudal vertebra
n/a	COLM-PAL-95-G	Burro Canyon Fm.	Sauropoda indet.	partial limb
n/a	COLM-PAL-02-D	Morrison Fm., Salt Wash Mbr.	Unionidae indet.	clam fragments
n/a	COLM-PAL-04-O	Morrison Fm., Salt Wash Mbr.	Sauropoda indet.	sauropod tracks
n/a	COLM-PAL-13-E	Wingate Ss.	cf. *Thalassinoides* isp.	burrows
n/a	COLM-PAL-13-O	Morrison Fm., Salt Wash Mbr.	Sauropoda indet.	sacrum fragments
n/a	COLM-PAL-23-F	Morrison Fm., Tidwell Mbr.	*Therangospodus pandemicus*	tridactyl track
n/a	COLM-PAL-23-D	Morrison Fm., Salt Wash Mbr.	cf. Crocodylomorpha indet., Osteichthyes indet., Unionidae indet., Gastropoda indet.	bone fragments (incl. vertebrae), otoliths, snail/clam shells

Table 7 (continued). Paleontological specimens currently housed within COLM collections. Some specimens (e.g., those lacking locality information) may have not come from within COLM boundaries.

Catalog #	Locality #	Geologic Unit	Taxa	Element(s)
n/a	COLM-PAL-23-G	Morrison Fm., Salt Wash Mbr.	Vertebrata indet.	bone fragment (?limb)
n/a	COLM-PAL-23-N	Morrison Fm., Salt Wash Mbr.	Unionidae indet.	clam shells
n/a	COLM-PAL-13-T	Burro Canyon Fm.	Plantae indet.	petrified wood (incl. fragments)
n/a	COLM-PAL-23-E	Morrison Fm., Tidwell Mbr.	*Deltapodus* cf. *brodricki*	stegosaur manus/pes tracks
n/a	COLM-PAL-23-T	Morrison Fm., Tidwell Mbr.	Plantae indet.	carbonized wood
n/a	COLM-PAL-23-AC	Morrison Fm., Tidwell Mbr.	cf. *Megalosauripus* isp.	tridactyl track
n/a	COLM-PAL-23-AJ	Morrison Fm., Brushy Basin Mbr.	Macronaria indet.	tooth fragments
n/a	COLM-PAL-23-BZ	Naturita Fm.	cf. Angiospermae indet.	leaf
n/a	COLM-PAL-23-CH	Burro Canyon Fm.	Bryozoa indet., Brachiopoda indet., Crinoidea indet.	fossiliferous clast fragments
n/a	COLM-PAL-23-CI	Morrison Fm., Brushy Basin Mbr.	Sauropoda indet.	ungual
n/a	COLM-PAL-23-CP	Naturita Fm.	Plantae indet.	petrified wood
n/a	COLM-PAL-23-CQ	Kayenta Fm.	Vertebrata indet.	bone fragments
n/a	COLM-PAL-04-B	Morrison Fm., Salt Wash Mbr.	cf. *Metatetrapous* isp.	?ankylosaur track
n/a	COLM-PAL-77-B	Morrison Fm., Salt Wash Mbr.	Dinosauria indet.	bone fragments
n/a	COLM-PAL-24-B	Naturita Fm.	cf. Hadrosauromorpha indet.	dinosaur skin impression

Table 8. COLM paleontological specimens currently housed at MWC (Dinosaur Journey).

Catalog #	Locality #	Geologic Unit	Taxa	Element(s)
COLM 5168	COLM-PAL-13-B	Morrison Fm., Salt Wash Mbr.	*Chelonipus* isp.	turtle tracks
COLM 5171	?	Morrison Fm., Salt Wash Mbr.	Bivalvia indet.	clam shells
COLM 5172	COLM-PAL-23-F	Morrison Fm., Tidwell Mbr.	cf. *Rhynchosauroides* isp., cf. *Trypanites* isp.	lepidosaur tracks & worm burrows
COLM 5173	?	Morrison Fm., Salt Wash Mbr.	cf. Sauropoda indet.	possible juvenile tracks

Quaternary Specimens

The paleontological specimens collected from the Quaternary sediments (including middens) of COLM are currently housed at the Museum of Northern Arizona. These 333 specimens are represented by catalog numbers COLM 1883 through COLM 2215, as well as eight uncatalogued specimens.

Appendix C: Repository Contact Information

Contact information for institutions known to have collections from COLM are included below. Addresses, phone numbers, links, and email addresses to departments are included as available. This information is subject to change, particularly hyperlinks.

MUSEUM OF NORTHERN ARIZONA
3101 N Fort Valley Rd
Flagstaff, AZ 86001
(928) 774-5213
https://musnaz.org/

MUSEUMS OF WESTERN COLORADO, DINOSAUR JOURNEY
550 Jurassic Ct
Fruita, CO 81521
(970) 242-0971
https://www.museumofwesternco.com/visit/dinosaur-journey/

Appendix D: Paleontological Resource Law and Policy

The following material is reproduced in large part from Henkel et al. (2015); see also Kottkamp et al. (2020).

In March 2009, the **Paleontological Resources Preservation Act (PRPA)** (16 USC 460aaa) was signed into law (Public Law 111–11). This act defines paleontological resources as

> *...any fossilized remains, traces, or imprints of organisms, preserved in or on the [E]arth's crust, that are of paleontological interest and that provide information about the history of life on [E]arth.*

The law stipulates that the Secretary of the Interior should manage and protect paleontological resources using scientific principles. The Secretary should also develop plans for

> *...inventory, monitoring, and deriving the scientific and educational use of paleontological resources.*

Paleontological resources are considered park resources and values that are subject to the "no impairment" standard in the National Park Service Organic Act (1916). In addition to the Organic Act, PRPA will serve as a primary authority for the management, protection, and interpretation of paleontological resources. The proper management and preservation of these non-renewable resources should be considered by park resource managers whether or not fossil resources are specifically identified in the park's enabling legislation.

The **Paleontological Resources Management section of NPS Reference Manual 77** provides guidance on the implementation and continuation of paleontological resource management programs. Administrative options include those listed below and a park management program will probably incorporate multiple options depending on specific circumstances:

- **No action**—no action would be taken to collect the fossils as they erode from the strata. The fossils would be left to erode naturally and over time crumble away, or possibly be vandalized by visitors, either intentionally or unintentionally. This is the least preferable plan of action of those listed here.
- **Surveys**—will be set up to document potential fossil localities. All sites will be documented with the use of GPS and will be entered into the park GIS database. Associated stratigraphic and depositional environment information will be collected for each locality. A preliminary fossil list will be developed. Any evidence of poaching activity will be recorded. Rates of erosion will be estimated for the site and a monitoring schedule will be developed based upon this information. A NPS Paleontological Locality Database Form will also be completed for each locality. A standard version of this form will be provided by the Paleontology Program of the Geologic Resources Division upon request and can be modified to account for local conditions and needs.

- **Monitoring**—fossil-rich areas would be examined periodically to determine if conditions have changed to such an extent that additional management actions are warranted. Photographic records should be kept so that changes can be more easily ascertained.
- **Cyclic prospecting**—areas of high erosion which also have a high potential for producing significant specimens would be examined periodically for new sites. The periodicity of such cyclic prospecting will depend on locality-specific characteristics such as rates of sediment erosion, abundance or rarity of fossils, and proximity to visitor use areas.
- **Stabilization and reburial**—significant specimens which cannot be immediately collected may be stabilized using appropriate consolidants and reburied. Reburial slows down but does not stop the destruction of a fossil by erosion. Therefore, this method would be used only as an interim and temporary stop-gap measure. In some situations, stabilization of a locality may require the consideration of vegetation. For example, roots can destroy in situ fossils, but can also protect against slope erosion, while plant growth can effectively obscure localities, which can be positive or negative depending on how park staff want to manage a locality.
- **Shelter construction**—it may be appropriate to exhibit certain fossil sites or specimens in situ, which would require the construction of protective shelters to protect them from the natural forces of weathering and erosion. The use of shelters draws attention to the fossils and increases the risk of vandalism or theft, but also provides opportunities for interpretation and education.
- **Excavation**—partial or complete removal of any or all fossils present on the surface and potentially the removal of specimens still beneath the surface which have not been exposed by erosion.
- **Closure**—the area containing fossils may be temporarily or permanently closed to the public to protect the fossil resources. Fossil-rich areas may be closed to the public unless accompanied by an interpretive ranger on a guided hike.
- **Patrols**—may be increased in areas of known fossil resources. Patrols can prevent and/or reduce theft and vandalism. The scientific community and the public expect the NPS to protect its paleontological resources from vandalism and theft. In some situations a volunteer site stewardship program may be appropriate (for example the “Paleo Protectors” at Chesapeake & Ohio Canal National Historical Park).
- **Alarm systems/electronic surveillance**—seismic monitoring systems can be installed to alert rangers of disturbances to sensitive paleontological sites. Once the alarm is engaged, a ranger can be dispatched to investigate. Motion-activated cameras may also be mounted to visually document human activity in areas of vulnerable paleontological sites.

National Park Service Management Policies (2006; Section 4.8.2.1) also require that paleontological resources, including both organic and mineralized remains in body or trace form, will be protected, preserved, and managed for public education, interpretation, and scientific research. In 2010, the National Park Service established National Fossil Day as a celebration and partnership organized to promote public awareness and stewardship of fossils, as well as to foster a greater appreciation of their scientific and educational value

(https://www.nps.gov/subjects/fossilday/index.htm). National Fossil Day occurs annually on Wednesday of the second full week in each October in conjunction with Earth Science Week.

Related Laws, Legislation, and Management Guidelines

National Park Service Organic Act

The NPS Organic Act directs the NPS to manage units

> *...to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such a manner as will leave them unimpaired for the enjoyment of future generations. (16 U.S.C. § 1).*

Congress reiterated this mandate in the Redwood National Park Expansion Act of 1978 by stating that the NPS must conduct its actions in a manner that will ensure no

> *...derogation of the values and purposes for which these various areas have been established, except as may have been or shall be directly and specifically provided by Congress. (16 U.S.C. § 1 a-1).*

The Organic Act prohibits actions that permanently impair park resources unless a law directly and specifically allows for the acts. An action constitutes an impairment when its impacts

> *...harm the integrity of park resources or values, including the opportunities that otherwise would be present for the enjoyment of those resources and values. (Management Policies 2006 1.4.3).*

Paleontological Resources Protection Act (P.L. 111-011, Omnibus Public Land Management Act of 2009, Subtitle D)

Section 6302 states

> *The Secretary (of the Interior) shall manage and protect paleontological resources on Federal land using scientific principles and expertise. The Secretary shall develop appropriate plans for inventory, monitoring, and the scientific and educational use of paleontological resources, in accordance with applicable agency laws, regulations, and policies. These plans shall emphasize interagency coordination and collaborative efforts where possible with non-Federal partners, the scientific community, and the general public.*

Federal Cave Resources Protection Act of 1988 (16 USC 4301)

This law provides a legal authority for the protection of all cave resources on NPS and other federal lands. The definition for "Cave Resource" in Section 4302 states

> *Cave resources include any material or substance occurring naturally in caves on Federal lands, such as animal life, plant life, paleontological deposits, sediments, minerals, speleogens, and speleothems.*

NPS Management Policies 2006

NPS Management Policies 2006 include direction for preserving and protecting cultural resources, natural resources, processes, systems, and values (National Park Service 2006). It is the goal of the NPS to avoid or minimize potential impacts to resources to the greatest extent practicable consistent with the management policies. The following is taken from section 4.8.2.1 of the NPS Management Policies 2006, "Paleontological Resources and Their Contexts":

> *Paleontological resources, including both organic and mineralized remains in body or trace form, will be protected, preserved, and managed for public education, interpretation, and scientific research. The Service will study and manage paleontological resources in their paleoecological context (that is, in terms of the geologic data associated with a particular fossil that provides information about the ancient environment).*
>
> *Superintendents will establish programs to inventory paleontological resources and systematically monitor for newly exposed fossils, especially in areas of rapid erosion. Scientifically significant resources will be protected by collection or by on-site protection and stabilization. The Service will encourage and help the academic community to conduct paleontological field research in accordance with the terms of a scientific research and collecting permit. Fossil localities and associated geologic data will be adequately documented when specimens are collected. Paleontological resources found in an archeological context are also subject to the policies for archeological resources. Paleontological specimens that are to be retained permanently are subject to the policies for museum objects.*
>
> *The Service will take appropriate action to prevent damage to and unauthorized collection of fossils. To protect paleontological resources from harm, theft, or destruction, the Service will ensure, where necessary, that information about the nature and specific location of these resources remains confidential, in accordance with the National Parks Omnibus Management Act of 1998.*
>
> *Parks will exchange fossil specimens only with other museums and public institutions that are dedicated to the preservation and interpretation of natural heritage and qualified to manage museum collections. Fossils to be deaccessioned in an exchange must fall outside the park's scope of collection statement. Systematically collected fossils in an NPS museum collection in compliance with 36 CFR 2.5 cannot be outside the scope of the collection statement. Exchanges must follow deaccession procedures in the Museum Handbook, Part II, chapter 6.*
>
> *The sale of original paleontological specimens is prohibited in parks.*
>
> *The Service generally will avoid purchasing fossil specimens. Casts or replicas should be acquired instead. A park may purchase fossil specimens for the park museum collection only after making a written determination that*

- *The specimens are scientifically significant and accompanied by detailed locality data and pertinent contextual data;*
- *The specimens were legally removed from their site of origin, and all transfers of ownership have been legal;*
- *The preparation of the specimens meets professional standards;*
- *The alternatives for making these specimens available to science and the public are unlikely;*
- *Acquisition is consistent with the park's enabling legislation and scope of collection statement, and acquisition will ensure the specimens' availability in perpetuity for public education and scientific research.*

All NPS construction projects in areas with potential paleontological resources must be preceded by a preconstruction surface assessment prior to disturbance. For any occurrences noted, or when the site may yield paleontological resources, the site will be avoided or the resources will, if necessary, be collected and properly cared for before construction begins. Areas with potential paleontological resources must also be monitored during construction projects.

(See Natural Resource Information 4.1.2; Studies and Collections 4.2; Independent Research 5.1.2; and Artifacts and Specimens 10.2.4.6 in NPS 2006, available here. Also see 36 CFR 2.5.)

NPS Director's Order-77, Paleontological Resources Management

DO-77 describes fossils as non-renewable resources and identifies the two major types, body fossils and trace fossils. It describes the need for managers to identify potential paleontological resources using literature and collection surveys, identify areas with potential for significant paleontological resources, and conduct paleontological surveys (inventory). It also describes appropriate actions for managing paleontological resources including: no action, monitoring, cyclic prospecting, stabilization and reburial, construction of protective structures, excavation, area closures, patrols, and the need to maintain confidentiality of sensitive location information.

Excerpt from Clites and Santucci (2012):

Monitoring

An important aspect of paleontological resource management is establishing a long-term paleontological resource monitoring program. National Park Service paleontological resource monitoring strategies were developed by Santucci et al. (2009). The park's monitoring program should incorporate the measurement and evaluation of the factors stated below.

Climatological Data Assessments

These assessments include measurements of factors such as annual and storm precipitation, freeze/thaw index (number of 24-hour periods per year where temperature fluctuates above and below 32 degrees Fahrenheit), relative humidity, and peak hourly wind speeds.

Rates of Erosion Studies

These studies require evaluation of lithology, slope degree, percent vegetation cover, and rates of denudation around established benchmarks. If a park does not have this information, there may be opportunities to set up joint projects, because erosion affects more than just paleontological resources.

Assessment of Human Activities, Behaviors, and Other Variables

These assessments involve determining access/proximity of paleontological resources to visitor use areas, annual visitor use, documented cases of theft/vandalism, commercial market value of the fossils, and amount of published material on the fossils.

Condition Assessment and Cyclic Prospecting

These monitoring methods entail visits to the locality to observe physical changes in the rocks and fossils, including the number of specimens lost and gained at the surface exposure. Paleontological prospecting would be especially beneficial during construction projects or road repair.

Periodic Photographic Monitoring

Maintaining photographic archives and continuing to photo-document fossil localities from established photo-points enables visual comparison of long-term changes in site variables.

Appendix E: Paleontological Locality Data

During the 2023 field inventory, 226 localities were documented within the boundaries of COLM, and two more were found in March 2024. These localities were confirmed to either possess paleontological resources currently or have produced fossil specimens currently within the collections at COLM. The following tables contain basic information on the verified localities, including stratigraphy, lithology, and the fossils/taxa observed. A number of sites comprise multiple fossil occurrence in close proximity; additional information such as this is documented at COLM in locality forms. To enhance readability, the list of localities has been divided into five chronological tables (Tables 9–13), for localities reported in 1977, the 1990s, the 2000s, the 2010s, and 2023 and 2024, respectively. Sensitive locality information has been removed from this version of the inventory report.

Table 9. COLM paleontological locality data, for localities reported in 1977.

Locality #	Formation	Member	Lithology	Taxa	Fossil Description	Specimen(s) Collected
COLM-PAL-77-A	Morrison	Brushy Basin	sandstone	Dinosauria	bone fragments	–
COLM-PAL-77-B	Morrison	Brushy Basin	mudstone	Dinosauria	bone fragments	uncatalogued
COLM-PAL-77-C	Morrison	Brushy Basin	mudstone	Charophyta, Dinosauria, Gastropoda, Testudines	fragments	COLM 2222
COLM-PAL-77-D	Morrison	Brushy Basin	mudstone	Sauropoda	bone fragments	–
COLM-PAL-77-E	Morrison	Brushy Basin	mudstone	Testudines	bone fragments	–
COLM-PAL-77-F	Morrison	Brushy Basin	mudstone	Dinosauria	bone fragments	–
COLM-PAL-77-G	Morrison	Brushy Basin	limestone	Charophyta, Gastropoda	agatized snail shells & algal structures	–
COLM-PAL-77-H	Morrison	Salt Wash	sandstone	Sauropoda	caudal vertebra, rib/bone fragments	uncatalogued
COLM-PAL-77-I	Morrison	Salt Wash	mudstone	Dinosauria	bone fragments	–
COLM-PAL-77-J	Morrison	Salt Wash	sandstone	Sauropoda	ischium	–

Table 10. COLM paleontological locality data, for localities reported in the 1990s.

Locality #	Formation	Member	Lithology	Taxa	Fossil Description	Specimen(s) Collected
COLM-PAL-90-A	Chinle	“Red siltstone”	sandstone	cf. *Grallator*	tridactyl tracks	–
COLM-PAL-95-B	Morrison	Salt Wash	sandstone	Sauropoda	limb (incl. fragments)	–
COLM-PAL-95-C	Morrison	Brushy Basin	sandstone	Dinosauria	bone fragments	–
COLM-PAL-95-D	Morrison	Brushy Basin	mudstone	Dinosauria	bone fragments	–
COLM-PAL-95-E	Morrison	Brushy Basin	mudstone	Dinosauria	bone fragments	–
COLM-PAL-95-F	Burro Canyon	–	conglomeratic sandstone	Sauropoda	limb (incl. fragments)	–
COLM-PAL-95-G	Burro Canyon	–	conglomeratic sandstone	Sauropoda	vertebrae, limb, rib/bone fragments	uncatalogued
COLM-PAL-95-H	Morrison	Salt Wash	sandstone	Sauropoda	pelvic bone, vertebra	–
COLM-PAL-95-I	Morrison	Salt Wash	sandstone	cf. *Cylindricum*	burrows	–

Table 10 (continued). COLM paleontological locality data, for localities reported in the 1990s.

Locality #	Formation	Member	Lithology	Taxa	Fossil Description	Specimen(s) Collected
COLM-PAL-95-J	Morrison	Salt Wash	sandstone	cf. *Cylindricum*, cf. *Planolites*	burrows	–
COLM-PAL-95-K	Morrison	Salt Wash	mudstone	Sauropoda	caudal vertebra	COLM 2219
COLM-PAL-95-L	Morrison	Brushy Basin	mudstone	cf. *Dryosaurus*	ischium fragment	COLM 2220
COLM-PAL-95-M	Morrison	Salt Wash	sandstone	Sauropoda	sauropod tracks	–
COLM-PAL-95-N	Morrison	Salt Wash	limestone	Unionidae	clam fragments	COLM 2221
COLM-PAL-95-O	Morrison	Salt Wash	mudstone	Unionidae	clam fragments	–
COLM-PAL-95-P	Morrison	Salt Wash	mudstone	Unionidae	clam fragments	–

Table 11. COLM paleontological locality data, for localities reported in the 2000s.

Locality #	Formation	Member	Lithology	Taxa	Fossil Description	Specimen(s) Collected
COLM-PAL-01-A	Morrison	Salt Wash	sandstone	Sauropoda	sauropod track	–
COLM-PAL-01-B	Morrison	Salt Wash	sandstone	Sauropoda	sauropod track	–
COLM-PAL-01-C	Morrison	Tidwell	sandstone	Sauropoda	sauropod tracks	–
COLM-PAL-02-C	Morrison	Salt Wash	sandstone	cf. *Cochlichnus*	burrows	–
COLM-PAL-02-D	Morrison	Salt Wash	sandstone	Unionidae	clam fragments	uncatalogued
COLM-PAL-02-E	Morrison	Salt Wash	sandstone	cf. *Cochlichnus*, cf. *Cylindricum*, *Steinichnus*	burrows	–
COLM-PAL-02-F	Morrison	Salt Wash	sandstone	cf. *Celliforma*	burrows	–
COLM-PAL-02-G	Morrison	Salt Wash	sandstone	Dinosauria	bone fragments	–
COLM-PAL-02-I	Morrison	Salt Wash	sandstone	*Anomoepus*	tridactyl tracks	COLM 5092
COLM-PAL-02-J	Burro Canyon	–	orthoquartzite	cf. *Planolites*	burrows	–
COLM-PAL-02-L	Morrison	Salt Wash	sandstone	Cyanophyta	microbialite structures (oncoid/stromatolite)	–
COLM-PAL-02-M	Wingate	–	sandstone	cf. *Planolites*	burrows	–

Table 11 (continued). COLM paleontological locality data, for localities reported in the 2000s.

Locality #	Formation	Member	Lithology	Taxa	Fossil Description	Specimen(s) Collected
COLM-PAL-02-R	Wingate	–	sandstone	cf. *Planolites*	burrows	–
COLM-PAL-02-S	Kayenta	–	conglomeratic mudstone	Vertebrata	bone fragment	–
COLM-PAL-02-T	Wingate	–	sandstone	cf. *Planolites*	burrows	–
COLM-PAL-02-U	Wingate	–	sandstone	cf. *Planolites*	burrows	–
COLM-PAL-02-V	Wingate	–	sandstone	cf. *Thalassinoides*	burrows	–
COLM-PAL-02-X	Entrada	“Board Beds”	sandstone	Crinoidea	crinoid fragments	–
COLM-PAL-02-AC	Morrison	Salt Wash	mudstone	Unionidae	clam fragments	–
COLM-PAL-02-AD	Morrison	Salt Wash	mudstone	Unionidae	clam fragments	–
COLM-PAL-04-A	Morrison	Salt Wash	sandstone	Sauropoda, cf. *Taenidium*	rib impressions, sauropod tracks, burrows	–
COLM-PAL-04-B	Morrison	Salt Wash	sandstone	Sauropoda, cf. *Taenidium*, cf. *Metatetrapous*	dinosaur tracks, burrows	uncatalogued
COLM-PAL-04-D	Chinle	“Red siltstone”	mudstone	cf. *Brachychirotherium*, cf. *Atreipus*, cf. *Scoyenia*, cf. *Beaconites*, cf. *Taenidium*, cf. *Thalassinoides*, cf. *Cochlichnus*, cf. *Planolites*	tracks, burrows	–
COLM-PAL-04-E	Morrison	Salt Wash	sandstone	Plantae	plant fragments	–
COLM-PAL-04-F	Burro Canyon	–	FLOAT	Dinosauria	bone fragments	–
COLM-PAL-04-G	Morrison	Salt Wash	sandstone	*Dinehichnus*	tridactyl track	–
COLM-PAL-04-H	Wingate	–	sandstone	*Grallator*	tridactyl tracks	–
COLM-PAL-04-I	Wingate	–	sandstone	*Grallator*	tridactyl tracks	–
COLM-PAL-04-L	Wingate	–	sandstone	*Grallator*, cf. *Brasilichnium*, Chirotheriidae	tracks	–
COLM-PAL-04-M	Wingate	–	sandstone	*Grallator*, cf. *Brachychirotherium*	tracks	–
COLM-PAL-04-N	Wingate	–	sandstone	*Grallator*, Tetrapoda	tracks	–
COLM-PAL-04-O	Morrison	Salt Wash	sandstone	Sauropoda	sauropod tracks	uncatalogued

Table 11 (continued). COLM paleontological locality data, for localities reported in the 2000s.

Locality #	Formation	Member	Lithology	Taxa	Fossil Description	Specimen(s) Collected
COLM-PAL-04-P	Kayenta	–	conglomeratic mudstone	Vertebrata	bone fragments	uncatalogued
COLM-PAL-04-R	Morrison	Tidwell	FLOAT	*Ceratodus*	tooth	uncatalogued
COLM-PAL-04-S	Wingate	–	sandstone	*Grallator*, *Eosauropus*, cf. *Brachychirotherium*, cf. *Anchisauripus*	tracks	COLM 4029
COLM-PAL-04-T	Entrada	"Board Beds"	sandstone	Invertebrata	burrows	COLM 5093
COLM-PAL-04-U	Kayenta	–	sandstone	cf. Dinosauria	possible track	–

Table 12. COLM paleontological locality data, for localities reported in the 2010s.

Locality #	Formation	Member	Lithology	Taxa	Fossil Description	Specimen(s) Collected
COLM-PAL-13-A	Burro Canyon	–	FLOAT	Dinosauria	bone fragments	–
COLM-PAL-13-B	Morrison	Salt Wash	mudstone	*Chelonipus*, *Dinehichnus*, *Pteraichnus*, cf. *Grallator*, Sauropoda, Invertebrata	tracks	COLM 5072, COLM 5168
COLM-PAL-13-E	Wingate	–	sandstone	cf. *Thalassinoides*	burrows	uncatalogued
COLM-PAL-13-I	Morrison	Salt Wash	sandstone	Invertebrata	burrows	–
COLM-PAL-13-J	Wingate	–	sandstone	cf. *Thalassinoides*	burrows	–
COLM-PAL-13-L	Morrison	Salt Wash	sandstone	Invertebrata	burrows	–
COLM-PAL-13-M	Morrison	Salt Wash	sandstone	Sauropoda	sauropod tracks	–
COLM-PAL-13-N	Morrison	Salt Wash	sandstone	Invertebrata	burrows	–
COLM-PAL-13-O	Morrison	Salt Wash	sandstone	Sauropoda	sacrum	uncatalogued
COLM-PAL-13-P	Morrison	Salt Wash	sandstone	Invertebrata	burrows	–
COLM-PAL-13-Q	Morrison	Salt Wash	sandstone	Vertebrata	bone fragment	–
COLM-PAL-13-R	Morrison	Salt Wash	sandstone	cf. *Beaconites*	burrows	–
COLM-PAL-13-S	Morrison	Salt Wash	sandstone	Sauropoda	sauropod tracks	–

Table 12 (continued). COLM paleontological locality data, for localities reported in the 2010s.

Locality #	Formation	Member	Lithology	Taxa	Fossil Description	Specimen(s) Collected
COLM-PAL-13-T	Burro Canyon	–	sandstone	Plantae	petrified wood, plant impressions	uncatalogued
COLM-PAL-13-U	Morrison	Salt Wash	sandstone	Sauropoda	sauropod track	–
COLM-PAL-13-V	Morrison	Salt Wash	sandstone	Sauropoda	sauropod track	–
COLM-PAL-13-W	Morrison	Salt Wash	sandstone	Invertebrata	burrow	–
COLM-PAL-18-A	Morrison	Brushy Basin	mudstone	Dinosauria	bone fragments	–

Table 13. COLM paleontological locality data, for localities reported in 2023 and 2024.

Locality #	Formation	Member	Lithology	Taxa	Fossil Description	Specimen(s) Collected
COLM-PAL-23-B	Morrison	Salt Wash	sandstone	cf. *Hatcherichnus*, Cyanophyta	swim trace, oncoids	–
COLM-PAL-23-C	Morrison	Salt Wash	mudstone	Unionidae	clam fragments	–
COLM-PAL-23-D	Morrison	Salt Wash	mudstone	Unionidae, Gastropoda, cf. Crocodylomorpha, Osteichthyes	clam fragments, snail shells, bone fragments, vertebrae, otoliths	uncatalogued
COLM-PAL-23-E	Morrison	Tidwell	sandstone	Dinosauria, *Deltapodus*, Sauropoda, *Lockeia*	stegosaur & sauropod tracks, bone fragments, clam traces	uncatalogued
COLM-PAL-23-F	Morrison	Tidwell	sandstone	cf. *Hatcherichnus*, *Therangospodus pandemicus*, cf. *Rhynchosauroides*	tracks, swim traces	uncatalogued
COLM-PAL-23-G	Morrison	Salt Wash	mudstone	Vertebrata	limb fragment	uncatalogued
COLM-PAL-23-H	Morrison	Salt Wash	sandstone	Invertebrata	burrows	–
COLM-PAL-23-I	Morrison	Salt Wash	sandstone	Sauropoda	sauropod trackway	–
COLM-PAL-23-J	Morrison	Salt Wash	limestone	Cyanophyta	microbialite structures (oncoids)	–

Table 13 (continued). COLM paleontological locality data, for localities reported in 2023 and 2024.

Locality #	Formation	Member	Lithology	Taxa	Fossil Description	Specimen(s) Collected
COLM-PAL-23-K	Morrison	Salt Wash	limestone	Cyanophyta	microbialite structures (oncoids)	–
COLM-PAL-23-L	Morrison	Salt Wash	limestone	Cyanophyta, Sauropoda	oncoids, sauropod track	–
COLM-PAL-23-M	Morrison	Salt Wash	mudstone	Vertebrata, Unionidae	bone fragments, clam fragments	–
COLM-PAL-23-N	Morrison	Salt Wash	mudstone	Unionidae	clams (complete/fragments)	uncatalogued
COLM-PAL-23-O	Morrison	Salt Wash	sandstone	Invertebrata	burrows	–
COLM-PAL-23-P	Morrison	Salt Wash	sandstone	cf. *Fuersichnus*	burrows	–
COLM-PAL-23-Q	Morrison	Salt Wash	sandstone	cf. *Dinehichnus*	tridactyl track	–
COLM-PAL-23-R	Morrison	Salt Wash	mudstone	Unionidae	clam fragments	–
COLM-PAL-23-S	Morrison	Salt Wash	mudstone	Unionidae	clam fragments	–
COLM-PAL-23-T	Morrison	Tidwell	sandstone	Plantae	carbonized wood	–
COLM-PAL-23-U	Morrison	Tidwell	sandstone	Plantae	plant cast	–
COLM-PAL-23-V	Morrison	Salt Wash	mudstone	Unionidae, Gastropoda	clam fragments, snail shells	–
COLM-PAL-23-W	Morrison	Salt Wash	sandstone	cf. Iguanodontipodidae	tridactyl track	–
COLM-PAL-23-X	Morrison	Brushy Basin	mudstone	Dinosauria	bone fragments	–
COLM-PAL-23-Y	Morrison	Brushy Basin	mudstone	Vertebrata	bone fragments	–
COLM-PAL-23-Z	Burro Canyon	–	sandstone	Plantae	petrified wood	–
COLM-PAL-23-AA	Morrison	Brushy Basin	sandstone	Dinosauria	bone fragments	–
COLM-PAL-23-AB	Morrison	Brushy Basin	mudstone	Vertebrata	bone	–
COLM-PAL-23-AC	Morrison	Tidwell	limestone	cf. *Megalosauripus*	tridactyl track	uncatalogued
COLM-PAL-23-AD	Morrison	Salt Wash	limestone	Cyanophyta	microbialite structures (stromatolite)	–
COLM-PAL-23-AE	Morrison	Brushy Basin	mudstone	Dinosauria	bone fragments	–
COLM-PAL-23-AF	Wingate	–	sandstone	cf. *Planolites*	burrows	–

Table 13 (continued). COLM paleontological locality data, for localities reported in 2023 and 2024.

Locality #	Formation	Member	Lithology	Taxa	Fossil Description	Specimen(s) Collected
COLM-PAL-23-AG	Wingate	–	sandstone	cf. *Planolites*	burrows	–
COLM-PAL-23-AH	Wingate	–	sandstone	cf. *Planolites*	burrows	–
COLM-PAL-23-AI	Morrison	Brushy Basin	mudstone	Vertebrata	bone fragments	–
COLM-PAL-23-AJ	Morrison	Brushy Basin	mudstone	Macronaria	partial tooth	uncatalogued
COLM-PAL-23-AK	Morrison	Brushy Basin	mudstone	Vertebrata	rib fragment	–
COLM-PAL-23-AL	Morrison	Brushy Basin	mudstone	Vertebrata	bone fragments	–
COLM-PAL-23-AM	Morrison	Tidwell	mudstone	cf. Testudinata	bone fragments	–
COLM-PAL-23-AN	Morrison	Tidwell	mudstone	Unionidae	clam fragments	–
COLM-PAL-23-AO	Morrison	Salt Wash	mudstone	Vertebrata	limb fragments	–
COLM-PAL-23-AP	Morrison	Salt Wash	mudstone	Vertebrata	bone fragment	–
COLM-PAL-23-AQ	Morrison	Salt Wash	mudstone	Unionidae	clam fragments	–
COLM-PAL-23-AR	Morrison	Brushy Basin	mudstone	Dinosauria	bone fragments (limb?)	–
COLM-PAL-23-AS	Morrison	Brushy Basin	mudstone	Vertebrata	bone fragment	–
COLM-PAL-23-AT	Morrison	Salt Wash	mudstone	Cyanophyta, Vertebrata	bone fragments, microbialite structures (oncoids)	–
COLM-PAL-23-AU	Morrison	Salt Wash	mudstone	Vertebrata	bone fragment	–
COLM-PAL-23-AV	Morrison	Salt Wash	mudstone	Vertebrata	bone fragment	–
COLM-PAL-23-AW	Morrison	Salt Wash	mudstone	Vertebrata	bone fragment	–
COLM-PAL-23-AX	Morrison	Salt Wash	mudstone	Vertebrata	bone fragment	–
COLM-PAL-23-AY	Morrison	Salt Wash	sandstone	Invertebrata	burrows	–
COLM-PAL-23-AZ	Morrison	Salt Wash	mudstone	Vertebrata	bone fragment	–
COLM-PAL-23-BA	Morrison	Salt Wash	mudstone	Unionidae	clam fragments	–
COLM-PAL-23-BB	Morrison	Salt Wash	sandstone	Invertebrata	burrows	–
COLM-PAL-23-BC	Morrison	Brushy Basin	mudstone	Vertebrata	bone fragments	–
COLM-PAL-23-BD	Morrison	Brushy Basin	mudstone	Vertebrata	bone fragment	–
COLM-PAL-23-BE	Morrison	Brushy Basin	mudstone	Vertebrata	bone fragments	–

Table 13 (continued). COLM paleontological locality data, for localities reported in 2023 and 2024.

Locality #	Formation	Member	Lithology	Taxa	Fossil Description	Specimen(s) Collected
COLM-PAL-23-BF	Morrison	Brushy Basin	mudstone	Vertebrata	bone fragment	–
COLM-PAL-23-BG	Morrison	Brushy Basin	mudstone	Vertebrata	bone fragments	–
COLM-PAL-23-BH	Kayenta	–	conglomeratic sandstone	Plantae	petrified wood	–
COLM-PAL-23-BI	Burro Canyon	–	conglomeratic sandstone	cf. Sauropoda	assorted bones, bone fragments	–
COLM-PAL-23-BJ	Burro Canyon	–	conglomeratic sandstone	Plantae, cf. Sauropoda	assorted bones, bone fragments, plant fragments	–
COLM-PAL-23-BK	Burro Canyon	–	conglomeratic sandstone	Plantae, *Gleichenia*	plant fragments	–
COLM-PAL-23-BL	Burro Canyon	–	conglomeratic sandstone	cf. *Planolites*	burrows	–
COLM-PAL-23-BM	Burro Canyon	–	conglomeratic sandstone	cf. *Planolites*	burrows	–
COLM-PAL-23-BN	Burro Canyon	–	conglomeratic sandstone	Dinosauria	bone	–
COLM-PAL-23-BO	Burro Canyon	–	conglomeratic sandstone	Dinosauria	bone fragment	–
COLM-PAL-23-BP	Burro Canyon	–	conglomeratic sandstone	Dinosauria	bone fragments	–
COLM-PAL-23-BQ	Burro Canyon	–	conglomeratic sandstone	Dinosauria	bone fragment	–
COLM-PAL-23-BR	Naturita	–	conglomeratic sandstone	Plantae	plant fragments	–
COLM-PAL-23-BS	Naturita	–	sandstone	Plantae	petrified wood	–
COLM-PAL-23-BU	Naturita	–	sandstone	Plantae, *Hadrosauropodus*	plant fragments, tridactyl tracks	–
COLM-PAL-23-BV	Naturita	–	sandstone	*Hadrosauropodus*	tridactyl track	–
COLM-PAL-23-BW	Naturita	–	sandstone	*Hadrosauropodus*, cf. *Magnoavipes*	tridactyl tracks	–

Table 13 (continued). COLM paleontological locality data, for localities reported in 2023 and 2024.

Locality #	Formation	Member	Lithology	Taxa	Fossil Description	Specimen(s) Collected
COLM-PAL-23-BX	Naturita	–	conglomeratic sandstone	*Hadrosauropodus*	tridactyl tracks	–
COLM-PAL-23-BY	Naturita	–	sandstone	Plantae	plant fragments	–
COLM-PAL-23-BZ	Naturita	–	sandstone	Plantae, cf. Angiospermae	plant fragments, leaves	uncatalogued
COLM-PAL-23-CA	Naturita	–	sandstone	*Hadrosauropodus*, *Tetrapodosaurus*, cf. *Magnoavipes*	tridactyl tracks, ankylosaur manus/pes	–
COLM-PAL-23-CB	Naturita	–	sandstone	*Hadrosauropodus*	tridactyl tracks	–
COLM-PAL-23-CD	Burro Canyon	–	orthoquartzite	cf. *Planolites*	burrows	–
COLM-PAL-23-CE	Burro Canyon	–	orthoquartzite	cf. *Planolites*	burrows	–
COLM-PAL-23-CF	Burro Canyon	–	orthoquartzite	cf. *Planolites*	burrows	–
COLM-PAL-23-CG	Morrison	Brushy Basin	mudstone	Sauropoda	limb chunks	–
COLM-PAL-23-CH	Burro Canyon	–	conglomeratic sandstone	Bryozoa, Brachiopoda, Crinoidea	fossiliferous chert	uncatalogued
COLM-PAL-23-CI	Morrison	–	mudstone	Sauropoda	ungual (weathered)	uncatalogued
COLM-PAL-23-CJ	Burro Canyon	–	conglomeratic sandstone	Dinosauria	rib fragments	–
COLM-PAL-23-CK	Morrison	–	mudstone	Vertebrata	bone fragment	–
COLM-PAL-23-CL	Burro Canyon	–	orthoquartzite	cf. *Planolites*	burrows	–
COLM-PAL-23-CM	Burro Canyon	–	conglomeratic sandstone	Dinosauria	partial limb	–
COLM-PAL-23-CN	Naturita	–	sandstone	cf. *Magnoavipes*	tridactyl track	–
COLM-PAL-23-CO	Naturita	–	mudstone	Plantae	petrified wood	–
COLM-PAL-23-CP	Naturita	–	mudstone	Plantae	petrified wood	uncatalogued
COLM-PAL-23-CQ	Kayenta	–	conglomeratic mudstone	Vertebrata	bone fragments	uncatalogued
COLM-PAL-23-CR	Wingate	–	sandstone	cf. *Fuersichnus*	burrows	–
COLM-PAL-23-CS	Wingate	–	sandstone	cf. *Planolites*	burrows	–
COLM-PAL-23-CT	Wingate	–	sandstone	cf. *Thalassinoides*	burrows	–

Table 13 (continued). COLM paleontological locality data, for localities reported in 2023 and 2024.

Locality #	Formation	Member	Lithology	Taxa	Fossil Description	Specimen(s) Collected
COLM-PAL-23-CU	Wingate	–	sandstone	cf. *Planolites*	burrows	–
COLM-PAL-23-CV	Wingate	–	sandstone	cf. *Planolites*	burrows	–
COLM-PAL-23-CW	Wingate	–	sandstone	cf. *Thalassinoides*	burrows	–
COLM-PAL-23-CX	Wingate	–	sandstone	cf. *Planolites*	burrows	–
COLM-PAL-23-CY	Chinle	“Red siltstone”	sandstone	cf. *Planolites*	burrows	–
COLM-PAL-23-CZ	Wingate	–	sandstone	cf. *Arenicolites*	burrows	–
COLM-PAL-23-DA	Morrison	–	sandstone	cf. *Hatcherichnus*, Dinosauria	swim traces, tridactyl track	–
COLM-PAL-23-DB	Morrison	–	sandstone	*Dinehichnus*, cf. *Parabrontopodus*	tridactyl track, sauropod tracks	–
COLM-PAL-23-DC	Morrison	Salt Wash	sandstone	cf. Dinosauria	tridactyl swim trace	–
COLM-PAL-23-DD	Morrison	Salt Wash	sandstone	cf. *Taenidium*	burrow (meniscate)	–
COLM-PAL-23-DE	Morrison	Salt Wash	sandstone	Sauropoda	sauropod tracks	–
COLM-PAL-23-DF	Morrison	Salt Wash	sandstone	Dinosauria, *Cochlichnus*, Invertebrata	possible tridactyl tracks, burrows	–
COLM-PAL-23-DG	Morrison	Salt Wash	sandstone	Sauropoda, Invertebrata	sauropod tracks, burrows	–
COLM-PAL-23-DH	Morrison	Salt Wash	sandstone	cf. *Anomoepus*, Invertebrata	tridactyl tracks, burrows	–
COLM-PAL-23-DI	Morrison	Salt Wash	sandstone	Sauropoda	sauropod tracks	–
COLM-PAL-23-DJ	Morrison	Brushy Basin	sandstone	cf. *Stegopodus*	tracks	–
COLM-PAL-23-DK	Morrison	Salt Wash	sandstone	cf. *Dinehichnus*	tridactyl track	–
COLM-PAL-23-DL	Burro Canyon	–	sandstone	Dinosauria	bone fragments	–
COLM-PAL-23-DM	Naturita	–	sandstone	Plantae	petrified wood	–
COLM-PAL-23-DN	Naturita	–	sandstone	Plantae	petrified wood	–
COLM-PAL-23-DO	Naturita	–	sandstone	Plantae	petrified wood	–
COLM-PAL-23-DP	Naturita	–	sandstone	Plantae	petrified wood	–
COLM-PAL-23-DQ	Naturita	–	sandstone	*Hadrosauropodus*	tridactyl track	–

Table 13 (continued). COLM paleontological locality data, for localities reported in 2023 and 2024.

Locality #	Formation	Member	Lithology	Taxa	Fossil Description	Specimen(s) Collected
COLM-PAL-23-DR	Naturita	–	sandstone	*Tetrapodosaurus*, Invertebrata	ankylosaur manus, burrows	–
COLM-PAL-23-DS	Naturita	–	sandstone	*Hadrosauropodus*	tridactyl track	–
COLM-PAL-23-DT	Naturita	–	sandstone	cf. *Magnoavipes*, cf. *Tetrapodosaurus*	tridactyl track, possible ankylosaur manus	–
COLM-PAL-23-DU	Naturita	–	sandstone	Plantae	petrified wood	–
COLM-PAL-23-DV	Naturita	–	sandstone	cf. Magnoliaceae	partial leaf	–
COLM-PAL-23-DW	Naturita	–	sandstone	*Tetrapodosaurus*, cf. *Hadrosauropodus*, Dinosauria	ankylosaur pes tracks & partial manus, tridactyl tracks	–
COLM-PAL-23-DX	Naturita	–	sandstone	Dinosauria	partial tridactyl track	–
COLM-PAL-23-DY	Naturita	–	sandstone	*Tetrapodosaurus*, *Hadrosauropodus*	ankylosaur pes, tridactyl track	–
COLM-PAL-23-DZ	Naturita	–	sandstone	*Tetrapodosaurus*, *Hadrosauropodus*, Dinosauria	ankylosaur manus tracks & pes, tridactyl tracks	–
COLM-PAL-23-EA	Naturita	–	sandstone	Plantae, cf. *Tetrapodosaurus*	petrified wood, partial ankylosaur pes	–
COLM-PAL-23-EB	Naturita	–	sandstone	*Hadrosauropodus*	tridactyl tracks	–
COLM-PAL-23-EC	Naturita	–	sandstone	*Hadrosauropodus*	tridactyl tracks	–
COLM-PAL-23-ED	Naturita	–	sandstone	cf. *Magnoavipes*, *Hadrosauropodus*	tridactyl tracks	–
COLM-PAL-23-EE	Naturita	–	sandstone	cf. *Hadrosauropodus*	elongate tridactyl track	–
COLM-PAL-23-EF	Naturita	–	sandstone	cf. *Hadrosauropodus*	tridactyl track	–
COLM-PAL-23-EG	Naturita	–	sandstone	cf. *Tetrapodosaurus*	partial ankylosaur pes	–
COLM-PAL-23-EH	Naturita	–	sandstone	cf. *Magnoavipes*, *Hadrosauropodus*	tridactyl tracks	–

Table 13 (continued). COLM paleontological locality data, for localities reported in 2023 and 2024.

Locality #	Formation	Member	Lithology	Taxa	Fossil Description	Specimen(s) Collected
COLM-PAL-23-EI	Naturita	–	sandstone	cf. *Hadrosauropodus*, cf. *Tetrapodosaurus*, Dinosauria	tridactyl tracks, ankylosaur manus	–
COLM-PAL-23-EJ	Naturita	–	sandstone	cf. *Tetrapodosaurus*	possible ankylosaur pes	–
COLM-PAL-23-EK	Naturita	–	sandstone	*Hadrosauropodus*	tridactyl track	–
COLM-PAL-23-EL	Naturita	–	sandstone	cf. *Hadrosauropodus*, cf. *Tetrapodosaurus*, Dinosauria	tridactyl tracks, ankylosaur pes	–
COLM-PAL-23-EM	Naturita	–	sandstone	Plantae, *Hadrosauropodus*	tridactyl tracks, petrified wood fragments	–
COLM-PAL-23-EN	Naturita	–	sandstone	*Hadrosauropodus*	tridactyl tracks	–
COLM-PAL-23-EO	Morrison	Salt Wash	sandstone	Sauropoda	sauropod tracks	–
COLM-PAL-23-EP	Morrison	Salt Wash	sandstone	cf. *Pteraichnus*	possible pterosaur track	–
COLM-PAL-23-EQ	Morrison	Salt Wash	sandstone	Vertebrata	swim trace	–
COLM-PAL-23-ER	Morrison	Salt Wash	sandstone	cf. Theropoda	partial tridactyl track	–
COLM-PAL-23-ES	Morrison	Tidwell	sandstone	Dinosauria	probable tridactyl track	–
COLM-PAL-24-A	Morrison	Salt Wash	sandstone	Dinosauria	bone fragments	–
COLM-PAL-24-B	Naturita	–	sandstone	*Hadrosauropodus leonardii*, cf. *Magnoavipes*, cf. Hadrosauromorpha indet.	tridactyl tracks, dinosaur skin	uncatalogued

Appendix F: Geologic Time Scale

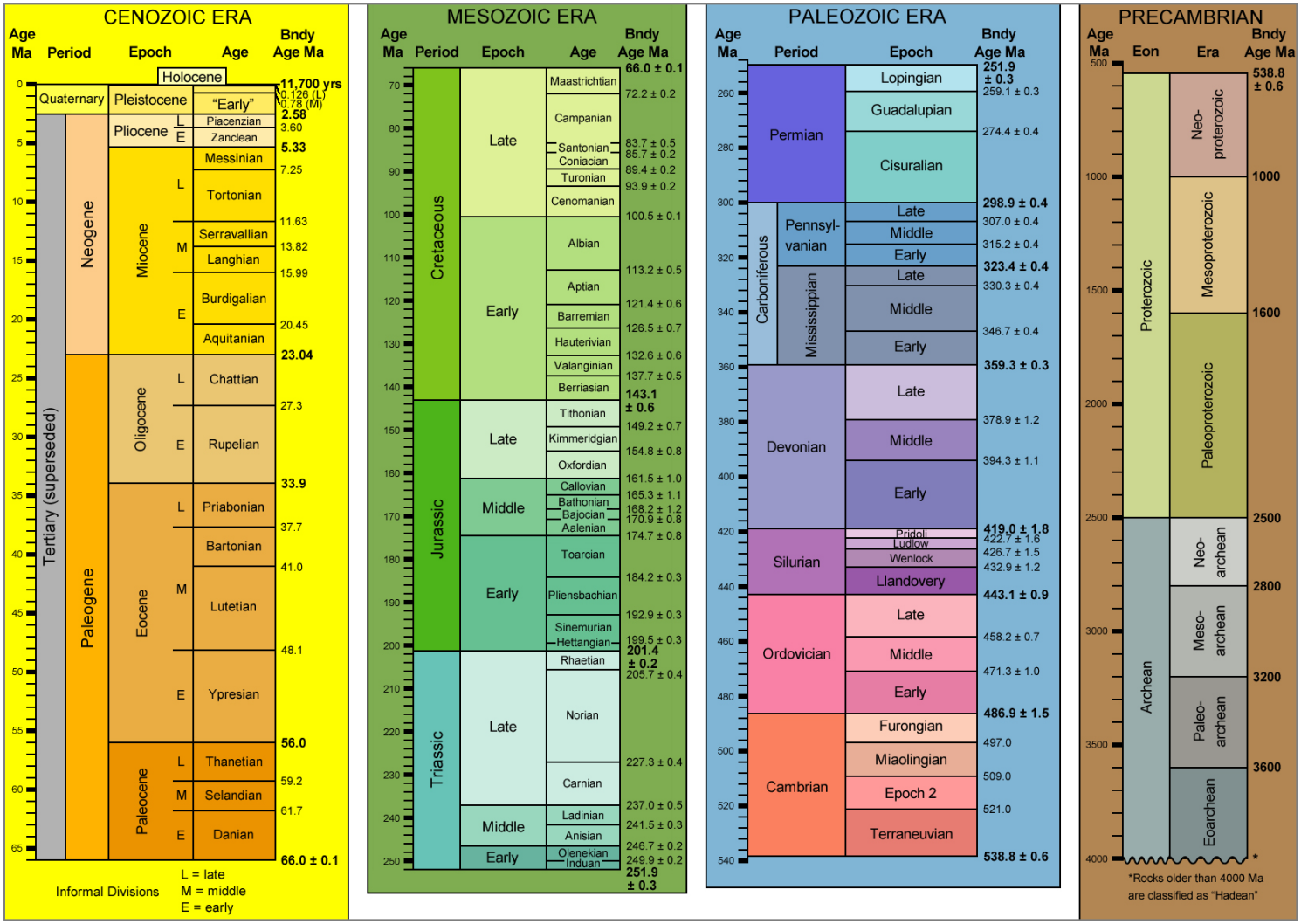


Figure 66. Geologic time scale. **Ma**=Millions of years old. **Bndy Age**=Boundary Age. Layout after 1999 Geological Society of America Time Scale (https://rock.geosociety.org/net/documents/gsa/timescale/timescl-1999.pdf). Dates after Gradstein et al. (2020).

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