National Park Service
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Natural Resource Stewardship and Science

Mesa Verde National Park

Guide to the Fossils of the Cretaceous Cliff House Sandstone

ON THE COVER

Stelleroidea, a fossil starfish from the Cretaceous Cliff House Sandstone of Mesa Verde National Park, Colorado. Photo by Bianca Santucci.

Mesa Verde National Park

Guide to the Fossils of the Cretaceous Cliff House Sandstone

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December 2020

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

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Introduction

This guide to the common fossils of the Upper Cretaceous Cliff House Sandstone at Mesa Verde National Park (MEVE) is intended to support park staff with a reference for the identification of fossils from this fossiliferous geologic formation in the park. Specifically, the focus of this guide is to help assist park staff and volunteers with preliminary field identification of fossils which may be observed during paleontological resource monitoring activities associated with the Mesa Loop Road Construction Project planned at MEVE (see Appendix A). The project involves three segments of park roads, including: Mesa Top Loop Road (4.7 miles; 7.6 km), Cliff Palace Loop Road (4.1 miles; 6.6 km), and Sun Temple Loop Road (0.4 miles; 0.6 km) (Figure 1).

Acknowledgements

We extend our appreciation to a number of Mesa Verde National Park staff including: Tova Spector (Chief of Natural Resources), Tara Travis (Supervisory Museum Curator), Tim Hovezak (Archeologist), and Elizabeth Dickey (Compliance Specialist). We recognize the important previous work on the paleontology of the Cliff House Sandstone by paleontologists William Harrison (MEVE) and Phil Varela (CHCU) which have aided the development of this report. Additional thanks to Tim Connors (Geologist, NPS Geologic Resources Division) for the review of this document.

Pre-construction Paleontological Resource Assessment

In 2019, the staff at MEVE contacted the NPS Paleontology Program seeking assistance with a pre-construction assessment of potentially fossiliferous strata along the Mesa Loop Road. A technical assistance request (STAR# 10724) was submitted by the park seeking support with the paleontological resource assessment and to provide training for park staff. Between June 2 and 6, 2019, NPS Senior Paleontologist Vincent L. Santucci visited MEVE to meet with park staff and to complete a pre-construction assessment of the proposed area of disturbance within the Cliff House Sandstone. The primary paleontological resources documented during this assessment included invertebrate trace fossils (ichnofossils) (Figure 2).

Park staff, including a number of archeologists, participated in a paleontological resource training session and visited several fossil localities along the Mesa Loop Road. The field visits provided the opportunity to observe in situ fossils and to discuss methods for monitoring and documentation of fossils encountered during the ground disturbing activities once construction begins. The park staff requested the development of a guide to the common fossils from the Cliff House Sandstone which is contained in this report. During the construction, the staff are encouraged to maintain communication with the NPS Paleontology Program for consultation as fossils are exposed. MEVE staff are welcome to email photographs of fossils observed during construction (with a scale bar) for identification by the paleontologists in the NPS Paleontology Program.

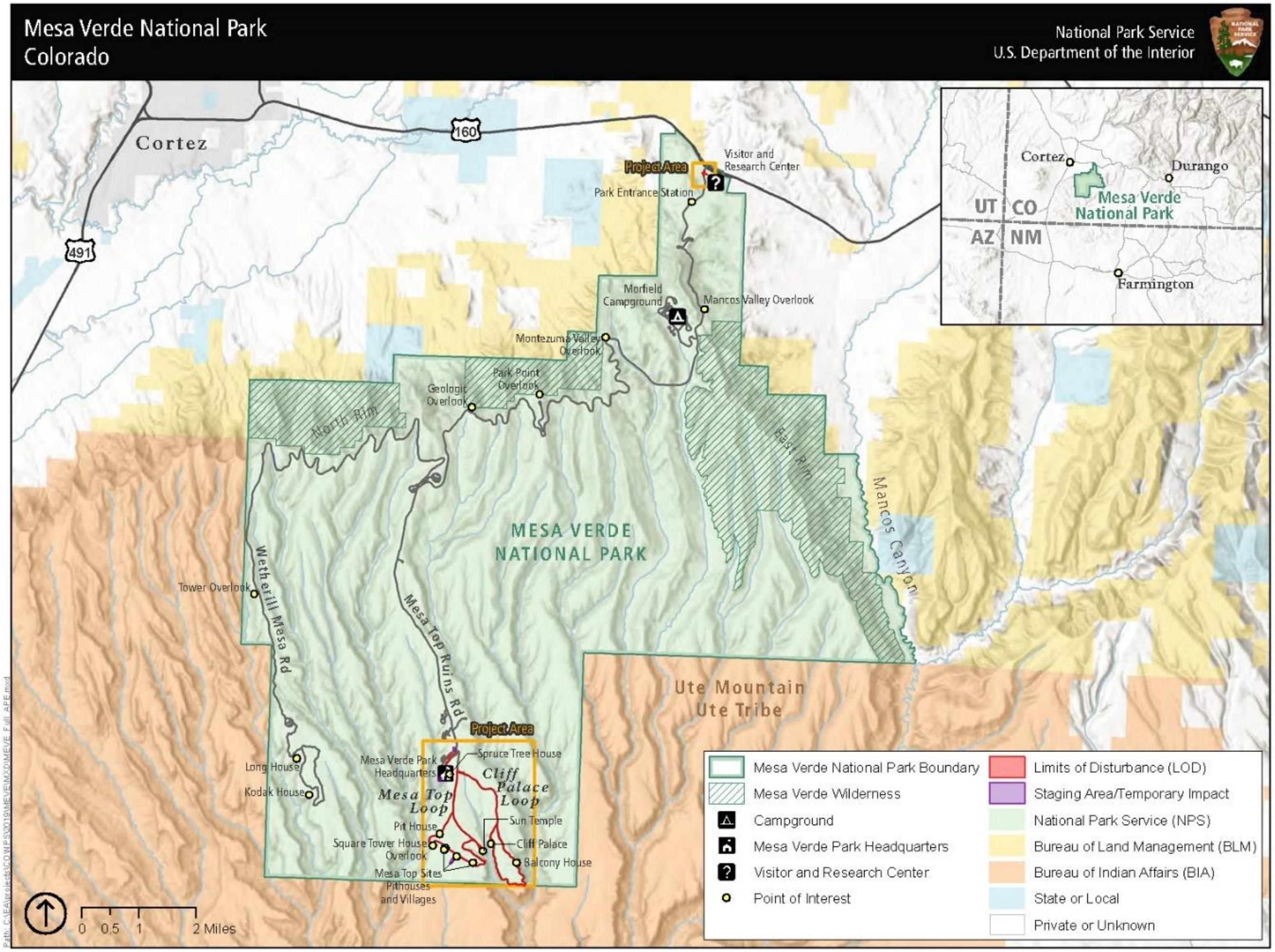

Figure 1. Map of Mesa Verde National Park showing the limits of disturbance along the park loop road system during proposed road work (NPS).

Figure 2. Fossil invertebrate burrows preserved in a block of Cliff House Sandstone at MEVE.

Geology

This guide provides basic geologic information regarding the Cretaceous Cliff House Sandstone, which is the only stratigraphic unit occurring within the construction area blueprint and area of potential disturbance. This summary of the geology is not intended to be comprehensive; additional information on the geology of MEVE and the Cliff House Sandstone is available in several documents, including Wanek (1954, 1959), Griffitts (1990), Graham (2006), and the MEVE paleontological resource inventory prepared by Harrison et al. (2017).

Several formations of Cretaceous age are exposed in the park (Figure 2), in ascending order the Mancos Shale, Pictured Cliffs Sandstone, Menefee Formation, and the Cliff House Sandstone (Figures 3 and 4). The Cliff House Sandstone is also the uppermost unit of the Mesaverde Group, which was named for rocks exposed in Mesa Verde National Park. The Cliff House Sandstone was named as the uppermost formation of the Late Cretaceous Mesaverde Group for exposures in canyons about the cliff houses of Mesa Verde National Park, Montezuma County, Colorado, in Paradox Basin (Collier 1919). No type locality was formally designated for the Cliff House Sandstone. This prominent, cliff forming sandstone is approximately 120 m (400 ft) thick in the park and originally was referred to as the "Upper Escarpment" in early reports.

As described in Harrison et al. (2017), the Cliff House Sandstone is:

> *Pale to dark yellow-orange cliff-forming cross-bedded sandstone... Locally several tongues can be distinguished near the base. The formation is approximately 120 m (400 ft) thick in the area, but the top is not present in the park (Wanek 1959). In the southern part of MEVE, the formation is usually composed of two sandstone units separated by softer sandy shale. The cliff dwellings were mostly developed in the upper sandstone unit. Farther north in the park, the upper unit transitions into alternating thinner bedded sandstone and sandy shale from slightly deeper water. Cliff dwellings could not be developed in the northern facies (Griffitts 1990). Deposition ended in the MEVE area around 77.5 Ma* [million years ago] *(M. Griffitts, pers. comm. to MEVE, 2006).*

This formation was deposited during an advance of the Western Interior Seaway, a vast shallow body of water that from approximately 100 million years ago to 70 million years ago. This seaway covered much of central and western North America which was low-lying at the time. Prehistoric marine life flourished in the shallow sea, at the sea floor, and within the uppermost levels of the marine sediment, leaving behind abundant fossils.

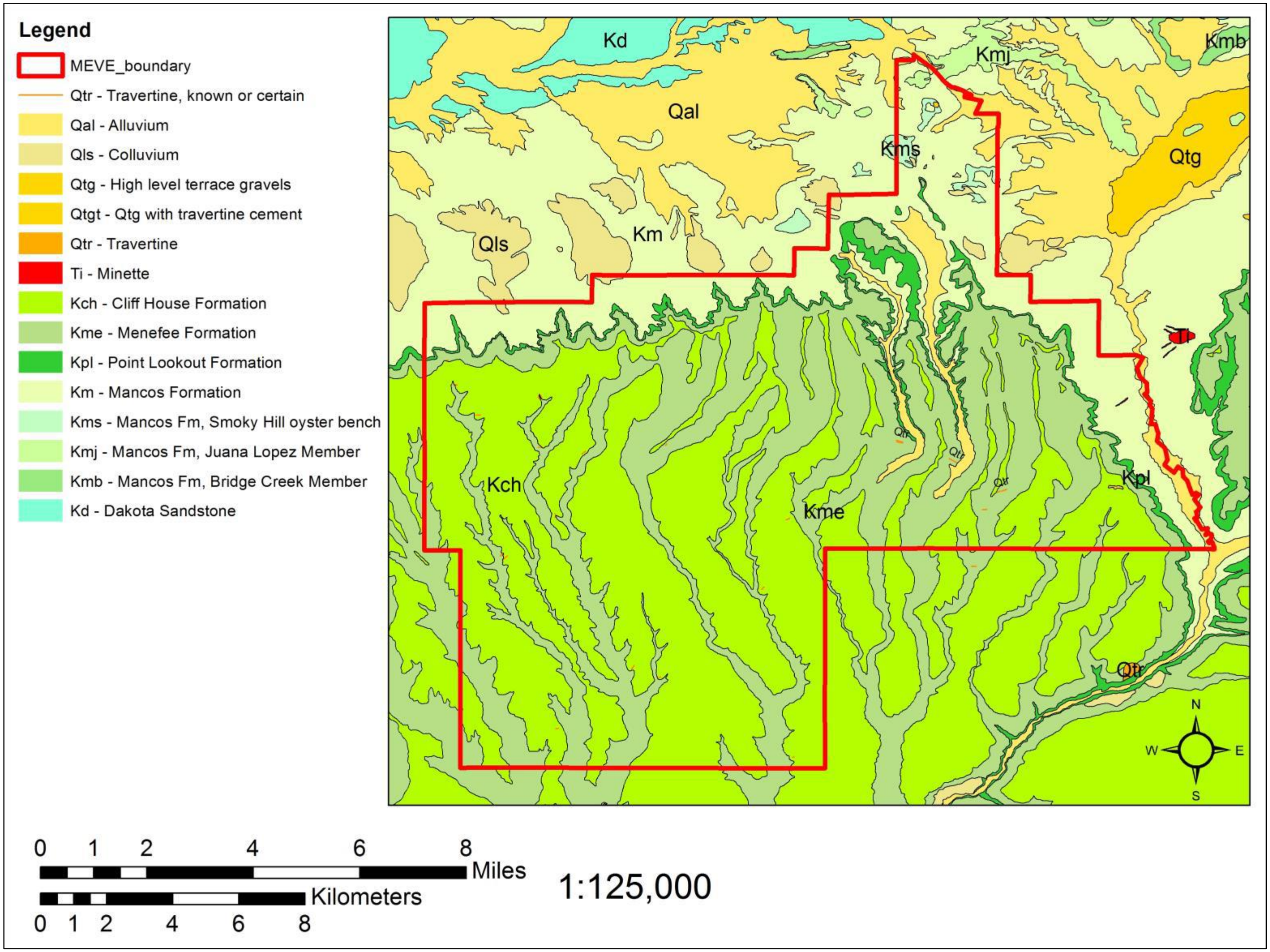

Figure 3. Basic geologic map for Mesa Verde National Park showing the geologic formations exposed at the surface.

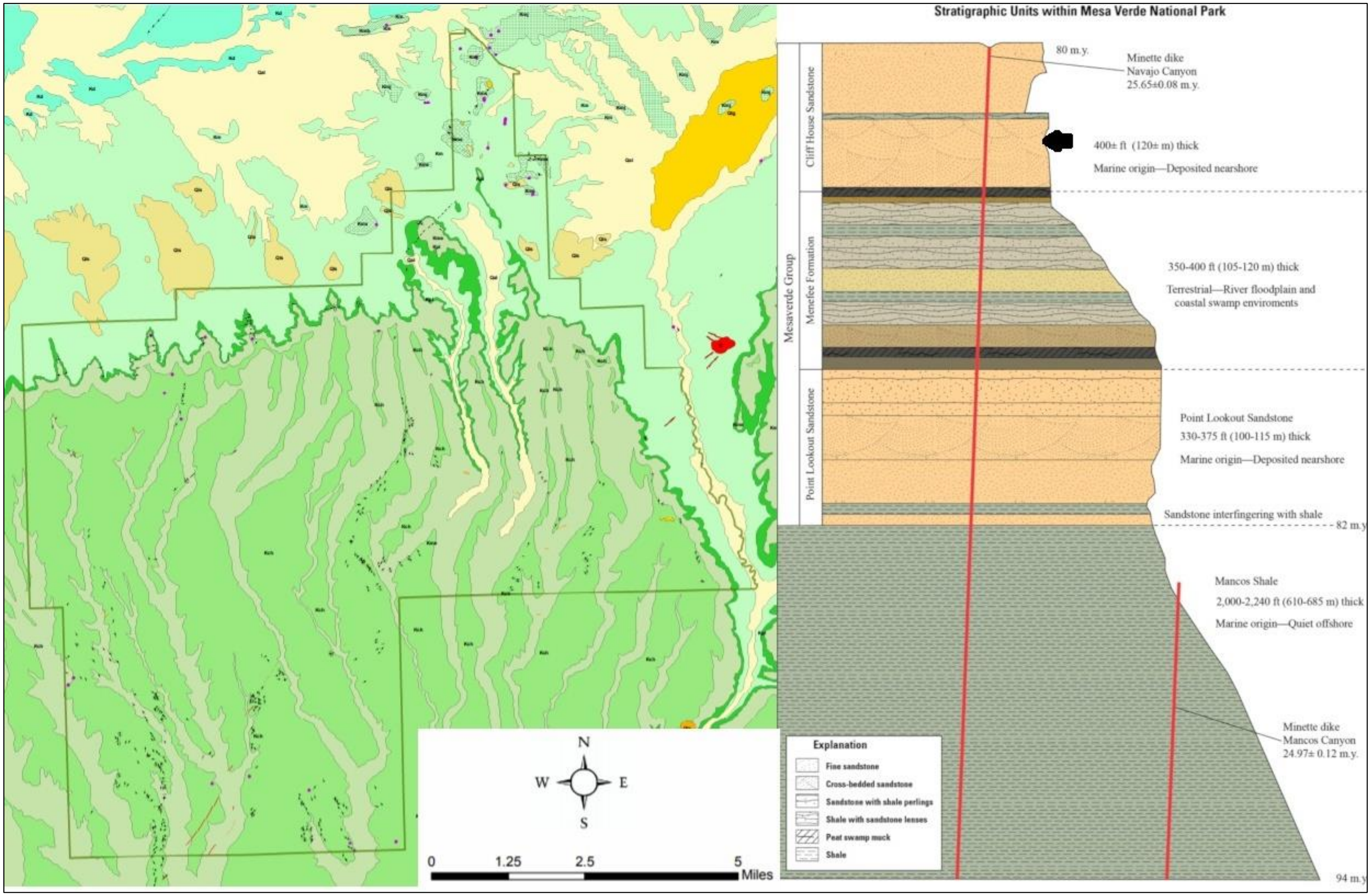

Figure 4. Geologic map and stratigraphic section for Mesa Verde National Park (Harrison et al. 2020).

Paleontology

The paleontology of the park has been documented in an inventory produced by Harrison et al. (2017). Types of fossils previously documented from the Cliff House Sandstone at MEVE include: wood and other plant debris; shells of bivalves, ammonites, and gastropods; undetermined shells; bones, teeth, and other fossils of rays, sharks, bony fishes, turtles, plesiosaurs, mosasaurs, dinosaurs, and undetermined reptiles and vertebrates; invertebrate trace fossils (borings, tracks, and burrows); and chimaera egg capsules (Harrison et al. 2017). Similar but more diverse fossils have been found in the Cliff House Sandstone at Chaco Culture National Historical Park (CHCU) (Varela et al. 2019); photos and information from CHCU have been included to supplement the MEVE material. The most likely types of fossils to be found are mollusk shells, teeth and bones of marine vertebrates, and invertebrate burrows. Because the Cliff House Sandstone represents a high-energy nearshore sandstone, fossils are frequently broken, worn, or otherwise incomplete.

Invertebrate Body Fossils

<u>Mollusks</u>

Fossil mollusks of the Cliff House Sandstone include bivalves, ammonites, and gastropods. Bivalves, which include modern groups such as clams, oysters, and scallops, and gastropods, which include modern snails and slugs, produce typical "sea shells". Complete fossils of bivalve shells and gastropod shells will probably look familiar to anyone who has looked for shells on a beach, although they will generally not be shiny, because that material is chemically unstable on geologic time scales and usually converts to a duller mineral in shells of this age. Not infrequently the shell is lost entirely and a natural internal cast (a "steinkern") is left behind. Ammonites belong to an extinct group of cephalopods. They are known for their coiled, chambered shells, resembling shells of the modern *Nautilus*, but a minority of ammonites had other shell forms. Despite their *Nautilus*-like appearance, they were more closely related to octopuses and squids.

Mollusks: Bivalves

Bivalves are the most diverse group known to date from the Cliff House Sandstone of MEVE. At least ten genera have been reported. Although bivalves have two shells in life, usually the shells separate upon death. Bivalve shells are generally asymmetric, and if well-preserved often show concentric growth lines (sometime as pronounced ridges, as in *Inoceramus*), although some shells are smooth or have heavy radial ribbing that masks growth lines (as in *Cardium* or *Ethmocardium whitei*, a species reported from MEVE).

Distinguishing bivalves to genus or species is best handled by a specialist, but several basic shapes can be distinguished. Several figures have been taken from Harrison et al. (2017) (Figure 5), Varela et al. (2019) (Figure 6), and Griffitts (1990) (Figure 5) to illustrate these common shapes and others. Complete shells of bivalves reported from the Cliff House Sandstone of MEVE can be broadly described as resembling a right triangle (*Cymbophora* [Figure 5c], *Nucula*, *Tellina*); gently rounded in all views (*Cardium* and allies [Figures 5D, 6D, and 11D]); rounded and ridged like a soft cap set on a flat surface (*Inoceramus* [Figures 5A–C, 6C, 7A]); elongate oval, triangular, or rectangular and rising to a peak in one corner (*Modiolus*, *Volsella*); resembling an acute triangle (*Pinna*); overall circular but with one side drawn out to a point (*Tancredia*); or extremely variable (*Ostrea*, familiar as modern oysters [Figure 5E]).

The bivalves of MEVE's Cliff House Sandstone have not been investigated in great detail, and there is the potential that many other genera are represented as well. Shapes known from bivalves present in the same rocks at CHCU include: claw-like "devil's toenail" shells (*Exogyra*, some *Pycnodonte* [Figure 3F; can also be ear-shaped and frequently found in dense accumulations of small shells, sometimes encrusting other shells]); overall round but slightly skewed and with an offset "peak" (*Anomia*, *Cyprimeria*, *Idonearca*); scallop-shaped (*Oxytoma*); purse- or wing-shaped (*Pteria*); and teardrop-shaped (some *Yoldia*).

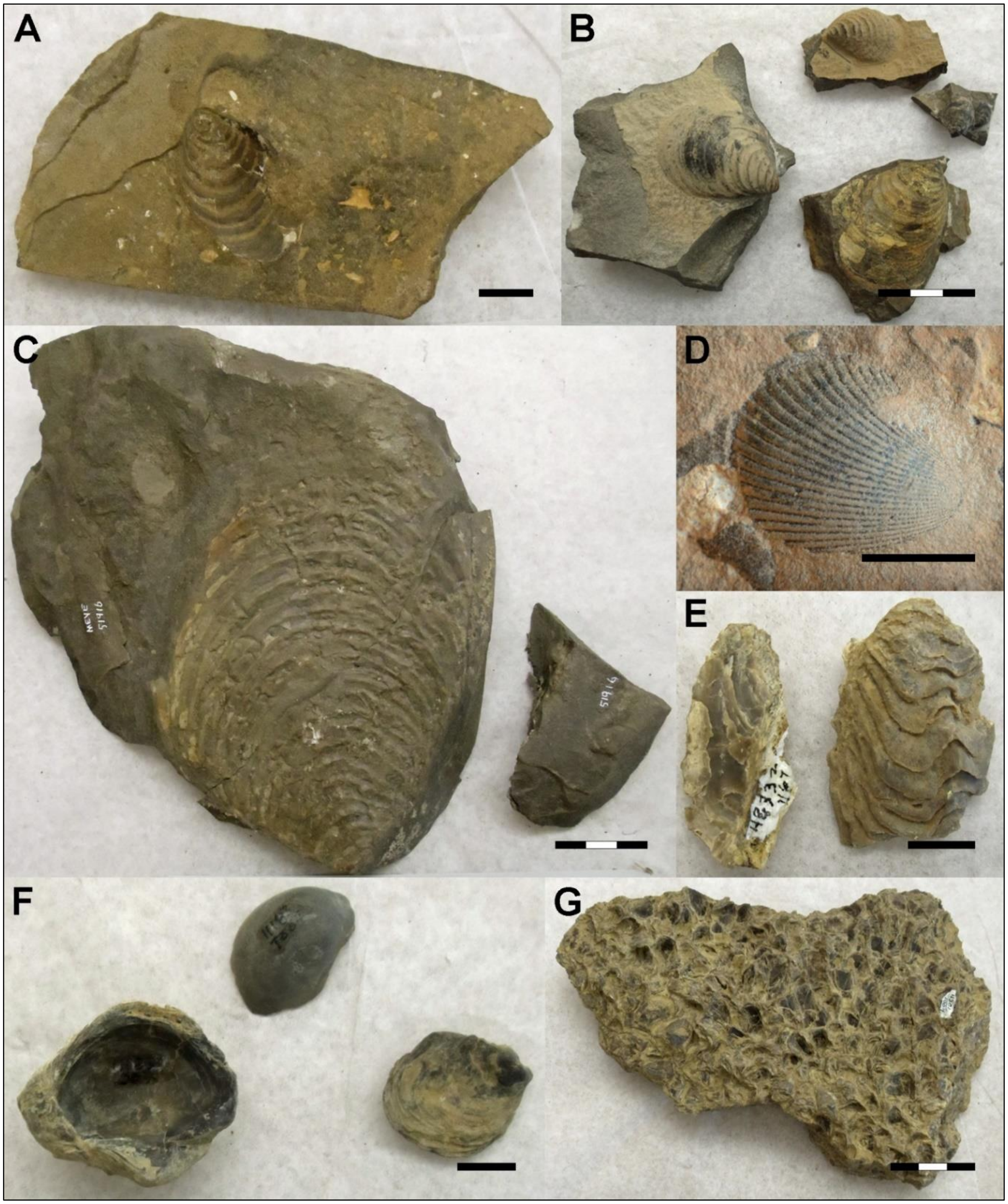

Figure 5. Figure 17 from Harrison et al. (2017) (NPS/G. WILLIAM M. HARRISON). Black bars are 1 cm; black and white bars are 3 cm. Only D and E are from the Cliff House Sandstone, but relatives of the other shells can be found in the formation. A) *Inoceramus perplexus* external mold from the Mancos Shale (MEVE 11242). B) *Inoceramus dimidius* cast from the Mancos Shale outside of MEVE (MEVE 78541). C) *Inoceramus subquadratus crenelatus* impression from the Mancos Shale (MEVE 51916). D) An *Ethmocardium* cast in the Cliff House Sandstone. E) Nearly complete *Ostrea russelli* from the Cliff House Sandstone of MEVE (MEVE 48332). F) Loose *Pycnodonte newberryi* likely from the Mancos Shale (MEVE 11183). G) A bed of *Pseudoperna bentonensis* from the Mancos Shale (MEVE 11301).

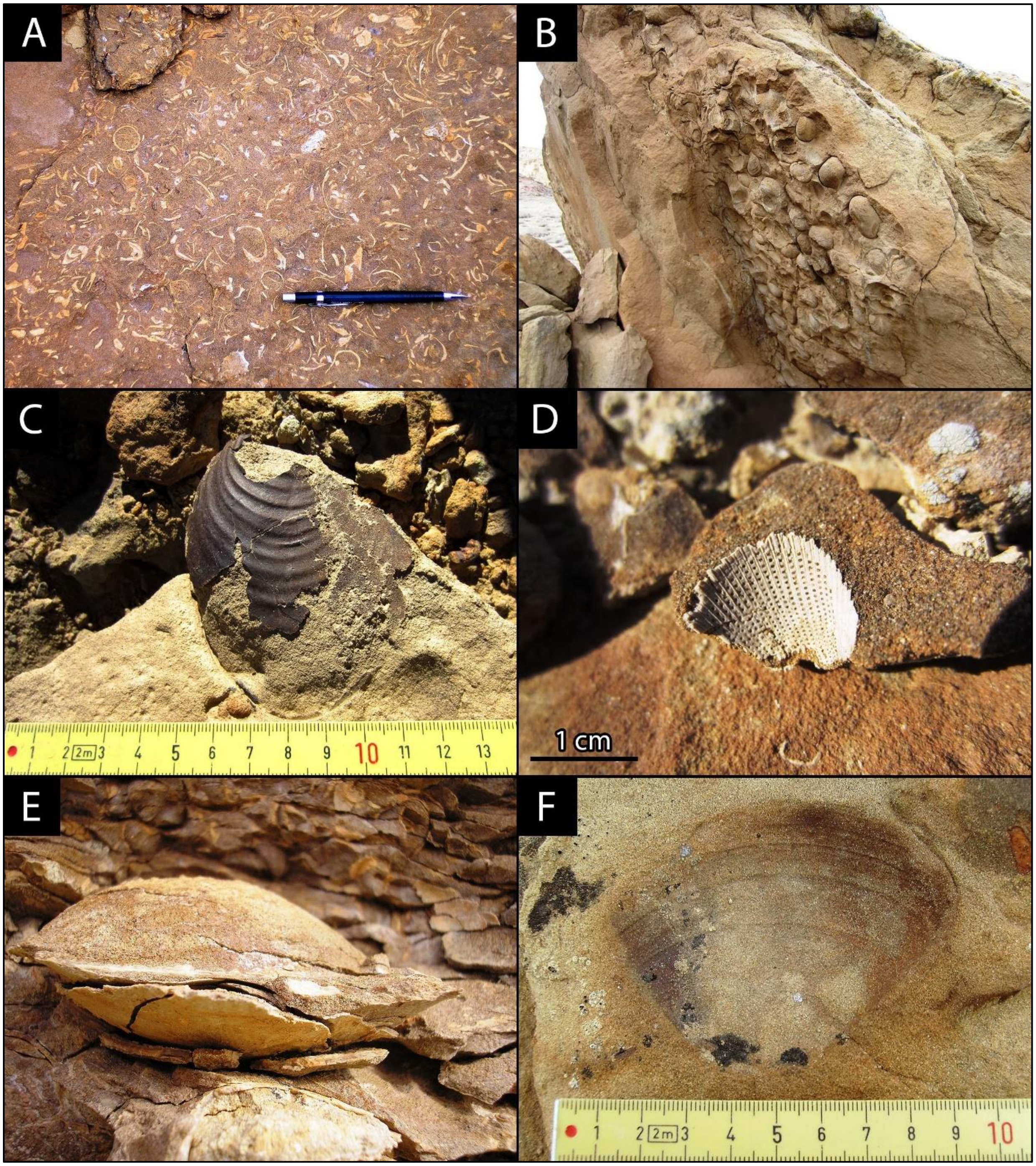

Figure 6. Figure 10 from Varela et al. (2019). Fossil bivalves in the Cliff House Sandstone of CHCU. A) Fossiliferous sandstone containing abundant invertebrate (bivalve and gastropod) fragments, typical of many lower and upper Cliff House Sandstone exposures (NPS/TOM LYTTLE); B) Molds and casts of *Inoceramus* accumulation in a fallen sandstone boulder (NPS/PHIL VARELA); C) Fossilized shell material of an *Inoceramus* (NPS/PHIL VARELA); D) Fossil shell material of cf. *Granocardium* (NPS/PHIL VARELA); E) Steinkern of fossil bivalve (NPS/TOM LYTTLE); F) Mold (impression) of fossil bivalve (NPS/PHIL VARELA).

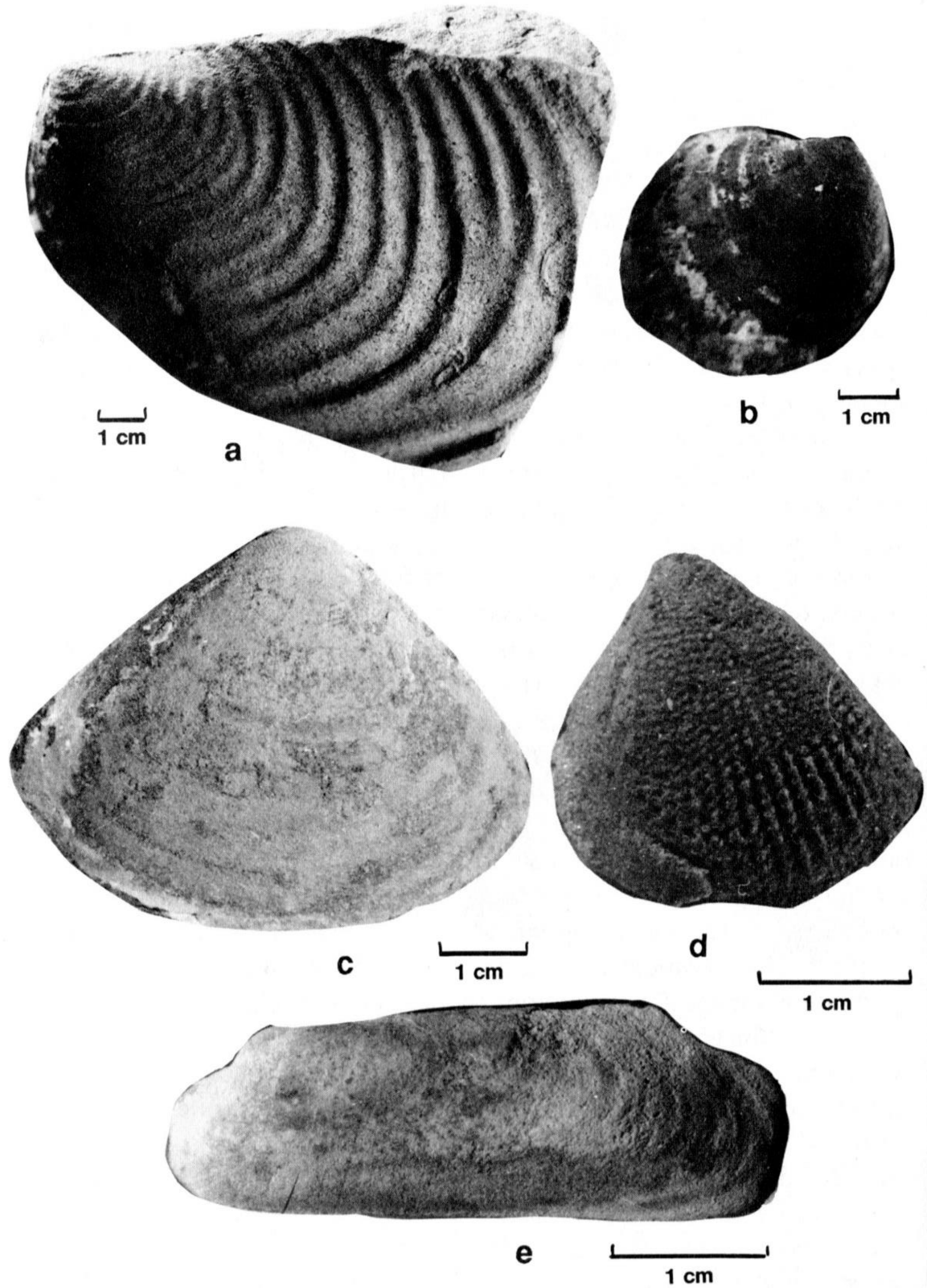

Figure 40. Some typical fossil clams of the Cliff House Formation: a.) ***Inoceramus*****; b.)** ***Dosinopsis*****; c.)** ***Cymbophora*****; d.)** ***Ethmocardium*****; e.)** ***Modiolus*****. One centimeter scale indicates size of specimen.**

Figure 7. Figure 40 from Griffitts (1990) showing several bivalves from the Cliff House Sandstone of the Mesa Verde area.

Mollusks: Ammonites

Two genera of ammonites have been identified from the Cliff House Sandstone of MEVE, and can be easily distinguished. One genus, *Placenticeras*, has the classic coiled shell shape (Figures 9A, 9C, 9E, 12A). Complete examples have a discoidal shape with the outer whorl overlapping the inner whorls. The divisions of the chambers are marked by squiggly sutures. The other genus, *Baculites*, had a long tapering shell, straight to slightly curved, and oval to pear-shaped in cross-section (Figures 8, 9B, 9D, 9F, 12B). As with *Placenticeras* the divisions of the chambers are marked by squiggly sutures. *Baculites* fossils are frequently found as disassociated pieces consisting of one or more internal casts of chambers. The complex sutures give these pieces a sinusoidal appearance in side view.

Figure 8. Figure 18 (G) from Harrison et al. (2017). A series of *Baculites* chamber casts from the Cliff House Sandstone of MEVE (MEVE 7257). Scale 1 cm (NPS/G. WILLIAM M. HARRISON).

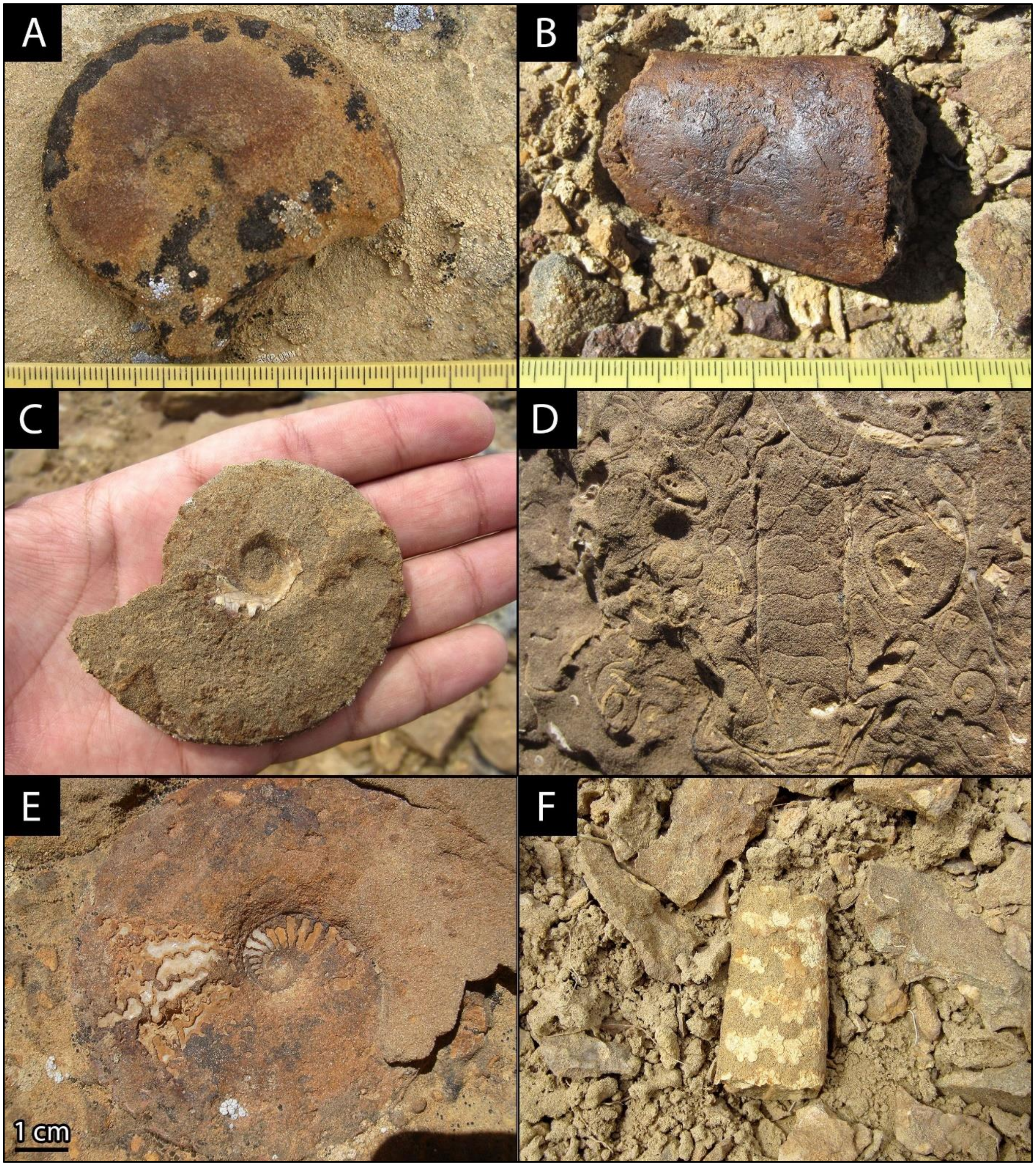

Figure 9. Figure 11 from Varela et al. (2019). Fossil cephalopods from the lower (Kchl) and upper (Kchu) units of the Cliff House Sandstone of CHCU (NPS/PHIL VARELA): A) Undetermined ammonite cast (CHCU 121701) (Kchu); B) *Baculites* sp. cast (CHCU 131419) (Kchu); C) Undetermined ammonite cast (Kchl); D) *Baculites* sp. impression (Kchu); E) Undetermined ammonite cast; F) *Baculites* sp. cast.

Mollusks: Gastropods

Snails are poorly known from the Cliff House Sandstone of MEVE. A few specimens are known which resemble a spiraling ice-cream cone (Figure 8). Snail fossils are frequently internal casts (steinkerns), which form when sediment fills an empty shell and the calcitic shell later is lost to chemical dissolution. As with bivalves, a much more diverse assemblage of snails is known from the Cliff House Sandstone at CHCU (Figure 9). They generally range in size from less than an inch to a few inches long. In hand sample, major differences include the ornamentation on the shell (if the shell is present) and how steeply the shell coils or spirals. Most of the snail shells that might be predicted at MEVE run the gamut from a tall, skinny spiral (as in *Mesalia* or *Turritella*) to a very low angle of coiling (as in *Solarium*). There are exceptions, though, such as the limpet-like *Anisomyon*; cap-like shell of this form can be mistaken for bivalve shells, but do not have hinges because they were single shells, not part of a pair. Most tall shells taper, but some do not, like *Holospira*, which looks something like a skinny beehive with an exhaust pipe. The outer whorl of the shell is sometimes exaggerated, giving the shell a bulbous scroll or jar-like appearance, such as in *Euspira*, *Gyrodes*, or *Haminea*. Part of the outer whorl can be extended into a point, such as in *Volutoderma* or *Volutomorpha*.

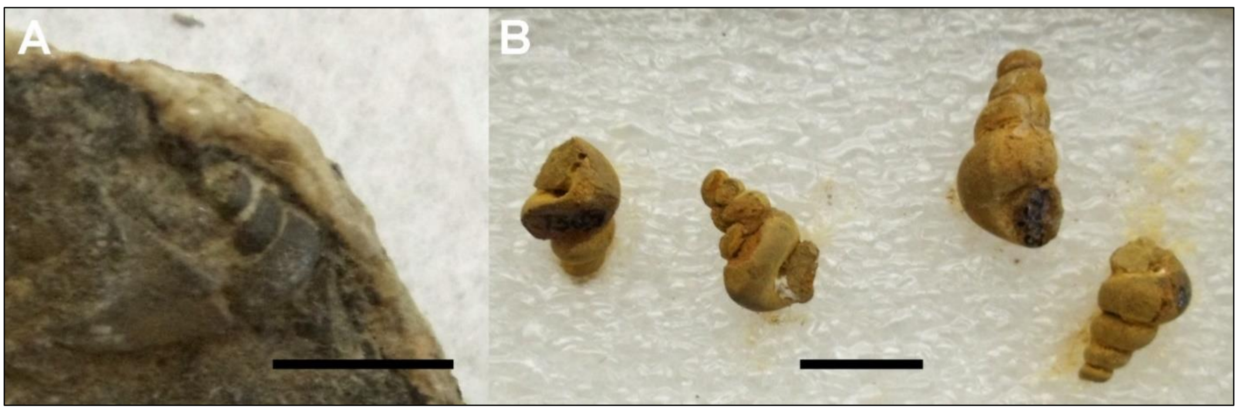

Figure 10. Figure 19 from Harrison et al. (2017). Gastropods (NPS/G. WILLIAM M. HARRISON). Black bars are 1 cm. A) *Turritella* cf. *whitei* collected by Mary Griffitts in the Mancos Shale (MEVE 71612). B) Gastropods from the Cliff House Sandstone of MEVE (MEVE 7301).

Other Invertebrates

Mollusks dominate the Cliff House Sandstone of the MEVE area, and few other invertebrate groups have been reported from the formation. Any specimens that are not mollusks would be notable. Miller et al. (1991), working outside of MEVE, briefly mentioned fossils of bryozoans, a type of colonial invertebrate. Bryozoans are notable encrusters, so they may be found as colonies on other fossils. They have sub-millimeter-scale pinprick-like pores that held the individual bryozoan animals. A Cliff House Sandstone asteroid (sea star) from MEVE or the immediate vicinity was illustrated in Griffitts (1990) (Figure 10E) and is a rare find because sea stars usually disaggregate into small fragments upon death. A specimen of the echinoid (sea urchin) *Hardouinia taylori* has been reported from CHCU (Siemers and King 1974; Varela et al. 2019); such a fossil would have a shape between a cone and a dome, with six small holes near the center of the flat side in a star pattern, a star shape with perforate loop arms on the convex side, and a large hole off-center from the loop star. Other echinoids would look broadly similar, with a bulbous body and features with five-sided symmetry.

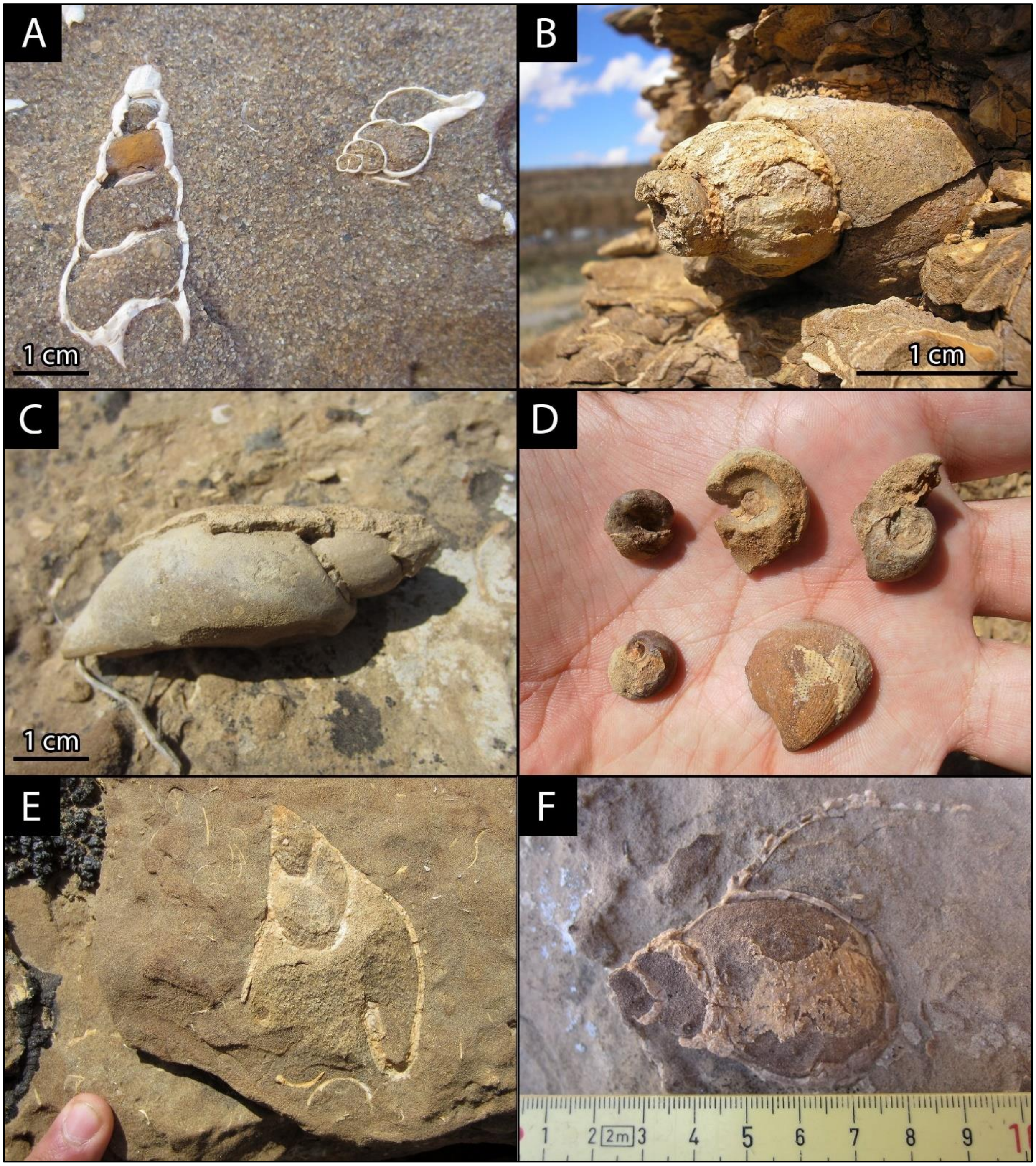

Figure 11. Figure 12 from Varela et al. (2019). Fossil gastropods from the Cliff House Sandstone of CHCU. A) Fossil gastropods *in situ* (NPS/PHIL VARELA); B) *Volutomorpha* sp. gastropod cast *in situ* (NPS/TOM LYTTLE); C) Fossil gastropod cast (NPS/PHIL VARELA); D) cf. *Gyrodes* sp. gastropod casts and cf. *Granocardium* sp. bivalve cast (NPS/PHIL VARELA); E) Fossil gastropod *in situ* (NPS/PHIL VARELA); F) Fossil gastropod *in situ* (NPS/PHIL VARELA).

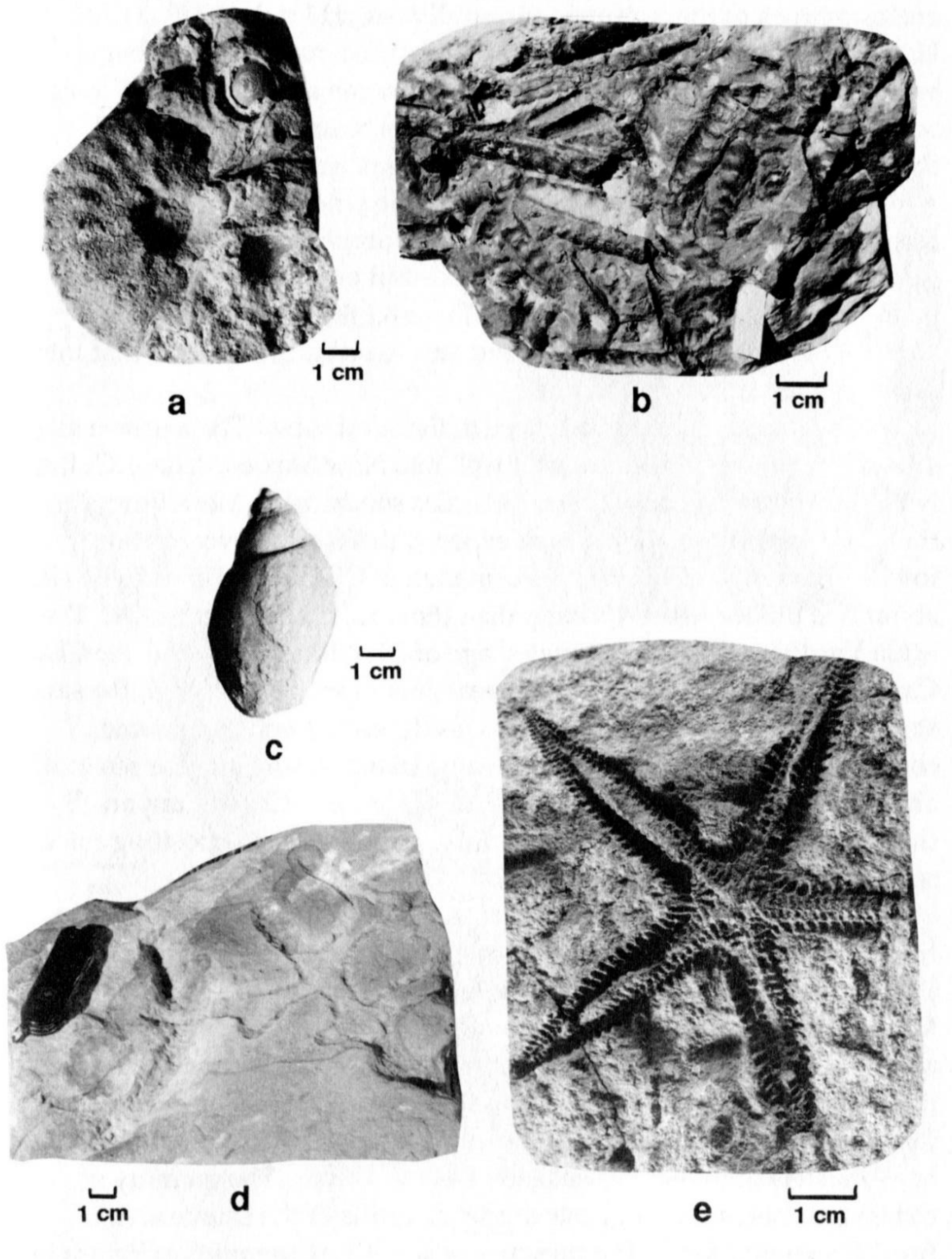

Figure 41. Invertebrate Fossils of Cliff House Formation: a.) tightly coiled, disc-shaped ammonites (*Placenticeras*); b.) slab with numerous straight ammonites (*Baculites maclearni*); c.) snail; d.) Crustacean burrows (*Ophiomorpha*); e.) starfish. One centimeter scale indicates size of specimen.

Figure 12. Figure 41 from Griffitts (1990) showing several types of non-bivalve invertebrates and other fossils from the Cliff House Sandstone of the MEVE area. Part d is labeled *Ophiomorpha* but is more typical of *Thalassinoides*.

Invertebrates other than mollusks are rare in general in the rocks of the Western Interior Seaway. Kauffman (1967, 1969) noted that sponges, corals, bryozoans, non-ammonoid cephalopods, barnacles and other crustaceans, and echinoderms were rare or essentially absent, and that even though gastropods were diverse, they were also rare in most assemblages. Several groups of invertebrates are potentially present as body fossils in the Cliff House Sandstone because they are known from trace fossils, or have been found in other Upper Cretaceous formations in the area. Photos of examples can be found on the online "Cretaceous Atlas of Ancient Life" (https://www.cretaceousatlas.org/). The information below summarizes the invertebrate paleontology of the Cliff House Sandstone.

- Sponges and annelid worms are poorly represented by body fossils, because of their soft bodies. However, their presence can be inferred by certain trace fossils (see "Trace Fossils" below). There is some potential for finding serpulid worm tubes, which are calcareous tubes constructed as dwellings by serpulid worms. These tubes would be most likely found encrusting shells and generally resemble small worms (mm-scale diameter) turned to stone.

- Brachiopods, also known as lamp shells because some resemble ancient oil lamps, are a minor constituent of Western Interior Seaway assemblages. Some are known from the Mancos Shale just outside of MEVE, including *Disciniscа* and *Lingula*. *Discinisca* shells are more round while *Lingula* shells are more ovoid to rectangular and tend to be smaller, but neither are usually much larger than 1 cm. Unlike mollusks, their shells are dark and glossy because they are made of a phosphatic material similar to our fingernails. Concentric growth lines are prominent.

- True nautiloid mollusks of the Western Interior Seaway are best represented by *Eutrephoceras*, which can be distinguished from coiled ammonites by its simple chamber sutures. It can further be distinguished from the ammonite *Placenticeras* by its bulbous rather than flattened shell. Detached *Eutrephoceras* chambers have a horseshoe-like appearance. This genus is known from many Western Interior Seaway formations.

- Scaphopod mollusks, also known as tusk shells, dwell at or within the seafloor and are known for their elongate conical shells, which are open at both ends and are generally gently curved. These shells are 15 cm (5.9 in) long or less, usually less than half of that. Although found in other Western Interior Seaway formations, they prefer soft substrates and therefore are unlikely to have been a major component of the Cliff House Sandstone fauna.

- Crustaceans, which include barnacles, crabs, lobsters, and shrimp, are not known from body fossils in the Cliff House Sandstone, but it is known that shrimp-like crustaceans were part of the fauna due to trace fossils (see below). Barnacles may be represented by individual plates or their entire nut-like bodies, and may be found attached to larger shells. Other crustaceans are unlikely to be found as complete specimens, especially considering the energetic sandy environment of the Cliff House Sandstone, but fragments of their limbs and carapaces may be present. Their phosphatic composition may give these thin pieces a dark appearance.

- Crinoids, also known as sea lilies (when attached to something) or feather stars (when free-living), are echinoderms which feed by filtering particles out of the water with a crown of arms attached to a central body called a calyx. The calyx in turn may or may not be connected to a hard object with a stalk. Practically the entire hard framework of a crinoid is made up of small disk- or column-like pieces (stalk, arms) or plates (calyx) which disassociate upon death. Free-floating crinoids are known from various Western Interior Seaway formations (*Uintacrinus*), so it is possible that crinoid fragments may be found in the Cliff House Sandstone. However, these pieces will be smaller than 1 cm (0.4 in) and therefore probably not immediately obvious.

Vertebrate Body Fossils

Isolated bones and teeth of marine vertebrates are the most likely vertebrate body fossils to find in the Cliff House Sandstone. The relatively high energy of the depositional setting makes it unlikely that complete skeletons will be found. Teeth are usually the most durable part of a skeleton, and in many groups of vertebrates the teeth are continually shed and replaced, making them abundant fossils. Shark teeth, ray teeth, bony fish teeth, and marine reptile teeth have all been found in the Cliff House Sandstone of MEVE (Harrison et al. 2017) and are also well-represented at CHCU (Varela et al. 2019). Teeth may be found in partial or complete jaw bones, which tend to be among the most durable bones of the skull due to their use in feeding.

The teeth of sharks and rays frequently have prominent roots supporting blade-shaped serrated teeth, sometimes with small accessory points at the base of the tooth (Figures 13, 15C, 16). Teeth of the shark *Scapanorhynchus* are typical (Figures 15C and 16F). The ray *Ischyrhiza* is represented by small pointed teeth (Figure 13D). Several other genera are represented in the Cliff House Sandstone at CHCU (Figure 16).

The bony fish *Enchodus* is represented at MEVE by elongate, spine-like teeth (Figures 14 and 15A). Mosasaurs, large marine reptiles, are represented by stout conical teeth at MEVE (Figure 17B). Mosasaur teeth may have distinct cutting edges with small serrations. Some mosasaurs that lived at the same time as the Cliff House Sandstone had distinctive bulbous peg- or marble-like teeth for crushing hard objects (*Globidens*), but they have not been reported from this formation yet. (Bulbous crushing teeth were also present in a group of sharks that went extinct before the Cliff House Sandstone, but which are found in older rocks in the MEVE area [Figure 13C].) Plesiosaurs, a second group of marine reptiles, are known from a few bones in the Cliff House Sandstone at MEVE, and so their teeth may also be present. Their teeth will resemble pointed conical mosasaur teeth. It can be difficult to distinguish between mosasaur teeth and plesiosaur teeth, especially if the tooth is fragmentary or otherwise poorly preserved, because the two groups overlapped in size and prey items. Plesiosaur teeth tend to be proportionally skinnier than mosasaur teeth, and although there are often ridges or wrinkles running the length of the tooth, there are no true serrated cutting edges.

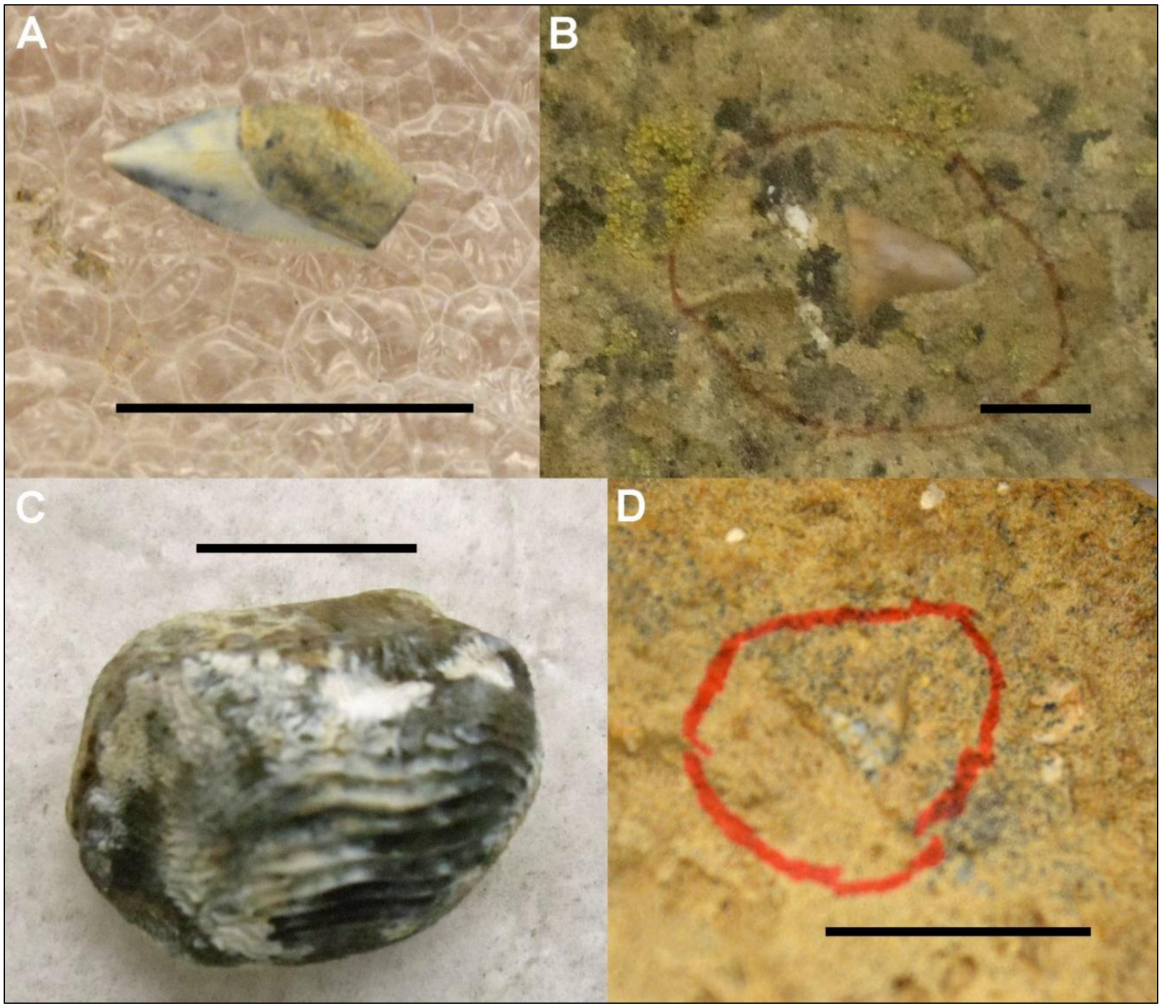

Figure 13. Figure 22 from Harrison et al. (2017). Teeth of cartilaginous fishes (NPS/G. WILLIAM M. HARRISON). Black bars are 1 cm. A) *Squalicorax* tooth from the Mancos Shale outside of Mesa Verde (MEVE 51220). B) Lamnid shark tooth likely from the Cliff House Sandstone (MEVE 73667). C) *Ptychodus decurrens* tooth from the Mancos Shale outside of Mesa Verde (MEVE 51222). *Ptychodus* probably crushed mollusks with its bulbous teeth, and appears to have gone extinct several million years before the deposition of the Cliff House Sandstone. D) *Ischyrhiza* tooth likely from the Cliff House Sandstone (MEVE 73670).

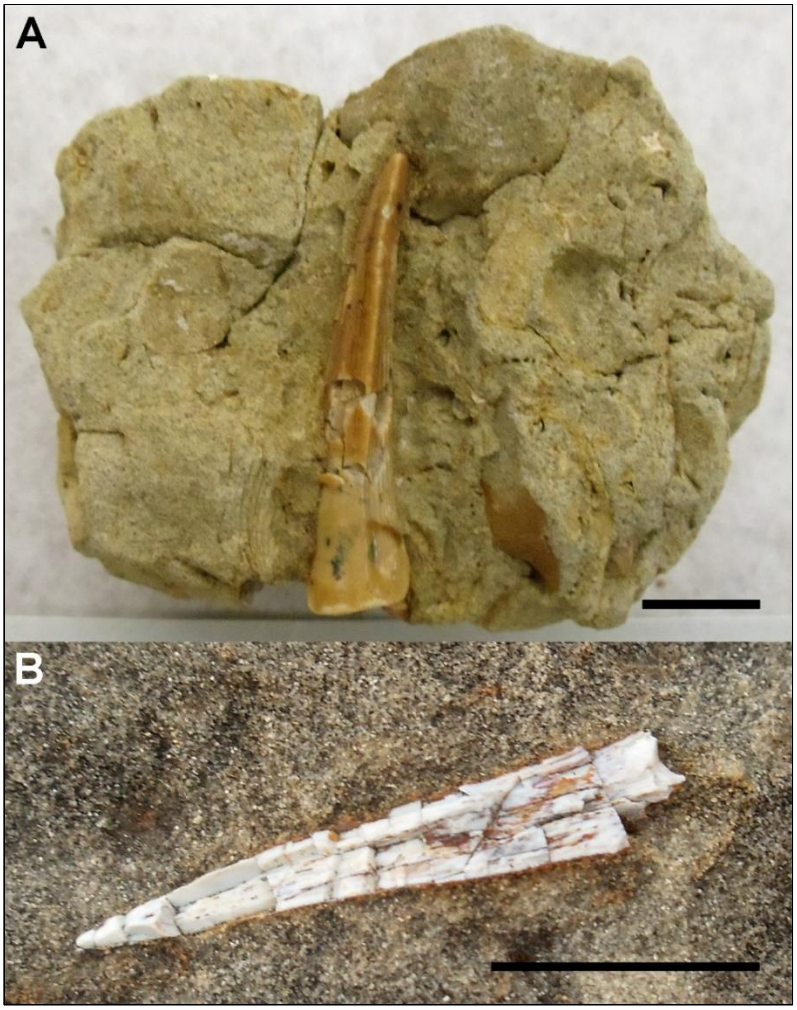

Figure 14. Figure 23 from Harrison et al. (2017). Teeth of bony fish. A) *Enchodus* tooth collected during the construction of the Chapin Museum (MEVE 43908) (NPS/G. WILLIAM M. HARRISON). B) *Enchodus* tooth as it appears in the field (NPS/GEORGE SAN MIGUEL). Both are from the Cliff House Sandstone in MEVE. Black bars are 1 cm.

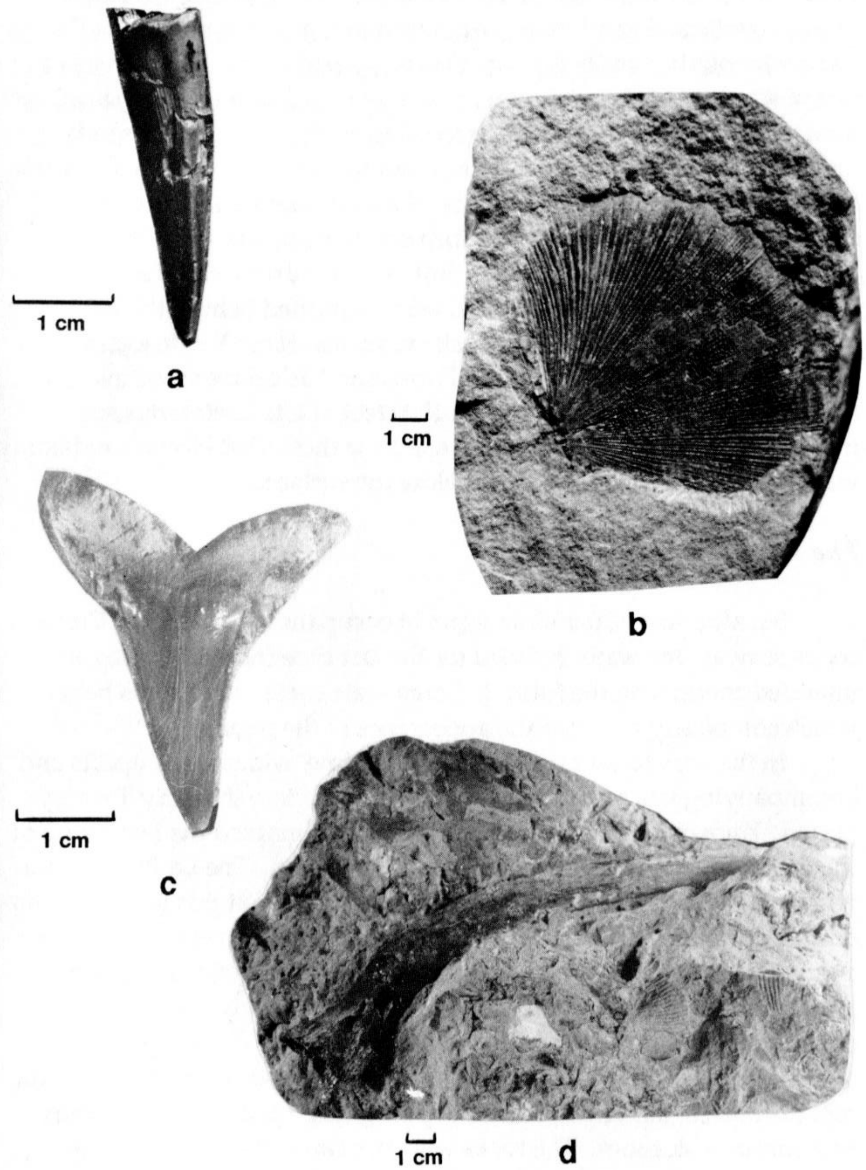

Figure 42. Some vertebrate fossils of Cliff House Formation: a.) tooth of large fish (*Enchodus*); b.) gill cover of large fish (*Enchodus*); c.) shark tooth (*Scapanorhyncus*); d.) rib of Plesiosaur or dinosaur (note impressions of small clams also). One centimeter scale indicates size of specimen.

Figure 15. Figure 42 from Griffitts (1990) illustrating typical vertebrate fossils known from the Cliff House Sandstone of the MEVE area.

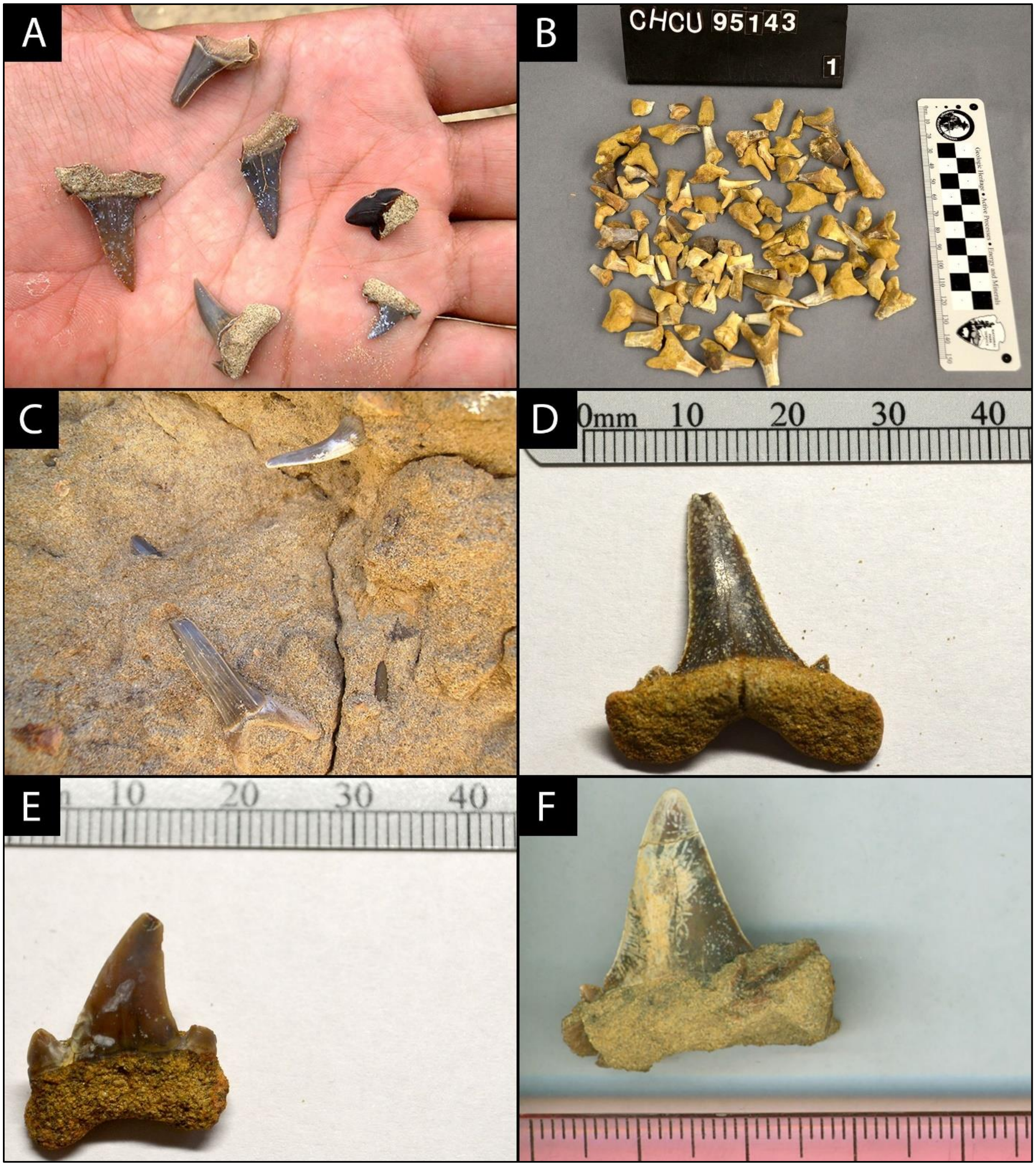

Figure 16. Figure 13 from Varela et al. (2019). Fossil shark teeth from the Cliff House Sandstone of CHCU (NPS/PHIL VARELA). A) Assorted shark teeth found in float including *Squalicorax* sp. and other unidentified shark teeth; B) Bulk collection of unidentified shark teeth (CHCU 95143); C) Undetermined shark teeth *in situ* eroding out of sandstone; D). cf. *Serratolamna* sp. shark tooth; E) *Archaeolamna kopingensis* shark tooth (CHCU 131416); F) *Scapanorhynchus texanus* shark tooth.

Bones are most likely to be isolated vertebrae (fish and reptiles) and partial to complete ribs, limb, and girdle bones (reptiles). Most vertebrae are composed of a cylindrical main body called a centrum and a series of projecting bony struts and spars, which vary depending on the animal and the position of the vertebra in the spinal column. These bony processes serve various functions such as articulating with other vertebrae, attaching to ribs or the pelvis, or providing anchor points for soft tissues such as muscles and ligaments. Processes may be broken off after death, especially if they are thin and spine-like, or may separate from their centrum because the animal was not fully grown and the bones were not fully fused. A centrum typically has a length-vs-diameter ratio between a hockey puck and a can of soup. It may have distinctive ridges and hollows. The ends of a centrum may be flat, convex, concave, or saddle-shaped, depending on the animal and position of the vertebra.

The classic fish vertebra has a centrum with a series of struts and troughs from one end to the other, and concave ends (Figure 18). The ends may be so deeply concave that a hole is present in the middle of the centrum. If the vertebra is well-preserved, it may show long spiny projections, but these are easily broken, leaving only the centrum. Most marine reptiles are much larger than fish, and so are their vertebrae, although some large fish overlap the body sizes of small and young marine reptiles. Marine reptile vertebrae also are not as strongly concave on the ends of the centrum, do not have elaborate struts and troughs on the centrum, and have sturdier projections. If the vertebra is not broken and came from an adult, there will be an arched feature attached to the centrum, often with several bony projections, that encloses a tubular passage which held the spinal cord (Figure 19C). Fish vertebrae also have this canal, but it is not as often seen because of damage.

Other than vertebrae, fish bones are uncommon or at least difficult to recognize as isolated bones, being mostly delicate ribs and fin rays; they are best seen in more complete specimens (Figure 18A). The limb bones and ribs of large reptiles are stouter and are known in small numbers from MEVE (Figures 15D and 17A) and CHCU (Figure 19). Reptile bones will have a brown color (Figures 17A and 19) and broken surfaces will often have a spongy texture, or may be splintering if the damage has just occurred. Pieces of cylindrical bones with curvature can be identified as partial ribs (Figures 15D and 17A). The bones making up the paddles of marine reptiles may be blocky to I-shaped, while the large limb bones (humerus or upper arm, and femur or thigh bone) are flattened and roughly triangular to elongate (plesiosaurs) or more dumbbell-shaped (mosasaurs). The shoulder girdles of mosasaurs and plesiosaurs are composed of broad flat irregular bones. This is also true of the plesiosaur hip but not the mosasaur hip, which is composed of smaller and more rod-like bones.

Other groups of reptiles may be found in the Cliff House Sandstone at MEVE. Turtles are known from this unit at CHCU (Varela et al. 2019) and are known for their dense bones. Western Interior Seaway turtles were enormous marine turtles and their shells were not solid throughout, but pieces of the shell may be found. Dinosaur bones are uncommon in nearshore sandstones, but isolated teeth (blade-like and carnivorous, or faceted and herbivorous) and bones may be present. Their limb bones can be distinguished from marine reptile limb bones because they are cylindrical. Marine avian dinosaurs such as the famous flightless toothed bird *Hesperornis* are another possibility; these bones may outwardly resemble modern bird bones but are much denser to decrease buoyancy. Scott et al. (2001) reported amphibians in the Cliff House Sandstone, but did not provide specifics.

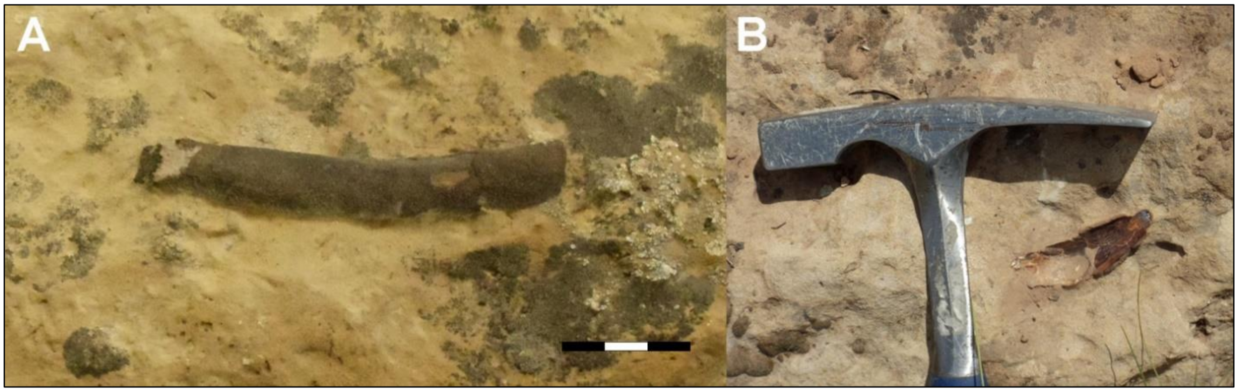

Figure 17. Figure 24 from Harrison et al. (2017). Reptile bones (NPS/G. WILLIAM M. HARRISON). A) Reptile bone collected from the Cliff House Sandstone (MEVE 10358). Black and white bar is 3 cm. B) Mosasaur tooth found in the Cliff House Sandstone above an alcove.

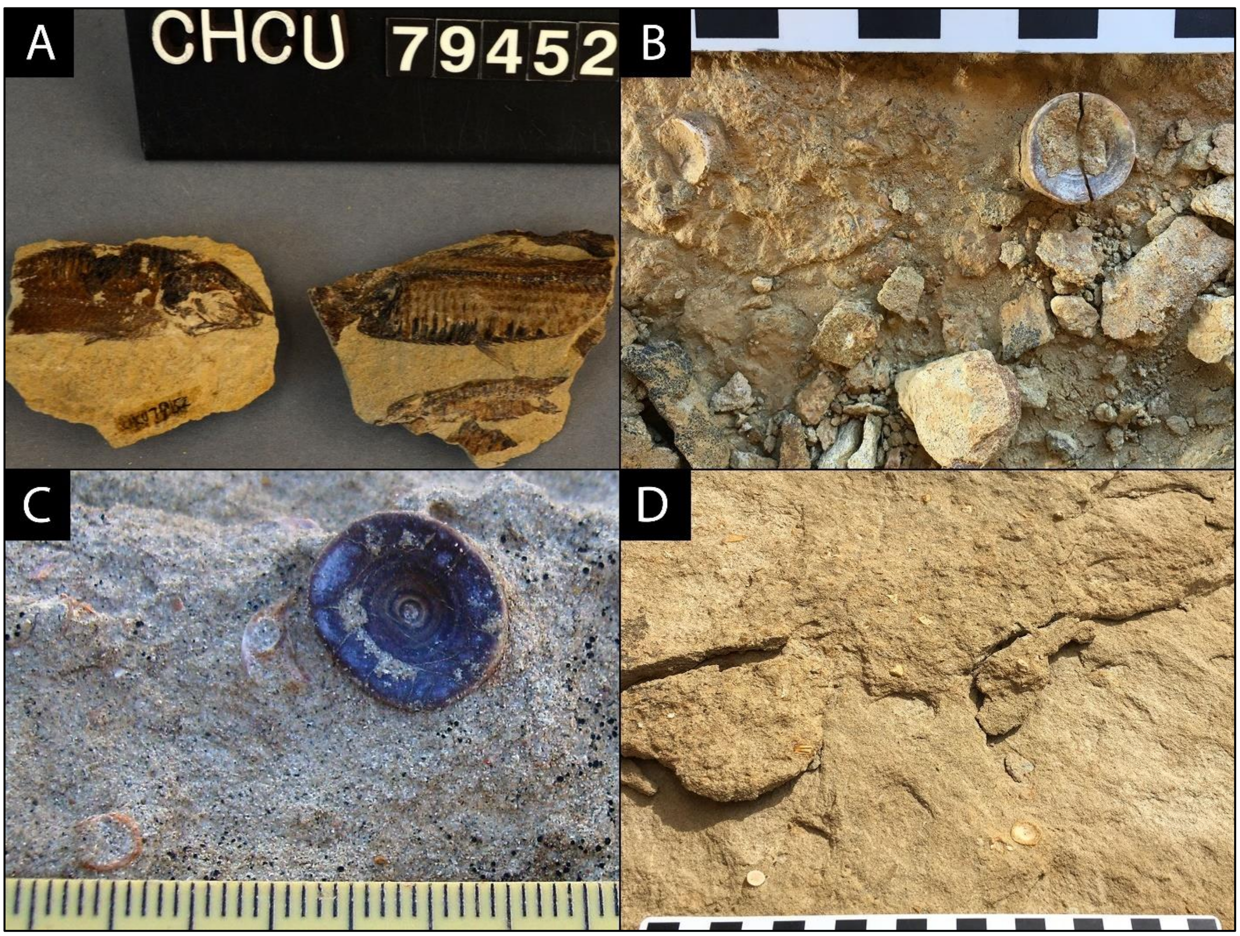

Figure 18. Figure 14 from Varela et al. (2019). Fossil fish from the Cliff House Sandstone of CHCU (NPS/PHIL VARELA). A) Clupeiform fish (cf. Paraclupeidae) (CHCU 79452); B) Unidentified fish vertebra; C) Unidentified fish vertebra *in situ*; D) Unidentified fish vertebrae *in situ* in a fossiliferous horizon.

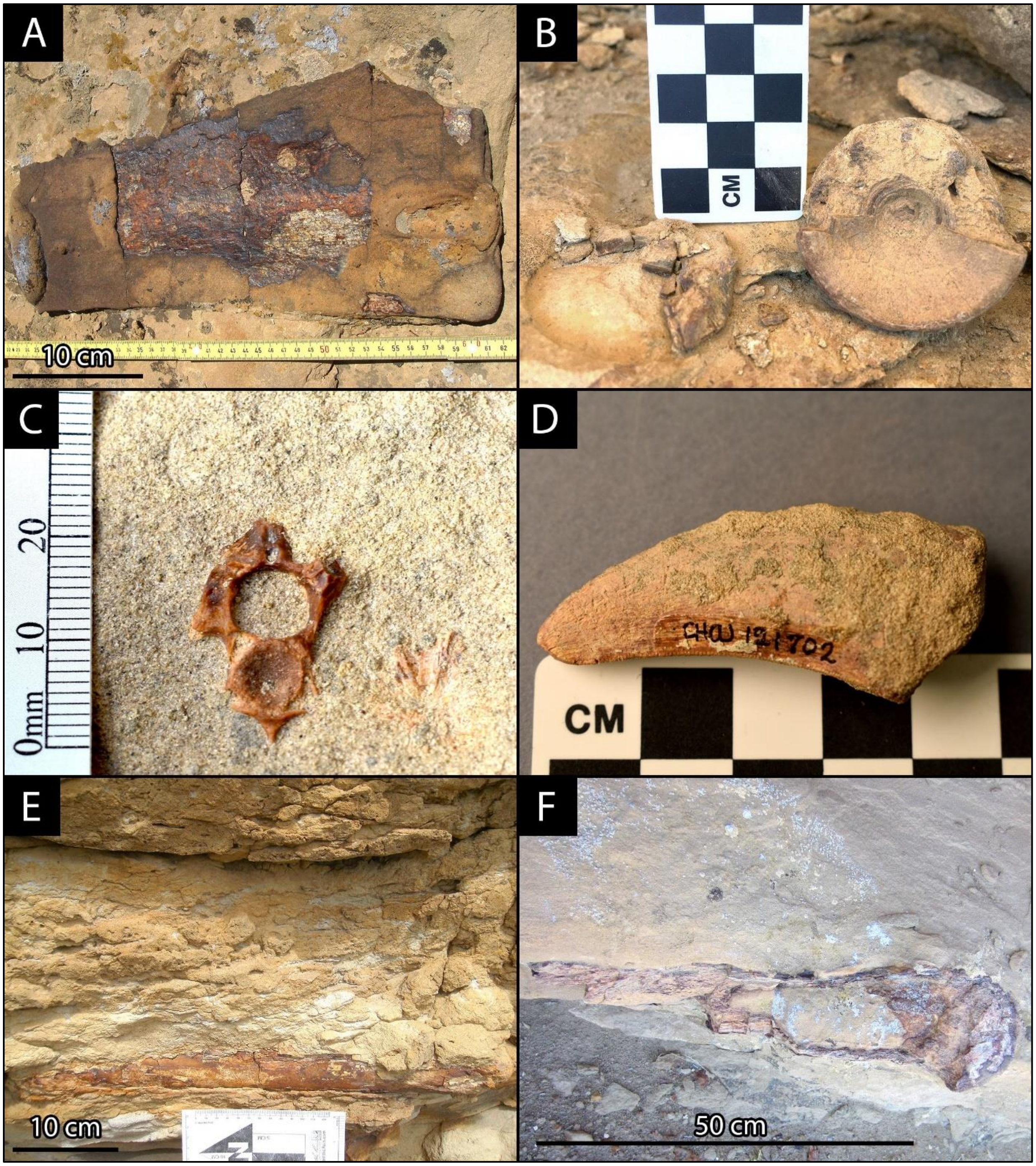

Figure 19. Figure 16 from Varela et al. (2019). Fossil Reptilia from the Cliff House Sandstone of CHCU. A) Possible plesiosaur humerus (NPS/PHIL VARELA); B) Vertebrae of undetermined marine reptile (NPS/PHIL VARELA); C) Vertebra of a turtle or bird (NPS/PHIL VARELA); D) Possible theropod dinosaur tooth (CHCU 121702) (NPS/PHIL VARELA); E) Long bone from undetermined marine reptile? (NPS/PHIL VARELA); F) Limb bone from undetermined reptile (NPS/PHIL VARELA).

Trace Fossils

Trace fossils, also known as ichnofossils, differ from body fossils in that they record the activities of living organisms, rather than parts of dead organisms. Trace fossils include types of fossils such as burrows, tracks, root traces and casts, coprolites (fossil feces), animal middens, nests, microbial structures, and under some definitions include eggs. Trace fossils are often more common than reported, because they are not usually familiar to inexperienced observers and are not usually the subject of detailed study. Invertebrate trace fossils often record the presence of soft-bodied animals or animals with few hard parts, which are otherwise poorly represented in the fossil record. The Cliff House Sandstone has primarily yielded trace fossils produced by invertebrates, because the marine setting would not have been appropriate for plant roots or vertebrate footprints, but chimaera (ratfish) egg cases have been found.

Three kinds of invertebrate trace fossils have been reported by scientific name from the Cliff House Sandstone of MEVE, but there are doubtless others. Distinguishing kinds of invertebrate traces can be difficult, but fortunately each of the three known from MEVE is very distinctive in some way. Burrows called *Ophiomorpha* (Figures 20E and 20F) often have a surface texture resembling corn-on-the-cob because the burrowing animal (a kind of shrimp-like crustacean) would pack fecal pellets into the walls as a structural support. If this surface texture is missing, the burrow will look like a simple tubular structure. *Ophiomorpha* can be many inches long and more than an inch in diameter. Burrows called *Thalassinoides* form three-dimensional “boxwork” networks of branching tubular burrows. *Thalassinoides* burrows are similar in scale to *Ophiomorpha* burrows, and may have been made by the same kind of animals. Finally, burrows called *Teredolites* (Figures 20C and 20D) are simple short flask-like burrows typically found in groups in pieces of fossil wood. They were made by shipworms, which despite the name are actually specialized bivalves with reduced shells. All three of these types of burrows are produced by animals that still exist today, which allows comparisons between modern and ancient environments.

Several other kinds of invertebrate trace fossils have been reported from the Cliff House Sandstone of CHCU, and therefore may be found at MEVE eventually. These include the simple branching root-like burrow *Chondrites*; *Gyrochorte*, which is composed of two parallel adjacent furrows; and two types of borings, made by clionid sponges and polydorid worms. These animals bore into hard substrates, including shells. Sponge borings are typically single holes 1 mm or smaller in diameter. The worm borings are also diminutive, but can be distinguished because they typically have the form of a figure-8 or a pair of glasses, representing paired openings of a tight U-shaped burrow.

A rare and unusual type of vertebrate trace fossil has been reported from the Cliff House Sandstone of MEVE: egg cases of ratfish (Figure 20B). These egg cases are elongate ovoid objects with strong ribbing resembling the veining of a leaf and a central rib marked by a depression.

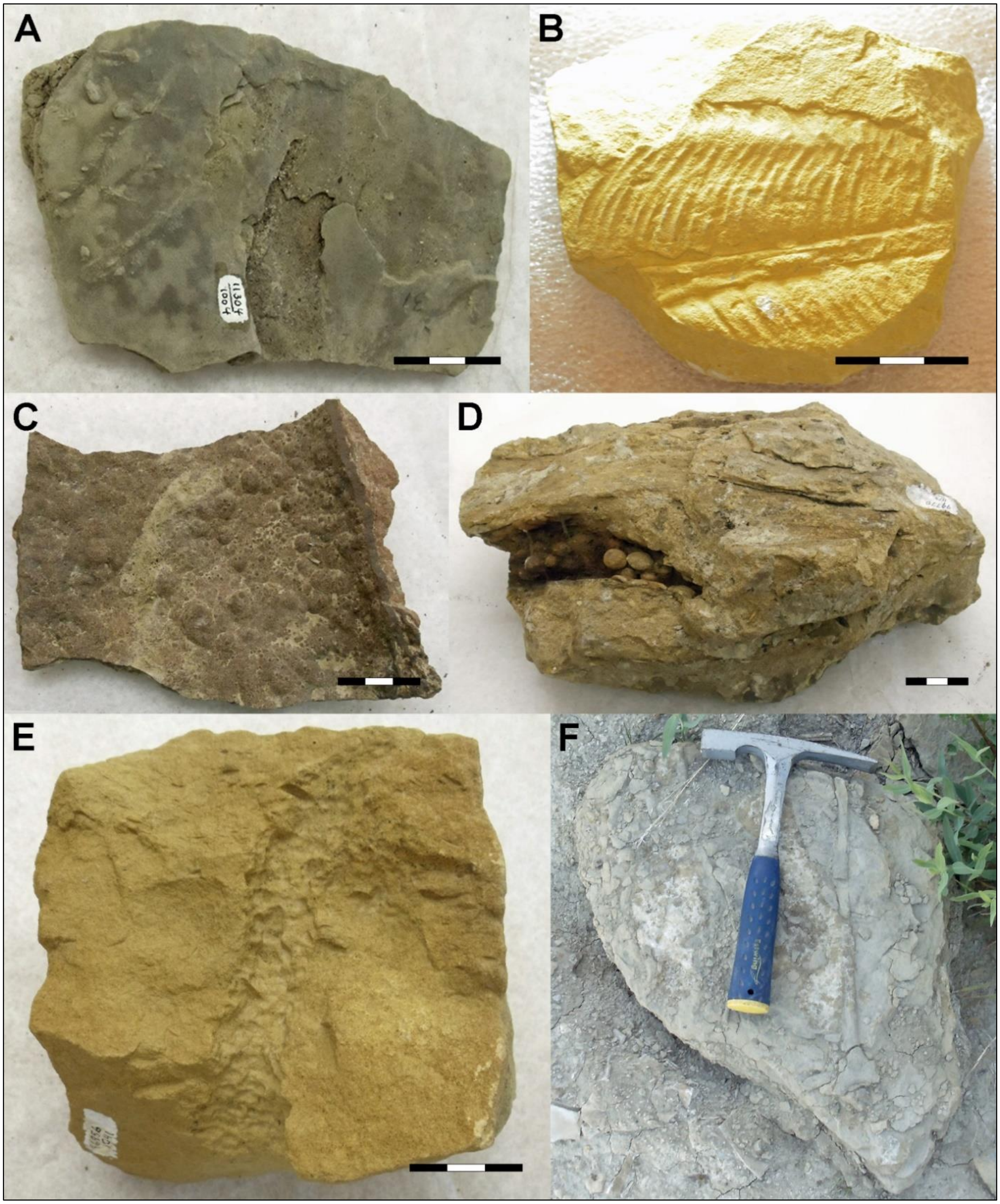

Figure 20. Figure 25 from Harrison et al. (2017). Ichnofossils from MEVE (NPS/G. WILLIAM M. HARRISON). Black and white bars are 3 cm. A) Crustacean tracks found in MEVE (MEVE 11304). B) A ratfish egg capsule discovered in the Cliff House Sandstone in 2015. C) *Teredolites* discovered in the Cliff House Sandstone (MEVE 10342) and D) Menefee Formation (MEVE 99778). E) *Ophiomorpha* burrow external molds in the Cliff House Sandstone (MEVE 46956) and F) casts in the Point Lookout Sandstone.

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Additional images of the fossils discussed here and similar fossils from Western Interior Seaway rocks can be found at https://www.cretaceousatlas.org/ and http://oceansofkansas.com/.

Appendix A

Potential Alternatives

Mesa Verde Loop Roads Project

Mesa Verde National Park (Mesa Verde NP or park), located in southwestern Colorado, encompasses 52,485 acres. The park is easily accessible from US Highway 160, from the Durango area, 35 miles (56.3 km) to the northeast, and the city of Cortez, 7 miles (11.3 km) to the west. Most park visitors, approximately 600,000 annually, travel the Mesa Top Loop, Cliff Palace Loop, and Sun Temple Loop roads (historically and collectively called "Ruins Loop Road"). See figure 1.

The National Park Service (NPS), in cooperation with the Federal Highway Administration (FHWA), is proposing to rehabilitate three loop roads, improve physical accessibility at adjacent overlooks, sidewalks and parking areas, and replace the current Visitor and Research Center intersection. The NPS is also considering widening the two-way sections of Mesa Top Loop and Sun Temple Loop roads to accommodate a bike lane.

The roads are built on unstable rock and clay ridden terrain. The soils are subject to rapid expansion, shrinkage, and slippage during wet weather. The road base has been damaged from water infiltration, and the pavement on the roadway is settling, cracking, and breaking apart. The traction course has been worn away making surfaces slick during snows. Years of patching and applying overlays has created over steepened and uneven shoulders.

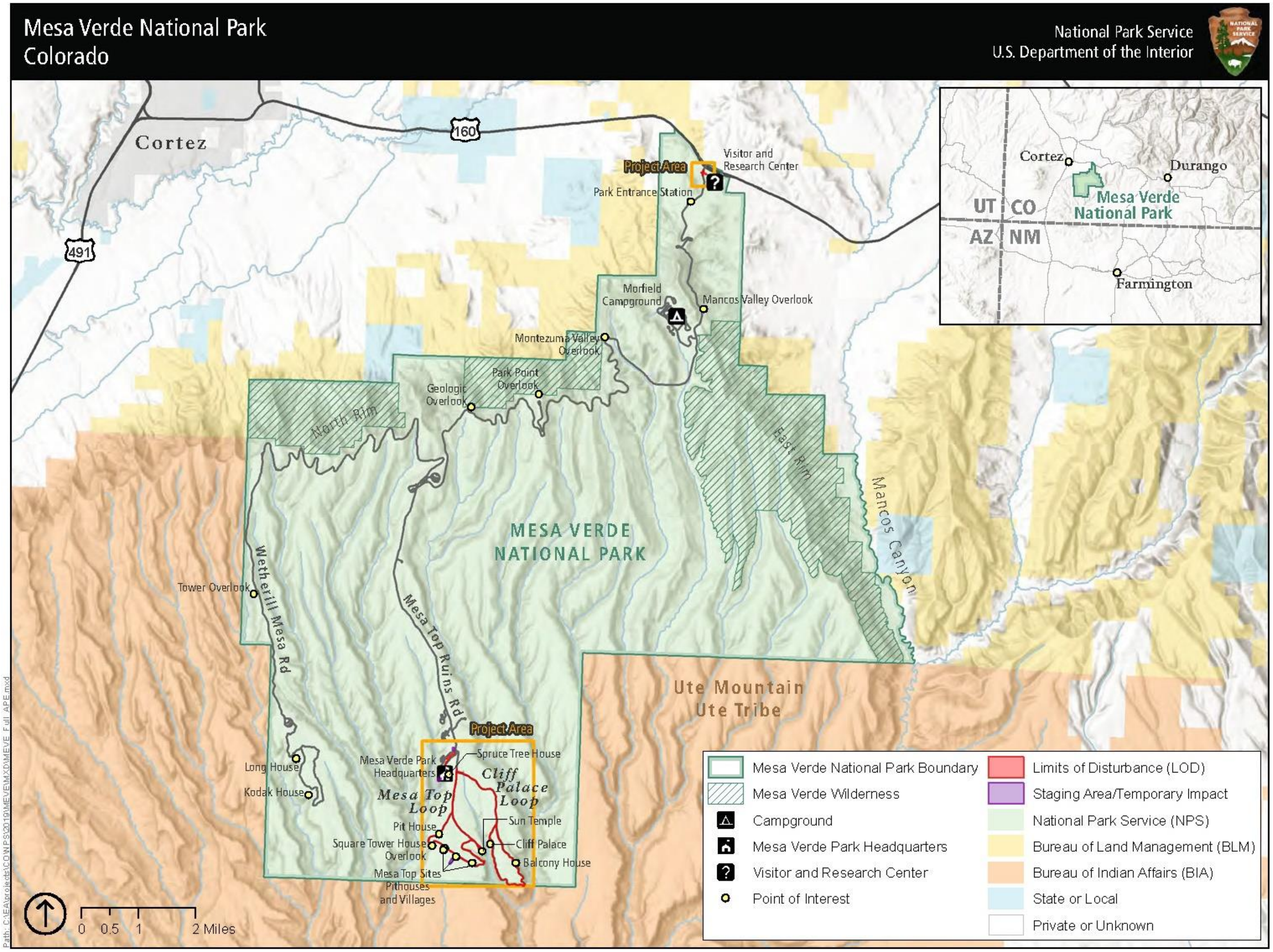
Description of the Alternatives

This document includes three alternatives: the no action (alternative A) and two action alternatives (alternatives B and C). The elements of these alternatives are described in the following sections and a comparison of the alternatives is presented in table 1. In addition, this document also describes the alternative elements that were considered but dismissed from detailed analysis (table 2).

Alternative A – No-action Alternative

Mesa Top Loop Road is 4.7 miles (7.6 km), Cliff Palace Loop Road is 4.1 miles (6.6 km), and Sun Temple Loop Road is 0.4 miles (0.6) long. Approximately 0.8 miles (1.3 km) of Mesa Top Loop Road is two-way, and the remainder is a one-way loop. The Cliff Palace Loop Road has approximately 1.5 miles (2.4 km) of two-way road and a 2.6-mile (4.2 km) one-way loop. The Sun Temple Loop Road has 0.1 mile (0.16 km) of two-way travel with the remainder comprising a one-way loop. Numerous overlooks with parking lots, rest rooms, picnic areas, shade structures, and sidewalks are accessed from the loop roads.

The loop roads were last resurfaced in 1998. Since then, they have degraded from water infiltration through cracked and worn pavement. Blade patching and overlays applied over the years have created over steepened and dangerously uneven shoulders. There is currently a four-way intersection at the park entrance for accessing the Visitor and Research Center, the entrance station/kiosks, Highway 160, and the park's water treatment plant. The four-way intersection is off-set (the roads to do not intersect at 90-degree angles) (figure 2). Traffic entering the park to the entrance station does not stop, while all other traffic is required to stop. The off-sets and stop signs can be confusing for drivers and have led to several near-miss accidents. Under the No-action alternative, the roads would not be rehabilitated, failing sections would continue to be patched, and the Visitor and Research Center intersection would not be altered.



Appendix A Figure 1. Vicinity Map and Project Area.

Appendix A Figure 2. Current Park Entrance

Alternative B – 3R Alternative

The term 3R stands for resurfacing, restoration, and rehabilitation projects. 3R projects typically involve pavement improvement work (short of full-depth replacement) and targeted safety improvements. Alternative B would represent a 3R road project involving Mesa Top Loop, Cliff Palace Loop, and Sun Temple Loop roads and the intersection at the park entrance. Elements of this alternative are described in the following paragraphs and presented in figure 2.

Loop Roads. Under alternative B, the current lanes of the Mesa Top Loop, Cliff Palace Loop, and Sun Temple Loop roads would be widened to 10.5 feet (3.2 m) to meet standards and grading and elevation issues (super-elevations) would be fixed. All worn and failing road surfaces would be replaced, including associated parking lots. This would include road base repairs on all lanes, replacement or repair of failing drainage systems, resurfacing pull-outs, and shoulder repairs. All resurfacing would be accomplished by recycled overlaying processes, which would level and smooth defects. After resurfacing, lane marking would be replaced. Informal pull-outs would be either formalized and paved in asphalt or eliminated and revegetated.

Sidewalks and Overlooks. Asphalt sidewalks along Mesa Top Loop, Cliff Palace Loop, and Sun Temple Loop roads would be replaced with colored concrete sidewalks and curbs and ABA ramps. Asphalt pavement at the overlooks would also be replaced with colored concrete pavement. A new accessible ramp would be constructed at Sun Point Overlook on Mesa Top Loop Road. Other accessibility improvements, such as modifications to ramps and leveling walking areas at overlooks, would be completed if the work can be accomplished without causing adverse impacts to historic properties.

Shade Structure at Balcony House. The existing Juniper shade structure above Balcony House would be removed during construction of the sidewalk, and a new shade structure would be constructed. The new structure would be the same size as the existing structure.

Headquarters Infield Parking and Walkway. The developed portion of the infield (gravel parking lot used by park and concessioner staff) on the Headquarters Loop Road would be converted to a parking area that would be open to the public and accommodate approximately 60 vehicles. Millings from the asphalt removed from the existing road would be used to create the parking area at the infield. Concrete wheel stops would be placed to delineate the parking area and indicate angled parking. A metal gate would be installed at the south end of the parking lot to discourage people from driving/walking on the unpaved section of the infield parking lot (the remnants of the old road). This parking area would not expand the footprint of the existing developed area (0.7 acre). This additional parking may be needed due to the increased dwell time anticipated once the Spruce Tree house is re-opened. The utilities at the infield—water and electric—would be avoided, and existing swales and ditches would be cleared of vegetation and rocks to restore drainage functions.

There is an existing asphalt trail (approximately 800 feet; 244 m) that originates on the eastern side of the infield parking lot. A new walkway would be constructed connecting this existing trail to the concrete sidewalk north of Spruce Tree Terrace. The new walkway would be an asphalt trail approximately 160-feet (48.8 km) long by 5-feet (1.5 km) wide that would travel through a wooded area. At the end of the asphalt trail, a sidewalk of natural gray concrete 25-feet (7.6 km) long by 5-feet (1.5 km) wide would be constructed parallel to Headquarters Loop Road to connect to the exiting concrete sidewalk north of Spruce Tree Terrace. The corridors for these routes will be 9-feet (2.7 m) wide to account for construction activities. A wood, two-rail fence would be installed on the downhill side of the new asphalt trail to discourage visitors from creating social trails through the native vegetation. Signage would be installed, as appropriate, to direct visitors from the infield parking lot to the Headquarters Area, and from the Headquarters Loop Road to the infield parking lot.

Entrance Roundabout. The existing off-set four-way intersection at the park entrance, Visitor and Research Center, and water treatment plant access road would be improved with a roundabout (figure 4).

Staging Areas. Three potential staging areas could be used during construction. These include the overflow parking lot in the Headquarters Loop Road, northwest of the Headquarters four-way intersection (burn pile), and in the Chapin Mesa Material Storage Yard. Staging areas would be confined to previously disturbed areas. Staging may also take place on the roads.

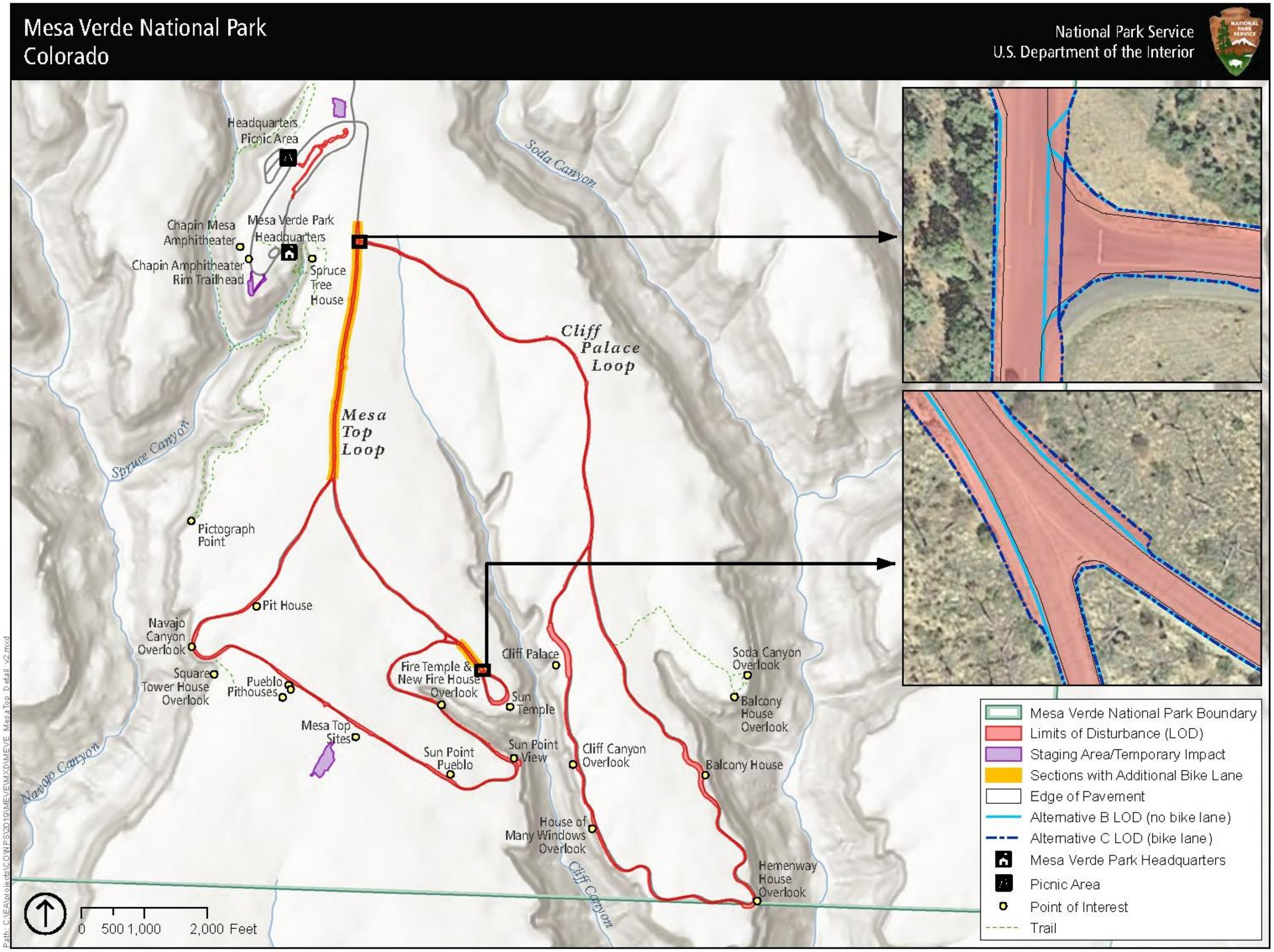
Alternative C – 3R Plus Bike Lane Alternative

Alternative C would be the same as alternative B, but this alternative would include the addition of bike lanes. Approximately 0.8 mile (1.3 km) of Mesa Top Loop Road and 0.1 mile (0.16 km) of Sun

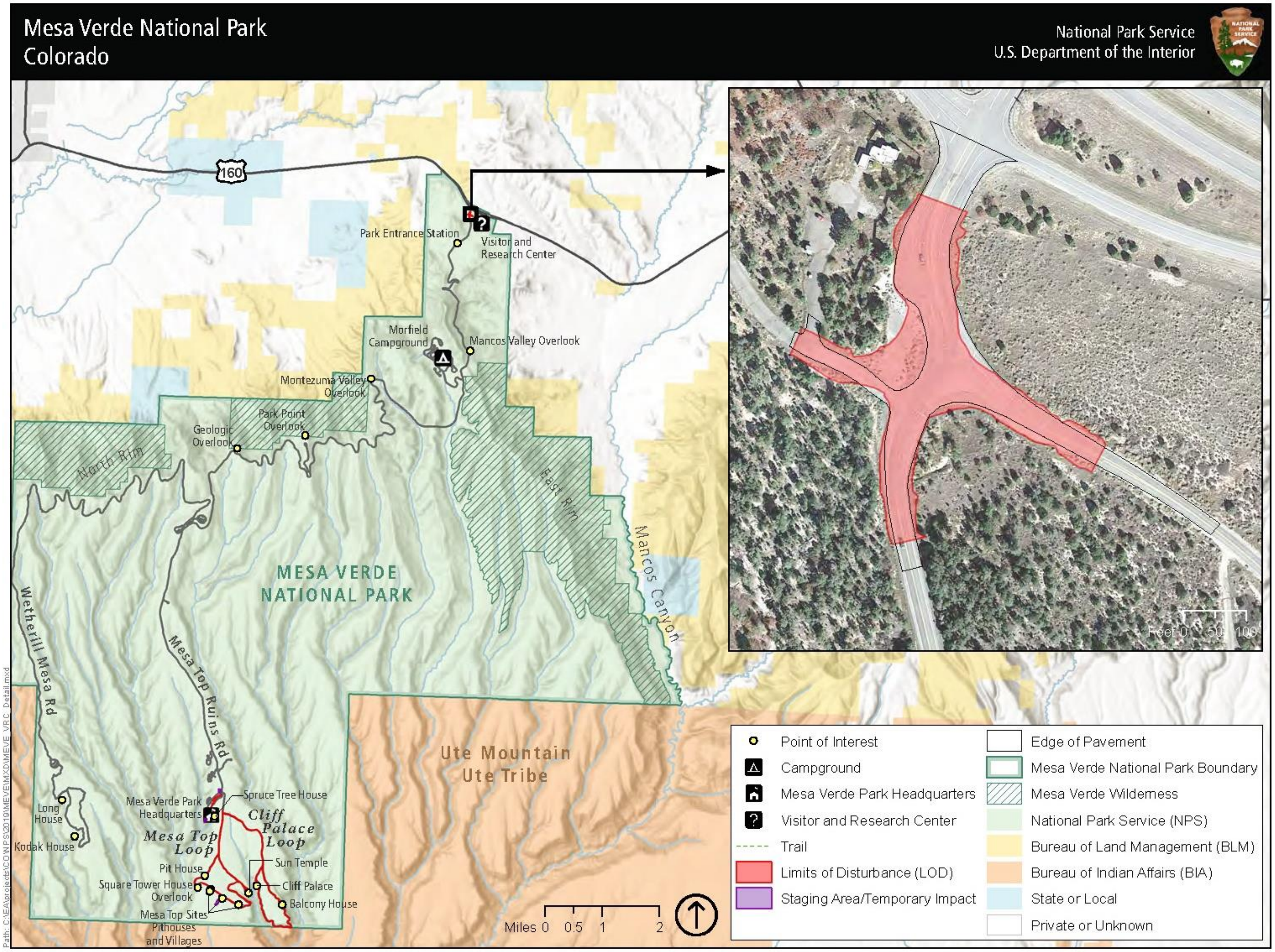
Temple Loop Road would be widened to accommodate a 4-foot (1.2 m) bike land on both sides of the two-way traffic portion of the roads. A bike lane would be striped along the one-way sections of these loop roads; however, widening of the road would not be required. Figure 3 shows the portions of Mesa Top Loop and Sun Temple Loop roads that would be widened for the bike lanes.

Common to Both Action Alternatives

The direction of the one-way traffic flow around Headquarters Loop Road may be changed during construction only. This would be to reduce construction and visitor traffic conflicts.



Appendix A Figure 3. Loop Road Sections showing 3R and 3R plus Bike Lanes



Appendix A Figure 4. Intersection at the Park Entrance

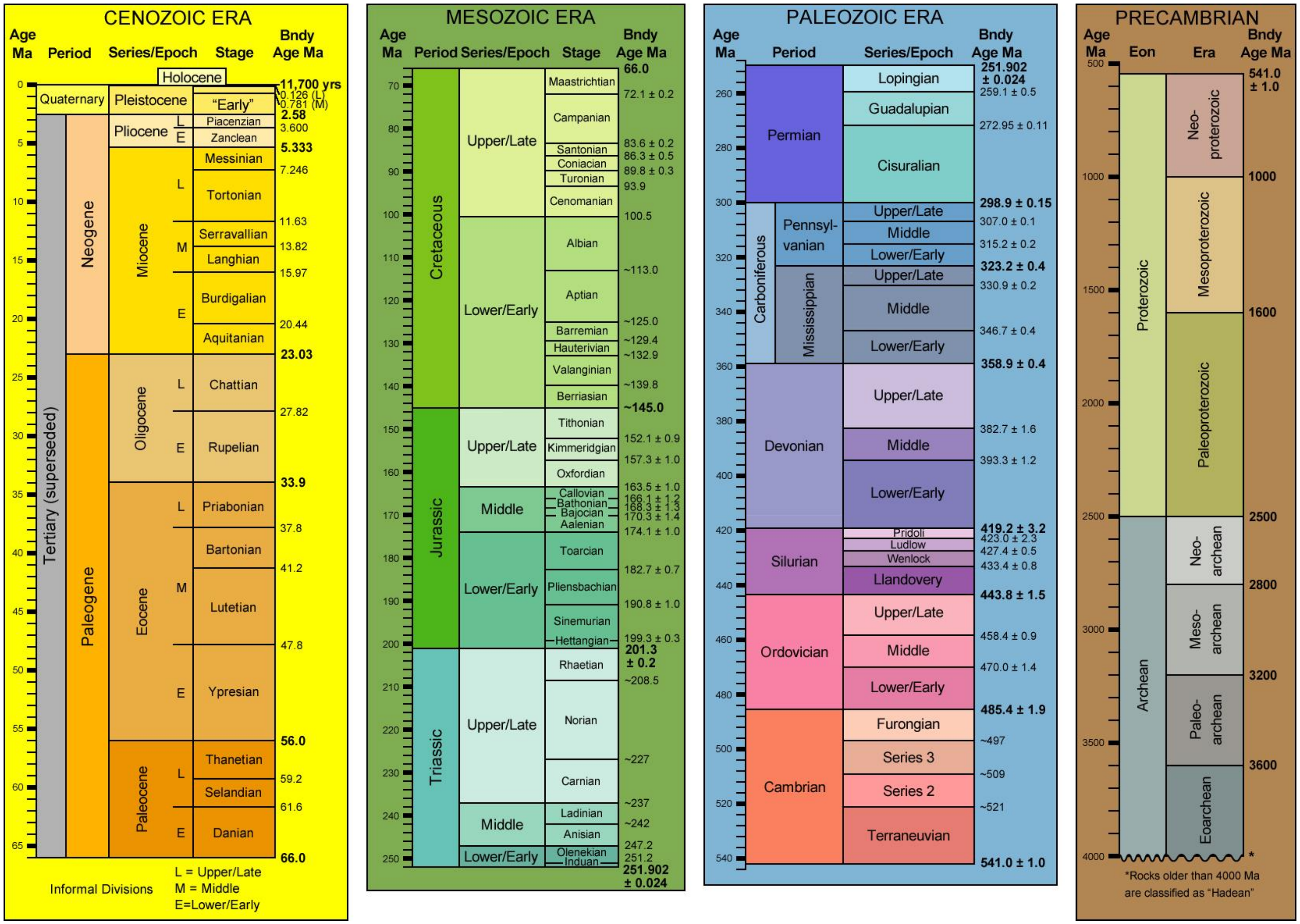
Appendix A Table 1. Comparison of the Alternatives

Element	Alternative A: No-Action Alternative	Alternative B: 3R Alternative	Alternative C: 3R Plus Bike Lane Alternative
Loop Roads Improvements	The loop roads would not be rehabilitated. Failing sections would continue to be patched.	Rehabilitate the Cliff Palace Loop and Mesa Top Loop roads, sidewalks, and parking areas.	Same as Alternative B
Visitor and Research Center intersection	Visitor and Research Center intersection would not be altered.	Replace the current Visitor and Research Center intersection with a roundabout.	Same as Alternative B
Accessibility	N/A	Improve physical accessibility at adjacent overlooks.	Same as Alternative B
New Bike Trail	N/A	N/A	Widen the two-way sections of Mesa Top Loop and Sun Temple Loop roads for a bike lane
Shade Structure	N/A	Replace the deteriorating shade structure adjacent to the Balcony House parking area (Cliff Palace Loop Road)	Same as Alternative B
Parking Lot at the Infield Area	N/A	Rehabilitation of the existing gravel parking lot in the Headquarters "infield" area (to accommodate longer dwell times). Construct trail to connect infield parking with Spruce Tree Terrace sidewalk.	Same as Alternative B
Staging Areas	N/A	Staging areas for equipment and materials along the road and in parking lots	Same as Alternative B
Change in Traffic Flow	N/A	The one-way traffic flow direction around Headquarters Loop road may be changed during construction only, to reduce traffic conflicts.	Same as Alternative B

Appendix A Table 2. Alternative Elements Considered but Dismissed

Alternative Elements Considered	Reason for Dismissal
Rehabilitate the loop roads with no improvements to sidewalks or overlooks	The National Park Service is required to meet the requirements of the ABA for accessibility. The purpose of the project is to provide more reliable access to popular visitor destinations. Conducting the improvements during the 3R project makes this element more economical and confines the disruptions to the public to one construction period. Therefore, this alternative element was dismissed.
Create safe conditions for cyclists through measures, such as reducing speeds and providing pullouts for slower traffic on the existing surface.	Although no traffic incidents have been documented to date, there is not enough room for a vehicle to pass a bike without going into the opposing traffic lane. This would be problematic and likely create unsafe conditions, particularly during high visitation periods.
A bike trail that leaves the roadway in the two-way areas or a fully separate bike lane.	Development of a separate bike trail would not be economically feasible, as the National Park Service would likely be unable to build an appropriate separate bike lane for the same cost as adding the lane to the existing road during the 3R project. It would also be more complicated and may require additional rulemaking. The entire mesa top is rich with resources. Routing of a separate bike lane may be able to avoid cultural resources but could have more impacts to natural resources. A separate bike lane may also result in the creation of social trails. Therefore, this alternative was dismissed.
Prohibit bicycling through the rulemaking procedure.	This does not meet the need to promote the health and personal fitness of the general public (Executive Order 13266) and increase recreational opportunities (DOI Secretarial Order 3366). Therefore, this alternative element was dismissed.

Appendix B: Geologic Time Scale



Ma=Millions of years old. **Bndy Age**=Boundary Age. Modified from 1999 Geological Society of America Time Scale (https://www.geosociety.org/documents/gsa/timescale/timescl-1999.pdf). Dates and additional information from International Commission on Stratigraphy update 2019/05 (https://stratigraphy.org/chart) and USGS Fact Sheet 2007-3015 (https://pubs.usgs.gov/fs/2007/3015/).

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

NPS Paleontology Program Technical Report, December 2020

National Park Service
U.S. Department of the Interior

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