I-70 Mountain Corridor PEIS Paleontological Resources Technical Report

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Table of Contents

List of Figures

List of Tables

Section 1. Purpose of the Report

This *I-70 Mountain Corridor PEIS Paleontological Resources Technical Report* supports the information contained in **Chapter 3, Section 3.15** of the *I-70 Mountain Corridor Programmatic Environmental Impact Statement* (PEIS). It provides additional technical explanation of the methodologies for assessing paleontologic sensitivity and describes the geologic formations referenced in **Chapter 3, Section 3.15** of the *I-70 Mountain Corridor PEIS* in more detail.

Section 2. Background and Methodology

The fossil record is the only evidence that life on earth has existed for more than 3.6 billion years. Fossils are considered nonrenewable resources because the organisms from which they derive no longer exist. Thus, after it is destroyed, a fossil can never be replaced.

Fossils are important scientific and educational resources because they are used to:

- Study the evolutionary relationships between extinct organisms and their relationships to modern organisms
- Understand the conditions under which fossils are preserved
- Reconstruct ancient environments, climate changes, and paleoecological relationships
- Provide an independent measure of relative dating of geologic units
- Study the geographic distribution of organisms and tectonic movements of land masses and ocean basins through time
- Study patterns and processes of evolution, extinction, and speciation
- Identify past and potential future effects of human activities on global environments and climates

A variety of federal, state, and local regulations and policies protect paleontological resources. These include the National Environmental Policy Act (NEPA), federal Antiquities Act of 1906, National Natural Landmarks Program, Federal Land Policy and Management Act of 1976, and the recently enacted federal Paleontological Resources Preservation Act. Colorado's Historical, Prehistorical, and Archaeological Resources Act, also known as the State Antiquities Act, governs fossils on state-owned lands. As an indication of the importance of paleontological resources in Colorado, the Colorado Department of Transportation (CDOT) maintains a dedicated Paleontology Program to evaluate potential effects on paleontological resources for all construction and maintenance activities.

The paleontologic potential and sensitivity of each geologic unit affected by ground disturbance during the construction phase of the Action Alternatives were evaluated using widely accepted paleontological resource assessment criteria developed by:

- Society of Vertebrate Paleontology (SVP)
- United States Forest Service
- Bureau of Land Management
- National Academy of Sciences

These systems assign a sensitivity rating and associated paleontologic potential to each geologic unit. Each organization's guidelines and criteria are summarized below.

2.1 Society of Vertebrate Paleontology (SVP)

In its “standard guidelines for the assessment and mitigation of adverse impacts on nonrenewable paleontologic resources,” SVP (1995 p. 23) defines three categories of paleontologic sensitivity (potential) for rock units: high, low, and undetermined.

- **High Potential.** Rock units from which vertebrate (animals with skeletons) or important invertebrate (animals without skeletons) fossils or suites of botanic (plant) fossils have been recovered and are considered to have a high potential for containing significant nonrenewable fossiliferous resources. These units include, but are not limited to, sedimentary formations and some volcanic formations that contain significant nonrenewable paleontologic resources anywhere within their geographical extent, and sedimentary rock units of a suitable structure or age that support the preservation of fossils. Sensitivity includes both (1) the potential for yielding abundant or significant vertebrate fossils or for yielding a few significant fossils, large or small, vertebrate, invertebrate, or botanical and (2) the importance of recovered evidence for new and significant scientific data. Areas that contain potentially datable older organic remains, including deposits associated with nests or middens, and areas that may contain new vertebrate deposits, traces (marks of animal activities), or trackways (footprints) are also classified as significant.
- **Low Potential.** Reports in the paleontological literature or field surveys by a qualified vertebrate paleontologist may determine some areas or units have low potential for yielding significant fossils. Such units will be poorly represented by specimens in institutional collections.
- **Undetermined Potential.** Specific areas underlain by sedimentary rock units for which little information is available are considered to have undetermined fossiliferous potential.

For geologic units with high potential, full-time monitoring is generally recommended during any project-related ground disturbance. For geologic units with low potential, protection or salvage efforts are not generally required. For geologic units with undetermined potential, a qualified vertebrate paleontologist should conduct field surveys to specifically determine the paleontologic potential of the rock units present within the study area.

Society of Vertebrate Paleontology has established standard guidelines (SVP, 1995, 1996) that outline professional protocols and practices for conducting paleontological resource assessments and surveys; monitoring and mitigation; data and fossil recovery; sampling procedures and specimen preparation; identification and analysis; and curation. Most practicing professional vertebrate paleontologists in the nation adhere closely to the SVP’s assessment, mitigation, and monitoring requirements as specifically provided in its standard guidelines. Most state regulatory agencies with paleontological laws, ordinances, regulations, and standards (LORS) accept and use the professional standards set forth by SVP.

As defined by SVP (1995, p. 26), significant nonrenewable paleontologic resources are defined as:

> *“fossils and fossiliferous deposits…restricted to vertebrate fossils and their taphonomic and associated environmental indicators. This definition excludes invertebrate or paleobotanical fossils except when present within a given vertebrate assemblage. Certain invertebrate and plant fossils may be defined as significant by a project paleontologist, local paleontologist, specialists, or special interest groups, or by lead agencies or local governments.”*

As defined by SVP (1995, p. 26), significant fossiliferous deposits are defined as:

> *“a rock unit or formation which contains significant nonrenewable paleontologic resources, here defined as comprising one or more identifiable vertebrate fossils, large or small, and any associated invertebrate and plant fossils, traces and other data that provide*

> *taphonomic, taxonomic, phylogenetic, ecologic, and stratigraphic information (ichnites and trace fossils generated by vertebrate animals, e.g., trackways, or nests and middens which provide datable material and climatic information). Paleontologic resources are considered to be older than recorded history and/or older than 5,000 years, BP."*

Based on SVP's significance definitions (1995), all identifiable vertebrate fossils are considered to have significant scientific value. This position is adhered to because vertebrate fossils are relatively uncommon, and only rarely will a fossil locality yield a statistically significant number of specimens of the same genus. Therefore, every vertebrate fossil found has the potential to provide significant new information on the taxon it represents, its paleoenvironment, and/or its distribution. Furthermore, all geologic units in which vertebrate fossils have previously been found are considered to have high sensitivity. Identifiable plant and invertebrate fossils are considered significant if found in association with vertebrate fossils, or if defined as significant by project paleontologists, specialists, or local government agencies.

A geologic unit known to contain significant fossils is considered "sensitive" to adverse impacts if there is a high probability that earth-moving or ground-disturbing activities in that rock unit will either disturb or destroy fossil remains directly or indirectly. This definition of sensitivity differs fundamentally from the definition for archaeological resources (as follows):

> *"It is extremely important to distinguish between archaeological and paleontological (fossil) resource sites when defining the sensitivity of rock units. The boundaries of archaeological sites define the areal extent of the resource. Paleontologic sites, however, indicate that the containing sedimentary rock unit or formation is fossiliferous. The limits of the entire rock formation, both areal and stratigraphic, therefore define the scope of the paleontologic potential in each case"* (SVP, 1995).

Many archaeological sites contain features that are visually detectable on the surface. In contrast, fossils are contained within sediments or bedrock, and therefore, not observable or detectable unless exposed by erosion or human activity. Therefore, paleontologists cannot know either the quality or quantity of fossils prior to natural erosion or exposure by human activity. As a result, even in the absence of surface fossils, it is necessary to assess the sensitivity of rock units based on their known potential to produce significant fossils elsewhere within the same geologic unit (both within and outside of the study area), a similar geologic unit, or whether the unit was deposited in a type of environment known to be favorable for fossil preservation. Monitoring by experienced paleontologists greatly increases the probability that fossils will be discovered during ground-disturbing activities and that, if these remains are significant, successful mitigation and salvage efforts may be undertaken to prevent adverse impacts on these resources.

2.2 Probable Fossil Yield Classification

The paleontologic sensitivity of the study area was evaluated using criteria proposed by Raup (1987) and the Probable Fossil Yield Classification (PFYC) developed by the United States Forest Service.

The PFYC has been modified to include fossil plants. This five-tier scheme is summarized below.

- **Class 1.** Igneous and metamorphic geologic units (excluding tuffs) that are not likely to contain recognizable fossil remains. Ground-disturbing activities will not require mitigation, except in rare circumstances.
- **Class 2.** Sedimentary geologic units that are not likely to contain vertebrate fossils or scientifically significant invertebrate (or plant) fossils. Ground-disturbing activities are not likely to require mitigation.

- **Class 3.** Fossiliferous sedimentary geologic units where fossil content varies in significance, abundance, and predictable occurrence. Ground-disturbing activities will require sufficient mitigation to determine whether significant paleontologic resources occur in the area of a proposed action. Mitigation beyond initial findings will range from no further action necessary to full and continuous monitoring of significant localities during the action.
- **Class 4.** Class 4 geologic units are Class 5 units with lowered risks of adverse impacts of human activities and/or lowered risks of natural degradation. Proposed ground-disturbing activities will require assessment to determine whether significant paleontologic resources occur in the area of a proposed action and whether the action will affect the resources. Mitigation beyond initial findings will range from no further mitigation necessary to full and continuous monitoring of significant localities during the action. Often this classification is not applied until after on-the-ground assessments are made.
- **Class 5.** Highly fossiliferous geologic units that regularly and predictably produce vertebrate fossils and/or scientifically significant invertebrate (or plant) fossils, and that are at high risk of natural degradation and/or adverse impacts of human activities. These areas are likely to be poached. Mitigation of ground-disturbing activities is required and may be intense. Areas of special interest and concern should be designated and intensely managed.

2.3 Bureau of Land Management

In a 1978 memorandum, Griswold E. Petty (then acting director of the Bureau of Land Management) proposed the following guidelines to determine the significance of a paleontological resource. A paleontological resource is considered significant if any of the following conditions are met:

- It provides important information on evolutionary trends, relating living organisms to extinct organisms.
- It provides important information on biological community development and zoological/botanical biota interaction.
- It demonstrates unusual circumstances in biotic history.
- It consists of a limited sample size; is in danger of depletion or destruction by natural processes, vandalism, or commercial exploitation; or is found in no other geographic location.

Fossils of scientific significance are those of particular interest to scientists, educators, and the public, and are afforded protection under federal law. Current Bureau of Land Management guidelines identify significant paleontological resources as having the following characteristics: (1) preservation of soft body parts; (2) preservation of delicate or uncommon shell or skeletal parts of invertebrates; (3) close or intimate association of plants and animals; (4) preservation of the skull, whole isolated bones, or other diagnostic materials, or poorly known or unknown vertebrates; (5) fossils with unique or significant geographic or stratigraphic position such as type, locality, or only known occurrence; and (6) fossils having the potential for clarifying the evolutionary structure, development, and behavior of the organism and/or its environment.

The *Bureau of Land Management Paleontology Resources Management Manual and Handbook H-8270-1* established a classification system for ranking paleontological areas in terms of their potential for noteworthy occurrences of fossils: “Public lands may be classified based on their likelihood to contain fossils, using the following criteria:

- **Condition 1.** Areas that are known to contain fossil localities. Consideration of paleontological resources will be necessary if available information indicates that fossils are present in the area.

- **Condition 2.** Areas with exposure of geological units or settings that are likely to contain fossils. The presence of geologic units from which fossils have been recovered elsewhere will require an assessment of these units if they occur in the area of consideration.
- **Condition 3.** Areas that are unlikely to produce fossils based on their surface geology (for example, igneous or metamorphic rocks; extremely young alluvium, colluvium, or mollusk deposits).

In keeping with the historic policies adopted by the Bureau of Land Management, these classification guidelines apply primarily to vertebrate fossils. However, where noteworthy occurrences of invertebrate or plant fossils are known or expected, the same procedures shall be followed."

2.4 National Academy of Sciences

The Committee of Guidelines for Paleontological Collecting at the National Academy of Sciences established the following criteria for the evaluation of paleontologic resources (Raup, 1987):

- **Type 1.** Formations known to produce large numbers of vertebrate fossils are considered to have high paleontologic sensitivity.
- **Type 2.** Formations known to produce abundant numbers of invertebrate, plant, and trace fossils, and that more rarely produce vertebrate fossils, are considered to have moderate paleontologic sensitivity.
- **Type 3.** Formations that only rarely produce fossils are considered to have low paleontologic sensitivity.

In general, invertebrate, plant, and trace fossils that occur in large numbers when they are found are not considered as significant as relatively uncommon vertebrate fossils.

Section 3. Description of Alternatives

This section summarizes the alternatives considered in the I-70 Mountain Corridor PEIS. A more complete description of these alternatives is available in **Chapter 2** of the PEIS and in the *I-70 Mountain Corridor PEIS Alternatives Screening and Development Technical Report* (CDOT, August 2010).

3.1 Minimal Action Alternative

The Minimal Action Alternative provides a range of local transportation improvements along the Corridor without providing major highway capacity widening or dedicated transit components. The Minimal Action Alternative includes elements of the Transportation System Management family and the Localized Highway Improvements family, including: transportation management, interchange modifications, curve safety modifications, and auxiliary lanes. These elements are also incorporated into the other Action Alternative Packages.

3.2 Transit Alternatives

Four Transit alternatives are considered in the PEIS as a reasonable range representing the Fixed Guideway and Rubber Tire Transit families:

- Rail with Intermountain Connection Alternative
- Advanced Guideway System Alternative
- Dual-Mode Bus in Guideway Alternative
- Diesel Bus in Guideway Alternative

3.2.1 Rail with Intermountain Connection

The Rail with Intermountain Connection Alternative would provide rail transit service between the Eagle County Regional Airport and C-470. Between Vail and C-470 the rail would be primarily at-grade running adjacent to the I-70 highway. The segment between Vail and the Eagle Count Airport would be constructed within the existing Union Pacific Railroad right-of-way. A new Vail Transportation Center, including new track, would be constructed between Vail and Minturn to complete the connection between the diesel and electric trains. This alternative also includes auxiliary lane improvements at eastbound Eisenhower-Johnson Memorial Tunnels to Herman Gulch and westbound Downieville to Empire and the other Minimal Action Alternative elements except for curve safety modifications at Dowd Canyon, buses in mixed traffic and other auxiliary lane improvements.

3.2.2 Advanced Guideway System

The Advanced Guideway System Alternative would provide transit service between the Eagle County Regional Airport and C-470 with a 24-foot-wide, 118 mile, fully elevated system. The Advanced Guideway System Alternative would use a new technology that provides higher speeds than the other Fixed Guideway Transit technologies studied for the PEIS. Any Advanced Guideway System would require additional research and review before it could be implemented in the Corridor. Although the Federal Transit Administration-researched urban magnetic levitation system is considered in the PEIS, the actual technology would be developed in a Tier 2 process. This alternative includes the same Minimal Action elements as described previously for the Rail with Intermountain Connection Alternative.

3.2.3 Dual-mode Bus in Guideway

This alternative includes a guideway located in the median of the I-70 highway with dual-mode buses providing transit service between the Eagle County Regional Airport and C-470. This guideway would be 24 feet wide with 3 foot high guiding barriers and would accommodate bidirectional travel. The barriers direct the movement of the bus and separate the guideway from general purpose traffic lanes. While traveling in the guideway, buses would use guidewheels to provide steering control, thus permitting a narrow guideway and providing safer operations. The buses use electric power in the guideway and diesel power when traveling outside the guideway in general purpose lanes. This alternative includes the same Minimal Action Alternative elements as described previously for the Rail with Intermountain Connection Alternative.

3.2.4 Diesel Bus in Guideway

This includes the components of the Dual-mode Bus in Guideway Alternative except that the buses use diesel power at all times.

3.3 Highway Alternatives

Three Highway alternatives are advanced for consideration in the PEIS as a reasonable range and representative of the Highway improvements, including Six-Lane Highway 55 mph, Six-Lane Highway 65 mph, and Reversible/HOV/HOT Lanes. The Highway alternatives considered both 55 and 65 mph design speeds to 1) establish corridor consistency and 2) address deficient areas within the Corridor. The 55 mph design speed establishes a consistent design speed throughout the Corridor, which currently does not exist. The 65 mph design speed further improves mobility and addresses safety deficiencies in key locations such as Dowd Canyon and the Twin Tunnels. Both the 55 mph and the 65 mph design speed options are augmented by curve safety improvements, but the 65 mph design speed constructs tunnels in two of the locations: Dowd Canyon and Floyd Hill/Hidden Valley.

3.3.1 Six-Lane Highway 55 mph Alternative

This alternative includes six-lane highway widening in two locations: Dowd Canyon and the Eisenhower-Johnson Memorial Tunnels to Floyd Hill. This alternative includes auxiliary lane improvements at eastbound Avon to Post Boulevard, both directions on the west side of Vail Pass, eastbound Frisco to Silverthorne and westbound Morrison to Chief Hosa, and the Minimal Action Alternative elements except for buses in mixed traffic and other auxiliary lane improvements.

3.3.2 Six-Lane Highway 65 mph Alternative

This alternative is similar to the Six-Lane Highway 55 mph Alternative; it includes the same six-lane widening and all of the Minimal Action Alternative elements except the curve safety modification at Dowd Canyon. The higher design speed of 65 mph alternatives requires the curve safety modifications near Floyd Hill and Fall River Road to be replaced with tunnels.

3.3.3 Reversible Lanes Alternative

This alternative is a reversible lane facility accommodating high occupancy vehicles and high occupancy toll lanes. It changes traffic flow directions as needed to accommodate peak traffic demands. It includes two additional reversible traffic lanes from the west side of the Eisenhower-Johnson Memorial Tunnels to just east of Floyd Hill. From the Eisenhower-Johnson Memorial Tunnels to US 6, two lanes are built with one lane continuing to US 6 and the other lane to the east side of Floyd Hill. This alternative includes one additional lane in each direction at Dowd Canyon. This alternative includes the same Minimal Action Alternative Elements as the Six-Lane Highway 55 mph Alternative.

3.4 Combination Alternatives

Twelve Combination alternatives, combining Highway and Transit alternatives are considered in the PEIS. Four of these alternatives involve the buildout of highway and transit components simultaneously. Eight alternatives include preservation options, the intent of which is to include, or not preclude, space for future modes in the I-70 Mountain Corridor. The Combination alternatives all include the Six-Lane Highway 55 mph Alternative for highway components.

Combination Rail and Intermountain Connection and Six-Lane Highway Alternative—This alternative includes the 55 mph six-lane highway widening between Floyd Hill and Eisenhower-Johnson Memorial Tunnels, the Rail and Intermountain Connection transit components, and most of the components of the Minimal Action Alternative. The exception is that only one of the Minimal Action auxiliary lane improvements (from Morrison to Chief Hosa westbound) is included.

Combination Advanced Guideway System and Six-Lane Highway Alternative—This alternative includes the 55 mph six-lane highway widening between Floyd Hill and Eisenhower-Johnson Memorial Tunnels and the Advanced Guideway System transit components. It includes the same Minimal Action Alternative elements as the Combination Rail and Intermountain Connection and Six-Lane Highway Alternative.

Combination Bus in Guideway (Dual-Mode) and Six-Lane Highway Alternative—This alternative the 55 mph six-lane highway widening between Floyd Hill and Eisenhower-Johnson Memorial Tunnels and the dual-mode bus in guideway transit components. It includes the same Minimal Action Alternative elements as the Combination Rail and Intermountain Connection and Six-Lane Highway Alternative.

Combination Bus in Guideway (Diesel) and Six-Lane Highway Alternative—This alternative includes the 55 mph six-lane highway widening between Floyd Hill and Eisenhower-Johnson Memorial Tunnels and the diesel bus in guideway transit components. It includes the same Minimal Action

Alternative elements as the Combination Rail and Intermountain Connection and Six-Lane Highway Alternative.

Combination Rail & Intermountain Connection and Preservation of Six-Lane Highway Alternative—This alternative includes the Rail and Intermountain Connection Alternative and preserves space to construct the Six-Lane Highway 55 mph at a later point.

Combination Advanced Guideway System and Preservation of Six-Lane Highway Alternative— This alternative includes the Advanced Guideway System and preserves space to construct the Six-Lane Highway 55 mph at a later point.

Combination Bus in Guideway (Dual-Mode) and Preservation of Six-Lane Highway Alternative— This alternative includes the Combination Bus in Guideway (Dual-Mode) Alterative and preserves space to construct the Six-Lane Highway 55 mph at a later point.

Combination Bus in Guideway (Diesel) and Preservation of Six-Lane Highway Alternative—This alternative includes the Bus in Guideway (Diesel) Alternative and preserves space to construct the Six-Lane Highway 55 mph at a later point.

Combination Preservation of Rail and Intermountain Connection and Six-Lane Highway Alternative—This alternative includes the Six-Lane 55 mph Highway Alternative and also preserves space to construct the Rail and Intermountain Connection at a later point.

Combination Preservation of Advanced Guideway System and Six-Lane Highway Alternative— This alternative includes the Six-Lane 55 mph Highway Alternative and also preserves space to construct the Advanced Guideway System at a later point.

Combination Preservation of Bus in Guideway (Dual-Mode) and Six-Lane Highway Alternative— This alternative includes the Six-Lane Highway Alternative and also preserves space to construct the Bus in Guideway (Dual-Mode) at a later point.

Combination Preservation of Bus in Guideway (Diesel) and Six-Lane Highway Alternative—This alternative includes the Six-Lane Highway Alternative and also preserves space to construct the Bus in Guideway (Diesel) at a later point.

3.5 Preferred Alternative—Minimum and Maximum Programs

The Preferred Alternative provides for a range of improvements. Both the Minimum and the Maximum Programs include the Advanced Guideway System Alternative. The primary variation between the Minimum and Maximum Programs is the extent of the highway widening between the Twin Tunnels and the Eisenhower-Johnson Memorial Tunnels. The Maximum Program includes six-lane widening between these points (the Twin Tunnels and the Eisenhower-Johnson Memorial Tunnels), depending on certain events and triggers and a recommended adaptive management strategy.

3.6 No Action Alternative

The No Action Alternative provides for ongoing highway maintenance and improvements with committed funding sources highly likely to be implemented by the 2035 planning horizon. The projected highway maintenance and improvements are committed whether or not any other improvements are constructed with the I-70 Mountain Corridor project. Specific improvements under the No Action Alternative include highway projects, park and ride facilities, tunnel enhancements, and general maintenance activities.

Section 4. Affected Environment

The following discusses the geology of the Corridor as it relates to the potential presence of paleontological resources. The geology of the Corridor from Glenwood Springs to C-470 was mapped by Kellogg, 1998, 2002; Kellogg, Bartos, and Williams, 2002; Kellogg, Bryant, and Redsteer, 2003; Kirkham, Streufert, and Cappa, 1995, 1997; Lidke, 1998, 2002; Scott, 1972; Scott, Lidke, and Grunwald, 2002; Sheridan, Reed Jr., and Bryant, 1972; Sims, 1964; Streufert, Kirkham, Widmann, and Schroeder II, 1997; Streufert, Kirkham, Schroeder II, and Widmann, 1997; Taylor, 1976; Tweto, Moench, and Reed Jr., 1978; Widmann and Miersemann, 2001; and Widmann, Kirkham, and Beach, 2000. A geologic time scale is provided in **Figure 1** for reference.

Table 1 presents the results of the ratings for each of the four systems referenced in **Section 2** of this Technical Report and provides a combined sensitivity ranking that is presented in **Chapter 3, Section 3.15** of the *I-70 Mountain Corridor PEIS*. **Figure 2 through Figure 8** provide geologic maps of the Corridor (according to geologic period).

Figure 1. Geologic Time Scale

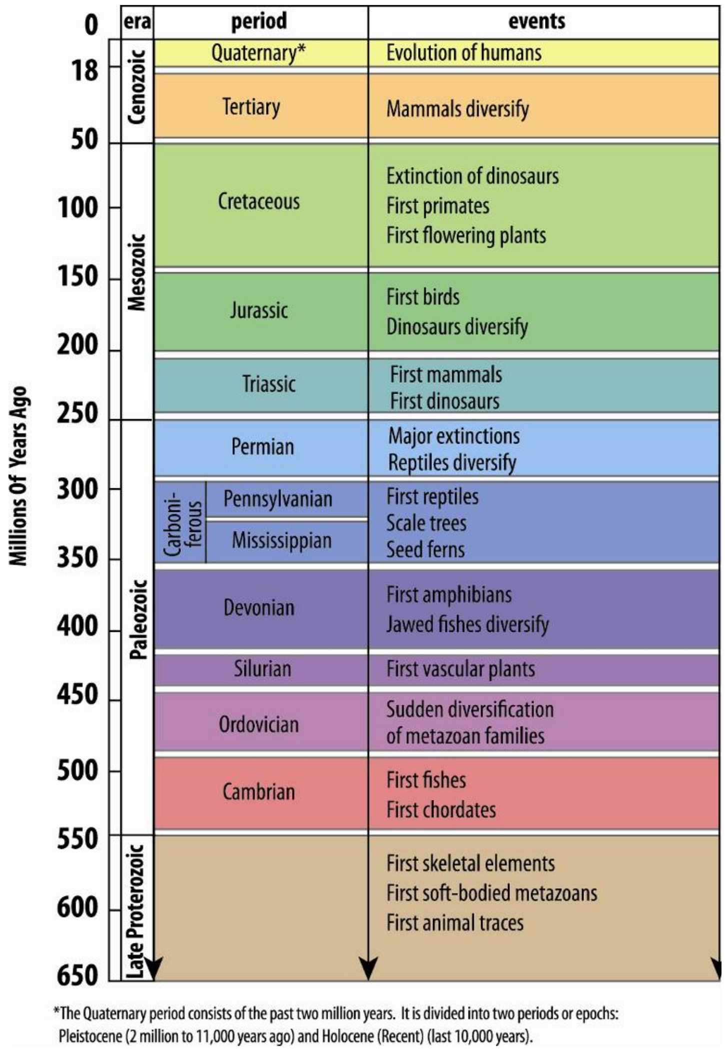


Table 1. Paleontological Sensitivity Ranking for Geologic Units along the Corridor

Geologic Unit	Geologic Period	Known Fossil Types	SVP	USFS	BLM	NAS	Combined Sensitivity Ranking
Morrison Formation	Late Jurassic	Vertebrates, invertebrates, plants, trace fossils	High	Class 5	Condition 1	Type 1	High
Pierre Shale	Late Cretaceous	Marine & nonmarine vertebrates, marine invertebrates, fossil wood, trace fossils	High	Class 3	Condition 2	Type 2	High
Denver Formation	Late Cretaceous	Vertebrates, plants, invertebrates	High	Class 3	Condition 2	Type 2	High
Minturn Formation	Pennsylvanian	Marine invertebrates, vertebrates, plants, trace fossils	High	Class 3	Condition 2	Type 2	Moderate
Chaffee Group	Devonian	Fish, invertebrates	High	Class 3	Condition 2	Type 2	Moderate
Ralston Creek Formation	Late Jurassic	Marine invertebrates, vertebrates, plants	High	Class 3	Condition 2	Type 2	Moderate
Arapahoe Formation	Late Cretaceous	Rare vertebrate bone fragments, wood	Low	Class 3	Condition 2	Type 2	Moderate
Benton Shale	Late Cretaceous	Vertebrates, marine invertebrates	High	Class 3	Condition 2	Type 2	Moderate
Dakota Sandstone	Early Cretaceous	Vertebrates, marine invertebrates, plants, trace fossils	High	Class 3	Condition 2	Type 2	Moderate
Fox Hills Sandstone	Late Cretaceous	Marine invertebrates, trace fossils	High	Class 3	Condition 2	Type 2	Moderate
Laramie Formation	Late Cretaceous	Plants, invertebrates, vertebrates	High	Class 3	Condition 2	Type 2	Moderate
Lytle Formation	Early Cretaceous	Wood, invertebrate burrows	Low	Class 3	Condition 2	Type 2	Moderate
South Platte Formation	Early Cretaceous	Marine mollusks	High	Class 3	Condition 2	Type 2	Moderate
Leadville Limestone	Mississippian	Marine invertebrates, rare vertebrates	High	Class 3	Condition 2	Type 2	Moderate
Manitou Formation	Early Ordovician	Marine vertebrates	High	Class 3	Condition 2	Type 2	Moderate
Lyons Sandstone	Early Permian	Trace fossils (trackways)	High	Class 3	Condition 2	Type 2	Moderate
Belden Shale	Early Pennsylvanian	Marine invertebrates	High	Class 3	Condition 2	Type 2	Moderate
Eagle Valley Formation	Middle Pennsylvanian	Marine invertebrates	High	Class 3	Condition 2	Type 2	Moderate
Eagle Valley Evaporite	Middle Pennsylvanian	Marine invertebrates (rare)	Low	Class 2	Condition 2	Type 3	Moderate
Maroon Formation	Middle Pennsylvanian / Early Permian	Marine & nonmarine invertebrates, plants, trace fossils	High	Class 3	Condition 2	Type 2	Moderate
Chinle Formation	Late Triassic	Marine & nonmarine vertebrates, marine invertebrates, plants, trace fossils	High	Class 3	Condition 2	Type 2	Moderate
Dotsero Formation	Late Cambrian	Marine invertebrates	High	Class 3	Condition 2	Type 2	Moderate
Fountain Formation	Pennsylvanian / Early Permian	Invertebrates, rare marine invertebrates	High	Class 3	Condition 2	Type 2	Moderate

Geologic Unit	Geologic Period	Known Fossil Types	SVP	USFS	BLM	NAS	Combined Sensitivity Ranking
State Bridge Formation	Late Permian/ Early Triassic	Rare invertebrates, plants (algae)	Low	Class 2	Condition 2	Type 3	Low
Lykins Formation	Permian/Triassic	Stromatolites, rare vertebrates	Low	Class 3	Condition 2	Type 3	Low
Pleistocene Alluvium (stream channel, floodplain & low-terrace deposits) & loess	Quaternary	Vertebrates, invertebrates, plants	Low	Class 2	Condition 2	Type 3	Low
Piney Creek Alluvium[a]	Quaternary	Vertebrates, invertebrates	Low	Class 2	Condition 2	Type 3	Low
Slocum Alluvium	Quaternary	Vertebrates, invertebrates	Low	Class 2	Condition 2	Type 3	Low
Pre-Bull Lake Till	Quaternary	Vertebrates	Low	Class 2	Condition 2	Type 3	Low
Bull Lake Till	Quaternary	Vertebrates	Low	Class 2	Condition 2	Type 3	Low
Pinedale Till	Quaternary	Vertebrates	Low	Class 2	Condition 2	Type 3	Low
Pinedale Outwash Deposits	Quaternary	Vertebrates	Low	Class 2	Condition 2	Type 3	Low
Till, undivided	Quaternary	Vertebrates	Low	Class 2	Condition 2	Type 3	Low
Holocene Alluvium (stream-channel, floodplain, and low-terrace deposits[a])	Quaternary	Vertebrates, invertebrates	Low	Class 2	Condition 2	Type 3	Low
Holocene Loess, Colluvium, Talus & Landslide Deposits[a]	Quaternary	Vertebrates, invertebrates	Low	Class 2	Condition 2	Type 3	Low
Unnamed Early Proterozoic Metamorphic Rocks	Precambrian	None	None	Class 1	Condition 3	Type 3	None
Cross Creek Granite	Precambrian	None	None	Class 1	Condition 3	Type 3	None
Silver Plume Granite	Precambrian	None	None	Class 1	Condition 3	Type 3	None
Sawatch Quartzite	Late Cambrian	None	None	Class 1	Condition 3	Type 3	None
Artificial Fill	Quaternary	None	None	Class 1	Condition 3	Type 3	None
Modified Land-Surface Deposits	Quaternary	None	None	Class 1	Condition 3	Type 3	None

[a] *If sediments are older than 5,000 years Before Present (BP) based on SVP (1995) guidelines.*

Key to Abbreviations/Acronyms

SVP = Society of Vertebrate Paleontology
BLM = Bureau of Land Management
USFS = United States Forest Service
NAS = National Academy of Sciences

Figure 2. Geologic Units of the Paleontological Resources in the Corridor (Window 1 of 7)

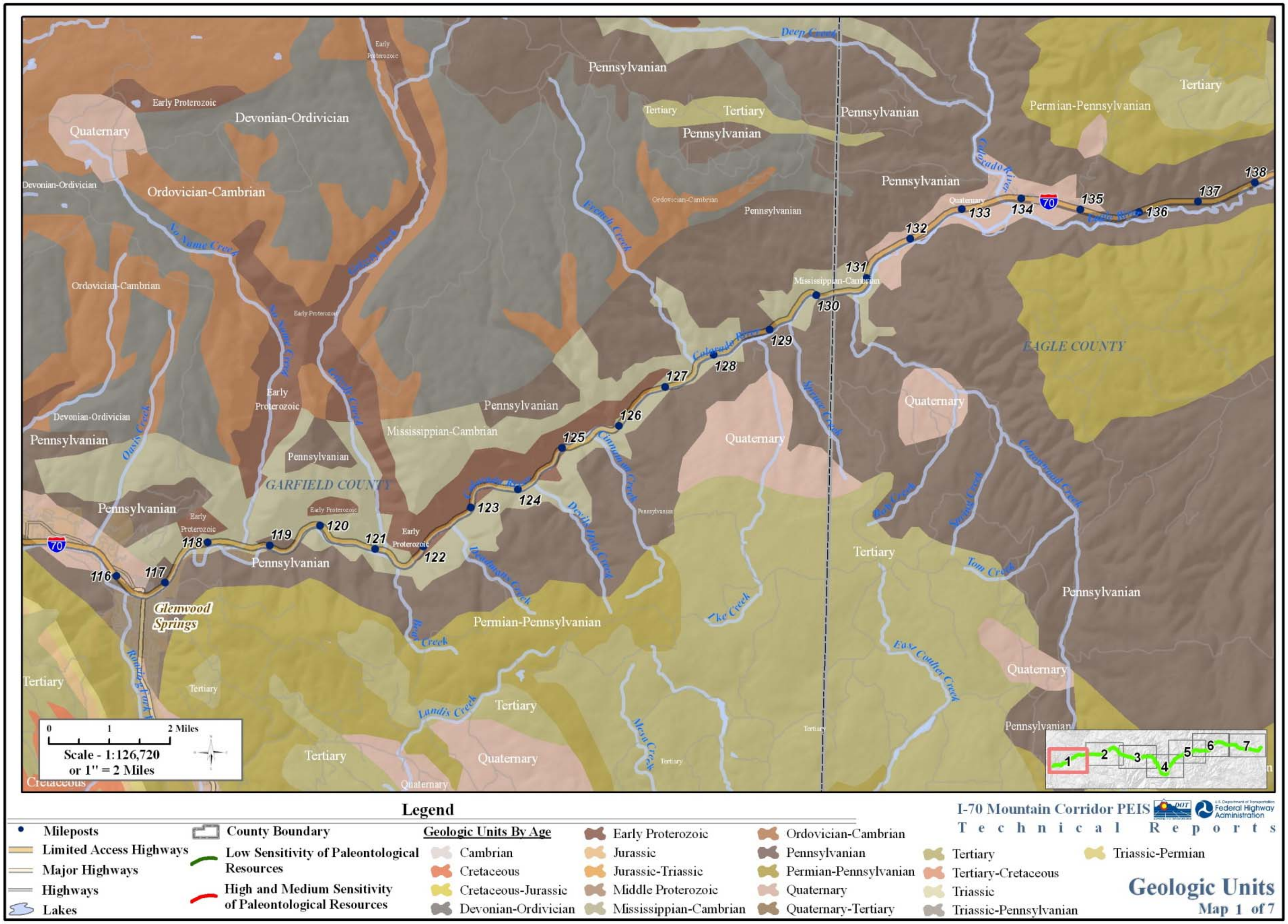


Figure 3. Geologic Units of the Paleontological Resources in the Corridor (Window 2 of 7)

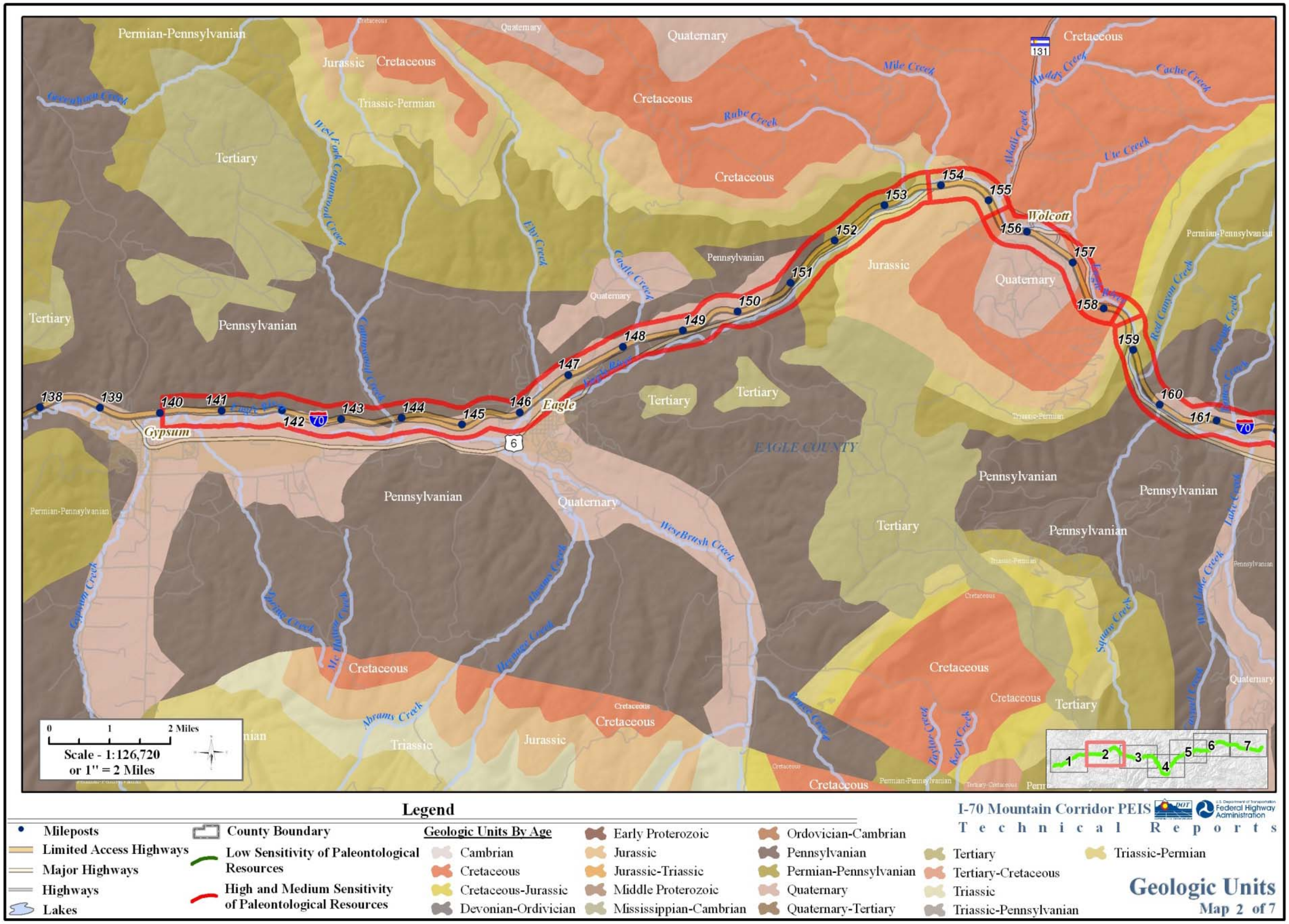


Figure 4. Geologic Units of the Paleontological Resources in the Corridor (Window 3 of 7)

Figure 5. Geologic Units of the Paleontological Resources in the Corridor (Window 4 of 7)

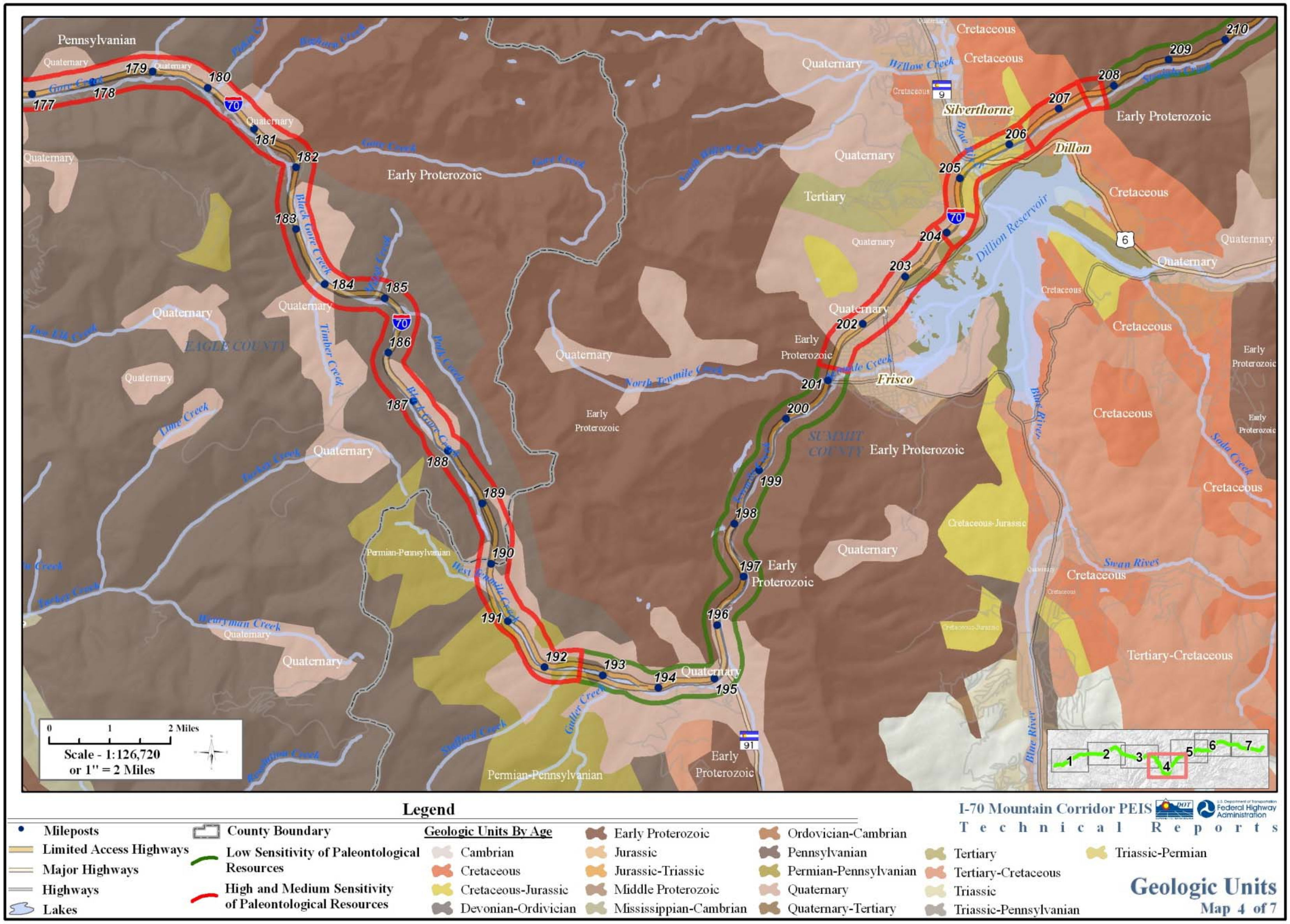


Figure 6. Geologic Units of the Paleontological Resources in the Corridor (Window 5 of 7)

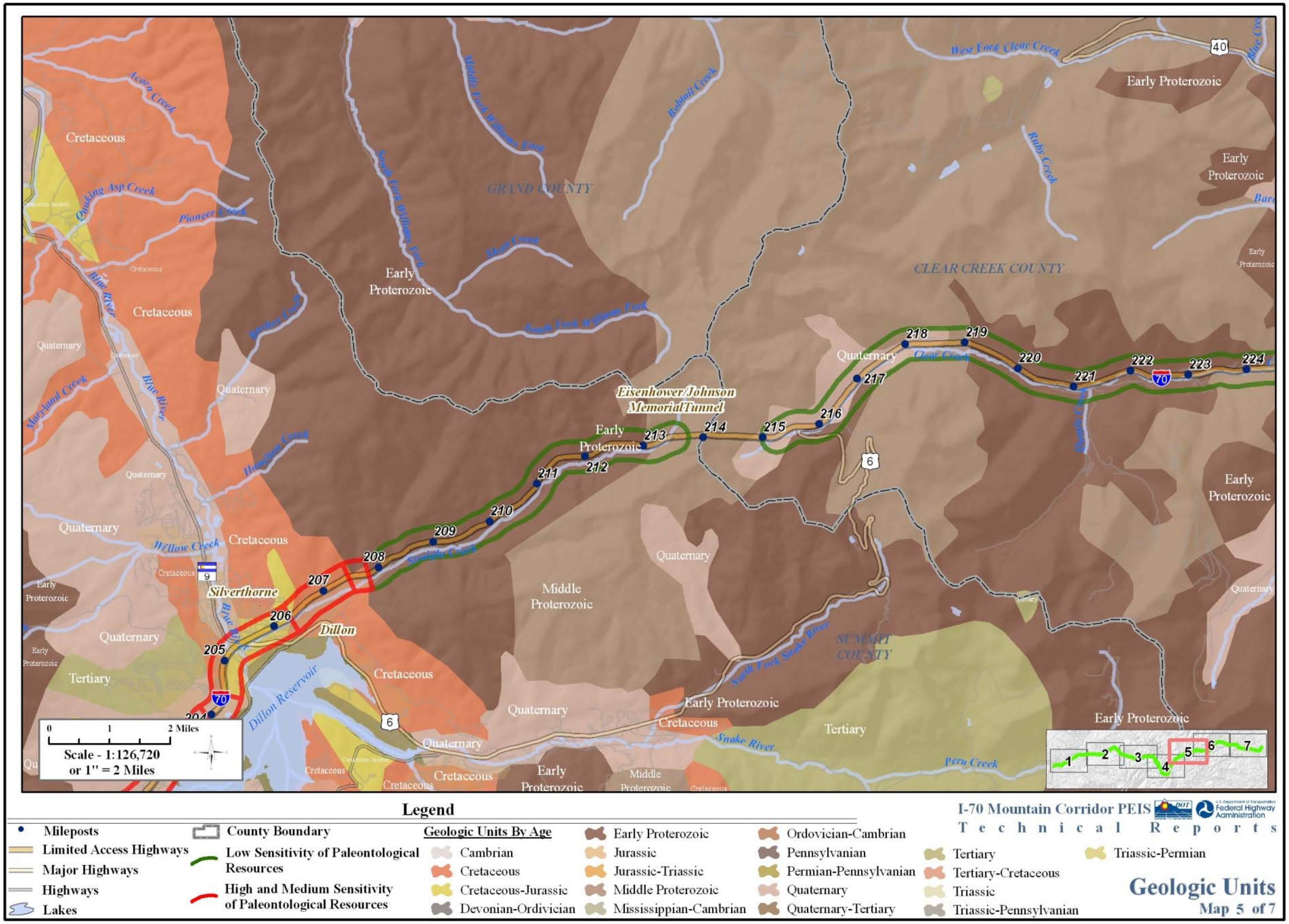


Figure 7. Geologic Units of the Paleontological Resources in the Corridor (Window 6 of 7)

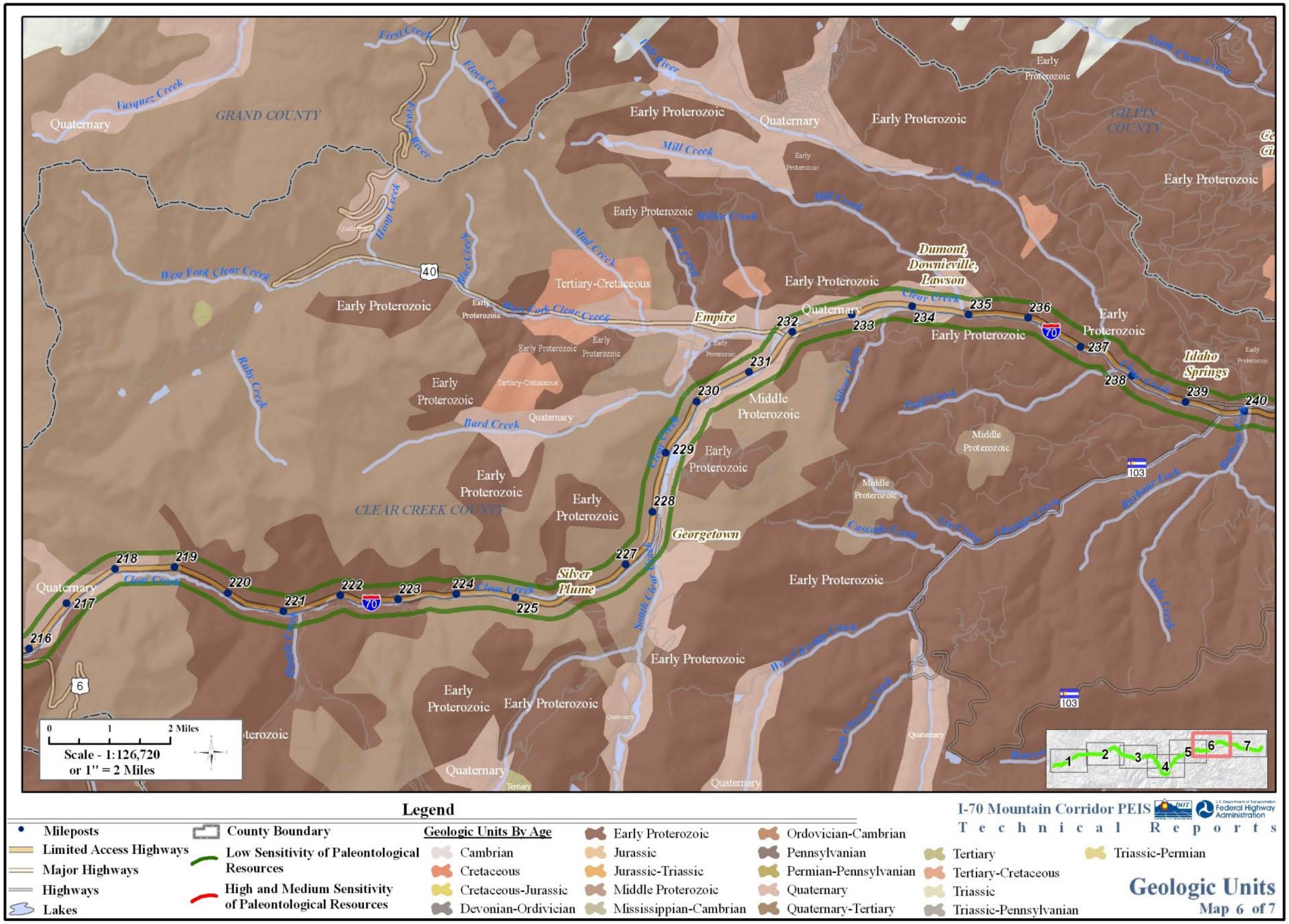
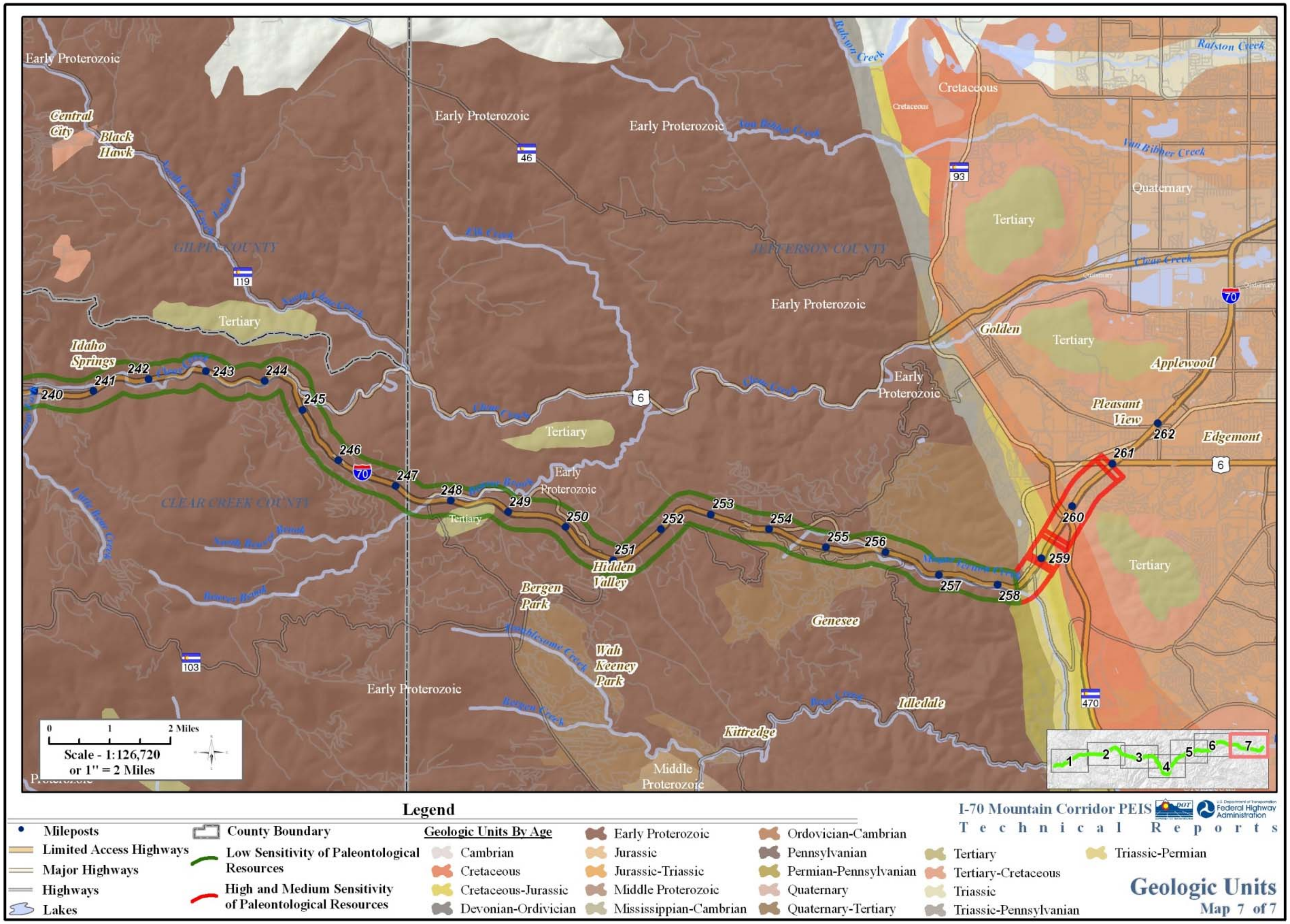


Figure 8. Geologic Units of the Paleontological Resources in the Corridor (Window 7 of 7)



The following text provides additional discussion of the geologic units encountered along the Corridor.

Morrison Formation

The widely distributed and highly fossiliferous Late Jurassic Morrison Formation was deposited in a combination of fluvial (river) and lacustrine (lake) environments. It is composed of variegated red, green, and gray mudstone and claystone, with tan sandstone and siltstone and gray limestone (Bryant et al. 1981). The Morrison Formation is well known for the large number of dinosaur remains that are preserved within it, including many historically important holotypes (original specimens used to name species) now stored in museums around the world. Dinosaur bones and teeth and fragments of fossil wood are perhaps the most common Morrison fossils, although an extremely diverse fish, nondinosaur reptilian, mammalian, plant, and trace fossil assemblage has also been documented. The geology and paleontology of the Morrison Formation has been studied extensively (Armstrong and Kihm, 1980, Armstrong et al., 1987, Bilbey, 1992, Dodson et al., 1980, Peterson, 1988, Tidwell, 1990, and numerous other references).

Sensitivity level – High

Pierre Shale

The Late Cretaceous Pierre Shale is marine in origin. Lithologies (physical characteristics) of the Pierre Shale include hard platy to flaky gray, dark gray, brownish-gray, grayish-black, tan, and silty shales; light olive gray silty bentonitic shales; limestones; and ironstone concretions (Carroll and Crawford, 2000; Haymes, 1989; Gill and Cobban, 1966; Scott and Wobus, 1973; Thorson et al., 2001; Thorson and Madole, 2002; and Wood et al., 1957). The invertebrate and vertebrate fossil faunas of the Pierre Shale in Colorado, Wyoming, South Dakota, Montana, Kansas, and New Mexico have been the subject of far more studies than can be cited here (Bergstresser, 1981; Bishop, 1985; Carpenter, 1996; Cobban et al., 1993; Gill and Cobban, 1966; Kauffman and Kesling, 1960; Lammons, 1969; Martz et al., 1999; Scott and Cobban, 1986, and many others). The invertebrate fauna includes a diverse assemblage of mollusks (primarily ammonites and inoceramids), as well as other bivalves, bryozoans, and gastropods. The ichnofauna consists primarily of trails, burrows, tubes, fecal pellets, and raspings on shells (Gill and Cobban, 1966). The vertebrate fauna is also diverse, containing various fish, turtles, mosasaurs, plesiosaurs, and more rare dinosaurs, pterosaurs, and birds (Carpenter, 1996). The Pierre Shale contains abundant invertebrate fossils and less common but scientifically important vertebrate fossils.

Sensitivity level – High

Denver Formation

The Denver Formation consists of dark brown, yellowish-brown, and grayish-olive tuffaceous claystones, mudstones, and sandstones embedded with scattered conglomerates (Bryant et al., 1981; Soister, 1978, and Trimble and Machette, 1979). It is Late Cretaceous in age. The Denver Formation is largely composed of altered andesitic (volcanic) debris. It is considered to have moderate to high paleontological sensitivity because it contains locally abundant and scientifically significant plant fossils (Brown, 1943, 1962; Ellis et al., 2003; Johnson and Ellis, 2002; and Knowlton, 1930), and a less abundant but scientifically important fossil vertebrate fauna (Eberle, 2003; and Middleton, 1983). The geology and paleontology of the Denver Formation is the subject of active research by scientists and students at the Denver Museum of Nature and Science (DMNS) and the University of Colorado Museum (UCM). This work has added considerably to the scientific understanding of the geologic and biologic history of the Denver Basin and surrounding areas during the Late Cretaceous and Paleocene (Eberle, 2003; Ellis et al., 2003; Johnson and Ellis, 2002; and Johnson and Raynolds, 1999). Ongoing work by scientists and students at the DMNS and UCM seeks to better document the stratigraphy and sedimentology of the Denver Formation and associated rocks. Future fossil finds from the Denver Formation will add to this ongoing research effort, and because it is largely covered throughout its distribution in the Denver area, excavations associated with new construction that exposes Denver Formation rocks are an important data source.

Sensitivity level – High

Minturn Formation

The Middle Pennsylvanian Minturn Formation consists of lenticular conglomerates, sandstones, and shales, with some intercalated (layered) and laterally persistent limestones and dolomites. Rocks of the Minturn Formation are typically gray but are red in the upper part of the formation (Tweto and Lovering, 1977, and Tweto et al., 1978). The Minturn Formation records two alternating depositional environments, one marine and one nonmarine (primarily fluvial). Although marine invertebrates in limestones are by far the most numerous fossils (bivalves, horn corals, gastropods, cephalopods, and brachiopods), plant fossils (*Cordaites* sp.), footprints, and other trace fossils also occur. Vertebrates include palaeoniscoid fish and shark teeth (Houck and Lockley, 1986; Lockley, 1984; Lockley and Hunt, 1995; Rigby and Church, 1993; Stevens, 1962, 1965, 1971; Tweto and Lovering, 1977; and Webster and Houck, 1998).

Sensitivity level – Moderate

Chaffee Group

The Devonian Chaffee Group is composed of two lithologically distinct members, the lower Parting Sandstone, which comprises the lower one-third, and the overlying Dyer Limestone (Bass and Northrop, 1953; Campbell, 1966, 1972; and Rettew, 1978). Both members are fossiliferous. The Parting Sandstone is paleontologically important because it contains fragmentary fish fossils (bones and dermal plates) from an important time period in the evolution of fish (Bass and Northrop, 1953; and Robinson, 1976). The Dyer Limestone contains a diverse invertebrate fauna including brachiopods, bryozoans, gastropods, bivalves, corals, stromatoporoids, and crinoids (Bass and Northrop, 1953; and Webster et al., 1999).

Sensitivity level – Moderate

Ralston Creek Formation

The Late Jurassic Ralston Creek Formation consists of a sequence of light gray to green argillaceous and gypsiferous sandstone and siltstone, green claystone, gray limestone, and white gypsum (Johnson; 1962; and O'Sullivan, 1992). It is interpreted to represent an intermixing of freshwater, evaporite-basin and possibly shallow-water marine deposits (Johnson, 1962). Shell fragments of *Ostrea* have been identified that are similar to an oyster species found in the Morrison Formation (Van Horn, 1957). O'Sullivan (1992) believes the upper part of the Ralston Creek Formation should be reassigned to the lower part of the Morrison Formation because a fossil algal plant, *Aclistochara*, is present in both the Ralston Creek Formation and in the lower 40 to 50 feet of the Morrison Formation. This species indicates a fresh or brackish water environment, suggesting that the sediments were deposited in swamps or lakes similar to those of the overlying Morrison Formation deposits (Van Horn, 1957). Articulated fish skeletons have been reported from near Cañon City (Dunkle, 1942).

Sensitivity level – Moderate

Arapahoe Formation

The Arapahoe Formation consists of coarse- and fine-grained arkosic sandstone, siltstone, claystone, and thin pebble beds in the upper part, and white, yellowish-gray, and yellowish-orange coarse-grained sandstone with poorly sorted pebble conglomerate in the lower part. The conglomerate contains cobbles and boulders of shale, chert, and petrified wood (Scott, 1972). Silicified wood and dinosaur bone have been collected; however, it is believed that these fossils were reworked from the underlying Laramie Formation. Concretions and layered concentrations of ironstone and dinosaur bones have also been reported (Scott, 1972). Because of facies-related thickness changes, it is difficult in most places to distinguish the Arapahoe Formation from overlying and underlying units based on lithology even a short distance to the east of the Front Range foothills, and the Arapahoe Formation is commonly combined with the overlying Denver Formation on geologic maps.

Sensitivity level – Moderate

Benton Shale

The Late Cretaceous Benton Shale is primarily composed of shale embedded with bentonite, siltstone, and limestone. It is divided into three subunits based on lithologic and paleontologic evidence and is equivalent to rocks that are recognized elsewhere as distinct formations. The lowermost unit, the Graneros Shale equivalent, is composed of dark gray, noncalcareous shale embedded with thin beds of very light gray to yellowish-orange bentonite and dark gray siltstone (Van Horn, 1957). The middle unit, the Greenhorn Limestone equivalent, consists of black to light gray clayey shale. It contains a few beds of very light colored bentonite and a few thin yellowish-gray limestone beds. These limestone beds contain an important guide fossil, *Inoceramus prefragilis.* The upper part of the formation is known as the Carlile Shale equivalent. It is mainly composed of medium-dark gray siltstone with a few thin beds of fine-grained sandstone. Numerous fossil shark teeth have come from the upper 6 inches of this unit (Van Horn, 1957). The Benton Shale is dominated by locally abundant marine invertebrate fossils.

Sensitivity level – Moderate

Dakota Sandstone

The Early Cretaceous Dakota Sandstone is composed of light gray sandstone, conglomeratic chert-pebble sandstone, and light bluish-gray to light green claystone, shale, and siltstone with a maximum thickness of about 100 feet in the Denver area (Ellis et al., 1987). Deposited during the first major transgression of the Cretaceous Interior Seaway, rocks of the Dakota Group contain a moderately diverse fossil fauna and flora. The unit is well known for its fossil footprints and other trace fossils. Dakota Sandstone fossils have been the subject of numerous paleontologic studies (Chamberlain, 1976; Elliot and Nations, 1998; Hagen, 1882; Lockley, 1987, 1990, 1992; Mehl, 1931; Snow, 1887; Rushforth, 1971; Waage and Eicher, 1960; and Young, 1960).

Sensitivity level – Moderate

Fox Hills Sandstone

In Eagle County, the Late Cretaceous Fox Hills Sandstone Formation is composed of yellowish-gray, very fine-grained sandstone and a few interbeds of gray to brown sandy shale and coal (Gill et al., 1970; and Scott, 1972). Several species of foraminifera and ammonites have also been reported, as have bivalves and gastropods. The formation also contains the important trace fossil *Ophiomorpha*, which are 0.5- to 1-inch diameter burrows formed by the tunneling activities of callanassid shrimp. These fossils indicate a marginal marine to littoral unit deposited in a tidal area (Rigby and Rigby, 1990). In the Green River Basin in Wyoming, the Fox Hills Formation consists mostly of quartz sandstone that coarsens upward and contains oyster shells and trace fossils, indicating the eroded remnants of a barrier island depositional environment (Roehler, 1993). In McCone County, Montana, the formation consists mostly of uniform, consistently cross-bedded, well-sorted, very fine-grained, gray to yellow ledge-forming sandstone that shows little variation. Fossils are mostly flora and *Ophiomorpha* burrows (Rigby and Rigby, 1990).

Sensitivity level – Moderate

Laramie Formation

Deposited between about 69 and 68 million years ago, the Late Cretaceous Laramie Formation is divided into three informal members (Thorson et al., 2001). The lower member consists of light gray to light brownish-gray very fine-grained sandstone embedded with gray sandy shale and minor brown organic-rich shale, as well as sub-bituminous coal. It is about 115 feet thick. The middle sandstone member consists of thick to very thick bedded, light-colored, cross-bedded fine to coarse sandstones embedded with thin-bedded gray and brown shale. It is about 200 feet thick. The upper member consists of brownish-gray sandy shale and very fine-grained shaly sandstone, thin coal beds, and channel fillings of fine- to medium-grained light-colored sandstone. It is about 400 feet thick. The Laramie Formation is interpreted as a complex of channel, overbank, deltaic, and swamp deposits that were deposited shortly after, and in association with, the retreat of the Western Interior Cretaceous Sea (Weimer and Land, 1975). It was deposited on a low-lying coastal plain that existed before the uplift of the Rocky Mountains in Colorado and is one of the few formations of its age to preserve terrestrial fossil plant material. Significant vertebrate fossils are far less common than plants and invertebrates, although a relatively rich concentration of microvertebrates from Weld County, Colorado, was described by Carpenter (1979). These fossils are housed at the University of Colorado Museum. It contains locally abundant plant fossils but few vertebrate fossils.

Sensitivity level – Moderate

Lytle Formation

The Early Cretaceous Lytle Formation is the lowest subunit of the Dakota Group and is composed of sandstone, conglomeratic and variegated claystone deposits. At some localities, it rests disconformably above the Morrison Formation (Waage, 1955). Kues and Lucas (1987) found predominately chert clasts with occasional fragments of petrified wood and indeterminate burrows in the conglomerate beds.

Sensitivity level – Moderate

South Platte Formation

Named as the upper formation in the Dakota Group, the South Platte Formation is Early Cretaceous in age and contains locally abundant marine mollusks (Waage, 1955). No single exposure is typical, but generally the unit consists of a nonmarine clastic phase that grades laterally into a marine nonclastic phase. Sediments consist of alternating gray to black shale and fine-grained sandstone, and a marine phase that is primarily calcareous shale containing thin beds of fossiliferous silty limestone. A thin white, yellow, or light gray claystone is presumed to be altered volcanic ash (Waage, 1955). The South Platte Formation locally contains marine mollusks (*Inoceramus* sp., UCM unpublished paleontological data).

Sensitivity level – Moderate

Leadville Limestone

The Mississippian Leadville Limestone is marine in origin and is composed primarily of limestone, although the lower one-third of the formation contains embedded dolomite and limestone with dark-gray chert (Bass and Northrop, 1953; and Richards, 1982). Sandy limestones occur locally (Conley, 1968). Vertebrate fossils have not been reported from this formation. Invertebrate fossils are reported to be uncommon in the Leadville Limestone, although a fairly diverse fossil assemblage has been collected from Glenwood Canyon and several other localities in Garfield, Eagle, and Pitkin counties (Scott, 1954; and Armstrong and Mamet, 1976). These fossils include very rare fish teeth, foraminifera, crinoids, bryozoans, brachiopods, and stromatolites (Armstrong and Mamet, 1976).

Sensitivity level – Moderate

Manitou Formation

The Early Ordovician Manitou Formation is composed of medium-bedded, brown dolomite, limestone, and sandstone with thin beds of gray, flat-pebble limestone conglomerate embedded with greenish-gray calcareous shale (Streufert et al., 1997). The formation is divided into two formal members, the upper Tie Gulch Member and the lower Dead Horse Conglomerate Member. The unit ranges between 156 and 167 feet and unconformably underlies the Devonian Chaffee Group. The Manitou Formation contains a diverse fossil fauna including trilobites, brachiopods, gastropods, cephalopods, conodonts, sponge spicules, crinoids, and graptoloites (Bass and Northrop, 1953).

Sensitivity level – Moderate

Lyons Sandstone

The Early Permian Lyons Sandstone consists of yellowish-gray and yellowish-orange iron-stained fine-grained cross-stratified sandstone that grades upwards into yellowish-gray conglomerate that is composed of Precambrian detritus with clasts as large as 2 inches across. The thickness of the unit is about 190 feet. The Lyons Sandstone is best known for its insect and amphibian fossil footprints (unpublished UCM paleontological data) and has been widely used, as has flagstone, in urban construction in Colorado.

Sensitivity level – Moderate

Belden Formation

The Early Pennsylvanian Belden Formation (Belden Shale) was deposited in a low-energy marine environment in the Central Colorado Trough (Kirkham et al., 1997). It is composed predominantly of gray to black carbonaceous shale and thin beds of fossiliferous dark gray to black limestone with minor beds of fine- to medium-grained sandstone and siltstone (Kirkham et al., 1997; and Tweto, 1949). The limestone contains a marine invertebrate fauna of early Pennsylvanian age (Brill, 1942, 1944). The fauna includes corals, crinoids, bryozoans, and brachiopods. In the Greater Green River Basin, workers have identified abundant fusilinids, algae, brachiopods, corals, bryozoans, crinoid fragments, foraminifera, trilobites, and bivalves (Thompson, 1945).

Sensitivity level – Moderate

Eagle Valley Formation

The Middle Pennsylvanian Eagle Valley Formation is composed of embedded reddish-brown, gray, reddish-gray, and tan siltstone, shale, gypsum, gypsiferous siltstone, sandstone, and carbonate rocks. It is generally considered conformable and intertonguing with the underlying Eagle Valley Evaporite and overlying Maroon Formation. Unit thickness is variable and ranges from 500 to 1,000 feet thick (Streufert et al., 1997). Fossils include locally abundant invertebrates (Bass and Northrop, 1953).

Sensitivity level – Moderate

Eagle Valley Evaporite

The Middle Pennsylvanian Eagle Valley Evaporite is composed of a sequence of subaqueous evaporitic rocks, mainly consisting of anhydrite, halite, and gypsum, which are embedded with light-colored, fine-grained sands and thin carbonate beds (Streufert et al., 1997). The unit is commonly deformed from dissolution-induced subsidence, metamorphism, and regional tectonism among other processes. The unit thickness is about 1,800 feet depending on localized deformation. The Eagle Valley Evaporite contains few fossils and could be considered to have low paleontological sensitivity. However, because it can locally be difficult to distinguish from the overlying Eagle Valley Formation, it is considered to have moderate paleontological sensitivity in this study.

Sensitivity level – Moderate

Maroon Formation

The Middle Pennsylvanian to Early Permian Maroon Formation is fluvial in origin and is composed principally of reddish conglomerates, conglomeratic sandstones, arkosic and commonly cross-bedded sandstones, siltstones, mudstones, claystones, and shale with minor thin nonmarine limestones (Bass and Northrop, 1963). Total unit thickness is about 3,000 to 5,000 feet thick. The limestones contain scattered brachiopods, crinoids, corals, and bivalves. Fossil plants, insects, and footprints have also been reported (Stark et al., 1949).

Sensitivity level – Moderate

Chinle Formation

The reddish-brown conglomerate, sandstone, siltstone, and mudstone of the Late Triassic Chinle Formation is a succession of fluvial channel, floodplain, lacustrine-deltaic, lacustrine, and eolian (wind) deposits (Dubiel et al., 1991). The formation has been divided into many formal and informal members that can be reduced to two main groups: (1) a lower bentonitic sequence that was deposited by streams, soil zones, ash-fall, or ash and pumice carried by streams; and (2) upper redbeds that range from quiet water and lake and stream deposits (Stewart et al., 1972). The conglomerate was deposited in paleovalleys cut into the underlying State Bridge Formation by rivers carrying sediments from the Uncompahgre, Front Range, and Mogollon highlands. The Chinle Formation contains locally abundant fossils including fish scales and bones, lungfish burrows, *Scoyenia* (worm burrows), coprolites, conchostracans, ostracods, gastropods, and bivalves (Dubiel, 1987; Dubiel et al., 1991; and Stewart et al., 1972). Plants (fossilized wood) from the Chinle Formation at Petrified Forest National Park in Arizona are world-renowned. Vertebrates include phytosaurs, aetosaurs, lungfish, coelacanths, and early dinosaurs (unpublished UCM paleontological data). A tropical monsoon climate is suggested for early Chinle time, while eolian deposits in the upper part are due to drier climatic conditions caused by the northward migration of Pangaea (Dubiel et al., 1991). The Chinle Formation contains fewer fossils in Colorado than farther to the south, which is partly due to the fact that it is less widely exposed.

Sensitivity level – Moderate

Dotsero Formation

The Late Cambrian Dotsero Formation is composed of thinly bedded, tan to gray silty and sandy dolomite, green dolomitic shale, dolomitic sandstone, limestone, and dolomite conglomerate, with pinkish light gray and white to lavender weathering algal limestone (Streufert et al., 1997). Two formal members are recognized, the upper Clinetop Member and the lower Glenwood Canyon Member. Fossils include graptolites, trilobites, brachiopods, crinoids, and algae (Bass and Northrop, 1953).

Sensitivity level – Moderate

Fountain Formation

The Pennsylvanian to Early Permian Fountain Formation consists of thick-bedded coarse-grained (arkosic) sandstone and conglomerate containing thin layers of dark maroon micaceous silty fine-grained sandstone that are more abundant in the lower part. Well-developed crossbedding and poor sorting characterize the coarse clastic facies. Interbeds of locally fossiliferous limestone also occur. Color is generally reddish with local variations of white, green, and gray, and the unit is about 1,650 feet thick. Fine-grained facies (limestone and siltstone) locally contain a diverse invertebrate fauna, including gastropods, crinoids, echinoderms, brachiopods, and echinoids. Fossil amphibian footprints and rare fish bone fragments also occur along the Front Range (unpublished UCM paleontological data).

Sensitivity level – Moderate

State Bridge Formation

The Early Triassic and Late and Early Permian State Bridge Formation was first proposed by Donner in his 1936 University of Michigan Ph.D. thesis, but first formally described by Brill (1942). The unit is similar in composition to the Early Permian to Middle Pennsylvanian age Maroon Formation. The State Bridge Formation, however, typically contains rounded sand grains and thin beds of laminated sandstone and siltstone that are absent in the Maroon Formation (Kellogg et al., 2002). The State Bridge Formation is composed of brick red, purple gray, limey, micaceous, ripple-marked siltstone; brick red, locally bleached yellow and gray shale; mottled purple beds and interbeds of resistant, fossiliferous limestone (Donner, 1949). Fossils are rare but include bivalves and algae (Brill, 1942).

Sensitivity level – Low

Lykins Formation

The Late Permian and Early Triassic Lykins Formation is about 150 feet thick and is composed of pink wavy-laminated sandy marine limestone and maroon and green siltstone containing laminated red-weathering gray crystalline sandy limestone. Paleontologically, it is best known for its algal stromatolites, but rare fossil bone has also been reported (unpublished UCM paleontological data). The Lykins Formation is subdivided into four members: the Forelle Limestone, Bergen Shale, Falcon Limestone, and Harriman Shale. The Lykins Formation contains few fossils.

Sensitivity level – Low

Pleistocene Alluvium (Stream Channel, Floodplain, and Terrace Deposits)

Alluvial deposits typically consist of stream-deposited cobble to pebble gravel, sand, silt, mud, and clay. Alluvium is typically present in low-lying valleys, stream channels, and adjacent floodplains. Pleistocene-aged fossils are generally uncommon in the intermontane basins of Colorado. Lewis (1970) reported mammoth fossils from near Fairplay. Cook (1930, 1931) reported bison and mammoth remains from five montane localities. Emslie (1986) reported fossils recovered from a Late Pleistocene cave deposit in Gunnison County. Cockerell (1907) reported mammoth and horse remains from south of Florissant in Teller County. Barnosky and Rasmussen (1988) have reported on the fauna of Porcupine Cave in Park County; this cave remains the subject of ongoing fieldwork by workers at the DMNS.

The most common Pleistocene fossils include the bones of mammoth, bison, deer, and small mammals (Cook, 1930, 1931; Hunt, 1954; and Emslie, 1986).

Sensitivity level – Low

Piney Creek Alluvium

The Piney Creek Alluvium consists of dark gray to reddish-brown humic clayey silt and sand containing layers of pebbles generally in the lower part, with a thickness of 15 to 20 feet (Lindvall, 1978; and Scott, 1972). The Piney Creek Alluvium is Holocene in age and may be too young to contain fossils according to SVP 1995 guidelines, although it varies in age.

Sensitivity level – Low

Slocum Alluvium

The Pleistocene Slocum Alluvium is composed of moderate reddish-brown pebbly silt and clay interlayered with gravel, with larger and more abundant boulders closer to the mountains. With an average thickness of about 15 feet, clasts within this unit are typically altered by weathering and coated with calcium carbonate. Although the remains of bison, horse, prairie dog, gopher, Richardson's ground squirrel, and mollusks have been found in this unit (Scott, 1963, 1972), these fossils are uncommon.

Sensitivity level – Low

Pre-Bull Lake Till

Two or more Pre-Bull Lake Tills are generally recognized. Pre-Bull Lake Tills are old gravels and alluvium that are preserved as isolated, strongly weathered, and eroded glacial till that occurs in patches. Fossils are rare in glacial deposits such as the Pre-Bull Lake Till, but mammoth and bison have been reported (Cook 1930, 1931).

Sensitivity level – Low

Bull Lake Till

The Bull Lake Till is Late to Late-Middle Pleistocene in age and consists of matrix-supported, unsorted, unstratified boulders to granules in a matrix of silty, poorly sorted sand. It is exposed in the Gore Creek and Piney River valleys. Soil horizons are well developed and surface clasts are weathered and unlikely to contain intact fossils. The Bull Lake Till is estimated to have been deposited between 140,000 and 150,000 years ago (Scott et al., 2002). It is recognized in broad end moraines that commonly extend farther downvalley than moraines of younger glaciations. Fossils are rare in glacial deposits such as the Bull Lake Till, but mammoth and bison have been reported (Cook 1930, 1931).

Sensitivity level – Low

Pinedale Till

The Late Pleistocene Pinedale Till consists of bouldery deposits that form steep-sided, hummocky moraines. It is estimated to have been deposited between 12,000 and 35,000 years ago. The deposits are matrix-supported, unsorted, unstratified boulders to granules in a matrix of silty, poorly sorted sand. Lithologies of the clasts generally consist of granite, gneiss, and schist from the Cross Creek Granite and other nearby formations. Surface clasts are essentially unweathered, and soil horizons are thin and poorly developed. Fossils are rare in glacial deposits such as the Pinedale Till, but mammoth and bison have been reported (Cook 1930, 1931).

Sensitivity level – Low

Pinedale Outwash Deposits

These deposits occur downstream from the Pinedale Till and appear as moderately sorted and stratified gravel, sand, and silt covered by 1 to 2 meters of silty sand or loess. As with the Pinedale Till, fossils are rare.

Sensitivity level – Low

Till, Undivided

Occurring on the steep sides of valleys, erosion and/or colluvial deposits have modified or covered till deposits so that it is now impossible to differentiate between the Pinedale Till and Bull Lake Till units, and the paleontological sensitivity of this unit is low like the Pinedale Till and Bull Lake Till. These undivided till deposits are matrix-supported, unsorted, unstratified boulders to granules in a matrix of silty, poorly sorted sand (Scott et al., 2002)

Sensitivity level – Low

Holocene Alluvium (Stream Channel, Floodplain, and Low-Terrace Deposits)

Holocene alluvial deposits typically consist of stream-deposited cobble to pebble gravel, sand, silt, mud, and clay. Younger alluvium is typically present in low-lying valleys and stream channels. Terrace deposits are formed by downcutting of active stream channels and subsequent abandonment of the old channel/floodplain, resulting in a stairstep sequence of older terraces located above modern stream channels. Alluvial deposits less than 5,000 years old are too young to contain fossils, although they may contain cultural and biological remains.

Sensitivity level – Low

Holocene Colluvium, Talus, and Landslide Deposits

Colluvium and landslide deposits consist of rock material that has moved under the influence of gravity. Talus and cliff debris are included in colluvial deposits. Debris flows, debris slides, rockslides, debris slumps, slump earthflows, and earthflows are included in landslide deposits. Lithologies of these deposits vary and are dependent on the type of source rock. Landslides have formed on unstable slopes that are underlain by the Dakota Sandstone, Morrison, Maroon, Eagle Valley, and Minturn formations, and on older colluvium deposits. Slopes that are underlain by the Morrison Formation are particularly prone to landslides because it contains expansive clays that lose shear strength when saturated with water (Scott et al., 2002). In general, landslides and debris flows are much less likely to contain well-preserved fossils than intact native sediments. Landslide material is often subjected to increased groundwater percolation, which tends to have a negative effect on the preservation of fossils, and gravitationally induced movements of sediment can also destroy fossil remains through abrasion and breakage. Additionally, when the original stratigraphic position of the sediments is disturbed, there are varying degrees of information loss with the severity of changes to the slide mass.

Sensitivity level – Low

Quaternary Loess

Loess deposits of Holocene and Pleistocene age are common in Colorado and elsewhere and consist of wind-blown sand and silt. Although fossils are rare in loess, fossil horse and camel bones have been collected south of Littleton (Scott, 1963). The Colorado Department of Transportation staff paleontologist has documented a much more diverse fauna from Pleistocene loess deposits in eastern Colorado, which includes badger, cottontail, jackrabbit, black-tailed prairie dog, the extinct white-tailed prairie dog, Richardson’s ground squirrel, pocket gopher, vole, sagebrush vole, field mouse, and possibly bison (Steven Wallace, written communication, 2000).

Sensitivity level – Low

Quaternary Glacial Deposits

The glaciers that deposited the Pinedale and Bull Lake Tills originated in the Gore Mountain Range north of Vail and flowed down through the mountain valleys. Bull Lake glaciations took place about 130,000 to 300,000 years ago. The youngest, extensive glaciations are the Pinedale. Evidence of the Pinedale glaciations is visible in well-preserved moraines in the Piney River valley and its tributaries. Undrained depressions, kettle holes, bogs, ponds, and lakes are common on or between Pinedale moraines. Fossils are rare in glacial deposits, but mammoth and bison have been reported (Cook, 1930, 1931).

Scott et al. (2002) estimated the age of glacial till deposits based on the amount of clay in the soil horizons, the degree of weathering of clasts, and the degree of modification of glacial landforms caused by erosion. The Bull Lake Till is estimated to have been deposited between 140,000 and 150,000 years ago, and the Pinedale Till from between 12,000 and 35,000 years ago (Scott et al., 2002).

Glacial till is nonstratified material deposited directly by glacial ice and is made up of gravel, sand, silt, and clay. Glacial outwash deposits are produced by glacial meltwater streams and occur as broad, relatively flat plains. They generally consist of stratified unconsolidated sand and gravel.

Sensitivity level – Low

Quaternary Surficial Deposits

Alluvium, colluvium, loess, and fill Pleistocene and Early Holocene surficial deposits, particularly alluvium, may contain mineralized or partially mineralized animal bones, invertebrates, and plant remains of paleontological significance. These fossils typically occur in low density and consist of scattered and poorly preserved remains. In Colorado the most common Pleistocene vertebrate fossils include the bones of mammoth, bison, deer, and small mammals, but other taxa including horse, lion, cheetah, wolf, camel, antelope, peccary, mastodon, and giant ground sloth have been documented (Cook, 1930, 1931; Emslie, 1986; Hunt, 1954; Lewis, 1970; Scott, 1963; and unpublished UCM and DMNS collections data). Pleistocene and Early Holocene fossils are generally rare and at most noncave localities consist of isolated poorly preserved remains.

Sensitivity level – Low

Unnamed Early Proterozoic Metamorphic Rocks

Early Proterozoic metamorphic rocks within the Corridor include biotite gneiss; felsic gneiss; interlayered felsic, hornblende, biotite and calc-silicate gneiss; granitic gneiss, magmatitic quartzo-feldspathic gneiss; hornblende gneiss; amphibolite; hornblende-plagioclase gneiss; migmatite; biotite-muscovite gneiss; sillimanitic biotite gneiss; biotite-muscovite-sillimanite gneiss; and shist. Although metamorphic rocks of sedimentary origin such as marble can contain fossils, metamorphosed igneous rocks cannot. Metamorphic rocks such as gneiss, migmatite, amphibolite, and schist do not contain fossils because they were formed deep under the earth’s surface at extreme pressures and/or high temperatures.

Sensitivity level – None

Cross Creek Granite

The Cross Creek Granite is an Early Proterozoic rock unit composed of medium- to coarse-grained, gray to pinkish-gray, texturally diverse monzogranite, tonalite, and granodiorite. It is an igneous rock body that formed from molten material at depth and was later uplifted and eroded to its present condition. It contains no fossils.

Sensitivity level – None

Silver Plume Granite

The Middle Proterozoic Silver Plume Granite differs from other granitic bodies in Clear Creek County in its abundant and striking porphyritic potassium feldspar crystals. These crystals are elongated tabular grains that can be as much as 1 inch in length; at the turn of the century, local miners called it “corn rock.” It is a good source of building stone, riprap, and aggregate (Widmann and Miersemann, 2001). The Silver Plume Granite is an igneous rock body that formed from magma at depth and contains no fossils.

Sensitivity level – None

Sawatch Quartzite

The Upper Cambrian Sawatch Quartzite is a metamorphic rock unit that is a gray-orange, brown-weathering, vitreous orthoquartzite occurring in beds from 1 to 3 feet thick with interbeds of massive brown sandy dolomite (Streufert et al. 1997). Regional or thermal metamorphism has recrystallized the original sandstone into a harder, denser rock and destroyed any evidence of fossil remains.

Sensitivity level – None

Artificial Fill

Artificial fill composes the roadbed and embankments along and adjacent to many portions of the I-70 highway. It consists of compacted and uncompacted rock fragments and finer sediments derived from the excavation of the highway. It is too young and disturbed to contain fossils.

Sensitivity level – None

Modified Land-Surface Deposits

This type of Late Holocene deposit consists mostly of compacted rock, sand, and silt added by humans during extensive landscaping in urban areas. It contains no fossils.

Sensitivity level – None

Section 5. Environmental Consequences

All of the alternatives have potential to directly affect paleontological resources. Alternatives could affect paleontological resources if sensitive geologic units are directly disturbed during construction. Impacts on paleontological resources are often highly localized and require more detailed design or even construction to assess fully. None of the alternatives avoid disturbing important geologic units, which occur generally between mileposts 140 and 192, 202 and 207, and 259 and 260. Curve safety modifications, interchange modifications, and auxiliary lane construction potentially affect sensitive geologic units and are included to some extent in all alternatives. Potential impacts of the alternatives are described below.

5.1 No Action Alternative

The No Action Alternative includes several planned or permitted projects, which could disturb areas of moderate and high sensitivity for paleontological resources. Any areas of paleontological sensitivity will require additional evaluation based on the construction (disturbance) footprint developed in final design. It is possible that all of these projects could avoid disturbing rock formations because they are relatively limited in scope compared to the Action Alternatives.

5.2 Minimal Action Alternative

Direct adverse impacts on paleontological resources may result from ground-disturbing activities, including construction at the following sensitive locations:

- Mileposts 153 to 155 – Potential adverse impacts on the Morrison Formation could occur as a result of curve safety modification construction. This formation has a high paleontological sensitivity ranking.
- Mileposts 167 to 169 – Potential adverse impacts on the Minturn Formation could occur as a result of interchange modification and westbound auxiliary lane construction. This formation has a moderate paleontological sensitivity ranking.

- Mileposts 169 to 173 – Known adverse impacts on the documented fossil locality at mileposts 171 to 173 could occur as a result of curve safety modifications, including the proposed Dowd Canyon Tunnel. Although the Minturn Formation has moderate paleontological sensitivity, the fossil locality has a higher sensitivity ranking because impacts on the resource would be known.
- Milepost 206 – Potential adverse impacts on the Pierre Shale Formation could occur as a result of interchange modification construction. This formation has a high paleontological sensitivity ranking.
- Mileposts 258 to 259 – Potential adverse impacts on the Morrison Formation could occur as a result of interchange modification construction. This formation has a high paleontological sensitivity ranking.

5.3 Transit Alternatives

All Transit alternatives would have direct impacts on paleontological resources of moderate and high sensitivity from Eagle County Airport to Vail Pass, mileposts 140 to 192.6, because of the extended footprint and alignment along the outside of the highway. The Rail with IMC and AGS alternatives could affect sensitive formations between C-470 and Vernon Canyon. Potential adverse impacts on the highly sensitive Pierre Shale could occur at milepost 206. The construction of tracks between mileposts 258 to 259 could impact the Morrison Formation.

5.4 Highway Alternatives

The Construction of two additional lanes may potentially adversely affect paleontological resources that are moderately sensitive between mileposts 169 to 173. Auxiliary lane construction between mileposts 169 to 173 would impact sensitive formations in this area. The new tunnel bore proposed for Dowd Canyon may adversely affect the Minturn Formation and a known fossil locality. This formation has moderate sensitivity.

5.5 Combination Alternatives

The Combination alternatives would have a higher level of effect on paleontological resources, combining the effects of the Transit-only and Highway-only alternatives.

5.6 Preferred Alternative

The Preferred Alternative would have effects in the range of the other Action Alternatives. The Minimum Program would have impacts similar to the Transit-only alternatives, and the Maximum Program, if fully implemented, would have effects similar to the Combination alternatives.

Section 6. Tier 2 Processes

The Tier 2 process will use information gathered in Tier 1 to focus additional field surveys in areas of high or moderate paleontological potential. The Tier 2 process will include:

- Identification of any newly recorded and/or relocated previously recorded fossil localities,
- An assessment of the scientific importance of identified sites, and
- A recommendation for mitigation if appropriate.

During Tier 2 processes, CDOT and the Federal Highway Administration will:

- Develop specific and more detailed mitigation strategies and measures, and best management practices specific to each project; and
- Adhere to any new laws and regulations that may be in place when Tier 2 processes are underway.

Section 7. Mitigation Strategies

The following describe mitigation strategies that would be undertaken for Tier 2 processes that have the potential to affect paleontological resources. These procedures are consistent with CDOT and SVP best practices.

7.1 Programmatic Mitigation Strategies

7.1.1 Preconstruction Survey and Excavation

Paleontological assessments of potentially sensitive geologic units along the Corridor would include a literature and museum record search to determine whether any previously known fossil localities occur within or near the project Corridor, and a field survey of project areas containing geologic units with moderate and high paleontological sensitivity. Mitigation during field survey would include documentation and collection of surface fossils. The results of the searches and field survey would be compiled in an assessment report, which would include recommendations for additional paleontological mitigation work, including construction monitoring in moderately or highly sensitive units. The assessment report could recommend additional surface collecting, systematic excavation of a representative sample of the fossils present at a known locality before construction, and/or construction monitoring.

7.1.2 Construction Monitoring

- Paleontological monitoring would include inspection of exposed rock units and microscopic examination of matrix to determine if fossils are present. This work would take place during construction. Paleontological monitors would follow earth-moving equipment and examine excavated sediments and excavation sidewalls for evidence of significant fossil resources. The monitors would have authority to temporarily divert grading away from exposed fossils to professionally and efficiently recover the fossil specimens and collect associated data. All efforts to avoid delays to construction would be made.
- If construction personnel find any subsurface bones or other potential fossils during construction, work in the immediate area would cease immediately and the CDOT staff paleontologist or other qualified and permitted paleontologist would be contacted immediately to evaluate the significance of the find. Once salvage or other mitigation measures (including sampling) are complete, the paleontologist would notify the construction supervisor that paleontologic clearance has been granted.
- Paleontological monitors would be equipped with the necessary tools for the rapid removal of fossils and retrieval of associated data to prevent construction delays. This equipment includes handheld geographic positioning system or GPS receivers, digital cameras, cell phones, and laptop computers, as well as a toolkit containing specimen containers and matrix sampling bags, field labels, daily monitoring forms, field tools (such as awl, hammer, chisels, and shovel), and a plaster kit. Trucks would transport specimens and samples to an appropriate paleontological laboratory for processing.

- In the laboratory, all fossils would be prepared, identified, analyzed, and inventoried. Specimen preparation and stabilization methods would be recorded for use by the designated curation facility. All specimens would be transferred to the designated curation facility and accompanied by the final paleontologic resources report and all data in hard and electronic copy.

A final paleontological resources report would include the results of the monitoring and mitigation program, an evaluation and analysis of the fossils collected (including an assessment of their significance, age, and geologic context), an itemized inventory of fossils collected including photographs where appropriate, an appendix of locality and specimen data with locality maps and photographs, an appendix of curation agreements and other appropriate communications, and a copy of the project-specific paleontological monitoring and mitigation plan.

7.2 Project-Specific Mitigation Strategies

7.2.1 Preconstruction Survey and Excavation

Before construction, a qualified and permitted paleontologist would be retained to conduct project-specific paleontological assessments in areas of high, medium, or unknown paleontological sensitivity. Literature and museum record searches would be conducted to determine whether previously documented fossil localities occur within or near the project area, or elsewhere within the same geologic unit. Depending on the results of the searches, the anticipated impact on the unit, and the unit's sensitivity, a field survey would be required. The field survey would include a visual inspection of all potentially fossiliferous outcrops within the study area. All fossil occurrences, whether significant or not, would be documented. Documentation would include a complete record of the geographic coordinates and stratigraphic context of the fossils, and the lithologies of the fossil-bearing strata. All significant fossils would be collected during the survey, if possible, depending on the number present and their size. This is because it is often difficult to relocate small fossils, and erosion and weathering are adverse impacts on fossils that can be prevented if the fossils are collected and removed from the site. The results of the searches and field survey would be analyzed and presented in an assessment report. This report would include a discussion of the geology and paleontology of the project area, a paleontological sensitivity evaluation, a list of all fossils collected and/or observed and their significance, fossil locality data sheets, the paleontological permit number under which the work was performed, and the name of the curation facility in which the fossils were reposited, if applicable. The assessment report would also include resource mitigation recommendations. If no significant fossils were found in the searches and/or observed during the field survey, paleontologic clearance would typically be recommended. If all the significant fossils or a statistically significant sample thereof were collected from the surface of the locality during the survey, paleontologic clearance would also typically be recommended. Additional mitigation work would be recommended if significant fossils were known to remain on the surface or were partially exposed, or if there is a high probability that significant subsurface fossils exist in the study area. This work could include additional surface collecting or systematic excavation of a locality to salvage a significant fossil or collect a statistically significant sample of the fossil taxa present at the locality. If significant subsurface fossils may be further affected during ground disturbance, construction monitoring may be recommended.

7.2.2 Construction Monitoring

- Before the construction permit is issued, a qualified and permitted paleontologist would be retained to produce the mitigation plan and would be responsible for implementing the mitigation measures. This includes supervising the monitoring of construction excavations in areas with paleontological sensitivity (see below).
- The qualified paleontologist would attend preconstruction meetings to consult with the grading and excavation contractors.

- Language would be placed in the construction specifications to state that the paleontological monitor would be onsite during grading or trenching operations. The construction contractor would be instructed via the written specifications and at the preconstruction meeting to stop construction if fossils, as verified by the paleontological consultant, were unearthed. Work would cease in the vicinity of the fossils so that they could be recovered and removed from the site.
- If microfossils were present, the monitor would collect matrix for processing. To expedite removal of fossiliferous matrix, the monitor may request heavy machinery assistance to move large quantities of matrix out of the path of construction to designated stockpile areas. Testing of stockpiles would consist of screen-washing small samples (approximately 200 pounds) to determine whether significant fossils were present. Productive tests would result in screen-washing of additional matrix from the stockpiles to a maximum of 6,000 pounds per locality to ensure recovery of a scientifically significant sample.
- At each fossil locality, field data forms would be used to record the locality, measured stratigraphic sections, and appropriate scientific samples that were collected and submitted for analysis.
- In the event of discovery of unanticipated fossil remains such as unexpected concentrations of fossils, unusually large specimens, or unexpected discoveries in sediments, all ground disturbances in the area would cease immediately. The qualified paleontologist and appropriate project personnel would be notified immediately to assess the significance of the find and make further recommendations.

7.2.3 Mitigation Strategies in Areas of High Paleontological Sensitivity

Before initiation of any earth-moving construction activities in rock units of high paleontological sensitivity, a preconstruction paleontological survey would be required, followed by continuous paleontological monitoring during all phases of construction. This monitoring protocol would apply to construction activities that occur in the Morrison Formation, the Pierre Shale Formation, and the Denver Formation.

7.2.4 Mitigation Strategies in Areas of Moderate Paleontological Sensitivity

Before initiation of any earth-moving construction activities in those formations with moderate paleontological sensitivity, including the Minturn, Dotsero, Manitou, Chaffee Group, Leadville Limestone, Belden, Eagle Valley, Maroon, Fountain, Lyons Sandstone, Chinle, Ralston Creek, Dakota Sandstone, South Platte, Lytle, Benton Shale, Fox Hills Sandstone, Laramie, and Arapahoe Formations, a preconstruction paleontological survey and the Worker Awareness Training Program would be performed. Construction work conducted in these units would be then monitored on a spot-check basis.

7.2.5 Mitigation Strategies in Areas of Low Paleontological Sensitivity

Monitoring would not be required in areas of low or no paleontological sensitivity but if a fossil was discovered during construction, the CDOT paleontologist would be consulted to assess the importance of the discovery.

Section 8. References

Armstrong, H.J., and A.J. Kihm. 1980. *Fossil vertebrates of the Grand Junction area.* Prepared for the Grand River Institute and Bureau of Land Management. 211 pages.

Armstrong, A. K., and B.L. Mamet. 1976. *Biostratigraphy and regional relations of the Mississippian Leadville limestone in the San Juan Mountains, southwestern Colorado.* United States Geological Survey (USGS), Geological Survey Professional Paper.

Armstrong, H.J., and E.S. McReynolds. 1987. *Stratigraphic correlation of dinosaur quarries near Grand Junction, Colorado* in *Paleontology and geology of the dinosaur triangle.* W.R. Averett, editor. Museum of Western Colorado guidebook. Grand Junction, Colorado. Pages 45–54.

Barnosky, A.D., and D.L. Rasmussen. 1988. *Middle Pleistocene arvicoline rodents and environmental change at 2,900 meters elevation, Porcupine Cave, South Park, Colorado.* Annals of the Carnegie Museum, v. 57, number 12, pages 267–292.

Bilbey, S.A. 1992. *Stratigraphy and sedimentology of the Upper Jurassic-Lower Cretaceous rocks at the Cleveland-Lloyd Dinosaur Quarry with a comparison to the Dinosaur National Monument Quarry, Utah.* Unpublished University of Utah doctoral dissertation. 295 pages.

Bass, N.W., and S.A. Northrop. 1953. *Geology of Glenwood Springs quadrangle and vicinity, northwestern Colorado*. USGS bulletin 1142-J, 74 pages, 2 plates, scale 1:31,680.

Brill, K.G. Jr. 1942. *Late Paleozoic stratigraphy of Gore area, Colorado.* American Association of Petroleum Geologists Bulletin, v. 26, number 8, pages 1375–1397.

—. 1944. *Late Paleozoic stratigraphy, west-central and northwestern Colorado*. Geological Society of America bulletin, v. 55, pages 621–656.

Brown, R.W. 1943. *Cretaceous-Tertiary boundary in the Denver Basin, Colorado.* Geological Society of America Bulletin, v. 54, pages 65–86.

—. 1962. *Paleocene flora of the Rocky Mountains and the Great Plains.* USGS professional paper 375, 119 pages.

Bryant, B., L.W. McGrew, and R.A. Wobus. 1981. *Geologic map of the Denver 1º x 2º quadrangle, north-central Colorado.* USGS miscellaneous investigations map I-1163, scale 1:250,000, 2 sheets.

Carpenter, K. 1979. *Paleontological resources of Fort Carson, Colorado.* Unpublished report prepared for Grand River Consultants, Inc. Grand Junction, Colorado. 68 pages.

—. 1996. *Sharon Springs member, Pierre Shale (lower Campanian): depositonal environment and origin of its vertebrate fauna, with a review of North American cretaceous plesiosaurs.* University of Colorado doctoral dissertation. 251 pages.

Campbell, J.A. 1966. *The devonian system of west-central Colorado.* Unpublished doctoral dissertation, University of Colorado. Boulder, Colorado. 113 pages.

—. 1972. *Lower Paleozoic systems, White River plateau* in Quarterly of the Colorado School of Mines, volume 67, number 4, pages 37–62.

Chamberlain, C.K. 1976. *Field guide to trace fossils of the Cretaceous Dakota hogback along Alameda Avenue, west of Denver, Colorado* in *Studies in Colorado field geology*. R.C. Epis and R.J. Weimer, editors. Professional contributions of the Colorado School of Mines, v. 8, pages 242-250.

Cockerell, T.D.A. 1907. *An enumeration of the localities in the Florissant Basin, from which fossils were obtained in 1906.* American Museum of Natural History bulletin, v. 12, number 4, pages 127-1332.

Conley, C.D. 1968. *Fossil beachrock in Mississippian Leadville limestone, White River plateau, Colorado.* Geologic Society of America special paper, pages 42–43.

Cook, H.J. 1930. *Occurrence of mammoth and giant bison in glacial moraines in the high mountains of Colorado.* Science, v. 72, number 1855, page 68.

—. 1931. *More evidence of mammoths in the high mountains of Colorado.* Science, v. 73, number 1889, pages 283-284.

Dodson, P., A.K. Behrensmeyer, R.T. Bakker, and J.S. McIntosh. 1980. *Taphonomy and paleoecology of the dinosaur beds of the Jurassic Morrison Formation.* Paleobiology, v. 6, number 2, pages 208-232.

Dubiel, R.F. 1987. *Sedimentology and new fossil occurrences of the Upper Triassic Chinle Formation, southeastern Utah* in *Geology of Cataract Canyon and vicinity, 1987 field symposium.* Four Corners Geological Society guidebook 10.

Dubiel, R.F., G. Skipp, and S.T. Hasiotis. 1991. *Continental depositional environments and tropical paleosols in the Upper Triassic Chinle Formation, Eagle Basin, eastern Colorado.* Society of Economic Paleontologists and Mineralogists guidebook.

Dunkle. 1942. *A new fossil fish of the family leptolepidae.* Cleveland Museum of Natural History Scientific Publications, v. 8, pages 61–64.

Eberle, J.J. 2003. *Puercan mammalian systematics and biostratigraphy in the Denver Formation, Denver Basin, Colorado.* Rocky Mountain Geology, volume 38, number 1, pages 143–169.

Elliott, D.K., and J.D. Nations. 1998. *Bee burrows in the late Cretaceous (late Cenomanian) Dakota Formation. northeastern Arizona.* Ichnos, v. 5, number 4, pages 243–253.

Ellis, E., K.R. Johnson, and R.E. Dunn. 2003. *Evidence for an in situ early Paleocene rainforest from Castle Rock, Colorado.* Rocky Mountain Geology, v. 38, number 1, pages 73–100.

Emslie, S.D. 1986. *Late Pleistocene vertebrates from Gunnison County, Colorado.* Journal of Paleontology, v. 60, number 1, pages 170–176.

Gill, J.R., and W.A. Cobban. 1966. *The Red Bird section of the upper Cretaceous Pierre Shale in Wyoming.* USGS professional paper 393-A, 73 pages.

Gill, J.R., E.A. Merewether, and W.A. Cobban. 1970. *Stratigraphy and nomenclature of some upper Cretaceous and lower Tertiary rocks in south-central Wyoming.* USGS professional paper 667.

Hagen, H.A. 1882. *Fossil insects of the Dakota Group.* Nature. London, England. Pages 265–266.

Houck, K., and Lockley, M. 1986. *A field guide to the Pennsylvanian biofacies of the Minturn formation, Bond-McCoy area, central Colorado trough.* University of Colorado at Denver Geology Department publication, pages 51–54.

Lockley, M.G. 1984. *Pennsylvanian predators; a preliminary report on some Carboniferous shark remains.* University of Colorado Denver Geology Department magazine, fall issue, pages 18–21.

Hunt, C.B. 1954. *Pleistocene and recent deposits in the Denver area, Colorado.* USGS bulletin 996-C. Pages 91–140.

Johnson, R.B. 1962. *The Ralston Creek Formation of late Jurassic age in the Raton Mesa region and Huerfano Park, south-central Colorado.* USGS professional paper 450-C.

Johnson, K., and R.G. Raynolds. 1999. *Field trip guide to upper Cretaceous and Tertiary Formations and fossils plants and vertebrates of the northwestern Denver Basin.* Society of Vertebrate Paleontology field trip guidebook for annual meeting. Denver, Colorado. 13 pages.

Johnson, K.R., and E. Ellis. 2002. *A tropical rainforest in Colorado: 1.4 million years after the Cretaceous-Tertiary boundary.* Science, v. 296, pages 2379–2383.

Kirkham, R.M., R.K. Streufert, and J.A. Cappa. 1997. *Geologic map of the Glenwood Springs quadrangle, Garfield County, Colorado.* Colorado Geological Survey map series 31.

Knowlton, F.H. 1930. *The flora of the Denver and associated formations in Colorado.* USGS professional paper 130, 175 pages.

Kues, B.S., and S.G. Lucas. 1987. *Cretaceous stratigraphy and paleontology in the Dry Cimarron Valley, New Mexico, Colorado, and Oklahoma.* New Mexico Geological Society guidebook for 38th field conference, pages 167–198.

Lewis, G.E. 1970. *New discoveries of Pleistocene bison and peccaries in Colorado.* USGS professional paper 700-B, pages B137–B140.

Lindvall, R.M. 1979. *Geologic map of the Arvada quadrangle, Adams, Denver, and Jefferson counties, Colorado.* USGS map GQ-1453, scale 1:24,000, 1 sheet.

Lockley and Hunt 1995

Lockley, M.G. 1987. *Dinosaur footprints from the Dakota group of eastern Colorado.* The Mountain Geologist, v. 24, number 4, pages 107–122.

—. 1990. *A field guide to Dinosaur Ridge*. Friends of Dinosaur Ridge. Morrison, Colorado. 29 pages.

—. 1992. *Dinosaurs near Denver.* Colorado School of Mines quarterly, v. 92, number 2, pages 47–58.

Mehl, M.G. 1931. *A new bird record from the Dakota sandstone of Colorado.* Geological Society of America bulletin, v. 42, number 1, page 331.

Middleton, M.D. 1983. *Early Paleocene vertebrates of the Denver Basin, Colorado.* University of Colorado doctoral dissertation. Boulder, Colorado. 402 pages.

O'Sullivan, R.B. 1992. *Jurassic Wanakah and Morrison Formation in the Telluride-Ouray-western Black Canyon area of southwest Colorado.* USGS bulletin 1927.

Peterson, F. 1988. *Stratigraphy and nomenclature of Middle and Upper Jurassic rocks, Western Colorado plateau, Utah and Arizona.* USGS bulletin 1633-B, pages 17–56.

Raup, D.M. 1987. *Paleontological collecting.* Committee on Guidelines for Paleontological Collecting, National Academy of Sciences, National Academy Press. Washington, DC. 243 pages.

Rettew, D.M. 1978. *Paleoenvironmental study of the Chaffee Group (Upper Devonian) in north-east Gunnison County, Colorado.* University of Kentucky master's thesis (unpublished). 85 pages.

Rigby, J.K., and S.B. Church. 1993. *Wewokella and other sponges from the Pennsylvanian Minturn Formation of north-central Colorado.* Journal of Paleontology, v. 67, number 6, pages 909–916.

Rigby, J.K., and J.K. Rigby, Jr. 1990. *Geology of the San Arroyo and Bug Creek quadrangles, McCone County, Montana.* Brigham Young University Studies, v. 36, pages 69–134.

Roehler, H.W. 1993. *Stratigraphy of the upper Cretaceous Fox Hills Sandstone and adjacent parts of the Lewis Shale and Lance formation, east flank of the Rock Springs uplift, southwest Wyoming.* USGS professional paper 1532.

Rushforth, S.R. 1971. *A flora from the Dakota Sandstone Formation (Cenomanian) near Westwater, Grand County, Utah.* Brigham Young University Biological Series, v. 14, 44 pages.

Scott, G.R. 1963. *Quaternary geology and geomorphic history of the Kassler Quadrangle, Colorado.* USGS professional paper 421-A, 70 pages.

Scott, G.R. 1972. *Geologic map of the Morrison Quadrangle, Jefferson County, Colorado.* USGS miscellaneous investigations map I-790-A, scale 1:24,000, 1 sheet.

Scott, R.B., D.J. Lidke, and D.J. Grunwald. 2002. *Geologic map of the Vail west quadrangle, Eagle County, Colorado.* USGS miscellaneous field studies map MF-2369, scale 1:24,000, 1 sheet.

Snow, F.H. 1887. *On the discovery of a fossil bird track in the Dakota sandstone.* Transactions of the Kansas Academy of Science, v. 10, pages 3–6.

Society of Vertebrate Paleontology. 1995. *Assessment and mitigation of adverse impacts to nonrenewable paleontologic resources—standard guidelines.* Society of Vertebrate Paleontology news bulletin, v. 163, pages 22–27.

Soister, P.E. 1978. *Stratigraphy of uppermost Cretaceous and lower Tertiary rocks of the Denver Basin,* in *Energy resources of the Denver Basin.* J.D. Pruit and P.E. Coffin, editors. Rocky Mountain Association of Geologists. Pages 231–235.

S Stark, J.T., J.H. Johnson, and C.H. Behre, Jr. 1949. *Geology and origin of South Park, Colorado*. Geological Society of America Memoir 33.

Stevens, C.H. 1962. *Stratigraphic significance of Pennsylvanian brachiopods in the McCoy area, Colorado*. Journal of Paleontology, v. 36, number 4, pages 617–629.

—. 1965. *Faunal trends in near-shore Pennsylvanian deposits near McCoy, Colorado*. The Mountain Geologist, v. 2, number 2, pages 71–77.

—. 1971. *Distribution and diversity of Pennsylvanian marine faunas relative to water depth and distance from shore*. Lethaia, v. 4, number 4, pages 403–412.

Stewart, J.H., F.G. Poole, and R.F. Wilson. 1972. *Stratigraphy and origin of the Chinle Formation and related upper Triassic strata in the Colorado Plateau region.* USGS professional paper 690.

Streufert, R.K., R.M. Kirkham, T.J. Schroeder II, and B.L. Widmann. 1997. *Geologic map of the Dotsero quadrangle, Eagle and Garfield counties, Colorado.* Colorado Geologic Survey open file report 97-2.

Thompson, M.L. 1945. *Pennsylvanian rocks and fsuilinids of east Utah and northwest Colorado correlated with Kansas section*. State Geological Survey of Kansas Bulletin 60, part 2.

Thorson, J.P., C.J. Carroll, and M.L. Morgan. 2001. *Geologic map of the Pikeview quadrangle, El Paso County, Colorado.* Colorado Geologic Survey open file report 01-3, scale 1:24,000, 1 sheet and booklet.

Tidwell, W.D. 1990. *Preliminary report on the megafossil flora of the upper Jurassic Morrison Formation.* Hunteria, v. 2, number 8, 12 pages.

Trimble, D.E., and M.N. Machette. 1979. *Geologic map of the greater Denver area, Front Range urban corridor, Colorado.* USGS miscellaneous geologic map I-856-H, scale 1:100,000, 1 sheet.

Tweto, O., R.H. Moench, and J.C. Reed, Jr. 1978. *Geologic map of the Leadville 1ºX 2º quadrangle, northwestern Colorado.* USGS map 1-999, scale 1:250,000, 1 sheet.

Tweto, O. 1949. *Stratigraphy of the Pando area, Eagle County, Colorado*. Colorado Scientific Society Proceedings, v. 15, number 4, pages 149–235.

Tweto, O., and T.S. Lovering. 1977. *Geology of the Minturn 15-minute quadrangle, Eagle and Summit counties, Colorado*. USGS professional paper 956, 96 pages.

Van Horn, D. 1957. *Bedrock geology of the Golden quadrangle, Colorado.* USGS map GQ 103.

Waage, K.M. 1955. *Dakota group in northern Front Range foothills, Colorado.* USGS professional paper 274-B.

Waage, K.M., and D.L. Eicher. 1960. *Dakota group in northern Front Range area* in *Guide to the geology of Colorado*. Rocky Mountain Association of Geologists. Pages 230–237.

Wallace, S.M. 2000. Written communication regarding fossil content of Pleistocene loess.

Webster, G.D., and K.J. Houck. 1998. *Middle Pennsylvanian (late Atokan-early Desmoinesian) echinoderms from an intermontain basin; the Central Colorado Trough.* Journal of Paleontology, v. 72, number 6, pages 1054–1072.

Webster, G. D., D. J. Hafley, D. B. Blake, and A. Glass. 1999. *Crinoids and stelleroids (Echinodermata) from the Broken Rib Member, Dyer Formation (Late Devonian, Famennian) of the White River Plateau, Colorado*. Journal of Paleontology, v. 73. May.

Weimer, R.J., and C.B. Land. 1975. *Maestrichtian deltaic and interdeltaic sedimentation in the Rocky Mountain region of the United States.* Geological Association of Canada special paper 13, pages 632–666.

Widmann, B.L., and U. Miersemann. 2001. *Geologic map of the Georgetown quadrangle, Clear Creek County, Colorado.* Colorado Geological Survey open file report 01-5.

Young. R.G. 1960. *Dakota group of the Colorado plateau.* Bulletin of the American Society of Petroleum Geologists, v. 44, number 2, pages 156–194.