Paleontological Resource Overview of the Royal Gorge Field Office Planning Area

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July 2015

BLM

Royal Gorge Field Office • COLORADO

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<u>Prepared for</u>
U.S. Department of the Interior
Bureau of Land Management
Royal Gorge Field Office
Cañon City, CO

July 2015

ACKNOWLEDGMENTS

This report was prepared at the request of the Royal Gorge Field Office (RGFO) of the U.S. Department of the Interior, Bureau of Land Management (BLM). The purpose of the report is to provide an overview of paleontological resources in the RGFO Planning Area. In this report, we have attempted to synthesize and summarize the monumental efforts of a large number of scientists who have focused their research on paleontological and geological questions in the eastern half of Colorado. These efforts have been ongoing for more than 145 years. During the course of our research, we were humbled by the sheer number of paleontological investigations that have been conducted in the RGFO Planning Area. Working within a limited timeframe, we sought to capture the most important research in our report; despite our best efforts, however, we know that this document is not comprehensive.

Specifically, we thank Melissa Smeins, Geologist with the RGFO, and Harley Armstrong, Regional Paleontologist with the BLM Colorado State Office, for direction and guidance while preparing this report. We are grateful to Ken Carpenter, Director of the Utah State University Eastern Prehistoric Museum, for allowing us to use his imaginative artwork for the front and back covers of this report. We thank the Denver Museum of Nature & Science and artists Jan Vriesen, Donna Braginetz, and Gary Staab for permission to use the set of images entitled "Ancient Denvers" in this report. For access to fossil locality data, we thank the curatorial staff at the Denver Museum of Nature & Science, the University of Colorado Museum of Natural History, History Colorado, the Morrison Natural History Museum, the Royal Gorge Regional Museum & History Center, Friends of Dinosaur Ridge, the U.S. Geological Survey, the University of California Museum of Paleontology, the Smithsonian Institution, the American Museum of Natural History, and the Yale Peabody Museum of Natural History. Special thanks are extended to individuals who provided information concerning past and present paleontological research and answered questions about specific fossil localities. These include Professor Emmett Evanoff of the University of Northern Colorado, U.S. Forest Service Paleontologist Bruce Schumacher, University of Colorado Museum Curator Emeritus Peter Robinson and Collections Manager Toni Culver, and Denver Museum of Nature & Science Curator Emeritus Richard Stucky, Curator of Vertebrate Paleontology Joe Sertich, Curator of Paleobotany Ian Miller, and Collections Manager Logan Ivy.

Finally, we extend our deepest thanks to the many professional and avocational paleontologists and geologists who have contributed to the wealth of knowledge that now exists about the ancient environments, biotas, and geologic history of the region now known as eastern Colorado. Their efforts have included countless hours in the field and laboratory and have resulted in an unprecedented understanding of this region. Future scientific methods and improved technologies will facilitate the advancement of our knowledge about the history of this region while continuing to provide educational opportunities for future generations.

ABOUT THE AUTHORS

Paul C. Murphey

Paul Murphey received a doctorate in geological sciences with an emphasis in vertebrate paleontology from the University of Colorado at Boulder in 2001. His professional experience includes appointments as the Collections Manager of Paleontology, Geology and Osteology in the Geology Section of the University of Colorado Museum; instructor in the Museum and Field Studies Program at the University of Colorado Museum; and graduate faculty member in the Department of Geological Sciences at the University of Colorado. He was an Associate Curator in the Department of Paleontology and the Associate Director of the Department of PaleoServices at the San Diego Natural History Museum. Dr. Murphey has been working as a Principal Investigator for paleontological resource impact mitigation projects throughout the United States for approximately 20 years. He was the Principal Paleontologist of the nationwide Paleontological Resources Program at SWCA Environmental Consultants for 11 years. In 2014, he joined Los Angeles–based Paleo Solutions as a partner and Vice President, forming Denver-based Rocky Mountain Paleo Solutions. Dr. Murphey is currently a research associate in the Department of Earth Sciences at the Denver Museum of Nature and Science and the Department of Paleontology at the San Diego Natural History Museum. His research is focused on the evolutionary history, stratigraphy, biochronology, and depositional environments of Paleogene fossil mammals and associated rock units in the Rocky Mountain region and southern California.

Kate D. Zubin-Stathopoulos

Kate Zubin-Stathopoulos received a bachelor of science degree in geology with honors from St. Lawrence University in 2008 and her master of science degree in geoscience from the University of Calgary in Alberta in 2011. Her master's thesis research focused on the biostratigraphy and paleobiogeography of Upper Paleozoic conodonts, brachiopods, crinoids, and *Palaeoaplysina* from British Columbia. While in graduate school she taught lab sections in paleobiology, biostratigraphy, sedimentology and stratigraphy, field mapping, and geomorphology. Ms. Zubin-Stathopoulos has extensive field experience in northwestern Canada, central and western United States, and overseas. After working as a Staff Paleontologist at SWCA Environmental Consultants from 2012 to 2014, she joined Rocky Mountain Paleo Solutions, where she serves as an Assistant Project Manager and Field Supervisor. Her paleontological resource impact mitigation project experience includes oil and gas well fields, transportation, transmission, and renewable energy.

Courtney D. Richards

Courtney Richards earned a bachelor of science degree in earth and space sciences from the University of Washington in 2006 and a master of science degree in biological sciences with an emphasis in paleontology from Marshall University in 2011. Her master's thesis research focused on plesiosaur body shape and its influence on hydrodynamic properties. Her previous professional experience includes appointments as the vertebrate paleontology collection assistant at the Burke Museum of Natural History and Culture and Paleontology Supervisor and Assistant Field Director at Cogstone Resource Management, Inc. Ms. Richards has conducted paleontological field work in Mesozoic, Eocene, and Oligocene rock units in Montana, Utah, and Wyoming and Pliocene and Pleistocene surficial deposits throughout California. She has extensive experience with supervision of field crews; paleontological surveys; construction monitoring; geologic mapping; fossil salvage; and fossil preparation for transportation, water, energy, and land development projects. Ms. Richards joined Paleo Solutions as an Assistant Project Manager and Field Supervisor in 2014.

Meredith A. Fontana

Meredith Fontana received a bachelor of science degree in evolutionary biology from the University of Texas at Austin in 2011 and a master of science degree in evolutionary biology with an emphasis in vertebrate paleontology from The George Washington University in 2014. Her master's thesis research was a redescription and phylogenetic analysis of the Cretaceous fossil lizard *Polyglyphanodon sternbergi*. Her paleontological experience spans nearly 10 years and includes research, fieldwork, and laboratory work at institutions such as the Smithsonian National Museum of Natural History, The Field Museum, and Petrified Forest National Park. She has conducted fieldwork throughout the southwestern United States, including Arizona, Utah, and Wyoming. Ms. Fontana also has extensive experience with fossil preparation and conservation, which she acquired during her work in the vertebrate paleontology collections at the Texas Memorial Museum and the Houston Museum of Natural Science. She joined Rocky Mountain Paleo Solutions as a Staff Paleontologist in 2015.

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ABSTRACT

The Bureau of Land Management's (BLM) Royal Gorge Field Office (RGFO) Planning Area encompasses more than 35 million acres of central and eastern Colorado. This includes 668,000 surface acres of public lands and 6.8 million subsurface acres. The RGFO Planning Area is known to contain some of the most fossiliferous sedimentary rock sequences in North America. Because of their rich fossil content, these sequences have been the focus of continuous scientific inquiry for approximately the past 145 years. The fossil record of this area ranges from the Upper Cambrian Period to the end of the Pleistocene Epoch and represents a temporally discontinuous span of approximately 520 million years. Collectively, these geologic units (formations and members thereof) have produced more than a million catalogued fossil specimens from thousands of fossil localities, over 136 of which are located on lands managed by the BLM.

The BLM RGFO contracted Rocky Mountain Paleo Solutions (RMPS) to provide information about area paleontological resources for agency consideration in resource management planning and decision making associated with revision of the Eastern Colorado Resource Management Plan. RMPS investigated the paleontological resources of the RGFO Planning Area through review of published and unpublished literature and geologic maps, museum record searches, geographic information systems analysis, review of newspaper articles, and consultation with paleontologists with expertise in the region. RMPS analyzed the existing BLM Potential Fossil Yield Classification (PFYC) assignments of the 94 named and unnamed geologic units within the RGFO Planning Area mapped on the Geologic Map of Colorado (Tweto, 1979), and then re-arranged, combined and/or further subdivided them according to the USGS stratigraphic lexicon into 16 igneous and metamorphic rock units, 72 bedrock sedimentary rock units, and 14 surficial sedimentary deposits for more thorough paleontological analysis and PFYC assignment evaluation. This report provides an overview of these investigations and analyses and offers management recommendations. RMPS also reviewed and analyzed existing paleontological data obtained from 10 institutions and synthesized that data with existing BLM paleontological data to compile a fossil locality geodatabase as a standalone deliverable separate from this report.

NOTATION

The following is a list of the abbreviations, acronyms, and units of measure used in this document. Some acronyms and abbreviations used only in tables are defined only in those tables and are not listed here.

GENERAL ACRONYMS AND ABBREVIATIONS

ACEC	Area of Critical Environmental Concern
AMNH	American Museum of Natural History
APE	Area of Potential Effect
BLM	Bureau of Land Management
BP	Years before present
CDOT	Colorado Department of Transportation
DMNS	Denver Museum of Nature & Science (formerly DMNH, Denver Museum of Natural History)
EIS	Environmental impact statement
Ga	Gigannum (billions of years ago)
GIS	Geographic information system
Ma	Megannum (millions of years ago)
NALMA	North American Land Mammal “Age”
NMNH	Smithsonian Institution (National Museum of Natural History)
PFYC	Potential Fossil Yield Classification
RGFO	Royal Gorge Field Office
RMP	Resource Management Plan
RMPS	Rocky Mountain Paleo Solutions
SHPO	State Historic Preservation Office
UCM	University of Colorado Museum of Natural History
UCMP	University of California Museum of Paleontology
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
YPM	Yale University Peabody Museum of Natural History

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Cover artwork by Dr. Kenneth Carpenter: Collages of late Jurassic environments, depositional settings, and modern views of Cope's Nipple (front cover) and the Marsh/Felch Quarry (back cover) in the Garden Park Paleontological Area, an Area of Critical Environmental Concern and National Natural Landmark within the Bureau of Land Management Royal Gorge Field Office Planning Area.

1.0 INTRODUCTION

1.1 PURPOSE AND SCOPE

The RGFO Planning Area is known to contain some of the most fossiliferous sedimentary rock sequences in North America. Because of their rich fossil content, these sequences have been the focus of continuous scientific inquiry for approximately the past 145 years. The fossil record of this area ranges from the Upper Cambrian Period to the end of the Pleistocene Epoch and represents a temporally discontinuous span of approximately 520 million years. Collectively, these geologic units (formations and members thereof) have produced more than 1 million catalogued fossil specimens from thousands of fossil localities, over 136 of which are located on lands managed by the BLM. Paleontological and associated geological fieldwork in the study area has produced an unprecedented amount of scientific data that are continually used to study a wide variety of aspects of Paleozoic, Mesozoic, and Cenozoic biotas, including their evolution, biostratigraphy, paleobiogeography, paleoenvironments, taphonomy, and paleoecology. The fossils from the study area include highly diverse assemblages of vertebrates (fishes, amphibians, reptiles, birds, and mammals), invertebrates (mollusks, arthropods, and insects), and plants, including the holotypes of many presently recognized fossil taxa. These fossils are housed in museums throughout the world and have been the subject of thousands of published scientific studies. The application of new technologies to future fossil collections from the area and associated research and educational opportunities will undoubtedly refine and supplement our present knowledge of the history of life.

The BLM RGFO contracted RMPS to provide information about area paleontological resources for agency consideration in resource management planning and decision making associated with revision of the Eastern Colorado RMP. This project included two ambitious tasks: the production of a paleontological resource overview report and the compilation of a fossil locality geodatabase. The scope of the overview report includes all geologic units and paleontological resources within the RGFO Planning Area, as depicted in Figure 1. The report also covers applicable geologic units and paleontological resources in geologically related areas of Colorado and adjacent states. RMPS analyzed the existing BLM Potential Fossil Yield Classification (PFYC) assignments of the 94 named and unnamed geologic units within the RGFO Planning Area mapped on the Geologic Map of Colorado (Tweto, 1979), and then re-arranged, combined and/or further subdivided them according to the USGS stratigraphic lexicon into 16 igneous and metamorphic rock units, 72 bedrock sedimentary rock units, and 14 surficial sedimentary deposits for more thorough paleontological analysis and PFYC assignment evaluation. The fossil locality geodatabase includes only those previously recorded fossil localities that are located on BLM-managed surface or split estate lands with BLM subsurface management. The latter category includes privately owned, State owned, Department of Defense owned, local government owned, National Park Service managed, and U.S. Forest Service managed surface.

1.2 STUDY AREA

The BLM RGFO Planning Area encompasses more than 35 million acres of central and eastern Colorado. This includes 668,000 surface acres of BLM-managed public lands and 6.8 million subsurface acres with BLM-managed mineral rights (Figure 1). The RGFO Planning Area includes 38 counties and has been subdivided by the BLM into 8 physiographic regions (Figure 2).

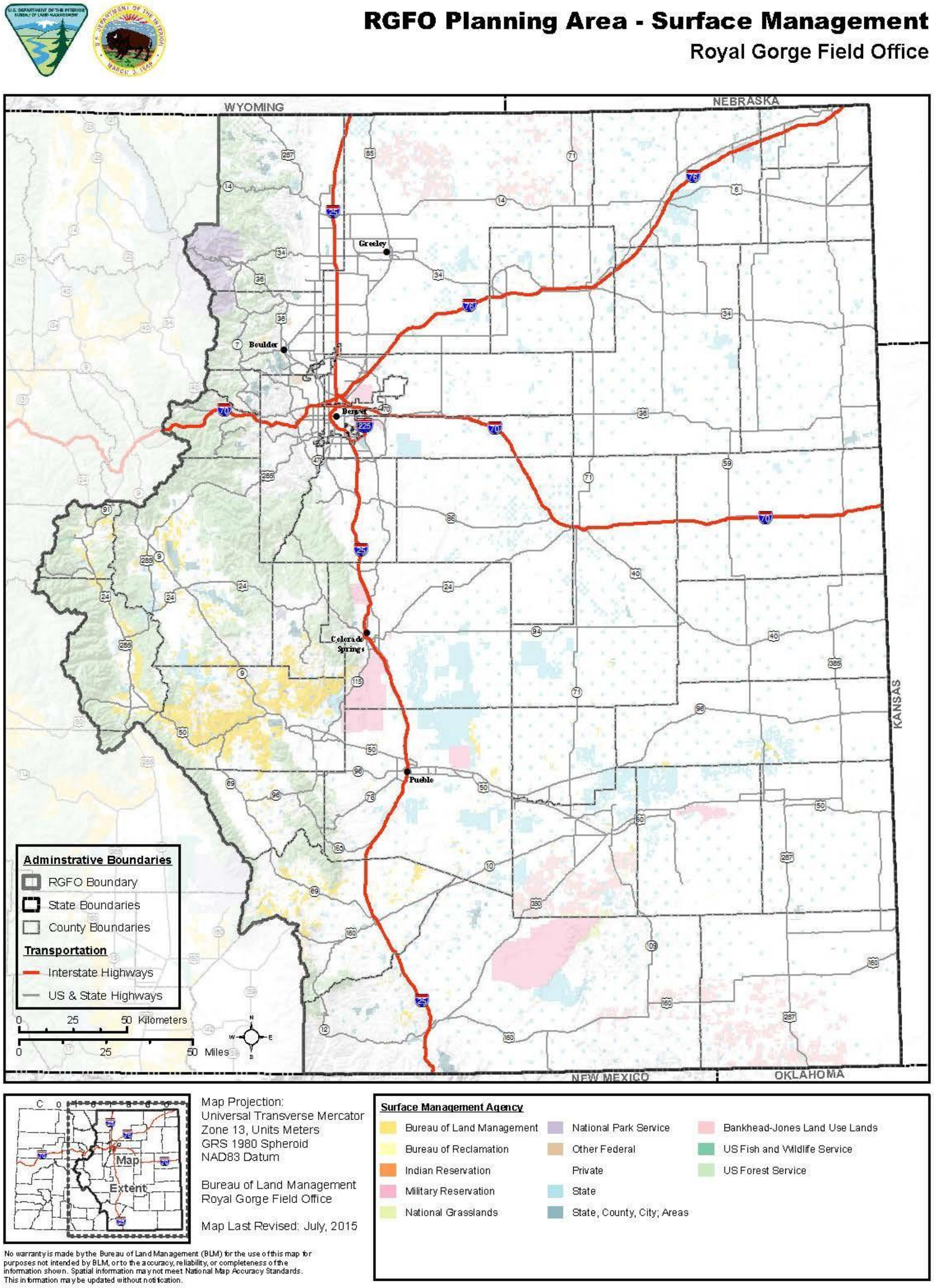

FIGURE 1. Overview map of the BLM RGFO Planning Area.

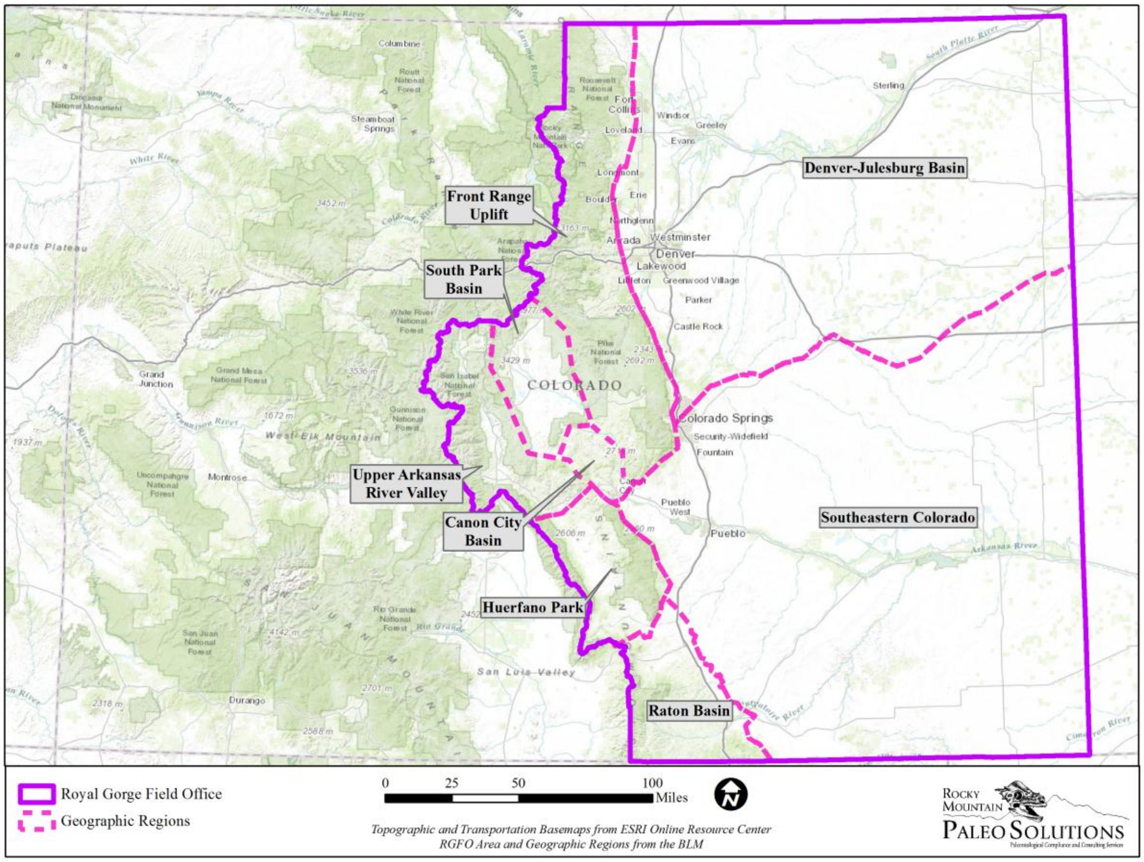

FIGURE 2. Map of physiographic regions within the BLM RGFO Planning Area.

1.3 DEFINITION AND SIGNIFICANCE OF PALEONTOLOGICAL RESOURCES

Paleontology is a multidisciplinary science that combines elements of geology, biology, chemistry, and physics in an effort to understand the history of life on earth. Paleontological resources, or fossils, are the remains, imprints, or traces of once-living organisms preserved in rocks and sediments. These include mineralized, partially mineralized, or unmineralized bones and teeth, soft tissues, shells, wood, leaf impressions, footprints, burrows, and microscopic remains. Paleontological resources include not only fossils themselves, but also the associated rocks or organic matter and the physical characteristics of the fossils' associated sedimentary matrix. 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 they represent no longer exist. Thus, once destroyed, a fossil can never be replaced (Murphey and Daitch, 2007). Fossils are important scientific and educational resources because they are used to:

- Study the phylogenetic relationships amongst extinct organisms, as well as their relationships to modern groups;
- Elucidate the taphonomic, behavioral, temporal, and diagenetic pathways responsible for fossil preservation, including the biases inherent in the fossil record;
- Reconstruct ancient environments, climate change, and paleoecological relationships;
- Provide a measure of relative geologic dating that forms the basis for biochronology and biostratigraphy and serves as an independent and corroborating line of evidence for isotopic dating;
- 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; and
- Identify past and potential future human-caused impacts on global environments and climates (Murphey and Daitch, 2007).

According to BLM IM 2009-011 (BLM, 2008), a "Significant Paleontological Resource" is defined as:

> Any paleontological resource that is considered to be of scientific interest, including most vertebrate fossil remains and traces, and certain rare or unusual invertebrate and plant fossils. A significant paleontological resource is considered to be scientifically important because it is a rare or previously unknown species, it is of high quality and well-preserved, it preserves a previously unknown anatomical or other characteristic, provides new information about the history of life on earth, or has identified educational or recreational value. Paleontological resources that may be considered to not have paleontological significance include those that lack provenience or context, lack physical integrity because of decay or natural erosion, or that are overly redundant or are otherwise not useful for research. Vertebrate fossil remains and traces include bone, scales, scutes, skin impressions, burrows, tracks, tail drag marks, vertebrate coprolites (feces), gastroliths (stomach stones), or other physical evidence of past vertebrate life or activities.

2.0 METHODS

The purpose of this paleontological resource overview study was to analyze and evaluate the paleontological sensitivities of geologic units within the RGFO Planning Area and compile a fossil locality geodatabase to support the revision of the Eastern Colorado RMP. RMPS compiled the information in this report from scientific literature, geologic maps, unpublished technical reports (many of which were furnished by the BLM), newspaper articles, and consultation with professional paleontologists with expertise on the study area. RMPS also used the information to evaluate the BLM's existing PFYC assignments for units in the area (see Section 3.0 for PFYC description).

2.1 PERSONNEL

Paul C. Murphey, Ph.D., Kate D. Zubin-Stathopoulos, M.S., Meredith A. Fontana, M.S., and Courtney D. Richards, M.S, conducted research for and prepared this report. Vanessa R. Hastings, B.S., and Katie E. Schortmann, B.S. edited the document. The GIS analysis for the report and the compilation of the confidential fossil locality geodatabase was completed by Paul R. Nesbit, M.S., and Barbara J. Webster, M.S.

2.2 LITERATURE REVIEW

The geographic area encompassed by the literature review included the entire RGFO Planning Area, essentially all of the geologic units and paleontological resources known from the region of central and eastern Colorado depicted in Figure 1 as well as geologically related areas adjacent to the RGFO Planning Area.

The information in this report was compiled from scientific literature, geologic maps, unpublished technical reports (many of which were furnished by the BLM), newspaper articles, and consultation with professional paleontologists with expertise on the study area. The individuals who provided the information included in this report are listed in the acknowledgements. The report includes a history of paleontological investigations and a summary of geological and paleontological history for the RGFO Planning Area, followed by descriptions of the geology and paleontology of each of the mapped geologic units within the area (see tables 3, 4 and 5). These descriptions are divided into three categories: igneous and metamorphic rock units, sedimentary rock units, and surficial sedimentary deposits.

In addition to reviewing their own published papers and books, the authors of this report conducted library research online or in person at libraries at the following institutions: the University of Colorado, The George Washington University, The University of Texas, the University of Washington, and the University of Buffalo. Online sources primarily included Academia.edu, BioOne, GeoRef, Google Scholar, Google e-books, Jstor, Science Direct, Wiley Online Library, and GeoScience World. Some of the papers obtained from libraries that were not available as PDF files were scanned. RMPS provided all PDFs obtained during the literature review to the BLM as reference documents for this report. The bibliography of published literature cited in this report is by no means intended to be comprehensive but serves as an attempt to capture the most relevant publications.

2.3 GEOLOGIC MAP REVIEW

Colorado's BLM Regional Paleontologist, with input from other professional paleontologists and BLM paleontological resource coordinators in field offices throughout the state, have assigned PFYC designations to each geologic unit mapped on the Geologic Map of Colorado (Tweto, 1979).

RMPS further subdivided the geologic units for this study to achieve a meaningful level of precision for analyzing the paleontological resource potential of the study area because many of the named formations appear only on larger scale maps. Published geologic maps that cover the RGFO Planning Area were reviewed and compared to the Geologic Map of Colorado (Tweto, 1979) to accomplish this. Appendix A contains a list of these geologic maps with hyperlinks.

2.4 FOSSIL LOCALITY GEODATABASE

The purpose of compiling the fossil locality geodatabase was to correct inaccurate information in the existing BLM RGFO fossil locality records and add missing information to them. Because fossil locality data are considered confidential and are exempt from the Freedom of Information Act, RMPS provided the fossil locality geodatabase to the BLM as a standalone deliverable separate from this report. RMPS requested fossil locality data from the institutions listed in Table 1 for inclusion in the geodatabase. With the exception of the NMNH and AMNH, all of the institutions provided the requested data. It is possible that the NMNH and AMNH will provide requested fossil locality data to the BLM in the future.

Unlike the literature review area, which includes the entire RGFO Planning Area (Figure 1), the area for the fossil locality search includes only BLM-managed lands within the RGFO Planning area. This includes BLM-managed surface acres and subsurface acres with BLM-managed mineral rights.

Using GIS, RMPS compared the fossil locality search results to the existing BLM RGFO fossil locality database. The comparison resulted in the addition of missing data to the existing database, the addition of new records to the database, and the correction of some inaccurate data. In addition, RMPS identified and flagged a small number of problem records for future troubleshooting by the BLM.

TABLE 1. Summary of Locality Search Results.

Institution (Acronym)	Contact Person	Contact Date	Response
Denver Museum of Nature and Science (DMNS)	Logan Ivy	1/6/2015	43 localities for which BLM is listed as land owner returned
University of Colorado Museum (UCM)	Tonia Culver	1/6/2015	776 localities returned; 766 lack land ownership data. 10 localities recorded as located on BLM land
History Colorado (SHPO)	Mary Sullivan and Robert Cronk	2/13/2015	0 localities with BLM as land owner returned.
Morrison Natural History Museum	Matthew Mossbrucker	2/4/2015	Museum does not hold any fossils collected on federal land.
Royal Gorge Regional Museum and History Center	Lisa Studts	2/13/2015	Digital copy of locality database obtained in person, and locality maps were photographed; 77 localities for which BLM is listed as landowner returned
Friends of Dinosaur Ridge	Joe Temple	2/13/2015	0 localities with BLM as land owner returned.
US Geological Survey (USGS)	Kevin (Casey) McKinney	3/3/2015	16 localities with BLM as land owner returned.
University of Colorado at Denver (UCD)	Martin Lockley	2/13/2015	No response to request. However, all UCD fossil localities are believed to be on file at UCM.

Institution (Acronym)	Contact Person	Contact Date	Response
University of California Museum of Paleontology (UCMP)	Ken Finger	2/26/2015	Returned results for 68 localities located in the 38 counties within the RGFO. Land ownership remains to be determined.
Smithsonian Institution (NMNH)	Kathy Hollis	2/26/2015	No response to data request received by June 30, 2015.
American Museum of Natural History (AMNH)	Ruth O'Leary	2/26/2015	Search was not completed due to current database format, which does not permit searches by land owner. AMNH plans to upgrade database within a year.
Yale University Peabody Museum (YPM)	Tim White	2/26/2015	Returned results for 1,008 vertebrate localities, 242 invertebrate localities, and 157 paleobotanical localities within Colorado. Land ownership remains to be determined.

3.0 POTENTIAL FOSSIL YIELD CLASSIFICATION

The PFYC System is a predictive resource-management tool founded on two basic facts of paleontology: Occurrences of paleontological resources are closely tied to the geologic units (i.e., formations, members, or beds) that contain them, and the likelihood of the presence of fossils can be broadly predicted from the distribution of geologic units at or near the surface (Table 2). Therefore, geologic mapping, as the documentation of geologic unit distribution, is a reliable method for assessing the potential of geologic units to preserve fossils.

The PFYC System classifies geologic units on the relative abundance of scientifically significant vertebrate, invertebrate, or plant fossils and their sensitivity to adverse impacts, with a higher classification number indicating a higher potential for fossil occurrences. Among paleontologists, it is understood that this classification is preferably applied to the geologic formation, member, or other distinguishable unit at the most detailed mappable level. Currently, most BLM PFYC maps are available only at the scale of 1:500,000 (state geologic maps). The PFYC is not intended to be applied to specific paleontological localities or small geographic areas within geologic units. Although significant localities may occasionally occur in a geologic unit, the existence of a few important fossils or localities widely scattered over a large area does not necessarily indicate a higher classification for the unit. The relative abundance of significant localities is intended to serve as the major determinant for the class assignment. The PFYC System is intended to provide baseline guidance for predicting, assessing, and mitigating impacts on paleontological resources.

TABLE 2. The PFYC, summarized from BLM IM 2008-009 (2007).

PFYC Designation	Assignment Criteria Guidelines and Management Summary
1 = Very Low Potential	Geologic units are not likely to contain recognizable fossil remains.
	Units are igneous or metamorphic, excluding reworked volcanic ash units.
	Units are Precambrian in age or older.
	Management concern is negligible, and impact mitigation is unnecessary except in rare circumstances.
2 = Low Potential	Sedimentary geologic units are not likely to contain vertebrate fossils or scientifically significant nonvertebrate fossils.
	Vertebrate or significant invertebrate or plant fossils are not present or are very rare.
	Units are generally younger than 10,000 years BP.
	Eolian deposition has occurred recently.
	Sediments exhibit significant physical and chemical changes (i.e., diagenetic alteration).
	Management concern is low, and impact mitigation is usually unnecessary except in rare circumstances.
*3 = Moderate Potential	Fossiliferous sedimentary geologic units in which fossil content varies in significance, abundance, and predictable occurrence or sedimentary units of unknown fossil potential are present.
	Fossils are often marine in origin with sporadic known occurrences of vertebrate fossils.
	Vertebrate fossils and scientifically significant invertebrate or plant fossils known to occur intermittently; predictability known to be low
	Surface-disturbing activities require sufficient assessment to determine whether significant paleontological resources occur in the area of a proposed action and whether the action could affect the paleontological resources. Management options could include pre-disturbance surveys, monitoring, or avoidance. Opportunities may exist for hobby collecting.
*U = Unknown	Unit is poorly studied and/or poorly documented; potential yield cannot be assigned without ground reconnaissance.

PFYC Designation	Assignment Criteria Guidelines and Management Summary
Potential	Geologic units in this class may eventually be placed in another class after sufficient survey and research is performed.
	Management concern cannot be determined from existing data.
*4 = High Potential	Geologic units containing a high occurrence of significant fossils are present. Vertebrate fossils or scientifically significant invertebrate or plant fossils are known to occur and have been documented but may vary in occurrence and predictability.
	Surface-disturbing activities may adversely affect paleontological resources in many cases.
	Management concern is moderate to high depending on the proposed action. A field survey by a qualified paleontologist is often needed to assess local conditions. On-site monitoring or spot-checking may be necessary during construction activities. Management prescriptions for resource preservation and conservation through controlled access or special management designation should be considered.
5 = Very high Potential	Highly fossiliferous geologic units that consistently and predictably produce vertebrate fossils or scientifically significant invertebrate or plant fossils are present and are at risk of human-caused adverse impacts or natural degradation.
	The probability for impacting significant fossils is high. Vertebrate fossils or scientifically significant invertebrate fossils are known or can reasonably be expected to occur.
	Management concern is high to very high. A field survey by a qualified paleontologist is usually necessary before surface disturbance or land tenure adjustments. Impact mitigation will often be necessary before and/or during these actions. Official designation of areas of avoidance, special interest, and concern may be appropriate

*****Descriptions modified from BLM IM 2008-009 based on input from BLM paleontologists Harley Armstrong and Scott Foss.

4.0 SUMMARIZED GEOLOGICAL AND PALEONTOLOGICAL HISTORY OF THE RGFO PLANNING AREA

The rocks and fossils of the region known today as eastern Colorado record an epic and fascinating history. The Red Creek Quartzite is the oldest rock unit in Colorado but occurs only in the northwest corner of the state near Browns Park. For the most part, Colorado's oldest exposed rocks are granitic and metamorphic rocks that formed during the Colorado Orogeny approximately 1.6 to 1.8 Ga, and they comprise much of the crystalline basement of the state. During the Colorado Orogeny, rocks were accreted to the North American Continent in a series of subduction zone collisions. More granitic rocks, including the Pikes Peak Batholith, were added to the Precambrian basement during the subsequent Berthoud and Grenville Orogenies. During the late Proterozoic, between about 1.1 Ga and 510 Ma, a long period of erosion called the Great Unconformity planed off the Precambrian basement. During this time, all sedimentary rocks eroded away except for the Uncompahgre Formation and the Uinta Mountain Group in southwestern and northwestern Colorado, respectively; the location of these units within deep Proterozoic rift basins apparently offered protection from the forces of nature.

During the late Cambrian, a shallow sea transgressed over the region from the east, blanketing the Precambrian basement with quartz-rich beach sands represented today by the Sawatch Formation. For most of the ensuing Paleozoic, between the late Cambrian until the early Pennsylvanian, Colorado was located near the equator and was covered by a shallow tropical sea. Great thicknesses of sandstone, limestone, and shale were deposited on the eroded Precambrian basement surface. During the Ordovician, limestones and sandstones of the Manitou Formation, Harding Sandstone, and Fremont Dolomite were deposited in a shallow sea inhabited by marine invertebrates. Evidence of the earliest vertebrates in the form of isolated bony dermal scales and complete armored fish is preserved in the Harding Sandstone, which was likely deposited in close proximity to an ancient shoreline. All sediments deposited in Colorado during the Silurian were apparently eroded away during the early Devonian, when Colorado rose above sea level. The only remaining evidence of the Silurian consists of limestone fragments in kimberlite pipes in the northern part of the state close to the Colorado-Wyoming border.

By the late Devonian, a shallow, tropical sea transgressed over the state and deposited rocks of the Chaffee Group and its stratigraphic equivalents. The sea persisted throughout most of the Mississippian and deposited the widespread Leadville Limestone. By the time the sea had nearly dried up, its waters had regressed enough in places to expose the upper strata of the Leadville Limestone to erosion, forming karst topography, some of which is visible today. The sea continued to regress during the Pennsylvanian, resulting in the deposition of the Belden and Glen Eyrie Formations. During the middle Pennsylvanian, as the supercontinent Pangaea initially assembled, an episode of mountain building formed the ancestral Rocky Mountains, which consisted of an eastern range called Frontrangia and a western range called Uncompahgria; these ranges were separated by the Maroon Basin, also referred to as the central Colorado trough. This trough was episodically filled with the evaporitic deposits of gypsum, halite, and anhydrite as shallow seaways transgressed and then dried up. These briny waters were inhabited by diverse and abundant marine invertebrate faunas and less commonly fish. The evaporites contributed to rock units such as the Eagle Valley Formation and the Eagle Valley Evaporite, which are exposed today in the vicinity of Eagle, Gypsum, Glenwood Springs, and Carbondale, CO, west of the RGFO Planning Area. The Ancestral Rocky Mountain Orogeny shed vast amounts of red arkosic conglomerates onto coalescing alluvial fans represented today by rock units such as the Fountain Formation, Sangre de Cristo Formation, Hermosa Group, and lower Maroon Formation. Fine-grained facies of the Fountain Formation preserve the trackways of primitive tetrapods, and the Sangre de Cristo Formation withgin the RGFO Planning Area has produced body fossils of early amphibians, primitive reptiles, and mammal-like reptiles. The arkosic conglomerates are locally interbedded with or stratigraphically equivalent to marine or partially marine rock units such as the Minturn Formation, which preserve highly diverse and abundant fossil marine invertebrates and less commonly remains of fish, vertebrate trackways, and plants. As the ancestral Rockies eroded through the late Pennsylvanian and Permian, the sediments shed from them became more fine grained and in the early Permian formed the eolian sand dune fields of the Lyons Sandstone, which preserve tracks of vertebrates and insects. By the late Permian, the ancestral Rockies were completely eroded away, and Colorado was at least partially covered once again by a shallow sea in which the coastal mudflat deposits of the stromatolitic Lykins Formation were formed, preserving a low diversity of marine invertebrate fauna and scattered rare bone fragments.

The largest extinction event in Earth's history marks the end of the Paleozoic and the beginning of the Mesozoic at the Permian-Triassic boundary about 252 Ma, when 95 percent of all marine species and 70 percent of terrestrial species went extinct. The causes of this mass extinction are poorly understood but were possibly related to a combination of environmental, atmospheric, and extraterrestrial events. During the late Permian and Triassic, as the supercontinent Pangaea became fully assembled, North America was largely located latitudinally within the planet's northern desert belt. Low-relief, arid mudflats episodically inundated with volcanic ash appear to have been the dominant environment in Colorado and across the southwest at this time. The formations that comprise the Dockum Group and correlative units are representative of these conditions and preserve a diverse assemblage of Triassic animals, including early dinosaurs, crocodilians, pterosaurs, and mammal-like reptiles.

The early Jurassic was similar to the Triassic environments in western Colorado, as exemplified by the Navajo Sandstone, Carmel Formation, and the Entrada Sandstone, which consist of alternating mudflat and sand dune desert environments. Of these units, only the Entrada extends eastward into central Colorado and into the RGFO Planning Area. Fossils are comparatively rare in these units, with well-preserved trackways the most common evidence of early Jurassic fauna. Pangaea began to break apart during the middle Jurassic, and North America moved north close to its current latitude, resulting in a lush tropical environment that was flat and close to sea level. Episodic marine transgressions of the Sundance Sea during the middle and early late Jurassic today preserve marine invertebrates, vertebrates, and trackways in the Sundance Formation (mostly in Wyoming) and marine invertebrates and associated ichnofossils in the Curtis Formation. The Ralston Creek and Summerville Formations were deposited on broad, muddy floodplains, today containing evidence of brief marine transgressions but few fossils. The Morrison Formation was deposited in river channels, on floodplains, and in poorly drained lakes. This rock unit, which is of historic importance in Colorado, preserves an incredible array of late Jurassic terrestrial and aquatic plants, invertebrates (including insects and sponges), and vertebrates and is world renowned for the relatively abundant and complete dinosaur skeletons it contains.

Early Cretaceous sedimentation on floodplains and in stream channels resulted in the deposition of the Cedar Mountain Formation in Utah and the equivalent Burro Canyon Formation in Colorado. Uplift in Utah resulted in increased drainage across Colorado and deposition of the stream channel–dominated Lytle Formation of the Dakota Group. In the middle Cretaceous, due to a prolonged period of rapid seafloor spreading in combination with the Sevier Orogeny, which in turn led to the development of a foreland basin, the Western Interior Cretaceous Seaway transgressed across North America from the Gulf of Mexico and the Arctic, meeting in southeast Colorado about 100 Ma. The resulting sedimentary deposits preserve the ensuing 30-million-year geologic record of marine transgressions and regressions. Shoreline deposits of the initial marine transgression are preserved as the South Platte Formation of the Dakota Group, which contains well-preserved vertebrate tracks, invertebrate trace fossils and plants, and scattered and mostly fragmentary vertebrates. These beach, estuarine, Barrier Island, and deltaic deposits were covered by a succession of open water limestones and shales with a significant volcanic ash component, represented in eastern Colorado today by the Colorado Group, Niobrara Formation, and Pierre Shale. These are all geologically widespread rock units that locally preserve diverse marine invertebrate and vertebrate faunas with occasional occurrences of terrestrial vertebrates and plants that were washed into the shallow seaway before sinking to the bottom and being covered with sediment. The final regression of the Cretaceous Interior Seaway and the end of marine deposition in Colorado is recorded in the rocks of the Fox Hills Sandstone and Laramie Formation, which are equivalent to the Mesaverde Group in western Colorado. In Colorado, the Fox Hills Sandstone contains mostly invertebrate ichnofossils and poorly preserved plants, whereas the Laramie Formation contains locally abundant plant fossils and reptiles including dinosaurs and late Cretaceous (Lancian) mammals.

The uplift of the modern Rocky Mountains began approximately 72 Ma with the onset of the Laramide Orogeny, which lasted until the late middle Eocene, about 40 million years ago. Volcanism accompanied the Laramide Orogeny in Colorado, but most evidence of that phenomenon in the area has been eroded away with the exception of the 62 to 63 million year old basalt flows on North and South Table Mountains west of Denver. The Arapahoe Conglomerate and Denver Formation are synorogenic deposits that were deposited in the Denver Basin as the Rocky Mountains rose to the west, and the largely volcaniclastic Denver Formation reflects the onset of volcanism in the Front Range highlands. Latest Cretaceous rock units in the Denver Basin and Raton Basin preserve the Cretaceous-Tertiary (K-T) Boundary, the global extinction event that led, at least partially, to the extinction of the dinosaurs as well as 75 percent of all the plant and animal species on Earth, usually dated to around 66 Ma. The K-T boundary is typically indicated around the world by a combination of the presence of iridium, shocked quartz, a spike in the amount of fern pollen overlying the boundary horizon, and a lack of dinosaur and other Cretaceous fossils overlying the boundary horizon. The Denver and Raton Formations preserve both Cretaceous and Paleocene floras, and the Denver Formation preserves Cretaceous dinosaurs and other reptiles below the K-T boundary and earliest Paleocene (Puercan) mammals above it. The Denver Formation in the Denver Basin is one of the few places in North America where Paleocene sediments that preserve earliest Tertiary mammals are present and exposed. Paleobotanical evidence indicates that the recovery of plant communities was remarkably rapid after the K-T boundary extinction, with fossil localities such as the DMNS Castle Rock Rainforest Site attesting to the diversity and rapid recovery of early Paleocene floras in Colorado.

Consisting of floodplain and river channel deposits formed in tropical forests and open plains, early Eocene rocks in eastern Colorado are represented only by the Huerfano Formation, the Cuchara Formation, and the "D2" (uppermost) portion of the Denver Formation. The Huerfano and Cuchara Formations are locally highly fossiliferous, preserving diverse assemblages of fish, reptiles, birds, and mammals. The first of three post-Laramide volcanic phases is represented in eastern Colorado by the 37 Ma Wall Mountain Tuff, an ignimbrite with a source in the Mount Princeton area that blanketed the western part of the Denver Basin with up to 400 feet of volcanic ash (the second phase occurred during the Oligocene, and the third during the Miocene and Pliocene). A rare example of the preservation of an upland ecosystem is represented by the world renowned late Eocene Florissant Formation, located close to the geographic center of the state. This volcaniclastic and mostly lacustrine rock unit contains giant sequoia stumps, exquisitely preserved insects and plants, fish, and land mammals. Late Eocene and Oligocene sedimentary rocks in northeastern Colorado are represented by the volcaniclastic and highly fossiliferous White River Group, which contains diverse assemblages of fossil vertebrates, especially mammals. Miocene rock units in eastern Colorado include the volcaniclastic Arikaree and Troublesome Formations, both of which contain fossil mammals. Of Miocene and Pliocene age, the alluvial, eolian, and colluvial Ogallala Formation formed as alluvial fans along the Front Range built eastward and coalesced on the plains from Wyoming to New Mexico. These sediments were originally deposited horizontally but now dip eastward in response to regional uplift. The Ogallala was deposited on savanna grasslands episodically inundated with volcanic ash, and the formation comprises the surface geology of much of Colorado's eastern plains today.

During the latter part of the Pleistocene, from about 1.8 Ma to 10,000 year BP, large valley glaciers were present in all of the high mountain ranges of Colorado. Evidence of two glacial advances has been recorded on the Colorado landscape. The first, the Bull Lake glaciation, occurred between about 125,000 and 50,000 years BP. The second, the Pinedale glaciation, occurred between about 29,000 and 7,600 years BP. Colorado was inhabited by highly diverse assemblages of animals and plants during the Pleistocene, and numerous fossil localities have been documented, especially in alluvium, cave and lake deposits. Pliocene through Holocene deposition and erosion formed the modern topography of eastern Colorado, and with the terminal Pleistocene extinction of the last of the megafauna, modern ecosystems of the area were largely established.

5.0 HISTORY OF PALEONTOLOGICAL INVESTIGATIONS WITHIN THE RGFO PLANNING AREA

Residents of the geographic region now known as Colorado used paleontological resources long before they were recognized as the remains of once-living organisms and well before paleontologists documented them. BLM Colorado Regional Paleontologist Harley Armstrong has recorded a number of examples of this (written communication, 2015). For example, crinoid stem beads were observed at a Ute wickiup village near the town of Eagle. Chipped stone tools made of dinosaur bone have been found near Grand Junction. In Unaweep Canyon south of Grand Junction, a rancher discovered part of a coiled ammonite that had been used to grind red ochre. And a number of large hafted biface tools made of silicified wood and other stone tools made of silicified wood and bone most likely from the Morrison Formation were documented during archaeological and paleontological surveys of Fort Carson south of Colorado Springs in the early 1980s (Alexander et al., 1983). Of these archaeological artifacts made of fossils, only the Fort Carson discoveries were located within the RGFO Planning area. The remainder of this section offers a history of paleontological investigations within the RGFO Planning area compiled from scientific papers, published and unpublished historical accounts, and discussions with local paleontologists. This history, especially for the second half of the twentieth century to the present day, is far from comprehensive but attempts to cover some of the more interesting episodes and paleontological accomplishments that took place. It should be noted that much of the more recent paleontological work within the RGFO Planning area is summarized and cited in Section 6.0 of this report.

The first fossils that were scientifically collected in Colorado were fossil insects discovered in rocks of what would later be recognized as the Green River Formation. Professor W. Denton collected them in 1865 from bluffs along the White River near the present location of the Colorado-Utah border (Armstrong and Wolny 1989). Beginning in 1867, Samuel H. Scudder, the founder of American insect paleontology, one-time assistant to Louis Agassiz (1862–1864), and later USGS Paleontologist (1886–1892), confirmed Denton's discoveries and spent the following 30 years collecting and describing fossil insects of northwestern Colorado. Many of these specimens were included in Scudder's classic monograph, The Tertiary Insects of North America (1890).

The first scientifically collected vertebrate fossil reported from Colorado was discovered during the Hayden survey of 1869. This fossil, a broken caudal (tail) vertebra of a theropod dinosaur discovered in the late-Jurassic Morrison Formation in Middle Park, Colorado, was thought to be a "petrified horse hoof" by the field party that collected it. The specimen was scientifically described by prominent early north American paleontologist Joseph Leidy. Leidy later assigned the generic name genus *Antrodemus* to this specimen, but the name *Antrodemus* was subsequently synonymized with the genus *Allosaurus*, which had nomenclatural priority because it was based on a much more complete skeleton discovered by O.C. Marsh in 1877 in Fremont County, Colorado (Armstrong and Wolny 1989). According to University of Colorado Museum Curator Emeritus Peter Robinson, the *Antrodemus* caudal vertebra may have been discovered near the Green Mountain Dam in Middle Park (P. Robinson, personal communication, 2000).

In 1870, Professor O.C. Marsh and a group of students from Yale University spent most of his first dedicated fossil collecting expedition to the west visiting various locations in Wyoming and Utah, but they set aside a week for prospecting outcrops of Tertiary rocks in northeastern Colorado. The Marsh party collected a variety of mammal fossils from the vicinity of Little Crow Creek and "along the hills known as Chalk Bluffs" in western Weld County and about 5 miles south of the Colorado-Wyoming border (Marsh, 1870:292). Marsh noted the presence of "Titanotherium beds" and "above these…similar clay deposits…marked by abundant remains of *Oreodon culbertsoni*" (Marsh, 1870:292). His 1870 report noted that presence of about 150 feet of White River beds and 200 feet of post-Oligocene beds.

Most of Chalk Bluffs now lies within the Pawnee National Grassland. E. Berthoud noted the presence of fossils in the Crow Creek area during a search for paleoindian sites in 1871 (see Galbreath, 1953).

Other early paleontological work in northeastern Colorado was undertaken by paleontologist E.D. Cope of the Academy of Natural Sciences of Philadelphia, who visited northeastern Colorado during the summer and fall of 1873 and again in the fall of 1879, collecting fossils and studying the geology of the area. Cope recognized the general similarity of the Tertiary deposits of this region to those of Nebraska and South Dakota, and he published on the geology and fossils of the area (Cope, 1874). Of all the early expeditions, only Cope's work resulted in what is considered a major publication on the geology and paleontology of northeastern Colorado. In 1882, a Princeton University expedition collected in the vicinity of Chalk Bluffs (see Galbreath, 1953). In 1898, 1901, and 1902, field parties from the AMNH led by W.D. Matthew worked in northeast Colorado in the Chalk Bluffs region (e.g., see Matthew, 1901; Osborn, 1918).

The first dinosaur fossils reported from the Denver Basin were described in a letter from E. Berthoud to Marsh as having been discovered in an excavation for a well in Golden in 1867. Berthoud also reported other fossil remains from the Golden area. One specimen, sketched in an 1874 letter to Marsh, is now believed to be the first known specimen (a tooth) of *Tyrannosaurus rex*. It had been collected from the Denver Formation on South Table Mountain by Arthur Lakes, a part-time professor at what later became the Colorado School of Mines in Golden. G.L. Cannon, W. Cross, and G. Eldridge initiated the first study of the geology of the Denver Basin in 1896 and reported additional fossil localities, the richest located on Green Mountain and along the South Platte River.

In March 1877, Arthur Lakes discovered a large fossil vertebra near the town of Morrison while searching for fossil leaves in the Dakota Sandstone with friend and U.S. Navy Captain H.C. Beckwith. The vertebra was found embedded in a sandstone on the west-facing hillside below the Dakota Hogback. Lakes sent a sketch of the specimen to Marsh, who replied that he could identify it if he could examine the fossil in person. Lakes continued to prospect for fossils in what is now known as the Morrison Formation, a geographically widespread rock unit of upper Jurassic age that is now world renowned for its dinosaur fossils. The stratotype sequence of the Morrison Formation is located at the town of Morrison near Lakes' original dinosaur quarry. Since Marsh was then the official vertebrate paleontologist of the USGS, Lakes sent him 1,500 pounds of dinosaur bones for study. Marsh paid Lakes $100 for the specimens, and Lakes began working as a professional fossil collector for Marsh by 1878. Among these fossils was a dinosaur described by Marsh in the American Journal of Science as the largest land animal theretofore known, the sauropod *Apatosaurus ajax*. The holotype of *Stegosaurus armatus* (Colorado's state fossil) was also among the fossils described by Marsh as part of Lakes' excavation near the town of Morrison (Lakes' dinosaur quarries are located on the west side of the hogback ridge west of Green Mountain). Around the same time, Lakes sent specimens to Marsh's bitter rival Cope, quite innocently igniting a simmering feud between these two paleontologists. Later known as the "Bone Wars," the conflict led to decades of competition and controversy between the two men.

In 1876, H. Felch, the brother of local rancher M.P. Felch, discovered some dinosaur bones in the area now known as Garden Park in the Morrison Formation to the north of Cañon City. The bones were the subject of an article in the Cañon City Times in 1877. That same year, O.W. Lucas, Fremont County School Superintendent, discovered dinosaur bones north of Cañon City and sent them to Cope for study. By 1883, when the quarrying ceased, Lucas and his brother had excavated many bones for study and scientific description. Among these was the sauropod *Camarasaurus supremus*, which Cope described, noting that one of the vertebrae was from a larger dinosaur than the one recently described by Marsh. Cope visited the quarry sites from which the bones were collected in 1879, and eventually named 18 new species based on the bones collected from the Cope-Lucas quarries (most of these species are no longer considered to be valid). Some of the most well-known Cope-Lucas dinosaur quarries were situated around a small butte called Cope's Nipple. In 1877 and between 1882 and 1888, B. Mudge, S. Williston, and M.P. Felch worked what became known as the Marsh/Felch Quarries #1 and #2, sending the excavated bones to Marsh for study (Figure 3). Type specimens described by Marsh from these quarries include *Diplodocus longus*, *Allosaurus fragilis*, *Stegosaurus stenops*, and *Ceratosaurus nasicornis*. Well-known fossil collector J.B. Hatcher and his associate W. Utterback from the Carnegie Museum of Natural History worked in the Garden Park area in 1900 and 1901, expanding Marsh/Felch Quarry #1 to twice its original size and collecting and describing the type specimens of *Haplocanthosaurus priscus* and *H. utterbacki*. The Marsh/Felch Quarries and Cope's Nipple are located in the Garden Park Paleontological Area, an Area of Critical Environmental Concern and National Natural Landmark within the BLM RGFO Planning Area.

FIGURE 3. Views of the Marsh-Felch Quarry in 1888 (Courtesy of the USGS).

In 1887, high school teacher and geologist G.L. Cannon found one of the best known and historically important early fossil specimens from the Denver Basin. This fossil, first described by Marsh in 1887 as the type specimen of an extinct bison he named *Bison alticornis*, consists of only a pair of supraorbital horn cores (now USNM 4739). On the basis of this fossil, Marsh considered the strata from which the horn cores were recovered to be Pliocene in age. This led to a considerable degree of confusion about the age of what was then referred to the Denver Formation of the Laramie Group, and for which all other fossil indicators pointed to a Cretaceous and/or early Tertiary age. In subsequent years, even the location of the original discovery site was confused. Carpenter (2007) provides an excellent account of the history of this specimen and other early dinosaur fossil discoveries in the Denver area. In this paper, Carpenter also re-establishes the location of the original fossil site along a portion of Lakewood Gulch about 2.8 miles west of downtown Denver (Carpenter, 2007, p. 361-362). Based on the discovery of more complete comparative material, Marsh (1889) ultimately conceded that the specimen was Cretaceous and not Pliocene in age and that it belonged to a ceratopsian; he also referred the specimen to *Ceratops alticornis* instead of *Bison alticornis*. In 1907, J.B. Hatcher assigned the specimen to *Triceratops alticornis*.

In 1873, A.J. Peale, a geologist attached to the F.V. Hayden Survey, explored the area now known as Florissant Fossil Beds National Monument and noted the presence of fossil lake deposits and 20 to30 large petrified tree stumps. Together with fellow expedition members, he collected some fossils that were later described by scientists. In 1877, Princeton University students W.B. Scott, H.F. Osborn and F. Speir, collected fossils in the area as part of what was later named the Princeton Scientific Expedition of 1877, which also included fossil-collecting stops at other localities around the Rocky Mountain Region. Approximately 180 of the fossil plants and insects they collected later became type specimens. Paleobotanist Leo Lesquereux was the first to formally describe Florissant fossils and named more than 100 new taxa from samples collected by the 1873 Hayden Survey and the 1877 Princeton Scientific Expedition and from fossils purchased from local homesteader Charlotte Hill. A. J. Lakes and S.H. Scudder arrived in Florissant in August 1877, shortly after the departure of the Princeton Scientific Expedition. Scudder, a paleontologist and entomologist, made the first stratigraphic measurements of the lake-bed strata. Over the course of his career, Scudder was to describe nearly 600 species of fossil insects in 23 scientific papers focused on the paleontology and geology of Florissant. His 1890 monograph, The Tertiary Insects of North America, is considered a classic work of North American paleontology. UCM paleontologist T.D.A Cockerell collected fossils at Florissant between 1906 and 1908 and published prolifically on Florissant fossils, including the giant Tsetse fly *Glocina oligocaena*, which is thought to have fed on the blood of large latest Eocene mammals such as brontotheres. Paleobotanist H.D. MacGinitie continued the pioneering work on Florissant fossils, collecting specimens in 1936 and 1937 and using plant fossils to interpret the paleoecology, paleoclimate, and paleoelevation of Lake Florissant. MacGinitie's work culminated in his classic 1953 monograph, Fossil Plants of the Florissant Beds, Colorado.

In 1912, Professor J. Henderson, an invertebrate paleontologist and founder of the UCM, initiated a field study of the Cretaceous-age formations of northeastern Colorado that was finally published in 1920. This was a pioneering study that, although undertaken primarily for the purpose of determining the stratigraphic position of coal beds, led to a large collection of Cretaceous marine invertebrates and helped establish the stratigraphic framework for the Front Range and eastern plains of Colorado.

Arguably the most noteworthy fossil locality of Tertiary age in eastern Colorado was discovered in the White River Formation in the early 1920s. Located on the Toedtli Ranch north of Stoneham, the *Trigonias* Quarry (actually two quarries) has yielded a large collection of thousands of specimens, including well-preserved skeletons of the small rhinoceros *Trigonias osborni*, entelodonts such as *Archaeotherium*, and other large and small mammals and birds. The excavations were initiated by the Colorado Museum (now the DMNS), and the first scientific studies of fossils from the quarry were published by Colorado Museum Curator H.J. Cook, Professor W.K. Gregory, and H.E. Wood. The *Trigonias* Quarry was later re-excavated by amateur paleontologist J. Mellinger in the 1930s and 1950s, resulting in many more fossils, which are now housed at the UCM. Roger Hamilton of the British Museum had plans to re-open the quarry in the early 1970s, but he passed away unexpectedly (Peter Robinson, written communication, 2011).

In 1937, hundreds of dinosaur tracks, mostly of an Iguanodon-like hadrosaurid and small species of theropod, were discovered on the east side of Dinosaur Ridge during the construction of West Alameda Parkway. These well-preserved dinosaur tracks represent a small sample of a massive trackway assemblage made mostly by dinosaurs, crocodilians, and birds in sandy beach deposits preserved within a 30-foot-thick interval of the Dakota Group; the assemblage is thought to extend across a 50,000-square-mile area spanning from Boulder, CO, to northern New Mexico. More recently, this “megatracksite” has been the subject of study and numerous publications by M. Lockley of the University of Colorado Denver and his students and colleagues.

In 1940, G.E. Lewis and R.W. Wilson began an intensive investigation of the Tertiary stratigraphy and mammalian paleontology of northeastern Colorado. World War II interrupted this project, which students subsequently continued. E. Galbreath published his doctoral dissertation (University of Kansas) on the Tertiary geology and paleontology of northeastern Colorado in 1953. Galbreath’s work greatly refined the stratigraphy with a series of stratigraphic sections and geologic maps, and he described in detail the highly diverse vertebrate fossil fauna of the area and its biostratigraphic significance. Much of the geographic area that contains Tertiary strata in northeastern Colorado has been unavailable for study since the 1950s, primarily due to lack of access to private property. However, an important exception remains Pawnee National Grassland.

Other important paleontological work in Colorado during the 1940s included pioneering studies of the evolutionary history of prairie grasslands and other Tertiary plant fossils completed by Elias (1942, 1946, and 1948). USGS paleobotanist F.H. Knowlton made an important contribution to paleontological work in eastern Colorado with his 1930 publication on the flora of the Denver Formation and associated formations in Colorado. R.W. Brown, another USGS paleontologist, was an important contributor to the stratigraphy and paleontology of the Denver Basin from the late 1930s to the 1960s. His work led to the recognition of the Cretaceous-Tertiary (K-T) boundary in the Denver Formation on the southeast flank of Table Mountain, discoveries of new earliest Paleocene (Puercan) mammal taxa such as *Baioconodon denverensis* Gazin 1941, and the discovery of various dinosaur fossils, and he made important contributions to paleobotany with his descriptions of the Paleocene age flora of the Rocky Mountains and Great Plains. Many other USGS geologists and paleontologists have made important contributions to paleontological and geological work in eastern Colorado. Two particularly noteworthy examples include W.A. Cobban for his work on Cretaceous molluscan biostratigraphy and G.R. Scott for his geologic mapping and documentation of Quaternary vertebrates and their biostratigraphic significance as well as the superpositional relationships and nomenclature of Quaternary deposits.

Since the 1960s, a large number of paleontological studies in Colorado have been completed by scientists, students, and avocational paleontologists affiliated with a variety of universities, museums, and agencies. More specifically, this includes a vast amount of research completed by museum curators, faculty, research associates, and students at the UCM, CU Boulder, CU Denver, the DMNS, the USFS, the BLM, and other institutions and government agencies in and outside the state. Significant scientific achievements have been made as the result of studies of Paleozoic invertebrates and early vertebrates in the Cañon City Basin, Sangre de Cristo Mountains, and the Front Range Uplift; studies of Mesozoic marine biostratigraphy and terrestrial vertebrate paleontology in the Cañon City Basin, the Front Range Uplift, the Denver-Julesberg Basin, the Raton Basin, and southeastern Colorado; studies of the vertebrate paleontology and paleobotany across the K-T Boundary section in the Denver Basin; studies of Tertiary vertebrate paleontology and biostratigraphy in areas such as the Huerfano Basin, Denver-Julesberg Basin, and Middle Park; and studies of paleobotany, paleoentomology, and mammalian paleontology at Florissant Fossil Beds. Additionally, the past 50 years have seen a great advancement of knowledge about the Pleistocene fossil record of the RGFO Planning Area and elsewhere in the state. See Section 6.0 of this report for specific examples of both historical and relatively recent paleontological research and resulting publications that are focused on the RGFO Planning area.

6.0 GEOLOGY AND PALEONTOLOGY

This section of the report describes the geology and paleontology of each of the geologic units within the RGFO Planning Area. The section is divided into three subsections: 1) igneous and metamorphic rock units; 2) bedrock sedimentary units; and 3) surficial sedimentary deposits. Each subsection is organized stratigraphically from oldest to youngest.

6.1 IGNEOUS AND METAMORPHIC ROCK UNITS

Igneous and metamorphic rock units are classified as PFYC 1, and have very low potential to produce scientifically important paleontological resources. The RGFO Planning Area contains 15 PFYC 1 geologic units, as mapped by Tweto (1979) (Table 3). No changes to the PFYC assignments of these units are recommended.

Igneous rocks are crystalline or non-crystalline rocks that form through the cooling and subsequent solidification of lava or magma. Intrusive (plutonic) igneous rocks form below the earth's surface, and extrusive (volcanic) rocks form on the earth's surface. Lava and magma are formed by the melting of pre-existing plutonic rocks in the earth's crust or mantle due to increases in temperature, changes in pressure, or changes in geochemical composition. Extreme temperatures in the environments in which intrusive igneous rocks form prevent the preservation of fossils. The formation of extrusive igneous rocks as a result of volcanic processes is associated with extremely high temperatures that also prevent the preservation of fossils. However, some rare instances of fossil preservation in volcanic rocks have been documented. For example, human remains at the Roman cities of Pompeii and Herculaneum serve as poignant reminders of the eruption of Vesuvius in AD 79. Volcanic ash and pyroclastic debris suffocated many victims at Pompeii, and their bodies left voids in the rock that archaeologists later filled with plaster to create casts. An example of similar preservation in North America comes from the Columbia River Basalts in Washington State. The so-called "Blue Lake Rhino" is a mold of a middle Miocene (Barstovian) baby rhinoceros preserved along with a few bones in pillow basalt. A cast was made from the mold, and copies are housed at the University of California Museum of Paleontology and the Burke Museum of Natural History and Culture.

Closer to home, in western Colorado but outside of the RGFO Planning Area, wood buried beneath Colorado's youngest volcanic eruption at Dotsero near the junction of the Eagle and Colorado rivers was used to carbon date the event at 4,200 years BP. The overlying deposits of scoria that formed during the eruption also preserve plant fragments. According to Professor Emmett Evanoff of the University of Northern Colorado (written communication, 2015), several fossils are known from volcaniclastic rocks in the San Juan Mountains of southern Colorado. Ashy beds in the Oligocene (Orellan) Saguache Creek Caldera contain poorly preserved petrified wood, and Oligocene (Orellan) eolian pumice-rich sandstone beds interbedded with welded ash-flow tuffs preserve footprints along Saguache Creek. In addition, and an anecdotal report describes a rancher's discovery of an Arikareean (?) oreodont from fine-grained ashy sediments of the Cochetopa caldera. RMPS encountered no reports of fossil occurrences in volcanic rocks in the RGFO Planning Area. However, it is possible that volcanic rocks such as the Wall Mountain Tuff within the RGFO Planning Area could yield similar but sparse and poorly preserved fossils.

Although they originated from volcanoes, volcanic ash fall deposits are considered to be tuffaceous sedimentary rock units that are known to form rocks that are favorable for fossil preservation and which have a higher PFYC designation than that of igneous and metamorphic rocks (PFYC 1). Examples in the RGFO Planning Area include the Florissant Formation to the east of the South Park Basin and the White River Formation in the Denver-Julesburg Basin. These formations are discussed in Section 6.2.

Metamorphic rocks result from the transformation of other rocks due to high temperature and high pressure. The parent rock can be igneous, sedimentary, or a pre-existing metamorphic rock. Metamorphic rocks comprise a large portion of the earth's crust and are classified on the basis of their chemistry and mineralogy. Most do not preserve fossils due to the conditions under which they were formed. However, metasedimentary rocks are formed from common sedimentary rock types such as limestone, shale, mudstone, siltstone, sandstone, and conglomerate. These types of metamorphic rocks do sometimes preserve fossils, but rarely fossils of scientific importance. Examples of fossils in metasedimentary rock include mollusks preserved in marble and echinoderms and graptolites preserved in slate. Metasedimentary rock units containing well-preserved, rare, or otherwise noteworthy occurrences of fossils could be classified as PFYC 2 (low potential) or even PFYC 3 (moderate potential). However, the research undertaken for this report indicates that no such fossiliferous metasedimentary rock units are known from within the RGFO Planning area (Table 3).

TABLE 3. Igneous and Metamorphic Rocks Mapped within the RGFO area (as mapped by Tweto, 1979).

Formation	Physiographic Region	Abbreviation	RGFO PFYC	Age
Ash-Flow Tuff of Main Volcanic Sequence	Front Range Uplift, Upper Arkansas River Valley, South Park Basin, Cañon City Basin, Huerfano Park	Taf	1	Upper Oligocene
Intra-Ash Flow Andesitic Lavas	Upper Arkansas River Valley, South Park Basin, Cañon City Basin, Huerfano Park	Tial	1	Upper Oligocene
Intra-Ash Flow Quartz Latitic Lavas	Front Range Uplift, Cañon City Basin, Huerfano Park	Tiql	1	Upper Oligocene
Basaltic Flows in Denver Formation Near Golden	Denver-Julesburg Basin	Tdv	1	Upper Cretaceous-Paleocene
Felsic and Hornblendic Gneisses, Separate of Interlayered	Cañon City Basin, Front Range Uplift, Huerfano Park, Raton Basin, South Park Basin, Southeastern Colorado, Upper Arkansas River Valley	Xfh	1	Precambrian
Quartzite Conglomerate, and Interlayered Mica Schist	Front Range Uplift, Cañon City Basin	Xq	1	Precambrian
Mafic Rocks (1700my)	Front Range Uplift, Upper Arkansas River Valley, Huerfano Park	Xm	1	Precambrian
Metamorphic Rocks, Biotitic Gneiss, Schist, and Migmatite	Cañon City Basin, Denver-Julesburg Basin, Front Range Uplift, Huerfano Park, Raton Basin, South Park Basin, Southeastern Colorado, Upper Arkansas River Valley	Xb	1	Precambrian

Formation	Physiographic Region	Abbreviation	RGFO PFYC	Age
Basalt Flows and Associated Tuff, Breccia, and Conglomerate	Southeastern Colorado, Upper Arkansas River Valley, South Park Basin, Huerfano Park, Raton Basin	Tbb	1	Pliocene
Volcanic Rocks (7-33my)	Front Range Uplift	Tv	1	Oligocene-Pliocene
Pre-Ash Flow Andesitic Lavas, Breccias, Tuffs, and Conglomerates	South Park Basin, Upper Arkansas River Valley, Cañon City Basin, Front Range Uplift, Huerfano Park	Tpl	1	Oligocene
Basaltic Intrusive Rocks Related to Basalt Flows	Southeastern Colorado	Tbbi	1	Miocene
Rhyolitic Intrusive Rocks and Flows of Late-Volcanic Bimodal Suite	Upper Arkansas River Valley	Tbr	1	Miocene
Wall Mountain Tuff	Cañon City Basin, Denver-Julesburg Basin, Front Range Uplift, South Park Basin, Upper Arkansas River Valley	Twm	1	Lower Oligocene
Middle Tertiary Intrusive Rocks (20-40my)	Front Range Uplift, Upper Arkansas River Valley, South Park Basin, Cañon City Basin, Huerfano Park, Raton Basin, Southeastern Colorado	Tmi	1	Eocene-Oligocene

6.2 BEDROCK SEDIMENTARY UNITS

The RGFO Planning Area contains 59 bedrock sedimentary units as mapped by Tweto (1979) (Table 4; Figure 4). These are further divided into 72 units for the purpose of this report. Each unit is discussed in detail below Table 4, and they are organized stratigraphically from oldest to youngest.

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TABLE 4. Bedrock Formations Mapped within the RGFO Planning Area
(listed in approximate descending stratigraphic order. Asterisk denotes mapped in Colorado, but not present on the surface within the RGFO Planning Area according to information reviewed for this report).

FM: Tweto geologic map	Terminology in this report	Equivalent Units Colorado	Members	Physiographic Region Within RGFO Planning Area	RGFO PFYC	Recommended PFYC	Age	Type Locality	Depositional Environment	Common Fossils	Primary Lithology
Dry Union Formation	Dry Union Formation			Upper Arkansas River Valley, South Park Basin	5	4	Late Miocene and Early Pliocene	Type section not designated, named for Dry Union Gulch 5 miles south of Leadville, Lake County, CO (Tweto, 1961)	Fluvial, alluvial, and lacustrine	Vertebrates including horse, mastodon, camel, deer, and rabbit; invertebrates including bivalves, gastropods and ostracods; plants including cattail and locust	Claystone, siltstone, and sandstone with volcanically derived clasts
Ogallala Formation	Ogallala Group: Martin Canyon Formation, Pawnee Creek Formation, Upper Ogallala Conglomerate	Browns Park Formation (Partial)		Southeastern Colorado, Front Range Uplift, Denver-Julesburg Basin	5	4	Middle Miocene and Pliocene	Type section not designated, named for exposures in western Nebraska around Lodgepole Creek (Darton, 1899)	Alluvial, colluvial, and eolian	Mammals	Sandstone and conglomerate
Santa Fe Formation	Santa Fe Formation			Upper Arkansas River Valley, Huerfano Park	3	U (unknown)	Oligocene to Pliocene	Type locality inferred from notable exposures in the Rio Grande Valley, Santa Fe County, NM (Hayden, 1869)	Fluvial	Mammal bone fragments	Sandstone
Troublesome Formation	Troublesome Formation	Martin Canyon Formation, North Park Formation, Browns Park Formation (Partial)		North Park Basin	Not listed	4	Late Oligocene and Early Miocene	Named for occurrence in the valley of Troublesome Creek near Kremmling, Grand County, CO (Lovering and Goddard, 1950)	Alluvial	Mammals, reptiles, amphibians, and wood	Mudstone and sandstone
Arikaree Formation	Arikaree Formation (This unit does not occur in Colorado, but is included in this analysis because it is mapped in Colorado by Tweto [1979] and others.)	Martin Canyon Formation, Troublesome Formation, North Park Formation, Browns Park Formation (Partial)		Denver-Julesburg Basin	3	3	Late Oligocene and Early Miocene	Named for the Arikaree Indians (Darton, 1899)	Fluvial and lacustrine	Oreodonts, ostracods, and trace fossils	Buff, very fine-grained sandstone
Oligocene Sedimentary Rocks	Brule Formation	White River Formation (Group) (Partial)	Cedar Creek Member, Vista Member	Denver-Julesburg Basin	Not listed	5	Oligocene	Named for the Brule Indians from South Dakota (U.S. geologic names lexicon, USGS Bull. 896; see Darton, 1899)	Fluvial	Mammals, gastropods, and ostracods	Cross-bedded sandstone interbedded with mudstone and calcareous claystone
White River Formation	White River Formation (Group): Chadron Formation, Brule Formation	Castle Rock Conglomerate, Antero Formation, Florissant Formation (Partial)	Brule Member, Horsetail Creek Member	Southeastern Colorado, Front Range Uplift, Denver-Julesburg Basin	5	5	Late Eocene and Oligocene	Named for occurrence near the mouth of the White River, SD (Meek and Hayden, 1858 and 1862)	Volcaniclastic	Mammals and reptiles	Volcaniclastic mudstone, siltstone, and sandstone
Oligocene Sedimentary Rocks (*Age now corrected to late Eocene*)	Castle Rock Conglomerate	White River Formation (Group), Antero Formation, Florissant Formation (Partial)		Upper Arkansas River Valley, South Park Basin, Front Range Uplift	Not listed	2	Late Eocene	Named for typical outcrop on Castle Rock butte, Douglas County, CO (Lee, 1902)	Fluvial	Rare mammal bone fragments	Conglomerate
Oligocene Sedimentary Rocks (*Age now corrected to late Eocene*)	Antero Formation	Florissant Formation, White River Formation (Group), Castle Rock Conglomerate (Partial)		Denver-Julesburg Basin, South Park Basin	Not listed	4	Late Eocene	Type area south and west of Hartsel in T12 to 15S, R75 and 76W, Park County, CO (Johnson, 1937; Stark et al., 1949)	Fluvial and lacustrine	Mammals and well-preserved plants	Sandstone, conglomerate, and tuff

FM: Tweto geologic map	Terminology in this report	Equivalent Units Colorado	Members	Physiographic Region Within RGFO Planning Area	RGFO PFYC	Recommended PFYC	Age	Type Locality	Depositional Environment	Common Fossils	Primary Lithology
Oligocene Sedimentary Rocks (*Age now corrected to late Eocene*)	Florissant Formation	White River Formation (Partial), Antero Formation, Castle Rock Conglomerate (Partial)		Upper Arkansas River Valley, South Park Basin, Front Range Uplift	5	5	Late Eocene	Florissant, Teller County, Pikes Peak region, CO (Cross, 1894)	Lacustrine	Insects, mammals, birds, and plants	Sandstone, siltstone, and shale with abundant volcaniclastics
Cuchara Formation	Cuchara Formation	Huerfano Formation, Wasatch Formation (DeBeque Formation), Green River Formation (Partial), San Jose Formation (Partial)		Raton Basin, Huerfano Park	5	4	Early Eocene	Named for exposures along Cuchara River north of La Veta, Huerfano County, CO (Hills, 1893?)	Fluvial	Mammals including primates, ungulates, and rodents; fish; reptiles; birds; rare invertebrates including gastropods; plants	Conglomerate, sandstone, and mudstone
Huerfano Formation	Huerfano Formation	Cuchara Formation, Wasatch Formation (DeBeque Formation), Green River Formation (Partial), San Jose Formation (Partial)		Raton Basin, Huerfano Park	5	5	Eocene	Type section not designated (Hills, 1888)	Fluvial-floodplain	Vertebrates including mammals, fish, turtles, squamates, crocodiles, and birds	Variegated shale and white sandstone
South Park Formation	South Park Formation		Link Spring Tuff Member, Reinecker Ridge Volcanic Member	South Park Basin	3	3	Paleocene	Type area in South Park, Park County, CO (Wyant and barker, 1976)	Volcaniclastic and fluvial	Well-preserved leaves	Tuff, andesite, and conglomerate
Lower part of Dawson Arkose	Dawson Formation	Denver Formation		Denver-Julesburg Basin	5	5	Late Cretaceous-Early Eocene	Type section not designated, named for Dawson Butte 7 miles southwest of Castle Rock, Douglas County, CO (Richardson, 1912)	Fluvial	Plants and bone fragments from dinosaurs and mammals	Conglomerate, siltstone, and sandstone
Upper Part of Dawson Arkose	Dawson Formation	Denver Formation		Denver-Julesburg Basin	3	5	Late Cretaceous-Early Eocene	Type section not designated, named for Dawson Butte 7 miles southwest of Castle Rock, Douglas County, CO (Richardson, 1912)	Fluvial	No known fossils	Claystone with minor amounts of sandstone and conglomerate
Poison Canyon Formation	Poison Canyon Formation	Denver Formation		Cañon City Basin, Southeastern Colorado, Raton Basin, Huerfano Park	5	4	Late Cretaceous and Paleocene	Type section not designated, probably named for exposures in Poison Canyon and across Muddy Creek to Promontory Bluffs, Huerfano County, CO (Hills, 1888)	Fluvial	Plants and rare vertebrates including turtles and mammals	Sandstone, conglomerate, and shale
Denver Formation	Denver Formation	Raton Formation, Poison Canyon Formation, Fort Union Formation, San Jose Formation (Partial)	Golden Member, Pleasant View Member	Front Range Uplift, Denver-Julesburg Basin	5	5	Late Cretaceous and Paleocene	Type section not designated, named from Denver, CO (Cross, 1888)	Fluvial and alluvial	Well-preserved abundant plants; rare vertebrates including dinosaurs and mammals	Claystone, mudstone, and sandstone with abundant volcanic debris
Raton Formation	Raton Formation	Denver Formation		Cañon City Basin, Southeastern Colorado, Raton Basin, Huerfano Park	5	4	Late Cretaceous and Paleocene	Type area at a high mesa between Trinidad, CO, and Raton, NM (Hayden, 1896; Lee, 1917)	Fluvial	Well-preserved plants	Sandstone, mudstone, and coal
Arapahoe Formation	Arapahoe Formation			Denver-Julesburg Basin	3	2	Late Cretaceous	Arapahoe County, CO (USGS Bull. 896, 1200)	Fluvial and alluvial	Sponges, silicified wood, and dinosaur bone fragments	Sandstone, siltstone, and claystone
Vermejo Formation	Vermejo Formation	Laramie Formation	Rockvale Sandstone Member	Cañon City Basin, Southeastern Colorado, Raton Basin, Huerfano Park	5	4	Late Cretaceous	Type section at Vermejo Park, Colfa County, NM (Lee, 1917)	Freshwater	Well-preserved plants	Shale, sandstone, and coal
Laramie Formation	Laramie Formation	Vermejo Formation		Southeastern Colorado, Denver-Julesburg Basin	3	4	Late Cretaceous	Type section not designated (King, 1876)	Fluvial and deltaic	Plants and vertebrates including dinosaurs	Sandstone and conglomerate
Fox Hills Sandstone	Fox Hills Formation	Trinidad Shale, Mesaverde Group (Partial)	Milliken Member	Southeastern Colorado, South Park Basin, Denver-Julesburg Basin	3	3	Late Cretaceous	Type area in Corson, Dewey, and Ziebach Counties, SD (Waage, 1968)	Marginal marine	Invertebrates including bivalves, gastropods, bryozoans, echinoids, crabs, and foraminifera; vertebrates including fish, mammals, dinosaurs, amphibians, and reptiles	Gray, fissile shale grading upwards to cross-bedded sandstone

FM: Tweto geologic map	Terminology in this report	Equivalent Units Colorado	Members	Physiographic Region Within RGFO Planning Area	RGFO PFYC	Recommended PFYC	Age	Type Locality	Depositional Environment	Common Fossils	Primary Lithology
Pierre Shale	Pierre Formation	Mesaverde Group	Apache Creek Sandstone Member, Beecher Island Member, Gammon Member, Hygiene Sandstone Member, Larimer Sandstone Member, Mitten Member, Richard Sandstone Member, Rocky Ridge Sandstone Member, Sharon Springs Member, Terry Sandstone Member	Cañon City Basin, Southeastern Colorado, Front Range Uplift, Denver-Julesburg Basin	3	3	Late Cretaceous	Named from exposures at old Fort Pierre, SD (Meek and Hayden, 1862)	Marine	Marine reptiles; fish; birds; pterosaurs; dinosaurs; invertebrates including ammonites, bivalves, and gastropods	Shale
Niobrara Formation	Niobrara Formation	Benton Group (Partial)	Fort Hayes Limestone Member, Smoky Chalk/Shale/Marl Member	Cañon City Basin, Southeastern Colorado, Raton Basin, Huerfano Park	3	3	Late Cretaceous	Type section not designated, named from the Niobrara River in Knox County, NE (Meek and Hayden, 1862)	Nearshore marine	Fish, marine reptiles, birds, and pterosaurs	Shale and limestone
Benton Shale	Benton Group: Colorado Group + Niobrara Formation	Colorado Group (Partial)	Colorado Group + Fort Hayes Limestone Member, Smoky Hill Shale Member of Niobrara Formation, Mowry Member of Benton Shale	Denver-Julesburg Basin, South Park Basin	3	3	Late Cretaceous	Named from Fort Benton on the upper Missouri River, ~40 miles below Great Falls, Chouteau County, MT (Meek and Hayden, 1862; Wilmarth, 1938)	Marine	Invertebrates including foraminifera, brachiopods, bivalves, and ammonites; plant debris; rare vertebrates including fish, sharks, plesiosaurs, and ichthyosaurs	Black shale
Colorado Group	Colorado Group: Graneros Shale, Greenhorn Limestone, Carlile Shale, Codell Sandstone	Benton Group (Partial)	Graneros: Thatcher Limestone Member Greenhorn: Bridge Creek Member, Hartland Shale Member, Lincoln Limestone Member, Pfeifer Shale Member Carlile Shale: Blue Hill Member, Codell Sandstone Member, Fairport Chalky Shale Member, Juana Lopez Member,	Cañon City Basin, Southeastern Colorado, South Park Basin, Huerfano Park, Front Range Uplift, Denver-Julesburg Basin	3	3	Late Cretaceous	No type section designated, named from exposures along the eastern base of the Front Range, CO (Hayden, 1876)	Marine	Invertebrates including ammonites, foraminifera, bivalves, and gastropods; vertebrates including fish	Shale with minor amounts of sandstone and conglomerate
Dakota Sandstone	Dakota Group: Lytle Formation, South Platte Formation	Cedar Mountain Formation*, Burro Canyon Formation*, Lytle Formation, Muddy Sandstone, Naturita Formation*, Omadi Sandstone, Plainview Formation, Romeroville Sandstone*, Skull Creek Shale, South Platte Formation, Dry Creek Canyon Member	South Platte Fm: Plainview Member, Kassler Sandstone Member, Van Biber Shale Member	Cañon City Basin, Southeastern Colorado, Huerfano Park	3	3	Early Cretaceous	Type locality of group is ~2 miles north of Bellevue, Larimer County, CO (Lee, 1923)	Proximal marine	Trackways and dinosaur and marine reptile bone fragments	Siltstone, sandstone, and conglomerate
Burro Canyon Sandstone	Burro Canyon Formation	Dakota Formation (Partial), Cedar Mountain Formation	Karla Kay Conglomerate Member	Southeastern Colorado, South Park Basin, Raton Basin, Huerfano Park	5	4	Early Cretaceous	Type section in Burro Canyon, Section 29, T44N, R18W, San Miguel County, CO (Stokes and Phoenix, 1948)	Fluvial	Invertebrates including ostracods, bivalves, and gastropods; plants; fish scales	Alternating beds of conglomerate, sandstone, and mudstone
Morrison Formation	Morrison Formation		Bluff Sandstone Member, Brushy Basin Member, Recapture Member, Salt Wash Member, Tidwell Member, Westwater Canyon Member	Cañon City Basin, Front Range Uplift	5	5	Late Jurassic	Type section along the north side of West Alameda Parkway roadcut, 2 miles north of the town of Morrison in the SE/4 of Section 23, T4S, R70W, Jefferson County, CO (Waldschmidt and LeRoy, 1944)	Fluvial and lacustrine	Dinosaurs, fish, mammals, and reptiles	Variegated mudstone and sandstone
Ralston Creek Formation	Ralston Creek Formation			Denver-Julesburg Basin, Raton Basin	3	3	Late Jurassic	Type Section on the south side of Ralston Creek in the NWSW of Section 5, T3S, R70W, Jefferson County, CO (Van Horn, 1957)	Lacustrine and fluvial with some marine influence	Gastropods and algae	Sandstone, mudstone, and limestone
Summerville Formation	Summerville Formation			Front Range Uplift	3	3	Late Middle Jurassic	The Section near head of Summerville Wash at Summerville Point, Emery County, UT (Gilluly and Reeside, 1938)	Shallow marine	Pterosaur trackway	Mudstone and sandstone
Curtis Formation	Curtis Formation	Summerville, Wanaka and Sundance Formations		Park Uplift	3	3	Middle Jurassic	Curtis Point, in Section 34, T19S, R13E, Emery County, UT (Gilluly and Reeside, 1928)	Marine	Crinoids, gastropods, echinoids, cephalopods, bivalves, and an unidentifiable jaw bone fragment	Fine-grained sandstone
Sundance Formation	Sundance Formation	Entrada Sandstone	Canyon Springs Sandstone Member, Lak Member, Pine Butte Member, Redwater Shale Member	Denver-Julesburg Basin, North Park Basin	3	3	Middle to early Late Jurassic	Type section not designated with typical measured sections in the Black Hills, SD, and probably named from Sundance, Crook County, WY (Darton, 1899)	Marine	Fish, marine reptiles, and echinoderms	Calcareous shale, sandstone, and limestone

FM: Tweto geologic map	Terminology in this report	Equivalent Units Colorado	Members	Physiographic Region Within RGFO Planning Area	RGFO PFYC	Recommended PFYC	Age	Type Locality	Depositional Environment	Common Fossils	Primary Lithology
Entrada Sandstone	Entrada Sandstone	Sundance Formation	Dewey Bridge Member, Moab Member, Rehoboth Member, Slick Rock Member	Denver-Julesburg Basin	3	3	Late Middle Jurassic	Type section at Entrada Point, northern San Rafael Swell, Emery County, UT (Gilluly and Reeside, 1928)	Eolian	Dinosaur trackways	Fine-grained, cross-bedded sandstone
Chinle Formation	Chinle Formation			South Park Basin	3	3	Late Triassic	Named for Chinle Valley, Apache County, AZ (Gregory, 1917)	Fluvial and lacustrine	Vertebrates including amphibians, reptiles, fish, the mammal-like cynodont; invertebrates including brachiopods and bivalves; plant fossils including horsetails, ferns, conifers, and ginkgos	Variegated claystone, siltstone, and sandstone
Dockum Group	Dockum Group (Chinle Formation)	Chinle Formation (Partial)		Southeastern Colorado	3	3	Late Triassic	Named for exposures in the vicinity of the town of Dockum, Dickens County, western TX (Cummins, 1890)	Alluvial and lacustrine	Vertebrates including amphibians, reptiles, fish, the mammal-like cynodont; invertebrates including brachiopods and bivalves; plant fossils including horsetails, ferns, conifers, and ginkgos	Variegated claystone, siltstone, and sandstone
Jelm Formation	Jelm Formation		Red Draw Member, Sips Creek Member	Front Range Uplift	3	3	Late Triassic	Type section at the base of Jelm Mountain, Laramie Quadrangle, Albany County, WY (Pipiringos, 1968).	Fluvial	Unidentifiable bone fragments and an isolated reptile tooth	Shale, siltstone, and sandstone
Chugwater Formation	Chugwater Group (Jelm Formation)	Jelm Formation, Red Peak Formation* (also Member)		Denver-Julesburg Basin	3	3	Triassic	Named for Chugwater Creek near Iron Mountain, Platte County, WY (Darton, 1904)	Fluvial	One reptile tooth another unidentifiable bone fragments	Fine-grained, cross-bedded calcareous sandstone
Lykins Formation	Lykins Formation	Blaine Gypsum Member, Bergen Shale Member, Falcon Limestone Member, Forelle Limestone Member, Glennon Limestone Member, Harriman Shale Member, Park Creek Limestone Member, Chaquaqua Member, Strain Shale Member, Minnekahta Limestone, Taloga Formation, Day Creek Dolomite, Whitehorse Group*		Southeastern Colorado	3	3	Late Permian-Early Triassic	Lykins Gulch, in T2N, R71W, Boulder Count., CO	Marine	Stromatolites and rare bone fragments	Sandstone, siltstone, and limestone
Satanka Formation (Shale)	Satanka Formation			Front Range Uplift	3	3	Middle Permian	Named for the Satanka Rail Road Station a few miles south of Laramie, southeastern WY (Darton, 1908)	Marine	Invertebrates including scaphopods, pelecypods, gastropods, nautiloids, and fusulinids	Limestone
Lyons Sandstone	Lyons Sandstone	Stone Corral Formation*, Nippewalla Group*		Southeastern Colorado, Front Range Uplift, Denver-Julesburg Basin	3	3	Early Permian	Best developed in Lyons, CO (Fenneman, 1905)	Eolian	Insects, amphibian footprints, and ichnofossils	Cross-bedded sandstone
Ingleside Formation	Ingleside Formation			Front Range Uplift	3	2	Early Permian	Ingleside, Larimer County, CO, S/2 of Section 24, T9N, R70W (Maughan and Wilson, 1960)	Marine and eolian	A single fusulinid (foraminifer)	Limestone and sandstone
Casper Formation	Casper Formation	Darwin Sandstone Member		Denver-Julesburg Basin	3	3	Middle Pennsylvanian-Early Permian	No designated type section; Casper Mountain, Natrona County, CO (Darton, 1908)	Shallow marine with some eolian influence	Invertebrates including bryozoans, cephalopods, crinoids, and foraminifera	Limetone and dolostone interbedded with arkosic sandstone
Maroon Formation	Maroon Formation	Chubb Member, Crestone Conglomerate Member, Fryingpan Member, Pony Spring Member, Schoolhouse Member		Upper Arkansas River Valley, South Park Basin	3	3	Middle Pennsylvanian-Early Permian	Maroon Creek, Pitkin County, CO (Eldridge, 1984)	Fluvial and eolian	Invertebrates including brachiopods, crinoids, corals, and bivalves	Conglomerate, sandstone, and mudstone

FM: Tweto geologic map	Terminology in this report	Equivalent Units Colorado	Members	Physiographic Region Within RGFO Planning Area	RGFO PFYC	Recommended PFYC	Age	Type Locality	Depositional Environment	Common Fossils	Primary Lithology
Minturn Formation	Minturn Formation	Chubb Siltstone Member, Coffman Conglomerate Member, Elk Ridge Limestone Member, Hornsilver Dolomite Member, Jacque Mountain Limestone Member, Lionshead Dolomite Member, Resolution Dolomite Member, Robinson Limestone Member, Swissvale Gypsum Member, Wearyman Dolomite Member, White Quail Limestone Member		Cañon City Basin, Upper Arkansas River Valley, South Park Basin, Raton Basin, Huerfano Park	3	3	Middle Pennsylvanian	Section 22, T5S, R80W, to SE/4 of Section 13, T6S, R81W, Eagle County, CO (Tweto and Lovering, 1977)	Marine	Invertebrates including foraminifera, bryozoans, brachiopods, echinoderms, bivalves, corals, gastropods, and cephalopods; fish and shark teeth; conodonts	Limestone, sandstone, and conglomerate
Sangre De Cristo Formation	Sangre De Cristo Formation	Crestone Conglomerate Member		Upper Arkansas River Valley, Southeastern Colorado, Raton Basin, Huerfano Park	5	4	Middle Pennsylvanian-Early Permian	East of Crestone, CO, on west flank of central anticline between Crestone Needle on south and Eureka Mountain on North, Saguache County, CO (Bolyard, 1959)	Fluvial and shallow marine	Plants, rare fish, and amphibians	Sandstone and conglomerate
Belden Shale	Belden Shale	Newett Limestone (Subunit)		Raton Basin	3	3	Early and Middle Pennsylvanian	North side of Rock Creek Valley along US Highway 24, 0.2 miles north of Gilman, Eagle County, CO (Brill, 1942)	Marine	Invertebrates including corals, crinoids, bryozoans, and brachiopods	Gray to black carbonaceous shale
Fountain Formation	Fountain Formation	Glen Eyrie Shale Member, Morrow Formation, Atoka Formation, Cherokee Group*, Marmaton Formation*, Pleasanton Group*, Kansas City Formation, Lansing Group*, Douglas Group*, Shawnee Formation, Wabaunsee Formation (?)		Cañon City Basin, Southeastern Colorado, Huerfano Park, Front Range Uplift, Denver-Julesburg Basin	3	3	Early Pennsylvanian-Early Permian	Fountain Creek below Manitou Springs, El Paso County, CO (Cross, 1894)	Fluvial and alluvial	Invertebrates including gastropods, crinoids, echinoderms, and brachiopods; amphibian trackways	Arkosic coarse-grained sandstone and conglomerate
Leadville Limestone	Leadville Limestone	Castle Butte Member*, Red Cliff Member*, Warsaw Limestone, Hardscrabble Limestone, Beulah Limestone, St. Louis Limestone*		Denver-Julesburg Basin, South Park Basin	3	3	Early and Middle Mississippian	Principal reference section: Rock Creek, 0.4 miles northwest of Gilman, Lake County, CO (Beaty et al., 1988)	Marine	Fish teeth; invertebrates including foraminifera, crinoids, bryozoans, brachiopods, and stromatolites	Limestone
Gilman Sandstone	Gilman Sandstone	Leadville Limestone, Warsaw Limestone		South Park Basin	3	2	Late Devonian or Early Mississippian	Eagle Canyon, Gilman, Pando Area, Eagle County, CO (Tweto, 1949)	Shallow marine	No known fossils	Medium- to coarse-grained buff sandstone
Williams Canyon Formation (Limestone)	Williams Canyon Formation (Limestone)			Cañon City Basin, Upper Arkansas River Valley, South Park Basin, Huerfano Park	3	3	Early Mississippian	Cave of the Winds, Williams Canyon at Manitou, El Paso County, CO (Brainerd et al., 1933)	Marine	Crinoids, corals, bivalves, brachiopods, and ostracods	Limestone and dolostone
Chaffee Group	Chaffee Group: Dyer Dolomite, Gilman Sandstone, Parting Formation	Dyer Dolomite, Gilman Sandstone, Parting Formation		South Park Basin	Not listed	3		No designated type section; named from Chaffee County, CO (Kirk, 1931)	Marine	Fragmentary fish; invertebrates including brachiopods, bryozoans, bivalves, corals, stromatoporoids, and crinoids	Dolomite and cross-bedded, coarse-grained quartzite
Dyer Dolomite	Dyer Dolomite	Leadville Limestone, Broken Rib Member*, Coffee Pot Member*		South Park Basin	3	3		No designated type section; named from West Dyer and Dyer Mountain, 5 miles east of Leadville, Lake County, CO (Behre, 1932)	Marine-sublittoral and littoral	Stromatoporoids; stromatolites; invertebrates including sponges, corals, brachiopods, nautiloids, crinoids, gastropods, and bryozoans; vertebrate remains including shark and conodont teeth	Limestone and dolostone
Parting Formation	Parting Formation	Leadville Formation		South Park Basin	3	3	Late Devonian	Parting Spur, West Dyer Mountain, Lake County, CO (Kirk, 1931)	Shallow marine to intertidal	Invertebrates including brachiopods, bivalves, and crinoids; fish	Sandstone and sandy dolostone
Fremont Formation	Fremont Formation	Priest Canyon Member*		Cañon City Basin, Upper Arkansas River Valley, Southeastern Colorado, Front Range Uplift	5	3		Harding's Quarry, 1 mile northwest of State Penitentiary at Cañon City, CO (Walcott, 1892)	Marine	Invertebrates including coral, nautiloids, and brachiopods	Dolostone

FM: Tweto geologic map	Terminology in this report	Equivalent Units Colorado	Members	Physiographic Region Within RGFO Planning Area	RGFO PFYC	Recommended PFYC	Age	Type Locality	Depositional Environment	Common Fossils	Primary Lithology
Harding Sandstone	Harding Sandstone	Simpson Group		Denver-Julesburg Basin, South Park Basin	5	4	Middle Ordovician	Harding's Quarry, 1 mile northwest of State Penitentiary at Cañon City, CO (Walcott, 1892)	Marine	Invertebrates including gastropods, bivalves, brachiopods, crinoids, and bryozoans; vertebrates including primitive fish	Shale, silty mudstone, and sandstone
Manitou Limestone	Manitou Limestone	Arbuckle Group, Dead Horse Canyon Member*, Tie Gulch Dolomite Member*, Helena Canyon Member*, Ptarmigan Chert Member*, Leavick Tarn Dolomite Member*		Denver-Julesburg Basin, Las Animas Arch, South Park Basin	3	3	Early Ordovician	SW/4 Section 32, T13S, R67W, El Paso County, CO (Brainerd et al., 1933; Gerhart, 1974)	Marine	Invertebrates including trilobites, brachiopods, gastropods, cephalopods, sponge spicules, crinoids and graptolites; conodonts	Limestone and sandstone
Peerless Formation	Peerless Formation			Denver-Julesburg Basin, South Park Basin	3	3	Upper Cambrian	Peerless Mountain, 6 miles east-southeast of Leadville, CO (Behre, 1932)	Shallow marine shelf	Trilobites and brachiopods	Dolostone and sandstone
Sawatch Quartzite (Sandstone)	Sawatch Quartzite (Sandstone)	Leadville Formation		Front Range Uplift	3	2	Lower-Upper Cambrian	Deadmans Gulch, Gunnison County, CO (Bush and Bush, 1974)	Fluvial and shallow marine	Trace fossils	Sandstone, dolostone, and conglomerate

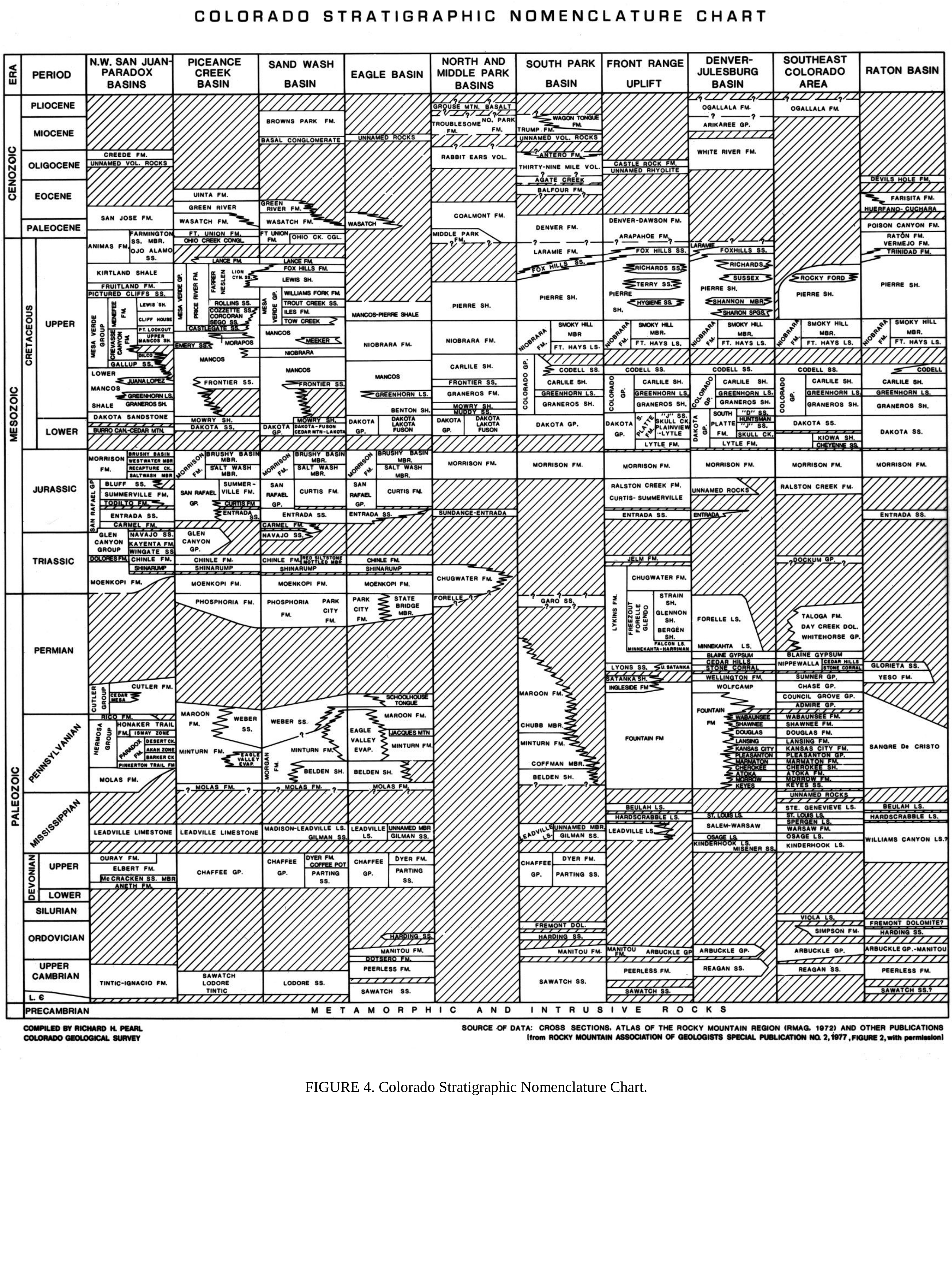

FIGURE 4. Colorado Stratigraphic Nomenclature Chart.

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6.2.1 Sawatch Quartzite

The Sawatch Quartzite is a Late Cambrian formation with a type section in Gunnison County, west-central Colorado, near Deadmans Gulch (Section 14, Township 14 South, Range 84 West; Bush and Bush, 1974). The formation was first named and described in 1894 by G.H. Eldridge, who named it after its common outcrops around the flanks of the Sawatch Range (Emmons et al., 1894). The Sawatch Quartzite is found in central Colorado, and in the Sawatch Range it averages 151 feet thick. It is equivalent stratigraphically to the Lodore Formation of northwestern Colorado, the Ignacio Quartzite in southwestern Colorado, and the Reagan Sandstone of the central midcontinent. The formation nonconformably overlies Proterozoic Pikes Peak granite and sharply underlies the Peerless Formation (Dyman and Charpentier, 1992). The Sawatch Quartzite was subdivided by Anderson (1970) into a coarse-grained lower unit and a quartzitic sandstone upper unit (Dyman and Charpentier, 1992). It is composed of gray-orange to white, locally dull pink, brown-weathering, vitreous orthoquartzite occurring in beds from 1 to 3 feet thick with interbeds of massive brown sandy dolomite. Thin lenses of quartz-granule conglomerate occur locally at its base (Streufert et al., 1997a; Streufert et al,. 1997b; Tweto, 1974). Depositional environments in ascending order beginning at the bottom of the formation include sheetflood deposits of braided streams, a shallow marine environment, a tidal-channel environment, a low-energy subtidal marine shelf environment, and a shallow-water sabka environment (Dyman and Charpentier, 1992). Trace fossils are the most commonly reported fossils in the Sawatch Quartzite and occur in the lower strata of this formation (Dyman and Charpentier, 1992). The Sawatch Quartzite has low paleontological potential (PFYC 2).

6.2.2 Peerless Formation

The Upper Cambrian Peerless Formation was named by Behre (1932) for rocks that crop out on Peerless Mountain north of Leadville, CO. Originally considered a member of the Sawatch Quartzite, the formation is mapped within the Denver-Julesburg Basin, the Eagle Basin, and the South Park Basin within Colorado. At its type section, the Peerless Formation consists of approximately 100 feet of brown and brownish-maroon dolomitic sandstone, sandy dolomitic shale, and dolomite. This unit was deposited on a shallow marine shelf, with deeper water facies to the east.

Fossils documented in the Peerless Formation include poorly preserved trilobites and brachiopods. Trilobite taxa identified include *Tellerina* sp., *Saukia* sp., *Briscoia* sp., *Ptychaspis granulosa*, *Ellipsocephloides butleri*, and *Idahoia wisconsensis* (Berg and Ross, 1959). Identified brachiopod taxa includes *Dicellomus?* cf. *mosaica*. The Peerless Formation has moderate paleontological potential (PFYC 3).

6.2.3 Manitou Limestone

The Early Ordovician Manitou Limestone is a member of the Horseshoe Mountain Group. It was named from Manitou Springs in El Paso County, eastern Colorado, by Cross in 1894. Its type locality is north of Manitou above the Narrows of Williams Canyon. The Manitou Limestone is stratigraphically equivalent to the Arbuckle Group and is geographically restricted to Colorado. In ascending order, this formation is divided into the Dead Horse Canyon, Tie Gulch Dolomite, Helena Canyon, Ptarmigan Chert, and the Leavick Tarn Dolomite Members. The unit ranges between 156 and 167 feet thick. It conformably underlies the Harding Sandstone and unconformably underlies the Chaffee Formation. The Manitou is composed of medium-bedded brown dolomite, limestone, and sandstone with thin beds of gray, flat-pebble limestone conglomerate interbedded with greenish-gray calcareous shale (Streufert et al., 1997).

The Manitou Limestone contains a diverse marine invertebrate fauna, including trilobites, brachiopods, gastropods, cephalopods, conodonts, sponge spicules, crinoids, and graptolites (Bass and Northrop, 1953). It has moderate paleontological potential (PFYC 3).

6.2.4 Harding Sandstone

The Middle Ordovician Harding Sandstone was named for its type section at Harding's quarry outside of Cañon City by Walcott (1892). It is exposed along the Front Range in central Colorado and is overlain by the Upper Ordovician Fremont Formation and underlain by the Lower Ordovician Manitou Limestone (Allulee and Holland, 2005). This thin, discontinuous unit is 86 feet thick at its type section and up to 151 feet thick in Priest Canyon (Maher, 1950). The base of the formation is composed of white to pink sandstone with quartz pebbles and underlies increasing amounts of calcareous matter and lesser amounts of siltstone and shale (Walcott, 1892; Maher, 1950; Tweto, 1974). The depositional environment for the Harding Sandstone remains unresolved, with different researchers interpreting a estuarine, open marine, or fluvial environment (Fischer, 1978; Spjeldnaes, 1979; Graffin, 1992; Allulee and Holland, 2005). Most recent research on the depositional environment and fauna of the Harding Sandstone points toward a littoral open marine (near shore) environment that was proximal to a lagoon or bay (Allen, 2003).

The Harding Sandstone is locally fossiliferous and paleontologically important because it contains remains of some of the earliest vertebrates preserved in subtly different paleoenvironments. The vertebrate fauna is dominated by two taxa, the jawless fishes *Astraspis desiderata* and *Eriptychius americanus* (Allen, 2003; Allulee, 2005; Smith and Sansom, 1997). Dermal bony plates (primitive fish scales) which are locally abundant in the Harding are mostly disarticulated, although articulated and partially articulated skeletal remains have now been reported (Smith and Sansom, 1997; Spjeldnaes, 1979). Smith and Sansom (1997) report that the fish fauna is far more diverse than previously described. The scales of sharks, thelodonts, unidentified fish, and dermal skeletal fragments of *Skiichthys halsteadi*, a possible acanthodian or placoderm, have been documented. Conodont teeth, including ones from the genus *Chirognathus,* are also well preserved, abundant, and diverse within the Harding Sandstone. The formation also has a diverse assemblage of trace fossils such as *Rusophycus* and *Cruziana* and has produced a number of type specimens (Fischer, 1978; unpublished UCM paleontological data). The diverse invertebrate assemblage of the formation includes gastropods, bivalves, brachiopods, crinoids, and bryozoans. Most of these fossils are disarticulated or broken, indicating that they had been transported, though some facies (sandstone) contain *in-situ* shells from bivalves and brachiopods (Spjeldnaes, 1979). The Harding Sandstone is one of the oldest formations containing such a well-preserved and diverse vertebrate fauna, and its fossils are locally common. The Harding Sandstone has high paleontological potential (PFYC 4).

6.2.5 Fremont Formation

The Fremont Formation is an Upper Ordovician deposit overlying the Harding Sandstone and underlying the upper Parting Formation. The unit was first described and named by Charles Walcott in 1892 from exposures of the post-Manitou rocks on the lower slopes of Fremont Peak near Cañon City, which he divided into the Harding and Fremont Formations (Sweet, 1955; Sweet, 1961). Sweet (1954) later divided the Fremont into two members: a lower massive dolomite member and the upper Priest Canyon Member. The massive dolomite member is no more than 208 feet thick and is composed of buff or gray dolomite with some chert in its mid-section. The Priest Canyon Member is thin bedded with a maximum thickness of 211 feet and is composed of argillaceous, fine-grained dolomite (Sweet, 1955). The Fremont Formation is bounded by a lower unconformity with the Harding Sandstone, indicating a transition from a clastic shelf to marine carbonate sedimentation due to the expansion of epicontinental seas throughout North America. Other strata that correlate at least in part to the Fremont Formation include the Fish Haven Dolomite (Utah), the Bighorn Dolomite (northern Rockies), the Viola Limestone (midcontinent), and the Montoya Group (New Mexico) (Molenaar and Wilson, 1990). The most prominent outcrops of the Fremont Formation have been described in the northernmost part of Garden Park and west of Cañon City (Fisher, 1979).

The most abundant fossils found in the Fremont Formation are marine invertebrates. The lower massive dolomite member contains a fauna of *Receptaculites*, *Halysites*, *Calapocia*, and at least 17 genera of nautiloids (Sweet, 1954). Some of the taxa representing this nautiloid fauna include *Actinoceras*, *Beloitoceras*, *Cyclendoceras*, *Ephippiorthoceras*, *Endoceras*, *Kionoceras*, *Lambeoceras*, *Probillingsites*, and *Spyroceras* (Sweet, 1955). The upper Priest Canyon Member is dominated by a different fauna of marine invertebrates, including a diverse assemblage of corals and brachiopods (Sweet, 1954). The lower 5 feet of this member are the most fossiliferous, and specimens become relatively sparse in its upper strata (Sweet, 1955). These fossils were deposited as epeiric seas transgressed into the North American interior during the Middle and Late Ordovician (Witzke, 1980). The Fremont Formation has moderate paleontological potential (PFYC 3).

6.2.6 Chaffee Group

The Devonian Chaffee Group was originally named the Chaffee Formation from exposures in Chaffee County, CO, though no type section has been designated (Kirk, 1931). It is composed of three lithologically distinct formations that were originally considered members of the Chaffee Formation: the lower Parting Formation, which comprises the lower one-third of the unit, the overlying Dyer Dolomite, and the upper Gilman Sandstone (Bass and Northrop, 1953; Campbell, 1966, 1972; Rettew, 1978). Figure 5 shows the paleogeography of northwestern Colorado during the Late Devonian to Early Mississippian, when the Chaffee Group was formed.

Both the Parting Formation and Dyer Dolomite within the Chaffee Group in Colorado are fossiliferous. The Parting Formation is paleontologically important because it contains fragmentary fish fossils (bones and dermal plates) from an important period in the evolution of fishes (Bass and Northrop, 1953; Robinson, 1976). The Dyer Dolomite contains a diverse invertebrate fauna that includes brachiopods, bryozoans, gastropods, bivalves, corals, stromatoporoids, and crinoids (Bass and Northrop, 1953; Webster et al., 1999). Fossils are not known from the Gilman Sandstone. The lithology, depositional environments and paleontology of the Parting Formation, Dyer Dolomite, and Gilman Sandstone are described in detail below. . The Chaffee Group has moderate paleontological potential (PFYC 3).

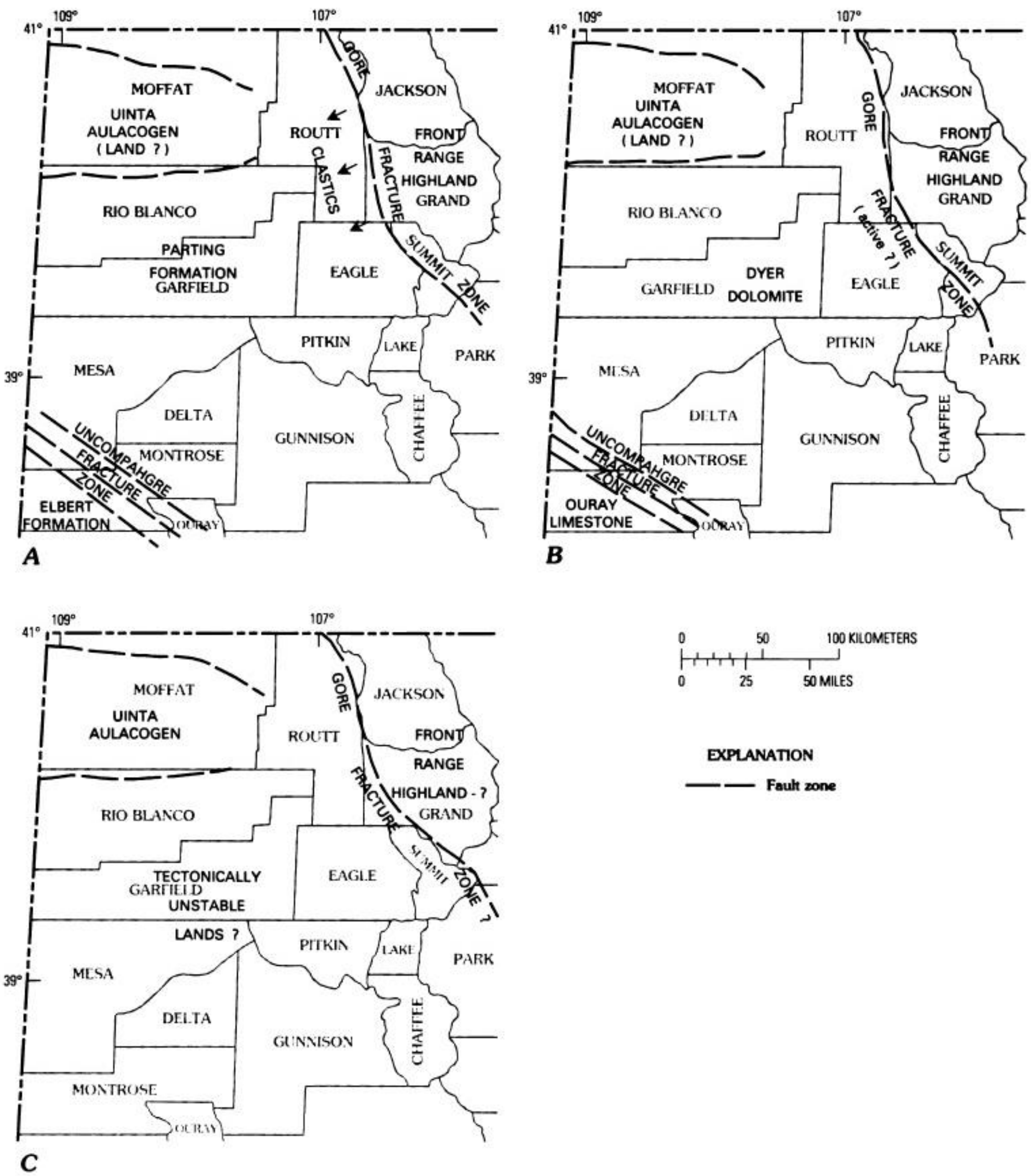

FIGURE 5. Paleogeography of northwestern Colorado from the Late Devonian to Early Mississippian. **A**. Frasnian(?) or Famennian (Parting Formation); **B**. Famennian (Dyer Dolomite); **C**. Famennian or earliest Mississippian (Kinderhookian) (Gilman Sandstone) (from Molenaar and Wilson, 1990; Figure 13).

6.2.6.1 Parting Formation

The Parting Formation is the basal formation of the Chaffee Group and is Late Devonian to possibly Early Mississippian in age (Tweto and Lovering, 1977). The type area is located at Parting Spur, West Dryer Mountain in Lake County, CO (Kirk, 1931). The Parting Formation is present in a small area of central Colorado (Sando and Sandberg, 1987), where it unconformably overlies a number of formations, including the Ordovician Harding Sandstone and Manitou Limestone, Cambrian Peerless Formation and Sawatch Quartzite, and Precambrian rocks, and it conformably underlies the Dyer Dolomite (Tweto and

Lovering, 1977). Previously, the Parting Formation was described as the lowest member of the Chaffee Formation and was referred to as the Parting Quartzite, a term first used by Emmons in 1882 (Singewald and Butler, 1941). The designation "Quartzite" was later changed to "Formation" due to the Parting's variable lithology, which is not limited to quartzite (Campbell, 1970; Tweto and Lovering, 1977). The Parting Formation has been correlated with the Fremont Canyon Sandstone of the Laramie Range in Wyoming (Sando and Sandberg, 1987).

Lithologies and thicknesses of the Parting Formation are variable across the extent of the unit. It ranges from 10 to 65 feet thick, with an average thickness of 45 feet (Tweto and Lovering, 1977). At Parting Spur, the formation is composed of tan to white, poorly sorted, cross-bedded, coarse-grained quartzite and conglomerate with local interbeds of mottled turquoise-green and maroon shale (Tweto and Lovering, 1977). Three lithologic units were recognized by Campbell (1970) in west-central Colorado: Unit A, Unit B, and Unit C. Basal Unit A is characterized by medium- to coarse-grained, cross-bedded sandstone with occasional burrows and ripple marks. Unit B is composed of shale, dark-gray dolomite, sandy dolomite, and dolomitic sandstone. Unit C is composed of gray to green, locally dolomitic shale interbedded with dense dolomite beds and fine- to medium-grained sandstone and siltstone beds (Campbell, 1970; Anderson, 1980). The Parting Formation was deposited in a nearshore, shallow marine to intertidal environment (Campbell, 1981).

Fossil fish (Tweto and Lovering, 1977); conodonts (Sando and Sandberg, 1987); and an abundance of brachiopod, bivalve, and crinoid casts and molds have been documented in the Parting Formation. Recovered fish primarily consist of freshwater and brackish forms, such as *Bothriolepis*. Identified invertebrate fossils include *Schizophoria striatulata*, *Spirifer* (*Cyrtospirifer*) *whitneyi*, *Productella* sp., *Paurorhynca endlichi*, and *Aviculopecten*? sp. (Tweto and Lovering, 1977). It has moderate paleontological potential (PFYC 3).

6.2.6.2 Dyer Dolomite

The Dyer Dolomite, or Dyer Formation, is a Late Devonian unit that is restricted to Colorado. It overlies the Parting Formation (Campbell, 1970). The Dyer is mostly composed of fine-grained and thin-bedded dolomite that breaks into small, sharp fragments (Sheridan et al., 1976). It is subdivided into two members: the lower Broken Rib Member and the upper Coffee Pot Member. The Broken Rib Member consists of dark-gray, dolomitic fossiliferous limestone that is interpreted to have formed by sediments deposited in a marine environment within the sublittoral zone. The Coffee Pot Member consists of light gray, dense stromatolitic dolomite formed by the trapping of algae living in the littoral zone that existed at the margins of a retreating Devonian sea (Campbell, 1970; Soule, 1990).

The Dyer Dolomite is significant because it spans the end-Famennian mass extinction and is highly fossiliferous. The diverse assemblage of fossil plants and animals in the Dyer disappear between the Broken Rib Member and the Coffee Pot Member at the end of the Famennian (Wistort et al., 2014). The most abundant fossils in Broken Rib Member include corals, brachiopods, orthocone nautiloids, crinoids, gastropods, bryozoans, and teeth of holocephalians, acanthodians, elasmobranchs and conodonts. sponges, stromatoporoids, and stromatolites. The Coffee Pot Member, in contrast, is unfossiliferous and indicates changing sea water conditions. This change appears in the geologic record just before the Hangenber Event, or Devonian extinction (Hagadorn et al., 2013). The Dyer Dolomite has moderate paleontological potential (PFYC 3).

6.2.6.3 Gilman Sandstone

The Gilman Sandstone is a Late Devonian to Early Mississippian unit in central Colorado that comprises the upper part of the Chaffee Group (Soule, 1990). Overlying the Dyer Dolomite and underlying the Leadville Limestone, the unit is characterized as a thin layer of sandstone that ranges from

10 to 50 feet in thickness (Tweto and Lovering, 1977). The stromatolitic dolomite of the Dyer Dolomite abruptly changes to orthoquartzite where it contacts the Gilman Sandstone (Nadeau, 1972). The sandstone in this formation is medium- to coarse-grained, yellow, buff and gray, and has well-rounded sand grains that are cemented by carbonates and silica deposited in a marine environment (Tweto, 1949). Its upper disconformity, thinness, and lithology show that it was likely deposited in shallow water as the environment changed due to the strengthening of the Antler orogeny in Utah and Nevada during the Devonian (Soule, 1990). This orogeny caused a regression in the White River Uplift area, leading to an influx of sand that later formed the Gilman Sandstone (Campbell, 1981). The Gilman Sandstone is not fossiliferous, according to the literature reviewed for this study. Therefore, the unit has low paleontological potential (PFYC 2).

6.2.7 Williams Canyon Formation

The Williams Canyon Formation is Early Mississippian in age (Poole and Sandberg, 1991), although the unit was originally believed to have been deposited during the Devonian Period (Brainerd et al., 1933). Typical exposures were described by Brainerd et al. (1933) near the Cave of the Winds in Williams Canyon at Manitou in El Paso County, CO. The William Canyon Formation unconformably overlies Ordovician beds belonging to the Manitou Limestone, Harding Sandstone, and Fremont Formation and underlies the Mississippian Madison Limestone (Brainerd et al., 1933). Before 1933, strata of the Williams Canyon Formation and overlying Madison Limestone comprised the Millsap Limestone of Cross (1894); however, when Brainerd and colleagues (1933) reported an unconformity within the Millsap, it was split into two units and the name "Millsap Limestone" was abandoned. The Williams Canyon Formation has been recognized in El Paso, Fremont, Douglas, and Pueblo Counties in the Denver Basin of Colorado, and in Custer County, CO, in the Las Vegas-Raton (Maher, 1950). The Williams Canyon Formation is believed to be equivalent to the Dyer Dolomite (Ross and Tweto, 1980).

The Williams Canyon Formation is approximately 80 feet thick along the Front Range (Brainerd et al., 1933). The formation typically consists of thin-bedded, purple to gray, fine-grained to crystalline limestone, dolomite, and sandy dolomite with occasional beds of fine- to medium-grained sandstone and shale (Maher, 1950). Fossil discoveries within the Williams Canyon Formation are relatively sparse (Lindsey, 1983) and all belong to well-known taxa (Fischer, 1981). Recorded fossils include crinoids (Brainerd et al., 1933), rugose corals, bivalves (Fischer, 1981), ostracods (Poole and Sandberg, 1991), and brachiopods (Poole and Sandberg, 1991; Fischer, 1981). The Williams Canyon Formation has moderate paleontological potential (PFYC 3).

6.2.8 Leadville Limestone

The early to middle Mississippian Leadville Limestone was named for characteristic exposures in the Leadville District, Lake County, CO (Emmons and Eldridge, 1984). The unit is composed primarily of limestone, although the lower one-third of the formation contains interbedded dolomite and limestone with dark-gray chert (Bass and Northrop, 1953; Richards, 1982). Sandy limestone beds occur locally (Conley, 1968). The Leadville Limestone is up to 230 feet thick, though its thickness is noticeably variable. The irregularities in the thickness of this unit are the result of uneven erosion below a karst surface. The Leadville Limestone is mapped within the subsurface of northwestern New Mexico and the surface in southwestern, south-central, and central Colorado, and the unit unconformably overlies the Williams Canyon Formation in central Colorado (Armstrong et al., 1992). The Leadville Limestone was deposited in shallow marine subtidal and supratidal environments (Armstrong et al., 1992). An overview of the Precambrian and lower Paleozoic sedimentary rocks in northwestern Colorado is provided in Figure 6.

Invertebrates are the most common fossils found within the Leadville Limestone, though rare vertebrate fossils (fish teeth) have been reported. Additionally, conodonts are fairly common within the Leadville

(Armstrong and Mamet, 1976). A fairly diverse invertebrate fossil assemblage has been collected from Glenwood Canyon and several other localities in Garfield, Eagle, and Pitkin Counties, CO (Scott, 1954; Armstrong and Mamet, 1976). These fossils include foraminifera, crinoids, bryozoans, brachiopods, and stromatolites (Armstrong and Mamet, 1976). The Leadville Limestone has moderate paleontological potential (PFYC 3).

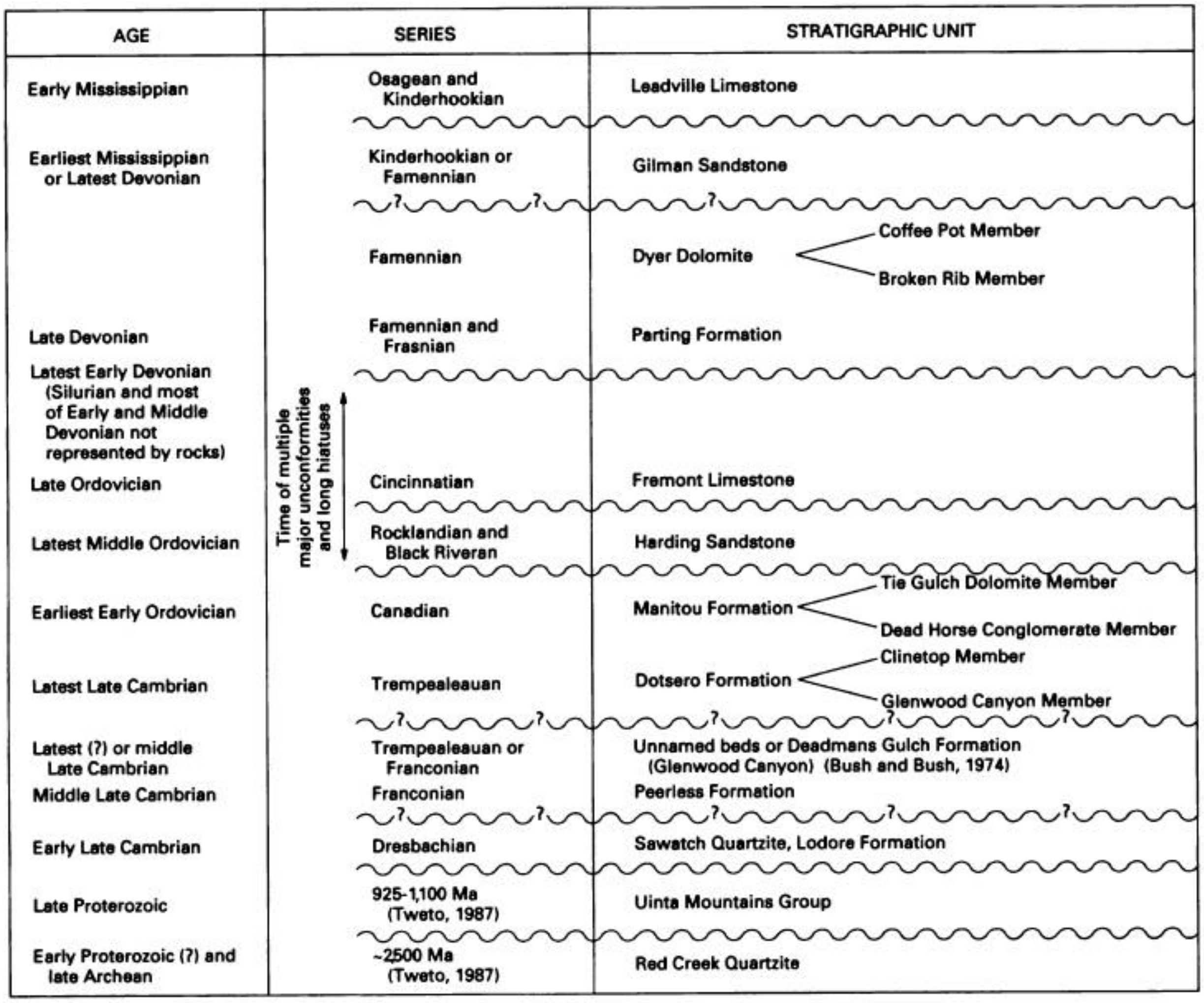

FIGURE 6. Precambrian and lower Paleozoic sedimentary rocks in northwestern Colorado (from Molenaar and Wilson, 1990; Figure 2).

6.2.9 Fountain Formation

The Middle Pennsylvanian to Lower Permian Fountain Formation consists of thick-bedded, coarse-grained arkosic sandstone and conglomerate containing thin layers of dark maroon, silty, fine-grained micaceous sandstone that are more abundant in the lower part of the unit. The coarse clastic facies are characterized by well-developed crossbedding and poor sorting (Scott, 1972; Trimble and Machette, 1979; Van Horn, 1972). Interbeds of locally fossiliferous limestone also occur. Color is generally reddish with local variations of white, green, and gray. The Fountain Formation is 4,050 feet thick at its type locality along Fountain Creek in the Manitou Springs Quadrangle (Keller et al., 2005) and 1,000 feet thick in the Eldorado Springs Quadrangle (Kellogg et al., 2008). The unit was deposited mostly in alluvial fans and braided streams during the uplift of the ancestral Rocky Mountains. Figure 7 is an artist's rendition of the Denver-area landscape during the deposition of the Fountain Formation. The Fountain Formation is extremely well exposed within the Front Range of Colorado, forming the Flatirons, Devils Thumb, and other notable landmarks such as Red Rocks near the town of Morrison.

Fine-grained facies (limestone and siltstone) of the Fountain Formation 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 museum data). One noteworthy fossil specimen is the ichnotype of the fossil amphibian track *Brachydactylopus fontis,* which is housed at the UCM (UCM 18633, Loc. 69039). This specimen was collected from a quarry west of Boulder on Flagstaff Mountain. The discovery of additional fossils in the unit, especially vertebrates and vertebrate trace fossils, would be quite scientifically important. The Fountain Formation is considered to have moderate paleontological potential (PFYC 3).

FIGURE 7. Artist's rendition of the Denver area during deposition of the Fountain Formation, titled Ancestral Rockies (courtesy of the DMNS and Jan Vriesen).

6.2.10 Belden Shale

The Lower Pennsylvanian Belden Shale was originally named as a member of the Battle Mountain Formation near Gilman, CO, and later assigned to formation status (Brill 1942, 1944). The unit is found in the Eagle Basin, Las Vegas-Raton Basin, and Piceance Creek Basin in Colorado and was deposited in a low-energy marine environment in the Central Colorado Trough (Kirkham et al., 1997). The formation is composed predominantly of gray to black carbonaceous shale and contains thin beds of fossiliferous dark-gray to black limestone with minor beds of fine- to medium-grained sandstone and siltstone (Kirkham et al., 1997).

Belden limestone beds have produced a marine invertebrate fauna of early Pennsylvanian age (Brill 1942, 1944). This fauna includes corals, crinoids, bryozoans, and brachiopods. In the Greater Green River Basin in Wyoming, workers have identified abundant fusulinids (foraminifera), algae, brachiopods, corals, bryozoans, crinoids, bivalves, and trilobites (Thompson, 1945). The Belden Shale has moderate paleontological potential (PFYC 3).

6.2.11 Sangre de Cristo Formation

The Sangre de Cristo Formation is Upper Pennsylvanian and Lower Permian in age. The unit's type locality is located east of Crestone in Saguache County, south-central Colorado (Bolyard, 1959). Exposures are geographically distributed throughout south-central Colorado and northern New Mexico. In the Coyote Creek District of northern New Mexico, the Sangre de Cristo has been divided into six units, which have been described in ascending order as red arkose, transition beds, fluviatile sandstone, red siltstone, variegated sandstone, and conglomeratic sandstone (Brown, 1984). The upper and lower contacts of the unit are usually faulted, and its thickness is greater than 3,500 feet. The formation consists of reddish-brown non-marine arkosic sandstone and conglomerate with minor interbeds of shale and limestone. The sandstone beds are generally indurated and locally cemented with calcite and epidote (Boylard, 1959; Lindsey, 1984; Scott et al., 1976; Vine, 1974). Brown (1984) divided the Sangre de Cristo Formation into three distinct depositional systems, which, in ascending order, include a distal alluvial fan with an associated floodplain, a progradational fluvial system, and a shallow marine bar and valley fill. The formation is interpreted to have formed from deposits in the Paleozoic Rowe-Mora Basin of northern New Mexico and south-Central Colorado (Brown, 1984).

Fossils are relatively rare in the Sangre de Cristo Formation. The most common fossils in the unit are woody fragments and carbonaceous plant debris (Vine, 1974) as well as enigmatic sedimentary structures that may be burrows or root traces (author's personal observation). Specimens of the Permian plant taxon *Callipteris conferta* have also been reported (Wanek and Read, 1956). Vertebrate fossils are extremely rare in the Sangre de Cristo Formation. However, significant vertebrates have been collected at the "Badger Creek Locality" in the northern Sangre de Cristo Mountains in Colorado. This locality has produced an important and diverse faunal assemblage including pelycosaurian-grade synapsids; (Sumida and Berman, 1993), diadectomorph, anthracosaurian, temnospondyl, and lepospondyl amphibians; and elasmobranch and palaeoniscoid fishes (Berman and Sumida, 1990, 1995; Sumida and Berman, 1993; Vaughn, 1969, 1972). The fossils at the Badger Creek Locality were preserved in a lenticular 2- to 3-foot-thick black shale (Vaughn, 1972), an uncommon lithology in the Sangre de Cristo Formation and correlative units. Because of the scientific importance of the vertebrate fossils and the potential for additional significant discoveries in the Sangre de Cristo Formation, the unit is considered to have high paleontological potential (PFYC 4).

6.2.12 Minturn Formation

The Middle Pennsylvanian Minturn Formation has a type locality near Minturn, CO, and is named for exposures along the east side of Eagle Valley (Tweto and Lovering, 1977). The unit overlies the Leadville Limestone and underlies the Maroon Formation in central and western Colorado. The Minturn Formation has seven identified members, but only three are widely used. These include the Robinson, White Quail, and Jacque Mountain Members (Tweto and Lovering, 1977). The Minturn Formation is approximately 6,300 feet thick at its type section and generally consists of gray, pale-greenish-gray, yellowish-gray, grayish-red, pale-red, and pale-gray calcareous, arkosic sandstone, siltstone, conglomerate and scattered beds of gray marine limestone. The Robinson Limestone Member consists of at least four sequences each approximately 65 feet thick and consisting of gray to yellowish-gray, fine- to medium-grained, locally fossiliferous, medium- to thick-bedded marine limestone and dolomitic limestone. Each carbonate sequence is interbedded with pinkish-tan and light-tan, cross-bedded, arkosic, micaceous, pebbly sandstone and light-grayish-pink sandy siltstone and shale. This member is approximately 722 feet thick at its type section (Kellogg et al., 2003). The White Quail Member consists of beds of dark fossiliferous limestone separated by clastic rocks, and the Jacque Mountain Member predominantly consists of gray to light-bluish-gray, fine-grained limestone that is oolitic in part and is the most continuous limestone of all of the members within the Minturn Formation (Tweto and Lovering, 1977). The Minturn Formation records two alternating depositional environments, one marine and one non-marine (primarily fluvial).

The marine (limestone) facies is much more fossiliferous than the fluvial (clastic) facies. Marine invertebrates in limestone and dolomite beds are by far the most diverse and numerous fossils in the Minturn Formation. These consist primarily of a diverse assemblage of fusulinid foraminiferans, bryozoans, brachiopods, echinoderms, bivalves, horn corals, gastropods, and cephalopods (Itano and Bateman, 2001). The fusulinids provide the most important data for the age constraint of the Minturn Formation, giving it an age of Atokan to Desmoinesian. Plant fossils such as *Lepidodendron* sp., and *Cordaites* sp., the latter a representative of an extinct group of gymnosperms, are also known. Ichnofossils, including footprints, burrows, and others also occur. Known vertebrate fossils include palaeoniscoid fish, shark teeth, and a diverse assemblage of conodonts (Houck and Lockley, 1986; Lockley, 1984; Lockley and Hunt, 1995; Murray, 1964; Rigby and Church, 1993; Stevens, 1962, 1965, 1971; Tweto and Lovering, 1977; Webster and Houck, 1998). Because the Minturn Formation contains locally abundant invertebrate fossils but less common vertebrate fossils, the unit as a whole has moderate paleontological potential (PFYC 3).

6.2.13 Maroon Formation

The Middle Pennsylvanian to Early Permian Maroon Formation was named for typical exposures at Maroon Creek in west-central Colorado (Emmons et al., 1884). Lithologically, the unit is composed principally of reddish conglomerate, conglomeratic sandstone, arkosic and commonly cross-bedded sandstone, siltstone, mudstone, claystone, and shale with thin, minor non-marine limestone beds (Bass and Northrop, 1963). The Maroon Formation is arkosic and very micaceous, and its total unit thickness is approximately 3,000 feet on the Storm King Mountain Quadrangle (Bryant et al., 2002). The formation is fluvial and possibly eolian in origin (Tweto and Lovering, 1977).

The limestone beds contain scattered brachiopods, crinoids, corals, and bivalves. Thin section samples of fossil wood identified as belonging to the genus *Dadoxylon* have been reported as featuring abundant microfossils including fecal pellets, ostracods, and globules suggestive of a siphonaceous alga similar to *Gymnocodium* (written communication from Scott, 1961, cited by Tweto and Lovering, 1977). Vertebrate body fossils and tracks have recently been discovered by researchers working in the Maroon Formation on BLM managed land in the Eagle Basin west of the RGFO Planning Area. These include hundreds of vertebrate and invertebrate tracks and trackways at Maroon Bells near Aspen (Voigt et al., 2005), more recently in the Eagle Basin (Huttenlocker, 2014) west of the RGFO Planning Area. Although fossils are uncommon in the Maroon Formation, additional discoveries would be very scientifically important. This unit is considered to have moderate paleontological potential (PFYC 3).

6.2.14 Casper Formation

The Pennsylvanian to Early Permian Casper Formation was named after Casper Mountain in central Wyoming, but no type section has been designated (Darton, 1908). This formation is considered the southward extension of the Amsden and Tensleep Formations in Wyoming. The Fountain and Ingelside together are equivalent with the Casper Formation, and the Ingelside is largely considered the Colorado equivalent to the Casper Formation of Wyoming, which is found in central and southern Wyoming and extends into northern Colorado (Hoyt, 1962). The Casper Formation consists of massive, 300- to 400-foot-thick limestone and dolostone with interbedded arkosic sandstone at Casper Mountain (Darton, 1908). The limestone beds were deposited on a shallow marine shelf and contain marine fossils, though some studies point toward an eolian origin for some of the interbedded sandstone units (Miller and Thomas, 1936).

Fossils within the Casper Formation represent an entirely marine invertebrate fauna; are primarily found within the limestone units; and consist of bryozoans, brachiopods, trilobites, cephalopods, crinoids, and foraminifera (Miller and Thomas, 1936; Heiman, 1971). These fossils are generally well preserved and abundant. Representative taxa include the cephalopods *Pseudorthoceras knoxense*, *Mooreoceras* sp., *Coloceras* sp., and *Metacoceras knighti*, among many others, and the fusulinid *Triticites ventricosus*, which point to a late Pennsylvanian to early Permian age (Miller and Thomas, 1936). Conodonts including *Idiognathodus* and *Hindeodus* also recovered from the limestone units are rare but very well preserved (Sando and Sanberg, 1987). The Casper Formation is considered to have moderate paleontological potential (PFYC 3).

6.2.15 Ingleside Formation

The Early Permian Ingleside Formation conformably overlies the Fountain Formation and consists of marine carbonates, eolian deposits, and evaporites (Lovering and Goddard, 1950). For more information about the Ingleside, see Section 6.2.14. A single Early Permian fusulinid foraminifer was found from the base of the Ingleside Formation at its type section in Owl Canyon, CO (Hoyt and Chronic, 1961), but no other marine invertebrates or fossils have been reported. Therefore, the unit has low paleontological potential (PFYC 2).

6.2.16 Lyons Sandstone

The Middle(?) and Upper Permian Lyons Sandstone is well exposed north of Boulder, CO (Fenneman, 1905). The formation is primarily found in Colorado along the Front Range and extends into southern Wyoming. The Lyons Sandstone consists of pink to pinkish-gray, cross-laminated, silica-cemented, fine- to coarse-grained eolian sandstone. The unit is 250 feet thick in north-central Colorado and contains conglomerate near its base (Kellogg et al., 2008; Lovering and Goddard, 1950). Well-preserved fossil sand dune ripple marks and mud cracks are commonly found in this unit, which was deposited as sand dunes. The formation's laminated rock slabs have been quarried and widely used as flagstone in urban construction in Colorado and for the construction of University of Colorado Boulder buildings. An artist's rendition of the Denver-area landscape during deposition of the Lyons Sandstone is depicted in Figure 8.

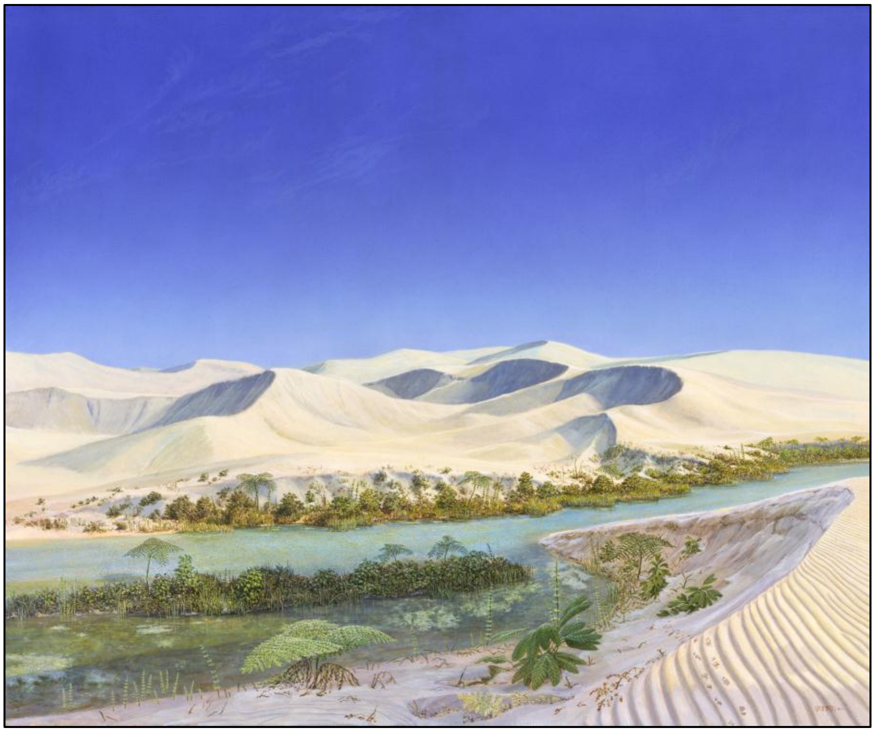

FIGURE 8. Artist's rendition of the Denver area during deposition of the Lyons Sandstone, titled Sand Planet (courtesy of the DMNS and Jan Vriesen).

The Lyons Sandstone is best known for its fossilized insect and amphibian footprints and other ichnofossils. Particularly well-preserved amphibian tracks including the ichnotype of *Laoporus coloradoensis* were collected from a Lyons Sandstone quarry near the town of Lyons, CO (Loc. 71175, UCM, 14190, 14191, 14192). Another important fossil specimen, the trackway of the arthropod *Palaeohelcura lyonensis* (Loc. 69038, UCM 18632), was collected from the Lyons Sandstone south of Boulder in 1935. Another locality is recorded in the Lyons Sandstone at Sanitarium Quarry (UCM Loc. 96365), although the information obtained for this report does not describe what was collected there. The Lyons Sandstone is sparsely fossiliferous and has produced few fossils, but those that have been discovered are highly scientifically significant. Therefore, the Lyons Sandstone is considered to have moderate paleontological potential (PFYC 3).

6.2.17 Satanka Formation

The Permian Satanka Formation is equivalent to units within the Chugwater Group, which includes the Jelm Formation (see Section 6.2.19). The unit is marine in origin and consists of red shale and gray limestone with abundant amounts of gypsum (Barnett, 1912). Fossils reported from this formation include marine invertebrates including scaphopods, pelecypods, gastropods, nautiloids, and fusulinids (Paleobiology Database, 2015). The Satanka Formation is considered to have moderate paleontological potential (PFYC 3).

6.2.18 Lykins Formation

The Upper Permian and Lower Triassic Lykins Formation is named for exposures in Lykins Gulch, Boulder County, CO (Fenneman, 1905). The Lykins is at least partially equivalent with the Chugwater, Dinwoody, Thanes, Spearfish, Jelm, Ankareh, Woodside, Lykins, Chinle, and Dolores Formations and the Glen Canyon and Dockum groups. The unit lies along the Front Range and in southeastern Colorado

(Fenneman, 1905; Duce, 1924). The Lykins is composed of the Harriman Shale, Bergen Shale, Forelle Limestone, and Strain Shale Members. The Harriman Shale Member and the overlying Bergen Shale Member have a combined thickness of about 131 feet and consist of maroon and green siltstone separated by a 3-foot-thick, laminated, red-weathering limestone bed. The Forelle Limestone Member consists of about 16 feet of pink, wavy-laminated marine algal limestone. The Strain Shale Member consists of about 295 feet of maroon, stratified, micaceous, fine-grained, silty sandstone and siltstone with some green siltstone beds (Kellogg et al., 2008; Butters, 1913). The Lykins Formation was deposited in a shallow marine environment in the intertidal zone in an epicontinental lagoon (Maughan, 1980). An artist's rendition of the Denver-area landscape during deposition of the Lykins Formation is depicted in Figure 9.

FIGURE 9. Artist's rendition of the Denver area during deposition of the Lykins Formation, titled Slimy Shoreline (courtesy of the DMNS and Jan Vriesen).

The Lykins contains few identifiable fossils and is best known for algal stromatolites within the Forelle Limestone Member. The carbonate beds within this member exhibit a laminated texture indicative of algal mats in a shallow marine environment (Keller et al., 2005). Rare fossil bones, mollusks (bivalves, gastropods), and brachiopods have also been discovered in the Lykins Formation (unpublished UCM data). Because of the scarcity of fossils within Lykins Formation, the unit is considered to have moderate paleontological potential (PFYC 3).

6.2.19 Chugwater Group

The Triassic Chugwater Group was originally named as the Chugwater Formation from Chugwater Creek near Iron Mountain in Platte County, WY (Darton, 1904). The formation was later assigned group status in Wyoming by High and Picard (1967). The Chugwater Group is equivalent, in part, to the Sundance Formation and the Lykins Formation (Pipiringos and O'Sullivan, 1976). The group is widely distributed throughout Wyoming but in Colorado is limited to the part of the Denver-Julesburg Basin that overlaps with the north-central part of the state (Lovelace, 2012). There, the group consists of the subsurface Red Peak Formation and 100-foot-thick orange-pink or reddish-brown, fine-grained, cross-bedded calcareous sandstone named the Jelm Formation (Courtright and Braddock, 1989).

Fossils of the Chugwater Group (which is equivalent to the Dinwoody, Thanes, Spearfish, Jelm, Ankareh, Woodside, Chinle, and Dolores Formations, in part, and the Glen Canyon and Dockum groups, in part) are known primarily from the vicinity of the Wind River Basin in Wyoming. These fossils include marine and non-marine reptiles and amphibians, some specimens of which are notably well preserved and scientifically important. Dawley and colleagues (1979) described a partial thecodont skeleton and skull from the Popo Agie Formation of the Chugwater in Natrona County; the specimen represents the first occurrence of the family Rauisuchidae in North America. Zangerl (1963) reported a nothosaur skull, the first known from North America, from the Alcova Limestone of the Chugwater in Natrona County near Casper. Although information gathered for this report contained no specific reports of vertebrate fossils from the Chugwater in Colorado, vertebrate trackways are known from correlative strata in Colorado (Conrad and Lockley, 1992; Hunt and Lucas, 1992). Because sparse but scientifically important vertebrate fossils have been found in the group outside Colorado and new discoveries in the unit within the state would be scientifically important, the Chugwater Group is considered to have moderate paleontological potential (PFYC 3). Since the Jelm Formation is the only unit of the Chugwater Group that is exposed at the surface in Colorado, the unit is described in greater detail in the following subsection.

6.2.19.1 Jelm Formation

The Late Triassic Jelm Formation is named for Jelm Mountain in Albany County, WY, with its principle reference section at Red Mountain in Albany County (Lee, 1927; Pipiringos, 1968). In Colorado the Jelm outcrops in the north-central part of the state in the Front Range uplift and consists of two members: the Red Draw and Sips Creek. The unit as a whole unconformably underlies the Sundance Formation, and the unconformity is marked by the presence of conspicuous chert pebbles (Braddock et al., 1988a, 1988b). Varying from 90 to 134 feet thick, the Red Draw Member is composed of orange-pink and reddish-brown, cross-bedded, fine-grained calcareous sandstone. The Sips Creek Member overlies the Red Draw Member, and the contact between the two is often recognized by the presence of a conglomerate (Pipiringos, 1968). The Sips Creek is composed of up to 300 feet of sandstone and siltstone, and is often cliff forming at its type section in south-central Wyoming (Pipiringos, 1968). The Jelm Formation represents a fluvial (stream channel) deposit (Lee, 1927).

Few fossils have been reported from the Jelm Formation. The University of Wyoming Museum of Geology houses an isolated and unidentified reptile tooth collected from the unit, and unidentifiable bone fragments in a Jelm conglomerate were reported by Pipiringos (1953). However, Heckert and others (2012) have recently identified fossils previously thought to be from the middle Jurassic Entrada Sandstone to be correlative with the Red Draw Member of the Jelm Formation, extending the distribution of this unit much farther south than previously thought. These fossils include tooth and bone fragments from metoposaurs, phytosaurs, and aetosaurs (Heckert et al., 2012). Any additional fossil discoveries would be of great importance to efforts to constrain the age of this unit, which is considered to have moderate paleontological potential (PFYC 3).

6.2.20 Dockum Group

The Late Triassic Dockum Group was named by W.F. Cummins in 1890 for exposures near the town of Dockum in Dickens County, TX. While the Dockum is mostly known from its exposures in Texas and New Mexico, it is also present in southeastern Colorado and western Oklahoma. The formations comprising the Dockum Group include the Baldy Hill Formation, the Santa Rosa Formation, the Tecovas Formation, the Trujillo Formation, and the Cooper Canyon Formation. The Chinle Formation (see below) is also sometimes considered part of the Dockum or totally equivalent with it, as the Chinle and Dockum are clearly correlated in many places across the Colorado Plateau (Sues and Fraser, 2010). The stratigraphic nomenclature in terms of the usage of the name Dockum versus Chinle for rocks in western and southeastern Colorado is controversial and currently unresolved. Generally, these rocks are composed of channel-related facies made up of coarse-grained clastics, and overbank facies composed of fine-grained clastics (Lehman and Chatterjee, 2005). The Dockum accumulated in a variety of depositional environments including meandering streams, alluvial fans and fan deltas, distributary-type lacustrine deltas, short- and long-lived lakes, and mud flats (McGowen et al., 1983).

The Dockum Group preserves one of the richest and most diverse fossil records of Late Triassic fossils in the world. Invertebrates, fish, plants, and tetrapods including mammals, birds, dinosaurs, pterosaurs, rauisuchids, crocodylomorphs, lissamphibians, trolophosaurs, lepidosaurs, phytosaurs, aetosaurs, temnospondyls, prolacertiforms, cynodonts, dicynodonts, and turtles comprise the major clades represented in the Dockum. The majority of these fossils are found in the Cooper and Tecovas Formations, which continue to produce new and exciting discoveries (Lehman and Chatterjee, 2005).

Some of the richest fossil localities in the Dockum Group are found in lacustrine facies known from localities such as the Kirkpatrick Ranch, Walker's Tank, Kirkpatrick Quarry, Little Sunday Canyon, and the Neyland Site. Lacustrine deposits in the Dockum are exemplified by the Neyland Site in the Cooper Canyon Formation, which has yielded the phytosaur *Paleorhinus*, the temnospondyl *Buettneria*, the trilophosaurids *Malerisaurus* and *Protoavis*, and an abundance of petrified wood. In the Tecovas Formation, the Kirkpatrick Quarry preserves an abundance of microvertebrates and fish (e.g. *Ceratodus, Semionotus,* and *Xenacanthus*), procolophonids, a sphenodontid, and the two temnospondyls *Buettneria* and *Apachesaurus* (Lehman and Chatterjee, 2005).

Several examples of well-preserved, densely concentrated vertebrate assemblages have been discovered in channel facies, some of which include the Elkins Place Bone Bed in Scurry County and the Patricia Site in Garza County, TX. Bone accumulations in these channels consist of isolated bones, disarticulated partial skeletons, and complete skeletons, typically of aquatic tetrapods such as metoposaurs and phytosaurs. Vertebrate assemblages deposited in floodplains are typical of those found in the Post Quarry and Otis Chalk localities. These quarries are composed of massive, red mudstone deposits, where isolated and scattered bones with small areas of highly concentrated bones are common. The Post Quarry in the Cooper Canyon Formation is notable for producing fish; the metoposaurid *Apachesaurus*; the temnospondyl *Rileymillerus*; the phytosaur *Pseudopalatus;* the aetosaurs *Desmatosuchus, Paratypothorax,* and *Typothorax*; the rauisuchians *Poposaurus*, *Postosuchus*, and *Shuvosaurus*; and dinosauriform archosaurs including *Shuvosaurus* (Sues and Fraser, 2010). The Otis Chalk also contains a rich but different fossil assemblage that is represented by the temnospondyl *Buettneria*; the archosauromorph *Trilophosaurus*; a prolacertiform *Malerisaurus*; the phytosaurs *Paleorhinus* and *Rutiodon;* the aetosaurs *Longosuchus* and *Desmatosuchus*; and the rauisuchids *Poposaurus, Postosuchus, Lythrosuchus,* and *Chatterjeea* (Lehman and Chatterjee, 2005)

Tetrapod fossil assemblages from the Dockum are highly important, as workers have used them extensively for biostratigraphic correlation of Late Triassic strata throughout the Southwest (Lucas 1993, 1997, 1998; Lucas and Huber, 2003). These fossils also record the initial radiation of several major groups of tetrapods, including birds, mammals, archosaurs, squamates, and lissamphibians (Lehman and Chatterjee, 2005). Fewer exposures of the Dockum Group exist in southern Colorado than in other areas of the Southwest, and this is undoubtedly at least partially responsible for the fact that fewer fossils have been discovered in the unit in Colorado. In Colorado, the Dockum Group has moderate paleontological potential (PFYC 3).

6.2.20.1 Chinle Formation

The Upper Triassic Chinle Formation is one of the more conspicuous and well-known formations of the Southwest, with its characteristic red beds, spectacular exposures in Arizona's Painted Desert, and the world-famous fossilized logs (and other fossils) of Petrified Forest National Park. H.E. Gregory (1917) was the first to describe the Chinle, which he named after exposures along Chinle Wash near the settlement of Chinle in northeast Arizona (O'Sullivan, 1974). The Chinle Formation lies unconformably above the Moenkopi Formation and has an extensive geographic distribution throughout most of the Colorado Plateau, with exposures in Utah, Colorado, Arizona, and New Mexico (Stewart et al., 1972). According to Stewart and colleagues (1959:500), the unconformity at the base of the Chinle is "the most conspicuous and widespread break in the sequence of the Permian and Triassic rocks and is marked by many channels that cut a few feet to several tens of feet into the Moenkopi surface." Repenning and colleagues (1969) reported that this channelization of the Moenkopi surface actually has a relief of between 30 and 275 feet. The Chinle Formation is unconformably (and possibly locally conformably) overlain by the Wingate Sandstone.

Gregory established the first stratigraphic subdivisions of the Chinle Formation, which were called divisions D, C, B, and A, from lowest to highest. As first defined, the Chinle Formation did not include the underlying Shinarump Conglomerate. In east-central and southeastern Utah and Arizona's Monument Valley, the Chinle Formation is presently divided into seven members. In ascending stratigraphic order, they are the Temple Mountain, Shinarump, Monitor Butte, Moss Back, Petrified Forest, Owl Rock, and Church Rock Members. Apparently there are no named member of the Chinle Formation recognized in Colorado. The entire formation ranges in thickness from approximately 1,500 feet in the Zuni Mountains of Arizona to about 800 feet near the Colorado and San Juan Rivers in southeastern Utah (Repenning et al., 1969). The unit becomes thinner in northwestern Colorado, where it is typically no more than a few hundred feet thick (Stewart et al., 1972). Typical lithologies of the Chinle Formation include variegated claystone, siltstone, sandstone, and conglomerate with minor amounts of limestone and limestone-pebble conglomerate (Stewart et al., 1959). The Temple Mountain Member is a thin unit that composed largely of siltstone and is restricted to the San Rafael Swell. The Shinarump and Moss Back Members consist of widespread beds of sandstone and conglomerate. The Monitor Butte and Petrified Forest Members are composed primarily of bentonitic claystone and clayey sandstone. The Monitor Butte Member contains lenticular sandstones. The Owl Rock and Church Rock Members are primarily composed of reddish siltstone, although the Owl Rock Member contains minor amounts of limestone (Stewart et al., 1959). At most localities, the Shinarump and Moss Back Members are lithologically distinctive. However, lithologic differences between the Monitor Butte, Petrified Forest, Owl Rock, and Church Rock Members are slight at most localities, and locally these members are difficult to differentiate because they intertongue and intergrade.

The Chinle Formation is predominantly fluvial in origin, with only minor amounts of lacustrine rocks. The lower strata of the unit were created by lake and stream deposits on floodplains. The Shinarump and Moss Back Members were likely point-bar deposits created by meandering streams. Detritus from the ancestral Rocky Mountains and the Uncompahgre and Front Range highlands in Colorado also contributed to the formation of the lower Chinle. The Chinle Formation's upper strata are interpreted to be mostly lacustrine. In southwestern Colorado, cross-stratified sandstone layers deposited in stream channels are abundant. This belt of sandstone in the upper Chinle, which also extends to central Utah, was also partially formed by the deposition of sediments from the Uncompahgre and Front Range highlands of western Colorado (Stewart et al., 1972).

The Chinle Formation has yielded a highly diverse late Triassic fossil fauna and flora, and a number of workers have noted the distribution and abundance of fossils within the unit. The most abundant fossils include fish, reptiles, amphibians, gastropods, arthropods, pelecypods, and a diverse assemblage of plants.

Fossil invertebrates are locally abundant but are not taxonomically diverse in the Chinle, including only one genus of brachiopod and one genus of bivalve (Ash, 2005). Fish fossils include at least 13 genera of sharks, palaeoniscids, semionotids, redfieldiids, colobontids, coelacanths, lungfish, and others (Ash, 1978; Parker, 2005; Schaeffer and Dunkle, 1950). Amphibian fossils include the temnospodyls *Buettneria, Apachesaurus,* and *Metoposaurus*. Reptile fossils include an unidentified procolophonid and a diverse assemblage of archosauromorphs, including *Trilophosaurus, Rutiodon, Phytosaurus, Desmatosuchus, Coelophysis,* and many others (Colbert, 1952, 1972: Long and Padian, 1986; Parker, 2005). Mammal-like reptile fossils include an unidentified cynodont. Vertebrate and invertebrate ichnofossils including trackways have also been reported. Parker (2005) thoroughly reviewed the Chinle fauna, pointing out that it includes 18 vertebrate holotypes. The flora of the Chinle is diverse, featuring horsetails, lycopods, quillworts, cycads, ginkgos, 11 genera of primitive ferns, 2 genera of seed ferns, 16 genera of conifers, at least 16 forms of pollen, and a number of unidentified taxa (Ash, 1972, 1978a,b,c, 2001, 2005). According to Parrish (1999), while diverse and abundant vertebrate faunas have been discovered in Arizona and New Mexico, far fewer vertebrate fossils have been recovered from the Chinle in Utah. Parrish (1999) suggests that this is true, at least in part, because the Chinle tends to outcrop as vertical exposures instead of badlands in Utah, and associated inaccessibility has made it more difficult to prospect in many areas. Camp (1930) reported that the lower part of the Chinle (in Arizona) contains abundant wood and vertebrate remains but fossils are uncommon in the upper part of the Chinle (divisions A and B). O'Sullivan (1970) reported that fossils have been found throughout the Chinle Formation in southeastern Utah, including the Owl Rock Member in the upper part of the formation. Repenning and colleagues (1969) noted that vertebrate remains have been found in most places in the Chinle Formation in northeastern Arizona but are most common in the Petrified Forest Member. Colbert (1952) remarked that, with the exception of isolated fish scales and teeth, almost all vertebrate fossils in the unit are from large animals, indicating a taphonomic bias against small animals. Foster and colleagues (2001) commented on the importance of the Chinle Formation because it contains some of North America's earliest dinosaurs. Small and Martz (2013) recently described a new genus and species of aetosaur (*Stenomyti huangae*) from the Chinle Formation based on fossils discovered on BLM land in the Eagle Basin, west of the RGFO Planning Area. The Chinle Formation is considered to have moderate paleontological (PFYC 3) potential in the RGFO Planning Area, but has very high potential (PFYC 5) elsewhere in the state.

6.2.21 Entrada Sandstone

The type section of the Middle Jurassic Entrada Sandstone is located at Entrada Point in the northern San Rafael Swell in Utah (Gilluly and Reeside, 1928). It is equivalent to the Sundance Formation in Colorado; overlies the Sangre de Cristo Formation in central Colorado; and outcrops in Arizona, New Mexico, Utah, and Colorado (Johnson, 1959). It is much more well developed and described in Utah and New Mexico. Four mapped members of the Entrada Sandstone lie in Colorado; in ascending stratigraphic order, they are the Dewey Bridge, Moab, Rehoboth, and Slick Rock Members. The Dewey Bridge Member consists of red silty sandstone that forms hoodoos. The Moab Member consists of white to gray, evenly bedded, fine-grained sandstone. The Rehoboth Member consists of red, silty sandstone that forms hoodoos. The Slick Rock Member consists of salmon-colored to pink, fine-grained, generally cross-bedded sandstone, with scattered grains of medium- to coarse-grained sand near the base of the unit (O'Sullivan, 2003). The Entrada Sandstone is eolian in origin.

The Entrada Sandstone has produced few body fossils but has yielded well-preserved fossil trackways, including those of theropod dinosaurs from the Twentymile Wash locality in southern Utah (Graversen et al., 2007); large vertebrate burrows from the Escalante Member in south-central Utah (Loope, 2006); and a variety of small to large theropod dinosaur tracks from near Escalante, UT (Milan and Loope, 2007). BLM Colorado Regional Paleontologist Harley Armstrong has documented dinosaur tracks in the Entrada in the Grand Junction CO area (H. Armstrong, personal communication, 2015). Although the Entrada

Sandstone contains few reported body fossils, the unit localities in Utah have produced scientifically important fossil trackways. In Colorado, the Entrada Sandstone is considered to have moderate paleontological potential (PFYC 3).

6.2.22 Sundance Formation

The Upper and Middle Jurassic Sundance Formation was first named by Darton (1899). Though Darton (1889) did not reference the origin of the name he used for this formation, it was likely named for the City of Sundance in Crook County, WY. Typical sections of this formation occur throughout the Black Hills in South Dakota (Darton, 1899). The Sundance lies unconformably above the Chugwater Group and below the Morrison Formation. Lithologically, it consists of two parts. The upper part is comprised of olive-gray calcareous shale; sandstone; and gray, glauconitic, oolitic limestone containing foraminifera and mollusks. The lower part is composed of soft, buff to salmon-pink sandstone. The total exposed thickness is reported to range from 0 to 200 feet (Snyder, 1980a, 1980b). This unit is mostly marine in origin, deposited in the Jurassic "Sundance Sea."

The Sundance Formation preserves locally abundant marine vertebrate and invertebrate fossils and well-preserved trackways. However, most reports of fossils from this unit come from Wyoming and South Dakota, and identifiable fossils from this unit in Colorado appear to be extremely rare. Notable Sundance Formation fossil occurrences in Wyoming and South Dakota include well-preserved fishes, multiple ichthyosaur taxa, plesiosaurs (including juveniles), sea stars, sea urchins, lobsters (Drake and Wahl, 1994; Schaeffer and Patterson, 1984), and pterosaur trackways (Logue, 1977). Discovered in 1997, the Red Gulch Dinosaur tracksite near Shell, WY, preserves more than 1,000 dinosaur tracks in shoreline facies of the Sundance Formation. Although the unit is sparsely fossiliferous in Colorado, any new fossil discoveries would be highly significant. Therefore, the Sundance is considered to have moderate paleontological potential (PFYC 3).

6.2.23 Curtis Formation

The Curtis Formation is a shallow Late Jurassic marine deposit that formed during a major expansion of an epeiric sea into the western interior of the United States (Hoggan, 1970). The formation was originally described by James Gilluly and J.B. Reeside, Jr., in 1928 based on the type locality at Curtis Point, Emery County, UT, in the Paradox Basin (Gilluly and Reeside, 1928). Geographically the unit is restricted to Colorado and Utah, overlies the Entrada Sandstone within the San Rafael Group, and underlies and lies lateral to the Summerville Formation. The light-greenish-gray color of the Curtis Formation, caused by the presence of glauconite, distinguishes the unit from stratigraphically related strata. The formation ranges between 76 to 252 feet thick and consists of an upper member and a lower member . The lower member typically contains 3 to 20 feet of conglomerate consisting of well-rounded pebbles of chert and flint in a grainy matrix (Lee, 1927). The majority of the formation consists of a fine sandstone that sometimes contains green shale pellets. The upper member of the formation contains flaky, laminated shale (Lee, 1927).

Fossils of the Curtis Formation are predominantly marine invertebrates, including Naticacean gastropods, crinoid ossicles, echinoid spines, holothuroids, and foraminifera, as well as brachiopods, bivalves, cephalopods, worms, arthropods, echinoderms, and ammonites (Hoggan, 1970). Some of the species commonly found include *Kallirhynchia myrina*, *Cidaris* sp., *Pentacrinus asteriscus*, *Eumicrotis eurta*, *Ostrea stingilecula*, *Camptonectes stygius*, and *Tancredia inornata*. This same fossil assemblage also exists in the Sundance Formation of Wyoming (Lee, 1927). A single vertebrate fossil—a jaw bone fragment that has not been identified—is known from the Curtis Formation (Hoggan, 1970). Ichnofossils are also prevalent throughout the formation and are mostly represented by burrows and trails of small marine invertebrates. Most fossils in the unit are preserved as glauconitized molds and casts, though the brachiopods, with preserved calcium carbonate shells, are relatively unaltered. The Curtis Formation is thought to have originated as a basal conglomerate that formed as the epieric seaway transgressed onto land. The upper member was deposited in a shallow, infralittoral environment as the sea regressed (Hoggan, 1970). The Curtis Formation has a moderate paleontological potential (PFYC 3).

6.2.24 Summerville Formation

The Summerville Formation is the youngest formation of the San Rafael Group of Colorado and is late Middle Jurassic in age (Peterson, 1988). Gilluly and Reeside (1928) named the formation after its type section, which is located at Summerville Point near the head of Summerville Wash in Emery County, UT. The unit unconformably underlies the Morrison Formation, conformably overlies the Curtis Formation at the type section, and unconformably overlies the Entrada Sandstone (Gilluly and Reeside, 1928) and Todilto Limestone elsewhere (Harshbarger et al., 1957; Anderson and Lucas, 1992). The Summerville Formation has been mapped in the Paradox Basin of southwestern Colorado, southeastern Utah, northwestern New Mexico, and northeastern Arizona. However, the geographic distribution, nomenclature, and stratigraphic equivalents of the Summerville are subjects of debate within the geologic community (O'Sullivan, 2010; Condon and Peterson, 1986; Codon and Huffman, 1988; Anderson and Lucas, 1992; Lucas and Heckert, 2003). Some geologists have assigned the Summerville to the Wanakah Formation or Wanakah Member of the Morrison Formation (O'Sullivan, 2010; Condon and Peterson, 1986; Condon and Huffman, 1988). Codon and Peterson (1986) advised that the usage of the Summerville Formation be discontinued in Colorado and Utah and replaced with Wanakah Formation, with the exception of rocks in the San Rafael Swell area of Emery County, UT. This recommendation was based on work completed by R.B. O'Sullivan in the early 1980s, which reported that the Summerville Formation was truncated by faulting (as cited in Condon and Huffman, 1988). In 1988, Codon and Huffman expanded the revision to strata assigned to the Summerville Formation in New Mexico and Arizona (Condon and Huffman, 1988). These revisions were rejected by researchers, including Anderson and Lucas (1992) and Lucas and Heckert (2003). Strata of the Summerville Formation have been correlated with the Ramana Sandstone of the Kaiparowits Basin (Peterson, 1988).

The thickness of the Summerville Formation is 163 feet at the type locality, with a maximum thickness of 331 feet (Gilluly and Reeside, 1928) and a minimum thickness of 4 to 5 feet (O'Sullivan, 1980, as cited in Anderson and Lucas, 1992). Gilluly and Reeside (1928) described the type Summerville as thin alternating beds of chocolate-brown gypsiferous mudstone and laminated sandstone with minor red clay at the base and visible ripple marks. The formation comprises two informal members. Harshbarger and colleagues (1957) describes the composition of the lower member as grayish-orange-pink to moderate-reddish-brown, fine-grained, poorly sorted, calcareous silty sandstone and mudstone (member present at the type Summerville section) and the composition of the upper member as moderate-reddish-brown, fine-grained, well-sorted quartz sandstone. Peterson (1988) describes these units as the chocolate lower member and brick-red upper member. Gilluly and Reeside (1928) postulated that the Summerville Formation was deposited in a calm, shallow marine environment. Further examinations of the formation suggest that the chocolate-brown member is a shallow, hypersaline marine deposit and the brick-red member is an overbank mudflat deposit (Peterson, 1988). The paleoenvironment is interpreted as a widespread, low-lying coastal plain with lagoonal deposits adjacent to a seaway that encroached into eastern Utah and western Colorado during the end of the middle Jurassic and beginning of the late Jurassic (Lockley and Hunt, 1999).

No vertebrate body fossils have been reported from the Summerville Formation of Colorado; however, dinosaur fossils have been recovered from the formation in Utah and New Mexico, including fossils attributed to the sauropod *Camarasaurus* sp. and a scapula, ulna, partial radius, and partial manus belonging to the sauropod *Dystrophaeus viaemalae* (Weishampel et al., 2004). It has produced trackways in Utah, New Mexico, and Colorado, including the purported pterosaur *Pteraichnus* trackway (Mickelsen et al., 2004) and dinosaur trackways (Lucas and Heckert, 2000; Weishampel et al., 2004). The formation has also produced marine invertebrate fossils in Utah, and gastropods have been documented at Colorado National Monument (H. Armstrong, personal communication, 2015). Because the Summerville Formation produces scientifically important fossils elsewhere and has the potential to produce scientifically significant fossils in Colorado, the unit is considered to have moderate paleontological potential (PFYC 3).

6.2.25 Ralston Creek Formation

The Ralston Creek Formation was formed during the Late Jurassic epoch. Microfossil studies indicate that the Formation is primarily Kimmeridgian in age but is possibly latest Oxfordian at its base (Peterson and Turner, 1998). The type locality is west of Denver, CO, between Ralston Reservoir and Weaver Gulch on the south side of Ralston Creek and was recorded from a composite of two exposures. Specifically, it is located on the NW ¼ of the SW ¼ of Section 5, Township 3 South, Range 70 West, on the Ralston Buttes Quadrangle in Jefferson County, CO (LeRoy, 1946; Van Horn, 1957; Peterson and Turner, 1998). The unit was first described by L.W. LeRoy in 1946 and was given the name “Ralston Formation”; however, in 1957, Richard Van Horn changed the name to “Ralston Creek Formation,” as the previous name was preoccupied (Van Horn, 1957; Peterson and Turner, 1998). In most areas, the Ralston Creek Formation is correlative with the Late Jurassic Morrison Formation. Middle Jurassic beds have been incorrectly assigned to the Ralston Creek Formation in some areas of Colorado, especially in the vicinity of Cañon City. However, the Ralston Creek Formation is recognized only in the Front Range foothills area of east-central Colorado, where it conformably underlies and interfingers with the Morrison Formation (Peterson and Turner, 1998; Turner and Peterson, 2004) and unconformably overlies the Permian to Triassic Lykins Formation (LeRoy, 1946; Carpenter, 1979).

The average thickness of the Ralston Creek Formation is 110.5 feet, with a maximum measured thickness of 138 feet and a minimum of 25 feet. Peterson and Turner (1998) described four units at the type locality: Bed A, Red Unit, Yellow Unit, and Upper Unit. Bed A is the base of the formation and is composed of thinly bedded, fine-grained sandstone with scattered coarser grains and pebbles. The Red Unit is comprised of a dark dull-red to grayish-red mudstone. The Yellow Unit includes interbedded grayish-yellow or gray mudstone with occasional red or calcareous mudstone and limestone beds. The Upper Unit is composed of variegated mudstone with a few thin beds of light-gray limestone and more rare sandstone beds (Peterson and Turner, 1998). LeRoy (1946) recognized two facies of the formation: a shale-marlstone facies consisting of gray to dull-red shale, sandy gray marlstone, and calcareous yellow sandstone at the type locality and a gypsiferous facies composed of gypsum and thin layers of gypsiferous silt south of Morrison (LeRoy, 1946; Peterson and Turner, 1998). The mudstone facies was deposited in lacustrine and mud flat environments. The sandstone deposits at the top of the formation represent overbank floodplain deposits of stream channels. The gypsum-rich facies was in an evaporate basin that was likely a hypersaline marine embayment (Peterson and Turner, 1998).

No vertebrate and few invertebrate and plant fossils have been recovered from the Ralston Creek Formation. Collected specimens include the freshwater gastropods *Gyraulus veternus* and *Lymnaea morrisonensis* and algae identified as *Echinochura spinosa* and *Aclistochara* (Fischer, 1981; O’Sullivan, 1992) recovered from the limestone beds in the upper portion of the Formation (Scott, 1963). The Ralston Creek Formation contains a low-diversity assemblage of fossil invertebrates and plants, and the discovery of any vertebrate fossils verifiably in the Ralston Creek Formation rather than the lower Morrison Formation would be scientifically important. The Ralston Creek is considered to have moderate paleontological potential (PFYC 3).

6.2.26 Morrison Formation

The Upper Jurassic Morrison Formation was named by G.H. Eldridge in 1896 after its type locality in the town of Morrison, Jefferson County, CO. The unit is widely distributed throughout the Rocky

Mountain Region, and in eastern Colorado it is mostly exposed in the Cañon City Basin and the Front Range Uplift. In Colorado, the Morrison Formation has been locally subdivided into the Brushy Basin, Westwater Canyon, Recapture Creek, Salt Wash, and Bluff Sandstone Members. Emmons and colleagues (1896) describe the Morrison Formation as averaging about 200 feet thick in the Denver area and along the eastern base of the Rockies. Lithologically, the Morrison Formation is predominantly composed of variegated red, green, and gray mudstone and claystone, with secondary tan sandstone and gray limestone (Braddock et al., 1988a, 1988b; Bryant et al., 1981). Sediments of the Morrison Formation were deposited following the fourth and last Jurassic marine transgression (Dodson et al., 1980). The Morrison largely consists of cross-laminated sandstone and conglomeratic sandstone lenses laid down in a fluvial environment as well as claystone and horizontally bedded sandstone deposited in a floodplain environment (Craig et al., 1955). Fossil evidence (see below) also suggests that parts of the Morrison were deposited in a semi-arid environment (Dodson et al., 1980).

The Morrison Formation is famous for being one of the world's richest sources of dinosaur fossils. The geology and paleontology of the Morrison Formation have been extensively studied (Armstrong and Kihm, 1980; Armstrong and McReynolds, 1987; Bilbey, 1992; Carpenter, 1979; Dodson et al., 1980, Peterson, 1988; Tidwell, 1990; and others). Historically important fossil localities within the Morrison Formation are numerous and include Como Bluff in Wyoming, Dinosaur National Monument in Utah, and localities near Morrison (the type locality of the Morrison Formation) and Cañon City, CO, among others (Figure 10). Dinosaur bones, teeth, footprints, and fragments of fossilized wood are perhaps the most common and well-known fossils in the Morrison Formation. Some of the most common dinosaurs include *Camarasaurus, Apatosaurus, Diplodocus, Allosaurus, Stegosaurus,* and *Camptosaurus* (Dodson et al., 1980). The Purgatoire Valley dinosaur tracksite in southeastern Colorado is one of the largest and most famous dinosaur tracksites in the world and preserves hundreds of theropod and sauropod footprints (Schumacher and Lockley, 2014). Last Chance Quarry is another fossil locality in the Purgatoire River valley of southeastern Colorado where partial skeletons and scattered elements of several sauropods, including *Camarasaurus* and *Apatosaurus*, have been discovered (Schumacher, 2008). In addition, an extremely diverse assemblage of fish, non-avian archosaurs including pterosaurs (Jensen and Ostrom, 1977), crocodiles, squamates (Evans and Chure, 1998), mammals, plants, and trace fossils have also been documented. In Temple Canyon Park near Cañon City, the Morrison has produced a flora consisting of algae, bryophytes (*Marchantiolites* and *Thallites*), horsetails (*Equisetum*), ferns (*Gleichenites*), cycads (*Nilssonia*), ginkgophytes (*Baiera*), bennettites, and conifers (Cupressaceae and Araucariaceae). The Morrison Formation in this area has also preserved a fossil fauna of vertebrates and invertebrates that includes fish, gastropods, turtles, insects, and a possible amphibian (Gorman et al., 2008). An artist's rendition of the Denver-area landscape during deposition of the Morrison Formation is depicted in Figure 11.

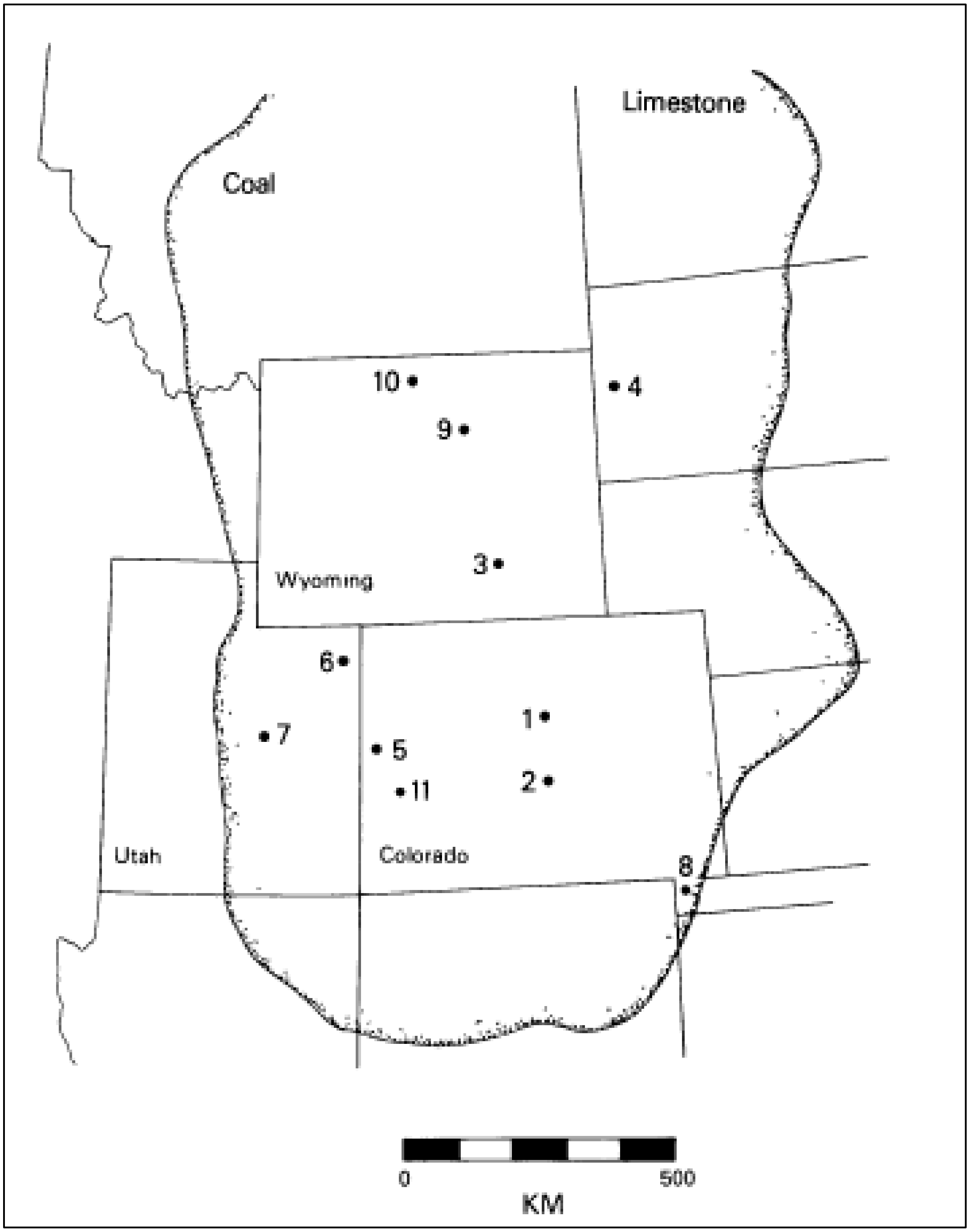

FIGURE 10. Distribution of the Morrison Formation and its principal fossil localities (from Dodson et al., 1980; Figure 1).

FIGURE 11. Artist's rendition of the Denver area during deposition of the Morrison Formation, titled Long Neck Meadow (courtesy of the DMNS and Jan Vriesen).

The Morrison Formation is taphonomically unique in comparison with other formations in that is has many localities over a wide geographic distribution that contain very dense accumulations of dinosaur bones. The unit also is unusual in that most of the dinosaur assemblages it contains include few articulated specimens, making associating skulls with skeletons difficult. In contrast, it is typical in the overlying Cretaceous formations to find isolated, highly articulated specimens, which indicate that before burial, dinosaurs in the Morrison Formation were disarticulated and scattered to a much greater extent after death. Paleoenvironmental conditions of the Morrison have been interpreted based on these taphonomic patterns, which indicate that that most dinosaurs in this formation likely decomposed on land in dry, open areas or channel deposits where they could be altered before burial (Dodson et al., 1980). Due to the abundance and scientific significance of the fossils from the Morrison, it is considered to have a very high paleontological potential (PFYC 5).

6.2.27 Burro Canyon Formation

The Burro Canyon Formation is Lower Cretaceous in age. Specifically, palynomorphs of two shale units in the upper part of the Burro Canyon are Aptian to early Albian in age and may even be late Barremian in age (Tschudy et al., 1984). The type locality is located in Burro Canyon, for which it is named, in San Miguel County, CO, where it was first described by W.L. Stokes and D.A. Phoenix (Stokes and Phoenix, 1948). The formation is stratigraphically equivalent with the Cedar Mountain Formation of Utah, with the Colorado Serving as the informal geographic boundary between the two units (Jim Kirkland, personal communication, 2012). The Burro Canyon is recognized in southeastern Utah, western Colorado, and northern New Mexico (Tschudy et al., 1984). The Karla Kay Conglomerate Member is the basal conglomerate of the formation and is recognized in Colorado (Ekren and Houser, 1959).

The Burro Canyon Formation ranges in thickness from 150 to 260 feet and consists of alternating beds of gray, yellow, brown, and green conglomerate, sandstone, and mudstone and varicolored beds of shale, limestone, and chert. The lower contact is defined as the base of the lowest resistant light-colored conglomeratic sandstone above the Brushy Basin Member of the Morrison Formation. The Burro Canyon is distinguished from the Brushy Basin by the presence of coarse, generally conglomeratic sandstone beds and interbedded dominantly greenish-gray mudstone beds composed of non-swelling clay, whereas the Brushy Basin has few conglomeratic sandstone beds, contains swelling clays, and forms distinct color-banded outcrops. The upper contact is defined as above the highest varicolored beds and green mudstone beds and below the carbonaceous organic-rich shale, lignite or coal beds, and distinctive sandstone beds of the Dakota Formation (Tschudy et al., 1984). The underlying contact with the Brushy Basin Member is conformable, and the two units intertongue (Aubrey, 1992), while the upper contact with the Dakota Sandstone is unconformable (Ekren and Houser, 1959). Sprinkel and colleagues (2012) reported that the lower contact of the Cedar Mountain Formation in Utah is unconformable with the underlying Morrison Formation. Though most workers agree that the Burro Canyon and Cedar Mountain Formations are physically continuous with one another, palynomorphs suggest that the upper part of the Burro Canyon is older than the upper part of the Cedar Mountain and that a portion of the former may have been eroded (Tschudy et al., 1984). Coarse sand and conglomerate of the Burro Canyon Formation are interpreted as being deposited in a braided-river system, with mudstone beds representing floodplain deposits (Cole, 2014).

Fossils of the Burro Canyon Formation (and homotaxial Cedar Mountain Formation) include freshwater ostracods, bivalves and gastropods, plant microfossils and macrofossils, and fish scales, but identifiable fossils are generally sparse (Aubrey, 1992; Tschudy et al., 1984). Sparse fossil bivalves and conifer fossils have been used to correlate between the Burro Canyon and Cedar Mountain Formations (Simmons, 1957). Land vertebrates, once considered rare in the Cedar Mountain Formation, now include a diverse reptile (including dinosaur) and mammal assemblage, including a steadily increasing number of taxa new to science (Jim Kirkland, personal communication, 2012) represented by skeletal and dental remains, eggshell, and tracks (Eaton, 1988; Kirkland et al., 1999; Lockley, 1992). Fewer land vertebrates are known from the Burro Canyon Formation. It is thought that if and when paleontologists focus on this unit with the same level of dedication with which the Cedar Mountain Formation has been investigated over the past two decades, the Burro Canyon Formation will yield additional scientifically important fossils. Therefore, it has high paleontological potential (PFYC 4).

6.2.28 Dakota Group

The Late Cretaceous Dakota Group, or Dakota Sandstone, was originally named by Meek and Hayden (1862) for the town of Dakota, NE, where the group is well exposed and extensive. The type locality of the Dakota Group is 2 miles north of Bellevue in Larimer County, CO (Lee, 1923). The Dakota Group outcrops throughout the Rocky Mountain Region and much of the Southwest and comprises more than 20 formations. In Colorado, two formations with exposures are in the RGFO Planning Area: the South Platte Formation and underlying Lytle Formation (Figure 12). In the Denver West quadrangle in north-central Colorado, the South Platte Formation is approximately 220 feet thick and consists of two or three yellowish-gray, well-sorted, cross-stratified, porous, fine- to medium-grained quartz sandstone sequences separated by dark-gray, silty, hard, locally carbonaceous shale interbedded with thin quartz sandstone beds and clay beds. The Lytle Formation is about 79 feet thick and consists of yellowish-gray, medium- to fine-grained sandstone and conglomerate that is locally iron-stained. The conglomerate is generally near the base of the unit (Kellogg et al., 2008).

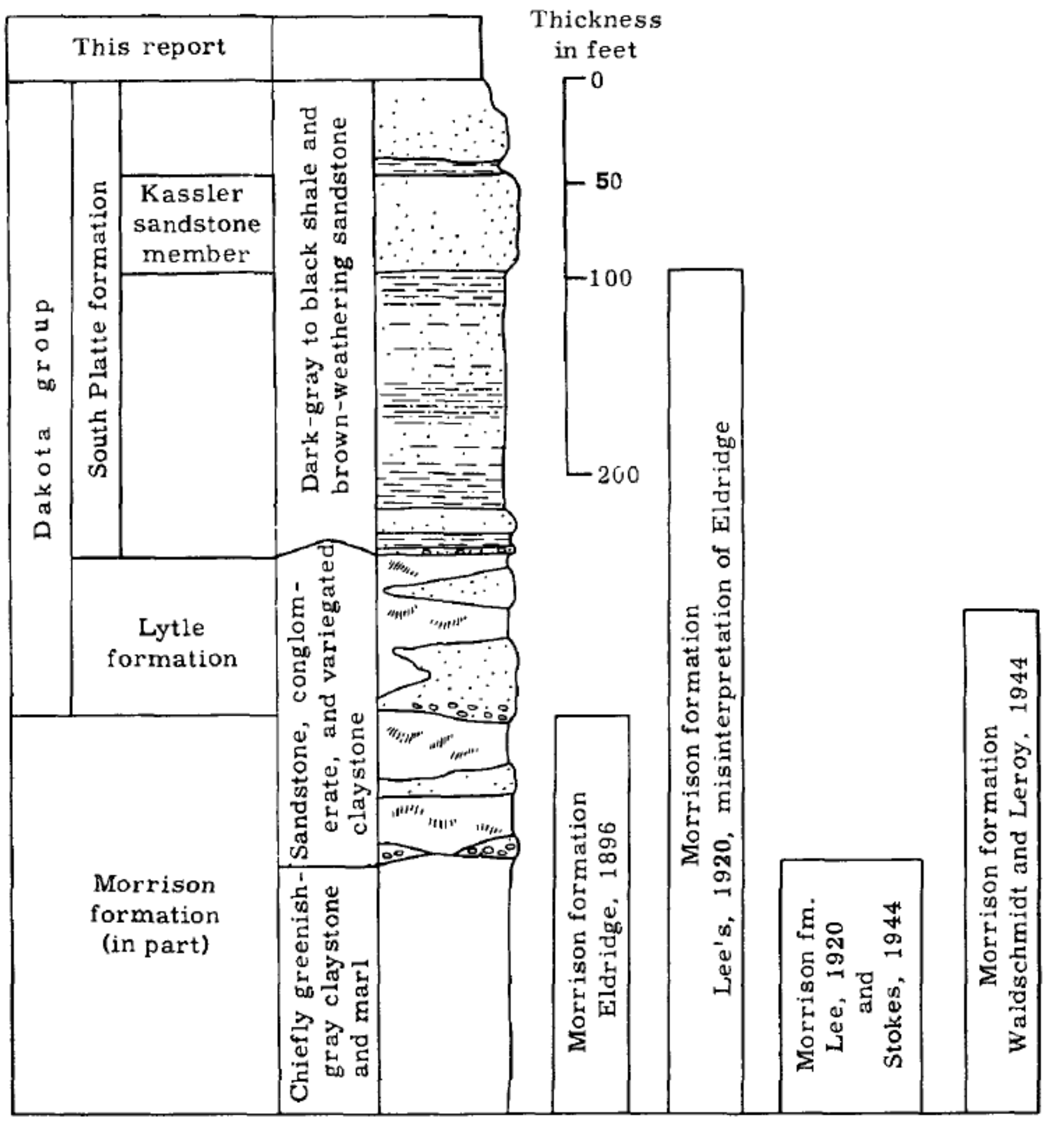

FIGURE 12. Several interpretations of the contact between the Morrison Formation and the Dakota Group in the Denver area (from Waage, 1955, Figure 7).

The Dakota Group was deposited during the first major transgression of the Cretaceous Interior Seaway in beach, estuarine, and other proximal shoreline depositional environments. An artist's rendition of the Denver-area landscape during deposition of the Dakota Group is depicted in Figure 13. The group is well known for its fossil footprints and other trace fossils and also contains scattered bones and locally well-preserved plant remains. Dinosaur track sites from near the top of the Dakota Group have been reported from numerous localities in Colorado (Lockley, 1987). Waage (1955) cited plesiosaur vertebrae in the Dakota Group in northern Colorado, and Dakota Sandstone fossils have been the subject of numerous paleontologic studies (Chamberlain, 1976; Elliot and Nations, 1998; Lockley, 1987, 1990, 1992; Mehl, 1931; Snow, 1887; Rushforth, 1971; Waage and Eicher, 1960; Young, 1960). In 1878, a partial dinosaur skull was discovered in the Lytle Formation in the Garden of the Gods area near Colorado Springs. This specimen was later identified as a new genus and species of iguanodont dinosaur, *Theiophytalia kerri*, and was formally described by Brill and Carpenter (2006). The Dakota Group has a high paleontological potential (PFYC 3). The constituent formations of the Dakota Group in Colorado's Front Range are discussed individually in the following subsections.

FIGURE 13. Artist's rendition of the Denver area during deposition of the Dakota Group, titled Colorado's East Coast (courtesy of the DMNS and Jan Vriesen).

6.2.28.1 Lytle Formation

The Lower Cretaceous Lytle Formation, or Lytle Sandstone, is the lowest (oldest) unit of the Dakota Group. The formation was first described by G.I. Finaly in 1914 and named after Lytle, CO, in the valley of Turkey Creek. The unit occurs in Colorado, New Mexico, and Oklahoma and is continuously exposed from Folsom, NM, to north of Boise City, OK. In the Dry Cimarron Valley, the Lytle is no more than 65 feet thick and averages about 33 feet thick (Kues and Lucas, 1987). The Lytle Formation is composed of grayish-pink, pale-red, and pale-olive sandstone, conglomerate, and variegated claystone. At some localities, the unit disconformably overlies the Morrison Formation (Waage, 1955) and underlies the South Platte Formation (Waage, 1955; Scott, 1963). The sandstone beds are quartzose and usually fine grained and exhibit planar crossbeds (Kues and Lucas, 1987). The Lytle Formation was deposited in a near-shore marine environment and represents deposition on a beach (Scott, 1963).

Kues and Lucas (1987) reported predominant clasts with occasional fragments of petrified wood and indeterminate burrows in the Lytle Formation. The unit is considered to have moderate paleontological potential (PFYC 3).

6.2.28.2 South Platte Formation

The type section of the Early Cretaceous South Platte Formation is located 0.5 mile north of Kassler, CO, in the NE ¼ of the NW ¼ of Section 27, Township 6 South, Range 69 West (Waage, 1955). The unit overlies the Lytle Formation and underlies the Graneros Shale (called Benton Shale in Figure 14). Stratigraphic equivalents in southern Colorado include the Glencairn, Dry Creek, and Kiowa Shale Members of the Dakota Sandstone (formation level) and the Newcastle, Skull Creek, Fall River, Thermopolis Shale, and Cloverly Formations (in part) in Wyoming (Figure 15) (Waage, 1961). The South Platte Formation is present in the Northern Front Range of Colorado. Three named members of the unit are in the Front Range: the Van Bibber Shale, Kassler Sandstone, and Plainview Sandstone Members

(Waage, 1955). In the Front Range of Colorado, the unit consists of 200 to 350 feet of beds of gray to black shale alternating with brown, fine-grained sandstone (Waage, 1961). Both marine and non-marine deposits lie within this formation, which was deposited in a deltaic setting (MacMillan, 1974).

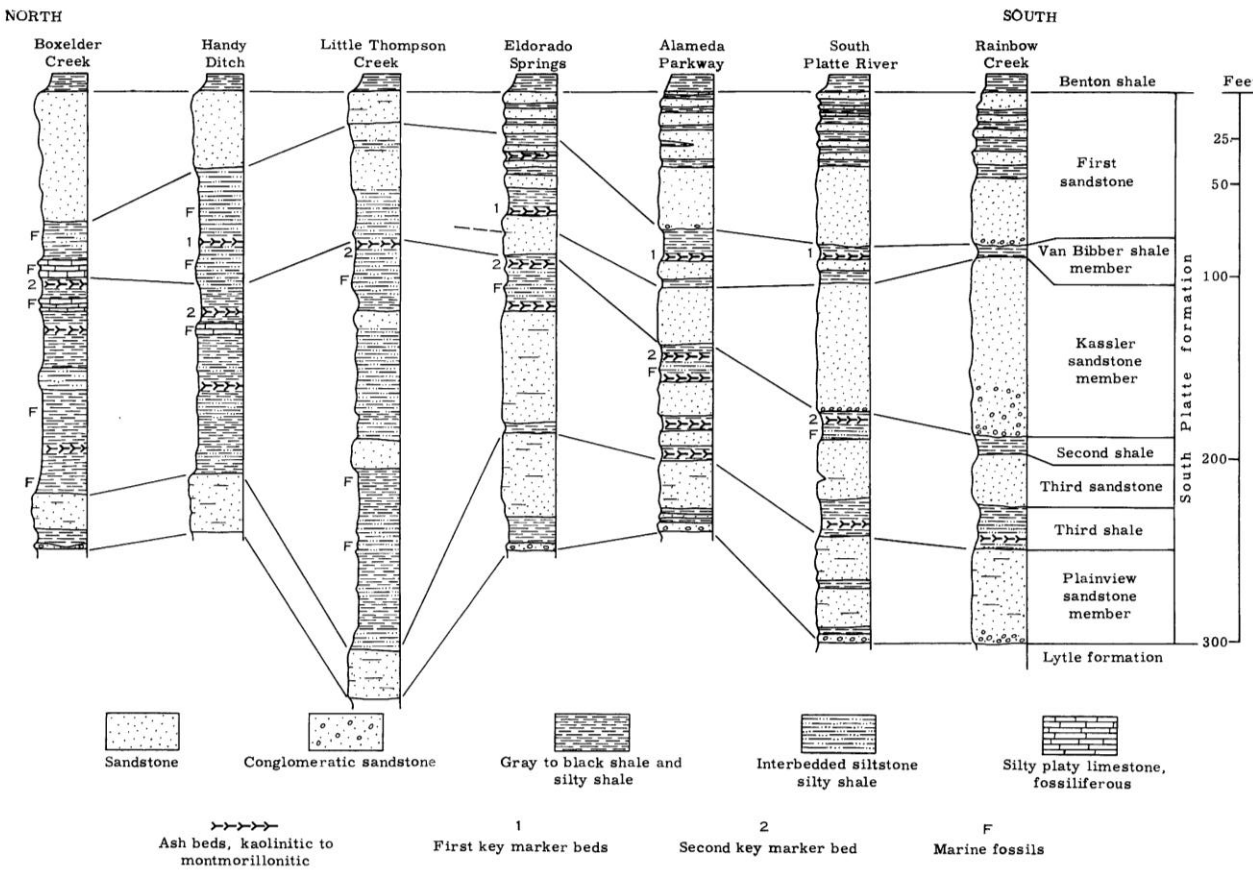

FIGURE 14. Lateral changes in the South Platte Formation (called Benton Shale in this diagram) along the northern Front Range Foothills (from Waage, 1955; Figure 17).

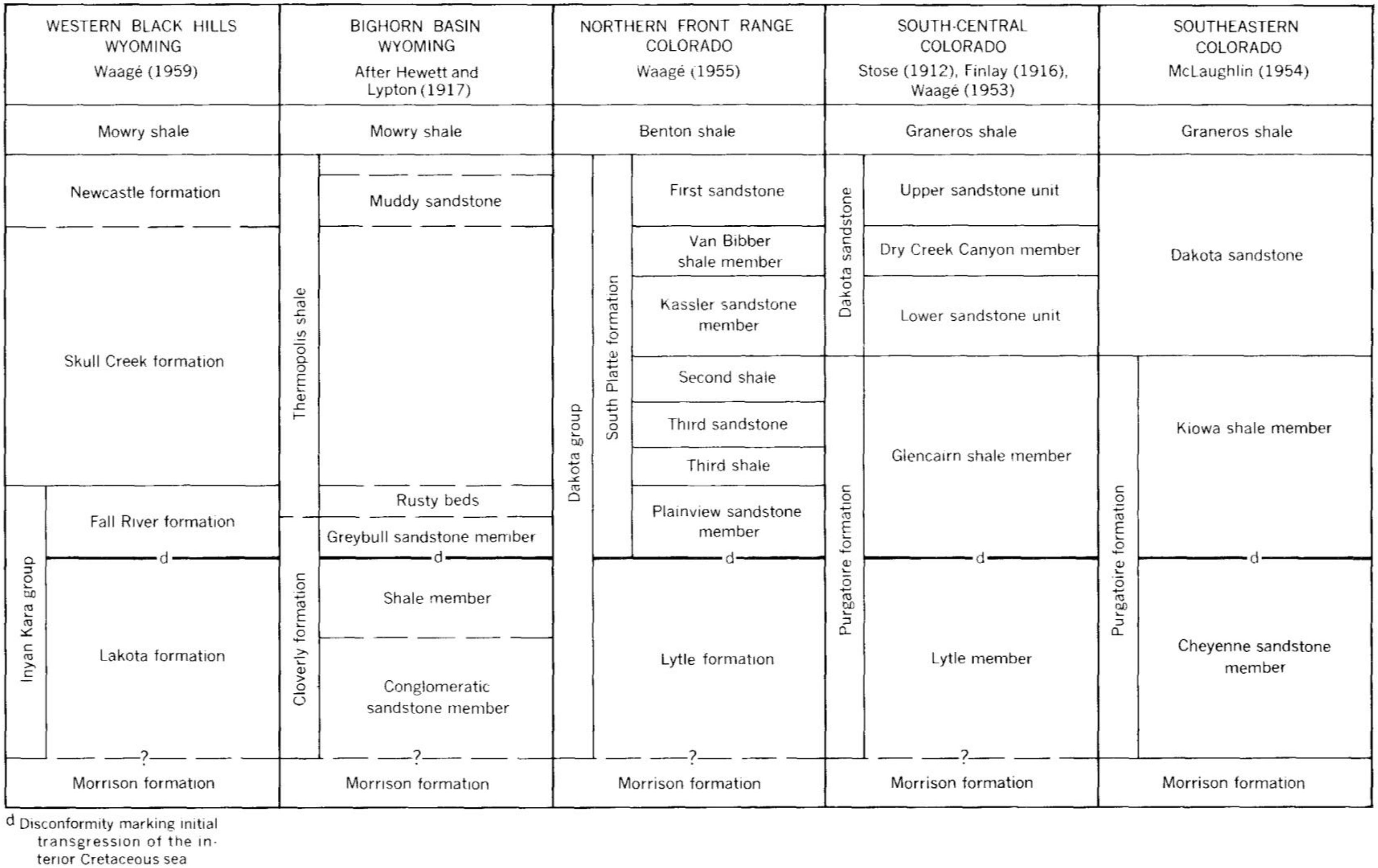

FIGURE 15. Nomenclature and probable equivalency of outcropping pre-Benton Cretaceous strata in eastern Colorado and adjacent areas (from Waage, 1961, Figure 2).

The South Platte Formation contains a diverse fossil assemblage dominated by marine invertebrates that are very abundant toward the top of the unit and predominantly found in platey siltstone and silty limestone beds. Mollusks are the most common fossil and provide important data about the age of the formation. The important stratigraphic taxa include the bivalves *Inoceramus comancheanus*, *I. bellvuensis*, *Pteria salinensis*, *Ostrea larimerensis*, *O. noctuensis* and *Anchura kiowana*, which indicate a late Albian age (Waage, 1955). Other invertebrates found within this formation include poorly preserved linguloid brachiopods from the Plainview Member and unidentifiable ammonite remains from the uppermost sandstone bed. Fossil plants are also common within the South Platte Formation and are mostly restricted to the non-marine units of the Kassler Member. Vertebrate fossils are also known from the South Platte Formation but are poorly preserved and uncommon. These include ankylosaur trackways, fish, and a plesiosaur vertebrae (Waage, 1955). This unit is considered to have moderate paleontological potential (PFYC 3).

6.2.29 Colorado Group

The Late Cretaceous Colorado Group was named for exposures along the Front Range in Colorado (Hayden, 1876) and is equivalent to the Benton Group, in part. The group is predominantly well developed in the Western Canada Sedimentary Basin, where it is often referred to as the Alberta Group. From there, the group extends south through Montana and Wyoming with limited exposures in Colorado. The stratigraphic nomenclature associated with this widely distributed Upper Cretaceous unit, its various formations/members, and their stratigraphic equivalents is complex. The Graneros Shale, Greenhorn Limestone and Carlile Shale, listed in ascending stratigraphic order, comprise the Colorado Group (Carroll and Crawford, 2000). The dominant lithology of the Colorado Group is shale with minor amounts of thinly bedded sandstone and conglomerate. The group is up to 300 feet thick in Colorado (Courtright and Braddock, 1989). It was deposited in the Western Interior Seaway and represents deposition on a marine slope with some proximal pro-delta and shelf environments (Leckie et al., 1994).

As discussed in the following subsections, the formations that comprise the Colorado Group are locally very fossiliferous and stratigraphically restricted. Some of the common fossils in the group include ammonites, foraminifera, bivalves, gastropods, and fish (Leckie et al., 1994; Reeside, 1923). Ammonites and foraminifera provide significant biostratigraphic data for the whole of the Colorado Group and constrain its age to Albian to Santonian in the Western Canada Sedimentary Basin and Cenomian to Coniacian in Colorado (Leckie et al., 1994; Cobban, 1951). Details about the specific lithologies, depositional environments, and fossil descriptions for individual formations are described in the following subsections. As a whole, the Colorado Group is considered to have moderate paleontological potential (PFYC 3).

6.2.29.1 Graneros Shale

The Graneros Shale, or Graneros Formation, is a Late Cretaceous (Cenomanian) unit named after Graneros Creek in Pueblo County, CO (Gilbert, 1896). The formation has a wide geographic distribution throughout the Southwest and Northern Plains, and in Colorado it outcrops in the southeastern region of the state. In Pueblo, the Graneros Shale is representative of most of the formation throughout the Front Range in southern Colorado. The unit overlies the Dakota Group and measures 200 to 210 feet thick at its type locality. There it is divided into three members: the lower shale member, the middle Thatcher Limestone Member, and the upper shale member. The typical lithology of the Graneros is dark-gray, silty, well-laminated clay shale. The Graneros was deposited in a marine environment during the first major transgression of the Western Interior Seaway during the Late Cretaceous (Kauffman, 1988).

Marine invertebrates are the most common fossils of the Graneros Shale and are mostly represented by foraminifera and mollusks, although palynomorphs are also present (Cobban and Merewether, 1983; Cobban and Scott, 1972). Marine vertebrates, though less common, have also been reported from this formation and include several different taxa of chondrichthyan fishes (e.g. *Meristodonoides*) and osteichthyan fishes, turtles, and a plesiosaur (Jansen et al., 2012; Maglei et al. 2013). The Graneros is considered to have moderate paleontological potential (PFYC 3).

6.2.29.2 Greenhorn Limestone

The Greenhorn Limestone, or Greenhorn Formation, was originally named by Gilbert (1896) after Greenhorn Station in Pueblo, CO. This formation lies disconformably above the Graneros Shale and below the Carlile Shale. In Colorado it is divided (in ascending stratigraphic order) into three members: the Lincoln Limestone, the Hartland Shale, and the Bridge Creek Limestone. The Lincoln Limestone is 16 feet thick, the Hartland Shale is 62 feet thick, and the Bridge Creek Limestone is 43 feet thick. The lithology of the lower members is dominated by calcareous shale interbedded with thin calcarentite beds, and the upper member mostly consists of chalky limestone interbedded with chalky shale and shaly chalk (Schumacher, 2012). The formation was deposited during the maximum transgressive phase of the Western Interior Seaway, when eastern Colorado was at the sea's deepest depth (Shimada et al., 2006).

The Greenhorn Limestone preserves a rich and diverse fauna of marine vertebrates and invertebrates. The lower Lincoln Limestone Member yields numerous vertebrate taxa primarily represented by chondrichthyan fish but also includes osteichthyan fish and marine reptiles. Teeth from the extinct sharks *Cretoxyrhina*, *Squalicorax*, and *Ptychodus* are commonly found along the surface of exposures of the Lincoln Limestone. The Greenhorn also preserves the first known North American occurrences of many chondrichthyan taxa, including *Squalicorax falcatus*, *Protosphyraena* sp., *Xiphactinus audax*, *Pachyrhizodus* sp., and *Coniasaurus crassidens*. Invertebrates found in this formation mostly include inoceramid bivalves and foraminifera (Shimada et al., 2006).

The Greenhorn Limestone and other deposits from the Cenomanian are significant because they document a major transition in the history of carnivorous marine vertebrates marked by the disappearance of ichthyosaurs and the first appearance of mosasauroids (Shimada et al., 2006). The rare discovery of rudist bivalves in the Greenhorn of southeastern Colorado is also significant, as it indicates the beginning of an episode of global warming during the Middle Cretaceous (Schumacher, 2012). Because fossil vertebrates are less common in the Greenhorn Limestone in Colorado then elsewhere, the formation is considered to have moderate paleontological potential (PFYC 3).

6.2.29.3 Carlile Shale

The Carlile Shale, or Carlile Formation, is a Late Cretaceous (Turonian) unit named after Carlile Spring and Carlile Station near Pueblo in eastern Colorado (Gilbert, 1896). This formation has a broad geographic distribution, appearing as far east as Kansas and extending throughout the Southwest and north to Montana and Minnesota. In Colorado, the Carlile is divided into four members: the Blue Hill Member, the Codell Sandstone, the Fairport Chalky Shale or Fairport Member, and the Juana Lopez Member. In the Colorado counties of Fremont and Pueblo, the Blue Hill Member is 98.0 feet thick, the Codell is 6.6 to 30.8 feet thick, and the Juana Lopez is 13.0 to 49.0 inches thick. The Carlile Shale is primarily composed of dark-gray shale interbedded with thin beds of dark brown sandstone, yellowish-brown siltstone, and gray limestone. This formation was deposited in a marine environment formed by the Western Interior Seaway during the Late Cretaceous (Pinel, 1983).

Fossils are locally common and diverse in the Carlile. They include trace fossils, fossil wood and plant debris, foraminifera, barnacles, brachiopods, bivalves, gastropods, ammonites, radiolarians, fish scales, other fish remains including those of sharks, and marine reptiles including plesiosaurs and ichthyosaurs (Cobban and Kennedy, 1989; Cicimurri, 2001; Hanson and Connely, 2006; Knechtel and Patterson, 1962; Massare and Dain, 1989; Merewether, 1996; Romer, 1968; Stewart et al., 1994; Stewart and Hakel, 2006; Yacobucci, 2004). Foraminifera and palynomorphs are also abundant and diverse in this formation

(Courtinat, 1993; Fox, 1954; Merewether, 1996; Okumura, 1994). The uppermost Codell Sandstone Member of the Carlile Shale has produced burrows and feeding trails of marine invertebrates and sharks teeth (Milito, 2008). Although fossil invertebrates are locally abundant in the Carlile Shale in Colorado, fossil vertebrates are uncommon, and the formation is therefore considered to have moderate paleontological potential (PFYC 3).

6.2.30 Benton Group

The Late Cretaceous Benton Group was originally named the Fort Benton Group by Meek and Hayden (1862) for exposures in Fort Benton along the upper Missouri River, Montana. For the purpose of this report, the Benton Group is considered equivalent to all of the Colorado Group (Graneros Shale, Greenhorn Limestone and Carlile Shale) plus the Niobrara Formation. See the descriptions for the individual formations within the Colorado Group in the previous subsection and the description for the Niobrara Formation in the following subsection. In general, the upper part of the Benton Group consists of petroliferous calcarenite coquina underlain by non-resistant black shale and hard siliceous black shale and has abundant fish scales at its base. The lower portion generally consists of petroliferous calcareous coquina and fine-grained, shaly sandstone with inoceramid shell fragments of the Juana Lopez Member, and bluish-gray limestone and black non-calcareous shale the Greenhorn Limestone and Graneros Shale. The Benton Group has an exposed thickness reaching more than 1,000 feet (Snyder, 1980a, 1980b) and is marine in origin.

Fossils are locally common and diverse in the Benton Group. They include trace fossils, fossil wood and plant debris, foraminifera, barnacles, brachiopods, bivalves, gastropods, ammonites, radiolarians, fish scales and other fish remains including those of sharks, and marine reptiles including plesiosaurs and ichthyosaurs (Cobban and Kennedy, 1989; Cicimurri, 2001; Hanson and Connely, 2006; Knechtel and Patterson, 1962; Massare and Dain, 1989; Merewether, 1996; Romer, 1968; Stewart et al., 1994; Stewart and Hakel, 2006; Yacobucci, 2004). Foraminifera and palynomorphs are also abundant and varied in this group (Courtinat, 1993; Fox, 1954; Merewether, 1996; Okumura, 1994). Although fossil invertebrates are locally common in the Benton, fossil vertebrates are uncommon in Colorado; however, some specimens have been discovered in the Niobrara Formation. Therefore, the Benton Group is considered to have moderate paleontological potential (PFYC 3).

6.2.31 Niobrara Formation

The Upper Cretaceous Niobrara Formation is named for exposures along the Missouri River, where it forms cliffs in Knox County, NE (Meek and Hayden, 1862). The unit is widely distributed in South Dakota, North Dakota, Montana, Wyoming, and Nebraska and extends through Kansas and Arkansas into Texas and New Mexico. The unit is found along the Colorado Front Range and has been subdivided into the Fort Hays Limestone Member and the conformably overlying Smoky Hill Shale Member. It is partially stratigraphically correlative with the Mancos Shale, which occurs farther to the west (Figure 16) (Scott and Cobban, 1964). The Smoky Hill Shale Member consists of yellowish-orange to brown shale interbedded with thin gray and white chalk beds and thin rare limestone beds. The Fort Hays Limestone Member is composed primarily of gray limestone with lesser amount of chalky limestone and shale. The combined thickness of both members is approximately 410 feet (Kellogg et al., 2008). The Niobrara Formation is widely distributed and was deposited mostly in nearshore marine settings during the second late Cretaceous transgressive-regressive cycle.

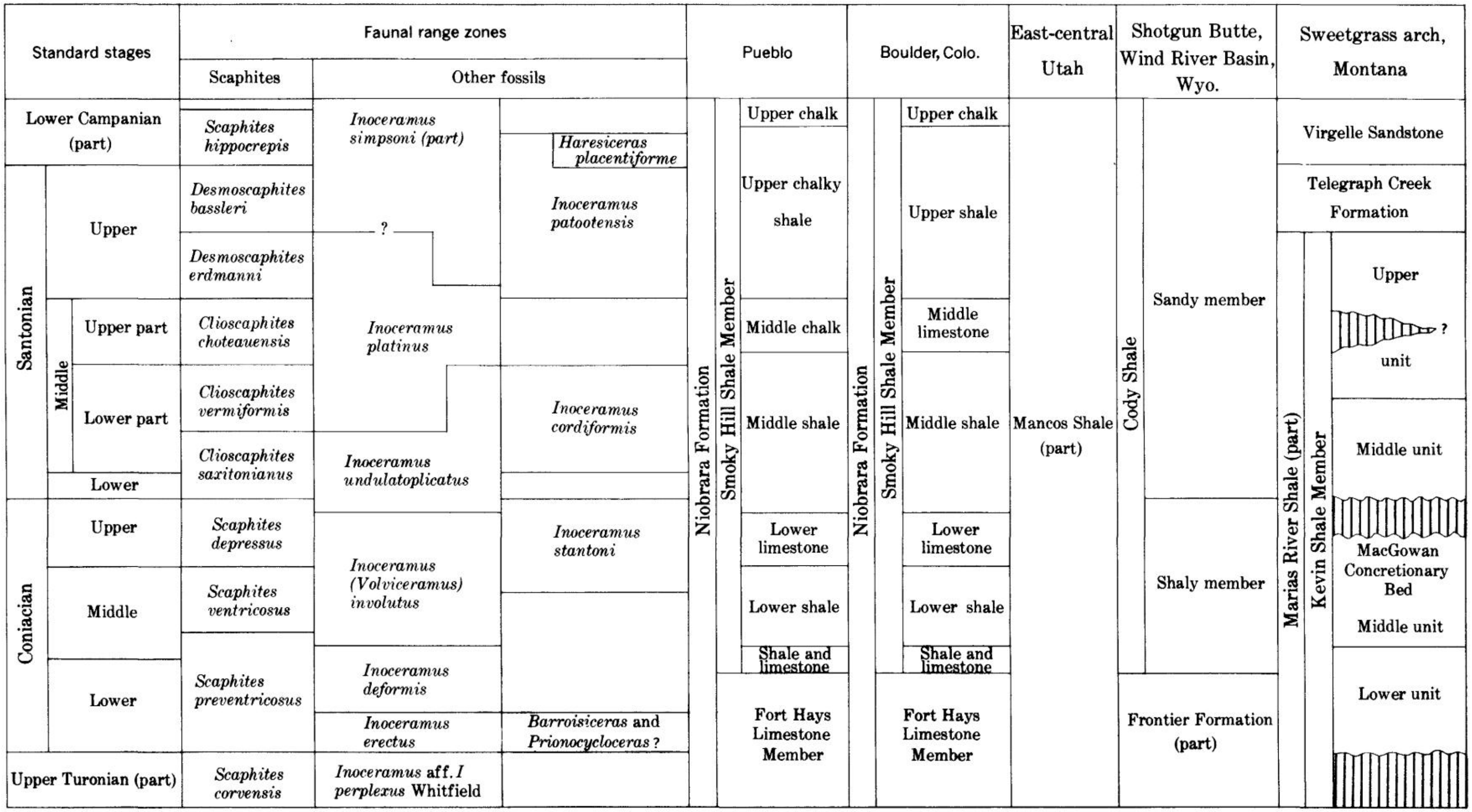

FIGURE 16. Simplified stratigraphic chart showing the faunal zones of the Niobrara Formation and equivalent units (from Scott and Cobban, 1964, Table 3).

Most fossil vertebrates known from the Niobrara Formation have been discovered in the Smoky Hill Shale Member in Kansas; other geographic areas have produced less abundant and fewer well-preserved vertebrate remains. Among the best known Niobrara Formation fossils from Kansas are articulated skeletons of pterosaurs, fishes (including rare sharks), birds, and numerous plesiosaurs, mosasaurs, and turtles. Free swimming crinoids (sea lilies) have also been reported (Cobban, 1995). Mosasaurs, plesiosaurs, and fishes have been discovered within the Smoky Hill Shale Member of the Niobrara Formation in Larimer County, CO (Anthony and Smith, 1992; Martz, 1996). Fossil marine mollusks, cephalopods, and foraminifers are also locally abundant throughout the distribution of the Niobrara Formation. Niobrara Formation fossils have been the subject of numerous paleontological studies (Anthony and Smith, 1992; Cobban, 1995; Feager and Smidt, 1992; Martz, 1996; Russell, 1993; and many others). Although fossil invertebrates are locally abundant, the Niobrara Formation contains less abundant fossil vertebrates throughout most of its distribution, including Colorado. Therefore, the unit is considered to have moderate paleontological potential (PFYC 3).

6.2.32 Pierre Formation

The Upper Cretaceous Pierre Formation (Campanian-Maastrichtian) is named for exposures at old Fort Pierre in either Stanley or Hughes County, SD (the exact location of old Fort Pierre is unknown) (Meek and Hayden, 1862). In Colorado, the unit overlies the Niobrara Formation and underlies the Fox Hills Formation and is partially equivalent to the Mesaverde Group. It occurs in Montana, North Dakota, South Dakota, Wyoming, and Colorado. In South Dakota, the Pierre has been elevated to group status (Martin et al. 2007). Several distinct units are mapped in Colorado, including the Sharon Springs, Kremmling Sandstone, Muddy Buttes, Hygiene Sandstone, Carter Sandstone and Gunsight Pass Members in addition to several unnamed units (Scott, 1962; Scott and Cobban, 1963; Izett et al., 1971). The Pierre is variable in thickness but is more than 7,000 feet thick along the Front Range of Colorado (Trimble and Machette, 1979). Generally, lithologies of the Pierre Formation include hard, platey to flaky gray, dark-gray, brownish-gray, grayish-black, tan shale and silty shale; light-olive-gray, silty bentonitic shale; limestone, 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; Wood et al., 1957). The Pierre Shale is marine in origin and was deposited on both pro-delta and shelf environments (Nwangwu, 1977). An artist’s rendition of the Denver-area landscape during deposition of the Pierre Formation is depicted in Figure 17.

FIGURE 17. Artist's rendition of the Denver area during deposition of the Pierre Formation, titled Submarine Colorado (courtesy of the DMNS and Donna Braginetz).

The invertebrate and vertebrate fossil faunas of the Pierre Formation in Colorado, Wyoming, South Dakota, Montana, Kansas, and New Mexico have been the subject of far more studies than can be cited here (e.g., 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, 1965, 1986a, 1986b; and many others). The invertebrate fauna includes a diverse assemblage of mollusks (primarily ammonites and inoceramids), other bivalves, bryozoans, and gastropods. The trace fossils (ichnofauna) consist primarily of trails, burrows, tubes, fecal pellets, and raspings on shells and gastroliths (Gill and Cobban, 1966). Plant fossils are rare, consisting of logs and wood fragments. The vertebrate fauna is also diverse, containing a variety of fish, turtles, mosasaurs, plesiosaurs, and rarer dinosaurs, pterosaurs, and birds (Carpenter, 1996). However, occurrences of vertebrate fossils are more localized than occurrences of invertebrates. Most vertebrate fossils have been discovered in the Sharon Springs Member of the Pierre in Wyoming, South Dakota, and Kansas. Additional vertebrate fossils are known from the Pierre Formation in the Walsenburg area of southern Colorado. According to former Colorado Department of Transporation (CDOT) Staff Paleontologist Steven Wallace (written communication, 2007), the UCM has a mosasaur jaw that was collected from the Pierre Formation north of Pawnee Pass (west of Sterling) in northeastern Colorado, and this specimen is the only vertebrate fossil known from the Pierre in that part of the state. A mosasaur jaw was found in the Pierre north of Wolcott, CO, and mosasaur vertebrae and sharks teeth have been found in the BLM Kremmling Field Office area (H. Armstrong, personal communication, 2015). The paleontological sensitivity of the Pierre Formation is difficult to assess in Colorado based on published literature alone. However, the overall lack of published information and the low number of fossil localities in museum databases suggest that the Pierre is less fossiliferous in Colorado than in other parts of its distribution. Furthermore, the relatively low relief topography in much of eastern Colorado where the Pierre Formation is exposed greatly limits those exposures, so opportunities to prospect for fossils in those areas are few. Because the Pierre Formation generally contains locally abundant invertebrate fossils but less common vertebrate fossils, it is considered to have moderate paleontological potential (PFYC 3).

6.2.33 Fox Hills Formation

The Upper Cretaceous Fox Hills Formation, also known as the Fox Hills Sandstone, conformably overlies the Pierre Formation and conformably underlies the Laramie Formation (Roehler, 1993). The unit was referred to as "Formation # 5" by Meek and Hayden in 1956 and was described from exposures in a poorly defined area of the Fox Hills between the Cheyenne and Moreau rivers in Dewey and Ziebuck Counties, SD (Cvancara, 1976). The formation is widely distributed in Colorado, Wyoming, Montana, North Dakota, South Dakota, and Nebraska (Roehler, 1993). Along Colorado's Front Range, the Fox Hills Formation is approximately 300 feet thick and consists of tan, cross-bedded sandstone that grades downward into brown, fine-grained silty sandstone interbedded with gray fissile shale. Locally, the unit contains thin coal beds (Colton, 1978; Gill et al., 1970; Scott, 1972). The formation is commonly exposed as sandstone ridges in areas of steeply dipping beds along the mountain front; these ridges are raised above topographically lower areas of Pierre and Laramie Formations (Trimble and Machette, 1979). 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. The unit was deposited in regressive marine and paralic environments (Roehler, 1993).

Fossils reported from the Fox Hills Formation include invertebrates such as bivalves, gastropods, and ammonites (Erickson, 1974, 1978a, 1978b); bryozoans (Cobban and Kennedy, 1992; Cuffey et al., 1981); echinoids (Holland and Feldmann, 1967); crabs (Feldmann et al., 1976); beetles (Northrop, 1928); and several species of foraminifera. Plant fossils have also been described in the unit (Dorf, 1942). The Fox Hills also contains the important trace fossil *Ophiomorpha*, which consists of half- to one-inch-diameter burrows formed by the tunneling activities of callianassid shrimp. Other reported trace fossils include structures interpreted as sea turtle nests (Bishop and Anonymous, 2002). Although much less common than invertebrates, vertebrate fossils have been collected and studied (Cope, 1876; Hoganson et al., 1994; Hoganson and Erickson, 2004); these include fish (Hoganson and Erickson, 2005); mammals (Clemens et al., 1979; Wilson, 1987); and dinosaurs, amphibians, and reptiles (Nelson et al., 2003). The Red Owl and Iron Lightning localities are two famous Fox Hills terrestrial mammal localities in northwestern South Dakota (Clemens et al., 1979; Wilson, 1987). Collectively, Fox Hills Formation fossils indicate marginal marine to littoral conditions deposited in tidal environments (Rigby and Rigby, 1990). In Colorado, the Fox Hills is less fossiliferous than elsewhere in its distribution; therefore, the unit is considered to have moderate paleontological potential (PFYC 3).

6.2.34 Laramie Formation

The Laramie Formation is Upper Cretaceous (Maastrichtian) in age and was deposited between approximately 69 and 68 million years ago. It was named by Clarence King in 1876 from outcrops in northeastern Colorado, but a type locality was not designated. The Laramie conformably overlies the Fox Hills Formation and unconformably underlies the Arapahoe Formation (Keroher, 1966). The formation is restricted to the Denver Basin of Colorado and is correlative with the lower portion of the Lance Formation in Wyoming and the Hell Creek Formation in Montana and the Dakotas.

The Laramie Formation is up to 900 feet thick (Lindvall, 1978). The upper part of the unit is composed of light-gray micaceous siltstone stained yellowish-orange, light-olive and pinkish-gray silty claystone, grayish-brown lignitic claystone, minor white and yellowish-orange friable ridge-forming sandstone, and thin layers of conglomerate derived from sedimentary rocks near its top. The upper part also contains common yellowish-brown sandy ironstone concretions. The lower part is composed almost entirely of yellowish-gray iron stained and white friable sandstone composed of quartz, biotite mica, and kaolinized feldspar (Scott, 1972). The Laramie Formation has been interpreted as a complex of channel, overbank, deltaic, and paludal deposits that were deposited shortly after and in association with the retreat of the

Western Interior Cretaceous Sea. It was deposited on a low-lying coastal plain in swamps and estuaries that existed before the Laramide uplift of the Rocky Mountains in Colorado (Weimer and Land, 1975).

The Laramie Formation is important because it is one of the few formations of its age to preserve terrestrial plant fossils (Johnson et al., 2003; Knowlton, 1930). Vertebrate fossils are far less common than plant fossils in the unit and consist mostly of poorly preserved bone fragments. However, a number of identifiable dinosaur fossils, including teeth and bones of ceratopsians, hadrosaurs, and other dinosaurian taxa, are known from the Laramie Formation in Weld County, CO, and from the Denver Basin (Carpenter and Young, 2002). A relatively rich microvertebrate fauna from a locality in Weld County was described by Carpenter (1979), and Wilson et al. (2010) more recently described latest Cretaceous (Lancian) mammalian fossils discovered at localities in northeastern Colorado. Well-preserved trace fossils, including dinosaur tracks, also occur in the Laramie Formation (Wright and Lockley, 2001). The Laramie Formation is considered to have high paleontological potential (PFYC 4).

6.2.35 Vermejo Formation

The Late Cretaceous Vermejo Formation is named for the type exposure first described by W.T. Lee in Vermejo Park, Colfax County, NM (Lee, 1917). The Vermejo Formation was originally referred to as the Laramie Formation but was later determined to be comprised of two distinct formations separated by a period of erosion: the Cretaceous Vermejo Formation and overlying Eocene Raton Formation. The Upper Cretaceous Vermejo Formation conformably overlies the Cretaceous Trinidad Sandstone. The Vermejo contains a flora that is distinct from the Laramie flora in the Denver Basin (Lee, 1917). The formation is further divided into the Rail Canyon Member in New Mexico and the Rockvale Sandstone Member of the Denver Basin, which was named for exposures near Rockvale, Fremont County, in eastern Colorado (Lee, 1917; 1924).

The type locality of the Vermejo has a maximum thickness of 375 feet and consists of lenticular beds of shale, granular sandstone, and coal. The unit ranges in color from yellow-white to black. The sandstone is coarse to fine grained, soft, and friable and is usually light gray in color. Much of the shale is carbonaceous with numerous seams or thin beds of coal and ranges in color from black to buff and tan. The Vermejo Formation consists of coal-bearing sandstone and shale deposited primarily in a fresh water environment. Lee (1917) interpreted the depositional environment of the coal layers as a low-lying swamp near sea level. This is corroborated by the fact that the plant fossils are terrestrial in origin with the exception of two fossil seaweeds (Lee, 1917).

A locally abundant, diverse, and well-studied fossil flora is known from the Vermejo Formation. It represents more than 100 taxa of leaves, fruits, nuts, woods, and palynomorphs, with many of the specimens showing exceptional preservation (Lee, 1917; Fischer, 1979). Collected specimens include terrestrial taxa such as *Ficus speciosissima*, *Pterospermites undulates*, *Sequoia obovata*, *Sabal montana*, *Zizyphus paliurifolius*, and rare marine taxa from the lowest shale layers, including *Halymenites major* and *Cardium* sp. Fossils primarily consist of leaf impressions collected from shale overlying the coal layers (Lee, 1924); however, invertebrate fossils are also known from the formation and include marine bivalves such as *Avicula linguiformis*, *Mactra warrenana*, and *Tancredia Americana* (Lee, 1917). One of the most extensive collectors of Vermejo fossils was George Hadden, a superintendent at the Coal Creek Mine near Rockvale, CO. A large portion of this collection was eventually donated to the United States National Museum (Lee, 1917). Because of the scientific importance of the Vermejo's fossil flora, the unit has high paleontological potential (PFYC 4).

6.2.36 Arapahoe Formation

The Upper Cretaceous Arapahoe Formation was named for exposures in Arapahoe County, CO, by Eldridge (1889) in USGS Bulletin 896, the U.S. Geologic Names Lexicon. The unit is exposed in small pockets along the Colorado Front Range within the Denver-Julesburg Basin (Van Horn, 1972). Because of facies-related thickness changes, in most places it is difficult 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 is commonly combined with the overlying Denver Formation on geologic maps. The formation is 400 to 500 feet thick. Its upper part consists of coarse- and fine-grained arkosic sandstone, siltstone, claystone, and thin pebble beds, while its lower part consists of white, yellowish-gray, and yellowish-orange coarse-grained sandstone with poorly sorted pebble conglomerate. The conglomerate contains cobbles and boulders of shale, chert, and petrified wood (Scott, 1972). The Arapahoe Formation was deposited in a freshwater environment of alluvial fan and fluvial origin (Van Horn, 1972).

Fossils within the Arapahoe Formation are rare and include freshwater sponges, silicified wood, and dinosaur bone fragments. Van Horn (1972) reported sponge fossils (Family Spongillidae) which were found within the claystone facies of the unit. 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 bone fragments have also been reported (Scott, 1972). Because the Arapahoe Formation appears to contain no in-situ vertebrate fossils, the unit has low paleontological potential (PFYC 2).

6.2.37 Raton Formation

The Upper Cretaceous and Paleocene Raton Formation was originally named by Hayden in 1869 for the coal-bearing rocks he found near Raton Mesa. The unit's type locality is located in the high mesa region between Trinidad, CO, and Raton, NM (Lee, 1917). This formation overlies the Late Cretaceous Vermejo Formation, underlies the Paleocene Poison Canyon Formation, and is roughly correlative with the Denver and Dawson Formations to the north. It reaches a maximum thickness of about 2,000 feet at Raton Mesa (Lee, 1917). Phillmore (1976) divided the Raton Formation into three general field divisions; in ascending order, these are a conglomeratic sandstone zone, a sandstone and mudstone zone, and a coal-bearing zone largely composed mudstone sandstone and siltstone with beds of coal.

The Raton Formation has a highly diverse and abundant plant fossil record that comprises more than 150 taxa (Lee, 1917). The unit preserves two floras: a lower flora of upper Cretaceous age and an upper flora of Paleocene age (Ash and Tidwell, 1976; Lee, 1917). The lower flora, which is less diverse and less well preserved, is represented by the palm fruit *Palmocarpon*, the palm leaf *Sabalites*, and the plant *Palaeoaster*, which has an unknown systematic relationship. The upper flora is more diverse and well preserved, and contains at least 50 species of plant fossils. It consists of angiosperms (though no gymnosperms) and five ferns, including *Allantodiopsis*, *Blechnum*, and *Dryopteris*. Dicotyledonous species include the waterlily *Nymphaea* and the sour gum *Nyssa*. Various species of oak, cottonwood, and sycamore and six species of monocotyledons are also present. These plants grew in and around swamps and marshes that were present near the retreating epeiric seaway. Based on the presence of tropical plants and the abundance of coal beds in the upper part of the formation, the climate is interpreted to have been hot and humid. In the Raton Formation and the underlying Vermejo Formation, the fossil record is of particular interest because it helps identify the Mesozoic-Cenozoic (= Cretaceous-Tertiary) boundary in the Raton Basin and the paleoecological conditions in the basin when these formations were deposited (Ash and Tidwell, 1976). Because of the scientific importance of the Raton Formation's plant fossils, the unit has high paleontological potential (PFYC 4).

6.2.38 Denver Formation

The Late Cretaceous Denver Formation was named by Cross in 1888 for its exposures in the Denver-Julesburg Basin near Denver, CO. This formation unconformably overlies the Laramie and Arapahoe Formations and unconformably underlies widely distributed Pleistocene- and Holocene-age surficial sedimentary deposits to the east of the Front Range foothills in the basin. The unit is stratigraphically equivalent to the Raton, Poison Canyon, Dawson, and Fort Union Formations and, in part, to the San Jose Formation. To the north the unit is equivalent with the upper portions of the Lance Formation in Wyoming and the Hell Creek Formation in Montana and the Dakotas. The unit is geographically isolated to Colorado and was originally divided into the Golden and Pleasant View Members (LeRoy, 1946), stratigraphic terminology that is no longer recognized. The formation is reported to be as much as 565 feet thick (Colton, 1978). It consists of dark-brown, yellowish-brown, and grayish-olive tuffaceous claystone, mudstone, and sandstone beds interbedded with scattered conglomerate (Bryant et al., 1981; Colton, 1978; Soister, 1978; Trimble and Machette, 1979).

The Denver Formation is largely composed of altered andesitic (volcanic) debris and was deposited during the Laramide uplift of the Rocky Mountains in rivers and on alluvial floodplains in a tropical forest environment. An artist's rendition of the Denver-area landscape during deposition of the Denver Formation strata and stratigraphically equivalent units is depicted in Figures 18 through 20. Specifically, they show the transition from the Upper Cretaceous (Figure 18) to Paleocene (Figures 19, 20) during the formation of the "D1" Denver Formation strata that preserve the Cretaceous-Tertiary boundary. Spanning from the latest Cretaceous (Maastrichtian) to the Paleocene (Puercan), D1 deposits of the Denver Formation preserve the Cretaceous-Tertiary boundary (dinosaur mass extinction event), which is reflected by the presence of dinosaur fossils below the boundary and early Paleocene-age mammal fossils above the boundary. D1 Denver Formation strata unconformably underlie "D2" strata, which are early Eocene in age based on scant fossil evidence (a single tooth of the early Eocene mammal *Coryphodon*). The boundary between D1 and D2 strata consists of a widely distributed paleosol deposit (Johnson and Raynolds, 1999; Raynolds and Johnson, 2003).

FIGURE 18. Artist's rendition of the Denver area during deposition of the Cretaceous D1 Denver Formation strata titled, Castle Rock Floods (courtesy of the DMNS and Gary Staab).

FIGURE 19. Artist's rendition of the Denver area during deposition of the earliest Paleocene D1 Denver Formation strata, titled After Armageddon (courtesy of the DMNS and Donna Braginetz).

FIGURE 20. Artist's rendition of the Denver area during deposition of the early Paleocene D1 Denver Formation strata, titled The First Rainforest (courtesy of the DMNS and Jan Vriesen).

The Denver Formation preserves locally abundant and scientifically significant plant fossils (Brown, 1943; 1962; Ellis et al., 2003; Johnson and Ellis, 2002; Knowlton, 1930) and a less abundant but scientifically important vertebrate fossil fauna (Eberle, 2003; Middleton, 1983). The flora is highly diverse and has been documented from 149 stratigraphically controlled localities, including the well-publicized Castle Rock Rainforest Site along Interstate 25 south of Denver (Johnson et al., 2003). Vertebrate fossils include a diversity of Cretaceous-age dinosaurs and early Paleocene-age mammals (Carpenter and Young, 2002; Eberle, 2003). Both the DMNS and UCM have recorded numerous Denver Formation localities around the Denver Basin.

The geology and paleontology of the Denver Formation remains the subject of research by scientists and students at the DMNS and the University of Colorado. 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 Period and Paleocene Epoch (Eberle, 2003; Ellis et al., 2003; Johnson and Ellis, 2002; Johnson and Raynolds, 1999). Future fossil finds from the Denver Formation will add to this ongoing research effort. Because the Denver Formation contains locally abundant and well-preserved plant fossils and less common but locally well-preserved and scientifically important vertebrate fossils, the unit has high paleontological potential (PFYC 5).

6.2.39 Poison Canyon Formation

The Early Paleocene Poison Canyon Formation was first named and described by R.C. Hills in 1888 as a unit in the Tertiary beds of the Huerfano River Basin. The formation is partially stratigraphically equivalent to the Denver Formation and the Dawson Formation and is geographically isolated to Colorado, where it is exposed in the Cañon City Basin, Southeastern Colorado, the Raton Basin, and Huerfano Park, a 240-square-mile area in the northern part of the Raton Basin. The unit ranges from a few feet to about 2,000 feet in the Huerfano Park area (Johnson, 1958). The Poison Canyon Formation unconformably overlies the Vermejo Formation and conformably underlies the Huerfano Formation (Robinson, 1966) and is composed of arkosic sandstone, conglomerate, and mudstone of fluvial origin. The unit’s outcrops are typically characterized by persistent brown-weathering sandstone beds. It is generally coarser grained than the Raton Formation but interfingers with this unit in the Raton Mesa area (Johnson, 1958; Robinson, 1966; Vine, 1974). The sediments of the Poison Canyon Formation were deposited in a terrestrial environment on piedmont surfaces during the Paleocene (Johnson, 1958).

Few published reports of fossils in the Poison Canyon Formation exist. Impressions of fossil leaves are common in the formation’s shale beds (Johnson, 1959). Hills (1888) was the first author to report fossils including turtle carapace fragments and *Coryphodon* bones in the unit. Lee and Knowlton (1917) reported that the scant Poison Canyon flora contained several taxa in common with the Raton and Denver Formations. Some examples of species from the Poison Canyon Formation that are also found in the Raton Formation include *Ficus denveriana*, *Ficus latifolia*, *Leguminosites arachioides*, and *Palmocarpon palmarum* (Lee and Knowlton, 1917). Briggs and Goddard (1956) reported a tropical flora similar to that of the Denver Formation. The Poison Canyon is less fossiliferous than the Raton and Vermejo Formations and the Trinidad Sandstone but is still considered to have high paleontological potential (PFYC 4) because it contains locally well-preserved plant fossils and sparse but scientifically important vertebrate fossils.

6.2.40 Dawson Formation

The Dawson Formation, commonly referred to as the Dawson Arkose, is a Late Cretaceous through Early Tertiary unit located in the Denver Basin. Eldridge (1889) originally named the formation Willow Creek; the unit was later renamed the Arapahoe Formation before receiving its current name. The

Dawson is stratigraphically equivalent to the Denver Formation, and measures about 1,450 feet thick. Recent work has resulted in the reassignment of the lower part of the Dawson Formation to the D1 sequence (See Denver Formation description) within the Denver Basin and the upper part of the Dawson Formation to the D2 sequence of the Denver Basin (See Denver Formation description) (Johnson et al., 2001). The Dawson Formation has essentially been synonymized with the Denver Formation by most workers. The Dawson's dominant lithology as formerly described consists of conglomerate, sandstone, and siltstone (Scott, 1963) with layers interbedded shale (Lee and Knowlton, 1917). The Dawson was deposited in a fluvial environment as the Front Range was uplifted during the Laramide Orogeny (Scott, 1963). An artist's rendition of the Denver-area landscape during deposition of the Dawson Formation is depicted in Figure 21.

FIGURE 21. Artist's rendition of the Denver area during deposition of the Dawson Formation (= Denver Formation D2 sequence), titled Red Dirt World (courtesy of the DMNS and Jan Vriesen).

As in the Denver Formation, plant fossils are the most common fossils found in the Dawson Formation. At least 45 different plant species are typically found throughout the formation in shale beds that are interbedded with massive beds of arkose. While far less common, vertebrate fossils, including the remains of dinosaurs and mammals, have also been discovered in the unit (Lee and Knowlton, 1917). The Dawson Formation, like the Denver Formation with which it is now synonymized, is considered to have high paleontological potential (PFYC 4).

6.2.41 South Park Formation

The Paleocene South Park Formation was named for the town of South Park, Park County, CO, by Wyant and Barker (1976). The South Park Formation consists of two members: the Reinecker Ridge Volcanic Member and the Link Springs Tuff Member. The base of the Reinecker Ridge Volcanic Member is composed of andesitic flows, breccia, tuffaceous sandstone, and conglomerate, while the middle portion is composed of conglomerate containing abundant volcanic clasts and sedimentary clasts that increase upwards and underlie sandstone and mudstone beds interbedded with conglomerate (Bryant et al., 1980). The Link Springs Tuff Member is composed of tuff, tuffaceous conglomerate, and andesite underlying conglomerate, mudstone, tuff and boulder conglomerate.

The South Park Formation is primarily a volcanic unit, but well-preserved fossilized leaves are found in the mudstone and conglomerate beds within the Reinecker Ridge Volcanic Member (Wyant and Barker, 1976). This formation is considered to have moderate paleontological potential (PFYC 3).

6.2.42 Huerfano Formation

The Huerfano Formation is an Eocene rock unit that was originally named by R.C. Hills in 1888 for Tertiary beds in the Huerfano River Basin. Other formations in Colorado that are stratigraphically equivalent or partially equivalent to the Huerfano include the Cuchara, Wasatch, Green River, and San Jose Formations. The Huerfano Formation is fairly restricted in extent, occurring only in southeastern Colorado and northeastern New Mexico. Its thickness approaches 2,800 feet in the Huerfano Park area but reaches 5,000 feet farther to the south (Robinson, 1966). The Huerfano Formation unconformably overlies the Paleocene Poison Canyon Formation and the Cretaceous Pierre Formation and primarily consists of variegated maroon shale and tan, red, and white sandstone (Johnson, 1959). The depositional environment of this formation was a floodplain in the Raton Basin that existed during the Eocene (Johnson and Wood, 1956).

The Huerfano Formation has produced numerous well-known mammal fossil localities (Bown and Kihm, 1981; Robinson, 1966). This formation preserved two faunas of fossilized mammals: the Garcia Canyon fauna of late early Eocene age and the younger Garden Butte fauna of earliest middle Eocene age. Mammal fossil groups represented include marsupials, insectivores, primates, tillodonts, taeniodonts, rodents, carnivores, condylarths, pantodonts, perissodactyls, and artiodactyls. Non-mammalian taxa include freshwater fish, gastropods, turtles, squamates, crocodilians, and birds (Cracraft, 1969; Robinson, 1966). Because of the Huerfano Formation's abundant and taxonomically diverse vertebrate fossils, the unit is considered to have very high paleontological potential (PFYC 5).

6.2.43 Cuchara Formation

The Cuchara Formation is an Early Eocene rock unit located in New Mexico and Colorado; in the latter state the unit is exposed in Huerfano Park (Johnson, 1959). The lower Cenozoic rocks of Huerfano Park were originally described in 1888 in a paper by Hills, in which he named the Huerfano beds and Poison Canyon series. In 1891, Hills renamed these rocks, subdividing them into the Huerfano beds, Cuchara beds, and Poison Canyon beds. The Cuchara beds in particular were named after the beds exposed along the Cuchara River Valley and north and south of La Veta, CO (Robinson, 1966). Several authors, including Robinson (1966), equate the Cuchara Formation with the Huerfano Formation, using their names interchangeably. Scott and Taylor (1975) further argued in favor the use of the name Huerfano in reference to the Cuchara Formation. According to these authors, the Cuchara Formation is an intimate mixture of the Huerfano Formation and the Farisita Conglomerate found in the lower Eocene of Huerfano Park and the Wet Mountain Valley. The Cuchara has a thickness that ranges from 2,800 feet (Robinson, 1966) to at least 5,000 feet on the northern slope of West Spanish Peak at the center of the basin (Johnson et al., 1956). The unit's lithology consists mostly of yellowish-gray conglomerate, sandstone, and mudstone (Scott and Taylor, 1975). Huerfano Park is an example of the effects of sedimentary compression due to the eastward thrust of the Sangre de Cristo Mountains on the west and vertical uplifting of the east during the Laramide Orogeny (Johnson, 1959). The Huerfano beds of the Cuchara were formed during a relatively inactive period in the Laramide Orogeny, when the surrounding mountain areas deposited fine-grained sedimentary rocks (Robinson, 1966).

The Cuchara Formation consists of a diverse assemblage of vertebrate fossils represented by at least 46 genera of mammals such as primates, ungulates, and rodents. Other taxa include fish (e.g., *Lepisosteus* sp.); multiple squamate clades, including anguids (e.g. *Glyptosaurus hillsi*, *Peltosaurus* sp.) and varanids (e.g. *Saniwa* sp.); crocodilians; and birds. Some invertebrates, including three species of snails, are also present. Based on the fossil assemblage of the unit, the paleoenvironment was likely warm, with permanent rivers, forests, and open plains. The Cuchara and Huerfano Formations are unique in that they provide rare examples of mammal-bearing formations that formed during a period of orogenesis, or mountain building (Robinson, 1966). Due to the Cuchara Formation's locally abundant vertebrate fossils, the unit is considered to have high paleontological potential (PFYC 4).

6.2.44 Florissant Formation

The late Eocene Florissant Formation was originally named the Florissant Lake beds after the town of Florissant in Teller County, CO, by Cross (1894). It was later redefined as the Florissant Formation by Evanoff et al. (2001). The Florissant Formation is found only in central Colorado with principal exposures in Florissant Fossil Beds National Monument, and the unit is a well-known lagerstätten (Cross, 1984; Evanoff et al., 2001; Wobus and Epis, 1978). The formation unconformably overlies the Proterozoic Pikes Peak Granite in some areas and conformably overlies the late Eocene Wall Mountain Tuff in other areas. It unconformably underlies Pleistocene and Holocene surficial sedimentary deposits. This formation is divided into six informal units: the lower shale, the lower mudstone, the middle shale, the cap-rock conglomerate, the upper shale, and the upper pumice conglomerate (Evanoff et al., 2001). The Florissant Formation is up to 150 feet thick and consists of a variety of lithologies, including arkosic granule conglomerate, volcaniclastic conglomerate, pumice conglomerate, sandstone, tuffaceous mudstone and siltstone, carbonaceous shale and diatomaceous shale (Evanoff et al., 2001; Wobus and Epis, 1978). The Florissant Formation is equivalent to the Antero Formation and, in part, to the White River Formation. Several facies represent varying depositional environments within this dominantly lacustrine deposit. Evanoff et al. (2001) identified six informal stratigraphic units, which are described below in ascending stratigraphic order.

Unit 1: Exposures of the lower shale occur at Clare Quarry south of Florissant and at a road cut east of the town, where the formation is up to 37.4 feet thick. Unit 1 is composed of tuffaceous siltstone and paper shale beds that have alternating laminae of diatomite and volcanic ash (altered to smectite clays) (Evanoff et al., 2001). Granular conglomerate with granite, pumice sandstone, and pumice conglomerate are scattered throughout this unit. The unit represents deposition in the early stages of the expansion of Florissant Lake (Evanoff et al., 2001). Fossils found within this unit include insects, plants, most of the fish, and all of the birds known from the formation.

Unit 2: The lower mudstone unit is up to 34.1 feet near the north entrance road of Florissant Fossil Beds National Monument and is composed of a sequence of gray tuffaceous mudstone beds, muddy pumiceous conglomerate beds, and rare cross-bedded sandstone with conglomerate lenses capped by weakly bedded tuffaceous sandy mudstone. The lower part of this unit was deposited in the primary stream flow, with the paleocurrent direction to the south along the main axis of the valley; the upper portion represents a mudflow that buried the forest in the valley. This unit is well known for fossilized *Sequoia* stumps.

Unit 3: The middle shale unit is up to 29.5 feet thick and is well exposed at the mouth of the Grape Creek arm of the paleovalley by the "big stump" (Figure 22). This unit is characterized by platey to papery shale beds interbedded with thin pumiceous conglomerate. The laminations in the papery shale beds are composed of alternating laminae of diatomite and smectite clay (McLeroy and Anderson, 1966; Evanoff et al., 2001). This unit is entirely lacustrine, records episodes of volcanic activity, and includes most of the well known plant and insect localities as well as less common fish, mollusks, and ostracods.

Unit 4: The tuffaceous volcanicalstic conglomerate is up to 24 feet thick by the "big stump" and is composed of conglomerate containing granite granules and pebbles to granules of intermediate volcanic rocks with poorly developed grading in a fining upward sequence. The clasts were originally part of a lahar deposit but were reworked by lacustrine processes after deposition. The only fossils that occur within this unit are freshwater finger clams.

Unit 5: The upper shale unit is up to 18.4 feet thick with its most prominent exposures along Boulder Creek. It is composed of brownish-gray paper shale, blocky mudstone, and pumice conglomerate. This unit is a lacustrine deposit that was laid down after the influx of the cap rock lahar deposits from the Unit 3 (tuffaceous volcanicalstic conglomerate). Common fossils that occur within this unit are plants, insects, fish scales, and ostracods.

Unit 6: The upper pumice conglomerate unit is up to 74.8 feet thick and is exposed only at the head of the western tributary valleys of the main paleovalley. The unit is composed of pumice-rich white sandstone and conglomerate. The pumice clasts are granular and typically white or pink. This unit is structureless at its base and has cross beds near the top. The lower structureless part of this unit was deposited in Florissant Lake, while the upper, cross-bedded portion represents deposition within streams. The only fossils that occur within this unit are fresh water finger clams.

The Florissant Formation is well known for its exceptionally well-preserved insect and plant fossils, but the unit also contains fish, birds, land mammals, and a variety of invertebrates that have been the subject of numerous studies (Worley-Gorge and Eberle, 2006; Lloyd et al., 2008; Smith, 2008; Leopold et al., 2008; O'Brien et al., 2008; Thoene, 2011). The flora and fauna have also been the subject of taphonomic studies because of their exceptional preservation (Thoene 2011; O'Brien et al., 2008). In 1878 Cope described most of the fish in the Florissant Formation, including the taxa *Trichophanes*, a genus of ray-finned fish, before the unit was officially recognized (Cope, 1878). Plant fossils in the Florissant Formation include palm, fern, elm, birch, walnut, and water lilies, among others, and are the most abundant type of fossil found in the unit. More than 114 species have been identified from leaves and fruits, and more than 150 phenotypes have been described from pollen and spores (Leopold and Clay-Poole, 2001). Common plant taxa include leaves and fruits from *Cedrelospermum* (in the elm family), *Asterocarpinus* (birch), and *Florissantia* (extinct Sterculiaceae) (Manchester, 2001). Many of the plant taxa from the Florissant Formation indicate a warm-temperate to subtropical environment; among these taxa are *Cyclocarya*, *Juglans*, and *Platycarya* (Leopold and Clay-Poole, 2001). The low-diversity mammalian assemblage of the formation includes the rodents *Paradjidaumo trilophus*, *Adjidaumo minimus*, *Pelycomys*, and *Ischyromys typus*; the rabbit *Palaeolagus*; the horse *Mesohippus*; and the brontothere *Megacerops.* Some of these mammalian taxa provide important stratigraphic information, constraining the age of the Florissant Formation to the Chadronian (latest Eocene) NALMA. Mammals preserved within the Florissant Formation are interpreted to have lived in a variety of niches, including forests and grasslands in a high-elevation, moist, warm-temperate, montane wetland and woodland environment (Lloyd et al., 2008). More than 1,500 insect and arachnid species have been described; the most common are from the orders Hymenoptera, Coleoptera, Diptera, and Hemiptera (Theone, 2011). Due to the abundance, exceptional preservation, and scientific significance of the fossils from the Florissant Formation, the unit is considered to have very high paleontological potential (PFYC 5).

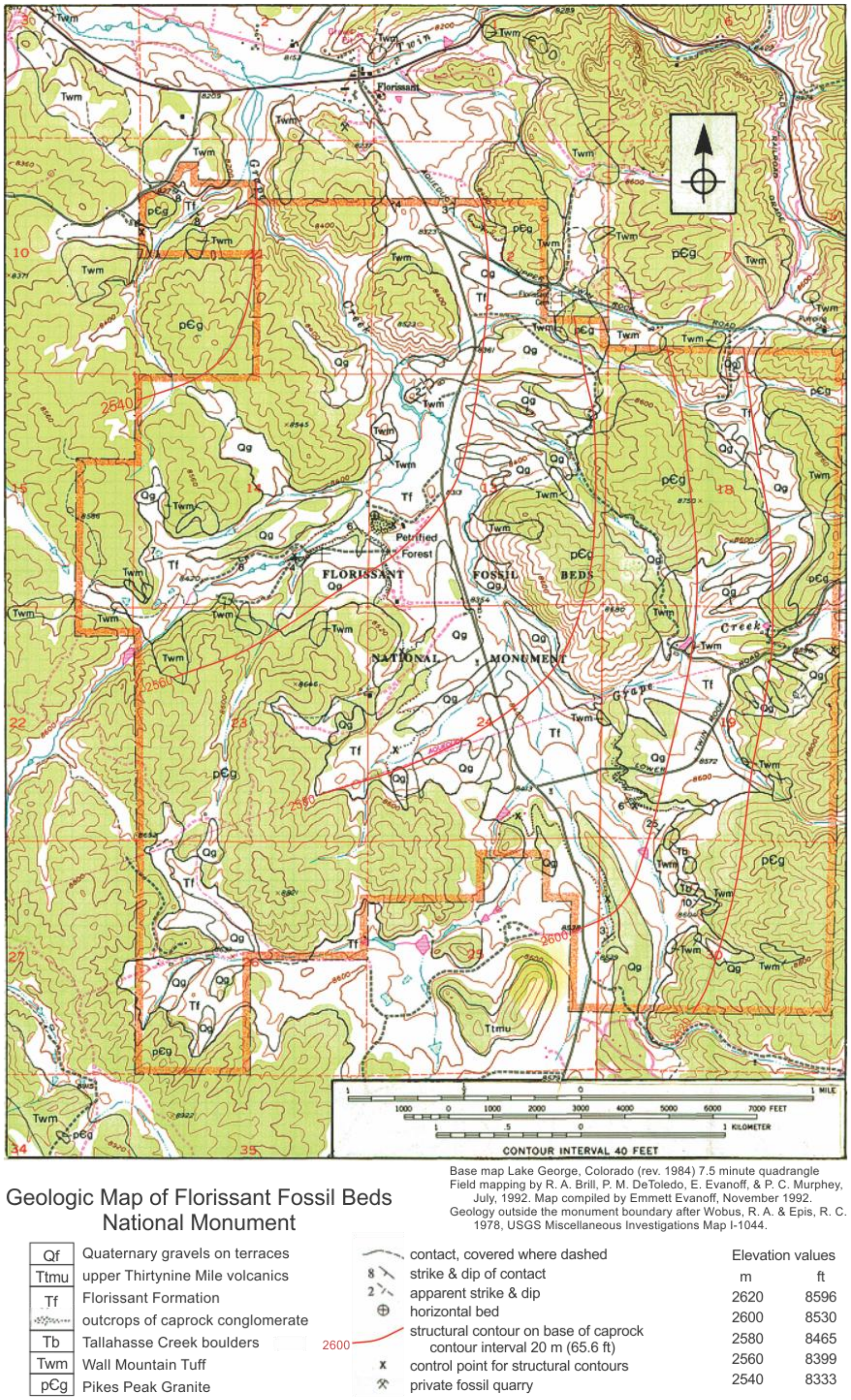

FIGURE 22. Map of the distribution of the Florissant Formation in and around Florissant National Monument (Courtesy of E. Evanoff).

6.2.45 Antero Formation

Radiometric dating of the Antero Formation indicates that its deposition coincided with the Eocene-Oligocene boundary (33.7-33.9 million years ago) (Walker, 2011). The unit was first described by J.H. Johnson from the type area located southwest of Hartsel in Park County, CO (Keroher, 1966). The formation unconformably overlies the Paleocene Denver Formation (Lloyd, 2007) and unconformably underlies the Miocene Wagontongue Formation (Keroher, 1966). Early documents state that the Antero conformably overlies the Balfour Formation (Stark et al., 1949; Durden, 1966). However, in 1978 the name Balfour Formation was abandoned and that unit was assigned to the Antero Formation because the two are equivalent in lithology, origin, and age (Scott et al., 1978). The Antero has also been considered to be contemporaneous with the Florissant Formation (Durden, 1966), but recent radiometric dating suggests that the Antero is actually slightly younger in age (Walker, 2011). Strata of the Antero are restricted to the South Park Basin of central Colorado (Stark et al., 1949; Durden, 1966; Lloyd, 2007).

The Antero Formation varies between 9.8 and 1998 feet thick (Stark et al., 1949; Lloyd, 2007) and consists a series of shale and tuff beds (Lloyd, 2007). The Formation is subdivided into three units: the lower member, middle member, and top member. The lower member consists of arkosic conglomerate, sandstone, tuffs, and minor thin shale. Sediments of the middle member consist of fine-grained tuff, shale, and limestone. Poorly consolidated conglomerate and sandy interbeds comprise the top member (Stark et al., 1949; Durden, 1966; Lloyd, 2007). The Antero Formation was deposited in a lacustrine basin during the cooling period between the Eocene and Oligocene (Walker, 2011). Volcanic deposits within the Antero originated from the Mount Aetna cauldron in Central Colorado (Lloyd, 2007). Vertebrate fossils from the Antero Formation include specimens of horse (*Mesohippus*), bronthothere, rhinoceros (*Trigonias*, *Hyracodon*, *Caenopus*), oreodont (*Agrichoerus*), rabbit (*Palaeolagus*), and a deer-like ruminant (*Leptomeryx*) (Stark et al., 1949; Durden, 1966). Fossil insects, ostracods, and well-preserved plants are also known from the Antero Formation (Durden, 1966; Walker, 2011), including a large collection (consisting primarily of insects) made by Christopher Durden from Chase Basin in Park County, CO, for the YPM (Durden, 1966). The flora of the Antero Formation is dominated by montane conifers such as firs (*Abies*), pines (*Pinus*), and spruce (*Picea*), suggestive of a temperate coniferous forest (Walker, 2011). Because the Antero Formation contains well-preserved plant and insect fossils and a low-diversity mammal fossil assemblage, the unit is considered to have high paleontological potential (PFYC 4).

6.2.46 Castle Rock Conglomerate

The Late Eocene Castle Rock Conglomerate, originally termed the Castle Conglomerate by Lee (1902) for typical exposures at Castle Rock Butte in eastern Colorado, is the youngest preserved sedimentary rock unit in the Denver-Julesburg Basin (Lee, 1902; Evanoff, 2007). This unit is restricted to the south-central portion of the Denver-Julesburg Basin. It is composed of up to 90 feet of arkosic, cross-bedded and normally graded conglomerate containing large blocks of granite, conglomerate derived from the Fountain Formation and the Wall Mountain Tuff. The conglomerate is interbedded with tuffaceous brown mudstone that preserves sparse mammal fossils (Evanoff, 2007). The Castle Rock Conglomerate was deposited in rivers during times of massive discharges interpreted as storm events that were able to transport large boulders many miles downstream (Figure 23).

Rare bone fragments from late Eocene brontotheres identified as *Titanotherium* by J.W. Gidley are the only fossils reported from the Castle Rock Conglomerate. These were discovered in the mudstone facies (Knowlton, 1922) of the formation. Because the Castle Rock Conglomerate contains only sparse and questionably identifiable bone fragments, the unit is considered to have low paleontological potential (PFYC 2).

FIGURE 23. Artist's rendition of the Denver area during deposition of the Castle Rock Conglomerate, titled Castle Rock Floods (courtesy of the DMNS and Jan Vriesen).

6.2.47 White River Formation

The White River Formation (or Group) is Late Eocene and Oligocene in age. The unit was named in 1858 by Meek and Hayden for exposures near the mouth of the White River in South Dakota. This formation (or its formations/members) is partially equivalent to the Yoder or White River Formations in Wyoming; the Dunbar, Climbing Arrow, and Renova Formations in Montana; the Florissant and Antero Formations in Colorado; and numerous other units throughout the Rocky Mountains and Great Plains. The White River Group is geographically distributed throughout a broad area of Nebraska, South Dakota, North Dakota, Wyoming, and Colorado. In the Big Badlands area of South Dakota, the White River Group has been subdivided into the Chamberlain Pass, Chadron, and Brule Formations (described below), from lowest to highest, and the unit unconformably overlies the late Cretaceous Pierre Formation and Fox Hills Formation.

Stratigraphic terminology for the White River Group in South Dakota varies regionally. For example, in the Slim Buttes area (Harding County), the Chadron Formation has been informally subdivided into three members: the "golden brown," "dazzling white," and "typical Chadron" (Lillegraven, 1970). In Wyoming and Nebraska, the Chadron Formation has been subdivided into the lower Peanut Peak Member and upper Big Cottonwood Creek Member, and the unit locally overlies the Chamberlain Pass Formation (Terry, 1998). In Nebraska, the Brule Formation has been subdivided into the Orella, Whitney, and "Brown Siltstone" Members and unconformably underlies the Arikaree Group. In North Dakota, the Chadron Formation unconformably overlies the Fort Union Formation, and the Brule Formation unconformably underlies the Arikaree Formation (Hoganson and Lammers, 1985). In Colorado, the White River Formation (or Group) has been stratigraphically subdivided into the Horsetail Creek and the Brule Formation, which has been subdivided into the Cedar Creek Member and the Vista Member (Tedford, 1999). In South Dakota, the Brule Formation has been subdivided into the Scenic and Poleslide

Members (LaGarry, 1998), and the latter has been further subdivided into the Lower and Upper Poleslide Members in the Big Badlands area (Evanoff et al., 2010).

Lithologically, the White River Group is composed of volcaniclastic mudstone, siltstone, and fine-grained sandstone and less abundant claystone, conglomerate, limestone, and ash-fall tuff. In northeastern Colorado, the White River Formation is composed of light-greenish-gray, light-brown to tan tuffaceous mudstone and siltstone and is 440 feet thick at Pawnee Buttes. The White River sequence represents a depositional pulse in the Great Plains resulting from a massive influx of volcanic ash from the west (Evanoff et al., 2010). It has been estimated that this blanket of volcaniclastic sediment had a volume of approximately 25,000 cubic kilometers (Larson and Evanoff, 1998).

The White River Formation (or Group) is world renowned for its ubiquitous, highly diverse, and exquisitely preserved vertebrate fossils, including perfectly preserved articulated skeletons and skulls of primarily mammals and reptiles (Clark, 1954; Evanoff et al., 1992; Larson and Evanoff, 1998; Lillegraven, 1970; Meek and Hayden, 1857; Terry, 1998). The fossil fauna of the White River has been studied intensively; resulting in far more publications than can be cited here. This fauna represents the most important record of late Eocene and Oligocene mammals in North America, documenting the faunal transition between the Eocene and Oligocene and the faunal transition between the Oligocene and Miocene (Cope, 1891; Emry, 1979; Galbreath, 1953; Gawne, 1978; Gustafson, 1986; Hoganson and Lammers, 1985; Korth, 1987; Lillegraven, 1970; Olson, 1976; Osborn and Scott, 1890; Osborn and Wortman, 1894; and many others). Mollusks include bivalves and gastropods (Evanoff et al., 2010). Fossil vertebrates in the unit include fish, amphibians, reptiles, birds, and mammals (Clark et al., 1967). The fauna includes at least 8 orders and more than 25 families of mammals, including marsupials, insectivores, carnivores, lagomorphs, rodents, perissodactyls, and artiodactyls. The artiodactyls, particularly oreodonts, are extremely well represented in terms of number of specimens. However, perissodactyls (Cope, 1891; Emry, 1979; Leite, 1984), lagomorphs (Gawne, 1978), and rodents (Howe, 1966; Korth, 1980, 1987; Martin, 1986; Reeder, 1960) are also abundant. Reptiles include turtles, lizards, snakes, and crocodilians (Evanoff et al., 2010). The White River Formation also has a rich record ichnofossils that provide an exceptional record of the paleoclimatic and paleoenvironmental changes resulting from the global cooling event that began in the Late Eocene (Hembree and Hasiotis, 2007). Because of the abundance, high taxonomic diversity, and excellent preservation of fossils in the White River Formation in Colorado, the unit there is considered to have very high paleontological potential (PFYC 5).

6.2.48 Brule Formation

The Brule Formation is Oligocene in age and comprises the upper formation of the White River Group. Darton (1899) named this formation for the Brule Indians, who roamed an area in South Dakota, where the unit is extensively exposed. The Brule Formation is exposed in northeastern Colorado, especially in the Pawnee Buttes area (Tedford, 2004), where it is subdivided into the Cedar Creek Member and the Vista Member (Tedford, 1999). In northeastern Colorado, the Cedar Creek Member is composed of pink and tan siltstone and sandstone, and the Vista Member is composed of massive, tan siltstone with a highly calcareous zone at its base (Matthew, 1901).

Fossil vertebrates from the Brule Formation in northwestern South Dakota (Slim Buttes, Harding County) are abundant and diverse and include turtles, lizards, birds, mammals, and mammal tracks. Mammals include marsupials, insectivores, lagomorphs, rodents, carnivores, perissodactyls, and artiodactyls (Lillegraven 1970). The only record of the giant rodent *Manitsha* and a single specimen of the brontothere *Titanotherium* also come from this area. Fossil wood is commonly found throughout the Brule Formation, as well (Lillegraven, 1970; Simson, 1941; Darton, 1909). In Colorado, the Brule has yielded a vertebrate fauna similar to that of the unit in South Dakota, with representatives from the major clades listed above. Matthew (1901) gives a comprehensive species list of the fossils known from both of the Cedar Creek and Vista Members. The Brule Formation has high paleontological potential in Colorado (PFYC 5).

6.2.49 Arikaree Formation

The late Oligocene to Early Miocene Arikaree Formation is named for the Arikaree Indians, who were identified in the area in Nebraska where the formation is most well developed (Darton, 1899). The unit is recognized in western Nebraska, southeastern Wyoming, and southern South Dakota. Although mapped in Colorado by Scott (1978) and Tweto (1979), Tedford (2004) demonstrated that the rocks mapped as Arikaree Formation in Colorado are in fact the Martin Canyon Formation of Hemingfordian NALMA, and that there is in fact no Arikaree Formation in Colorado (Emmett Evanoff, personal communication, 2015). Because the Arikaree Formation does not occur in Colorado, its PFYC assignment is irrelevant to this report. See section 6.2.52 for a discussion of the Martin Canyon Formation and its fossils.

6.2.50 Troublesome Formation

The upper Oligocene to lower Miocene Troublesome Formation was first formally named by Lovering and Goddard (1950) for exposures in the valley of Troublesome Creek near Kremmling in Middle Park, northwestern Colorado. It is partially stratigraphically equivalent to the North Park Formation, the Ogallala Formation and the Browns Park Formation (Figure 24).

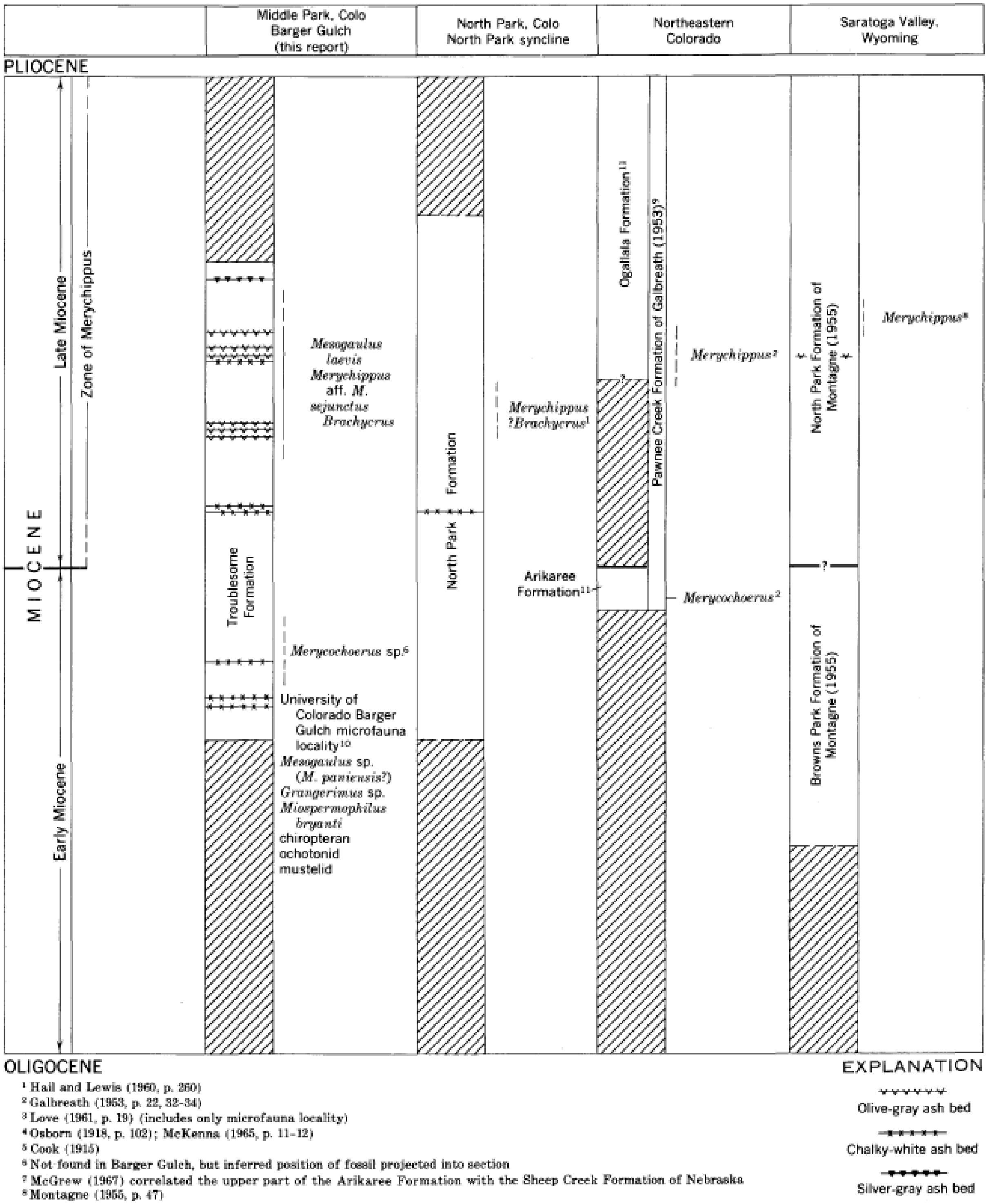

FIGURE 24. Correlation diagram showing an interpretation of time relations of Miocene rocks in Middle Park, CO, and selected areas in Colorado and Wyoming (from Izett, 1968).

The aptly named Troublesome Formation is mostly of Hemingfordian and Barstovian NALMA, but it does yield Arikareean fossils at its base and several localities near the top of the sequence produce late Barstovian fossils (Peter Robinson, personal communication, 2015). The Troublesome Formation is geographically restricted to north-central Colorado, occurring mostly in the Middle Park Basin. The thickness of this unit varies greatly, with a maximum measured thickness of 960 feet. In the Kremmling area, the unit averages about 200 to 300 feet thick where it outcrops north of the Colorado River. South of the river, the unit averages about 400 feet thick. In the Kremmling area, the formation is about 200 to 300 feet thick north of the Colorado River and about 400 feet thick south of the Colorado River. The Troublesome lies unconformably above older rocks of varying ages. In some places the formation overlies the Niobrara Formation, while in others, it overlies the Middle Park Formation (Izett, 1968).

Izett (1968) divided the Troublesome Formation into two distinct parts based on lithology. The upper part of the Troublesome is composed of clayey tuffaceous siltstone facies, which are predominantly grayish-orange to gray, light-brown, and light green. The lower part is characterized by variegated conglomeratic facies with tuffaceous swelling claystone and sandstone lenses. At the formation's thickest location near Kremmling, its upper 800 feet contain claystone and fluvial sandstone interbedded with volcanic ash beds up to 30 feet thick. The formation is typically covered by grasses and sagebrush and is poorly exposed in most of the areas where it occurs (Izett, 1968).

The Troublesome Formation is thought to have formed from the fluvial deposition of pyroclastic material from the Rabbit Ears Range following a period of volcanism in the middle Tertiary. The ash beds present in the formation indicate that volcanism from distant locations persisted throughout its deposition. The presence of a small number of freshwater limestone beds also indicates that some small, transient ponds were likely in the depositional environment (Izett, 1968).

Although fossil localities in the Troublesome Formation are sparse due to the mostly vegetated landscape, the unit does preserve a highly diverse vertebrate fossil fauna represented mostly by mammals. The first fossil discovered in the Troublesome Formation was a *Parahippus* specimen reported by Cockerell in 1908. Since then, the Troublesome Formation has yielded a diverse array of vertebrate fossils, including frogs, turtles, bats, various insectivores, rodents, camels, antelope, deer, rhinoceros, horses, mastodons, gomphotheres, rabbits, pika, and carnivores including canids, felids, mustelids, and the enigmatic bear dog *Amphicyon major* (Izett 1974; Kron, 1988) (Figure 25). Izett and Lewis (1963) discovered several fossil localities while mapping in Grand County, CO, where they collected *Merychippus, Aphelops,* and *Merycochoerus*. In the 1960s, workers at the University of Colorado discovered numerous fossil localities that produced more than 101 mammalian species (34 unique to the area) (see Kron, 1988). In the lower part of the Troublesome, the oreodont *Merycochoerus* and the rodent *Mesogaulus* are commonly preserved. The upper third contains a much larger and diverse fauna, including mammals such as the rhinoceros *Aphelops;* the three-toed horse *Merychippus;* several genera of camel including *Protolabis, Aepycamelus,* and *Oxydactylus;* and the mylagaulid rodent *Mesogaulus laevis*. Many of these fossils have been used to date the Troublesome Formation to the Miocene and index fossils to correlate and date other formations with similar fossil assemblages. The Troublesome is also an important formation paleontologically because it is one of a few known formations that records the mammalian fauna of an upland basin during the late Oligocene and Miocene. Therefore, the unit is considered to have high paleontological potential (PFYC 4).

[Identification by G. E. Lewis, U.S. Geol. Survey, except where noted. Locality numbers not arranged in stratigraphic order]

Locality on fig. 2	Lithology	Fossils
		Upper part
(1)	Orange-gray clayey siltstone.	*Merychippus* aff. *M. sejunctus*. *Merychippus* sp. ?*Anchitherium* sp.[2] *Aphelops profectus*? *Protolabis angustidens* *Aepycamelus* sp. *Oxydactylus*- or *Protolabis*-like camel. *Brachycrus* sp. Merycodont. *Mesogaulus laevis*. *Monosaulax* sp.[2]
		Lower part
1	Greenish-gray sandy claystone.	*Merycochoerus* sp.; ramal fragment.
2	Reddish-brown siltstone containing conglomeratic stringers.	*Merycochoerus* sp.; three imperfect skulls and other skeletal parts. ?*Amphicyon* sp.; imperfect skull.
3	----------do----------	*Mesogaulus* sp.; two ramal fragments. ?Blastomerycine; two ramal fragments.
4	Gray sandy granulitic claystone.	?*Aepycamelus* sp. or ?*Hesperocamelus* sp.; fragmentary symphysis and right ramus. Camelid; distal fragment of radius. Small ruminants, genera and species indeterminate; fragments of radius, calcaneum, and phalanx.
4a	Gray sandstone and claystone.	Camelid, genus and species indeterminate; partial cuboid of size comparable to that of *Oxydactylus*.
5	Gray sandy tuffaceous claystone containing conglomerate lenses.	Ochotonid sp.; two cheek teeth.
6	Gray tuffaceous siltstone and claystone.	Ochotonid sp.; upper cheek tooth.
7	Gray to yellowish-gray sandy granulitic claystone.	*Metechinus marslandensis*.[2] Soricid, possibly *Limnoecus*.[2] Several other insectivores.[2] Sciurid.[2] Cricetids, several species.[2] Heteromyid.[2] Geomyid.[2] *Plesiosminthus* sp.[2] ?*Desmatolagus* sp.[3] Merycoidodont.[2] Antilocaprid.[2]
(4)	Orange-gray tuffaceous siltstone and dirty white ash bed.	*Mesogaulus* sp. (*M. paniensis*?).[2] *Grangerimus* sp.[2] *Miospermophilus bryanti*.[2] Chiropteran.[2] Ochotonid.[3] Mustelid.[2]

[1] From upper part of Troublesome, primarily in Barger Gulch.
[2] Identified by Peter Robinson.
[3] Identified by M. R. Dawson.
[4] From lower part of Troublesome in Barger Gulch.

FIGURE 25. Fossil vertebrates from the Troublesome Formation (Miocene) (from Izett, 1968, Figure 9).

6.2.51 Santa Fe Formation

The Oligocene to Pliocene Santa Fe Formation was named for exposures in the Rio Grande Valley, Santa Fe County, NM (Hayden, 1869). Scott and Taylor (1975) infer a Miocene and Pliocene age for the Santa Fe Formation in southern Colorado based on superpositional relationships and lithologic similarities to the Santa Fe Formation in New Mexico (Sharp, 1978). The unit is exposed in northern New Mexico and in south-central Colorado. In the Wet Mountain Valley and vicinity, the Santa Fe Formation overlies the Oligocene and Miocene Devils Hole Formation and underlies Verdos Alluvium or younger Quaternary deposits. The formation is the uppermost Tertiary unit in the Wet Mountain Valley and, based on its inferred age, is probably at least partially correlative with the Dry Union and Troublesome Formations in the Rocky Mountains and the Ogallala Formation in the Great Plains. The Santa Fe Formation appears to exceed 1,200 feet in thickness (Scott and Taylor, 1975; Sharp, 1978). It is composed of irregularly stratified fine to coarse, reddish-orange silty sandstone with interbedded pebbles, cobbles, and boulders (Scott and Taylor, 1975; Sharp, 1978). The coarser beds are lenticular and discontinuous. Lithologies of the clasts in the conglomerates vary by location within the depositional basin. The clasts are derived primarily from volcanic rock units but also include fragments of igneous, metamorphic, and sedimentary rock. Santa Fe Formation strata in the Wet Mountain Valley are nearly flat lying and are deeply dissected. At most locations, the unit is covered by gently sloping Pleistocene terrace gravels derived from the Wet Mountains. The gently sloping terrace gravels prevent the formation of exposures that might otherwise produce surface fossils from the Santa Formation (Scott and Taylor, 1975). The Santa Fe Formation is a basin fill that was fluvially deposited by streams and rivers.

No identifiable age-diagnostic vertebrate fossils have been reported from the Santa Fe Formation. Evanoff and colleagues (2001) reported observing mammalian long bone fragments embedded in rocks of the Santa Fe Formation. They were not collected because they are not identifiable, but they are significant because they are the first occurrences of fossil bones reported from the Santa Fe Formation. Mammalian fossils that were earlier reported to have been collected from the Santa Fe Formation were later determined to have originated in deposits of alluvium now mapped as Verdos Alluvium and were discovered in association with deposits of Type O Pearlette Ash (~600,000 years B.P.). Scott and Taylor (1975) provided clarification regarding the provenance of these fossils, which include camel and horse. Because the Santa Fe Formation has not been adequately sampled and the discovery of identifiable vertebrate fossils there would be of great scientific importance, the unit is considered to have unknown paleontological potential (PFYC Class 3b).

6.2.52 Ogallala Group

The Ogallala Group (or Formation) is middle Miocene to Pliocene in age (Hemingfordian to Blancan NALMA). It and its stratigraphic equivalents are present over a large area including Montana, Wyoming, Colorado, New Mexico, Kansas, Oklahoma, Texas, South Dakota, and Nebraska. Some of the formations of the Ogallala Group include the Rosebud, Oak Creek, and Thin Elk Formations in South Dakota and the Valentine, Ash Hollow, Kimball, Sydney, and Snake Creek Formations in Nebraska. In Colorado, the Ogallala Group includes the Martin Canyon and Pawnee Creek Formations and the "Upper Ogallala Group" (Tedford, 1999, 2004). Thicknesses of the unit are highly variable, and it commonly forms paleovalleys and otherwise reflects paleotopography. Lithologically, the Ogallala consists predominantly of light-gray, dark-gray, tan, light-brown, and brown, soft to indurated, arkosic muddy sandstone, sandstone, conglomerate, and scattered limestone beds. The Ogallala is primarily alluvial, colluvial, and eolian in origin (Galusha, 1975). Depositional environments include savanna grassland with river and floodplains periodically inundated with volcanic ash.

Rocks of the Ogallala Group contain locally abundant vertebrate fossils, especially mammals (Voorhies, 1990). Particularly significant fossil quarries include Ashfall Fossil Beds State Park in Nebraska (Valentine and Ash Hollow Formations), the Kepler and Greenwood Canyon Quarries (Breyer, 1985), the Hazard Homestead Quarry (Voorhies and Kue, 1983), the Hotell Ranch Rhino Quarries (Voorhies et al., 1987), and the Gaedke and Medich Localities (Tanner et al., 1986). Many of these quarries have yielded complete skeletons and skulls.

Tedford (2004) summarized the composite fauna of the Martin Canyon Formation, concluding that it is of early Hemingfordian age and closely resembles the fauna of the Runningwater Formation of northwestern Nebraska. As defined by Galbreath (1953), the Martin Canyon local fauna was collected from University of Kansas Quarry A and nearby localities in the same horizon, and includes 21 taxa. These include several insectivores, a rabbit, several rodents including the beaver *Euroxenomys*, the borophagine canids *Tomarctus* and *Phlaocyon*, the chalicothere *Macrotherium*, the horses *Merychippus* and *Parahippus*, the rhinoceros *Aphelops*, a peccary, a camel, the oreodonts *Merycochoerus proprius magnus* and *Merychyus elegans*, and the musk deer *Blastomeryx*. Tedford (2004) noted that the fauna of the Martin Canyon Formation at Pawnee Buttes closely resembles that of the Martin Canyon local fauna. Most of the fossils known from the Martin Canyon Formation come from the lower and middle parts of the unit (Matthew's horizons C and D). It is less fossiliferous than the Pawnee Creek Formation.

The Pawnee Creek Formation contain locally abundant vertebrate fossils, whereas the "Upper Ogallala Group" contains scattered vertebrate fossils (Evanoff et al., 1999; Tedford, 1999, 2004). Characteristic fossils of the Ogallala Group and its members include rhinoceros, tapir, five species of horse, three species of camel, the diminutive antilocaprid (pronghorn) *Merycodus*, primitive deer-like palaeomerycids, gomphothere, primitive dogs and dog-like carnivores, the primitive cat *Pseudaelurus*, rodents including horned mylagaulids and beavers, insectivores, rabbits, birds including secretary bird and crowned crane, reptiles including snakes and giant tortoise, and amphibians including frog and giant salamander (Galbreath, 1953; Green and Holman, 1977; MacDonald, 1960; Skinner and Taylor, 1967). Although the Martin Canyon Formation and "Upper Ogallala Group" are less fossiliferous than the Pawnee Creek Formation, the Ogallala Group as a whole is considered to have high paleontological potential (PFYC 4) in Colorado because its constituent formations are lumped on geologic maps.

6.2.53 Dry Union Formation

The Dry Union Formation, originally named the "Arkansas Marl" by Hayden (1869), who interpreted the unit as Pliocene lake deposits, is late Miocene and early Pliocene in age. The Dry Union is mostly covered by Quaternary deposits but is locally exposed as badlands in the Upper Arkansas River Valley and the South Park Basin. The formation probably underlies most of the Arkansas Valley from Leadville to Salida, ranging in thickness from 260 feet near Salida to up to 10,000 feet thick in a fault trough to the west of the Arkansas River (Van Alstine, 1974). The unit consists of massive, brown, sandy silt and interbedded, poorly sorted gravel, sand, and volcanic ash (Van Alstine and Cox, 1969; Van Alstine, 1974). The formation contains white to gray beds of volcanic ash and includes gray, yellowish-gray, reddish-gray, or greenish-gray strata composed of clay, silt, sand, and gravel derived primarily from volcanic rocks but also containing Precambrian rocks.. The unit's lower part contains fragments of Wall Mountain Tuff, ash flow from a caldera near Mount Aetna, Badger Creek Tuff, Mount Antero Granite, Nathrop Volcanics, and Palaeozoic chert and Quartzite. Some strata are cemented with calcium carbonate, and many sand and gravel beds are cross-bedded and are locally tilted. The Dry Union is comprised chiefly of angular grains of fresh rock derived from nearby mountains, and the unit was deposited in alluvial fans, river channels, lakes, and ponds and on floodplains. The formation is likely more than 5,000 feet thick where it is dropped down along the deep western side of the upper Arkansas Valley graben (Scott, 1975; Scott et al., 1975).

The Dry Union Formation locally contains vertebrate, invertebrate, and plant fossils. Reported vertebrate fossils include several genera of horses, a genus of mastodon, a genus of camel, the rare cervid *Yumaceras*, the antilocaprid *Plioceras*, and the leporid *Hypolagus* (Van Alstine, 1974; unpublished museum data). Plant fossils include the cattail *Typha lesquereuxi* and an undetermined locust (Van Alstine and Cox, 1969; Van

Alstine, 1974). Invertebrates include mostly indeterminate smooth-shelled bivalves, gastropods, and ostracods, which occur in the Dry Union pond deposits. Charophytes, the remains of the alga *Chara* (stonewort), have also been reported (Van Alstine and Cox, 1969; Van Alstine, 1974). The Dry Union Formation has produced a diversity of scientifically important fossils, although they are generally rare; as a result the formation is considered to have high paleontological potential (PFYC 4).

6.3 SURFICIAL SEDIMENTARY DEPOSITS

Surficial sedimentary geologic units have low (PFYC 2) or moderate (PFYC 3) potential to produce scientifically important paleontological resources depending upon their age, composition, and depositional history. These units include sediments of latest Tertiary (Pliocene) and Quaternary (Pleistocene or Holocene) age. Nine surficial sedimentary deposits are mapped within the RGFO Planning Area by Tweto (1979) (Table 5). These are further subdivided into 14 corresponding surficial sedimentary deposits that represent named and unnamed geologic units on larger-scale geologic maps. These 14 geologic units are ranked as PFYC 2 or 3 (Table 5).

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TABLE 5. Quaternary Surficial Deposits within the RGFO Area (Geologic Map Units from Tweto, 1979).

Map Unit Name	Dominant Lithology	Equivalent Units	Physiographic Region	Abbreviation	BLM PFYC	Recommended PFYC	Age	Type Locality	Typical Fossils
Bouldery Gravel on Old Erosional Surfaces of Front Range	Bouldery gravel	N/A	Front Range Uplift	Tgv	2	2	Pliocene	N/A	No reports of fossils
Older Gravels and Alluviums (Qgo)	Brown to reddish-brown well stratified pebbly clay and silt interlayered with gravel, cobbles and boulders, with larger and more abundant boulders closer to the mountains	Slocum Alluvium	Cañon City Basin, Upper Arkansas River Valley, Southeastern Colorado, South Park Basin, Raton Basin, Huerfano Park, Front Range Uplift, Denver-Julesburg Basin	Qs	3	3	Pleistocene	Slocum Ranch, Douglas County, CO (Scott, 1960)	Bison, horse, prairie dog, gopher Richardson's ground squirrel, and mollusks,
	Light brown to reddish-brown poorly sorted stratified gravel containing lenses of clay, silt and sand, with larger and more abundant boulders near the mountains. Locally contains Pearlette Type O volcanic ash.	Verdos Alluvium	Cañon City Basin, Upper Arkansas River Valley, Southeastern Colorado, South Park Basin, Raton Basin, Huerfano Park, Front Range Uplift, Denver-Julesburg Basin	Qv	3	3	Pleistocene (contains ash dated 6000,000 BP)	Verdos Ranch, Douglas County, CO (Scott, 1960)	Horse and large Camel (Scott, 1978; unpublished USGS data)
	Reddish-brown to light brown poorly sorted coarse sand and gravel, cobbles and scattered boulders	Rocky Flats Alluvium	Cañon City Basin, Upper Arkansas River Valley, Southeastern Colorado, South Park Basin, Raton Basin, Huerfano Park, Front Range Uplift, Denver-Julesburg Basin	Qrf	3	3	Pleistocene-Nebraskan	Rocky Flats Jefferson County, CO (Scott, 1960)	*Stegomastodon elegans* (Proboscidean), Horse (*Dolichohippus* sp.), prairie dog
	Brownish-gray to pale gray boulder alluvium, crudely stratified, poorly sorted	Nussbaum Alluvium	Cañon City Basin, Upper Arkansas River Valley, Southeastern Colorado, South Park Basin, Raton Basin, Huerfano Park, Front Range Uplift, Denver-Julesburg Basin	Qn	3	3	Pliocene and Pleistocene (Blancan and Irvingtonian)	Likely Nussbaum Spring east of Pueblo, CO (Gilbert, 1987)	*Stegomastodon*, bison, horse, camel, ground squirrel, Prairie dog, and bird
Older Glacial Drift	See "Glacial Drift (Qd)"	N/A	Upper Arkansas River Valley, South Park Basin	Qdo	3	3	Pleistocene-Pre-Bull Lake Age	N/A	See "Glacial Drift (Qd)"
Older Eolian Deposits	See "Eolian Deposits (Qe)"	Loveland Loess	Denver-Julesburg Basin	Qeo	3	3	Pleistocene	Harrison County, IA (Daniels and Handy, 1959)	See "Eolian Deposits (Qe)"
Gravels and Alluvium (Qg)	Pink to light brown, generally well stratified sand and gravel in well-defined terraces	Broadway Alluvium	Cañon City Basin, Upper Arkansas River Valley, Southeastern Colorado, South Park Basin, Huerfano Park, Front Range Uplift, Denver-Julesburg Basin	Qb	3	3	Pleistocene-Wisconsin Age	Gravel Pit in Adams County, CO (Scott, 1960)	Mammoth, horse, bison, camel, and small mammals
	Reddish- to yellowish-brown pebbly arkosic sand, coarse sand, cobble-sized gravel, and occasional boulders. Includes lenticular masses of silt and clay, commonly with contorted bedding	Louviers Alluvium	Cañon City Basin, Upper Arkansas River Valley, Southeastern Colorado, South Park Basin, Huerfano Park, Front Range Uplift, Denver-Julesburg Basin	Qlo	3	3	Pleistocene-Bull Lake and Pinedale Age	Gravel Pit on northeast edge of Louviers, CO (Scott, 1960)	Mammoth, bison, horse, camel, jackrabbit, ground squirrel, gopher, and prairie dogs
Glacial Drift	Brownish-gray to light gray sandy bouldery alluvium with boulders ranging from about ten inches to four feet in diameter, moderately well sorted, moderately stratified, and composed of Tertiary igneous and Precambrian metamorphic and igneous rocks	N/A	Upper Arkansas River Valley, South Park Basin, Raton Basin, Huerfano Park, Front Range Uplift	Qd	3	3	Pleistocene-Pinedale and Bull Lake Glaciations	N/A	Bison and mammoth
Eolian Deposits	Windblown clay, silt, silty sand to medium-grained sand deposited as barchans, linear, and domelike dunes, sand sheets, and also as veneer on uplands. They are generally structureless, but are locally cross-bedded. Loess deposits are extensive in eastern Colorado	Unnamed Eolian Deposits and Peoria Loess	Southeastern Colorado, Denver-Julesburg Basin	Qe	3	3	Pleistocene and Holocene	Peoria: Tindall School Section south of Peoria, IL (Hansel and Johnson, 1966)	Mammoth, camel, bison, horse, badger, and several species of rodents
Landslide Deposits	Chaotically bedded debris to intact bedrock slump blocks including earth slides, earth flows, rocks slides, and debris slides. Also includes colluvium.	N/A	Cañon City Basin, Upper Arkansas River Valley, Southeastern Colorado, Raton Basin, Huerfano Park, Front Range Uplift, Denver-Julesburg Basin	Ql	3	2	Pleistocene and Holocene	N/A	Unknown
Modern Alluvium (Qa)	Brown, light brown, and light to dark-gray interbedded sand, silt and clay	Piney Creek Alluvium	Cañon City Basin, Upper Arkansas River Valley, Southeastern Colorado, South Park Basin, Raton Basin, Front Range Uplift, Denver-Julesburg Basin	Qp	2	2	Holocene	Piney Creek, Arapahoe County, CO (Hunt, 1954)	Too young to contain in-situ fossils
	Light to dark-grayish-brown clay, sand, silt and small amounts of gravel, and dark brown and dark bluish-black humic bog clays, locally interbedded with sand and silt	Post-Piney Creek Alluvium	Cañon City Basin, Upper Arkansas River Valley, Southeastern Colorado, South Park Basin, Raton Basin, Front Range Uplift, Denver-Julesburg Basin	Qp	2	2	Holocene	Unknown	Too young to contain in-situ fossils

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Surficial sedimentary deposits within the RGFO Planning Area include a variety of sediments deposited by rivers and streams, glacial activity, wind, colluvium, and landslides. Surficial deposits of Holocene age, regardless of their depositional history, are less than 10,000 years old by definition and are generally considered too young to contain in-situ fossils of paleontological importance. On the other hand, surficial deposits of Pliocene and Pleistocene age, particularly alluvium, may contain mineralized, partially mineralized, or non-mineralized animal bones, invertebrates, and plant remains of paleontological importance. With the exception of some caves, hot springs, and tar deposits, Pleistocene fossil localities typically occur in low to moderate density. Nevertheless, a number of rich and scientifically important localities are present in alluvium, lacustrine, and cave deposits in Colorado, including the RGFO Planning Area.

Eolian deposits, which consist of windblown silt and sand, do preserve fossils but only rarely and typically as isolated specimens or in small assemblages. Hunt (1954) reported fossils of mammoth and camel that were collected from Pleistocene-age eolian deposits at five localities in the Denver area. Additional fossil discoveries include horse and camel bones from south of Littleton (Scott, 1963) and badger, cottontail, jackrabbit, black-tailed prairie dog, the extinct white-tailed prairie dog, Richardson's ground squirrel, pocket gopher, vole, sagebrush vole, field mouse, pocket mouse, and possibly bison recorded by now retired CDOT Staff Paleontologist Steve Wallace in eastern Colorado (S. Wallace, written communication, 2000).

Colluvium and landslide deposits consist of rock and soil that have moved under the influence of gravity. These deposits form on slopes, and their lithologies are variable depending upon the source material. Generally, colluvium and landslides are much less likely to contain well-preserved fossils than intact native sediments. Both landslide material and colluvium are 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, varying degrees of information loss occur with the severity of changes to the slide mass. In particular, slopes that are underlain by the Morrison Formation are particularly prone to landslides because the Morrison contains swelling clays that lose shear strength when saturated with water.

Fossils of Pliocene age are not common in Colorado, and they are therefore scientifically important when discovered there. Geologic units of at least partial or potential Pliocene age include the Nussbaum Alluvium and the Dry Union, Ogallala, and Troublesome Formations, all of which are located, at least in part, within the RGFO Planning Area. The latter units are discussed in Section 6.2 of this report. However, the Nussbaum Alluvium is discussed here along with surficial deposits because it may include sediments and fossils of Pleistocene age. Unfortunately, due to the scarcity of localized fossils in the Nussbaum, constraining the age of the formation remains problematic. The Nussbaum has reportedly produced vertebrate fossils, including the remains of *Stegomastodon*, bison, horse, camel, ground squirrel, and prairie dog (Scott, 1963b; unpublished UCM paleontological data) (Table 5). Many Nussbaum specimens, including horse, camel, bison, squirrel, ground squirrel, and passeriform bird, were discovered at localities in the Corral Bluffs area near Colorado Springs. However, the provenance of some of the putative Nussbaum localities has been questioned, and the Corral Bluffs specimens may have been collected from younger late Pleistocene sediments or even Holocene loess rather than alluvium (Steve Wallace, written communication, 2013).

In summary, it is uncertain whether the Corral Bluffs fossils are in fact derived from Nussbaum Alluvium and also whether the Nussbaum locally includes sediments of Pleistocene or younger age, which would be contrary to the Pliocene age upon which the unit was originally defined.

Pleistocene fossils are commonly unearthed by construction excavations. Numerous such reports exist for the Denver area. For example, C.B. Hunt reported that more than 100 "collections" of Pleistocene and Holocene mammal remains were made during the fieldwork for his 1954 study, with an additional 32 previously curated "collections" housed at the Denver Museum of Natural History (now the DMNS). These specimens were found in alluvium (Hunt, 1954, p. 118), and practically all of them consist of "single bones, and a large proportion of them are fragmentary." Hunt's report attests to the mostly isolated nature of Pleistocene skeletal remains in the Denver area. Hunt (1954, p. 107) lists other fossils discovered in Pleistocene alluvial sediments in the general vicinity of central Denver, including the Piney Creek Alluvium (Hunt, 1954) and deposits that were later recognized and mapped as Broadway Alluvium and Louviers Alluvium (e.g. Scott, 1962). These fossils were identified by paleontologist C.L. Gazin of the NMNH and include camel bones, bison teeth, and antelope bones. In Colorado and the Rocky Mountain region in general, the most common Pleistocene fossil vertebrate fossils are mammoth, horse, bison, deer, and camel. However, numerous other taxa, including diverse small vertebrate, invertebrate, and plant assemblages, have been reported (Anderson, 1965; Barnosky, 2004; Cook, 1930, 1931; Emslie, 1986; Gillette and Miller, 1999; Gillette et al., 1999a, b; Graham and Lundelius, 1994; Heaton, 1999; Hunt, 1954; Lewis, 1970; Scott, 1963a; Smith et al., 1999; unpublished paleontological data, DMNS).

In 1960, a rancher discovered horse, mammoth, bison, camel, and pronghorn bones while digging a stock pond in Littleton. The fossils were apparently associated with archaeological artifacts in sediments originally deposited around an ancient spring, leading to intensive excavations in 1961 through 1962 and 1980 through 1981 by paleontologists, archaeologists, and geologists from the NMNH, USGS, the University of Nebraska State Museum, the University of Michigan, and the Illinois State Museum. This important site, now known as the Lamb Spring Archaeological Preserve, yielded more than 30 Columbian mammoths and skeletal remains of camel, wolf, ground sloth, horse, and bison. Spear points and bison bones are evidence of a hunt at the spring about 9,000 years ago. Most of the fossils are housed at the NMNH. However, in 2002, Jim Dixon and Paul Murphey, along with their students in the CU Museum and Field Studies Program Field School, re-excavated a mammoth skull that had been originally discovered by NMNH crews and then reburied. The skull, which belonged to a female Columbian mammoth, was transported to the DMNS for preparation and temporary display and is now housed in the museum's collections until a visitors center is constructed at the Lamb Spring Archaeological Preserve.

Gravel pits provide an excellent example of construction excavations in Pleistocene alluvium that have the potential to yield scientifically important assemblages of fossils. Two recently discovered localities include a gravel pit near Holyoke on the eastern plains within the RGFO Planning Area and a gravel pit near Villa Grove on BLM land managed by the San Luis Valley Field Office. Both sites were the focus of crews from the DMNS led by now retired Curator Richard Stucky during the 2011 and 2012 field seasons. The Weis gravel pit near Holyoke produced approximately 18 individuals of *Stegomastodon*, horse, an antelope-sized artiodactyl, camel, bison, a small rodent, and a vulture-sized bird. The age of this assemblage was estimated at approximately 1.2 million years BP based on the degree of enamel infolding in the *Stegomastodon* teeth. There was some field evidence, though inconclusive, of the preservation of tracks of medium- and large-sized artiodactyls or perissodactyls such as camels and horses. The *Stegomastodon* remains were deposited in an oxbow lake, while the smaller vertebrate fossils were deposited in a stream (fluvial) environment (R. Stucky, personal communication, 2015). The Villa Grove gravel pit yielded more than 100 specimens believed to be of Rancholabrean NALMA age (= late

Pleistocene, or approximately between 126,000 and 10,000 years BP), including Columbian mammoth, bison, camel, horse, dire wolf, rabbit, prairie dog, ground squirrel, and snails (DMNS, unpublished paleontological data). The diverse fauna from this site is currently being studied, and the research will soon be submitted for publication (Richard Stucky, personal communication, 2015).

There are a number of reports of Pleistocene fossils from the intermontane basins of Colorado, some of which are from within the RGFO Planning Area. Lewis (1990) reported mammoth fossils from near Fairplay. Cook (1930, 1931) reported bison and mammoth remains from five montane localities, including glacial moraines. Cockerell (1907) reported mammoth and horse remains from south of Florissant, CO, in Teller County. Emslie (1986) reported on fossils recovered from the latest Pleistocene Haystack Cave deposit at an altitude of 8,040 feet in Gunnison County. This fauna contains still extant local taxa in combination with other extant taxa that currently occupy higher elevation habitats or drier environments in Colorado. This type of "disharmonious fauna" has been well documented elsewhere in sedimentary deposits of late Wisconsin age elsewhere in North America. Within the BLM's San Luis Valley Field Office area, studies of Pleistocene fossil localities have shed light on ancient climatic fluctuations and paleoenvironmental change. For example, Dennis Stanford's (NMNH) work on the Zapata Mammoth Site just to the west of the Great Sand Dunes demonstrated that Clovis people hunted mammoth in the San Luis Valley during the latest Pleistocene. From 1979 to 1984, Karel Rogers of Alamosa College documented a number of Irvingtonian fossil localities from the Alamosa Formation on Alamosa National Wildlife Refuge. The Hansen Bluff Site and other nearby localities yielded an incredibly diverse fauna including ostracods, mollusks, fish, amphibians, reptiles, birds, and mostly small mammals (Rogers, 1984). Detailed faunal and stratigraphic analysis correlated the localities to two interglacial and one glacial period and documented the climatic and environmental changes indicated by the fossils and a record of nearly continuous sedimentation from approximately 2.67 million to 670,000 years BP (Rogers et al., 1992). In the early 1950s, while digging a cattle pond, a rancher discovered the Magna Site east of Saguache. In 1972, UCM curators Peter Robinson and Joe Ben Wheat and students excavated the site, which featured two vertically positioned mammoth limbs, indicating that the animal must have died in standing position. More than 100 other fossils including mammoth, ground sloth, wolf, bison, and camel were collected (Peter Robinson, written communication, 2015).

Located in Park County 30 miles south of Hartsel and within the RGFO Planning Area, the early and middle Pleistocene (1,500,000 to 600,000 year old) Porcupine Cave site is arguably the richest locality of Irvingtonian age in the world. The cave was originally discovered by miners in the 1860s, but it wasn't until 1981 that oil geologist Dan Rasmussen noticed fossils there during exploration with his son Larry. Largely preserved in pack rat middens, thousands of fossil bones and teeth were excavated by paleontologists from the Carnegie Museum of Natural History, the DMNS, and other institutions for nearly 10 field seasons beginning in 1992. At 9,500 feet, the cave yielded an incredibly diverse and well-preserved assemblage of amphibians, reptiles, 19 species of birds, and more than 75 species of mammals including camel, sloth, wolf, coatimundi, peccary, and cheetah (Barnosky, 2004; Barnosky and Rasmussen, 1998). Porcupine Cave fossils are housed at the DMNS, the UCMP, the Carnegie Museum of Natural History, and the University of Kansas Natural History Museum. The Porcupine Cave fauna remains the subject of ongoing research. Much of the work completed thus far has shed light on Pleistocene environmental change and the timing and modes of extinction and speciation during the middle Pleistocene (Barnosky, 2004). Another cave locality, this one managed by the BLM Colorado River Valley Field Office, was test excavated by the DMNS (then DMNH) in 1991. Because this cave remains a sensitive resource that has not yet been fully explored and excavated, it is not identified here by name. Among the findings was a specimen initially identified as a human canine tooth from cave sediments that were initially estimated to be 700,000 years old, far older than any other human remains known from the western hemisphere. Twenty years later, the tooth was reexamined and was determined not to be human, thereby resolving a potential conundrum in North American archaeology (Harley Armstrong, written communication, 2015).

Although the exceptionally rich, unusually diverse, and well-preserved middle to late Pleistocene Ziegler Reservoir fossil locality it is not located within the RGFO Planning Area, the site is worth mention because it has implications for the paleontological resource potential of similar deposits in montane environments within the RGFO Planning Area. This locality was discovered by bulldozer driver Jesse Steele while he worked on the expansion of Ziegler Reservoir near Snowmass Village in 2010. The subject of the largest paleontological salvage project in Colorado history over a total of seven weeks in 2010 and 2011, the locality was nicknamed the "Snowmastodon" site by the crew from the DMNS that recovered associated fossils. The locality yielded more than 4,000 well-preserved vertebrate specimens. The assemblage is dominated by mastodon remains but also includes mammoth, ground sloth, the giant *Bison latifrons*, camel, deer, a variety of small mammals, tiger salamander, and numerous other taxa. Exquisitely preserved plant fossils were also salvaged and provide an unprecedented nearly continuous record of alpine plant communities between approximately 140,000 and 55,000 years BP (Johnson et al., 2011; Johnson and Miller, 2012; Miller et al, 2014). Pleistocene fossils are generally rare in glacial and associated montane deposits, typically consisting of isolated poorly preserved skeletal remains. The Ziegler Reservoir fossils were deposited over many thousands of years in a small, alpine lake (Pigati et al., 2014). The site demonstrates the paleontological potential of similar sediments in the Rocky Mountains, the vast majority of which are rarely disturbed and hence provide few opportunities to sample and study their fossil record. An artist's rendition of the Denver-area landscape during the Pleistocene is depicted in Figure 26.

FIGURE 26. Artist's rendition of the Denver area during deposition of the Quaternary surficial sediments, titled Ice Age Summer (courtesy of the DMNS and Jan Vriesen).

With the exception of landslide deposits and colluvium for which PFYC assignments of 2 are recommended, all types of pre-Holocene surficial sedimentary deposits analyzed for this report should be assigned PFYC 3. Holocene surficial sedimentary deposits should be assigned PFYC 2. If the age of the unit is reported as Pleistocene and Holocene, it should be assigned PFYC 3.

7.0 CONCLUSIONS AND RECOMMENDATIONS

As analyzed herein, the RGFO Planning Area includes 62 geologic units with moderate to very high potential to contain scientifically significant paleontological resources. These include 42 geologic units with moderate potential (PFYC 3), 12 with high potential (PFYC 4), and 8 with very high potential (PFYC 5). Only one geologic unit, the Santa Fe Formation, is considered to have unknown potential (PFYC U). At least 136 fossil localities have been recorded on BLM managed lands within the RGFO Planning Area, including 101 on BLM owned surface and 35 for which the BLM owns only the mineral rights. The large number of publications devoted to paleontological resources collected within the RGFO Planning Area clearly demonstrate the richness and scientific importance of the fossil record in this area, its potential for future research and educational opportunities, and the importance of future management efforts.

Based on the results of this study, RMPS makes the following recommendations:

1. Two of the institutions contacted while preparing this report— the AMNH and NMNH (see Table 2) — were unable to provide paleontological locality data in time for potential inclusion in the locality geodatabase accompanying this report. It is highly likely that these institutions have records of fossil localities within the RGFO Planning Area, and it is possible that some of these localities are located on BLM managed lands (surface and/or mineral rights). RMPS recommends that the BLM follow up with the AMNH and NMNH in order to obtain and analyze fossil locality data when it becomes available.

2. Eleven fossil locality records identified in the fossil locality geodatabase were found to have problematic data that can likely be corrected with a limited amount of additional research.

3. The BLM provided numerous documents, pertaining to paleontological resources for review as part of this study. The review resulted in a list of 253 records that RMPS provided to the BLM separately from this report. RMPS recommends that the BLM review these records to determine 1) those localities that are located on BLM managed land; 2) those that are already included in the BLM's fossil locality geodatabase; and 3) those that are not included in the fossil locality geodatabase but should be.

4. The BLM should review the recommended PFYC assignments listed in the report text and summarized in Tables 4 and 5 and consider the changes recommended. RMPS recommends no changes to the PFYC assignments listed in Table 3 for igneous and metamorphic rock units.

5. A PFYC assignment of 3 (moderate potential) is recommended for alluvial and eolian sedimentary units that are known to be 10,000 years old or older, whereas a PFYC designation of 2 is recommended for younger sedimentary geologic units that are known to be less than 10,000 years old, and Pliocene and Pleistocene age sedimentary units that only rarely yield fossils such as landslide deposits and colluvium (Table 5). If the age of a surficial sedimentary unit is uncertain, or if the unit is thought to include both Pleistocene and Holocene sediments, the higher PFYC assignment (PFYC 3) should be used. Given the large number of Pleistocene fossil localities in eastern Colorado reported in the literature and represented by museum records, the determination of PFYC assignments for the latest Tertiary and Quaternary surficial deposits warrants special consideration for three reasons. First, the age of surficial sediments is not always readily apparent. As a result, it is difficult in certain geologic settings to distinguish Pleistocene from Holocene sediments. PFYC 2 (low potential) geologic units are defined as those units that are "generally younger than 10,000 years before present," and in which "vertebrate or significant invertebrate or plant fossils are not present or are very rare" (BLM,

2007). Second, unlike bedrock, surficial sediments are frequently vegetated, generally making it more difficult to locate fossils in outcrop because there are fewer exposures. Third, many late Pleistocene fossils are less mineralized than older fossils, making them more vulnerable to taphonomic effects of secondary weathering, mechanical breakage, and degradation due to groundwater and other surface and subsurface environmental factors. In combination, this makes them less likely to be found on the surface than older, more mineralized fossils that weather onto the surface from eroding bedrock. Nevertheless, museum records and published literature indicate that while Pleistocene fossils are rarely exposed on the ground surface, they are often preserved in certain types of surficial sediments, especially alluvium and cave deposits. PFYC 3 (moderate and unknown potential) geologic units are defined as those units whose "fossil content varies in significance abundance and predictable occurrence, or sedimentary units of unknown fossil potential." Furthermore, geologic units of moderate potential (PFYC 3) are "often marine in origin with sporadic known occurrences of vertebrate fossils," and "vertebrate fossils and scientifically significant invertebrate fossils known to occur intermittently; predictability known to be low" (BLM, 2007).

6. Appendix A is a hyperlinked list of geologic maps covering the RGFO Planning Area. For future project specific analyses, RMPS recommends that the most detailed (largest scale) maps available be used.

7. Fossil localities that produce common types of fossil invertebrates and plants may provide opportunities for recreational collecting. Recreational collecting could be beneficial to overall management efforts because the activity channels fossil collecting to specific locations where it can be more easily monitored. In theory, recreational collecting may also reduce unlawful collecting activities by providing an alternative and legal opportunity to collect fossils. Previously recorded fossil localities in PFYC 3 geologic units located on BLM owned surface should be evaluated for their suitability for hobby collecting. Easily accessible localities with abundant fossils consisting of common taxa that are already well represented in museum collections are the most suitable for hobby collecting. Given the locally abundant marine invertebrate fossils in previously well-sampled Cretaceous rock units in eastern Colorado, it is likely that fossil localities can be identified that would promote interest in the fossil record and the science of paleontology while instilling respect for lawful fossil collecting practices.

8. This report focuses on the geology and paleontology of the RGFO Planning Area. A logical next step, which was beyond the scope of this study, would be to determine the geology of BLM-managed parcels individually in order to identify parcels with PFYC 4 and 5 geologic units in order to focus paleontological resource management efforts on these areas. This could be accomplished using detailed geologic maps and aerial imagery.

9. Previously recorded fossil localities on BLM lands include those that are still productive and those that aren't. For those that commonly produce vertebrate fossils in PFYC 4 and 5 geologic units, this is particularly important. Additionally, some localities may have historic importance (e.g., the Marsh and Cope quarries in the Garden Park Paleontological Area). RMPS recommends that the BLM individually assess the status of its existing fossil localities that have the potential to produce fossils of scientific importance. Those localities that are productive and/or have historic importance should be subject to periodic monitoring and other resource-management strategies to protect the resources in-situ or collect them if they are threatened by environmental factors or human activities. In some cases such as localities that have not been recently worked, this would require field assessments of individual fossil localities.

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APPENDIX A. Geologic Maps of the RGFO Planning Area

GeoTIF	Scale 1:24,000	USGS Quad	County
	Widmann, B.L., Bartos, P.J., Madole, R.F., Barba, K.E., and Moll, M.E., 2004, Geologic Map of the Alma Quadrangle, Park and Summit Counties, Colorado: Colorado Geological Survey, Open-File Report OF04-03, scale 1:24,000.	Alma	Park + Summit
X	Lindvall, R.M, 1979, Geologic map of the Arvada quadrangle, Adams, Denver, and Jefferson Counties, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-1453, scale 1:24,000.	Arvada	Adams, Denver, + Jefferson
X	Lindvall, R.M., 1972, Geologic map of the Arvada quadrangle, Adams, Denver, and Jefferson Counties, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-348, scale 1:24,000.	Arvada	Adams, Denver, + Jefferson
X	Bryant Bruce 1976 Reconnaissance geologic map of the Bailey quadrangle Jefferson and Park Counties Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-816 scale 1:24:000	Bailey	Jefferson + Park
X	Lindsey, D.A., Johnson, B.R., Soulliere, S.J., Bruce, R.M., and Hafner, Katrin, 1986, Geologic map of the Beck Mountain, Crestone Peak, and Crestone quadrangles, Custer, Huerfano, and Saguache Counties, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-1878, scale 1:24,000.	Beck Mountain, Crestone Peak, + Crestone	Custer, Huerfano, + Saguache
	Sheridan, D.M. and Reed, J.C., 1971, Preliminary geologic map of the Bergen Park area, Jefferson and Clear Creek Counties, Colorado: U.S. Geological Survey, Open-File Report OF-71-256, scale 1:24,000.	Bergen Park	Jefferson + Clear Creek
X	Theobald, P.K., 1965, Preliminary geologic map of the Berthoud Pass quadrangle, Clear Creek and Grand Counties, Colorado: U.S. Geological Survey, Miscellaneous Geologic Investigations Map I-443, scale 1:24,000.	Berthoud Pass	Clear Creek + Grand
X	Scott, G.R. and Taylor, R.B., 1973, Reconnaissance geologic map of the Beulah quadrangle, Pueblo County, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-551, scale 1:24,000	Beulah NE	Pueblo
X	Scott, G.R., 1972, Reconnaissance geologic map of the Beulah NE quadrangle, Pueblo County, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-352, scale 1:24,000.	Beulah NE	Pueblo
X	Abbott J.T. 1976 Geologic map of the Big Narrows quadrangle Larimer County Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ-1323 scale 1:24:000	Big Narrows	Larimer
	Thorson, J.P., 2003, Geologic Map of the Black Forest Quadrangle, El Paso County, Colorado: Colorado Geological Survey, Open-File Report OF03-06, scale 1:24,000.	Black Forest	El Paso

X	Taylor, R.B., 1975, Geologic map of the Black Hawk quadrangle, Gilpin, Jefferson, and Clear Creek Counties, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-1248, scale 1:24,000.	Black Hawk	Gilpin, Jefferson, + Clear Creek
X	Wrucke, C.T. and Wilson, R.F., 1967, Geologic map of the Boulder quadrangle, Boulder County, Colorado: U.S. Geological Survey, Open-File Report OF-67-281, scale 1:24,000.	Boulder	Boulder
	Wallace, C., Keller, J., McCalpin, J., Bartos, P., Route, E., Jones, N., Gutierrez, F., Williams, C., and Morgan, M. L., 2005, Geologic Map of the Breckenridge Quadrangle, Summit and Park Counties, Colorado: Colorado Geological Survey, Open-File Report 02-07, scale 1:24,000.	Breckenridge	Summit + Park
X	Braddock W.A. O'Connor J.T. and Curtin G.C. 1989 Geologic map of the Buckhorn Mountain quadrangle Larimer County Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ-1624 scale 1:24:000	Buckhorn Mountain	Larimer
	Keller, J.W., McCalpin, J.P., and Lowry, B.W., 2004, Geologic Map of the Buena Vista East Quadrangle, Chaffee County, Colorado: Colorado Geological Survey, Open-File Report OF04-04, scale 1:24,000.	Buena Vista East	Chaffee
	McCalpin, J.P. and Shannon, J.R., 2005, Geologic Map of the Buena Vista West Quadrangle, Chaffee County, Colorado: Colorado Geological Survey, Open-File Report OF05-08, scale 1:24,000.	Buena Vista West	Chaffee
Shapefiles	McCalpin, J.P., Temple, Jay, Sicard, Karri, Mendel, David, and Ahmad, Bashir, 2012, Climax Quadrangle Geologic Map, Lake and Park Counties, Colorado: Colorado Geological Survey, Open-File Report , scale 1:24,000.	Buena Vista West	Chaffee
	Eppinger, R.G., Theobald, P.K., and Carlson, R.R., 1984, Preliminary geologic map of the western and southern parts of the Byers Peak, the northwestern part of the Loveland Pass, and the eastern part of the Ute Peak 7-1/2 minute quadrangles, Clear Creek and Grand Counties, Colorado: U.S. Geological Survey, Open-File Report OF-84-274, scale 1:24,000.	Byers Peak + Loveland Pass	Clear Creek + Grand
	Morgan, M.L. and Barkmann, P.E., 2012, Eastonville Quadrangle Geologic Map, El Paso and Elbert Counties, Colorado: Colorado Geological Survey, Open-File Report , scale 1:24,000.	Cabin Gulch	Elbert
	Wallace, C.A. and Lawson, A.D., 1998, Geologic map of the Cameron Mountain quadrangle, Chaffee, Fremont and Park Counties, Colorado: Colorado Geological Survey, Open-File Report OF-98-4, scale 1:24,000.	Cameron Mountain	Chaffee, Fremont, + Park
	Wallace, C.A. and Lawson, A.D., 2008, Geologic Map of the Cameron Mountain Quadrangle, Chaffee, Fremont and Park Counties, Colorado: Colorado Geological Survey, Open-File Report 08-12, scale 1:24,000.	Cameron Mountain	Chaffee, Fremont, + Park
X	Scott, G.R., 1977, Reconnaissance geologic map of the Canon City quadrangle, Fremont County, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-892, scale 1:24,000.	Canon City	Fremont County

X	Braddock W.A. Nutalay Prinya and Colton R.B. 1988 Geologic map of the Carter Lake Reservoir quadrangle Boulder and Larimer Counties Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ-1628 scale 1:24:000	Carter Lake Reservoir	Boulder + Larimer
	Morgan, M.L., Siddow, C.S., Rowley, P.D., Temple, J., Keller, J.W., Archuleta, B.H., and Himmelreich, J.W., 2004, Geologic Map of the Cascade Quadrangle, El Paso County, Colorado: Colorado Geological Survey, Open-File Report OF03-18, scale 1:24,000.	Cascade	El Paso
	Wobus, R.A. and Scott, G.R., 1977, Reconnaissance geologic map of the Cascade quadrangle, El Paso County, Colorado: U.S. Geological Survey, Open-File Report OF-77-138, scale 1:24,000.	Cascade	El Paso
	Thorson, J.P., 2004, Geologic Map of the Castle Rock South Quadrangle, Douglas County, Colorado: Colorado Geological Survey, Open-File Report OF04-05, scale 1:24,000.	Castel Rock S	Douglas
	Wallace, C.A. and Keller, J.W., 2003, Geologic Map of the Castle Rock Gulch Quadrangle, Chaffee and Park Counties, Colorado: Colorado Geological Survey, Open-File Report 01-01, scale 1:24,000.	Castle Rock Gulch	Chaffee + Park
	Thorson, J.P., 2005, Geologic Map of the Castle Rock North Quadrangle, Douglas County, Colorado: Colorado Geological Survey, Open-File Report OF05-02, scale 1:24,000.	Castle Rock N	Douglas
X	Pillmore, C.L., 1966, Geologic map of the Catskill NW quadrangle, New Mexico and Colorado: U.S. Geological Survey, Open-File Report OF-66-104, scale 1:24,000.	Catskill NW	
	Sims, P.K. and Gable, D.J., 1967, Petrology and structure of Precambrian rocks, Central City quadrangle, Colorado: U.S. Geological Survey, Professional Paper 554-E, scale 1:24,000.	Central City	
X	Sims, P.K., 1964, Geology of the Central City quadrangle, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-267, scale 1:24,000.	Central City	
X	Eggler, D.H. and Braddock, W.A., 1988, Geologic map of the Cherokee Park quadrangle, Larimer County, Colorado, and Albany County, Wyoming: U.S. Geological Survey, Geologic Quadrangle Map GQ-1615, scale 1:24,000.	Cherokee Park	Larimer
	Thorson, J.P., 2004, Geologic Map of the Cherry Valley School Quadrangle, Elbert, Douglas, El Paso Counties, Colorado: Colorado Geological Survey, Open-File Report OF04-06, scale 1:24,000.	Cherry Calley School	Elbert, Douglas, + El Paso
	Rowley, P, Himmelreich, J.W., Kupfer, D.H., and Siddoway, C.S., 2004, Geologic Map of the Cheyenne Mountain Quadrangle, El Paso County, Colorado: Colorado Geological Survey, Open-File Report OF02-05, scale 1:24,000.	Cheyenne Mountain	El Paso
Shapefiles	Kellogg, K.S., Ruleman, C.A., Shroba, R.R., and Braddock, W.A., 2010, Geologic map of the Clark Peak quadrangle, Jackson and Larimer Counties, Colorado: U.S. Geological Survey, Scientific Investigations Map SIM-3010, scale 1:24,000.	Clark Peak	Jackson + Larimer
Shapefiles	Morgan, M.L., 2009, Geologic Map of the Elizabeth Quadrangle, Elbert County, Colorado: Colorado Geological Survey, Open-File Report 09-03, scale 1:24,000.	Climax	Lake + Park
	Carroll C.J. and Crawford T.A. 2000 Geologic map of the Colorado Springs quadrangle El Paso County Colorado: Colorado Geological Survey Open-File Report OF-00-3 scale 1:24:000	Colorado Springs	El Paso

Shapefiles	Lindvall, R.M., 1979, Preliminary geologic map of the Commerce City quadrangle, Adams and Denver Counties, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-1067, scale 1:24,000.	Commerce City	Adams + Denver
X	Lindvall, R.M., 1980, Geologic map of the Commerce City quadrangle, Adams and Denver Counties, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-1541, scale 1:24,000.	Commerce City	Adams + Denver
	Widmann, B.L., Kirkham, R.M., Keller, J.W., Poppert, J.T., and Price, J.B., 2006, Geologic Map of the Como Quadrangle, Park County, Colorado: Colorado Geological Survey, Open-File Report OF05-04, scale 1:24,000.	Como	Park
X	Bryant Bruce 1974 Reconnaissance geologic map of the Conifer quadrangle Jefferson County Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-597 scale 1:24:000	Conifer	Jefferson
X	Wobus, R.A., Chase, R.B., Scott, G.R., and Taylor, R.B., 1985, Reconnaissance geologic map of the Cooper Mountain quadrangle, Fremont County, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-1762, scale 1:24,000.	Cooper Mountain	Fremont
	Widmann, B.L., Bartos, P.J., McCalpin, J.P., and Jackson, J., 2004, Geologic Map of the Copper Mountain Quadrangle, Summit, Eagle, Lake, and Park Counties, Colorado: Colorado Geological Survey, Open-File Report OF03-20, scale 1:24,000.	Copper Mountain	Summit, Eagle, Lake + Park
X	Soister, P.E., 1968, Geologic map of the Corral Bluffs quadrangle, El Paso County, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-783, scale 1:24,000.	Corral Bluffs	El Paso
X	Braddock W.A. and LaFountain L.J. 1988 Geologic map of the Crystal Mountain quadrangle Larimer County Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ-1623 scale 1:24:000	Crystal Mountain	Larimer
X	Lindsey, D.A., 1995, Geologic map of the Cuchara quadrangle, Huerfano County, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-2283, scale 1:24,000.	Cucharas Pass	Huerfano
X	Lindsay, D.A., 1996, Reconnaissance geologic map of the Cucharas Pass quadrangle, Huerfano and Las Animas Counties, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-2294, scale 1:24,000.	Cucharas Pass	Huerfano + Las Animas
	Kirkham, R.M., Keller, J.W., Price, J.B., and Lindsay, N.R., 2006, Geologic Map of the Southern Half of the Culebra Peak Quadrangle, Costilla and Las Animas Counties, Colorado: Colorado Geological Survey, Open-File Report OF05-03, scale 1:24,000.	Culebra Peak	Costilla + Las Animas
	Temple, Jay, Busacca, Alan, Mendel, David, and Sicard, Karri, 2008, Geologic Map of the Dakan Mountain Quadrangle, Douglas, Teller, and El Paso Counties, Colorado: Colorado Geological Survey, Open-File Report 08-16, scale 1:24,000.	Dakan Mountain	Douglas, Teller, + El Paso
	Morgan, M.L., Temple, Jay, Grizzell, M.T., and Barkmann, P.E., 2005, Geologic Map of the Dawson Butte Quadrangle, Douglas County, Colorado: Colorado Geological Survey, Open-File Report OF04-07, scale 1:24,000.	Dawson Butte	Douglas

X	Taylor, R.B., 1974, Reconnaissance geologic map of the Deer Peak quadrangle and southern part of the Hardscrabble Mountain quadrangle, Custer and Huerfano Counties, Colorado: U.S. Geological Survey, Miscellaneous Investigations Series Map I-870, scale 1:24,000.	Deer Peak + Hardscrabble Mountain	Custer + Huerfano
X	Braddock W.A. Cole J.C. and Eggler D.H. 1989 Geologic map of the Diamond Peak quadrangle Larimer County Colorado and Albany County Wyoming: U.S. Geological Survey Geologic Quadrangle Map GQ-1614 scale 1:24:000	Diamond Peak	Larimer
	Temple, Jay and Busacca, A.J., 2009, Geologic Map of the Divide Quadrangle, Teller County, Colorado: Colorado Geological Survey, Open-File Report 09-02, scale 1:24,000.	Divide	Teller
X	Braddock W.A. Nutalaya Prinya Gawarecki S.J. and Curtin G.C. 1970 Geologic map of the Drake quadrangle Larimer County Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ-829 scale 1:24:000	Drake	Larimer
X	Young, E.J., 1991, Geologic map of the East Portal quadrangle, Boulder, Gilpin, and Grand Counties, Colorado: U.S. Geological Survey, Miscellaneous Investigations Series Map I-2212, scale 1:24,000.	East Portal	Boulder, Gilpin, + Grand
	Morgan, M.L., Barkmann, P.E., and Keller, S.M., 2012, Elbert Quadrangle Geologic Map, Elbert and El Paso Counties, Colorado: Colorado Geological Survey, Open-File Report , scale 1:24,000.	Eastonville	El Paso + Elbert
Shapefiles	Workman, J.B., 2008, Geologic map of the Eaton Reservoir quadrangle, Larimer County, Colorado and Albany County, Wyoming: U.S. Geological Survey, Scientific Investigations Map SIM-3029, scale 1:24,000.	Eaton Reservoir	Larimer
X	Wells, J.D., 1963, Preliminary geologic map of the Eldorado Springs quadrangle, Boulder and Jefferson Counties, Colorado: U.S. Geological Survey, Miscellaneous Geologic Investigations Map I-383, scale 1:24,000.	Eldorado Springs	Boulder + Jefferson
X	Wells, J.D., 1967, Geology of the Eldorado Springs quadrangle, Boulder and Jefferson Counties, Colorado: U.S. Geological Survey, Bulletin 1221-D, scale 1:24,000.	Eldorado Springs	Boulder + Jefferson
X	Lindsey, D.A., Soulliere, S.J., and Hafner, Katrin, 1985, Geologic map of Electric Peak and southwestern part of Beckwith Mountain quadrangles, Custer and Saguache Counties, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-1786, scale 1:24,000.	Electric Peak + Beckwith Mountain	Custer + Saguache
Shapefiles	Morgan, M.L., 2014, Geologic Map of the Cabin Gulch quadrangle, Elbert County, Colorado: Colorado Geological Survey, Open-File Report 14-01, scale 1:24,000.	Elizabeth	Elbert
Shapefiles	Ruleman, C.A. and Bohannon, R.G., 2008, Geologic map of the Elkhorn quadrangle, Park County, Colorado: U.S. Geological Survey, Scientific Investigations Map SIM-3043, scale 1:24,000.	Elkhorn	Park County
	Madole, R.F. and Thorson, J.P., 2003, Geologic Map of the Elsmere 7.5 Minute Quadrangle, El Paso County, Colorado: Colorado Geological Survey, Open-File Report OF02-02, scale 1:24,000.	Elsmere	El Paso

	Braddock W.A. 1967 Geologic map of the Empire quadrangle Grand Gilpin and Clear Creek Counties Colorado: U.S. Geological Survey Open-File Report OF-67-27 scale 1:24:000	Empire	Grand Gilpin + Clear Creek
X	Braddock W.A. 1969 Geology of the Empire quadrangle Grand Gilpin and Clear Creek Counties Colorado: U.S. Geological Survey Professional Paper 616 scale 1:24:000	Empire	Grand Gilpin + Clear Creek
X	Shroba, R.R., 1980, Geologic map and physical properties of the surficial and bedrock units of the Englewood quadrangle, Denver, Arapahoe, and Adams Counties, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-1524, scale 1:24,000.	Englewood	Denver, Arapahoe, + Adams
X	Colton R.B. and Anderson L.W. 1977 Preliminary geologic map of the Erie quadrangle Boulder Weld and Adams Counties Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-882 scale 1:24:000	Erie	Boulder, Weld, + Adams
X	Spencer, F.D., 1986, Coal geology and coal, oil, and gas resources of the Erie and Frederick quadrangles, Boulder and Weld counties, Colorado: U.S. Geological Survey, Bulletin 1619, scale 1:24,000.	Erie + Frederick	Boulder + Weld
X	Sheridan, D.M., Reed, J.C., and Bryant, Bruce, 1972, Geologic map of the Evergreen quadrangle, Jefferson County, Colorado: U.S. Geological Survey, Open-File Report OF-72-1711, scale 1:24,000.	Evergreen	Jefferson
X	Sheridan, D.M., Reed, J.C., Jr., and Bryant, Bruce, 1972, Geologic map of the Evergreen quadrangle, Jefferson County, Colorado: U.S. Geological Survey, Miscellaneous Geologic Investigations Map I-786-A, scale 1:24,000.	Evergreen	Jefferson
	Kirkham, R.M., Keller, J.W., Houck, K.J., and Lindsay, N.R., 2006, Geologic Map of the Fairplay East quadrangle, Park County, Colorado: Colorado Geological Survey, Open-File Report 06-09, scale 1:24,000.	Fairplay East	Park
	Widmann, B.L., Kirkham, R.M., Houck, K.J., and Lindsay, N.R., 2006, Geologic Map of the Fairplay West quadrangle, Park County, Colorado: Colorado Geological Survey, Open-File Report 06-07, scale 1:24,000.	Fairplay West	Park
	Morgan, M.L. and White, J.L., 2012, Falcon Quadrangle Geologic Map, El Paso County, Colorado: Colorado Geological Survey, Open-File Report , scale 1:24,000.	Falcon	El Paso
	Madole, R.F., 2003, Geologic Map of the Falcon NW 7.5 Minute Quadrangle, El Paso County, Colorado: Colorado Geological Survey, Open-File Report OF03-08, scale 1:24,000.	Falcon NW	El Paso
X	Lindvall, R.M., 1976, Preliminary geologic map of the Fort Logan quadrangle, Jefferson, Denver, and Arapahoe Counties, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-831, scale 1:24,000.	Fort Logan	Jefferson, Denver, + Arapahoe

X	Lindvall, R.M., 1978, Geologic map of the Fort Logan quadrangle, Jefferson, Denver, and Arapahoe Counties, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-1427, scale 1:24,000.	Fort Logan	Jefferson, Denver, + Arapahoe
X	Soister, P.E., 1965, Geologic map of the Fort Lupton quadrangle, Weld and Adams Counties, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-397, scale 1:24,000	Fort Lupton	Weld + Adams
	Kirkham, Robert, Houk, Karen, Lindsay, Neil, and Keller, Steven, 2007, Geologic Map of the Garo Quadrangle, Park County, Colorado: Colorado Geological Survey, Open-File Report 07-06, scale 1:24,000.	Garo	Park
	Widmann, B.L. and Miersemann, U., 2002, Geologic Map of the Georgetown 7.5 Minute Quadrangle, Clear Creek County, Colorado: Colorado Geological Survey, Open-File Report OF01-05, scale 1:24,000.	Georgetown	Clear Creek
X	Bucknam R.C. and Braddock W.A. 1989 Geologic map of the Glen Haven quadrangle Larimer County Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ-1626 scale 1:24:000	Glen Haven	Larimer
X	Wobus, R.A., 1976, Reconnaissance geologic map of the Glentivar quadrangle, Park County, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-759, scale 1:24,000	Glentivar	Park
X	Gable, D.J., 1980, Geologic map of the Gold Hill quadrangle, Boulder County, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-1525, scale 1:24,000.	Gold Hill	Boulder
X	Van Horn, Richard, 1972, Surficial and bedrock geologic map of the Golden quadrangle, Jefferson County, Colorado: U.S. Geological Survey, Miscellaneous Geologic Investigations Map I-761-A, scale 1:24,000.	Golden	Jefferson
X	Van Horn, Richard, 1957, Bedrock geology of the Golden quadrangle, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-103, scale 1:24,000.	Golden	
Shapefiles	Shroba, R.R., Kellogg, K.S., and Brandt, T.R., 2014, Geologic map of the Granite 7.5' quadrangle, Lake and Chaffee Counties, Colorado: U.S. Geological Survey, Scientific Investigations Map SIM-3294, scale 1:24,000.	Granite	Lake + Chaffee
	Thorson, J.P., 2003, Geologic Map of the Greenland Quadrangle, Douglas and El Paso Counties, Colorado: Colorado Geological Survey, Open-File Report 03-09, scale 1:24,000.	Greenland	Douglas + El Paso
	Wallace, C.A, Cappa, J.A., and Lawson, A.D., 1999, Geologic map of the Gribbles Park quadrangle, Park and Fremont Counties, Colorado: Colorado Geological Survey, Open-File Report OF-99-3, scale 1:24,000.	Gribbles Park	Park + Fremont
X	Soister, P.E., 1968, Geologic map of the Hanover NW quadrangle, El Paso County, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-725, scale 1:24,000.	Hanover NW	El Paso
Shapefiles	Kellogg, K.S., Lee, Keenan, Premo, W.R., and Cosca, M.A., 2013, Geologic map of the Harvard Lakes 7.5' quadrangle, Park and Chaffee Counties, Colorado: U.S. Geological Survey, Scientific Investigations Map SIM-3267, scale 1:24,000.	Harvard Lakes	Park + Chaffee
X	Maberry, J.O. and Lindvall, R.M., 1977, Geologic map of the Highlands Ranch quadrangle, Arapahoe and Douglas Counties, Colorado: U.S. Geological Survey, Geologic Quadrangle	Highlands Ranch	Arapahoe + Douglas

	Map GQ-1413, scale 1:24,000.		
X	Scott, G.R., 1972, Reconnaissance geologic map of the Hobson quadrangle, Pueblo and Fremont Counties, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-353, scale 1:24,000.	Hobson	Pueblo
X	Tweto, Ogden, 1971, Geologic map of the Holy Cross quadrangle, Eagle, Lake, Pitkin, and Summit Counties, Colorado: U.S. Geological Survey, Open-File Report OF-71-286, scale 1:24,000.	Holy Cross	Eagle, Lake, Pitkin, + Summit
X	Tweto, Ogden, 1974, Geologic map and sections of the Holy Cross quadrangle, Eagle, Lake, Pitkin, and Summit Counties, Colorado: U.S. Geological Survey, Miscellaneous Investigations Series Map I-830, scale 1:24,000.	Holy Cross	Eagle, Lake, Pitkin, + Summit
X	Lindsey, D.A., Scott, G.R., Soulliere, S.J., and DeAngelis, B.L., 1984, Geologic map of the Horn Peak quadrangle, Custer and Saguache Counties, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-1623, scale 1:24,000.	Horn Peak	Custer + Saguache
X	Braddock W.A. Calvert R.H. O'Connor J.T. and Swann G.A. 1973 Geologic map and sections of the Horsetooth Reservoir quadrangle Larimer County Colorado: U.S. Geological Survey Open-File Report OF-73-29 scale 1:24:000	Horsetooth Reservoir	Larimer
X	Braddock W.A. Calvert R.H. O'Connor J.T. and Swann G.A. 1989 Geologic map of the Horsetooth Reservoir quadrangle Larimer County Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ-1625 scale 1:24:000	Horsetooth Reservoir	Larimer
X	Olson, J.C., 1976, Geologic map of the Houston Gulch quadrangle, Gunnison and Saguache Counties, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-1287, scale 1:24,000.	Houston Gulch	Gunnison + Saguache
X	Soister, P.E., 1965, Geologic map of the Hudson quadrangle, Weld and Adams Counties, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-398, scale 1:24,000.	Hudson	Weld + Adams
X	Madole, R.F., Braddock, W.A., and Colton, R.B., 1998, Geologic map of the Hygiene quadrangle, Boulder County, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-1772, scale 1:24,000.	Hygiene	Boulder
	Widmann, B.L., Kirkham, R.M., and Beach, S.T., 2000, Geologic map of the Idaho Springs quadrangle, Clear Creek County, Colorado: Colorado Geological Survey, Open-File Report OF-00-2SR, scale 1:24,000.	Idaho Springs	Clear Creek
X	Bryant Bruce Miller R.D. and Scott G.R. 1973 Geologic map of the Indian Hills quadrangle Jefferson County Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ-1073 scale 1:24:000	Indian Hills	Jefferson

X	Scott, G.R., 1961, Preliminary geologic map of the Indian Hills quadrangle, Jefferson County, Colorado: U.S. Geological Survey, Miscellaneous Geologic Investigations Map I-333, scale 1:24,000.	Indian Hills	Jefferson
X	Olson, J.C., 1976, Geologic map of the Iris quadrangle, Gunnison and Saguache Counties, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-1286, scale 1:24,000.	Iris	Gunnison + Saguache
X	Hedlund, D.C. and Olson, J.C., 1974, Geologic map of the Iris NW quadrangle, Gunnison and Saquache Counties, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-1134, scale 1:24,000	Iris NW	Gunnison + Saguache
	Wallace, C.A., Apeland, A.D., and Cappa, J.A., 2000, Geologic map of the Jack Hall Mountain quadrangle, Fremont County, Colorado: Colorado Geological Survey, Open-File Report OF-00-1, scale 1:24,000.	Jack Hall Mountain	Fremont
X	Barker Fred and Wyant D.G. 1976 Geologic map of the Jefferson quadrangle Park and Summit Counties Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ-1345 scale 1:24:000	Jefferson	Park + Summit
	Widmann, B.L., Kirkham, R.M., Houck, K.J., and Lindsay, N.R., 2012, Jones Hill Quadrangle Geologic Map, Park County, Colorado: Colorado Geological Survey, Open-File Report , scale 1:24,000.	Jones Hill	Park
X	Scott, G.R., 1963, Bedrock geology of the Kassler quadrangle, Colorado: U.S. Geological Survey, Professional Paper 421-B, scale 1:24,000.	Kassler	
X	Machette, M.N., 1975, Geologic map of the Lafayette quadrangle, Adams, Boulder, and Jefferson Counties, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-656, scale 1:24,000.	Lafayette	Adams, Boulder, + Jefferson
X	Machette, M.N., 1977, Geologic map of the Lafayette quadrangle, Adams, Boulder, and Jefferson Counties, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-1392, scale 1:24,000.	Lafayette	Adams, Boulder, + Jefferson
X	Braddock W.A. Connor J.J. Swann G.A. and Wohlford D.D. 1988 Geologic map of the Laporte quadrangle Larimer County Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ-1621 scale 1:24:000	Lapore	Larimer
X	Braddock W.A. Connor J.J. Swann G.A. and Wohlford D.D. 1973 Geologic map and sections of the Laporte quadrangle Larimer County Colorado: U.S. Geological Survey Open-File Report OF-73-30 scale 1:24:000	Laporte	Larimer
	Thorson, Jon, Temple, Jay, Busacca, Alan, and Berg, William, 2008, Geologic Map of the Larkspur Quadrangle, Douglas and El Paso Counties, Colorado: Colorado Geological Survey, Open-File Report 08-17, scale 1:24,000.	Larkspur	Douglas + El Paso
	Thorson, J.P., 2005, Geologic Map of the East Half of the Larkspur Quadrangle, Douglas and El Paso Counties, Colorado: Colorado Geological Survey, Open-File Report OF05-07, scale 1:24,000.	Larkspur E	Douglas + El Paso

	McCalpin, J.P., Funk, Jonathan, and Mendel, David, 2012, Leadville South Quadrangle Geologic Map, Lake County, Colorado: Colorado Geological Survey, Open-File Report , scale 1:24,000.	Leadville South	Lake
X	Scott, G.R., 1962, Geology of the Littleton quadrangle, Jefferson, Douglas, and Arapahoe Counties, Colorado: U.S. Geological Survey, Bulletin 1121-L, scale 1:24,000.	Littleton	Jefferson, Douglas, + Arapahoe
X	Braddock W.A. Wohlford D.D. and Connor J.J. 1988 Geologic map of the Livermore quadrangle Larimer County Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ-1618 scale 1:24:000	Livermore Mountain	Larimer
X	Braddock W.A. and Connor J.J. 1988 Geologic map of the Livermore Mountain quadrangle Larimer County Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ-1617 scale 1:24:000	Livermore Mountain	Larimer
X	Spencer, F.D., 1961, Bedrock geology of the Louisville quadrangle, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-151, scale 1:24,000.	Louisville	
X	Braddock W.A. Houston R.G. Colton R.B. and Cole J.C. 1988 Geologic map of the Lyons quadrangle Boulder County Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ-1629 scale 1:24:000	Lyons	Boulder
X	Danilchik, Walter, 1979, Geologic and coal outcrop map of the Madrid quadrangle, Las Animas, Colorado: U.S. Geological Survey, Open-File Report OF-79-377, scale 1:24,000.	Madrid	Las Animas
	Keller, J.W., Siddoway, C.S., Morgan, M.L., Route, E.E., Grizzell, M.T., Sacerdoti, R., and Stevenson, A., 2004, Geologic Map of the Manitou Springs Quadrangle, El Paso and Teller Counties, Colorado: Colorado Geological Survey, Open-File Report 03-19, scale 1:24,000.	Manitou Springs	El Paso + Teller
	Houck, K.J., Funk, J.A., Kirkham, R.M., Carroll, C.J., and Heberton-Morimoto, A.D., 2012, Marmot Peak Quadrangle Geologic Map, Park and Chaffee Counties, Colorado: Colorado Geological Survey, Open-File Report , scale 1:24,000.	Marmot Peak	Park + Chaffee
X	Braddock W.A. Calvert R.H. Gawarecki S.J. and Nutalaya Prinya 1970 Geologic map of the Masonville quadrangle Larimer County Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ-832 scale 1:24:000	Masonville	Larimer
	Shannon, J.R. and McCalpin, J.P., 2006, Geologic Map of the Maysville Quadrangle, Chaffee County, Colorado: Colorado Geological Survey, Open-File Report 06-10, scale 1:24,000.	Maysville	Chaffee
X	Lindsey, D.A., 1995, Geologic map of the McCarty Park quadrangle, Costilla and Huerfano Counties, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-2282, scale 1:24,000.	McCarty Park	Costilla + Huerfano
X	Johnson, B.R., Bruce, R.M., and Lindsey, D.A., 1989, Reconnaissance geologic map of the Medano Pass quadrangle and part of the Liberty quadrangle, Alamosa, Huerfano, and Saguache Counties, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-2089, scale 1:24,000.	Medano Pass + Liberty	Alamosa, Huerfano, + Saguache

X	Wyant, D.G. and Barker, Fred, 1976, Geologic map of the Milligan Lakes quadrangle, Park County, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-1343, scale 1:24,000.	Milligan Lakes	Park
	Thorson, J.P. and Madole, R.F., 2004, Geologic Map of the Monument Quadrangle, El Paso County, Colorado: Colorado Geological Survey, Open-File Report OF02-04, scale 1:24,000.	Monument	El Paso
	Gable, D.J., 1968, Geology of the crystalline rocks in the western part of the Morrison quadrangle, Jefferson County, Colorado: U.S. Geological Survey, Bulletin 1251-E, scale 1:24,000.	Morrison	Jefferson
X	Scott, G.R., 1972, Geologic map of the Morrison quadrangle, Jefferson County, Colorado: U.S. Geological Survey, Miscellaneous Geologic Investigations Map I-790-A, scale 1:24,000.	Morrison	Jefferson
	Scott, G.R., 1972, Map showing some points of geologic interest in the Morrison quadrangle, Jefferson County, Colorado: U.S. Geological Survey, Miscellaneous Geologic Investigations Map I-790-E, scale 1:24,000.	Morrison	Jefferson
	Smith, J.H., 1964, Geology of the sedimentary rocks of the Morrison quadrangle, Colorado: U.S. Geological Survey, Miscellaneous Geologic Investigations Map I-428, scale 1:24,000.	Morrison	
	Temple, Jay, Madole, Rich, Keller, J.W., and Martin, Dawn, 2007, Geologic Map of the Mount Deception Quadrangle, Teller and El Paso Counties, Colorado: Colorado Geological Survey, Open-File Report 07-07, scale 1:24,000.	Mount Deception	Teller + El Paso
	Morgan, Matthew L, Temple, Jay, and Martin, Dawn, 2006, Geologic Map of the Mount Pittsburg Quadrangle, El Paso, Pueblo, and Fremont Counties, Colorado: Colorado Geological Survey, Open-File Report 06-05, scale 1:24,000.	Mount Pittsburg	El Paso, Pueblo, + Fremont
Shapefiles	Bohannon R.G. and Ruleman C.A. 2013 Geologic map of the Mount Sherman 7.5' quadrangle Park and Lake Counties Colorado: U.S. Geological Survey Scientific Investigations Map SIM-3271 scale 1:24:000	Mount Sherman	Park + Lake
X	Brock M.R. and Singewald Q.D. 1968 Geologic map of the Mount Tyndall quadrangle Custer County Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ-596 scale 1:24:000	Mount Tyndall	Custer
X	Gable, D.J., 1969, Geologic map of the Nederland quadrangle, Boulder and Gilpin Counties, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-833, scale 1:24,000.	Nederland	Boulder + Gilpin
X	Trimble, D.E., 1975, Geologic map of the Niwot quadrangle, Boulder County, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-1229, scale 1:24,000.	Niwot	Boulder
X	Scott, G.R., 1973, Reconnaissance geologic map of the Owl Canyon quadrangle, Pueblo County, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-547, scale 1:24,000.	Owl Canyon	Pueblo
X	Olson, J.C., 1977, Preliminary geologic map of part of the Pahlone Peak quadrangle, Gunnison, Saguache, and Chaffee Counties, Colorado: U.S. Geological Survey, Open-File Report OF-77-325, scale 1:24,000.	Pahlone Peak	Gunnison, Saguache, + Chaffee

	Keller, John W., Morgan, Matthew L., Thorson, Jon P., Lindsay, Neil R., and Barkmann, P.E., 2006,Geologic Map of the Palmer Lake Quadrangle, El Paso County, Colorado: Colorado Geological Survey, Open-File Report 06-06, scale 1:24,000.	Palmer Lake	El Paso
X	Maberry, J.O. and Lindvall, R.M., 1972, Geologic map of the Parker quadrangle, Arapahoe and Douglas Counties, Colorado: U.S. Geological Survey, Miscellaneous Geologic Investigations Map I-770-A, scale 1:24,000.	Parker	Arapahoe + Douglas
	Maberry, J.O., 1972, Map showing erodibility of geologic materials in the Parker quadrangle, Arapahoe and Douglas Counties, Colorado: U.S. Geological Survey, Miscellaneous Geologic Investigations Map I-770-G, scale 1:24,000.	Parker	Arapahoe + Douglas
X	Soister, P.E., 1972, Geologic map of the Peoria quadrangle, Arapahoe and Adams Counties, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-875, scale 1:24,000.	Peoria	Arapahoe + Adams
X	Wobus, R.A., Chase, R.B., Scott, G.R., and Taylor, R.B., 1985, Reconnaissance geologic map of the Phantom Canyon quadrangle, Fremont County, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-1764, scale 1:24,000	Phantom Canyon	Fremont
	Thorson, J.P., Carroll, C.J., and Morgan, M.L., 2002, Geologic Map of the Pikeview 7.5 Minute Quadrangle, El Paso County, Colorado: Colorado Geological Survey, Open-File Report OF01-03, scale 1:24,000.	Pikeview	El Paso
X	Bryant Bruce 1974 Reconnaissance geologic map of the Pine quadrangle Jefferson County Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-598 scale 1:24:000	Pine	Jefferson
X	Punongbayan, Raymundo, Cole, J.C., Braddock, W.A., and Colton, R.B., 1989, Geologic map of the Pinewood Lake quadrangle, Boulder and Larimer Counties, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-1627, scale 1:24,000.	Pinewood Lake	Boulder + Larimer
X	Nesse, W.D. and Braddock, W.A., 1989, Geologic map of the Pingree Park quadrangle, Larimer County, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-1622, scale 1:24,000.	Pingree Park	Larimer
X	Peterson, W.L., 1964, Geology of the Platte Canyon quadrangle, Colorado: U.S. Geological Survey, Bulletin 1181-C, scale 1:24,000.	Platte Canyon	
X	Soister, P.E., 1965, Geologic map of the Platteville quadrangle, Weld County, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-399, scale 1:24,000.	Platteville	Weld
X	Van Alstine, R.E. and Cox, D.C., 1969, Geology and mineral deposits of the Poncha Springs NE quadrangle, Chaffee County, Colorado with a section on fluorspar mines and prospects: U.S. Geological Survey, Professional Paper 626, scale 1:24,000.	Poncha Springs NE	Chaffee
X	Van Alstine, R.E., 1974, Geology and mineral deposits of the Poncha Springs SE quadrangle, Chaffee County, Colorado: U.S. Geological Survey, Professional Paper 829, scale 1:24,000.	Poncha Springs SE	Chaffee
	Thorson, J.P., 2007, Geologic Map of the Ponderosa Park Quadrangle, Douglas and Elbert Counties, Colorado: Colorado Geological Survey, Open-File Report 07-04, scale 1:24,000.	Ponderosa Park	Douglas + Elbert
X	Braddock W.A. Abbott J.T. Connor J.J. and Swann G.A. 1988 Geologic map of the Poudre Park quadrangle Larimer County Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ-1620 scale 1:24:000	Poudre Park	Larimer

X	Hedlund, D.C. and Olson, J.C., 1975, Geologic map of the Powderhorn quadrangle, Gunnison and Saguache Counties, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-1178, scale 1:24,000.	Powderhorn	Gunnison + Saguache
	Scott, G.R., 1964, Geology of the northwest and northeast Pueblo quadrangles, Colorado: U.S. Geological Survey, Miscellaneous Geologic Investigations Map I-408, scale 1:24,000.	Pueblo	
X	Scott, G.R., 1964, Geology of the northwest and northeast Pueblo quadrangles, Colorado: U.S. Geological Survey, Miscellaneous Geologic Investigations Map I-408, scale 1:24,000.	Pueblo NE + NW	
X	Scott, G.R., 1969, Geologic map of the Southwest and Southeast Pueblo quadrangles, Colorado: U.S. Geological Survey, Miscellaneous Geologic Investigations Map I-597, scale 1:24,000.	Pueblo SE + SW	
X	Sheridan, D.M., Maxwell, C.H., Albee, A.L., and Van Horn, Richard, 1958, Preliminary map of bedrock geology of the Ralston Buttes quadrangle, Jefferson County, Colorado: U.S. Geological Survey, Mineral Investigations Field Studies Map MF-179, scale 1:24,000.	Ralston Buttes	Jefferson
X	Olson, J.C. and Steven, T.A., 1976, Geologic map of the Razor Creek Dome quadrangle, Saguache County, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-748, scale 1:24,000.	Razor Creek Dome	Saguache
X	Lindsey, D.A., Soulliere, S.J., Hafner, Katrin, and Flores, R.J., 1985, Geologic map of Rito Alto Peak and northeastern part of Mirage quadrangles, Custer and Saguache Counties, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-1787, scale 1:24,000.	Rito Alto Peak + Mirage	Custer + Saguache
X	Scott, G.R. and Taylor, R.B., 1974, Reconnaissance geologic map of the Rockvale quadrangle, Custer and Fremont Counties, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-562, scale 1:24,000.	Rockvale	Custer + Fremont
X	Olson, J.C., 1974, Geologic map of the Rudolph Hill quadrangle, Gunnison, Hinsdale, and Saguache Counties, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-1177, scale 1:24,000.	Rudolph Hill	Gunnison, Hinsdale, + Saguache
	Thorson, Jon P., 2006, Geologic Map of the Russellville Gulch Quadrangle, Douglas and Elbert County, Colorado: Colorado Geological Survey, Open-File Report 06-08, scale 1:24,000.	Russellville Gulch	Douglas + Elbert
X	Shaver, K.C., Nesse, W.D., and Braddock, W.A., 1988, Geologic map of the Rustic quadrangle, Larimer County, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-1619, scale 1:24,000.	Rustic	Larimer
X	Lindvall, R.M., 1980, Geologic map of the Sable quadrangle, Adams and Denver Counties, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-1180, scale 1:24,000.	Sable	Adams + Denver

X	Lindvall, R.M., 1983, Geologic map of the Sable quadrangle, Adams and Denver Counties, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-1567, scale 1:24,000.	Sable	Adams + Denver
	Wallace, C.A., Cappa, J.A, and Lawson, A.D., 1997, Geologic map of the Salida East quadrangle, Chaffee and Fremont Counties, Colorado: Colorado Geological Survey, Open-File Report OF-97-6, scale 1:24,000.	Salida East	Chaffee + Fremont
	Lipman, P.W. and Sawyer, D.A., 1988, Preliminary geology of the San Luis Peak quadrangle and adjacent areas San Juan volcanic field, southwestern Colorado: U.S. Geological Survey, Open-File Report OF-88-359, scale 1:24,000.	San Luis Peak	
Shapefiles	Workman, J.B and Braddock, W.A., 2010, Geologic map of the Sand Creek Pass quadrangle, Larimer County, Colorado, and Albany County, Wyoming: U.S. Geological Survey, Scientific Investigations Map SIM-3133, scale 1:24,000.	Sand Creek Pass	Larimer
X	Olson, J.C. and Steven, T.A., 1976, Geologic map of the Sawtooth Mountain quadrangle, Saguache County, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-733, scale 1:24,000.	Sawtooth Mountain	Saguache
	Morgan, M.L., McHarge, J.L., and Barkmann, P.E., 2005, Geologic Map of the Sedalia Quadrangle, Douglas County, Colorado: Colorado Geological Survey, Open-File Report OF05-06, scale 1:24,000.	Sedalia	Douglas
X	Olson, J.C., Steven, T.A., and Hedlund, D.C., 1975, Geologic map of the Spring Hill Creek quadrangle, Saguache County, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-713, scale 1:24,000.	Spring Hill Creek	Saguache
X	Sheridan, D.M. and Marsh, S.P., 1976, Geologic map of the Squaw Pass quadrangle, Clear Creek, Jefferson, and Gilpin Counties, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-1337, scale 1:24,000.	Squaw Pass + Clear Creek	Jefferson + Gilpin
X	Soister, P.E., 1972, Preliminary geologic map and lignite deposits of the Strasburg NW quadrangle, Arapahoe and Adams Counties, Colorado: U.S. Geological Survey, Open-File Report OF-72-353, scale 1:24,000.	Strasburg NW	Arapahoe + Adams
Shapefiles	Bohannon R.G. and Ruleman C.A. 2009 Geologic map of the Sulphur Mountain quadrangle Park County Colorado: U.S. Geological Survey Scientific Investigations Map SIM-3082 scale 1:24:000	Sulphur Mountain	Park
X	Scott, G.R., 1972, Reconnaissance geologic map of the Swallows quadrangle, Pueblo County, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-354, scale 1:24,000.	Swallows	Pueblo + Fremont
X	Courtright, T.R. and Braddock, W.A., 1989, Geologic map of the Table Mountain quadrangle and adjacent parts of the Round Butte and Buckeye quadrangles, Larimer County, Colorado, and Laramie County, Wyoming: U.S. Geological Survey, Miscellaneous Investigations Series Map I-1805, scale 1:24,000.	Table Mountain, Round Butte, + Buckeye	Larimer

X	Wallace, A.R. and Lindsey, D.A., 1996, Geologic map of the Trinchera Peak quadrangle, Costilla, Huerfano, and Las Animas Counties, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-2312-A, scale 1:24,000.	Trinchera Peak	Costilla, Huerfano, + Las Animas
X	Gable, D.J., 1972, Geologic map of the Tungsten quadrangle, Boulder, Gilpin, and Jefferson Counties, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-978, scale 1:24,000	Tungsten	Boulder, Gilpin, + Jefferson
	Gable, D.J., 1973, Map showing rock fractures and veins in the Tungsten quadrangle, Boulder, Gilpin, and Jefferson Counties, Colorado: U.S. Geological Survey, Miscellaneous Investigations Series Map I-792-A, scale 1:24,000.	Tungsten	Boulder, Gilpin, + Jefferson
X	Johnson, B.R. and Bruce, R.M., 1991, Reconnaissance geologic map of parts of the Twin Peaks and Blanca Peak quadrangles, Alamosa, Costilla, and Huerfano Counties, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-2169, scale 1:24,000.	Twin Peaks + Blanca Peak	Alamosa, Costilla. + Huerfano
X	Lindsey, D.A. and Soulliere, S.J., 1987, Geologic map and sections of the Valley View Hot Springs quadrangle, Custer and Saguache Counties, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-1942, scale 1:24,000.	Valley View Hot Springs	Custer + Saguache
X	Pillmore, C.L., 2003, Geologic map of the Vermejo Park quadrangle, Colfax County, New Mexico, and Las Animas County, Colorado: U.S. Geological Survey, Open-File Report OF-2003-438, scale 1:24,000.	Vermejo Park	Las Animas
X	Braddock W.A. Eggler D.H. and Courtright T.R. 1989 Geologic map of the Virginia Dale quadrangle Larimer County Colorado and Albany and Laramie Counties Wyoming: U.S. Geological Survey Geologic Quadrangle Map GQ-1616 scale 1:24:000	Virginia Dale	Larimer
X	Gable, D.J. and Madole, R.F., 1976, Geologic map of the Ward quadrangle, Boulder County, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-1277, scale 1:24,000.	Ward	Boulder
X	Danilchik, Walter, 1979, Geologic and coal outcrop map of the Weston quadrangle, Las Animas County, Colorado: U.S. Geological Survey, Open-File Report OF-79-927, scale 1:24,000.	Weston	Las Animas
X	Taylor, R.B. and Scott, G.R., 1973, Reconnaissance geologic map of the Wetmore quadrangle, Custer and Pueblo Counties, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-548, scale 1:24,000.	Wetmore	Custer + Pueblo
X	Wobus, R.A. and Scott, G.R., 1977, Reconnaissance geologic map of the Woodland Park quadrangle, Teller County, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-842, scale 1:24,000.	Woodland Park	Teller
X	Bruce R.M. and Johnson B.R. 1991 Reconnaissance geologic map of parts of the Zapata Ranch and Mosca Pass quadrangles Alamosa and Huerfano Counties Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-2168 scale 1:24:000	Zapate Ranch + Mosca Pass	Almosa + Huerfano
	Leibold, A.M., Detra, D.E., and Motooka, J.M., 1987, Geochemical evaluation of the mineral resources of the Browns Canyon area, Chaffee County, Colorado: U.S. Geological Survey,		Chaffee

	Open-File Report OF-87-508, scale 1:24,000.		
	Leibold, A.M., Worl, R.G., Martin, R.A., and Zelten, J.E., 1986, Mineral resources of the Browns Canyon Wilderness Study Area, Chaffee County, Colorado: U.S. Geological Survey, Bulletin 1716-C, scale 1:24,000.		Chaffee
X	Sharp, W.N., 1976, Geologic map and details of the beryllium and molybdenum occurrences, Mount Antero, Chaffee County, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-810, scale 1:24,000.		Chaffee
	Toulmin, Priestley and Hammarstrom, J.M., 1990, Geology of the Mount Aetna volcanic center, Chaffee and Gunnison Counties, Colorado: U.S. Geological Survey, Bulletin 1864, scale 1:24,000.		Chaffee + Gunnison
	Sharp, W.N., 1978, Geologic map of the Silver Cliff and Rosita volcanic centers, Custer County, Colorado: U.S. Geological Survey, Miscellaneous Investigations Series Map I-1081, scale 1:24,000		Custer
	Sheridan, D.M., Maxwell, C.H., and Albee, A.L., 1967, Geology and uranium deposits of the Ralston Buttes district, Jefferson County, Colorado with sections on Paleozoic and younger sedimentary rocks: U.S. Geological Survey, Professional Paper 520, scale 1:24,000.		Jefferson
	Kirkham, R.M., Houck, K.J., Carroll, C.J., and Heberton-Morimoto, A.D., 2012, Antero Reservoir Geologic Map, Park and Chaffee Counties, Colorado: Colorado Geological Survey, Open-File Report , scale 1:24,000.		Park + Chaffee
	Hawley, C.C. and Wobus, R.A., 1977, General geology and petrology of the Precambrian crystalline rocks, Park and Jefferson Counties, Colorado: U.S. Geological Survey, Professional Paper 608-B, scale 1:24,000.		Park + Jefferson
	Hawley, C.C., 1969, Geology and beryllium deposits of the Lake George (or Badger Flats) beryllium area, Park and Jefferson Counties, Colorado: U.S. Geological Survey, Professional Paper 608-A, scale 1:24,000.		Park + Jefferson
	Lindsey, D.A., Hassemer, J.R., Abrams, G.A., Taylor, R.B., and Hannigan, B.J., 1985, Mineral resources of the Black Canyon and South Piney Creek Wilderness Study Areas, Saguache County, Colorado: U.S. Geological Survey, Bulletin 1716-A, scale 1:24,000.		Saguache
	Olson, J.C., 1983, Geologic and structural maps and sections of the Marshall Pass mining district, Saguache, Gunnison, and Chaffee Counties, Colorado: U.S. Geological Survey, Miscellaneous Investigations Series Map I-1425, scale 1:24,000.		Saguache, Gunnison, + Chaffee
	Koschmann, A.H., 1949, Structural control of the Gold deposits of the Cripple Creek district, Teller County, Colorado: U.S. Geological Survey, Bulletin 955-B, scale 1:24,000.		Teller
	Abbott J.T. 1970 Geology of Precambrian rocks and isotope geochemistry of shear zones in the Big Narrows area northern Front Range Colorado: U.S. Geological Survey Open-File Report OF-70-1 scale 1:24:000		
	Bergendahl M.H. and Koschmann A.H. 1971 Ore deposits of the Kokomo-Tenmile district		

	Colorado: U.S. Geological Survey Professional Paper 652 scale 1:24:000		
	Himmelreich, J.W., Jr. and Noe, D.C., 1999, Map of areas susceptible to differential heave in expansive, steeply dipping bedrock, city of Colorado Springs, Colorado: Colorado Geological Survey, Map Series MS-32, scale 1:24,000.		
	Lindsey, D.A., 2001, Log for joint SEPM - Colorado Scientific Society field trip, September 20-21, 1986: Late Paleozoic sedimentation and Laramide tectonics of the Sangre de Cristo Range, from Westcliffe to Crestone, Colorado: U.S. Geological Survey, Open-File Report OF-2001-249, scale 1:24,000.		
	Robinson, C.S., Warner, L.A., and Wahlstrom, E.E., 1974, General geology of the Harold D. Roberts tunnel, Colorado: U.S. Geological Survey, Professional Paper 831-B, scale 1:24,000.		
	Singewald, Q.D. and Butler, B.S., 1941, Ore deposits in the vicinity of the London fault of Colorado: U.S. Geological Survey, Bulletin 911, scale 1:24,000.		
	Tur, S.M. and Flores, R.M., 1980, Lithologic descriptions of measured sections of Upper Cretaceous Trinidad Sandstone, northern Raton Basin, Colorado: U.S. Geological Survey, Open-File Report OF-80-818, scale 1:24,000.		
	Wells, J.D., Sheridan, D.M., and Albee, A.L., 1964, Relationship of Precambrian quartzite-schist sequence along Coal Creek to Idaho Springs Formation, Front Range, Colorado: U.S. Geological Survey, Professional Paper 454-O, scale 1:24,000.		

GeoTif	**Scale between 1:24,000 and 1:100,000**	**USGS Quad**	**County**
X	Epis, R.C., Wobus, R.A., and Scott, G.R., 1979, Geologic map of the Black Mountain quadrangle, Fremont and Park Counties, Colorado: U.S. Geological Survey, Miscellaneous Investigations Series Map I-1195, scale 1:62,500.	Black Mountain	Adams + Weld
X	Epis, R.C., Wobus, R.A., and Scott, G.R., 1979, Preliminary geologic map of the Black Mountain quadrangle, Fremont and Park Counties, Colorado: U.S. Geological Survey, Open-File Report OF-79-652, scale 1:62,500.	Black Mountain	Boulder
	Van Alstine, R.E., 1975, Geologic map of the Bonanza NE quadrangle, Chaffee and Saguache Counties, Colorado: U.S. Geological Survey, Open-File Report OF-75-53, scale 1:62,500	Bonanza NE	Boulder
X	Scott, G.R., 1975, Reconnaissance geologic map of the Buena Vista quadrangle, Chaffee and Park Counties, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-657, scale 1:62,500.	Buena Vista	Boulder + Grand
X	Wrucke, C.T. and Dings, M.G., 1979, Geologic map of the Cameron Mountain quadrangle, Colorado: U.S. Geological Survey, Open-File Report OF-79-660, scale 1:62,500.	Cameron Mountain	Boulder + Grand
X	Pillmore, C.L., 1969, Geologic map of the Casa Grande quadrangle, Colfax County, New Mexico and Las Animas County, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-823, scale 1:62,500.	Casa Grande	Boulder + Weld

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X	Epis, R.C., Wobus, R.A., and Scott, G.R., 1979, Preliminary geologic map of the Cover Mountain quadrangle, Fremont, Park, and Teller Counties, Colorado: U.S. Geological Survey, Open-File Report OF-79-427, scale 1:62,500.	Cover Mountain	Chaffee + Park
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X	Wobus, R.A. and Epis, R.C., 1974, Reconnaissance geologic map of the Florissant 15-minute quadrangle, Park and Teller Counties, Colorado: U.S. Geological Survey, Open-File Report OF-74-95, scale 1:62,500.	Florissant	Custer + Saguache
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X	Epis, R.C., Wobus, R.A., and Scott, G.R., 1979, Preliminary geologic map of the Guffy quadrangle, Park County, Colorado: U.S. Geological Survey, Open-File Report OF-79-426, scale 1:62,500.	Guffey	Fremont + Custer

X	Taylor, R.B., Scott, G.R., and Wobus, R.A., 1975, Reconnaissance geologic map of the Howard quadrangle, central Colorado: U.S. Geological Survey, Miscellaneous Investigations Series Map I-892, scale 1:62,500.	Howard	Fremont + Custer
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X	Wood, G.H., Northrup, S.A., and Griggs, R.L., 1953, Geology and stratigraphy of Koehler and Mount Laughlin quadrangles and parts of Abbott and Springer quadrangles, eastern Colfax County, New Mexico: U.S. Geological Survey, Oil and Gas Investigations Map OM-141, scale 1:63,360.	Koehler + Mount Laughlin	Fremont + Park
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X	Lovering, T.S., 1935, Geology and ore deposits of the Montezuma quadrangle, Colorado: U.S. Geological Survey, Professional Paper 178, scale 1:62,500.	Montezuma	Fremont, El Paso, + Teller
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