National Park Service
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Natural Resource Program Center

Florissant Fossil Beds National Monument

Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2006/009

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Geologic Resources Division
Natural Resource Program Center
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Executive Summary

This report has been developed to accompany the digital geologic map produced by Geologic Resource Evaluation staff for Florissant Fossil Beds National Monument in Colorado. It contains information relevant to resource management and scientific research.

The purpose of Florissant Fossil Beds National Monument, as stated in its enabling legislation, is: "To preserve and interpret for the benefit and enjoyment of present and future generations the excellently preserved insect and leaf fossils and related geologic sites and objects." Other legislation affecting the national monument includes the Organic Act of 1916, the National Environmental Policy Act, the National Historic Preservation Act, and the Endangered Species Act.

Florissant Fossil Beds National Monument is significant for: providing recreational and educational opportunities, providing wildlife habitat in a developing region, acting as stimulus to the regional tourism economy, preserving natural solitude and beauty, maintaining the absence of light pollution, and preserving cultural resources. Its primary goal is to preserve, protect and interpret its paleontological resources and geologic significance.

- The Florissant Formation contains one of the largest varieties of fossil Arthropods (insects and spiders) found anywhere in the world.
- The abundance of finely detailed dragonflies, beetles, ants, butterflies, flies, fish, plants, ferns, leaves, pollen, flowers, mammals, and birds and the enormity of the petrified redwood stumps evoke a sense of wonder for visitors.
- The ancient Florissant ecosystem furnishes critical evidence regarding the environment during the late Eocene Epoch, which is important in the global interpretation of biologic and climatic change and tectonic and uplift chronologies.
- Florissant's 34- million- year- old ecosystem, which immediately preceded a very significant cooling of the world's climate, impacts the national debates on evolution and global climate change.
- The newly hypothesized mode of exceptional fossil preservation (i.e., diatom mats) at the monument could have far- reaching implications for other lacustrine sites.
- The monument provides unparalleled paleontological research possibilities by virtue of its high concentration of indigenous plant and animal species that lived 34 million years ago.
- Opportunities exist to research, compare, and contrast ancient ecosystems with the present, providing insights to our current ecological dilemmas.
- Buried within the Florissant Formation, sediments and delicate fossils provide future research opportunities for paleontologists using methods and skills not existing today.

In addition to Florissant's exquisite paleontological resources, other geologic features and processes include:

- The late Eocene erosion surface, which is significant for reconstructing the erosional, climatic, and tectonic history of the southern Rocky Mountains;
- Tors formed beyond the limit of glaciation and important for interpreting the glacial history of the region; and,
- Unconformities are significant for understanding the span of geologic time and the processes that shape the earth.

Lastly, geologic issues of significance for resource managers at Florissant include: disturbed lands, agricultural terraces, removal of dams and restoration of streams, and past and present mining activity in the area. The following geologic issues may warrant attention from resource managers:

- Development—Management concerns arise from possible impacts on natural resources from rapid subdivision development adjacent to the monument and the anticipated increase in visitor use. These concerns include preservation of current viewsheds and lightscapes and the protection of water resources. Also, any development within the monument requires attention to paleontological resources, especially undiscovered buried stumps.
- Water Resources—With many unknown factors regarding water resources (e.g., locations, number, and quality of wells, seeps, springs, and streams) a need exists to inventory, assess, and monitor the water resources of the monument, as well as to develop a water resources management plan.

Research Opportunities:

- Investigators have long speculated about possible sources of pumice and ash of the Florissant Formation, but have not studied the sources conclusively. Information gained from a study is significant for scientific interpretations and the monument's interpretive program.
- Florissant represents the world's most significant upland fossil deposit from the Eocene- Oligocene transition (33–34 million years ago), immediately preceding a global cooling event. Collecting fossil leaf assemblages from several stratigraphic levels at different sites around the Eocene Florissant lake basin would provide new evidence to interpret the small-scale variability of biotic communities and microclimatic conditions around the lake basin in time and space. A comparison of Florissant fossils with the

fossil plants from other localities will provide an ideal basis for studying the impacts and nature of climate change over a wide geographic area.

- Paleoelevation Estimates—Most of the recent estimates of Florissant's elevation during the late Eocene range from 6,235 feet (1,900 m) to 13,450 ft (4,100 m). The most important point to emerge from the numerous studies conducted during the 1990s is that paleoelevation appears to have been much higher than originally estimated by MacGinitie in 1953, which served as the benchmark for decades.
- Preservation of Fossil Stumps—Because the exposed fossil stumps are a primary park resource and the only paleontological resource that can be seen easily by visitors along the trails, reburial is not an option for preservation. Nevertheless, exposure to the elements is deteriorating this valued resource. However, the results of recent investigations, using techniques and methods from cultural conservation of historic buildings and gravestones, may help seal the stumps and reduce spalling of pieces of petrified wood. By proactively identifying and preserving the stumps, opportunities for further vandalism and theft would diminish.
- Protection of Paleontological Resources—Florissant Fossil Beds has a pro- active program to educate visitors on the scientific importance of in- situ fossil materials in the park. Park staff work vigilantly with law enforcement officials and museums to protect paleontological resources and recover stolen fossils. Additionally, in order to monitor paleontological resources, the National Park Service has established a system of measurable indicators of change to resource conditions. The strategy includes assessment of climatological data, rates of erosion, human activity and behavior, and site monitoring of destroyed (lost) or exposed (gained) fossils at the surface.

Introduction

The following section briefly describes the National Park Service Geologic Resource Evaluation Program and the geologic setting of Florissant Fossil Beds National Monument.

Purpose of the Geologic Resource Evaluation Program

Geologic features and processes serve as the foundation of park ecosystems and an understanding of geologic resources yields important information for use in park decision making. The National Park Service Natural Resource Challenge, an action plan to advance the management and protection of park resources, has focused efforts to inventory the natural resources of parks. Ultimately, the inventory and monitoring of natural resources will become integral parts of park planning, operations and maintenance, visitor protection, and interpretation. The geologic component is carried out by the Geologic Resource Evaluation (GRE) Program administered by the NPS Geologic Resources Division. The goal of the GRE Program is to provide each of the identified 270 "Natural Area" parks with a digital geologic map, a geologic resource evaluation report, and a geologic bibliography. Each product is a tool to support the stewardship of park resources and is designed to be user friendly to non-geoscientists.

GRE teams hold scoping meetings at parks to review available data on the geology of a particular park and to discuss specific geologic issues affecting the park. Park staff are afforded the opportunity to meet with experts on the geology of their park during these meetings. Scoping meetings are usually held for individual parks although some meetings address an entire Vital Signs Monitoring Network.

Bedrock and surficial geologic maps and information provide the foundation for studies of groundwater, geomorphology, soils, and environmental hazards. Geologic maps describe the underlying physical habitat of many natural systems and are an integral component of the physical inventories stipulated by the National Park Service (NPS) in its Natural Resources Inventory and Monitoring Guideline (NPS-75) and the 1997 NPS Strategic Plan. The NPS GRE is a cooperative implementation of a systematic, comprehensive inventory of the geologic resources in National Park System units by the Geologic Resources Division, the Inventory, Monitoring, and Evaluation Office of the Natural Resource Program Center, the U.S. Geological Survey, and state geological surveys.

For additional information regarding the content of this report, please refer to the Geologic Resources Division of the National Park Service, located in Denver, Colorado with up-to-date contact information at the following website: http://www2.nature.nps.gov/geology/inventory/

Geologic Setting

Past geologic studies have considered the age of the deposits at Florissant to be Pliocene, Miocene, Oligocene, or Eocene (figure 1). MacGinitie (1953) made the first reliable age determination from his study of fossil plants and other fragmentary evidence of fossil mammals. In 1992 a field crew from the University of Colorado Museum found fragments of a brontothere, which in addition to other previously discovered mammal fossils (i.e., *Merycoidodon* [oreodont], *Mesohippus* [horse], and *Peratherium* [mouse opossum]), indicated that the Florissant Formation is late Eocene age (Evanoff and de Toledo, 1993). In 2003 a systematic investigation greatly increased the known mammal diversity from the Florissant Formation (Worley, 2004). The co-occurrence of these fossils places the deposition of the Florissant Formation at the same time as the Chandron Formation in Badlands National Park, which occurred at the very end of the Eocene Epoch. In addition, an $^{40}Ar/^{39}Ar$ age of 34.07 ± 0.10 million years supports a Late Eocene time frame (Evanoff and others, 2001).

The Eocene rocks at Florissant Fossil Beds National Monument contain fragile insects, tree foliage, and other forms of life, which are completely absent or extremely rare in most paleontological sites. According to Meyer (2003), the fossil-bearing shales have yielded more than 40,000 specimens that contain more than 1,500 described species of insects and spiders. The Florissant Formation includes more known fossil butterflies than any other locality, as well as more than 140 plant species, and several species of fish, birds, and small mammals. Pleistocene fossils, such as mammoth bone, are also present in the monument. In addition a petrified forest of Eocene *Sequoia*-like stumps is preserved in tuffaceous mudstone, formed by a volcanic debris flow (lahar).

The strata of the Florissant valley, deposited on the eroded surface of the 1.08-billion-year-old Pikes Peak Granite (Wobus, 2001), are primarily but not exclusively volcanic. They consist of lava flows, massive pumiceous tuffs, river gravels, agglomerates, and finely laminated fossiliferous paper shales. Although lacustrine shales form the most prominent outcrops, they constitute only a minor part (16%) of the total thickness of the formation. As emphasized by Evanoff and others (2001), instead of forming a single unit, the Florissant Formation—of which the fossiliferous lake beds are a part—comprises a complex and varied series of sediments and volcanics, which have been divided into six informal units. From oldest to youngest they are: (1) lower shale unit, (2) lower mudstone unit, (3) middle shale unit, (4) caprock conglomerate unit, (5) upper shale unit, and (6) upper pumice conglomerate unit.

The Florissant Formation was deposited within a valley that was episodically blocked by lahar deposits that dammed the streams and formed Lake Florissant. As interpreted by Evanoff and others (2001), the Florissant Formation probably records two episodes of lake generation: the first represented by the lower shale unit; the second represented by the middle and upper shale units, which are divided by the caprock conglomerate throughout most of the monument. The two ages of lakes are separated by the lower mudstone unit, a fluvial deposit. Eventually the lacustrine deposits were buried by pumice gravel and lahars from the Thirtynine Mile volcanic field.

Although some investigators concluded that complex faulting and subsequent erosion created the present outline of the lake beds, mapping of the Florissant Formation found no evidence of major faulting (Evanoff and Doi, 1992). Hence, the current interpretation contends that the exposure pattern reveals the extent of the ancient lake and that much of the present distribution of the Florissant Formation reflects the original area covered by paleovalley fill (Evanoff and others, 2001).

Eon	Era	Period		Epoch	Age (Ma)	Age of
Phanerozoic	Cenozoic	Neogene	Quaternary	Holocene	0.01	Mammals
				Pleistocene	1.81	
			Tertiary	Pliocene	5.33	
				Miocene	23.0	
		Paleogene		Oligocene	33.9	
				Eocene	55.8	
				Paleocene	65.5	
	Mesozoic	Cretaceous			145.5	Reptiles
		Jurassic			199.6	
		Triassic			251.0	
	Paleozoic	Permian			299	Amphibians
		Carboniferous	Pennsylvanian		318	
			Mississippian		359.2	
		Devonian			416.0	Fish
		Silurian			443.7	
		Ordovician			488.3	Invertebrates
		Cambrian			542.0	
Proterozoic	(Precambrian)				2,500	
Archean					2,500–3,800?	
Hadean					3,800–4,600?	

Figure 1. Geologic Time Scale. Dates listed in the table are in millions of years (Ma) and reflect the International Union of Geological Sciences (IUGS) International Stratigraphic Commission (ICS) International Stratigraphic Chart (2003) at http://www.stratigraphy.org/chus.pdf. Exceptions include the boundary between Archean and Hadean, which the International Stratigraphic Commission does not list. However, the U.S. Geological Survey lists the boundary between Hadean and Archean at approximately 3,800 Ma and the formation of Earth at approximately 4,600 Ma, which are used here. Mississippian and Pennsylvanian are terms used primarily in North America, and Tertiary and Quaternary are no longer accepted by the International Commission on Stratigraphy (2003) but are included here because they are still in common use.

Geologic Issues

A GRE scoping session was held in Florissant Fossil Beds National Monument on October 21, 1998, to discuss geologic resources, address the status of geologic mapping, and assess resource management issues and needs. The following section synthesizes the scoping results—in particular, those issues that may require attention from resource managers.

Protection of Paleontological Resources

The act establishing Florissant Fossil Beds national Monument was signed into law on August 20, 1969 (Public Law 91- 60). In the statute, Congress underscored the importance of protecting "the excellently preserved insect and leaf fossils and related geologic sites and objects" at the monument. Congress also directed that the unit be managed in accordance with the National Park Service Organic Act.

As required by the Organic Act of 1916, 16 U.S.C. §§ 1 *et seq*., and *Management Policies 2001*, the National Park Service strives to protect, preserve, and manage paleontological resources—including both organic and mineralized remains in body or trace form—for public education, interpretation, and scientific research. According to the *Management Policies 2001*, "the Service will study and manage paleontological resources in their paleoecological context (that is, in terms of the geologic data associated with a particular fossil that provides information about the ancient environment)."

According to the "Scope of Collections Statement" for Florissant Fossil Beds National Monument, staff should be alert for confiscated archaeological and paleontological objects (National Park Service, 1998). These are objects recovered from unauthorized and illegal activities. They might include unearthed fossils, artifacts, eco- facts, and human remains illegally excavated or surface collected by unauthorized individuals within the monument boundaries. Museum personnel should be consulted as soon as possible to ensure proper handling and transportation of these materials. Such objects might be held temporarily as evidence if legal action is to be taken, but should be formally turned over to museum personnel as soon as possible. Once all legal questions are resolved, objects of particular significance from a known context will be added to the museum collection (Herb Meyer, Florissant Fossil Beds National Monument, written communication, May 2, 2005).

Guidelines are in place at Florissant Fossil Beds National Monument for protecting and preserving the monuments fossils. The ability to manage and protect fossils is contingent upon an understanding of the occurrences and distributions of fossils, both geologic and geographic, and upon the factors threatening stability (Santucci and Koch, 2003) (table 1).

For example, heavy cattle grazing in the late 1800s and early 1900s reduced plant cover and created sheet and gully erosion in what is now Florissant Fossil Beds National Monument (Florissant Fossil Beds National Monument, 1983c). Cutting of trees was also widespread (Herb Meyer, Florissant Fossil Beds National Monument, written communication, May 2, 2005). These examples show how human activities may initiate and accelerate erosion, which in turn may impact paleontological resources in the monument.

In order to quantify loss, the National Park Service has established a system of measurable indicators of change to resource conditions (table 1). Paleontological localities vary widely in terms of rock types, fossil preservation, geomorphic characteristics, and human accessibility. Therefore, any specific indicator may not be useful or appropriate at all fossil sites. However, Santucci and Koch (2003) present an initial monitoring strategy for the National Park Service to assess or measure impacts to in situ paleontological resources. The new strategy is referred to as paleontological resource stability indicators (PRSI), as in the following list:

Climatological Data Assessment PRSI

This indicator allows the researcher to assess data on annual precipitation, rainfall intensity, relative humidity, wind speed, and freeze- thaw index (number of 24- hour periods per year when temperature fluctuates above and below 32°F [0°C]).

Rates of Erosion Assessment PRSI

This indicator allows the researcher to assess data on both inherent and dynamic factors such as specific rock characteristics, slope, soil loss, vegetation cover, and rates of denudation for fossiliferous rock units.

Human Activity and Behavior Assessment PRSI

This indicator allows the researcher to assess data on visitor use, visitor access routes and their proximity to fossil localities, documented cases of theft or vandalism, and commercial market values of fossils.

Periodic Site Assessment PRSI

This indicator allows the researched to assess data on the relative turnover rate of specimens at each fossil locality by monitoring the numbers of specimens destroyed or exposed at the surface.

The use of these paleontological resource stability indicators provides a multidimensional approach to assessing the conditions of in situ fossils. Adoption of Servicewide protocols for monitoring these resources will further enable assessment of the threats and

conditions affecting fossils throughout the National Park System (Santucci and Koch, 2003).

Preservation of Fossil Stumps

Fossilized redwood stumps that have been excavated are a primary park resource and the only paleontological resource that visitors can easily see in their natural setting. They are a major visitor attraction – about 95% of the monument's 80,000 annual visitors view them. The stumps are located prominently along two short trails leading out from the visitor center: the closest stump is about 100 feet (30 m) down the trail and two others are about 150 feet (46 m) farther. The "Big Stump" is located about 0.25 mile (0.4 km) from the visitor center.

Prior to the establishment of the monument, a number of petrified stumps were unearthed for commercial tourism. The unearthing (said to have included dynamite) exposed the stumps to harsh climatic conditions causing substantial deterioration. Park staff reburied some stumps in the late 1980s. However, because of the popularity of the stumps and their significance as an interpretive resource, reburial is not generally a preservation option.

Park staff assume that temperature changes and moisture are responsible for the deterioration of the stumps. The stumps are only moderately silicified, and after repeated freezing and thawing, moisture infiltrating the porous cell structures results in spalling of the exterior. Due to the lesser degree of permineralization at Florissant, the fossil stumps have a higher porosity than most petrified wood, allowing for the absorption of low viscosity fluids As the stumps continue to weather, large chunks of petrified wood flake and fall from the trees, adding to an existing vandalism and theft problem. Continued exposure of the petrified stumps to the elements will result in their eventual disintegration by natural processes. The rate of deterioration is unknown, however, monument staff are developing an annual photo monitoring program to document deterioration (Florissant Fossil Beds National Monument, 1983c).

Little is known about protecting such artifacts in situ, and no comprehensive conservation study of petrified wood has ever been conducted. However, because buildings are exposed to the same natural weathering processes as the tree trunks at Florissant, materials used for cultural conservation (e.g., historical building stones and gravestones) are being tested on petrified wood samples exposed to the elements at Florissant (figure 6).

Other research involves an effort to understand the causes of deterioration, the geochemical properties of the petrified wood and the climatic impacts on the fossils. X- ray diffraction, x- ray fluorescence, and scanning electron microscopy can be used to study the mineralization process that the wood has undergone. This information will be compared to fossil wood samples from other localities. Results of this study will guide efforts to stabilize the in situ stumps (Jennifer Young, written communication, March 2, 2005).

Other investigations have placed data- loggers into two stumps: one under the newly constructed shelters and one still exposed to the elements. These loggers will record temperature and relative humidity levels and are designed to fit into tight spaces. Investigators also placed a data- logger on top of both stumps. These micro-stations will record differences between surface conditions and internal conditions every three hours and log data for later analysis. These data will add to the documentation of the impact that fluids have on the samples by recording a year of weather conditions, to help determine which of the test materials best conserved the test samples under prevailing climatic conditions (Jennifer Young, Smithsonian Institute, written communication, March 2, 2005).

When the testing of products is completed, conservation can take place in two phases. The first phase is the reconstruction of the trunks by reattaching some of the larger loose pieces using one or more adhesives.. The second phase is the prevention of further deterioration. Large fissures in the trunks require a filler material, while the finer cracks and pores require a less viscous fluid that will repel water (Jennifer Young, Smithsonian Institute, written communication, March 2, 2005).

Estimates of Paleoelevation

One of the significant aspects of the fossil flora at Florissant is its application in estimating past elevation (paleoelevation) during the Eocene Epoch. Indeed, few topics in the history of scientific research at Florissant have attracted as much published attention as paleoelevation (Meyer, 2001). The reason for this attention is that the results are important on many scientific fronts; the outcome will affect the work of paleobotanists, stratigraphers, climatologists, and structural geologists.

Interpretations of the tectonic history and timing of uplift in the southern Rocky Mountains are based on the results of paleoelevation studies from Florissant. The Florissant Formation was deposited on the late Eocene erosion surface of the southern Rocky Mountains (see "Late Eocene Erosion Surface" in the "Geologic Features and Processes" section). For decades, geologists have used this erosion surface to reconstruct the erosional, tectonic, and climatic history of the southern Rocky Mountains. Marvine first recognized and reported the erosion surface in 1874. MacGinitie provided the first estimate of paleoelevation for Florissant in 1953. MacGinitie concluded, "the plant association indicates a region of moderate elevation, probably not more than 3000 nor less than 1000 feet." This estimate has been widely accepted and cited as evidence for significant uplift of the region during the late Tertiary (e.g., Epis and Chapin, 1975).

The most commonly used method for determining paleoelevation from fossil floras uses estimates of mean annual temperature from isochronous sea- level and upland paleofloras in conjunction with terrestrial lapse rates (the rate at which temperature decreases with

increasing elevation) (Axelrod, 1965; Axelrod and Bailey, 1976). In other words, researchers calculate paleoelevation by using fossil plants to estimate two paleotemperatures: that at Florissant and that from another fossil flora of the same age and at the same latitude at sea level. By taking the difference in paleotemperature between sea level and Florissant, and multiplying that difference by the "appropriate lapse rate" of elevation change for 1°C, researchers can calculate estimates of paleoelevation. Reliable estimates of paleoelevation must include continentality (temperature variations between the coast and continental interior), paleogeography (latitudes of continents during the geologic past), and fluctuations in sea level.

Considerable research on the paleoelevation at Florissant was done during the 1990s. One worker used paleoenthalpy (moist static energy in the atmosphere) for the purpose (table 2). Most estimates range from 6,235 feet (1,900 m) to more than 13,450 feet (4,100 m); however, Axelrod (1998) estimates 1,495 feet (455 m).

All the studies using various methodologies to estimate Florissant's Eocene elevation suggest a much higher paleoelevation than that of MacGinitie (1953). The various methods for calculating paleoelevation are problematic, making estimated paleoelevations speculative. Nevertheless, they are a useful framework for comparison with other interpretations regarding late Eocene elevation in the southern Rocky Mountain region (Meyer, 2001).

Development

According to the U.S. Census Bureau, Colorado is the third- fastest growing state in the United States. Florissant Fossil Beds National Monument is located in Teller County which experienced a 64.9% increase in population between 1990 and 2000 making it the 10th fastest growing county in Colorado.

In 1969, because of the threat of development and loss of paleontological resources, Congress set aside 5,992 acres (2,425 ha) of mountain meadows and forested, rolling hills as Florissant Fossil Beds National Monument. Today subdivisions surround the monument (Florissant Fossil Beds National Monument, 1983c), making it "a significant piece of protected, accessible, and interpreted open space in an increasingly developed mountain landscape" (Florissant Fossils Beds National Monument, draft comprehensive Interpretive Plan, July 30, 2004).

Approximately 95% of the monument is classified as "natural zone," incorporating, among other things, the ancient Lake Florissant and the undeveloped areas surrounding the lakebed. Approximately 11 acres (4.5 ha) or a fraction of 1% of the total acreage are classified as "historic zone," including the Hornbek Homestead. The remaining 4% of the monument is classified as "developed zone," which encompasses concentrated visitor and staff use areas, such as county roads, headquarters and visitor contact buildings, maintenance facilities, picnic area, residences, related parking areas, and utilities (Florissant Fossil Beds National Monument, 1983a).

Periodically, proposed development outside the boundary of the monument threatens the values held within: wildlife habitat, its undeveloped character, a place where plant and animal populations and communities are monitored for health, and a place where natural geologic processes such as erosion and groundwater movement are allowed to proceed unimpeded by human impact (Florissant Fossils Beds National Monument, draft comprehensive interpretive plan, July 30, 2004). For example, in 1986 the county planned to locate a landfill adjacent to the northwest corner of the monument. This action would have had serious aesthetic and environmental consequences for the monument (McChristal, 1994). Superintendent Tom Wylie (1985–1988) announced that the National Park Service had filed suit in state court to block approval of the dump site. This pressure caused the contractor to withdraw his proposal (*Colorado Springs Sun*, February 12, 1986; *Colorado Springs Gazette Telegraph*, February 11, 1986).

The natural resource management plan (1983) for the monument addresses impacts to natural resources from rapid expansion of subdivisions adjacent to the monument and the anticipated increase in visitor use, by stating that "the monument will maintain a boundary fence to discourage adverse use of monument properties." Protection is required for key resources, which were significant in the establishment of the monument, that is, the paleontological resources. These resources are very fragile and subject to impacts of development especially when excavation is necessary. Realizing the fragile nature of these resources as well as the need to provide adequate facilities to meet visitor and administrative needs, investigators conducted a stratigraphic survey to define the location of the various paleontological layers and significant geological conditions (Florissant Fossil Beds National Monument, 1983a). Upon identifying the potential developable sites, soil borings were taken to determine the depth and condition of soils. These data were one of the primary factors in developing the alternatives identified in the environmental assessment for the general management plan development concepts (1983).

Buried Stumps

Of primary concern for development within Florissant Fossil Beds National Monument is the discovery of as yet unknown buried stumps. Knowledge of their locations and distributions will give planners a guide for the suitability and appropriateness of future development locations, and will aid paleobotanists to more accurately describe Florissant paleoenvironments (Florissant Fossil Beds National Monument, 1983b). Construction of building and shelter foundations, underground utilities, a water tank, and a septic leach field will require excavation into the soils and bedrock to depths ranging from 4 to 16 feet (1.2 to 4.9 m) (Chen Northern, Inc., unpublished geotechnical engineering report, job no. 1 562 90, October 17, 1990). Excavation in the soils,

consisting of clay, clayey to silty sand, and clayey gravel can probably be accomplished with conventional earth excavating equipment. Construction of buildings often requires excavating into the rocks of the Florissant Formation, not just the soil (Herb Meyer, Florissant Fossil Beds National Monument, written communication, May 2, 2005).

Excavation in the underlying bedrock, consisting of shale units (sandstone, siltstone, and claystone), will likely require heavy duty earth excavating equipment. Difficult excavation conditions could occur if cemented zones are encountered in the rock. Pneumatic chisels, ripping or blasting may be required, particularly in confined excavations such as trenches. Consideration should be given to the use of heavy duty trenching machines for utility trench excavations, and possibly building foundations (Chen Northern, Inc., unpublished geotechnical engineering report, job no. 1 562 90, October 17, 1990).

Most petrified stumps or logs within 1 or 2 feet (0.3 or 0.6 m) of the surface can be readily located by high concentrations of petrified wood fragments at the surface. Stumps more deeply buried are not so easily detected. For this reason, investigators have periodically pursued the question of how best to locate more deeply buried stumps by remote detection (Florissant Fossil Beds National Monument, 1983b).

According to the 1983 report, *Stratigraphic Surveys for Site Selection of Visitor and Administrative Facilities*, of all the geophysical methods examined at the time, investigators considered the electrical conductivity method the most feasible; they also studied seismic, ground magnetometer, gravity, and electrical resistivity. This preferred technique depends upon the electrical conductivity of earth materials, which is directly proportional to the amount of underground moisture. A conductivity meter, mounted on a 15- foot (4.6- m) long boom, broadcasts and receives RF radio frequencies of 9.8 KHz, which can measure ground conductivity up to 30 feet (9 m) in depth under optimum soil moisture conditions. An abrupt change in ground conductivity is an indicator of a buried petrified stump. The instrument and boom are carried by hand across the ground, with sampling transects approximately 10 feet (3 m) wide, and readings taken every 5 feet (1.5 m) along the transect. The technique is totally nondestructive, and is estimated to take approximately 20 hours for a 3- to- 4- person crew to survey 1 acre (0.4 ha). Although this type of survey may not be able to detect stumps of less than 15 feet (4.6 m) in diameter, the ease and rapidity of sampling makes it the most feasible of all the geophysical methods that have been examined to date (Florissant Fossil Beds National Monument, 1983b).

Groundwater

Groundwater level and quality will also be impacted by development. Groundwater feeds seeps and springs, which are generally areas of high biodiversity. An undetermined number of springs occur in the monument. The quality and quantity of these springs—and the quality of the two major perennial streams—are unknown (Florissant Fossil Beds National Monument, 1983c). Groundwater level is significant for management because a decrease in groundwater level could have a direct effect on the monument's resources, in particular, seeps and springs and the plants and animals that depend on this source of water. Quantifying groundwater level is important because park managers could use this information for planning and future decision making related to development outside the monument's boundary.

According to the monument's natural resource management plan and environmental assessment (1983), the monument contains only a portion of land within the watershed. All surrounding subdivisions have individual septic tanks and no sewer systems, and all have individual wells within the aquifer. The primary land uses outside the monument are for residential dwellings and livestock. A potential for contamination of monument waters from outside sources exists (Florissant Fossil Beds National Monument, 1983c).

Two major wells within the monument provide water for human consumption. One well, located adjacent to the visitor center, is 165 feet (50 m) deep and capable of pumping an estimated 4–6 gallons (15–23 L) per minute into a 50 gallon (189 L) pressure tank. Water quality is poor because of high mineral content, but treatment using filters and chlorination makes it potable (Florissant Fossil Beds National Monument, 1983c).

A second well is located near a residence in park housing at the eastern edge of the monument. This well is 60 feet (18 m) deep and is capable of producing an estimated 0.5–1 gallon (2–4 L) per minute. This water also has a high mineral content and is used for sanitation purposes only (Florissant Fossil Beds National Monument, 1983c). Other abandoned wells are known to be in the monument but their numbers, locations and quality and quantity of water is not known (Florissant Fossil Beds National Monument, 1983c).

With many unknowns, a need exists to inventory, assess, and monitor the water resources of the monument. In addition, a water resources management plan is needed (Florissant Fossil Beds National Monument, 1983c).

Dam Removal and Stream Restoration

A number of small intermittent spring- fed streams flow through Florissant Fossil Beds National Monument and into Grape Creek. Many dry gulches also exist. In the 1930s and 1940s, ranchers and farmers constructed 44 earthen dams in many of these drainages. These dams were intended to provide erosion control and facilitate water retention and diversion for agriculture. It has been National Park Service policy to restore native communities and natural processes.

Since the earthen dams interrupted natural drainage and altered natural hydrologic and geomorphic processes in

the monument, they did not comply with National Park Service policy. The earthen dams posed an ongoing threat to the natural landscape of Florissant by: 1) inhibiting natural processes and scenic beauty; 2) altering the natural occurrence and function of wetlands, floodplains, and riparian areas; 3) raising concern for sedimentation to downstream wetlands; and 4) creating a potential flood hazard. A breach or failure of one or more of the dams and the resultant flooding, accelerated erosion, and increased sedimentation of downstream wetlands made the structures a threat to the natural resources of Florissant. In the event of heavy rainfall, the earthen dams would likely fail because of their small sizes and lack of structural integrity.

In 1997 all 44 earthen dams were inventoried and evaluated by ranking the removal of each earthen dam based on effects on wetlands, hydrologic alteration, size, vegetation alteration, accessibility to equipment, erosion concerns (past, present, and predicted), use as a wildlife resource and critical habitat, aesthetics, and other potential benefits such as flood control and water sources for fire suppression (Birchfield, 2000). The dams that were recommended for removal had the fewest benefits, greatest impacts, and greatest likelihood of restoration success (Florissant Fossil Beds National Monument, 2001) (IT Corporation, 2001a).

During the course of the Boulder Creek reclamation and restoration, five dams were removed and re- vegetated and one culvert (Structure 33) was replaced (figure 4). Approximately 15,454 cubic yards (11,814 m^3) of material was moved from the former dam structures and placed in fill areas to blend inconspicuously into the surrounding topography (table 3). After reclamation, the areas disturbed by the dam removal—approximately 4.5 acres (1.8 ha) of land: 2 acres (0.8 ha) of wetlands and 2.5 acres (1.0 ha) of dry uplands—were seeded or re- vegetated. Success of the re- vegetation effort will not be immediately evident. The National Park Service will need to conduct monitoring to detect any potential problems and to evaluate the effectiveness of the reclamation efforts.

On October 19, 2001, staff members from the National Park Service, the U.S. Army Corps of Engineers, and IT Corporation conducted a final walk- through after which National Park Service representatives accepted the work as complete. However, on October 30, 2001, the National Park Service notified IT Corporation and U.S. Army Corps of Engineers that the straw crimping was insufficient and had to be redone because much of the straw had blown away from the upland slopes during high winds. Additional straw was placed and hand crimped during the week of October 29, but high winds continued to dislodge the straw. The National Park Service requested additional erosional control mats for the most exposed areas. These mats were installed during the weeks of October 29 and November 5, 2001 (IT Corporation, 2001b).

Agricultural Terraces

In the 1930s, the Civilian Conservation Corps (CCC) built terraces to irrigate potatoes, and perhaps lettuce, fields (figure 3). Farmers harvested the last potato crop from the monument property in the 1970s (Beth Simmons, written communication, May 23, 2005). The terraces were also meant to mediate the flow of water on the landscape in order to prevent soil erosion during the drought of the 1930s. At the time, governmental incentive programs for farmers required terracing. Farmers would not receive loans or futures if they did not cooperate with “contour” or “strip” farming.

The terraces disturbed the natural flow of water by trapping and holding water at higher than natural water levels (in order to water potatoes). Natural conditions would have been lower (to feed beaver ponds). The terraces redirected flowing water after rainstorms, potentially creating a zone of unnatural saturation.

Abandoned Mine Land Site

An abandoned mine land (AML) site was located south of the Florissant Cemetery just inside the north boundary of the monument along Upper Twin Rock Road. The adit was cut into decomposed Pikes Peak Granite and had no apparent mineralization. The site was reclaimed in August 2000 by backfilling with native rock followed by waste rock and soil. No other AML sites are known in the park.

Mining

As in most units of the National Park System, federal mineral leasing and the location of mining claims are prohibited inside the monument. The monument is not known to contain any privately owned mineral rights and less than 6 acres of the park are non- federally owned. While some limited mining occurred inside the monument prior to its inclusion in the National Park System, no mining occurs today.

The Cripple Creek mining district, 15 miles (24 km) southeast of Florissant, is the richest gold producing area in Colorado with more than 21,000,000 troy ounces produced (Davis and Streufert, 1990). Gold mining continues in Cripple Creek today.

In their report, Rogers and Alberts refer to “lava flows associated with the lake beds at certain points” that jut out as promontories “into the lake on either side.” Scudder (1883) called these flows “trachyte”—fine-grained, generally porphyritic, extrusive igneous rock, usually containing biotite, hornblende, and pyroxene. According to Rogers and Alberts, many of these trachytic exposures still bear marks of prospecting from miners during the Cripple Creek boom. Lakes (1899), mentions that “every bed of tuff and breccia” was tunneled and prospected for gold, without profit. Optimism for another “Cripple Creek” in the Thirtynine Mile volcanics was so high that the town of Freshwater (now Guffey) was platted, but the bonanza never occurred (Evanoff, 1994).

Potential Research

Eruptive Source of Pumice and Ash

The eruptive source of the pumice and ash in the Florissant Formation is unknown. This is a significant piece of missing information for interpreting the geologic story at Florissant Fossil Beds National Monument. Geologists and park interpreters would like to know more precisely the source and age of the volcanic ash in which Florissant fossils are found (Florissant Fossil Beds National Monument, draft comprehensive interpretive plan, July 30, 2004).

Evanoff and others (2001) briefly address possible sources for the Florissant ash and pumice and identify three possible sources: (1) early, pre- ignimbrite eruptions from the 33.8- million- year- old (Ma) Mount Aetna caldera, (2) late, post- ignimbrite eruptions from the 34.3- Ma Grizzly Peak caldera, or (3) eruption of local rhyolite dome in the vicinity of Florissant (figure 5). The Guffey volcanic center is another possible source of volcanic material (Herb Meyer, Florissant Fossil Beds National Monument, written communication, May 2, 2005).

The suitability of these possibilities as the source of Florissant ash and pumice is questionable, however. First, sanidine—used in $^{40}Ar/^{39}Ar$ age dating—from the Antero Tuff (erupted from the Mount Aetna caldera) has a measurably younger age than the Florissant Formation, and significantly higher K/Ca ratios (68.1 ± 16.4 Ma) (McIntosh, unpublished data, 2001)—calculated from K-derived ^{39}Ar and Ca- derived ^{37}Ar. Second, investigators have not identified any outflow ignimbrites from the Grizzly Peak caldera, and sanidine samples of ignimbrites from the Grizzly Peak intracaldera are older than the Florissant Formation sanidine, and also have higher K/Ca ratios (84.4 ± 6.2 Ma) (McIntosh, unpublished data, 2001). Third, geologic mapping in the Florissant area has not identified any rhyolitic dome in the appropriate 34-million- year- old age range, though investigators suggest that such domes may have been present but are now eroded or covered (Evanoff and others, 2001).

In an attempt to determine the eruptive source, one possible way is to study the Florissant Formation in the field and analyze samples in the laboratory to develop a detailed microstratigraphic framework. This would help determine the source(s) for the volcanic sediments of the Florissant Formation by analyzing trace elements that can “fingerprint” the various ash layers within the Florissant Formation. New radiometric dates will better resolve the age and duration of the Florissant Formation.

Eocene-Oligocene Climate Change and Fossil Resources

Florissant Fossil Beds National Monument contains the world’s most significant upland fossil deposit during the Eocene- Oligocene transition (see figure 1). This time interval, immediately preceding a global cooling event, is the most pronounced climate change of the Paleogene Period (see figure 1). In order to determine paleoclimatic parameters such as mean annual temperature and mean annual precipitation, park managers have proposed collecting fossil leaf assemblages from several stratigraphic levels at different sites around the Eocene Florissant lake basin. This will provide new evidence to interpret the small- scale variability of biotic communities and microclimatic conditions around the lake basin in time and space. A comparison of Florissant fossils with the fossil plants from other localities, such as the John Day basin, will provide an ideal basis for studying the impacts and nature of climate change over a wide geographic area.

Active paleontological research at Florissant Fossil Beds National Monument provides a means for educating visitors about fossil resources and demonstrating what fossils can reveal about climates and ecosystems of the past. Additional fossil specimens will enhance the monument’s existing, small collection and ensure that park staff will be able to construct new exhibits that do not rely solely on long- term loans from other museums.

Most of the existing collections of Florissant fossils were made and studied by non- National Park Service workers long before the establishment of the monument. Many of these collections are housed at other museums, including the University of California at Berkeley, the University of Colorado, the National Museum of Natural History (Smithsonian), and Yale University. Unfortunately, few early collectors noted important aspects of stratigraphic position or even precise locality information severely limiting the utility of these collections in discerning patterns of biotic change though time and space around the Eocene lake basin at Florissant. It is important to collect new paleobotanical specimens from the field in order to form a more accurate basis for comparison with the fossils from John Day and other fossil localities from western North America. This will also result in large collections of fossil insects that will be of use in new exhibits and available for related research.

Table 1. Factors that Affect the Stability of In Situ Paleontological Resources

SURFACE

Physical	Chemical	Biological	Human
Tectonics • seismicity • folding/faulting • extrusive events (lava flows) *Weathering/Erosion* • solar radiation • freeze/thaw • wind • water • fire • gravity • mass wasting • abrasion during transport	• surface water • soil/rock pH • mineral replacement • oxidation (rust, pyritization)	*Displacement* • pack rats • harvester ants *Destruction/Damage* • burrowing organisms • trampling ungulates • vegetation (root and lichen growth)	• construction (buildings, roads, dams) • mining • military activities (construction, vehicles, ballistics) • theft/vandalism • poor science and recovery techniques • livestock • agriculture • recreational activities (offroad vehicle travel)

SUBSURFACE

Physical	Chemical	Biological	Human
Tectonics • seismicity • folding/faulting • intrusive events • metamorphism *Weathering/Erosion* • freeze/thaw (permafrost) • water movement (piping, cavern formation) • gravity • mass wasting • compaction • rock falls	• groundwater • soil/rock pH • mineral replacement • metamorphism (partial melt, recrystallization)	*Displacement* • root growth • bioturbation *Destruction/Damage* • burrowing organisms • root growth	• construction (buildings, roads, dams) • mining • military activities (construction, ballistics) • theft/vandalism • poor science and excavation technique (dynamite)

Source: Santucci and Koch (2003).

Table 2. Estimates of Florissant Paleoelevation

Year	Investigators	Estimate
1953	MacGinitie	1,000–3,000 ft (305–915 m)
1986, 1992	Meyer	8,040 ft (2,450 m) Range: 6,230–7,550 ft (1,900–2,300 m)
1992	Wolfe	8,860–9,515 ft (2,700–2,900 m)
1992	Gregory and Chase	7,550–10,500 ft (2,300 m ± 400 m–3,200 ± 800 m)
1994 (a and b)	Wolfe	13,560 ft (4,133 m) and 7,400 ft (2,255 m)
1994	Gregory	7,550–10,830 ft (2,300 ± 370 m–3,300 ± 750 m)
1995	Forest et al.	9,515 ft (2,900 ± 670 m)
1996	Gregory and McIntosh	6,235–10,170 ft (1,900 ± 500 m–3,100 ± 800 m)
1997	Axelrod	1,495 ft (455 m)
1998	Wolfe et al.	12,470 ft (3,800 ± 800 m)

Table3. Structure Cut and Fill Volumes

Structure	Location	Approximate Volume of Soil in cubic yards (m^3)
47	Boulder Creek, midstream (dry)	59 (45)
32	Boulder Creek, upstream (dry)	1,010 (772)
31	Boulder Creek, upstream (pond)	1,680 (1,284)
33	Culvert along path over Boulder Creek	0
9	Southernmost, along Route 1 (dry)	10,095 (7,718)
14	Easternmost, across from visitor center, along Route 1 (pond)	2,610 (1,995)
Total		**15,454 (11,814)**

Source: IT Corporation (2001b).

Figure 2. Abandoned Mine Land Site. Reclamation of a small adit prospect in Florissant Fossil Beds National Monument occurred on August 3, 2003. Staff of the National Park Service Geologic Resources Division and volunteers from the San Juan County Youth Corps completed the work. National Park Service photo by John Burghardt.

Figure 3. Agricultural Terrace West of Hornbeck Homestead. The Civilian Conservation Corps (CCC) built the terraces in order to irrigate agricultural fields. The terraces were also meant to mediate the flow of water on the landscape to prevent soil erosion during the drought of the 1930s. However, they disrupt natural flow after rainfall events. National Park Service photo.

Figure 4. Dam Removal and Stream Restoration. In 2001, Structure 32, a dam on Boulder Creek, was removed along with other structures during a dam removal and stream reclamation project in Florissant Fossil Beds National Monument. The IT Corporation, a contractor of the U.S. Army Corps of Engineers Rapid Restoration Group, conducted the work. National Park Service photos by Hal Pranger.

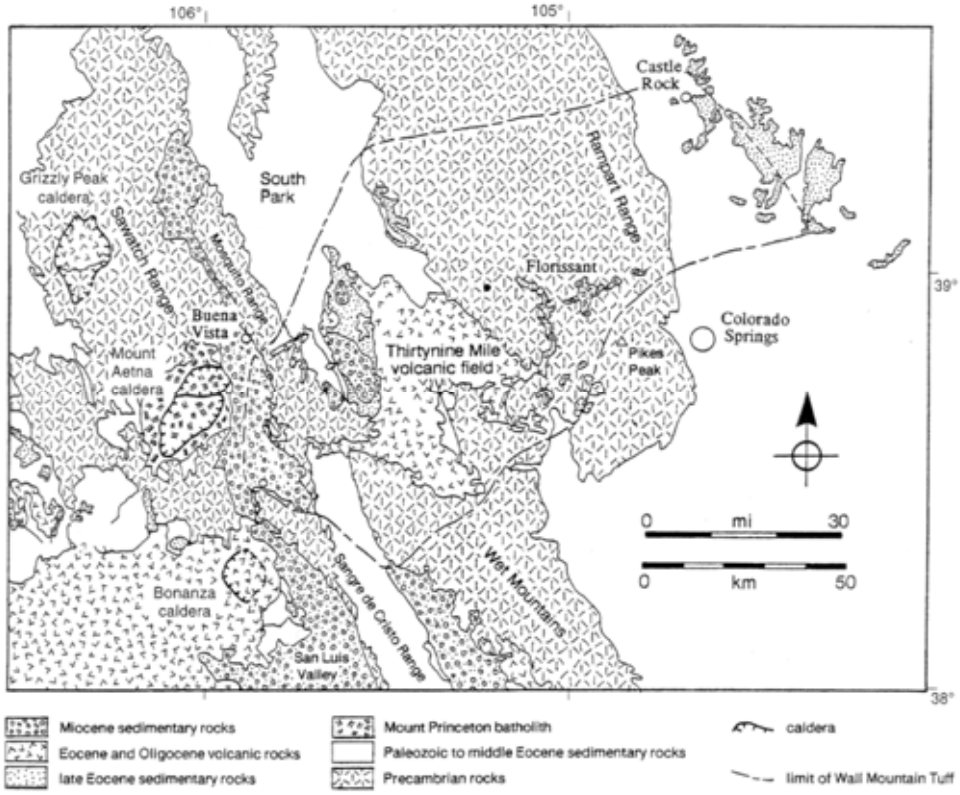


Figure 5. Regional Map of Central Colorado. Investigators have suggested three possible sources of the pumice and ash in the Florissant Formation: Mount Aetna caldera, Grizzly Peak caldera, and a local rhyolite dome in the vicinity of Florissant. The Guffey volcano complex is another possible eruptive source. *Source*: Evanoff and others (2001).

Figure 6. Preservation of Fossil Stumps. The excavated, fossilized *Sequoia*-like stumps are a primary park resource and the only in situ paleontological resource that can be seen easily by visitors in their natural setting. For these reasons, they cannot be buried for protection; however, a scientist from the Smithsonian Institute is investigating materials used in cultural conservation to potentially protect these resources against further deterioration. Photo by Katie KellerLynn.

Geologic Features and Processes

This section provides descriptions of the most prominent and distinctive geologic features and processes in Florissant Fossil Beds National Monument.

Evolution and Global Climate Change

Because of its world- renowned reputation for fossils as part of an ancient ecosystem, Florissant Fossil Beds National Monument plays an important role in the present- day debate about evolution. Florissant provides evidence that organisms and ecosystems evolve, and that different groups of organisms such as plants and mammals—and different type of organs, such as leaves and flowers—have evolved at difference rates (Meyer, 2003).

Most of the fossil plants and many of the fossil insects at Florissant can be placed into modern genera. On the other hand, the few fossil mammals from Florissant all represent extinct genera, and in the case of the brontotheres and the oreodont, extinct families.

About 280 genera of insects and spiders found at Florissant Fossil Beds National Monument have been described as extinct. Several plant genera are also extinct including the two most abundant plants at Florissant, *Cedrelospermum* and *Fagopsis*, extinct members of the elm and beech families (Meyer, 2003) However, most of the fossil plants and insects represent genera that still live today. However, many of their modern distributions do not overlap. These genera that once lived side by side in the late Eocene forest at Florissant are represented by related living species now restricted to widely separated parts of the world (Meyer, 2003). Florissant's ancient community includes organisms whose modern relatives occupy not only different regions, but also different climatic habitats (Boyle, 2004; Meyer, 2003). Nowhere in the modern world is the same association of plants and insects found living together. Among the fossils at Florissant, plants and insects that today are subtropical are juxtaposed beside others that are typically cool-temperate in modern distribution (Meyer and Weber, 1995).

Although the ancient Florissant community shows just one snapshot in a long sequence of ecosystem evolution (Meyer, 2003), the data it furnishes has contributed to national debates on evolution and global climate change, which are in need of salient information. Because Florissant was an ancient upland ecosystem that existed immediately preceding a very significant cooling of the world's climate, the clues it preserves in the rock record provide important insights for understanding of the evolution of North American biotic communities and their response to climate change.

Late Eocene Erosion Surface

The high meadow in which Florissant Fossil Beds National Monument lies has caught the attention of geologists and visitors alike. Geologists interpret this feature as the remains of an extensive erosion surface developed by stable rivers, and visitors wonder that such moderate relief is possible at 8,200 feet (2,500 m). Since this erosion surface was first recognized and reported (Marvine, 1874), it has been controversial. Bradley (1987) makes three pertinent points about the erosion surfaces in the Front Range: (1) they are cut chiefly on Precambrian granitic and metamorphic rocks, (2) they can be no older than Tertiary because they are carved into rocks deformed during the Laramide Orogeny, and (3) they show a broad relationship to crystalline lithology. The surfaces are flattest and most extensive in those areas where granitic rocks are most abundant as in a southern area around Pikes Peak in Pikes Peak Granite (about 1.08 billion years old), and in a northern area that extends onto the Laramie Range in Sherman Granite and associated intrusives (all approximately 1.4 billion years old). Between these two areas, metamorphic rocks are relatively more abundant and the erosion surfaces have greater local relief.

Basic questions about the erosion surfaces remain regarding (1) the number of surfaces—investigators have recognized as few as one to as many as 11 surfaces; (2) the age—early or late Tertiary, that is 20 million or 50 million years old; and (3) the genesis—peneplain (forming at low elevations and with low river gradients) vs. pediment (forming under arid conditions along mountain fronts or plateaus).

The most recent interpretation regarding the number and ages of erosion surfaces identifies one major subsummit (lower, older [late Eocene]) surface, including the surface at Florissant, and a second (higher, younger [late Tertiary]) summit surface, for example, the smoothly rolling tundra surface in Rocky Mountain National Park. Although most workers agree that the higher erosion surface has been affected by Quaternary periglacial activities, the question of genesis—peneplanation vs. pedimentation—remains largely unresolved (Bradley, 1987). The higher surface is much less extensive than the lower subsummit surface. Studies have concentrated on the lower erosion surface that has been called "Rocky Mountain," "Sherman," "Late Eocene," and "Subsummit," which leaves the full significance of the higher surface, which has been called "Flattop" and "Summit," inconclusive (Bradley, 1987).

Because peneplains were believed to form at low elevations and with low river gradients, substantial uplift was required to bring them to their present elevations. Using this kind of evidence, investigators estimated late Cenozoic uplift to be between 5,000 and 9,000 feet (1,524 and 2,743 m) (Davis, 1911; Chamberlain, 1919). However, reclassifying peneplains as pediments greatly reduced the amount of uplift required (Johnson, 1931, 1932; Mackin,

1947). Uplift was then estimated from displaced flora and fauna, for example using fossils from Florissant, Colorado (Epis and Chapin, 1975). In the 1980s, the outcome seemed ironic, that is, magnitude of uplift based on paleontology is approximately the same as it was when based on peneplains (Bradley, 1987). During the 1990s, however, investigators developed new methods that used estimates of paleoclimate and lapse rates—the rate at which temperature decreases with increasing elevation—to measure paleoelevation (methodologies summarized in Meyer, 2001). Another method uses principles of atmospheric energy conservation to determine paleoelevation from estimates of paleoenthalpy—a thermodynamic property (heat content) of the atmosphere, which can be estimated from fossil plants. Using these methods, investigators consistently concluded that during the Eocene Florissant was as high as today, or perhaps even higher (Meyer, 2003). Nevertheless, depending on the method used, current estimates cover a broad range—from much lower than today to much higher than today. Hence, the debate about Florissant's elevation 34 million years ago continues.

Geologists have studied erosion surfaces so extensively because of the implications for reconstructing the erosional, tectonic (uplift), and climatic history of the Rocky Mountain region. For decades geologists have used erosion surfaces as clues to the post- Laramide deformational history of the middle and southern Rocky Mountains. The outcome has at least three significant implications: (1) Did global climate change or did uplift influence the sharp contrast between ancient and modern ecosystems at Florissant? (2) When did most of the uplift of the southern Rocky Mountains occur, before the late Eocene during the Laramide Orogeny, or as post- Laramide deformation? and (3) Can regional erosion surfaces form at high elevations? Additional questions ponder the erosional history of the surfaces: How much has the lower erosion surface been lowered since the late Eocene? And, how much lowering of the late Eocene surface is permissible for it still to be called the late Eocene surface, and beyond which it should be called a younger surface?

The Florissant area remains part of this continued controversy. For example, Divide, Colorado, is situated on a prominent erosion surface, which rises to the south and southeast of the town and extends to the north and east onto the Rampart Range. Investigators have considered this surface to be an exhumed part of the late Eocene surface (Epis and Chapin, 1975; Scott and Taylor, 1986). However, a few features related to this surface cast some doubt on this interpretation: no outcrops of the Wall Mountain Tuff occur on this surface, and the oldest deposits on this surface are the gravels at Divide, which contain clasts derived from the Cripple Creek volcanic field (Epis and Taylor, 1975; Epis and others, 1980). The gravels at Divide on this surface and the truncation of the Wall Mountain outcrops east of Florissant suggest that this surface is not a simple exhumed surface of late Eocene age. The modern low- level surface probably acquired its present form in the Miocene (Evanoff, 1994).

If the Rampart- Divide surface is an exhumed late Eocene surface, then erosion must have removed all of the exposures of Wall Mountain Tuff without significantly eroding the Proterozoic crystalline rocks. Another interpretation is that this surface developed over a longer period of time, from exposure of Proterozoic rocks in the Paleocene until the Miocene, when the Divide drainage was graded to the Ogallala Formation of eastern Colorado. This second interpretation implies that the granite continued to be eroded between the late Eocene and Miocene, and that the elevation difference between Florissant and the Divide area may have been greater in the late Eocene than it is today (Evanoff, 1994).

Paleontological Resources

The incredible fossil record at Florissant, which consists of organisms that are not ordinarily fossilized, has enabled paleontologists and geologists to reconstruct a relatively brief moment of time at the end of the Eocene Epoch (about 34 million years ago). The fossils at Florissant are of five types:

1. Plants—redwood stumps; palynomorphs (pollen and spores); leaves, fruits, seeds, and flowers
2. Diatom mats (see "Sedimentation and Fossilization" section)
3. Spiders, insects, and myriapods (multi- legged arthropods)
4. Mollusks (clams and snails) and ostracods (microscopic crustaceans)
5. Vertebrates—fish, birds, and mammals

In 2003 the Smithsonian Institute published *Fossil of Florissant* by Herbert W. Meyer. This book includes a complete listing of the fossil organisms from Florissant and descriptions of the five types of fossils. In addition, the monument's Web site hosts a fossil database that brings together collections that are now in at least 17 different museums throughout North America and Europe. This database integrates taxonomic, museum collection, and publication data into a single virtual museum. It includes new photographs for almost all of the published Florissant specimens. Three different portals accommodate users: scientific researchers, educators and students, and the layperson.

Since publishing *Fossils of Florissant*, investigation has revealed additional information about fossil mammals at Florissant (Worley, 2004). Hence, this information is provided in some detail in this report. Other fossils are discussed generally in order to highlight the types of paleontological resources at Florissant Fossil Beds National Monument. However, readers of this report are encouraged to consult *Fossils of Florissant* for a thorough summary and descriptions of fossil resources, which is beyond the scope of this report.

Fossil Plants

From giant redwood stumps to microscopic pollen grains, plant fossils include leaves, fruits, seeds, cones, and flowers from about 140 species. Angiosperms (flowering plants) dominate the flora, but conifers are also conspicuous (e.g., yews, Cyprus, and pine). Families of flowering plants include: birthwort, laurel, barberry, sycamore, beech, birch, walnut, storax, willow, basswood, cocoa, elm, spurge, currant, rose, evening primrose, legumes, bladdernut, maple, citrus, tree of heaven, torchwood, cashew, spindle tree, buckthorn, grape, hydrangea, hard- rubber tree, ginseng, elder, honeysuckle, sweetsop, morning glory, olive, greenbrier, yam, sedge, grass, palm, and cattail.

More than 50 families are represented by fossil pollen at Florissant, possibly including the world's earliest known record of the sunflower family, which is today the largest family of flowering plants (Meyer and Weber, 1995). Most of the leaf and fruit fossils come from trees and shrubs, and only rarely are the small herbaceous plants represented. In some instances the leaf cuticle is preserved, showing details of the outermost layer of the leaf's cells.

Fossil Stumps

The petrified forest is one of the main attractions at Florissant Fossil Beds National Monument. Using their remains as indicators, these trees must have been spectacular when they were living—forming a grove along the valley bottom with a forest canopy at least 197 feet (60 m) high (Meyer, 2003). For example, the Big Stump measures 12 feet (3.7 m) tall, 38 feet (12 m) around, and may have been greater than 230 feet (70 m) tall when the mudflow buried the base of the 750- year- old tree (Florissant Fossil Beds National Monument, *Petrified Forest Walk*).

The ancient redwoods formed a forest that bordered the old drainage of the Florissant valley. During the late Eocene a single mudflow from the Guffey volcano covered the forest floor with 16 feet (5 m) of volcanic mud. Although modern coast redwoods are known to survive partial burial by sprouting new roots at a higher level (Helley and LaMarche, 1968), investigators have observed no such features in the exposed trunks at Florissant (Gregory- Wodzicki, 2001). Therefore, the trees were probably killed by the mudflow and died when the roots could no longer receive sufficient oxygen. Even though the trees died because of this event, the mudflow also helped preserve their remains for 34 million years. Geologic processes, a combination of mudflows, silica- rich groundwater flow, and permineralization, preserved the stumps. Stumps are preserved within the lower mudstone unit of the Florissant Formation. Mapping of 31 stumps at Florissant revealed that they occur in a single plane, and 91% of them are vertical (Evanoff and Doi, 1992). Hence, the stumps represent a single in situ forest where the trees were encased while in a rooted position, and not transported to their current location by the mudflow.

Unfortunately, the stump locations reveal little about the late Eocene forest spacing because the area has been heavily collected. A. C. Peale of the Hayden Survey described the Florissant area in 1874, mentioning 20 or 30 stumps visible above ground. In a history of the Florissant valley, Kimmet (1986) asserted that an "early photo of the forest shows such a profusion of petrified stumps, limbs, and branches that the area seemed almost impassable." By 1882, however, geologists were already complaining of "vandal tourists" breaking up the stumps and logs and hauling them away (Kimmet, 1986). Material was removed until 1969, when the area became a national monument; the only stumps left were those too large to be moved or those still buried. In 1984 the National Park Service reburied some stumps to prevent vandalism and further deterioration (Gregory- Wodzicki, 2001).

In the remaining stumps, cellular details of the anatomy and structure of the trees can still be observed in the preserved wood, which have enabled paleobotanists to identify the wood types (primarily *Sequoia*- like trees) and to examine tree growth rings for information about paleoclimate (Wheeler, 2001). Tree rings are the result of varying seasonal growth rates. During spring and summer when growing conditions are favorable, the trees add large cells to their outer layer of wood. When the cold, dry winter comes, smaller cells are added. The two types of cells give the appearance of light and dark rings (figure 7). These rings can provide clues to the age of trees, climatic conditions, and fire and disease history (Florissant Fossil Beds National Monument, *Petrified Forest Walk*).

Fossil Spiders, Insects, and Myriapods

The extensive fossil record of the Florissant Formation is notable for the outstanding details, number, and diversity of the delicate, preserved remains of insects. Just as in modern environments, spiders and insects are a hugely diverse group, with more than 1,500 species described from Florissant. Future studies may compress the number of described species of Florissant spiders and insects into a smaller number of valid species. At the same time, researchers may add descriptions of new species.

Fossil insects include flies (e.g., march, dance, bee, hover, and tsetse), mayflies, scorpion flies, katydids, crickets, mantids, moths, cockroaches, termites, earwigs, waterscorpions, leafbugs, assassin bugs, froghoppers, cicadas, aphids, lacewings, beetles and ladybugs, wasps, bees, and ants. The 12 species of fossil butterflies from Florissant provide the world's richest diversity of fossil butterflies (Meyer and Weber, 1995).

The myriapods are a group of multi- legged arthropods including centipedes and millipedes. At Florissant the group is represented by the class Diplopoda (millipedes) and includes two families, each with a single species (Meyer, 2003). The reclusive lifestyle of millipedes explains their rarity in the fossil record.

Because of the unusual taphonomic (burial) conditions required for their preservation, spiders and insects are

much less common than plants in the world's fossil record, making their occurrence at Florissant even more significant. Fossil plant sites abound globally, but insect sites are rare. The abundance of insects at Florissant results partly from the unusual conditions of taphonomy, facilitated largely by the presence of diatom mats, which provided a rare mechanism of entrapment favoring insect preservation (Meyer, 2003). Fossil insects at Florissant typically consist of entire bodies. The different parts of a spider or insect are usually preserved "in attachment," making it easier for scientists to reconstruct the entire organism.

Ostracods and Mollusks

According to Meyer (2003), invertebrates other than insects and spiders at Florissant include a species of ostracod (*Cypris florissantensis* [mussel shrimp]) and both freshwater and terrestrial mollusks. The most abundant and diverse group of mollusks at Florissant are gastropods (snails). Only one species of freshwater clam, questionably placed in the genus *Sphaerium*, has been described.

Vertebrate Fossils

Vertebrate fossils are rare at Florissant. For the most part we are left to wonder what kinds of vertebrate animals once lived here. The rarity of vertebrate fossils at Florissant is the result of taphonomic biases and the nature of sedimentary environments in which the fossils were preserved. In part, terrestrial vertebrates are rare in lake deposits simply because it was uncommon for their dead carcasses to be transported into the lake. In addition, acidity in the lake, caused by decaying plant material or volcanic ash falls, may have inhibited the fossilization of vertebrates by dissolving bone material (Meyer, 2003).

Birds

Some vertebrate fossils do occur in the Eocene sediments, for example, three exemplary bird fossils, all from the lake shale units of the Florissant Formation. One specimen is tentatively identified as belonging in the Coraciiformes order (e.g., rollers and kingfishers). The phylogenetic relationships of the other two species are unclear and they have been placed into Aves: incertae sedis ("classification uncertain"). A particular fossil with an almost complete skeleton, except for the skull, is a very important find. This specimen has been described as a new genus and species, *Eocuculus cherinae*, with affinities to the arboreal cuckoos (Cucuiformes, Cuculindae, Cuculinae) of the Old World (Chandler, 1999). Like the better known insects and plants, the extraordinary quality of the preservation is shown by the presence of feather impressions on the slab and counter slab of *Eocuculus* (Chandler, 1999).

In 1997 the finest bird specimen to date to come from the Florissant fossil beds was uncovered: a complete, extremely well- preserved, new species possibly related to plovers, with long legs and extended beak (Meyer, 2003). "New discoveries such as this assure that the study of Florissant's paleontology remains an exciting story, and one that is never completely concluded" (Meyer, 2003).

Fish

Fish are the most abundant vertebrate fossils at Florissant. They include bowfins, suckers, catfishes, and pirate perches. During the mid- 1870s, E. D. Cope originally described the Florissant fish, at the same time he was describing dinosaurs from Jurassic deposits a few miles south of Florissant.

Most of the Florissant fish, except for pirate perches, were bottom dwellers, and many were tolerant of poor water conditions. Fossil fish seem to be more common in some shale layers than others, perhaps indicating that water conditions in the lake changed through time (Meyer, 2003).

Mammals

Until recently, discoveries of fossil mammals have been serendipitous. Mammal fossils found in the Florissant Formation include an entire body of a small extinct mouse opossum (*Peratherium*), fragmentary remains of a small, three- toed horse (*Mesohippus*), brontothere (an extinct rhinoceros- like animal), and oreodont (an extinct ungulate, resembling a pig). However, in summer 2003 a systematic investigation of the fluvial lower mudstone unit greatly increased the known mammal diversity from the Florissant Formation (Worley, 2004). The discovery of a single large molar confirms the presence of eubrontotheres in the monument, which had been inferred previously from a large atlas and tooth enamel fragments. Two artiodactyls taxa are represented by isolated lower molars, *Leptomeryx cf L. speciosus*, and a second yet to be identified. Additionally, the rodents *Eutypomys parvus*, *Adjidaumo minimus*, *Pelycomys*, and *Ischyromys douglassi* occur as Florissant mammalian fauna. Worley also recovered insectivoran jaws, representing the soricid *Domnina thompsoni*, the geolabidid *Centetondon magmun*, and a tiny proscalopid (Worley, 2004).

In addition, Quaternary deposits at the monument have yielded mammoth bones, including a molar with an associated portion of the jaw, dated at 49,830 ± 3,290 years B.P. (Meyer, 2003).

Unconformities

Unconformities are "gaps in the rock record" during which either no rocks were deposited, or since deposition have been eroded away. Tertiary rocks of the Florissant area lie unconformably on the eroded surface of the Pikes Peak Granite. The unconformity represents a long interval of erosion that followed Precambrian mountain building. Many thousands of feet of rock were removed, thereby exposing the deeper crystalline mountain roots. Paleozoic seas swept across the area burying the ancient erosion surface with sediment and producing a major unconformity. In Florissant, late Eocene streams cut a long dendritic valley into the exposed Precambrian rocks, in which volcanic rocks and sediment later accumulated. Local relief on this

unconformity is as great as 980 feet (300 m) near the southern end of the paleovalley (Evanoff and others, 2001). This particular break in the rock record represents more than 1.04 billion years of missing time. All Paleozoic, Mesozoic, Paleocene, and early Eocene rocks have been eroded away.

The youngest unconformity rests above the pumice conglomerate unit of the Florissant Formation and represents missing time from the Oligocene, Miocene, and Pliocene Epochs (see figure 1). These rocks were stripped away by erosion. The unconformity is locally capped by Quaternary deposits and represents about 32 million years of missing time.

Another unconformity, less conspicuous than the one that separates Precambrian and Tertiary rocks in the area, lies between the Wall Mountain Tuff (Eocene) and the next youngest rocks that remain. Not all rocks eroded evenly at all locales. Depending on the exposure, this may be between the Wall Mountain Tuff and Florissant Formation or between the Wall Mountain Tuff and the boulder conglomerate. This unconformity represents missing time (hiatus) during the Eocene Epoch.

Tors

Tors are isolated rock towers that rise prominently above otherwise level terrain. At Florissant they are composed of Precambrian Pikes Peak Granite, which is very jointed. Tors may assume peculiar or fantastic shapes. Investigators think that periglacial processes may be important in the formation of tors (Bates and Jackson, 1987). Investigators also have identified tors as indicators of non- glaciation (Street, 1973). Tors remain in areas that were beyond the limit of glaciation; otherwise, glaciers would have modified or destroyed them.

Sedimentation and Fossilization

The pattern of sedimentation in Lake Florissant is significant for the ultimate preservation of fossils. In past descriptions, volcanism is given full credit for fossilization; however, more recently, the story has become more complicated, albeit more accurate. For example, Kiver and Harris (1999) state,

> Here, insects and plants were snuffed out rapidly as ash fell in large volumes. Both ash and insects settled to the bottom of Lake Florissant and compression under the weight of additional sediment and rock produced carbon films. The finer than talcum- powder- size ash faithfully preserves minute anatomical details enabling paleontologists to study everything except internal organs and the original color of insects. Delicate antennae, legs, and hairs on the bodies are often preserved. Butterfly and moth wings often show the patterns of spots and other markings.

This description of the fossils is accurate, but the process of fossilization lacks a significant component. Although some of the ash that ended up in the lake was directly deposited from the atmosphere, as Kiver and Harris describe, much of the ash had fallen across the landscape and later washed into Lake Florissant. Moreover, most of the ash and pumice layers are sparsely fossiliferous or entirely devoid of fossils because they were deposited too rapidly and are too coarse in texture to incorporate and preserve delicate plants and insects.

The silica- rich ash weathered into clay and washed into the lake, enriching the lake's chemistry. Weathering, therefore, is now recognized as a significant step in the fossilization process at Florissant (Harding and Chant, 2000; O'Brien and others, 2002; O'Brien and others, 1998). The abundance of silica in the lake allowed diatoms—microscopic algae—to live and form hard siliceous shells. Periodically, diatoms bloomed into abundant populations, which were followed by massive die- offs caused by overpopulation that depleted lake water of silica and other nutrients. As the diatoms died, billions upon billions of their microscopic siliceous shells settled to the lake bottom, forming a thin layer above the layer of ash- clay. The micro- layers of ash- clay and diatoms compacted to form the well- known "paper shales." Geologists refer to the lake beds as shale because of their clay content and laminated character. Explicitly calling them diatomaceous tuffaceous shales highlights the significance of the two- fold sedimentation process that includes (1) diatoms and ash- clay layers and (2) volcanic ash eruptions.

Identifying the process of sedimentation is important for understanding the preservation of fossils at Florissant: plants and insects became entrapped in mucous-secreting mats of surface water blooms of planktonic diatoms in Lake Florissant. As the mats and incorporated organisms settled out of the water column, the mucilaginous mats and their associated bacterial communities arrested decay and promoted preservation of refractory tissues. Thus, ash fall and the diatom mats preserved the fossils in Lake Florissant. Moreover, diatom mats preserve soft tissue in a way previously suggested for cyanobacterial mats (Harding and Chant, 2000). Generally speaking, this mode of preservation may be an important causative factor in the formation of exceptionally preserved lacustrine fossil biota like those at Florissant.

Figure 7. Tree Growth Rings of Petrified Wood. Paleontologists examine tree growth rings, which are a result of varying seasonal growth rates, for information about paleoclimate. Cellular details of the wood's anatomy and structure can still be observed in petrified wood at Florissant Fossil Beds National Monument. Photo by Katie KellerLynn.

Map Unit Properties

This section provides a description for and identifies many characteristics of the map units that appear on the digital geologic map of Florissant Fossil Beds National Monument. The table is highly generalized and is provided for informational purposes only. Ground disturbing activities should not be permitted or denied on the basis of information contained in this table. More detailed unit descriptions can be found in the help files that accompany the digital geologic map or by contacting the National Park Service Geologic Resources Division.

Geologists have mapped and described the rocks and unconsolidated deposits that occur in Florissant Fossil Beds National Monument, and from this, they have deciphered the nature and sequence of geologic events. The geology of Florissant is composed of three formal units: Pikes Peak Granite, Wall Mountain Tuff, and the Florissant Formation; one informal unit—boulder conglomerate (equivalent to the Tallahassee Creek Conglomerate); and three deposits of Pleistocene or Holocene age: gravels, alluvium, and colluvium.

The table that comprises this section is meant to complement the digital geologic map of Florissant Fossil Beds National Monument (see included CD). The map units listed in the table correspond to this geologic map; however since 1992, Evanoff and others (2001) updated and divided the Florissant Formation into six units, with the addition of the lower shale unit. The five alphanumeric designations (Tf1, Tf2, Tf3, Tf4, and Tf5) were used for classification of mapped outcrops in the monument, but were not intended to be used outside the monument. The six informal units of the Florissant Formation are from oldest to youngest (bottom to top) (1) lower shale unit, (2) lower mudstone unit (referred to as Tf1), (3) middle shale unit (referred to as Tf2), (4) cap rock conglomerate unit (referred to as Tf3), (5) upper shale unit (referred to as Tf4), and (6) upper pumice conglomerate unit (referred to as Tf5). Although the lower shale unit does not occur within the monument's boundary and is not included on the geologic map, it has been included in the table in order to provide a full description of the Florissant Formation and to complete the geologic story that includes two generations of Lake Florissant.

Map Unit Properties Table

Age	Unit Name (Symbol)		Description	Depositional Setting	Local and Global Significance	Development Potential	Paleontological Resources
Quaternary	Colluvium (Holocene and Pleistocene) (Qc)		Thin gravels mantling slopes, composed of granular grus derived from the Pikes Peak Granite, rhyolitic gravel derived from the Wall Mountain Tuff, and shale, mudstone, sandstone, and silicified wood fragments derived from the Florissant Formation	Brought to the foot of a slope or cliff by gravity	None		Redeposited silicified wood fragments from the Florissant Formation
	Holocene alluvium (Qal)		Brown unconsolidated humus- rich (peat) sands and gravelly sand	Occurs along streams	None	Rich riparian habitats	
	Pleistocene gravels (Qg)		Thick gravels mainly composed of granular grus derived from the Pikes Peak Granite, also scattered fragments of Wall Mountain Tuff	Stream deposits (alluvial fan and terrace)	None		Source of gravel, redeposited silicified wood fragments from the Florissant Formation, vertebrate fossils (including mammoth, radiocarbon dated at 49,830 ± 3,290 B.P.)
unconformity							
Tertiary (Eocene)	Florissant Formation	Unit 5 (Tf5)	Upper pumice conglomerate unit: pumice- rich white sandstones and conglomerates, structureless to locally trough cross- bedded; numerous pink pumice clasts near top; poorly sorted brown pumiceous sandstones interbedded with scattered lenticular mudstones and shales (near south entrance); maximum measured thickness 75 ft (22.8 m).	Lacustrine at base (deposited in Lake Florissant), fluvial at top (streams in tributary valleys washed pumice pebbles into lake)	Age: 34.07 ± 10 Ma (based on $^{40}Ar/^{39}Ar$ dating); dates come from Tf3, Tf4, and Tf5 (Evanoff and others, 2001)		Locally abundant fingernail clams, rare plant, and lymnaeid snail fossils
		Unit 4 (Tf4)	"Upper lake shale" (upper shale unit): gray to greenish- brown paper shales and blocky mudstones; interbedded with planar, thin yellow to white pumiceous sandstone beds; maximum measured thickness 18 ft (5.6 m) in the NW corner of the monument; unit thins to the south.	Lacustrine (represents younger generation of Lake Florissant)	Prolific fossil- bearing unit	Very sensitive to disturbance	Fossiliferous gray to yellowish- brown sandstones interbedded with diatomaceous mats* (near the south entrance); fossils include leaves, insects, ostracods, fish scales, and fingernail clams
		Unit 3 (Tf3)	"Cap rock" (cap rock conglomerate unit): yellowish- gray conglomerate with subangular to rounded clasts of tuff, quartz, and andesite; locally contains blocks of andesite, pumiceous sandstones, and blocky mudstone; typically graded, otherwise structureless to crudely horizontally bedded; maximum thickness 26 ft (7.9 m) measured near Lodge stump (E of Scudder pit); thins to the north and is not present in the NW corner of the monument.	Volcanogenic debris: flow deposit in Lake Florissant, later reworked by lacustrine processes; vertical tubes represent water- escape structures	Protects Tf2 from erosion		Scattered fingernail clam fossils in upper half of unit
		Unit 2 (Tf2)	"Lower lake shales" (middle shale unit): interbedded brown paper shales, grayish brown blocky mudstones, thin yellowish pumiceous sandstones, and thin granular pumice conglomerates; maximum thickness 30 ft (9 m).	Lacustrine (represents younger generation of Lake Florissant); also may represent marginal swamp environments; volcanic fallout in lake	Most of the fossil quarries occur in this unit (e.g., Princeton quarry and Tennessee pit)	Very sensitive to disturbance	Abundant plant fossils with less abundant insects and planorbid snails; diatomaceous mats; rare fish, mollusks, and ostracod fossils
		Unit 1 (Tf1)	"Lower fluvial sequence" (lower mudstone unit): tan to gray blocky tuffaceous mudstones interbedded with yellowish gray pumiceous sandstones and rare arkosic sandstone ribbons, which typically have abundant trough cross- bedding; bottom contact poorly exposed; maximum thickness 34 ft (10.4 m).	Fluvial (with rare channel deposits) topped by a volcanogenic mudflow deposit on valley bottom; not in Lake Florissant	Upper 16 feet (5 m) is a single mudflow deposit that buried stumps; probably associated with down- valley debris flow that dammed Lake Florissant		Fossils include stumps and logs of gymnosperms and angiosperms, scattered leaves, and rare mammal bones (e.g., *Mesohippus* and brontothere)
			Lower shale unit: alternating tuffaceous siltstone and paper shale beds (alternating laminae of diatomite and volcanic ash altered to smectite clays); thin pumice conglomerate with granite and volcanic clasts scattered throughout. Note: Florissant Fm. underlies about one- third of monument; total thickness 23 ft (75m)	Lacustrine (represents earlier Lake Florissant)	Lowest occurrence of prominent paper shales	Very sensitive to disturbance	Plant and insect fossils, contains most of the fish and almost all of the bird fossils known from the Florissant Formation; outcrops do not occur within the monument
	Boulder Conglomerate (Tb)		Lenticular boulder conglomerate composed primarily of large rounded blocks of Pikes Peak Granite, and secondarily of gneiss and rhyolite cobbles and boulders; rhyolite clasts rounded to subangular and derived from the Wall Mountain Tuff; interbedded with Tf1, and rests on surface cut into the Wall Mountain Tuff and the Pikes Peak Granite; maximum thickness about 49 ft (15 m).	Fluvial and debris- flow deposit	Probable equivalent of the Tallahassee Creek Conglomerate exposed south of Wrights Reservoir (Wobus and Epis, 1978)		According to Evanoff (2001), scattered silicified wood fragments from Tf1 occur in this unit (may be stratigraphically questionable (Herb Meyer, Florissant Fossil Beds National Monument, written communication, May 2, 1005)
unconformity							
Tertiary (Eocene)	Wall Mountain Tuff (Twm)		Rhyolitic welded tuff, brownish- gray to dark gray; abundant sanidine and less abundant biotite, argillized plagioclase, and magnetite; weathers to large angular to subangular blocks; maximum thickness 49 ft (15 m) in lower exposures.	Pyroclastic flow from the southwest (probable source is Mount Princeton batholith), strongly controlled by paleotopography, mantles sides of the Florissant paleo- valley	Oldest Tertiary rock in the monument—37.73 ± 0.07 Ma (average of two ages reported by McIntosh and Chapin, 1994)		No fossils
unconformity							
Precambrian	Pikes Peak Granite (pCg)		Medium to coarsely crystalline reddish granite and quartz monzonite; contains abundant perthitic microcline, quartz, and biotite; contains micro- joints.	Emplaced during a time of crustal extension, perhaps associated with continental epeirogenic uplift and doming	Oldest rocks in the monument, but among the youngest Proterozoic rocks in Colorado—1.08 Ga (Unruh and others, 1995), Lake Florissant formed on the eroded surface of this unit	Weakest of the Precambrian batholiths in area; forms domes, tors, and boulder piles; weathers into grus	No fossils

Sources: Evanoff (1992, 1994), Evanoff and others (2001), Gregory- Wodzicki (2001), Meyer (2003), Wobus (2001).
*Diatom mats were originally interpreted as stromatolites (Evanoff and Doi. 1992).

Geologic History

This section highlights the map units (i.e., rocks and unconsolidated deposits) that occur in Florissant Fossil Beds National Monument and puts them in a geologic context in terms of the environment in which they were deposited and the timing of geologic events.

The late Eocene deposits at Florissant Fossil Beds National Monument, with their world- famous plant and insect fossils, lie in a paleovalley incised into Pikes Peak Granite, the oldest rocks in the monument (about 1.08 billion years old) (Wobus, 2001). The Pikes Peak batholith, formed when the granite cooled from magma deep beneath Earth's surface, is bounded on all sides by older batholiths and plutons. The intrusive episode that formed the Pikes Peak Granite is the last of three events that occurred at about 1.7, 1.4, and 1.0 billion years ago.

The oldest rocks in the area, into which these batholiths intruded, consisted of a combination of regionally metamorphosed sediments (dominantly marine mudstones) and some volcanic rocks. Emplacement of the Pikes Peak Granite, the last of the Precambrian (figure 1) igneous events, was more localized than the other two igneous episodes. It is the largest Precambrian pluton in the southern Rocky Mountains. Emplacement probably occurred during a time of crustal extension or rifting, rather than mountain building; the event formed the basement rock of the present- day monument.

The Precambrian crystalline rocks of Florissant were uplifted, beginning most recently about 70 million years ago during the Laramide orogeny. As mountain- building and uplift progressed, layers of previously deposited Paleozoic and Mesozoic rocks were eroded from the uplifted area and redeposited as sediments in the surrounding Denver and South Park basins. Because of uplift during the Laramide orogeny, Pikes Peak Granite, forming the core of the uplift, was exposed at the surface. Erosion cut an irregular surface into the exposed granite, creating an unconformity at Florissant, and streams cut a long dendritic valley. Pikes Peak Granite is exposed as boulders, tors, and isolated knobs and hills on the flanks of the paleovalley.

Wall Mountain Tuff rests unconformably on the irregular erosion surface of Pikes Peak Granite and mantles the sides of the paleovalley. About 37 million years ago, during a time of increased volcanic activity, a thick pyroclastic flow followed drainages and draped welded tuff over the local topography. The ash flow that produced the Wall Mountain Tuff must have been a tremendous event. The Wall Mountain Tuff is a welded tuff (ignimbrite) that formed from a hot (1,292°F [>700°C]) cloud consisting of volcanic glass, crystals, rock fragments, and hot gases (nuée ardente). No one in modern times has observed an eruption that has produced a volume of tuff the size of Wall Mountain Tuff, but such eruptions have been modeled using their rock records as constraints. During such events, the hot material probably erupts in such a huge vertical column that the column collapses and flows along the topography like a very hot, subaerial turbidity current. This hot flowing mass can be more than a mile thick and travel at velocities greater than 225 miles per hour (100 m/sec) (Cas and Wright, 1987). As the cloud slows, the liquid and solid components settle and blanket the topography, with low areas receiving the thickest mantles. Also as the cloud settles, the hot glass particles coalesce and weld together. The Wall Mountain Tuff is welded even in its farthest reaches, indicating it had to be formed quickly to retain its heat. Considering the velocity of such pyroclastic flows, the tuff may have been deposited over its 4,015- square- miles (10,400- km^2) extent within an hour or two (McIntosh and Chapin, 1994). Wall Mountain Tuff has also provided the basis for reconstructing regional paleodrainages (Epis and Chapin, 1975).

The source of the tuff was a volcanic center near present- day Mount Princeton, about 129 miles (80 km) west of the monument. An immense caldera formed when the eruptive center collapsed into the depleted magma chamber following the eruption. Although this caldera was large, it is no longer evident in the modern topography.

A limited exposure of boulder conglomerate overlies the Pikes Peak Granite and Wall Mountain Tuff on the southeastern side of the monument. This conglomerate is equivalent to the Tallahassee Creek Conglomerate and contains huge boulders and cobbles of granite; the largest boulders span 19 feet (5.8 m) in diameter. The conglomerate also contains cobbles and boulders of gneiss, schist, welded tuff (from the Wall Mountain Tuff), and scattered silicified wood fragments. The conglomerate was deposited by streams and debris flows.

The primary fossil- bearing rocks in the area make up the Florissant Formation. The Florissant paleovalley was episodically dammed by volcaniclastic debris flows (lahars) derived from the Thirtynine Mile volcanic field, including the massive Guffey volcano, to the southwest. Like modern stratovolcanoes, the Guffey volcano was active sporadically over a long period, perhaps several hundred thousand years (Meyer, 2003). Lahar activity progressed northward into the paleovalley and acted as dams to the Florissant valley drainage, creating the ancient Lake Florissant. Lahars also covered the forest floor and buried the stumps that would become the petrified forest. Therefore, the Florissant Formation is not simply composed of "lake beds" but contains a variety of lithologies, including sandstone, siltstone, shales, mudstone, and conglomerate. Scientists have estimated the duration of Lake Florissant to be about

2,500 to 5,000 years (McLeroy and Anderson, 1966). The source of the ash and pumice that make up the Florissant Formation is unknown, although investigators have speculated about some options: (1) early, pre- ignimbrite eruptions from the 33.8- million- year- old (Ma) Mount Aetna caldera, (2) late, post- ignimbrite eruptions from the 34.3- Ma Grizzly Peak caldera, (3) eruption of a local rhyolite dome in the vicinity of Florissant (Evanoff and others, 2001), and (4) the Guffey volcanic complex.

At the time of deposition of the late Eocene fluvial, lacustrine, and volcanic rocks in paleovalleys at and near Florissant, the topography of the region probably resembled that of today, controlled by the relative resistance of the Proterozoic (Precambrian) rocks. Ridges and hills, then as now, were supported by the more resistant, fine- grained rocks. In contrast, the most common but least resistant rock in the area, coarse-grained Pikes Peak Granite, produced a more subdued surface often thickly mantled with grus. Not surprising, then, the paleovalley which became the site of Lake Florissant was developed in this most highly erodible Proterozoic unit (Wobus, 2001).

One topographic difference from today was that the Florissant Formation was deposited within a valley that then drained to the south. Land that had been draining into the Arkansas River now drains into the Platte. The modern drainage divide that separates the Platte and Arkansas drainages occurs within the area of paleodrainage and is located just south of the monument. This reversal in streamflow direction indicates tilting after deposition of the Florissant Formation and after the valley was buried by volcanics and sediment (Evanoff, 1992).

The present topography of the region is probably the result of Laramide uplift and subsequent erosion later in the Cenozoic (Pederson and others, 2002). This interpretation is based on a method that uses geographical information system (GIS) to evaluate the history of erosion and uplift. However, though the mechanism is becoming clear, the actual elevation of Florissant 34 million years ago is still a controversial enigma. Recent paleobotanical estimates argue that the late- Eocene elevation was at or exceeded its present elevation, subsequently subsiding. However, some geologists remain skeptical of this interpretation and argue that post- Laramide uplift has been extensive, which suggests a lower Eocene elevation. In either case, Florissant fossils remain a means for solving this controversial issue.

Most of the rocks that covered the Florissant Formation before the beginning of the Pleistocene Epoch have been stripped away by erosion. However, some remnants are still present, including later volcanic lava flow deposits from the Guffey volcano. For example, during the later part of Tertiary time, sand and gravel deposits formed a layer that is now exposed several miles to the east of Florissant, near Divide, Colorado (Meyer, 2003). The erosional episode that occurred between the Eocene and the Pleistocene, which stripped the rocks from the Florissant Formation, created this unconformity in the monument.

During the ice ages of the Pleistocene Epoch, glaciers were present only on the highest reaches of Pikes Peak and did not extend into the Florissant valley. At Florissant, Pleistocene deposits consist of sand and gravel from weathered Pikes Peak Granite, Wall Mountain Tuff, and fragments of shale, mudstone, sandstone, and silicified wood derived from the Florissant Formation. These deposits, composed of debris accumulation along the bases of slopes and from sediments washed into the valleys by streams, form a thin mantle above the Florissant Formation. Investigators have found fossil mammal bones, including mammoth, in these sediments. Typical erosion patterns in hilly country have taken their toll on the fossil beds. Today bits and pieces of the beds are exposed around the perimeter of the old lake.

References

This section provides a listing of references cited in this report. A more complete geologic bibliography is available and can be obtained through the National Park Service Geologic Resources Division. Additionally, the Florissant Fossil Beds National Monument Web site hosts a database of paleontological references, which includes digital files of many of the older references.

Axelrod, D.I., 1965, A method for determining altitudes of Tertiary floras: The Paleobotanist, v. 14, p. 144–171.

Axelrod, D.I., 1997, Paleoelevation estimated from Tertiary floras: International Geology Review, v. 39, p. 1124–1133.

Axelrod, D.I., and Bailey, H.P., 1976, Tertiary vegetation, climate, and altitude of the Rio Grande depression, New Mexico–Colorado: Paleobiology, v. 2, p. 235–254.

Bates, R.L., and Jackson, J.A., eds., 1987, Glossary of geology (3d ed.): Alexandria, Virginia, American Geological Institute, 788 p.

Birchfield, W.A., 2000, Evaluating dams for removal and setting restoration priorities using the decision advancement method (DAM) [M.S. thesis]: Fort Collins, Colorado State University, 38 p.

Boyle, B., 2004, Estimating paleoclimate based on contemporary forest inventories—a search for the modern analog of the Florissant fossil flora: GSA Abstracts with Programs, v. 26, no. 5, p. A- 41, http://gsa.confex.com/gsa/2004AM/finalprogram/abstract_79833.htm (July 2005).

Bradley, W.C., 1987, Erosion surfaces of the Colorado Front Range—a review, *in* Graf, W.L., ed., Geomorphic systems of North America: Boulder, Colorado, Geological Society of America, Centennial Special Volume 2, p. 215–220.

Cas, R.A.F., and Wright, J.V., 1987, Volcanic successions, modern and ancient: London, Chapman and Hall, 528 p.

Chamberlain, R.T., 1919, The building of the Colorado Rockies: Journal of Geology, v. 27, p. 145–164, 225–251.

Chandler, R.M., 1999, Fossil birds of Florissant, Colorado—with description of a new genus and species of Cuckoo, *in* Santucci, V.L., and McClelland, L., eds., National Park Service paleontological research 4: Geologic Resources Division Technical Report, NPS/NRGRD/GRDTR- 99/03, p. 49–53.

Davis, M.W., and Streufert, R., 1990, Gold occurrences of Colorado: Denver, Colorado Geological Survey, Resource Series 28, 101 p.

Davis, W.M., 1911, The Colorado Front Range—a study in physiographic presentation: Association of American Geographers Annals, v. 11, p. 21–83.

Department of the Interior, 2000, Fossils on federal & Indian lands: Washington, D.C., Department of the Interior, 49 p., http://www.doi.gov/fossil/fossilreport.htm (September 2004).

Eicher, D.L. 1976. Geologic time (2d ed.): Englewood Cliffs, New Jersey Prentice- Hall, Inc., 150 p.

Epis, R.C., and Chapin, C.E., 1975, Geomorphic and tectonic implications of the post- Laramide, late Eocene erosion surface in the southern Rocky Mountains, *in* Curtis, B.F., ed., Cenozoic history of the southern Rocky Mountains: Geological Society of America Memoir 144, p. 45–74.

Epis, R.C., Scott, G.R., Taylor, R.B., and Chapin, C.E., 1980, Summary of Cenozoic geomorphic, volcanic, and tectonic features of central Colorado and adjoining areas, *in* Kent, H.C., and Porter, K.W., eds., Colorado geology: Denver, Rocky Mountain Association of Geologists, p. 135–156.

Evanoff, E., 1992, Introductory remarks on the geology and paleontology of Florissant Fossil Beds National Monument, *in* Evanoff, E., and Doi, K., eds., The stratigraphy and paleontology of Florissant Fossil Beds National Monument—a progress report [unpublished]: Boulder, Colorado, University of Colorado Museum, p. 1- 1–1- 30.

Evanoff, E., ed., 1994, Late Paleogene geology and paleoenvironments of central Colorado with emphasis on the geology and paleontology of Florissant Fossil Beds National Monument, Guidebook for the field trip May 6–8, 1994: Boulder, University of Colorado Museum, 99 p.

Evanoff, E., and de Toledo, P.M., 1993, New fossil mammals found at Florissant Fossil Beds NM: Park Science v. 13, no. 4, p. 13.

Evanoff, E., and Doi, K., eds., 1992, The stratigraphy and paleontology of Florissant Fossil Beds National Monument—a progress report [unpublished]: Boulder, University of Colorado Museum, 169 p.

Evanoff, E., Brill, R.A., de Toledo, P.M., Murphey, P.C., and Cushman, R.A. Jr., 1992, Surficial geologic map of Florissant Fossil Beds National Monument, Colorado, *in* Evanoff, E., and Doi, K., eds., The stratigraphy and paleontology of Florissant Fossil Beds National Monument—a progress report [unpublished]: Boulder, Colorado, University of Colorado Museum, plate 1, scale 1:10,000.

Evanoff, E., McIntosh, W.C., and Murphey, P.C., 2001, Stratigraphic summary and $^{40}Ar/^{39}Ar$ geochronology of the Florissant Formation, Colorado, *in* Evanoff, E., Gregory- Wodzicki, K.M., and Johnson, K.R., eds., Fossil flora and stratigraphy of the Florissant Formation, Colorado, Proceedings of the Denver Museum of Nature & Science, ser. 4, no. 1: Denver, Colorado, Denver Museum of Nature & Science, p. 1–16.

Florissant Fossil Beds National Monument, 1983a, Environmental assessment for the general management plan development concepts: Washington, D.C., National Park Service and U.S. Government Printing Office, 117 p.

Florissant Fossil Beds National Monument, 1983b, Stratigraphic surveys for site selection of visitor and administrative facilities: Washington, D.C., National Park Service, 43 p.

Florissant Fossil Beds National Monument, 1983c, Natural resource management plan and environmental assessment [unpublished NPS report]: Florissant, Colorado, Florissant Fossil Beds National Monument, 56 p.

Florissant Fossil Beds National Monument, 2001, Finding of no significant impact—future management of seven earthen dams, Florissant Fossil Beds National Monument: Florissant, Colorado, Florissant Fossil Beds National Monument, 16 p., http://www.nps.gov/flfo/FINALFONSI.pdf (August 2004).

Forest, C.E., Molnar, P., and Emanuel, K.A., 1995, Palaeoaltimetry from energy conservation principles: Nature v. 374, p. 347–350.

Gregory, K.M., 1994a, Paleoclimate and paleoelevation of the 35 Ma Florissant flora, Front Range, Colorado: Palaeoclimates, v. 1, p. 23–57.

Gregory, K.M., 1994b, Paleoclimate and paleoelevation of the Florissant flora, *in* Evanoff, E., ed., 1994, Late Paleogene geology and paleoenvironments of central Colorado with emphasis on the geology and paleontology of Florissant Fossil Beds National Monument, Guidebook for the field trip May 6–8, 1994: Boulder, University of Colorado Museum, p. 59–68.

Gregory, K.M., and Chase, C.G., 1992, Tectonic significance of paleobotanically estimated climate and altitude of the late Eocene erosion surface, Colorado: Geology, v. 20, p. 581–585.

Gregory, K.M., and McIntosh, W.C., 1996, Paleoclimate and paleoelevation of the Oligocene pitch- pinnacle flora, Sawatch Range, Colorado: GSA Bulletin, v. 108, p. 545–561.

Gregory- Wodzicki, K.M., 2001, Paleoclimatic implications of tree- ring growth characteristics of 34.1 Ma *Sequoioxylon pearsallii* from Florissant, Colorado, *in* Evanoff, E., Gregory- Wodzicki, K.M., and Johnson, K.R., eds., Fossil flora and stratigraphy of the Florissant Formation, Colorado, Proceedings of the Denver Museum of Nature & Science, ser. 4, no. 1: Denver, Colorado, Denver Museum of Nature & Science, p. 163–186.

Harding, I.C., and Chant, L.S., 2000, Self- sedimented diatom mats as agents of exceptional fossil preservation in the Oliogocene Florissant lake beds, Colorado, United States: Geology v. 28. no. 3, p. 195–198.

Helley, W.J., and LaMarche, V.C., 1968, December 1964, a 400- year flood in northern California: U.S. Geological Survey Professional Paper 600- D, p. D34–D37.

IT Corporation, 2001a, Work plan—Boulder Creek dam reclamation project, Florissant Fossil Beds National Monument, Teller County, Colorado [final document, unpublished, October 2001]: Greenwood Village, Colorado, IT Corporation, 22 p., 4 tables., 6 figs., 6 appendices.

IT Corporation, 2001b, Field report—Boulder Creek dam reclamation project, Florissant Fossil Beds National Monument, Teller County, Colorado [draft document, unpublished, November 2001]: Greenwood Village, Colorado, IT Corporation, 20 p., 5 tables., 4 figs., 8 appendices.

Johnson, D., 1931, Planes and lateral corrosion: Science, v. 73, p. 174–177.

Johnson, D., 1932, Rock fans of arid regions: American Journal of Science, v. 23, p. 389–416.

Kimmet, L., 1986, Florissant, Colorado: Cañon City, Colorado, Master Printers, 120 p.

Kiver, E.P., and Harris, D.V., 1999, Geology of U.S. parklands (5th ed.): New York, John Wiley & Sons, Inc., 902 p.

Lakes, A., 1899, The Florissant basin—a prospecting trip in the volcanic region between Cripple Creek and South Park: Mines and Minerals, v. 20, p. 179–180.

Leopold, E.B., and Clay- Poole, S.T., 2001, Florissant leaf and pollen floras of Colorado compared—climatic implications, *in* Evanoff, E., Gregory- Wodzicki, K.M., and Johnson, K.R., eds., Fossil flora and stratigraphy of the Florissant Formation, Colorado, Proceedings of the Denver Museum of Nature & Science, ser. 4, no. 1: Denver, Colorado, Denver Museum of Nature & Science, p. 17–69.

MacGinitie, H.D., 1953, Fossil plants of the Florissant beds, Colorado: Washington, D.C., Carnegie Institution of Washington, 198 p.

Mackin, J.H., 1947, Altitude and local relief of the Bighorn area during the Cenozoic: Wyoming Geological Association, 2d annual field conference guidebook, p. 103–120.

Marvine, A.R., 1874, Report for the year 1873, *in* 7th annual report of the United States Geological and Geographical Survey of the Territories (Hayden Survey): Washington, D.C., p. 83–192.

McChristal, J., 1994, A history of Florissant Fossil Beds National Monument—in celebration of preservation [unpublished report]: Florissant, Colorado, Florissant Fossil Beds National Monument, 106 p.

McIntosh, W.C., and Chapin, C.E., 1994, $^{40}Ar/^{39}Ar$ geochronology of ignimbrites in the Thirtynine Mile volcanic field, Colorado, *in* Evanoff, E., ed., Late Paleogene geology and paleoenvironments of central Colorado with emphasis on the geology and paleontology of Florissant Fossil Beds National Monument, guidebook for the field trip May 6–8, 1994: Boulder, University of Colorado Museum, p. 23–27.

McLeroy, C.A., and Anderson, R.Y., 1966, Laminations of the Oligocene Florissant lake deposits, Colorado: Geological Society of America Bulletin v. 77, p. 605–608.

Meth, C., and Applegate, D., 2003, Fossils and public lands (7- 23- 03): Alexandria, Virginia, American Geological Institute, http://www.agiweb.org/gap/legis108/fossils_cont.html (September 2004).

Meyer, H.W., 1986, An evaluation of the methods for estimating paleoaltitudes using Tertiary floras from the Rio Grand rift vicinity, New Mexico and Colorado [Ph.D. thesis]: Berkeley, University of California, 217 p.

Meyer, H.W., 1992, Lapse rates and other variables applied to estimating paleoaltitudes from fossil floras: Palaeogeography, Palaeoclimatology, and Palaeoecology, v. 99, p. 71–99.

Meyer, H.W., 2001, A review of the paleoestimates for the Florissant flora, Colorado, *in* Evanoff, E., Gregory-Wodzicki, K.M., and Johnson, K.R., eds., Proceedings of the Denver Museum of Nature & Science, Fossil flora and stratigraphy of the Florissant Formation, Colorado, ser. 4, no. 1, p. 205–216.

Meyer, H.W., 2003, The fossils of Florissant: Washington, D.C., Smithsonian Books, 258 p.

Meyer, H.W., and Weber, L., 1995, Florissant Fossil Beds National Monument—preservation of an ancient ecosystem: Rocks & Minerals, v. 70, p. 232–239.

National Park Service, 1998, Florissant Fossil Beds National Monument scope of collections: Florissant, Colorado, National Park Service, 13 p.

National Park Service, 2001, Management policies 2001: Washington, D.C., National Park Service, 137 p.

O'Brien, N.R., and Fuller, M., 1998, Sedimentology and taphonomy of the Florissant lake shales, Colorado: GSA Abstracts with Programs v. 30, no. 7, p. A- 162.

O'Brien, N.R., Meyer, H.W., Reilly, K., Ross, A.M., and Maguire, S., 2002, Microbial taphonic processes in the fossilization of insects and plants in the late Eocene Florissant Formation, Colorado: Rocky Mountain Geology, v. 37, no. 1, p. 1–11.

Peale, A.C., 1874, Report of A.C. Peale M.D., geologist of the South Park division, in 7th annual report of the United States Geological and Geographical Survey of the Territories (Hayden Survey): Washington, D.C., p. 193–273.

Pederson, J.L., Mackley, R.D., and Eddleman, J.L., 2002, Colorado Plateau uplift and erosion evaluated using GIS: GSA Today, v. 12, no. 8, p. 4–10.

Rogers, E.B., and Alberts, E.C., 1953, Florissant fossil shale beds, Colorado [unpublished NPS report, D- 5, file 10]: National Park Service, 30 p.

Santucci, V.L., and Koch, A., 2003, Paleontological resource monitoring strategies for the National Park Service: Park Science, v. 22, no. 1, p. 22–25.

Scott, G.R., and Taylor, R.B., 1986, Map showing late Eocene erosion surface, Oligocene- Miocene paleovalleys, and Tertiary deposits in the Pueblo, Denver, and Greeley 1° × 2° quadrangles, Colorado: U.S. Geological Survey Miscellaneous Investigations Map I- 1022, scale 1:250,000.

Scudder, S.H., 1883, Tertiary lake- basin at Florissant, Colorado, between South and Hayden Parks, *in* 12th annual report of the United States Geological and Geographical Survey of the Territories: Washington, D.C., p. 271–293.

Street, F.A., 1973, A study of tors in the Front Range of the Rocky Mountains in Colorado, with special reference to their value as an indicator of non-glaciation [M.S. thesis]: Boulder, Colorado, University of Colorado, 241 p.

Wheeler, E.A., 2001, Fossil Dicotyledonous woods from Florissant Fossil Beds National Monument, Colorado, *in* Evanoff, E., Gregory- Wodzicki, K.M., and Johnson, K.R., eds., Proceedings of the Denver Museum of Nature & Science, Fossil flora and stratigraphy of the Florissant Formation, Colorado, ser. 4, no. 1, p. 187–203.

Wobus, R.A., 2001, Precambrian igneous and metamorphic rocks in the Florissant region, central Colorado—their topographic influence, past and present: Florissant, Colorado, Pikes Peak Research Station, Colorado Outdoor Education Center, Bulletin 5, 9 p.

Wolfe, J.A., 1992, An analysis of present- day terrestrial lapse rates in the western conterminous United States and their significance to paleoaltitudinal estimates: U.S. Geological Survey Bulletin 1964, 35 p.

Wolfe, J.A., 1994, Tertiary climatic changes at middle latitudes of western North America: Palaeogeography, Palaeoclimatology, and Palaeoecology, v. 108, p. 195–205.

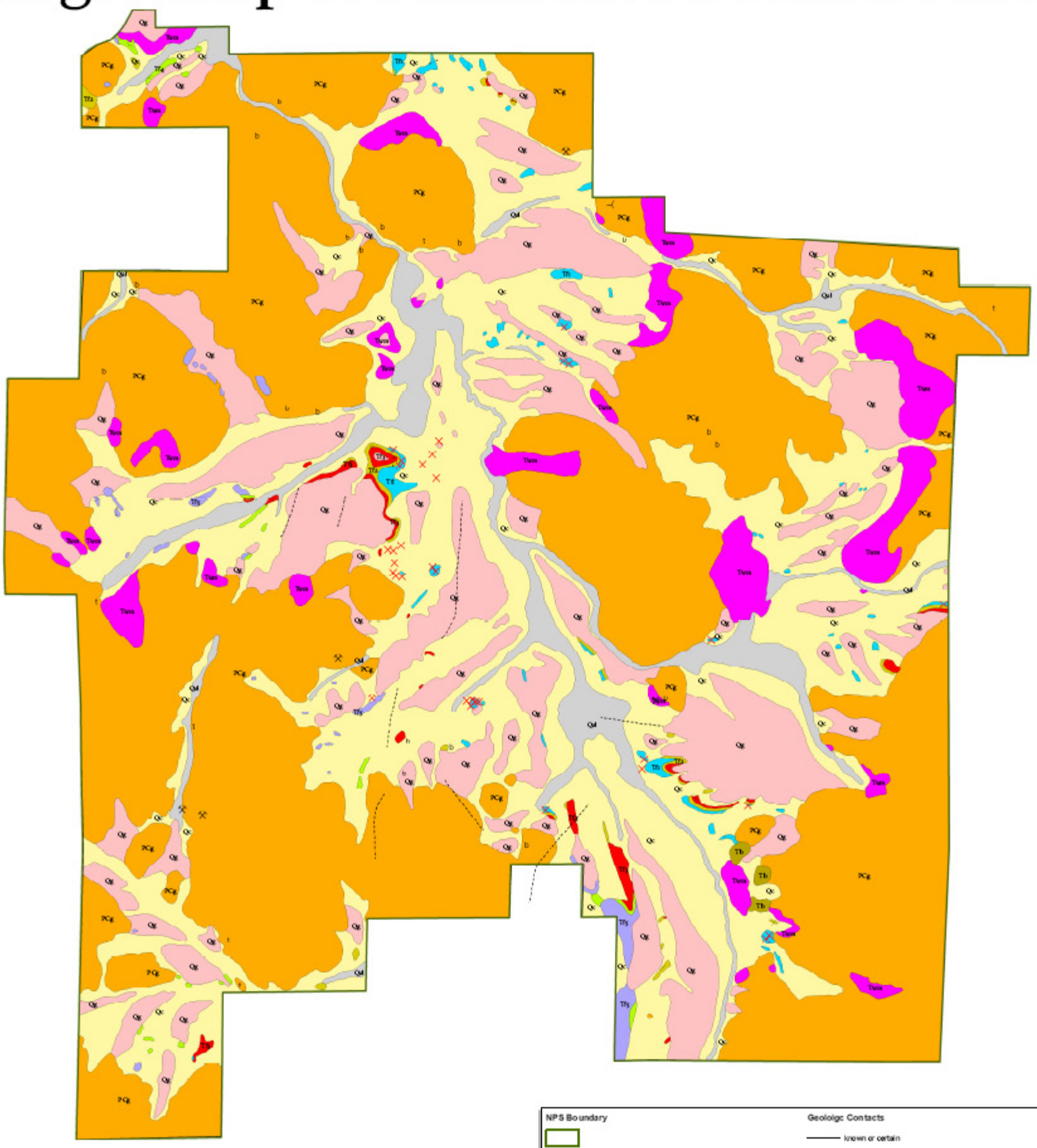
Wolfe, J.A., Forest, C.E., and Molnar, P., 1998, Paleobotanical evidence of Eocene and Oligocene paleoaltitudes in midlatitude western North America: GSA Bulletin, v. 110, p. 664–678.

Worley, M., 2004, New additions to the Chadronian mammalian fauna from the Florissant Formation, Florissant Fossil Beds National Monument, Florissant, Colorado [M.S. thesis]: Boulder, Colorado, University of Colorado, 83 p.

Appendix A: Geologic Map Graphic

The following page provides a preview or "snapshot" of the geologic map for Florissant Fossil Beds National Monument. For a poster size PDF of this map or for digital geologic map data, please see the included CD or visit the GRE publications webpage: http://www2.nature.nps.gov/geology/inventory/gre_publications.cfm

Geologic Map of Florissant Fossil Beds NM



The original map digitized by NPS staff to create this product was:

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

Digital geologic data and cross sections for Florissant Fossil Beds National Monument, and all other digital geologic data prepared as part of the Geologic Resources Divisions Geologic Resource Evaluation program, are available online: http://www2.nature.nps.gov/geology/inventory/gre_publications.cfm

NPS Boundary

Geologic Attitude and Observation Points
- strike and dip of beds
- horizontal beds
- vector mean of crossbedding

Mine Point Features
- adit
- gravel quarry

Unique Point Features
- fossil quarry in the Florissant Formation
- fossil stumps - silicified stumps of gymnosperms and angiosperms
- tors - large granite knobs in outcrops of the Pikes Peak Granite
- large granite boulders

Faults
- fault, unknown offset, inferred

Geologic Contacts
- known or certain
- map boundary

Geologic Units
- Qal - Holocene alluvium
- Qc - Quaternary colluvium
- Qg - Pleistocene gravels
- Tfs - Florissant Formation (Unit 5 - lacustrine / fluvial)
- Tfl4 - Florissant Formation (Unit 4 - lacustrine)
- Tfl3 - Florissant Formation (Unit 3 - volcanigenic debris flow)
- Tfl2 - Florissant Formation (Unit 2 - lacustrine)
- Tfl1 - Florissant Formation (Unit 1 - fluvial / volcanigenic mudflow)
- Tb - Eocene boulder conglomerate
- Twm - Wall Mountain Tuff
- pCg - Pikes Peak Granite

0 0.5 1 2 Kilometers

0 0.375 0.75 1.5 Miles

N W E S

Appendix B: Scoping Summary

The following excerpts are from the GRE scoping summary for Florissant Fossil Beds National Monument. The scoping meeting occurred on October 21, 1998; therefore, the contact information and Web addresses referred to herein may be outdated. Please contact to the Geologic Resources Division for current information.

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Agenda

Meet at park headquarters

9:00—Introductions, milling around

9:15—NPS Geological Resources Inventory

What we hope to accomplish (Bruce Heise, Geologic Resources Division [GRD])

9:30—Field Trip

Geologic Setting, Geologic Issues Confronting the Park (park staffs and outside experts)

12:00—Lunch (suggest a brown bag)

12:30—NPS Geologic Resources Inventory, I&M, and GRD Program Overview (Bruce Heise and other GRD staff)

1:15—Geological Resources Needs and Issues at FLFO (Herb Meyer, Tom Ulrich, other park staffs)

2:00—GIS/Geologic Map/Digital Status (Sarah Beetch, Anne Poole)

2:30—Continued Discussion

- Additional park needs
- Summary of USGS geological mapping and research
- Other cooperators and discussion
- Authors for report and/or other papers
- Deliverables from mapping, cooperators, and NPS inventory

4:45—Meeting Wrap- up and Feedback

Workshop Cooperators

Name	Affiliation
Bruce Heise	NPS, Geologic Resources Division
Tim Connors	NPS, Geologic Resources Division
Herb Meyer	FLFO, Paleontologist
Jean Rodeck	FLFO, Superintendent
Tom Ulrich	FLFO, Chief Ranger
Anne Poole	BLCA/CURE, GIS
Sarah Beetch	BLCA/CURE, GIS
Barb Mieras	Geological Society of America
Emmett Evanoff	University of Colorado Museum
Jim Wood	NPS, Geologic Resources Division

After introductions by the participants, Bruce Heise (filling in for Joe Gregson who could not attend the meeting) presented overviews of

- NPS I&M Program
- Status of both the natural and geologic resources inventories
- Organization of the Natural Resource Stewardship and Science Washington Office, GRD, and the Colorado pilot project

Afterward, Sarah Beetch and Anne Poole presented their progress on digital geologic maps.

The main items of discussion for this workshop centered on the following:

- Existing geologic maps
- Park natural resource management needs
- RMP statements
- Usefulness of existing published literature to serve as a sufficient geologic report for the monument

Geologic Maps

Some of the available geologic maps (paper copies) come from the following sources:

- Preston Louis Nieson (1969), New Mexico
- Ralph Root (1981), USGS- BRD, this map has been digitized (Anne Poole held up a copy); however, questions arose about problems with this map (i.e., it was digitized off of copies, and Emment Evanoff disagrees with the denoted faults). Emmett would like to schedule some time in the field with Ralph Root to examine evidence for faults in the valley. According to park staff, this field work did occur (Herb Meyer, Florissand Fossil Beds National Monument, written communication, May 2, 2005). Ralph Root was with the NPS GIS Division. His map was digitized using Grass software and paper maps that were spliced together. Also, GIS folks from Curecanti National Recreation Area were concerned that the existing maps do not extend beyond the park boundary.
- Evanoff and others (1992), University of Colorado at Boulder—surficial map
- Evanoff (1994), University of Colorado at Boulder; this map is published in a 1994 Geological Society of America field guide and was deemed sufficient by the group to serve as the geologic map to use for our report. However, Evanoff believes we should have a map that shows the breakdown of the Florissant Formation units as he sees them. He says he can get a map together in a month or so.

Needs

Some of the addressed needs for Florissant Fossil Beds included

- Better Quaternary map

- Paleontology intern for working on Web pages—Tom Ulrich specifically mentioned Marc Duggan. Tom was trying to help Marc find some work with us. He said Marc is going to help them, but wanted to know if we were interested in picking him up to work on our projects out of Fort Collins.
- Students/interns—semester students were preferred over quarter students because of the starting times (available May through August when housing was most likely to be provided by the park; cannot offer housing in September).
- Funding—Tom Ulrich mentioned that the park has applied for a Canon grant to support a winter/spring intern to work on park databases and environmental education programs.
- Fee money for excavations ?
- Park brochure—FLFO staff is looking into redesigning their park brochure through Harpers Ferry Center and may need additional funding. The redesign will remove the "age of mammals" thematic panel and replace it with a park map and park specific information. Staff at Florissant Fossil Beds National Monument and other fossil parks have expressed a desire to develop a Servicewide NPS fossils thematic brochure.

RMP Statements

- According to Tom, Herb Meyer has done an excellent job in developing and implementing RMP statements since his arrival.
- The park's proposals for GeoScientist- in- the- Parks funding from the Geological Society of America are closely tied to existing RMP statements and offer a diverse range of experiences and training.

Report

A geologic report for the monument could be generated from one of the following notable publications:

- Herbert W. Meyer and Laine Weber $1.00 publication that can be found in the bookstore entitled "Preservation of an Ancient Ecosystem." Herb is also currently writing a summary of the paleontological features of the monument; his database is his major source of documentation for this.
- Emmett Evanoff's 1994 GSA field guide
- Emmett Evanoff's 1992 ring binder that was compiled for a field course that he taught at Florissant
- Ralph Root's 1981 report that accompanies his maps
- Jim McChristal files on early history of geology of area
- The topic of "disturbed lands" from past agricultural activities and subsequent dams was also discussed and should be mentioned in the report. Alex Birchfield (CSU) and Tom Ulrich are working on developing models to estimate the failure potential for some of these artificial retention structures. Given the potential for failure, it is possible that any breaching of these structures can serve as a major threat to the natural resources of the monument. Any publications on this subject should be incorporated into this final report.
- Also, both the Evanoff and Meyer reports have good references.

Action Items

1. Evanoff will return to the area in November to complete mapping of the monument to fill in what he feels are gaps in the breakdown of the Florissant Formation members (as he sees them). He feels he can be finished around Thanksgiving. Soon after he felt he could turn over the maps to Beetch and Poole for digitizing.
2. Evanoff mentioned that he has detailed stratigraphic sections that he will provide for the report. He also has designated a few type sections within monument boundaries and will provide write- ups on those as well. Connors needs these as part of a preliminary inventory and will pursue getting this information.
3. It was mentioned that several of the older paper maps are out of print and unavailable at this time. Heise will look into the ability of the USGS to update maps and reprint out of stock originals (I- 1044 was specifically mentioned).
4. Evanoff mentioned that he would soon be conducting research in Badlands National Park; he should be added to the list of cooperators for that park because of his help and interest at Florissant Fossil Beds National Monument.

Overview of Geologic Resources Inventory

The NPS Geologic Inventory is a collaborative effort of the NPS Geologic Resources Division (GRD) and Inventory and Monitoring (I&M) Program with assistance from the U.S. Geological Survey (USGS), American Association of State Geologists (AASG), and numerous individual volunteers and cooperators at National Park System units, colleges, and universities.

From the perspective of the Servicewide I&M Program, the primary focus (level 1) of the geological inventory is

1. to assemble a bibliography of associated geological resources for National Park System units with significant natural resources,
2. to compile and evaluate a list of existing geologic maps for each unit,
3. to develop digital geologic map products, and
4. to complete a geologic report that synthesizes much of the existing geologic knowledge about each park.

The emphasis of the inventory is not to routinely initiate new geologic mapping projects, but to aggregate existing information and identify where serious geologic data needs and issues exist in the National Park System.

The NPS Geologic Resources Division is an active participant in the I&M Program and has provided guidance and funding in the development of inventory goals and activities. The Geologic Resources Division

(GRD) administers the Abandoned Mine Lands (AML) and GeoScientists- in- the- Parks (GIP) programs, which contribute to the inventory. NPS paleontologists, geologists, and other natural resource professionals also contribute to inventory planning and data. A major goal of the collaborative effort is to provide a broad baseline of geologic data and scientific support to assist park managers with Earth resource issues that may arise.

For each National Park System unit, a cooperative group of geologists and NPS personnel (the Park Team) will be assembled to advise and assist with the inventory. Park Teams will meet at the National Park System unit to discuss and scope the geologic resources and inventory, which is the subject of this report. If needed, a second meeting will be held at a central office to evaluate available geologic maps for digital production. After the two meetings, digital geologic map products and a geologic report will be produced. The report will summarize the geologic inventory activities and basic geology topics for each park unit. Because of the variety of geologic settings throughout the National Park System, each report will vary in subject matter covered, and section topics will be adapted as needed to describe the geologic resources of each unit. Whenever possible the scientific sections of the report will be written by knowledgeable cooperators and peer reviewed for accuracy and validity.

Florissant Fossil Beds National Monument

Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2006/009
NPS D-37, March 2006

National Park Service

Director • Fran P. Mainella

Natural Resource Stewardship and Science

Associate Director • Michael A. Soukup

Natural Resource Program Center

The Natural Resource Program Center (NRPC) is the core of the NPS Natural Resource Stewardship and Science Directorate. The Center Director is located in Fort Collins, with staff located principally in Lakewood and Fort Collins, Colorado and in Washington, D.C. The NRPC has five divisions: Air Resources Division, Biological Resource Management Division, Environmental Quality Division, Geologic Resources Division, and Water Resources Division. NRPC also includes three offices: The Office of Education and Outreach, the Office of Inventory, Monitoring and Evaluation, and the Office of Natural Resource Information Systems. In addition, Natural Resource Web Management and Partnership Coordination are cross-cutting disciplines under the Center Director. The multidisciplinary staff of NRPC is dedicated to resolving park resource management challenges originating in and outside units of the national park system.

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