Florissant Fossil Beds National Monument

Mike Viney

"Big Stump" Type Specimen
Sequoioxylon pearsallii (Andrews 1936)
Eocene; Florissant Formation
Colorado

Florissant Settlement

The small town of Florissant Colorado is located along U.S. Highway 24 just 56 km west of Colorado Springs. Judge James Castello (1814-1878) emigrated from Florissant, Missouri following his interest in gold during the mid 1860s to what is now Fairplay, Colorado. In 1870 he moved to a mountain valley just west of Colorado Springs, building a home and hotel. Two years later, Judge Castello added a trading post, general store, and post office. He christened his new settlement Florissant, a name derived from the French word for "flowering" (nps.gov site).

The grassy mountain valley just south of Florissant held treasures past and present. Summer wildflowers, a petrified forest, and shale containing fossil leaves and insects attracted the attention of both tourists and scientists. Scientific interest in Florissant blossomed early.

Scientific Pioneers of Florissant

For nearly 140 years scientists have been studying Florissant. If, on average, a career spans 30 years, then over 4 "generations" of scientists have worked at this fossil site. This scientific work, accumulated over lifetimes, has illuminated the changing geology and ecology of Florissant during the late Eocene, approximately 36-34 Ma. The rich fossil assemblage allows scientists to estimate the paleoclimate and paleoelevation at the time of deposition. Studies on the microscopic structure of Florissant lake shales have revealed the possible role of biofilms in fossil preservation. Volcanic sediments and key mammalian fossils allow scientists to test and corroborate multiple techniques for determining the age of the Florissant Formation. Comparisons between younger and older fossil deposits provide insights into paleoclimates, biogeography, and the evolution of plants and animals during the Paleogene.

This summary will highlight the work of key individuals to gain an appreciation for the important work accomplished by people past and present. A more complete and in-depth history of the scientific work at Florissant can be found in *The Fossils of Florissant* (Meyer 2003) and *History of paleontology at the Florissant fossil beds, Colorado*

(Veatch and Meyer, 2008). *Saved in Time: The Fight to Establish Florissant Fossil Beds National Monument* (Leopold and Meyer, 2012) and *A History of Florissant Fossil Beds National Monument: In Celebration of Preservation* (McChristal, 1994) also provide some interesting perspectives on the history of Florissant.

Albert Charles Peale (1849-1913), a geologist working with the Hayden Survey, explored the Florissant Valley in 1873. Peale mentions the fossil lake deposits and notes the existence of 20 to 30 stumps of silicified wood, known to the locals as "Petrified Stumps." Members of the Hayden Survey collected vertebrate, insect, and plant fossils that would later be described by other scientists.

Three students from the College of New Jersey organized what is now known as the Princeton Scientific Expedition of 1877. The goal of the expedition was to collect vertebrate fossils in Colorado, Wyoming, and Utah. In 1877, the three students, William Berryman Scott (1858-1947), Henry Fairfield Osborn (1857-1935), and Frank Speir Jr. (?) spent two days in July collecting fossils at Florissant. These two days would prove to be very fruitful. At least 180 of the expedition's plant and insect fossils became type specimens. A new species of fish was also discovered. Charlotte Hill (1849-1930) and Adam Hill (1834-?), homesteaders who lived near the Big Stump, shared some of their fossil finds with the three students. The Princeton Scientific Expedition of 1877 marked the start of an important relationship with the Hills and scientific investigators. Charlotte Hill was the first person to find a fossil butterfly at Florissant--the first of its kind to be found in America. This butterfly would latter be described by Samuel H. Scudder.

Leo Lesquereux (1806-1889) was a watchmaker, bryologist and paleobotanist. Lesquereux initially pursued a teaching career, which was cut short after suffering hearing loss. Lesquereux's hearing loss was the result of an illness during the 1830s, just two years after getting married. Treatments for the hearing loss left him deaf. Lesquereux gave up teaching and joined his father as a watchmaker. In his spare time he collected mosses, which would eventually lead to a scientific career. To read a more detailed account of Lesquereux's life, visit the Leo Lesquereux Autobiography on the American Philosophical Society website.

Lesquereux is best known for his work on the origin of peat, the study of living mosses, and Carboniferous fossil flora. Lesquereux was the first to describe fossil plants from Florissant, naming over 100 new species sampled from the Hayden Survey, the Princeton Scientific Expedition of 1877, and fossils purchased by Scudder from Charolette Hill. Lesquereux described a rose plant found by Mrs. Hill, naming it *Rosa hilliae* (Lesquereux 1883) in her honor. Lesquereux was the first person to write a scientific paper on Florissant and in 1883 he published *Contribution to the fossil flora of the Western Territories*, which included his work from Florissant.

Samuel Hubbard Scudder (1837-1911), F.C. Bowditch (?-1927) and Arthur Lakes (1844-1917) arrived in Florissant in August of 1877, just weeks after the Princeton Scientific Expedition. The trio collected for 5 days. Scudder, an American entomologist and paleontologist, made the first measurements of Florissant lake deposits near the Big Stump. Arthur Lakes, a geologist, often captured his fieldwork with sketches and watercolors. Lakes made the first sketch depicting the geology of Florissant during this trip. He later made a watercolor of his sketch entitled "Map of Sedimentary Lacustrine basin at Florissant near South Park, Supposed to be Upper Miocene, drawn by A. Lakes, Colorado, Feb 20, 1878" (Meyer, 2003, p. 9). Scudder acquired many excellent specimens from the Hills and would later visit the area two more times.

Scudder became very familiar with the insects of Florissant, working with specimens collected as part of the Hayden Survey. During his career, Scudder described roughly 600 species and produced 23 papers on Florissant. Much of Scudder's early work on Florissant was included in his 1890 monograph *The Tertiary Insects of North America*. Scudder was the first person to use the insect fauna to interpret a warmer paleoclimate for Florissant.

Scudder described and named possibly the finest butterfly compression fossil known to exist, which was found by Charlotte Hill. The butterfly, *Prodryas persephone* (Scudder 1878), is now housed at the Museum of Comparative Zoology at Harvard University (Pick & Sloan, 2004, pp. 64 & 65). The name *persephone* alludes to Persephone, the daughter of Zeus. As a ninth grader, Frank M. Carpenter, saw a picture of *P. persephone* in Scudder's book *Frail Children of the Air*, which inspired his career studying insect fossils (Brosius, 1994, p. 120). Frank Morton Carpenter (1902-1994) became one of the most influential paleoentomologists of his time, working as the curator of fossil insects at the Harvard Museum of Comparative Zoology for over 60 years.

T.D.A. Cockerell (1866-1948) of the University of Colorado organized expeditions to Florissant from 1906 to 1908. Cockerell studied both plants and animals and published more articles on Florissant than any other paleontologist. Cockerell was the first to document the different collecting sites at Florissant. He was also the first person to describe tsetse fly specimens from Florissant, the discovery of which was a great surprise as living species are restricted to sub-Saharan Africa. S.H. Scudder described *Palaestrus oligocenus* in 1892 believing it was in the family Oestridae. Flies in this family are commonly known as botflies, warbler flies, heel flies and gadflies. The larvae of all of these flies are internal parasites to mammals. At the turn of the century better preserved specimens showing a clear proboscis were discovered. Cockerell recognized the new fossils and Sudder's earlier specimen as belonging to the genus of tsetse flies *Glossina*. Tsetse flies are sanguivores, feeding on the blood of vertebrates. *Glossina oligocena* (Cockerell in 1908) is twice the size of living species (Gimaldi and Engel, 2006, p. 545).

Harry D. MacGinitie (1896-1987) was a paleobotanist who spent most of his career teaching at Humbolt State College in northern California. Early in his career MacGinitie worked for the University of Colorado where he was encouraged by Cockerell and Childs Frick (1883-1965), an American vertebrate paleontologist, to revise earlier work on the fossil plants of Florissant. MacGinitie excavated new sites at Florissant in 1936 and 1937 to collect additional specimens. In 1953 MacGinitie published the culmination of this work in his classic monograph *Fossil Plants of the Florissant Beds, Colorado*.

MacGinitie revised the work of earlier paleontologists and was the first to consider Florissant fossil plants as a community, comparing them with modern vegetation. MacGinitie also used the fossil plant community to make inferences about the ancient ecology, climate, and elevation of Florissant.

The development of new technologies and techniques allow scientists to collect empirical data not accessible to explorers of the past. Thus, Florissant is a frontier that still has its modern day pioneers. A few examples are in order. *Fossil Flora and Stratigraphy of the Florissant Formation, Colorado* (Evanoff, Gregory-Wodzicki, and Johnson, 2001) includes papers exploring the stratigraphy, geochronology, paleoclimatic implications of the leaf and pollen floras, updates on megafossil flora, climatic implications from tree ring analysis of permineralized *Sequoioxylon pearsallii* specimens, identification of fossil dicots, and a review of paleoelevation estimates. This volume extends the work of MacGinitie.

Papers exploring the history of scientific work on Florissant, the role of biofilms in fossil preservation, paleoclimate, biogeography, spider identification, mammal fauna, preservation and conservation of fossil wood, as well as the development of a web-based paleontological database, were published together in *Paleontology of the Upper Eocene Florissant Formation, Colorado* (Meyer and Smith, 2008).

Herbert W. Meyer is a paleontologist with the U.S. National Park Service. In addition to his scientific papers, he is also author of *The Fossils of Florissant* (Meyer, 2003), the most important and detailed book on Florissant. The book is a true gem. Meyer has a gift for making scientific work public. Over a period of 130 years more than 1700 fossil species have been described in more than 300 publications and dispersed to roughly 15 museums. Meyer has been instrumental in developing an on-line database, which digitally updates and archives this previously dispersed work (Meyer, Wasson, and Frakes, 2008, pp. 159-177).

Early work at Florissant clearly revealed this site to be a paleontological "goldmine". One would think the site would have received national monument status early on, but this was not to be. Private owners used the fossil site to attract tourists. I was one of those tourists and remember visiting the Big Stump at the Colorado Petrified Forest as a small child in 1964 (Figure 1). Literature recounting the commercial history of Florissant can be found in *The Fossils of Florissant* (Meyer, 2003) and *Saved in Time: The Fight to Establish Florissant Fossil Beds National Monument* (Leopold and Meyer, 2012). In the late 1960s, real estate developers mapped out a plan to build a subdivision of A-frame cabins on the fossil beds. The Defenders of Florissant was formed by concerned citizens and scientists including Estella Leopold and Beatrice Willard. The battle between these two groups got the attention of the U.S. Congress. In the end the area was granted protection from private interests when President Richard Nixon signed the act into law allowing for the purchase and establishment of Florissant Fossil Beds National Monument.

Figure 1 Colorado Petrified Forest, 1964
Wynona and Don Viney stand by the "Big Stump"
Peggy Ashworth holds Mike Viney age 2 ½

Establishment of a Monument

In 1969 Florissant Fossil Beds National Monument was established on 2,428.1 ha (6,000 acres) of land to preserve one of the world's most important Late Eocene fossil deposits (Figure 2). The famous fossil site is situated in a mountain valley just south of the town of Florissant in Teller County, Colorado. At an elevation of 2,560 m Ponderosa Pine, Quaking Aspen, Douglas-fir, and Englemann Spruce make up the dominant trees of this montane life zone. Large mammals found in the area include elk, mule deer, coyote, foxes, bear, and mountain lions. Birds, squirrels, and mice live in the meadows and along the ridges. The Florissant Formation provides a window into the Late Eocene, illuminating an environment much different from the one we enjoy today. Rocks that make up this beautiful mountain landscape hold clues to the area's geologic and biologic past.

Figure 2 Florissant Fossil Beds National Monument Entrance Sign

Pikes Peak, at an elevation of 4,300 m, is just 19 km southeast of Florissant. Pikes Peak granite has a radiometric age of 1,080 Ma (Evanoff, McIntosh & Murphy, 2001, p. 3).

The billion year old pink Pikes Peak granite (Figure 3) formed as an intrusive batholith during the Precambrian and covers 2,978 square kilometers (Foos & Hannibal, 1999, p. 1). The mountain building episode known as the Larimide Orogeny, which started in the Late Cretaceous 65 to 70 Ma ago, created the current Rocky Mountains and resulted in the uplift and exposure of the Pikes Peak Granite (Meyer, 2003, p. 23). During the Late Eocene, rivers eroded the granite to form a valley. Late Eocene sediments from volcanic activity, lakes, and rivers, filled the valley depositing the rock units in the Florissant Formation.

Figure 3 Mary Klass, resting comfortably atop Pikes Peak Granite

The Wall Mountain Tuff, dated at 36.7 Ma, records the oldest known Paleogene volcanic activity at Florissant. An explosive volcanic eruption 80 km to the west of Florissant resulted in a pyroclastic flow--an incandescent cloud of gas and debris with temperatures of $1,000^0$C traveling at speeds of 160 km/h or more. The gasses in ash flows suspend the hot debris, which allow the volcanic material to travel as far as 120 km or more

(Matthews, KellerLynn & Fox, 2003, p. 10). The pyroclastic flow followed the contours of the landscape and swept through the Florissant valley. As the flow came to rest, the hot material fused into an ignimbrite or welded rhyolitic tuff. The Wall Mountain Tuff carpeted the Florissant paleovalley and, subsequently, experienced erosion before the deposition of the Florissant Formation.

Unconformities represent gaps in the sedimentary geologic record between two rock masses of different ages and indicate that the deposition of sediments was not continuous. An unconformity can represent either time during which no sediments were deposited or time during which rock layers have been eroded away. The unconformity between the Pikes Peak Granite and the Wall Mountain Tuff represents 1.04 billion years of missing time. All of the Paleozoic, Mesozoic, Paleocene and early Eocene rock units have been eroded away (KellerLynn, 2006, p. 21).

Today, outcrops of the Wall Mountain Tuff appear throughout the Florissant Valley (Figure 4). Remnants of the Wall Mountain Tuff in Castle Rock, just south of Denver, indicate that this ancient pyroclastic flow traveled at least 150 km from the eruption site (Meyer, 2003, p. 25). Castle Rock Rhyolite is a dimensional stone made from the Wall Mountain Tuff. The gray blocks used to construct Molly Brown's house were quarried from the Wall Mountain Tuff in Castle Rock (Mathews et al., 2003, p. 122).

Another unconformity lies between the eroded surface of the Wall Mountain Tuff and younger sedimentary rock units. In most areas the unconformity is between the Wall Mountain Tuff and the Florissant Formation. There are some places in which the Florissant Formation abuts laterally against the Wall Mountain Tuff, an unusual arrangement for an unconformity. On the southeast side of the monument it lies between the Wall Mountain Tuff and the Tertiary boulder conglomerate. The Tertiary boulder conglomerate contains boulders and cobbles of granite, gneiss, schist, clasts of tuff from the Wall Mountain Tuff and fragments of petrified wood. Streams and debris flows deposited the Tertiary boulder conglomerate. This unconformity represents missing time during the Eocene (Evanoff et al., 2001, p. 4; KellerLynn, 2006, p. 21 & 25).

Figure 4 Wall Mountain Tuff Exposure at Barksdale Picnic Area

Florissant Formation

Two million years after the formation of the Wall Mountain Tuff, volcanic activity in an area known as the Thirtynine Mile volcanic field, located a mere 25 to 30 km southwest of the ancient Florissant basin, would help to form the famous fossil beds at Florissant. The Guffey volcano was situated among a cluster of towering stratovolcanoes within the Thirtynine Mile area. Eruptions from the Guffey volcano produced pyroclastic flows, ash falls, and lahars (volcanic mudflows). Periodically, the lahars acted as dams to the Florissant valley, creating ancient Florissant lakes (Evanoff et al., 2001, p. 8). The rock units of the Florissant Formation record the existence of rivers, volcanic activity, and lakes within Florissant valley. Fossils from some of these rock units faithfully record portions of Florissant ecosystems of the Late Eocene.

The Florissant Formation was deposited upon the eroded surfaces of the Pikes Peak Granite and the Wall Mountain Tuff. Six informal units make up the Florissant Formation and include from bottom to top: the lower shale, the lower mudstone, the middle shale, the caprock conglomerate, the upper shale, and the upper pumice conglomerate (Evanoff et al., 2001, p. 8).

Multiple lines of evidence indicate a late Eocene age for the Florissant Formation, which accords with the current placement of the Eocene-Oligocene boundary at 33.7 Ma. The Florissant Formation is dated at 34.07 Ma based on volcanic minerals in the formation (Evanoff et al., 2001, p. 14). The overlapping range of brotontheres and *Mesohippus* indicates a Chadronian age (37-34 Ma) for the mammalian fauna of Florissant. The 70 meter Florissant Formation is almost entirely reversed in polarity and is most logically correlated with Chron C13, which spans 33.7-34.7 Ma (Prothero & Sanchez, 2004, p. 145). Thus, radiometric dating, mammalian fossil fauna, and the magnetic stratigraphy of Florissant corroborate a latest Eocene age for the Florissant Formation.

The Florissant Formation represents both fluvial (river) and lacustrine (lake) environments. An initial lake in the paleovalley became filled with sediments over many years, after which a stream valley developed. Evidence suggests lahars traveling down side tributary valleys eventually formed a natural dam, re-establishing lake conditions. Renewed volcanic activity resulted in a lahar deposit that entered parts of the second reservoir-like lake. Eventually, the deposition of a pumice conglomerate marks the end of lake conditions. Let's take a closer look at the major units in the Florissant Formation.

Lower Shale Unit

The lower shale unit represents deposition within an early Florissant lake and is composed of alternating paper shale and tuffaceous siltstone. Volcanic conglomerates are also interspersed throughout the unit. Repeated deposition of ash and clay at the bottom of Lake Florissant trapped a variety of organisms. The shale from this unit contains the fossils of plants, insects, fish, and birds. Insects and leaves from the lower shale unit can be collected at the private Florissant Fossil Quarry, just outside Florissant Fossil Beds National Monument (Figure 5).

Figure 5 Lower Shale Unit at Florissant Fossil Quarry

Lower Mudstone Unit

The lower mudstone unit consists of mudstones, conglomerates, and sandstones. Ribbons of sandstones and conglomerates within this unit trace the course of stream channels. The lower mudstone unit represents a river system within the Florissant Valley. A 5 meter layer of sandy mudstone at the top of this unit records a lahar deposit that buried parts of a forest growing by the stream in the ancient Florissant valley. The mudflow represents a single event that encased trees *in situ* (Gregory-Wodzicki, 2001, p.164). Over time, trees buried in place were permineralized with silica released from the volcanic rocks to form a petrified forest. The lower mudstone unit is exposed behind the Big Stump with the middle shale unit and caprock conglomerate above (Figure 6).

Figure 6 Big Stump with Lower Mudstone Unit

Middle Shale Unit

Additional lahars flowed down the valley eventually damming the Florissant drainage. Water filled the valley and its tributaries forming a second lake Florissant, which was 1.5 kilometers wide and 20 km long (Meyer, 2003, p. 29). The middle shale unit consists of paper shales, pumice conglomerate, and volcanic siltstone beds (Evanoff et al., 2001, p. 7). Paper shales found within the Florissant Formation consist of alternating layers of diatomite and volcanic ash-clay. Repeated deposition of volcanic ash within the lake triggered abundant diatom growth. Fossils are found within the layers formed by the deposition of diatoms (O'brien, Meyer, Reilly, Ross, and Maguire, 2002). Within the monument, it is the middle shale unit that provides the wealth of fossil insects and leaves. Fossils of fish, mollusks, and ostracods are rare within the middle shale unit.

Caprock Conglomerate

The caprock conglomerate consists of granular muddy conglomerate beds. The caprock conglomerate overlies parts of the middle shale unit and protects it by slowing the erosional process. The caprock conglomerate represents debris flow perhaps a lahar that entered the lake. The middle shale unit and caprock conglomerate can be seen in several locations along the trails (Figure 7).

Figure 7 Middle Shale Unit and Caprock Conglomerate

Upper Shale Unit

The upper shale unit follows the caprock conglomerate and represents lacustrine or lake deposition after the lahar entered the lake. In the northwest corner of the monument the upper shale unit overlies the middle shale unit. Like the middle shale unit, the upper shale unit consists of alternating paper shales and pumice conglomerate beds. Fossils of plants, insects, fish scales and ostracods are found within this unit. The upper shale unit is different from the middle shale unit in its abundance of ostracods and fingernail clam shells (Evanoff et al., 2001, p. 11). The upper shale unit is exposed along Boulder Creek (Figure 8).

Figure 8 Florissant Upper Shale and Upper Pumice Conglomerate

Upper Pumice Conglomerate

The upper pumice conglomerate unit consists of pumice-rich white sandstones and conglomerates. Fossil finger clams found in the lower part of this unit indicate the pumice conglomerate was deposited into Lake Florissant. The upper cross-bedded conglomerate beds represent deposition by streams within the valley, recording an end to the Florissant lake. The upper pumice conglomerate is exposed north of Boulder Creek (Evanoff et al., 2001, p. 11).

The youngest unconformity rests between the upper pumice conglomerate and Quaternary deposits. This unconformity represents 32 million years of missing time from the Oligocene, Miocene, and Pliocene Epochs (KellerLynn, 2006, p. 21). Pleistocene deposits at Florissant are composed of weathered and eroded Pikes Peak Granite, Wall Mountain Tuff, and fragments of shale, mudstone, sandstone, and fossil wood from the Florissant Formation. Parts of the Florissant Formation that have survived weathering and erosion are exposed around the perimeter of the old lake (KellerLynn, 2006, p. 26).

Fossil Forming Environments at Florissant

Very different volcanic deposits preserved Eocene age life at Florissant. A destructive lahar provided a geologic environment in which wood became permineralized with silica. The petrified wood at Florissant is found in the lahar at the top of the mudstone. Although rare, fossil leaf impressions and compressions can be found in some parts of the mudstone. The delicate structures of leaves and insects are more commonly found in the shale units deposited within a lake environment.

Preservation in the Lower Mudstone Unit

During the late Eocene a lahar or volcanic mudflow from the Guffey volcano entombed redwood trees growing in the lower Florissant valley. The volcanic material that ended the life of these trees would also help to preserve them in stone. Portions of trees encased within the mudflow were permeated with groundwater carrying dissolved silica from the volcano, eventually forming petrified wood. Mustoe (2008) concluded that petrification at Florissant occurred in several stages. First, amorphous silica precipitated on cell wall surfaces of the wood. Second, opal-CT and chalcedony filled cell lumina (cell spaces). Finally, chalcedony filled fractures that crosscut permineralized tissues in some specimens. Spaces between adjacent tracheids in the *Sequoioxylon* were often unmineralized, making the fossil wood permeable to water and susceptible to cleaving radially, tangentially, and transversely from freeze-thaw weathering. This finding has important implications for the preservation of specimens at Florissant Fossil Beds National Monument (p. 127).

Fossil trees in the main Petrified Forest represent *Sequoioxylon*, which is a name for fossil wood closely related to the *Sequoia* growing along the coast of present day California. The largest stump has a diameter of 4.1 m when measured at breast height (1.5 m) above the ground. This size suggests a canopy height of 60 m. We can infer from the preserved annual rings that these redwoods were fast growing reaching diameters of 3 m within 500 to 700 years (MacGinitie, 1953, p. 21). Fossil *Sequoioxylon pearsallii* from Florissant has a higher mean ring width when compared with the modern coast redwood (*Sequoia sempervirens*) and the giant sequoia (*Sequoiadendron giganteum*), indicating more favorable growing conditions for the fossil trees. Two of the fossil stumps have been cross-dated, which demonstrates they grew in a single forest (Gregory-Wodzicki, 2001, p. 163). Three interconnected stumps (known as the "Redwood Trio") share a root system and represent a clone (Figure 9). These characteristics are very much like what is seen in present day forests of *Sequoia* trees (Nudds & Selden, 2008, p. 214).

Figure 9 *Sequoioxylon pearsalli* "Trio"

Chadronoxylon, an angiosperm dicot, is also present among the *Sequoioxylon* stumps. *Chadronoxylon florissantensis*, the most abundant angiosperm wood at Florsissant, is a diffuse porous wood with affinities to the families Salicaceae (willows) and Phyllanthaceae (Wheeler and Meyer, 2012, p.9). Four additional angiosperm woods occur in the lower mudstone unit, but not in the main Petrified Forest. Interestingly, these woods are ring porous, indicative of seasonal environments. Two of the ring porous woods share characteristics with the elm family Ulmaceae and resemble *Zelkova*. A fourth resembles *Koelreuteria* of the soapberry family Sapindaceae. A fifth specimen is the first reported occurrence of a *Hovenia* like wood, from the buckthorn family (Rhamanaceae), in North America (Wheeler and Meyer, 2012, p.1). *Zelkova*, *Koelreuteria*, and *Hovenia* genera are restricted to East Asia today. The occurrence of these fossil woods at Florissant is evidence of Tertiary exchange between East Asia and North America. A sixth, *Robinia*-like wood (black locust) of the family Fabaceae was found in the caprock conglomerate (Wheeler, 2001, p. 187). One wonders what other wood types may have been present before the area was subjected to scavenging by souvenir collectors between the 1870s and 1969.

The lower mudstone unit has also produced evidence of mammals including rodents, lagomorphs, insectivores, and ungulates. *Oreotalpa florissantensis* is the oldest known occurrence of a fossil mole (Family Talpidae) in North America (Lloyd and Eberle, 2008, p. 539). Several even-toed ungulates including the oreodont *Merycoidodon* and the deer-like *Leptomeryx* are represented at Florissant. Two odd-toed ungulates *Mesohippus*, a three-toed collie-sized horse, and a species of *Megacerops*, a large brontothere were also a part of the Florissant fauna. The Florissant mammalian fauna indicates a Chadronian or latest Eocene age for the Florissant Formation (Lloyd, Worley-Georg & Eberle, 2008, pp. 122 & 123; Prothero and Sanchez, 2004, p. 146).

Preservation in the Shale Units

The lacustrine or lake paper shales are made of alternating layers of diatoms and ash-clay. O'Brien et al (2002) used scanning electron microscopy and energy dispersive X-ray analysis to examine these alternating layers. The diatomite layer is lighter in color and consists of the frustules of diatoms. Diatoms are single-celled protists that make their protective shells or frustules of silica. Fossils are almost exclusively found imbedded within the diatomite layers. Furthermore, these diatomite layers are covered by a mucous layer, which was secreted by diatoms and bacteria. Ash-clay layers appear darker in color. The diatomite and ash-clay layers form what is known as a couplet 0.1 to 1.0 mm in thickness. Typically, layers of 3 to 10 couplets are sandwiched between pumice layers, which are several millimeters to centimeters in thickness (pp. 3 & 4). O'Brien et al (2002), proposed the following events for the deposition of the Florissant Fossiliferous shale:

1. Volcanic ash weathering into clay washed into Lake Florissant from the surrounding terrain.
2. The volcanic sediment was deposited as a thin layer of ash-clay, enriching the lake water with silicon.
3. Diatoms bloomed as a result of the added silicon and formed polysaccharide mucus mats.
4. It is hypothesized that the diatom and bacterial mucous film sealed and protected the organisms from decomposition.
5. Mucus mats sank to the lake bottom and formed thin, diatom-rich laminae.
6. The organisms were subsequently fossilized (p. 6).

The paper shale is made of many couplet layers suggesting seasonality to the cycle above. The couplets may be varves representing annual layers. The pumice layers interbedded at irregular intervals within the paper shales record sporadic volcanic eruptions that produced volumes of ash and pumice. These layers were formed rapidly and are much thicker than the couplets (Figure 10).

Figure 10 Cross-Section of Paper Shale from Lower Shale Unit (1.8 cm thick)

Both insects and leaves preserved in the Florissant beds are often carbonized (Figures 11 and 12). Insects and leaves entangled in the diatom mucus mats were incorporated into layers of sediments and volcanic ash at the bottom of Lake Florissant. Many of these insects and leaves decomposed leaving imprints. As the sediments compacted and hardened into shale the imprints became impression fossils. Some organisms only partially decayed retaining a dark colored carbon residue to become compression fossils (carbonization). Many insects have their wings preserved as impressions (no organic residue) while their bodies retain organic residue forming dark compressions. Compressions are often flattened, having a two-dimensional appearance. However, the preservation in diatom layers allows some organisms to retain their three-dimensional character. Some insects are found with organs and appendages. Some leaves can be found with internal structures (Meyer, 2003, pp. 35-37).

Figure 11 *Fagopsis* Lower Shale Unit

The paper shales act as nature's "plant and insect press" and make Florissant a fossil lagerstätten. Florissant has produced roughly 1700 described species of plants and animals (Meyer, Veatch & Cook, 2004, p. 151). Impressions of leaves, fruits, seeds and flowers account for about 120 species (Manchester, 2001, p. p. 137).

Figure 12 Crane Fly Lower Shale Unit

Palynology, the study of microscopic plant fossils, such as pollen and spores, adds another 25 genera to the fossil flora of Florissant (Leopold & Clay-Poole, 2001, p. 17). Over 1500 of the 1700 described species at Florissant are insects and spiders (Meyer et al., 2004, p. 158). The most common vertebrate found in the fossil shale are fish, with the majority representing bottom dwellers. Four genera representing catfish, suckers, a bowfin and a pirate perch have been described. Although rare, birds are represented by a small plover, roller, and cuckoo. Only one mammal, a small opossum, has been found within the shale beds. Interestingly, no amphibians or reptiles have been found at Florissant (Nudds & Shelden, 2008, pp. 227 & 228).

It is clear that the fossil bearing shale at Florissant has received a lot of attention from paleontologists over the years. However, within the shale units different depositional environments are also represented by layers of mudstone and siltstone. A recent study comparing shale, mudstone, and siltstone within the middle shale unit at Florissant found that the abundance and preservation quality of the most commonly found insect orders in lacustrine settings did not differ across these different sedimentary environments (Henning, Smith, Nufio, and Meyer, 2012, p. 481).

The findings of this study are surprising for a couple of reasons. Diatoms have been thought to play a major role in the preservation quality of insects found within the shale. However, mudstone is not typically associated with diatom layers indicating that the presence of diatoms may not enhance preservation (Henning et al., 2012, p. 487). Siltstone represents a higher energy depositional environment with larger grain sizes than mudstone or shale. Interestingly, the preservation quality and abundance of fossils found within the siltstone was equal to mudstone and shale. Perhaps the paper shale has been favored over the years because it is easier to split open. The surprising results of this study suggest paleontologists broaden their search for fossils by including the mudstone and siltstone layers found within the shale units at Florissant.

Climate, Elevation and Ecology

The great diversity of fossils found at Florissant provides insights into the ecology, climate, and elevation of Florissant during the late Eocene. It is well known that the distribution of modern plants correlates well with climate. Methods that use biological evidence to estimate paleoclimate fall into two broad categories: leaf morphology and taxonomic composition. Leaf marginal analysis (LMA) and Climate-Leaf Analysis Multivariate Program (CLAMP) are based on the leaf morphology of angiosperm dicots. The Nearest Living Relative (NLR) method and taxonomic calibration are based on taxonomic composition.

The Nearest Living Relative method (NLR) compares fossil plants to their nearest living relatives, whose current climatic tolerances are used to infer past climate. Paleoclimate is estimated by establishing the climatic overlap of modern living relatives of fossils found in the assemblage. Proper identification is critical and it must be remembered that organisms may evolve adaptations which change their climatic tolerances. The nearest living relative method works best if the fossil assemblage has a modern analog.

Taxonomic calibration uses environmental variables, such as mean annual temperature and mean annual precipitation, to calibrate mathematically the relationship between climate and the taxonomic composition of modern vegetation. The taxonomic composition of extant taxa found within the fossil assemblage can then be compared with the modern taxon-climate calibration to infer paleoclimate. Taxonomic calibration is usually performed at the species level. Boyle, Meyer, and Enquist (2008) used taxonomic calibration at the genus and family levels to identify the closest modern analog for Florissant fossil flora and to infer paleoclimate. The study used the taxonomic composition of 241 modern forest plots to calibrate multiple climate variables with forest type. At both the genus and family level their analysis placed the Florissant fossil flora between modern deciduous forests of the eastern United States and the humid subtropical montane forests of central and northeastern Mexico. Estimates for the mean annual temperature for Florissant during the Eocene using their calibration with modern forest plots ranged from $14.7 \pm 2.2\ ^0$C using the genus level to $15.6 \pm 2.5\ ^0$C using the family level. This range of temperatures is consistent with a warm temperate lowland or subtropical to tropical highland climate (Boyle et al, 2008, p. 42). This study demonstrates the possibility of using taxa higher than the species level as paleoecological and paleoclimatic indicators. NLR and taxonomic calibration at the species level require precise identification of taxa. Taxonomic calibration using higher taxa requires only approximate identifications to the family level.

Leaf physiognomy refers to estimating paleoclimate using leaf morphology. Leaf physiognomy has the advantage of not requiring plant identification and is said to be ataxonomic. Leaf physiognomy analysis takes advantage of the fact that extant angiosperm dicots exhibit certain leaf structures, which correlate to precipitation, humidity, and temperature. Convergent evolution produces similar leaf adaptations for similar environmental conditions among flowering plants of different lineages. For example, evergreen leaves in humid environments usually have drip-tips, compound leaves are frequently associated with deciduous forests, and leaves with serrated margins dominate humid, cool environments while leaves with entire margins prevail in humid, warm environments (Stewart & Rothwell, 1993, p. 494). Eight leaf characters often used in this approach include leaf size distribution, leaf margin type, drip tips, organization (simple or compound), venation-pattern, venation density, leaf texture, and leaf base type (Cleal & Thomas, 2009, p. 34). Two methods utilize leaf physiognomy to reconstruct paleoclimate: Climate-Leaf Analysis Multivariate Program (CLAMP) and Leaf Margin Analysis (LMA).

Climate-Leaf Analysis Multivariate Program (CLAMP) utilizes a data base that correlates modern vegetative types to climate for estimating paleoclimatic variables among fossil leaf assemblages. CLAMP uses 31 leaf character states of at least 20 species of woody dicots to map out the vegetation within a small area associated with a climate station (Wolfe, 1995, p. 122). The modern data base now represents 173 plant communities mostly from Northern American forests. Leaves of a fossil assemblage can be scored using the same 31 leaf character traits and positioned on the physiognomic space defined by present day plant communities. In this way, CLAMP can provide climatic parameters related to precipitation, humidity, and temperature. Scoring the multiple characteristics used for CLAMP requires expertise and may be challenging for fossil leaves.

Leaf Margin Analysis (LMA) is a univariate approach which correlates leaf margin (entire vs. toothed) with mean annual temperature (MAT). Warmer climates have a higher percentage of smooth-edged species than cooler climates. Another univariate approach correlates leaf surface area with mean annual precipitation (MAP). Leaves tend to be small in hot, dry climates and larger in wetter climates. A univariate approach only allows you to evaluate one parameter of climate at a time. However, scoring one character trait at a time may make a univariate approach less ambiguous (Wilf, 1997, p. 385).

Modern Florissant has a MAT of around 4 ^{0}C and an annual precipitation of 38 centimeters (Meyer, 2003, pp. 51 & 52). How does the present day MAT and annual precipitation compare with Florissant during the latest Eocene as estimated by paleobotanical methods? NLR, taxonomic calibration, and CLAMP have been used to estimate the paleoclimate of Florissant. The CLAMP estimates of MAT range between 10.7^{0}C and 12.8^{0}C (Meyer, 2001, p. 210). In general, this range is consistent with a temperate climate and, at the low end, implies a high frequency of freezing temperatures during the winter months. Estimates based on NLR give a MAT of around 18^{0}C. In general, this mean annual temperature is consistent with a warm temperate climate that boarders on subtropical. MacGinite used the composition of the fossil flora to estimate a MAT of 65 ^{0}F or 18.3^{0}C (MacGinite, 1953, p. 57). The addition of a palm leaf fossil to the Florissant fossil flora and an analysis of fossil pollen and spores add support for a warm temperate climate that was relatively frost free (Leopold & Clay-Poole, 2001, p. 29). The MAT estimates based upon taxonomic calibration fall between the cool temperatures predicted by leaf physiognomy and the higher temperatures predicted by the nearest living relative method (Boyle et al., 2008, p. 33). Smaller leaves with serrated margins are associated with seasonally dry climates. Fossil leaves at Florissant have been used to estimate an annual precipitation of 50-80 cm per year with a dry season (Leopold & Clay-Poole, 2001, p. 48; Meyer, 2003, p. 52).

Like modern plants, the distribution of many insect taxa correlates well with climate. Three methods have been developed that utilize the ecological tolerances of extant insect taxa to infer past climate and include; the modern analog approach, the nearest living relative approach (NLR), and the mutual climatic range (MCR) approach. All three methods have been used primarily for estimating the paleoclimate of Quaternary fossil assemblages.

The modern analog approach uses the composition of extant climate indicator insect species found within a fossil assemblage to infer the paleoclimate of the ancient community. The NLR approach uses the climatic tolerances of modern insects believed to be the nearest living relatives of extinct taxa within the fossil assemblage to infer paleoclimate. Modern analog and NLR approaches are qualitative in that they have no specified number or method for selecting taxa to be used in a study. The MCR approach is quantitative and typically uses the overlapping climatic ranges of all extant, non-phytophagous beetle species within a fossil assemblage to infer paleoclimate.

Moe and Smith (2005) used the MCR approach with fossil Diptera from the Florissant Formation to test the accuracy with which pre-Quaternary insect fossils can be used to determine paleoclimate (pp. 203-214). Moe and Smith used extant Diptera genera found within the Florissiant Formation for their MCR analysis. MCR analyses were performed using all extant fossil Diptera genera and then again with non-host-specific taxa. It is assumed that insects with host specific relationships with plants (phytophages) or animals (sanguivores) skew the data because their presence may reflect the climate range of the host instead of the insect. Their MCR analysis using only non-host-specific taxa yielded a climate range equivalent to a MAT of 12^{o}C to 16^{o}C. The Köppen climate classification places this MAT within the warm-temperate to temperate climate range which is consistent with the majority of climate estimates for Florissant using paleobotanical methods. The authors also used habitat preferences of the extant Diptera genera to interpret the paleoenvironment of Florissant as a forested area with open areas near freshwater. Moe and Smith's study (2005) provides evidence that the MCR approach can be used for pre-Quaternary insect fossil assemblages.

The incredible fossil assemblage at Florissant includes extant taxa that now inhabit a wide variety of climates from cool temperate to tropical. The Eocene started out as the warmest time on Earth during the Paleogene period. In fact subtropical forests extended into the arctic. The transition from the Eocene to the Oligocence marks a cooling trend that resulted in a global climate change. The Florissant fossil communities lived at a time that was very close to these changes in climate. These facts spark our curiosity about what the climate was like at Florissant during the latest Eocene. We do not have direct measurements of paleoclimatic factors. However, as we have seen, multiple methods using fossils as proxy sources for climatic values have been applied to Florissant Fossil Beds. Some lines of evidence from fossil flora to fauna support a warm temperate to temperate climate with moderate rainfall in the summer and dry, mild winters (Leopold & Clay-Poole, 2001, p. 18) whereas other evidence indicates that cooler conditions prevailed. All of the estimates are much warmer than Florissant's current MAT of 4^0C.

Today, Florissant is at an elevation of between 2,500 and 2,600 meters (Meyer, 2003, p. 62). Multiple methods have been used to estimate the paleoelevation of the fossil ecosystems of Florissant. MacGinite was the first person to estimate the paleoelevation of Florissant using the composition of fossil vegetation. MacGinite estimated the paleoevlevation of Florissant to be no more than 3000 ft. or around 900 meters (MacGinite, 1953, p. 57). During the 1990s paleotemperatures and lapse rate were used to estimate paleoelevation. The paleotemperature of Florissant can be compared to the paleotemperature of a similar aged fossil flora at the same latitude, but at sea level. Taking into account the lapse rate or how temperature changes with altitude, a paleoelevation can be estimated. Depending upon the lapse rate and paleotemperature used elevations ranging from around 900 meters to 4133 meters can be calculated. A third method of estimating paleoelevation uses fossil plant characteristics to infer paleoenthalpy or heat content of the atmosphere. The paleoaltitude calculated for the Florissant basin using this method is 2,700 meters (Leopold & Clay-Poole, 2001, p. 50). Recent paleoelevation estimates are much higher than MacGinite's original estimate. The paleoelevation may have been closer to present day Florissant.

The Florissant fossil flora seems to have grown in an upland environment. The equable climate was most likely warm temperate with an MAT of 12-14 ^{0}C and an annual precipitation of 50 to 80 cm of annual rainfall (Meyer, 2003, p. 52). Growth rings on fossil trees and laminated shales record the seasonality of this climate. Rainfall came mostly in the spring and summer months with winters that were mild but dry.

Plants living near streams and lakes are more likely to be represented as fossils in the sedimentary deposits than those living in drier environments farther away. However, considering the relative abundance of fossil pollen and plants along with the preferred environments of their nearest living relatives one can make inferences about the patterns of vegetation across this ancient landscape (Meyer, 2003, p. 53).

Algae, free-floating water ferns (*Azolla*), water lilies in the family Nymphaeaceae, cat-tails (*Typha*), and pondweed (*Potamogeton*) indicate a freshwater lake with marshy areas near the shoreline. Fossil leaves and pollen suggest a carpet of deciduous forests surrounding the lakeside and in valley bottoms along riparian zones bordering streams. Beech (*Fagopsis)*, *Cedrelospermum*, Poplar (*Populus)*, Willow (*Salix)*, *Sequoia*, and White Cedar or false cypress (*Chamaecyparis)* trees would be found in these forests near water sources. Smaller trees and shrubs made up the understory of these lush forests including hickory (*Carya*), maple (*Acer*), soapberry (*Sapindus*), raintree (*Koelruteria)*, and *Paracarpinus*. Epiphytes in these forests included the ferns *Lygodium* and *Selaginella* and possibly monocot bromeliads. Forests growing in this basin were humid and damp during the summer. A transition zone between moist forests in the basin and those growing in drier areas along ridges and hills may have been populated by shrubs such as sumac (*Rhus*), *Rosa*, serviceberry (*Amelanchier*), current (*Ribes*), and bladdernut (*Staphylea*). Plants such as Mormon tea (*Ephedra*) and members of the family Amaranthaceae which are drought and salt tolerant plants suggest the existence of salty microenvironments. The upland woodland areas above the *Sequoia* and deciduous forest were dryer and composed of montane elements such as Pine (*Pinus)* and Oak (*Quercus*). Spruce (*Picea*) and Fir (*Abies*) most likely occupied cool forest pockets in the draws or along the higher slopes of the volcano (Leopold & Clay-Poole, 2001, p. 42; Meyer, 2003, p. 53-54; Nudds & Selden, 2008, p. 248).

The life cycles of insects also provide clues to the mosaic of microhabitats that may have existed at Florissant during this time. Dragonfly larvae are often found inhabiting water with vegetation such as cattails, while many caddisfly larvae flourish in streams littered with pebbles. The life cycle of butterflies and bees is completed in terrestrial environments and their presence suggests open areas such as meadows (Meyer, 2003, p. 54). The great diversity of fossils found at Florissant give insights into a mosaic of probable microenvironments found from an ancient lake to the surrounding hills of a volcano.

To a casual observer many of the insects, arachnids, fish, birds, and plants making up the ancient Florissant ecosystem would have looked familiar. Spiders, mayflies, dragonflies, damselflies, ants, termites, flies, beetles, bees, wasps, and butterflies would have looked somewhat familiar. But even the casual observer would be taken aback by the beautiful spoon-winged lacewing *Marquettia americana* and the large tsete flies whose living relatives are now restricted to the tropics. So too, the rain tree *Koelreuteria* and tree of heaven *Ailanthus* whose living relatives are found only in southeast Asia might capture attention. These American "castaways" would have looked out of place. Even the casual observer would be shocked to see the now extinct mammalian fauna including oreodonts, brontotheres, and the three-toed horse *Mesohippus*.

It is through the hard work of geologists and paleontologists that we gain an insight into casts of characters who interacted within these ancient lake and river ecosystems. The fossil record affords only pieces of the past. Science uses these pieces to work out a puzzle using a system of independent empirical verification. Together, impressions of the past explored by this most important human epistemology work out to be a way for nature to remember itself. Imagination fueled by empirical evidence is a true joy of science!

Conclusion

The great diversity of ancient organisms at Florissant gives us a window into the ecology of this area during the latest Eocene. The fossil flora of Florissant is most like present day flora growing in temperate and subtropical climates. Florissant's fossil flora has its strongest affinities with present day floras of northeast Mexico, southern Texas, Southeast Asia, Pacific North America, southern Rockies, and southern Appalachians (Leopold & Clay-Poole, 2001, pp. 39-41; Nudds & Selden, 2008, p. 228). The fossil fauna and flora that comprised the biotic portion of the ancient ecosystems found at Florissant do not exist anywhere in the world today. Some of the organisms are extinct, while some have descendents with very different biogeographical distributions. Different aged fossil deposits from around the world teach us that different organisms have lived at different times. The rock in which these fossils are embedded is geologic truth, speaking to the fact that environments change. So, it is revealed through fossil lagerstätten, such as Florissant, that ecosystems evolve through time.

You can take a virtual tour of the Florissant Formation by visiting the Virtual Petrified Wood Museum: http://petrifiedwoodmuseum.org/Eocene.htm

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Pieces of broken, rusted saw blades are artifacts recording an attempt to remove the Big Stump in small sections over 100 years ago. The Big Stump is estimated to weigh over 60 metric tons. There was interest in displaying a Florissant stump at the United States Centennial Exhibition of 1876 and the World's Columbian Exposition of 1893 (Meyer, 2003, pp. 7 & 8).