Evaluation of West Bijou Site

Arapahoe and Elbert Counties, Colorado

Photo: Richard M. Wicker, Denver Museum of Nature and Science

For its Merit in Meeting National Significance Criteria as a
National Natural Landmark

in Representing

Geologic History of Cretaceous Period in the Age of the Reptiles,

the Paleocene Epoch during the Emerging Dominance of Mammals,

and the Western Shortgrass Plains

in the Great Plains Province

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EXECUTIVE SUMMARY

West Bijou Site, in Arapahoe and Elbert Counties, Colorado is recommended for designation as a National Natural Landmark in the Great Plains biophysiographic province. The primary features of the 7,613 acre site represent the Triassic-Cretaceous Periods and Paleocene-Eocene Epochs geologic themes. The secondary features of the site represent the Short-grass plains ecological sub-theme. Gullies along the floodplain of West Bijou Creek contain some of the most important examples of the Cretaceous-Tertiary(K-T) [Cretaceous-Paleogene (K-Pg)] boundary in the world. The boundary is represented by a thin band of sediments marking the end of the Cretaceous period of the Mesozoic Era, and the beginning of the Paleogene period of the Cenozoic. The band identifies a critical event in Earth's history when the dinosaurs and other terrestrial vertebrates, along with many species of ammonites and other marine invertebrate fauna, became extinct. The K-T boundary at the West Bijou Site is used by researchers as an important resource for calibrating the geologic timescale for all of Earth's history. West Bijou Creek flows through the site, and maintains a natural hydrologic pattern, meandering through a mosaic of upland and riparian shortgrass prairie plant communities. These communities provide habitat for a diversity of common and rare plains wildlife species including Ferruginous Hawk, Burrowing Owl, pronghorn, and black-tailed prairie dog. Taken together, the primary and secondary features at West Bijou Site are an excellent example of a valuable geological resource located within a natural shortgrass prairie ecosystem.

INTRODUCTION

Source of Site Proposal

The National Park Service (NPS) conducted a review of existing National Natural Landmarks (NNL) in Colorado and the Great Plains biophysiographic region to identify gaps in resource representation. The K-T boundary, a significant geological signature, was identified as a natural resource feature not currently represented. The NPS selected the West Bijou Site as a Potential NNL (PNNL) to evaluate its national significance and quality of representation of this feature.

Evaluator(s)

The evaluation presented here was conducted by the Colorado Natural Heritage Program (CNHP).

Scope of Evaluation

Research materials used to complete this evaluation include academic journal articles and primary literature on the K-T boundary, the geology and natural history of the shortgrass prairie, and the history of the West Bijou Creek area. The statewide database maintained by CNHP, in addition to reports authored by CNHP ecologists, provided information on the biological components of the site. Existing management plan reports developed by the Plains Conservation Center (PCC) were also used. A site visit was conducted by the author and the Regional NNL coordinator on July 15, 2013 to verify biological and geological information and to discuss current management with PCC director Jeff Su. A tour of the K-T boundary site was provided by paleontologist Ian Miller, Denver Museum of Nature and Science.

PNNL SITE DESCRIPTION

Brief Overview

West Bijou Site is located in Arapahoe and Elbert Counties, Colorado, approximately 50 kilometers (31 miles) east of the city of Denver (Figure 1). The site encompasses 7,613 acres, and includes approximately six miles of West Bijou Creek, along with adjacent upland areas, and is owned by the Plains Conservation Center (Figure 2). PCC is a non-profit organization that strives to connect people with the natural and cultural history of the high plains through preservation, education, research and nurturing sound conservation and environmental ethics. The PCC owns and preserves over 10,000 acres of shortgrass prairie split between two locations. The primary location in Eastern Aurora, encompassing approximately 1,100 acres, includes a visitor center and hiking trails. The West Bijou Site is located within the PCC's West Bijou property, an area used for guided education tours, research, and bison ranching. At this time, site visitors must be accompanied by PCC staff to access the site.

Figure 1. Location of the West Bijou Site in Colorado.

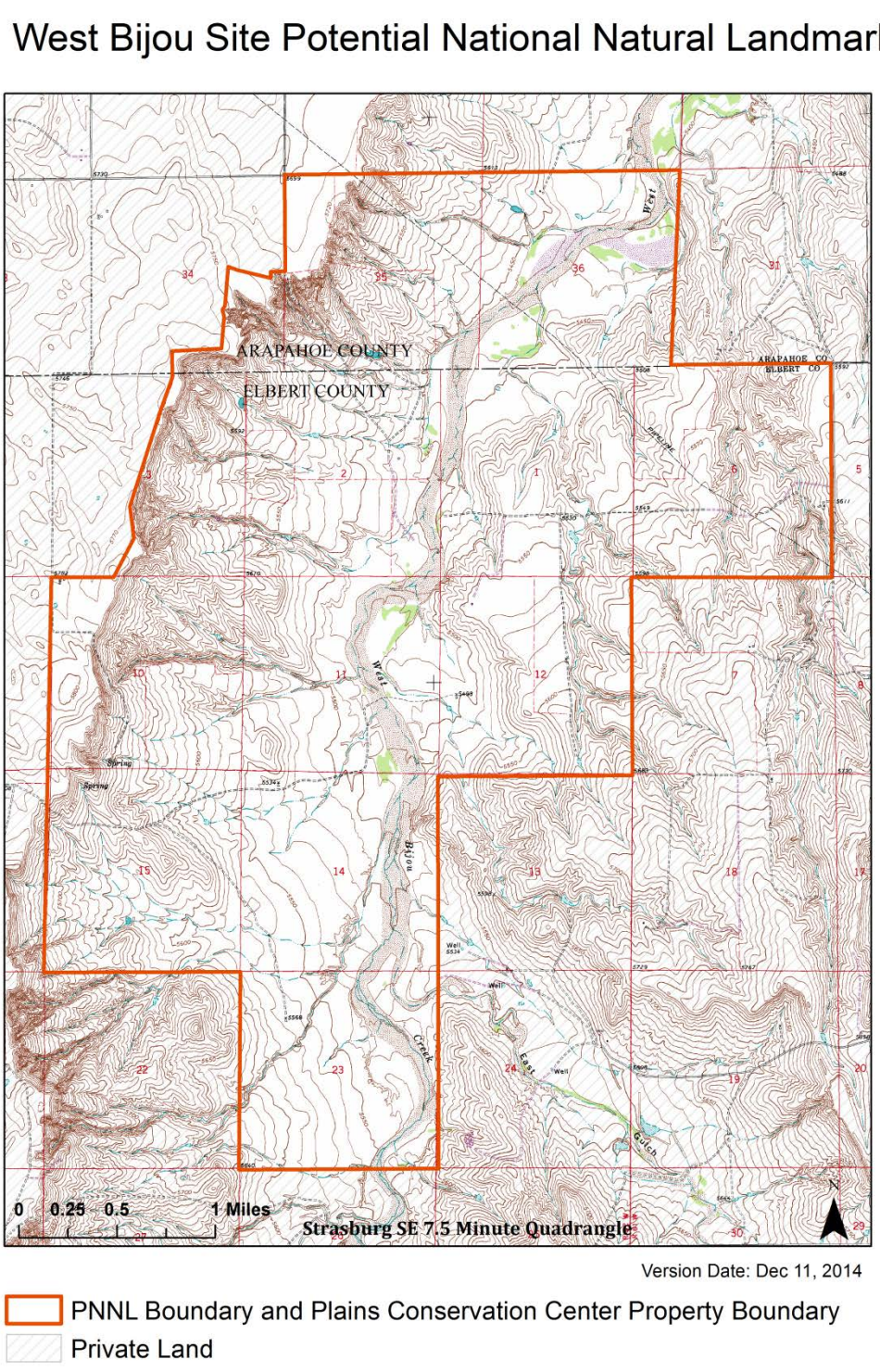

Figure 2. Proposed boundary and land ownership of the West Bijou Site.

Natural History Themes Represented

Primary and secondary natural features of the West Bijou Site fit into the following themes and subthemes:

- Geological natural history themes, Group 2, Geologic History:
  Theme: Triassic-Cretaceous Periods-Age of the Reptiles (~220 – 70 mya.)
  Sub-theme: Cretaceous Period
- Geological natural history themes, Group 2, Geologic History:
  Theme: Paleocene-Eocene Epochs-Emerging (~70 – 40 mya.)
  Sub-theme: Paleocene Epoch
- Ecological natural history themes, Group 3, Land Ecosystems:
  Theme: Grassland (steppe)
  Sub-theme: Short-grass plains (western and central plains)

Primary Natural Features

K-T Boundary at West Bijou Site

West Bijou Creek is an ephemeral stream located within the boundaries of the West Bijou property, owned by the Plains Conservation Center. The eroded hills and gullies on the west side of the creek contain some of the most scientifically important evidence of one of the five large mass extinctions that have occured in the past 500 million years. The most recent global mass-extinction event occurred ~65-66 million years ago, at the end of the Cretaceous Period. Nearly 75-80% of all plant and animals species that occurred in the Cretaceous Period did not exist in the Paleogene (aka Tertiary) Period that followed. (Jablonski and Chaloner 1994). Physical evidence of this massive event is preserved in the geologic record and is referred to as the Cretaceous-Tertiary (K-T) or Cretaceous-Paleogene (K-Pg) boundary. [Note: While it is more commonly still refered to as the Tertiary Period, this period is no longer recognized by the International Commission on Strigraphy. The correct technical term is the Cretaceous-Paleogene Boundary; however, the more commonly known and recognized vernacular of Cretaceous-Tertiary (K-T) Boundary is used throughout the report.]

The K-T boundary is a term used to describe a geologic signature, or horizon, composed of a band of sediments that specifically marks the end of the Cretaceous period of the Mesozoic era, and the beginning of the Paleogene period of the Cenozoic Era (see Appendix A for geologic timescale). It marks the extinction of the dinosaurs on land, as well as the ammonites and other marine invertebrate fauna in the oceans (Nichols and Johnson 2008); and provides an important resource for calibrating the geologic timescale for all of Earth's history (Dalton 2007).

Exposures of the K-T boundary at West Bijou are approximately 3 cm (1.18 in) thick, and occur within siltstone, sandstone, lignite, and mudstone that comprise the Dawson and Dawson Arkose Formations (Figure 3). Vertebrate and plant fossils located within these strata have helped researchers locate the exact layers of the K-T Boundary. These fossil resources include Cretaceous-aged pollen, Paleocene plant megafossils, hadrosaurian dinosaur teeth and a ceratopsian dorsal vertebra found 4 m below the K-T boundary, and a Paleocene mammal jaw (Barclay et al. 2003;

Eberle 2003). The abundant fossil leaves and pollen contained within the site have been used to expand our understanding of Paleocene floras and its recovery following the K-T extinctions (Barclay et al. 2003; Barclay et al. 2004; Barclay and Johnson 2004; Nichols and Johnson 2008).

Discovery

Paleobotanist Roland Brown discovered the first K-T boundary site in North America at Table Mountain in Golden, Colorado (Brown 1943). He located the boundary between a layer of sediments containing *Triceratops* fossils and a layer containing Paleocene mammal remains. Since this discovery, there has been much speculation and debate in the scientific community as to the possible causes of this great extinction. Four main hypotheses exist surrounding the cause of this mass extinction event, including asteroid impact, climate change, volcanic eruption, and marine regression (Alvarez et al. 1980; Archibald 1996; Hildebrand et al. 1991; Nichols and Johnson 2008).

In 1980, a team led by Luis Alvarez discovered that iridium, a metal found in meteorites, was present in sedimentary layers at many K-T boundary sites across the world (Alvarez et al. 1980). This discovery led to the development and advancement of the impact hypothesis, which proposes that the mass extinction event represented at the boundary was caused by the impact of a large (10 km diameter) asteroid crashing into the Earth (Alvarez et al. 1980). Eager to explore the evidence for and against the hypothesis, researchers searched for additional K-T boundary sites across North America. In 1997, researchers from the Denver Museum of Nature and Science (DMNS) launched efforts to locate more K-T boundary sites in the Denver Basin. As part of the project, Bob Raynolds and Kirk Johnson, along with a small team, dug a 688 meter (2,257 ft) well in 1999 known as the Kiowa Core (Raynolds and Johnson 2002). By systematically sampling sediments throughout the core using palynology (pollen records) and magnetostratigraphy, researchers located the K-T boundary at a depth of 302 meters (990 ft) (Hicks et al. 2003; Nichols and Fleming 2002). DMNS researchers created geospatial models using the known position of the boundary in the Kiowa Core, which resulted in the discovery of the West Bijou Creek K-T boundary site (Raynolds and Johnson 2002; Barclay et al. 2003).

The West Bijou Site is remarkable in that it contains many features in close proximity used to define the K-T boundary section. These include 1) palynology that marks the extinction of late Cretaceous palynoflora, a spike in fern spore abundance, and subsequent appearance of early Paleocene palynoflora 2) iridium and shocked-minerals at the same level as the palynofloral extinction 3) datable volcanic ash beds above and below the K-T boundary 4) paleomagnetic data at the subchron-level resolution 5) diagnostic fossils of mammals from the Paleocene above the boundary, and fossils of dinosaurs from the late Cretaceous below the boundary (Barclay et al. 2003; Hicks et al. 2002; Nichols 2007). Many of the roughly 100 terrestrial K-T boundary sites contain some but not all of these features. Notably, they are present at the West Bijou Site in an area less than one square kilometer, and are easy for researchers to access. Furthermore, the features are protected from vandalism by a locked gate. Development on the site is limited by a conservation easement held by PCC through Colorado Open Lands.

Global significance

Although the K-T boundary has been documented at more than 350 locations worldwide, only a portion (~100) of these are located in sedimentary rocks exposed in terrestrial locations (Plains

Conservation Center 2012; Schulte et al. 2010). The majority of the terrestrial sites are scattered throughout the center of North America, stretching from Alberta to central New Mexico. The West Bijou Site is unique among the terrestrial sites due to its datable volcanic ash beds. The K-T boundary at the West Bijou Site is regarded by some paleobotanists as the most complete single K-T boundary section known in nonmarine rocks due to its palynological (pollen) extinction level, fern-spore spike, iridium anomaly, and shocked quartz (Nichols and Johnson 2008).

Figure 3. Carol Lucking from the Denver Museum of Nature and Science, touches the strata of the K-T boundary along a gully at the West Bijou Site PNNL site. Photo by Richard M. Wicker.

Secondary Natural Features

Ecological natural history themes, Group 3, Land Ecosystems:
Theme: Grassland (steppe)
Sub-theme: Short-grass plains (western and central plains)

The West Bijou Site is located within the Central Shortgrass Prairie Ecoregion in the western portion of the Great Plains (Bailey 2004). This region encompasses 56 million acres, and includes parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, Texas and Wyoming. West Bijou Creek is a tributary to the South Platte, one of the ecoregion's largest rivers. The climate at West Bijou Site is semi-arid, and annual precipitation is 14.86 inches (High Plains Regional Climate Center 2014). The floodplain is dominated by a suite of species commonly found throughout riparian areas of the Central Shortgrass Prairie: plains cottonwood (*Populus deltoides*), peachleaf willow (*Salix amygdaloides*), crack willow (*Salix fragilis*), and coyote willow (*Salix exigua*). The uplands surrounding the creek are dominated by common prairie grasses including sideoats grama (*Bouteloua curtipendula*), buffalograss (*Buchloe dactyloides*), and blue grama (*Bouteloua gracilis*). Some non-native grass species, such as crested wheat (*Agropyron cristatum*) are present in patches. Several shrub species, such as rabbitbrush (*Chrysothamnus nauseosus*) and soapweed yucca (*Yucca glauca*) are present on drier terraces above the creek (Figure 5). The creek is ephemeral, and flows are primarily driven by spring and summer precipitation events. The flash floods that results from these events create moist bare sand along the channel and a high water table, allowing seeds from plains cottonwood and willows to germinate and survive as seedlings. These natural processes that result in regeneration of willow and cottonwood stands are increasingly rare along rivers and streams in the region due to hydrologic alteration.

The mosaic of upland and riparian plant communities at the site provides habitat for a diversity of bird species. A 2004 survey documented 63 species from the West Bijou Site (Plains Conservation Center 2004). Red-winged blackbirds (*Agelaius phoeniceus*) occupy emergent wetland sites along the stream channel, the Western Meadowlark (*Sturnella neglecta*), lark bunting (*Calamospiza melanocorys*), Burrowing Owl (*Athene cunicularia*), and the Horned Lark (*Eremophila alpestris*) are common in upland areas dominated by prairie grasses and shrubs. The site serves as important habitat for shortgrass prairie wildlife species that have experienced severe habitat loss in the last century and are now considered rare. These species are tracked by the Colorado Natural Heritage Program (CNHP), and include Cassin's Sparrow (*Peucaea cassinii*), Ferruginous Hawk (*Buteo regalis*), and black-tailed prairie dog (*Cynomys ludovicianus*) (Figures 4 and 5).

The site has been recognized in the last two decades for its ecological importance, especially in the context of regional development pressures. In 1994, it was designated as a Potential Conservation Area by CNHP, noted for its natural hydrology and diversity of shortgrass prairie plant species (CNHP 1994). Later, in 1999, Kathy Karsey proposed the site as a potential Colorado Natural Area (Karsey 1999). Her proposal included a four mile stretch of West Bijou Creek, its floodplain, and adjoining uplands, encompassing a total of 3,919 acres. The 1999 evaluation focused on the Creek as an excellent representation of a true plains stream located within a shortgrass prairie ecosystem. The site was never designated as a Colorado Natural Area (CNA), and to date no CNAs have been established in Arapahoe or Elbert counties. The Plains Conservation Center was established in 1949 as a facility for members of the public to learn about past and present land use on Colorado's eastern plains. The West Bijou Site was purchased by PCC in 2001 and later placed under a conservation easement with Colorado Open Lands on December 12, 2012.

Figure 4. The uplands surrounding West Bijou Creek contain large expanses of shortgrass prairie that provides habitat for wildlife species like the black-tailed prairie dog (left) and a Cassin's Sparrow (right). Photos by Lorraine Yeatts.

Figure 5. Soapweed yucca (*Yucca glauca*), Indian paintbrush (*Castilleja integra*), winterfat (*Krascheninnikovia lanata*), are common shortgrass species found growing in uplands surrounding West Bijou Creek. Photo by Lorraine Yeatts.

Physical Setting

The West Bijou Site PNNL is located in northeastern Colorado, approximately 50km (31 miles) east of Denver, in the Great Plains biophysiographic province (Figure 1) (NPS 2007). The PNNL boundary is entirely within the boundaries of land owned by the Plains Conservation Center (PCC) (Figure 1). West Bijou Creek flows north through the site, and is a tributary of Bijou Creek. Bijou Creek has three main branches: West, East and Middle. These branches converge, becoming the larger Bijou Creek just north of Byers, Colorado, and flow intermittently for 128 km (80 miles) before reaching the South Platte River near Fort Morgan (McKee et al. 1967). The climate is considered semi-arid, and the mean annual precipitation is 37.7 cm (14.86 inches) (High Plains Regional Climate Center 2014). During the hot summer months (mean maximum temperature is 87°F), spring rains and summer thunderstorms bring most of the annual precipitation that falls on the site. These events can cause major flooding along the branches of Bijou Creek, sometimes producing as much as the mean annual precipitation in a few hours (Matthia 1969). Winters are cold and dry. Elevation at the site ranges from 1645-1737 meters (5,400-5,700 ft.).

The site is located within the Denver Basin, a large structural depression that extends from the Front Range to the eastern plains of Colorado, stretching from Boulder to the north, Colorado

Springs to the south, and east to Limon (Barclay and Johnson 2004). The basin contains strata deposited during the uplift of the Rocky Mountain Front Range in the Late Cretaceous and Paleogene Period (Barclay et al. 2003; Kirkham and Ladwig 1979; Raynolds and Johnson 2002). The uplift of the Rockies occurred in two phases. These two phases are represented by rock sequences known as D1 and D2, produced during the late Cretaceous (68 million years ago) and the late Paleocene (~60 million years ago), respectively. The K-T boundary at West Bijou Site occurs in the 394-meter-thick D1 sequence, in rocks from the Denver Formation and the Dawson Arkose Formation (Figures 6 and 7) (Barclay and Johnson 2004). The most common strata contained in the D1 sequence are siltstone, sandstone, lignite, and mudstone (Barclay et al. 2003).

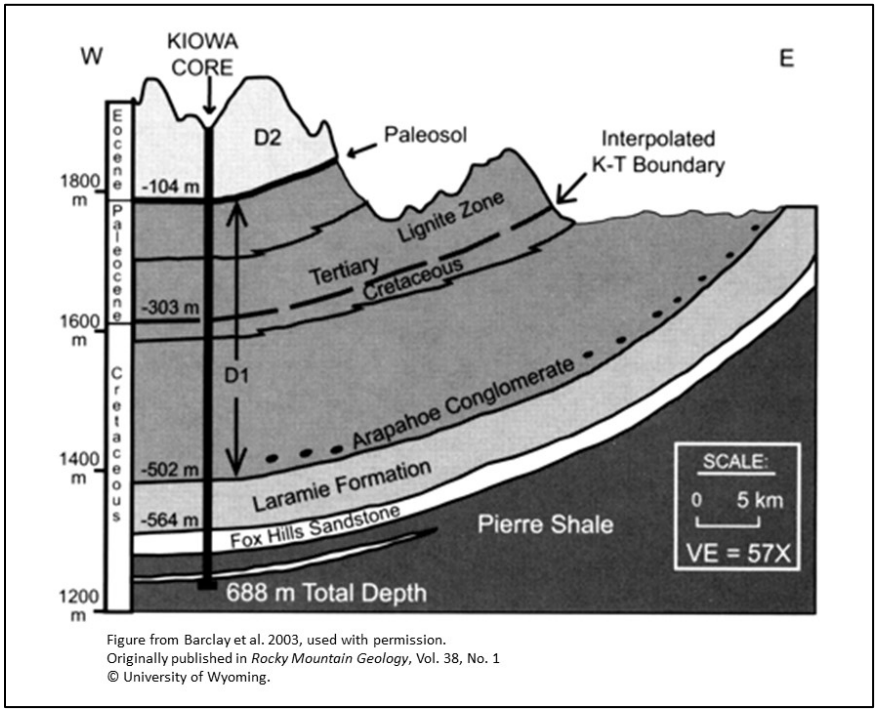

Figure from Barclay et al. 2003, used with permission.
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Figure 6. Cross section (west to east) through Cretaceous and Paleogene strata in the Denver Basin. The D1 and D2 rock sequences produced during the uplift of the Rockies are shown. Elevation (meters) above sea level is shown in the vertical measurements along the left side of the figure.

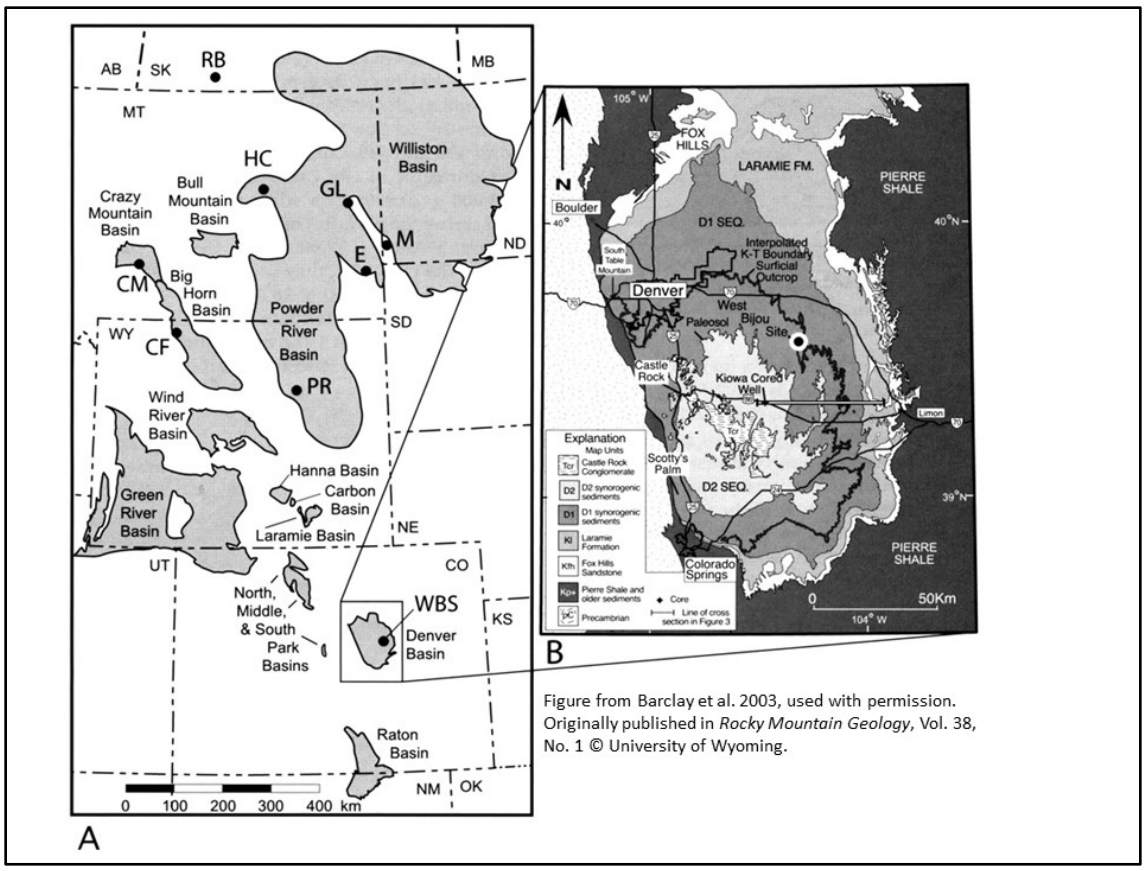

Figure from Barclay et al. 2003, used with permission. Originally published in *Rocky Mountain Geology*, Vol. 38, No. 1 © University of Wyoming.

Figure 7. Map of sites with K-T boundary disaster-recovery flora in the Laramide Basins of the Intermountain West with West Bijou Creek labeled as WBS (Box A at left). Geological map of Denver Basin synorogenic sedimentary rocks, and position of West Bijou Site (Box B at right). Created by Robert G. Raynolds and Adrian Kropp.

Land Use and Condition

Although Colorado's eastern plains have supported human occupation for at least 13,000 years, the region remained sparsely populated until the arrival of horses in the seventeenth century (Gunnerson 1987; Yohe and Bamforth 2013; Weber 1994). The introduction of the horse enabled many Indian groups to become nomadic hunters on the bison-rich plains. The Great Plains—especially the riparian zones along the South Platte and other rivers—saw a dramatic increase in human use (Hämäläinen, 2009; West 2000). The West Bijou Creek area likely served as hunting grounds for the Arapaho and Cheyenne since the early eighteenth century (Fowler 1989). These tribes occupied parts of Wyoming, Kansas, Nebraska, and eastern Colorado. In the mid-nineteenth century, white settlers moved into the area, slaughtering bison herds and creating conflict with the Arapaho and Cheyenne tribes and other Indian people. Miners, farmers, city-dwellers, and politicians following the Colorado Gold Rush streamed into the area in the 1850s and 1860s, making nomadic lifestyles ever more difficult (Fowler 1986; West 2000). In 1869, the United States Government compelled many Arapaho and Cheyenne to abandon their territory, relocating them to a new reservation in Oklahoma.

Historically operated as a cattle ranch with a few dryland wheat fields since the early 1900s, the first parcels of the West Bijou were purchased by the West Arapahoe Conservation District (WACD) in 1997 and an additional parcel was purchased in 2006. In 2012, a collaborative effort between WACD, Great Outdoors Colorado, Arapahoe County Open Space, South Metro Land Conservatory and Trust for Public Land purchased another strategic 1,083 acres. Additionally, in 2012 Conservation easements were established over the entire site and ownership was conveyed to Plains Conservation Center. Although the entire West Bijou property consists of a total of 8,970 acres, only 7,613 are included in the PNNL site boundaries. The site is located within five different Character Areas as defined in the PCC Master Plan: 1) Education and Orientation Zone 2) Natural Immersion 3) Backcountry Exploration and Restoration 4) Guided Expedition and 5) Operations and Research Base. Future management plans involve building an entrance station and allowing public access to trails and picnic areas in these areas. However, the West Bijou Site is currently only accessible through a locked gate and visitors must be accompanied by a guide to minimize impacts to natural resources.

Threats

The West Bijou PNNL site is open to visitors through guided tours with PCC staff, but the total number of visitors a year is relatively low (approximately 1,000). No camping is allowed in the area, and the site is protected by a locked gate. The site is not permanently staffed, making it vulnerable to vandalism or accidental damage. However, future plans include creating an entrance station staffed by PCC personnel (Plains Conservation Center 2012).

Other threats to the site include mineral extraction and erosion. Mineral rights for the site are not owned by the PCC. Several oil and gas wells are present within the site boundaries, but are limited to areas outside the K-T boundary. Precipitation events combined with soil disturbance from hikers could expose and degrade fossils at the site by accelerating erosional processes. Areas surrounding the site are rural with few buildings and major roads. Crop fields occur along the western and northern boundaries of the site, while the eastern and southern boundaries are surrounded by shortgrass prairie that is managed for domestic livestock grazing.

Sensitive or Hazardous Resources

The fossils, K-T boundary, and datable volcanic ash beds at the West Bijou Site offer tremendous potential for research and educational outreach to visitors (Johnson 2012). Fossil plants are common at the site, while vertebrate fossils are small, rare, and difficult to find. Both plants and vertebrate fossils require excavation. Management plans for the area allow fossil collection by researchers under permits from the State archaeologist. The Denver Museum of Nature and Science serves as the repository for these fossils. The incidence of fossil collection or damage to the K-T Boundary by visitors is unlikely as access to the site is through a locked gate, and visitors are accompanied by a PCC staff member (Plains Conservation Center 2012). Future plans include building an interpretive overlook and a trail for visitors to access the K-T boundary (Plains Conservation Center 2012). The southeastern portion of the site, which does not include the K-T boundary, is leased to a local bison rancher. Risk of injury from bison is low, as PCC visitors are only allowed to view the bison while inside a vehicle driven by PCC staff.

COMPARATIVE ASSESSMENT

Regional Site Inventory

There are more than 50 well-documented K-T boundary sites in North America, stretching from New Mexico to Canada (Nichols 2007). However, there are no known sites within the Great Plains biophysiographic province that share all of the features of the West Bijou Site: Cretaceous and Tertiary palynology, iridium and shocked minerals, magnetostratigraphy, radiometric dating, datable claystone layer derived from volcanic ash, and Cretaceous and Tertiary vertebrate fossils. Similar sites in the region include the Dogie Creek, Teapot Dome, and Sussex sites in Wyoming, Mud Buttes in North Dakota, and Brownie Butte in Montana. A comparison of the features included at each K-T boundary site is included below (Table 1 and Site Description section).

Table 1. Comparision of Terrestrial K-T boundary sites and their respective features in the Great Plains biophysical region.

Rank	Name	County, State	Comments
1	West Bijou Site	Arapahoe, Elbert, CO	Private, non-profit ☑ K-T boundary site. ☑ K palynology and T palynology. ☑ Spike in fern spores present. ☑ Contains iridium and shocked minerals. ☑ Contains claystone layer derived from volcanic ash. ☑Magnetostratigraphy dating completed. ☑ Radiometric dating completed. ☑ K vertebrates below. ☑ T vertebrates above.
2	Brownie Butte	Garfield, MT	Federal BLM ☑ K-T boundary site. ☑ K palynology and T palynology. ☑ Spike in fern spores present. ☑ Contains iridium and shocked minerals. ☑ Contains claystone layer derived from volcanic ash. ☑Magnetostratigraphy dating completed. ☑ Radiometric dating completed. ☑ K vertebrates below. ☐ T vertebrates above.

Rank	Name	County, State	Comments
3	Mud Buttes	Bowman, ND	Federal BLM ☑ K-T boundary site. ☑ K palynology and T palynology. ☑ Spike in fern spores present. ☑ Contains iridium and shocked minerals. ☑ Contains claystone layer derived from volcanic ash. ☑Magnetostratigraphy dating completed. ☐ Radiometric dating completed. ☑ K vertebrates below. ☑ T vertebrates above.
4	Dogie Creek	Niobrara, WY	Federal BLM ☑ K-T boundary site. ☑ K palynology and T palynology. ☑ Spike in fern spores present. ☑ Contains iridium and shocked minerals. ☑ Contains claystone layer derived from volcanic ash. ☐Magnetostratigraphy dating completed. ☐ Radiometric dating completed. ☑ K vertebrates below. ☑ T vertebrates above.
5	Sussex	Johnson, WY	Federal BLM ☑ K-T boundary site. ☑ K palynology and T palynology. ☑ Spike in fern spores present. ☑ Contains iridium and shocked minerals. ☑ Contains claystone layer derived from volcanic ash. ☐Magnetostratigraphy dating completed. ☐ Radiometric dating completed. ☑ K vertebrates below. ☐ T vertebrates above.

6	Teapot Dome	Converse, WY	Federal BLM ☑ K-T boundary site. ☑ K palynology and T palynology. ☑ Spike in fern spores present. ☑ Contains iridium and shocked minerals. ☑ Contains claystone layer derived from volcanic ash. ☐Magnetostratigraphy dating completed. ☐ Radiometric dating completed. ☐ K vertebrates below. ☐ T vertebrates above.

Site Descriptions

Brownie Butte

Brownie Butte is located in Garfield County, Montana in the Williston Basin. The Bureau of Land Management (BLM) is the surface owner of the site. The area contains rolling prairies, broad shallow valleys, and scattered buttes (NRCS 1999). The K-T boundary at Brownie Butte occurs in an area with extensive badlands, just south of Fort Peck Reservoir, and is contained in the Hell Creek and Fort Union Formations. K and T palynology samples have been collected and analyzed from the site (Sweet et al. 1999; Tschudy 1970; Tschudy et al. 1984). The K-T strata here are similar to West Bijou Site as they contain a fern spore spike, iridium and shocked minerals, claystone layer, K vertebrates have been discovered above the boundary, but no T vertebrates have been found below (Nichols and Johnson 2008). Magnetostratigraphy and radiometric dating had been done at the site.

Mud Buttes

Mud Buttes are located in southwestern North Dakota in Bowman County, an area characterized by rolling plains punctuated by buttes and badlands (Bryce et al. 1998). The site, like Brownie Butte, is also within in the Williston Basin. Here, the K-T boundary is also found within the Hell Creek and Fort Union Formations. Although it contains nearly the entire suite of K-T boundary features found at West Bijou Site (See Table 1), radiometric dating has not been conducted for the site (Nichols and Johnson 2002; Nichols and Johnson 2008). Surface ownership is BLM.

Dogie Creek

Dogie Creek is located in Niobrara County, Wyoming. This site is within the Powder River Basin, and the surrounding landscape is characterized by irregular and dissected plains and low hills. The K-T boundary at Dogie Creek is contained in the Lance and Fort Union Formations. Surface ownership is BLM, but the site is somewhat difficult to access as it is surrounded by private land (Karl Osvald pers. comm. 2014).This site contains most of the features of West Bijou Site's K-T boundary, but no radiometric or magnetostratigraphy studies have been completed for the site (Bohor et al. 1987; Nichols and Johnson 2008).

Sussex

The Sussex site is located in Johnson County, Wyoming. The site is within the Powder River Basin near the abandoned town of Sussex. Access to the site is relatively easy, and the surface ownership is BLM (Karl Osvald pers. comm. 2014). Like Dogie Creek, the K-T boundary is located in the Lance and Fort Union Formations. The site contains several of the same features as West Bijou Site, but lacks vertebrate fossils from the Tertiary period, and no magnetostratigraphy and radiometric dating studies have been completed for the site (Nichols et al. 1992).

Teapot Dome

Teapot Dome is located near the Sussex site in Converse County, Wyoming. Like Dogie Creek and Sussex, the site is within the Powder River Basin and the K-T boundary is located within the Lance and Fort Union Formations. Surface ownership is private, and the site may have limited access (Karl Osvald pers. comm. 2014). The site contains several of the same features as West Bijou Site, but lacks vertebrate fossils from the Cretaceous and Tertiary periods, and no magnetostratigraphy and radiometric dating studies have been completed for the site (Nichols and Johnson 2008; Wolfe 1991).

Comparative Analysis and Discussion

Illustrative Character

West Bijou Site, and the five sites described all contain terrestrial exposures of the K-T boundary within the Great Plains biophysiographical province. Although all of these sites have been recognized as critical resources for studying Earth's history (Schulte et al. 2010), the essential difference between them is the degree to which the primary features, Geologic History of Cretaceous Period in the Age of the Reptiles, the Paleocene Epoch during the Emerging Dominance of Mammals, are represented at each site. West Bijou Site alone contains all of the following features: Cretaceous and Tertiary palynology, iridium and shocked minerals, magnetostratigraphy, radiometric dating, datable claystone layer derived from volcanic ash, and Cretaceous and Tertiary vertebrate fossils.

In a comparison of illustrative character, only Brownie Butte and Mud Buttes contain nearly all of the features of the West Bijou Site. However, no Tertiary vertebrate fossils have been found at Brownie Butte, and no radiometric dating has been conducted at Mud Buttes.

Present Condition

The present condition of all of the K-T Boundary sites listed in Table 1 is similar, with little or no development at all sites. With the exception of West Bijou Creek, they are also located in remote areas. West Bijou Creek is located in an area that is relatively close to a major metropolitan area, and the researchers are encouraged to study both the K-T Boundary and shortgrass prairie resources at the site. Furthermore, the staff at PCC provides education and outreach regarding the value of these resources. Present management varies among the six sites. Brownie Butte, located south of Fort Peck Reservoir, is leased for cattle grazing by the BLM (Miles City, Montana BLM Field Office, pers. comm. 2014). Mud Buttes is a remote site leased by the BLM for grazing as well as oil and gas extraction. It is under consideration as an Area of Critical Environmental Concern due to its paleontological resources, but no formal designation has occurred (Tim Zachmeier, North Dakota

BLM Wildlife Biologist, pers. comm. 2014). At Dogie Creek, oil and gas wells are present, and the site is also grazed (Newcastle Wyoming BLM Field Office, pers. comm. 2014). The Sussex site is leased by the BLM for grazing (Karl Osvald pers. comm. 2014). Teapot Dome is on private land and is part of a large cattle ranch (Karl Osvald pers. comm. 2014).

Access and protection at each site varies. At West Bijou Site, researchers can gain access by contacting the Plains Conservation Center. The site is protected by a locked gate, and was placed under a conservation easement with Colorado Open Lands to ensure the site remains undeveloped. The site is also used for public education by the PCC, and members of the public are encouraged to take guided tours through the site. Brownie Butte, Mud Buttes, Dogie Creek, and Sussex are located on BLM lands, but currently there are no protections, special designations, or formal public education opportunities in place for the sites. Teapot Dome was formerly located on BLM lands, but is now on private land and access for researchers may be limited (Karl Osvald pers. comm. 2014). Currently, no formal protection, special designation or formal public education program is in place for Teapot Dome.

All of these sites are in the shortgrass prairie region, but little information exists on the ecological condition of the comparison sites. Therefore, no official comparison of the secondary feature of shortgrass prairie is provided in this report; however, a synopsis of these features at the West Bijou Site is provided.

Rarity

Colorado's shortgrass prairie covers 27 million acres, and is one of the most imperiled ecosystems in the U.S. (National Policy Consensus Center 2003). Major threats to this ecosystem include agricultural plowing, water and wind erosion, development of dams and irrigation, decreasing water availability, energy development, and the loss of important herbivores like prairie dog and bison (National Policy Consensus Center 2003). The West Bijou Site is unique in that it contains high quality shortgrass prairie and riparian woodland in an area that has a high concentration of crop fields and is near a major urban center. The shortgrass prairie at the site provides habitat for several rare species that are tracked by the Colorado Natural Heritage Program including Cassin's Sparrow (*Peucaea cassinii*), Ferruginous Hawk (*Buteo regalis*), and black-tailed prairie dog (*Cynomys ludovicianus*). The riparian zone along West Bijou Creek is a Plains Cottonwood Riparian Woodland dominated by peachleaf willow (*Salix amygdaloides*), coyote willow (*Salix exigua),* and plains cottonwood (*Populus deltoides*). This plant community is also tracked by the Colorado Natural Heritage Program.

Diversity

The shortgrass prairie and riparian woodland support a diverse flora, and over 275 species of plants have been identified and collected at the site (Plains Conservation Center 2012). In turn, this diverse assemblage of plant species provide habitat for a number of bird species. A 2004 survey documented 63 species from the West Bijou Site (Plains Conservation Center 2004). The presence of black-tailed prairie dogs at the site was found to increase diversity of small mammals and herptiles such as plains garter snake (*Thamnophis radix*), prairie rattlesnake (*Crotalus viridus*), short-horned lizard (*Phrynosoma hernandesi*), pocket gopher (*Geomys bursarius*), and northern grasshopper mouse (*Onychomys leucogaster*) (Shipley and Reading 2006).

Value for Science and Education

The shortgrass prairie ecosystem and the K-T Boundary at the site provide ecologists and paleontologists with outstanding resources that are located in close proximity to Denver. Future planned research at the site includes work on the volcanic ash beds, microstratigraphy, osmium isotopes, platinum-group metals, early Paleocene vertebrate fossils, and fossil plants (Plains Conservation Center 2012). Furthermore, the mission of the PCC is to share the results and implications of this research with the public (Plains Conservation Center 2012). Education and outreach is one of the major tenants of the PCC's mission, making this site extremely valuable for both scientific research and public education.

Discussion

In summary, the primary features are best represented at the West Bijou Site. The site not only contains all of the features researchers typically use to study the K-T boundary listed in Table 1, it is also an excellent representation of a true plains stream located within a shortgrass prairie ecosystem. Furthermore, the site is easy for researchers to access, is relatively protected from vandalism by a locked gate, and serves as a valuable public education tool for the PCC.

EVALUATION RECOMMENDATIONS

The West Bijou Site qualifies for designation as a National Natural Landmark.

Summary Significance Statement

West Bijou Site is unique in the Great Plains biophysiographic province as it contains one of the most important examples of the K-T (Cretaceous-Tertiary) boundary and features in the world. These exposures are a critical resource for understanding one of the largest mass extinction events in Earth's history. The site is remarkable among K-T boundary sites globally because of its palynology, iridium and shocked minerals, radiometric dating, datable claystone layer derived from volcanic ash, and vertebrate fossils. West Bijou Creek, an ephemeral plains stream with natural hydrologic processes, bisects the site, forming a riparian zone nested in a semi-arid shortgrass prairie ecosystem. The plant diversity in the riparian and upland areas provide habitat for plains wildlife species that have experienced severe habitat loss and degradation in the last century, such as pronghorn and Burrowing Owls. The site is dominated by open prairie, and only a few residential properties are located in the area.

Proposed Landmark Boundary and Ownership Maps

The proposed landmark boundary (Figure 2) is drawn along section and quarter section lines encompassing West Bijou Creek, the gullies that contain exposures of the K-T boundary, and adjacent shortgrass prairie uplands. The segments of the proposed NNL boundary in T5S, R62W, section 34 and T6S, R62W, section 3 that deviate from the section/quarter section lines, follow the boundary of the "Marrs Property," as referred to by the Plains Conservation Center. These areas, as well as all of T6S, R62W, section 10, were transferred to PCC in December 2012. The proposed NNL boundary encompasses 7,613 acres, and is located entirely within lands ownd by the Plains Conservation Center.

The following is a description of the Township, Range, and Sections. If the entire section is not within the boundary, quarter sections are noted:

- T5S, R62W, 34, portions of SE1/4, SW1/4, and NE1/4 (see Figure 2)
- T5S, R62W, 35
- T5S, R62W, 36
- T6S, R61W, 6
- T6S, R62W, 1
- T6S, R62W, 2
- T6S, R62W, 3, portions of NE1/4, SE1/4, SW1/4 (see Figure 2)
- T6S, R62W, 10
- T6S, R62W, 11
- T6S, R62W, 12
- T6S, R62W, 14
- T6S, R62W, 15
- T6S, R62W, 23

Natural Landmark Brief

Name: West Bijou Site

Location: Arapahoe and Elbert Counties, Colorado

Description:

West Bijou Site, located approximately 50 kilometers (31 miles) east of the city of Denver, contains some of the most important exposures of the Cretaceous-Tertiary (K-T)[Cretaceous-Paleogene (K-Pg)] boundary in the world. The boundary is a 3 cm (1.18 in) band of sediments that represents the end of the Cretaceous period of the Mesozoic Era, and the beginning of the Paleogene period of the Cenozoic Era, and is a critical resource for calibrating the geologic timescale for all of Earth's history. The band marks a significant event in Earth's history: a massive extinction of dinosaurs and other terrestrial vertebrates, along with many species of ammonites and other marine invertebrate fauna. The K-T boundary at the West Bijou Site is unique in the Great Plains Region due to its palynological extinction level, fern-spore spike, iridium anomaly and shocked quartz, Cretaceous and Tertiary (Paleogene) vertebrate fossils, magnetostratigraphy, and radiometric dating.

West Bijou Creek is an ephemeral stream that maintains a natural hydrologic regime, as it contains surface water only after precipitation events. It supports a mosaic of upland and riparian shortgrass prairie plant communities, and has been designated a Potential Conservation Area by the Colorado Natural Heritage Program. Native willows (*Salix exigua*, *Salix amygdaloides*) and plains cottonwood (*Populus deltoides*) dominate the floodplain, and small emergent wetlands are present in patches along the channel. Above the channel, drier upland sites support prairie grasses and shrubs, including sideoats grama (*Bouteloua curtipendula*), buffalograss (*Buchloe dactyloides*), blue grama (*Bouteloua gracilis*), and rabbitbrush (*Chrysothamnus nauseosus*) and a diverse assemblage of prairie forbs including Indian paintbrush (*Castilleja integra*). These habitats support a high diversity of prairie wildlife species that have experienced severe habitat loss in the last century and

are now considered rare. These species are tracked by the Colorado Natural Heritage Program, and include Cassin's Sparrow (*Peucaea cassinii*), Ferruginous Hawk (*Buteo regalis*), and black-tailed prairie dog (*Cynomys ludovicianus*).

Significance:

West Bijou Site contains some of the most scientifically important evidence associated with the Cretaceous-Tertiary (K-T) [Cretaceous-Paleogene (K-Pg)] boundary in the world. The K-T boundary at the West Bijou Site contains several features that contribute to our understanding of the most recent of the five large mass extinctions in Earth's history. These features include Cretaceous and Tertiary (Paleogene) pollen records and vertebrate fossils, minerals and metals that support the hypothesis of asteroid impact as the cause of extinctions. Unlike many of the K-T sites in the region, magnetostratigraphy and radiometric dating have been completed at the site. Bisecting the site, West Bijou Creek, maintains a natural hydrologic pattern, flowing through a mosaic of upland and riparian shortgrass prairie plant communities, supporting a diversity of common and rare plant and wildlife species. West Bijou Site provides an excellent example of a valuable geologic resource located within a natural shortgrass prairie ecosystem.

Ownership: Private

Designation:

Evaluation: Bernadette Kuhn, Colorado Natural Heritage Program

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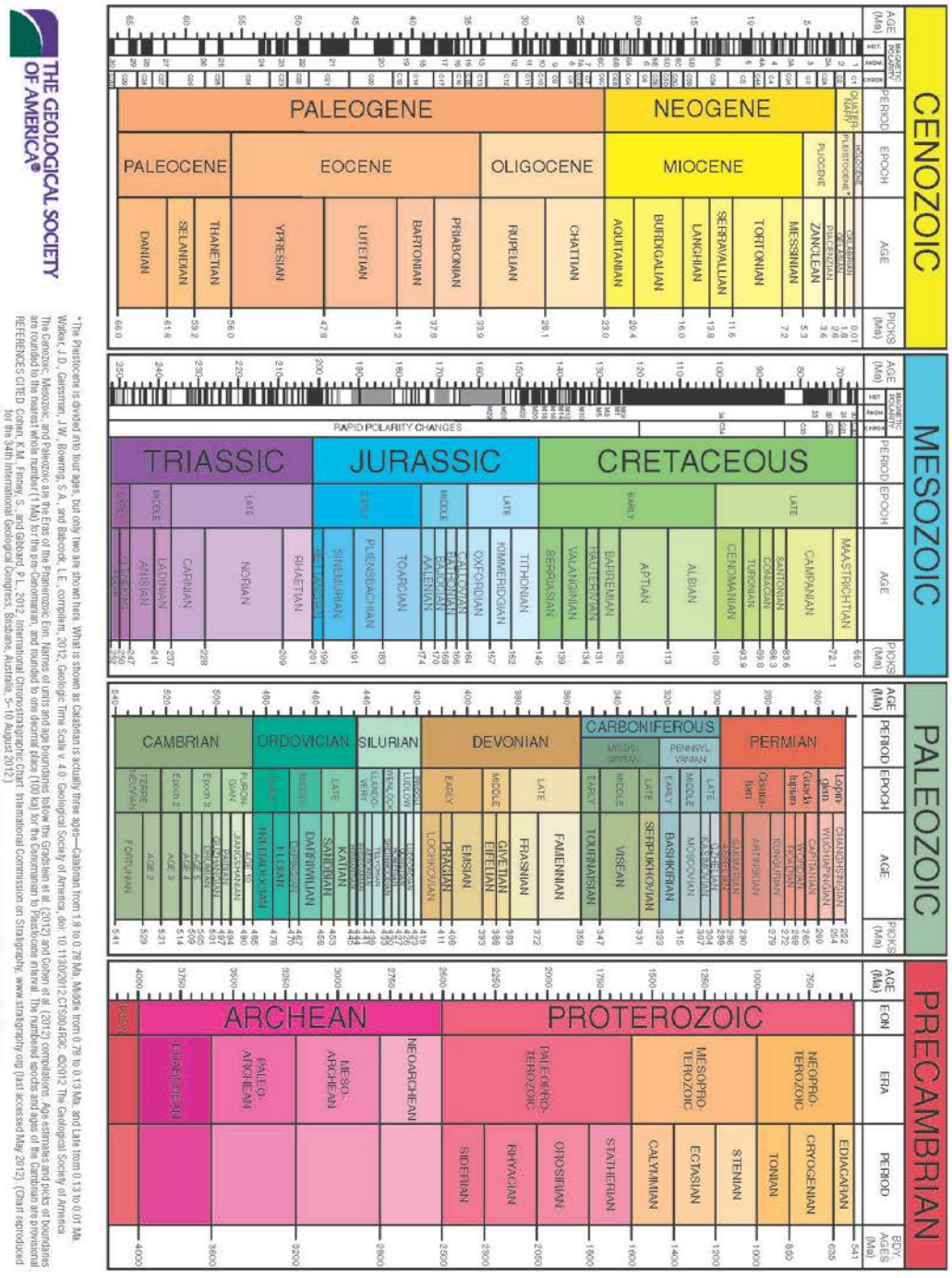
Appendix A: Geologic Timescale



* The Pleistocene is divided into four ages, but only two are shown here. What is shown as Calabrian is actually three ages—Calabrian from 1.8 to 0.78 Ma, Middle from 0.78 to 0.13 Ma, and Late from 0.13 to 0.01 Ma.

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The Cenozoic, Mesozoic, and Paleozoic are the Eras of the Phanerozoic Eon. Names of units and age boundaries follow the Gradstein et al. (2012) and Cohen et al. (2012) compilations. Age estimates and picks of boundaries are rounded to the nearest whole number (1 Ma) for the pre-Cenomanian, and rounded to one decimal place (100 ka) for the Cenomanian to Pleistocene interval. The numbered epochs and ages of the Cambrian are provisional.

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