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ROCKS AND FAUNAS, OGALLALA GROUP, PAWNEE BUTTES AREA, WELD COUNTY, COLORADO

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HISTORY OF INVESTIGATION

Discovery and exploitation of the Miocene deposits in the Pawnee Buttes area of Weld County, northeastern Colorado, began soon after the Civil War with O. C. Marsh's reconnaissance of 1870. He recognized equivalents of the White River beds and post-White River deposits exposed along the "Chalk Bluffs," a 150-mile long escarpment extending east-west just south of the state line in northeastern Colorado (Fig. 15). These deposits are exposed along the eroded southern edge of the "Gangplank", a wedge of Tertiary sediments extending from the Front Range eastward across southeastern Wyoming and into adjacent Nebraska and Colorado. Marsh led the first Yale Student Expedition to these deposits in August 1872. They collected fossils principally from exposures of the White River Group, at the head of Crow Creek

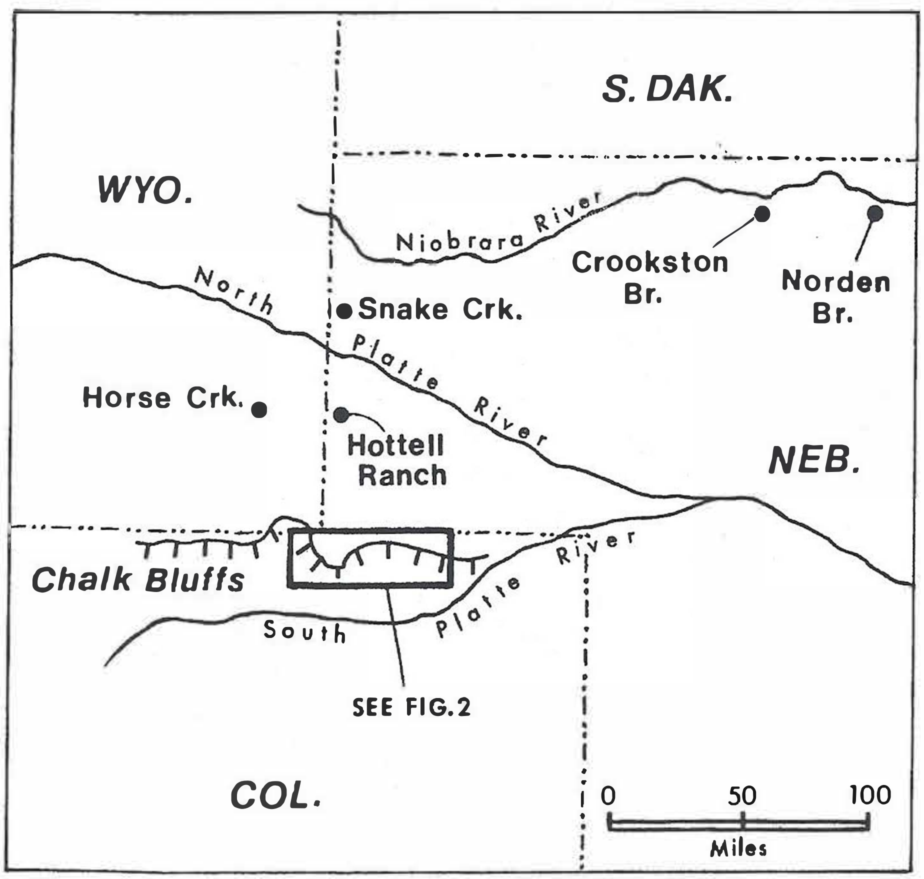
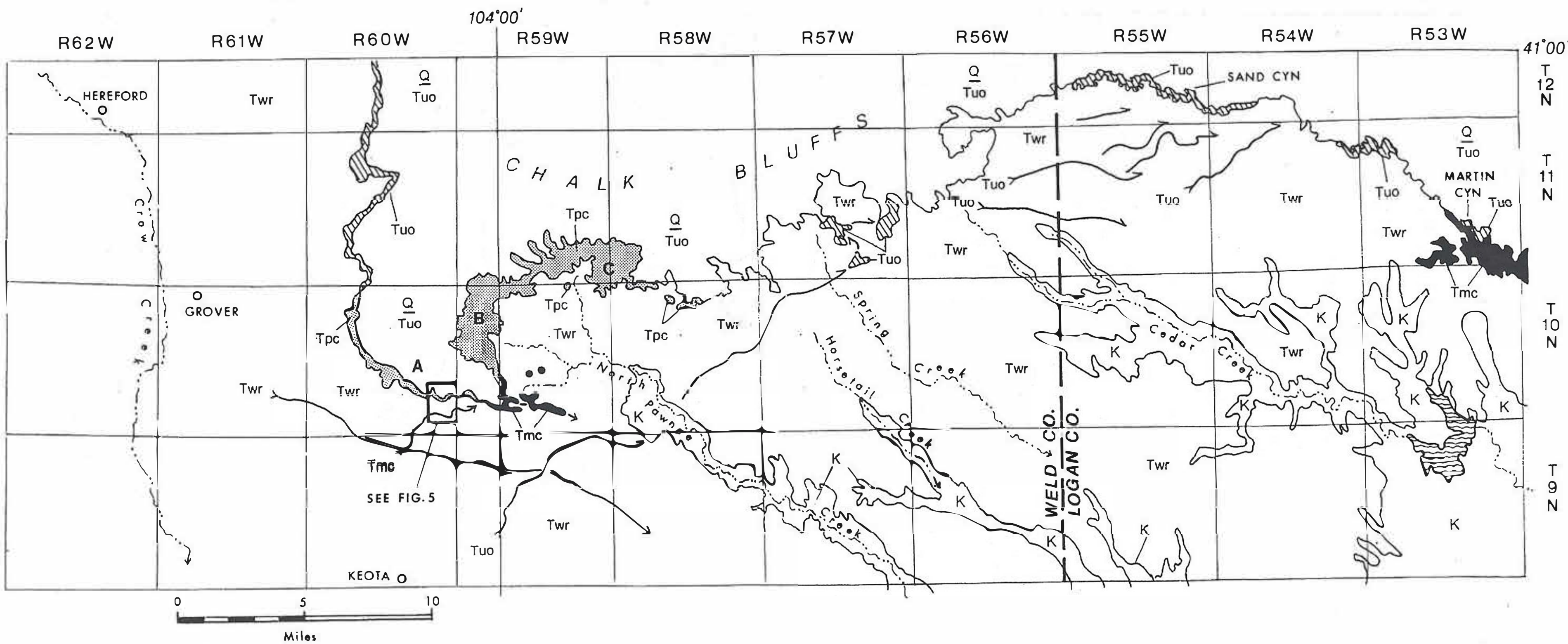


Figure 15. Location map for sites mentioned in the text, the area of Figure 16, and the approximate extent of the Chalk Bluffs that represent of the outcrops of the Tertiary alluvial apron at the southern edge of the Gangplank.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HEREFORD
GROVER
KEOTA
CHALK BLUFFS
SAND CYN
MARTIN CYN
Crow Creek
North Pawnee Creek
Spring Creek
Horsetail Creek
Cedar Creek
WELD CO.
LOGAN CO.
Q
Tuo
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0
5
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Figure 16. Geological map of the Pawnee Buttes area (the Buttes themselves are in center T1 0N R59W) and the Chalk Bluffs east to Martin Canyon based on Scott, 1982 with additions by the author west of long. 1040 00'. Rock unit symbols: K, undivided Cretaceous marine sediments; Twr, White River Group; Tmc, Martin Canyon Formation (black); Tpc, Pawnee Creek Formation (in the sense of this paper, oblique ruled); Tuo, upper Ogallala Group, undivided shown as dots; Q/Tuo, upper Ogallala Group where concealed by younger alluvium, aeolian deposits and soil. Sinuous lines terminating in arrowheads show axial channel trends and transport directions (up, position of Uhl Pit on bend of a Tuo channel). Approximate geographic locations of columnar sections A, B and C, of Fig. 18, and location of Fig. 19 indicated.

in the vicinity of the present towns of Hereford and Grover just south of the Colorado-Wyoming border (Fig. 16; Schuchert and LeVene, 1946).

In 1873 E. D. Cope made the first of two trips to the Pawnee Buttes area east of Marsh's exploration and extended his work further eastward to the head of Cedar Creek in western Logan County, Colorado (Fig. 17). He made a major collection from White River and post-White River deposits from June through August of that year. His studies (1873, 1 874a-b among others) of these collections constituted the first substantial description of the White River fauna and many of the important elements from the younger deposits (then usually called the "Loup Fork beds"). Cope revisited the White River deposits at the head of Cedar Creek in November 1879 during additional work for the Hayden Survey. In 1882, W. B. Scott lead the first Princeton University Expedition to the Chalk Bluffs in the vicinity of Sand Canyon, western Logan County, Colorado (Fig. 16; Scott, 1939).

In 1898, 1901 and 1902 W. 0. Matthew and party from the American Museum of Natural History (Barnum Brown and Bill Thomson) plus Handel T. Martin of Kansas (only in 1898) and Frederick Loomis of Amherst systematically prospected the White River and Loup Fork deposits from Lewis Canyon, northeast of Sterling, Colorado westward along the flats (White River) and Chalk Bluffs (Loup Fork) across Logan County to the head of Cedar Creek (1898), the Pawnee Buttes area of Weld County (1901) and the west-facing bluffs east of Grover (1902) bringing together a substantial collection rivaling Cope's pioneering effort.

In 1901, Matthew described the 1898 collection, but there was not a complete account of the 1901-2 collection beyond Matthew's faunal list of 1909 until the review of Galbreath (1953). The importance of these historic collections is illustrated from the data in the latter publication: of the 59 species recorded from the "Pawnee Creek Fauna" (Galbreath 1953, p. 34) 61% are types of new species and higher taxa. As is evident in Matthew's (1909, p. 114-115) faunal lists for the "middle Miocene Deep River sequence," the "Pawnee Creek" formed the major basis for the previous century's knowledge of the fauna of this important interval.

In this century many institutions have made collections in the post-White River rocks in the Pawnee Buttes area including University of Kansas (H.T. Martin in the early part of the century and E.C. Galbreath in the late 1940's early 1950's), University of California (R. A. Stirton and C.J. Hesse in the 1930's) and the Denver Museum (Markman, Figgins and others in the 1920's-1930's). Intensive work by the Frick Laboratory of the American Museum of Natural History began in 1931-33 by J.C. Blick, and was continued in 1941-42 by C.H. Falkenbach and N.J. Vaughn and in 1950-51 by N.Z. Ward. This work was focused in the Pawnee Buttes area of Weld County and principally on the post -White River deposits. However, only a few taxa were described from the several thousand remains obtained: *Ursavus* (Frick 1926), mastodonts (Frick

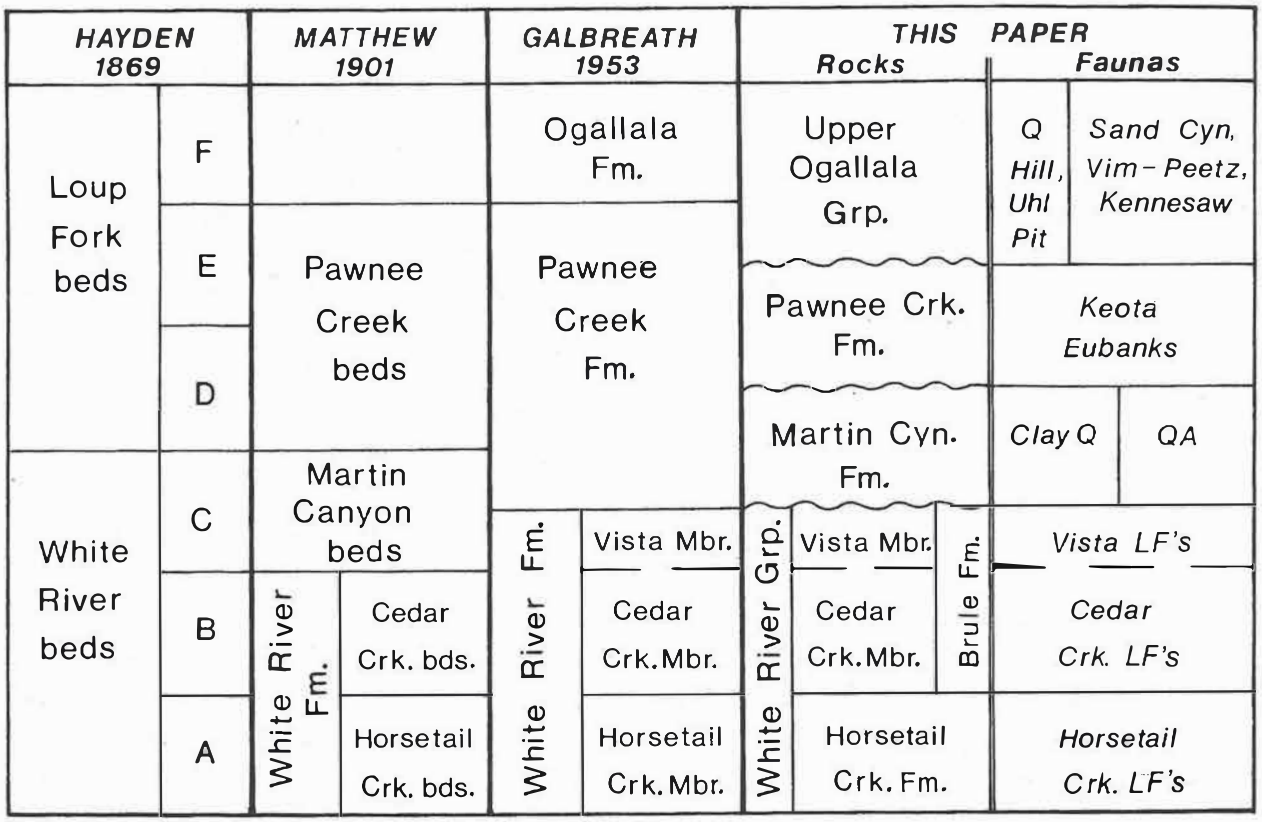

Figure 17. Comparison of lithostratigraphic concepts from their initiation by Hayden (1869), through Matthew's (1901) application to outcrops in northwestern Colorado, and Galbreath's (1953) adaptation, and the system advocated here. Faunas delineated in the text are grouped into rock units as presently recognized.

1933), ruminants (Frick 1937), oreodonts (Schultz and Falkenbach, 1941), and *Protolabis* (Frick and Taylor, 1971).

The larger features of the stratigraphic sequence of the Chalk Bluffs were apparent to the earliest workers (Hayden in Leidy, 1869), namely that the Cretaceous marine deposits were overlain by a generally fine-g rained Tertiary sequence that closely resembled the lithology of the White River Group of Nebraska and the Dakotas. Overlying these rocks was a coarser sequence, referred to the Loup River (later Loup Fork) beds that extended northward into Wyoming and Nebraska. Hayden further subdivided these lithostratigraphic units by into "beds" designated by letters. The Loup River contained beds D, E and F whose general a real extent, lithologic characters, and fossil mammal content were listed in Hayden's preface to Leidy's monograph of 1869 (p. 29-30). These data provided a biostratigraphic basis for subdivision of the Loup Fork (Fig. 17).

The history of stratigraphic analysis and nomenclature of this region is bound up in the attempts to relate the biostratigraphy of the "Colorado Loup Fork beds" to the faunal sequence generalized by Matthew (1899) and by Osborn and Matthew (1909) as a series of chronostratigraphic units for North America as a whole (see Tedford 1970, pp. 667-673, for further discussion). Matthew's first year (1898) along the Chalk Bluffs in Logan County, and especially his observations in the vicinity of Martin Canyon (Matthew, field notes 1898, AMNH Archives), show his concerns with interpreting the evidence as it was uncovered (Fig. 17).

In 1898, the American Museum party discovered in Martin Canyon (Fig. 16) the magnificent *Merycochoerus proprius magnus* block with its tucked-in *Phlaocyon leucosteus* (holotypes of both taxa). These fossils were entombed in fine-grained, thin-bedded strata that seemed to Matthew (1898 field notes, AMNH Archives) to be continuous with the upper White River, bed C, deposits. Yet the fauna resembled elements from the "John Day beds" (the John Day "*Merycochoerus*" was not yet distinguished from *Promerycochoerus*) suggesting that much younger beds were included in the Colorado White River. A lithic conglomerate (reworked calcareous nodules) separated these beds from the overlying nodular, massive silty sands that Matthew recognized as the Loup Fork, bed D or "Deep River beds" (a faunal correlation with Montana). Finally the pebble gravels and interbedded coarser sand of the Loup Fork, bed E, "like the Kansas Loup Fork", capped the local outcrop. The collections from Martin Canyon were initially segregated according to this stratigraphic scheme. The work had not gotten beyond Martin Canyon by the time Matthew had to leave the collecting to Barnum Brown and the party (July 19th). At that point Matthew had concluded that "the Loup Fork beds may grade into the Deep River, tho' in one or two places resting on their eroded surface. The Deep River thins out to S and NW (i.e. along the outcrop of the bluffs at Martin Canyon) and nearly or quite disappears. It is unconformable over the 'John Day' the conglomerate being an eroded surface" (Matthew, 1898, field notes AMNH archives). In his published account of this work, Matthew (1901) continued to use these temporal terms in the text but he now believed that in this area the lithic distinction between beds D and E 'appears to be very inconstant" and that "the difference in fauna is equally unsatisfactory, and the separation will not be maintained here" (p. 359), a view that was reiterated in the postscript to the monograph (p. 445). He reinforced his opinion by introducing, in paragraph headings rather than in the body of the work, two new stratigraphic terms for the sequence under discussion: 1) the "Martin Canyon beds" for the *Lepauchenia* bearing rocks, including the strata with the *Merycochoerus* block (i.e., bed C of the White River Group); and 2) the "Pawnee Creek beds" for Loup Fork, beds D and E combined (Fig. 17). As was common practice at the time, no type sections were defined, although the known geographic limitation of the Martin Canyon beds clearly indicates that canyon as the type area. The use of the name Pawnee Creek, however, refers to strata in the headwaters of that drainage and involves a correlated westward extension of 25 miles (40 km; Fig. 16).

Critical review of Matthew's conclusions came fifty years later when E. C. Galbreath (1953), based almost exclusively on field studies in Logan County, concluded that the Martin Canyon beds of Matthew could be lithically, as well as faunally, distinguished from the uppermost White River deposits (his "Vista member") by their slightly coarser grain size (fine sand rather than clay), more conspicuous bedding, and evidence of strong disconformity with the White River on a regional scale. At Martin Canyon the top of the White River had been removed and the Martin Canyon superposed directly on the underlying Cedar Creek member (Galbreath, 1953, p. 19). Despite these distinctions, Galbreath inexplicably recommended (1953, p. 20) that the term Martin Canyon be "abandoned as a name for a lithologic unit" that was separate from the Pawnee Creek beds on the basis that "the section did not exist as described: the lower part is assigned to the White River formation and lithologically the upper part cannot be distinguished from similar beds that grade up into the Pawnee Creek formation". Matthew's faunal lists for Horizon D are clearly composites and reflect his party's confusion of units in the field that lead to their being merged (Fig. 17). Subsequent careful stratigraphic collecting by University of Kansas parties under Galbreath and Wilson (1960) have shown that the lower part of the "Pawnee Creek beds" have a distinctive fauna that does not include taxa found in the younger beds assigned to this unit or their equivalents in the vicinity (see discussion of "Martin Canyon Local Fauna" in Galbreath 1953, p. 32-34). In modern terms the "Martin Canyon Local Fauna" is clearly Hemingfordian; the younger deposits are Barstovian.

As we have seen Matthew did not designate a type section for his Pawnee Creek beds in 1901, but Galbreath believed (1953, p. 18) that since Matthew's monograph of 1901 had been delayed in publication until after completion of the field work of that year, that the term was introduced based on his additional experience in Weld County. Handel T. Martin, a member of the 1898 team, indicated that Matthew's concept was drawn from the outcrops in the vicinity of the Eubanks Ranch house near Dolan Springs, north of the Pawnee Buttes. In any event, the lectotype section selected by Galbreath is in the NE1/4 sec. 1, T. 10 N., R. 59 W. in Weld County. This is a good choice since at that site the Pawnee Creek rests disconformably on the White River without intervening Martin Canyon deposits.

A minor incident in the history of investigation of the Pawnee Creek area lead ultimately to a further refinement in the biostratigraphic analysis of the post-White River rock units. In 1922, W.D. Matthew took Childs Frick and his wife Frances on a tour of some significant fossil deposits in the northern Great Plains. The party stopped for lunch "in full view of the two great Pawnee Buttes" (letter C. Frick to J. Blick, 27 May 31*)* and near the lunch site Frick discovered the holotype of *Ursavus pawniensis* Frick 1926, the first record of this bear in North America. This striking serendipity lead to hiring Harvey C. Markman, of the Denver Museum, to make a thorough exploration of the region west of the buttes. The deposits that contained the bear were poorly consolidated sands and gravels that blanket the underlying more indurated Pawnee Creek deposits. These deposits contain scattered broken and water worn bones, mostly *Teleoceras* but also *Cosoryx*, *Mylagaulus*, horse, camel and mastodont remains. Such gravels are included in the top of Galbreath's lectotype section for the Pawnee Creek Formation and the Frick Laboratory parties found that they were widespread and often lie with spectacular disconformity on all older rocks along the edge of the Chalk Bluffs escarpment in the vicinity of the Pawnee Buttes.

The significance of the regional extent of these sands and gravels became apparent to Morris F. Skinner of the Frick Lab who joined Falkenbach in 1953 in a stratigraphic reconnaissance of the Pawnee Butte collecting ground. This was reinforced in a review of localities during stratigraphic studies of Skinner and Tedford with N.Z. Ward in 1969. With Ward's help nearly all the Frick collecting sites were located and many stratigraphic sections were measured and lithologic correlations made so that a regional stratigraphy for the area could be advanced. I have belabored this historical account to help explain my proposals to utilize the term Martin Canyon Formation for similar rocks in Weld County and also to limit the term Pawnee Creek Formation to distinguish it from fossiliferous deposits within the younger part of the Ogallala Group.

STRATIGRAPHY

All the post-White River Tertiary rocks can be placed in the Ogallala Group on the basis of their epiclastic nature, which, although marked to a certain degree by locally incorporated lithic debris, still includes an important component of igneous, metamorphic and pre-Tertiary sedimentary clasts. The situation is paralleled in the Ogallala deposits of the Gangplank in Wyoming and Nebraska. Nevertheless it seems unwise to extend the more detailed lithostratigraphy from that region into the southern rim of the Gangplank although paleontology allows correlations to be made with sections to the north. In the Pawnee Butes area three disconformity-bounded, post-White River, lithostratigraphic units can be recognized. Each is apparently contained within a single (or closely related) paleodrainage and all are successively incised through each other and into the White River Group. The deep axial facies of each includes distinctive conglomerate assemblages reflecting local and distant westward sources. One of the most striking geomorphic features of this region is the "reversed" topographic expression of these axial gravels after escarpment retreat has left them isolated as gravel-supported chains of hills on the low relief surface south of the Chalk Bluffs (Fig. 16). This fortunate circumstance allows observation of axial trends and relative sinuosity as well as provides outcrops of the entrained finer facies, which are fossiliferous.

Martin Canyon Formation. – Lithologically, this unit closely resembles its type section in Martin Canyon, especially that part of the section containing the lithic conglomerate (Galbreaths 1953, units 4-6, section XVI) and overlying finer grained nodule-bearing sediments (Ibid. unit 7). In the Pawnee Buttes area these rocks form the bedded gray-weathering caprock of the Buttes and they crop out in the escarpment rim immediately to the west and southwest of the Buttes. In the latter area they represent the northern side of a paleodrainage whose axial deposits form a sinuous lithic gravel train just south of the southernmost Chalk Buttes escarpment (Fig. 16). This reversed topographic remnant of a paleovalley joins the escarpment where the road to the Buttes observation point ascends the escarpment. Eastward from this point the gravel holds up a rather linear series of hills that extend 3 mi southeast from the observation point.

The axial gravels of the Martin Canyon Formation consist of 90% or more pebbles and cobbles of rolled calcareous siltstone and fine sandstone nodules. Other clasts include a variety of pebbles and occasional cobbles of crystalline rocks including light-colored granite (Silver Plume granite), red granite (Sherman granite) and andesite (part of Specimen Mountain volcanic complex) all indicating sources to the west in Rocky Mountain National Park. Volcanics from the Specimen Mountain field limit the age of the conglomerates to younger than 28 Ma. All indicate much higher gradients than the present day Platte River at this distance from the Front Range.

Lateral to-the axial part of the Martin Canyon paleovalley the base of the unit is usually marked by only a thin lithic conglomerate or it may lack conglomerate. The body of the Martin Canyon Formation is a light-tan claystone, siltstone or silty fine sand, thinly bedded or laminated and cemented by groundwater into bench-forming ledges that can be traced laterally for long distances at the outcrop scale. The unit contains small rhizoconcretions but little evidence of pedogenesis. In the Pawnee Buttes area the Martin Canyon Formation attains thickness approaching 180 ft (55 m).

Pawnee Creek Formation. - Galbreath (1953, p. 18) designated the area just east of the old Eubanks Ranch house in the NE 1/4 sec 1, T10N, R59W as the type section and gave a measured section (section 1, p. 20-22) and description of the sequence of 7 units for a total thickness of 155 ft (47 m; Fig. 18). The seventh unit, a capping gravel, was questionably referred to the Pawnee Creek Formation. Throughout the Pawnee Buttes area the Pawnee Creek paleovalley has incised through the Martin Canyon Formation into the Cedar Creek Member of the Brule Formation, but not much deeper than the Martin Canyon valley indicating some fidelity of base-level during the early and medial Miocene (Fig. 18).

From the type section the Pawnee Creek Formation can be walked out eastward for 6 miles until the capping gravels or sod covers it. To the west and southwest it holds up the large salient of the Chalk Bluffs that extends southeast of Grover (Fig. 16). The escarpment in that region lies mostly on the old Davis Ranch where Matthew's party did part of their work in 1901 (Fig. 18). The outcrops there show an oblique cross-section through the Pawnee Creek

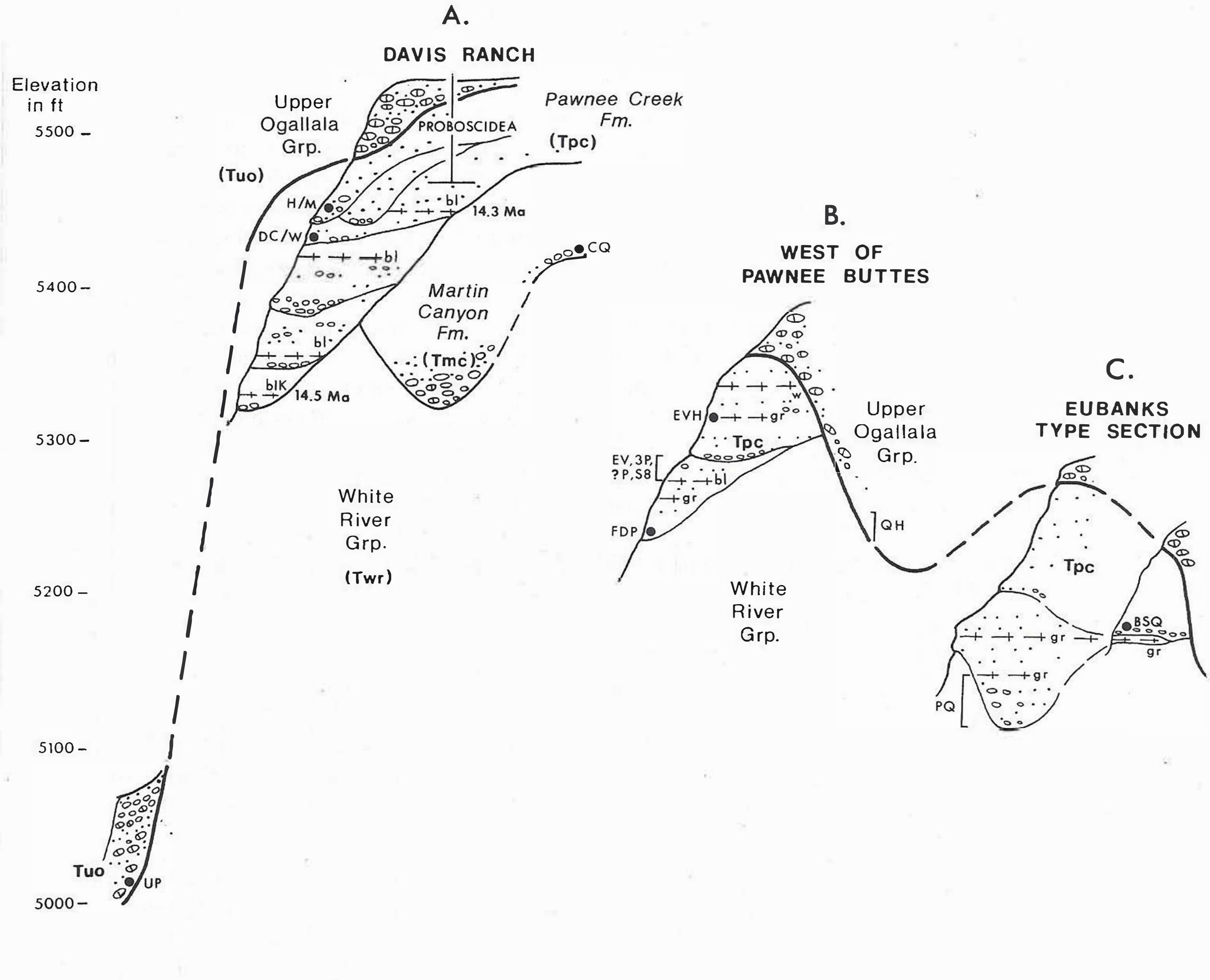

Figure. 18. Three generalized stratigraphic columns (areal positions indicated on Fig. 2) showing the relationships between units in space and time (cross-cutting) against elevation. Pawnee Creek Formation subdivided into fining upward cycles and showing ash beds (colors: bl, blue; gr, gray; blk, black; wh, white) stratigraphic positions of Frick Quarries shown: BSQ, Big Spring Quarry; CQ, Clay Quarry; FOP, Frick's Dinner Pit; DC/W, Dark Cap and West Quarries; EV, East Valley Pits; EVH, East Valley High Pit; H/M, Horse and Mastodon Quarry; 3P, Three Points pits; P0, Pawnee Quarry; ?P Question Mark Pit; OH, Quarry Hill; S8, Section 8 Quarries; UP, Uhl Pit.

paleovalley that is at least 2 miles (3.2 km) wide and trending northeasterly. Its eastern side can be traced northward, west of the Pawnee Butte, and eastward along the northern escarpment of the Pawnee Creek valley where the type section lies on the southern margin of the paleovalley. The Buttes can thus be seen as part of the White River and Martin Canyon terrain that formed the confining eastern wall of the paleovalley.

The Pawnee Creek Formation contains no coarse axial facies, but the unit differs from the Martin Canyon Formation in being coarser grained (fine-medium sand), more irregularly bedded (thin to thick bedded with shallow channel fills common), with abundant pedogenetic (rhizonodules) and groundwater cementation and greater oxidation (reddish tan average color, but with locally reduced greenish-gray finer grained facies).

The conglomeratic lenses bear pebbles of the same suite of crystalline rocks and pre-Tertiary sediments seen in the Martin Canyon Formation and similarly lithic conglomerates dominate, often auto-derived. The striking lithologic attribute of this unit is the abundance of vitric tuffs of a range of colors (reflecting different compositions) from white, light and dark gray to blue-gray. The unit is probably tuffaceous as a whole, although no comprehensive petrographic studies have been made.

In the Davis Ranch cross-section (Fig. 18) the internal stratigraphy of the 220 ft (67 m) thick Pawnee Creek Formation can be divided into six disconformable fining-upward cycles. Each begins with conglomeratic sands and ends with truncated concretionary, silty, fine sand. This stratigraphy indicates spasmodic filling of the paleovalley and a significant passage of time. Radiometric dates from ash beds discussed below suggest the accumulation of the Pawnee Creek Formation took at least 0.5 my. Correlation of the ash-bed sequence in the Davis Ranch section to sections west of the Buttes and across to the type section cannot be clearly affected without chemical signatures. These later sections show only two fining upward cycles so they must be incomplete representations of the Pawnee Creek Formation as a whole.

Upper Ogallala beds. - As detailed above, one of the discoveries stemming from the field investigations of the Frick Laboratory was the recognition of a widespread and strongly disconformable gravel sheet that caps the Pawnee Creek deposits. These sands and gravels are represented by unit 8 of Galbreath's Pawnee Creek type section (Galbreath 1953, p. 20), and questionably assigned by him to the latter. They can be traced southwestward from the type section, to deep, narrow paleovalleys that cut through the Miocene rocks into the top of the White River (Fig. 18). Two of these narrow valleys trend northeastward and lie side-by-side on either side of County Road 107 where it ascends the escarpment just east of the Davis Ranch outcrops (Fig. 19). The deposits filling these paleovalleys are pebbles, cobbles and occasionally boulders, of dominantly crystalline rocks with little or no lithic debris. The range of clasts includes most of those seen in older Miocene units, except that the plutonic and volcanic rock types are more varied. The axial facies is particularly coarse and forms gravel supported chains of hills. Such a ridge that bends south in NW 14 sec. 1, T. 9 N., R. 59 W., includes sand and silt lenses within a point bar. These finer deposits are locally fossiliferous (Uhl Pit site of Ward, 1952, Figs. 16 and 18) and bear the same fauna Frick and Markman found in the gravels west of the Buttes.

These are the youngest Tertiary rocks visible along the Chalk Bluffs escarpment in the vicinity of Pawnee Buttes. They can be traced northward toward Pine Bluffs (Fig. 16) and into the upper part of the Lodgepole Creek valley, southeastern Wyoming. Loomis and Thomson followed them in that direction in 1902, but the rocks have suffered much pedogenetic modification and fossils were very scarce. It's conceivable that they form part of the Ogallala

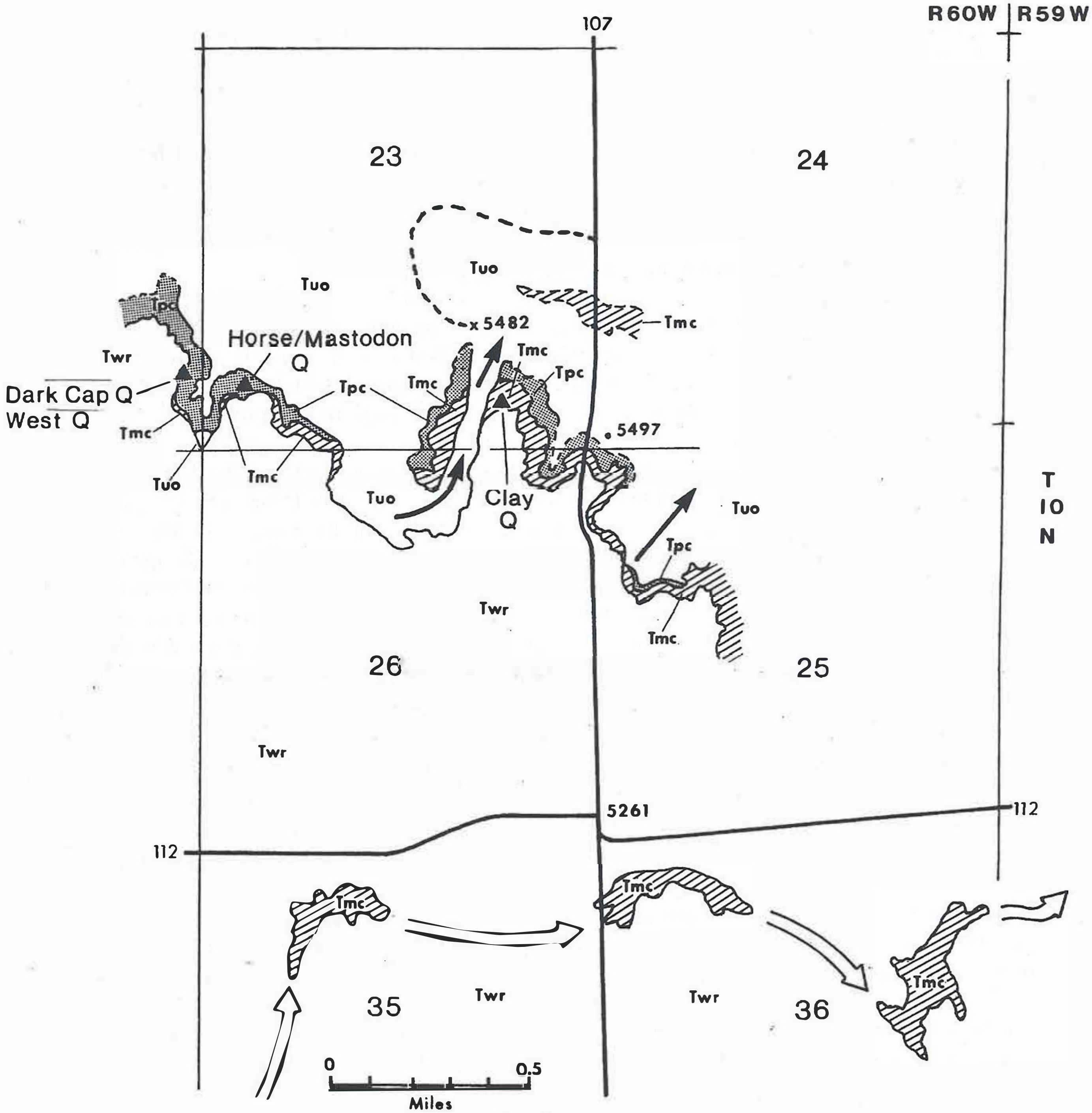

Figure 19. Geologic map of the area in SW corner T10N R6OW around Clay Quarry and the Horse/Mastodon Quarry showing the areal relationships of outcropping post White River units: Twr, White River Group undivided; Tmc, Martin Canyon Formation, and axial facies forming "reversed topography" in sec. 35-36, axial trend and transport direction shown by open arrows; Tpc, Pawnee Creek Formation; Tuo, upper Ogallala Group, with axial facies trends and direction of transport indicated by bold arrows.

blanket that crops out on either side of the Lodgepole valley from Sydney to Kimball in Nebraska.

The lack of continuous outcrops prevents direct tracing of any of the Miocene units eastward into the better-studied outcrops from Sand Canyon east to Martin Canyon and further. Galbreath correlated the Pawnee Creek Formation with the post-White River deposits in Logan County as did Cope, Matthew and most other investigators. Paleontologic evidence can be used to test this correlation now that a better biostratigraphy is available for both regions.

BIOSTRATIGRAPHY

Martin Canyon Formation: Much of the stratigraphic basis for the paleontology of this unit has been alluded to above, but it is worth reiterating that the first modern analysis was that of Galbreath (1953) who, despite his adherence to the lithostratigraphy of Matthew, fully realized that the outcrops at Martin Canyon yielded a fauna markedly older than that of the type section of the Pawnee Creek Formation. Galbreath's "Martin Canyon Local Fauna" still groups the taxa from the rocks containing the AMNH *Merycochoerus* site (Galbreath 1953, Section XVI, unit 2) with those above the lithic conglomerate ("rubble, nodular," units 4 and 6, Section XVI; "cobble, derived from weathered Oligocene nodules", unit 3, sect. XV) containing University of Kansas Quarry A and scattered specimens at the same horizon. None of the taxa from the lower level have been positively identified at the upper level suggesting that there may be a significant temporal hiatus beneath the base of the conglomerate. For the purposes of this discussion we will restrict the term Martin Canyon Local Fauna to the assemblage above the conglomerate. This restriction as is more consonant with the use of the term "local fauna."

The occurrences of fossil mammals in the Martin Canyon Formation of the Pawnee Buttes area all come from the lower part of the unit. *Aletomeryx* sp. and *Moropus* cf. *matthewi* occur in fine-grained lenses within the axial gravels southeast of the Buttes. Clay Quarry, just above the basal conglomerate exposed on the southeastern escarpment immediately west of County Road 107 (Figs. 18 and 19), and scattered sites to the west, have "*Monosaulax* cf. *curtus,*" *Parahippus pawniensis, Anchitherium* cf. *clarencei, Menoceras* cf. *barbouri, Barbouromeryx* sp. and *Problastomeryx* sp. Childs Frick collected a skull and jaws of *Michenia* sp. from the Martin Canyon outcrop on top of the east Pawnee Butte. There have also been scattered finds of *Merycochoerus* sp. and *Merychyus* cf. *elegans* from the escarpment immediately southwest of the Buttes. The composite fauna is of early Hemingfordian age and closely resembles that of the Martin Canyon Local Fauna and the fauna of the Runningwater Formation of northwestern Nebraska.

Pawnee Creek Formation. - Galbreath (1953, p. 31-32) gives a cogent history of the use of the composite term "Pawnee Creek fauna" of Matthew (1901) and later authors (particularly Osborn, 1918). Galbreath began a more careful dissection of this composite by distinguishing a "Eubanks local fauna" (Fig. 17) that was "based on specimens collected from the Pawnee Buttes ash layer and the beds immediately above and below it at the type locality of the Pawnee Creek Formation." It is evident from their field notes that Cope (1873), and Matthew and party (1901) also found these same channel fills that are so rich in fragmental fossil remains. This is the same locality as Falkenbach's Pawnee Quarry (of 1941), which taps the lowest 35 ft (10.7 m) of the type section (Fig. 18). At this site there is a sequence of greenish, cross-bedded, interlensed medium to fine sands with lithic pebbles and granules, containing the light gray vitric "Pawnee Buttes Ash" near the top. These beds fill part of a deep (50 ft, 15 m) cut into the White River Group (Fig. 18). Higher in this fining-upward cycle, greenish pebbly fossiliferous sands, diatomites and interbedded gray vitric tuff rest on the White River "bank" of the deep channel incision. These beds crop out also resting directly on the White River Group, 5 miles to the east of the type section (Fig. 18) where they are disconformably overlain by greenish pebbly medium sand containing the Big Spring Quarry discovered by Vaughn in 1941. A salient of the Chalk Bluffs escarpment lying immediately to the southeast of the latter site is held up by massive claystones of the White River that form a platform topped by a few feet of fossiliferous pebbly sands of the Pawnee Creek Formation. This site, Big Springs Prospect, is stratigraphically equivalent to the quarry. Cope found this locality on 22 July 1873, and collected from it. These localities are rich in fragmented horse and rhino remains and probably are the source of Cope's types of Pawnee Creek horse taxa based on isolated teeth or jaw fragments.

West of the Buttes, the edge of the Pawnee Creek paleovalley is exposed, and the lower 40 ft (12 m) contains a number of fossil concentrations (discovered by Ward, 1950-51) associated with light-gray vitric tuft similar to those of the type section (Fig. 18). In the Davis Ranch area (Fig. 18) there is a concentration of fossil material in the lower two cycles (the lower 70 ft, 21 m) although the associated ash beds are dark gray and blue-gray and not obviously correlative with those exposed in the more northerly part of the paleovalley fill. Nevertheless I am going to generalize the "Eubanks Local Fauna" to a "Eubanks Fauna" for discussion purposes. This is understood as the fauna of the oldest two cycles of the exposed valley fill until better means of local correlation can be effected. Above these levels the occurrence of fossils decreases until the fourth and higher cycles are reached. These-levels have such a limited areal distribution that they probably did not contribute significantly to the historic collections. The faunal list for the Eubanks Fauna in the sense used here would include the taxa indicated in Table 3. This fauna is of later early Barstovian age. It contains a number of taxa in common with the Lower Snake Creek Fauna of Nebraska (Matthew, 1924; Skinner et al., 1977), but is derived in the variety of equine horses, the appearance of *Aelurodon, Ustatochoerus* (with *Ticholeptus*) and *Cranioceras* (with *Dromomeryx*) heralding the composition of the early late Barstovian faunas at the beginning of that span of great diversity, the "late Miocene" chronofauna.

Proboscidea first appear in the Davis Ranch section at the top of the fourth fining-upward cycle, and then are well represented in the sixth or uppermost cycle in that sequence. Frick Laboratory parties under J. C. Blick in 1931-1 933 discovered and made extensive collections from the eventually conjoined Horse and Mastodon Quarries (Fig. 17 and 19). Falkenbach and Ward added extensions to these quarries. By the end of the 1933 season over 400 specimens had been obtained. I introduce here the term Keota Fauna for these upper levels. The name is taken from the old county road to Keota as it crosses the entire section exposed on the Davis Ranch not far west of the Horse and Mastodon Quarry. The Keota Fauna (Table 3) contains both gomphotheriid (*Gomphitherium* cf. *productum*, (including G. *proavus**, and *Rhyncotherium rectidens*) and mammutid (*Zygolophodon* sp. including "*Miomastodon*" *merriami*) mastodonts; *Ticholeptus* no longer occurs and *Ustatochoerus medius* is the only oreodont. *Cranioceras* and *Dromomeryx* continue their joint occurrence. The horse fauna remains diverse and includes most of the species of the Eubanks Fauna with the exception of *Desmatippus* and *Merychippus insignis*. This fauna is very early in the late Barstovian by virtue of the first appearance of Proboscidea only slightly lower in the section. The accompanying fauna shows the nature of the transition in the Great Plains from assemblages typical of the early to those of the late Barstovian.

Upper Ogallala beds. - These deposits yield scattered fossil mammal remains, usually large taxa, and fragmentary remains of smaller forms from the sandy lenses in the gravel sheet. Only a single concentration of remains has been found in a point bar within the axial facies at a site south of the Chalk Buttes escarpment (Figs. 16 and 18). This was discovered and worked by N. Z. Ward in 1951, and called the "Uhl Pit" after the landowner. The site produced partial skeletons of *Neohipparion coloradense* (MacFadden, 1984). Teeth of *Cormohipparion quinni* and *Protohippus* sp. a maxillary fragment of *Ursavus paniensis* and a palate of *Procamelus leptocolon.* Sand lenses in the associated gravels yielded *Cosoryx* horns as well. Other scattered sites (including "Quarry Hill" of Markman, worked in 1922, which yielded the holotype ramus of *Ursavus pawniensis*, Fig. 18) produced the holotype of *Teleoceras medicornutum* Osborn, 1904 (found by Loomis and Thomson 15 miles northeast of Grover during the 1902 exploration), and remains of Proboscidea, *Neohipparion coloradense, Ustatochoerus*, camels, *Cosoryx* and *Mylagaulus laevis*. This composite assemblage is best compared with the Kennesaw and Vim-Peez local faunas from the lower part of the referred Pawnee Creek Formation in Logan County (Galbreath 1953, p. 35). The strong similarities of the horse fauna are the most significant element in this comparison. The occurrence of *Neohipparion coloradense* is particularly noteworthy on account of the long controversy about the occurrence of the holotype at Sand Canyon in Logan County where it occurs with *Cormohipparion quinni, Calippus proplacidus, Pliohippus campestris, Gomphotherium, Procamelus leptocolon* and rhinos (Galbreath 1953, p. 35-6). Most of these elements are present in the Uhl Pit and other sites in the enclosing gravels in the Weld County area and this fauna is now seen as typical of an early phase of the later Barstovian "late Miocene" Chronofauna of the Great Plains. Its correlates in north central Nebraska would include the faunas of the Cornell Dam, Crookston Bridge and Devil's Gulch members of the Valentine Formation, and the Ogallala strata at the Hottell Ranch Quarry in nearby Banner County, southwestern Nebraska (Voorhies et al., 1987).

GEOCHRONOLOGY

The relatively thick and fine-grained sediments of the Pawnee Creek Formation and their contained ash beds appear to provide a favorable target for radioisotopic dating, ash chemical composition and magnetostratigraphic study. Preliminary work by Carl Swisher, Steve Barghoorn and the writer in 1988 gave promising results at the Pawnee Creek Formation type section and more successfully at the Davis Ranch section. As it may be some time before such studies are brought to satisfactory conclusions, I want to share the preliminary results to show their ultimate promise rather than their present inadequacy.

Radioisotopic dating. - Carl Swisher (Berkeley Geochronological Center) has kindly allowed publication of the two dates obtained from ash samples he collected at the Davis Ranch section. Out of five ash beds sampled only two had fresh glass that could be dated (Fig. 18). The oldest was the dark gray ash in the lowest fining-upward cycle: $^{40}Ar/^{39}Ar$, 14.5 + 0.09 Ma. The other successful determination was on a blue-gray ash, 25 ft (7.6 m) below the first occurrence of Proboscidea in the upper part of the third fining-upward cycle: K/Ar, 14.3 $\pm$ 0.02 Ma. Both of these dates are plausible for latest early and transitional early-late Barstovian faunas based on data elsewhere (Barstow Formation, MacFadden et al.; Woodburne et al. 1990; Tesuque Formation, Barghoorn, 1981).

Chemical Composition. - The chemical composition of vitric ash shards is usually unique and potentially traceable to source volcanic centers. Preliminary work by William Hart (Miami University) using Direct Current Argon Plasma Spectroscopy indicated that the two dated ashes have distinct chemistries that suggest they may be recognizable elsewhere in the

Pawnee Buttes area on the basis of their compositions. This is also a hopeful indication for other Pawnee Creek ashes. The trace element composition suggests comparison of the lowest ash with that from the upper part of the Olcott Formation (Mill Quarry Level, Skinner et al., 1977, p. 303) in agreement with the late early Barstovian nature of the fauna and age for that ash bed.

Magnetostratigraphy. - Steve Barghoorn took oriented samples from 21 sites in the Davis Ranch section and 11 in the Pawnee Creek type section with an average sampling interval of 10-15 ft (3.0 to 4.6 m). These single samples, when thermally cleaned at 400^0C did yield clear indications of polarity in about half the samples from each section. The data indicates a mixed polarity interval is being sampled in agreement with the isotopic dates. The available evidence from the Davis Ranch Section would fit the interval from Chron 5Brl through Chron 5ACr, or a span of about 1 my between 14 and 15 Ma. The type section represents a shorter interval also of mixed polarity, but a better means of correlation with the Davis Ranch Section is needed perhaps by using ash-bed chemistry.

CORRELATION

First in significance are the local correlations between outcrops around Pawnee Buttes in Weld County and those 25 miles to the east around Sand Canyon, and further to Martin Canyon in Logan County (Fig. 16). I have tried to show that there are clear lithic and paleontologic correlations of the Martin Canyon deposits of early Hemingfordian age between these localities. There are no transitional early to late Barstovian faunas in Logan County nor are there any deposits in Logan County that are like the tuffaceous Pawnee Creek Formation in the sense of its type section and local correlates in Weld County. This unit seems to be confined to a single, broad paleovalley. The referred "Pawnee Creek Formation" of Logan County can be correlated with the Upper Ogallala Group deposits that cap the Pawnee Creek in Weld County. These conclusions are the basis for Figure 17 which shows the historical development of knowledge of this region.

Looking further a field, the Barstovian successions in northwestern (Olcott Formation) and north-central (Valentine Formation) Nebraska have historically been reference successions for this span of time (Fig. 15). Matthew (1924, p. 71-72) specifically correlated the Lower Snake Creek Fauna (Olcott Formation) with the "Pawnee Creek beds" of his concept and believed that differences in faunal composition were the result of ecological and preservational contrasts between these sites. However, subsequent research has shown that there are derived elements in the Eubanks Fauna, both as members of Lower Snake Creek clades (e.g. *Hypohippus osborni vs. H. pertinax*) and as new genera, especially those that become important elements in the "late Miocene" chronofauna (viz. *Aelurodon, Calippus, Protohiopus, Megahippus, Ustatochoerus,* and *Cranioceras*) that suggest that the Eubanks Fauna is chronologically younger than the Lower Snake Creek. This view may be strengthened chemically if the correlation of the oldest Pawnee Creek ash (at Davis Ranch) with the youngest Olcott ash is verified.

A chronological cap can be placed on the Pawnee Creek Formation if our correlation of the upper Ogallala Group gravels across Weld and Logan counties is accepted. The fauna of these deposits (Uhl Pit in Weld County; Kennesaw, Vim-Peetz and Sand Canyon faunas in Logan County, Galbreath 1953), contains even more derived elements (asterisks denotes holotypes from Logan County): *Neohipparion coloradense**, *Cormohipparion quinni Pliohippus campestris**, *Calippus proplacidus**, *Tomarctus brevirostrus**, *Cynarctus saxatilus**, *Ceratogaulus rhinocerus**, *Mylagaulus laevis**, *Procamelus leptocolon**, and *Ramoceras osborni**. Most of these taxa were typified from the early collections of Cope and Matthew and not all have been identified in the Valentine Formation of north-central Nebraska, but the stage-in-evolution of this facies of the "late Miocene" chronofauna is clearly related to the faunas of the Crookston Bridge and Devil's Gulch members of that unit. Woodburne (1996, p. 11-12) specifically identifies a skull (PU 12291, formerly referred by Osborn 1918 to "M." *sphenodus*) from the vicinity of Sand Canyon with Cormohipparion quinni a taxon confined to the indicated interval in the Valentine Formation. Even the Norden Bridge Local Fauna at the base of the Valentine (Cornell Dam Member of Skinner and Johnson, 1984) is more derived than the Horse and Mastodon Quarry assemblage, although like the latter it contains some taxa whose clades are more typical of the early Barstovian (Voorhies, 1990). The Hurlbut Ash near the top of the Cornell Dam yielded an initial fission track age of 13.6+1.3 Ma (see discussion in Skinner and Johnson, 1984 'p. 252, 256), which has been confirmed (13.6±0.2) by a recent program of chemical characterization of High Plains ash beds by Michael Perkins (University of Utah).

Despite his simplified lithostratigraphy, it is quite clear from Galbreath's discussion and summary figure (1953, p. 36, fig. 10) that his ideas on the age and relationships of the faunal units he recognized are much the same as concluded here. These chronological data suggest that the faunas within the Pawnee Creek Formation exposed in the Pawnee Buttes area fit into the hiatus between the better known early and late (medial sensu Voorhies, 1990) Barstovian faunas of Nebraska. A similar conclusion could be made for the faunal succession described from sites in Horse Creek, Wyoming (Cassiliano, 1980) and at the Hottell Ranch sites in southwestern Nebraska (Voorhies et al. 1987) both of which exposed Gangplank not far from near the Pawnee Buttes (Fig. 15). All these assemblages record an earlier phase in the assembly of the taxa that become integral parts of the "late Miocene" chronofauna. Understanding of the ecological dynamics and faunal response to this major biotic event will be greatly assisted by further work in the Pawnee Buttes and adjacent areas.

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Table 3. Occurrence and Stratigraphic Distribution of Mammals from the Pawnee Creek Formation, Weld County, Colorado

Taxon	Eubanks Fauna	Keota Fauna
Castoridae:		
"*Monosaulax*" *curtus*	X	X
?*Hystricops* sp.	X	
Mylagaulidae:		
*Mesogaulus paniensis*** [1]	X	
Amphicyonidae		
*Amphicyon sinapius**	X	X
A. ingens	X	X
*A. reinheimeri**	X	
Canidae		
Microtomarctus conferta	X	X
*Tomarctus brevirostris***	X	X
Aelurodon asthenostylus	X	X
Carpocyon compressus		X
Leptocyon sp.	X	
Mustelidae:		
Mionictis sp.		X
Brachypsalis modicus	X	X
Leptarctus primus	X	
Mammutidae		
Zygolophodon sp.		X
Gomphotheriidae		
Gomphotherium cf. *productum*		X
Rhinoceratidae		
*Aphelops-megalodus***	X	X
Teleoceras medicornutum [2]	X	X
Tapiridae		
Tapiravus sp.	X	X
Equidae		
*Hypohippus osborni**	X	X
Megahippus cf. mckennai	X	X
*Desmatipus coloradensis**	X	
Merychippus insignis	X	
*M. sphenodus**	X	X
"*Merychippus*" sp.	X	X
*Protohippus proparvulus** [3]	X	
*P. eohipparion**	X	
*Calippus labrosus**	X	X
"*Pliohippus*" *sejunctus**	X	X
Cormohipparion paniense *		X
Tayassuidae		
"*Prosthennops*" *xiphidonticus* [4]		X
?*Dyseohyus* sp.		X

Table 3, Continued.

Taxon	Eubanks Fauna	Keota Fauna
Merycoidodontidae:		
Ticholeptus zygomaticus	X	X
Brachycrus sp.	X	
Ustatochoerus medius	X	X
Camelidae		
*Miolabis fissidens**	X	X
Nothotylopus sp.	X	X
Michenia n. sp.	X	X
Protolabis heterodontus **[6]	X	X
Aepycamelus giraffinus	X	X
Aepycamelus sp.	X	
Dromomerycidae		
*Dromomeryx pawniensis**	X	X
*Cranioceras (Procranioceras) pawniensis**[7]	X	X
Moschidae		
*Blastomeryx gemmifer***	X	X
Antilocapridae		
*Paracosoryx pawniensis**[8]	X	X
Cosoryx furcatus	X	X

*species holotype or ** genotypic species from Pawnee Creek Formation.

1) Cope collected the type from "Courthouse Butte." From his field notes of 1873, he distinguishes between the Pawnee Buttes and "Courthouse" and "Old Castle" buttes which are 2 miles south of a "running water camp" (probably Dolan Springs) northeast of the Pawnee Buttes. -These buttes, unnamed on modern maps, are located in sec. 2, T10N R59W, and expose White River Group rocks overlain by the Pawnee Creek Formation.

2) Includes "*Aphelops*" *planiceps** Osborn 1904.

3) Includes *Protohippus eoplacidus** Osborn 1918.

4) Following Wright (1998) includes *Dyseohyus stirtoni** Woodburne 1969.

5) Includes material referred to *Ustatochoerus? schrammi* by Schultz and Falkenbach 1940.

6) Includes *Protolabis angustidens** Cope 1874.

7) Includes *Bouromeryx pawniensis** Frick 1937.

8) Emnedation of *Meryceros (Submeryceros) minor pawniensis** Frick 1937.