An Early Miocene Dome-Skulled Chalicothere from the "Arikaree" Conglomerates of Darton: Calibrating the Ages of High Plains Paleovalleys Against Rocky Mountain Tectonism

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An Early Miocene Dome-Skulled Chalicothere from the ''Arikaree'' Conglomerates of Darton: Calibrating the Ages of High Plains Paleovalleys Against Rocky Mountain Tectonism

ROBERT M. HUNT, JR.[1]

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ABSTRACT

Fragmentary skeletal remains discovered in 1979 in southeastern Wyoming, associated with a mammalian fauna of early Hemingfordian age (~18.2 to 18.8 Ma), represent the oldest known occurrence of dome-skulled chalicotheres in North America. The chalicothere and accompanying fauna were found in silica-cemented fluvial sandstones and conglomerate capping a series of west-to-east trending buttes in Goshen County, Wyoming, extending eastward into Sioux County, Nebraska. These butte caprocks, herein named the Carpenter Ranch Formation, are the reversed topographic remnants of a major paleovalley incised in the early Miocene and filled with coarse granitic/mafic gravels and sands derived from Precambrian-cored upifts to the west. The Carpenter Ranch Formation is identified as a coarser-grained, westward extension of the early Hemingfordian Runningwater paleovalley of Skinner, Skinner, and Gooris (1977) situated in northwest Nebraska. The age-diagnostic mammal faunas and coarse crystalline gravels of the Carpenter Ranch Formation of Wyoming and the coeval Martin Canyon beds of northern Colorado document the timing of tectonic rejuvenation of Rocky Mountain uplifts to the west in the early Hemingfordian.

A second line of buttes situated 3 miles (~ 4.8 km) north of the Carpenter Ranch paleovalley includes the regional landmark recorded as ''Spoon Butte'' in 19th century military and topographic surveys of the region. Spoon Butte, its caprock in northwest-southeast alignment with adjacent satellite buttes, represents a second and younger mid-Miocene paleovalley trend, characterized by silica-cemented sandstones and basal granitic/chert gravel with Barstovian mammals.

N.H. Darton and G.I. Adams of the U.S. Geological Survey first described these caprocks as Arikaree conglomerates and mistakenly assumed they were of the same age as the caprock at Spoon Butte and its accompanying buttes to the north. However, this investigation shows that (a) mammal faunas from the two caprock trends are of markedly different ages; (b) the clast composition of the gravels is distinct; and (c) the paleovalleys align along two entirely different geographic trends.

Furthermore, a loose gravel found on top of Spoon Butte, previously believed to date the caprock, is identified as a lag deposit sharing the same distinctive clast composition as high Quaternary terrace gravels in the vicinity. These terrace gravels include acid volcanics (not present in the Carpenter Ranch and Spoon Butte basal gravels) and a composite assemblage of water-worn mammal bones of Barstovian, Clarendonian, and Pleistocene ages. Thus they demonstrate that late Cenozoic deposits once occupied the extensive tableland east of the Hartville Uplift, but were later removed by erosion and reworked into Pleistocene and Holocene drainages.

INTRODUCTION

Miocene chalicotheres are uncommon in North American faunas, yet when present are often preserved in riverine environments and waterholes. Chalicotheres apparently were water-dependent mammals, their teeth and skeleton indicating a browsing habit in well-vegetated settings. Bones of chalicotheres should resist damage and disintegration simply because of their large size, and so their scarcity in most Miocene faunas contributes to the belief that they were restricted in habitat and limited in numbers of individuals.

The Chalicotheriidae comprise two subfamilies, the Chalicotheriinae and the Schizotheriinae. The Chalicotheriinae are confined to the Old World, whereas the Schizotheriinae occur in both Eurasia and North America. North American schizotheriines are of early and mid-Miocene age, and are represented by two genera (Coombs, 1998, 2004), *Moropus* and *Tylocephalonyx*.

Dome-skulled chalicotheres were first described by Munthe and Coombs (1979), following the discovery of two North American skulls with dorsally inflated or ''domed'' crania. Coombs (1979) created the genus *Tylocephalonyx* for these mammals, based on dental, cranial, and postcranial remains from the western United States. Fossils attributed to the genus have been recorded from the late Hemingfordian of Nebraska, Wyoming, Colorado, Utah, and Oregon, and from the late Hemingfordian and early Barstovian of Montana.

During exploration of the Patrick Buttes in

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southeastern Wyoming by University of Nebraska paleontologists in 1979, chalicothere bones were discovered in indurated gravels and sandstones capping several of the buttes. Although much of this material was fragmentary, a mandible, a few postcranial elements, and a partial skull indicated the presence of a large chalicothere similar in size to the early Miocene schizotheriine *Moropus elatus*, so abundantly represented in the Agate waterhole bonebed in western Nebraska (Hunt, 1990). Recently, removal of coarse-grained sediment enclosing the partial skull revealed the expanded cranial architecture of a dome-skulled chalicothere. Associated with the skull at the site of collection were a mandible and partial femur, probably from the same individual, which are here attributed to the schizotheriine *Tylocephalonyx*. The Patrick Buttes chalicothere displays the largest cranial dome yet discovered, and it is presumed to belong to a male.

Fossil mammals associated with the chalicothere indicate an early Hemingfordian age; hence these remains represent the oldest record of a dome-skulled individual in North America. Additional fragmentary chalicothere limb elements were found in the caprock of adjacent buttes in the same fluvial sands and gravels as the dome and mandible and are provisionally attributed to *Tylocephalonyx*. The species is considered indeterminate pending discovery of more complete specimens.

Abbreviations

AMNH	Division of Paleontology, American Museum of Natural History, New York
CM	Division of Vertebrate Fossils, Carnegie Museum of Natural History, Pittsburgh
F:AM	Frick Collection, American Museum of Natural History, New York
FMNH	Field Museum of Natural History, Chicago
UNSM	University of Nebraska State Museum, Lincoln

GEOLOGIC SETTING

The Patrick Buttes are situated in northeastern Goshen County, Wyoming, extending ~5 mi eastward into Sioux County, Nebraska (fig. 1). They occupy an area ~14 mi west-east by 9 mi north-south. More than 20 sandstone-capped buttes are aligned along two trends, which represent the vestiges of two deeply incised Miocene paleovalleys in southeastern Wyoming. The buttes occur within the boundaries of the U.S. Geological Survey 30-minute Patrick Quadrangle (104° to 104°30′W, 42° to 42°30′N), first topographically mapped in 1895 and named for the Patrick Post Office on Rawhide Creek, Goshen County, Wyoming (Adams, 1902: pl. 3). Rising dramatically from the surrounding plains, the buttes were first mentioned in early military surveys (Warren, 1857, 1875) and also noted during the initial geological reconnaissance studies of western Nebraska and southeastern Wyoming by the U.S. Geological Survey (Darton, 1899; Adams, 1902). They were visited briefly by paleontologists exploring in the region (Peterson 1907, 1909; Osborn, 1909), but apparently they failed to yield noteworthy fossils.

The buttes are capped by indurated Miocene fluvial sandstone and granitic gravel, commonly silica-cemented, with occasional lenses of soft interbedded silty to clayey sandstones lacking intergranular cement. The fluvial deposits deeply incise tuffaceous sandstones and siltstones of the Arikaree and White River Groups that form the lower slopes of the buttes.

The age of the capping sandstones remained enigmatic until 1977–1980, when a geological survey of the buttes was undertaken by University of Nebraska paleontologists. Prior to this, Adams (1902) had mapped the butte caprocks as basal Arikaree conglomerate (implicitly late Oligocene); Love et al. (1980) assigned them to the upper Miocene; and others have considered their age uncertain (Rapp et al., 1957; Denson, 1974). We were encouraged when an initial geological reconnaissance in 1977–1978 produced a few fossil mammals indicating a Miocene age. Summer field seasons in the buttes in 1979 and 1980 resulted in the discovery of fossil mammals from nearly all butte caprocks and demonstrated that the capping sandstones were of two different ages, early Miocene and medial Miocene.

Sedimentary structures, geometry of sand and gravel bodies, and paleochannel cut-and-fill features indicate that the capping sand-

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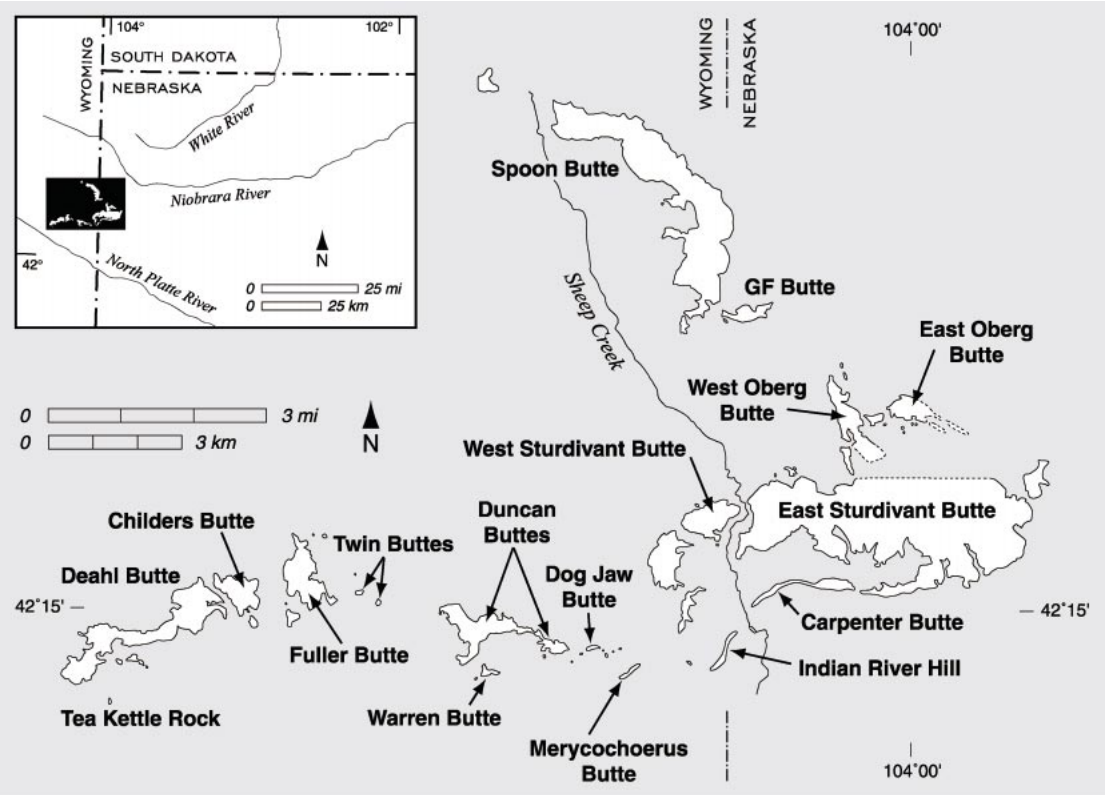

Fig. 1. Geographic map of the Patrick Buttes, Wyoming-Nebraska. The areal extent of each butte is indicated by solid and/or dashed lines marking the limits of the butte caprocks, formed by silica-cemented sandstone. Names for individual buttes are derived from historical usage, local practice, and UNSM field terms.

stones and gravels are fluvial in origin. Two major fluvial systems can be distinguished by gravel content, linear channel trend, paleocurrent data, and contained fossil mammals (fig. 2). A northern butte line (including Spoon Butte, a regional landmark 3.5 mi in length and up to 1 mi in width) of medial Miocene age is dated by a Barstovian fauna of mesodont equids (*Merychippus* s.l., *Protohippus*, *Desmatippus*), tapir, rhinoceros, gomphothere proboscidean, dromomerycid and merycodont artiodactyls, camels, peccary, and canid and amphicyonid carnivores. The southern butte line of early Miocene age yielded an early Hemingfordian fauna that included the dromomerycid *Aletomeryx*, moschid *Pseudoblastomeryx*, oreodonts *Merycochoerus* and *Merychyus*, canid *Phlaocyon*, amphicyonid *Daphoenodon*, the camels *Protolabis* and *Michenia*, a large entelodont, a rhinoceros, and the chalicothere *Tylocephalonyx*.

The linear courses of the northern and southern butte lines are evident in satellite photo imagery as axial paleovalleys trending eastward from the Rocky Mountain uplifts onto the plains. The northern butte line is aligned from northwest to southeast; the southern butte line trends west to east, turning to the northeast at its eastern terminus. Topographic mapping of the base of the fluvial deposits of the southern buttes indicates an eastward decrease in elevation of about 17 ft/mi; the northern butte line is similar. At several localities, paleovalley geometry is observable in cross-section and/or plan view, revealing steep lateral margins and sinuous trends (fig. 3). Maximum observed depth of incision in the northern buttes occurs where a paleochannel cuts 140 ft into Arikaree

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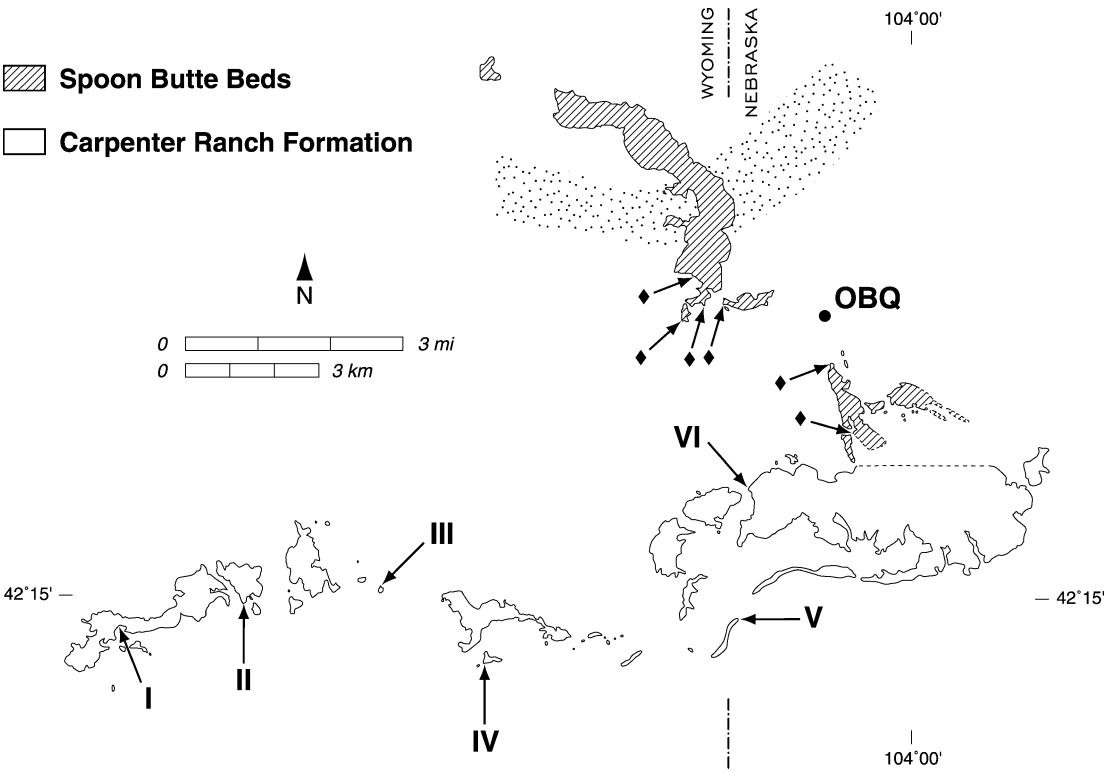

Fig. 2. Geology of the capping sandstones and gravels of the Patrick Buttes. Cross-hatching indicates buttes of the northern trend capped by the Barstovian Spoon Butte Beds; an open pattern indicates buttes of the southern trend capped by the early Hemingfordian Carpenter Ranch Formation. Gravels of the Carpenter Ranch Formation (table 1) were sampled at sites marked I through VI; gravels from localities marked by black diamonds were combined to form the composite Spoon Butte Beds sample. Site OBQ marks the acid volcanic-bearing terrace gravel of the Oberg Quarries. A stippled pattern shows the reconstructed areal extent of the Lay Ranch Beds, an early Miocene paleovalley fill containing latest Arikareean mammals.

rocks. Maximum observed incision of the southern paleovalley in outcrop is ~100 ft, but true topographic relief could have been as much as 350 ft if paleovalley incision is measured from the highest topographic elevation of Arikaree rocks in the vicinity. Maximum thickness of the capping sandstones ranges from 100 to 140 ft; however, average thickness for both butte lines is ~30 to 40 ft.

Pebble gravel from the northern and southern buttes was sampled with −3ø and −4ø sieves (U.S. Standard, W.S. Tyler Co.). Lithologically distinctive gravel fractions characterized each fluvial system (table 1). The southern buttes are distinguished compositionally by a granitic/mafic gravel with rare anorthosite and chert clasts—these gravels are devoid of acid volcanics (rhyolite, dacite). The northern buttes generally lack pebble (or coarser) gravel; their caprocks are chiefly an indurated cross-bedded sandstone, but within the base of the caprock unit are rare pebbles of pink orthoclase granite and a distinctive yellow-brown chert, either floating in sandstone matrix, or as clasts within a matrix-supported basal conglomerate of rounded Tertiary sandstone blocks up to several feet in diameter. Pink orthoclase granite and yellow-brown chert can be traced westward to the granites and Paleozoic limestones of the Hartville Uplift 30 mi to the northwest, indicating the provenance of the basal gravel of the northern buttes. The source of the gravels of the southern butte line are likely

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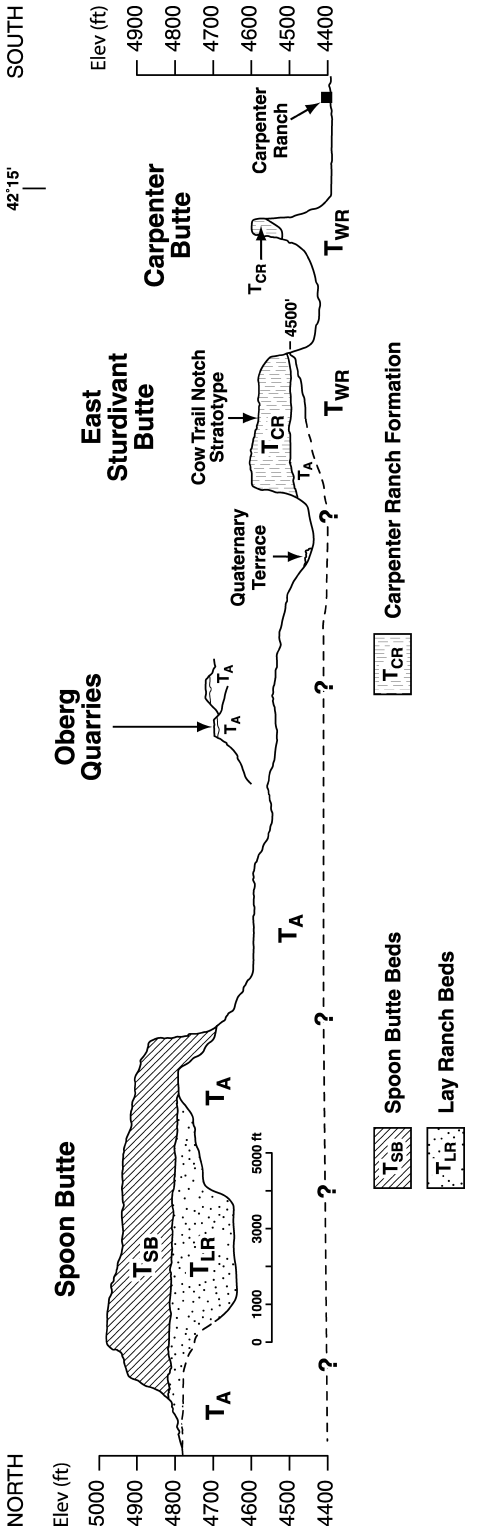

derived from the Laramie Mountains, either as primary clasts or reworked from older fluvial gravels.

Over 15 geographically isolated buttes comprise the southern butte line, extending from Tea Kettle Rock on the west, through Sturdivant Gap, to East Sturdivant Butte on the east (figs. 1, 2), a distance of ~15 miles. The lithologic composition of the capping sandstones and gravels and the manner of occurrence of the fossils are alike on all buttes of the southern trend. The caprocks are fine- to coarse-, but chiefly medium-grained, silica-cemented feldspathic sandstone (table 2: a subarkose to arkose, with 24–27% feldspar content) and pebble gravel, the gravel scattered throughout in lenses and stringers. Although silica-cemented sandstone and gravel is the dominant lithology, occasional lenses of fine-grained, beige- or cream-colored, uncemented silty sand occur at various levels within these caprocks and have yielded age-diagnostic fossils like those of the more indurated beds.

Fossils occur as isolated specimens on all southern buttes, and they are usually more complete than those from the northern butte line. Bones are often well preserved with little evidence of reworking: a large femur at one locality had been broken during scavenging, yet the angular pieces remained unabraded and in close association in the cap-

←

Fig. 3. Geologic cross-section from Spoon Butte to East Sturdivant Butte and Carpenter Butte (north-south profile, vertical exaggeration, X10). Barstovian silica-cemented sandstone ($\mathbf{T_{SB}}$) caps Spoon Butte and incises latest Arikareean sediments ($\mathbf{T_{LR}}$) of the Lay Ranch paleovalley. The caprocks of East Sturdivant Butte and Carpenter Butte preserve a transverse profile of the Carpenter Ranch paleovalley where sandstones and gravel of the early Hemingfordian Carpenter Ranch Formation ($\mathbf{T_{CR}}$) represent the stratotype at Cow Trail Notch. Acid volcanic-bearing gravels distinguish Holocene terraces of the modern drainage system that have been reworked from high terrace gravels (~4700 ft, Oberg Quarries, east of cross-section) yielding mid- and late Miocene mammals and rare Pleistocene fossils. $\mathbf{T_A}$, Arikaree Group undifferentiated; $\mathbf{T_{WR}}$, White River Group.

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TABLE 1

Pebble Composition (in %) of Crystalline Gravels of Carpenter Ranch and Runningwater Formations, Spoon Butte Beds of O.A. Peterson, and Oberg Quaternary Terrace Gravel, Goshen County, Wyoming, and Sioux County, Nebraska

Sample no.	Gravel size (ø)	Granitic	Mafic	Gneiss	Chert	Acid volcanic	Other	Total pebbles
Carpenter Ranch Formation								
I	−3 to −4	85.0	13.6	1.4	0	0	0	421
II		42.1	57.9	0	0	0	0	152
III		83.0	16.4	0.6	0	0	0	477
IV		51.1	47.0	1.0	0.6	0	0.3	313
V		58.1	40.3	0.4	0.6	0	0.6	479
VI		67.1	31.9	1.0	0	0	0	417
I	>−4	95.6	3.3	0.8	0	0	0.3	359
II		83.9	15.8	0	0	0	0.3	291
III		97.0	1.3	0.4	0	0	1.3[a]	232
IV		59.1	36.4	0	2.7	0	1.8	110
V		64.1	33.1	2.1	0.7	0	0	145
VI		80.8	16.0	3.2	0	0	0	94
Runningwater Formation (USGS Benchmark J58 locality, Sioux County, Nebraska)								
	−3 to −4	94.6	5.4	0	0	0	0	1617
	>−4	99.5	0.5	0	0	0	0	202
Runningwater Formation (average for 33 localities, northwestern Nebraska, Yatkola, 1978, table 2)								
	−2 to −3.5	88.4	10.6	0.4	0.6	0	0	6584
Spoon Butte Beds (composite sample from Spoon Butte, GF Butte, and West Oberg Butte)								
	−3 to −6	91.6	1.2	0	6.0[b]	0	1.2	491
Oberg Ranch gravel (S1/2, SE1/4, SW1/4, sec. 18, T27N, R57W, Sioux County, Nebraska)								
OBQ	−3 to −4	65.3	8.8	0	12.5	9.9	3.5	375
	>−4	69.3	5.5	0	11.0	7.9	6.3	127

Note: Mafic clasts in Carpenter Ranch gravel are amphibolite (metabasalt, metagabbro).

[a]Includes graphic granite.

[b]All chert is a mottled yellow-brown variety from limestones in the Hartville Uplift.

rock, indicating a synchronous burial undisturbed by later cut-and-fill. Yet only three localities in the southern buttes have provided most of the age-diagnostic mammals (fig. 4). No record of fossils from these buttes had been published prior to the UNSM study. However, in September 1968, M.F. Skinner of the American Museum (New York) found a castorid mandible (F:AM 42983) in a talus block, presumably from the caprock at Merycochoerus Butte, the first fossil mammal recorded from the southern buttes.

It was believed at first (Adams, 1902; Darton, 1899) that the sandstones capping both the northern and southern buttes might be part of a single fluvial system that simply migrated laterally as it filled its valley. The topographically low capping sandstones of the southern buttes supposedly represented the initial filling of the valley, and the higher caprock of the northern buttes marked the terminal phase of aggradation (fig. 5). Fossil mammals discovered by us, however, prove that this cannot be the correct interpretation: deposition of the northern and southern caprock sandstones was separated by at least 3 million years. The markedly different clast content of the gravels, the temporally distinct mammal faunas, and the divergent linear trends of the northern and southern paleovalleys demonstrate the existence of two discrete Miocene fluvial systems. In the eastern part of the study area, the northern and southern butte lines converge, and here where they

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TABLE 2

Petrography (in %) of the Indurated Sandstone Caprocks of the Southern and Northern Patrick Buttes, Goshen County, Wyoming, and Sioux County, Nebraska

Sample	Monocrystalline			Polycrystalline						
no.	Qtz	K-spar	Plag	Qtz+Plag	K-spar+Plag	K-spar+Qtz	Chert	Other	Percent	Grains
Carpenter Ranch Formation (southern buttes)										
CR-1	60.0	12.5	15.0	—	1.2	1.2	6.3	3.8	100.0	80
CR-2	62.9	14.3	10.0	1.4	—	—	11.4	—	100.0	70
Spoon Butte Beds (northern buttes)										
SB-3	70.5	12.4	7.7	0.9	0.9	3.8	3.8	—	100.0	105
SB-4	53.7	13.7	16.8	—	1.1	3.1	10.5	1.1	100.0	95

Notes:

1. If intergranular cement and clay matrix are included in the grain counts, then: Sample CR-1 includes 3.4% clay matrix and no silica cement; CR-2 includes 12.7% clay matrix and 29.4% silica cement; SB-3 includes no clay matrix and 34.0% silica cement; SB-4 includes 5.8% clay matrix and 17.5% silica cement. There is no calcareous cement in these sandstones.

2. CR-1 is a semiconsolidated medium-to-coarse cross-stratified sandstone, somewhat poorly sorted, grains well-rounded, that yielded a juvenile *Merychyus* mandible (UNSM 6115-79), from the east end of Merycochoerus Butte. CR-2 is a well-indurated fine-to-medium-grained silica-cemented sandstone, moderately well-sorted, grains rounded, that contained a distal femur (UNSM 44807) of *Tylocephalonyx* from Childers Butte. SB-3 is an extremely well-indurated fine-to-medium-grained silica-cemented sandstone, well-sorted, grains well-rounded, that yielded a partial molar of a small gomphothere proboscidean from the southeastern corner of Spoon Butte. SB-4 is semi-consolidated fine-to-medium-grained sandstone, moderately sorted, grains well-rounded, from the southwestern corner of Spoon Butte.

are in closest proximity, the incised bases of the two paleovalleys are ~200 ft apart in elevation.

The capping sandstones and gravels of the southern butte line have not been formally named. An informal term, Carpenter Ranch beds, was applied to these rocks at the conclusion of our initial survey (Hunt, 1985a). Because of their mappability, distinguished by a uniform and distinctive lithology (with emphasis on the characteristic gravel composition), and the geographically well-circumscribed outcrops, identified and mapped in their entirety in the region (fig. 2), the Carpenter Ranch beds merit formation-rank designation as a formal lithostratigraphic unit. This rock unit is herein designated the *Carpenter Ranch Formation,* from the location of important and accessible fossiliferous exposures in the Carpenter Ranch 7.5-minute quadrangle (secs. 7–10, T26N, R60W) in proximity to the headquarters of the Carpenter Ranch (NE1/4, SE1/4, NW1/4, sec. 12, T26N, R58W) at the southern entrance to historic Sturdivant Gap. The exposures in Sturdivant Gap (fig. 6A,B) can be considered the type area of the formation (W1/2, sec. 36, T27N, R58W, extending southwest into the extreme southeast corner of sec. 34, T27N, R60W, Spoon Butte 7.5-minute quadrangle, 1990); the measured section at Cow Trail Notch (figs. 6A, 7) is designated the stratotype. The gap is situated astride the Wyoming-Nebraska state boundary where it is traversed by Sheep Creek, a small spring-fed stream. Outcrops in and adjacent to the gap are readily accessible by a maintained gravel road. Early Hemingfordian mammals have been collected from the stratotype section at the Cow Trail Notch promontory (fig. 7).

The early Hemingfordian mammal fauna of the Carpenter Ranch Formation is most similar to fossil mammals from the lower part of the Runningwater Formation (Northeast of Agate local fauna, MacFadden and Hunt, 1998). The Northeast of Agate local fauna comes from Runningwater strata ~20 mi northeast of the eastern terminus of the Carpenter Ranch paleovalley. The Carpenter Ranch mammals are also similar to species from Runningwater Quarry, which is stratigraphically low in the Runningwater Formation and contains one of the oldest of the Runningwater fossil assemblages. The prox-

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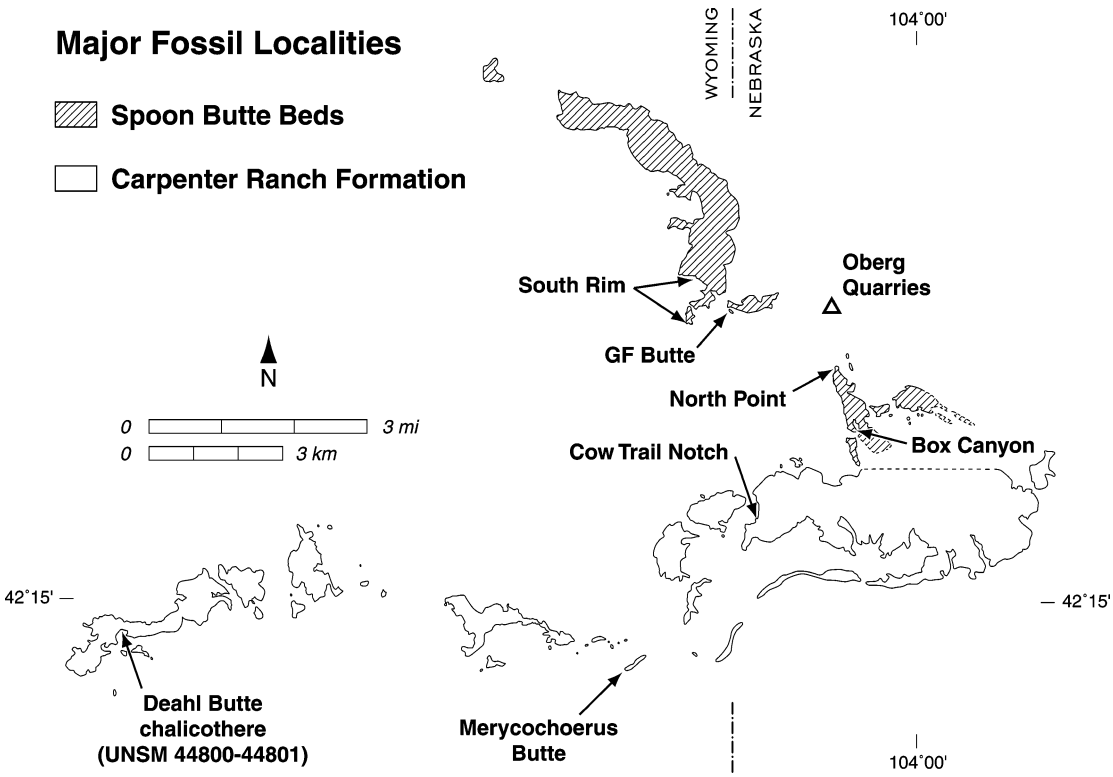

Fig. 4. Principal fossil mammal localities (indicated by arrows) in the capping sandstones of the Patrick Buttes. Cow Trail Notch at East Sturdivant Butte and sites at Merycochoerus Butte have yielded most of the age-diagnostic specimens in the early Hemingfordian Carpenter Ranch Formation. Deahl Butte produced the partial dome and mandible of the chalicothere (UNSM 44800, 44801). Barstovian sites in the Spoon Butte Beds include South Rim, GF Butte, North Point and Box Canyon. The Oberg Quarries are gravel pits containing waterworn mid- and late Miocene mammals and Pleistocene *Equus*.

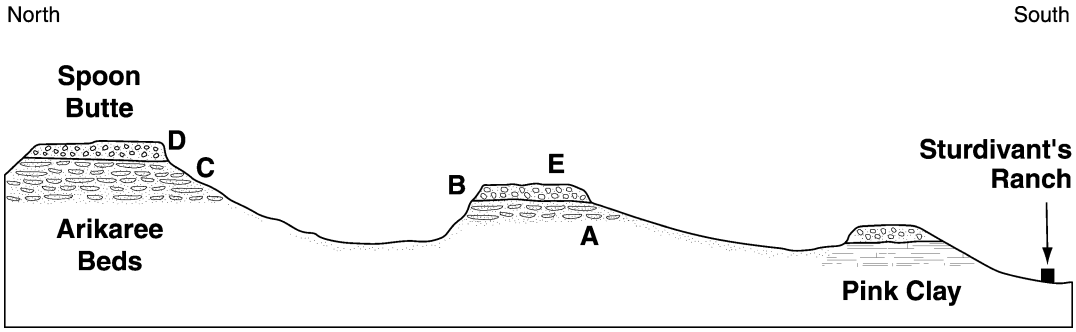

Fig. 5. Redrafted version of N.H. Darton's cross-section (1899: fig. 213) from Spoon Butte to Sturdivant's Ranch, showing the silica-cemented sandstone caprocks descending in elevation to the south. Darton regarded all the caprocks as ''Arikaree'' conglomerates, ''consisting in large part of crystalline rocks and apparently lying on a steeply sloping surface''. The letters A-E were not explained in his caption. Note correspondence to figure 3.

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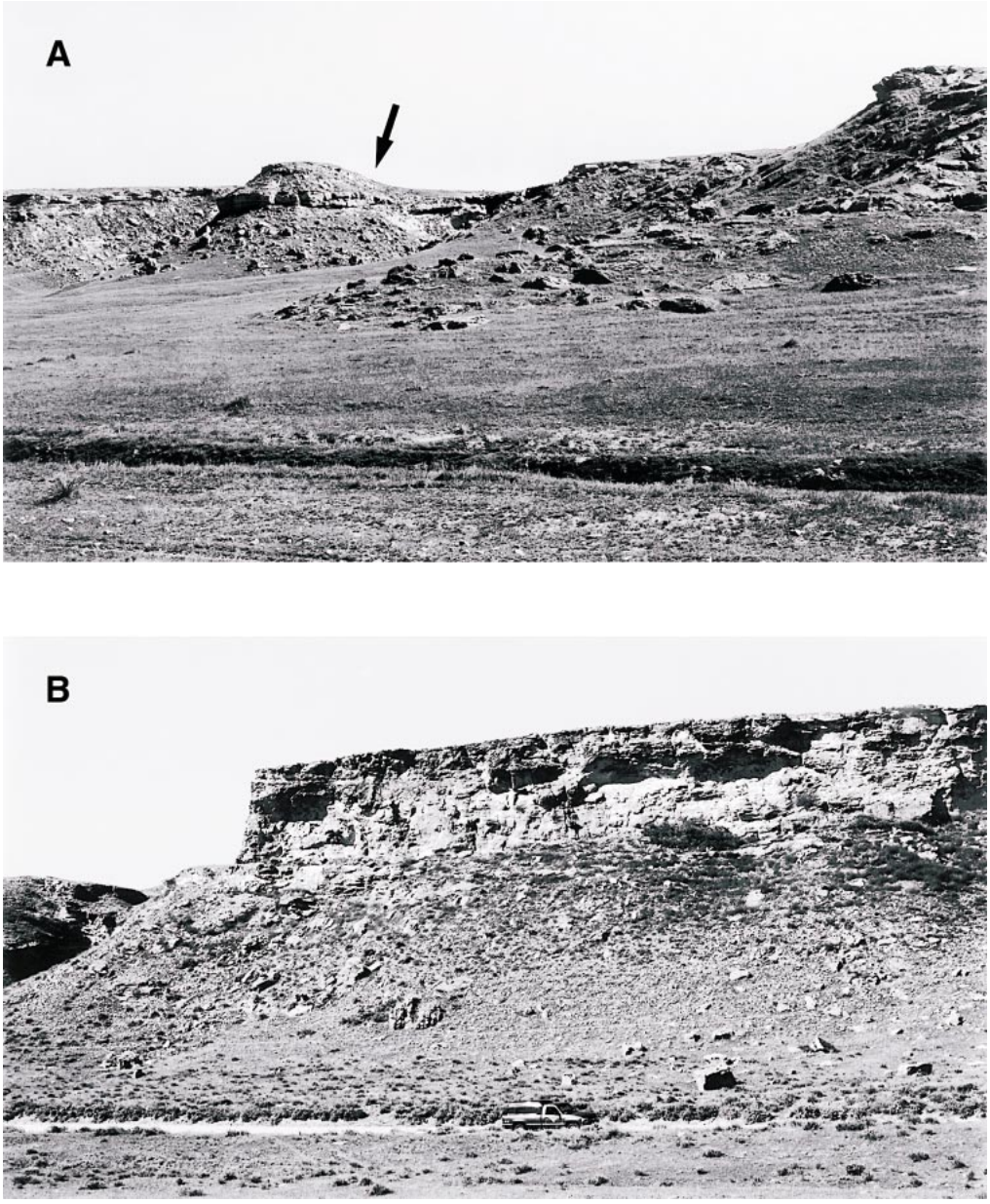

Fig. 6. Type area of the Carpenter Ranch Formation, early Miocene, Wyoming-Nebraska: (**A**) Cow Trail Notch stratotype section (at arrow) in NW1/4, SW1/4, NE1/4, SW1/4, sec. 36, T27N, R58W, Sioux County, Nebraska, looking northeast toward the west escarpment of East Sturdivant Butte within Sturdivant Gap. The Cow Trail Notch fauna was collected entirely from the promontory where the section was measured. The high surface of East Sturdivant Butte is mantled by a thin lag deposit of Oberg gravel not to be confused with the indurated Carpenter Ranch Formation gravel in the type section and contiguous outcrops in the gap. Sheep Creek runs in the foreground. (**B**) East escarpment of West Sturdivant Butte in Sturdivant Gap, looking west, immediately opposite figure 6A, showing the cliff-forming Carpenter Ranch Formation caprock overlying fine-grained Arikaree and White River strata. Truck on access road through the gap is situated at the Wyoming-Nebraska state boundary.

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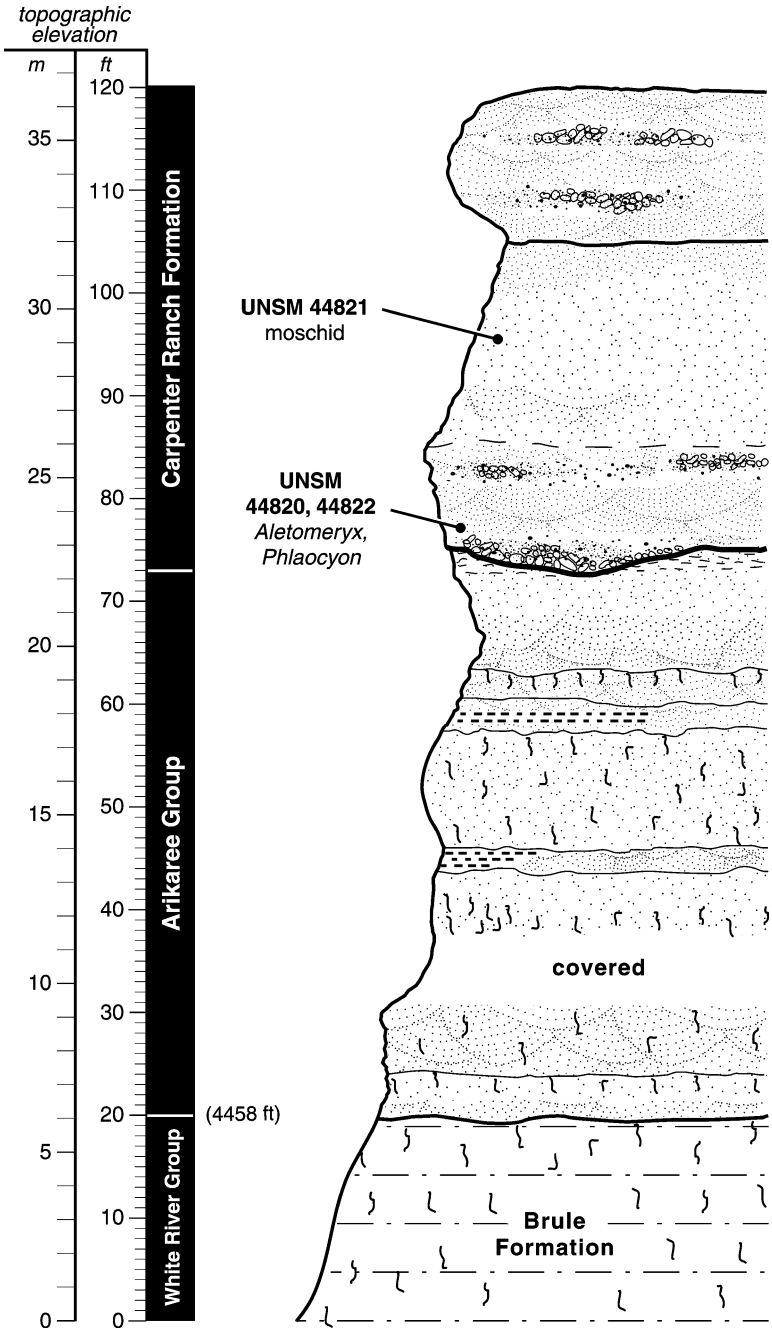

Fig. 7. Stratotype section of the Carpenter Ranch Formation (fig. 6A), west escarpment of East Sturdivant Butte, Sioux County, Nebraska, which includes the Cow Trail Notch local fauna. Early Hemingfordian mammals of the Cow Trail Notch local fauna include the dromomerycid *Aletomeryx*, moschid *Pseudoblastomeryx*, and canid *Phlaocyon*. Lithic symbols as in fig. 9.

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imity of the Runningwater and Carpenter Ranch paleovalleys and their similarly aligned west-southwest to east-northeast trend suggest that the Runningwater paleovalley is the northeastward continuation of the Carpenter Ranch trend. This conclusion is supported by the gravel composition of the two formations, characterized by a granitic/mafic gravel with rare anorthosite clasts and an absence of acid volcanic rock fragments (table 1).

Massive pink tuffaceous mudstones of the White River Group exposed at the base of the buttes of the southern line yield Oligocene mammals typical of the Brule Formation (fig. 8). The Carpenter Ranch fluvial system deeply incised these White River deposits, in the process removing almost all strata of the Arikaree Group, but at some buttes remnants of gray Arikaree sandstones intervene (fig. 7). At some localities the surface of the White River Group is a deeply weathered carbonate-impregnated paleosol. All White River fossils found by our field party come from outcrops at Dog Jaw Butte and Merycochoerus Butte in sections 8–9, T26N, R60W. Arikaree outcrops exposed along the southern butte line are nearly barren of fossil mammals.

SYSTEMATIC PALEONTOLOGY

ORDER PERISSODACTYLA

FAMILY CHALICOTHERIIDAE GILL, 1872

SUBFAMILY SCHIZOTHERIINAE HOLLAND AND PETERSON, 1914

Tylocephalonyx Coombs, 1979

TYPE SPECIES: *Tylocephalonyx skinneri* Coombs, 1979: 10.

INCLUDED SPECIES: The type species only.

KNOWN DISTRIBUTION: Early Hemingfordian to early Barstovian of western North America.

DIAGNOSIS: As given in Coombs (1979: 7).

REMARKS: This report extends the temporal range of the genus reported by Coombs (1979) to include the early Hemingfordian chalicothere hypodigm from the Carpenter Ranch Formation, Goshen County, Wyoming. Material listed below generally conforms in anatomical detail to the descriptions given by Coombs (1979), but the species is considered indeterminate due to the fragmentary nature of much of the skeleton.

REFERRED MATERIAL: Included in this indeterminate species from the Carpenter Ranch Formation are a right mandible with m2–3, a partial cranial dome, and the diaphysis of the left femur, all found together at the same stratigraphic level within a 2-m interval (fig. 9); also a proximal right ulna; a distal metapodial; a proximal left metacarpal 4 and the dorsal process of an ungual phalanx; a distal right femur (the first evidence of this chalicothere found in the caprock sandstones of the southern buttes); a distal left femur in two parts (scavenged by an entelodont) found within 5 m of a proximal left humerus at the same stratigraphic level; a distal right tibia; a glenoid-bearing fragment of the scapula; and a fragment of the ectoloph of a right M3.

Localities and dates of collection of these elements are listed in table 3.

HORIZON AND AGE: All referred material is from the early Hemingfordian Carpenter Ranch Formation, Goshen County, Wyoming. The associated mandible (UNSM 44800), cranial dome (UNSM 44801), and partial femur (UNSM 44802) were found in place in a fluvial lens of sand and gravel exposed in a south-facing cliff at the western end of Deahl Butte (fig. 9). Here a channel of the Carpenter Ranch paleovalley had incised, and mostly removed, the gray Arikaree sands, cutting to the level of the local paleosurface of the White River beds at the chalicothere locality. The dome, mandible, and femur were found within a single gravel lens at the same stratigraphic level, situated ~25 ft (7.6 m) above the base of the channel.

DESCRIPTIVE OSTEOLOGY

MANDIBLE AND DENTITION: The mandible (UNSM 44800) preserves ~24 cm of the horizontal ramus from the angle forward to below m1 (figs. 10, 11). Height of the mandible below the center of m3 is 67.6 mm, and below the center of m2 is 60.6 mm. Greatest mandibular width below m3 is 37.4 mm. The horizontal ramus appears to rapidly diminish in height from m3 forward, suggesting that the length of the premolar row was somewhat reduced.

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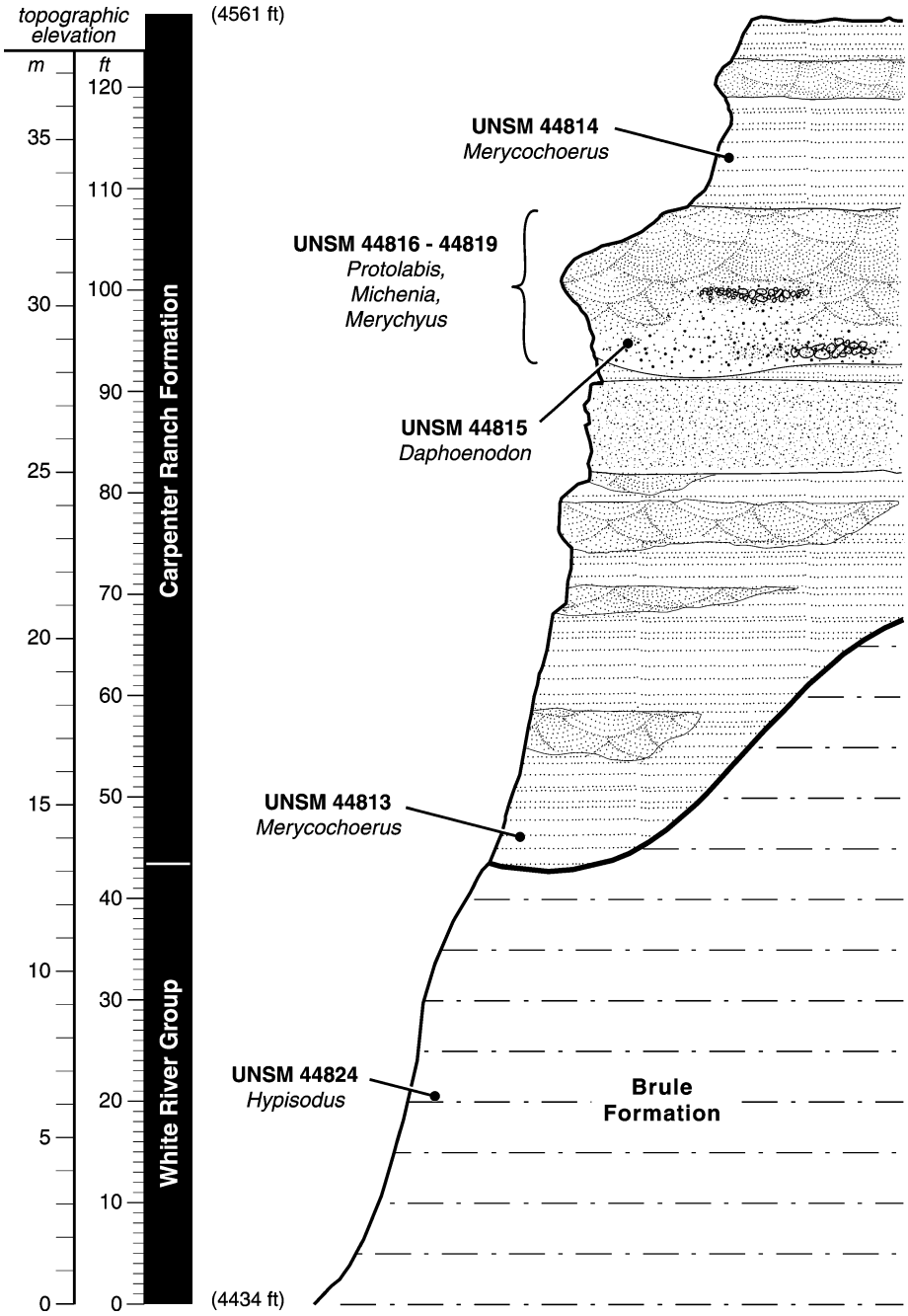

Fig. 8. Measured reference section of the Carpenter Ranch Formation at Merycochoerus Butte, Goshen County, Wyoming. The large oreodont *Merycochoerus magnus* was found at both low and high stratigraphic levels in Carpenter Ranch sediments filling a deeply incised early Hemingfordian paleovalley cut into the Brule Formation. Lithic symbols as in fig. 9.

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TABLE 3

Referred Material of the Dome-Skulled Chalicothere *Tylocephalonyx* from the Carpenter Ranch Formation, Goshen County, Wyoming

UNSM no.	Field no.	Element	Locality and date of collection
44800	6084-79	Right mandible with m2-3	Deahl Butte, west end, 2 m west of cranial dome, in place, 8-1-79
44801	6085-79	Cranial dome, partial	Deahl Butte, west end, 2 m east of mandible, in place, 8-1-79
44802	6083-79	Diaphysis of left femur	Deahl Butte, west end, 2 m east of mandible adjacent to dome, in place, 8-1-79
44803	6086-79	Distal metapodial	Deahl Butte, west end, in talus of Carpenter Ranch Fm. but above base of unit, 8-2-79
44804	6087-79	Proximal left metacarpal 4	Small satellite butte south of Deahl Butte, in talus of Carpenter Ranch Fm. but above base of unit, 8-2-79
44805	6087-79	Dorsal process of ungual phalanx	As for UNSM 44804
44806	6089B,C-79	Left femur in 2 parts: 6089B, diaphysis 6089C, distal end	Childers Butte, south point, in place, 8-3-79
44807	none	Right distal femur	Childers Butte,11-6-77 in place
44808	403-79	Left partial ectoloph of M3	West Sturdivant Gap Butte, 6-27-79
44809	407A-79	Right distal tibia	Duncan Buttes, in place, 7-12-79
44810	412-79	Right proximal ulna	Duncan Buttes, in place, 7-13-79
44811	408-79	Partial glenoid of scapula	Duncan Buttes, in talus block of Carpenter Ranch Fm.,7-12-79
44812	6089A-79	Left proximal humerus	Childers Butte, south point, in place, 8-3-79

Locality Data

UNSM 44800-44803	SE1/4, NW1/4, sec. 8, T26N, R61W, Tea Kettle Rock Quadrangle (1963)
UNSM 44804-44805	N1/2, NW1/4, SE1/4, sec. 8, T26N, R61W, Tea Kettle Rock Quadrangle (1963)
UNSM 44806, 44812	SW1/4, SW1/4, SW1/4, sec. 3, T26N, R61W, Tea Kettle Rock Quadrangle (1963)
UNSM 44807	NE1/4, SE1/4, SE1/4, sec. 4, T26N, R61W, Spoon Butte SW Wyoming Quadrangle (1974)
UNSM 44808	N1/2, SE1/4, SW1/4, SE1/4, sec. 34, T27N, R60W, Spoon Butte Wyoming-Nebraska Quadrangle (1990): section 34 is emarginated on its eastern border by the Wyoming-Nebraska state line so that the eastern portion of section 34 is absent.
UNSM 44809	N1/2, SE1/4, SE1/4, NW1/4, sec. 8, T26N, R60W, Carpenter Ranch Wyoming-Nebraska Quadrangle (1963)
UNSM 44810	NW1/4, SW1/4, SE1/4, NW1/4, sec. 8, T26N, R60W, Carpenter Ranch Wyoming-Nebraska Quadrangle (1963)
UNSM 44811	S1/2, SW1/4, SE1/4, NW1/4, sec. 8, T26N, R60W, Carpenter Ranch Wyoming-Nebraska Quadrangle (1963)

The m2–3 are larger and more robust than these molars in *Moropus elatus*, including those of large males. Maximum antero-posterior length of m3 is 55.5 mm and of m2 is 52.1 mm. Greatest width of the m3 trigonid is 29.1 mm and of the m3 talonid, 27.9 mm. The combined length of m2–3 is 108.8 mm. The m2 is moderately worn, the m3 fully erupted and essentially unworn. The crown of m3 is intact and shows an anterior lophid with a low yet distinct small paraconid, a higher protoconid, and an even taller metaconid, which is the tallest cusp. The metaconid and metastylid are distinctly separated cusps. The metastylid is the tallest cusp of the posterior lophid, whereas the somewhat

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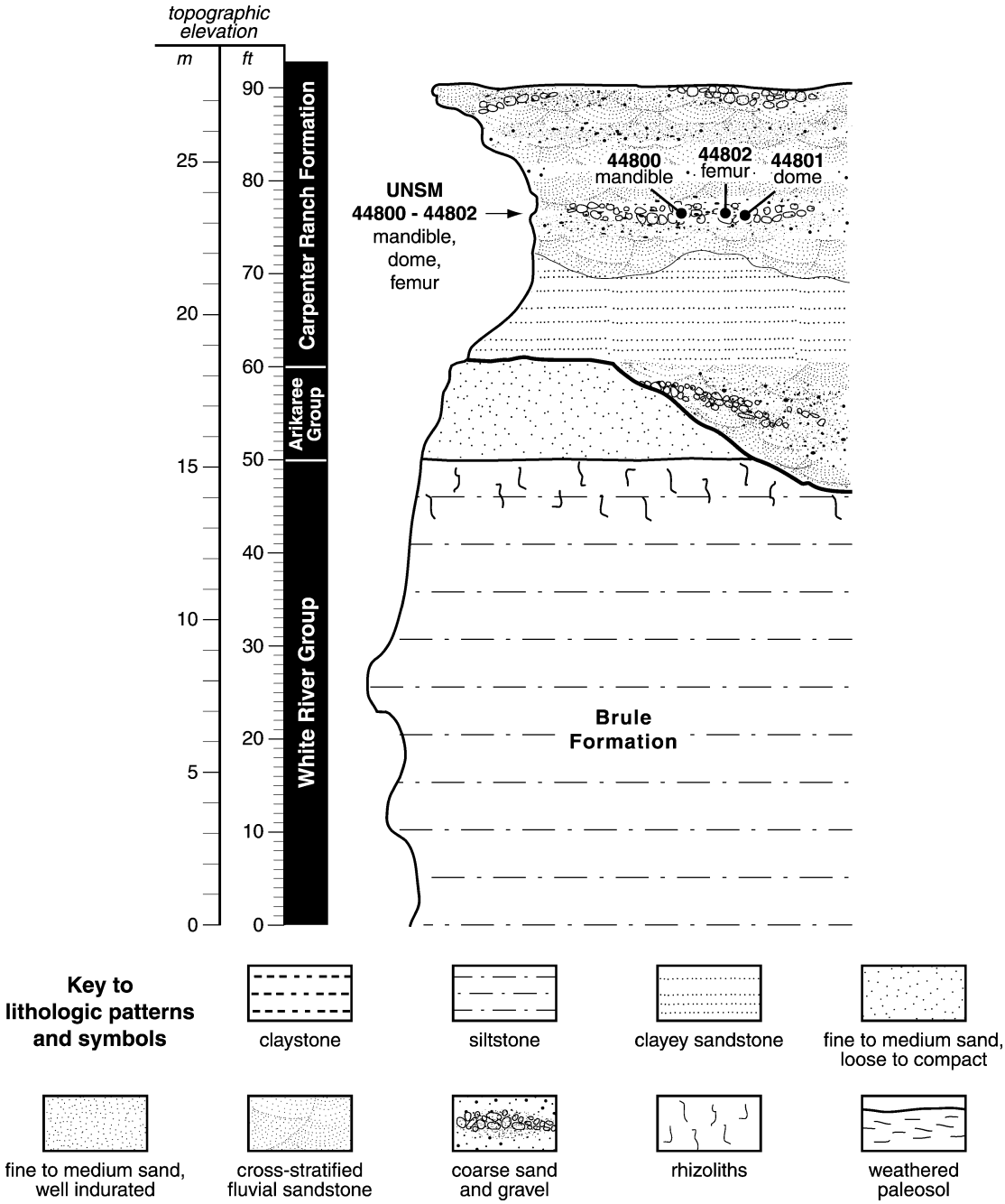

Fig. 9. Measured section of the Carpenter Ranch Formation at Deahl Butte at the locality yielding the partial cranial dome (UNSM 44801) and mandible (UNSM 44800) of the chalicothere *Tylocephalonyx* (table 3). The dome, mandible, and diaphysis of a femur (UNSM 44802) were found in proximity within a crystalline gravel lens. Here Arikaree gray sands intervene between the incised Carpenter Ranch paleovalley and Brule Formation. Lithic symbols apply to figures 7–9.

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Fig. 10. Partial right mandible of the chalicothere *Tylocephalonyx* (UNSM 44800) with m3 and partial m2, labial view, Carpenter Ranch Formation, from the south escarpment of Deahl Butte, Goshen County, Wyoming (locality data provided in table 3).

lower hypoconid and entoconid are of about equal height.

Although only part of an upper molar (UNSM 44808, presumably M3) represents the upper dentition, several characters indicate its referral to the family and to Schizotheriinae. Coombs (1989: 438) noted that chalicotheres are distinguished by upper molars with a complete metaloph with no metaconule and an incomplete protoloph in which the paraconule is retained. UNSM 44808 preserves part of the ectoloph from the mesostyle forward to the paracone. If the ectoloph is restored, based on the M3 of *Moropus*, its length is estimated at ~52 mm. A small protoloph 12 mm in length, typical of schizotheriine chalicotheres, extends linguad from the paracone, and includes the paraconule. The ectoloph height measured at the unworn paracone is ~34.7 mm, indicating a relatively tall-crowned molar typical of schizotheriines, and similar to molar crown heights (e.g., M3, 38.2 mm) known in *Moropus elatus*. The enamel rib found on the labial face of the ectoloph in schizotheriines such as *Moropus elatus* is absent in UNSM 44808, and thus is similar to *Tylocephalonyx*, which also lacks these ribs.

CRANIAL DOME: Found at the same level ~2 m from the mandible, the cranial remnant appears to represent only half of the dome, broken to reveal an apparent sagittal section that exposes a massive boxwork of compartmentalized sinuses reinforcing the interior of the dome (figs. 12, 13). At the time of its discovery, the boxwork was packed with coarse sand and gravel. It likely survived due to rapid burial, presumably after the carcass was scavenged, because the bone shows no evidence of prolonged exposure to subaerial weathering. It is larger in its dimensions than any of the previously reported *Tylocephalonyx* specimens: height of the dome from base to summit is ~247 mm; anteroposterior length at its base is ~278 mm, gradually tapering upward so that 10 cm above the base this length is 178 mm, and 4.5 cm below the apex it is 114 mm.

The orientation of the partial dome is somewhat uncertain: the presumed posterior face tapers downward more gradually than the anterior surface, which descends more abruptly (fig. 12). The external surface is moderately rugose, more so toward the posterior margin. Small nutrient vascular foramina are clustered toward the posterior base, similar to parietal-squamosal vascular foramina found in some mammalian skulls. Com-

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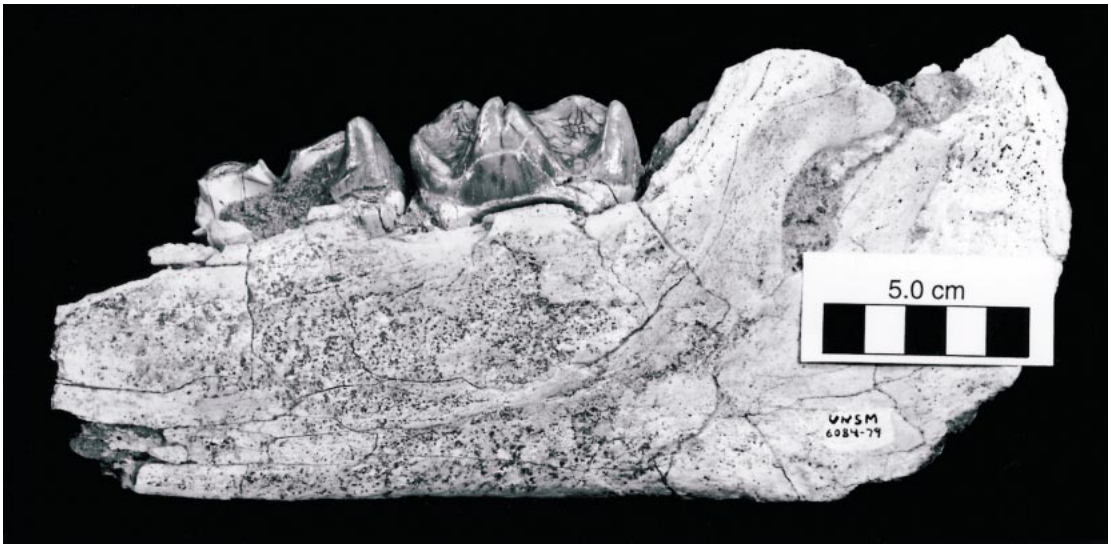

Fig. 11. Partial right mandible of the chalicothere *Tylocephalonyx* (UNSM 44800) with m3 and partial m2, lingual view, Carpenter Ranch Formation, from the south escarpment of Deahl Butte, Goshen County, Wyoming. Note distinct m3 metastylid.

pact bone 4 cm thick occurs at the posterior base of the dome, interpreted as a remnant of the skull roof. Thick bone may have continued forward under the dome but this part of the skull has been lost. At the anterior base of the dome the bone transforms from an open network of thick-walled sinuses to a more normal, finely cancellous structure that parallels the skull surface, suggesting that one is observing the transition between the interior of the dome and the surface of the skull in the fronto-parietal region.

Forelimb

Scapula: A scapular fragment (UNSM 44811) about 14 cm in length that includes the glenoid fossa appears to belong to a chalicothere. It compares with the glenoid of *Moropus elatus* and is similar in size to some individuals from the Agate bonebed. Only ~7–8 cm of the glenoid rim are preserved, heavily reinforced by thick bone with abundant nutrient vascular foramina.

Humerus: A proximal left humerus (UNSM 44812), damaged by preburial scavenging, was found within 5 m of a distal femur at Childers Butte. The distal femur displays a percussion fracture produced by a large entelodont (fig. 14), and it seems likely that the damaged humerus and femur came from the same scavenged carcass. The form of the proximal humerus does not differ in any respect from that of *M. elatus*. The antero-posterior length of the humeral head in this case is 16.2 cm whereas the same dimension in a large *M. elatus* from University Quarry is 19.2 cm.

Coombs (1979: 23) observed that none of the humeri of *Tylocephalonyx skinneri* retains the proximal end, so a comparison with UNSM 44812 is not possible. Scavengers often damage the proximal humerus when focusing on the concentration of muscle available in the shoulder region. The proximal humerus was also damaged or destroyed in individuals of *M. elatus* from University Quarry, where evidence of scavenging is commonplace in the Agate waterhole bonebed (Hunt, 1990).

Ulna: A proximal ulna (UNSM 44810) preserves the olecranon process, semilunar notch, and coronoid process, demonstrating the nature of the articulation with the radius. The proximal ulna was similar in size and form to the ulna of *M. elatus*. Features of *M. elatus* mentioned by Coombs (1978) are present: a prominent anconeal process, deep semilunar notch with strong medial expan-

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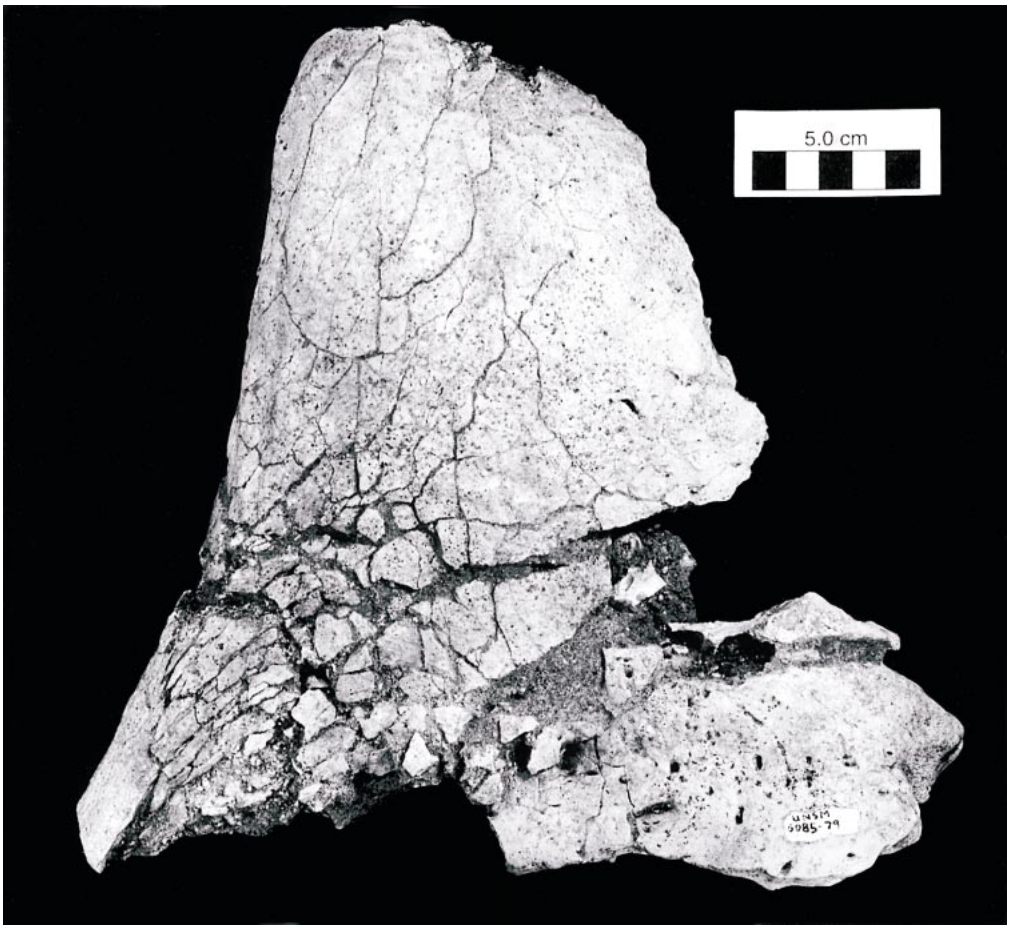

Fig. 12. Cranial dome of the chalicothere *Tylocephalonyx* (UNSM 44801), external surface of the dome, Carpenter Ranch Formation, Deahl Butte, Goshen County, Wyoming (presumed anterior face to left, dorsal upward).

sion, radius facet distal and at an acute angle to the semilunar notch and forming a deep articular fossa. Ulnar width at the level of the coronoid process is ~11 cm. The shape of the semilunar notch for articulation with the humerus and the reduced coronoid process demonstrate that the radial head, which fits tightly against the radial notch, was immobile and did not rotate. Only extension and flexion occurred at the elbow; there was no rotation of the radius around the ulna, an aspect of the anatomy of *M. elatus* previously noted by Coombs (1978: 25). The ulnar fragment exhibits considerable preburial flaking and cracking of the cortical bone—it must have been scavenged and exposed to weathering for some time prior to burial.

Coombs (1979: 23) regarded the radius/ulna of *Tylocephalonyx skinneri* as little different from that of *M. elatus*. She did note that the lateral extent of the proximal facet on the ulna for the radial head is slightly smaller in *T. skinneri*; despite the damaged state of UNSM 44810, it seems to show this more restricted condition of the proximal facet. In both species the radius and ulna were incapable of independent movement—locked by fusion of the distal shafts, the form of the proximal articulation, and by strong interosseous ligaments.

METACARPAL: A massive, robust proximal metacarpal 4 (fig. 15, UNSM 44804) was found in talus of the Carpenter Ranch Formation at a small satellite butte ~0.6 km

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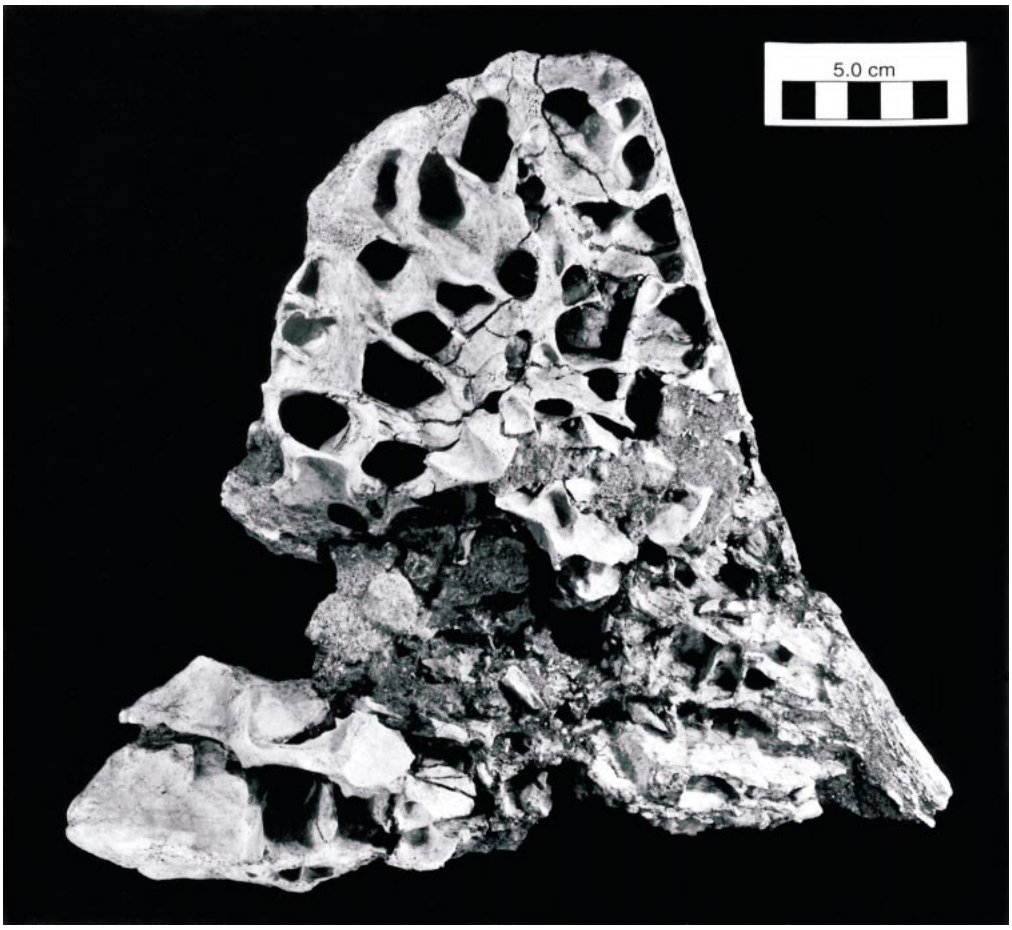

Fig. 13. Cranial dome of the chalicothere *Tylocephalonyx* (UNSM 44801), internal surface of the dome showing the well-developed compartmentalized architecture, Carpenter Ranch Formation, Deahl Butte, Goshen County, Wyoming (presumed anterior face to right, dorsal upward).

southeast of the site at Deahl Butte where the dome and mandible occurred. It was found above the base of the formation and can only have been derived from that rock unit.

The articular surfaces and facets for the unciform and for metacarpals 3 and 5 are diagnostic for various chalicotheres, and it is worthwhile to describe these in some detail for UNSM 44804.

The radial side of metacarpal 4 (UNSM 44804) bears two articular facets for metacarpal 3: a dorsal facet and a volar facet (fig. 15A). In *M. elatus* the two facets are in contact, the volar facet placed somewhat more proximally on the side of the metacarpal, and only slightly smaller in area than the dorsal facet. In UNSM 44804 the volar facet appears reduced in area relative to the dorsal facet, and is separated from it by a ~1 cm gap. In addition, the volar facet does not extend proximad above the dorsal facet as it does in *M. elatus* but rather is situated directly posterior to it.

The greater part of the dorsal surface of metacarpal 4 (fig. 15B) is for articulation with the unciform. This surface is much wider and appears to be flatter than those of either males or females of *M. elatus* from University Quarry at Agate National Monument. However, this configuration may be influenced by the robust size of UNSM 44804, probably a large male. In larger individuals of *M. elatus* the articular surface for the unciform becomes broader and more planar

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Fig. 14. Distal chalicothere femur (UNSM 44806) in posterior view, referred to *Tylocephalonyx*, Carpenter Ranch Formation, Childers Butte, Goshen County, Wyoming. A circular percussion fracture (at the arrow) produced by the premolar of a large entelodont suggests postmortem scavenging of the chalicothere carcass. No other mammal identified in early Hemingfordian faunas can have made these circular bite marks.

than seen in small individuals, but not to the extent evident in UNSM 44804.

UNSM 44804 demonstrates that the Carpenter Ranch chalicothere had retained a reduced metacarpal 5 in the manus as does *M. elatus*. On the ulno-volar side of proximal metacarpal 4 in *M. elatus*, Coombs (1978: 31) described a facet for the articulation of metacarpal 5, located on the ulno-volar angle of metacarpal 4 and separated from the proximal edge by paired tubercles. This facet was ''on the distal volar surface of the ulnar tubercle''. On two metacarpal 4s of *M. elatus* in the UNSM collection from University Quarry, this facet is present, as well as a second articular facet behind it, the two facets together creating a modest concavity for the head of metacarpal 5, which clearly was a reduced element. UNSM 44804 also shows a facet for a reduced metacarpal 5, slightly concave, and similarly situated on the distal volar surface of the ulnar tubercle. However, the second facet found in *M. elatus* is questionable in UNSM 44804, in which a very small, smooth articular(?) surface does occur directly behind the principal facet, separated from it by a deep channel ~7 mm in width. This could represent a secondary area of contact for metacarpal 5.

Coombs (1979: 11) listed three metacarpal 4s belonging to *Tylocephalonyx skinneri*, one of which was complete (F:AM 54887b). Of the two facets (dorsal and volar) for metacarpal 3 present on the proximal metacarpal 4 of *M. elatus*, *T. skinneri* entirely lacked the volar facet, which Coombs considered an important distinction. However, UNSM 44804 displays both a volar and dorsal facet, which are of a different shape and placement than those seen in *M. elatus* and *T. skinneri*. Other subtle differences from the metacarpal 4 of UNSM 44804 can be seen in photographs of the *T. skinneri* metacarpal 4 (Coombs, 1979: 33, figs. 16B, C, D), and these suggest that the manus of the early Hemingfordian Carpenter Ranch chalicothere was somehow differently configured relative to the manus of the late Hemingfordian *T. skinneri*. Because the presence of both a dorsal and volar facet for metacarpal 3 represents a plesiomorphic trait, it is possible that early Hemingfordian *Tylocephalonyx* possessed both facets, with

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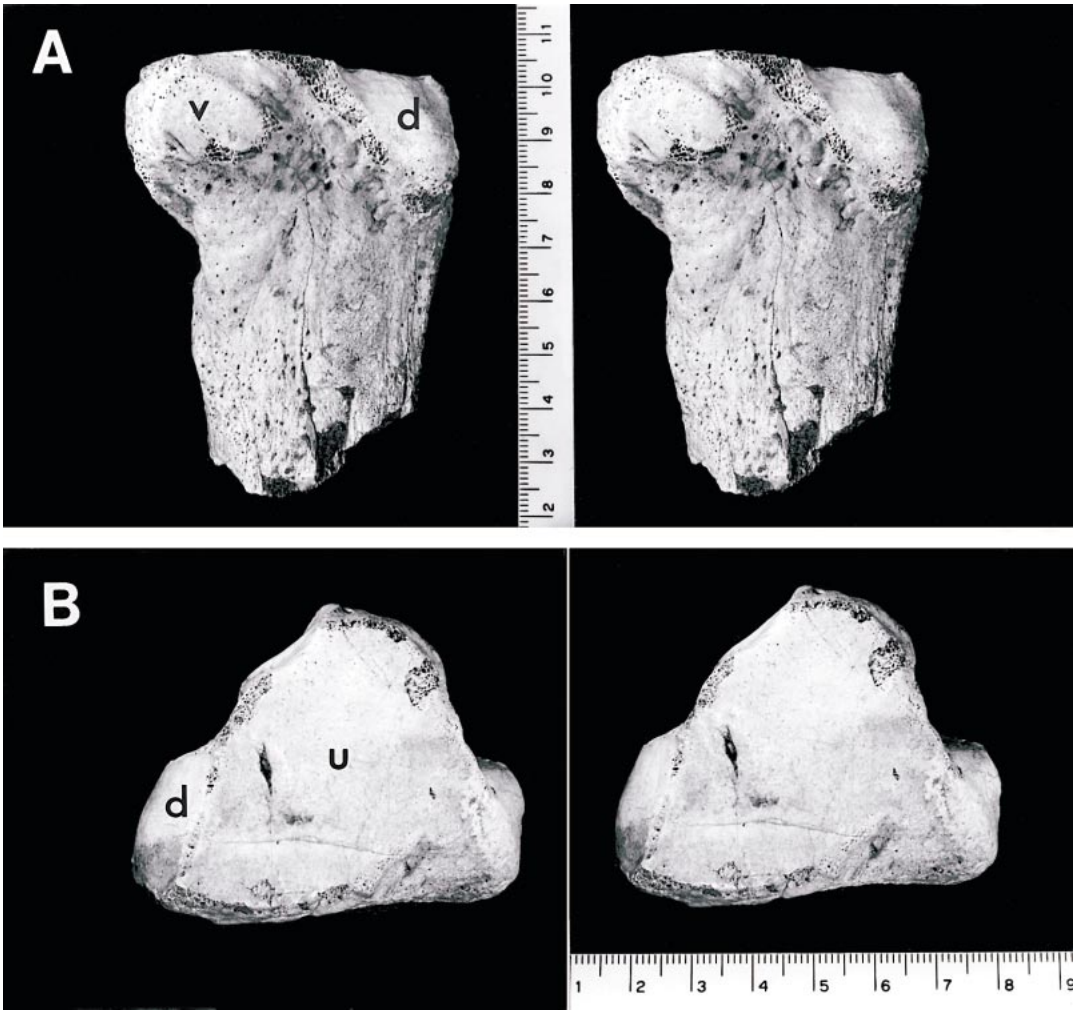

Fig. 15. Proximal metacarpal 4 (UNSM 44804) referred to (?)*Tylocephalonyx*, Carpenter Ranch Formation, Goshen County, Wyoming: **A,** radial face showing the dorsal (d) and volar (v) facets for metacarpal 3; **B,** proximal articular surface for the unciform (u). Stereopairs. Finest divisions of scale in mm.

only the dorsal facet retained in late Hemingfordian *T. skinneri*.

Coombs (1978: 53, figs. 25C,D) also illustrated the metacarpal 4 of *Moropus hollandi* (FMNH P13000) from near Jay-Em, Wyoming, presumably from the Upper Harrison beds. The placement of the facets for articulation of metacarpal 3 shows a closer correspondence to that of UNSM 44804 than to *M. elatus* or *T. skinneri*; the dorsovolar length measured across these facets on the radial side of metacarpal 4 is ~48 mm in *M. hollandi* and 63.5 mm in UNSM 44804, the latter a much larger individual, probably male. Coombs (1978: 50), on good evidence, believed P13000 to be a female. One can entertain the possibility that the Carpenter Ranch metacarpal 4 might represent the earlier *M. hollandi* and not the dome-skulled *Tylocephalonyx*. However, the only known skull of *M. hollandi* (FMNH P12094) lacks any indication of doming, but whether a dome was an exclusively male trait is not known because of the scarcity of intact skulls (Munthe and Coombs, 1979: 85).

UNGUAL PHALANX: A dorsal process of the

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Fig. 16. Diaphysis of chalicothere limb bone (UNSM 44825) showing green-bone fracturing produced by scavengers, with broken margins overprinted by preburial abrasion, East Sturdivant Butte, Cow Trail Notch local fauna, Carpenter Ranch Formation, Sioux County, Nebraska. Note marrow cavity packed with granitic gravel.

ungual phalanx of a chalicothere (UNSM 44805) was found at the same locality as UNSM 44804 (proximal metacarpal 4). The remnant of the process is 4.6 cm in length and ~2.5 cm in width; it includes the apical termination of the process and much of the articulation with the intermediate phalanx. Its robust size and rugosity suggest it is the dorsal process of the ungual phalanx of digit II of the manus.

Hindlimb

Femur: Remains of several femora, including a diaphysis of a left femur (UNSM 44802) found in proximity to the dome and mandible described above, come from sites at Deahl Butte and adjacent Childers Butte. A distal right femur (UNSM 44807) found at Childers Butte in November 1977 provided the first evidence of the presence of chalicotheres in the Carpenter Ranch Formation. These femora differ in no evident features from those of *M. elatus*, showing the same placement and development of the lesser trochanter and conspicuous third trochanter. Such bones often display green bone fractures and appear to be scavenged (fig. 16).

Another distal left femur and accompanying diaphysis (UNSM 44806) were found in outcrop in 1979, together with a proximal humerus (UNSM 44812), over a distance of ~5 m at the same stratigraphic level on Childers Butte. Despite damage due to preburial scavenging, the distal femur and diaphysis (UNSM 44806) can be identified confidently as chalicothere. These pieces show green-bone fractures, and the distal femur carries a depressed circular percussion fracture produced by the premolar of a large entelodont (fig. 14). This femur had an estimated length of ~60 cm, thus a size similar to the femur of *M. elatus*. Lengths of the femur in male and female *M. elatus* have been reported as 65 and 43 cm, respectively (Holland and Peterson, 1914:362), and two intact femora from University Quarry in the University of Nebraska collections measure ~60 and 64 cm in length.

Tibia: A distal right tibia (UNSM 44809) from the Duncan Buttes is similar to that of *M. elatus*. Coombs (1978: 55) noted that both the tibia and femur of *M. hollandi* could not be distinguished from these same bones of *M. elatus*. The tibia of *Tylocephalonyx skinneri* was also considered by Coombs

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(1979: 34) to be ''similar in proportions and morphology to tibiae of *Moropus*''. The few differences she cited do not involve the distal part of the bone. A fibula articulated with the distal tibia in these chalicotheres: the distal facet for attachment of the fibula is present in UNSM 44809 and suggests a fibula much like that of *M. elatus* (Holland and Peterson, 1914: pl. 71).

Of some importance is that the distal tibia preserves the articular surface for the astragalus and demonstrates rather shallow grooves for the astragalar trochlea relative to those of *M. elatus* (particularly with regard to the medial trochlear depression). The width of the astragalar trochlea in *M. elatus*, based on specimens in the UNSM collection from the Agate waterhole bonebed, ranges from 58.6 to 79.6 mm ($N = 14$; mean, 69.3 mm). Measurement across the trochlear depressions in the distal tibia of UNSM 44809, which serves as a proxy for the width of the astragalar trochlea, indicates that the Carpenter Ranch chalicothere had a broad astragalus with a trochlear width of ~92 mm, larger than that of *M. elatus*. However, in addition to this difference in size, it is the relative proportions of these astragalar depressions that suggest referral of the Carpenter Ranch chalicothere to *Tylocephalonyx*. Coombs (1979: 34, fig. 19A) observed that the tibial and fibular parts of the astragalar trochlea in *T. skinneri* are of about equal width, whereas in *M. elatus* the tibial part of the trochlea is narrower, occupying less than half the trochlear width (Coombs, 1978: 33, figs. 14C,D). In UNSM 44809 the trochlear width of the tibial side is 45 mm, and the fibular side 47 mm, which is more similar to *Tylocephalonyx*. These same measurements taken from a tibia of *M. elatus* from University Quarry are 31 mm and 40 mm, respectively.

Discussion

The tall-crowned molar fragment lacking an enamel rib on the ectoloph, the large and robust m2–3, a distal tibia, and the cranial dome all suggest identification of the material as the schizotheriine *Tylocephalonyx*. The partial femora, humerus, ulna, and other fragments do not in themselves provide a reliable generic identification for this chalicothere. Until discovery of more complete material proves otherwise, I have assumed that chalicothere elements from the Carpenter Ranch beds belong to a single species. It is improbable that any of the chalicothere fossils from the Carpenter Ranch Formation belong to a taxon such as *Moropus elatus*, since the presence of two such similar chalicotheres in the same environment seems unlikely, and because none of the remains shows any particular affinity to the Agate species. Specifically, the length and width of the m2–3 exceed almost all known *M. elatus* molars in size, the proportions of the astragalar trochlea differ from *Moropus*, and domed skulls are unknown in *M. elatus* males and females.

Among the postcranial elements referred here to *Tylocephalonyx*, it is the metacarpal 4 that is the most difficult element to include in that genus; it does not appear to correspond to that bone in *T. skinneri* but better matches metacarpal 4 of *Moropus hollandi*. Nonetheless, because the size and form of chalicothere postcranial elements from the southern buttes suggest the presence of only a single species, and the postcranial elements occur with dental and cranial material attributable to a dome-skulled animal, all chalicothere elements from the Carpenter Ranch beds are tentatively attributed here to *Tylocephalonyx*, while recognizing the possibility of the presence of a second species similar to or the same as *M. hollandi*.

At the time of the initial discovery of dome-skulled chalicotheres, Munthe and Coombs (1979) did not describe the internal architecture of the dome in detail due to the existence of only three skulls. Although radiographic examination of the two complete skulls provided no additional information, cranial fractures did allow construction of transverse sections of one of the skulls, including a schematic profile through the dome. They reported ''bony partitions connecting the dome to the roof of the braincase which divided this cavity into a series of irregularly shaped sinuses'' (Munthe and Coombs, 1979: 82).

The partial dome of the Carpenter Ranch chalicothere (UNSM 44801) preserves a boxwork of compartmentalized sinuses extending from the summit to the base of the

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dome (fig. 13), which conforms to the preliminary observations of Munthe and Coombs (1979: 82, fig. 6). In domed skulls from the Split Rock Formation (Wyoming) and from Greenside Quarry (Nebraska), they found evidence of a similar internal osseous boxwork, a remnant of which can be seen in their photograph of the Greenside Quarry skull (Munthe and Coombs, 1979: fig. 3; note bony septa immediately above the roof of the braincase). However, they were not able to determine the exact location and orientation of the cranial sinuses from the available skulls. Thus, UNSM 44801 makes possible for the first time an examination of the internal architecture of the dome.

UNSM 44801 shows that the interior of the dome was entirely supported by the sinusoidal boxwork from the base to the summit (figs. 13, 17). The sinuses are nearly intact in the upper half of the dome, an area of ~17 by 14 cm seen in parasagittal section: about 40 sinus compartments occupy the interior of the dome as preserved, with individual diameters ranging from ~9mm to 3 cm (fig. 17A). The diameters of 20 of these compartments measured at random in the upper half of the dome averaged 16 mm. Similarly, the thickness of the bony partitions (septa) separating the compartments averaged 3.3 mm with a range from 1.6 to 6.0 mm. In the upper part of the dome the thickness of the bone forming the roof ranges from thin (3.2 mm) to very thick (24 mm). Of considerable interest is that the inner margins of almost all septa in the upper half of the dome are smooth, in life apparently covered by membrane, indicating that one is observing the intact, unbroken inner edges of individual compartments. However, compartments in the lower part of the dome exhibit broken margins, suggesting that they were continuous across the base of the dome, and were broken apart at the time the skull was damaged, presumably by scavengers.

Thus, the interior of the dome, at least in its upper part, must have been an open air-filled space, yet strongly reinforced along the sides by bone. This morphology provides a plausible explanation for the fact that only half of the dome was found, for if scavenged or otherwise damaged, the dome might tend to split apart into two halves along a mid-sagittal plane through the hollow upper portion. One can conclude that the dome probably had a hollow dorsal cavity, bordered on its margins by strong sinusoidal bone reinforcing the walls throughout, and with a network of sinus compartments continuous across the basal part of the dome above the braincase.

In their evaluation of the functional role of the dome, Munthe and Coombs (1979) considered several plausible hypotheses. Although recognizing that information at their disposal was limited, they suggested that the dome may have been involved in acoustic signaling, in visual displays, or for low-impact butting (or some combination of these behaviors). UNSM 44801 fortunately supplies evidence, lacking in the Munthe and Coombs study, that establishes the thickness, orientation, and distribution of the dome's internal bony partitions. The pronounced thickness of the walls of the sinus compartments and their distribution within the dome indicate a well-reinforced architecture. Robust bony struts bridge the area above the braincase, supporting the walls of the dome from base to apex. Only the upper part of the dome appears to have been hollow. One can conclude that the dome was reinforced, durable, and could have withstood fairly strong external impacts.

After carefully considering a variety of possible hypotheses, Munthe and Coombs (1979: 88) focused their attention on low-impact flank-butting behavior in the living giraffe (*Giraffa camelopardalis*). The skull of a male giraffe, which they examined in sagittal section, contained a cranial sinus dorsal to the braincase, partitioned by bony septa, that they judged similar in form and size to that of the dome-skulled chalicothere. Considering that the internal septa of the Carpenter Ranch dome are thicker and more robust than those of the giraffe, low-impact butting cannot be ruled out. However, other functions attributed to the dome seem equally plausible: as a male visual display or (if both sexes possessed the domed skull) in species recognition. In addition, the air sinuses within the dome also might have served an acoustic role similar to that attributable to the expanded cranial sinuses in the living African and Asian elephants (*Loxo-*

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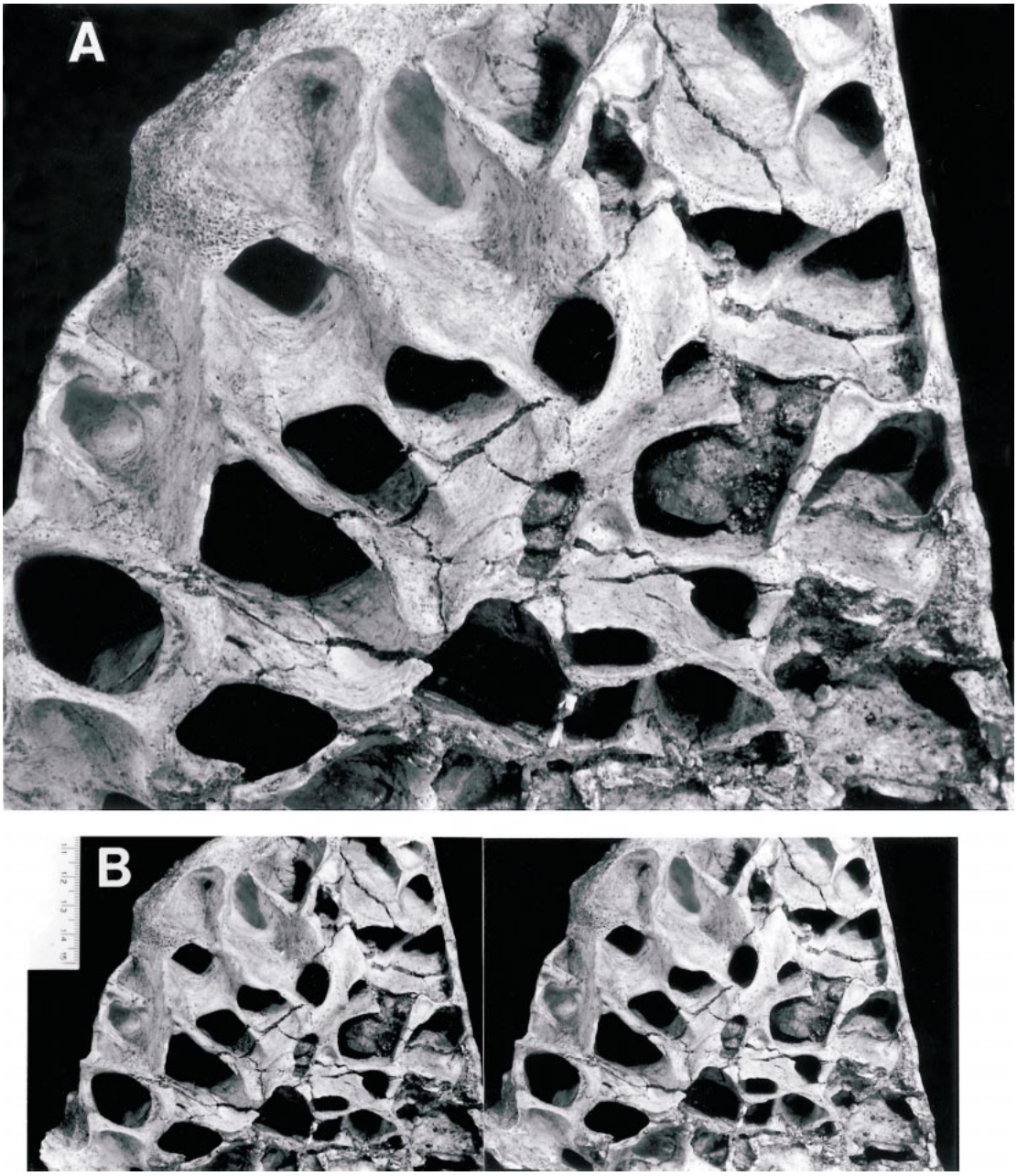

Fig. 17. Detail of the internal compartmentalized architecture of the cranial dome of *Tylocephalonyx* (UNSM 44801), Deahl Butte, Carpenter Ranch Formation, Goshen County, Wyoming. **A,** Enlarged view of the sinus compartments showing the smooth unbroken edges of septa in the central part of the dome; **B,** Stereopair of the dome interior shown in A. Finest divisions of scale in B in mm.

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donta africana, *Elephas maximus*). Elephants are known to employ low-frequency sound in communication over long distances (Payne et al., 1986; Poole et al., 1988). Low-frequency sound perception is enhanced when middle ear volume is expanded so that the ossicular vibrations within the middle ear are not damped by an air space of small volume. The living African elephant possesses a large foramen in the exoccipital bone forming a passageway between its middle ear and the voluminous cranial sinuses in its skull. This communication between middle ear and cranial air sinuses would prevent ossicular damping and favor the perception of low frequency sound. Possibly a similar passageway existed in dome-skulled chalicotheres between their middle ear and the sinuses in the dome, but if so, domes would be expected in both sexes. Only dissection or noninvasive CT (computerized tomography) scanning of a complete skull can demonstrate the presence of such an anatomical arrangement in these large perissodactyls.

Another rationale for the dome lies in the enhancement of olfaction. Negus (1958) noted that to obtain greater room for ethmoturbinals, hence improved olfaction, extension into surrounding bones and the development of spaces dorsal to the braincase were viable strategies. Extension of the ethmoturbinals covered with olfactory mucosa often occurs in mammals by invasion of the frontal and sphenoid paranasal sinuses. In some Carnivora, such as felids, the ethmoturbinals invade newly created spaces within the frontal and nasal bones, which Negus (1958: 300) considered as ''the construction of a superimposed upper story'' added to the dorsal surface of the skull. The extension of ethmoturbinals into paranasal sinuses clearly serves an olfactory role because olfactory nerves supply the invading turbinals.

Most such olfactory extensions occur in living Carnivora but it is noteworthy that among living perissodactyls the tapir has evolved olfactory penetration into both the nasal and frontal areas of the frontal sinus, and the horse has a very small olfactory extension into the nasal (not frontal) part. Negus (1958: fig. 147) reported that a rhinoceros (species not indicated) retained very large nasal and frontal parts of an enlarged frontal sinus but that these spaces were nonolfactory. However, the horse, tapir, and rhinoceros all have large sphenoidal sinuses invaded by olfactory tissue. In his survey of paranasal sinuses, Negus (1958) remarked on the presence in many ungulates of ''supracranial cavities'' in the frontal, parietal, and occipital areas of the skull that did not contain ethmoturbinals but that communicated with the nasal region. Based on the limited anatomical evidence, invasion of the chalicothere dome by olfactory ethmoturbinals seems unlikely, but it is possible that a passage from the dome into the nasal cavity existed. Such a connection between the frontal sinus and nasal cavity occurs in many ungulates (Sisson and Grossman, 1953; Negus, 1958: fig. 156). The broad enlarged snout of chalicotheres suggests that the ethmoturbinals may have been sufficiently well developed within the nasal fossa such that no need existed for ethmoturbinal invasion of the cranial dome.

Evidence reported above demonstrates that large entelodonts scavenged the remains of these chalicotheres (only entelodont teeth match bite marks in these bones). It is significant that no complete chalicothere limb bones, despite their large size and durability, survived intact in the sands and gravels of this fluvial system. All limb bones have been broken, and several show green-bone fractures that would have required considerable force to produce (fig. 16). The record of entelodont tooth marks on chalicothere limb bones has now been documented at three localities of early Miocene age in the Great Plains: (1) the late Arikareean waterhole bone bed at Carnegie Hill, Agate Fossil Beds National Monument, Sioux County, Nebraska (Hunt, 1990: fig. 25); (2) the latest Arikareean Lay Ranch paleovalley, Anderson Ranch Formation at Spoon Butte, Goshen County, Wyoming (fig. 18); and (3) early Hemingfordian fluvial sediments of the Carpenter Ranch Formation, Goshen County, Wyoming (fig. 14).

Coombs (1979: 5) visualized *Tylocephalonyx* as a browsing ungulate of the temperate forests of northwestern North America with ''a significant distribution onto the Great Plains, perhaps associated with riparian communities''. The presence of a dome-skulled

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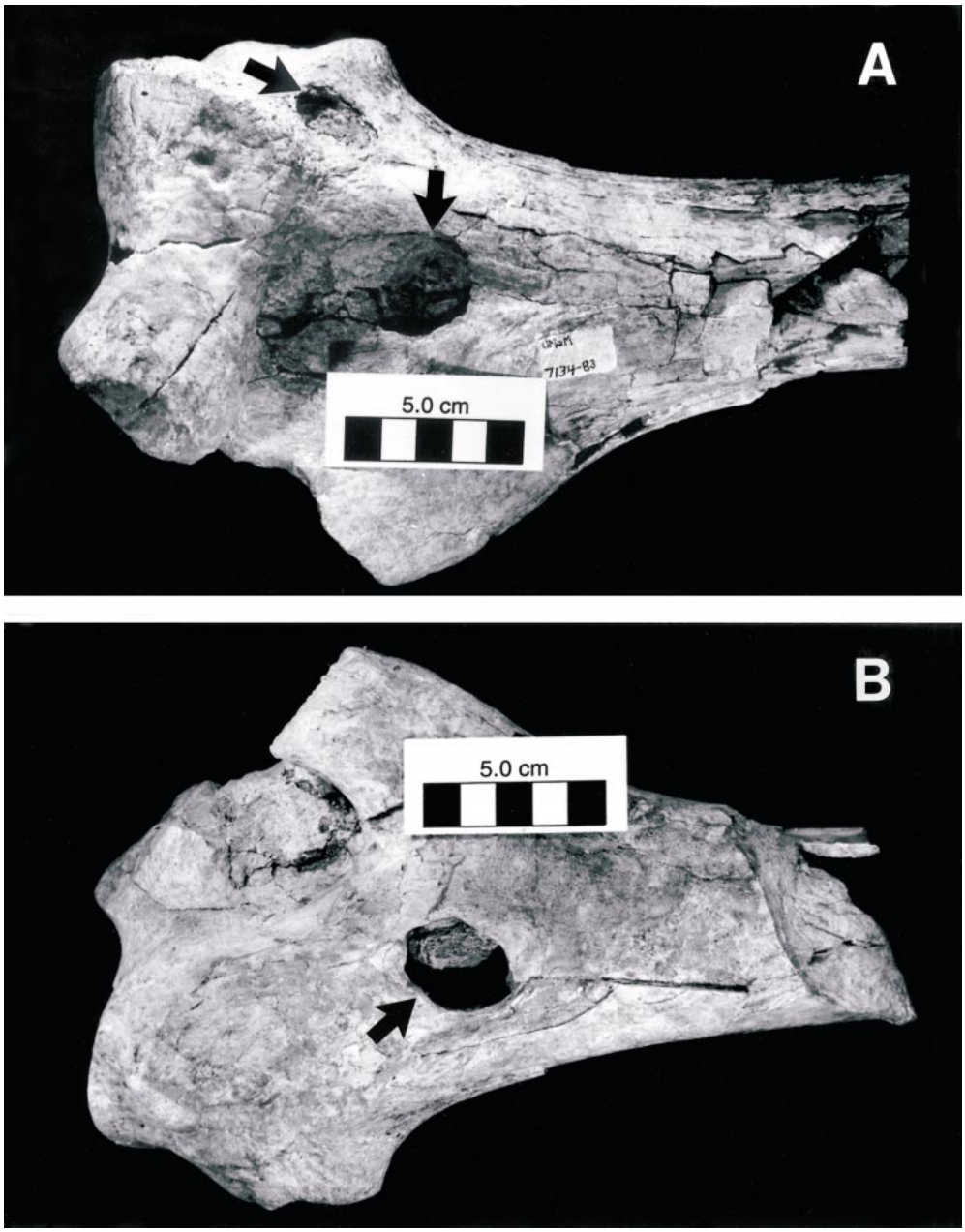

Fig. 18. Chalicothere left distal humerus (UNSM 44826) scavenged by a large entelodont, showing bite marks on both (**A**) anterior and (**B**) posterior surfaces of the bone, Lay Ranch beds (a paleovalley fill within the Anderson Ranch Formation, latest Arikareean), east side of Spoon Butte, 500 ft west of the Wyoming-Nebraska state boundary, Goshen County, Wyoming. Arrows mark the principal percussion fractures.

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chalicothere apparently referable to *Tylocephalonyx* in association with abundant silicified wood in fluvial sediments of a major early Miocene paleovalley in the central Great Plains, supports her hypothesis. Chalicotheres in the Miocene of the Great Plains are commonly found in fluvial and waterhole settings, where they have been regarded as water-dependent mammals in recent field studies (Hunt, 1990).

AGE OF THE DOME-SKULLED CHALICOTHERE

Coombs (1979) and Munthe and Coombs (1979) attributed all known fossils of the dome-skulled *Tylocephalonyx* to the mid-Miocene, that is, to the late Hemingfordian and early Barstovian land mammal ''ages''. They believed that none of these remains was older than ~17 Ma. The fauna associated with the dome-skulled chalicothere in the Carpenter Ranch Formation is of early Hemingfordian age, and is representative of the earliest assemblage of Hemingfordian mammals yet identified in the Great Plains. Mammalian faunas of similar age are now known from western Nebraska (Northeast of Agate local fauna, MacFadden and Hunt, 1998; Tedford et al., 1987) and northeastern Colorado (Martin Canyon local fauna, Tedford, 1999), and from less well-known assemblages from near Wheatland in southeastern Wyoming (Hunt, unpublished observations), and from the Troublesome Formation in north-central Colorado (Izett, 1968). These strata record a regional tectonic/climatic event identified by the first appearance of Hemingfordian faunas in the Great Plains and adjacent Rocky Mountain basins. At this time an influx of coarse sands and granitic gravels indicates increased competence of streams bringing Rocky Mountain detritus from the uplifts eastward onto the Great Plains.

The Northeast of Agate local fauna has been paleomagnetically calibrated and is considered to fall in Chron C5E of the Magnetic Polarity Time Scale (Berggren et al., 1995), dated at ~18.2 to 18.8 Ma. This local fauna comes from the stratigraphically lowest exposures of the Runningwater Formation in western Nebraska (MacFadden and Hunt, 1998), best developed northeast of the Agate post office in central Sioux County where these pale orange-brown sandstones yield a fauna of earliest Hemingfordian aspect. A key index taxon in this assemblage is the large oreodont *Merycochoerus magnus*, which occurs both in the Northeast of Agate local fauna and in the Carpenter Ranch mammal assemblage.

These earliest Hemingfordian faunas in western North America are considered to fall within the 18.2–18.8 Ma interval, hence older than any of the previously reported occurrences of dome-skulled chalicotheres.

Here I summarize mammals contributing to the age assessment of the Carpenter Ranch beds: the oreodont *Merycochoerus*, a dromomerycid *Aletomeryx*, the moschid *Pseudoblastomeryx*, the small canid *Phlaocyon*, and the amphicyonid carnivore *Daphoenodon*.

ORDER ARTIODACTYLA

FAMILY OREODONTIDAE

Merycochoerus magnus
Figure 19

Remains of this large oreodont were found both near the base and at the uppermost levels of the Carpenter Ranch beds at Merycochoerus Butte (fig. 8), and they demonstrate that nearly the entire paleovalley fill at that locality is within the temporal range of this species. A right mandible (UNSM 44813) was found within a meter of the basal contact of the Carpenter Ranch beds with the underlying White River sediments, establishing the age of the earliest fluvial deposits in the paleovalley at this location. An edentulous maxilla and associated fragmentary postcranial bones (UNSM 44814) occurred 67 ft higher in the section, 14 ft below the top of the butte. This was the only locale in the southern buttes in which *Merycochoerus* occurred.

The stage of evolution of the three species of *Merycochoerus* can be estimated by the degree of fusion of the premaxillae, which is an index of the degree of nasal retraction developed in this oreodont lineage over time, plotted against a measure of the size of M3 (Hunt and Stepleton, 2004: fig. 18). The earliest species, *M. matthewi*, precedes the larger *M. magnus*, which is followed by the ter-

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Fig. 19. Right mandible (UNSM 44813) and maxilla (UNSM 44814) of the oreodont *Merycochoerus magnus* from the Carpenter Ranch Formation, Merycochoerus Butte, Goshen County, Wyoming.

minal species, *M. proprius*. This species progression underwent a shortening of the skull, nasal retraction likely indicating the development of a fleshy proboscis, and an increase in molar dimensions.

When compared with representative samples of these three species, the mandible from Merycochoerus Butte compares most closely with those of *M. magnus* from the lowermost Runningwater Formation northeast of Agate post office in Sioux County, Nebraska. The maxilla from the higher level on the butte is also similar to maxillae of *M. magnus*, yet appears somewhat more gracile. Because it lacks teeth, and its degree of nasal retraction can only be estimated, it is less certainly referred to that species. This oreodont suggests an earliest Hemingfordian age, equivalent to the fauna from the lowermost Runningwater Formation northeast of Agate, Nebraska.

ORDER ARTIODACTYLA

FAMILY DROMOMERYCIDAE

Aletomeryx gracilis

Figure 20

A right mandible with dp4 and m1 (UNSM 44820) was found in sands and gravels of the Carpenter Ranch beds at East Sturdivant Butte in close proximity to the maxilla of the small canid *Phlaocyon* (fig. 7). The dp4 and m1 are most similar to these teeth in *Aletomeryx* specimens from the Runningwater Formation in western Nebraska.

From their first occurrence in the early Hemingfordian of North America, species of *Aletomeryx* gradually increase in size, eventually evolving into the larger descendant genus *Sinclairomeryx* in the late Hemingfordian. This size increase is documented by mandibular teeth such as dp4 and m3. Also, over this interval the premolar row (p2–4) shortens relative to the length of the molars (m1–3).

Table 4 shows that the dp4 dimensions of the Carpenter Ranch specimen fall within the lower part of the range of a population of juvenile *Aletomeryx* found in Runningwater Quarry (UNSM locality Bx-58). Similarly, m1 measurements fall almost exactly at the mean values for this same population sample (table 4). This quarry occurs in the lowermost part of the Runningwater Formation in the type section, located in the northwest cor-

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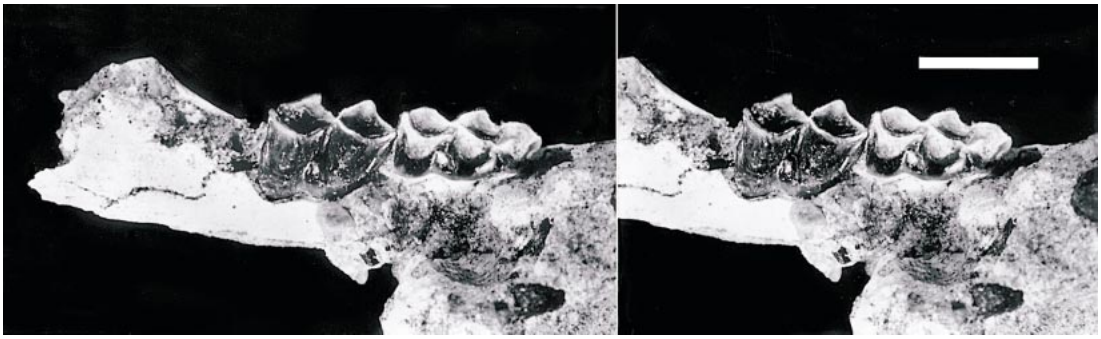

Fig. 20. Right mandible of a juvenile dromomerycid *Aletomeryx gracilis* (UNSM 44820) with dp4 and m1, Cow Trail Notch local fauna, Carpenter Ranch Formation, East Sturdivant Butte, Sioux County, Nebraska. Stereopair. Scale bar, 1 cm.

ner of Box Butte County, Nebraska. UNSM localities south of the Niobrara River in Box Butte County, collectively termed the Hemingford Quarries, sample the upper part of the Runningwater Formation. From one of these quarries, UNSM Hemingford Quarry 7B, over 30 juvenile *Aletomeryx* provide an adequate sample of dp4 for comparison with the Runningwater Quarry population (table 5). The Quarry 7B sample shows a significantly larger dp4 than the population from Runningwater Quarry, and it is evident that the dp4 from the Carpenter Ranch beds falls entirely outside the range of the Quarry 7B sample. Considering this evidence, an age coeval with the upper part of the Runningwater Formation is unlikely.

TABLE 4
Dimensions of dp4 and m1 (in mm) of Juvenile *Aletomeryx*
[from Runningwater Quarry (UNSM Locality Bx-58), Box Butte Co., Nebraska, and from the Northeast of Agate local fauna, Sioux Co., Nebraska, compared to the juvenile *Aletomeryx* from East Sturdivant Butte]

UNSM no.	dp4 L × W	m1 L × W
Runningwater Quarry		
4069-74	12.9 × 5.4	11.5 × 7.3
4120-74	13.3 × 5.2	11.3 × 7.2
4176-74	13.8 × 5.9	12.1 × 7.1
4----74[a]	13.4 × 5.9	11.5 × 7.0
4105-74	12.4 × 5.5	11.3 × 6.7
4297-74	13.1 × 5.7	11.9 × 6.9
4245-74	12.4[b] × 5.1	10.7 × 6.5
4178-74	13.0 × 5.3	—
4066-74	12.6 × 5.6	10.9 × 6.2
4159-74	13.4 × 5.9	11.1 × 6.5
4244-74	14.0 × 5.5	11.4 × 6.9
4167-74	12.5 × 5.5	11.0 × 6.2
4299-74	13.3 × 5.7	—
4251-74	13.8 × 5.4	—
4129-74	—	11.2 × 6.8
Northeast of Agate local fauna		
F:AM NEA 3-23	12.9 —	11.4 —
AMNH[a]	13.6 —	11.3 —
Carpenter Ranch Fm., East Sturdivant Butte		
44820	12.4 × 5.2	11.3 × 6.8

[a]Catalog number unavailable.
[b]Estimated measurement.

Other than at Runningwater Quarry, fossiliferous strata of the lower Runningwater Formation containing *Aletomeryx* occur northeast of Agate post office in Sioux County, where they have yielded two juvenile individuals that retain dp4 and m1 (Northeast of Agate local fauna, MacFadden and Hunt, 1998). The dimensions of these teeth from the two individuals fall within the documented range of dp4 and m1 measurements from Runningwater Quarry (table 4). Specimens found northeast of Agate were identified as *Aletomeryx marshi* by Frick (1937: 160); however, they are not distinguishable from the Runningwater Quarry sample on present criteria—additional specimens from the lower Runningwater Formation, northeast of Agate, would be necessary to determine whether they are in fact a different population from the Runningwater Quarry species. Here I employ the name *Aletomeryx gracilis* Lull 1920 for the species from the lower Runningwater Formation, and *Aletomeryx marslandensis* Frick 1937 for the specimens from upper Runningwater strata.

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TABLE 5

Comparison of dp4 and m1 (in mm) of *Aletomeryx* from Runningwater Quarry (lower Runningwater Fm., *A. gracilis*) and Hemingford Quarry 7B (upper Runningwater Fm., *A. marslandensis*)

	Runningwater Quarry		Hemingford Quarry 7B	
	dp4 length[a]	dp4 width[b]	dp4 length[a]	dp4 width[b]
N	14	14	32	32
mean	13.1	5.5	14.2	5.7
1SD	0.53	0.26	0.53	0.24
1SE	0.14	0.07	0.09	0.04
CV	4.0	4.6	3.8	4.2
	m1 length[c]	m1 width[d]	m1 length[c]	m1 width[d]
N	12	12	35	35
mean	11.3	6.8	12.6	6.6
1SD	0.40	0.36	0.58	0.33
1SE	0.11	0.11	0.10	0.06
CV	3.5	5.4	4.6	5.0

Note: Each sample was collected from a quarry accumulation of individuals presumably representing a coeval population.
[a]Greatest length.
[b]Greatest posterior width.
[c]Greatest lingual length.
[d]Width across anterior pair of selenes, measured at enamel base.

There is some question whether *Aletomeryx* might be present in strata of late Arikareean age; no confirmed Arikareean occurrences are known at this time. The association of *Aletomeryx* with early Hemingfordian species such as *Merycochoerus magnus* in the Carpenter Ranch fauna indicates that the East Sturdivant Butte occurrence of the small dromomerycid is not likely to be of late Arikareean age. An earliest Hemingfordian age is supported here for the Carpenter Ranch *Aletomeryx*.

ORDER ARTIODACTYLA

FAMILY MOSCHIDAE

Pseudoblastomeryx sp., cf. *P. schultzi*
Figure 21

A partial maxilla with M1–3 of a small moschid (UNSM 44821) was found in the Carpenter Ranch beds at East Sturdivant Butte (fig. 7) ~18 ft above the specimens of *Aletomeryx* and *Phlaocyon*. Although the labial aspect of these molars was damaged, the molar row (length ~23.4 mm) corresponds

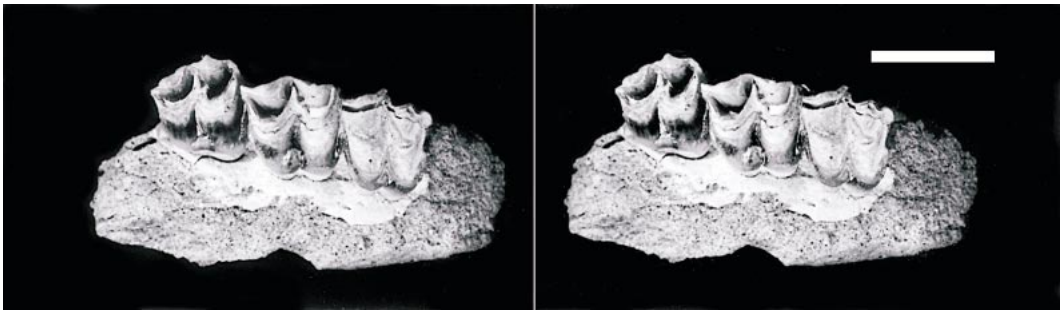

Fig. 21. Right maxilla of the moschid *Pseudoblastomeryx* (UNSM 44821) with M1–3, Cow Trail Notch local fauna, Carpenter Ranch Formation, East Sturdivant Butte, Sioux County, Nebraska. Stereopair. Scale bar, 1 cm.

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in its dimensions and form of the teeth to several of the small late Arikareean and early Hemingfordian blastomerycine moschids. These small moschids require taxonomic revision and so a specific identification is uncertain; however, the molars show close correspondence to those of *Pseudoblastomeryx schultzi* from the Bridgeport Quarries, Morrill County, Nebraska, of early Hemingfordian age. UNSM 44821 is tentatively referred to that species pending discovery of more complete material.

ORDER CARNIVORA

FAMILY AMPHICYONIDAE

Daphoenodon, advanced species
Figure 22

A partial left mandible with m1–3 and a damaged p4 (UNSM 44815) can be referred to an advanced species of the beardog *Daphoenodon*. It was discovered in an indurated fluvial sandstone at Merycochoerus Butte, 95 ft above the base of the Carpenter Ranch beds (fig. 8). Coarse, granitic gravel lenses occurred above and below the mandible, which was found 18 ft below the maxilla of *Merycochoerus* (UNSM 44814).

Although the molars are heavily worn, their form, size, and the squared posterior border of p4 establish its identity as *Daphoenodon*. *Daphoenodon* evolved from the smaller late Arikareean *D. superbus* into a much larger early Hemingfordian species that occurs in the Runningwater Formation. This increase in size is reflected in larger, more robust skulls, teeth, and postcrania. The molars and p4 establish that UNSM 44815 was a carnivore larger than *D. superbus* from the late Arikareean of western Nebraska, yet smaller in molar dimensions than the large terminal species of *Daphoenodon* from the upper Runningwater beds of Box Butte County and the Bridgeport Quarries in Morrill County (table 6). Although *Daphoenodon* is represented by only a few individuals in the lower Runningwater Formation, including one from the exposures northeast of Agate, they compare most closely with the Carpenter Ranch mandible, and suggest an early Hemingfordian age corresponding to the age of the Northeast of Agate local fauna.

ORDER CARNIVORA

FAMILY CANIDAE

Phlaocyon leucosteus
Figure 23

A left maxilla with P3-M2 (UNSM 44822) belonging to a small canid is attributable to *Phlaocyon*, a hypocarnivorous borophagine lineage noted for the addition of accessory cusps to its P4 and molars. It was found in a sand-and-gravel lens at East Sturdivant Butte at the same stratigraphic level as *Aletomeryx* (UNSM 44820, fig. 7). The Carpenter Ranch maxilla belongs to a continuum of species whose members progressively increase in size, beginning in the late Arikareean with *Phlaocyon annectens* (Agate National Monument, Quarry 3 carnivore dens, Peterson, 1907: 53); continuing through *Phlaocyon leucosteus* from the lower Runningwater Formation; and terminating in the large, robust species, *P. marslandensis* from the Hemingford Quarries of the upper Runningwater Formation, Nebraska. Table 7 presents measurements of the upper carnassial and molars of these species taken from individual specimens, supplemented by measurements recently provided by Wang et al. (1999). Inspection of these data indicates that UNSM 44822 is best referred to *Phlaocyon leucosteus* of early Hemingfordian age, coeval with faunas from the lower part of the Runningwater Formation of Nebraska.

BIOSTRATIGRAPHIC SUMMARY: Taken together, the age-diagnostic genera from the Carpenter Ranch sands and gravels indicate an early Miocene age (table 8). The stage of evolution of the species, however, is earliest Hemingfordian, age-equivalent or possibly slightly older than the mammalian fauna from the lower part of the Runningwater Formation northeast of Agate post office (Northeast of Agate local fauna, MacFadden and Hunt, 1998).

THE "ARIKAREE" CONGLOMERATES OF N. H. DARTON (1899)

The fluvial gravels and sands here referred to the Carpenter Ranch Formation and the previously established Spoon Butte beds were recognized in the earliest geologic reconnaissance studies in southeastern Wyo-

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Fig. 22. Left mandible of the amphicyonid *Daphoenodon* (UNSM 44815) with m1–3, partial p4, Merycochoerus Butte, Carpenter Ranch Formation, Goshen County, Wyoming. Scale bar, 1 cm.

ming and western Nebraska conducted by the U.S. Geological Survey (Darton, 1899; Adams, 1902). A summary of this work on the butte caprocks will supply historical background necessary to understanding UNSM field efforts in the region.

In N.H. Darton's (1899) classic study of the geology of western Nebraska, the Ogallala and Arikaree Formations were identified, named, and mapped for the first time, and conspicuous conglomerate beds were recognized in both formations. Darton noted that ''the basal Ogallala beds are mainly conglomeratic'' and illustrated this with measured sections in the southern Nebraska panhandle (Darton, 1899: 744, pls. 87–88). Ogallala conglomerates were recognized as crystalline gravels derived from the Rocky Mountains to the west. In contrast, the Arikaree conglomerates were lithically heterogeneous, and were restricted to the Wildcat Ridge, south of Scottsbluff, Nebraska, and the vicinity of Spoon Butte in Wyoming (Darton, 1899: 735).

At Wildcat Ridge, Darton did not consider the conglomerates as the earliest Arikaree deposits, reporting that they occurred *above* the base of the Arikaree within the formation. The Arikaree conglomerates at Wildcat Ridge are composed primarily of stream-rounded sandstone concretions cemented by calcite, mixed with granitic sand and gravel. Based on faunal content, they were thought to represent the channel deposits of a late Arikareean fluvial system later mapped by Vondra (Vondra et al., 1969), who referred them to the Harrison Formation. Darton (1899: 746, fig. 212) illustrated the stratigraphic relationships of these Arikaree conglomerates in sufficient detail that they can be readily identified today south of Gering, Nebraska, along the Wildcat Ridge, where they contain the UNSM late Arikareean mammal locality Sf-105.

Darton (1899: 747) reported that the ''Arikaree'' conglomerates in the vicinity of Spoon Butte differed from those along the Wildcat Ridge in their chiefly crystalline gravel composition. We can be certain of the location and identity of these conglomerates because he published a stratigraphic profile from Spoon Butte south to Sturdivant Gap (redrafted as fig. 5), showing the conglomerates overlying Arikaree beds on the north and White River Brule clay to the south (Darton, 1899: fig. 213, pl. 85[1]). His profile shows the conglomerates as descending in elevation southward, deposited on a ''steeply sloping sur-

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TABLE 6

Dental Dimensions (in mm) of the Early Miocene Amphicyonid *Daphoenodon* from Western Nebraska

	p4 length	p4 width	m1 length	m1 width	m2 length	m2 width
Daphoenodon superbus (Sioux County, NE)						
N	10	10	13	13	11	8
mean	17.8	8.8	25.6	11.5	15.1	10.4
1SD	1.04	0.65	0.93	0.25	1.02	0.57
1SE	0.33	0.20	0.26	0.07	0.31	0.20
CV	5.8	7.4	3.6	2.2	6.7	5.5
Daphoenodon (Bridgeport Quarries, Morrill County, NE)						
N	5	5	9	9	6	6
mean	20.3	10.7	30.0	14.4	18.5	12.5
1SD	1.53	0.69	1.78	0.70	1.18	1.50
1SE	0.68	0.31	0.59	0.23	0.48	0.61
CV	7.5	6.5	5.9	4.8	6.4	12.0
Daphoenodon (upper Runningwater Formation, Hemingford Quarries, Box Butte County, NE)						
N	12	11	11	10	10	7
mean	21.3	11.4	31.3	15.3	19.1	12.6
1SD	0.89	0.72	1.20	0.59	0.61	0.55
1SE	0.26	0.22	0.36	0.19	0.19	0.21
CV	4.2	6.3	3.8	3.9	3.2	4.4
Daphoenodon (lower Runningwater Formation, Sioux County, NE, and stratigraphic equivalent in WY)						
N	3	3	3	3	3	2
mean	18.8	9.8	28.0	14.0	16.6	11.6
1SD	0.38	0.43	0.72	0.45	0.55	0.21
1SE	0.22	0.25	0.42	0.26	0.32	0.15
CV	2.0	4.4	2.6	3.2	3.3	1.8
Daphoenodon (Carpenter Ranch Formation at Merycochoerus Butte) UNSM 44815						
	19[e]	11.2	27.2	13.8	17.5	11.8

[e]Estimated measurement.

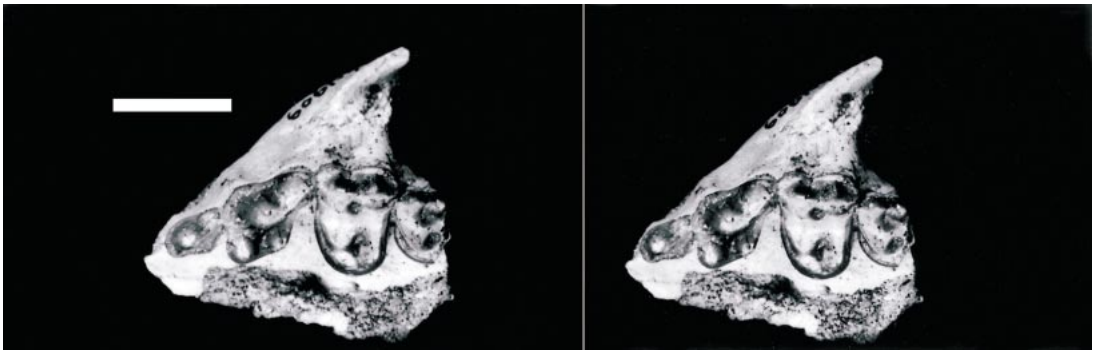

Fig. 23. Left maxilla of the canid *Phlaocyon leucosteus* (UNSM 44822) with P3-M2, Cow Trail Notch local fauna, Carpenter Ranch Formation, East Sturdivant Butte, Sioux County, Nebraska. Stereopair. Scale bar, 1 cm.

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TABLE 7
Dental Dimensions (in mm) of the Borophagine Canid *Phlaocyon*

Museum no.	P4 L × W[a]	M1 L × W	M2 L × W
Phlaocyon annectens			
CM 1602	8.5 × 5.1	6.6 × 8.2	3.6 × 6.1
F:AM 49006	8.2 × 6.5	6.2 × 9.0	—
CM 11332	7.4 × 5.6	5.3[b] × 8.3[b]	3.0 × 6.5
Phlaocyon leucosteus			
AMNH 8768	9.0 × 7.8	7.2 × 10.7	4.3 × 7.0
F:AM 99349	8.6 × 7.6	7.4 × 10.7	4.5 × 7.4
F:AM 99348	8.6 × 7.7	7.8 × 10.9	4.4 × 7.2
UNSM 44822[c]	8.5 × 6.5	7.0 × 9.9	4.6 × 7.2
UNSM 26524	8.0 × 6.3	7.0 × 9.8	4.5 × 6.6
Phlaocyon marslandensis			
FMNH P26314	9.7 × 9.3	8.3 × 12.3	—
F:AM H419-3209	9.4 × 8.0	8.3 × 11.9	5.4 × 7.8
UNSM 26153	9.9 × 10.2	9.1[b] × 13.9	—
UNSM 25607	10.1 × 9.8	8.7 × 13.0	—
UNSM 25659	10.4 × 9.8	9.0 × 12.6	—
UNSM 4506-41	10.4 × 8.8	9.0 × 13.0	4.7 × 7.8

P4–M2 Dental Measurements of *Phlaocyon* (Wang et al., 1999: 381–382)

	Phlaocyon annectens	*P. leucosteus*	*P. marslandensis*
P4L	7.6–8.6 ($N = 4$)	7.9–9.2 ($N = 5$)	9.8–10.4 ($N = 5$)
M1L	5.5–6.5 ($N = 4$)	7.2–8.0 ($N = 5$)	8.5–9.5 ($N = 5$)
M2L	3.0–4.0 ($N = 3$)	4.5–4.7 ($N = 4$)	5.2 ($N = 1$)
P4W	4.9–5.8 ($N = 4$)	6.2–7.2 ($N = 5$)	7.0–8.3 ($N = 3$)
M1W	7.5–7.6 ($N = 2$)	9.0–10.0 ($N = 5$)	10.0–12.0 ($N = 5$)
M2W	4.9–6.5 ($N = 3$)	6.6–7.3 ($N = 4$)	6.9 ($N = 1$)

[a]L = length, W = width.
[b]Estimated measurement.
[c]From the Carpenter Ranch Formation, East Sturdivant Butte.

face'', which led Darton to regard them as strata within a single paleovalley of considerable width. He was aware that nowhere in the Spoon Butte area were these capping conglomerates overlain by Arikaree sediments (as they were at Wildcat Ridge), but this did not seem to influence his belief that they belonged to the Arikaree Formation.

George Adams (1902) extended Darton's geological mapping into southeastern Wyoming, summarized in U.S. Geological Survey Water-Supply Paper No.70 on the geology and water resources of the Patrick and Goshen Hole quadrangles. That region at the time of Adams' work was undergoing accelerated development for the raising of livestock, and ranching operations were rapidly invading semiarid grasslands distant from the local rivers and streams. The ability to drill deep wells far from these streams, permitting the use of windmills and irrigation, led to increasing human settlement and a growing interest in a geologic survey of water resources.

Although Darton (1899) mentioned Spoon Butte and the adjacent buttes to the south, Adams (1902: pl. 3) was the first to map and clearly illustrate the topographic trends of the northern and southern buttes. He published the first and, to date, the only photograph of the Carpenter Ranch beds, shown capping Deahl Butte (Adams, 1902: pl. VIa, Point of Rocks). Adams confirmed the ''Arikaree'' conglomerates as fluvial deposits, and he explained their occurrence at various topographic levels as explicit evidence of stream aggradation, in which ''the sediments en-

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TABLE 8
Mammalian Fauna of the Carpenter Ranch Formation, Goshen County, Wyoming, and Sioux County, Nebraska

Museum no.	Field no.	Family	Genus and species	Element(s)
Carpenter Ranch Formation				
UNSM 44800–44812	see table 3	Chalicotheriidae	*Tylocephalonyx* sp.	see text
UNSM 44813[a]	3999-77	Oreodontidae	*Merycochoerus magnus*	right mandible
UNSM 44814	6064-79	Oreodontidae	*Merycochoerus magnus*	partial right maxilla and postcranial fragments
UNSM 44815	6070-79	Amphicyonidae	*Daphoenodon* sp.	left mandible, m1-m3, partial p4
UNSM 44816	404-79	Camelidae	*Protolabis* sp.	metatarsals 3-4, fused
UNSM 44817	6119-79	Camelidae	*Michenia* sp.	right p2
UNSM 44818	6114-79	Camelidae	*Michenia* sp.	left calcaneum
UNSM 44819	6116-79	Oreodontidae	*Merychyus* sp.	partial symphysis, p2-3
UNSM 44820	8403-78	Dromomerycidae	*Aletomeryx gracilis*	right mandible, dp4-m1
UNSM 44821	8406-78	Moschidae	*Pseudoblastomeryx* sp.	right maxilla, M1-M3
UNSM 44822	6061-79	Canidae	*Phlaocyon leucosteus*	left maxilla, P3-M2
UNSM 44823	6072-79	Canidae	small borophagine	right mandible, m1-3
White River Beds				
UNSM 44824	8402-78	Hypertragulidae	*Hypisodus* sp.	left partial mandible, m1-3

[a]UNSM 44813–44819 and 44824 are from Merycochoerus Butte; UNSM 44820–44822 are from East Sturdivant Butte; UNSM 44823 is from Dog Jaw Butte.

croached upon the higher levels''. His chosen example was taken from Sturdivant Gap north to Spoon Butte (Adams, 1902: 17):

> The relation of these [conglomeratic] lenses is best seen in the locality of Spoon Butte, in the Patrick quadrangle, and for a short distance to the south. In the escarpment and lone hills north of Sturdivant's ranch, conglomerates [Carpenter Ranch Formation] are seen resting on Brule clay, or separated from it by a very thin bed of Arikaree sand. In Spoon Butte the lenses are coarse sandstones exhibiting a cross-bedded structure, and their occurrence is 400 ft above the lowest exposed portion of the Arikaree. In the intermediate localities the lenses occur at somewhat lower horizons and seem to justify perfectly the interpretation [of progressively aggrading fluvial deposits] here placed upon them.

If Adams had known of the fossil content of these conglomerates capping the buttes, he might have realized that separate fluvial systems were indicated, but paleontologists who visited the buttes at about the same time failed to note any fossil occurrences of significance.

O.A. Peterson (1907: 23) of the Carnegie Museum of Natural History (Pittsburgh) was the first paleontologist to report an attempt to find fossils in the caprock of Spoon Butte. He described the caprock as ''a hard pinkish-gray sandstone, 35–50 ft in thickness. In this hard cap of sandstone, which is regarded as the top of the Upper Harrison beds, our party found no fossils''. Peterson failed to find fossil mammals because the caprock itself is almost entirely barren of mammalian remains; only in the basal sands and gravels of the Spoon Butte beds at a few select localities do any mammalian fossils occur, and Peterson must have bypassed these sites. His allocation of the caprock to the Upper Harrison beds, today considered a unit of the Arikaree Group, suggests that he was aware of Adams' description of the Spoon Butte caprock as an Arikaree conglomerate.

Later, Peterson (1909: 74–75, fig. 27) reconsidered this opinion, suggesting that the

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age of the caprock might be as young as Pliocene, and again remarked on the absence of fossils. It was at this time that he named the caprock at Spoon Butte the ''Spoon Butte beds''. At about the same time, the paleontologist H.F. Osborn (1909: 73, fig. 14), in a survey of Cenozoic mammal horizons of western North America, included the caprock at Spoon Butte in the broadly construed Arikaree Formation of Darton, but apparently he was unaware of Peterson's suggestion of a much younger age.

The only published claim of anyone having found fossils at Spoon Butte occurred in 1956 when Paul O. McGrew of the University of Wyoming (in L. McGrew, 1963; also Rapp et al., 1957) collected ''waterworn fragments of Pliocene(?) horse teeth . . . found in gravels on top of Spoon Butte and other hills in T.27N., R.60W''. This statement appears to be the basis for later assignment of the Spoon Butte caprock to the Pliocene or late Miocene. A loose lag gravel does occur at a few localities on top of Spoon Butte, and it contains stream-rounded and abrasion-resistant Miocene mammal fossils, including fragments of equid teeth. However, this lag gravel is a much younger deposit than the basal Spoon Butte gravel, and it contains more diverse and exotic clasts, particularly acid volcanics (rhyolite) never found in the Spoon Butte sandstone caprock or in the basal Spoon Butte gravel.

In fact, the lag gravel on Spoon Butte has a complex history and is similar in composition to loose fluvial lag gravels mantling low hills, ridges, and stream terraces at much lower topographic elevations in the valleys adjacent to Spoon Butte (fig. 3, Quaternary terraces). These granitic gravels contain conspicuous amounts of both acid volcanics and chert in a matrix of loose quartz sand (table 1, Oberg gravels). Angular blocks of the Spoon Butte caprock contained in some of these gravels indicate that they postdate the Spoon Butte beds, a fact confirmed by teeth and bone fragments of late Miocene mammals in the gravel. On the George Oberg ranch, immediately east of the butte, a high terrace gravel deposit of this type (figs. 2–4, Oberg Quarries) yielded a single tooth of Pleistocene *Equus*, found with water-worn bones of Clarendonian mammals, indicating that late Miocene beds were once present in the region and were subsequently removed by erosion. These acid volcanic–bearing gravels derive from mid- and late Miocene deposits once present on the Hartville tableland that were reworked during the Pleistocene and Holocene into stream terraces and low hills that correspond to the present local topography.

The Spoon Butte caprock continued to be mistakenly regarded as Pliocene or late Miocene in age for the next two decades. Denson (1974) mapped the caprock of Spoon Butte as Ogallala Formation, at that time considered to be Pliocene or upper Miocene ''poorly cemented calcareous claystone, siltstone, sandstone, and conglomerate of fluviatile origin''. Whereas this quote adequately describes the lithologic character of typical Ogallala strata to the south, the Spoon Butte beds are characterized by silica-cemented sandstones and basal granitic/chert gravel and are thus lithically distinct from the Ogallala strata; evidently the Spoon Butte beds were not actually visited during the mapping. Crist (1977), in a hydrologic study of the area, followed Denson in showing the Spoon Butte caprock as Ogallala Formation of late Miocene age.

Love et al. (1980), in their compilation of the geology of the Torrington Quadrangle in southeastern Wyoming, indicated that the capping sandstone of Spoon Butte and the adjacent buttes of the northern butte line, the caprocks of the southern butte line (Carpenter Ranch beds), as well as similar sandstone butte caprocks east of and within the Hartville Uplift (Flattop, Sheep Mountain) were all of late Miocene age. They noted Denson's mapping of some of these as Ogallala Formation. No mention was made of the uniform, silica-cemented sandstone lithologic composition typical of these butte caprocks. It was only when mammalian fossils from Spoon Butte and the adjacent buttes to the south became available to UNSM paleontologists from 1977–1980 that their divergent ages became apparent.

Today we recognize that the northern caprocks on Spoon Butte and adjacent buttes of the northern trend are Barstovian (mid-Miocene) in age, and the caprocks of the southern buttes are early Hemingfordian (early

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Miocene). These areas represent two unrelated paleovalley systems separated by a significant interval of time. Late Miocene and younger sediments were deposited in the region east of the Hartville Uplift, and then nearly entirely removed by later erosion, so that the geographic distribution of these strata is difficult to reconstruct.

We now realize that silica-cemented capping sandstones of the numerous buttes east of, and within, the Hartville Uplift are of diverse ages. Nevertheless, insofar as is known, all fall within the Miocene. These caprocks record multiple episodic intervals of fluvial deposition, during which crystalline sands and gravels derived from the Laramie Mountains and Hartville Uplift were transported eastward to the bordering plains.

The provenance of the Carpenter Ranch gravels is of particular interest because, together with the gravels of the Runningwater Formation, the clast types indicate derivation from either the Precambrian core of the north-central Laramie Mountains or possibly from the southern Hartville Uplift. Archean granitic and gneissic rocks cut by numerous amphibolite dikes form the greater part of the northern and central Laramie Mountains (Condie, 1969; Sims and Day, 1999; Sims and Stein, 2003). To the south, these Archean rocks are bordered by the Proterozoic Laramie anorthosite body.

Archean granites of the northern Laramie Mountains are separated from an orthogneiss terrain to the south by the Laramie Peak shear zone (Condie, 1969; Chamberlain et al, 1993; Resor 1996; Sims and Day, 1999), also termed the Garret-Fletcher Park-Cottonwood Park shear zone (Snyder et al., 1995), which includes deformed granitic and gneissic rocks, quartzite, and amphibolite dikes. Mafic amphibolite dikes of the north-central Laramie Mountains often exhibit a relict igneous texture that characterizes Carpenter Ranch amphibolite clasts. Streams accessing the Precambrian core of the north-central Laramie Mountains are capable of transporting granitic/gneissic gravel with high amphibolite content. Sampling of surficial stream and pediment gravels east of the Laramie Mountains from the vicinity of Wheatland north to Esterbrook suggests that terrace gravel of the Laramie River north of Wheatland carries a granitic/amphibolite/anorthosite clast content most similar to that of the Carpenter Ranch Formation.

Mapping of Precambrian rocks of the southern Hartville Uplift (Millgate, 1965; Snyder, 1980; Sims et al., 1997; Sims and Day, 1999) identified a granite dome (Haystack Range) in contact with quartzofeldspathic schists, metadiabase/amphibolite dikes, and pegmatite east of the north-trending Hartville Fault. Metadolomite, metaconglomerate, schist, phyllite, maroon quartzite, and banded ironstone of the Precambrian Whalen Group occur west of the fault. Granite, gneiss and amphibolite in the Haystack Range are similar to Carpenter Ranch gravel, which lacks metasediments, despite proximity of the Whalen Group only 20 miles (~32 km) west of the Carpenter Ranch Formation. Arikaree sediments buried much of the Hartville Uplift in the early Miocene and it remains an open question as to what extent the southern part of the uplift was accessible to these streams.

Carpenter Ranch and Runningwater gravels are granitic in composition, with amphibolite (metabasalt, metagabbro) common, gneiss, chert and quartzite present, and anorthosite rare. Based on clast content, the provenance for these early Miocene gravels would seem to be the north-central Laramie Mountains. The Haystack Range possibly contributed during the Carpenter Ranch fluvial cycle, but lack of metasediments in the gravels favors the Laramie Mountains as the principal source. Scarcity of anorthosite clasts suggests that the streams originated in granitic terrain north of the Laramie anorthosite body.

The west-to-east stream-flow trend of the Carpenter Ranch Formation caprock belt is evident from topographic maps and satellite photoimages. Our field inspection of Carpenter Ranch outcrops from Duncan Buttes in Wyoming eastward to Carpenter Butte in Nebraska revealed a major paleochannel incised into the White River beds (fig. 24). It represents the deepest incision of the paleovalley and confirmed the west-to-east alignment of the paleotrend. The paleovalley then turns to the northeast upon entering Nebraska.

The easternmost exposures of the Carpenter Ranch Formation that we have identified oc-

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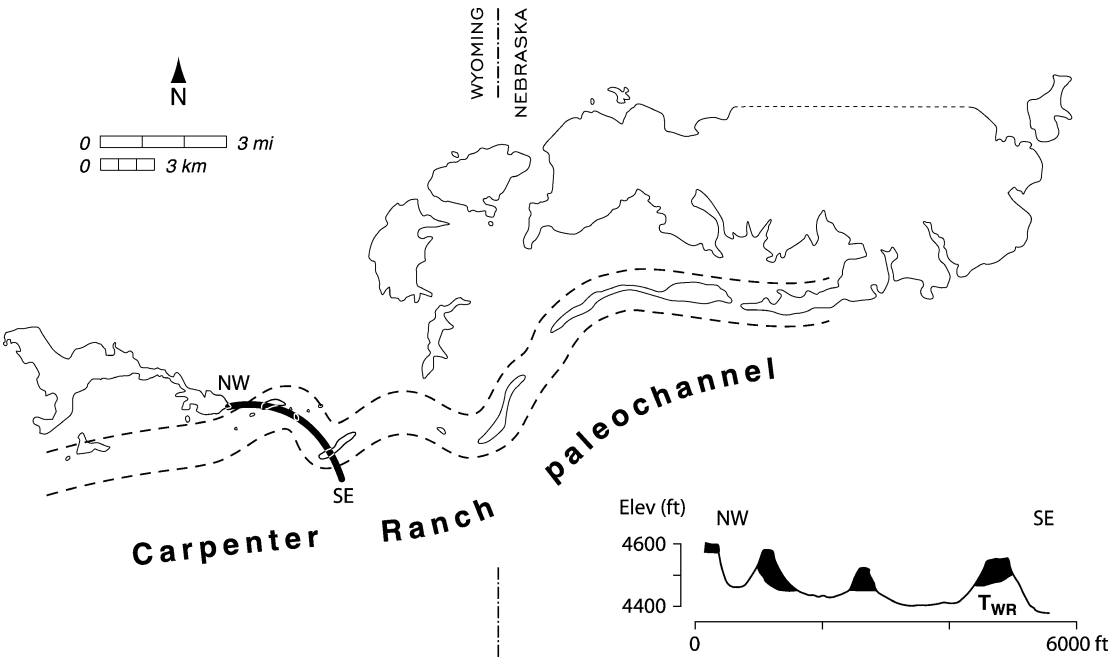

Fig. 24. Interpretive restoration of sinuous west-to-east trend of the Carpenter Ranch paleochannel axis incised into rocks of the White River Group, Goshen County, Wyoming, and Sioux County, Nebraska. Inset illustrates a typical northwest-to-southeast cross-section of the paleochannel from Duncan Buttes to Merycochoerus Butte.

cur at the northeastern limit of East Sturdivant Butte in the NE1/4, NE1/4, sec. 27, T27N, R57W (Agate SW 7.5-minute quadrangle). These outcrops indicate that the paleovalley has reoriented to a northeasterly course. At this locality, Carpenter Ranch outcrops disappear beneath Quaternary dune sands, which then blanket the landscape for ~10 miles to the northeast. When Miocene sediments eventually reappear beyond the dune field in the eastern half of T28N, R56W, granitic gravel and tuffaceous sandstones have been assigned to the Runningwater Formation and represent the westernmost outcrops of that rock unit currently recognized (Skinner et al., 1977). The mammals from tuffaceous sandstones of the lower Runningwater beds northeast of Agate are close in age to the Carpenter Ranch fauna and, together with the paleovalley trend, suggest that the Runningwater paleovalley identified by Skinner et al. (1977) is a direct continuation of the Carpenter Ranch trend (fig. 25).

The Carpenter Ranch mammals appear less advanced than those from the upper Runningwater granitic gravels and sands that yielded most of the classic Runningwater fauna to the east in Dawes and Box Butte counties, where most productive quarries have been located. However, the stratigraphically lowest sites in that area, such as Runningwater Quarry, show an affinity to the Carpenter Ranch fauna and to the fauna from lower Runningwater strata northeast of Agate. The evident similarity in age of the Northeast of Agate fauna to the Carpenter Ranch mammals suggests that the pale orange-brown tuffaceous sandstones northeast of Agate are a fine-grained sedimentary equivalent of the Carpenter Ranch fluvial sands and gravels, the two lithofacies together representing the earliest deposits of the Runningwater/Carpenter Ranch paleovalley system established in the earliest Hemingfordian of the central Great Plains.

POST-LARAMIDE EVOLUTION OF THE ROCKY MOUNTAINS

Coarse epiclastic debris dispersed by post-Laramide fluvial systems into the mid-con-

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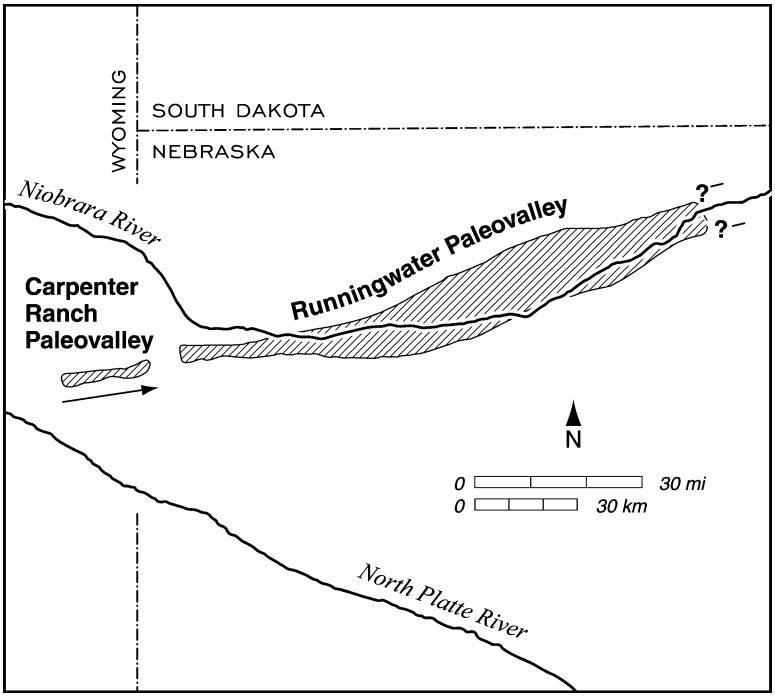

Fig. 25. Alignment of the Carpenter Ranch and Runningwater paleovalley systems in southeastern Wyoming and western Nebraska. Fossil mammals in these early Miocene fluvial sediments indicate an early Hemingfordian age.

tinent documents a mid- to late Cenozoic record of episodic uplift of the adjacent Rocky Mountain ranges. Mammalian fossils preserved in the sedimentary fill of major paleovalleys emerging from the uplifts in southeastern Wyoming, northeastern Colorado, and western Nebraska provide the basis for a highly resolved tectonic chronology. These paleovalleys are often identified by a reversed topography of geographically aligned butte caprocks, forming conspicuous linear trends within and east of the uplifts. Recovery of mammalian faunas from the Carpenter Ranch and Spoon Butte paleovalleys in southeastern Wyoming demonstrated unexpected ages for two such fluvial systems. Similar fluvial trends east of the Laramie Mountains and Hartville Uplift could also represent more diverse ages than previously supposed. Many remain to be examined for biochronologically useful faunas.

The oldest widely recognized post-Laramide fluvial activity east of the Laramie Mountains begins in the late Eocene with widespread sands and gravel of the White River Group (Stanley, 1976). Following this initial pulse of coarse granitic debris from the Laramie Mountains, transported eastward by basal White River channels of Chadronian age, no significant evidence of regional uplift recurs until the initiation of late Oligocene stream incision, evidenced by basal Arikaree paleovalleys flowing eastward from the Laramie Mountains and Hartville Uplift (Vondra et al., 1969; Swinehart et al., 1985). Early Arikareean mammals and $^{40}Ar/^{39}Ar$ radiometry (~28.1–28.3 Ma) date this tectonic event (Tedford et al., 1996). Removal of a considerable volume of lower Arikaree Group strata by late Arikareean incision is documented by east-northeast trending paleovalleys in western Nebraska at Wildcat Ridge (Vondra et al., 1969) and along the Niobrara River at Agate National Monument (Hunt, 1985b). At the latter locality both mammals and an $^{40}Ar/^{39}Ar$ date of 22.9 ± 0.08 Ma (Izett and Obradovich, 2001) establish the approximate time of regional inci-

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sion, and deposition of the Harrison Formation.

Fine-grained sheetlike sediments of the Arikaree Group continued to accumulate east of the Laramie and Hartville uplifts, represented by the Anderson Ranch Formation (Hunt, 2002). These sediments incorporate a significant eolian tuffaceous component with latest Arikareean mammals. Only a single major paleovalley (fig. 3, Lay Ranch beds) within the Anderson Ranch Formation has been recognized and mapped; it deeply incises undifferentiated Arikaree rocks at Spoon Butte in southeastern Wyoming (Hunt, 1985a, 1990). This valley, emerging from the vicinity of the southern Hartville Uplift, carried fine-grained tuffaceous fluvial sands and silts with only minor amounts of epiclastic granitic sand and granule gravel. The scarcity of latest Arikareean paleovalleys on the Hartville tableland suggests that this was a tectonically quiescent interval. The granitic cores of the mountains to the west were likely nearly buried by tuffaceous Arikaree strata, evidenced today by the onlap of the Anderson Ranch Formation on the granites of the Hartville Uplift (Hunt, 2002: fig. 1) and by residual Arikaree deposits bordering the Laramie Mountains.

The conclusion of Arikaree deposition east of the Hartville Uplift at ~19 Ma is evidenced by the development of multiple siliceous paleosols found throughout the upper part of the Anderson Ranch Formation (previously Upper Harrison beds of Hunt, 1990: figs. 7, 8, 10). Densely packed, fine siliceous rhizoliths of uniform diameter (0.5 mm) form highly anastomosed root networks in these paleosols typical of grasslands. The rhizolith networks are restricted to level geomorphic surfaces that can be traced over 1200 km^2 east of the Hartville Uplift, demonstrating the regional extent of these early Miocene grasslands. However, Arikaree deposition continued into Hemingfordian time in central Wyoming (Split Rock Formation, Love, 1970; Munthe, 1988) and eastward in the vicinity of the Laramie Mountains (McGrew, 1963). An $^{40}Ar/^{39}Ar$ date (17.4 ± 0.08 Ma, Izett and Obradovich, 2001) and mammal fauna from the Split Rock Arikaree outcrops of Munthe (1988) indicate a medial Hemingfordian age.

Evidence of a major early Miocene tectonic event involving regional uplift of the Laramie Mountains and Rocky Mountain Front Range is documented by the appearance of paleovalley systems of early Hemingfordian age (fig. 26) carrying coarse granitic debris into the central Great Plains (Skinner et al., 1977; Hunt, 1985a; Flanagan and Montagne, 1993; Tedford, 1999). Trending east-northeast from the mountains, a northern paleovalley transporting sediments of the Carpenter Ranch and Runningwater Formations traverses southeastern Wyoming and continues into western Nebraska. The gravel composition of this system is chiefly granitic, lacking any evidence of rhyolitic or other acid-volcanic clasts (Yatkola, 1978; Hunt, 1985a). To the south in northern Colorado, a second major system represented by sediments of the Martin Canyon Formation (Scott, 1982; Tedford, 1999) follows a similar direction across northeastern Colorado. Here the lithic composition includes not only granitic debris, but also volcanic clasts (rhyolite, andesite), indicating a source in the Rocky Mountains involving the Never Summer Range–Specimen Mountain volcanics (Wahlstrom, 1944; Corbett, 1968).

These paleovalleys contain earliest Hemingfordian mammal faunas that firmly establish their contemporaneity and allow the sediments to be correlated with considerable precision. The occurrence of the large oreodont *Merycochoerus magnus* matches them with a third locale in the Rocky Mountains at Middle Park, Colorado, where early Miocene sediments of the Troublesome Formation overlie a weathered Cretaceous paleosurface (Izett, 1968). Evidently, regional uplift of the Front Range–Laramie Mountain axis initiated simultaneous deposition on both the western and eastern flanks of the range at ~18.2–18.8 Ma. It has not escaped our notice that the early Hemingfordian paleovalleys of the High Plains trend northeast, indicating a topographic gradient in that direction. The sediments of these early Miocene paleovalleys, primarily confined to the linear trend of the stream courses, differ in the lithologic composition of their axial gravels, which clearly reflect local source terrain in the mountains to the west. The early Hemingfordian valley fills are followed in time by mid- and late Miocene Ogallala sands and

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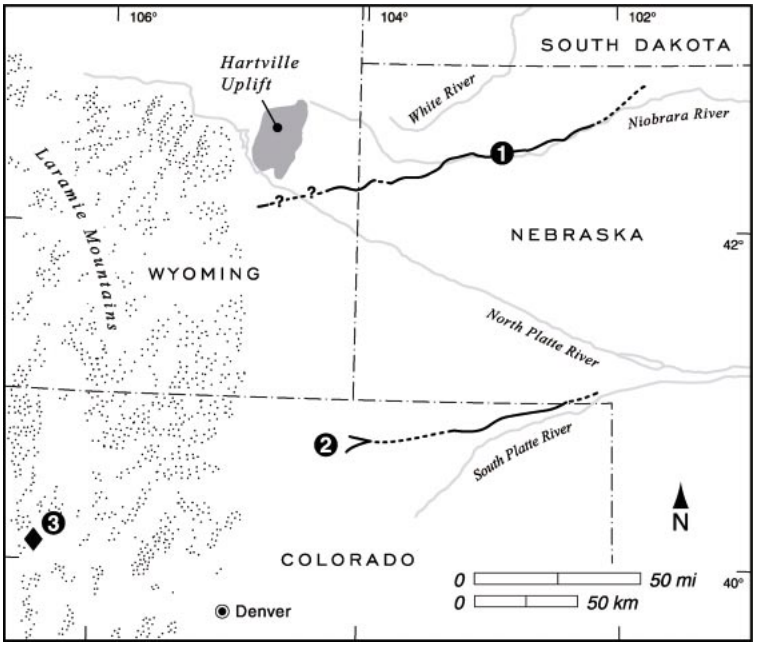

Fig. 26. Trend of early Miocene paleovalleys of early Hemingfordian age east of the Rocky Mountain Front Range and Laramie Mountains in Colorado, Wyoming, and Nebraska. Oldest mammal faunas in the valley fills document the initiation of regional uplift at ~18.2–18.8 Ma. **1,** Carpenter Ranch-Runningwater paleovalley; **2,** Martin Canyon paleovalley; **3,** Troublesome Formation basin-fill, Middle Park, Colorado.

gravels within paleovalleys and alluvial aprons derived from continuing regional uplift of the Rocky Mountain plateau.

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