

Lithostratigraphy, Biostratigraphy, and Magnetostratigraphy of Arikareean Strata West of The Continental Divide in Montana

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ABSTRACT

Arikareean strata exposed in several intermontane basins of western Montana are composed mostly of aeolian derived tuffaceous material deposited in fluvial, lacustrine, and paludal environments. Streams were principally aggrading; lakes were shallow, ephemeral and confined mainly to two adjoining basins; and swamps were very local with abundant plant material and occasional lignites. Bedded gypsum and gypsum cement in lacustrine strata indicate periods of dryness. Locally abundant invertebrate and vertebrate fossils are found mainly in fine-grained fluvial overbank, lacustrine, and lacustrine delta-fill deposits; logs, branches, and other large pieces of wood are found in fluvial channel deposits; leaves, wood, fusain, and other plant fragments are common in paludal deposits; and root traces and burrows are very common in all fluvial and paludal deposits and some lacustrine deposits.

The Arikareean strata are bounded by unconformities and have been subdivided into three biostratigraphic intervals using diagnostic mammalian and molluscan fossil assemblages. Mammalian assemblages and magnetostratigraphy data allow important correlations with Arikareean strata in the northern Great Plains and in the Columbia Plateau. The lithostratigraphy and fossil assemblages indicate climatic conditions with mild winters and alternating humid and semiarid seasons.

INTRODUCTION

Arikareean strata mapped west of the Continental Divide in western Montana (Fig. 1) have been collectively called the Cabbage Patch beds (Konizeski and Donohoe, 1958) and are known from numerous contiguous and isolated outcrops of tuffaceous strata in the Blackfoot, Flint Creek, Deer Lodge, and Divide intermontane basins (Douglass, 1899, 1901, 1903, 1909; Konizeski, 1957, 1965; Gwinn, 1960, 1961; Loen, 1986; Rasmussen 1969, 1973, 1977, 1989). These strata were once more widely distributed, having been deposited during the Arikareean within a single large depositional "basin" (proto-"Clark Fork Basin" as defined by Rasmussen, 1977), of which the four

present intermontane basins and their adjacent areas are structural and erosional remnants. The Cabbage Patch beds are time equivalent and similar in lithology and paleontology to strata assigned to the upper Renova Formation of the Bozeman Group in intermontane basins east of the present Continental Divide in western Montana (Fig. 2; Kuenzi and Fields, 1971; Fields, et al., 1985; Rasmussen, 2003, this volume), and correspond to "Sequence 3" of Hanneman and Wideman (1991) and Hanneman, et al. (2003, this volume). The Cabbage Patch beds, as a whole, are here considered a third-order stratigraphic sequence, but there may be considerable problems identifying finer internal fourth-order and fifth-order sequences using the current stratigraphic knowledge of the

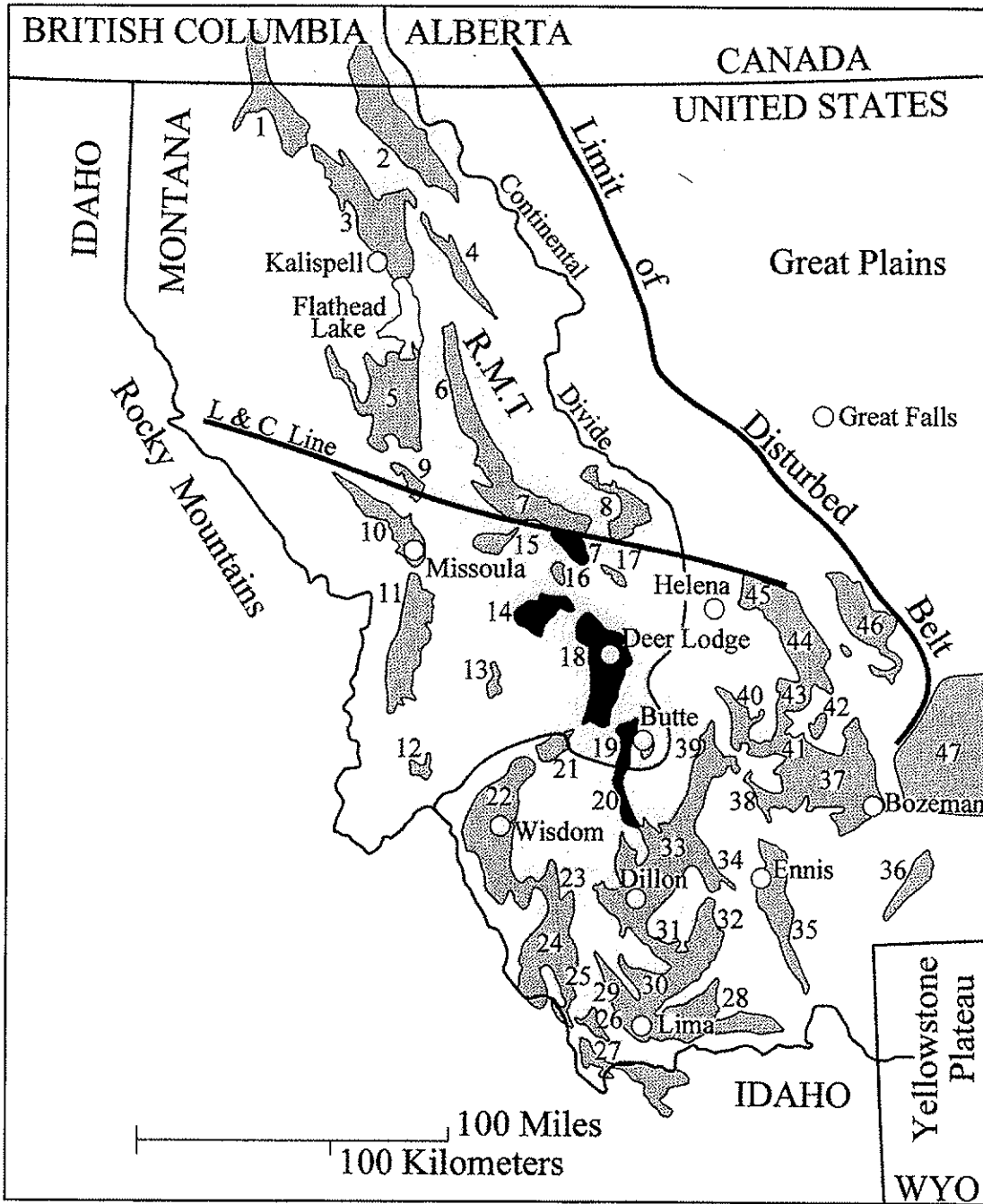


Figure 1: Index map of intermontane basins (valleys) in western Montana: 1. Tobacco Plains (Eureka); 2. Kischenehn (North Fork Flathead); 3. Flathead; 4. South Fork Flathead; 5. Mission; 6. Swan; 7. Blackfoot/Clearwater; 8. Lincoln; 9. Jocko; 10. Missoula; 11. Bitterroot; 12. E. Fork Bitterroot; 13. Philipsburg; 14. Flint Creek; 15. Potomac; 16. Douglas Creek; 17. Avon/Nevada Creek; 18. Deer Lodge; 19. Silverbow/Butte; 20. Divide; 21. French Gulch; 22. Big Hole; 23. Grasshopper; 24. Horse Prairie; 25. Medicine Lodge; 26. Muddy Creek; 27. Nicholia; 28. Centennial; 29. Red Rock River; 30. Sage Creek; 31. Blacktail Deer; 32. Upper Ruby; 33. Beaverhead; 34. Lower Ruby; 35. Upper Madison; 36. Upper Yellowstone; 37. Madison/Gallatin; 38. Norris; 39. Jefferson River; 40. North Boulder; 41. Three Forks; 42. Clarkston; 43. Toston; 44. Canyon Ferry; 45. Helena; 46. Smith River; 47. Crazy Mountain. Abbreviations: R.M.T., Rocky Mountain Trench (southern trend of); L&C Line, Lewis and Clark structural lineament. Continental Divide northwest of Wisdom, Montana follows Montana-Idaho state line to Wyoming border, and then enters Yellowstone Plateau. Basins with Arikareean Cabbage Patch strata are indicated by the dark solid color.

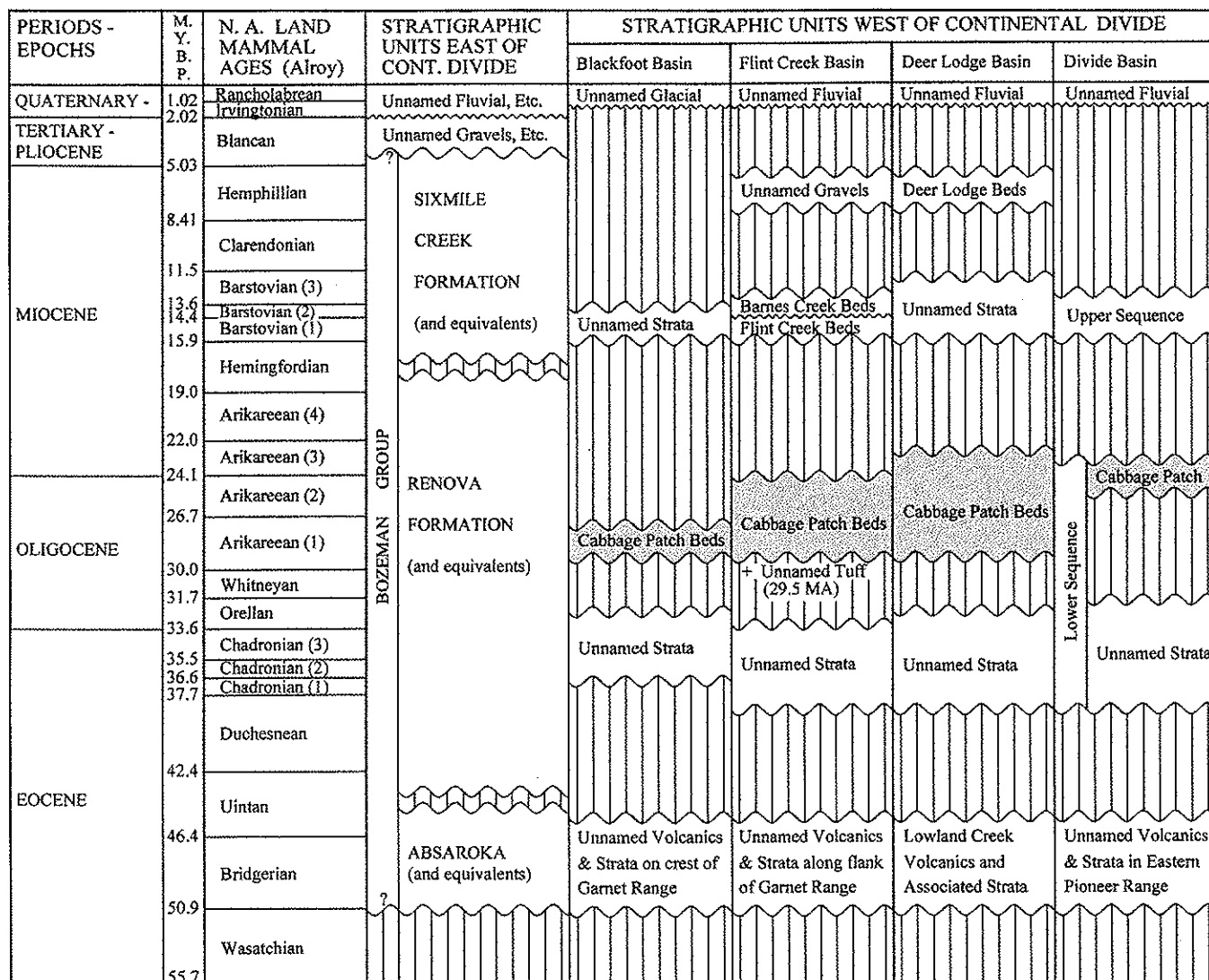


Figure 2: Correlation chart showing the distribution, stratigraphic position, and time relationship of the Cabbage Patch beds in four Cenozoic basins of central-western Montana. Modified from Fields, et al., 1985, Rasmussen, 1989, and Rasmussen, 2003, this volume. Arikareean Cabbage Patch Beds are highlighted by shading.

Cabbage Patch beds. For this paper, strata assigned to the Cabbage Patch beds will still be lithostratigraphically considered as part of the upper Renova Formation (as defined by Kuenzi and Fields, 1971, and as used by Rasmussen, 2003, this volume), and the name "Cabbage Patch beds" will still be used as a local name for Arikareean tuffaceous strata in the four intermontane basins west of the present Continental Divide in central-western Montana. Similar studies for older stratigraphic units east of the Continental Divide in Montana have been reported and reviewed by Tabrum, Prothero and Garcia (1996).

The Arikareean Cabbage Patch strata in the Divide, Deer Lodge, Flint Creek and Blackfoot intermontane

basins west of the Continental Divide in west-central Montana provide an excellent lithostratigraphic example of the varied sedimentologic, stratigraphic and paleontologic characters of a Tertiary stratigraphic sequence in western Montana.

LITHOSTRATIGRAPHY

As seen in and summarized from scattered outcrops (Figs. 2, 3), Cabbage Patch strata in the four intermontane basins are tilted, folded, faulted, and deeply eroded. The strata unconformably onlap an irregular topography of Precambrian to Mesozoic

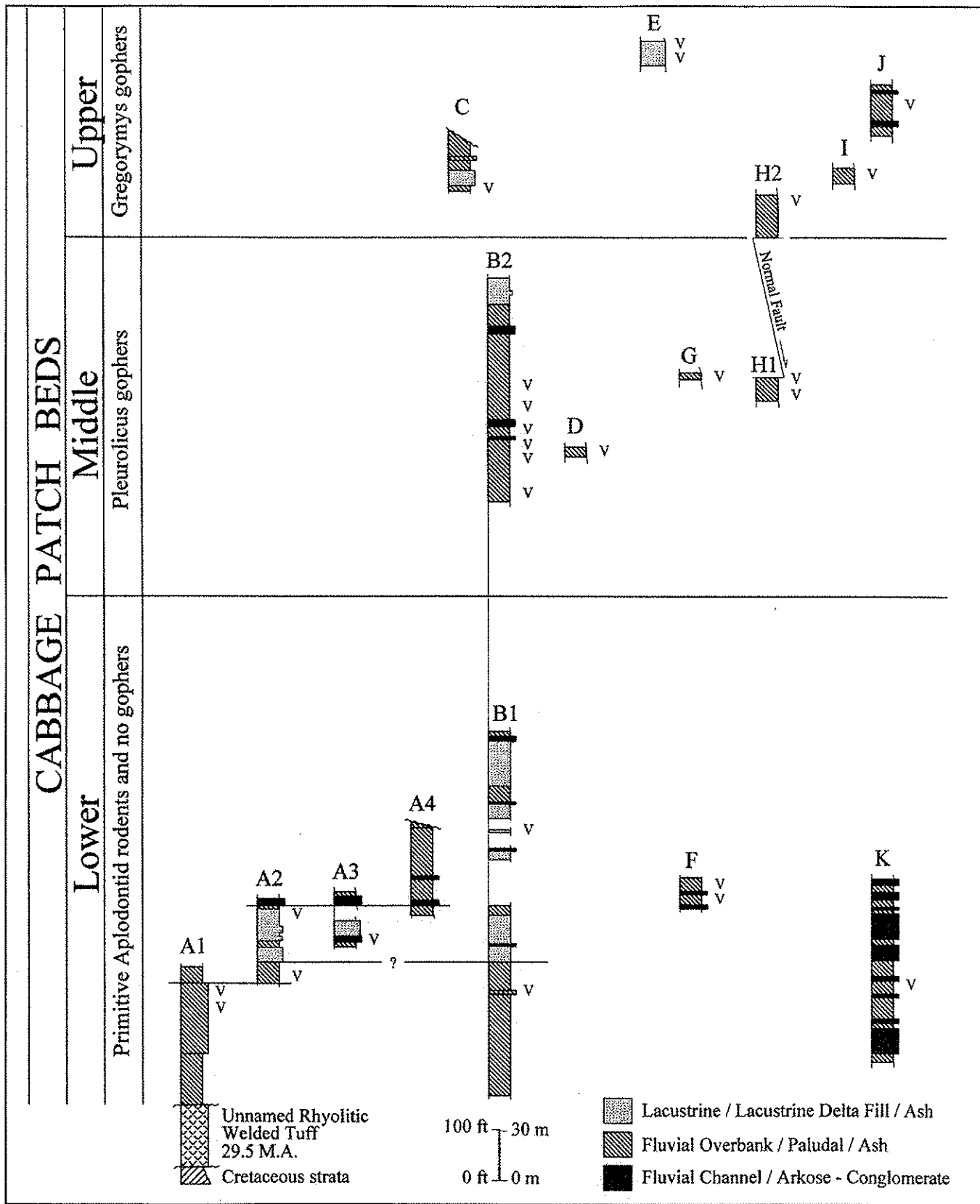




Figure 3: Summary of stratigraphic sections measured in the Flint Creek Basin (A-D), Deer Lodge Basin (E-H), Divide Basin (I, J), and Blackfoot Basin (K) showing mammalian biostratigraphic subdivisions and generalized depositional environments of the Cabbage Patch beds. Covered intervals are left blank. Vertebrate fossil horizons indicated by the letter "V". Modified from Rasmussen, 1977, 1989.

strata and locally onlap erosional remnants of older Tertiary strata (unnamed Eocene and Oligocene strata) and volcanics (Eocene Lowland Creek volcanics and strata, and an early Arikareean welded tuff and lahar deposit at the base of the Cabbage Patch strata). An angular unconformity ("mid-Tertiary unconformity") is present between the Cabbage Patch strata and the overlying late Miocene Flint Creek and Barnes Creek beds in the Flint Creek Basin, and unnamed late Tertiary and Quaternary strata unconformably onlap the Cabbage Patch strata in parts of the Blackfoot, Deer Lodge, and Divide basins (overlying Tertiary strata are equivalent to the Sixmile Creek Formation east of the Continental Divide). The upper contact of the Cabbage Patch strata is strictly erosional and at good exposures there does not appear to be significant weathering (with pedogenic clays) or an equivalent to the calcic paleosol reported at the upper boundary of "Sequence 3" east of the Continental Divide by Hanneman and Wideman (1991). Almost all of the outcrops of Tertiary strata with calcic paleosols reported by Hanneman, Wideman and Halvorson (1994) in the Deer Lodge Basin are post-Arikareean or remain undated (Hanneman, 2002, personal communication) and at this time none have been directly tied to the dated Arikareean Cabbage Patch beds that do contain calcic paleosols as identified and described in the northern part of the basin by Rasmussen (1977). In the northern part of the Flint Creek Basin, composite stratigraphic sections of Cabbage Patch strata approximate 700 meters, and an additional several hundred meters may have been removed by post-depositional erosion. Because of poor exposures, the top of the very youngest Cabbage Patch strata have not been measured in the Gold Creek area between the Deer Lodge and Flint Creek basins that contain the youngest Arikareean fossils, precluding the determination of the upper age limit and composite thickness for the Cabbage Patch strata. It is therefore uncertain when deposition of Cabbage Patch strata terminated in the latest Arikareean or earliest Hemingfordian west of the Continental Divide.

The Cabbage Patch strata are dominated by fresh volcanoclastics and montmorillonitic mudstones. These tuffaceous strata are usually poorly bedded

because of deposition and re-working in fluvial environments and the subsequent intense bioturbation by plants and invertebrates. Lacustrine, lacustrine delta fill, and paludal deposits are well-bedded, contain thin pure ash beds, and locally may be highly fossiliferous with plants, invertebrates, and vertebrates. Conglomerates, arkose, and other coarse clastics are locally derived and occur as scattered lenses throughout the entire Cabbage Patch stratigraphic sequence, and none appear to mark boundaries for finer (fourth-order or fifth-order) parasequences.

Disjunct structural and erosional remnants of Cabbage Patch strata in the present Blackfoot, Flint Creek, Deer Lodge, and Divide intermontane basins were all part of a larger depositional area now separated by Neogene faulting and erosion. Lacustrine strata in the Flint Creek Basin and northern Deer Lodge Basin (Gold Creek area) extend to the erosional limits of the Cabbage Patch strata in these areas, suggesting that some of the lakes in which the strata were deposited were large in size within the basin of deposition. However, the absence of even a single thick continuous section of lacustrine strata suggests that the lakes were ephemeral, perhaps lasting only a few thousand years at best. Lacustrine intervals within the Cabbage Patch strata are thin compared to fluvial intervals, and the oldest lacustrine strata recognized in the Flint Creek Basin occur well above the base of the Cabbage Patch strata. Some lacustrine stratigraphic intervals can be traced for several kilometers, but individual beds within the intervals usually cannot be traced beyond a few hundred meters. From the aquatic mollusks and associated aquatic fauna and flora, Pierce (1993) concluded that the lakes were "shallow, sub-permanent to permanent (several thousand years maximum), probably soft bottomed and well vegetated, and experiencing seasonal desiccations". Studies of the Cabbage Patch strata indicate that streams were principally aggrading; lakes were shallow, ephemeral and confined mainly to two adjoining areas; and swamps were very local with abundant plant material and occasional peat deposits (later becoming lignites). Bedded gypsum and gypsum cement in lacustrine strata indicate periods of dryness and the presence of playa lakes. Locally abundant

invertebrate and vertebrate fossils are found mainly in fine-grained fluvial overbank, lacustrine, and lacustrine delta-fill deposits; logs, branches, and other large pieces of wood are found in fluvial channel deposits; leaves, wood, fusain, and other plant fragments are common in paludal deposits; and root traces and burrows are very common in all fluvial and paludal deposits and some lacustrine deposits.

Lateral and vertical variations in physical, chemical, and paleontological characters occur throughout the Cabbage Patch strata. Lateral changes indicate deposition was contemporaneous in different environments, and changes in an upward direction indicate that environments, at any given place, changed through time (Rasmussen, 1977, 1989). From the observed physical, chemical, and paleontological characters, an environment of deposition was determined for each lithologic unit in the eleven stratigraphic sections measured in the four intermontane basins. This resulted in six basic types of depositional environments being recognized repeatedly throughout the measured sections: fluvial channel, fluvial overbank, lacustrine, lacustrine delta fill, paludal, and aeolian (undisturbed ash falls). As observed in the stratigraphic sections measured in the Flint Creek Basin, Cabbage Patch strata were predominantly fluvio-lacustrine in origin with fluvial strata four-to-five times as abundant as lacustrine strata; paludal and aeolian strata account for approximately three percent of the total Cabbage Patch strata. Lacustrine strata were mainly deposited in an area that includes parts of the present Flint Creek Basin and northern Deer Lodge Basin, and lacustrine strata are unknown and possibly absent or eroded away in the Divide and Blackfoot basins.

The greater volume of overbank deposits as compared to channel deposits (approximately 5:1 for the Cabbage Patch sediments in the Flint Creek Basin) suggests a high-suspended load capacity for the streams flowing into and through the basin of deposition. Poor sorting of the channel and overbank sediments indicates low-energy environments. Thus, the streams (rivers) flowing into and through the basin of deposition were probably small-to-medium in size, low in velocity, shallow, and principally aggrading. Abandonment of channels (avulsion) possibly occurred whenever the stream overflowed. This situation perhaps accounts for the limited areal extent of the channels and the rarity of multi-story channel deposits; however, thick sandstone sequences seen in a measured section in the Blackfoot Basin may be

considered multi-story. Avulsion probably was more common during or immediately following periods of extensive aeolian ash fall deposition. Streams that eroded and carried the newly deposited unconsolidated tuffaceous material would become overloaded and aggradational processes would be greater than the stream's ability to maintain its channel. During avulsion, coarse sediments in the channel may not have been moved by the stream and thus were buried at the bottom of the abandoned channel. With each new deposit of tuffaceous material on the floodplain there was extensive reworking and bioturbation mainly by vegetation and some by burrowing invertebrates and vertebrates, and occasionally the development and preservation of paleosols. With continued deposition a new stream course would be established to replace the previously abandoned channel but not always in exactly the same position. Eventually each new stream would cut a new channel into the underlying deposits and coarser clastics (arkose and gravels) would once again be moved from the upland areas and into the basin of deposition. Shallow lakes and ponds probably developed on the low deposition plain between previous channels.

Paleosols are common throughout the observed Cabbage Patch stratigraphic intervals and are most obvious by the preservation of abundant root molds and casts. The paleosols in the Cabbage Patch strata are pervasive but should not be considered to be stacked, are not so dominated by calcite to be considered limestones, but rather those with abundant calcite should be considered as calcretes, are not so dominated by silica cement as to be considered silcretes, and are not related to any unconformity surface (or parasequence boundary) within or at the top of the Cabbage Patch beds. Not to be confused with paleosols are case-hardened beds of a few centimeters to a meter in thickness and sometimes found in groups of several meters in thickness in exposures of the Cabbage Patch in the Flint Creek Basin. These case-hardened beds are common on sun-facing exposures where seasonal and storm-related wetting and drying has altered specific components within the Cabbage Patch beds. These case-hardened beds extend back into the outcrop for only a few centimeters to perhaps a meter and are usually composed of fine-grained silty and sandy strata highly cemented with opal and/or chalcedony and calcite, and with the unaltered strata behind the hardened beds containing abundant glass shards, marl and/or fossil shell debris. Years of alternating wetting and drying

of these strata has mobilized the silica from the glass shards and the calcite from the marl or shell debris to cement the stratum into something that appears much like a hard cherty or opalized limestone bed at first glance. Fossils that are common in the unaltered stratum disappear or appear highly replaced in the case-hardened stratum or are only represented by hollow molds. Where numerous beds occur in the same exposure they can be easily misidentified as a stacked sequence of lacustrine limestones or terrestrial paleosols, with the original environment of deposition of the beds something totally different.

The silt- to sand-sized glass shards in the Arikareean Cabbage Patch strata are fresh, which in the absence of vertebrate fossils can be used to initially identify isolated outcrops of Arikareean strata from similar-looking older Tertiary strata that contain only devitrified glass shards. Volcanic sources for this large amount of volcanoclastic debris have not been individually identified, but most material probably came from volcanoes far to the west (ancestral Cascade Mountains: Larson and Evanoff, 1998; Rasmussen, 2003, this volume) or the southwest contemporaneous large calderas in the northern Great Basin, with less material from more local sources, such as Crater Mountain (Melson, 1971) and Helena Field areas (Chadwick, 1978, 1985). Rhyolitic welded tuffs and associated lahar deposits underlying and perhaps intertonguing with the very basal Cabbage Patch strata east of Drummond probably originated several kilometers north of the Flint Creek Basin in the Crater Mountain area (Rasmussen, 1969; Melson, 1971; Chadwick, 1978, 1985). Tuffs and lahar deposits are not found interbedded with subsequent Cabbage Patch strata (Rasmussen, 1977).

Arkose found in channel sandstones was definitely derived from the nearby Boulder Batholith, and there is a clear decrease in pebbles and pebble size in the conglomerates to the west and northwest of the exposed batholith. This indicates that streams flowed west and/or northwest from the Boulder Batholith and into the area of Cabbage Patch deposition, including the present Divide, Deer Lodge, Flint Creek and Blackfoot basins. The outlet of the basin of deposition is unknown, but possibly was northward through the southern Rocky Mountain Trench in northwest Montana and eventually into a tributary of the ancestral Columbia River system or into a drainage system leading to Hudson Bay and the Labrador Sea in eastern Canada. There also might not have been an outlet as suggested by Pierce (1993)

who concluded, from his analysis of western Montana fossil aquatic mollusks, that "western Montana had not been part of an integrated system of through-flowing rivers for some period of time prior to the deposition of the Cabbage Patch strata and, although local permanent water may have existed, these ... basins must have been part of a basin of interior drainage ...".

BIOSTRATIGRAPHY

Taphonomy and Paleoecology of Arikareean Fossils

Most plant, invertebrate, and vertebrate fossils in the Cabbage Patch strata occur in fine-grained fluvial overbank, lacustrine, and lacustrine delta fill sediments. Only logs, branches, and smaller pieces of wood and, very rarely, waterworn bone or tooth fragments have been found in the sandstones and conglomerates. Leaves, wood, fusain, and other plant fragments are common in paludal strata but are less common in other types of strata. Diverse assemblages of fossils were the result of mixing and transportation; however, few remains were moved very far (except perhaps when in fluvial channel situations). Plant material and leaves may have moved the farthest since they were easily moved by flowing water and wind. Trace fossils, mainly root traces and burrows (hollow or filled), are very common in fluvial deposits. Burrowing by crayfish, insects, and other invertebrates, and estivating amphibians, and tunneling by earthworms, insects, moles, and rodents were not specifically identified but probably contributed to the common bioturbation seen in the Cabbage Patch strata.

Plants found in the Cabbage Patch strata are highly varied and range in size from microscopic diatoms to large logs (Table 1). No special effort was made to systematically collect the fossil flora from the Cabbage Patch strata, and only a few types of plants have been identified. Florules described from nearby slightly older Tertiary strata are diverse and have been extensively studied by Dr. Charles N. Miller, Jr. and his students at the University of Montana in Missoula. All of the wood fragments (logs, branches, etc.), seeds, leaves, and fusain found in the Cabbage Patch strata were transported to their burial site. No fossil stumps of trees were found, but large root traces and burrows seen in several fine-grained fluvial intervals indicate the probable common presence of trees. Local paleosols contain concentrated masses of root casts and on outcrop they may be cemented in

the tuffaceous rock matrix with calcite and silica, but the cement does not form the dominate rock type. Fossil wood is commonly opalized or carbonized, and the leaves, seeds, and other small unburned plant fragments have been compressed into thin carbonaceous films or oxidized away leaving faint impressions of their former presence. Burned wood fragments represented by fusain are usually uncompressed, occur in many different stratigraphic intervals, and are easily overlooked. Small beads of amber are rare and occur mainly in paludal deposits and lignites.

Invertebrate fossils are the most common fossil type found in the Cabbage Patch strata and are dominated by mollusks and ostracodes (Table 2). Mollusks are usually broken and fragmental, but locally, abundant complete shells are very well preserved with little evidence of transportation prior to final burial. At a few localities gastropods can be easily washed from weathered or poorly consolidated tuffaceous rock matrix and numerous complete shells can be obtained. In some intervals large aquatic gastropod shells have sediment plugs in their apertures and the empty upper whorls point upward. Usually these sediment-free whorls contain loosely packed juvenile gastropods, ostracodes, sponge spicules, charophytes, diatoms, and other fossil debris. The ostracodes and small gastropods can be picked directly from the hollow whorls with a small wet brush. Both valves of individual ostracodes are usually articulated and when broken apart in a drop of water on a glass slide, numerous diatoms can be found in the hollow interior. Several of the gastropods were also found to contain numerous short sections of tiny calcareous fluted tubes, perhaps from the calcified stems of a tiny aquatic plant. One would therefore interpret that the gastropods died in a quiet aquatic environment, that some of the gastropods were partially filled with gases which provided buoyancy and resulted in the whorls pointing upward in the standing water, and that ostracodes, diatoms, and other organisms occupied or were washed into the interior of the gastropods prior to their being encased in the ooze of tuffaceous mud on the bottom of the lake. Pierce (1992 and 1993), Pierce in Pierce and Rasmussen (1992) and Pierce in Pierce and Constenius (2001) has described all of the known Cabbage Patch mollusks and has provided important conclusions concerning environments of deposition, climate, drainage, biostratigraphy, biogeography, etc. Calcareous deposits, resulting from the abundance of invertebrates and calcareous algae, provided a buffered environment

Table 1

LIST OF PLANT GENERA FOR THE THREE
SUBDIVISIONS OF THE CABBAGE PATCH BEDS
Modified from Rasmussen (1977, 1989)

Taxonomy	Cabbage Patch Beds		
	L	M	U
Diatomophyceae (diatoms)			
Centrales			
?Melosira			x
Pennales			
(several unidentified forms)	x	x	x
Algae (charophytes)			
Characeae			
(several unidentified forms)	x	x	x
Gymnospermae			
Pinaceae			
Pinus (pine)	x	x	x
Taxodiaceae			
Sequoia (sequoia)	x	x	x
Angiospermae			
Typhaceae			
Typha (cattail)	x	x	x
Fragaceae			
Quercus (oak)	x	x	x

that allowed excellent preservation of the calcareous invertebrates and algae, vertebrate bones and teeth, and bird eggshell.

The common presence of fossils of aquatic mollusks, other aquatic invertebrates, and fish in the lacustrine intervals throughout most of the Cabbage Patch stratigraphic sequence suggests that the lakes were continuously fed by streams and rarely became saline, brackish, or alkaline during their ephemeral history. It is only in the top of the Cabbage Patch sequence in the Flint Creek Basin that evaporites (gypsum) were found to locally occur in the lacustrine intervals. The evaporite intervals are thin, and there does not appear to have been any significant disruption of the aquatic invertebrate and fish faunas in the subsequent lacustrine environments. Other evaporites (halite, natron) of the playa deposits may have been removed by later dissolution.

Vertebrate fossils are usually fragmental and disassociated, suggesting they were scavenged or ingested by carnivorous mammals and raptorial birds, although several partial and complete skeletons have been recovered (Table 3). Remains of small mammals are the most common vertebrate fossils recovered from the Cabbage Patch strata, and in decreasing

Table 2

LIST OF INVERTEBRATE GENERA FOR THE THREE
SUBDIVISIONS OF THE CABBAGE PATCH BEDS
Modified from Rasmussen (1977, 1989),
Pierce and Rasmussen (1992), Pierce (1992,
1993), and Pierce and Constenius (2001)

Taxonomy	Cabbage Patch Beds		
	L	M	U
Demospongiae (fresh water sponges)			
Monaxonida			
Spongillidae gen. sp. indet.	x	x	x
Gastropoda (aquatic and terrestrial)			
Oreohelicidae			
Oreohelix	x	x	x
Helminthoglyptidae			
Monadenia?			x
Valvatidae			
Valvata	x	x	
Viviparidae			
Viviparus		x	
Lymnaeidae			
Lymnaea	x	x	x
Planorbidae			
Planorbula	x	x	
Biomphalaria	x	x	x
Pupillidae			
Gastrocopta	x	x	x
Vertigo	x	x	x
Pupoïdes	x		x
Columella			x
Succineidae			
Catinella?	x		x
Valloniidae			
Vallonia	x	x	x
Zonitidae			
Nesovitrea	x		
Limacidae			
Deroceras	x	x	x
Punctidae			
Punctum	x		
Ammonitellidae			
Polygyroidea	x	x	x
Pelecypoda (pelecypods)			
Sphaeriidae			
Sphaerium		x	
Crustacea (ostracodes)			
Cypridae			
Cypris	x	x	
Cyprinotus	x	x	x
Candona	x	x	x
Cyclopyrididae			
Cyclopyris			x
Cypria			x
Ilyocyprididae			
Ilyocypris	x	x	x

order, the remains of frogs and other amphibians, large mammals, fish, reptiles, and birds are the other types recovered. The bones and teeth usually occur randomly scattered throughout certain stratigraphic units of the Cabbage Patch strata. Concentrations of vertebrate fossils by fluvial methods are almost non-existent; however, at one remarkable deposit, uncountable specimens (mostly bones of frogs and small mammals) have been concentrated into cross-bedded one-to-four inch thick lenticular beds, which form dark bands across the face of the outcrop.

Vertebrate remains are also sometimes found in concentrations that are clearly coprolites of carnivores or regurgitated "pellets" of raptorial birds. The coprolites contain remains of fish, amphibians, and/or mammals, usually roughly retain the shape of the original feces, and can clearly be distinguished from the surrounding rock matrix by having a darker color and a chalky texture. Teeth, original bone fragments, fine particulate bone, organic matter, and gas bubbles are still preserved in the coprolites. Bones found in the larger coprolites are very fragmental and the type of animal that was devoured usually cannot be distinguished unless ends of bones, jaws, or teeth are also included. Carnivore types that provided most of the coprolites found in the Cabbage Patch strata include coyote- and small fox-sized canids, and bobcat- and cougar-sized felids (probably the saber-toothed cat *Pogonodon* found elsewhere in Arikareean deposits in Montana).

Concentrations of bones and teeth attributed to raptorial bird pellets usually lack the original shape of the pellet, and there is no clear discoloration of the area from the surrounding rock matrix. One such concentration contains the partial skulls, ramii, and post-cranial skeletons of at least four small jumping mice, with fragmentation of bones comparable to that seen in a modern hawk or owl pellet. Although remains of several birds have been recovered from the Cabbage Patch strata, none are of raptorial birds that probably made the pellets.

Skeletons of large mammals were almost always disturbed and rarely can one find parts of articulated skeletons. In one quarry site, the partial skull, ramii, and partial post-cranial skeleton of a large rhinoceros (*Diceratherium*), the skull and partial post-cranial skeleton of a large oreodontid (*Megoreodon*), and the partial skeleton of a small pleurolicine gopher (*Pleurolicus*) were all found together. The skull of the rhino was upside down and separated vertically eight inches above the ramii, which were found lying on their side. Other bones of the skeleton lay at various

Table 3

LIST OF VERTEBRATE GENERA FOR THE THREE
SUBDIVISIONS OF THE CABBAGE PATCH BEDS
MODIFIED FROM RASMUSSEN (1977, 1989)
AND HENRICI (1994)

Taxonomy	Cabbage Patch Beds		
	L	M	U
Pisces (Osteichthyes)			
Amiiformes			
Amia (bowfin)	x	x	x
Cypriniformes			
Gila (minnow)	x	x	x
Amyzon (sucker)	x	x	x
Perciformes			
Lepomis (sunfish)	x	x	x
Sciaenidae gen. sp.			
indet.(drum)	x	x	x
Amphibia			
Anura			
?Ascaphus (tailed frog)	x	x	x
?Scaphiopus (pelobatid toad)	x	x	x
Tephrodytes (pelodytid toad)	x	x	x
?Rana (large frog)	x	x	x
Urodela			
Taricha (Palaeotaricha) (newt)		x	
Plethodon (woodland salamander)		x	
Reptilia			
Chelonia			
Testudo (tortoise)	x	x	x
Gen. sp. indet. (pond turtle)			x
Aves			
Galliformes			
Palaeonossax (cracid)		x	
Charadriiformes			
Gen. sp. indet. (large dowitcher)		x	
Gen. sp. indet. (sandpiper)	x		
Mammalia			
Marsupialia			
Herpetotherium (opossums, four sp.)	x	x	x
Peradectes (opossums, two sp.)		x	x
Insectivora			
Ocajila (hedgehog)	x	x	
Stenoechinus (hedgehog)			x
Amphechinus (hedgehog)		x	x
Parvericius (hedgehog)		x	
Gen. sp. indet. (hedgehog)		x	
Mystipterus (mole)	x	x	
Proscalops (moles, two sp.)		x	x
Gen. sp. indet. (moles, two gen.)	x		
Domnina (shrews, two sp.)	x		x

Table 3 Continued

LIST OF VERTEBRATE GENERA FOR THE THREE
SUBDIVISIONS OF THE CABBAGE PATCH BEDS
MODIFIED FROM RASMUSSEN (1977, 1989)
AND HENRICI (1994)

Taxonomy	Cabbage Patch Beds		
	L	M	U
Pseudotrimylus (giant shrews, two sp.)	x		
Lagomorpha			
Palaeolagus (rabbit)	x		
Archaeolagus (rabbit)		x	
Megalagus (rabbit)	x		
Desmatolagus (pika)	x		
Gripholagomys (pika)			x
Rodentia			
Downsimus (aplodontid)	x		
?Allomys (aplodontid)		x	
Niglarodon (aplodontids, three sp.)	x	x	x
Meniscomys (aplodontid)		x	x
Gen. sp. indet. (aplodontid, new gen. A)	x		
Gen. sp. indet. (aplodontid, new gen. B)		x	
Gen. sp. indet. (aplodontid, new gen. C)		x	
Gen. sp. indet. (squirrel)	x	x	x
Gen. sp. indet. (flying squirrel)		x	
Pseudotharionomys (eomyid)	x	x	x
Gen. sp. indet. (eomyids, four sp.)	x	x	x
Pleurolicus (gophers, three sp.)		x	
Tenudomys (small gopher)		x	x
Gregorymys (gophers, three sp.)			x
Entoptychus (gopher)			x
Mookomys (pocket mouse)			x
Agnotocastor (beaver)	x		
Monosaulax (beavers, two sp.)		x	x
?Capatanka (beaver)		x	
?Euhapsis (beaver)			x
Eutyromys (beavers, two sp.)	x	x	
Gen. sp. indet. (new beaver)	x	x	
Leidymys (mice, two sp.)	x	x	x
Pacifulus (mouse)		x	x
Plesiosminthus (jumping mice, two sp.)	x	x	x
Parasminthus (jumping mice, two sp.)	x	x	x
Carnivora			
?Cynodesmus (coyote-sized canid)		x	
Gen. sp. indet. (small fox-sized canid)	x	x	x
Gen. sp. indet. (bobcat-sized felid)		x	

Table 3 Continued

LIST OF VERTEBRATE GENERA FOR THE THREE
SUBDIVISIONS OF THE CABBAGE PATCH BEDS
MODIFIED FROM RASMUSSEN (1977, 1989)
AND HENRICI (1994)

Taxonomy	Cabbage Patch Beds		
	L	M	U
Gen. sp. indet. (mink-sized mustelid)	x		
Gen. sp. indet. (weasel-sized mustelid)	x		
Perissodactyla			
Miohippus (three-toed horse)		x	x
Parahippus? (three-toed horse)			x
Diceratherium (large rhinoceros)	x	x	
Gen. sp. indet. (Hyracodon-sized rhino)	x		
Artiodactyla			
Gen. sp. indet. (peccary)	x		
Daeodon (medium-sized entelodontid)	x		
Kukusepasutanka (anthracothere)	x		
Megoreodon (oreodontids, two sp.?)	x	x	
Desmatochoerus (oreodontids, three sp.?)	x		
Gen. sp. indet. (small oreodontid)			x
Pronodens (small ruminants, two sp.)	x	x	x

angles next to the skull and ramii. The upright skull, humerus, calcaneum, innominate, and vertebrae of the large oreodontid were found together in a small area about (1.2 m) from the rhino. The partially articulated skeleton of the small gopher was found beneath the tusks of the rhino. Burial of the rhino and oreodontid was gradual over a period of time as seen by thin layers of finely laminated mudstone in the rock surrounding the skeletons; however, the deposition of mudstone was disturbed as seen by mudstone laminations broken and oriented in many different angles. Abundant small root burrows and occasional large root burrows (or crayfish burrows) are present throughout the rock matrix and cut across the disturbed laminated mudstone. The disarticulation of the skeletons of the rhino and oreodontid suggest that these animals were scavenged by large carnivores,

which separated and spread the bones from the carcasses, and the odd orientation of the bones and the disturbed mudstone suggest that the remaining bones were trampled down into the mud by the carnivores and other large mammals. The gopher probably died much later in its burrow beneath the buried ramii of the rhino, although evidence of the actual burrow was destroyed by the subsequent intense growth of roots through the mud and soil prior to lithification.

An articulated skeleton of another gopher was also found in a probable burrow. The curled up male gopher was found lying on his left side, the same position as at the time of death. After careful preparation of the unsquashed skeleton from its encasement of tuffaceous mudstone, it was observed that the posterior end of the sternum had been partially pushed outward and the right hind leg had been slightly extended, both probably the result of bloating shortly after death. The scapulae were shifted slightly backward, and the right humerus was disarticulated and lying diagonally across the right mandible and forearm, also probably the result of bloating. Bloating was not too severe as the rib cage is mostly intact and the baculum is close to its normal position and can be seen resting near the heel of the left foot. The pristine condition of the skeleton clearly suggests that the gopher died in a secluded place well away from insect and vertebrate scavengers (probably deep in the gopher's burrow). After death and prior to final burial, bloating caused some bones to be shifted out of position while the gopher's soft parts slowly decayed. Final burial within the burrow occurred before the gopher's skeleton could become entirely disarticulated during decomposition of the soft parts and connecting tissues, and burial was possibly the result of the gentle collapse of the burrow walls or the flooding of the burrow with water and sediment. The absence or lack of preservation of fossil root burrows in the rock matrix surrounding the skeleton is unusual, but may be related to the diagenesis of the fine-grained tuffaceous mudstone matrix, which somehow also precluded the preservation of the outline of the gopher's burrow.

Remains of small mammals in the Cabbage Patch strata appear to be many times more common than the remains of large mammals when one considers the entire stratigraphic section and all the localities visited in each of the intermontane basins west of the Continental Divide in Montana. Most bones and teeth of small mammals are found in strata that also have fossil mollusks or contain calcareous cement. Although the conditions were favorable for the

presence of large mammals, these same beds usually contained very few of their remains, thereby suggesting a collecting bias where collecting sites were those favoring the preservation of small mammal remains. Large mammals may have been common residents and/or migrants in the basins and mountains of western Montana during the Arikareean.

Small Cabbage Patch mammals were primarily rodents, insectivores, and marsupials, whereas the large Cabbage Patch mammals were primarily browsing ungulates: *Miohippus* (three-toed horse), *Parahippus?* (three-toed horse), *Diceratherium* (rhinoceros), unidentified small *Hyracodon*-sized rhinoceros, *Kukusepasutanka* (anthracothere), unidentified small-sized peccary, *Daedon* (medium-sized entelodontid), *Megoreodon* (oreodontid), *Desmatochoerus* (oreodontid), unidentified small-sized oreodontid, and the small deer-like ruminant *Pronodens*. Remains of large browsing mammals and their large carnivorous predators are rare throughout the Cabbage Patch strata, except for certain localities in the lower Cabbage Patch strata where large mammals (mainly oreodontids) are found more frequently. This is not the situation for the Arikareean faunas known from the Great Plains and Columbia Plateau where large browsing and grazing ungulates are more commonly found and of greater variety. The rarity and types of large mammals probably reflect the less open habitats present in western Montana during the Arikareean (see also Nichols, 1976, 1979, 2001). Extensive open grassland habitats were probably absent, and the area was probably more heavily vegetated to brushy savanna-like instead. Very abundant root burrows throughout the Cabbage Patch fluvial strata, fossils of oak and sequoia, and an abundant and varied terrestrial molluscan fauna much like the faunas found in the present deciduous forests of the central and eastern United States support the theory of woodland environments as being more prevalent than open environments. The large mammals can therefore be considered as part of the woodland community. Small mammals found in the Cabbage Patch strata usually were found mixed with aquatic and terrestrial mollusks, fish, frogs, salamanders, etc. and thus can be considered to have been part of the lake-edge, pond-bank, swamp and stream-bank communities, yet small mammals were also probably an important part of the woodland community.

Paleoclimate

Climatic conditions during deposition of the Cabbage Patch strata can be determined from plants, some vertebrates, and especially mollusks. The

presence of sequoia leaf fossils throughout the Cabbage Patch strata suggests that the climate was sufficiently wet to support large trees. Tortoise (*Testudo*) remains suggest mild winters without frost or with very infrequent periods of freezing conditions. Opossums, moles, hedgehogs, and abundant rodents suggest sufficient moisture for soft soils and abundant vegetation. Estivating toads (Henrici, 1994) suggest seasonally drier conditions during part of each year. Pierce (1993) concluded from the terrestrial and aquatic mollusks that "the MAT (mean annual temperature) of western Montana was at least 2°C warmer than at the present ... probably 10°C, or greater, with a January (Winter) mean temperature probably not less than 5°C and a July (Summer) temperature probably 15-20°C". Pierce (1993) likewise determined that the MAP (mean annual precipitation) may have been 50 cm or less during semiarid conditions (lower and upper Cabbage Patch strata) and 75 cm or more during more humid conditions (middle Cabbage Patch strata). Roth (1986) reported similar alternating drier to wetter conditions and a mild MAT during deposition of Eocene and early Oligocene strata in the Three Forks Basin east of the Continental Divide in southwestern Montana, and suggested that the Three Forks Basin (during the Eocene-Oligocene) "was undoubtedly not in a Cordilleran rain shadow as at the present time". From land snails and the presence of tortoise (*Testudo?*) in the Flint Creek beds Pierce and Rasmussen (1989) determined that the Barstovian climate was "cooler and perhaps more seasonal than that of the Eocene-Oligocene", and without significant freezing during the winter months.

Biostratigraphy

Where thick sections of Cabbage Patch strata are best exposed in the Flint Creek Basin, there does not appear to be a reliable lithologic basis for subdividing the Cabbage Patch beds, and there is insufficient continuous lateral control to define fourth-order and fifth-order stratigraphic sequences. However, Cabbage Patch strata have been satisfactorily subdivided biostratigraphically into lower, middle, and upper parts based on the content of the mammalian and molluscan fossil assemblages found in each respective part (Fig. 3). Thinner stratigraphic sections exposed in the Deer Lodge, Blackfoot, and Divide intermontane basins likewise cannot be subdivided by lithologic means and cannot be distinguished from the Cabbage Patch beds in the Flint Creek Basin, but each contains well-identified mammalian and molluscan fossil

assemblages which can be correlated to equivalent assemblages found in the sections measured in the Flint Creek Basin.

The lower Cabbage Patch strata can be distinguished from the middle and upper strata by the presence of the following mammalian genera: *Pseudotrimylus*, Talpidae genus and species indet., *Paleolagus*, *Megalagus*, *Downsimus*, Aplodontidae genus and species indet., *Agnotocastor*, Castoridae genus and species indet., *Cynodesmus*, *Kukusepasutanka*, and *Desmatochoerus* (Rasmussen, 1989); and the following molluscan species: *Gastrocopta obesa*, *Gastrocopta conica*, *Vertigo arenula*, *Nesovitrea pulchra*, *Dero-ceras mahiz*, and *Punctum alveus* (Pierce, 1993). The middle Cabbage Patch strata are distinguished from the lower and upper strata by the presence of the following mammalian genera: *Parvericius*, *Archaeolagus*, *?Desmatolagus*, *Allomys*, *Pleurolicus*, and *Capatanka* (Rasmussen, 1989); and the following molluscan species: *Viviparus nanus*, *Lymnaea tumere*, and *Dero-ceras securis* (Pierce, 1993). The upper Cabbage Patch strata are distinguished from the lower and middle strata by the presence of the following mammalian genera: *?Gripholagomys*, *Gregorymys*, *Entoptychus*, *Mookomys*, and *Euhapsis* (Rasmussen, 1989); and the following molluscan species: *Gastrocopta oviforma*, *Gastrocopta minuscula*, and *Monadenia?* n. sp. A. For many localities where abundant mammalian fossils are present, referral to the lower, middle, or upper Cabbage Patch strata can usually be made since the lower strata have primitive aplodontid rodents but no gophers, the middle strata have more advanced aplodontid rodents and the gopher *Pleurolicus*, and the upper strata have more advanced aplodontid rodents and the gopher *Gregorymys* or *Entoptychus* (Fig. 3 and Table 3).

The three biostratigraphic subdivisions of the Cabbage Patch beds in central-western Montana can be correlated rather successfully, albeit roughly, with comparable biostratigraphic subdivisions of Arikareean strata in the Great Plains (in western Nebraska, southwestern South Dakota, and southeastern Wyoming), and the Columbia Plateau in northern Oregon (Rich and Rasmussen, 1973, p. 48-50; Rasmussen, 1977, p. 107-133; Prothero and Rensberger, 1985; Tedford, et. al, 1987; Tedford, et. al, 1995). Fossil mammals indicate the lower Cabbage Patch beds are equivalent to the Gering Formation of western Nebraska, the "lower Harrison" of southeastern Wyoming, the Sharps Formation of southwestern South Dakota, and the lower Turtle Cove Member of the John Day Formation of northern Oregon. The

middle and upper Cabbage Patch beds are equivalent to the Monroe Creek Formation of western Nebraska and adjacent southwestern South Dakota, the "upper Harrison" of southeastern Wyoming, and the upper Turtle Cove Member of the John Day Formation of northern Oregon.

MAGNETOSTRATIGRAPHY

Magnetostratigraphic sections were taken through several important Cabbage Patch localities in the Flint Creek and Deer Lodge basins during August 1988. The main section (Fig. 3 and Fig. 5) covered over 1500 feet (457 m) of the Cabbage Patch sequence in the Flint Creek Basin, beginning in the SW Sec. 6, T10N, R11W, and ending in the NW Sec. 12, T10N, R12W (measured sections B1, B2, and C of Rasmussen, 1977, p. 512-538). The section was measured using a sighting hand level and data were corrected for the 0-38° dips using the Hewett method. Single sections (Fig. 3) were taken at a Tavenner Ranch locality in the northern Deer Lodge Basin in the SE SE Sec. 10, T8N, R10W (measured section H1 of Rasmussen, 1977, p. 553-555), and at a Pikes Peak locality between the Flint Creek and Deer Lodge basins in the NW SW Sec. 30, T9N, R10W (measured section E of Rasmussen, 1977, p. 542-545). Three hand samples were taken at each sample site in the sections, and each sample was later trimmed down on a band saw with a tungsten-carbide blade into one-inch cubes for use in the cryogenic magnetometer at the California Institute of Technology paleomagnetism laboratory.

A pilot suite of samples was treated with AF (alternating field) demagnetization, and another with thermal demagnetization. Representative vector demagnetization ("Zijderveld") plots of the results are shown in Figure 4. Sample 348A shows a normal overprint at NRM (natural remnant magnetization), but temperatures of 200-400°C yielded a stable reversed component. The sample had lost nearly all its remnance by 400°C and began to behave erratically at 500-600°C, probably because of viscous components in such weakly magnetized rocks. Sample 358B shows similar behavior. After removal of overprints at 100°C, a stable reversed component appeared between 200-400°C, at which point magnetization has nearly vanished; the erratic results at 500 and 600°C are probably due to VRM.

The almost complete loss of magnetization by 400°C and the rapid decline in intensity under AF demagnetization suggest that the magnetization is

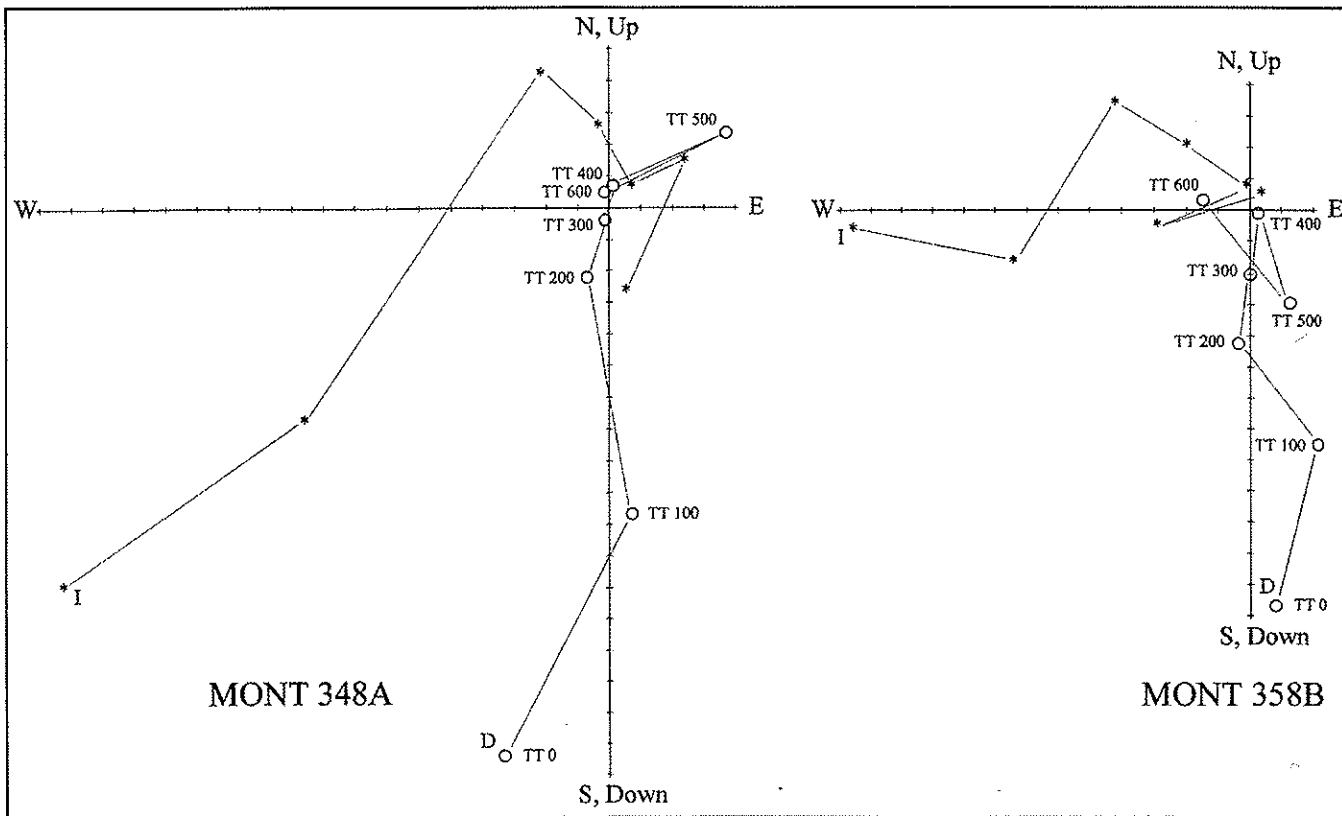


Figure 4: Vector demagnetization ("Zijderveld") plots of representative samples (Mont 348A and Mont 358B). Open circles show declination, and asterisks (*) show inclination. Each division = 10^{-5} emu. Thermal demagnetization temperatures (TT) are shown; "I" indicates the NRM direction of the inclination. In the left plot, a normal overprint is removed between NRM and 200°C, revealing a stable reversed component between 200-400°C; after this the sample is very weak and appears to be affected by viscous components. In the right plot, a normal overprint is again removed at 200°C, producing a stable reversed component between 200-400°C. As in the previous sample, the instability at 500 and 600°C is probably due to viscous components acting on a very weak signal.

carried by a low-coercivity, low-Curie point mineral such as magnetite, and is overprinted by a mineral removed at 200°C, such as goethite. This interpretation is corroborated by IRM (isothermal remnant magnetization) acquisition studies. A representative plot is shown in Figure 5. Under increasing IRM fields, the IRM saturated at about 500 mT (millitesla), and did not increase even at fields of 1300 mT, showing that magnetite is the primary carrier of remnance. During the IRM analysis, a modified Lowrie-Fuller test was also conducted (Johnson et al., 1975; Pluhar et al., 1991). This test compares the resistance to AF demagnetization of both the IRM produced in a 100-mT-peak field, and the ARM (anhysteretic remnant magnetization) gained in a 100 mT oscillating field. As can be seen in Figure 5, the ARM (solid squares) demagnetizes at lower fields than the IRM (open

squares), so much of the remnance appears to be carried by multi-domain grains.

Based on these results, all remaining samples were demagnetized in steps of 300, 400, and 500°C. If a stable component was apparent, its vector was averaged for those of the other two samples at that site using the methods of Fisher (1953; see also Butler, 1992). These yielded site statistics, which were classified following the system of Opdyke et al. (1977). Class I sites are significantly separated from random at the 95% confidence level, and are shown by the solid circles in Figure 6. Class II sites (triangles) had one sample missing, so site statistics could not be calculated, but a clear polarity was apparent from the remaining samples. Class III sites (open circles) had one sample divergent, so they did not cluster at the 95% confidence level, but their polarity was clear from the two remaining sites.

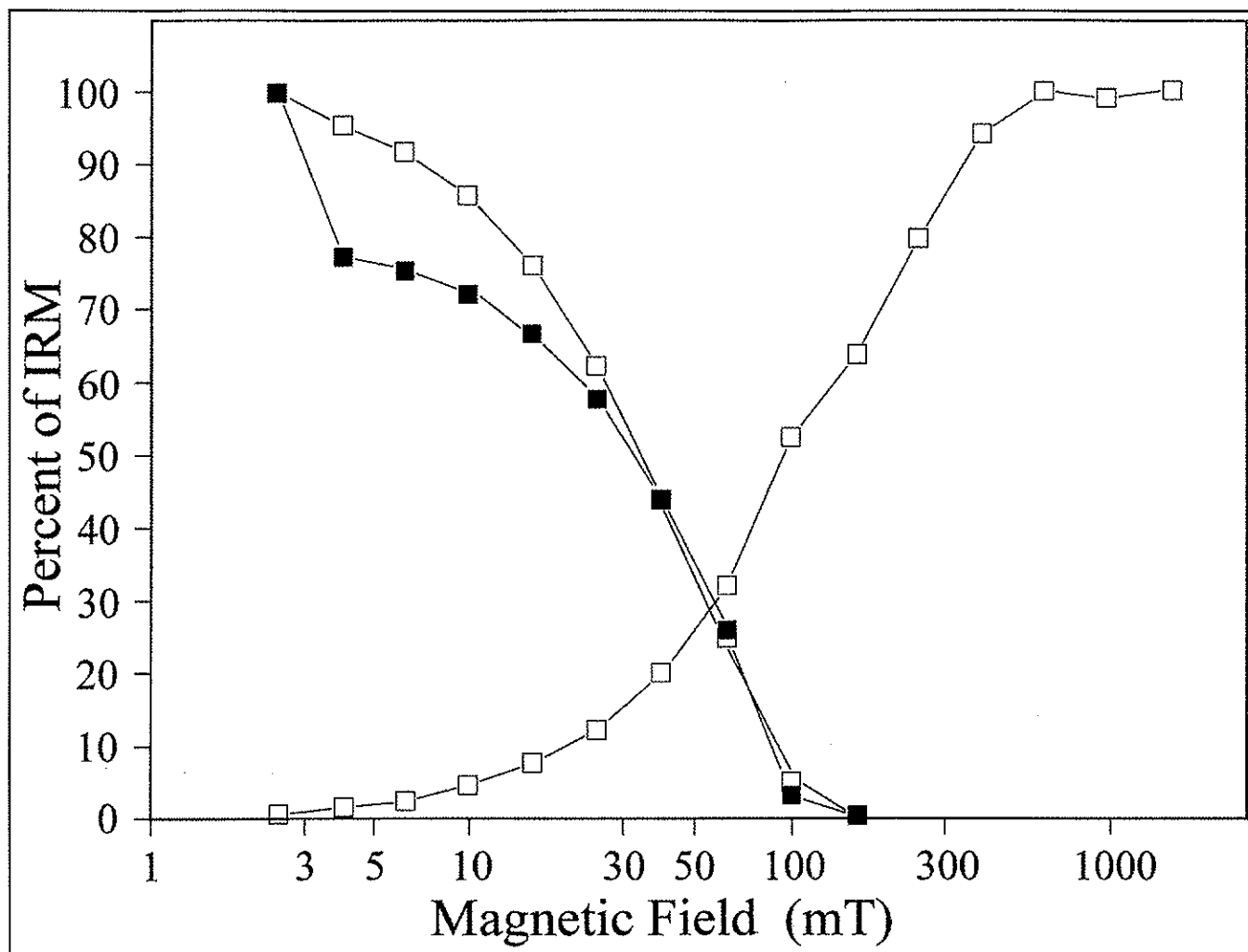


Figure 5: IRM acquisition and Lowrie-Fuller test of a representative sample from the Cabbage Patch beds. IRM values are shown by open squares; ARM by solid squares. IRM (ascending curve on right) clearly saturated by about 500 mT, showing that magnetite is the primary carrier of the remnance. In the Lowrie-Fuller test (Pluhar et al., 1991), the IRM is more resistant to AF demagnetization than the ARM (two curves descending on left), suggesting that multi-domain grains are important in this sample.

A few sites were too scattered, or yielded directions with no clear polarity preference; these were labeled "indeterminate."

The means for the normal and reversed sites were averaged using the methods of Fisher (1953). The mean for all Class I normal sites ($N = 30$) was $D = 348.6^\circ$, $I = 56.0^\circ$, $k = 11.7$, $a_{95} = 8.0$; the mean for all Class I reversed sites ($N = 31$) was $D = 195.1^\circ$, $I = -63.6^\circ$, $k = 8.4$, $a_{95} = 9.5$. These directions are antipodal within the a_{95} error estimates, so the magnetic vectors pass the reversal test and are probably due to primary magnetization, and not overprints.

The magnetostratigraphic pattern for the Cabbage Patch sections is shown in Figure 6. In the Flint Creek Basin, measured section B1 (Rasmussen, 1977, p. 512-520), the lower 34 feet (10 m) of section was reversed in polarity, but the section from 67 to 360 feet (20 to 110 m) in section was of normal polarity. This portion of the section includes the lower Cabbage Patch strata (Fig. 7) that contain an early Arikareean mammalian fauna similar to that of the Gering Formation in western Nebraska. From 485 to 722 feet (148 to 220 m) in the measured section, the exposures were poor and the few sample sites obtained were all of

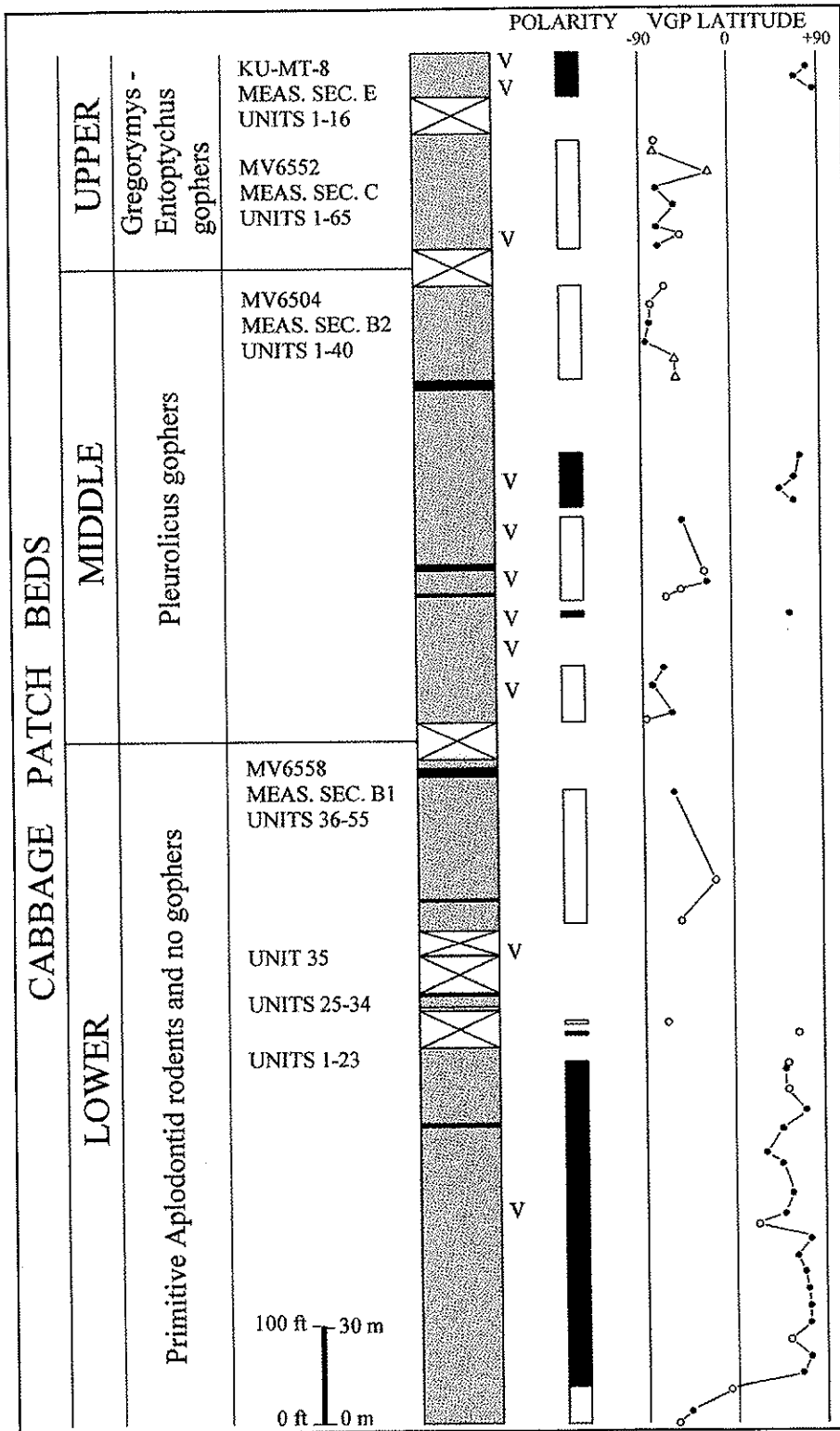


Figure 6: Magnetic polarity stratigraphy of selected Cabbage Patch sections. Solid circles are Class I sites of Opdyke et al. (1977), which were significantly separated from a random distribution at the 95% confidence level. Triangles are Class II sites, which were missing one sample and could not produce site statistics. Open circles are Class III sites, in which two samples showed a clear polarity preference, but the third was divergent. In stratigraphic section column, fluvial channel arkoses and conglomerates are shown by solid dark color, lacustrine, fluvial overbank and paludal fine-grained strata are indicated by shading, and covered intervals (not to scale) are shown by crossing diagonal lines (refer to Figure 3 and Rasmussen, 1977 for details). Vertebrate fossil horizons indicated by the letter "V".

reversed polarity. In measured section B2 (Rasmussen, 1977, p. 521-529), the entire section is mostly of reversed polarity, except for a zone of normal polarity at 108 feet (40 m) and between 218 and 260 feet (66 and 79 m) on the local section. This section of middle Cabbage Patch strata (Fig. 3 and Fig. 6) contains a medial Arikareean mammalian fauna, including the rodents *Pleurolicus* and *Meniscomys*. In measured section C (Fig. 6; Rasmussen, 1977, p. 530-538), the entire section is of reversed polarity and contains the upper Cabbage Patch strata (Fig. 3), including the late Arikareean gopher *Gregorymys*.

In the northern Deer Lodge Basin at the Tavenner Ranch localities (Fig. 3; measured sections H1 and H2 of Rasmussen, 1977, p. 553-557), samples were collected through 82 feet (25 m) of section. However, only the lowest three sample sites in section H1 produced usable magnetic results; the rest were along the crest of a ridge and had a strong magnetic overprint due to lightning. The lowest three sample sites are all of normal polarity, and are associated with a medial Arikareean mammalian fauna containing *Pleurolicus* (Fig. 3). The upper part of the section (H2) is late Arikareean, based on the presence of *Gregorymys*, but no suitable magnetic results could be obtained.

In the area between the Deer Lodge Basin and Flint Creek Basin, the Pike's Peak section (Fig. 3; measured section E of Rasmussen, 1977, p. 542-545) totaled 45 feet (13.7 m) in thickness and was entirely of normal polarity. The strata contain a late Arikareean mammalian fauna (Fig. 3, Fig. 6), including the gopher *Entoptychus* and a medium-sized horse (*Parahippus?*), and may be the youngest Arikareean strata known west of the Continental Divide in western Montana. Additional younger strata in the vicinity of the section measured at the Pike's Peak location have not been measured or carefully searched for vertebrate fossils (fossil invertebrates, however, are common suggesting additional lacustrine intervals).

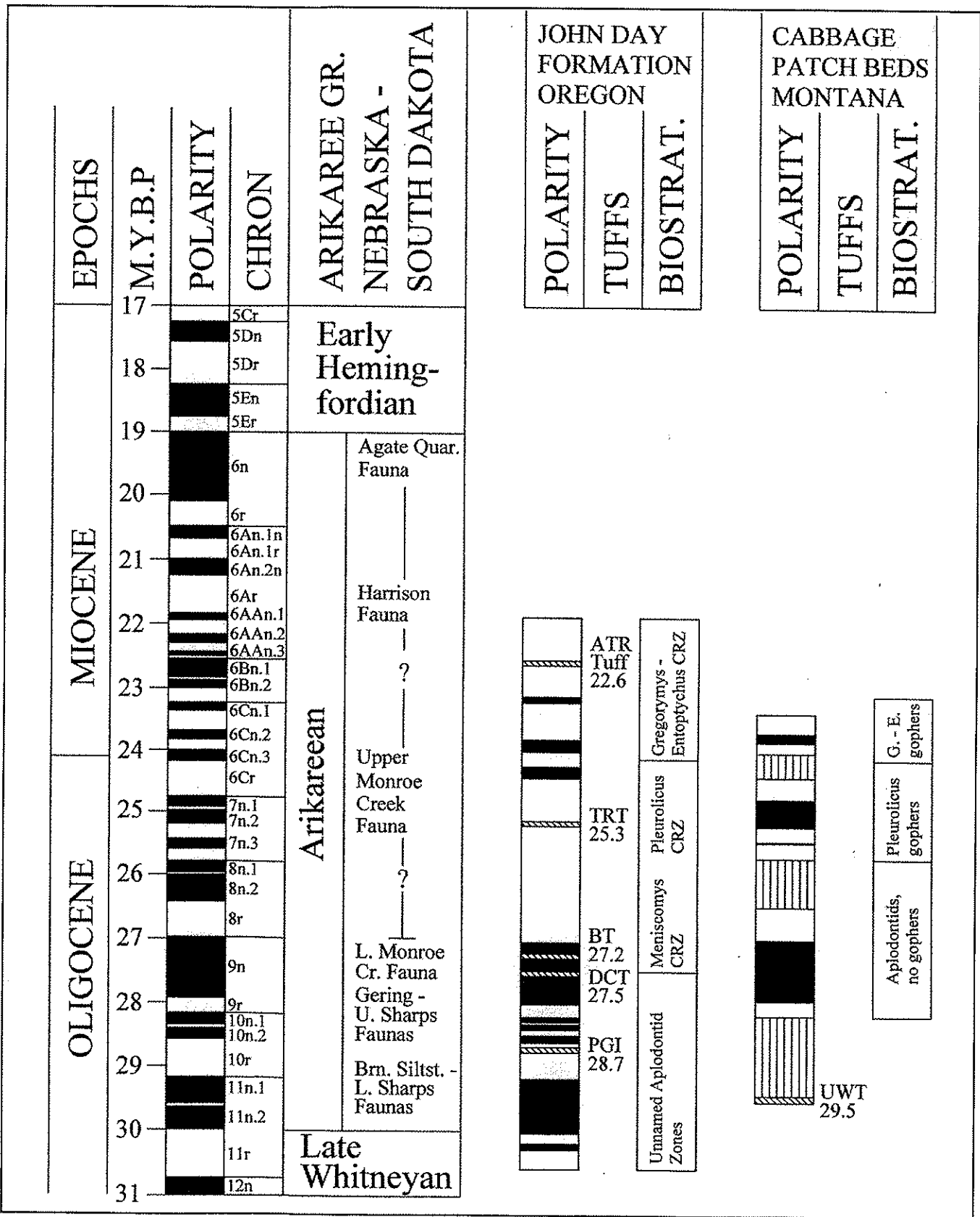
Based on the biostratigraphic and magnetostratigraphic constraints outlined above, some correlations can be made to the magnetic polarity time scale (Fig. 7). These correlations are aided by new stratigraphic data from the Gering and Monroe Creek formations in Nebraska (Tedford et al., 1996), and the new dates from the John Day Formation in Oregon (Fremd et al., 1994). The John Day sections were originally correlated to the magnetic polarity time scale by Prothero and Rensberger (1985), but new $^{40}\text{Ar}/^{39}\text{Ar}$ dates in these sections require revision of this correlation.

The lower Cabbage Patch sequence, with its reversed polarity and Gering-equivalent mammals,

can be confidently correlated with magnetic Chron C9r (28.0-28.3 Ma), based on the $^{40}\text{Ar}/^{39}\text{Ar}$ dates and magnetostratigraphy on the beds containing these faunas in the type Gering Formation (Tedford et al., 1996). The normal polarity zone above this is probably Chron C9n (27.0-28.0 Ma), which is correlative with the lowest Monroe Creek Formation in the Wildcat Ridge in Nebraska (Tedford et al., 1996), and also with the base of the *Meniscomys* Concurrent Range Zone in Oregon. The lower *Meniscomys* normal polarity zone was originally interpreted as Chron C8n (Prothero and Rensberger, 1985), but new $^{40}\text{Ar}/^{39}\text{Ar}$ dates (Fremd et al., 1994) of 27.2 Ma on the Biotite Tuff, and 27.5 Ma on the Deep Creek Tuff (which marks the base of the *Meniscomys* Concurrent Range Zone) force a re-correlation to Chron C9n.

Above this level, however, correlations with the magnetic time scale are less certain. The remaining portion of the late Oligocene and early Miocene magnetic polarity time scale is characterized by many short episodes of normal and reversed polarity, so there are relatively few long zones that can be confidently matched to terrestrial sections without $^{40}\text{Ar}/^{39}\text{Ar}$ dates. The magnetostratigraphy of the type sections of the Monroe Creek and Harrison formations in Nebraska is now published (MacFadden and Hunt, 1998), but presently there are few age constraints on the Harrison and Monroe Creek faunas. The John Day sections are also being reinterpreted with new stratigraphic work, new fossil collections, and new $^{40}\text{Ar}/^{39}\text{Ar}$ dates (Fremd et al., 1994). Thus, the few short normal intervals in the long section of reversed polarity above the Deep Creek Tuff (Prothero and Rensberger, 1985) probably correlates to much of Chrons C8, C7 and C6C, but detailed correlations are impossible at the present time. The $^{40}\text{Ar}/^{39}\text{Ar}$ dates of 22.6 on the ATR Tuff and 25.3 on the Tin Roof Tuff (Fremd et al., 1994) show that the John Day section must be at least as young as 22.6 Ma (Chron C6B), but more precise correlations are not yet possible. The first appearance of entoptychine gophers, which marks the late Arikareean in the John Day Formation, occurs between the ATR and Tin Roof Tuffs (Fremd, pers. commun. to DRP), but its exact level is not yet calibrated geochronologically or magnetically.

Given these problems, tentative correlations are still possible. The normal polarity zone in the middle Cabbage Patch section, with its medial Arikareean mammalian faunas including the rodents *Meniscomys* and *Pleurolicus*, most likely correlates with Chron C7n (24.7-25.3 Ma), although correlation with Chron C8n



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Figure 7: Magnetic correlation of the Cabbage Patch beds with other Arikareean sections. Time scale after Berggren et al. (1995). Correlation of the Arikaree Group in Nebraska and South Dakota is after Tedford et al. (1987). Correlation of the John Day Formation in Oregon is after Prothero and Rensberger (1985), with revisions from the tuff dates in Fremd et al. (1994). Dated tuffs (shown by diagonally hatched line) are as follows: TRT = Tin Roof Tuff; BT = Biotite Tuff; DCT = Deep Creek Tuff; PGI = Picture Gorge Ignimbrite; UWT = Unnamed Welded Tuff (at base of Cabbage Patch beds in the Flint Creek Basin). CRZ = Concurrent Range Zone. Time gaps and/or covered intervals in the Cabbage Patch column are indicated by vertical hachure lines.

is also possible given the loose constraints. The upper Cabbage Patch section is difficult to correlate precisely, since the first appearance of late Arikareean faunas (including entoptychines) is not yet calibrated to the magnetic time scale. The short reverse sequence at Tavenner Ranch, with its medial Arikareean mammalian faunas, could best be correlated with the reverse polarity event in Chron C7. The short normal section at Pike's Peak, with its late Arikareean mammalian faunas, could be correlated with several different short normal polarity episodes in Chron C6.

CONCLUSIONS

Arikareean strata west of the Continental Divide in Montana have been identified in numerous disjunct outcrops throughout four separate but interconnecting intermontane basins, and have been collectively assigned to the Cabbage Patch beds that were first identified east of Drummond, Montana (Flint Creek Basin) by Konizeski and Donohoe in 1958. Subsequent investigations by Gwinn (1960, 1961), Konizeski (1965) and Rasmussen (1969, 1973, 1977, 1989) suggest these strata were originally deposited within a broad single depositional area (proto-"Clark Fork Basin" as defined by Rasmussen, 1977), of which the four present intermontane basins and their adjacent areas are structural and erosional remnants.

The Cabbage Patch strata in the four intermontane basins cannot be further subdivided using lithostratigraphy. Strata deposited in fluvial environments are more common than strata deposited in lacustrine environments, yet lacustrine environments may have always been present somewhere in the original depositional area. The fluvial and lacustrine strata locally contain a great variety of fossils of plants, invertebrates and/or vertebrates that provide considerable taphonomic, paleoecologic and paleoclimatic data. Biostratigraphic relationships using mammalian and molluscan fossils have allowed the Cabbage Patch

strata to be successfully subdivided into upper, middle, and lower parts that can be satisfactorily correlated to Arikareean strata in Montana, Idaho and other states.

Magnetostratigraphic data obtained from numerous samples of Cabbage Patch strata in the Flint Creek and Deer Lodge basins confirms previous biostratigraphic correlations and provides important details for correlations with age-equivalent strata in the Great Plains (Arikaree Group of Nebraska and South Dakota) and Columbia Plateau (John Day Formation of Oregon). The lowermost Cabbage Patch strata unconformably overlie an unnamed welded tuff (29.5 Ma) in the Flint Creek Basin, but strata in the base of measured section B1 have only been reliably dated to approximately 28 Ma. Several hundred feet of covered older strata below B1 remain undated and may fill the missing gap between 29.5 and 28 Ma. Using mammalian biostratigraphy and magnetostratigraphy, the uppermost Cabbage Patch strata examined to date (at measured section E) are close to 23 Ma (earliest Miocene), however, even younger strata near measured section E remain to be dated and those Cabbage Patch strata may be younger than 23 Ma.

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