The Early Pleistocene (Latest Blancan–Earliest Irvingtonian) Froman Ferry Fauna and History of the Glenns Ferry Formation, Southwestern Idaho

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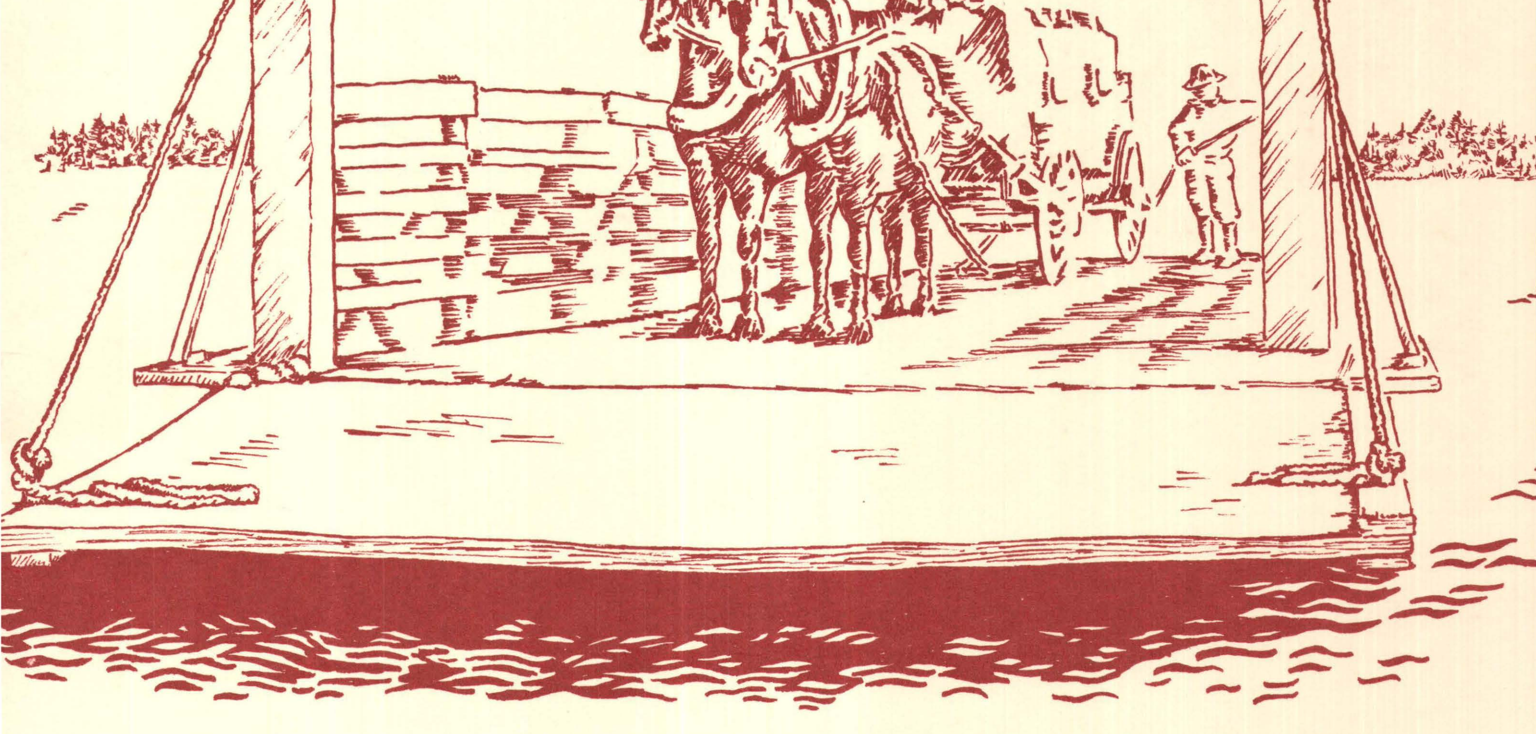

Cover.—Late 19th- or early 20th-century Idaho ferry, from photograph in James L. Huntley, "Ferry boats in Idaho" (1979), redrawn by Rob Wells.

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METRIC CONVERSIONS

To convert	To	Multiply by
Feet (ft)	Meters (m)	0.3048
Miles (mi)	Kilometers (km)	1.609
Pounds (lb)	Kilograms (kg)	0.454

THE EARLY PLEISTOCENE (LATEST BLANCAN–EARLIEST IRVINGTONIAN) FROMAN FERRY FAUNA AND HISTORY OF THE GLENNS FERRY FORMATION, SOUTHWESTERN IDAHO

By Charles A. Repenning, Ted R. Weasma,[1] *and* George R. Scott[2]

ABSTRACT

The Froman Ferry fauna of south-central western Idaho was discovered in about 1897 during an early survey of the mining districts in the mountains to the west and north of the western Snake River Plain. This survey was made by Waldemar Lindgren and party of the U.S. Geological Survey. The Froman Ferry fossil locality was visited next by John C. Merriam of the University of California in 1916, but seems not to have been examined again until 1988, when the Boise District Office, Bureau of Land Management, was conducting an inventory of fossil localities. Much of the neglect of this fauna appears to have resulted from an error in recording its locality description as "section 7," rather than "section 17," in the files of the University of California Museum of Paleontology; moreover, the construction of a bridge across the Snake River at the town of Marsing in 1921 resulted in the abandonment of the nearby Froman Ferry, the closest geographic reference in the description of the locality.

Most subsequent mention of the locality has assumed that the age of the Froman Ferry fossil fauna was that of the better known "Grand View" fauna from Jackass Butte, more than 50 miles to the southeast and near the city of Mountain Home. The recent collecting here described has established the age of the Froman Ferry fauna as being about half a million years younger than the Jackass Butte fauna.

The two faunas are quite similar, but have some differences that reflect this age difference. The Jackass Butte fauna is late Pliocene and typical of the Blancan V mammal age of Repenning (1987); the Froman Ferry fauna is Pleistocene and spans the boundary between the Blancan and Irvingtonian mammal ages in the Pacific Faunal Region of the United States, as herein recognized; both are in the Glenns Ferry Formation of Malde and Powers (1962), which is present throughout the western Snake River Plain.

Although primarily characterized by faunal elements that are also known from Jackass Butte, the Froman Ferry fauna differs in the appearance of an immigrant microtine rodent in the lower third of the fossiliferous section (a rodent known earlier from the Beringian Faunal Region adjacent to the Arctic Ocean), in a more evolved horse of intermediate condition between the Pliocene genus *Plesippus* (known from the older parts of the Glenns Ferry Formation) and the Pleistocene and Recent genus *Equus*, and in the oldest known record of the North American puma, although its ancestors are believed to be represented in the older Glenns Ferry faunas.

The Froman Ferry fauna also seems to lack some taxa that would be expectable, to judge by the older Jackass Butte fauna. These taxa include the cold-water stream sculpin *Cottus* (first known from Jackass Butte) and the giant beaver *Procastoroides* (known from most older fossiliferous horizons of the Glenns Ferry Formation); the first seems to be lacking in the Froman Ferry fauna because of environmental reasons (the Froman Ferry fauna represents warmer water than does Jackass Butte fauna) and the second appears to represent the extinction of the giant beaver because it is unknown from all other faunas of the same or younger age in the Pacific Faunal Region.

In addition, the archaic rabbit *Hypolagus gidleyi* was found high in the Froman Ferry faunal succession (perhaps little more than 1.5 million years old). This rabbit has not been found at Jackass Butte and was previously thought to have become extinct before the time of that fauna, perhaps by 3.0 million years ago.

The fossiliferous section containing the Froman Ferry fauna is, in places, nearly 500 feet thick and consists of abundant marsh and pond deposits with fluvial deposits that become increasingly prominent toward the top of the

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[1] Bureau of Land Management, Roseburg, Oregon.

[2] BLM Volunteer Program, Nampa, Idaho.

section. An overlying lava flow provides a minimum age of >1.5 Ma and paleomagnetic polarity determinations provide a maximum age of <1.67 Ma. As such, the fauna is the youngest known from the Glenns Ferry Formation of Malde and Powers (1962), and enables determination of the timing and history of the final drainage of the western Snake River Plain and the relationship of the formation to Hells Canyon, which now drains the area to the Columbia River in south-central Washington. Hells Canyon appears to be at least 3 Ma old and may have a history that dates back to the Miocene.

INTRODUCTION

To our knowledge nothing has been published indicating that vertebrate fossils have been collected from the Froman Ferry area, along the western margin of Canyon County and 14 miles west of Nampa, Idaho, since J.C. Merriam visited there in 1916 (Merriam, 1918). In 1988 Weasma, then in the Boise District Office of the Bureau of Land Management, was compiling an inventory of Idaho fossil localities and noted that the Froman Ferry area seemed not to have been examined in perhaps 72 years. Weasma inspected the area and found a few fossils, and suggested that Scott try to collect more under the sponsorship of the U.S. Government Volunteer Program. The locality was first collected, apparently by N.F. Drake, in 1897 (Lindgren, 1900).

Scott prospected the area and discovered fossils in and near the Chalk Hills on the Marsing 7.5 minute quadrangle (USGS) and in the area of the Cucumber vertical angle benchmark on the Lake Lowell 7.5 minute quadrangle to the east (figs. 1 and 2). The area includes the original Froman Ferry fauna of Lindgren, which is at the base of the fossiliferous section near the Snake River. These are not the Chalk Hills for which the Miocene Chalk Hills Formation was named (Malde and Powers, 1962); those Chalk Hills are about 75 miles to the southeast.

The only exposure of fossiliferous deposits along the Snake River about "two mi. plus NW of Froman Ferry [actually about 1.4 miles NW.], 7–8 mi. SW of Caldwell, Idaho, and in T.3N, R.4W, Sec. 7 [actually sec. 17]" (University of California Museum of Paleontology [UCMP] Locality 3036), is at a point along the Snake River that is closest to Chalk Hills of the present report. We believe that this exposure is probably the locality UCMP 3036C of Merriam (1918) in the upper 75–100 feet of the section; this locality has been renumbered in the UCMP locality files as 3036 and is the type locality of *Ischyrosmilus*? *idahoensis* Merriam and *Equus idahoensis* Merriam. Merriam (1918) and the UCMP locality records indicate two lower localities: (1) 3036A, from the base of the section 50–75 feet above the Snake River flood plain (now numbered V75043); and (2) 3036B in the middle of the section (now numbered V75044). These elevations are estimates made by the person recording the locality in the UCMP records, probably J.C. Merriam; the river bluff is no more than 140 feet high.

Although the UCMP localities are not exactly recoverable, as both the ferry and the road leading to it no longer exist, Scott found fossils at the highest horizon, apparently geographically and stratigraphically close to UCMP locality 3036 (Merriam's 3036C), and assigned his field locality number GS-211 to it. Thus old UCMP 3036C, renumbered UCMP 3036, and Scott's field number GS-211 are, in our opinion, the same or nearly the same locality. Scott found no fossils in the stratigraphically lower horizons, despite the UCMP locality records indicating that Merriam had. Examination of the fragmentary material in UCMP that Merriam collected in the two lower localities suggests that it may have been slope wash from the fossiliferous highest horizon.

These, or this, locality is the lowest fauna of the Froman Ferry faunal succession. Original records in the National Museum of Natural History [USNM] with the original material collected in 1897 and later by N.F. Drake (and W. Lindgren?) are located only in terms of distance from the ferry along the no-longer evident road to Caldwell and may or may not have also been slope wash, as the road would have crossed the highest fossil horizon at some point within 2 miles of the ferry. The former location of the ferry is here taken to be that indicated by Huntley (1979).

The bluff in which these localities occur is downsection and separate from the exposures in Chalk Hills a mile and less to the northeast of the Froman Ferry localities (fig. 2). The paleomagnetic polarity section made by Van Domelen and Rieck (1992) ran from the base of the Froman Ferry bluffs up to the top of Chalk Hills; it indicated that this entire section was reversely polarized. The paleomagnetic section was taken from the lowest exposures (below locality UCMP 3036 ±=GS-211) to locality GS-203, which are shown in figures 2 and 3.

Scott found fossil mammals about 25 feet below the top of the bluff adjacent to the Snake River near UCMP 3036, and we believe that this must be close to the original locality of Drake (Lindgren, 1900; Lindgren and Drake, 1904, p. 86), and essentially the same horizon as UCMP locality 3036. The bluff is not steep but is rather hummocky and now overgrown with vegetation, possibly shaped by a series of small slumps; cultivated and irrigated fields are on the surface above it.

The ferry, first built in about 1886 by G.W. Froman, hasn't been in existence for many years (since about 1921) and is not located on recent maps; it was located about 3 miles downstream (north) of the present bridge across the Snake River at Marsing, Idaho (Huntley, 1979). The bluff containing locality GS-211 is about 7,400 feet northwest of

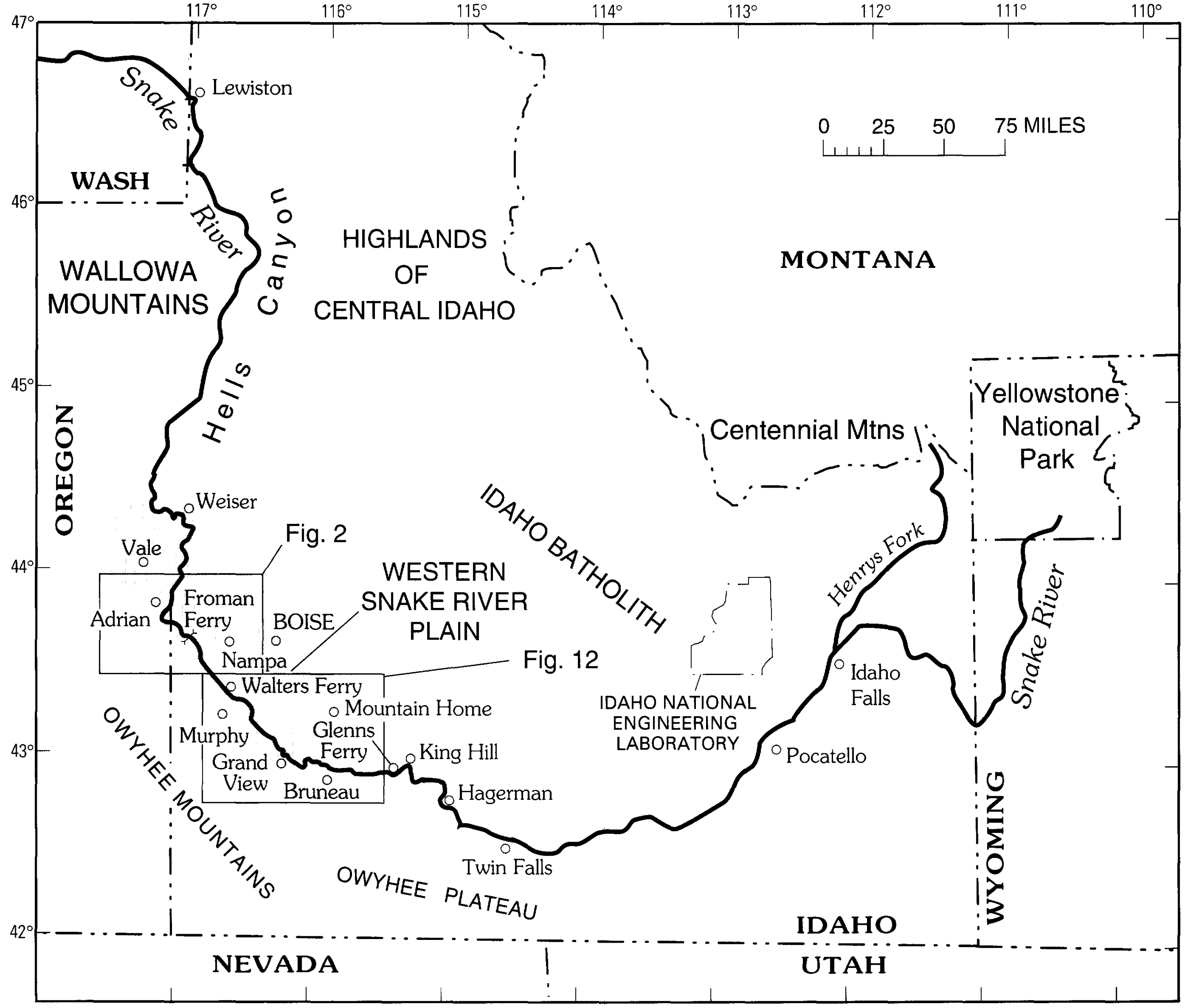


Figure 1. Southern Idaho and adjacent areas, showing the route of the Snake River, the western Snake River Plain, and some localities mentioned in the text. Areas of figures 2 and 12 are outlined.

the ferry site, in the NW ¼ sec. 17, T. 3 N., R. 4 W. (Boise base and meridian) and at present is largely covered by vegetation.

The many fossil localities found by Scott in the Froman Ferry area are here included under the more inclusive name "Froman Ferry faunal succession," enlarging the geographic and stratigraphic coverage of the original locality name, and including the field names: Froman Ferry (includes UCMP 3036), Chalk Hills, Cucumber, Lizard Butte, and Homedale areas (fig. 2). Most of these field area names include several individual localities that are fairly close together. The individual localities are distributed over about 13.5 miles, extending from east of Homedale on the north (downstream) to Pickles Butte, at the southern (upstream) limit of the Cucumber area. The mammal-bearing part of the Glenns Ferry Formation is at least 255 feet thick in the Froman Ferry–Chalk Hills area and appears to be nearly 500 feet thick in the Cucumber area; the difference appears to result from erosion that formed an overlying unconformity.

All localities were found on the east side of the Snake River; we have found only lake deposits of the Glenns Ferry Formation on the west side of the river, and these only south of Marsing. The fossiliferous deposits are essentially a single stratigraphic zone of the Glenns Ferry Formation; this zone appears to be more than 214 feet thick everywhere except near Homedale to the north. Except for the Homedale and Lizard Butte areas, all exposures are in nearly continuous outcrops.

The stratigraphically lowest specific locality here discussed is that bearing the field name Froman Ferry area (field locality GS-211, ?=UCMP 3036), which appears to be the locality, or at least the horizon, of most of the earlier published fossil records. GS-211 is also the topographically lowest locality and is about 2,398 feet above sea level and

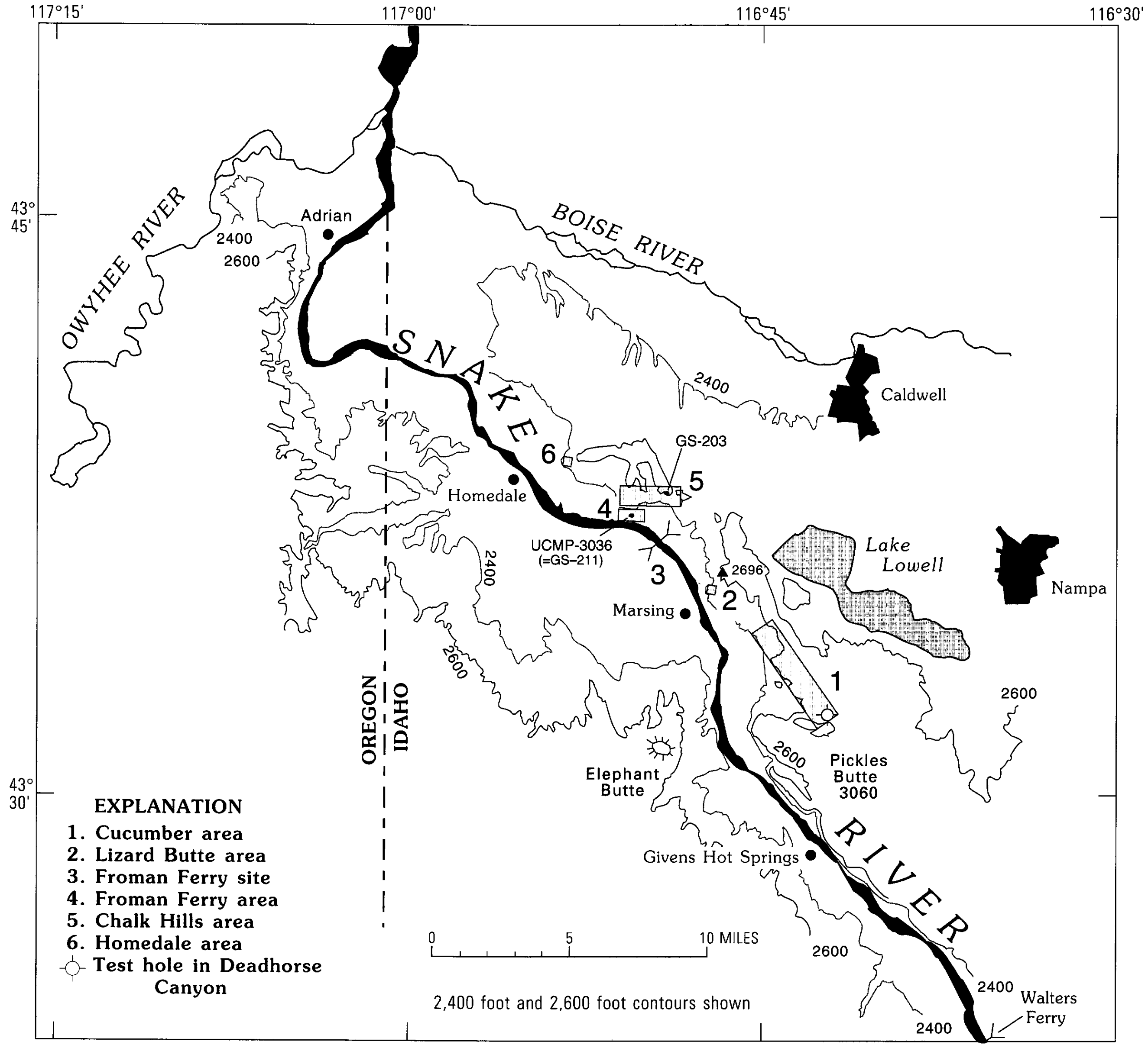


Figure 2. The Froman Ferry area, Idaho, showing localities mentioned in the text and the various fossil areas included under the name Froman Ferry faunal succession. The paleomagnetic section (fig. 3) was made from UCMP-3036 northeast to GS-203. Map is continued to south (at a different scale) in figure 12.

about 178 feet above the Snake River. This is the youngest horizon previously reported as the Froman Ferry locality in the University of California Museum of Paleontology records (UCMP 3036). All our localities are designated by the prefix GS-, and their descriptions are on file in the National Museum of Natural History (USNM) in Washington and in the Idaho Museum of Natural History (IMNH) in Pocatello.

Scott's collections from the Froman Ferry faunal succession consist largely of microtine rodents, fish, and amphibians, although a few remains of large mammals are present. There exists the possibility that local residents have picked the area clean; one of us (Scott) has seen some material in private hands. However, no privately owned collections that have been found appear to be extensive or significant.

The depositional nature of the fossil accumulation, in light-colored, flat-bedded silts and fine sands of shallow-water marsh deposits (containing abundant impressions and carbonized reeds and rushes) interbedded with less frequent, darker gray and siltier lake and crossbedded, sandy to pebbly sluggish stream deposits of a browner hue, suggests that rodents were actually the most abundant mammals present, and that the rarity of large mammals, and rodents other than microtines, reflects the environment of the fauna. Larger mammal remains are most often associated with stream deposits, and these are most common in the higher parts of the section, particularly in the Cucumber area. The absence of other rodents is taken as an environmental indication; as will be discussed, the climate appears to have been cloudy and cool, and ice may have formed locally in the marshes during the winter.

Pollen from the Glenns Ferry Formation, much farther upstream (from Bruneau and Hagerman), shows an alternation of pine and fir (with some spruce) forests and sage steppe (Thompson, 1992). These pollen records are, however, from an older part of the formation and pollen was not found in the Froman Ferry area.

The topographically and stratigraphically highest specific localities in the Froman Ferry faunal succession are from the area of Pickles Butte and near the Cucumber vertical angle bench mark on the Lake Lowell quadrangle. These are as much as 2,890 feet above sea level and are in deposits that have been elevated by slight tilting at the time of, and shortly before, the volcanic activity that formed Pickles Butte. Stratigraphically, they appear to be little higher than the top of Chalk Hills (2,630 feet above sea level).

Except in the area of Pickles Butte (where the strata are slightly tilted), the deposits are essentially flat lying, although dipping slightly southward toward the Snake River. They are composed of fine-grained lacustrine, paludal, and fluvial deposits that contain abundant marsh vertebrates and fresh-water mollusks, as well as plant remains (primarily of reeds and rushes); the nonmammalian fossils have not been studied, although Gerald R. Smith (University of Michigan Museum of Paleontology) has examined about 1,000 fish bones from the Cucumber area and Terrance Frest (Seattle, Wash.) is currently working on the mollusks.

The marsh deposits are highly diatomaceous, and the diatoms indicate shallow marshy environments (J.P. Bradbury, oral commun., 1990–1993). The diatoms were found in matrix containing fossil microtine rodents and in other deposits throughout the section. Small lake and pond deposits are abundantly interbedded with marsh deposits in the Froman Ferry sequence, as are less common lenticular bodies of medium-scale crossbedded fine fluvial sand. Although the section overlies typical Glenns Ferry lake beds, there is no depositional record of extensive or long-lasting lakes within the fossiliferous zone, suggesting that the Glenns Ferry lake was no longer present in this most downstream area of the western Snake River Plain. In the stratigraphically highest part of the deposits, near Pickles Butte, fluvial sands and gravels are more common and represent a large part of the formation. These, it seems, have resulted from the initial fluvial activity that later formed the eroded surface upon which the Pickles Butte basalt was deposited.

The deposits are typical of the "floodplain" facies of the Glenns Ferry Formation found farther upstream (southeast) at well-known localities, such as Grand View and Hagerman, although they have fewer channel sand deposits; they have been included in the Glenns Ferry Formation by Malde and Powers (1962) and Othberg and Stanford (1992). A generalized stratigraphic section, compiled by Van Domelen and Rieck (1992) while collecting samples for the magnetic polarity section, is shown in figure 3.

Although no deposits of large lakes are present in the outcrops of the Glenns Ferry Formation containing the Froman Ferry faunal succession, outcrops of the formation to the west of the Snake River in the Froman Ferry area are entirely lacustrine in origin and dip a few degrees northeastward toward the river. That these lacustrine deposits are lower in the Glenns Ferry section than the marsh deposits on the northeast side of the river is indicated by regional relationships and by one test hole that was drilled through the marsh beds and into the lake beds in the Cucumber area. The lake beds are also present beneath the capping basalt upstream from (south of) Pickles Butte in the high bluffs along the northeast side of the Snake River opposite Givens Hot Springs (fig. 2); but their relationship to the marsh deposits is obscured by cover where these bluffs disappear west of Pickles Butte. Downstream (north) of this area the basal contact of the fossiliferous marsh beds is covered by the more modern deposits of the Snake River and the lake beds are not known on the west side of the river.

At the Pickles Butte Sanitary Landfill of Canyon County, Idaho, located in Dead Horse Canyon on the north side of Pickles Butte, a test hole (at elevation 2,930 feet) drilled through the entire fossiliferous zone (marsh deposits) and entered lake beds of the Glenns Ferry Formation at a depth of 505 feet; the test hole bottomed at 520 feet in lacustrine silt (Bill Stroud, Holladay Engineering Co., Payette, Idaho, oral commun., 1992). In this area much later Pleistocene sands and silts, some probably eolian, are deposited on top of the Glenns Ferry Formation.

From a cursory inspection of the lake beds exposed southwest of the river, it is our opinion that the northeastward dips, which appear to be regional, result from regional uplift of the Owyhee Mountains some 4 miles west of the Snake River opposite the southern limit of the Froman Ferry faunal localities. Here, near Elephant Butte some 5.8 miles south-southwest of Marsing (fig. 2), the Glenns Ferry lake beds lap out against much more intensely deformed older Miocene rocks—the Chalk Hills Formation and an overlying unit of rust-colored medium- to coarse-grained sandstone that is oolitic in some places and relatively resistant to weathering in this area.

These deposits between Elephant Butte and the hills 2 miles south of Marsing are the most northerly exposures of the Glenns Ferry Formation on the southwest side of the Snake River. On the northeast side, Glenns Ferry deposits are present northward nearly to the Boise River south of Parma, Idaho, and perhaps 16 miles farther north than Marsing, Idaho (Othberg and Stanford, 1992). This would be about 9 miles north of the northernmost fossil localities here included in the Froman Ferry faunal succession. The formation in this northernmost area is thin and apparently all marsh deposits, but is poorly exposed.

Deposits in the region of Adrian, Oregon, containing fossil fish described by Kimmel (1975), were called the Deer Butte Formation by Kittleman and others (1965, 1967) and were then believed to be of early Pliocene age. At the time of these publications, the correlation of these ages to North American vertebrate faunal events was being reevaluated to late Miocene because of better age control of the Miocene-Pliocene boundary in Italy and newly developed radiometric age determinations. What was called early and middle Pliocene in the United States by vertebrate paleontologists in the mid 1960's is now called late Miocene (beginning, perhaps, with Repenning, 1968, and finalized, perhaps, by Tedford and others, 1987). Formations of this age are much older than the Glenns Ferry Formation.

Neither the Deer Butte Formation of Kittleman and others (1965, 1967), the Chalk Butte Formation of Corcoran and others (1962), nor the Payette Formation of Lindgren (1898) contains Pliocene deposits by modern correlations, and all three are part of the structurally deformed rocks in the foothills of the Owyhee Mountains (fig. 1) and the Salmon River Mountains of central Idaho to the north of the modern Boise River. These formations are traceable southward more than 70 miles, along the west side of the Snake River Plain, into the Chalk Hills Formation of Malde and Powers (1962; Ekren and others, 1981).

On the west side of the Snake River, the next extensive exposure of Tertiary sediments to the north is between Vale, Oregon, and Weiser, Idaho (fig. 1). These deposits, exposed in the region called Moores Hollow, contain upper Miocene mammals (Repenning, unpub. data, 1975) and seem to overlie older lake beds exposed opposite the town of Weiser that contain a diatom flora unrelated to that of the Glenns Ferry Formation (J.P. Bradbury, oral commun., 1993). On the northern rim of Moores Hollow, in a gravel quarry west of Interstate Highway 84, these deposits are overlain by a coarse, rusty sand with abundant fish remains that appears to be the oolitic rusty sand that separates the Glenns Ferry Formation from the underlying Miocene Chalk Hills Formation along the entire west edge of the Snake River Plain.

The Moores Hollow sediments are close in geography and age to the Payette Formation of Lindgren (1898), exposed to the east in Idaho along the Payette River valley, and they were included in this formation by Lindgren. Extension of the name "Payette Formation" from Lindgren's original definition, without sufficient justification, has led to considerable confusion; and the name has fallen into disuse. It has been replaced by a variety of other formation names, in part or entirely synonymous. It should be noted that Lindgren (1898) specifically separated the Payette Formation from the overlying Idaho Formation of Cope (1883), which was defined on the basis of fossil fish collected at Castle Creek, about 12 miles northwest (downstream) of Grand View (this report, fig. 12) and is clearly within the unit now called the Glenns Ferry Formation (Malde and Powers, 1962, p. 1201–1202). The history of stratigraphic nomenclature is discussed in the third major section of the present report, under the heading "Glenns Ferry Formation."

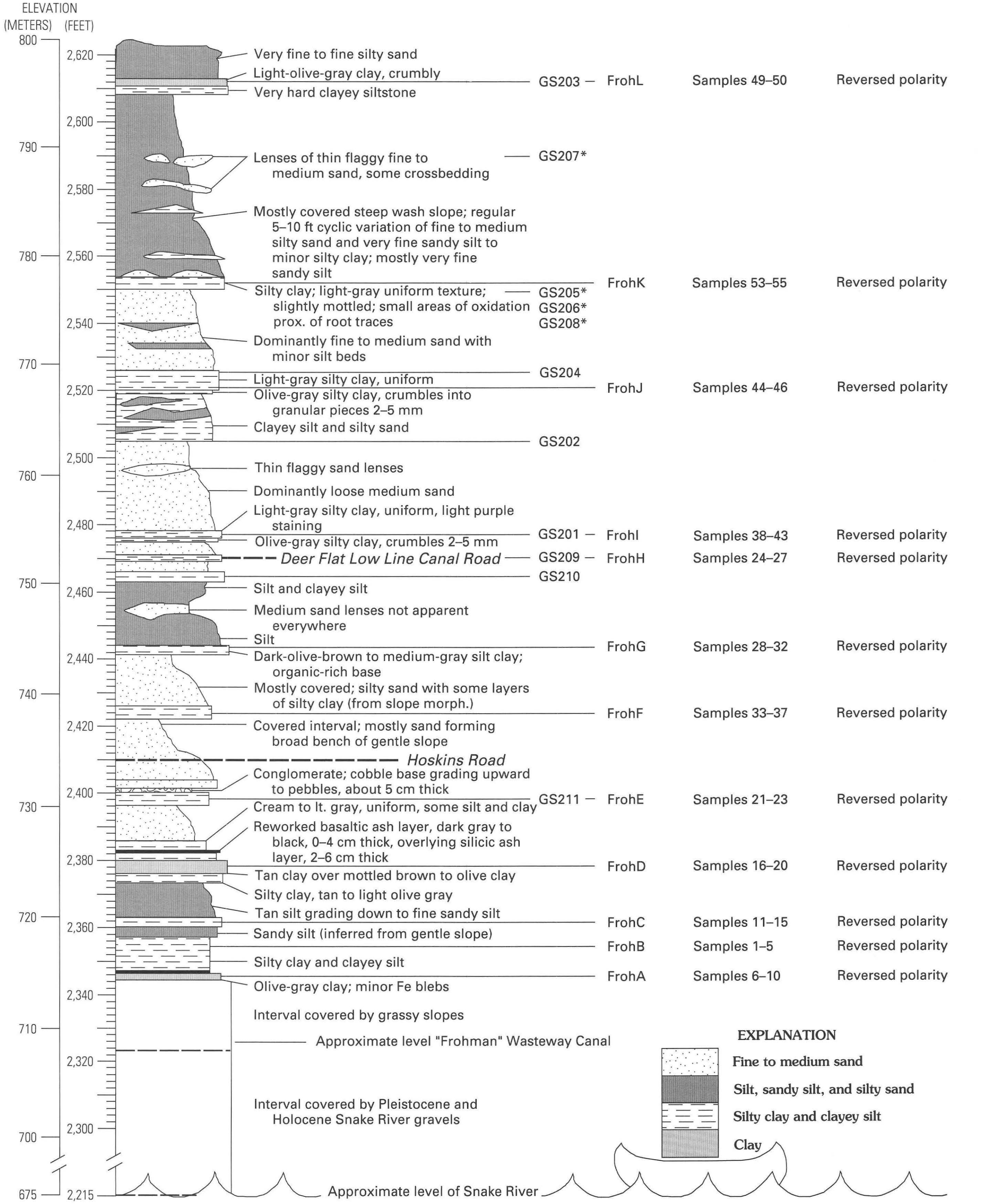
ORGANIZATION OF THIS REPORT

The purpose of this report is to record the mammalian fauna of the Froman Ferry faunal succession and to indicate its significance in the history of the Glenns Ferry Formation. The Froman Ferry faunal succession appears to be in the youngest part of this formation; it is very close to 1.6 million years old (>1.5 Ma and <1.67 Ma) while the oldest Glenns Ferry mammal faunas, from the world-famous Hagerman faunal succession 112 miles to the southeast, are as old as 3.6 million years. The oldest deposits of the formation are lake beds that seem to be nearly 4 million years old. Thus the formation was deposited over a period of nearly 2.5 million years.

The significant aspects of the Froman Ferry faunal succession are many, and to demonstrate these one must not only explain the contents of the fauna and its stratigraphic position within the Glenns Ferry Formation, but also outline (1) the history of the entire formation; (2) the relationships of the formation to older and younger stratigraphic units; (3) the prior and subsequent history of the western Snake River Plain that relates to the Glenns Ferry Formation; and (4) the records outside the area that have a bearing on these interpretations.

In order to do this, we divide this report into four major sections. The first is an enlarged introduction containing several sections that explain, primarily, various aspects of biochronologic, paleomagnetic, and climatic methods of correlation. Some of the concepts presented are relatively poorly known, and their explanation is

Figure 3 (facing page). Generalized composite stratigraphic column. Measured section of the Glenns Ferry Formation at Froman Ferry area (Marsing 7.5 minute quadrangle, Idaho; secs. 8, 9, 17, T. 3 N., R. 4 W.). Measured by David J. Van Domelen and Hugh J. Rieck and reproduced from their U.S. Geological Survey Open-File Report, 1992. Items noted by the prefix GS- are fossil localities discussed in the present report (those followed by an asterisk [*] have been projected into the section). Fifty-three samples were taken from 12 localities (FrohA to FrohL) and all were determined to have primary reversed polarity (Van Domelen and Rieck, 1992). Most were taken from fossiliferous marsh deposits (marked by GS- locality numbers), and some of these were examined by J.P. Bradbury and found to contain diatoms indicative of marsh deposits.



needed before they can be used in the sections to follow. A great many of the former differences of interpretation of the late Cenozoic history of the western Snake River Plain have arisen because of a lack of understanding of the meaning, and limitation, of age interpretations implicit in the use of fossil mammals.

The second major section is the discussion of fauna from the Froman Ferry faunal succession. This section is primarily a listing of specimens, including locality and elevation, and a discussion of the features that are pertinent to identification. In this discussion some well-established practices, primarily in taxonomic nomenclature, are discussed and modified. And in some places considerable space is used to discuss the history of particular taxa and varying nomenclature.

The third major section is of the geologic history of the Glenns Ferry Formation, in which age and depositional facies figure prominently. Also included is evidence of faunal affinity and history that goes as far afield from the western Snake River Plain as the States of California and Washington. Suggested climatic events of presumed significance to the timing of observed conditions within the Glenns Ferry Formation are introduced from as far away as Scandinavia. We point out that these are global climatic events that had an effect everywhere and that the choice of evidence is not so much dependent upon geographic position but on greatest temporal precision. A similar question of relevance could be made for paleomagnetic evidence; although the Olduvai Normal-paleomagnetic Subchron may have been named and identified in East Africa, for example, its recognition in North America is not alarming because it was a global event.

The fourth and final section, "Conclusions," is mercifully brief and consists only of a listing of those conclusions of the report that seem most significant to the authors.

This treatment, while logical in sequence, requires repeated mention of the same evidence. When this is done, an effort has been made to mention the page where the evidence is first or most completely discussed to eliminate as much duplication as possible. Yet the reader will usually recall its prior mention and be impressed by duplication of statements. For this we apologize.

The greatest deficiency of this study is the lack of complete coverage of the western Snake River Plain by adequate geologic mapping. H.E. Malde has spent the past 40 years in this effort, but the Snake River Plain is very large and major parts of the area discussed remain without adequate published geologic maps. The immediate area of the Froman Ferry faunal succession is covered by the excellent map of Othberg and Stanford (1992). A large part of the area discussed is covered by the fine map of Owyhee County, Idaho, by Ekren and others (1981), but unfortunately the attention of this work was not directed at the Glenns Ferry Formation, and its several facies are not recognized, although the recognition of these facies is the substance of the present report. To overcome this shortage of detailed geologic mapping, all of the area discussed has been covered in reconnaissance; positive statements have a basis in observation, and qualified statements are the most reasonable interpretation in the authors' minds or are approximations.

AGE ASSIGNMENTS AND AGE OF THE FROMAN FERRY FAUNAS

In this report, the ages of the faunas of the Snake River Plain are given in radiometric years and are correlated to established mammalian biochronology and magnetic polarity stratigraphy. These assignments and correlations are shown in figure 4. The temporal correlations of polarity-reversal events are those of Mankinen and Dalrymple (1979), which have been used in prior reports by Repenning. Minor changes in the age of the beginning of the Brunhes Normal-polarity Chron (Izett and Obradovich, 1991), the beginning of the Olduvai Normal-polarity Subchron (McDougall, 1985), and the addition of the Cobb Mountain event (Mankinen and others, 1978) have been made in consideration of more recent information.

We emphasize that in the following discussion the correlations of biochronologic and geologic evidence to geomagnetic polarity events are those reported in the references cited, but the ages of these events are basically those of the magnetic stratigraphy of Mankinen and Dalrymple (1979). In one example (Multi-ash section south of Oreana, Idaho; p. 49-51) we have revised the correlations originally made by Neville (1981) on the basis of new age information in the area (including the Birch Creek fauna).

In the past, the temporal calibration of magnetopolarity reversals has been made on the basis of three distinctly separate criteria: (1) radiometric age measurements; (2) Earth orbital parameters correlated with climatic events as inferred from oceanic isotope records; and (3) the assumption of uniform rates of sea floor spreading. Although surprisingly close in agreement, these different approaches to determining the ages of the magnetic events have resulted in somewhat different calibrations. The assumptions of an exact correlation of sea level change with orbital variations and of uniform rates of sea floor spreading have been disproved in detail and are based upon questionable assumptions (Repenning, 1992, 1993).

While not applicable in marine environments and while also subject to errors, those calibrations based upon radiometric age determinations are the least contradictory and are most useful in nonmarine environments, as they can be integrated directly with independent radiometrically measured dates where suitable rocks are stratigraphically related to fossils. As a result, only the radiometrically dated magnetopolarity chronology of Mankinen and Dalrymple (1979, and later revision by other authors) has been used in calibrating microtine rodent history in past reports (Repenning, 1987; Repenning and others, 1990; Repenning, 1992). For consistency, and because its use does not require the

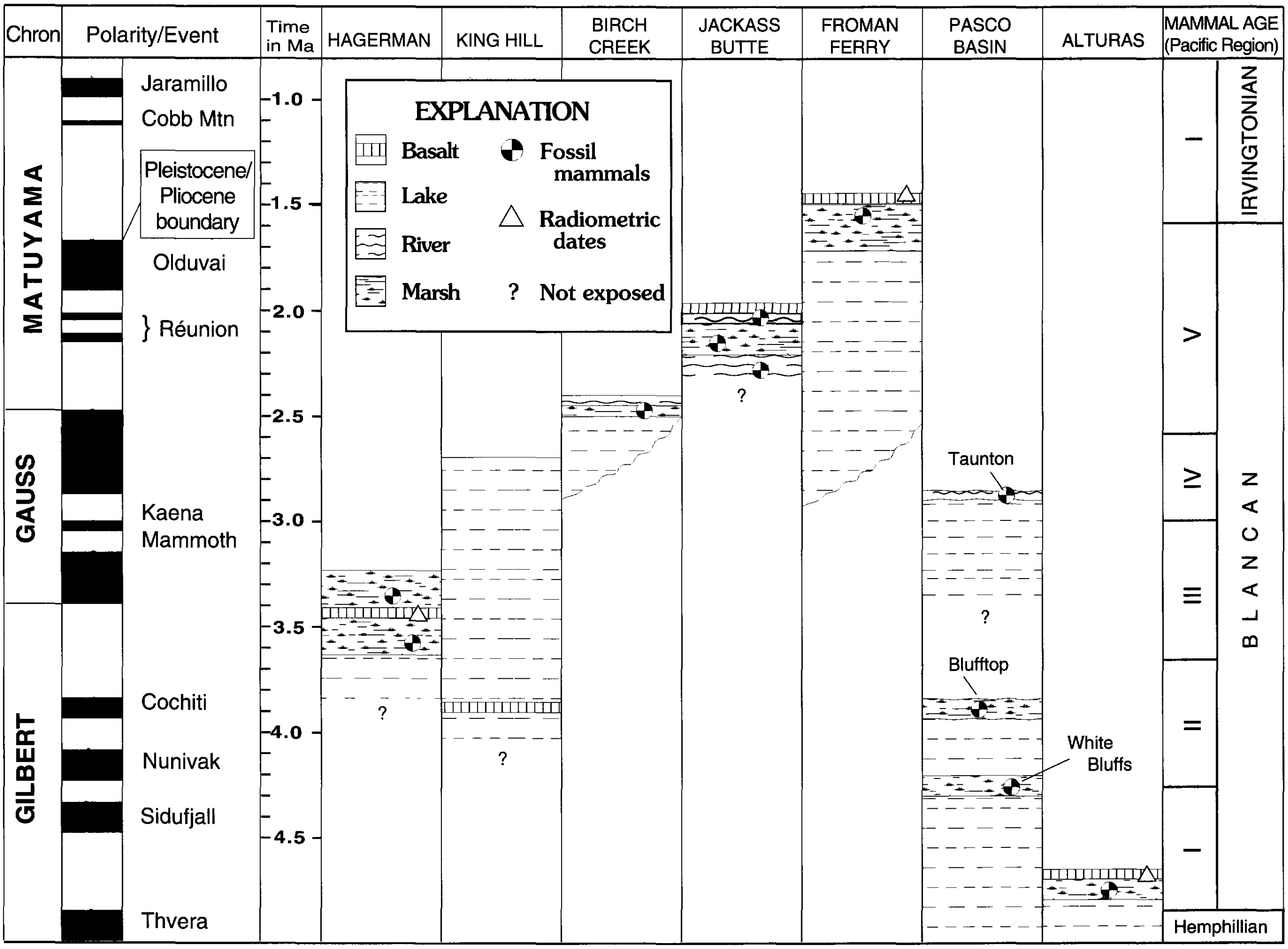


Figure 4. Correlation of deposits in areas discussed, showing paleomagnetic polarity chrons and events correlated with time, deposits, faunas, and mammal ages of the United States.

added uncertainties of correlating radiometric age determinations to marine evidence, the direct radiometric calibration of magnetopolarity stratigraphy is used in the present report.

The magnetic polarity of the section containing the Froman Ferry faunal succession was made (by Van Domelen and Rieck, 1992) from what we take to be the original Froman Ferry locality to the top of Chalk Hills, including most of the fossiliferous section. It was entirely of reversed polarity and, in combination with the radiometric age of the overlying Pickles Butte basalt (also of reversed magnetopolarity), indicates that the possible age of the fossil sequence is between 1.5 and 1.67 million years (fig. 4). Absence of the Olduvai event in the lower part of the Froman Ferry section and the unknown duration of the erosional interval disconformably separating the dated Pickles Butte lava from the Froman Ferry marsh beds further restrict this age to more than 1.5 and less than 1.67 million years ago.

Only one radiometrically determined date is available in the Froman Ferry area, taken from the basalt on the Snake River rim south of Pickles Butte and derived from the lava flow forming this butte (K.L. Othberg, written commun., 1993). Where the sample was taken, the Pickles Butte basalt overlies the Glenns Ferry lake beds (older than the fossiliferous marsh beds), but the basalt is continuous to Pickles Butte where it overlies the Froman Ferry marsh deposits of the Glenns Ferry Formation; a pre-basalt erosional unconformity is obvious but of unknown duration.

The Pickles Butte basalt was dated as 1.58±0.085 million years old by ^{40}Ar-^{39}Ar age determination at the Berkeley Geochronology Center, University of California, Berkeley (K.L. Othberg, written commun., 1993). The minimum date is here used throughout, as the maximum date would indicate the presence of the Olduvai event in the underlying Froman Ferry faunal succession, and this was not found in the magnetic section by Van Domelen and Rieck (1992). This basalt unconformably overlies both the marsh deposits, containing the Froman Ferry faunal succession, and the underlying lake beds of the Glenns Ferry Formation.

Although, from the preceding, erosion obviously separates the Pickles Butte basalt from the Glenns Ferry

Formation in this area, it is not possible at present to estimate the missing time; one of us (Weasma) has examined areas to the east of the Froman Ferry area and is of the opinion that in this direction the basalt, or its debris, is interbedded with Glenns Ferry deposits (apparently younger than the formation underlying the basalt in the Froman Ferry area). The entire Froman Ferry area was uplifted and eroded prior to the eruption; the beginning of this fluvial activity is incorporated in the deposits of the youngest parts of the Glenns Ferry Formation of the Cucumber area. This fluvial gravel contains a greater variety of large mammals than the marsh beds, as at locality GS-232 on the north side of Dead Horse Canyon.

The maximum age span of the Froman Ferry faunal succession is thus less than the 170,000 years between 1.5 million years ago (the age of the overlying basalt) and 1.67 million years ago (the age of the end of the Olduvai Normal-polarity Subchron of the Matuyama Reversed-polarity Chron, which lies an undetermined stratigraphic distance below the lowest fossil horizon). This time span must be reduced by the unknown time involved in the erosion that separates the youngest fossil deposits from the overlying lava and by the unknown time involved between the oldest fossil deposits and the unlocated top of the Olduvai event. The Olduvai event seems to have lasted 230,000 years itself, longer than the time involved in the Froman Ferry faunal succession, and thus is clearly not present in the paleomagnetic section of Van Domelen and Rieck (1992). That the record of the Olduvai event was not removed by the erosion separating the dated lava from the Froman Ferry faunal succession is indicated by the differences between the Froman Ferry fauna and the Jackass Butte fauna, which is as young as about 2 million years old, as will be discussed.

The Froman Ferry faunal succession is thus between >1.5 and <1.67 million years old. By interpolation of stratigraphic thickness, the arrival of the new immigrant *Phenacomys gryci* in the Froman Ferry faunal succession is thus believed to have been about 1.60 million years ago. This arrival marks the beginning to the Irvingtonian mammal age in the Pacific Faunal Region of the United States.

MAMMAL AGES AND PROVINCIALISM

Most of the mammal faunas of the Glenns Ferry Formation are representative of the Blancan mammal age of the United States. The Blancan mammal age is approximately equal to the Pliocene, as Blancan is defined by fauna and calibrated in radiometric years. The Blancan (defined by its mammals) began a bit more recently (4.8 Ma; Repenning, 1987; Repenning and others, 1990) than did the Pliocene (defined by the age of its type section), which began about 5.3 Ma.

Twenty years ago a difference of half a million years might have been disregarded as being within the margin of error in mammalian biochronology or any other chronology, but recent work (Repenning, 1992) has shown that, with ideal evidence, some mammalian groups indicate a biochronologic sensitivity approaching 5,000 to 10,000 years, and the entire Froman Ferry faunal succession was deposited in less than 170,000 years and contains at least one prominent and previously unknown faunal change within this time span: the immigration of a new taxon.

In most of the United States (east of the Rocky Mountains, the Eastern Faunal Region of Fejfar and Repenning, 1992), the Blancan mammal age ended a bit earlier than did the Pliocene. In this faunal region the Blancan ended at the beginning of the Olduvai Normal-polarity Subchron (1.9 Ma) with the immigration of the microtine genus *Allophaiomys* (Repenning, 1992), whereas the Pliocene is approximated as ending with the end of the Olduvai event in its type section (1.67 Ma; Aguirre and Pasini, 1985).

Allophaiomys is unknown west of the Rocky Mountains (in the Pacific Faunal Region; called Western Faunal Region by Fejfar and Repenning, 1992), and there is no faunal change upon which to base the end of the Blancan until after the beginning of the Pleistocene (beginning with the end of the Olduvai event). Thus the first faunal change (immigration of *Microtus* and *Phenacomys*) upon which the Irvingtonian mammal age could be based appears about 1.6 million years ago in the Pacific Faunal Region (age control from the Vallecito Creek faunal succession of the Anza-Borrego Desert, California, and, more precisely, from this discussion of the Froman Ferry faunal succession).

This date for the Blancan-Irvingtonian faunal age boundary is 300,000 years later than this mammal age boundary is recognized in the Eastern Faunal Region because this boundary is defined upon the immigration of distinctive Irvingtonian mammalian taxa, and the histories of immigration differ between the Eastern Faunal Region and the Pacific Faunal Region.

Available age control for the immigration into the Vallecito Creek faunal succession indicates a possible range that includes the age indicated in the Froman Ferry faunal succession. Because the immigration (from the Arctic) of these two new taxa appears to have been climatically controlled and because only one major, Northern Hemisphere climatic change is included in the possible time range, it is presumed that the two dispersing microtine rodents (*Microtus* and *Phenacomys*) appeared at the same time in the Pacific Faunal Region (Repenning, 1992). However, *Phenacomys* is missing farther south, in the Anza-Borrego Desert of southern California (the area is south of any record of *Phenacomys*), and *Microtus* is not present in the marsh beds of the Froman Ferry area.

Thus the end of the Blancan mammal age, and the beginning of the following Irvingtonian mammal age, varied between the east (late Pliocene) and west (early Pleistocene) sides of the Rocky Mountains because the times, and composition, of the first immigration of an Irvingtonian form varied by about 300,000 years between the two faunal regions (Repenning, 1992). Neither of the immigrants marking the beginning of the Irvingtonian mammal age in the United States is yet known at so early a date in the Mexican Faunal Region, and there the beginning of the Irvingtonian age (if these terms are to be used in that region) is yet to be discovered and the age boundary can only be approximate. Conversely, the immigrants are known (*Phenacomys*) or are assumed (*Microtus*) to have been present in the Arctic area (Beringian Faunal Region) at an earlier date.

This difference in the age of the first Irvingtonian faunas on either side of the Rocky Mountains will be disturbing to those who think of the Irvingtonian and Blancan mammal ages as time terms, rather than as faunal terms; but they are defined in faunal terms (Savage, 1951; Wood and others, 1941). One can hardly select a mammal age boundary at a time when there is no change in the mammal fauna. And, except for the immigrant microtine, the Froman Ferry fauna is a Blancan fauna between 1.5 and 1.67 million years old, based upon the minimum possible age given for the overlying Pickles Butte basalt and the 1985 approximation of the end of the Olduvai event by Aguirre and Pasini; neither date would claim a possible sensitivity of 5,000 years, as suggested for microtine biochronology on page 10 and again on page 13 (although the lava date was rather precise and claimed a possible laboratory error of only 85,000 years).

Although the genus *Microtus* was listed from the Irvington fauna (Pacific Faunal Region) by Savage (1951) when naming the Irvingtonian mammal age, no form of *Microtus* is known east of the Rocky Mountains before 0.83 million years ago (Repenning, 1992). Thus, if the arrival of *Allophaiomys* east of the Rocky Mountains is not used for the beginning of the Irvingtonian age in the Eastern Faunal Region, the difference in age for the beginning of the Irvingtonian mammal age (based upon the first *Microtus*) would be even greater in the two faunal regions. The genus *Phenacomys* may have arrived in both Pacific and Eastern Faunal Regions at the same time, but the earliest record east of the Rocky Mountains is in the Java fauna of South Dakota (Martin, 1989; as *Hibbardomys zakrzewskii*), which has no external (nonbiochronologic) age control.

A similar regional difference is associated with the beginning of the Blancan mammal age of the United States. West of the Rocky Mountains it is marked by two immigrant species of the microtine genus *Mimomys* (Wood and others, 1941; Repenning and others, 1990): *Mimomys* (*Cosomys*) *sawrockensis* and *Mimomys* (*Ophiomys*) *mcknighti*. These obviously followed a route down the Pacific coast from Beringia and are dated in the upper Alturas fauna of northeastern California at 4.8 million years ago. But at the beginning of the Blancan, no new microtine immigrants had arrived east of the Rocky Mountains; the first Pliocene use of a dispersal route from the Arctic region to the Eastern Faunal Region (east of the Rocky Mountains) was not until 2.56 million years ago, and marks the beginning of the fifth faunal age of the Blancan, Blancan V. This was the arrival of the genus *Plioctomys* (Repenning and Brouwers, 1992, p. 15), which coincides with the arrival of the closely related genus *Mictomys* in the Pacific Faunal Region at the beginning of the late Blancan (Blancan V).

One of the earliest Blancan immigrants, *Mimomys* (*Cosomys*) *sawrockensis*, is present to the south of the Alturas area in earliest Blancan faunas, in the Maxum fauna of the San Francisco area (May, 1981; May and Repenning, 1982; Repenning, 1987), and seems to have dispersed rapidly around the south end of the Rocky Mountains to the Great Plains, where it was named by Hibbard (1949) from the Saw Rock Canyon fauna of Kansas, but where its age can only be approximated by associated fauna; there is no paleomagnetic control of its type locality (Repenning, 1987, p. 254). Within the limits of available biochronologic resolution, the age of the type locality (Saw Rock Canyon fauna) seems to be about the same as the age in California so that there is thought to have been little age difference, and the beginning of the Blancan age is assumed to be the same on either side of the Rocky Mountains (about 4.8 Ma; Repenning, 1987).

The other earliest Blancan immigrant, *Mimomys* (*Ophiomys*) *mcknighti* (Gustafson), is not present south of the well-dated Alturas fauna in northern California, but is present in the White Bluffs fauna of Washington (type locality; 4.3+ Ma in Repenning, 1987), where some question exists of the correlation of magnetic events (Gustafson, 1985). *Mimomys mcknighti* moved southward and eastward from northern California slowly, and evolved into *Mimomys* (*Ophiomys*) *magilli* as it did so. This species is known in later faunas in the Kettleman Hills and Buttonwillow, California; Panaca, Nevada; Duncan, Arizona; Beck Ranch, Texas (Repenning, 1987); and Sand Draw, Nebraska, where it was named by Hibbard (Skinner and others, 1972). By the time that *Mimomys* (*Ophiomys*) had reached the Great Plains, *Mimomys* (*Cosomys*) had evolved into the new subgenus *Mimomys* (*Ogmodontomys*) in the Great Plains, the later history of which is documented by Zakrzewski (1967).

The Blancan mammal age was defined (Wood and others, 1941) long before its age (and that of the Pliocene) was known in terms of radiometric years. In addition, when the Blancan mammal age was first defined, it was believed to be only of late Pliocene age, and a three-part Pliocene (including the Clarendonian, Hemphillian, and Blancan mammal ages) was recognized in the mammalian faunas of the United States. Before the availability of radiometric age determinations, some had even considered the Blancan to be Pleistocene (McGrew, 1944) or had considered some deposits of the western Snake River Plain (Grand View and younger deposits) to be of late Pleistocene age (Hibbard, 1959). By the modern definition of Pliocene and Pleistocene, the Grand View deposits are clearly of Pliocene age and older than 1.67 million years (end of the Olduvai event). Such concepts are the subject of constant debate, and this is not to say that future agreement between international "authorities" will not change these statements.

In 1964 potassium/argon radiometric dates were first systematically correlated with North American mammal ages (Evernden and others, 1964). In 1968, the earlier correlation of North American mammalian faunas with the type Pliocene (in Italy) was first questioned by vertebrate paleontologists (Repenning, 1968). Those correlating by means of marine invertebrates had, for many years, disagreed with the mammalian correlations (see Repenning and Vedder, 1961). The Pliocene is now considered as beginning about 5.3 million years ago (rather than about 12 Ma in former mammalian paleontology usage).

As used herein, the Blancan is considered as beginning 4.8 million years ago based upon the age of the youngest Alturas fauna of California (Repenning, 1987; Repenning and others, 1990). The youngest Alturas fauna is considered to be of Blancan age because it contains the earliest United States record of *Mimomys*, perhaps the only taxon listed as first appearing in the Blancan in the original definition by Wood and others (1941) that appears so early but not in older Hemphillian faunas. Determination of the age of the beginning of the Blancan has been difficult to make because nearly all of the first appearances listed in Wood and others (1941) have been found to "first appear" at different times in the faunas of the United States, either in earlier faunas that Wood and others called Hemphillian, or much later within the Blancan than *Mimomys*.

By these definitions, the Hagerman fauna of the Glenns Ferry Formation in the western Snake River Plain, about 3.6 to 3.1 million years old, is roughly mid-Blancan (and mid-Pliocene) in age. In many reports it has been called "early Blancan" (for example, Neville and others, 1979), however, and in others it has been called "late Blancan" (for example, Repenning, 1967b; Hibbard, 1958).

The faunas of the Glenns Ferry Formation in the Froman Ferry area are herein considered as representing latest Blancan and earliest Irvingtonian. These mammal faunal terms are of latest Pliocene and earliest Pleistocene geochronologic age as herein dated in the United States west of the Rocky Mountains. The paleomagnetic determinations of Van Domelen and Rieck (1992) eliminate the possibility that Pliocene deposits are present in the Froman Ferry faunal succession: the Olduvai Normal-polarity Subchron is not present in the Froman Ferry faunal succession and by current modern convention the Pliocene ends with the end of the Olduvai event.

Originally defined as *North American* mammal ages by Wood and others (1941) and by Savage (1951), these mammal ages are here used as ages of only the *conterminous* United States, south of the Canadian border, because faunal criteria in North America (as elsewhere) are provincial in nature and vary greatly between, for example, Mexico and Alaska. The "North American mammal ages" cannot be used in Alaska without complete redefinition. This point is illustrated by the elephant *Mammuthus*, first appearing in Irvingtonian faunas in the conterminous United States, and by the bovid *Bison*, first appearing in the younger Rancholabrean faunas of the contiguous United States; both are present in the faunas of Alaska that correlate in time with the Blancan mammal age as defined by Wood and others (1941).

Although the position is here taken that a difference of 300,000 years can exist in the timing of mammal ages within the conterminous United States, because of varying regional faunal history, it does not seem that this position can be extended to differences as great as 2 million years for the same reason. With time differences this great, faunal differences become too great for the practical application of one faunal name. Instead, it is believed that Beringian (nonglaciated northeastern Siberia and northwestern North America) mammal ages merit their own system of regional mammalian ages. Sher (1986) has suggested such a set of regional mammal ages for Beringia, which indicates the need for the terms, but these ages have some weaknesses in definition and correlation (Repenning and Brouwers, 1992, p. 2).

Perhaps only because more attention has been paid to it, provincialism is most prominent in the history of microtine rodents and exists within the conterminous United States, on either side of the Rocky Mountains (Repenning, 1987), as well as between Alaska and Mexico. (See discussion in Repenning, 1992.) Hence the microtine (and to a varying extent other mammalian) faunal criteria for the recognition of mammal ages differ in time and taxa on either side of the Rockies—in the Pacific Faunal Region to the west, and in the Eastern Faunal Region to the east. (These are called "regions" because they also can be subdivided into faunal provinces by examining the less widely ranging, and more environmentally specific, taxa. Greater subdivision is not attempted here, however.)

Following the logic of defining the beginning of mammal ages by the earliest appearance of immigrants (expressed by Repenning, 1967b to the present), the southward dispersal of *Phenacomys gryci* and *Microtus californicus* from Beringia into the Pacific Faunal Region of the conterminous United States is considered the first indication of the beginning of the Irvingtonian mammal age in the Pacific Faunal Region, which includes the Snake River Plain, as discussed previously.

Both the Froman Ferry faunal succession of Idaho and the comparable part (Natural History Museum of Los Angeles County (LACM), California, locality LACM 6683) of the much longer sequence of the Vallecito Creek faunal succession in the Anza-Borrego Desert of southern California are otherwise characterized by typical Pacific region Blancan V microtines at the beginning of the Irvingtonian mammal age. Only the immigrant microtines are present to mark a change in the faunas and to provide a basis for the recognition of the Irvingtonian mammal age (at about 1.6 million years ago).

But even such a simple (and precise) definition of the beginning of a mammal age can have complications. From the beginning of the Blancan, 4.8 million years ago, until 2.56 million years ago, when the Blancan V age began, microtines followed only one dispersal route from Beringia to the conterminous United States; it was down the Pacific Coast and new immigrants can be nicely first recorded in faunas of the Pacific Northwest. But 2.56 million years ago immigrants first came south on both sides of the Rocky Mountains, and, also for the first time, immigrants began appearing first in the Great Plains, some never to disperse westward to the Pacific Faunal Region west of the Rocky Mountains.

This differing history of microtine immigration on either side of the Rocky Mountains causes the problem in the definition of the beginning of the Irvingtonian mammal age—the end of the Blancan mammal age. One can hardly consider faunas west of the Rocky Mountains to be of Irvingtonian age if they differ in no way from late Blancan faunas, even though they may be younger than earliest Irvingtonian faunas to the east of the Rocky Mountains.

Thus, mammal ages, based upon faunal composition, can represent different times in different faunal regions that happen to have different histories of immigration and, in fact, of evolution. As they do not indicate exactly the same times in different faunal regions, they must be defined separately in each region. If we find this situation disturbing it is because we were educated under the outmoded concepts of instantaneous global evolution and of global biohistoric events (biochronology). The biochronologic terms "First Appearance Datums" (FADs) and "Last Appearance Datums" (LADs) were generalities that became outmoded with the development of radiometric dating and recognition of globally synchronous events as changes in the Earth's magnetic polarity and climate, and, on a smaller geographic scale, ash falls and immigrations. FADs and LADs are of use in correlation only within specific faunal regions, and these regions have been only recently, and approximately, defined for microtine rodents (Fejfar and Repenning, 1992), and have not been defined for other fossil mammals in most parts of the world.

DISPERSAL

Evolution is broadly sequential and, within varying limits of precision, can indicate geologic time; but evolution is mostly mosaic in the sense that the same, or similar, events can happen in different regions at different times, at least within the present approximate taxonomic classification. Time and geography are important considerations of phylogeny and taxonomy, as well as of biochronology. Genetic potential is inherited and evolves, but its realization in new morphotypes is opportunistic, and opportunity to develop depends upon regional environmental conditions. Mammalian biochronology is not lost, because regional environmental changes result from climatic changes that are the result of global conditions; biochronology becomes more complicated but at the same time much more precise. And with this, evolution is better understood and taxonomy improved.

"Global" mammalian biochronology has relied upon the concept of simultaneous evolution for a century or more, with the help of other methods of indicating or correlating time when they become available (that, since 1964, can more precisely determine time). But no great attempt has been made to improve mammalian biochronology by documenting the greater detail of evolution that is available on a provincial or regional scale. Repenning (1992) has documented such intraregional detail for a few lineages of microtine rodents and has shown that it can detect age differences as brief as 5,000 years; this is an age discrimination so precise that there exists no external method of checking its precision beyond the effective range of carbon isotopes. Confirmation can come only by matching such a biochronology against similarly precisely determined biochronologies.

To merge provincial records into a global, or even continental, average is to lose detail that more precise methods of age determination, external to existing biochronology, provide. It "smooths out" the record of evolution and hides its detail. Because different biologic events occur at different times in different regions, documenting, rather than averaging, these can produce biochronologies that are more sensitive to time differences than current measurement of radioactive decay. With such a time-sensitive biochronology, dispersal history must be known to correlate the biochronology across faunal barriers between adjacent faunal regions. And an awareness of climate changes that may eliminate or modify faunal barriers or stimulate morphologic change (that has become potential because of genetic evolution) is a most valuable tool.

A number of microtine and other mammalian taxa have crossed the Rocky Mountain ecologic barrier between the Pacific and Eastern Faunal Regions, and most of the microtine crossings are well enough known that the route of a given dispersing taxon can be traced. They have dispersed either around the south end of the Rocky Mountains (through Arizona), or across Wyoming and through the Yellowstone pass, between the Snake River drainage of Idaho and the Great Plains of southern Wyoming.

Depending upon the region of their source, microtine taxa have moved either east or west along these avenues around or through the Rocky Mountains. These movements coincide with climatic events that have made these avenues environmentally acceptable to the specific constraints of individual taxa. They have also made these avenues filter barriers which some microtine taxa have never penetrated. Climate changes are difficult to correlate, because conditions vary with location, and one of the easiest ways to correlate them is by interregional correlation of microtine dispersals that have happened because environmental corridors have opened or closed.

Southward dispersal from Beringia down both sides of the Rocky Mountains to the conterminous United States has also occurred at particular times of climatically forced environmental conditions (Repenning, 1984, 1987, 1990, and 1992; Repenning and others, 1990; and Repenning and Brouwers, 1992). No immigrant microtine rodent can be demonstrated to have appeared in the United States both east and west of the Rocky Mountains at the same time. This fact speaks for a mountainous provincial barrier that continued westward beyond the Rocky Mountains, across the Bering Strait, and into Asia as the mountains of eastern Siberia, which separates the Asian part of the Beringian Faunal Region from the Oriental Faunal Region just as it separates the Eastern Faunal Region from the Pacific Faunal Region of the United States. (See discussion in Repenning, 1992.) However, some closely related forms have appeared at the same time on opposite sides of this mountain chain, as, the first *Mictomys* in the Pacific Faunal Region and the first *Plioctomys* (ancestral to *Mictomys*) in the Eastern Faunal Region, or different subgenera of the genus *Phenacomys*.

Immigrants dispersing from Beringia down the Pacific Coast route west of the Rocky Mountains to the Pacific Faunal Region of the contiguous United States usually are first recorded in the Pacific Northwest, often in the Snake River or Columbia River areas (late Miocene *Promimomys* [perhaps at 5.6 Ma], the early Pliocene smaller subgenus *Mimomys* (*Ophiomys*) [at 4.8 Ma], the late Pliocene bog lemming *Mictomys* [at 2.56 Ma], and the Pleistocene subgenus *Phenacomys* (*Paraphenacomys*) [at 1.6 Ma]). But, apparently, some crossed the Columbia River along the coast (before the Snake River was diverted into it at about 3.5 Ma) and left the Pacific Coast by dispersal up the Sacramento River system in the present State of California (the Pliocene larger subgenus *Mimomys* (*Cosomys*) [4.8 Ma], the muskrats [at 4.2 Ma] and perhaps the vole *Microtus* [at 1.6 Ma]). The Pacific Coast route seems to have been closed after 1.6 million years ago, but the route east of the Rockies opened 2.56 million years ago and the primitive bog lemming *Plioctomys* [2.56 Ma], the voles *Allophaiomys* and a more modernized *Mimomys* [1.9 Ma], the subgenus *Phenacomys* (*Phenacomys*) [perhaps 1.6 Ma], the vole *Lasiopodomys* and pine vole *Terricola* [0.85 Ma], and finally the modern vole *Microtus* [possibly 0.4 Ma] took advantage of it and first appeared in the Eastern Faunal Region. Details behind most of these dates appear later in this report.

For microtine rodents, these dispersals began in the late Hemphillian (*Promimomys*; latest Miocene), and some endemically derived North American microtines (*Microtoscoptes*) apparently dispersed in the opposite direction into Eurasia at the same time. The arrival of *Mimomys* early in the Pliocene defines the beginning of the Blancan mammal faunas of the United States (Wood and others, 1941; discussed in the previous section, p. 11). As will be discussed later, the muskrats appeared in the Pacific Faunal Region about 4.2 million years ago. Immigrants dispersing down the east side of the Rockies (to the Eastern Faunal Region) appear first in the Great Plains; this route was opened by *Plioctomys* at the beginning of the late Blancan (Blancan V), followed by *Allophaiomys* and a second immigration of *Mimomys* (1.9 Ma). Probably because of tectonic activity in the area of the Canadian Rockies near the Gulf of Alaska (Repenning, 1990), the Pacific coastal route was closed shortly after the immigration of *Phenacomys* and *Microtus* (1.6 Ma); all later microtine immigrations (*Terricola* and *Lasiopodomys* at 0.85 Ma and Old World *Microtus* perhaps at 0.45 Ma) appear to have come down the east side of the Rocky Mountains to the Great Plains and the Eastern Faunal Region.

The immigration of *Mictomys* (to the Pacific Region of the contiguous United States) and *Plioctomys* (to the Eastern Region) was about 2.56 million years ago (both marking the beginning of the Blancan V mammal age in their respective faunal regions). Repenning (1987) considered these immigrations as being 2.6 million years ago (on the basis of their earliest records about 15 feet below the end of the Gauss Normal-paleomagnetic Chron in Idaho, Arizona, and Texas), but the age was revised to 2.56 million years by Repenning and Brouwers (1992, p. 15) on the basis of better age control of the dispersal-controlling climatic change. This climatic change was the inception of the first recognized Neogene continental glaciation of the Northern Hemisphere, best dated by the activity of the Scandinavian Ice Sheet (Jansen and others, 1988; Repenning and Brouwers, 1992).

Mictomys, the immigrant to the Pacific Faunal Region, dispersed rapidly through the western Snake River Plain (Grand View faunas), southern Utah (Beaver fauna), and central Arizona (Tusker fauna) 2.56 million years ago, and onto the Great Plains (Borchers fauna) by 2.0 million years ago (Repenning, 1987). It also dispersed (with *Microtus*) to the Anza-Borrego Desert of southern California by 1.6 million years ago, presumably because climatic conditions had not earlier allowed it into this extreme southwestern area. *Plioctomys* first appeared in the Cita Canyon fauna of the Texas Panhandle in the same paleomagnetic position as *Mictomys* (about 15 feet below the end of the Gauss); the genus is known earlier from Hungary to Beringia in Eurasia and Alaska. (Where statements regarding the age of occurrence in specific faunas are made without reference, the reader is referred to the Appendix in Repenning, 1987.)

These dispersals suggest cool and rainy summers if one presumes that the modern environmental controls of these taxa apply to the earliest forms. And, indeed, continental glaciation began to accumulate 2.56 million years ago in both Laurentia and Scandinavia and reached a climax 2.1 million years ago when till was deposited in Iowa (Boellstorff, 1978; Repenning and Brouwers, 1992). At the same time, the Glenns Ferry lake of the Snake River Plain had a rise in water level, presumably a result of glaciation in Yellowstone, as is discussed on page 60.

Current information about the flora of the Glenns Ferry Formation (Bradbury and Krebs, 1982; Thompson, 1992) indicates pine and fir forests alternating with sage steppes in the western Snake River Plain, and a distinctive diatom flora in the Glenns Ferry lake. But the pollen record extends only to deposits as young as about 2.5 million years ago, about as young as the beginning of Blancan V faunas (Grand View faunas), and the floral environment at the glacial peak 2.1 million years ago is unknown, but presumed to be a continuation of fir forests because of contemporaneous hemispheric accumulation of continental ice. The diatom flora in the lake is known to persist to about 2.1 million years ago without change, and is assumed to extend to about 1.67 million years ago in the Froman Ferry area, although no evidence of the age of the lake beds is known in this area. The fluvial environment appears to change by 2.1 million years ago, as the modern cold water stream sculpin *Cottus* makes its earliest appearance in the Jackass Butte section (G.R. Smith, written commun., 1992). The Jackass Butte section includes 2.1 million years ago, as will be discussed; the arrival of the sculpin may reflect the glacial origin of the Snake River in the Yellowstone area.

Younger lake beds farther downstream (northwest, near the mouth of Sinker Creek; fig. 12) contain a diatom flora that is typical of the not-well-dated Bruneau Formation (J.P. Bradbury, oral commun., 1993). The Bruneau Formation is younger than the Glenns Ferry Formation at Froman Ferry on superpositional evidence, that is, younger than 1.5 Ma, as will be discussed. In all locations where the Bruneau Formation has been sampled (from the town of Bruneau northwest to Froman Ferry; figs 1, 2, 12), its diatom flora is distinct from that of the Glenns Ferry lake, and is like that found in modern lakes of the Pacific Northwest (J.P. Bradbury, oral commun., 1993). The formation contains only sage steppe pollen (Thompson, 1992), suggesting drier and, hence, interglacial climate with hotter summers and colder winters.

At the beginning of Blancan V time (Ninefoot Rapids—early Grand View faunas; Conrad, 1980) the microtines *Pliophenacomys osborni*, a genus known almost entirely from the Eastern Faunal Region, and *Ondatra idahoensis* dispersed to the Snake River Plain from the Great Plains, along with *Mictomys* from the Arctic. The westward dispersal route of *Pliophenacomys* and *Ondatra idahoensis* appears to have been by way of the Yellowstone pass, as Barnosky (1985; as "*Pliophenacomys primitivus*, advanced" and "*Pliopotamys* near *meadensis*"; also Repenning, 1987, under "Boyle Ditch, Wyoming") reported them from that area on the Continental Divide at this time. This glacial period correlates in time with the Praetiglian floras of the Netherlands. Whatever the environmental changes during the early part of this first continental glaciation of the Northern Hemisphere, they seem to have allowed *Pliophenacomys* and *Ondatra* to cross the Rocky Mountains from the Great Plains. The emigration of *Pliophenacomys* to the Pacific Faunal Region does not seem to have been successful, however, as the genus is not known from any other fauna in this region.

The immigration from the Great Plains of *Ondatra idahoensis* near the beginning of Blancan V faunas (Repenning, 1987) is discussed in more detail beginning on page 34–5. Subsequently discovered faunas (Conrad, 1980, and unpublished records of ours) in the Glenns Ferry Formation of an age intermediate between the Hagerman faunas and the late Grand View faunas (Jackass Butte) make the conclusions of Wilson (1934) and Zakrzewski (1969), that the Hagerman *Pliopotamys minor* evolved locally into the Grand View *Ondatra idahoensis*, seem improbable. If these muskrats represent the same lineage, these records show an inexplicable and abrupt increase in the animal's size shortly following the beginning of Blancan V faunas (see p. 34–5). The abrupt size difference seems most easily explained by an immigration of *Ondatra idahoensis* from the Great Plains and by the coincident extinction of *Pliopotamys minor* in earliest Blancan V faunas, as suggested by Repenning (1987).

By about 3 million years ago, *Pliopotamys* had dispersed southward to Nevada, Arizona, and the Great Plains (apparently with *Mimomys* (*Ophiomys*)) and evolved into the species *P. meadensis*. Advanced forms of *P. meadensis* are difficult to distinguish from *Ondatra idahoensis*; hence it is not possible to say that *O. idahoensis* did not evolve from *Pliopotamys* in the Great Plains.

The period of global cooling and initiation of continental ice that was contemporaneous with the Grand View faunas until about 2.0 million years ago (high in the Jackass Butte sequence) is called the Praetiglian in the fossil floras of Holland, and was followed by the Tiglian warm floras. The Tiglian floras ended late during the Olduvai Normal-polarity

Subchron and were followed, in turn, by the "cooler" floras of the Eburonian (van Kolfschoten, 1990).

Matching these cycles with the records of activity of the Scandinavian Ice Sheet (Jansen and others, 1988) indicates that the Eburonian floras ended about 1.6 million years ago, but with a maximum peak in Scandinavian ice activity (Repenning and Brouwers, 1992, fig. 2). This maximum peak appears to correlate with the immigration of *Phenacomys gryci* in the Froman Ferry faunal succession at 1.6 Ma, with *Microtus californicus* (and the arrival of *Mictomys vetus*) in the Anza-Borrego Desert record, and, presumably, with the arrival of *Phenacomys zakrzewskii* in the Java fauna of South Dakota (Martin, 1989) at about the same time.

The later history of *Mictomys* is abundantly recorded both east and west of the Rocky Mountains. There is no later record of *Plioctomys*, from which *Mictomys* evolved, after *Mictomys* reached the east side of the Rocky Mountains 2.0 million years ago, and *Plioctomys* is presumed to have become extinct (Repenning and Grady, 1988). *Mictomys* is abundant in the Froman Ferry faunal succession, both before and after the arrival of *Phenacomys*.

The same circumstance of related forms appearing on the opposite sides of the Rocky Mountains occurred with immigration of *Phenacomys* 1.6 million years ago. *Phenacomys* (*Paraphenacomys*) *gryci*, then appearing in the middle of the Froman Ferry faunal succession, is of a different subgenus (Repenning and Grady, 1988) than that which first appeared in the Great Plains, *Phenacomys* (*Phenacomys*) *zakrzewskii* (Martin). This earliest record of the genus in the Great Plains (Java fauna, South Dakota, as *Hibbardomys zakrzewskii*; Martin, 1989) is of uncertain age, as the locality lacks paleomagnetic polarity determination or any other age approximation evidence external to the fauna, but the fauna contains *Allophaiomys* and is unquestionably of an early Irvingtonian age with a high percentage of Blancan holdovers (Martin, 1989). These holdovers are of different taxa than the holdovers in the Froman Ferry faunal succession of the Pacific Faunal Region.

Because of the number of Blancan holdovers, the Java fauna appears to be about the same age as the Froman Ferry fauna, even without external age control; it seems likely that its magnetic polarity would be reversed and younger than the Olduvai event, should it be determined. But *Microtus*, immigrant with *Phenacomys* in the Pacific Faunal Region, did not yet exist in the Eastern Faunal Region. The microtine genus *Allophaiomys*, also in the Java fauna, immigrated (from Asia) to the Eastern Faunal Region 1.9 million years ago to provide a faunal basis for recognizing the beginning of Irvingtonian faunas, as has been mentioned, and is abundantly present in the faunas of the Eastern Region from then until about 830,000 years ago (Repenning, 1992).

Allophaiomys never dispersed west of the Rocky Mountains; one of its environmental preferences was a warm temperate environment, unlikely to have been present in the Yellowstone pass area at the peak of glaciation. This, however, says something about Beringian climate about 2 million years ago when *Allophaiomys* must have crossed the land bridge to North America (Repenning and Brouwers, 1992).

DISPERSAL EVENTS AND FAUNAL CHANGES

The history of dispersals of microtine rodents from Asia and through the Arctic region to the conterminous United States is strengthened by the age and composition of the Froman Ferry faunal succession. The fauna closely dates an immigration event at about 1.60 Ma, that is in the lower one-third of a section between the dates of <1.67 and >1.5 million years old. This immigration event was not recognized by Repenning (1987, fig. 8.1). It was not then recognized that a difference existed in the ages of dispersal to the regions east and west of the Rocky Mountains, but the event recorded in the Froman Ferry faunal succession shortly follows (by 300,000 years) dispersal event 7 of that reference, and marks the beginning of Irvingtonian faunas in the Pacific Faunal Region, as does dispersal event 7 in the Eastern Faunal Region.

Repenning (1987) assigned numbers to the microtine dispersal events as a matter of convenience, and these numbers have been followed in his later publications (for example, Repenning and others, 1990). The number to assign to this newly recognized dispersal event, evident in the Froman Ferry faunal succession by the arrival of *Phenacomys*, in the Vallecito Creek faunal succession by the arrival of *Microtus*, and in the Eastern Faunal Region at the Java fauna of South Dakota by the arrival of a different subgenus of *Phenacomys*, presents a problem to this numbering system.

As discussed later in the third section of this report ("Historic Setting of the Froman Ferry Faunal Succession"), the recognition of the primitive muskrat *Dolomys* in the Etchegoin Formation of California eliminates the evidence of dispersal event 4, formerly believed to be dated by the arrival of the more advanced muskrat *Pliopotamys* in the Hagerman fauna (Repenning, 1987). Thus the muskrats appear in North America during dispersal event 3, not 4 (which is now recognized as not being a dispersal event). Dispersal event 5 thus becomes event 4; dispersal event 6 (at the beginning of the Grand View faunal succession) becomes event 5, dispersal event 7 (beginning the Irvingtonian mammal age in the Eastern Faunal Region) becomes event 6, and the immigration of *Phenacomys* and *Microtus* to the Pacific Faunal Region may be considered dispersal event 7, also evident in the Eastern Faunal Region by the immigration only of *Phenacomys*. Present information does not exclude the possibility that

Phenacomys dispersed up the Columbia River route from the Pacific Coast, and that *Microtus* did not venture inland until reaching the Sacramento River farther south.

The date of this new dispersal event 7 derives from (1) the 1.5-million-year minimum age of the overlying Pickles Butte basalt flow; (2) the entirely reversed polarity of the Froman Ferry faunal succession and of the overlying Pickles Butte basalt; (3) the probable correlation of the dispersal event, as recorded in the Froman Ferry succession, to the less well dated Vallecito Creek faunal succession of California; (4) the history of climatic change in the Northern Hemisphere, and the dependence of dispersals on these climatic changes; and (5) the faunal differences between the Froman Ferry faunas and the faunas of other known ages, which indicate a change related to time. These changes include the modernization of the lineage of *Plesippus* and that leading to *Puma* throughout the records of Glenns Ferry faunas, the new immigrant, and the extinction of *Procastoroides*, all to be discussed. Minor differences in the microtine *Mimomys* (*Ophiomys*) *parvus* will also be noted.

The age of the underlying lacustrine deposits of the Glenns Ferry Formation is unknown in the Froman Ferry area, but the history of deposition of other known marsh deposits overlying lake beds (Hagerman, Sand Point, Poison and Birch Creeks, and Jackass Butte, to be discussed) suggests that no hiatus is present between the lake beds and the fossiliferous marsh deposits. In all but one of these localities (Jackass Butte), marsh deposition immediately follows the disappearance of the lake and can be seen to grade basinward into lake beds. The marsh deposits in the middle of the Jackass Butte faunal succession have fluvial deposits above and below them and thus appear to have resulted from a temporary rise in lake level, as will be discussed (p. 60–61).

Consideration of these factors suggests that the immigrant microtine, *Phenacomys gryci*, appeared about 1.60 million years ago, and that the entire faunal sequence lived between less than 1.67 (end of the Olduvai event) and more than 1.5 (unconformably capping Pickles Butte basalt) million years ago.

From the correlations made by Repenning and Brouwers (1992) between the activity of the Scandinavian Ice Sheet and the pollen floras of Holland, this date for the immigration of *Phenacomys* (1.60 Ma) would seem to have been near the end (and in the most glacially active part) of the Eburonian cold flora of northwestern Europe (Zagwign and de Jong, 1984). It might thus be assumed that summers were cool and winters warm (because of cloud cover). Evidence cited in Repenning and Brouwers (1992) indicates that the Arctic Ocean was not ice covered at this time. These conditions were needed for growth of continental ice fields, but at present the only evidence of ice sheet expansion at this time is from Scandinavia.

The presence of *Phenacomys* and that of the northern bog lemming *Mictomys* in the Froman Ferry faunal succession support this interpretation of climate. Living *Mictomys* avoids the hot summers of the modern temperate climate by now living to the north in Canada, but does not appear disturbed by the modern severity of the winters in this area. Living *Phenacomys* (*Paraphenacomys*) is more environmentally restricted and can endure neither hot summers nor severe winters of today and lives only in the forests of coastal Oregon, in perhaps the most equable climate in North America—even the severity of winters of coastal Washington now limits its range. In combination, the two common forms of microtines in the Froman Ferry faunas suggest cool winters, possibly cool enough to freeze at times, and cool rainy summers about 1.6 million years ago. The cold winter temperatures of the modern Canadian forests are ruled out by the subgenus of *Phenacomys* in the fauna, and hot sunny summer days, as are now typical of the Snake River Plain, are ruled out by both genera. In addition, the absence of subtropical mice, as *Sigmodon*, suggests that winters were cool enough to include some freezing temperatures.

The Froman Ferry faunal succession contains microtine and other taxa that are typical of the Blancan V age throughout the Pacific Faunal Region, including the Grand View faunas (2.5 to 2.0 Ma) of the Snake River Plain and the Vallecito Creek faunal succession (Natural History Museum of Los Angeles County (LACM) localities 6683 and 1357) of southern California (approximately 1.6 Ma and 2.1 Ma). These Blancan V microtine rodents are *Mimomys parvus*, *Mictomys vetus*, and *Ondatra idahoensis*. Thus, the older part of the Froman Ferry faunal succession, prior to the arrival of *Phenacomys*, is considered a Blancan V fauna, but younger than other known Glenns Ferry Formation faunas.

Only the introduction of the immigrant microtine, *Phenacomys* (*Paraphenacomys*) *gryci* (from the Arctic), marks a change in the higher parts of the Froman Ferry faunal succession, a change that is here used to identify the beginning of the Irvingtonian mammal age in the Pacific Faunal Region of the United States, close to 1.6 million years ago.

We point out that none of the large mammals from the Froman Ferry faunas are indicative of an Irvingtonian mammal age; most are usually thought of as being indicative of a Blancan age. The arrival of *Phenacomys gryci* is the first faunal change in the Snake River Plain of Idaho that would separate Irvingtonian faunas from Blancan faunas. But the age of this faunal change is not at all consistent with the age of the beginning of Irvingtonian mammals to the east of the Rocky Mountains in the Eastern Faunal Region of the United States, as has been discussed under the headings

"Mammal Ages and Provincialism" and "Dispersal" (pages 10 and 13).

COLLECTIONS

Very few large mammals and small mammals other than microtines are present in the Froman Ferry faunal succession, although an aquatic shrew is present in several localities, and leporids and a beaver are present, but rare. The scarcity of large mammals and the absence of many types of small mammals are thought to be a result of the environmental constraints of the ancient marsh.

Scott's collections were made by prospecting for marsh plant remains (reeds and rushes, usually visible only in freshly exposed material), and collecting and washing at least three burlap sacks of matrix (about 75 lb each) when these were found. As collecting proceeded, it became apparent that the great majority of small mammals were in those deposits that appeared as dark-gray layers because they were rich in carbonized plant matter and that were visible hundreds of feet away. Fragmented large mammals were most common in fluvial gravel beds, as at locality GS-232 in the Cucumber area. As judged by the scarcity of large mammal remains, however, the area would be considered sparsely fossiliferous.

The specimens from the Froman Ferry faunas here discussed are cataloged in the National Museum of Natural History, Smithsonian Institution, Department of Paleobiology, Vertebrate Paleontology Catalog (USNM). Only the most significant specimens described herein (figured or described in detail) have been assigned USNM numbers in this report; the others are designated only by George Scott locality field numbers (GS-XXX), which will also be on file at the USNM; these specimens will be cataloged in USNM at a later date.

Specimens collected by Scott subsequent to writing this report are being placed in the Museum of Natural History, Idaho State University, Pocatello, Idaho.

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THE FROMAN FERRY FAUNA

Fish remains are abundant throughout the Froman Ferry faunal succession; Gerald R. Smith (University of Michigan Museum of Paleontology) examined about 1,000 from the Cucumber area and identified the following forms (G.R. Smith, written commun., 1992):

Family Cyprinidae

Acrocheilus latus, chiselmouth chub; derived from the Columbia River drainage (common).

?*Gila* sp., chub.

Mylopharodon hagermanensis, minnow; derived from the Sacramento River drainage (abundant).

Family Catostomidae

Catostomus macrocheilus, sucker; derived from the Columbia River drainage (rare).

Chasmistes sp., lake sucker; derived from the Snake River drainage (not Columbia River) (rare).

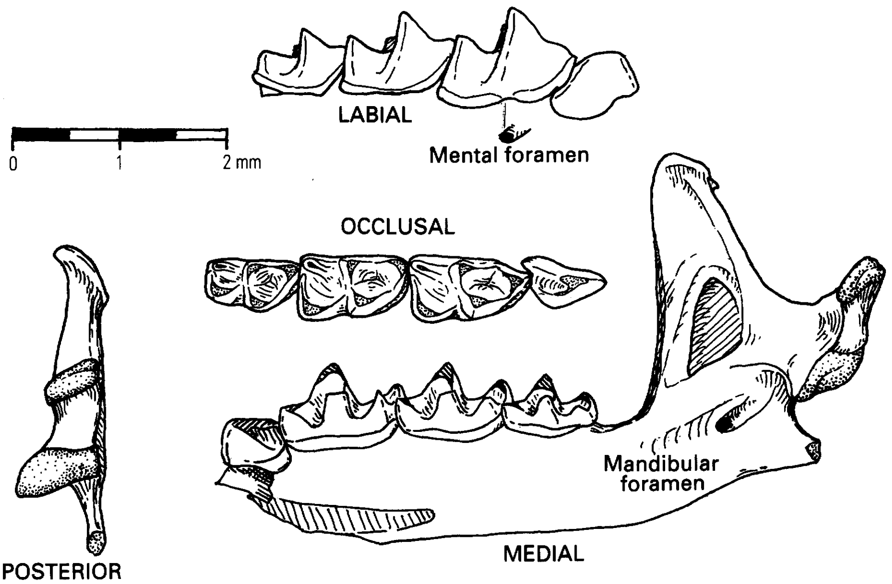


Figure 5. *Sorex* (*Otisorex*) *palustris* USNM 264328 from locality GS-225, Cucumber area, Froman Ferry faunal succession, Canyon County, Idaho. Medial, occlusal, and labial views of the lower dentition, and posterior view of the mandibular condyles. Scale as shown.

Family Ictaluridae

Ictalurus sp., catfish; now found only east of the Rocky Mountains (uncommon).

Smith (written commun., 1992) noted that all of the lake species and also the Columbia River fluvial species (sturgeon, peamouth chub, sculpins, rainbow trout, mountain whitefish) are missing, and that the fish fauna is a distinctly warm water one. The presence of stunted catfish and the absence of sunfish suggest a short growing season. He stated that "The fauna is most similar to that at Jackass Butte, but lacks the cold-water stream sculpin *Cottus*." As has been mentioned and is further discussed beginning on page 60, most of the Jackass Butte faunal sequence is from stream deposits apparently draining a glaciated headwaters in the Yellowstone Park area, and marsh deposits are lacking except in the middle part of the section that contains the older normal event of the Réunion Subchron (2.12–2.14 Ma), which also is present in glacial till in Iowa.

Smith and Patterson (1994) have recently published a summary of the temperature conditions in the Glenns Ferry lake, based upon the nature of the fish fauna and oxygen isotopic evidence. Although it is concerned mainly with the environment of the lake, the results are in good agreement with the climatic interpretations here made from the mammalian faunas.

Surprisingly few bird bones were found in the Froman Ferry faunal succession, and only the tarsometatarsus of a pintail, *Anas* sp. cf. *A. acuta*, was identified from GS-220 (2,630 feet elev., in the Cucumber area).

Abundant herpetofaunal and molluscan remains were not identified.

Order INSECTIVORA

Family SORICIDAE Gray, 1821

Subfamily SORICINAE Fisher von Waldheim, 1817

Genus *SOREX* Linnaeus, 1758

Subgenus *OTISOREX* De Kay, 1842

SOREX (*OTISOREX*) *PALUSTRIS* Richardson, 1828

Figure 5

Localities and material.—CHALK HILLS AREA: GS-209 (2,470 ft elev.): mandible fragment with M/1–2; mandible fragment with part of M/1 and M/2. LIZARD BUTTE AREA: GS-213 (2,440 ft elev.): mandible with M/1–3. CUCUMBER AREA: GS-217 (2,480 ft elev.): mandible fragment with M/3. GS-220 (2,630 ft elev.): partial mandible with P/4–M/3; mandible with M/1. GS-221 (2,650 ft elev.): mandible with M/1; mandible fragment with posterior structures; two mandible frags with M/1–2. GS-225 (2,640 ft elev.): five mandibles (one USNM 264328) and a maxillary with P\4–M\2. GS-230 (2,760 ft elev.): mandible with P/4–M/3. GS-234 (2,770 ft elev.): mandible fragment with M/1–2.

Eight localities; 2,440 to 2,770 feet elevation (uncorrected for structural uplift in the Pickles Butte area).

Discussion.—The genus *Sorex* has a rather large number of species and has been subdivided into subgenera in various ways; the presence of "postmandibular foramen" is possibly the most questionable criterion, as it has many exceptions and can result from ossification failure at the base of the internal temporal fossa. Nevertheless, it is here used as a character of the subgenus *Otisorex* (see Hall, 1981, p. 27) as all specimens (*N*=13) preserving this part of the mandible lack the postmandibular foramen. In contrast, those shrews belonging to the genus *Sorex* described from the Hagerman fauna (three species; Hibbard and Bjork, 1971) all have both a mandibular foramen and a postmandibular foramen.

Sorex palustris, a living species, appears to be present throughout the Froman Ferry faunal succession. There is only a single mandibular foramen, which may (*N*=4) or may not occur in a shallow depression or groove. A single unicuspid is present anterior to P/4. The mental foramen is below the paraconid of M/1 and slightly below and behind the labial flange of P/4. The talonid of M/3 is not greatly reduced and pigmentation is moderately variable in extent, but well developed. The mandibular condyles are typically soricine (Repenning, 1967a).

In size the Froman Ferry material seems to be slightly small for the species, and the length of M/1–M/3 averages 3.1 mm (*N*=13; range=2.7–3.5 mm). Modern specimens in the Denver Natural History Museum from Archuleta County, Colorado, average about 3.7 mm in this dimension but from Chaffee County, Colorado, about 3.2 mm in this dimension.

The specimens do not resemble any shrew species from the Hagerman faunas that Hibbard and Bjork (1971) assigned to the genus. These belong to the subgenus *Sorex* on the basis of the presence of a single postmandibular foramen. *Sorex palustris* is a more or less generalized species of the genus, but has exceptional aquatic adaptations; it is not surprising to find it in fair abundance in the Froman Ferry marsh beds.

Order CARNIVORA Bowdich, 1821

Family FELIDAE Gray, 1821

Subfamily MACHAIRODONTINAE Gill, 1872

Genus *ISCHYROSMILUS* Merriam, 1918

ISCHYROSMILUS IDAHOENSIS Merriam, 1918

This species was originally described from the Froman Ferry fauna (locality UCMP 3036, old 3036C) on the basis of a badly abraded and incomplete left mandibular ramus. Nothing more of the taxon has been recovered from the Froman Ferry area, but material from Grand View has been referred to the species (Shotwell, 1970; Conrad, 1980). A large and poorly preserved calcaneum (USGS locality M1346, unpublished) and a fourth metacarpal (Bjork, 1970) have been referred to the genus from Hagerman. Machairodont affinities and size, of course, are the only basis for these assignments, as the type is known only from the mandibular ramus.

The species is larger than *Ischyrosmilus ischyrus* from the Asphalto fauna of California (Merriam, 1905), probably of Irvingtonian I age (judging from its association with an advanced plesippine horse) and roughly the same age as the Froman Ferry fauna. *I. idahoensis* is slightly larger than *Ischyrosmilus johnstoni* Mawby (1965) from the Cita Canyon fauna of Texas (about the same age as the oldest part of the Grand View faunal succession), and Kurten (in Kurten and Anderson, 1980) noted a considerable range in size of these two species, apparently considering both synonymous under the prior name *I. idahoensis*.

Ischyrosmilus idahoensis from the Froman Ferry fauna has an elongate diastema between the stout lower canine and P/3 with a more sloping chin (hence a less blunted rostrum), and appears to have had a less prominent flange on the lower jaw for the upper canine than some sabertooth cats; the synonymy apparently intended by Kurten (in Kurten and Anderson, 1980) seems reasonable.

Subfamily FELINAE Trouessart, 1885

Genus *PUMA* Jardine, 1834

PUMA CONCOLOR (Linnaeus), 1758

Locality and material.—CUCUMBER AREA: GS-222 (2,650 ft elev.): left calcaneum. GS-221 (2,650 ft elev.): USNM 264337: two patellae, left and incomplete right astragali, incomplete left calcaneum, left and right cuboids, left navicular, left entocuneiform with typically reduced first metatarsal, incomplete left metatarsal II, distal half of right metatarsal III, head of left metatarsal IV, proximal third of right metatarsal V; right scapholunar, left trapezoid, left and right magnum, left and right unciform, left cuneiform, proximal half of right metacarpal II, complete left and head of right metacarpal III, heads of left and right metacarpal IV, heads of right first and third metacarpals; 18 sesamoids; 10 distal and many intermediate phalanges; last(?) caudal vertebra (elongate) and many vertebral fragments; distal articulations of fibula, ulna, and humerus; proximal articulation of radius; fragment of mandibular ramus at diastema with P/2 roots, two mental foramina, and worn canine; fragment of left premaxillary with alveoli for I\1,2,3 and C; GS-232, Sample 14 (2,815 ft elev. and 60 ft uphill from GS-232): proximal third of ulna.

Three localities; 2,650 to 2,815 feet elevation.

Comparison.—The generic allocation of species of cats is unstable. The cheetah *Acinonyx* and the unrelated and extinct North American cheetah *Miracinonyx* are almost always considered as genera separate from *Felis*; the large, roaring cats (lion, tiger, leopard, jaguar) are often considered separately in the genus *Panthera*; the bob-tailed intermediate-sized cats are often placed in the genus *Lynx*; and the large puma and small cats that do not clearly belong in any of the above are usually left in the genus *Felis*.

Living *Lynx rufus*, *L. canadensis*, and *L. caracal*, *Puma concolor*, *Panthera tigris* (two subspecies), *P. onca*, *P. pardus*, and *P. uncia*, *Felis pardalis*, *F. serval*, and domestic cat, as well as *Acinonyx jubatus* and the fossil

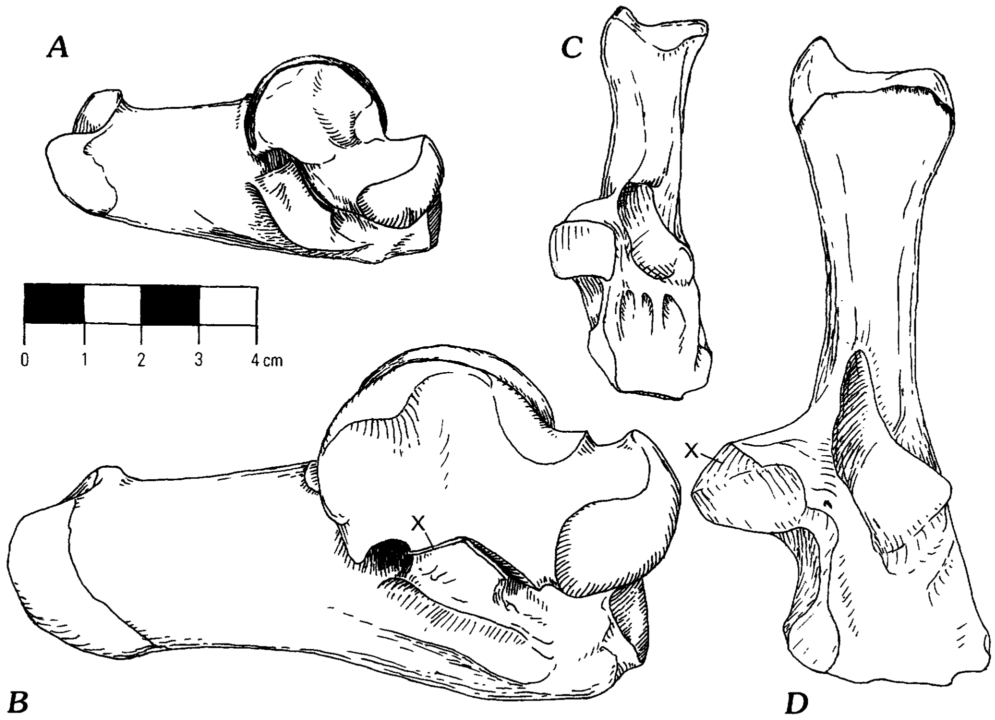


Figure 6. Modern specimens of *Puma concolor* and *Panthera tigris*, calcanea and astragali, showing differing articulations on the sustentaculum. Scale as indicated. *A*, *Puma concolor*, articulated left astragalus and calcaneum, medial aspect. *B*, *Panthera tigris*, articulated left astragalus and calcaneum, medial aspect. *C*, *Puma concolor*, calcaneum in tibial aspect. *D*, *Panthera tigris*, calcaneum in tibial aspect. X, posteroplantar articular facet on the sustentaculum.

Miracinonyx inexpectatus, were compared with the fossil material.

Although the comparisons made to identify the puma from the Froman Ferry faunal succession were by no means complete for the subfamily Felinae, they did lead to the observation that in most bones of the body of the puma, the genus is distinct, in varying degrees, from other cats, and that the puma is as logically considered as a separate genus as are any of the other often-recognized genera (see Honacki and others, 1982, p. 277–283). We therefore follow this reference with the exception that we also treat *Puma* as a full genus (Honacki and others included it in *Felis)*.

The living *Lynx canadensis* and *Lynx rufus* are very similar in skull size but differ in body size, *Lynx canadensis* having relatively larger body and longer legs than *Lynx rufus*. The difference between these two species is comparable to that between *Miracinonyx inexpectatus* and *Puma concolor*. Yet the lynxes are left in one genus (or subgenus) and the puma and the extinct North American cheetah (often considered as being closely related to the puma) are put in separate genera. However, in this review we do not advocate placing *Puma* and *Miracinonyx* in the same genus, although a comparison of the heads of these two does favor such a similarity (Savage, 1960). Many consistent differences exist in the postcranial skeleton and in their biogeographic history (Van Valkenburgh and others, 1990).

A single calcaneum of *Puma* was found at GS-222; it is unmistakably identical to that bone of the living *Puma concolor*. The bone is less similar to that of *Felis lacustris* from older faunas of the Glenns Ferry Formation, which is smaller (Gazin, 1933; Bjork, 1970; Conrad, 1980) and less similar to living puma. Length of the fossil calcaneum=61.4 mm (cuboid facet to lateral posterior process, the longer medial posterior process is missing because of damage).

The specimen from GS-221 (USNM 264337), about 150 feet from GS-222, is obviously the remains of a single individual, completely disarticulated and with the larger bones fragmented but not worn or weathered. Several bones are represented by both left and right elements and those that are preserved are sharply defined morphologically. The single calcaneum of this individual is smaller than that from GS-222 and measures 52.3 mm in the same dimension (cuboid facet to lateral posterior process; 85 percent the size of that from GS-222). In comparison with the calcaneum from GS-222, this is the same size difference as may be present in the sexual size difference of living *Puma concolor* (Hall, 1981, v. 2, p. 1039), although individual variability may exceed sexual variability. The size difference of the two

Froman Ferry individuals is interpreted as being a sexual difference, however. Considered together, both specimens seem possibly small in comparison with living puma, but within its size range. But the sample is small.

CALCANEUM.—The male and female calcanea from Froman Ferry have little similarity to that of the living Old World cheetah, *Acinonyx jubatus*; they also are not very similar to the calcaneum of the North American cheetah, *Miracinonyx inexpectatus*, as follows:

1. Like *Puma concolor*, the calcaneum is much smaller than that of *Miracinonyx*.

2. Like *Puma concolor*, the sustentacular articular facet on the male calcaneum from Froman Ferry has a distinct caudal (proximal) crestlike edge above the more prominent groove (for interosseous ligaments with the astragalus) that separates the two articular surfaces for the astragalus (noted by Van Valkenburgh and others, 1990).

In *Miracinonyx*, as in most living cats except puma, the caudal part of the sustentacular articular surface is varyingly bent, in a plantar-caudal direction, but is less developed in *Miracinonyx* than in most. Viewed in medial aspect this articulation between the calcaneum and the astragalus is distinctly an angled surface (about 130° between facets) in all cats (best developed in the tiger, see fig. 6), except *Puma*. In *Puma* and *Lynx rufus* only the primary facet is present and a caudal-plantar-directed portion of the surface is lacking. The caudal-plantar flexure is minimally developed in the Afroasian caracal (sometimes included in the subgenus *Lynx*), and is also weakly present in some individuals of North American *Lynx canadensis*, but not *Lynx rufus*. The articular surface in the Froman Ferry specimen is like that of puma, and has only the primary facet.

The lack of this downward flexure at the caudal limit of the sustentacular articulation is the strongest single feature that distinguishes the calcaneum of North American puma and lynx from other cats of the world, including jaguar. One calcaneum of *M. inexpectatus* from the Cheetah Room fauna, West Virginia (USNM 401092), and two unassociated calcanea from Cita Canyon, Texas (JWT 1950 and 608), were made available by B. Van Valkenburgh. On the West Virginia specimen the downward (caudal) flexure of the articular surface is clearly present, although weakly developed in comparison with many modern Old World cats, as tiger. It is even more weakly developed in the two specimens from Cita Canyon.

The calcaneum is not known from the specimen of *Miracinonyx inexpectatus* from Santa Clara County, California (USNM 184064), but the opposing articular surface on the plantar surface of the astragalus clearly shows this flexure, as is the case with the astragalus of the Old World cats. This downward, caudal bend of the articular surface on the calcaneum appears to be consistently absent in *Puma* and very weak in *Lynx* and *Miracinonyx*; it is weak to pronounced in other living felids.

On the Froman Ferry specimens, the sustentacular astragalar articulation is preserved only in the male from GS–222, but this specimen shows no sign of this downward-flexed caudal part of the articulation, comparing favorably with living puma.

3. The body of the *Miracinonyx* calcaneum, posterior to the astragalar articulations, is thickened dorso-plantarly, as though to provide additional strength to resist the strain of extension of the pes. This thickening is not evident on *Puma*, Old World *Acinonyx*, or other cats examined.

The calcanea of *Puma*, *Miracinonyx*, and *Acinonyx* are similar in having a more massive sustentacular process than do those of most Old World cats. In medial aspect of the calcaneum (fig. 6: *Puma*) of these forms, the entire sustentaculum is, relatively, thicker in a plantar-tibial direction and the plantar groove for the tendon of the flexor digitorum profundus is variably narrow and more sharply defined than on many (but not all) Old World cats.

The sustentaculum itself is not transversely elongate in puma, *Miracinonyx*, or *Lynx*, and its articular surface is approximately equidimensional, rather than transversely elongate as in some (but not all) Old World cats (fig. 6: tiger).

In summary, the *Puma* calcaneum from GS-222 resembles that of *Miracinonyx* about as much as does living *Puma*, and is identical to living *Puma*. Unlike *Miracinonyx* and like *Puma* it is smaller, has a less robust calcaneal tuber behind the astragalar articulations, has a deeper and more sharply rimmed trench between the sustentacular articulation and the body of the calcaneum, and shows no tendency toward a plantar-caudal flexure of its sustentacular articular facet. Disregarding size, there is no felinid that has a calcaneum which could be confused with *Puma* except within the genus *Lynx*.

ASTRAGALUS.—The downward fold of the astragalar articulation of the calcaneal sustentaculum in all but puma and lynx is matched on the opposing articular surface of the astragalus by a downward (plantar) bend at its caudal (proximal) limit. Thus the articular surface for the calcanear sustentaculum extends a short distance onto the base of the tibial trochlea of the astragalus in Old World cats. The available astragalus of *Miracinonyx inexpectatus* (USNM 184064) shows the Old World pattern. There are some individual exceptions, however, in the astragalus of both living puma and the Froman Ferry fossil from GS-221 (USNM 264337). In the astragalus of these a small posterior-plantar-directed surface is present at the back of the articular surface for the sustentaculum of the calcaneum. This small surface is not reflected on the opposing calcaneum in these individuals, but its presence on the plantar surface of the astragalus makes the character less reliable when judged by the astragalus than when judged by the calcaneum.

Similarly, the trench is narrower between the two astragalar articular surfaces for the calcaneum, on the plantar side of the astragalus, of puma and lynx than in some individuals of *Panthera*. This parallels the lack of transverse elongation of the sustentaculum, and the presence of a narrower, more sharply defined groove between the articulations for the astragalus on the calcaneum in puma and lynx. The trench of the astragalus and the groove of the calcaneum are relatively wide in some Old World cats, as, tiger and snow leopard, but not so in leopard and jaguar. Evaluation of puma characters of the astragalus is less certain than evaluation of the calcaneum.

ULNA.—As shown by Van Valkenburgh and others (1990, fig. 8) the distal radial articulation on the ulna of puma and Canadian lynx is pedestaled, it is on a process that holds it above the anterior surface of the ulna; this elevation of the articular facet above the ulna shaft is not so obvious in bobcat (*Lynx rufus*). Although apparently always present in *Puma*, the pedestaled radial articulation on the ulna seems to be a random condition in all other cats and not particularly diagnostic of species groups, except that it is remarkably reduced in the cheetahs and *Miracinonyx* and so its lack is presumably related to running.

A comparable structure is present on the distal end of the radius for the opposing articulation with the ulna in puma and other cats having the pedestal on the ulna. The result is that the radius and the ulna of puma, Canadian lynx, and some other cats are relatively more separated at their distal ends, suggesting a more massive wrist.

The distal radial articulation on the ulna of *Miracinonyx trumani* (not seen; Van Valkenburgh and others, 1990, fig. 8) appears intermediate, and the living cheetah appears almost not to have the articulation. The partial ulna from the female puma specimen of the Froman Ferry succession exactly matches living puma, and it bears no resemblance to the North American cheetah. The more proximal parts of the ulna were not found at GS-221, but an isolated proximal third of an ulna of *Puma* was found in the fluvial gravel of GS-232, Sample 14. It is well preserved, although the individual was a bit arthritic. In the region of the humeral socket, the posterior (ventral) margin of the puma ulna is straight or even a bit convex, whereas it is concave in some cats (as, tiger) because of a posterior curve of the olecranon process, and the humeral socket (semilunar notch) is deeper and nearly semicircular in puma. In these respects the proximal part of the *Lynx* ulna matches that of *Puma*.

RADIUS.—Only the proximal head of this bone was found with the female specimen. In puma and lynx the ringlike proximal articulation for the ulna does not completely circle the head of the radius but is incomplete at the most anterior point (on the side opposite the ulna); in all other cats seen the articular band completely circles the head, suggesting greater pronation-supination of the manus in most cats.

HUMERUS.—Only the distal articulation of a humerus was found with the female specimen from GS-221(USNM 264337). Orientation of the bridge for the entepicondylar foramen seems to vary in different cat lineages. In medial aspect of the humerus of the tiger, the internal epicondyle, and the bridge of the foramen proximal to it, originate centrally on, and lie in line with, the shaft axis. The bridge continues proximally, terminating in a more or less central position on the medial side of the shaft. In puma, lynx, leopard, snow leopard, and many others, the medial epicondyle is located more posteriorly—the bridge of the foramen begins at the flexor origins, and is oriented anteroproximal so that the foramen bridge is directed anteriorly as well as proximally up the shaft; at its proximal termination it is essentially at the anterior face of the shaft, not medial on the shaft as in tiger and a few other largest cats. Again, the condition seems variable in most cats except *Puma*.

Miracinonyx and *Acinonyx* have the puma-lynx pattern except that the bridge is remarkably broad. The distal articulation of the humerus from GS-221 clearly shows the puma-lynx pattern, and is not a relatively broad bridge as in *Miracinonyx*. The character seems intraspecifically variable and not diagnostic at the generic level, except that within *Puma* the condition is consistent in all individuals (*N*=6).

METACARPALS.—In the manus of all cats, the first metacarpal is reduced and has a uniform morphology, although varying in size. The fossil first metacarpal from the female specimen is identical to living felids and its size is that of a small female puma; as are all other bones, it is conspicuously larger than this bone of *Lynx*. The first metacarpal of *Miracinonyx* appears to be considerably larger (150 percent) than in male puma (Van Valkenburgh and others, 1990, p. 441, fig. 10).

The third metacarpal from GS-221 (female) is 6.7 cm long, and the same bone in a modern (wild) male puma is 7.8 cm long. Van Valkenburgh and others (1990, table 5) listed an average of 8.35 cm based upon eight specimens in the Natural History Museum of Los Angeles County. Their specimens are very large and may be animals from a zoo; the same greater size is evident in zoo animals in the Denver Natural History Museum. Captive puma grow to larger sizes than wild puma (Betty Mulcahy, Denver Zoo, oral commun., 1994); however, we know of no published size comparison between zoo and wild puma. (One of our wild specimens was killed by a bow hunter in southern Arizona and, by skull length, was said to be the seventh largest puma killed by a bow in Arizona; it cannot be considered a small puma.)

PES.—In addition to the astragalus and calcaneum, the tarsal elements from the Froman Ferry locality GS-221 include the cuboid, entocuneiform, and rudimentary first metatarsal of the right pes. Except that they are small, these also seem identical to *Puma concolor* but differ only slightly from those of other cats compared. The calcaneal facet of the cuboid is almost rectangular in tiger; in *Lynx rufus* it is rectangular but its posteromedial corner is enlarged in this direction, which is above the buttress that forms the groove for the peroneus longus. This expansion of the posteromedial corner of the calcaneal articulation of the cuboid is more pronounced in puma so that the articular surface could be described as a trapezoid, and this pattern is identical on the smaller cuboid from GS-221. There seems to be little consistency to the individual variation of this facet, however, and the jaguar and ocelot cuboids examined are like puma in this feature.

The fossil entocuneiform is rather narrow, conspicuously narrower (plantar-dorsally) than the first metatarsal at their articulation, but these conditions do not seem significantly different than in other cats. The distal phalanges are typically feline, and little can be said about the elongate caudal vertebra, except that the animal had a long tail, apparently as elongate as in living puma; the vertebra is 17.7 mm long and 6.5 mm thick at its proximal articulation and appears to have been nearly terminal by comparison with living puma.

Discussion.—Although the characters separating *Puma concolor* from other living cats are variable in other cats, they seem consistent within *Puma*. The elements preserved in the Froman Ferry fauna at localities GS-221 and GS-222 show the puma condition in all of them. The fossils from GS-222, GS-221, and GS-232 represent three individuals that are within the size range of the living (wild) form of the species, but apparently slightly smaller than the average, if our comparisons have not been influenced by the size difference between captive and wild individuals. The male calcaneum is larger than that of *Felis lacustris* from the older parts of the Glenns Ferry Formation, but even this population is within the rather large size range of the living species.

Both the fossil cats from the Glenns Ferry Formation and the living puma are morphologically dissimilar to and smaller than the North American cheetah, *Miracinonyx inexpectatus*, which lived contemporaneously with *Puma* from about 2.56 million years ago until at least 600,000 years ago and in all parts of the United States.

From the present fossil record, *M. inexpectatus* appears fully developed about 2.56 million years ago at Cita Canyon, Texas, and has no earlier North American record. It appears to have changed little over the following 2 million years that it is recognized as a species (Van Valkenburgh and others, 1990), suggesting that when it arrived in North America it was fully adapted and morphologically stable.

The time of arrival of *Miracinonyx* in North America was a time of conspicuous faunal dispersal from Eurasia to North America (beginning of Blancan V). This was also the time of the beginning of the first Tertiary buildup of continental ice in the Northern Hemisphere, as well as the first development of permafrost in Beringia (see Repenning and Brouwers, 1992, for a climatic summary). Glacial buildup was accompanied by the retraction of forests from the shores of the Arctic Ocean and the expansion of great areas of steppe grassland and of tundra environments in the Arctic region (because of the increasing development of the Arctic low over the Arctic Ocean and lowered summer temperatures). It is reasonable to expect the dispersal of steppe-adapted cats and other mammals at this time. There is, however, some basis for questioning the steppe adaptation of *Miracinonyx*, both because it was so very widespread across the United States (California to the Appalachian Mountains) and because the differences in body proportions between it and the puma are comparable to those between Canadian lynx and bobcat, the Canadian lynx being larger bodied and longer legged, but not generally considered a steppe cat.

Van Valkenburgh and others noticed no skeletal difference between the oldest specimens of the North American cheetah (Cita Canyon, Texas, 2.56 Ma) and the youngest (Cheetah Room, West Virginia, 0.84 Ma, and the undated Conard Fissure, Arkansas, which is, perhaps, as young as 0.61 Ma), suggesting that they were preadapted to take advantage of this climatic change and were relatively fixed morphologically. As Van Valkenburgh and others (1990, p. 452) noted, this evolutionary stasis of the cheetah-like cat seems to have ended during the possibly 600,000 years following its youngest record, if the late Pleistocene *Miracinonyx trumani* actually derives from *M. inexpectatus* as has been suggested. This departure from stasis also might be expected, as the youngest record, although undated, was during a time of global climate fluctuations: the beginning of the later, and most intense, part of the Ice Ages. This climatic instability could have forced major changes in adaptation, and may have stimulated renewal of morphologic evolution toward *M. trumani*. Although not so well known, *M. trumani* appears to have been restricted to steppe environments, and is known only from modern plains and desert areas whereas *M. inexpectatus* has been found from Florida to Pennsylvania and westward to California.

Not only was the Froman Ferry puma different in morphology and size from the contemporaneous immigrant, *M. inexpectatus*, it was not in morphologic stasis but was evolving in both size and morphology toward modern puma during deposition of the Glenns Ferry Formation, from *Felis lacustris* of the Hagerman fauna (about 3 Ma) and of the Jackass Butte fauna (about 2.2 Ma) to *Puma concolor* of the Froman Ferry fauna. The skeletal evolution seems to have been nearly complete by the time of the Froman Ferry faunal succession.

In the patterns of the limb skeletal elements described previously, the New World jaguar and ocelot appear to be like Old World cats and less similar to North

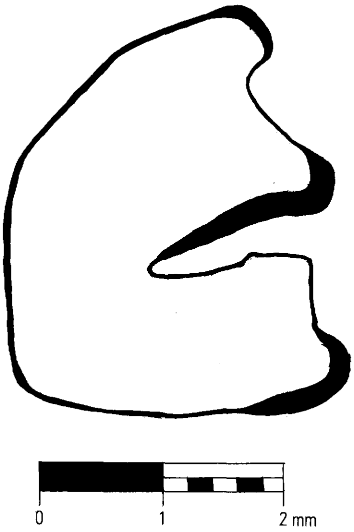


Figure 7. Occlusal enamel pattern of the third lower premolar of *Hypolagus gidleyi* from the right mandibular ramus of USNM 264338; locality GS-232, Sample 14, high in the section in the Cucumber area, Froman Ferry faunal succession, Canyon County, Idaho. Scale as shown. Enamel shown as black.

American puma, suggesting a later immigration to North America, possibly 840,000 years ago from the evidence in the Cheetah Room fauna of West Virginia (Van Valkenburgh and others, 1990). This also was at a time of major immigration to North America from Asia and the beginning of the "official" Ice Ages (Nebraskan glaciation). At this time Eurasia experienced the "End-Villafranchian" dispersal event of Azzaroli (1983), in which Arctic large mammals spread southward.

But the North American puma, dating back to the Froman Ferry fauna (close to 1.6 Ma, *Phenacomys gryci* was collected at the site of the female specimen) and evolving in the Glenns Ferry Formation from the Hagerman *Felis lacustris* (3.6 Ma) and from still earlier faunas in the Great Plains, appears to have entered North America possibly at the beginning of the Blancan faunas, 4.8 million years ago.

Thus, the fossil record seems to show at least three invasions of Old World Felidae into the Western Hemisphere: (1) The puma-lynx lineage appeared perhaps at the beginning of the Blancan mammal age of the United States (4.8 Ma). The time of division of these two genera appears to have been perhaps 3.4 Ma but is not well documented in the fossil record. (2) The North American cheetah appeared in North America in late Blancan time (2.56 Ma). (3) The *Panthera* lineage, in possibly several stages during the Pleistocene, begins with the jaguar (possibly 0.84 Ma ago), the only living New World species of *Panthera*. Only those of the most recent immigration seem identical to the living Old World cats. The North American cheetah is cheetah-like only in convergent adaptation; a number of features suggest a closer relationship to puma than to Old World cheetah, as has been noted by others, but if so, it evolved out of an Asian, not a North American, puma-like cat.

Although Savage (1960) and Bjork (1970) believed that *Felis lacustris* from the Hagerman fauna was not directly related to modern puma, the progressively increasing similarity to puma in younger parts of the Glenns Ferry Formation suggests that the cats of the Glenns Ferry Formation are the previously unknown origin of *Puma concolor*, a suggestion made much earlier by Glass and Martin (1978). If so, the frequently suggested relationship between *P. concolor* and *Miracinonyx inexpectatus* is not as close as has been thought; *P. concolor* was still evolving out of *F. lacustris* while *M. inexpectatus* was fully evolved and morphologically stable, with a head the size of *P. concolor* but much longer limbs.

As listed by Kurten (1976), most fossil records of *P. concolor* are of late Pleistocene or younger age. The Reddick IA, Florida, record may be of Irvingtonian age (but late rather than beginning Irvingtonian). The judgment of where the genus *Puma* should first be recognized is a hypothetical consideration, but here *Puma concolor* is recognized as having evolved before the Froman Ferry faunal succession (before the Irvingtonian mammal age in the Pacific Faunal Region).

Surprisingly, no other records of carnivores are identifiable from the Froman Ferry faunal succession, although a bear-like (agriotherine/tremarctine?) canine and partial radius (having a strong resemblance to the radius of *Agriotherium* sp. from the Hemphillian Edson fauna of Kansas (Harrison, 1983, fig. 10) and, somewhat less, to living *Tremarctos*) and a mandibular fragment of a small carnivore have been found in the fluvial gravel of GS-232.

Order LAGOMORPHA Brandt, 1855

Family LEPORIDAE Gray, 1821

Subfamily ARCHAEOLAGINAE Dice, 1929

Genus *HYPOLAGUS* Dice, 1917

HYPOLAGUS GIDLEYI White, 1987

Figure 7

Locality and material.—CUCUMBER AREA: GS-232, Sample 14 (2,815 ft elev. and 60 feet uphill from GS-232) USNM 264338 right mandibular ramus, incomplete, with P/3 to M/2.

Although a few leporid molars have been found throughout the Froman Ferry faunal succession, this is the only specimen containing a P/3, diagnostic in identification.

Discussion.—This specimen was recovered from the gravel deposits of a fluvial channel high in the Glenns Ferry Formation of the Cucumber area. The channel forms a band on the south-facing slope of the north side of Dead Horse Canyon and contained many fragmentary specimens of various mammals not otherwise common in the marsh deposits, including parts of an ursid (tremarctine?), puma, *Plesippus fromanius* n. sp., camel, and cervid, all of which have not been identified unless mentioned under the proper taxon. It is believed that these fluvial deposits high in the Glenns Ferry Formation of the Froman Ferry area represent the initial part of the fluvial regimen that ultimately resulted in the unconformity separating these deposits from the overlying Pickles Butte lava.

The specimen is from a large leporid. The length of the tooth row (P/3 to M/2) is 14.3 mm and the anteroposterior length of P/3 is 3.42 mm. John White, author of the species, has kindly examined a drawing of the P/3 of this specimen (fig. 7) and has confirmed its identification, saying (oral commun., 1994) that it was in the middle of the variation of about 50 specimens of the species. He also noted that this is a major revision in the known age range of both the species in North America, which had previously been considered as terminating before 2.5 million years ago, and of the genus in the United States, which was not believed to have survived beyond the end of the Blancan mammal age (J.A. White, oral commun., 1994).

The presence of this species and genus in deposits so young is surprising and contradicts the prior opinion that the genus did not survive the Pliocene in North America (the type locality is in the Hagerman faunal sequence). Although the species can no longer be considered as confined to mid-Blancan age and earlier deposits, the scarcity of its later records certainly indicates that the genus (and species) was not very common in the North American record of early Pleistocene date.

This may not be the first record from the Irvingtonian, however; Lucas and others (1993) also reported the genus, questionably referring it to the species *H. gidleyi*, from a possible Irvingtonian fauna in the Sierra Ladrones Formation (Tijeras Arroyo fauna) on the south side of Albuquerque, New Mexico. Based upon the preconception of the Blancan age significance of *Hypolagus* cf. *H. gidleyi* and associated *Equus* cf. *E. cumminsii* in the basal 8 m of their faunal sequence, they referred this part of the section to the Blancan. The overlying 64 m of the section contains a distinctly Irvingtonian mammal fauna, and, beginning above the basal 8 m (about 4 m above the *Hypolagus*), they reported clasts of pumice from the Bandelier Tuff (1.6–1.1 Ma). Lucas (written commun., 1994) reported that hand specimen examination of the pumice clasts suggests the oldest of this time range, but no mineralogic identification has been made.

Although Lucas and others (1993) inferred an unconformity to explain the Blancan age of the earliest mammals in their faunal sequence, they also noted that John Hawley (New Mexico Bureau of Mines and Mineral Resources) had informed them of pumice clasts believed to represent the Bandelier Tuff (<1.6 Ma) in water well cuttings stratigraphically well below the Tijeras Arroyo outcrop. More field study is required to resolve the question, but, at present, it is possible that the Tijeras Arroyo fauna is the latest record of *Hypolagus gidleyi* (and *Equus cumminsii*).

The mammalian fauna from the overlying, pumice-bearing zone in Tijeras Arroyo is a typical early Irvingtonian assemblage and contains two species of primitive *Mammuthus*; as such these may be the oldest known record of this genus in the United States.

Order RODENTIA Bowdich, 1821

Family CASTORIDAE Gray, 1821

Subfamily CASTORINAE Gray, 1825

Genus *CASTOR* Linnaeus, 1758

CASTOR CALIFORNICUS Kellogg, 1911

Localities and material.—FROMAN FERRY AREA: USNM 11607: exact locality uncertain. (USNM records indicate that it was collected by N.F. Drake in 1897 along the road from Froman Ferry to Caldwell, but not how far along the road or above the river; the road no longer exists; Hay (1927) cited only the Froman Ferry locality of Merriam (1918) and Lindgren (1900), both of whom listed the taxon as "*Castor*, possibly new species: P/4.") CUCUMBER AREA: GS-226 (2,690 ft elev.): incomplete P/4.

Apparently only these two teeth have been found in the area in the past 98 years. They are from near the top and near the bottom of the Froman Ferry faunal succession.

Discussion.—F.A. Lucas of the U.S. National Museum identified the fossil specimens collected by Lindgren and Drake in 1897 and later, and he assigned the single beaver P/4 (USNM 11607) to "*Castor*, possibly new species." Merriam (1918) followed this identification. Based upon no additional material, Hay (1927) provided the specific name *Castor accessor.* Shotwell (1970) stated that the single tooth from Froman Ferry could not be separated from other fossil or living species, and therefore selected one of the *Castor* specimens from Jackass Butte (youngest of the Grand View faunas) as the pleisiotype of *Castor accessor*, thinking that the geographic and temporal proximity of the Froman Ferry fauna to the Grand View faunas probably indicated specific identity. Shotwell did not know the age of the Froman Ferry fauna and apparently assumed that it was the same age as the fauna from Jackass Butte. In fact it is only about half a million years different in age, whereas the oldest fauna of the

Glenns Ferry Formation at Hagerman is as much as 1.3 million years older than the Jackass Butte faunas. These time differences were not known to Shotwell, however, when he studied and compared these faunas.

This same assumption of a similar age and fauna at Jackass Butte and Froman Ferry was made for the horses both earlier (Schultz, 1936) and later (Conrad, 1980; Azzaroli and Voorhies, 1993). In the case of the horses, however, Shotwell (1970) thought the horse from Jackass Butte was more like that from Hagerman. It was not until 1993 that Azzaroli and Voorhies indicated that at least two horses were present in the fauna from Jackass Butte.

Shotwell (1970, p. 39) stated, in his diagnosis of the referred material of *Castor accessor* from the Jackass Butte faunas, that the opposition of the hypostriid and the mesostriid on the Grand View beaver was dissimilar to that in living *Castor canadensis*, but this is not always true, and he stated that the stria and striids of the cheek teeth are longer than in the older fossil species *Castor californicus*, which does not seem true in the available material (*N*=4 P/4) of the older species from the type locality in Kettleman Hills, California.

Conrad (1980) compared a good sample of the beaver from Hagerman (which he referred to *Castor californicus*) with that from Jackass Butte, and concluded that they do not differ more than one would expect from the tooth variability of any species of *Castor*, and that both belong to the prior species name *Castor californicus*. He suggested that when enough material is known from Froman Ferry, this population will also appear assignable to *Castor californicus*. Not enough material is yet known to determine the variability of the Froman Ferry population (and recognition of proper specific assignment seems obviously defendable only upon differences in population composition), but the two known first lower premolars from the Froman Ferry faunal succession fall within the range of variability of *Castor californicus*, and there thus seems to be no reason to recognize Hays' species, or Shotwell's referral of the Jackass Butte population to it. Following Conrad (1980), we assign all of the Glenns Ferry samples of *Castor* to the species *Castor californicus* Kellogg, largely on the basis of priority.

This species remains separable from the living species on the basis of its external striae on the upper teeth and internal striids on the lower cheek teeth, which are of unequal length and average (on the basis of all assigned populations) shorter in length than in *Castor canadensis* (Stirton, 1935, p. 445). These grooves are cement-filled and often hard to see. The type of *Castor californicus* Kellogg is from the "Pecten bed" of the San Joaquin Formation in the Kettleman Hills of California, and is about 3 million years old, intermediate in age between the Hagerman and the Jackass Butte faunas.

Family CRICETIDAE Rochebrune, 1883

Subfamily LEMMINAE Gray, 1825

Tribe SYNAPTOMYININI Von Koenigswald and Martin, 1984a

Genus *MICTOMYS* True, 1894

MICTOMYS VETUS (Wilson, 1934)

Figure 8

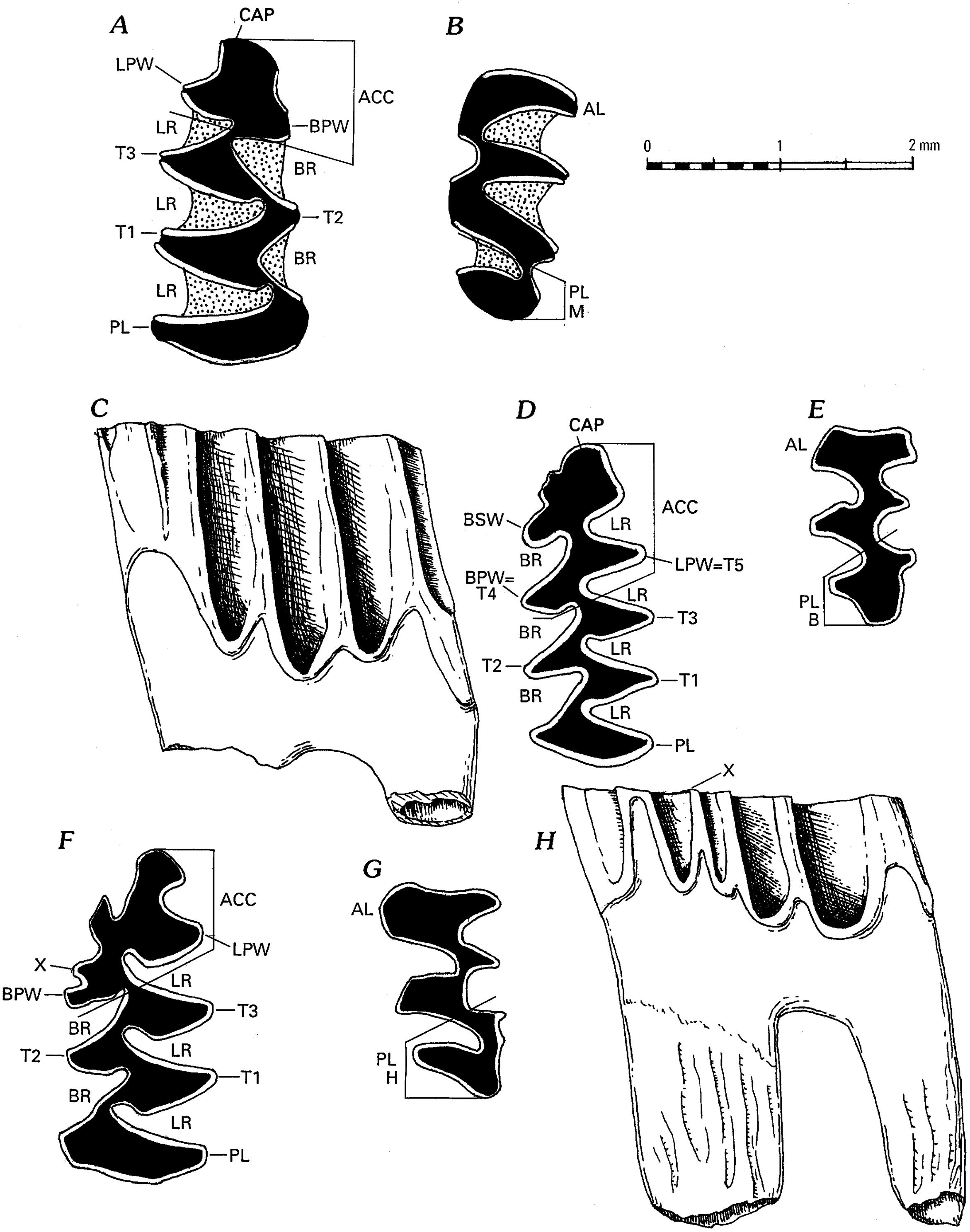
Localities and material.—HOMEDALE AREA: GS-212 (2,430 ft elev.): three-fourths of an M/1. CHALK HILLS AREA: GS-209 (2,470 ft elev.): M/1, M/2, M\3. GS-201 (2,477 ft elev.): two partial M/1, M/2. GS-208 (2,550 ft elev.): M/1. FROMAN FERRY AREA: GS-211 (2,398 ft elev.; =UCMP 3036?): incomplete M/1. CUCUMBER AREA: GS-215 (2,540 ft elev.): three M\2, four M/1 (one USNM 264331), M\3 (USNM 264332). GS-230 (2,750 ft elev.): four M/1, three M/2, M\1, five M\2. GS-232 (2,810 ft elev.): M/2, M/3, M\3. GS-233 (2,890 ft elev.): M/1, M\3, two partial M/1.

Nine localities; 2,398 to 2,890 feet elevation. The distinctive form of all cheek teeth of the genus enables their inclusion in the list of specimens, although the specific identification of those teeth other than the first lower and the last upper molars could not be verified.

Discussion.—*Mictomys vetus* (Wilson, 1934) was originally described as a species of *Synaptomys*, in which genus *Mictomys* had been placed, as a subgenus, since Miller (1896). This concept of the genus *Synaptomys* was so entrenched that, when an ancestral form of this otherwise North American genus group was found in lower Pliocene deposits of Bashkir (now Bashkiria), Russia, Suchov (1976) placed it in a new subgenus as *Synaptomys* (*Plioctomys*) *mimomiformis*. *S.* (*P.*) *mimomiformis* was subsequently recognized throughout much of Eurasia, usually as Suchov's species, and its youngest records are found in Beringia (Sher and others, 1979; Repenning and others, 1987).

In a detailed consideration of the forms included in *Synaptomys*, von Koenigswald and Martin (1984a) also recognized *Synaptomys* (*Plioctomys*) *rinkeri* (Hibbard, 1956) in the upper Pliocene deposits of the lower latitude United States. They removed *Mictomys* from the genus *Synaptomys* as a separate genus on the basis of differences in the Schmelzmuster (arrangement of the prisms or rods in the tooth enamel), but left Suchov's *Plioctomys* as a subgenus within *Synaptomys*. This was done because of the then-prevailing belief that *S.* (*P.*) *rinkeri* was ancestral to the living *Synaptomys cooperi*.

However, in 1988 Repenning and Grady discovered the surprising origin of living *Synaptomys cooperi* out of *Mictomys* in an 840,000-year-old fauna from the Cheetah Room of Hamilton Cave, West Virginia. They concluded that, despite morphologic similarities (not exact), it was misleading to put forms as old as 4 million years in a genus that is known to have evolved out of *Mictomys*



only 840,000 years ago, and they consequently raised the subgenera *Synaptomys* and *Plioctomys* to generic rank. As such, the oldest record of the genus *Synaptomys* is 840,000 years ago. The genus *Mictomys*, removed from *Synaptomys* by von Koenigswald and Martin (1984a), is known back to 2.56 million years ago and the genus *Plioctomys*, removed from *Synaptomys* by Repenning and Grady (1988), is known back to about 4 million years ago in Eurasia (Repenning and others, 1990). *Plioctomys* appears to have become extinct more than 2.0 million years ago, but *Synaptomys* and *Mictomys* remain as a part of the living fauna of North America.

The fossil record of *Mictomys* is rather abundant during the 1.15 million years when nothing called *Synaptomys*

Figure 8 (facing page). Microtine rodents of the Froman Ferry faunal succession, Canyon County, Idaho. Occlusal views and two buccal views. Dentine shown as black, cementum stippled, and enamel unpatterned in occlusal views. Scale the same for all drawings and as indicated. *A* and *B*, *Mictomys vetus* from locality GS-215, Cucumber area. *A*, USNM 264331: Right first lower molar in occlusal view; *B*, USNM 264332: Left last upper molar in occlusal view. *C, D,* and *E*, *Mimomys* (*Ophiomys*) *parvus* from locality GS-212, Homedale area. *C*, USNM 264333: Left first lower molar with little wear in buccal view. *D*, USNM 264333: Same as last, in occlusal view. *E*, USNM 264334: Left last upper molar in occlusal view. *F, G,* and *H*, *Phenacomys* (*Paraphenacomys*) *gryci* from locality GS-232, Cucumber area. *F*, USNM 264335: Left lower first molar with moderate wear in occlusal view. *G*, USNM 264336: Left upper last molar in occlusal view. *H*, Same as *F* but in buccal view. ACC, anteroconid complex; BR, buccal reentrant; LR, lingual reentrant; AL, anterior loop; PL, posterior loop; on last upper molars PL B, bell-shaped posterior loop; PL H, hooked posterior loop; and PL M, globular posterior loop of *Mictomys*; T, triangle (numbered from the back of the tooth), triangles 4 and 5 form from the primary wings; LPW, lingual primary wing; BPW, buccal primary wing; BSW, buccal secondary wing; x, "Mimomys Kante," present only on *F* and *H*.

existed in the world fauna. The recognized morphologic differences, that had been assigned subgeneric significance, assumed generic significance when it was realized that the earliest *Plioctomys* and the earliest *Synaptomys* were separated by almost 3.2 million years.

As the evolution of the group is now considered, *Plioctomys* is the ancestral form of about 4 million years ago (Simbugino fauna, Bashkir, Russia); its origin is unknown but apparently was in western Eurasia; *Plioctomys* dispersed to Beringia by 2.6 million years ago (Kutuyakh faunas, Yakutia, Russia; 2.4 Ma Fish Creek fauna of the Alaskan North Slope). Along the Pacific Coast of North America in the south-Alaskan Beringian Faunal Region (assumed; possibly farther south), *Plioctomys* evolved into *Mictomys* by about 2.6 million years ago and dispersed southward in North America west of the Rocky Mountains to the Pacific Faunal Region of the United States by 2.56 million years ago as *Mictomys vetus* (Grand View faunas, Idaho). At the same time *Plioctomys* remained unchanged in the north-Alaskan Beringian Faunal Region (Fish Creek fauna, Alaskan North Slope, 2.4 Ma) and dispersed southward on the east side of the Rocky Mountains, arriving in the United States in the Eastern Faunal Region as the slightly modified species *Plioctomys rinkeri* (Cita Canyon fauna, Texas, and other faunas); *Mictomys* rapidly dispersed southward from the Pacific Northwest and eastward around the south end of the Rocky Mountains (Beaver fauna, Utah; Tusker fauna, Arizona), and also possibly through the Yellowstone pass (Boyle Ditch, Wyoming) to the Great Plains before 2.0 million years ago (Borchers fauna, Kansas); *Plioctomys* became extinct by this time; *Mictomys* then occupied the entire United States until about 0.84 million years ago when *Synaptomys* evolved out of an Appalachian population (Cheetah Room fauna, West Virginia).

The primitive bog lemming, *Mictomys vetus*, occurs throughout the fossiliferous section in the Froman Ferry area. *Plioctomys* was extinct by this time (and is not known to have dispersed west of the Rocky Mountains) and *Synaptomys* had not yet evolved. The type locality of *Mictomys vetus* is at Jackass Butte of the Grand View faunas (Wilson, 1934; as *Synaptomys vetus*), and the genus is known in the Pacific Faunal Region of the United States from 2.56 million years ago (when it first immigrated to the United States from the Arctic) until the presently living fauna. The genus is, however, now known only from Alaska, Canada, and areas just south of the Canadian border in the States of Washington and Montana (and presumably Idaho, more than 350 miles north of the Froman Ferry area). It also crosses the border into the United States in northernmost Minnesota and the New England States of Maine and New Hampshire (Hall, 1981). The genus now clearly thrives in moist areas with cool summers, and its history is marked by repeated southward dispersal into the United States when these climatic conditions prevailed, which was during continental glacial accumulations that are also favored by this climate (Repenning, 1993).

Mictomys, and the related *Lemmus* and apparently unrelated *Dichrostonyx*, are the oldest extant microtine genera, depending upon how one classifies the primitive muskrat *Pliopotomys*.

Two million fifty-six hundred thousand years ago *Mictomys vetus* lived less than 50 miles from the Mexican border in Arizona (Tusker fauna; Repenning, 1987), and 1.6 million years ago it lived a similar distance north of the Mexican border in what is now the Anza-Borrego Desert of California (LACM locality 6683, Vallecito Creek faunal sequence; Zakrzewski, 1972, as *Metaxiomys anzaensis*; with the earliest *Microtus*); both times were presumably characterized by cool and cloudy summers during Northern Hemisphere glaciation, although Canadian ice did not, at these times, flow southward as far as the United States (Repenning and Brouwers, 1992). Canadian ice did extend into the United States, and left till in Iowa, about 2.1 million years ago, when *Mictomys* appeared in the Borchers fauna on the Great Plains, but *Mictomys* (apparently) still did not enter southern California, although the Grand View species *Mimomys parvus* did appear there at this time. The irregularity of the times when these species of *Mictomys* and *Mimomys*, seemingly constantly present in the Grand View and Froman Ferry faunas of Idaho, appeared in the Anza-Borrego Desert of southern California is not fully explainable, but it must record a difference in climatic patterns of these times.

Later, *Mictomys* moved northward as hot (interglacial) summers developed, but it returned southward repeatedly, during each glacial period. The obvious implication is that similar cool, cloudy summers prevailed in the Snake River Plain during the final episode of the Glenns Ferry deposition at Froman Ferry, as well as during the Grand View faunal succession. Faunas intermediate in age (between about 2.0 and 1.7 Ma) are not yet known in the Snake River Plain; drier climates (with hotter summers) prevailed during this time in many parts of the Northern Hemisphere (the Tiglian floras of northwestern Europe), and it is possible that *Mictomys* had, at this time, withdrawn from the Snake River Plain, after the Grand View faunas, and returned before the Froman Ferry faunas came into existence.

Before 2.0 million years ago *Mictomys vetus* (as *M. landesi*) dispersed eastward onto the Great Plains (Borchers fauna, Kansas); *Plioctomys* was by then, or as a consequence, presumably extinct as no later records are known. In the Great Plains (or to the north during a withdrawal), *Mictomys* evolved into the species *Mictomys kansasensis* by 1.2 million years ago and into *Mictomys meltoni* by 610,000 years ago. The salient evolutionary change consisted primarily of a shallowing of the buccal reentrants on the lower cheek teeth, particularly that reentrant immediately behind the anteroconid complex of the first lower molar so that the connection between this structure and the alternating triangles shifted buccally, with a corresponding deepening of the lingual reentrants (see fig. 6 of Repenning and Grady, 1988; and, for dental nomenclature, fig. 10 of Repenning, 1992). It is not certain that these species recognized east of the Rocky Mountains were present west of the Rocky Mountains, but similar changes also took place in the Pacific Faunal Region. The genus is a sensitive climate indicator, but one is inclined to wonder if its range was restricted to the north with the evolution of the living *Synaptomys cooperi* 840,000 years ago, which could have assumed the southern part of its former range; the modern distribution of *Mictomys* may not precisely reflect its climatic constraints before this time when *Mictomys* alone may have had the environmental range of both *Mictomys* and *Synaptomys* in the living fauna.

Despite a later, well-established trend in modernization of its morphotype, the specimens of *Mictomys vetus* from the Froman Ferry fauna show no difference from the older type population in the Grand View faunal succession.

Subfamily ARVICOLINAE Boneparte, 1837

Tribe ARVICOLINI Kretzoi, 1954

Genus *MIMOMYS* Major, 1902

Subgenus *OPHIOMYS* Hibbard and Zakrzewski, 1967

MIMOMYS (*OPHIOMYS*) *PARVUS* Wilson (1934)

Figure 8

Localities and material.—HOMEDALE AREA: GS-212 (2,430 ft elev.): seven M/1 (one USNM 264333), seven M\3 (one USNM 264334). CHALK HILLS AREA: GS-210 (2,464 ft elev.): two M/1. GS-201 (2,477 ft elev.): four M/1. GS-208 (2,550 ft elev.): five M/1, M\3. GS-204 (2,560 ft elev.): five M/1. FROMAN FERRY AREA: GS-211 (2,398 ft elev.; =UCMP 3036?): M/1, M\3. LIZARD BUTTE AREA: GS-213 (2,440 ft elev.): M/1. GS-214 (2,470 ft elev.): 11 M/1, M\3. CUCUMBER AREA: GS-218 (2,460 ft elev.): 11 M/1, 9 M\3. GS-217 (2,480 ft elev.): four M/1. GS-216 (2,485 ft elev.): four M/1, two M\3. GS-215 (2,540 ft elev.): 12 M/1, 8 M\3. GS-220 (2,630 ft elev.): six M/1, M\3. GS-223 (2,630 ft elev.): 14 M/1, 3 M\3. GS-219 (2,640 ft elev.): M/1. GS-221 (2,650 ft elev.): 13 M/1, 4 M\3. GS-222 (2,650 ft elev.): six M/1, four M\3. GS-229 (2,750 ft elev.): three M/1, two M\3. GS-232 (2,810 ft elev.): 6 M/1, 12 M\3. GS-233 (2,890 ft elev.): 11 M/1, 6 M\3.

Twenty localities: 2,398 to 2,890 feet elevation. This is the entire Froman Ferry faunal succession.

Discussion.—This is the youngest, and possibly the most northern, dated record of this species. The species is possibly the most abundant mammal in the faunal sequence. *Mimomys parvus* is present in the Vallecito Creek faunal succession of the Anza-Borrego Desert in southern California, but not at 1.6 million years ago (LACM locality 6683), the temporal equivalent of the immigration of *Phenacomys gryci* in the Froman Ferry faunal succession; this was the time of a rather mild glacial period with no known flow of ice into the United States. *Mimomys parvus* has been collected in the Vallecito Creek succession only at LACM locality 1357, which is well below the Olduvai event in the paleomagnetic section, representing an age that is comparable to that of some part of the Jackass Butte section of the Grand View faunas, possibly 2.2 to 2.3 million years old; this would have been during the time of the first major North American ice accumulation that climaxed 2.1 million years ago with till in Iowa. Unfortunately the position of the Réunion Normal-polarity Subchron was not identified in the paleomagnetic section of the Vallecito Creek faunal succession (Opdyke and others, 1977).

That *Mictomys* did arrive in southern California 1.6 million years ago with *Microtus*, whereas *Mimomys parvus* did not and only appeared this far south during the earlier and more extreme glacial buildup between 2.5 and 2.1 million years ago (but apparently without *Mictomys*), suggests that the species of *Mimomys* may have been even more climatically sensitive than *Mictomys*.

But, as just noted on pages 29–30, there seems to be some difference in climatic, or other, patterns that are not fully understood, as *Mictomys vetus* and *Mimomys parvus* lived together, sharing the same environment in the Snake River Plain from 2.56 to nearly 1.5 million years ago, yet *Mimomys parvus* is only known about 2.2 million years ago and *Mictomys vetus* only about 1.6 million years ago in the Anza-Borrego Desert area of southern California.

Mimomys (*Ophiomys*) *parvus* has a long history of differing generic assignments. Wilson (1934) questionably assigned it to *Mimomys* when describing it from Jackass Butte; Hibbard (1950, p. 157) assigned it to *Pliophenacomys*; Kretzoi (1955, p. 354) assigned it to the European genus *Pliomys,* to which its first lower molar bears a strong resemblance because of the well-developed primary wings (triangles 4 and 5); the M\3 (fig. 8*E*) does not so closely resemble *Pliomys*; Hibbard (1959) again assigned it to *Pliophenacomys*; Hibbard and Zakrzewski (1967) assigned it to the new genus *Ophiomys*; and Repenning (1980, 1987) returned it to the genus *Mimomys* but recognized it as belonging to a separate, North American subgenus *Ophiomys* that had been separated from Eurasian species since the beginning of the Blancan.

Von Koenigswald and Martin (1984b) examined the Schmelzmuster (arrangement of the prisms or rods in the tooth enamel) of a few North American species that Repenning (1980) had included in *Mimomys* and found differences (in the Schmelzmuster) between them and European species; they concluded that the genus *Mimomys* is unknown in North America. Later Repenning and von Koenigswald had the opportunity to discuss their concepts of the evolution of *Mimomys* and the forms from North America; they discovered that their opinions were essentially identical. The differences in published classification resulted only from differing taxonomic procedure. Von Koenigswald considered a genus to be monophyletic; Repenning as paraphyletic. (See Repenning, 1992.)

The oldest known *Mimomys* is *M. antiquus* (Zazhigin, 1980; as *Promimomys antiquus*) from the upper Miocene Pavlodar Series (Peshnovo Formation and locality, upper mollusk horizon) of Western Siberia. This species has a primitive, and, at this primitive stage, basically universal Schmelzmuster that cannot be used to define affinity. From this central Eurasian region the genus dispersed westward to Europe and eastward to North America, arriving at about the same time in both areas (early Pliocene), and both immigrant lineages retained the primitive Schmelzmuster. The two lineages that dispersed in opposite directions around the Northern Hemisphere never again had contact with each other and evolved in separate patterns, which included Schmelzmuster patterns.

Von Koenigswald and Martin (1984b) have assumed that, as European and North American immigrants represent different lineages, they also represent different genera. Repenning (1980) assumed that as long as the common ancestral group in central Eurasia was placed in the genus *Mimomys*, the two derived lineages should be placed in *Mimomys* but should be recognized by separate subgenera; this procedure is adopted in the present discussion of the Froman Ferry faunal succession. Article 42c ("Collective Groups") of the International Code of Zoological Nomenclature (revision of 1961) is not specific on this point. Some of the earlier North American forms, less derived than *Mimomys parvus*, could be mixed with a sample from Europe, and could not be separated back out without recourse to a scanning electron microscope (to examine the Schmelzmuster), and even this examination would reveal only the primitive, nondiagnostic Schmelzmuster.

There is ample reason to suspect a second invasion of *Mimomys* from Asia to North America in late Pliocene time (*Mimomys monohani* (Martin) from the Blancan V Mullen fauna, Nebraska) that persisted through early Pleistocene time (*Mimomys dakotaensis* Martin, 1989, from Irvingtonian I Java fauna, South Dakota; and *Mimomys virginianus* Repenning and Grady, 1988, from Irvingtonian II Cheetah Room fauna, West Virginia). More invasions of the genus dispersed from Asia to Europe than to North America.

Morphologically *Mimomys* (*Ophiomys*) *parvus* from the Froman Ferry faunal succession is very similar to the older (±2.2 Ma) type material from the Jackass Butte of the Grand View faunas. The material from Jackass Butte here used for comparison (*N*=12 M/1) was collected at the southwestern base of the butte (elevation 2,475 ft; USGS loc. M1361), about 125 feet below the marsh beds and the first event of the Réunion Subchron (2.1 Ma). The M/1s are quite uniform in morphology, but, as do all rooted microtine taxa, vary with wear.

In comparison with the species from the Froman Ferry localities, this Grand View sample has distinctly wider dentinal confluences between the three basic alternating triangles, not between basic triangle 3 and confluent triangles 4 and 5 (primary wings; dental nomenclature shown in fig. 8; also see Repenning, 1992, fig. 10; fig. 8). The type population also has a much lower percentage (about 15 percent) of individuals with a noticeable reduction of the confluence between triangles 4 and 5 (the primary wings of the anteroconid complex) than does the material from the Froman Ferry faunas (about 66 percent). This narrowness between the primary wings, in combination with a persistent teardrop shape of the anterior cap, results in a first lower molar dental pattern in the Froman Ferry specimens that is remarkably similar to that of living *Clethrionomys rutilus*, although tooth and dentine tract height and the most distinctively complex last upper molar of *Clethrionomys* make any thought of close relationship seem improbable. The M\3 of *Mimomys* (*Ophiomys*) *parvus* is the same in both Idaho localities and is quite simple, consisting of an anterior loop, two alternating triangles and a posterior loop of an upside-down-bell shape (Wilson, 1934, fig. 5a; this report, fig. 8*E*).

Genus *PHENACOMYS* Merriam, 1889

Subgenus *PARAPHENACOMYS* Repenning and Grady, 1988

PHENACOMYS (*PARAPHENACOMYS*) *GRYCI* Repenning, 1987

Figure 8

Localities and material.—CHALK HILLS AREA: GS-204 (2,526 ft elev.): mandible w. M/1–2, two M/1, M\3. GS-205 (2,550 ft elev.): mandible in matrix w. all teeth. LIZARD BUTTE AREA: GS-213 (2,440 ft elev.): two M/1. CUCUMBER AREA: GS-215 (2,540 ft elev.): two M/1, M\3. GS-223 (2,630 ft elev.): M/1, two M\3. GS-221 (2,650 ft elev.): mandible frag. w. M/1, M/1. GS-224 (2,650 ft elev.): 14 M/1, 5 M\3. GS-232 (2,650 ft elev.): two M/1 (one USNM 264335), seven M\3 (one USNM 264336).

Eight localities; from 2,440 to 2,650 feet elevation. The species is unknown in the lower 42 feet of the succession. Its first record is considered as marking the beginning of Irvingtonian faunas.

Discussion.—The primitive species *Phenacomys* (*Paraphenacomys*) *gryci* was described by Repenning (Repenning and others, 1987) from the Fish Creek fauna of the Alaskan North Slope. The Fish Creek section was deposited early (about 2.4 Ma) in the first recognized Neogene glacial cycle of the Northern Hemisphere (2.56 to 2.00 Ma). The Fish Creek records of *Phenacomys* (*Paraphenacomys*) *gryci* were interpreted as being very close to 2.4 million years old (Repenning and others, 1987; Repenning and Brouwers, 1992) largely on the basis of:

1. The stage of climatic change represented by older deposits in the Fish Creek area and by the fauna and flora in the Fish Creek section;
2. A continuous regressive marine sequence showing Arctic climates changing from much warmer than today to a climate comparable to that of today (in terms of water temperatures in the Arctic Ocean and the development of permafrost on land; Repenning and others, 1987);
3. The paleomagnetic polarity changes from the Gauss Normal-polarity Chron to the Matuyama Reversed-polarity Chron in exposures older than the Fish Creek section;
4. The correlation of climatic, floral, and faunal changes to a similar section in eastern Siberia; finally,
5. The Arctic Ocean was not covered by ice at the time of the Fish Creek mammal fauna, and permafrost, causing the development of wet (herb) tundra, first developed at this time and latitude in the Arctic Ocean Borderland (Repenning and others, 1987), both suggesting a preliminary climatic condition prior to the glacial maximum of 2.1 million years ago. Permafrost developed earlier at higher latitudes (Repenning and Brouwers, 1992).

One last upper third molar, apparently of *Phenacomys* (*Paraphenacomys*) *gryci*, the only record of the genus from Eurasia (but within the same Beringian Faunal Region), has been reported from the Krestovka sections of Yakutia (Sher and others, 1979; Repenning and others, 1987) in a very similar climatic and paleomagnetic sequence that is correlated with the Fish Creek fauna (Repenning and others, 1987; Repenning and Brouwers, 1992). This Siberian locality preserves a record of somewhat later and more severe climate change.

Repenning and Grady (1988) discussed the history and diversity of *Phenacomys* and established the subgenus *Paraphenacomys* (including the living white-footed tree vole *Phenacomys* (*Paraphenacomys*) *albipes*), lowered the genus *Arborimus* (Taylor, 1915; including the living red or long-tailed tree vole *Phenacomys* (*Arborimus*) *longicaudus*) to subgeneric rank within *Phenacomys*, and placed the living species *Phenacomys intermedius* (heather vole) in the subgenus *Phenacomys* (*Phenacomys*) as well.

All three subgenera have a fossil record (subgenus *Paraphenacomys* is the oldest), and all still live, but they represent markedly different environments, a factor usually not considered in interpretation of the late Pleistocene records of *Phenacomys* in the United States.

The immigration of *Phenacomys* (*Paraphenacomys*) *gryci* from the Arctic to the conterminous United States is first recorded in the Froman Ferry faunal succession of the Glenns Ferry Formation; the age of this immigration is approximated at 1.6 million years ago, as discussed on page 8 and following. The subgenus *Phenacomys* (*Phenacomys*) first immigrated to the conterminous United States on the east side of the Rocky Mountains at about the same time and is first known there from the Java fauna of South Dakota (Martin, 1989; as *Hibbardomys zakrzewskii*). The subgenus *Phenacomys* (*Arborimus*) appears to be a fairly recent innovation, based upon unpublished records of *Phenacomys* in the Booth Canyon fauna of eastern Idaho (Idaho Museum of Natural History collection) that show a population variation of morphotypes including those of both *Phenacomys* (*Phenacomys*) and *Phenacomys* (*Arborimus*). This subgenus appears to have developed during the Rancholabrean mammal age and in the Rocky Mountains; the Booth Canyon locality is close to the Continental Divide along the Snake River near the Wyoming border.

P. (*Phenacomys*) now lives in Canadian forest from the Atlantic to the Pacific, southward down the Rocky Mountains in the Canadian life zone of the United States, and in western Washington. *P.* (*Paraphenacomys*) and *P.* (*Arborimus*) now live in the southern coastal forests of the Pacific Northwest, avoiding colder winters in the State of Washington and hot summers in central California. During glacial periods, when seasonal equability was more pronounced, these two southern subgenera lived in areas that are now dry and have hot summers and cold winters from eastern Washington to central Nevada (Repenning and Grady, 1988).

Cool summers are indicated in the earliest Pleistocene of western Snake River Plain (Froman Ferry fauna) and in the late Pleistocene of eastern Washington (Kenniwick fauna; Rensberger and others, 1984) and central Nevada by the presence of *Mictomys* as well as that of *Phenacomys* (*Paraphenacomys*) and *P.* (*Arborimus*) (Mead and others, 1982; Grayson, 1983). The two coastal subgenera of *Phenacomys* (*Arborimus* and *Paraphenacomys*) also indicate warm winters. Although these two subgenera of *Phenacomys* are usually found in fossil faunas with *Mictomys* spp., their modern ranges are separate because these subgenera of *Phenacomys* are intolerant of cold winters and *Mictomys* is not.

Caution must be exercised in evaluating tolerance to cold winters of the subgenera *Paraphenacomys* and *Arborimus* in view of the earliest records of the former in areas of permafrost, and of the latter within a population of the subgenus *Phenacomys* (*Phenacomys*); it seems that the modern intolerance to cold winter temperatures may have evolved during the history of these subgenera. The absence of the subgenus *Phenacomys* in the late Pleistocene faunas of Nevada and eastern Washington is probably as climatically significant as is the presence of the subgenera *Arborimus* and *Paraphenacomys*. Furthermore, the evolution of living *Synaptomys* out of *Mictomys* about 840,000 years ago suggests that prior to that time the genus *Mictomys* may have had a range of environmental tolerance that included that of both living genera, which would make the presence of *Mictomys* within 50 miles of the Mexican border in Arizona and California a bit more understandable. Modern environmental preferences may not reflect those of any particular animal throughout the time of its existence.

To judge from the Alaskan (and Siberian) records of *Phenacomys* (*Paraphenacomys*), which are associated with developing permafrost but an unfrozen Arctic Ocean, this cool summer and warm winter environment in the Froman Ferry area 2.6 million years ago could have had a mean annual temperature as low as freezing (measured below any snow cover). It thus seems that only the extreme winter cold of the Canadian forests, tolerated by modern *Mictomys* and *Phenacomys* (*Phenacomys*), may have been missing during deposition of the Glenns Ferry Formation.

In contrast with this suggestion of the annual average temperature in Beringia, based upon the associated permafrost 2.5 million years ago, Smith and Patterson (1994) have recently defended the interpretation that the fish fauna of the Glenns Ferry lake indicates that water temperature seldom got below freezing in the winters nor above 69° F in the summers. They have also suggested that the large lake may have influenced the local climate near it toward this temperature equability, which would be more similar to the modern annual temperature range of the subgenus of *Phenacomys* present in the Froman Ferry fauna.

The Froman Ferry fauna, therefore, suggests that although winters may have reached freezing temperatures, very cold winter temperatures (comparable to modern central Canada) did not occur in the Snake River Plain during deposition of the Froman Ferry faunal succession; at the same time summer temperatures were cooler than now. Although *Phenacomys* (*Paraphenacomys*) lives today in coastal northern California and Oregon, coastal Washington appears to be too cold in the winter for the subgenus and it is replaced by *Phenacomys* (*Phenacomys*) of the modern Canadian forests. The Canadian heather vole, *Phenacomys* (*Phenacomys*) *intermedius*, was not present in the Pleistocene faunas of the Great Basin or the Snake River Plain, although present in the higher parts of the Continental Divide to the east and in the higher mountains and the Sierra Nevada to the west.

The suggestion of cool, not cold, winters and cool, not hot, summers is also based upon the assumption that the Canadian heather vole also has not changed in its environmental constraints. This assumption seems contradicted by the earliest record of this subgenus on the Great Plains, in the Java fauna of South Dakota. In this fauna the ancestor of the Canadian heather vole is associated with *Allophaiomys* sp. cf. *A. pliocaenicus*, a taxon whose every record throughout the Northern Hemisphere appears to indicate a warm temperate preference (Repenning, 1992, p. 6). The environmental constraints of fossil mammals merit considerably more study.

Phenacomys gryci is superficially similar to *Mimomys parvus* (fig. 8*D*, *F*). Its secondary wings are not so well developed, and the labial one (triangle 4) always has the slight flexure of enamel called a "Mimomys Kante" (Repenning and others, 1987, fig. 6; this report, fig. 8*F*); the cap of the anteroconid complex is not so uniformly teardrop-shaped as in *M. parvus*, and the dentine tracts are not nearly so highly developed. The last upper molar (M\3) has a posterior loop in the form of a "hook" rather than being the shape of an inverted bell (fig. 8*G*). They are related; Repenning and others (1987) speculated that *Phenacomys gryci* was derived from the Asiatic subgenus *Mimomys* (*Cromeromys*).

Subfamily ONDATRINAE Repenning, Fejfar, and Heinrich, 1990

Tribe ONDATRINI Kretzoi, 1954

Genus *ONDATRA* Major, 1902

ONDATRA IDAHOENSIS (Wilson, 1934)

Localities and material.—HOMEDALE AREA: GS-212 (2,430 ft elev.): ¾ and ¼ M/1. CHALK HILLS AREA: GS-201 (2,477 ft elev.): three M/1, M\3, two matrix slabs with frags. GS-204: (2,526 ft elev.): shattered jaw w. cheek teeth missing, three M/1, M\3. GS-208 (2,550 ft elev.): part M/1. GS-209 (2,470 ft elev.): mandible w. M/1–2, M\3. GS-210 (2,464 ft elev.): M/1, M\3. CUCUMBER AREA: GS-215 (2,540 ft elev.): two M/1, M\3. GS-218 (2,460 ft elev.): M/1. GS-221 (2,650 ft elev.): six M/1, two M\3. GS-224 (2,650 ft elev.): mandible ramus w. M/1–3. GS-225 (2,650 ft elev.): M/1. GS-232 (2,650 ft elev.): M/1. GS-230 (2,750 ft elev.): M/1.

Thirteen localities with first lower and last upper molars; other localities contain the taxon on the basis of other teeth (much larger than other microtine teeth), but were not counted; 2,430 to 2,750 feet elevation.

Discussion.—Although not so indicated above, because only those localities with first lower or last upper molars are listed and faunas containing only other teeth were not counted, the Idaho muskrat is a common taxon in the Froman Ferry faunal succession, about as common as *Mimomys parvus*. An initial impression was that the sample averaged somewhat larger in individual size than that from Jackass Butte (mid-Blancan V age; perhaps 2.3 to 2.0 Ma); however, measurement of 19 first lower molars from the Froman Ferry faunas indicates an average length of 4.7 mm, similar to that of Jackass Butte (4.79 mm, *N*=26; Conrad, 1980). The range of variation in length of the first lower molars at Froman Ferry was 4.4 mm to 5.1 mm, about the same as at Jackass Butte (4.19 mm to 5.30 mm; Conrad, 1980, whose sample presumably included specimens from all parts of the Jackass Butte section). Other characters of the species from the Froman Ferry faunas (for example, height of dentine tracts and degree of cementation) also appear similar to the Jackass Butte population.

This lack of noticeable change in the Froman Ferry muskrat from the condition of the taxon in the Jackass Butte localities of the Grand View faunal succession (the two are separated by as little as 400,000 years) contrasts strongly with the difference between the muskrat population from Jackass Butte and the early Blancan V Poison Creek and Birch Creek faunas, less than 100,000 years older than the estimated age of the oldest Jackass Butte faunas. We have only a few muskrat teeth from Birch Creek, but several first lower molars (*N*=5) from the Poison Creek localities. These have an average length of 4.46 mm, indicating a size increase of 0.2+ mm between 2.4 million years ago (Poison and Birch Creek) and an estimated 2.3 (older Jackass Butte) million years ago, but no increase between 2.0 (youngest Jackass Butte) and 1.6 million years ago (Froman Ferry). No attempt has been made to see if there is a size increase within the Jackass Butte faunal sequence, and there may be.

The smaller size of M/1 in the Poison Creek population appears to continue back in time to the Hagerman faunas (3.2–3.6 Ma), where the muskrat has an average first lower molar length of 4.1 mm in the available sample (*N*=4; Zakrzewski, 1969). The dentine tract on the buccal face of the anteroconid complex of the Hagerman population is very low, hardly higher than the more posterior tracts on the salient angles, and very high in the Jackass Butte population; those from Poison Creek are intermediate in height.

These two time spans, between Poison Creek and Jackass Butte and between Jackass Butte and Froman Ferry faunas, are marked by different climatic environments. Cool and cloudy continental glacial conditions were present during the first time period (early Blancan V: Poison Creek to early Jackass Butte faunas), which shows easily recognized size increase in the muskrats; warmer and sunny conditions were present during the last time period (later Blancan V: late Jackass Butte to Froman Ferry faunas), which shows no size change in the muskrats, but which is not recorded by intermediate faunas from the Glenns Ferry Formation. The last period ended with a global summer cooling and with the immigration of *Phenacomys* at the beginning of Irvingtonian faunas in the Froman Ferry succession, a climate more like that of the early Blancan V Grand View faunas.

Continental glaciation was not evident in temperate regions (in the United States) at either the beginning of the Pleistocene (1.67 Ma) or the beginning of Blancan V (2.56 Ma), but it is evident at these times in the Arctic Ocean region and is evident in the Mississippi River valley between them, by the end of the Grand View faunas at about 2.1 million years ago (Repenning and Brouwers, 1992). From this varied climatic record, it is difficult to infer climatic cause for the marked difference in size change in the muskrat lineage.

Speculation about the apparent cause of different rates of size increase may be pointless. In 1987 Repenning (p. 245) suggested that the Jackass Butte muskrat, *Ondatra idahoensis*, was an immigrant from the Great Plains, there derived from *Pliopotamys meadensis*, and that the Hagerman species *Pliopotamys minor* became extinct with this immigration. If so, the smaller muskrats, whose youngest records are in the Poison and Birch Creek faunas, may be the last, and most advanced, *Pliopotamys minor*; the larger mid to late Blancan V and early Irvingtonian I Glenns Ferry *Ondatra idahoensis* may be a derivative of the Great Plains *Pliopotamys meadensis*. Barnosky (1985) described "*Pliopotamys* near *meadensis*" from the Blancan V deposits of the Yellowstone Park area, suggesting such an immigration from the Great Plains. Thus the rapid increase in size of Blancan V muskrats between Poison Creek–Birch Creek populations (2.4 Ma) and earliest Jackass Butte populations (2.3 Ma) may result from immigration, not from some unusual ecologic stimulation.

These climatic changes between the early and late Blancan V are global climatic changes and well dated east of the Rocky Mountains and in the Arctic Ocean area (Repenning and Brouwers, 1992). The Snake River Plain probably followed a different weather pattern (in response to changes in the North Pacific Ocean) than the Great Plains (in response to the Bermuda High), but the times of change were the same, and the change in muskrat size took place during increasing continental glaciation in the Northern Hemisphere. As discussed on page 60, there appears to have been increased mountain glaciation in the Yellowstone Park area at this time which increased flow down the Snake River to the Glenns Ferry lake, and must have done so to the east as well, permitting Great Plains muskrats to disperse up the former North Platte River to the Continental Divide and down the Snake River to the west.

The available samples are small for all compared muskrat populations except that from the Froman Ferry faunal succession, but it seems reasonable that the size data approximate reality, and inferring a reason for the change in rate of size increase from the presumed climatic change is difficult. Thus, the suggestion of an immigration across the Rocky Mountains, rather than one of abrupt size increase in the local population of muskrats, is favored.

Order PROBOSCIDEA Illiger, 1811

Suborder ELEPHANTOIDEA Osborn, 1921

Family GOMPHOTHERIIDAE Cabrera, 1929

Subfamily ANANCINAE Hay, 1922

Genus *STEGOMASTODON* Pohlig, 1912

STEGOMASTODON MIRIFICUS (Leidy), 1858

Localities and material.—CHALK HILLS AREA: Locality number unassigned, near point of eastern of two southward-running ridges, NE¼SE¼ sec. 8, T. 3 N., R. 4 W., 800 ft W. and 2,200 ft N. of SE. section corner (2,500 ft elev.): M/2, nearly complete and little worn, other bones were associated but not collected. CUCUMBER AREA: GS-231 (2,750 ft elev.): patella. GS-232 (2,810 ft elev.): proximal articulation of ulna.

Three localities: 2,500 to 2,810 feet elevation; essentially from the upper part (Irvingtonian) of the Froman Ferry faunal succession.

Discussion.—The M/2 has strong internal proversion of lophids (terminology of Osborn, 1936, p. 1545–1549, and Savage, 1955, especially p. 59), indicating a lower tooth, but the roots are not preserved. The tooth is slightly worn; wear cuts through the enamel only on the top of the internal hemilophid of the protolophid, but wear facets are prominent on the enamel of the metalophid and the anterior faces of the tritolophid. One (posterior) entotrefoil is on the internal protolophid (the external protolophid is broken off), and moderately developed posterior entotrefoils are developed on all internal lophids, but are most sharply defined on the protolophid. No ectotrefoils are evident on the metalophid or tritolophid. The metalophid is the only loph with both anterior and posterior entotrefoils, and the tritolophid has only an anterior entotrefoil. A low tetartolophulid is present, formed by a central external cusp and an internal hemiloph, lacking trefoils but forming a heel on the tooth. Except that it appears less ptychodont, the tooth is similar to those described by Savage (1955) from the Cita Canyon fauna of Texas; it more resembles those described by Woodburne (1961, pl. IV) from the Pliocene of Kansas (especially KUMNH 4637).

The Froman Ferry tooth measures 108.6 mm in length and 65.2 mm across the tritolophid; this is somewhat smaller than those described by Savage (1955) from Cita Canyon, Texas, but within the range of the material Woodburne (1961) described from Kansas.

The proximal portion of the ulna from locality GS-232 is smaller than that of *Elephas* or *Mammuthus*, yet larger than that of any other possible taxon of the fauna. The semilunar notch is not nearly so deep as in these other proboscidians (the missing radius presumably bearing more of the weight of the animal than in the compared specimens). The facets for humeral articulation form a more openly curved surface that is not so deeply notched as in *E.* and *M.*; these facets form an angle close to 120° in the fossil, rather than about 100° as in *E.* and *M.* The articular facets for the radius are not evident on the specimen. The individual was young and the epiphysis for the olecranon process is missing at its unfused suture.

The patella from locality GS-213, is large and thick and can only belong to a proboscidean in this fauna. It does not seem otherwise distinctive.

Most students express the belief that all records of *Stegomastodon* in the United States represent the single, quite variable species, *Stegomastodon mirificus* (Leidy) (see Savage, 1955; Kurten and Anderson, 1980), and this small sample from the Froman Ferry succession can contribute little to this opinion. Shotwell (1970) attributed most of the material from Jackass Butte to this species, while Conrad (1980) expressed the belief that two and possibly three species may be present in the Jackass Butte faunas; he questionably referred a large scapula from the youngest part of the Jackass Butte sequence to *Stegomastodon arizonae* Gidley, 1926.

Order PERISSODACTYLA Owen, 1848

Family EQUIDAE Gray, 1821

Genus *PLESIPPUS* Matthew, 1924

PLESIPPUS IDAHOENSIS (Merriam), 1918

Figures 9 and 10

Localities and material.—FROMAN FERRY AREA: UCMP 3036 [old UCMP 3036C; =GS-211?] (2,398 ft elev.): Third upper premolar UCMP 22348 [type specimen] and UCMP 22347 lower fourth premolar. CUCUMBER AREA: GS-228 (Sample 4, which was collected 620 feet W. of the locality; 2,740 ft elev.): right P\3 (USNM 264329) and M\2? (USNM 264330). A fragment of an upper cheek tooth, preserving the complete prefossette, was found on the surface about 100 yards south of locality GS-221 (elev. 2,650 ft).

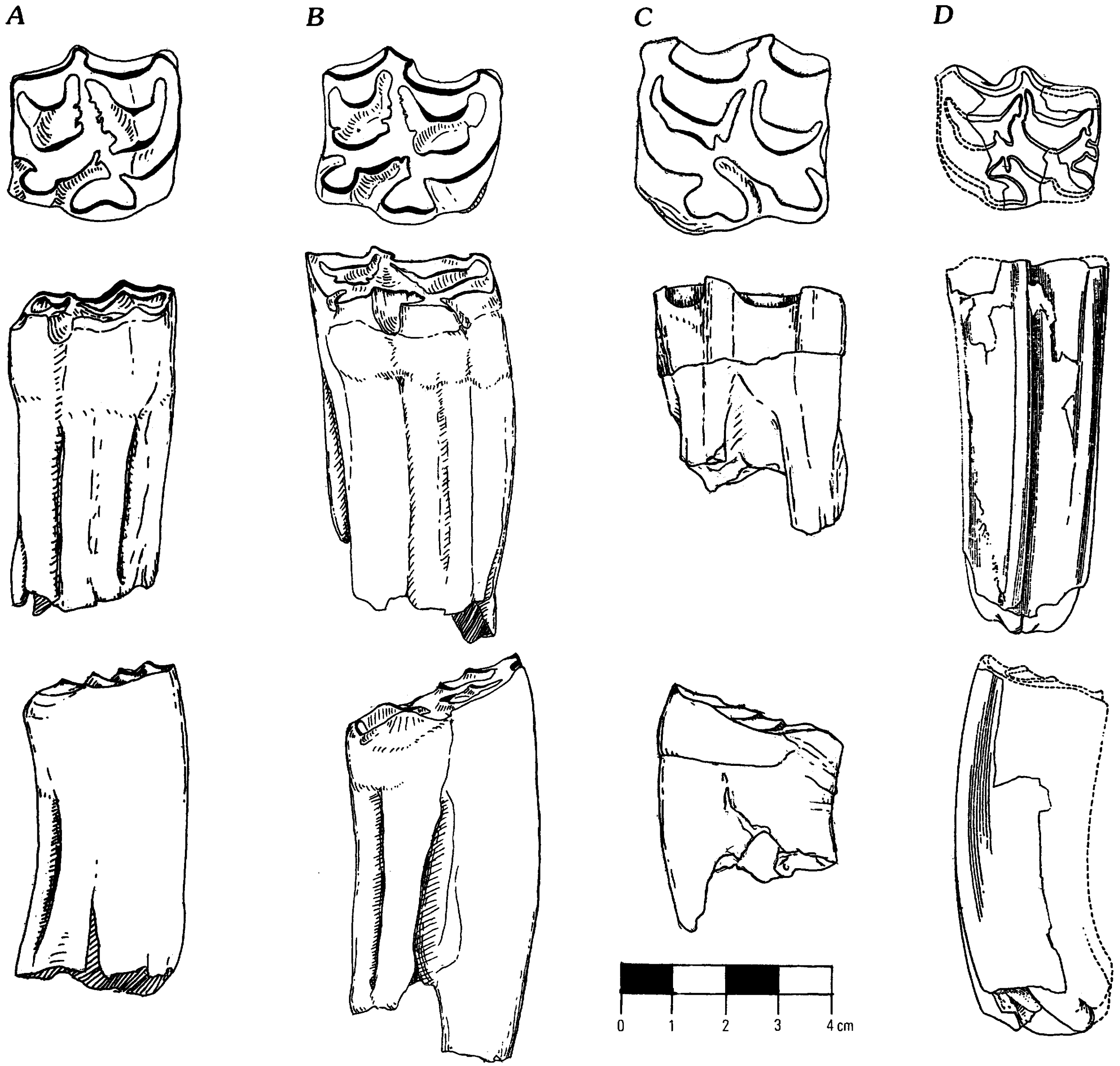


Figure 9. *Plesippus* cheek teeth. *A*, *B*, and *C*, *Plesippus idahoensis* (Merriam) teeth showing short protocones, simple fossettes, and minimal crown curvature, from Froman Ferry faunal succession, Canyon County, Idaho. *A* and *B* show occlusal, lingual, and anterior views from locality GS-228, Sample 4, Cucumber area; *C* is occlusal, buccal, and anterior views of type specimen from locality UCMP 3036 (= GS-211?) in Froman Ferry area. *A*, USNM 264330: Moderately worn second(?) right upper molar. *B*, USNM 264329: Moderately worn third right upper premolar. *C*, Type specimen, UCMP 22348: Very worn third left upper premolar (drawn from cast). *D*, *Plesippus simplicidens* (Cope) [as *Equus simplicidens*], type, Blanco fauna, Blanco Canyon, Crosby County, Texas, University of Texas specimen, copied from Osborn (1918, pl. 24-5), which was drawn from a cast; little-worn upper molar, probably a first molar, occlusal, buccal, and anterior views. Showing slight anteroposterior length of protocone at this stage of little wear, relatively simple fossettes, and smaller size in comparison with *Plesippus idahoensis*. This is one of the very few published illustrations of the species.

Three localities; 2,398 to 2,740 feet elevation. This is essentially the entire thickness of the fossiliferous section as the highest specimens were found only about 150 feet beneath the highest known fossil locality.

Discussion.—Most authors follow Opinion 271 of the International Commission on Zoological Nomenclature in placing the living species of equids (about seven) in the genus *Equus*, recognizing as subgenera several previously named genera that cover the variety of living domestic and wild species of Asia and Africa: the domestic horse (and wild tarpan), the asses (and wild African ass), and the still extant wild onager, kiang, and zebras.

When Morris Skinner (Skinner and others, 1972) decided that the North American Pliocene genus *Plesippus* (of Matthew, 1924) was the same as the living African zebra (subgenus *Equus* (*Dolichohippus*)), he was obliged to either follow the minority or to put the North American fossil species, which he assigned to the living subgenus *Dolichohippus*, in the genus *Equus*; he chose to follow the majority. Our recognition (to follow) of the differences, both morphologic and historic (pointed out earlier by others), between the North American Pliocene fossil forms and the living African Grévy zebra (*Equus* (*Dolichohippus*) *grevyi*) permits us to recognize Matthew's extinct taxon *Plesippus* as a full genus; it is not a living horse.

As far as the present fossil record reveals, not only the Grévy zebra but all living horses derive from North American *Plesippus*, as was believed by Matthew when erecting the genus in 1924 and as recently reinforced by Azzaroli and Voorhies (1993). The living Grévy zebra (subgenus *Dolichohippus*) may differ less than the other living horses from this ancestral *Plesippus*, but this does not indicate that they are the same. The later evolution of the Grévy zebra is fairly well documented in Africa (for example, Churcher and Richardson, 1978; Azzaroli and Voorhies, 1993), and certainly the several species of *Plesippus* have a much earlier record in North America.

The type specimen of *Plesippus idahoensis*, UCMP 22348, is a very worn upper premolar with less than an inch (Merriam gives 24.7 mm) of the enamel crown left above the roots (and this only at the least worn corner). The type tooth is distinctly more worn anteromedially relative to its vertical axis (J.H. Hutchison, oral commun., 1993) and appears, therefore, to be most likely a third upper premolar, although Merriam (1918, fig. 3) supposed that it was a P\4. As noted by Merriam (and Shotwell, 1970, p. 91), the tooth is so worn that it is not possible to approximate buccal curvature from base to top of the crown (but some is evident). The tooth is quite large, and Merriam measured it as 35.5 mm in anteroposterior length (presumably across the ectoloph), and 34.8 mm in transverse width (which is its width across the enamel, discounting the great thickness of cement at the protocone). The mesostyle has a conspicuously anteromedial slope to its external enamel face (fig. 9*C*).

The two upper teeth from near Cucumber locality GS-228 (fig. 9*A* and *B*) are equally large, and less worn; they confirm Merriam's inferences made from the well-worn type tooth. In addition they show that the short protocone of the type is not a result of its great wear but is short even with less wear, and that it has a prominent lingual groove at all stages of wear (at least on P\3 and M\2?). The protocone column does not taper toward the tooth base, reducing its anteroposterior length (fig. 9*A* and *B*). The upper tooth fragment found 100 yards south of Cucumber locality GS-221 shows a prefossette equal in size to that of the type tooth, and exhibits only slightly less wear than the type, further suggesting that *Plesippus idahoensis* is a consistently large species. However, the fossettes of the less worn teeth are only slightly more crenate than the type specimen, contradicting Merriam's inference, made from the very worn type specimen, that these would have been quite plicate with less wear.

All horses are rare in the Froman Ferry faunal succession, making the distinction between morphologic characters and individual variation vague. But the two teeth collected in the Cucumber area near GS-228 (a right P\3 and apparently a M\2) clearly are *Plesippus idahoensis*, and not the other horse known from the Froman Ferry faunal succession (figs. 10 and 11), although they may be 500,000 years younger than Merriam's type specimen. *P. idahoensis* had distinctly less buccal crown curvature than the other horse, *P. fromanius* (n. sp., discussed next), from the same fauna, had protocone columns with a short protocone and of a uniform anteroposterior length down the height of the crown, had less plicate fossettes, and the teeth were large (anteroposterior dimension across the ectoloph of P\3 is about 35 mm) and heavily cemented. The occlusal enamel pattern of the younger teeth is essentially identical to the that of type specimen (fig. 9*B* compared with 9*C*). These two new teeth clearly show that the size and enamel pattern of *P. idahoensis* are characters of the species and differ from those of *P. fromanius* n. sp. discussed next. Except for greater size, possibly more persistent protoconal gutter, thicker cement, and less curvature, the cheek teeth of *P. idahoensis* do not differ greatly from the type of *Plesippus simplicidens* (Cope) from the Blanco fauna near Lubbock, Texas (fig. 9*D*). They also show that the protocone column does not taper toward the roots and that the crown curvature is less than in the contemporaneous and older Glenns Ferry horses.

The curvature of the mesostyle column of M\2 (above the point where it flattens to merge with the crown base) is 2.5 mm across a 48.6 mm height of the column on the M\2 of *Plesippus idahoensis* (ratio for M\2×100=5.14). The mesostyle curvature is 6.85 mm across a 64.8 mm height of the column on the left M\2 mesostyle of *P. fromanius* from the Chalk Hills (ratio×100=10.57). The amount of curvature clearly varies with the tooth position and also varies between the mesostyle and the protocone of the same tooth (protocone curvature of *P. fromanius* on the same tooth has a ratio×100 of 12.89). The type P\3 of *P. idahoensis* has an occlusal length across the ectoloph of 35.5 mm and transverse width of 34.8 mm (enamel to enamel), compared to 34.4 mm and 31.3 mm of the P\3 of *P. fromanius* from Chalk Hills. The referred P\3 of *Plesippus idahoensis* (USNM 264329 from locality GS-228) is nearly as large as the type specimen and measures 35.1 mm in length and 33.2 mm in width.

The only lower cheek tooth known of *Plesippus idahoensis* is still the paratype described by Merriam (1918), UCMP 22347. It is large and heavily cemented in comparison with the lower tooth of the other horse from the Froman Ferry faunal succession (fig. 10*E*).

RELATIONSHIPS.—This is not the only record of a plesippine horse having these characters in the Glenns Ferry Formation. Horses of this nature, with a short, nontapering protocone, are inferred to have been an immigrant to the Snake River Plain before 2.1 million years ago.

Azzaroli and Voorhies (1993) have recently recognized two horses from the Glenns Ferry Formation exposed in Jackass Butte (their "Jackson Butte") northwest of Grand View, Idaho (the usual concept of the Grand View fauna; see p. 59). One of these was a large horse (USNM 23903, male skull and mandible; USNM 264281, female partial skull and mandible; and nine cataloged postcranial elements (others, mainly carpal and tarsal bones, are in the collection)). Except for the male skull and mandible, none were in articulated position as buried. All were collected in the same excavation with no other horse in association, although a few other mammal remains, as a *Stegomastodon* tooth and a badger mandible, were found. These horses were collected from a horizon estimated to be about 2.2 million years old from paleomagnetic control and supporting climatic evidence discussed later (p. 60). Azzaroli and Voorhies (1993) named this larger horse a new subspecies of Old World *Equus stenonis*, *E.* (*Dolichohippus*) *stenonis anguinus*, but for reasons discussed later in this report (on p. 44–46), we place the species in the genus *Plesippus* in North America. Although not mentioned by Azzaroli and Voorhies, some of the upper cheek teeth of this horse have protocones that taper toward the base of the tooth so that the anteroposterior length of the protocone decreases as the tooth wears.

The second horse that Azzaroli and Voorhies recognized in the Jackass Butte faunal succession was a slightly smaller species with a shorter and stouter muzzle, more massive premaxillaries, shallower narial notch, and more anteriorly located posterior palatine foramina (LACM (CIT) 118/892; the partial skull and jaw were discussed in 1936 by J.P. Schultz). Schultz (1936) referred this specimen to Merriam's *Equus idahoensis* (apparently on geographic grounds) and Azzaroli and Voorhies (1993) followed this assignment, although the distinguishing features of the skull are not known for Merriam's type material from Froman Ferry and the teeth from Jackass Butte are noticeably smaller.

Although Azzaroli and Voorhies (1993) mentioned Merriam's type material as being "obviously inadequate" for a species type, they cited dental similarities that suggest a relationship; the protocones on the upper teeth are short at the early stage of wear of the specimen (7–8 years old according to Azzaroli and Voorhies), especially on the P\3. This suggests that the protocone column does not taper toward the crown base. The teeth are also massively encased in cement, but the mesostyle of the upper teeth, especially the premolars, lacks the pronounced anteromedial slope of the external enamel surface found on the known topotypic specimens of *Equus idahoensis*. (The consistency of this feature is difficult to evaluate with so little topotypic material; it does not appear consistent in other horses, including *Plesippus fromanius*.)

The lower cheek teeth from Jackass Butte are very similar to the single topotypic lower premolar from Froman Ferry, except for their smaller size; and they have a heavy coat of cement.

Thus it seems probable that the new horse lineage leading to *Plesippus idahoensis* appeared in the Snake River Plain during deposition of the Grand View faunas, during the Blancan V mammal age of the United States. The decision of whether the form described by Schultz (1936) and Azzaroli and Voorhies (1993) from the Jackass Butte section should be assigned to the Froman Ferry species of Merriam (1918) probably should wait until more material has been found in both areas. Based upon the known teeth, *Plesippus idahoensis* is larger than the referred horse from Jackass Butte, seems to have slightly shorter protocones, and has a forward slant of the enamel forming the mesostyle; these may represent evolutionary trends during the 400,000 years that separate the two localities, or individual variations.

The Jackass Butte section is as young as about 2.0 million years based upon the presence of the older of the Réunion normal events (2.14 Ma) found in the marsh beds in the middle of the section and as old as possibly 2.3 million years based upon the thickness of the deposits and the absence of exposures of the 2.4-million-year-old Birch Creek fossil horizon in the immediate area. No attempt has been made to discover any faunal difference over this possibly 300,000 years of deposition at Jackass Butte.

The type and referred skulls of *Plesippus stenonis anguinus* were collected a short distance below marsh beds on Jackass Butte that contain the earlier event of the Réunion Normal-polarity Subchron (2.1 Ma), but the horizon of discovery of LACM (CIT) 118/892, referred to *Plesippus idahoensis*, is unknown to us.

***PLESIPPUS FROMANIUS* n. sp.**

Figures 10 and 11

Localities and material.—HOMEDALE AREA: GS-212 (2,430 ft elev.): two left cuboids (fourth tarsal bones). CHALK HILLS AREA: GS-203 (2,613 ft. elev.): (USNM 264339) the type left and right upper tooth rows, with fragments of the palate; the left side of the palate shows a minute (2.3 mm) alveolus for a P\1 (the palate is missing in this area on the right side). GS-208 (2,550 ft elev.):

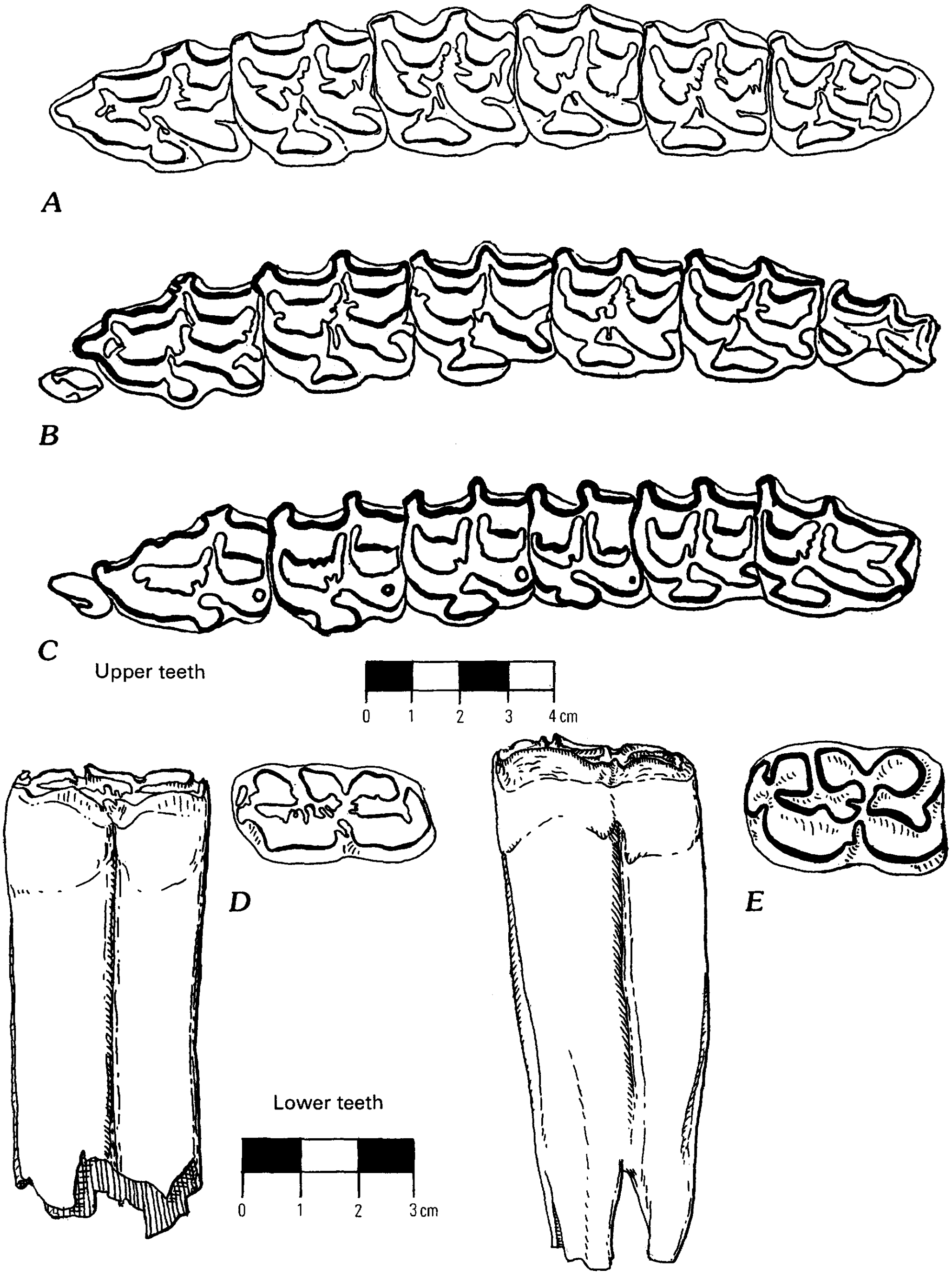


Figure 10. *Plesippus fromanius* from Froman Ferry faunal succession, Canyon County, Idaho; *P. shoshonensis* from Hagerman faunal succession, Gooding County, Idaho; and *Plesippus idahoensis* from Froman Ferry faunal succession. *A*, type *Plesippus fromanius*, USNM 264339: Right upper tooth row of type palate, locality GS-203, Chalk Hills area. Drawing reversed. *B* and *C*, *Plesippus shoshonensis*, left upper tooth rows showing change with wear. Copied from Gazin (1936, fig. 21). *B*, little worn; *C*, well worn. Note shortening of the protocone with wear. *D*, *Plesippus fromanius*, USNM 264340: little-worn right P/4 in occlusal and buccal views, from Cucumber area locality GS-221. *E*, *Plesippus idahoensis*, UCMP 22347: modestly worn right P/4 in occlusal and buccal views, referred by Merriam (1918), UCMP 3036, Froman Ferry area. Lower teeth shown larger, as indicated by different scales.

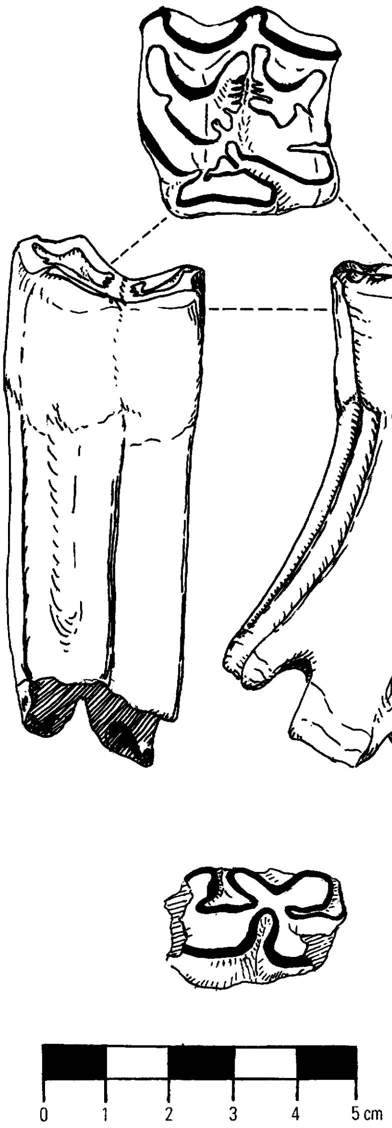


Figure 11. *Plesippus fromanius* second upper and third lower molars. Top: *Plesippus fromanius*, USNM 264339: left M\2 of the type specimen, locality GS-203, Chalk Hills area, Froman Ferry faunal succession, Canyon County, Idaho; occlusal, posterior, and lingual aspects. Showing buccal curvature of crown. Bottom: USNM 264341: *Plesippus fromanius*, occlusal surface of incomplete and well-worn M/3 from locality GS-232 Sample 15, Cucumber area, very high in the Froman Ferry faunal succession. Showing *Equus*-like enamel pattern in worn condition.

medial condyle of distal articulation of femur. CUCUMBER AREA: GS-221 (2,650 ft elev.): (USNM 264340) unrooted P/4. GS-229 (2,750 ft elev.): astragalus, metapodial splint. GS-234 (2,770 ft elev.): unerupted P/2 (onager?). GS-228 (2,770 ft elev.): distal epiphysis of radius, and proximal and middle phalanges (subadult). GS-232, Sample 15 (a rusty gravel bed 175 feet east of the locality, 2,810 ft elev.): M\3 and incomplete M/3 (USNM 264341), and miscellaneous postcranial elements.

Eight localities: 2,430 to 2,810 feet elevation; essentially throughout the Froman Ferry faunal succession. Although all postcranial elements found have been included here, there is no assurance that some do not belong to *Plesippus idahoensis*.

Etymology.—The species name *fromanius* (Latin; commemorative masculine) is in honor of George W. Froman who established, in the 1880's, a roadhouse on the road to Jordan Valley, Oregon, that was called Poison Creek Station. Mr. Froman built a ferry south of Chalk Hills in about 1886 to provide a more direct route to Caldwell, Idaho. The ferry operated until 1921, when a bridge was built across the Snake River at Marsing, 3 miles upstream (to the south) (Huntley, 1979, p. 170–176). According to Huntley, a Mrs. Velda Swinney, resident of the area, often crossed on the ferry with her horse and buggy and the horse always stopped in the middle of the ferry without command. When the bridge was built, Mrs. Swinney used it, and the horse stopped in the middle of the bridge as well.

Diagnosis.—A species of *Plesippus* with a protoconal column that tapers only at the base of P\4, M\1, and the M\2 (fig. 11), and that has strong buccal curvature of the crown (present but variably developed on the other cheek teeth except P\1–2), differing from *Equus*; differing from *Plesippus shoshonensis* from the Hagerman fauna (Gazin, 1936) and *P. stenonis anguinus* from the Grand View fauna (Azzaroli and Voorhies, 1993) in having a more elongate protocone (so that the cheek teeth resemble some species of the genus *Equus*), with tapering restricted to a very minor part (near the base) of the protocone column of only P\4 to M\2 to produce a *Plesippus* pattern with great wear; buccal curvature of the upper cheek teeth prominent and much greater than in *Plesippus idahoensis* or species of *Equus*. Lower teeth plesippine in having a V-shaped gutter between the metaconid and metastylid (fig. 10*D*), possibly excepting M/3 (fig. 11). This is a large horse; the complete cheek tooth row measures 198 mm in length.

Discussion.—USNM 264339 is the most complete specimen of this horse. It is a broken and incomplete palate with right and left dental rows (missing P\1s, although a very small alveolus for one is present on the left side). Casts of the right toothrow have been deposited with the material collected from Froman Ferry by Merriam in 1916 in the University of California Museum of Paleontology (UCMP) and in the Idaho Museum of Natural History (IMNH 1105/11890).

Although this horse is here believed to have evolved directly out of *Plesippus stenonis anguinus* (Azzaroli and Voorhies) from the Jackass Butte faunal succession, these authors based the specific identity of the Jackass Butte species on features of the skull (deep narial notch, preorbital pit) not known from the Froman Ferry species, as well as the teeth. Azzaroli and Voorhies (1993, p. 183) mentioned that *E.* (*D.*) *stenonis anguinus* has more posteriorly placed posterior palatine foramina, which is also true of *P. fromanius*, in which the foramina appear to have been behind the midpoint of M\3 (the foramina are broken away on the specimen and this statement is based upon projection from the limits of the breaks). This position appears to be slightly more posterior than in the Grand View and Hagerman specimens. Otherwise, these characters of the skull are not preserved in *Plesippus fromanius*, but the differences in the teeth from Froman Ferry are sufficient to show that *P. fromanius* is distinct from *P. stenonis anguinus* of Jackass Butte.

This North American lineage appears to have evolved the characters of Eurasian *E. stenonis* about 2.5 million years ago and dispersed to Eurasia, where the oldest forms are of about this age (Azzaroli and Voorhies, 1993, p. 183). Thus it also seems that the "stenonine" characters were relatively short lived in North America, but existed during the time that the lineage dispersed to Eurasia (although this is about 400,000 years earlier than the records from Jackass Butte). Although the "stenonine" characters persisted in the Eurasian clade, in North America the dental characters continue evolving toward the "caballine" condition. Thus, the species *stenonis* is not recognized again in later North American horses.

In North America the lineage evolved toward the modern horse while the Eurasian branch trended toward the modern zebras. The combination of *Plesippus fromanius* from Froman Ferry, of an evolutionary stage comparable with Old World zebras (and so named) from the Jackass Butte faunal sequence, and the more primitive *Plesippus shoshonensis* from Hagerman, all having dental features that suggest a single lineage (as will be discussed), presents a peculiar nomenclatorial situation: the evolution of the Glenns Ferry lineage appears to have lacked diversification and to have been *Plesippus shoshonensis* > *Equus* (*Dolichohippus*) *stenonis anguinus* > *Plesippus fromanius*. Because of this change in generic and subgeneric attribution in the middle of this sequence and because of arguments following as to the validity of these names in North America, we refer to the Jackass Butte species as *Plesippus stenonis anguinus* without comment regarding the proper nomenclature in Eurasia.

But there exists a peculiar circumstance in the last record, the species from Froman Ferry. As here interpreted, in *Plesippus fromanius* evolution has produced upper teeth that resemble *Equus* (*Equus*) species, especially *Equus scotti* of the early Irvingtonian faunas of the United States, although the lower teeth still appear to be those of *Plesippus*. The alternative interpretation is to recognize three horses from the Froman Ferry fauna: (1) a *Plesippus idahoensis*; (2) a species with *Equus*-like upper teeth and no known lower teeth; and (3) a species with *Plesippus*-like lower teeth, but no known upper teeth. The lower teeth here attributed to *Plesippus fromanius* have the character of the genus *Plesippus* (V-shaped metaconid-metastylid gutter: McGrew, 1944; Skinner in Skinner and others, 1972), even though the upper teeth have those of *Equus* (elongate protocone).

This situation of mixed "generic" characters between the upper and lower teeth is not unique to the Froman Ferry fauna, although the stratigraphic succession in the Glenns Ferry Formation showing the transition from *Plesippus* into this form may be unique in the stratigraphic record. The mixture of characters exists in some living horses (*Asinus*, *Dolichohippus*) that Opinion 271 places in the genus *Equus*, and in other fossil records.

For example, Akersten (1972), in describing the Red Light fauna of Texas, assigned only upper teeth (with the exception of one lower tooth, listed but not discussed) to *Equus scotti* and only lower teeth to *Plesippus simplicidens*. Akersten (1972, p. 36) recognized this problem and, in discussing the differences between his Red Light fauna and the nearby Hudspeth local fauna, having only *Plesippus*-like lower teeth (Strain, 1966), said, "There are two possible explanations for this situation. These two faunas [Red Light and Hudspeth] of equivalent age and separated only by a minor mountain range may have had a different species of large horse in each, or both may have had a single species of large horse in which the upper cheek teeth were similar to *E. scotti* and the lowers similar to *E.* (*P.*) *idahoensis*." He followed with, "I favor the latter explanation" but did not follow this in his identification. Had he done so, he would have recognized neither *Equus* aff. *scotti* nor *Plesippus* cf. *simplicidens* in the Red Light fauna, nor Strain's *Plesippus idahoensis* from the Hudspeth fauna on the other side of the mountains from Red Light.

The same mixture of *Equus*-like upper teeth and *Plesippus*-like lower teeth appears to be present in the oldest faunal horizon at Rock Creek, Texas (the type *Equus scotti* is from the middle horizon), and in the Aries fauna of southwestern Kansas according to G.A. Izett and J.G. Honey (oral commun., 1994).

During nearly all stages of tooth wear the Froman Ferry horse has a distinctly elongate protocone that is like that of species of the subgenus *Equus* (*Equus*) and quite similar to *Equus scotti* (?=*E. excelsus*). But, with great wear, the length of the protocone is shorter, most noticeably on the P\4 and M\1, and more like that of *Plesippus*. This is to say that the protocone is tapered near the base of the tooth, and this tapered protocone is also present, but extends farther down the tooth toward the occlusal surface, in *Plesippus stenonis anguinus* (Azzaroli and Voorhies) from Jackass Butte and in *P. shoshonensis* Gidley from the Hagerman fauna, in which Gazin (1936, fig. 21) illustrated a shortening of the protocone throughout wear.

The upper teeth on the type palate of *Plesippus fromanius* from Chalk Hills locality GS-203 (fig. 10*A*), 1.3 miles northeast of and about 215 feet higher in the section than the type locality of *P. idahoensis*, are only moderately worn (figs. 10*A* and 11), although roots had begun to form. The P\3 ectoloph measures 34.1 mm and the fossettes are amply plicated, more so than the little-worn teeth of *P. idahoensis* (fig. 9*A* and *B*). The mesostyles of the P\3 are strongly modified in the same way as those of *P. idahoensis*, with a conspicuous anterior slope of the ectoloph enamel, but this is not very evident in the other teeth of the type specimen. The crown of P\3 is 53.8 mm tall at the protocone on the type of *Plesippus fromanius* (avoiding root development).

Even with great wear, the protocone of P\3 is more elongate in *P. fromanius* than in *P. stenonis anguinus* from Jackass Butte, which is little altered from the condition in *P. shoshonensis* from Hagerman. Except for P\2, the protocone of P\3 is, however, the shortest of the tooth row, as is generally the case in all horses. The protocones of *P. shoshonensis*, *P. stenonis anguinus*, and *Plesippus fromanius* taper (shorten in anteroposterior length) toward their base; that of the P\3 of *Plesippus fromanius* is most advanced in that the protocone measures 13.1 mm in length at the occlusal surface of the type specimen, but is about 10.3 mm at the base; that of the P\4 has an anteroposterior length of 15.1 mm on the occlusal surface, and 13.6 mm at the base. As can be seen in Gazin's (1936, fig. 21) illustration of enamel patterns of *P. shoshonensis* from the Hagerman horse quarry (two reproduced here in fig. 10*B* and *C*), the same shortening of the protocone toward its base is found in the type population of this species. However, the elongation of the protocones in early wear is not so extreme in this population, and, as noted, the tapering of the protocone of *P. shoshonensis* is evident through the entire length of the column. The protocones of all three taxa have a moderate gutter running down their lingual surface which disappears before reaching the base of the tooth; it is, however, not so prominent as in *Plesippus idahoensis*.

The type and referred P\3 of *P. idahoensis* have ectoloph lengths of 35.5 mm and 35.2 mm, respectively, somewhat larger than the P\3 of *P. fromanius* (34.1 mm). Although the size of the type and referred upper teeth of *P. idahoensis* is great, it is little larger than *P. fromanius*; and Gazin (1936) noted that this ectoloph length is equalled or exceeded by two specimens of *P. shoshonensis* from Hagerman, although certainly the average from Hagerman is smaller. Both *Plesippus idahoensis* and *P. fromanius* are large horses.

All upper teeth but the P\2 of *Plesippus fromanius* from the Froman Ferry succession are moderately curved buccally; the amount of curvature of the protocone column is greatest in M\2 (fig. 11), as noted on page 37, and is 6.1 mm at its midpoint, and the protocone is 47.3 mm tall (ratio×100=12.89). The total occlusal-surface length of the cheek tooth row, P\2 to M\3, on the type specimen from Chalk Hills is 198 mm. There is a small (≈2 mm) alveolus for a P\1 on the type (left side only preserved), and *Plesippus fromanius* may also be more advanced in the reduction of this tooth than *P. shoshonensis* from Hagerman and *P. stenonis anguinus* from Jackass Butte, as well as in its more elongate protocone (the small alveolus is not shown in fig. 10*A*).

Of the lower teeth, the P/4 from locality GS-221 in the Cucumber area is shorter in crown height than the P/3 referred by Merriam (1918, fig. 5) to *Equus idahoensis* (UCMP 22347 from UCMP locality 3036). Although the Cucumber P/4 of *P. fromanius* is similar in generic characters, it is at a younger stage of growth and wear and smaller than the lower premolar of *P. idahoensis*, again illustrating the size difference (fig. 10*D* and *E*). Measured at the enamel boundaries (to avoid differences in cement thickness) the Cucumber P/4 is 33.5 mm long and 14.8 mm in transverse width at the occlusal surface (fig. 10*D*) and Merriam's referred P/3 is 34.6 mm long and 19.5 mm wide (fig. 10*E*). The base of the Cucumber tooth is not preserved and it is not possible to determine whether roots had yet formed, as they had begun to do in the tooth that Merriam described.

Like the specimen from the Froman Ferry area referred to *Plesippus idahoensis*, on the P/4 of *Plesippus fromanius* from the Cucumber area the metaconid-metastylid gutter is distinctly V-shaped, but the enamel plications, including the *plicaballinid*, are greater (fig. 10*D*). The occlusal surface of the Cucumber lower tooth of *Plesippus fromanius* has a remarkable amount of plication of the hypoconid wall of the posterior fossettid, which is not present at the broken base of the tooth; this also is evident in early wear of the lower teeth of the Grévy zebra as well as on the lower premolars of *Plesippus shoshonensis* and *P. stenonis anguinus*. A shallow gutter on the posterior face of the hypoconulid becomes more prominent toward the base of the tooth, and the tooth is so little worn that the hypoconulid is represented on the occlusal surface by two cusps. This hypoconulid groove is unusual in all *Plesippus* specimens seen and may only be an individual variation.

The incomplete M/3 from Cucumber locality GS-232 is a mature tooth with well-developed roots and is more than half worn (fig. 11). The buccal valley does not separate the fossettids, which are reduced in size because of wear, and the metaconid-metastylid gutter is shallow and broadly open because of wear. The tooth does not look particularly plesippine, but this is a variable and unreliable tooth for identification. It may show a tendency in the lower dentition toward an *Equus* tooth pattern.

The unerupted P/2 from locality GS-234, questionably assigned to *Plesippus fromanius*, is 41.1 mm long (in line with the tooth row), completely unworn, and of course has not developed roots. It is not possible to separate this tooth with certainty from the same tooth of the subgenus *Hemionus*.

We point out that the few available specimens of the horse from the nearly 1 million-years-older Birch Creek and Poison Creek areas of the Grand View faunal succession are considerably smaller (P\2 to M\2=144.7 mm; P\2–P\4=93.4 mm; P/2=37.7 mm; P/4=32.7 mm) and close to the average size of the tooth rows from Hagerman. Jonena Hearst (University of Kansas), currently studying the Birch Creek and Poison Creek faunas, has a more complete record of this horse, which may indicate that the small size we have seen is primarily an individual variation.

In summary, the teeth of *Plesippus fromanius* from the Froman Ferry faunal succession differ from the coeval *Plesippus idahoensis* in slightly smaller size, more elongate protocone, and greater buccal curvature of the upper tooth crowns; it differs from later species of *Equus* in this greater upper tooth crown curvature, in the shortening of the protocone of P\4 and M\1 with extreme wear, and in the retention of a V-shaped metaconid-metastylid gutter on the lower teeth, although this feature is not lost in all later *Equus* species.

Because the tapering of the protocone toward the roots and the crown curvature are also increasingly or equally evident in *Plesippus stenonis anguinus* from Jackass Butte of the Grand View faunas and in *Plesippus shoshonensis* from the Hagerman succession, the Froman Ferry species is considered part of a single horse lineage that was native to the western Snake River Plain throughout the history of the Glenns Ferry Formation. The Froman Ferry species differs from older populations of this lineage of the Glenns Ferry Formation in having greater elongation of the protocone, restriction of the protoconal tapering to the very base of the tooth, and in the reduction of P\1. The intermediate form of the lineage, *Plesippus stenonis anguinus* (Azzaroli and Voorhies) of the Jackass Butte faunas, had developed skull characters of this Eurasian lineage at the time that it dispersed to that supercontinent, and evidence indicates that subsequent evolution was not parallel in the two areas. In Eurasia *E.* (*D.*) *stenonis* continued to evolve in the direction of the living zebras, while, in North America, *Plesippus fromanius* evolved in the direction of living horses (and asses?).

The postcranial bones (listed on p. 38 and 40) provide little information and are not certainly assigned to *Plesippus fromanius*. The size indicated by all specimens is within the range of those tabulated by Shotwell (1970, table 22) for the Grand View faunal succession (Jackass and Wild Horse Butte areas), and larger than the range for those he tabulated for *Plesippus shoshonensis* from the Hagerman fauna. A large horse is indicated, but none are larger than the maximum Shotwell indicates for the horses in the Jackass Butte faunas. We do not know that the postcranial bones of *P. idahoensis* from Froman Ferry are as enlarged as are the teeth, although Azzaroli and Voorhies (1993) suggested, from evidence in other areas, that the species may also have had massive postcranial bones.

The ulna is fused to the radius as in modern horses and zebras and in the genus *Plesippus*; this is indicated on the radial epiphysis from GS-228, listed previously. This is the condition in all horses from the Glenns Ferry Formation. Skinner (in Skinner and others, 1972, p. 118) stated that the radius and ulna are not fused in the living *E.* (*Dolichohippus*) *grevyi*, which would be a very distinctive and primitive (or juvenile) feature, but his statment is not supported by the observation of others, as Gazin (1936, p. 308). We have not examined the postcranial skeleton of the Grévy zebra.

SPECIFIC NOMENCLATURE

That two horses are present in the Froman Ferry fauna seems clear, but what should they be called? Following Skinner (in Skinner and others, 1972), nearly every plesippine horse in North America has been assigned to the African zebra subgenus *Dolichohippus* of Heller (1912) and to the species *simplicidens* of Cope (1892), named from the Blanco fauna near Lubbock, western Texas (northern Crosby County), as has been mentioned (p. 37).

Cope's type, in the University of Texas collection, was a single incomplete upper tooth, reproduced here in figure 9*D* from Osborn (1918). Skinner assigned additional fossil horse specimens in the American Museum of Natural History (AMNH) from the Blanco fauna to *E.* (*Dolichohippus*) *simplicidens* with no explanation other than that they were topotypic. All these additional specimens from the Blanco fauna, collected by W.D. Matthew and G.G. Simpson in 1924, have quite worn teeth but give a much better idea of the nature of the species. In establishing the genus *Plesippus* Matthew had these specimens at hand, and this additional material was also assigned to Cope's species by Gidley (1930) and Gazin (1936): Skinner (Skinner and others, 1972) may have thought that an explanation of the assignment was not needed.

Unfortunately, the anterior portion of the protocone of Cope's type is missing and has been variously inferred; Cope (1892, fig. 1) inferred an anterior projection of the protocone as in *Equus*, and Osborn (1918, pl. 24-5, reproduced here in fig. 9*D*) inferred a *Pliohippus*-like anterior part of the protocone. However, it is evident from the illustrations of the type that it is a little-worn tooth (probably an M\1) and that, at this early stage of wear, even the posterior portion of the protocone is short in comparison with the tooth of little-worn *Plesippus shoshonensis* (compare fig. 9*D* with the M\1s of fig. 10*B* [little worn] and *C* [well worn]). If Cope's *Plesippus simplicidens* had a tapered protocone, as does Gidley's *Plesippus shoshonensis*, with great wear the protocone must have been very *Pliohippus*-like.

This is not evident in the worn teeth collected by Matthew and Simpson from the type locality.

Skinner (Skinner and others, 1972) stated that *Plesippus shoshonensis* Gidley, from the Hagerman faunal succession, was the same species as that described by Cope from the Blanco fauna, but without explanation and without mentioning the characters that Gazin (1936) gave as being different between the two species. Gazin, noting that the topotypic teeth were quite worn, believed that the strongest differences between *P. simplicidens* and the Hagerman horses were those of the skull and limb proportions.

The Glenns Ferry horse lineage (*Plesippus shoshonensis* > *P. stenonis anguinus* > *P. fromanius*) is not *Plesippus simplicidens* (figs. 9 and 10). Possibly the most conspicuous difference is that their upper cheek teeth have a protocone that resembles that of *Equus* in at least early wear. This feature gradually increases in development during deposition of the Glenns Ferry Formation until the representative from Froman Ferry has a *Plesippus*-like protocone only in the final stages of wear. *P. idahoensis* is possibly the most similar to Cope's species, but is much larger, its upper teeth are less curved, and it has a lingual gutter running down the protoconal column (fig. 9*A*, *B*, and *C*), a feature developed in a few teeth from the Blanco fauna.

From Shotwell's work, relative limb proportions seem to change from *P. shoshonensis* to *P. stenonis anguinus* (Hagerman to Jackass Butte). Although complete skeletons are known only from Hagerman, major elements of the postcranial skeleton were recovered with the two USNM skulls from Grand View (*P. stenonis anguinus* (Azzaroli and Voorhies) from Jackass Butte); and Shotwell (1970, table 22) had a large number of isolated postcranial elements from there, but did not recognize the presence of two horses. Without individual associated skeletons, determining whether the differences in limb sizes represent individual proportions, population variation, or different species is difficult.

Most importantly, dental characters change over this time (at least 2 million years), and the youngest population of the native Glenns Ferry lineage, *Plesippus fromanius* from Froman Ferry, had developing dental features in the upper teeth, particularly the elongate protocone, that would ordinarily cause them to be included in the subgenus *Equus*, rather than *Plesippus*. In contrast, *P. idahoensis*, also from the Froman Ferry faunal succession, developed a straighter crown, but retained a primitive protocone. On the other hand, *P. simplicidens* (Cope) from the Blanco fauna, Texas, seems to retain all primitive dental characters, a plesippine (almost pliohippine) protocone and a strongly curved upper cheek tooth (fig. 9*D*). The material of *P. simplicidens*, collected later by Matthew and Simpson from the type locality, is all rather well worn, but none have an elongate protocone like little-worn *Plesippus shoshonensis*.

Shotwell (1970) and Conrad (1980) assigned the Grand View horse material (Jackass Butte) to Merriam's species (*E. idahoensis*) from Froman Ferry, but to different subgenera (depending upon whether Skinner's statements had been published at the time of each one's writing); their assignments were hesitant because of the limited material available from Froman Ferry (then only Merriam's type material), and neither recognized two different horses from the Grand View faunas. Dalquest (1978) followed Skinner in accepting *Equus* (*Dolichohippus*) *simplicidens* as the name for most Blancan horses, and Kurten and Anderson (1980, p. 285) apparently followed Dalquest and assigned Merriam's two teeth from Froman Ferry, as well as all other Glenns Ferry horses, to *E.* (*Dolichohippus*) *simplicidens*.

Beyond the generic definition for *Plesippus* provided by Matthew (1924), Merriam's type specimen of *Equus idahoensis* from Froman Ferry (fig. 9*C*) bears little resemblance to Cope's *Equus simplicidens* (fig. 9*D*) from Blanco, Texas. Of the material from the Blanco fauna of Texas, only the type of *Plesippus simplicidens* is not greatly worn, and it has a *Pliohippus*-like short protocone on its occlusal surface at this early stage of wear, as does *Equus idahoensis*. This is quite different from the elongate protocone of little-worn *Plesippus fromanius* of the Froman Ferry faunal succession (fig. 10*A*) or *P. shoshonensis* from Hagerman (fig. 10*B* and *C*), end members of the lineage present throughout the Glenns Ferry Formation.

SUBGENERIC NOMENCLATURE

As with the felids (and many other mammalian groups such as the microtine rodents) the generic allocation of species of horses is unstable. There exist many concepts of the definition of a genus. We follow what seems to be current convention by considering many living taxa, initially considered as genera, to be subgenera of the genus *Equus*; however, we do not believe that this treatment should be carried back into fossil horses, as it tends to conceal biostratigraphic and phylogenetic significance. This is an approach similar to that taken with the cats (p. 20). But if the species *Equus* (*Dolichohippus*) *simplicidens* is recognized, why isn't the species *Equus* (*Dinohippus*) *mexicanus* recognized as well?

The upper dentition is the most critical in consideration of these species, as the lower teeth maintain a more uniform *Plesippus* pattern, a feature that may have led Skinner to such extensive synonymy, thus minimizing the usefulness of Blancan and early Irvingtonian horses in biochronology.

Although horse lower teeth are scarce in the Froman Ferry faunal succession, those that are known would indicate a biochronologic age spanning the Blancan United States mammal age and extending into the early Irvingtonian mammal age (4.8 to 1.5 Ma). The upper teeth, however, show a strong difference across the 400,000 years between the youngest horse whose age can be approximated at Jackass Butte (*Plesippus stenonis anguinus*) and the related horse in the Froman Ferry faunal succession (*Plesippus fromanius*); the upper teeth also seem most distinctive in comparing the Grand View *P. stenonis anguinus* to the Hagerman *P. shoshonensis*. It certainly is easier to use the lower teeth and call all Blancan horses "*Equus* (*Dolichohippus*) *simplicidens*," but it certainly is more informative to recognize the differences in the upper teeth of these horses and their biochronologic significance.

We note that if the upper teeth of the horses are considered, the difference over the span of time between Jackass Butte and Froman Ferry is more conspicuous than the difference observed in the native microtine rodent fauna. The lower horse teeth, however, appear inseparable, with the present limited number of specimens from Froman Ferry. Except for the immigration of a new microtine lineage (*Phenacomys*), the apparent extinction of *Procastoroides*, and the differences in the upper teeth of *Plesippus fromanius*, the two faunas are essentially identical.

According to Gazin (1936, p. 292), the horse from Hagerman, which Gidley (1930) named *Plesippus shoshonensis*, had many similarities to the living Grévy zebra, *Equus* (*Dolichohippus*) *grevyi*. (It is not indicated in Gazin's report whether other living zebras were available for comparison, but it can be so assumed, as he was working out of the National Museum of Natural History and also visited the American Museum of Natural History in New York.) He devoted about 18 pages to descriptive comparison of the Hagerman horse with the Grévy zebra and with domestic horse.

This morphologic comparison does not indicate that Gazin thought the Hagerman horse was a zebra any more than it indicates that he thought it was a domestic horse. Classification is based upon the interpretation of evolutionary history, which, in turn, is based on both morphologic similarities and the temporal and geographic distribution of these similarities. The temporal record of these morphologically similar forms indicates that *Equus* (*Dolichohippus*) *grevyi* evolved out of African *Equus stenonis*, which, in turn, had evolved out of North American *Plesippus shoshonensis*. These taxa lived during a sufficiently brief span of time that their morphologic similarity is great, and careful morphologic, temporal, and geographic consideration is needed to distinguish their fossil forms. The fauna of the world is not everywhere the same at any single instant, and the differences are what are important to interpretation. What both McGrew (1944) and Skinner (in Skinner and others, 1972) did was to rely entirely upon morphology, and in doing so they failed to note morphologic differences that are in agreement with, and made apparent by, the temporal and geographic record.

Matthew (1924) had introduced the generic name *Plesippus* for North American (**geography**) forms that appeared to be intermediate between the late Miocene (**time**) horse *Dinohippus* (included in *Pliohippus* before Quinn, 1955) and Pleistocene (**time**) *Equus*. Gazin (1936) followed Gidley (1930) and assigned the Hagerman horse to Matthew's extinct genus. That the *Plesippus* grade in horse evolution is little modified in the modern (**time**) zebra is coincidental; modern zebras certainly are not ancestral to modern *Equus*, and yet classification is supposed to reflect evolution.

The difference in approach is the difference between basing taxonomy upon evolutionary history and basing it on morphologic similarity. However, McGrew and Skinner misunderstood this point and said that *Plesippus* **was** a zebra because it was so morphologically similar (in their comparison) to the living forms. They compared the 3-million-year-old North American fossils with the living African Grévy zebra, but did not look for differences that this amount of time and geography might have produced.

Skinner, citing Heller (1912), stated that the correct generic (in original usage) assignment of Blancan plesippine horses was *Dolichohippus*, but otherwise was following McGrew's thinking. Skinner also used the zebrine genus as a subgenus following the International Commission on Zoological Nomenclature (mentioned on p. 36), and he recognized only one North American species, *Equus* (*Dolichohippus*) *simplicidens* (Cope), the type of Matthew's genus *Plesippus*. Although **using** Cope's **name** for a horse from Texas, Skinner **described** *E.* (*Dolichohippus*) *simplicidens* from Gazin's specimens of *Plesippus shoshonensis* from Hagerman, not from the type material, which was hardly mentioned in his report. Since then, Matthew's genus *Plesippus* has dropped from usage, its nature as an intermediate form between the late Miocene *Dinohippus* and the Pleistocene and modern horses (Matthew might have added "and zebras") has been ignored, and the similarity of *Plesippus* to the modern Grévy zebra has been emphasized. *Dolichohippus*, usually as a subgenus of *Equus*, has become the standard usage in North America, yet *Dolichohippus* evolved in Africa out of *Equus stenonis*, which evolved in North America out of *Plesippus shoshonensis*. Historically, Skinner's nomenclature is difficult to describe; it places extinct horses around the world in a living genus and subgenus.

Skinner's (in Skinner and others, 1972, p. 118) morphologic discussion in defense of his use of the subgenus *Dolichohippus* in North America, in preference to *Plesippus*, consisted of five paragraphs (in comparison with Gazin's 18 pages of comparison with *Dolichohippus*), and stressed its similarity with the living African species *E.* (*D.*) *grevyi*, with little comparison to any other horse, although he asserted that he had compared the fossil material to many species. His discussion completely ignored Matthew's concept of *Plesippus* as an intermediate between *Dinohippus* and modern horses (it has never been suggested that the Grévy zebra evolved out of *Dinohippus* and into domestic horse). And the morphologic similarity is not exact, as pointed out by Bennett (1980) and Azzaroli and Voorhies (1993). Most of Skinner's consideration was directed to the structure of the lower teeth, yet no discussion of the lower teeth of topotypic material of Cope's *Pliohippus simplicidens* from Blanco, Texas, was given. Skinner illustrated only lower dentitions from Nebraska and Idaho, with no defense of identification. As has been mentioned, lower teeth of *Dolichohippus* (Matthew's *Plesippus*) differ little throughout the Blancan United States mammal age, and the result has been that very little horse evolution has been recognized.

Not surprisingly, because of his strictly anatomical evaluation, Skinner also made no effort to explain any historical evidence that would suggest that the North American form dispersed to Africa to become the living species. Most disturbing, he made no mention of *Equus stenonis*, the then-well-known fossil plesippine of Asia, Europe, and North Africa. *Equus stenonis* has been favorably compared with both the living zebras and with North American horses at least since Lydekker (1887) and Boule (1899).

According to Churcher and Richardson (1978) the oldest African records of living *Dolichohippus* equate with the time between the youngest part of Jackass Butte and the Froman Ferry faunal succession (Ethiopia: Shungura members G-J; Tanzania: Olduvai Beds I-IV). Azzaroli and Voorhies (1993, p. 185) added additional data about the earliest records of *Equus stenonis* in Asia, Europe, and Africa, and noted that the living Grévy zebra "has progressed very little beyond the evolutionary stage of these [fossil] species; it is however apomorphic in its widely open facial angle and, to a lesser degree, in its dentition."

Bennett (1980) undertook an analysis of late Cenozoic and modern equids and came up with perhaps the most reasonable (at that time) hypothesis of their evolutionary history. Her discussion sparkled with logic, and her characters, several new to the literature, were interesting. Her cladistic analysis led to a phylogenetic diagram (her fig. 6) that has some very sensible aspects, which have not been sufficiently considered in some American literature (for example, that *E. grevyi* derives from European [or African] *E. stenonis*, rather than from the very similar North American "*E. simplicidens*"). In general, Bennett (1980) presented the same interpretations as Azzaroli and Voorhies (1993), but lacked as detailed a history of the lineage in Eurasia. Regrettably, the completion of her study, mentioned in her publication, has never been published.

Skinner's use of the African subgenus *Dolichohippus* in North America, as a replacement for Matthew's *Plesippus*, was based upon similarities in dental and cranial morphology which later authors (and earlier, as Gazin, 1936) have limited. The similarities are not complete: North American *Plesippus* is more primitive than African *Dolichohippus* in having a less open facial angle and much greater buccal curvature of the upper teeth; in addition the Glenns Ferry lineage, *Plesippus shoshonensis* > *P. stenonis anguinus* > *P. fromanius*, has more elongate protocones on their upper teeth in at least early stages of wear. We elect to restore Matthew's intermediate genus, *Plesippus*, in North America and to restrict *Dolichohippus* to Africa, following Gazin (1936) and Bennett (1980), and reversing Skinner (in Skinner and others, 1972) and McGrew (1944).

PHYLOGENETIC SUMMARY

Although specific assignment is a matter of opinion, there appears at present to be no great similarity, within *Plesippus*, between Cope's (1892) *Plesippus simplicidens* of Lubbock, Texas, and Gidley's (1930) *Plesippus shoshonensis* of Hagerman, Idaho, an appearance strengthened by Skinner's omission of an explanation when he placed them in synonymy. Thus, reinstatement of the Hagerman species appears reasonable to us on the basis of available information.

Figure 9*D* shows *Plesippus simplicidens* to be a more primitive taxon than *Plesippus shoshonensis* (fig. 10*B* and *C*) by virtue of its short (*Dinohippus*-like) protocone in little-worn teeth, lack or weak development of a lingual protoconal gutter, lack of a tapering protocone, and, possibly, greater crown curvature.

Merriam's *Plesippus idahoensis* (fig. 9*A, B,* and *C*) is more advanced toward modern horses than *P. simplicidens* in less crown curvature, presumably persistent lingual protoconal groove, heavy cementum, and larger size. *Plesippus shoshonensis* from Hagerman, *P. stenonis anguinus* from Jackass Butte, and *Plesippus fromanius* from Froman Ferry have tapering protocones, which are more elongate, at least with little wear, than *P. simplicidens*; in the youngest species (from Froman Ferry) they approach *Equus scotti* of the Irvingtonian faunas of the United States.

From the material now available, there appears to have been a new horse lineage (*Plesippus idahoensis*) introduced to the western Snake River Plain during the Blancan V United States mammal age; the lineage remained present during at least the earliest Irvingtonian I part of the Froman Ferry faunal succession, but no recognized record of this lineage appears in the Glenns Ferry faunas earlier than about 2.3 million years ago.

At the same time that the *Plesippus idahoensis* lineage appeared in the Snake River Plain, during the Blancan V mammal age, the Glenns Ferry native horse lineage dispersed to Eurasia as *Plesippus stenonis anguinus* (at which time it must assume the generic assignment of *Equus* to conform to Eurasian usage), and shortly thereafter to Africa, where it evolved into the living Grévy zebra, *Equus* (*Dolichohippus*) *grevyi*. In North America, however, the nondispersing branch of the lineage evolved in the direction of species that have been placed in *Equus* and by the end of the deposition of the Glenns Ferry Formation (>1.5 Ma) had come close to resembling later Pleistocene *Equus scotti*, as shown by *Plesippus fromanius* from the Froman Ferry faunal succession. In addition to the Froman Ferry record, this latest Blancan and earliest Irvingtonian transition from *Plesippus* into *Equus* is also recorded in the Red Light–Hudspeth faunas of western Texas (Akersten, 1972; Strain, 1966), the lower horizon of Rock Creek, Texas, and the Aries fauna of southwestern Kansas (J.G. Honey and G.A. Izett, oral commun., 1994).

As the fossil record indicates (Churcher and Richardson, 1978; Azzaroli and Voorhies, 1993), living *Equus* (*Dolichohippus*) *grevyi* evolved out of *Equus stenonis* in Africa about the same time that *Plesippus stenonis anguinus* evolved into *P. fromanius* in the Glenns Ferry Formation. Phylogenetic history might be better illustrated by the name *Plesippus stenonis* in Eurasia (rather than *Equus stenonis*), which would clearly indicate that it was an immigrant from North America, rather than from Africa.

Order ARTIODACTYLA Owen, 1848

Family CAMELIDAE Gray, 1921

Subfamily CAMELINAE Zittle, 1893

Genus *GIGANTOCAMELUS* Barbour and Schultz, 1939

GIGANTOCAMELUS SPATULUS (Cope), 1893

Localities and material.—CUCUMBER AREA: GS-234 (2,770 ft elev.): lateral condyle of the distal articulation of a radius-ulna, complete unciform. GS-227 (2,750 ft elev.): proximal phalanx.

Two localities: 2,750 to 2,770 feet elevation.

Discussion.—These few remains of the giant camel are much larger (and stouter) than comparable elements of other genera, as *Camelops*, and the proximal suspensory ligament scars on the posterior side of the proximal phalanx are W shaped and identical to those of *Gigantocamelus spatulus* (Cope) (Voorhies and Corner, 1986, fig. 5A). This appears to be the first Irvingtonian record of this typically Blancan species; it is earliest Irvingtonian and clearly higher in the section than the first record of *Phenacomys*, marking the first of the Irvingtonian mammal age in the Pacific Faunal Region of the United States.

Skeletal elements and teeth fragments of smaller camels have been found throughout the Froman Ferry faunal sequence, including unpublished material in the UCMP collected by Merriam. These are not identifiable.

Family CERVIDAE Gray, 1821

Unidentified cervid postcranial elements, largely phalanges, have been found from the lowest to the highest part of the Froman Ferry faunal succession. The size range varies from that of small elk to deer, but no effort has been made to improve this identification. One medial phalanx of near elk size was in Merriam's collection in UCMP, number 113695.

HISTORIC SETTING OF THE FROMAN FERRY FAUNAL SUCCESSION

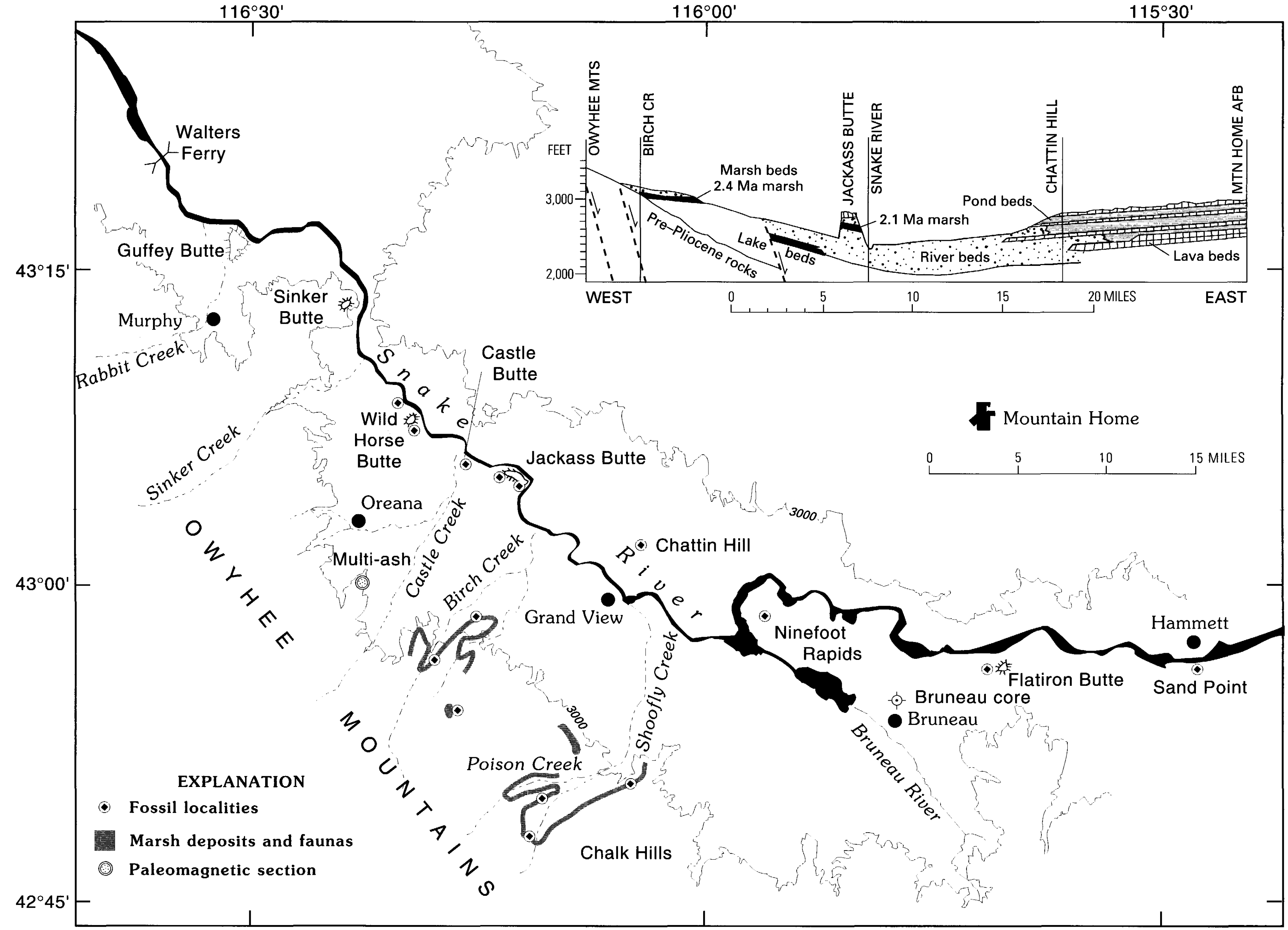
The marsh beds containing the Froman Ferry faunal succession are the final known depositional record of the 2.5-million-year history of the Glenns Ferry Formation (and lake) of the western Snake River Plain. To the east of the Froman Ferry area, near the then-existing (to be discussed) Snake River, lake, marsh, and fluvial deposition may have continued while erosion in the Froman Ferry area and the volcanic eruption of Pickles Butte took place, but this has not been confirmed.

The Froman Ferry marsh beds were not the first to form in the Glenns Ferry Formation as the lake withdrew. Repeatedly, throughout the history of deposition of the formation, marsh or stream deposits covered the lake beds as the lake withdrew from particular areas, and the marsh beds of the Froman Ferry area are only the most recent example. To explain the historic setting of the Froman Ferry faunal succession, it is necessary to record the 2.5-million-year history of deposition of the formation, of which the Froman Ferry fauna is only the final example. Also needed is some discussion of areas beyond the western Snake River Plain and events that preceded the deposition of the Glenns Ferry Formation in explanation of the origin and the end of the Glenns Ferry lake.

This discussion is complicated by many published interpretations of this history that must be considered in evaluating the most probable history of the Glenns Ferry lake and contiguous areas of deposition. Most critical to interpretation is the age of the youngest deposits of the Glenns Ferry lake; the age of these is not known but only suspected as being immediately older than the Froman Ferry faunal succession. The relationship of the Glenns Ferry Formation to the ancient Snake River, which has a prior history of major changes in its route, is also important in understanding the depositional history of the formation. These records are part of the consideration of history that the Froman Ferry faunal succession terminates.

YOUNGEST GLENNS FERRY LAKE BEDS

No evidence exists that lake deposition persisted later than about 2.1 million years ago—the approximate youngest known age of the "typical" Glenns Ferry lacustrine diatom flora with age control (Multi-ash paleomagnetic section south of Oreana; Neville, 1981; paleomagnetic correlation revised). In a test hole drilled near the town of Bruneau


116°30'
116°00'
115°30'
43°15'
43°00'
42°45'
Walters Ferry
Guffey Butte
Murphy
Rabbit Creek
Sinker Butte
Castle Butte
Snake River
Wild Horse Butte
Jackass Butte
Sinker Creek
Oreana
Castle Creek
Birch Creek
Multi-ash
OWYHEE MOUNTAINS
Chattin Hill
Grand View
3000
Ninefoot Rapids
Hammett
Flatiron Butte
Sand Point
Bruneau core
Bruneau
Bruneau River
Shoofly Creek
Poison Creek
Chalk Hills
Mountain Home
0
5
10
15 MILES
FEET
3,000
2,000
OWYHEE MTS
BIRCH CR
JACKASS BUTTE
SNAKE RIVER
CHATTIN HILL
MTN HOME AFB
Marsh beds
2.4 Ma marsh
2.1 Ma marsh
Pond beds
Pre-Pliocene rocks
Lake beds
River beds
Lava beds
WEST
EAST
0
5
10
15
20 MILES
EXPLANATION
Fossil localities
Marsh deposits and faunas
Paleomagnetic section

(Thompson, 1992), the youngest Glenns Ferry lake beds are about 2.5 million years old, based upon their normal magnetic polarity and the assumption that the time of their replacement by fluvial deposits in the Bruneau core was about the same throughout the Bruneau area. The closeness to Bruneau of the 2.4-million-year-old Poison Creek marsh beds (to be discussed; fig. 12) indicates that if this assumption is in error, it cannot be greatly so. In addition, the earliest Grand View (Blancan V) Ninefoot Rapids fauna is even closer to the core site (fig. 12) and believed to be slightly older than the Poison Creek marsh beds; it is nonlacustrine and about 2.56 million years old (p. 59). Hypothetically, because the area of the Bruneau core is a short distance upstream from these and the filling of the basin of the Snake River Plain was in a downstream direction (as will be discussed), the initiation of fluvial deposition in the Bruneau core should be slightly older than the Ninefoot Rapids fauna. The youngest paleomagnetic sample from the lake beds in the core is normally polarized, indicating that it is older than the termination of the Gauss Chron (2.48 Ma). The late Blancan IV Flatiron Butte fauna is upstream from the Bruneau core a distance somewhat less than the Ninefoot Rapids fauna is downstream (fig. 12), and indicates that fluvial deposition began before 2.56 million years ago at this position in the Snake River Plain, as the section is all normally polarized (Neville, 1981) but does not contain the immigrant microtine *Mictomys*.

The youngest known Glenns Ferry lake diatoms in the Grand View area are in a paleomagnetic section termed "Multi-ash" (Neville, 1981, p. 119) about 3 miles south of Oreana (fig. 12). This polarity section is the only one in the Glenns Ferry Formation in which the original polarity assignment is changed due to later information, as mentioned on page 8. The Multi-ash polarity section has the top of the Gauss Chron at least 59 feet above its base; above the Gauss is a long sequence (perhaps 132 feet) of reversely polarized lacustrine deposits of the Glenns Ferry lake, obviously representing the early part of the Matuyama Chron; the "typical" Glenns Ferry lacustrine diatom flora (p. 58) is present to the top of the section (J.P. Bradbury locality 13 IX 89-5A), and is unconformably overlain by fluvial deposits presumably of the Bruneau Formation (H.E. Malde, oral commun., 1979). These overlying deposits also contain some lake beds that have the typical Bruneau diatom flora (J.P. Bradbury, oral commun., 1992).

According to Neville (1981), the Multi-ash section is close above the locally oolitic rusty sand unit that is found beneath the Glenns Ferry Formation along the southwest side of the Snake River Plain. This unit had been included in the Glenns Ferry Formation, as the basal unit, and its presence shortly below the Multi-ash section led Neville (1981, p. 141) to assume that the lake beds in the Oreana area were the oldest part of the Glenns Ferry Formation. Her assumption was strongly supported (Neville, 1981, p. 141) by the local occurrence of the primitive rabbit *Hypolagus vetus* (later renamed *H. gidleyi* White, 1987). Although not clearly correlated to the Multi-ash section, the presence of this rabbit suggested, in 1981's state of knowledge, that the deposits of the Oreana area were rather old. Neville and associates were not aware that (1) the locally oolitic rusty sand unit lay unconformably beneath the Glenns Ferry lake beds (and thus had little bearing on the age of the lake beds); (2) the lake beds were transgressive against the underlying rocks (oolitic unit) toward the southwest side of the Snake River Plain (thus the oldest parts of the Glenns Ferry Formation were increasingly younger in this direction); (3) the rabbit *Hypolagus gidleyi* would be found high in the Froman Ferry faunal succession in post-Blancan deposits little more than 1.5 million years old (p. 25); (4) fossils in the vicinity of the Multi-ash section (the Birch Creek fauna, less than 5 miles to the southeast across almost continuous exposures) dated the lake beds as being the youngest so far discussed in the Glenns Ferry Formation (p. 61); and (5) the lacustrine diatoms at the base of the Hagerman section and associated with the Cochiti Normal-polarity Subchron (the obvious youngest possible correlation of the normal polarity at the base of the Multi-ash section in her thinking) were distinctly different ("oldest" diatom flora; p. 56, 58) than the diatom flora in the lake beds of the Multi-ash paleomagnetic section ("typical" and youngest diatom flora; p. 58).

These more recently learned facts completely invalidate Neville's reasoning for the correlation of the magnetic events in the Multi-ash polarity section and indicate that the polarity pattern can only be that of the top of the Gauss Chron overlain by a good thickness of reversed deposits of the early Matuyama Chron. She did not detect any brief normal events that would represent the Réunion Subchron, and thus the section seems to be older than 2.14 million years. The possibility is good, however, that her sampling missed these brief events, as 30–40 feet separate the two highest paleomagnetic samples of the Multi-ash section; the absence of the Réunion events cannot be positively demonstrated. Based upon relative thicknesses, and the assumption that the rate of deposition of lake beds at the Multi-ash section was about the same as nonlacustrine

Figure 12 (facing page). Snake River area between Sand Point and Walters Ferry, Idaho, showing some localities mentioned in the text, and fossil localities. Marsh beds of the Birch Creek and Poison Creek–Shoofly Creek areas are patterned; 3,000 foot contour shown to suggest relief. A generalized west to east section of the Glenns Ferry Formation in the central Snake River Plain, through Birch Creek, Jackass Butte, Chattin Hill, and Mountain Home, is shown inset at the upper right. Horizontal scales are different and the cross section has great vertical exaggeration. In the section dashed lines approximate the position of known or inferred faults; barb, direction of relative movement.

deposition at Jackass Butte, the upper, reversely polarized, lake beds of the Multi-ash section would seem not young enough to contain a record of the Réunion events, although almost so. The rise in lake level that brought marsh deposition into the middle of the Jackass Butte section (shortly before the earlier Réunion event; p. 60) may correlate with part of the lacustrine deposition in the upper part of the Multi-ash section.

Probably the first published recognition of the unconformity between the oolitic unit and the Glenns Ferry lake beds was the map of Owyhee County by Ekren and others (1981), which shows the oolitic unit dipping basinward more steeply than the modern drainages whereas the overlying Glenns Ferry lake beds (not separated from the Glenns Ferry marsh and fluvial deposits on their map) dipped basinward at a flatter gradient than the modern drainages. In every major drainage from Shoofly Creek northwest nearly to Murphy, this relationship was mapped, and the relationship continues northward to the Marsing area—although Ekren and others changed their mapping detail at about the position of Murphy and ceased recording this contact. Thus this structural implication is present along the southwest margin of the Snake River Plain for a distance of more than 70 miles.

This relationship between the oolitic unit and the Glenns Ferry lake beds, in combination with our own observations that the lake bed units gradually lap out against the top of the oolitic unit toward the southwest margin of the Snake River Plain, forms the major reason for removing the oolitic unit from the Glenns Ferry Formation (p. 54).

Neville (1981, p. 141) was following Malde and Powers (1962) in considering the oolite to be the basal unit of the Glenns Ferry Formation. The 2.4-million-year-old fauna from Birch Creek, about 5 miles to the southeast of the Multi-ash section, was undiscovered when she worked in the area, and the fact that it lay directly on top of the oolitic unit in the upstream part of Birch Creek was not known. Her (Neville, 1981, p. 141) only basis for fossil control of the age of the lake beds was the occurrence of the extinct rabbit *Hypolagus gidleyi* (called *H. vetus* when Neville did her work) in the Oreana area to the north of the Multi-ash section, which then was thought to indicate an age older than the Jackass Butte fauna of the Grand View area, a belief shattered by its discovery high in the Froman Ferry fauna (p. 25–26). She therefore considered Glenns Ferry lake beds in the Multi-ash section to be the oldest part of the formation and suggested that the long reversed section correlated with the Gilbert Reversed-polarity Chron (Neville, 1981, p. 121).

The diatom flora in the lake beds of the Multi-ash polarity section indicates otherwise, however, as will be noted in discussing the diatom flora of the oldest known lake beds of the Glenns Ferry Formation at the base of the Hagerman section (p. 56). The diatoms associated with these oldest lake beds at Hagerman (and with the Gilbert Chron) are very unusual and do not resemble the "typical" diatom flora present in the Multi-ash area and in the bottom of Birch Creek, some 200 feet below the Birch Creek marsh beds (2.4 Ma) (J.P. Bradbury, oral commun., 1993). These lake beds all pinch out against the oolitic unit upstream from this point, leaving the 2.4-million-year-old marsh beds lying directly on top of the oolitic unit in both Birch Creek and Shoofly Creek.

In fact, the ash beds, which are the source of the name of the "Multi-ash section," occur in the middle of the polarity section about 10–20 feet above the most probable position of the top of the Gauss Chron (Neville, 1981, fig. 5.5) and are the lacustrine equivalent of the ash beds found in the Birch Creek marsh deposits containing the Birch Creek fauna a short distance to the southeast; the Birch Creek fauna is a Blancan V fauna and is younger than 2.56 million years. From the position of the ash beds in the Multi-ash section above the top of the normal magnetozone, these ash beds are estimated as being 2.4 million years old, the Gauss Chron ending 2.48 million years ago. This age is, accordingly, also that of the ash beds in the Birch Creek marsh beds and of the fauna, 5 miles to the southeast.

We therefore revise Neville's identification of the polarity chrons by virtue of evidence unavailable to her: the normal magnetozone at the base of the Multi-ash section is the younger part of the Gauss Chron, and the overlying long section of reversely polarized lake beds (with a "typical" diatom flora to its very top) represents the early part of the Matuyama Chron. With the possible exception of the lake beds of unknown age underlying the Froman Ferry faunal succession, the Glenns Ferry lake beds in the Multi-ash (Oreana) area are the youngest known, rather than the oldest, as suggested by Neville (1981). The biochronologic suggestion of the age of the Multi-ash section (Neville, 1981, p. 141; also Conrad, 1980, p. 109) does not contradict this correlation because of more recently gained information about *Hypolagus gidleyi* from the Froman Ferry fauna. The diatoms in the lake beds of the Multi-ash polarity section, and the age of the ashes where present in the Birch Creek fauna, do contradict an age as old as the Gilbert Chron.

CORRELATION OF YOUNGEST LAKE BEDS

About 4.3 miles to the southeast of the Multi-ash paleomagnetic section, on the divide between Birch Creek and Castle Creek, the marsh beds of Birch Creek (about 2.4 Ma old and correlative to those of Poison Creek 10 to 15 miles farther to the southeast, as will be discussed on p. 62) grade to the northwest into the Glenns Ferry lake beds (fig. 12). Their horizon is not recognizable in the lake beds of the Multi-ash section except as a continuation of the associated ash beds for which the paleomagnetic section was named. Fine-grained fluvial deposits above the marsh beds near Birch Creek overlie the lake beds beyond the limit of marsh deposits in the Castle Creek area, but 4 miles farther northwest, at the Multi-ash paleomagnetic section, 125 feet of lake beds separate the fluvial deposits from the ash beds that correlate with the Birch Creek marsh deposits. Fluvial deposits of either the Glenns Ferry Formation or the younger Bruneau Formation overlie the lake beds throughout the Oreana area to the north.

The overlying 125 feet of lake beds in the reversely polarized part of the Multi-ash section can represent only the older part of the Matuyama Reversed-polarity Chron, and this correlation strongly suggests that the younger parts of the lake beds at the section are equivalent in age to part of the largely fluvial deposits of the Jackass Butte section of the Grand View area, estimated to be from about 2.3 to 2.0 million years old. The normal events of the Réunion Subchron were not found in the Multi-ash section, however, and the youngest lake beds of the Multi-ash section may be younger, or older, than 2.14 million years.

It is between 100 and 125 feet from the lowest fossils found at the base of Jackass Butte up to the first brief normal event of the Réunion (2.14–2.12 Ma). The end of the Gauss Chron, the multi-ashes, and a Birch-Creek-type fauna are not found at Jackass Butte, but 7.5 miles northwest of Jackass Butte, at an unnamed butte about a mile northwest of Wild Horse Butte, the end of the Gauss Chron was found about halfway up the section of sediments (Neville, 1981, p. 137–138; this report, p. 63). In 1979 G.S. Conrad (oral commun.) had found *Mictomys vetus*, *Mimomys parvus*, and *Ondatra* sp. at this section; the *Ondatra* is small, suggesting the Birch Creek fauna. The highest normal polarity of the Gauss Chron on this unnamed butte is at about the same elevation as the oldest of the Réunion events on Jackass Butte; obviously the two localities are separated by structure. Note, however, that the same time span as the Multi-ash polarity section, but no lacustrine deposits, occurs at "unnamed butte" (p. 63); the Glenns Ferry lake lay entirely west of this area during the time of Blancan V faunas.

A striking difference between the diatom flora of the Glenns Ferry lake and those of the lakes in which the Bruneau Formation was deposited is seen at the top of the Multi-ash polarity section, as well as at many other locations, and suggests that deposition of the Glenns Ferry lake had ended, in this area, well before the Pleistocene Bruneau beds were deposited. This is easily believed in most areas, where the youngest Glenns Ferry lake beds are of Pliocene age and the disconformably overlying Bruneau lake beds are of Pleistocene age. Whether this change in diatom flora is an ecologic or a time signal, or a combination of the two, is not known.

The youngest dated diatom floras of the Glenns Ferry lake beds are in the Multi-ash section and may or may not be as young as 2.14 million years; the lake beds beneath the Froman Ferry marsh beds contain the same "typical" diatom flora and could be this old or as young as the Olduvai Normal-polarity Subchron (<1.67 million years), to judge from the age of the overlying Froman Ferry faunal succession. As much as 470,000+ years may separate these two time possibilities.

The diatom flora of the Bruneau Formation at Guffey Butte is like that of the formation elsewhere, and like that of modern lakes in the Pacific Northwest (J.P. Bradbury, oral commun., 1994); and it lived at the time that the Pickles Butte lava dammed the Snake River (1.5 Ma) to form this Bruneau lake. The Bruneau diatom flora is thus little more than 170,000 years younger than the youngest possible age of the Glenns Ferry lake beds in the Froman Ferry area south of Marsing; it is little more than 640,000 years younger than the youngest age of the Glenns Ferry lake beds in the Multi-ash polarity section. Evolution of the Bruneau type of diatom flora in either time span seems out of the question as this extant flora has lived 1.5 million years without change since it existed at Guffey Butte and the "typical" Glenns Ferry lake diatom flora existed at least 1.36 million years before its youngest record in the Multi-ash section—both without significant change. It must be assumed that the Bruneau type of diatom flora existed elsewhere contemporaneous with the "typical" flora of the Glenns Ferry lake. Adam and others (1990) have reported the same diatom floral change, from a "typical" Glenns Ferry flora to a modern Bruneau-like flora in the Tule Lake basin of northern California nearly 3 million years ago.

Apparently the "Bruneau-like" diatom flora has existed with little change for at least the past 3 million years; its entry into the Snake River Plain marks only the end of a long stable Glenns Ferry lake environment and the beginning of a period of short-lived Bruneau lake basins. In contrast, the "typical" Glenns Ferry lake diatom flora may have lived with no change for about 2 million years, but in a single Glenns Ferry lake without interruption and with no basin dislocation (although there was some basin shifting without breaking the continuity of the lake). It seems more probable that the continued existence of the Glenns Ferry lake was the primary cause for the continued existence of the "typical" Glenns Ferry diatom flora, and that its presence in the lake beds beneath the Froman Ferry faunal succession has no bearing on the age of the lake deposits, only on the continuing presence of the lake until the time that the Froman Ferry marsh beds covered the area. Apparently the "typical" diatom flora of the Glenns Ferry lake was, at least in the later history of the lake, a relict flora that survived only because the Glenns Ferry lake persisted, and could not survive the disappearance of this lake. It was replaced, in later, short-lived lakes, by the Bruneau Formation type of diatom flora that can survive in relatively temporary lakes and that lives in such lakes today.

Although the presence of the "typical" Glenns Ferry lake diatom flora in the lake beds beneath the Froman Ferry faunal succession suggests that these lake beds can be no younger than their youngest dated record in the Multi-ash polarity section, its age significance is unclear. The alternate assumption, that no hiatus exists between the Froman Ferry marsh beds and the underlying lake beds of the Glenns Ferry Formation, is based upon four separate considerations:

1. The essential continuity of deposition between lake beds and overlying marsh beds at earlier times in the history of the Glenns Ferry lake makes a similar history seem more likely in the Froman Ferry area.

2. The contrast between the cool, cloudy and wet summers indicated by the Froman Ferry fauna (p. 29, 32–33) and the sage-steppe pollen flora of the Bruneau Formation (p. 15) does not favor contemporaneity—the immigrant *Phenacomys gryci* and the endemic *Mictomys vetus* suggest a climate other than the dry, moderately hot summers of a sage-steppe, implied by the pollen known from the Bruneau Formation. But no climatically informative fossil mammals have been found in the Bruneau.

3. It is difficult to model a situation in which the Glenns Ferry lake could disappear for 470,000 years with no record of desiccation, erosion, or subsequent marsh or fluvial deposition, and then be covered by marsh deposition. When the lake finally disappeared, it seems to have done so because a sufficient drain had been cut; but it was not at first cut so deeply that marsh beds could not form for perhaps another 100,000 years in the Froman Ferry area.

4. Although the youngest dated record of the "typical" Glenns Ferry diatom flora is about 2.14 million years, its survival, at the scale of time here discussed, seems not to depend so much on time as on constancy of its habitat. The distinctly different Bruneau diatom flora appears to overlap in time the "typical" Glenns Ferry flora in records outside the Snake River Plain, and it appears too quickly after the draining of the Glenns Ferry lake to be a result of evolving lake diatom floras.

SNAKE RIVER AND THE GLENNS FERRY FORMATION

The history of the Glenns Ferry lake began about 4.0 million years ago with the diversion of the Snake River, most likely near Twin Falls, Idaho, into the rift valley that now contains the western Snake River Plain. It ended, as we assume the age of the youngest lake beds, about 1.67 million years ago when deepening of Hells Canyon had become great enough to drain the last of the lake. The Froman Ferry marshes then formed on top of these lake beds until they too were drained. This interpretation involves much other evidence within and beyond the western Snake River Plain, and a synthesis of the history of the Glenns Ferry lake will put the Froman Ferry faunal succession into this historical scenario. This synthesis contains new information.

The boundaries of the State of Idaho appear to have been drawn to include as much of the Snake River as possible (fig. 1). Beginning at the Continental Divide in the Centennial Mountains at the northeast corner of southern Idaho, and in Yellowstone Park in adjacent northwest Wyoming, the Snake River drainage area incorporates all Pacific drainage until, two-thirds of the way down the Idaho-Wyoming border, the river and its drainage basin pass entirely into Idaho. South of this point westward drainage from the Continental Divide flows into the Great Salt Lake basin, and, farther south, into the Colorado River.

The Idaho and Wyoming headwaters of the Snake River join upstream from the city of Idaho Falls, still in the northeast quarter of the southern part of the State (fig. 1). The combined headwaters flow southwest from there through the eastern Snake River Plain to Twin Falls. Here, marching to a different drum, the Snake River abruptly turns about 90° and flows northwest, down the graben now filled by the western Snake River Plain, past the Froman Ferry area, and to the Idaho-Oregon State line west of Boise (fig. 1).

At the Oregon State line, the river turns again and flows north for about 200 miles, the longest northward course of any river in the United States. Along this northward route the Snake River first forms the Idaho-Oregon State boundary, and then the Idaho-Washington boundary. It turns west at Lewiston, Idaho, to join the Columbia River at Pasco, Washington (figs. 1 and 13). At the point where the Snake River leaves Idaho, it is 320 miles north of its most southerly point, near Twin Falls, and nearly 160 miles north of its headwaters in Yellowstone Park.

Over most of its course along the Idaho-Oregon State line, the Snake River flows through Hells Canyon, up to 1.5 miles deep (half again deeper than the Grand Canyon of Arizona). Hells Canyon cuts through the highland between the Salmon River Mountains of central Idaho and the Wallowa Mountains of northeastern Oregon (fig. 13). The Glenns Ferry Formation of the western Snake River Plain laps against these highlands, and its deposition was halted when Hells Canyon was cut to a level below the base level of the western Snake River Plain, beginning erosion of the Glenns Ferry Formation at its northwestern limit of deposition, the Froman Ferry area, and ending its deposition.

GLENNS FERRY FORMATION

The Glenns Ferry Formation was named by Malde and Powers (1962), and was at first thought to have formed in a large lake filling the entire basin of the western Snake River Plain. Earlier, Cope (1883) had called the lake Lake Idaho, and the deposits that formed in it the Idaho Formation. As originally conceived by Cope, Lake Idaho may have included more than just the lake in which the Glenns Ferry Formation was deposited, although he published no indication that he was aware of older lake beds. Although Cope was not specific about geographic extent, his information was based upon fossil fish collected at Castle Creek (fig. 13; Malde and Powers, 1962, p. 1201), 10 miles northwest of Grand View and unquestionably within the Glenns Ferry Formation, as used by Malde and Powers.

Lindgren (1898) believed that Cope intended the names "Idaho formation" and "Lake Idaho" to apply essentially to the Pliocene deposits that Malde and Powers later called the Glenns Ferry Formation (and the Glenns Ferry lake). He therefore put older (Miocene) lake and stream deposits above the Columbia River Basalt Group and beneath what is now called the Glenns Ferry Formation in his Payette Formation. The Payette Formation is present within, and deformed with, the highlands of central Idaho.

On the misconception that Lindgren's Payette Formation lay entirely within and beneath the Columbia River Basalt Group, Kirkham (1931) redefined Cope's Idaho Formation to include all deposits above the Columbia River Basalt Group, including, actually, both Cope's Idaho Formation and Lindgren's Payette Formation, although Kirkham thought that his usage separated the Idaho Formation from the Payette. Kirkham's error may have resulted, in part, from the erroneous correlation of some younger basalt units to the Columbia River Basalt Group, but he was primarily misled by earlier errors published by Buwalda (1923) who, in naming the Poison Creek Formation, stated that this formation contained Pliocene mammals (as they had come to be correlated by vertebrate paleontologists at this time) and overlay the "Payette" Formation of Miocene age (as originally and correctly dated by Lindgren). Earlier Miocene sediments are interbedded with the volcanic units of the Columbia River Basalt Group, but these are much older than what Lindgren called the Payette Formation.

This statement of Buwalda's was based upon the thinking of Merriam (1917, p. 432) who stated that "The Idaho formation is not yet satisfactorily separated from the Payette Eocene or Miocene, and from a Miocene or Pliocene stage which may intervene between the Payette and the Idaho," a statement that clearly reflected the uncertainty of mammalian biochronology in the region of the western Snake River Plain at that time, as well as the chronostratigraphic significance of the few fossils known from these units. Actually, all fossil mammals that appear to have come from the Payette Formation, and those that clearly do, are late Miocene in age; the Payette Formation probably includes the Poison Creek fauna, in its older part, now known to be of early late Miocene age. These faunas contain mammals that were all called early Pliocene by vertebrate paleontologists up until about 1970, although paleobotanical records from the Payette were placed in the Miocene.

Since about 1970, and certainly since Tedford and others (1987), these faunas have been recognized as being of late Miocene age; the recognition has been strongly reinforced by radiometric dates that became generally available in 1964 (Evernden and others, 1964). As the Miocene and Pliocene are now defined, the Payette Formation of Lindgren is of late Miocene age, older than the Pliocene Glenns Ferry Formation of Malde and Powers (equals Idaho Formation of Cope) and much younger than the Columbia River Basalt Group of middle Miocene age.

Malde and Powers (1962) were caught in the middle of this series of conflicting age claims and also thought that Cope applied his term (Idaho Formation) to more than the Glenns Ferry Formation, despite their statement that what Cope originally referred to was deposits from Castle Creek northwest of Grand View; and they thought that the Payette, because it was Miocene, must underlie the Pliocene Poison Creek deposits. They followed Kirkham (1931), Buwalda (1923), Merriam (1918), and Russell (1902), but not Lindgren (1898 and 1900), by including in Cope's Pliocene Idaho Formation the Miocene Chalk Hills and Poison Creek Formations—deposits that had been included in the concept of the Payette Formation by Lindgren.

Malde and Powers (1962) elevated Cope's Idaho Formation to the Idaho Group, which included the Poison Creek and Chalk Hills Formations (±Payette Formation), the Glenns Ferry Formation (± the Idaho Formation), and the newly named units Tuana Gravel, Bruneau Formation, and Black Mesa Gravel. Thus defined, the Idaho Group spanned at least the upper Miocene, the Pliocene, and the lower Pleistocene. But, at the time that they did this, all of these units were called Pliocene by vertebrate paleontologists. The group also includes the Banbury Basalt (between the Poison Creek and the Chalk Hills Formations).

As a result of this varied usage of geologic names, considerable confusion has developed about the stratigraphic contents of Lindgren's Payette Formation, and Cope's Idaho Formation. The name Glenns Ferry Formation has become firmly entrenched in usage as a replacement for Cope's Idaho Formation, but no suitable name is in general use that would replace the Payette Formation, and this name is seldom used in recent studies. The names "Poison Creek Formation," "Sucker (or Succor) Creek Formation," "Chalk Hills Formation" (equals the "Chalk Butte Formation" of Corcoran and others, 1962 and "Deer Butte Formation" of Kittleman and others, 1965), "Drip Spring Formation," and

"Bully Creek Formation" have sprung up in the place of parts of the Payette Formation of Lindgren, but each has a different meaning not matching the Payette Formation as defined by Lindgren. New names are still being proposed (see Othberg and Stanford, 1992, under "Sand and mudstone of stream and lake sediments"). Of these many names, only the unit called Chalk Hills Formation is exposed in the Snake River Plain, and it underlies the Glenns Ferry Formation. The Poison Creek Formation is exposed in the margins of the mountains to the southwest of the Snake River Plain. There are complicating duplications in names: the Poison Creek fauna of the Glenns Ferry Formation is not related to the Poison Creek Formation, and the Chalk Hills faunas of the Froman Ferry area have nothing to do with the Chalk Hills Formation. "Chalk" and "Poison" seem to be common features of the western Snake River Plain.

An intervening unit between the Glenns Ferry Formation and the underlying Chalk Hills Formation, a locally oolitic rusty sandstone, has been considered the basal unit of the Glenns Ferry Formation. (See p. 49 and following.) In terms of its relative thinness, different distribution, greater tectonic disturbance, and different lacustrine environment (Swirydczuk and others, 1979) than the Glenns Ferry Formation, this locally oolitic, rusty sand unit that Malde and Powers (1962) considered the basal member of the Glenns Ferry Formation is here considered a separate and older depositional sequence unconformably underlying the Glenns Ferry Formation. It also is unconformable on the still older Chalk Hills Formation and has a different magnetic polarity (Conrad, 1980, p. 76–77; Swirydczuk and others, 1979), and thus appears to be equally distinct from this unit. Thus the locally oolitic, rusty-stained sandstone seems, to the authors, to deserve separate formational recognition. It is a very extensive unit, separating the Chalk Hills and Glenns Ferry Formations, for over 110 miles along the entire southwest side of the Snake River Plain from southwest of the town of Bruneau to the northern limit of Moores Hollow, north of Vale and Ontario, Oregon.

The Chalk Hills Formation may be the lacustrine equivalent of the Payette Formation in the Moores Hollow area, an area that Lindgren included in the type definition of the Payette. Both formations are more severely deformed by tectonic activity than the Glenns Ferry Formation to the south. We are not aware of any published identification of exposures of the oolitic unit in the Moores Hollow area, although a rusty, coarse sand deposit, rich in fossil fish and exposed in a quarry west of Interstate 84 on the crest of the divide between Moores Hollow and Farewell Bend of the Snake River, appears to represent it. About 35 miles of little exposure or cover separates the Moores Hollow exposures from those of the Chalk Hills Formation and the overlying oolitic unit south of Marsing. Kimmel (1975) has described the fossil fish from these small exposures of the Chalk Hills (referred to the Deer Butte Formation) near Adrian, Oregon, and within this area of few exposures or cover.

Malde and Powers identified as "floodplain" deposits many marsh deposits (flat-bedded, lighter colored silt containing prominent diatomaceous beds and some ash) and stream deposits (crossbedded, browner colored, fine to pebbly sand and conglomerate). These "floodplain" deposits overlie the Glenns Ferry lake beds, and Malde and Powers included them in the Glenns Ferry Formation. In these marsh and stream deposits, many fossil mammals have been found, and they form the principal basis for the age assignment of the formation.

Although the three-dimensional, spatial relationships of lake and "floodplain" deposits have been difficult to recognize (Malde, 1972), a general picture has emerged that suggests that the Snake River Plain graben had (1) a deeper trench at the east end of the northeast side of the Snake River Plain (King Hill area) in which the lake first formed, followed by (2) progressive filling of the trench (by both sediment and lava) and displacement of the lake to the west across the Snake River basin; (3) deposition of younger lake beds against the basement rocks forming the west side of the Snake River Plain (the locally oolitic rusty sandstone beds overlying the Chalk Hills Formation), with (4) progressive filling, in a downstream direction, of the lacustrine basin to the west and northwest toward Hells Canyon; and (5) low-gradient stream sediments, brought into the graben by the Snake River and other drainages. These covered the lake and marsh beds as the lake basin filled.

Marsh beds seem to have accumulated in areas with no great stream inflow, and some persisted for nearly 170,000 years, as in the Froman Ferry area. All these depositional facies are included in the Glenns Ferry Formation. Marsh and fluvial deposition was followed by incision (by the Snake and other rivers) into the Glenns Ferry Formation. The entire sequence of deposition and erosion was a result of both filling of the structural basin and lowering of its base level at the outlet, Hells Canyon.

With canyon cutting of the Glenns Ferry Formation, gravel deposits of higher gradient (or lower silt and sand load) streams, derived both from northeastern and southwestern sources, blanketed parts of the low-gradient stream deposits. This "higher gradient" stream action progressed northwestward down the length of the Snake River Plain as the lake withdrew in the same direction. The oldest covering gravels are in the southeast end of the western Snake River Plain, and Malde (1991) has followed ancient, filled canyons from the Hagerman area, which was the upstream limit of the lake about 3.9 million years ago, to Jackass Butte, near Grand View, which was near the upstream limit of the lake about 2.1 million years ago. He followed one canyon northward nearly to the Nampa area. Upstream from the Grand View area the covering gravels, as well as the modern Snake River, have a steeper gradient than exists downstream from Grand View to the Froman Ferry area.

The depositional filling of the basin of the western Snake River Plain by the Glenns Ferry Formation took place over a long period of time, roughly 2.4 million years. It is inconceivable that a permanent Glenns Ferry lake could exist for 2.4 million years as an enclosed basin, having no outlet or through-flowing waters, without becoming saline. Yet evaporates are not conspicuous in any part of the Glenns Ferry lake deposits (they are more common in the Miocene lake deposits of the Chalk Hills Formation, underlying the Glenns Ferry Formation).

The biota of the Glenns Ferry lake beds also indicates fresh water throughout its existence. Because of the long life of the Glenns Ferry lake, most lacustrine biota developed specialized, endemic forms, particularly noticeable in the fish (Smith, 1975), mollusks (Taylor, 1966), ostracodes (Forester, 1991), and diatoms (Bradbury and Krebs, 1982). Moderately saline faunas and floras of the Glenns Ferry Formation have been found only in deposits of small lakes, marginal to Glenns Ferry lake and separated from its influence, so that evaporation could increase their salinity without dilution by waters of the main lake or inflowing streams.

The lack of abnormally saline deposits in the Glenns Ferry lake beds and the varied fauna and flora of the Glenns Ferry lake, both indicating normal salinity, certainly also indicate through-flowing waters during the entire existence of the lake (Middleton and others, 1985). A drain thus appears to have been present essentially from the beginning of the Glenns Ferry lake, perhaps 3.9 million years ago, but with a higher sill at the lake outlet than now exists, thus containing the lake. The basin is still entirely enclosed today and would still contain a lake except for the Hells Canyon drain.

Before, during, and after the Glenns Ferry lake, basaltic volcanic activity was prominent for many miles upstream from the lake (in the eastern Snake River Plain) and was also present along the south and north sides of the western Snake River Plain near the head of the Glenns Ferry lake. About 2 million years ago volcanic vents began developing along the axial part of the Snake River basin and became prominent features of the area during the late history of the lake and later (Malde, 1991, fig. 8).

GLENNS FERRY FORMATION NEAR HAGERMAN AND KING HILL

The oldest known parts of the Glenns Ferry Formation are lake beds in the Hagerman and King Hill region (figs. 1 and 13). At Hagerman, 40 miles down the Snake River from Twin Falls (fig. 13), the formation is nearly as old as 3.9 million years (older part of the Cochiti event of the Gilbert Chron; Neville and others, 1979). Hagerman is close to the east end of the northeast side of the Snake River Plain (and the Glenns Ferry lake). In the King Hill area, 25 miles northwest of Hagerman, the Clover Creek lava is believed to lie within the oldest known part of the Glenns Ferry Formation (Malde, 1972) and to be older than the Cochiti event (Neville and others, 1979; more than 3.9 Ma). Following the discussion by Neville and others (1979), Conrad (1980), and Repenning (1987), the Hagerman mammal faunas range in age from about 3.6 to 3.3 Ma in age. Although considered as being of early Blancan age in many reports (and late, in others), the Hagerman faunas lived midway through the Blancan mammal age of the United States (Blancan is 4.8 to 1.6 Ma old in the Pacific Faunal Region; see section on mammal ages, p. 10). Throughout the western Snake River Plain the youngest replacement of lake beds by overlying marsh or stream deposits is in the Froman Ferry area, and these are about 1.7 million years younger than the youngest marsh deposits at Hagerman and 2.1 million years younger than the oldest.

Both nonlacustrine and lacustrine deposits at Hagerman are included in the Glenns Ferry Formation by Malde and Powers (1962). The higher and major part of the Hagerman section consists of stream and marsh deposits (deltaic, with fossil mammals). Although rarely found in large lake deposits (and then mostly in marginal facies), mammal remains are relatively common in the paludal and fluvial deposits of the Glenns Ferry Formation. Many individual fossil localities in the bluffs across the Snake River from the town of Hagerman have been combined under the name "Hagerman fauna"; all are in the marsh and stream deposits.

Glenns Ferry lake deposits form the lowest part of the bluffs opposite Hagerman, near the pump station that lifts irrigation water from the Snake River 528 feet to the top of the bluffs. The lake beds are more extensive downstream (northwest) near the towns of Glenns Ferry and King Hill, where only lake beds represent the time of the Hagerman delta; here the lake beds extend well into the Gauss Normal-polarity Chron and, in part, are younger than any part of the Glenns Ferry Formation exposed near Hagerman (Neville and others, 1979).

Deposits in the high bluff on the west side of the Snake River across from Weiser, Idaho, are older, but are not well dated and appear to have no relationship to the Glenns Ferry Formation. They, and adjacent Miocene fluvial deposits, were included in Lindgren's (1898) Payette Formation. The lake beds contain a diatom flora that is different than any known from the Glenns Ferry lake deposits and that is known elsewhere only in the subsurface at the Idaho National Engineering Laboratory (INEL, fig. 1) in the eastern Snake River Plain north of Pocatello, and in the Klamath Lake basins of south-central Oregon and adjacent California. In the INEL core this diatom flora is of a greater age than floras similar to those known from the Glenns

Ferry lake, but younger than diatom floras that are also known from the Chalk Hills Formation (J.P. Bradbury, oral commun., 1992).

Deposits at Hagerman are essentially the easternmost deposits of the formation, and are at the head of the Glenns Ferry lake basin. To the east (upstream), deposits of the Glenns Ferry Formation are covered by, and interbedded with, extensive basalt flows. A test hole drilled north of Wendell, Idaho, less than 15 miles east of Hagerman (where the formation is perhaps 600 feet thick), shows that the Glenns Ferry Formation rapidly pinches out between lava flows (Whitehead and Lindholm, 1985; Malde, 1991).

Deposits of approximate Glenns Ferry age are known farther upstream only from drilled cores, such as at INEL; these are interbedded with lava flows and are presumed to represent deposition in local basins, rather than in the Glenns Ferry lake. Up the Snake River from Twin Falls there may have been, at times, a string of lakes, constrained by lava flows, of which the Glenns Ferry lake was only the most downstream and largest.

Because of the relationship of the Hagerman section to the apparent upstream limit of the Glenns Ferry lake basin, and because the marsh and stream deposits making up most of the Glenns Ferry section at Hagerman are, by far, the oldest nonlacustrine deposits of the formation and are restricted to a relatively small area near Hagerman, those deposits are believed to be deltaic and to have formed at the mouth of the ancient Snake River where it entered the Glenns Ferry lake. The deltaic environment was local: lake beds in the King Hill area, 25 miles northwest of Hagerman, are of an equal age as well as both older and younger than the Hagerman section, but they contain almost no marsh and stream deposits.

Insofar as published dates, based upon fossil mammals, are concerned, there seems to be no record of deposition between perhaps 8 and 4 million years ago in the western Snake River Plain. The sequence of diatom floras in the INEL cores suggests that the beds at Weiser (included in the type definition of the Payette Formation) may have been deposited during this hiatus. Some of the fission-track dates cited by Kimmel (1982, table 1) suggest a younger age for these pre-Glenns Ferry deposits. It is beyond our interests in the Froman Ferry faunal succession to try to clarify these uncertainties regarding the pre-Glenns Ferry deposits.

Sediments older than the Glenns Ferry Formation are exposed in Clover Creek, upstream from the oldest known Glenns Ferry Formation, at Strout Claim (the usual spelling "Stroud" is incorrect according to Mr. LeRoy Strout, of Gooding, Idaho). They are diatomite and contain early Hemphillian mammals; interbedded ash falls have been radiometrically dated at 10 Ma (Evernden and others, 1964; not corrected for revised decay constants), although the fossil mammals suggest an age of 9 million years or somewhat less. The Strout Claim diatomite may represent part of the Miocene Chalk Hills Formation, which underlies the Glenns Ferry Formation in most areas, but the deposits are not demonstrably the same unit because of tectonic scrambling and basalt cover.

The diatoms at the base of the Hagerman section suggest a smaller lake than that indicated for most of the Glenns Ferry lake beds (J.P. Bradbury, oral commun., 1992), and the associated ostracodes include few endemic forms, suggesting a lake with a briefer history than the later Glenns Ferry lake (Forester, 1991). Neither the ostracodes nor the diatoms resemble the fauna and flora of later stages of the Glenns Ferry lake, including those from the Multi-ash paleomagnetic section south of Oreana (p. 49–50). Thus the lake beds at Hagerman record different conditions early in the existence of the Glenns Ferry lake, than when the lake reached maximum size. This was roughly the time of the Cochiti event of the Gilbert Normal-polarity Chron.

The ostracodes and diatoms in the deltaic deposits of the Hagerman section differ from those in the lake beds at the base of this section ("oldest" flora) and from the temporally equivalent Glenns Ferry lake ("typical" flora) in other areas as the King Hill and Bruneau areas. The ostracodes and diatoms of the deltaic deposits reflect changing water levels, salinity, and temperatures in locations sufficiently isolated from the Glenns Ferry lake to reflect more varied environments (Forester, 1991).

As in all deltas, the sediments represent interbedded marsh, stream, and tongues of lacustrine deposits (marking high water stands). The indicated fluctuating environments agree with the deltaic origin suggested by the geographic restriction of these deposits and their proximity to the head of the Glenns Ferry lake and mouth of the ancestral Snake River. Although the lake beds in younger parts of the Glenns Ferry Formation have a unique and endemic fauna and "typical" flora, the associated marsh deposits contain a conventional biota little different than that found in similar environments today (Forester, 1991; Bradbury and Krebs, 1982).

To judge from the data in Neville and others (1979), the change from the small lake deposits at the base of the Hagerman section to deltaic marsh deposits was about 23 feet higher in the section than the end of the Cochiti event of the Gilbert Chron; this is interpolated to have been about 3.6 Ma ago. The oldest mammalian fauna was found as low as the very base of the delta beds. These are by far the oldest mammal faunas and marsh deposits in the Glenns Ferry Formation.

Although the oldest lake beds (about 3.8 Ma) in the Hagerman section contain evidence (diatoms and ostracodes) of only a small and juvenile lake, by the time of the youngest fluvial-deltaic deposits of the Hagerman section (Horse Quarry and younger, possibly as young as 3.2 Ma), the Glenns Ferry lake had filled most of the Snake

River graben and extended from the King Hill area to beyond Bruneau, and possibly to the Froman Ferry area. This is indicated by the uniformly present "typical" diatom flora in the lake beds of these areas downstream from Hagerman and by the development of an endemic ostracode fauna in the Glenns Ferry lake. Once the basin was filled to the preexisting sill level, drainage began. Downcutting of the sill then continued at a rate greater than the prior headwater drainage that had cut the embryonic Hells Canyon to sill depth; for then the headwaters of the Hells Canyon tributary to the Columbia River had the Snake River flowing down it.

LAKE, MARSH, AND STREAM FACIES, LONGITUDINAL RELATIONSHIPS

As lake level dropped, nonlacustrine deposits, usually called "floodplain" deposits, covered the exposed Glenns Ferry lake deposits. In the main channels of the Snake and other rivers, thick beds of crossbedded fine to medium sand accumulated. Between stream mouths marsh deposits were laid down, and these grade laterally into stream deposits or lake beds. Ash falls are common in the flat-bedded and finer grained marsh deposits, as the lack of significant currents in this environment did not disperse the tephra. Whitish diatom-rich beds are also common in the marsh beds, but they are less concentrated and widely dispersed in the lake deposits. As the lake withdrew, these marsh and fine-grained river deposits progressively extended to the northwest, down the Snake River graben, filling the basin with the locally youngest Glenns Ferry Formation.

Continued filling of the basin and drainage of the lake extended the marsh and low-energy fluvial cover downstream to the Froman Ferry area. Although this combination of filling and draining lasted 2 million years (earliest Hagerman delta deposits to latest Froman Ferry marsh beds), after the time of the marshes in the vicinity of Birch Creek (2.4 Ma; fig. 12), its history is not well recorded in existing exposures. Northwest of Oreana the belt of Glenns Ferry outcrop narrows between the Snake River and the southwest margin of the Snake River graben and consists only of fluvial deposits; it would seem that a major drainage from the west (across the modern Owyhee Mountains) entered the basin in this area. In the vicinity of Guffey Butte, along the Snake River north of Murphy (fig. 12), only a little of the lake beds are exposed beneath fluvial deposits, and younger lake beds, related to later canyon damming, overlie the fluvial deposits; these younger lake beds are included in the Bruneau Formation (Malde, 1985, p. 45–46) and have the distinctly different diatom flora (J.P. Bradbury, oral commun., 1993).

As mentioned, the oldest deposits of the Glenns Ferry Formation are both lacustrine (perhaps 4 Ma) and deltaic (about 3.6 Ma) in the King Hill–Hagerman area (fig. 1). At the Sand Point locality (Hibbard, 1959; Hibbard and Zakrzewski, 1967), on the south side of the Snake River opposite the town of Hammett (fig. 12), the fossiliferous marsh deposits apparently represent the margin of the delta about 3 million years ago (Repenning, 1987; Conrad, 1980). The marsh beds change to lake beds in the outcrop and are about the age of the youngest deltaic deposits at Hagerman (C. Neville, oral commun., 1978). They are also the same age as part of the lacustrine deposits in the King Hill area, 17 miles to the east.

Thirty to thirty-five miles west of Sand Point, on the east and west sides of Shoofly Creek (10 miles south of Grand View; fig. 12), lacustrine deposition persisted until 2.4 million years ago before the lake beds were covered by marsh and fluvial deposits. Lacustrine deposits as old as the older deltaic part of the Hagerman section are present some 17 miles closer to Sand Point in the Bruneau area (Neville and others, 1979, fig. 8) to the east of these marsh beds along Shoofly Creek. About 9 miles to the northwest of Bruneau, at Ninefoot Rapids (about 2.56 Ma), and about the same distance to the east, at Flatiron Butte (perhaps 2.6 Ma), deposits are deltaic and fluvial.

Eleven miles northwest of Shoofly Creek, the same marsh beds as at Shoofly Creek are present along Birch Creek, from about 13 to 6 miles west of Grand View (fig. 12; p. 49–50, 61 and following). Northwest of this point, from the vicinity of Oreana essentially to the Walters Ferry area, 22 miles farther northwest (fig. 12), marsh beds are not present and only fluvial deposits overlie the Glenns Ferry lake beds; at present these fluvial sediments have little age control. In this area lake beds are increasingly confined to the area close to the modern Snake River. In the Guffey Butte area north of Murphy, Glenns Ferry fluvial deposits lie on Glenns Ferry lake beds in the canyon of the Snake River and underlie Bruneau Formation lacustrine deposits in adjacent buttes. A major concern in correlating across this distance from Guffey Butte to Oreana is the possible presence of fluvial deposits correlative to the lake beds of the younger Bruneau Formation lying on top of similar beds of the Glenns Ferry Formation. Just north of Guffey Butte, the canyon of the Snake River opens out and Glenns Ferry lake beds are exposed over a somewhat wider area.

Between Walters Ferry and the Froman Ferry area there are no deposits of the Glenns Ferry Formation on the southwest side of the Snake River, and the northeast side of the river is marked by a high, lava-capped scarp composed of Glenns Ferry lake beds. At the north end of this scarp, the Glenns Ferry lake beds again are present on the west side of the Snake River, opposite the Froman Ferry area. Wherever these lake beds between Guffey Butte and the

Froman Ferry area have been sampled, they contain the "typical" diatom flora of the Glenns Ferry Formation.

Thus there are no marsh deposits for about 46 miles between Birch Creek and Froman Ferry, and only stream deposits overlie the Glenns Ferry lake beds. About 700,000 years also separate these two series of marsh deposits.

These sites of transition from lacustrine to marsh environments within the Glenns Ferry Formation, beginning 3.6 million years ago in the Hagerman area, advancing to Sand Point about 3.1 million years ago, to Shoofly and Birch Creeks 2.4 million years ago, and to Froman Ferry about 1.6 million years ago, rather clearly indicate a northwestward advance of nonlacustrine deposition down the western Snake River Plain. They also suggest that the mouth of the Snake River at the head of the lake was first near Hagerman and advanced, with the nonlacustrine deposits, to the foot of the lake at Hells Canyon. Fossil canyons, traced by Malde (1991), indicate that as the mouth of the Snake River advanced to the northwest down the Snake River Plain, the upstream part of the river incised the older deposits of the Glenns Ferry Formation.

Individual units of marsh deposits extend only short distances to the northwest, "downstream" toward the then-existing lake and the lake outlet; they are not continuous in this direction but are replaced, down-basin, by lake beds, as between Birch Creek and the Multi-ash paleomagnetic section (p. 50–51). Transverse to the axis of the basin and upsection upstream, marsh deposits are replaced by fluvial deposits. It seems probable that the development of marsh deposits was localized and that all grade into low-energy stream deposits where stream flow into the Glenns Ferry lake was prominent. Because of their proximity to the lake, the marsh deposits show no excessive salinity, although small-lake deposits that are removed from the Glenns Ferry lake do contain saline organisms, as will be discussed. Each of these different environments, large lake, marsh, and small lake or pond, has its own distinctive diatom flora, making depositional interpretations easily determinable.

Although the work, so far, has been of a reconnaissance nature, J.P. Bradbury has established a rough sequence of the lacustrine diatoms in the Glenns Ferry lake beds. In summary, this "sequence" is: (1) an "oldest" flora (about 3.8 Ma) found only at the base of the Hagerman section and associated with the Cochiti event of the Gilbert Chron (but other locations where this flora might be expected, as the oldest beds in the King Hill area, have not been examined); (2) an "intermediate" diatom flora that has been found at the base of the lake beds in areas where it was transgressing against the "basement," as west of Bruneau on top of the locally oolitic rusty sandstone and in the same position at the base of the lake beds at Elephant Butte in the Marsing area (fig. 2); and (3) a "typical" flora that has been found in many exposures (possibly older than 3.4 Ma in the Bruneau area, as young as 2.2 Ma in the Oreana area, and assumed to be as young as 1.67 Ma in the Froman Ferry area (p. 51, 52). This flora has been found about 200 feet stratigraphically below the 2.4-million-year-old marsh beds at Birch Creek and Poison Creek (fig. 12) and more than 100 feet above the Gauss Chron in the perhaps 2.1-million-year-old top of the Multi-ash paleomagnetic section south of Oreana (p. 51). It has not been looked for in deposits older than the Gauss Chron (>3.4 Ma) but is suspected to be that old. In the Froman Ferry area the flora occurs in the lake beds, underlying the marsh beds of less than 1.67 million years age, 2.5 miles south of Marsing on the west side of the Snake River, 7 miles southeast of Marsing in the bluffs along the east side of the river, and in a test hole drilled through the marsh beds to the lake beds in the Cucumber area of the Froman Ferry fossil localities.

In many areas, such as high in the King Hill area, and in the Oreana area only the "typical" diatom flora has been found. Although preliminary in nature, the determination of these different diatom floras has assisted in evaluating what part of the lake bed sequence is under consideration; for example, these data speak against Neville's correlation of the Multi-ash paleomagnetic section with the Gilbert Chron, as they provide no indication of the "oldest" diatom flora in the Multi-ash section (p. 50).

The age significance of these floras is questionable. The "oldest," at the base of the Hagerman section, is distinct and indicates a much smaller lake than the others; the "intermediate" flora has been found only at the base of the Glenns Ferry lake beds near the southwest side of the Snake River Plain and may represent an environmental condition associated with the transgressing lake as it was forced across the Snake River graben; and the youngest flora is that "typical" of most outcrops of the Glenns Ferry lake beds and indicates a large and stable lake environment for perhaps as much as 1.8 million years. This has been discussed on page 49, 50.

On the east side of the Snake River, the Glenns Ferry Formation is covered by extensive basalt flows, but Malde (1985 and 1991) reported that the longest fossil canyon dissecting the Glenns Ferry lake beds is identifiable beneath the lava cover in well records in the area to the northeast of Walters Ferry. This indicates the probability of the Glenns Ferry lake having existed mainly to the east of the present Snake River between Murphy and the Froman Ferry area, and being now largely covered by younger basalt flows. Examination of the facies relationships between Oreana and Froman Ferry is accordingly hampered.

In at least some areas the trench along the northeast side of the Snake River graben was filled both by volcanic flows and by the Glenns Ferry Formation. Parts of the trench (evident near Mountain Home, Idaho, and eastward; Lewis and Stone, 1988; Arney and others, 1984) are largely filled with volcanic flows, presumably both older and younger than the Glenns Ferry Formation, a situation comparable to that evident in the Wendell area a short distance east of and upstream from Hagerman.

This persistent lava source area along the northeast side of the Snake River Plain appears to have caused the Snake River to be confined to the central part of the basin in most areas upstream from the Oreana–Sinker Butte area. Its modern route along the western structural margin of the graben below Sinker Butte (fig. 12) appears to be the result of repeated damming by lava flows as described by Malde (1985).

Thus the Snake River basin was filled both from the northeast side by lava flows, and from its head by the Snake River. Possibly, streams entered the lake basin from the southwest side also. Lake bed deposition continued until the outlet of the basin was cut deep enough to drain the lake at its lowest point, in the Froman Ferry area, and Snake River sediment was then carried through the basin and down Hells Canyon.

LAKE, MARSH, AND STREAM FACIES, TRANSVERSE RELATIONSHIPS

The relationships of the depositional facies (lake, marsh, and stream) of the Glenns Ferry Formation across (rather than down) the Snake River Plain are well displayed in the vicinity of the town of Grand View (fig. 12). They represent conditions at the time of the Grand View faunal succession (early Blancan V; 2.56–2.0 Ma). At this time, and in this position within the graben, the marsh deposits first extended across the Snake River Plain from the underlying older rocks along the southwest side of the graben (Chalk Hills Formation and the overlying locally oolitic and rusty sand unit) to the fluvial deposits of the Snake River in the center of the basin. The Snake River was then, and in this area, essentially in its modern position, at the foot of the basaltic ramp flooding the east half of the basin from the northeastern margin of the graben in the vicinity of Mountain Home. By this time basaltic flows had filled the eastern part of the graben in the Grand View area and forced the Snake River to an axial position, and the Glenns Ferry lake to the west half. Farther downstream, the lake seems to have remained in the axial and northeastern part of the basin.

The Grand View faunas are about 130 miles downstream from Twin Falls (fig. 1) and the initial head of the Glenns Ferry lake. At many Grand View localities in the vicinity of the modern Snake River, the underlying Glenns Ferry lake beds, if present, are not exposed. They are exposed beneath Grand View faunas to the east (upstream), south, and west of the town of Bruneau (fig. 12), where the oldest exposed lake beds are older than the Hagerman horse quarry and the Gauss Chron (>3.4 Ma), although lake beds as old as the oldest part of the Hagerman section are not known (Neville and others, 1979, fig. 8, Bruneau section). Glenns Ferry lake beds are also present to the south of Grand View (below the Poison Creek fauna along Shoofly Creek), west (below the Birch Creek fauna), and northwest (below fluvial deposits in the Oreana area). A short distance north of the Bruneau area (toward Mountain Home), Glenns Ferry lacustrine and fluvial deposits disappear. They are replaced by increasing volumes of basaltic flows interbedded with pond deposits that had no connection with the then-existing Snake River. Glenns Ferry fluvial deposits of the ancient Snake River in this area are confined to the area of the modern Snake River, and it appears that the Snake River of that time ran along the east side of the lake basin and at the foot of the basaltic ramp from the Mountain Home area (fig. 12).

Many localities, as old as the Ninefoot Rapids fauna of Conrad (1980; probably about 2.56 Ma old although paleomagnetic control is lacking for this fauna), are here included in the late Pliocene Grand View faunal succession—used in a broad sense. This use of a Grand View faunal succession differs from that of Shotwell (1970), Conrad (1980), and all other previous writers, who included only the Jackass Butte faunas in the Grand View fauna. A minimum of 10 fossiliferous areas are here included in the Grand View faunal succession, each with one to many individual localities. These include Jackass Butte, Birch Creek, Chattin Hill, Black Butte, Castle Butte, Ninefoot Rapids, Oreana area, Poison Creek (Shoofly Creek of Shotwell, 1970), "unnamed butte" (of Conrad, 1980; p. 62–63), and Wild Horse Butte. Discussion of the first three, Chattin Hill, Jackass Butte, and Birch Creek, will suffice to illustrate the Glenns Ferry transverse-basin facies relationships at this time (in a northeast-southwest direction across Snake River Plain, see cross section of fig. 12). Jackass Butte is about 10 miles northwest of the town of Grand View and is the best known area of the Grand View faunal succession (Stirton, 1936).

CHATTIN HILL

Nearly 8 miles southeast of Jackass Butte, near the topographic feature called Chattin Hill 4 miles north and 2–3 miles east of the town of Grand View along the road to Mountain Home, the Glenns Ferry Formation is correlative to some part of the Jackass Butte section (unpublished, fossil mammals collected by H.E. Malde in 1979) and connected to it by nearly continuous exposures. But near Chattin Hill the Glenns Ferry Formation contains basaltic flows, most of which are not present at Jackass Butte. As mentioned, in the Mountain Home area the northeast side of the Snake River Plain graben is largely filled with basaltic flows.

The sediments in the Chattin Hill area appear to have been deposited in small, at least to some degree saline, lakes, possibly dammed behind lava flows; no Glenns Ferry lake, marsh, or fluvial deposits have been recognized. Both diatoms (J.P. Bradbury, oral commun., 1992) and ostracodes (Forester, 1991, as the Grand View locality) indicate varying salinity and temperatures, with no moderating influence from the Glenns Ferry lake or from the ancient Snake River. The diatom flora is characteristic of small ponds and not large lakes. The significant features of the Glenns Ferry Formation in the Chattin Hill area are the interbedded lavas, and pond deposits showing temperature and salinity variability, thus indicating no influence from either the then-existing Snake River or the Glenns Ferry lake.

JACKASS BUTTE

Marsh deposits are present in the middle part of the section at Jackass Butte, northwest of Chattin Hill. From a distance they stand out as white deposits in the middle of the section and, like the Birch Creek fauna, they contain the marsh-inhabiting giant beaver *Procastoroides idahoensis*, which is only found in this middle part of the section at Jackass Butte (Shotwell, 1970; Conrad, 1980). The lower and upper parts of this section are fluvial, with many cross-bedded and sandy channel deposits, containing all the taxa of the fauna except for *Procastoroides*. In these respects the Jackass Butte section differs from the older deposits at Birch Creek farther west: the latter are marsh deposits overlying lake beds and underlying fluvial deposits of a finer grained composition than at Jackass Butte. The Jackass Butte section also differs from the deposits of the Chattin Hill area, which are largely pond deposits and lava flows. The entire section exposed on Jackass Butte is between 100,000 and 400,000 years younger than the Birch Creek fauna, as mentioned on page 51.

From a sample collected high in the Jackass Butte section, near the locality where a *Stegomastodon* scapula was collected (Conrad, 1980, p. 236–241) and above the marsh deposits, Forester (1991) indicated that the ostracode fauna from Jackass Butte section consists of eurythermal taxa of unspecialized morphology, suggesting a modern-like seasonality and a lack of contact with the then nearly 2-million-year-old Glenns Ferry lake. This ostracode fauna is like that of Chattin Hill but lacks the suggestion of varying salinity, suggesting that it may have been flushed by the Snake River and thus subject to seasonal changes in water temperature, but not seasonal salinity. Forester saw no ostracodes from the underlying marsh deposits on Jackass Butte, and the seasonality that he detected applies to the fluvial deposits above the marsh beds.

Diatoms also were found only very near the top of the Jackass Butte section, about 20 feet lower than the ostracode sample and possibly also in the fluvial deposits. They were of modern aspect and, like those in the Chattin Hill section, indicated pond environments but did not suggest increased or varying salinity (J.P. Bradbury, oral commun., 1993).

A brief normal paleomagnetic event midway up the Jackass Butte section (elevation 2,600 feet and in that part composed of marsh deposits) is reported by Conrad (1980); it was also detected in the work of C.A. Neville (oral commun., 1978), but not reported in Neville and others (1979) or Neville (1981). In Neville's work the normal event was supported only by one sample, and its normal polarity was discredited because it was unconfirmed by other samples. But Conrad did further sampling and found the normal zone in other parts of the butte in the same apparent stratigraphic position. The event can only represent one of the two normal events of the Réunion Normal-polarity Subchron; the earlier (2.13 Ma) has been suggested by Conrad (1980), and the suggestion fits the climatic history of the Northern Hemisphere.

Two million one hundred thousand years ago pre-Nebraskan glacial till was deposited in Iowa, and the earlier of the two Réunion excursions occurs within this till (Easterbrook and Boellstorff, 1984). Although age control is poor, there appears to have been mountain glaciation in the Yellowstone Park area at about the same time that continental glaciation extended to Iowa (Richmond, 1986). Glaciation in the Yellowstone area, marking a period of increased precipitation, would have increased the flow of the Snake River that drained into the Glenns Ferry lake. G.R. Smith (written commun., 1992) noted that the modern cold-water stream sculpin *Cottus* makes its earliest appearance at Jackass Butte. Possibly the rise in the level of the Glenns Ferry lake, indicated by the return of marsh deposits to the Jackass Butte area, reflects this glacial period.

But by 2.0 million years ago, the time of the second brief normal excursion of the Réunion (not found at Jackass Butte), the Northern Hemisphere was experiencing a different climate with marked warmth (Repenning and Brouwers, 1992); the second event of the Réunion is found in deposits above the till in Iowa (Easterbrook and Boellstorff, 1984). This climatic change seems to be reflected in the renewed lowering of the Glenns Ferry lake level and the return of fluvial deposition to Jackass Butte, from which the ostracodes and diatoms were collected. Presumably the reduction of glaciation in the Yellowstone Park area resulted in this lowering of lake level, and in the seasonality indicated by the ostracodes found in the fluvial deposits overlying the marsh beds in the upper part of the Jackass Butte section. The significance of seasonality is that it results from less cloud cover, producing hotter summers and colder winters, and less runoff from precipitation.

The age of the Jackass Butte fauna has been erroneously indicated as Pleistocene. Hibbard (1959, p. 35–38) indicated that the Grand View fauna of Jackass Butte and younger deposits of the Glenns Ferry Formation as far north as the Froman Ferry fauna were of middle Pleistocene age, "most probably of Yarmouth age." His opinion was based upon two correlations: (1) the presence in the Grand View fauna of *Ondatra idahoensis*, *Mictomys vetus*, and *Mimomys parvus* correlated best with the Borchers fauna of Kansas; and (2) the Borchers fauna was in the top of the Cudahy ash (thus thought to be 0.61 Ma), which Hibbard considered to be of Yarmouth age. Later, it was determined that three separate ash beds, all derived from the Yellowstone area, were assigned to the Cudahy ash that Hibbard had found associated with the Great Plains mammal faunas he described. The ash containing the Borchers fauna was 2.01 million years old, rather than 0.61 million years old (Naeser and others, 1973).

Certain other considerations also suggested a Pleistocene age to Hibbard, such as the belief that Blancan was Pleistocene, but subsequent work (Shotwell, 1970; Neville and others, 1979; Conrad, 1980, and Repenning, 1987), and the refinement of the definition of the beginning of the Pleistocene (Aguirre and Pasini, 1985) have clearly shown that the Grand View faunal succession is late Pliocene in age and belongs in the Blancan V mammal age. The Grand View faunas were included in the Blancan mammal age in the original definition of that age (Wood and others, 1941, p. 20).

Hibbard's correlation of the Grand View fauna with the Borchers fauna of Kansas is reasonable in terms of faunal evolution and the age it indicates. Unknown to Hibbard (in 1959), the Borchers fauna is in close association with the second event of the Réunion Subchron and thus correlates closely with the fluvial deposits above the first Réunion event in the medial marsh beds of the Jackass Butte section. This rather remarkable biochronologic correlation by Hibbard was confirmed 21 years later by Conrad's (1980) paleomagnetic studies. The only difference between the Jackass Butte faunas of the Grand View faunal succession and the Borchers fauna is that the Jackass Butte section includes a considerable span of time (perhaps as much as 300,000 years), from early during the Matuyama Reversed-polarity Chron to the Réunion events, while the Borchers fauna of Kansas represents only one horizon in the reworked top of the Borchers ash and, essentially, one time (2.01 Ma). The two faunas are in different faunal regions and have different taxa, making Hibbard's correlation even more difficult.

The marsh deposits in the middle of Jackass Butte seem to indicate that this was the approximate limit of the river 2.1 million years ago.

BIRCH CREEK

Extending from 17 miles southwest to about 7 miles south of Jackass Butte (about 13 to 6 miles west of Grand View), the marsh beds containing the Birch Creek fauna overlie typical Glenns Ferry lake beds. The Birch Creek fauna is a part of the Grand View faunal succession of Blancan V age, but represents only an early part of that mammal age; it is 2.4 million years old based upon the correlation of its associated ash beds to the Multi-ash paleomagnetic section between 4 and 5 miles to the northwest (p. 50). This age is also indicated by the small size (in comparison with the Jackass Butte fauna) of the horse, *Plesippus* sp. aff. *P. shoshonensis*, of the giant beaver *Procastoroides idahoensis*, and of the muskrat *Pliopotamys minor*; and by the presence of the immigrant lemming *Mictomys vetus* (<2.56 Ma). These indicate an age between that of Hagerman and Jackass Butte and younger than 2.56 million years ago. The positioning of the ash above the top of the Gauss Chron in the Multi-ash paleomagnetic section sharpens this age assignment to about 2.4 million years. The advancement of the vole subgenus *Mimomys* (*Ophiomys*) to the species *M.* (*O.*) *parvus* is also suggestive, but represents a stage in a graded series that has been recognized in pre-*Mictomys* (late Blancan IV) faunas (as at the Flatiron Butte fauna). Jonena Hearst, University of Kansas, is currently (1994) studying the Birch Creek and Poison Creek faunas.

One of the outstanding features of the beaver genus *Dipoides* is the little size variation of its species. In fact, size varies little from its Clarendonian ancestor *Eucastor* so that the size remained stable in the lineage for about 6 million years. Thus the beginning of a trend toward larger size, appearing in Blancan faunas, marks the divergence of the large but similar genus *Procastoroides*. On this basis, Zakrzewski's (1969) large species *Dipoides intermedius* from the Hagerman fauna is here included in *Procastoroides*. *Procastoroides intermedius* (Zakrzewski) from the Hagerman fauna is smaller than *P. idahoensis* from the Grand View faunas (Zakrzewski, 1969), and for this reason Zakrzewski's species name is retained. The *Procastoroides* sp. from the Birch Creek fauna is intermediate in size.

The taxa in the Birch Creek fauna indicate an age younger than the Glenns Ferry faunas of Hagerman, Sand Point, and Flatiron Butte, but distinctly older than the faunas of Jackass Butte. They most closely resemble those of the Ninefoot Rapids fauna of Conrad (1980), but the Birch Creek fauna lacks the microtine *Pliophenacomys osborni*, an immigrant from the Great Plains. Ninefoot Rapids is a fluvial deposit, rather than a marsh deposit, and Conrad noted the lack of *Procastoroides* and the scarcity of the muskrat, which is of small size but which he referred to *Ondatra idahoensis*.

The Ninefoot Rapids fauna has no paleomagnetic polarity determinations; the biostratigraphic interpolation of its age, intermediate between the Flatiron Butte fauna in the younger part of the Gauss and the Birch Creek fauna just above the Gauss, suggests that it should be close to the top of the Gauss Normal-polarity Chron, and very close to the time of dispersal of *Mictomys vetus* 2.56 million years ago. The fact that it contains the only record in the Pacific

Faunal Region of *Pliophenacomys*, an obviously unsuccessful immigrant from the Great Plains, seems to favor this interpretation of an age very close to dispersal event 5. Barnosky (1985) reported *Pliophenacomys* from the Yellowstone area on the Continental Divide between the Snake River and the Great Plains. In all faunal elements, Barnosky's fauna seems to represent a record of this dispersal event in the Yellowstone pass area, a most remarkable record.

The marsh beds that contain the Birch Creek mammal fauna are coeval with (and can be traced into) the marsh beds containing the Poison Creek fauna, 10 miles south to south-southwest of Grand View (fig. 12). These marsh beds extend to the east across Shoofly Creek, and, as far as they are exposed (fig. 12), seem to be marking the northwestern limit of the Snake River 2.4 million years ago (southeastern limit of the Glenns Ferry lake at this time). The Poison Creek fauna was first mentioned by Shotwell (1970, in connection with *Procastoroides idahoensis*) as a locality along Shoofly Creek. Kimmel (1982, table 1, sample 19-A-02) cited a 2.5±1.0 million year fission-track date for an ash (one of the "multi-ashes") in the lower part of the Poison Creek marsh deposits in the vicinity of Shoofly Creek. This is permissive of the correlation but carries such a wide margin of error that it certainly does not provide confirmation. Both fossiliferous marsh deposits (Birch Creek and Poison Creek) overlie Glenns Ferry lake beds containing a "typical" diatom flora (of an uncertainty in age significance greater than that of the fission-track date).

Both Birch Creek and Poison Creek marsh deposits extend across the Snake River Plain from the vicinity of the Snake River (middle of the basin) to the southwest margin of the Glenns Ferry lake, where they lap against pre-Glenns Ferry Tertiary rocks: the now-familiar, locally oolitic rusty sand unit above the Chalk Hills Formation. The Glenns Ferry lake beds underlying the marsh deposits pinch out against the unconformity before the marsh beds do.

The marsh deposits of Birch Creek and Poison Creek appear to be the same age on the basis of mammalian fauna, outcrop tracing, ash deposits, underlying lake beds, and fission-track date, but are not continuous. Both are overlain by fine-grained and crossbedded fluvial deposits and, between Birch Creek and Poison Creek (a distance of about 10 miles), the marsh beds disappear and their stratigraphic position is marked only by the overlying fluvial deposits, which lie directly on the Glenns Ferry lake beds.

The outcrop pattern of the marsh deposits may represent sinuosity of the limits of marsh deposition, as between the two areas small exposures of marsh beds have been found at locations more marginal (to the southwest) within the basin (fig. 12); in these areas the marsh beds are also below the fluvial deposits. It seems probable that, as the lake drained, it was covered with marshes for a time great enough to accumulate a recognizable deposit only locally, and that fluvial deposits were left directly on the lake beds where there were streams entering the lake.

REGIONAL FACIES RELATIONSHIPS

To judge by the distribution of these nonlacustrine deposits, it seems evident that continuous, open waters of the Glenns Ferry lake did not extend southeast and east (upstream toward the Hagerman area) much farther than Shoofly Creek about 2.4 million years ago. The head of the lake was in the position of Oreana and the Multi-ash polarity section about 2.1 million years ago, at the time that shallow, marsh water had backed up some river channel to Jackass Butte. No lake deposits are known along the present route of the Snake River as far downstream as the unnamed butte north of Wild Horse Butte, although near-lake marsh deposits are present in the area of "unnamed butte" until about the time of the Birch Creek fauna; the oldest marsh deposits at "unnamed butte" are at river elevation and would seem, from the paleomagnetic pattern, to be correlative to some part of the lake beds beneath the Birch Creek fauna and the base of the Multi-ash polarity section. They must approximate the age of the Ninefoot Rapids fauna. The Glenns Ferry lake was clearly restricted to areas southwest of the modern river in the Oreana area during the approximate time span between Ninefoot Rapids, Birch Creek, and Jackass Butte faunas.

It is unknown whether the fluvial deposits in the Jackass Butte–Wildhorse Butte area, at the foot of the basalt ramp in the eastern parts of the Snake River Plain, were deposited by the Snake River or by streams flowing into the lake from the northeast basin margin. The basaltic composition is not conspicuous, but has not been carefully looked for.

Downstream (northwest) from the Birch Creek area, the marsh deposits feather out into lake beds before reaching the next modern drainage, Castle Creek, as noted on pages 50–51; but the continuation of the ash beds of the Birch Creek–Poison Creek marsh beds into lake beds, with 132 feet of lake beds overlying them at the Multi-ash paleomagnetic section, provides a convincing correlation of these localities. The youngest Glenns Ferry lake beds in the Multi-ash paleomagnetic section appear, on the basis of thickness, to be about the same age as the stream deposits at Jackass Butte; this assumes similar rates of deposition in stream and lake deposits.

Northwest from the Multi-ash section, in the vicinity of Oreana (16 miles northwest of Grand View) and farther, only fluvial deposits appear on top of the lake beds, and these may be of either Glenns Ferry or Bruneau Formations, although scattered fossils found in them in the Oreana area appear to represent a Glenns Ferry fauna (Conrad, 1980; Anderson, 1965, UCMP specimens). At the top of the

Multi-ash section, and possibly elsewhere, Bruneau deposits overlie the Glenns Ferry lake beds, apparently because of pre-Bruneau erosion that becomes more conspicuous farther downstream.

Although the 2.4-million-year-old Birch Creek marsh beds do not extend into the contemporaneous lake basin much more than a mile northwest of Birch Creek, they extend about 7 miles in a northeast direction from the southwest margin of the Snake River Plain nearly to Grand View. With the exception of exposures at Jackass Butte of younger age and those at Wild Horse Butte and the unnamed butte farther downstream, 6–8 miles northwest of Jackass Butte and as old as and older than Birch Creek, marsh beds are not again known to be present until the Froman Ferry area, where they are less than 500,000 years younger than those at Jackass Butte and, possibly, the youngest Glenns Ferry lake beds in the Oreana–Multi-ash area.

The marsh beds midway in the Jackass Butte section, and centering on the 2.1-million-year-old first normal event of the Réunion Subchron, lie about midway in the time interval separating Birch Creek and Froman Ferry. But, as discussed, in those areas downstream from Oreana (north, between Sinker Butte and Walters Ferry; fig. 12) the lake basin appears to have been largely east of the exposures along the Snake River, and the deposits are now covered by basalt flows.

A fauna comparable to that from Birch Creek has not been found at the heavily collected Jackass Butte exposures, which, because of regional dip (and basinward faulting), are topographically lower but stratigraphically higher than Birch Creek (fig. 12, section); the Jackass Butte faunas are too young to be identical to the Birch Creek fauna. Six miles northwest of Jackass Butte, at Wild Horse Butte, Shotwell (1970) collected fossil mammals, including *Procastoroides*, that he included with his Grand View fauna. These are more like the Birch Creek fauna (unknown to Shotwell) than the Jackass Butte faunas.

At the unnamed butte north of Wild Horse Butte, Neville (1981) measured a paleomagnetic section that included the younger part of the Gauss Chron and the overlying oldest part of the Matuyama Chron, nearly matching in its polarity record the Multi-ash section. Although Neville (1981) called the section the "Wildhorse Butte" section, because this was the closest named feature on the topographic map, Conrad (1980) referred to the locality as "unnamed butte" because Neville's section was actually collected on the south face of a butte having no name on the topographic quadrangle and about 1 mile north of Wild Horse Butte.

At "unnamed butte," however, the lake beds, if present, are well down in the Gauss magnetozone and are not exposed within the canyon of the adjacent Snake River; marsh beds with abundant carbonized plant remains are present at river level. Fossil mammals were found at "unnamed butte" both above and below the Gauss/Matuyama polarity reversal (2.48 Ma; about at the 2,542 ft elevation on "unnamed butte") in whitish marsh beds and in fluvial deposits above these. The fauna collected included *Mictomys vetus*, *Mimomys parvus*, and *Hypolagus* sp. from localities GS-236, Sample 1, and GS-237, Sample 2, both of which were in marsh deposits less than 25 feet below the top of the Gauss Chron. In the reversed part of the section (Matuyama Chron and fluvial deposits), *Hypolagus*, a peccary, and a fairly large camel were found. The specimens, collected by both Conrad and Scott, are accessioned in IMNH, and this locality was the basis for the statement of Repenning (1987) that the immigration of *Mictomys* was older than the end of the Gauss Chron in Idaho.

The Wildhorse Butte–"unnamed butte" deposits indicate that the lake was restricted to the west before the time of the Birch Creek section and the ash beds of the Multi-ash section. The Glenns Ferry lake was, at about 2.48 million years ago, less than 6 miles wide in the vicinity of Oreana–Wild Horse Butte.

Lowering of the Glenns Ferry lake level was reversed about 2.1 million years ago when marsh deposits appeared in the Jackass Butte area, marking the highest lake level recorded there. The 132 feet of lake beds above the Gauss Chron in the Multi-ash paleomagnetic section may include deposits reflecting this deepening. As has been noted (p. 60), this rise in lake level was contemporaneous with the other evidence of Northern Hemisphere continental glaciation, which began about 2.4 million years ago (to judge from oceanic oxygen isotope records and recorded activity of the Scandinavian Ice Sheet), and peaked about 2.1 million years ago (to judge from glacial deposits in Iowa and Yellowstone). The Birch Creek–Poison Creek marsh beds may easily owe their extensive nature to a resulting stasis in lowering of the level of the Glenns Ferry lake, and then the peak of glacial activity brought a temporary rise in lake level and the marsh environment upstream to Jackass Butte.

As the Jackass Butte marsh beds overlie fluvial deposits, it would seem possible that this marsh deposition was confined to a preexisting river valley at that point, but must represent a considerable rise in lake level, as they are the only marsh beds in the section. Considerable effort has been made to find possible lake deposits above the Birch Creek marsh deposits, with negative results. If the Birch Creek marsh beds represent a stasis in lake draining, it was resumed again before the rise recorded in Jackass Butte; this is not inconsistent with the pattern of ice activity of the Scandinavian Ice Sheet at this time (Jansen and others, 1988), although well removed from Scandinavia in terms of regional weather patterns.

In summary, a transverse section of the Glenns Ferry Formation in the vicinity of Grand View (fig. 12, section), midway down the axis of the western Snake River Plain, shows 2.4-million-year-old lake beds grading southward into Birch Creek marsh beds and lapping out against the underlying locally oolitic rusty sand at the southwest structural margin of the graben. At this time the lake beds did not extend as far to the northeast as the present position of the Snake River at "unnamed butte" north of Wild Horse Butte, but appear to have extended to the southeast, in the vicinity of the present Snake River, as far as Shoofly Creek. Marsh beds of Birch Creek extend a great distance to the northeast, across the basin toward the town of Grand View, in the center of the basin; they also extend to the southeast (up the basin) as far as Shoofly Creek, where the outcrop band of marsh beds swings northeast toward the Snake River and appears to mark the then-existing upstream limit of the Glenns Ferry lake. In this area the lake may have been more of an estuary of the main lake, extending upstream from Sinker Butte to the position of Oreana and Shoofly Creek, but largely to the west of the present position of the Snake River.

From the southwest side of the basin toward the present Snake River, the oldest lake beds are increasingly older; they are nearly 3.5 million years old in the lowest exposures near Bruneau (Neville and others, 1979, fig. 10), which is about 15 miles to the east of their closest exposures along Shoofly Creek, but are little older than the overlying marsh beds (2.4 Ma) where they pinch out against the locally oolitic rusty sand unit along Shoofly and Birch Creeks. The entire sequence dips toward the center of the basin, roughly at the modern Snake River, but the locally oolitic unit does so more steeply.

To the northwest of Birch Creek, the marsh beds feather out into lake deposits. Farther in this direction, at the Multi-ash paleomagnetic section 3 miles south of Oreana, these lake beds contain the ash beds found in marsh deposits at Birch Creek and extend upsection (about 132 feet in stratigraphic thickness) well into the Matuyama Chron (Neville, 1981, reinterpreted), but they may or may not contain the first normal event of the Réunion Subchron. Because this brief normal event of the Réunion was not found in the Multi-ash section, these reversed-polarity lake beds may be more than 2.1 million years old at their youngest point. However, Neville's paleomagnetic sampling was very widely spaced in that part of the Multi-ash section where the Réunion Subchron might be expected, and the normal events could easily have been missed; that the lake existed this recently is indicated by the appearance of high-water marsh beds on Jackass Butte. The Multi-ash section of Glenns Ferry lake beds is overlain by marginal lacustrine deposits of the Bruneau Formation, also of reversed geopolarity according to Neville (1981), and contain both fluvial gravels with fossil horses (unpub. data, collected by H.E. Malde, 1976) and lacustrine clays with a "Bruneau" diatom flora. The youngest Glenns Ferry lake beds may have been removed by pre-Bruneau erosion.

The youngest fluvial deposits at Jackass Butte are as young as about 2 million years, and, northeast of the town of Bruneau at the Ninefoot Rapids fauna, the fluvial deposits are as old as about 2.56 million years. Fluvial deposits are still older at Flatiron Butte to the east of Bruneau, and about 3.1 million years old at Sand Point. At Hagerman, the easternmost marsh and fluvial beds are as old as 3.6 million years.

The brief rise in lake level recorded in Jackass Butte appears to have been coincident with glaciation in Yellowstone Park; it was followed by renewed lowering of the level of Glenns Ferry lake. The lake did not rise high enough to deposit lake beds on top of marsh deposits in any examined exposure.

Although extending for some 7 miles across the basin from its southwest side toward the town of Grand View, the Birch Creek marsh beds extend to the northwest ("downstream" into the lake) only about a mile before grading into lake beds. In other directions they are replaced or overlain by fine-grained fluvial deposits. Farther to the northwest, beyond the Oreana area and continuing as far as Guffey Butte, fine-grained fluvial deposits overlie the Glenns Ferry lake beds in the exposures west of the Snake River; to the east they are covered by lava flows.

Northeast of Grand View (north of Bruneau), a ramp of multiple lava flows, interbedded with local ponds that appear to have had no contact with either the former Snake River or the Glenns Ferry lake, leads up to the northeast side of the Snake River basin in the direction of Mountain Home (fig. 12).

INCISION OF THE LAKE BEDS AND CANYON DAMMING

Incision began first in the more upstream parts of the Snake River Plain, where the gradient of the covering gravels (and of the modern river) is greater than in the lower half of the basin. Incision thus followed the Snake River delta downstream to the northwest. Several times the incised channel of the Snake River was obstructed by lava flows, forcing ponding and overflow down a new channel (Malde, 1985, 1991). In water impounded behind these dams, the sediments of the Pleistocene Bruneau Formation were deposited, making that formation a collection of several separate, but similar, depositional events.

Malde (1991, p. 263–266) has plotted the course of four former channels and provided dates of their damming, as all dams are composed of volcanic rocks. As tabulated by Malde (1991), these dates have a wide temporal range (2.06 to 0.78 Ma, with a range of 340,000 years for four samples from one locality), suggesting a problem with precision. We are unable to judge which is correct, and thus to infer a history.

The dates for the dams also suggest that some of the channels were dammed during deposition of Glenns Ferry lake beds farther downstream. But all impounded lakes apparently contained identical diatom floras of the Bruneau Formation type, and these differ distinctly from those known from the Glenns Ferry Formation, including those immediately underlying the Froman Ferry faunal succession. The Bruneau diatom flora resembles that of modern lakes in the Pacific Northwest (J.P. Bradbury, oral commun., 1993), but the deposits consistently show a reversed polarity and so must be older than the Bruhnes Normal-polarity Chron (>790,000 years). The modern character of the Bruneau diatom flora suggests a different and younger age for the Bruneau Formation in comparison with the Glenns Ferry lake flora, but records outside the Snake River Plain suggest that environmental differences, rather than age differences, may be responsible (p. 51). In the core drilled near Bruneau, the pollen flora found in the lake beds of the Bruneau Formation indicated only a sage-steppe environment, whereas the underlying Glenns Ferry Formation showed an alternation of conifer forests and sage steppes (Thompson, 1992). This would seem to suggest an environmental difference that was time-related. The problem of the relationship of the Bruneau Formation to the Glenns Ferry Formation is unresolved.

The present route of the Snake River from Walters Ferry to the junction with the Boise River, north of the Froman Ferry area (fig. 2), resulted from the damming of the Snake River by the eruption of Pickles Butte (and related volcanic centers) 1.5 million years ago (p. 9, minimum date here selected, as the maximum date would indicate the presence of the Olduvai Normal-polarity Subchron, which was not found in the measured polarity section of the underlying marsh beds). This eruption forced the river to the southwest structural boundary of the Snake River Plain; its overflow down a new route to the west of the Pickles Butte lava flows removed earlier deposits of the Glenns Ferry Formation, as well as the capping Pickles Butte basalt. In some areas it seems to have also removed parts of the underlying Miocene Chalk Hills Formation, although in others it appears to have scoured its bed across the resistant locally oolitic rusty sandstone that lies between the Chalk Hills and the Glenns Ferry Formations.

At Guffey Butte, south of Walters Ferry (fig. 12), there is exposed a considerable section of the Bruneau Formation downstream from the dams considered by Malde (1985, 1991); the Pickles Butte lava dam is the only known damming feature that would account for the Bruneau deposits at Guffey Butte. These deposits contain a Bruneau Formation diatom flora (J.P. Bradbury, oral commun., 1993).

No exposures of the Glenns Ferry Formation are present on the southwest side of the river from south of Walters Ferry (fig. 12) to north of Givens Hot Springs (fig. 2), although thick exposures of Glenns Ferry lake beds are present in the steep scarp that is capped by lava on the northeast side of the river in this area. The geographic distribution of sediments and lava clearly indicates that overflow, to initiate the modern drainage route in this area, was around the southwest edge of Pickles Butte lavas extending to (or nearly to) the structural boundary of the Snake River Plain. The relationships of preserved deposits in this area indicate that subsequent erosion by the Snake River has brought the river course eastward (and basinward) into the area formerly covered by the lava. The Glenns Ferry lake beds have been stripped off older deposits west of the present river course, and it was not until the Snake River reached the Marsing–Froman Ferry area that Glenns Ferry Formation again is present on both sides of the river, marking the approximate northwestern former limit of the Pickles Butte lava. This is close to the downstream part of the Boise River, north of which there are no preserved parts of the Glenns Ferry Formation.

In the Froman Ferry area, between the Snake and Boise Rivers, the lake beds have marsh beds above them, containing the Froman Ferry faunal succession, that are about 800,000 years younger than the Birch Creek marsh beds and about 500,000 years younger than the youngest marsh deposits of Jackass Butte in the Grand View area. The Glenns Ferry Formation of the Froman Ferry area was dissected by the modern Snake River following its overflow down a route west of the Pickles Butte lava field, and was, therefore, deposited in a basin into which the Snake River flowed farther east than its present route, possibly in the Nampa area, as suggested by the canyon traced beneath the lava surface by Malde (1991).

When the Glenns Ferry lake formed, the Snake River entered the lake in the Hagerman area (beginning perhaps about 4.0 Ma). By the time of the Sand Point fauna (about 3.1 Ma), the mouth of the Snake and head of the lake had moved downstream to the vicinity of Hammett. By the time of the earliest Grand View faunas (2.56 Ma), the Glenns Ferry lake was restricted to areas southwest of the modern Snake River (southwest half of the Snake River Plain) downstream from Bruneau and, by 2.4 million years ago, the lake was restricted to areas downstream from the marsh deposits containing the Poison Creek and Birch Creek faunas. By the time of the youngest Grand View faunas (2.0 Ma) the mouth of the Snake River was downstream from Jackass Butte, or the fluvial deposits along the river between Jackass Butte and "unnamed butte" derive from streams that entered the lake down the basalt ramp covering the east half of the basin.

At the Multi-ash section, 4 miles northwest of the point where the marsh deposits containing the Birch Creek fauna grade into lacustrine deposits of the Glenns Ferry lake, lacustrine deposition continued until perhaps 2.1 million years

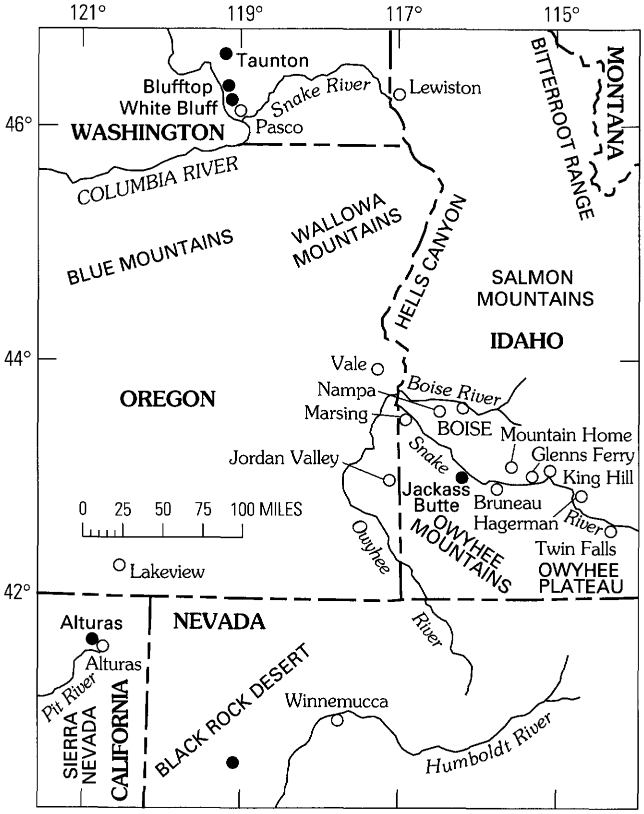


Figure 13. Idaho and adjacent areas showing approximate location of some localities discussed. Solid dot, Blancan locality.

ago, to judge by the 132 foot thickness of reversed lake beds above the top of the Gauss magnetozone. The youngest lacustrine deposits in the Froman Ferry area may be close to 1.67 million years old, but the end of the Olduvai event is not recorded in the paleomagnetic section of the fossiliferous marsh beds and no paleomagnetic section was made of the underlying lake beds.

According to Jansen and others (1988), evidence of the activity of the Scandinavian Ice Sheet began to abruptly increase 2.56 million years ago (the time of the immigration of *Mictomys* and the beginning of Blancan V), and reached a climax about 2.1 million years ago (glaciation in Iowa, presumably in Yellowstone, and rise in Glenns Ferry lake level at Jackass Butte). The first part of the Blancan V mammal age was a time of developing continental glaciation which would have been marked by increased precipitation. But, except for the brief rise in lake level 2.1 million years ago (Jackass Butte marsh beds) and a possible halt in the lowering of the lake level 2.4 million years ago (extensive Birch Creek–Poison Creek marsh beds), the water level of the Glenns Ferry lake was dropping. It is difficult to believe that the lake was not draining.

The assumption that the Glenns Ferry lake was draining down Hells Canyon to the Columbia River during most of its existence seems to follow from the records in the Hagerman, Sand Point, Grand View, and Froman Ferry areas. Although the Glenns Ferry lake seems to have been present for perhaps 2.5 million years, evaporates are not conspicuous in its deposits and the lacustrine fauna and flora indicate no saline waters; these conditions also suggest that the Snake River and the Glenns Ferry lake were parts of a through-flowing drainage system during all of this time. If so, there could be evidence of this drainage beyond the limits of the western Snake River Plain.

ADJACENT AREAS OF SIGNIFICANCE

From the preceding age and geographic data, this discussion assumes that the Snake River drained into the Glenns Ferry lake from the time of its inception and that the lake drained down Hells Canyon as soon as the basin filled to sill height. Hells Canyon is thus assumed to have been a pre-Glenns Ferry Formation feature that was further incised to completely drain the lake by the time of the Froman Ferry faunal succession.

There have been suggestions of drainage by other routes during the time that the Glenns Ferry lake was in existence. In addition, it is evident that the Snake River did not always drain down the western Snake River Plain, but was once connected to the Sacramento River drainage of California (see fig. 13). These points require consideration to complete the history of the Glenns Ferry Formation.

The hydrologic connection between the Glenns Ferry lake and the Sacramento River is defended on the basis of fossil fish and mollusks of the Sacramento drainage that are similar to those of the Glenns Ferry Formation. Diatoms and one mammal also suggest a connection. But much of this evidence of a connection is older than the Glenns Ferry lake.

PRE-GLENNS FERRY DRAINAGE

Wheeler and Cook (1954; followed by Miller, 1965; Taylor, 1966—his "Fish Hook" pattern, 1985; Middleton and others, 1985; and Malde, 1991) have suggested a former drainage of the Glenns Ferry lake up the course of the Owyhee River in southeast Oregon (fig. 13), then either westward to Klamath Falls (Taylor) or southward to Nevada (Miller), and then south or southwest to the Sacramento River. This route has also been suggested for the Snake River before the formation of the Glenns Ferry lake, as many of the faunal similarities are older than the lake.

No deposits of Glenns Ferry age (Blancan) are found anywhere in southeast Oregon, from the junction of the Boise River with the Snake River in Idaho, up the present Owyhee River in eastern Oregon, and west to Lakeview, Oregon. The area was a highland in the middle Miocene, when great sheets of ignimbrite flowed off it to the south into Nevada (almost exactly opposite the direction of flow of the modern Owyhee River); these welded tuffs have been broken up by north-south Basin-and-Range block faulting since then (at right angles to the proposed Snake River drainage to California), and in none of the resulting basins have any Blancan (Pliocene) age deposits been found (Walker and Repenning, 1965, 1966). The lack of Blancan deposits extends southward (with the ignimbrites) into northwesternmost Nevada. Southeast Oregon and adjacent Nevada were a highland well before the existence of the Glenns Ferry lake, and remain so today.

Deposits claimed to be of Pliocene age from the Danforth Formation southeast of Harney Lake, Oregon (Taylor, 1966; Taylor and Bright, 1987), are of Miocene age by modern correlations, as are all deposits of southeastern Oregon that were called "Pliocene" in the 1960's by Malde and Powers (1962), Walker and Repenning (1965, 1966), and Shotwell (1970). (See "Mammal Ages and Provincialism," p. 10–13.)

Informed discussion of the drainage route from southern Idaho before the Glenns Ferry lake formed and of the earliest flow of the Glenns Ferry lake down Hells Canyon to the Columbia River requires consideration of evidence beyond the limits of the western Snake River Plain. These drainages should have left records in other areas.

Drainage of southern Idaho, prior to the Glenns Ferry lake, is speculative; most evidence of the actual drainage route seems to have been destroyed by elevation of Basin and Range mountains and covered by volcanic flows; whatever the route, it was across the much older path of the Yellowstone "hot spot" and is likely to have been affected by both tectonism and volcanism. However, similarities in fossil and living freshwater fish (Miller, 1965, p. 576 and fig. 3) and mollusks (Taylor, 1966, p. 17–27) have long suggested a possible late Miocene route out of southern Idaho and into northern California, to join the Sacramento River drainage.

To a degree, the interpretation of this drainage route is also supported by diatom similarities in the Klamath Lake area of southern Oregon (J.P. Bradbury, oral commun., 1992) and a questionable record of the primitive muskrat *Dolomys* in central California; *Dolomys* was ancestral to *Pliopotamys* from the Glenns Ferry Formation. This record of *Dolomys* is a damaged lower jaw (UCMP 57958) from the uppermost part of the upper Miocene and lower Pliocene Etchegoin Formation (UCMP locality V3520) in the Kettleman Hills, California. The locality is stratigraphically near the Lawlor Tuff, which lies within the Nunivak event of the Gilbert Chron (Sarna-Wojcicki, 1991) and has a date of 4.1 million years; it is thus older than the earliest mammalian record from Hagerman.

The muskrats originated in Eurasia and this date is in the earlier, but not the earliest, part of their record there. The earliest record is in western Asia (Kazakhstan) and appears to be of latest Miocene age (Repenning and others, 1990).

The presence of a muskrat in the Etchegoin Formation suggests a surface-water connection between the Sacramento River system and the Snake River and Glenns Ferry lake, in which its descendant, *Pliopotamys minor*, is first known from the earliest faunas at Hagerman. The lack of the Ondatrinae (the muskrats) in the Columbia River basin until about 2.9 million years ago (to be discussed), but their presence in the oldest Hagerman faunas (3.6 Ma) and in the Sacramento River basin (4.1 Ma) suggests that the lineage arrived in Idaho up the Sacramento River drainage and that its later introduction to the Columbia River basin was down the Glenns Ferry lake–Snake River drainage (Hells Canyon). The record of the muskrats, as well as of mollusks and fish of the Sacramento area, thus suggests a connection with the Sacramento River drainage basin before the time that the Snake River first flowed into the Glenns Ferry lake; once the river flowed into the western Snake River Plain it could no longer flow to the Sacramento basin without crossing the southeast Oregon highland.

It is well known that this part of Oregon was uplifted by middle Miocene time, as just discussed (p. 66–67), and a series of late Miocene (pre-Glenns Ferry) basins are preserved, at progressively lower elevations, down the modern northward course of the Owyhee River from the southwesternmost corner of Idaho, through the Jordan Valley area, around the north end of the Owyhee Mountains of Oregon, and to the modern Snake River north of the Froman Ferry area near the junction of the Boise River. These basins correlate, but were not depositionally continuous, with Lindgren's Payette Formation. Although all these basins contain late Miocene deposits, only the Rome basin in the Jordan Valley area contains later deposits, and these are Irvingtonian in age, younger than the Glenns Ferry Formation. The Owyhee drainage has been flowing north since well before the deposition of the Glenns Ferry Formation.

To the west of the Owyhee River, across southeastern Oregon at least as far as Lakeview, modern topography is marked by Basin and Range mountains and basins, trending roughly north-south, at right angles to the trace of the proposed former route of the Snake River. No deposits of Blancan age have been found in any of these basins, as would be expected if the Snake River formerly drained westward across them (Walker and Repenning, 1965, 1966).

A more probable route, which at least has early Blancan deposits along it, runs from the present position of the Snake River near Twin Falls, Idaho, south through the eastern part of northern Nevada to the Humboldt River area, westward to Winnemucca and the Black Rock Desert in Nevada, and then to the Alturas lake basin and the Pit River in California (fig. 13). This route traverses several basins with upper Miocene and, particularly, some pre-Glenns Ferry Pliocene deposits that are entirely missing between Marsing, Idaho, and Klamath Lake, Oregon; it also detours the highland of southeastern Oregon.

This Nevada route also crosses the eastern scarp of the Sierra Nevada west of the Black Rock Desert and constrains this uplift to an age no older than early Pliocene (after about 4.7 Ma). The faunal and floral similarities of the Klamath Lake area, a strong point in the argument for the southern Oregon route, may indicate that the area was then tributary to the Sacramento River drainage, and not necessarily a part of the former Snake River.

The modern Pit River follows a series of lacustrine basins in northeast California, including that containing the lake beds of the Alturas Formation, and drains into the Sacramento River. These lacustrine basins may have been part of the former drainage route from southern Idaho, or may have been tributary to it. The history of these basins is poorly known, but they appear to have resulted from the damming of drainage by lava flows and faulting.

The lake beds in the vicinity of Alturas, California, 50 miles south of Lakeview, Oregon (fig. 13), are best exposed and best known; all other basins are downstream along the Pit River and, essentially, not dissected. All deposits in the Alturas basin are of an age that is older than the known age of the Glenns Ferry Formation, although they may equal the age of at least part of the older formations of the Snake River Plain. The youngest faunas of the Alturas lake basin are of earliest Blancan age (4.8 Ma: Repenning and others, 1990, p. 395–396). The oldest faunas in the Alturas basin are of Miocene age (greater than 5.3 Ma; Evernden and others, 1964). The presence of the diatom *Mesodictyon* in these older deposits of the Alturas basin suggests an age similar to that of the Chalk Hills Formation, underlying the Glenns Ferry Formation of the western Snake River Plain (J.P. Bradbury, written commun., 1993).

The earliest Blancan fauna of the lake beds of the Alturas Formation occurs in marsh deposits (flat-bedded, diatomaceous, silty deposits, with reed and rush remains and containing a prominent ash bed) that were marginal to the lake. The fauna contains the ancestors of the Glenns Ferry microtines, *Mimomys* (*Ophiomys*) *taylori* and *Mimomys* (*Cosomys*) *primus*, both known from the oldest marsh beds at Hagerman (Repenning, 1987). This Blancan fauna is well dated at 4.8 Ma by (1) a 4.7±0.5 Ma potassium/argon date of a lava flow on top of the lake beds and about 70 feet above the fauna (M.L. Silberman, written commun., 1978; three samples were run with good agreement); (2) paleomagnetic correlations (S.R. May, written commun., 1985); the early Blancan faunas lie about 15 feet above the Thvera event of the Gilbert Chron (younger than 4.85 Ma); and (3) a directly associated ash bed (the fauna is found both above and below the ash) that has been fingerprint-correlated with a tephra in a core off the California coast and there dated by marine biochronology at about 4.8 million years (A.M. Sarna-Wojcicki, written commun., 1985). These age controls are in addition to (4) the biochronologic correlation provided by the microtine rodents (Repenning and others, 1990, p. 396), which indicates an age about as old as the other evidence.

Deposits of a slightly younger age are known from the Ringold Formation in the Columbia River drainage basin near Pasco, Washington (fig. 13; White Bluffs fauna, ≈4.3 Ma; Gustafson, 1978; Repenning, 1987), but the mammalian similarity is weaker as the fauna contains no ancestor of *Mimomys* (*Cosomys*) *primus*, which became extinct in the Pacific Faunal Region about 3.0 million years ago and never appears, as a result, in the Columbia River basin.

Mimomys (*Ophiomys*) *mcknighti*, found in the Alturas fauna, was named from the White Bluffs fauna by Gustafson (1978). In the White Bluffs section there are overlying transitional faunas that show evolution of *M.* (*O.*) *mcknighti* into an intermediate form, informally called *Mimomys* (*Ophiomys*) *mcknighti-taylori*, that is present in abundance in the Blufftop faunas (Repenning, 1987; ≈3.9 Ma). *M.* (*O.*) *taylori* (the slightly younger species from Hagerman) is present in the younger Taunton fauna (≈2.9 Ma) of the Pasco basin. Here is a nice demonstration of an evolutionary sequence that bridges the time between the dated record from Alturas to the early Hagerman records and roughly to the Sand Point record in the Glenns Ferry Formation.

But there is no record of the lineage of *Mimomys* (*Cosomys*) at any time in the Pasco basin, nor any muskrat until the Taunton fauna (2.9 Ma).

Although both subgenera of *Mimomys* appear as immigrants from Eurasia 4.8 million years ago (Alturas fauna), from these fossil records *Mimomys* (*Cosomys*) seems to have followed the Pacific Coast from Beringia (and Eurasia) to the San Francisco area (where it alone is first found in UCMP locality V6869—Maxum fauna; Repenning, 1987, p. 254; May, 1981). It then appears to have moved up the Sacramento River to the Snake River, to be diverted into Glenns Ferry lake area at Hagerman with the primitive muskrat *Pliopotamys minor*, which arrived from Eurasia (as *Dolomys*) with the next dispersal event about 4.1 million years ago (Etchegoin fauna).

Mimomys (*Ophiomys*) immigrated at the same time but appears to have moved inland up the then-existing Columbia River, where it is later known from the White Bluffs fauna and can be stratigraphically followed upward as it evolved into the more advanced species of the Hagerman fauna. But before the White Bluffs fauna this immigrant moved southward as far as Alturas, California; its further dispersal southward in the Pacific Faunal Region was greatly delayed, presumably because Alturas was then at the southern limit of its temperature tolerance.

There is no recognized indication in the fossil record of why *Mimomys* (*Ophiomys*) was able to move southward from the Columbia River area to northern California, when

Mimomys (*Cosomys*) did not move northward over the same route. Both are present in the oldest faunas of the Glenns Ferry Formation of Idaho and in the Alturas Formation of northern California, and in no other known fauna of North America. By the time that *Mimomys* (*Ophiomys*) is known farther south than Alturas, *Mimomys* (*Cosomys*) had become extinct in the Pacific Faunal Region.

Mimomys (*Cosomys*) also moved southward from the San Francisco area, obviously down the San Joaquin River drainage, where it is known from the Kettleman Hills, in the "Pecten Bed" of the San Joaquin Formation—an approximate Hagerman equivalent (Repenning, 1987, p. 256). The species (*M.* (*C.*) *primus*) continued southward to the type locality in the Coso Mountains near what is now the Mojave Desert. But it is unknown in the Columbia River basin at any time, and was extinct by the time the muskrats entered that area from the Glenns Ferry lake.

Early Pliocene tectonic and volcanic activity of the Owyhee Plateau south of Twin Falls, Idaho (and along the older path of the Yellowstone "hot spot"), could have blocked flow of the Snake River southward into Nevada, and to the Sacramento drainage. This blocking could only direct the Snake River into the western Snake River Plain near Hagerman. Interestingly, this model would suggest the temporary creation of a pre-Glenns Ferry lake upstream from Twin Falls (possibly extending to INEL; fig. 1). Little direct evidence of a route southward from the area of Twin Falls (into northern Nevada) exists other than scattered basins with deposits of the proper late Miocene and early Pliocene age, and containing microtine faunas that were ancestral to those from the Glenns Ferry Formation. To our knowledge, the fish and mollusks of the Alturas lake beds have not been examined.

Presumably after 4.7±0.5 Ma (date of the lava capping the Alturas lake beds) and before 4.0 Ma (oldest known Glenns Ferry Formation near King Hill), the disruption of a southwestward drainage of the Snake River into Nevada and diversion to the northwest into the Snake River basin and the Columbia River took place. The Glenns Ferry lake then flooded parts of the western Snake River Plain until it reached the sill height of a preexisting Hells Canyon tributary of the Columbia River.

Formation, or deepening, of the Snake River graben happened either at the same time that activity on the Owyhee Plateau obstructed flow to Nevada, or the diverted Snake River flowed into preexisting small lakes within the graben. That these lakes existed seems indicated by the locally oolitic rusty sand unit and the underlying and saline Chalk Hills Formation. Both are more tectonically deformed than the Glenns Ferry Formation and are found unconformably beneath the Glenns Ferry Formation along the southwest side of the Snake River Plain as far northwest as Marsing and the northern limit of the Glenns Ferry Formation. The greater deformation of these earlier lake beds suggests that the Snake River graben was further deepened just before the Snake River was diverted into it. The pre-Glenns Ferry lake beds extend farther north than does the Glenns Ferry Formation, to the approximate latitude of Weiser, Idaho, and, west of the Snake River, Moores Hollow, Oregon.

From the delta deposits at Hagerman, it seems obvious that the Snake River drained into the Snake River Plain graben to form the Glenns Ferry lake before about 3.6 million years ago, possibly because of diversion of earlier flow through Nevada and into California. That diversion took place earlier is suggested by the inferred age of the oldest Glenns Ferry Formation in the King Hill area (>4.0 Ma) and by the youngest deposits of the Alturas lake beds (4.7±0.5 Ma).

There remains a gap of possibly 700,000 years between flow of the Snake River into California and the earliest record of flow into the Snake River Plain. Much of it could disappear into the "±" estimate of the radiometric ages involved, but not in the biochronology of the microtine rodents involved; fossil records are not, however, found in every foot of section under consideration. A lake along the Snake River upstream from Twin Falls, Idaho, could be responsible for only part of this time. During this time deposits are known in the Ringold Formation in the area of Pasco, Washington, but the faunas of this time in this area do not contain Sacramento River faunal elements. A delay occurred between flooding of the Snake River Plain and outflow to the Columbia River; in the same way, there was a delay between the Snake River flowing into Nevada and then into the Snake River basin.

GLENNS FERRY LAKE DRAINAGE

From the development of marsh cover across the Snake River Plain in the vicinity of Grand View 2.4 million years ago (p. 61–62) and from the lack of evidence of significant salinity in the lake beds, it seems obvious that the Glenns Ferry lake was draining somewhere and had reduced its area to less than half the area of the Snake River Plain by this time (it has not been established that the Glenns Ferry lake ever covered, at one time, the entire area of the western Snake River Plain).

The proposed route up the Owyhee River and across southeastern Oregon to the Sacramento River drainage is implausible, as this area shows all signs of being a drainage divide during the late Miocene and Pliocene, and contains no evidence of deposits of the appropriate age. One other drainage route of the Glenns Ferry lake has been suggested: into Oregon and west of the Wallowa Mountains to the Columbia River (Wheeler and Cook, 1954), but this route also contains no Blancan deposits, although middle and upper Miocene deposits are known. This route would also cross a highland between the Wallowa and Blue Mountains (fig. 13) to follow the Grande Ronde to the Columbia River, a highland that developed with the Blue Mountains and is much older than any drainage of the Snake River here considered. No outlet for the western Snake River Plain other than Hells Canyon seems possible.

Downstream from Hells Canyon, in the area of Pasco, Washington, where the Snake River now joins the Columbia River, extensive lacustrine and fluvial deposits are included in the Ringold Formation. This formation contains (fig. 4) (1) the River Road fauna (Gustafson, 1977) that is near the following fauna and is of Miocene age, possibly the age of the Chalk Hills Formation that underlies the Glenns Ferry lake beds and of the older part of the Alturas Formation of northeast California (the River Road fauna is in a coarse conglomerate rather than lake beds); (2) the White Bluffs fauna (Gustafson, 1978) that may be 4.3 Ma old (Repenning, 1987), older than any mammalian fauna in the Glenns Ferry Formation but of Blancan (Pliocene) age and younger than the youngest part of the Alturas lake beds of northeast California; (3) the Blufftop faunas (Gustafson, 1985; including Haymaker's Orchard locality of Repenning, 1987) that are about 3.9 Ma old (a little older than the oldest Hagerman mammals but possibly a bit younger than the oldest lake beds included in the Glenns Ferry Formation near King Hill); and (4) the Taunton fauna (Tedford and Gustafson, 1977; Morgan and Morgan, 1995) about 2.9 Ma old, younger than the Hagerman faunas and about the age of the Sand Point fauna of Idaho. Repenning (1987) assigned too old an age to the Taunton fauna, and an age of about 2.9 Ma has become evident with further collecting of the locality by James and Neil Morgan of Othello, Washington.

Pliopotamys minor, the small muskrat named from the Hagerman fauna (Wilson, 1934), is the oldest North American muskrat except for *Dolomys* (p. 16, 67) from the Kettleman Hills, California. Its first record at Hagerman is from the base of the deltaic deposits, above the lake beds in the oldest part of the Glenns Ferry section. Here it is about 3.6 Ma old and appears about 23 feet above the 3.8-million-year-old top of the Cochiti Normal-polarity Subchron of the Gauss Chron (Neville and others, 1979). In Idaho, this primitive muskrat is also known from the Sand Point and Birch Creek faunas; it was replaced by *Ondatra idahoensis* in Blancan V faunas of Jackass Butte (<2.4 Ma), and *Pliopotamys minor* has no younger record.

In the Ringold Formation of the Pasco basin, *Pliopotamys* is clearly not present in the White Bluffs fauna (4.3 Ma, older than any North American muskrat) or the Blufftop faunas (3.9 Ma, younger than the California record but older than the oldest Glenns Ferry record). Its first appearance in the Taunton fauna of the Ringold Formation (2.9 Ma), as an advanced form, is 700,000 years younger than the oldest Hagerman records, but no fauna of an intermediate age is known between the Blufftop faunas and the Taunton fauna of the Ringold Formation; *Pliopotamys* could have entered the Pasco basin any time between 3.6 and 2.9 million years ago.

The presence of the little muskrat from the Taunton fauna seems to indicate that the Glenns Ferry lake was draining down Hells Canyon at least by 2.9 million years ago. The lake may have been draining by this route since the earliest Glenns Ferry mammal records, because no older faunas are known from the Ringold Formation that postdate *Pliopotamys*' oldest Hagerman record.

As has been mentioned, the oldest Glenns Ferry Formation appears to be in the King Hill area, and is believed to be older than the oldest record of *Pliopotamys minor* at Hagerman. The King Hill record is reversely polarized and is presumed to be older than the Cochiti event recorded at the base of the Hagerman section (Neville and others, 1979). If it is this age, then the paleomagnetic position of the oldest Glenns Ferry lake beds seems to be about the same as that of the Blufftop fauna in the Pasco basin. No *Pliopotamys* has been found this old in the Glenns Ferry Formation, but the right environment is not involved: a muskrat finds little food in a large lake. Thus the oldest record of the Glenns Ferry lake is about contemporaneous with the Ringold Formation Blufftop fauna, and the absence of *Pliopotamys* in Blufftop may be due to delay of the muskrat in entering the Glenns Ferry lake, or to delay caused by the time involved in filling the western Snake River Plain to the then-existing sill at the head of the ancestral Hells Canyon. As has been noted (p. 56–57), the oldest lake beds at Hagerman appear to have been of limited extent, suggesting that the Snake River Plain basin had not yet filled to sill depth.

It is not likely that the little muskrat took an overland route, across the Salmon River Mountains of central Idaho from the Snake River Plain to the Pasco basin. The less aquatically adapted *Mimomys* (*Cosomys*) *primus* did not do so earlier (p. 68–69), and muskrats are closely tied to their habitat and seem to have little sense of direction. Erickson (1963) found that when he moved living muskrats about 2.5 miles from their home range, only 15 percent found their way back, whereas if he moved them only 1 mile, 57 percent found their way back to their former home area. A sense of direction is not important when dispersal routes are closely tied to water routes.

The record of *Pliopotamys* in the Taunton fauna is permissive of a through-flowing Snake River to the Columbia River system from the beginning of the Glenns Ferry lake almost 4 million years ago, and is indicative of such a drainage by nearly 3 million years ago.

The Taunton fauna also has the first (and only) record of the giant beaver *Procastoroides idahoensis* (small form) in the Columbia River basin. Expectably, because of the age of the fauna, the Taunton giant beaver is very similar in size to that from the Birch Creek fauna of the Glenns Ferry

Formation (p. 61); it is larger than *P. intermedius* from the Hagerman fauna, but smaller than typical *P. idahoensis* from Jackass Butte. Like the muskrats, *Procastoroides* appears to have been closely tied to standing water, and nearly all records are from marsh deposits (Kurten and Anderson, 1980, for *Castoroides*), and all are associated with muskrats.

The history of origin of *Procastoroides* is not so certain, however, and it may have derived from *Dipoides* in several areas—the Great Plains, the Snake River Plain; and Gustafson (1978) described a suitable ancestor from the White Bluffs fauna in the Ringold Formation.

Several other forms occurring in the Taunton fauna suggest a Glenns Ferry fauna of about the same age, but these aquatic mammals are most convincing of a hydrologic connection.

CONCLUSIONS

1. Because of the suggested prior history of the muskrat lineage in the Sacramento River drainage basin, *Pliopotamys* appears to have been introduced to the Snake River Plain by the diversion of the Miocene and early Pliocene Snake-Sacramento River drainage. Similarity in the fish and mollusk faunas has indicated, for over a quarter of a century, a probable early connection between the Snake and Sacramento Rivers.

2. The route of the Snake River to the Sacramento River system is not clear, but a route across southeast Oregon does not seem possible because this area has been a highland since about 15 million years ago. A route south from the present position of the Snake River near Twin Falls, Idaho, across northeastern Nevada (and the former path of the Yellowstone "hot spot") to the general area of the modern Humboldt River, west to the Black Rock Desert of western Nevada, through the Alturas lake basin and down the Pit River to the Sacramento River is suggested. This proposed route skirts the highlands of southeastern Oregon (which extend into northernmost western Nevada). Lacustrine basins in the Black Rock Desert, Nevada, and in the Alturas basin, California, contain deposits that range in age from late Miocene into early Pliocene, favoring this hypothesis of the earlier drainage of the Snake River.

The youngest lake beds in the Alturas basin, California, are about 4.7 (±0.5) million years old and (70 feet lower in the section) contain the ancestors of two microtine rodents that are first known in the Snake River Plain from the oldest nonlacustrine Glenns Ferry Formation (3.6 Ma). The oldest Glenns Ferry fossils also include the giant beaver *Procastoroides* (place of origin uncertain) and the first muskrat (derived from ?*Dolomys* of the Sacramento drainage). The youngest fossils of the Alturas lake beds are too old to contain the ancestor of the Glenns Ferry muskrat, first known about 4.1 million years ago in the Sacramento River basin.

Although the two subgenera of the microtine *Mimomys* from the Hagerman delta deposits are known by ancestral species from the Alturas faunas, only one, *M.* (*Ophiomys*), is also known from the Ringold Formation of the Columbia River basin, in the White Bluffs fauna that is 4.3 million years old. The other subgenus known from Hagerman, *Mimomys* (*Cosomys*), has never been reported from the Columbia River basin, but is first known from the San Francisco area and the Sacramento River system; it became extinct in the Pacific Faunal Region before the time of the Taunton fauna of the Ringold Formation.

The history of the dispersal of the subgenus *Mimomys* (*Ophiomys*) suggests that it dispersed from Asia, through Beringia, down the Pacific coast and up the Columbia River, south to the former Snake-Sacramento River drainage as far as the Alturas lake basin. Its earliest records in central and southern California, south of the Alturas area, are much younger than the earliest records in the Pacific Northwest. There is a suggestion that this subgenus was more inclined toward cooler climates than its associates in the Glenns Ferry Formation; for example, the subgenus (as *Mimomys* (*Ophiomys*) *parvus*) did not reach southern California except during a period of maximum glaciation in the United States (p. 30–31).

The other subgenus, *Mimomys* (*Cosomys*), that is present in the Alturas (4.8 Ma) and Hagerman faunas (3.6–3.2 Ma, youngest record is in the Hagerman horse quarry), is unknown in the Columbia River basin, as has been noted. This subgenus appears to have crossed the Columbia River drainage when dispersing southward down the Pacific Coast (about 1 million years before the Snake River was diverted into the Columbia) and moved on to the Sacramento drainage where its earliest records are among the oldest known. Its record in the San Francisco area (from the Maxum fauna; Repenning, 1987) is probably the oldest Blancan fauna in the United States (Blancan being defined by the arrival of *Mimomys*), but has only weak evidence of age. The subgenus appears to have become extinct about 3 million years ago in the Pacific Faunal Region; earlier it dispersed to the Great Plains where it evolved into the subgenus *Ogmodontomys* and persisted throughout the Pliocene.

The early muskrats followed the same route as *Mimomys* (*Cosomys*) perhaps 4.2 million years ago. But they did not become extinct so quickly and, with the giant beaver, appeared in the Columbia River basin by 2.9 million years ago.

From these two points, we believe that the Snake River was diverted from its route through northern Nevada, California, and the Sacramento River drainage, and into its present route down the Snake River Plain to the Columbia River drainage, between 4 and 3 million years ago. Insofar as records indicate, the Glenns Ferry lake began to drain down a preexisting Hells Canyon as soon as the Glenns Ferry lake filled to sill depth; this may have been by 3.9 million years ago and certainly was before 2.9 million years ago. Judging from the Bruneau paleomagnetic section of Neville and others (1979; typical Glenns Ferry lake deposits before 3.4 million years ago), the Glenns Ferry lake was fully developed to sill depth well before 3.4 million years ago.

3. Earlier lakes existed in the position of the Snake River Plain that appear not to have been entirely confined to that area, as defined by the modern topography. The most widespread deposits of these lakes are those of the Chalk Hills Formation of Malde and Powers (1962), which are exposed along the southwest side of the plain, and beyond, for more than 100 miles. This unit of late Miocene age is characterized by saline lake deposits (abundant gypsum, saline diatoms) and thus does not suggest as large an input of fresh water as that provided by the Snake River, nor through-flowing water. It also is more tectonically deformed and in many places is found beyond the boundary faults of the Snake River graben. The Chalk Hills Formation lies unconformably beneath the unnamed, locally oolitic rusty sandstone unit which, in turn, unconformably underlies the Glenns Ferry Formation.

Both of these older units are believed to predate the diversion of the Snake River into the Snake River Plain from its prior route to the Sacramento River system. Age control is not well defined at present, but the Chalk Hills Formation appears to be separated from the Glenns Ferry Formation by at least 4 million years, based upon published information.

Deposits of the approximate age of the Chalk Hills Formation are present beneath the lower Pliocene beds in the Black Rock Desert and in the Alturas basin along the proposed former route to the Sacramento River; in these areas there appears to have been continuous deposition from late Miocene time into earliest Pliocene time. Late Miocene deposits are also widely distributed in eastern Oregon and adjacent Washington and in Idaho beyond the limits of the western Snake River Plain, unlike the Glenns Ferry deposits of Pliocene age.

4. Filling of the Snake River Plain structural basin was by deposits brought into the Glenns Ferry lake by the Snake and apparently other rivers and by lava flows from the northeast flank of the graben. Apparently lava filling was less significant in the downstream part of the basin as the center of the lake, downstream from Oreana nearly as far as Walters Ferry, is progressively farther to the northeast and fluvial deposits are dominant along the southwestern margin. This situation abruptly changed downstream from Walters Ferry and lake beds again were deposited to the western margin of the Snake River Plain for the remaining distance to the Froman Ferry area and the head of Hells Canyon.

The age difference of the oldest lake deposits of the transgressing lake, from location to location, is marked; ages vary from perhaps 4 million years old in the King Hill–Hagerman area (supported by paleomagnetic determinations), to about 2.4 million years old at the southwest margin of the basin west of Bruneau and Grand View (supported by fossils in the overlying marsh beds and paleomagnetic determinations at the Multi-ash section). The youngest possible age of known lake deposition is about 1.7 million years old near the southwest margin of the basin in the Froman Ferry area, an age supported only by the age of the overlying marsh beds.

Along the southwest margin of the basin, from Oreana northwest to the Murphy–Guffey Butte area, Glenns Ferry lake beds are not present or are of only limited exposure; the formation is nonlacustrine in this area. Apparently a major source of fluvial material lay to the west of the Glenns Ferry lake in this area, perhaps an ancient Owyhee River passing through an embryonic Owyhee Mountains. These deposits have not been carefully prospected for fossils, and their age is uncertain. They overlie the Glenns Ferry lake beds that are little more than 2.1 million years old in the Oreana area and at Guffey Butte (not dated, but apparently less than 2.5 Ma). They were mapped as the Glenns Ferry Formation by Ekren and others (1981), but in part they could be a facies of the Bruneau Formation.

We believe it probable that the center of the Glenns Ferry lake was east of the modern Snake River in this downstream area north of Murphy–Guffey Butte and that its deposits are now covered by basalt flows. It is obvious from these relationships that the entire structural basin of the Snake River Plain did not fill completely once the Snake River had been directed into it. Shifting of the lake to the southwest margin of the graben in the Grand View area resulted from filling along the northeast margin; restriction of the lake to the northeast side of the structural basin in the Murphy–Guffey Butte area could have taken place because of filling from the southwest side.

5. In areas away from the lake and the then-prevailing Snake River, pond deposits indicate a lack of association with the river or lake because of the seasonal fluctuations in salinity and temperature they display. Only seasonal temperature changes are recorded in deposits of the Snake River, and deposits of the Glenns Ferry lake are uniform in both temperature and salinity. Marsh deposits, because of their close association with the lake, are also relatively free of indication of variation in both temperature and salinity, but (because they were covered by shallow water) the marshes were warmer than the open lake and were avoided by cold water fish. Their diatom flora and ostracode fauna were distinctly different than those of the open lake and they were the habitat of mammalian faunas.

6. As the lake receded from the head of the basin, either fine-grained fluvial or marsh deposits were deposited on top of the lake beds. Marsh deposits appear to have been deposited only in areas where tributary drainage into the lake was minimal, and are absent in the area of the mouth of the Snake River except as part of the deltaic deposits, where shifting distributaries left lenticular bodies of marsh deposits.

7. Marsh beds are not known for all stages of lake withdrawal, and thus their recognizable presence may record periods of stasis in lowering the level of the Glenns Ferry lake. They, and the overlying fluvial deposits, contain mammalian fossils and therefore are the best source of evidence for dating the stages of withdrawal of the lake. The known marsh deposits were formed 3.6–3.2 Ma (Hagerman; magnetic and faunal age control), 3.1 Ma (Sand Point; magnetic and faunal age control with a weak correlation to oceanic oxygen isotope records), 2.4 Ma (Poison and Birch Creeks; magnetic, climatic, and faunal age control), 2.1 Ma (mid-Jackass Butte; magnetic, climatic, and faunal age control), and <1.67–>1.5 Ma following the last withdrawal of the Glenns Ferry lake (Froman Ferry; magnetic, radiometric, climatic, and faunal age control).

Except for the oldest of these marsh deposits, which was a result of the Snake River delta when the lake first formed and presumably was tectonically timed, these times of marsh deposition are the same as those of known or suspected increasing Northern Hemisphere glaciation, and a climatic cause is suggested for their development. (Compare with figure 2 of Repenning and Brouwers (1992) to correlate with events in the Arctic Ocean region.) Times of increasing or maximum glaciation were times of increased precipitation, and the increased flow from the Snake River headwaters may have produced the stasis in the overall rate of lake drainage that allowed marsh deposits to accumulate in recognizable units.

8. The return of marshes to the Jackass Butte area around 2.0 Ma ago suggests that the outlet of the Glenns Ferry lake was sufficiently restricted that increased flow of the glacial Snake River could not be fully accommodated, forcing a rise in lake level. It seems possible, from hemispheric records, that the region became more arid after this rise in lake level, but the lake deposits did not become saline, suggesting that drainage continued.

The lake seems to have persisted until perhaps 1.7 million years ago in the Froman Ferry area. Hells Canyon must have been incised below the base level of the western Snake River Plain by the end of the Froman Ferry marsh deposition, and subsequent lacustrine deposition of the Bruneau Formation was dependent on the development of local basins behind lava dams across the Snake River.

9. Evidence from the Columbia River basin, near Pasco, Washington, indicates a through-flowing drainage of the Glenns Ferry lake down Hells Canyon after about 3.9 million years ago (after the Blufftop faunas) and before about 2.9 million years ago (before the Taunton fauna). Critical to this interpretation is the dispersal patterns of rodents (especially the dispersal of muskrats along streams), persistent lack of evidence of saline conditions throughout the 2.5 million year life of the Glenns Ferry lake, and the documentation of progressive filling of the western Snake River Plain throughout its history.

10. We postulate that initial drainage down Hells Canyon was by way of a preexisting tributary of the Columbia River and that consideration of the modern elevation of the Glenns Ferry Formation suggests that possibly one-third of the modern depth of Hells Canyon was already cut before the Glenns Ferry lake overflowed a sill and started draining down it. In view of the more limited flow available to cut Hells Canyon before overflow of the Glenns Ferry lake and drainage of the Snake River down it, Hells Canyon may well have begun to form in the Miocene.

11. In correlation with the climatic significance of marsh beds in the Glenns Ferry lake, listed in "7" above, the first record of the cold water stream sculpin is found in the Jackass Butte section, at a time marked by continental glaciation that advanced as far south as Iowa. Not surprisingly, this fish is absent in the younger and warmer marsh beds of the Froman Ferry area.

12. Although several authors have suggested otherwise, a relationship seems indicated between the North American puma and the cat known from the Hagerman faunas, *Felis lacustris*. Minor increase in size and minor morphologic changes throughout the deposition of the Glenns Ferry Formation culminate in a remarkably complete (although fragmented) skeleton from the Froman Ferry sequence indicating that this was the ancestor of the living puma. The Froman Ferry records are by far the oldest fossil puma so far published.

Comparisons of the Froman Ferry puma, and other records, suggest that the puma lineage was the first of the Old World cats to disperse to North America, at the beginning of the Blancan (4.8 Ma ago). The North American cheetah, *Miracinonyx*, was next, at about 2.56 million years ago; it arrived full size with larger limbs than the Froman Ferry (or modern) puma. The genus *Panthera* arrived last, by 840,000 years ago.

A number of features suggest that the living lynx may also have derived from the lineage, although by 1.6 million years ago the Glenns Ferry lineage was already too large (and still had a long tail and too many teeth) to be ancestral to the lynx. Savage (1960, p. 337) suggested that the subgenus *Felis* (*Lynx*) had been established by the time of the Cita Canyon fauna of Texas (about the age of the earliest of the Grand View faunas, ≈2.56 Ma), and Stephens (1959) indicated that the cat from the Rexroad fauna of Kansas (Cochiti event, ≈3.8 Ma; Repenning, 1987) was losing its P\2 in maturity; total loss of this tooth is a distinctive lynx character.

13. Unexpectedly, the only identifiable leporid was a specimen of *Hypolagus gidleyi* from very high in the Cucumber area, close to being the youngest horizon of the Froman Ferry faunal succession and associated with *Plesippus fromanius*. An Irvingtonian age is beyond doubt, and an estimated age of 1.55 million years seems reasonable, although made uncertain by lack of evidence to estimate the duration of the hiatus involved in the overlying unconformity beneath the dated basalt (minimum age 1.5 Ma).

This species has been believed to be no younger than about 2.6 million years old (Flatiron Butte), and the genus is generally considered to have become extinct by the end of the Blancan mammal age of the United States. This belief was a major factor in the erroneous correlation of the polarity pattern at the Multi-ash polarity section south of Oreana.

14. Two horses are present in the Froman Ferry fauna: *Plesippus idahoensis* (Merriam) and *Plesippus fromanius* n.sp., a descendant of the well-known Glenns Ferry horse *P. shoshonensis* Gidley. *P. fromanius* represents direct evolution from the Hagerman horse, through the Jackass Butte horse, *Plesippus stenonis anguinus* (Azzaroli and Voorhies) with persistent direction of changes in the dentition throughout the Glenns Ferry Formation. These evolving characters are in the direction of the subgenus *Equus* (*Equus*) in the upper teeth; the lower teeth retain a simple *Plesippus*-like enamel pattern throughout the Blancan.

The mixed characters (*Equus*-like upper teeth with *Plesippus*-like lower teeth) have been noted elsewhere in the Red Light fauna of western Texas (Akersten, 1972), in the lowest horizon of the type locality of *Equus scotti* at Rock Creek, Texas, and in the Aries fauna, southwestern Kansas (Rock Creek and Aries data from G.A. Izett and J.G. Honey, unpub., oral commun., 1993). According to Izett, the Rock Creek record has been dated close to 1.5 million years old, similar to the Froman Ferry record.

P. idahoensis appears to be a newly introduced lineage to the Snake River Plain in the Jackass Butte fauna, which preserved some plesippine characters but is advanced in its increased size and reduced upper tooth curvature. Both horses appear to be typically plesippine in their lower teeth.

The application of Cope's species *Plesippus simplicidens* to these horses is undefended, and the Glenns Ferry species do not resemble Cope's species. No attempt to defend the synonymy has ever been published and published illustrations show major differences. The use of the species name *Plesippus simplicidens* is here restricted to Cope's type, and to topotypic material collected by Matthew and Simpson in the AMNH.

The use of the genus-group name, *Dolichohippus*, for North American plesippine horses is poorly and, in part, incorrectly defended and biogeographically improbable as defended. It is not used here, and North American species are returned to Matthew's genus *Plesippus*. The subgenus *Dolichohippus* is restricted to the living and fossil African Grévys zebra. This is not to deny that they are closely related, but to emphasize the more advanced stage of evolution shown by the living form and to reflect phylogeny.

15. The realization that the Ondatrini (muskrats) probably arrived in North America about 4.1 million years ago nullifies the evidence of intercontinental dispersal event 4 of Repenning (1987) and Repenning and others (1990). Reevaluation of correlations based upon it is also needed. At present there appears to have been no intercontinental microtine dispersal event at 3.7 million years ago. The event had been only questionably recognized in Europe at the beginning of the Arondellian European small-mammal age (formerly referred to as the small-mammal Villafranchian age or, because of an erroneous assumption by Steininger and others, 1989, p. 24, earliest Villanyian).

Microtine dispersal event 3 is prominently recognized in Europe at the beginning of the Csarnotan small-mammal age, but did not seem to be present in North America (Repenning, 1987). However, if the ondatrine from the Kettleman Hills of California does represent this group (which is not seriously doubted although it is a damaged specimen), it indicates immigration during dispersal event 3 (at the base of the Nunivak Normal-polarity event, 4.2 Ma) and not dispersal event 4 (near the end of the Cochiti event, 3.7 Ma; Repenning and others, 1990). The original dispersal event 4 is not real, and, as in Eurasia, is not recognizable in the North American record. With renumbering because of this change, dispersal event 7 becomes dispersal event 6 (1.9 Ma, at the beginning of the Olduvai event and marking the Blancan/Irvingtonian faunal change in the Eastern Faunal Region of the United States [p. 10]). And the dispersal event introducing the first Irvingtonian forms, *Phenacomys* and *Microtus*, to the Pacific Faunal Region becomes the new dispersal event 7 (1.6 Ma shortly after the end of the Olduvai event; not previously recognized and not evaluated outside of the United States). Dispersal event 7 is recognized in the Eastern Faunal Region as well, by the immigration of *Phenacomys* (but not *Microtus*), as has been discussed (p. 10, 16, and 32).

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CORRECTION

Julia T. Sankey (1991, "A late Blancan–early Irvingtonian vertebrate fauna and magnetic stratigraphy from the upper Glenns Ferry and lower Bruneau Formations near Murphy, southwest Idaho": Northern Arizona University M.S. thesis, 206 p.) studied the fossiliferous section near Tyson Ranch, about 5 miles west of "unnamed butte" (p. 51, 59, 62, 63, 64, 65 of present report). Her paleomagnetic patterns are the same as those found by Neville (1981) at "unnamed butte" (Neville called it the Wild Horse Butte paleomagnetic section); both found a lower, normally polarized magnetozone overlain by a reversely polarized magnetozone. Sankey interpreted this as representing the Olduvai event overlain by younger reversely polarized parts of the Matuyama Chron; Neville believed that it represented the upper part of the Gauss overlain by the oldest part of the Matuyama Chrons. The difference in interpretation equals nearly a million years and can only be clarified by the associated fauna.

In about 1980, Conrad told Repenning of the "unnamed butte" paleomagnetic section, reporting at this time that he had found *Mimomys parvus*, *Mictomys vetus*, and "*Ondatra*" in the section and that the oldest *Mictomys* was about 15 feet below the top of the Gauss (using Neville's call of paleomagnetic events). This has been the basis for Repenning's belief that the earliest record of *Mictomys* in Idaho was about 15 feet below the top of the Gauss Chron (Repenning, 1987, and following). Scott has collected at the "unnamed butte" section several times and has been unable to find *Ondatra*, although *Mictomys* and *Mimomys* are quite common.

However, Sankey reported *Ondatra idahoensis* from the lower, normally polarized magnetozone of Tyson Ranch (oral and written commun., 1995). Her material suggests a slightly larger size than at the type locality, Jackass Butte; clearly not representing the much smaller *Pliopotamys minor* found shortly above the top of the Gauss in the Birch Creek and Poison Creek faunas (see p. 34). It seems reasonable to assume that the immigration of *Ondatra* resulted in the rapid extinction of *Pliopotamys*, but a period of different environmental preferences may have existed in the two muskrats during which the smaller was restricted to marsh environments (Poison Creek and Birch Creek) while the immigrant *Ondatra* was restricted to fluvial environments (Jackass Butte, Tyson Ranch, "unnamed butte"). This possibility cannot yet be evaluated; present evidence indicates only that the oldest *Ondatra* is younger than Birch Creek and the Gauss Chron.

The Tyson Ranch and "unnamed butte" sections can be approximately correlated by tracing a basaltic tuff (the Montini Tuff of Malde (1985)). Therefore, it seems probable that the normally polarized deposits at "unnamed butte" and Tyson Ranch represent the Olduvai event, as inferred by Sankey, and not the top of the Gauss Chron, as inferred by Neville. Statements made in the present report (p. 51 and 64) that suggest that "unnamed butte" appears to be the same age as the Multi-ash polarity section farther to the west seem to be incorrect. In addition, Repenning's statements (1987 and following) that *Mictomys* is found just below the top of the Gauss Chron in Idaho also seem to be incorrect. The oldest known *Mictomys* in Idaho therefore is in the Birch Creek fauna (with an advanced *Pliopotamys minor*) shortly above the top of the Gauss Chron, or in the Ninefoot Rapids fauna of Conrad (1980), which has no paleomagnetic control.

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