[AMERICAN JOURNAL OF SCIENCE, VOL. 279, MAY, 1979, P. 503-526]

MAGNETIC STRATIGRAPHY OF PLIOCENE DEPOSITS OF THE GLENNS FERRY FORMATION, IDAHO, AND ITS IMPLICATIONS FOR NORTH AMERICAN MAMMALIAN BIOSTRATIGRAPHY†

COLLEEN NEVILLE,* NEIL D. OPDYKE,*
EVERETT H. LINDSAY,** and NOYE M. JOHNSON***

ABSTRACT. Correlation of mammalian biostratigraphy with magnetic stratigraphy is here expanded to include terrigenous Pliocene deposits of the Glenns Ferry Formation of the western Snake River Plain. Weakly magnetized fine-grained sediments as well as basaltic lava flows are used to delineate a magnetic stratigraphy for the Glenns Ferry Formation extending from the Cochiti event of the Gilbert reversed epoch to the lowermost portion of the Matuyama epoch. Curie temperature analyses and isothermal remanent magnetization studies indicate that the dominant magnetic mineral in the sediment samples is Ti-rich magnetite, probably of detrital origin.

Previously established faunal localities and radiometrically dated basaltic lavas and pyroclastic beds provide chronologic controls for the magnetic stratigraphy. Three Blancan local faunas (Hagerman, Sand Point, and Grand View) characterize the deposits of the Glenns Ferry Formation. We propose four faunal datum planes based upon either the highest or lowest stratigraphic occurrence of a particular taxon as follows: *Cosomys* LSD (~3.75 mybp), *Equus* LSD (~3.7 mybp), *Prodipodomys* LSD (~3.6 mybp), and *Pratilepus* HSD (~3.2 mybp). Ages have been assigned to each datum plane by extrapolation from the magnetic stratigraphy for the formation. Perhaps the most significant faunal datum is *Equus* (~3.7 mybp) which may represent the earliest record of this post-Hemphillian genus in North America.

INTRODUCTION

Paleomagnetism has become an increasingly valuable tool in stratigraphic correlations as a result of successful attempts to delimit magnetic reversal patterns in terrestrial deposits. Early contributions to the investigations of the paleomagnetic properties of terrestrial materials include the works of Khramov (1958), van Montfrans and Hospers (1969), and Wensink (1972). The application of an extensive magnetic stratigraphy to North American terrestrial sediments and vertebrate faunas was completed by Johnson, Opdyke, and Lindsay (1975) on Plio-Pleistocene deposits of the San Pedro Valley in Arizona. Under some conditions, magnetic stratigraphy for deposits possessing a well defined biostratigraphy enables intercontinental correlation of isolated geologic sections while providing absolute ages for Cenozoic mammalian chronology.

Lindsay, Johnson, and Opdyke (1975) and Opdyke and others (1977) have recently reported the results of combined magnetic and biostratigraphic studies from several areas of the United States and have delimited a preliminary correlation between the magnetic reversal sequence and North American Land Mammal Ages.

The objective of the present study is to determine the magnetic polarity sequence from sediments of the Glenns Ferry Formation of southwest Idaho and to utilize these magnetic results to assign ages to four

† Lamont-Doherty Geological Observatory Contribution No. 2798
* Department of Geological Sciences, Columbia University and Lamont-Doherty Geological Observatory, Palisades, New York 10964
** Department of Geosciences, University of Arizona, Tucson, Arizona 95271
*** Department of Earth Sciences, Dartmouth College, Hanover, New Hampshire 03755

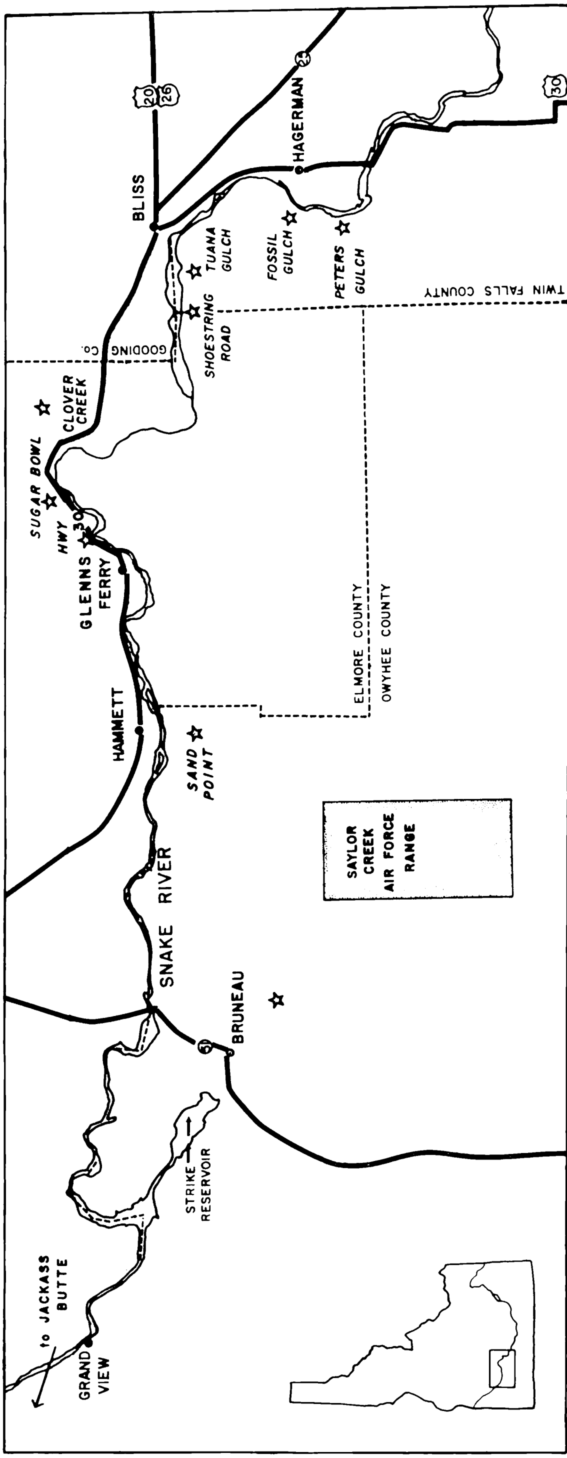


Fig. 1. Map of the study area. Sampling localities are identified by stars.

faunal changes within the Blancan faunal assemblages of the Glenns Ferry Formation.

GEOLOGIC BACKGROUND

Paleomagnetic sampling of the Glenns Ferry Formation of southwest Idaho was concentrated in the area shown in figure 1, part of the western Snake River Plain. Exposures of the Glenns Ferry Formation were sampled near the towns of Hagerman, Glenns Ferry, Bruneau, and Grand View.

Upon completing the first geologic survey of the Plio-Pleistocene deposits of this region, Cope (1884) grouped the entire sedimentary sequence into a single formation — the Idaho Formation. Early stratigraphic contributions were also made by Lindgren (1900) and Stearns (1936). Malde and Powers (1962) subdivided the Idaho Formation into seven distinct formations which now constitute the Idaho Group (fig. 2), and we adopt their definition of the stratigraphic relationships in this paper. Of specific interest to paleomagnetic investigations of the area is the Glenns Ferry Formation, because it contains vertebrate fossil localities and radiometrically-dated lava flows. The formation comprises a thick sequence of poorly indurated silt, clay, and sand, intercalated with olivine-rich basaltic lava flows, basaltic pyroclastic materials, and silicic ash beds. These deposits have an areal extent of several thousand square kilometers in southwest Idaho (Malde and Powers, 1962). Total thickness estimates exceed 600 m. Three depositional environments — fluviatile, lacustrine, and flood plain are characteristic of the formation. Sedimentary facies change sharply over short distances. Massive beds of tan silt and fine sand characterize the lacustrine sediments, while the fluviatile deposits consist of thick accumulations of brownish-gray sand which may display ripple marks or cross bedding. Flood plain deposits contain essentially horizontal beds of calcareous silt that grade into dark clay (Malde and Powers, 1962; Malde, 1972). Additionally, layers of sand, carbonaceous shale, ash, and basaltic lava flows are interbedded sporadically throughout the flood

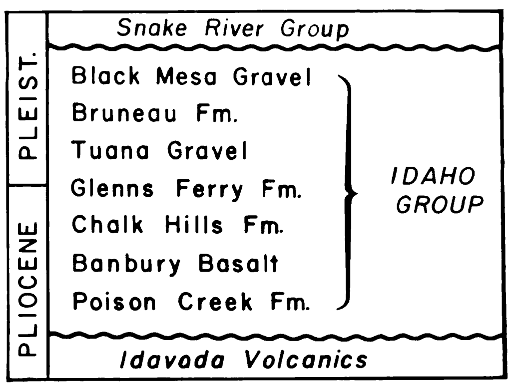


Fig. 2. Stratigraphic relationships of the individual formations comprising the Idaho Group (after Malde and Powers, 1962).

plain deposits. In the present study, most of the sampling localities are flood plain deposits. Exposures of the lacustrine facies crop out at Sugar Bowl and along Highway 30, outside the town of Glenns Ferry. Stratigraphic correlation between individual exposures of the Glenns Ferry Formation is accomplished by tracing local pyroclastic marker beds and lava flows, as described by Malde (1972).

The younger part of the Glenns Ferry Formation crops out approx 110 km west of Hagerman at Jackass, Wildhorse, and Castle buttes. Because lithologic similarities and stratigraphic position with respect to older and younger deposits are the sole means of identifying these localities as part of the Glenns Ferry Formation, it has not been possible to ascertain accurately the stratigraphic relationship between the older portion of the formation represented near Hagerman and the sections cropping out as Jackass Butte. The difficulty arises from the discontinuous exposure of the formation in the intervening areas. The total thickness of the formation, therefore, can only be estimated at present.

SAMPLING AND MAGNETIC MEASUREMENTS

1. *Sampling techniques.*—Samples were collected from 176 sites (170 sediment sites, 6 lava flows) at ten sections in the Glenns Ferry Formation of southwest Idaho (see fig. 1). Three oriented hand samples were chiseled from each horizon (site) after removal of weathered surficial material, and wherever feasible, a six-meter stratigraphic interval between sites was maintained. Sampling procedures involved shaping either a horizontal or vertical surface on each block with a Brunton Compass and inscribing an azimuth and dip symbol prior to removal from the outcrop. Poorly consolidated samples were impregnated with Glyptal to minimize disintegration. In the laboratory, sediment block samples were cut and sanded into 2.5 cm cubes, whereas basaltic samples were cored with a diamond drill bit.

2. *Natural remanent magnetization.*—The intensity and direction of natural remanent magnetization (NRM) of each sample was measured on a computerized 7-Hz fluxgate spinner magnetometer (Molyneux, 1971). Eighteen sampling sites were eliminated from the original 170 sediment sites due to either extremely weak magnetization of the sampled material or to the destruction of oriented block samples during transit. Mean NRM intensities (J_{NRM}) for lava sites range from 1.5×10^{-3} emu/g to 6.2×10^{-4} emu/g, while sediment sites record mean J_{NRM} values of 6.0×10^{-5} emu/g to 1.6×10^{-7} emu/g. Distribution of the average site values of J_{NRM} is plotted in figure 3. From this study, it appears that J_{NRM} is a function of the grain size of the sediment, with clays and ashes corresponding to the most weakly magnetized samples ($\sim 10^{-7}$ emu/g) while silts and sands record higher NRM intensities, on the order of 10^{-4} emu/g to 10^{-6} emu/g. The NRM values stronger than 10^{-4} emu/g are contributed by the lavas.

3. *Stability.*—A stereographic projection of the NRM mean directions for 157 sites is shown in figure 4. The directions are dispersed

around the direction of the present geomagnetic field. Alternating field (A.F.) demagnetization analyses were performed on pilot samples to determine the nature of the magnetization and to select a suitable blanket demagnetization field for the removal of secondary components in the other samples. Changes in the direction of magnetization with progressive A.F. demagnetization to 300 oe for typical samples from four sites is shown in figure 5A. From stereographic projections it is evident that a peak field of 300 oe is sufficient to permit the characteristic directions to be discerned, although in certain instances (for example 148B), A.F. demagnetization in stronger applied fields would be required to remove totally secondary overprinting. Figure 5B illustrates the accompanying

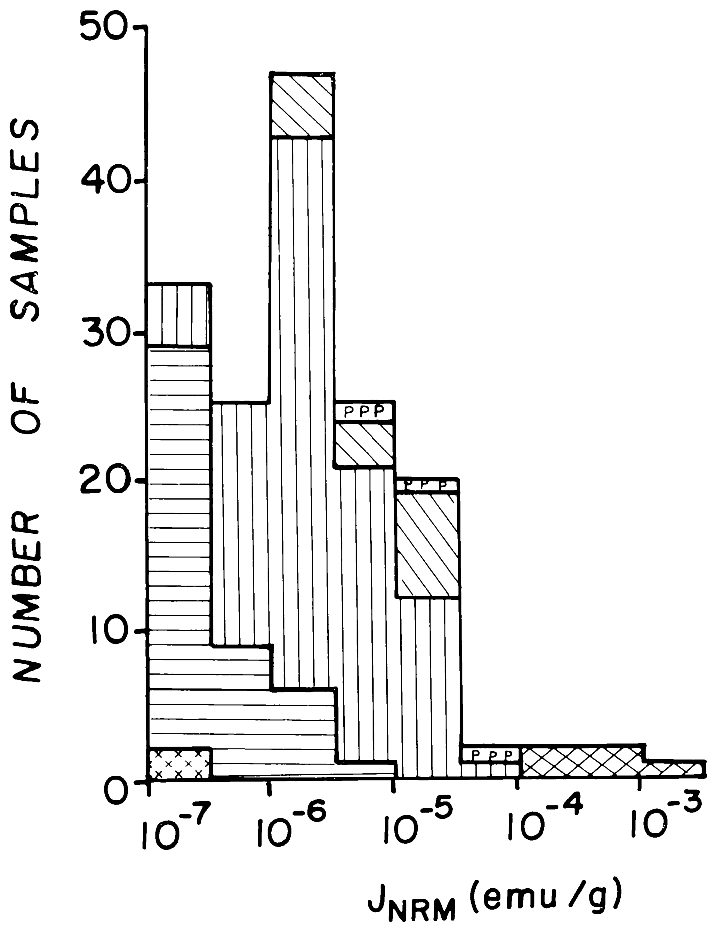
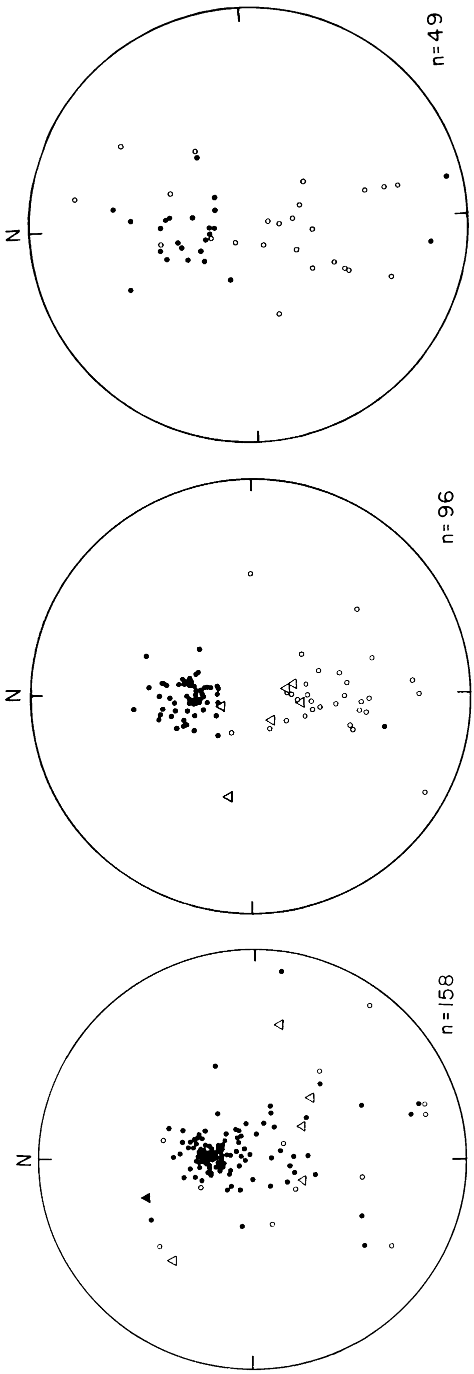


Fig. 3. Histogram distribution of NRM intensities and lithologic anffinities for 157 sites in the Glenns Ferry Formation. Lithologic symbols are as follows: horizontal lines — clay; vertical lines — silt and silty cla; diagonal lines — sand; crosses — ash; PPP — pyroclastics; and criss-crossed line — lava.

Figure 4



A. Stereographic projection of the site mean NRM directions of magnetization for N = 158 sites. In each stereographic projection, sediment sites are represented by circles — closed circles symbolize normally magnetized sites, open circles are reversely magnetized. Triangles symbolize lava sites.

B. Stereographic projection of A.F. demagnetized statistically significant CLASS I site (N = 96).

C. Stereographic projection of A.F. demagnetized sites for CLASSES II to IV. Random CLASS V results have been omitted.

intensity changes that result from A.F. demagnetization of these samples. Samples 163B and 189B display the behavior of normally magnetized samples, in which a large decrease in the J/J_{NRM} ratio occurs in the low fields of 50 to 100 œ, followed by a more gradual reduction in the value of J/J_{NRM} as the A.F. demagnetization field is increased. In a peak field of 300 œ, the value of J/J_{NRM} ranges from 0.2 to 0.3. The characteristic responses of reversely magnetized samples to A.F. demagnetization are illustrated by samples 148B and 150B. Reversely magnetized samples maintain higher J/J_{NRM} ratios than the normally magnetized samples, often recording values between 0.4 to 0.6 in the peak field of 300 œ. Figure 5B illustrates that secondary normal overprinting can be successfully removed from reversely magnetized samples via A.F. demagnetization. Variance in the coercivity of secondary components is reflected in the relative stability of the directions of magnetization.

Based upon pilot studies of specimens of varying lithologies from each locality, a peak field of either 200 or 300 œ was selected for blanket demagnetization of the remaining sediment samples. Fossil Gulch samples which exhibited very resistant secondary components required A.F. demagnetization at 400 œ. Lavas were routinely demagnetized at 150 œ, since preliminary demagnetization analyses indicated an extremely strong and stable nature of the original thermal remanence.

Due to the disparity in stability characteristics between the sites leading to a large variability of reliability between the sites, the site direction classification introduced by Opdyke and others (1977) is adopted in the presentation and interpretation of data in this paper. According to this classification, site directions are divided into five categories, based upon their statistical significance. Any site that is statistically significant (Watson, 1956) constitutes a CLASS I site. In instances where only two samples are available per site, and both yield concordant magnetic directions, a CLASS II site is established. CLASS III sites possess statistically random directions of magnetization, but with two of the three samples giving similar polarity information. When a strong distribution is evident, the site is assigned to CLASS IV, and random results to CLASS V. In this study, the breakdown of sites into respective classes is as follows: 96 CLASS I, 25 CLASS II, 20 CLASS III, 4 CLASS IV, and 13 CLASS V. Such a classification is useful in paleomagnetic studies of sediments, because it permits the fundamental magnetic stratigraphy of an area to be delineated on the basis of the statistically significant sites (CLASS I), while employing samples representing good, though not statistically significant site directions (for example, CLASSES II, III, and IV) to refine further the interpretation of the magnetic results.

The directions of the magnetically cleaned CLASS I sites are plotted on a stereographic projection in figure 4B. From this plot it is evident that a bimodal distribution of magnetic directions exists — one group of sites directed toward the north with positive inclinations and a second, approximately antipodal assemblage of sites, recording a southerly magnetic direction with negative inclinations. The mean direction of the first group (n = 58) is 359.1° Declination and 57.0° Inclination (α_{95} = 3.1), while that of the southerly group (n = 38) is 177.0° Declination and −50.8° Inclination (α_{95} = 10.4). A stereographic projection of all A.F. demagnetized samples is presented in figure 4C. A comparison between the two sets of results shows good agreement in the directions of magnetization and further attests to the reliability of results provided by samples from CLASSES II thru IV.

4. *Magnetic minerals.*—As a means of identifying the magnetic minerals that generate the natural remanence of these sediments, characteristic specimens of various lithologies of the floodplain facies at Peters Gulch were subjected to isothermal remanent magnetization (IRM) and Curie temperature (JsT) analyses. IRM acquisition curves for the Peters Gulch samples are illustrated in figure 6A. Each of the five specimens approaches saturation magnetization in an applied field of 1.5 kOe. The intensity of the lower curve in figure 6A is nearly an order of magnitude smaller than the intensities of the other four curves and may be explained by the fact that the susceptibility and J_{NRM} calculations for the sample are also an order of magnitude less than comparable measurements of the remaining samples. Exposing the samples to progressively

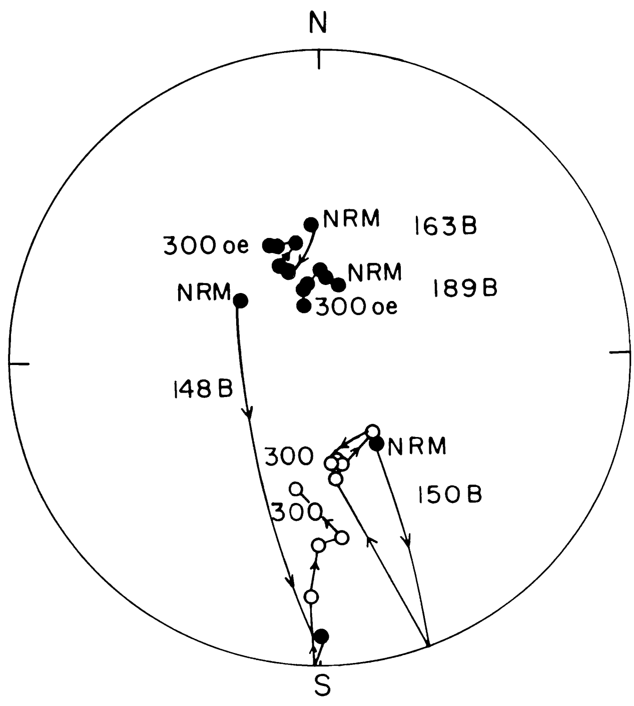
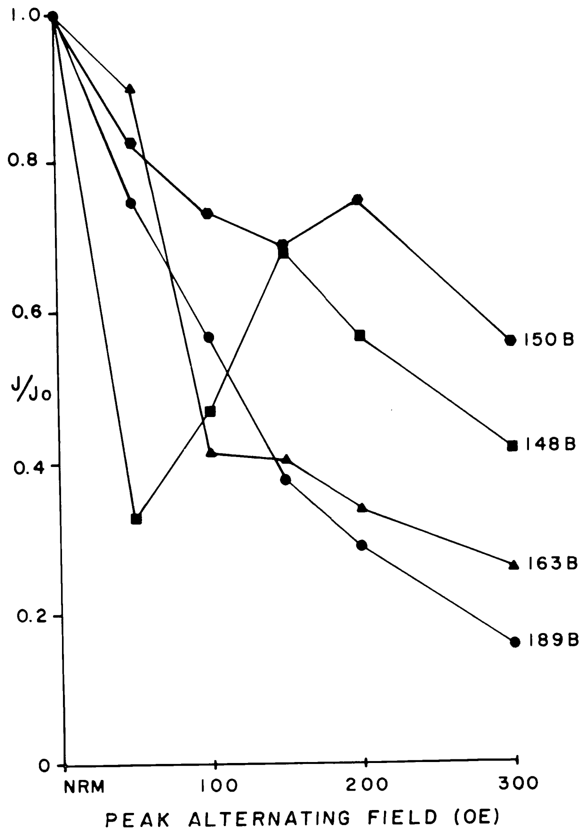


Fig. 5A. A.F. demagnetization curves for four samples showing the change in direction of magnetization plotted on a stereonet. Open and closed symbols follow the conventions stated in figure 4.

stronger opposing fields results in remanent coercivity values of 250 to 350 œ, as shown in figure 6B, except for the one sample whose coercivity was 650 œ. This strong coercivity (Hcr) was exhibited by the sample that yielded the lowest intensity IRM curve. This combination of high coercivity and low IRM value may point toward the presence of minor amounts of hematite in this particular sample.

Following the IRM study, Curie temperature analyses of the magnetic minerals of the sample were done. Magnetic minerals were extracted from the sediment samples by the technique outlined in Løvlie, Lowrie, and Jacobs (1971), and JsT analyses were conducted with a Curie balance, as described in Kent and Lowrie (1974). All samples were heated in air (from 20°-600°C in 10 min), and the resulting thermomagnetic curves were irreversible (fig. 7). The Curie temperatures for the minerals of these specimens fall in the range of 500° to 520°C, suggesting that the dominant magnetic mineral is magnetite containing small amounts of titanium



B. Plot of intensity changes resulting from A.F. demagnetization for the same four samples.

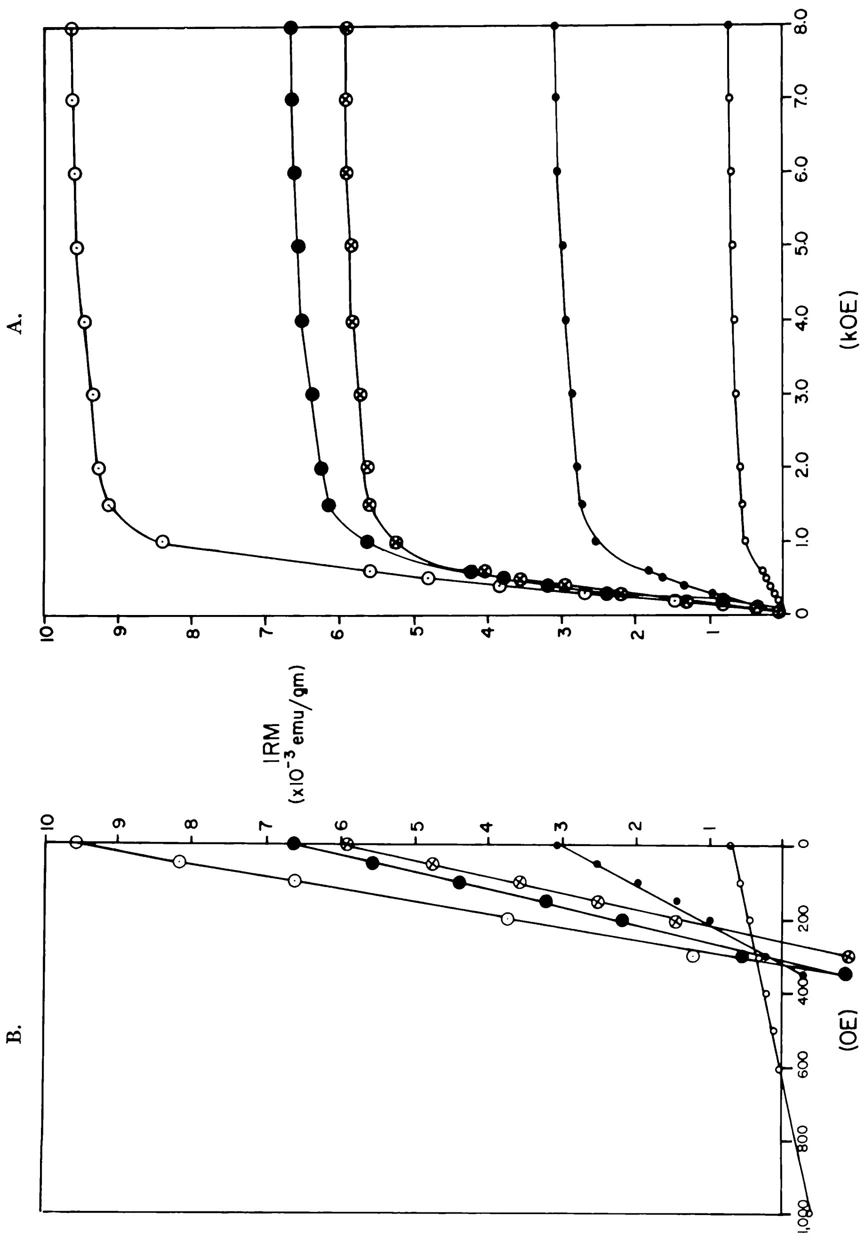
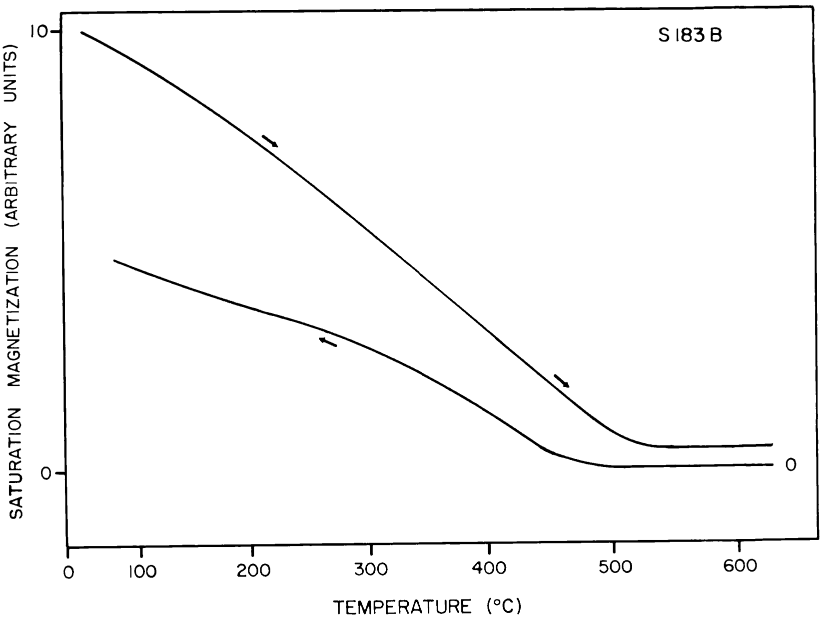


Fig. 6 (A) IRM acquisition curves and (B) remanent coercivity for five Peters Gulch samples.



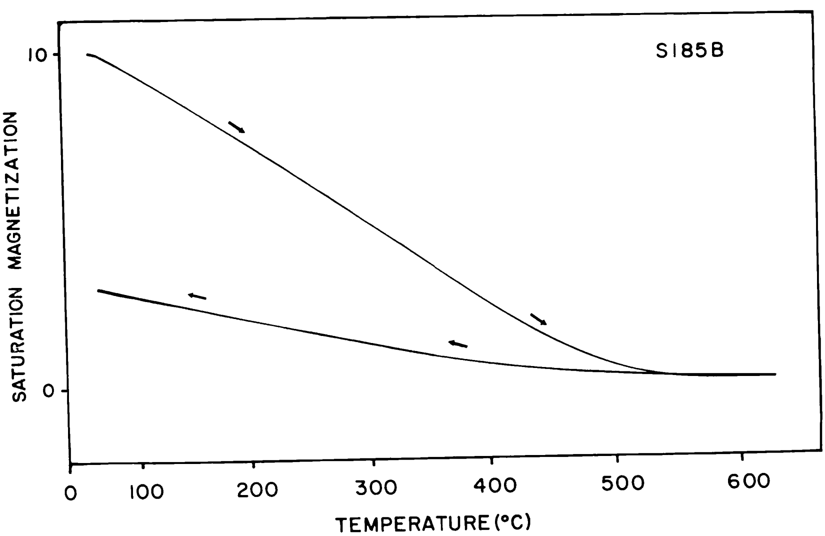


Fig. 7. Characteristic thermomagnetic curves for magnetic mineral extracts from two specimens from Peters Gulch. Curie temperatures of 520°C for S183 (silt) and 510°C for S185 (sand) indicate that Ti-rich magnetite is the dominant magnetic mineral in each instance.

in its crystal lattice. A second Curie temperature of 450°C was frequently detected on the cooling curve and may denote low temperature oxidation of members of the magnetite–ulvospinel solid solution series to form cation deficient titanomaghemites, which will eventually invert to a constituent of the hematite–ilmenite series (Haggerty, 1976). Since a sufficient amount of mineral extract could not be accumulated for the specimen with the high coercivity it was not possible to obtain Curie temperature data that could confirm the presence of hematite.

The Fe–Ti oxides that contribute to the magnetic properties of these sediments are probably detrital grains which may have been derived from the weathering of older basaltic volcanic rocks. If so, detrital remanent magnetization can be considered to account for the primary natural remanence of the sediments, while other forms of magnetization, such as chemical remanent magnetization and viscous remanent magnetization, may contribute to the secondary components.

MAGNETIC STRATIGRAPHY

The magnetic stratigraphy formulated for nine individual sections of the Glenns Ferry Formation is shown in figure 8. One of the four sections sampled in the Hagerman area, Peters Gulch, containing 190 m of sediments, provides the most continuous magnetic record of any sampling locality. The uppermost 12 m of sampled section at Peters Gulch record a period of reversed polarity. The underlying 56 m of sediments were deposited during a normal polarity interval. An extensive zone of reversed magnetic polarity characterized the underlying 120 m, and at the base of the section 2 m of sediment were normally magnetized. Both the Fossil Gulch and Peters Gulch ashes crop out in the lower reversed sequence. Bed I, the stratigraphic equivalent of the Shoestring Road Lava, was also deposited within the reversed polarity zone and crops out below the transition from reversed to normal polarity.

The next longest stratigraphic section was sampled at Fossil Gulch, where a well known fossil locality, the Hagerman Horse Quarry (Gazin, 1936) is situated. The sedimentary sequence of Fossil Gulch is correlative with Peters Gulch, and the magnetic column for Fossil Gulch consists of a reversed zone in the lower part of the section, followed by a transition to normal polarity in the upper portion. As in the case of Peters Gulch, both the Peters Gulch and Fossil Gulch ashes occur in the reversed polarity zone. At Fossil Gulch, Bed I lies 14 m below the polarity transition, while the Horse Quarry is exposed 21 m above the magnetic transition, in normally magnetized sediments.

Two other sampling localities at Tuana Gulch and Shoestring Road substantiate the magnetic results obtained from the longer sections at Fossil Gulch and Peters Gulch. The exposure sampled near Tuana Gulch is approx 75 m thick and is capped by the Shoestring Road Lava. Magnetic results reveal that the entire sedimentary sequence and the lava samples are reversely magnetized. At Shoestring Road the reversely magnetized Shoestring Road Lava forms the base of the section and is overlain by 45 m of normally magnetized sediments.

Malde (1972) has correlated the lacustrine facies of the Glenns Ferry Formation exposed at Sugar Bowl and along Highway 30 outside the town of Glenns Ferry with the lower portion of the formation in the Hagerman area by tracing pyroclastic marker beds. Bed J (approximately equivalent to Bed I) crops out in a reversely magnetized zone which roughly spans the lower 33 m of sediments at Sugar Bowl, and a transition to a normally magnetized sequence occurs 166 m above the top of Bed J. Stratigraphic relations of the individual exposures on Highway 30 were determined by tracing Beds P, Q, and R. Initial sampling reveals that these younger deposits represent a thick normal magnetozone.

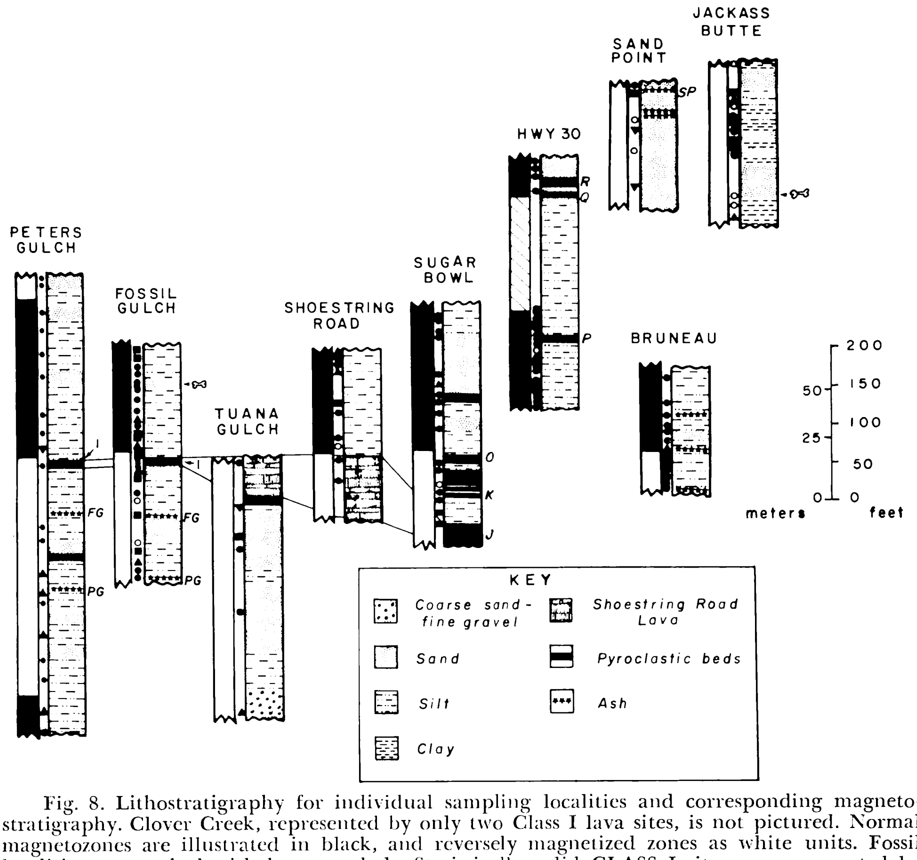


Fig. 8. Lithostratigraphy for individual sampling localities and corresponding magnetostratigraphy. Clover Creek, represented by only two Class I lava sites, is not pictured. Normal magnetozones are illustrated in black, and reversely magnetized zones as white units. Fossil localities are marked with bone symbols. Statistically valid CLASS I sites are represented by filled circles; CLASS II, filled triangles; CLASS III, filled squares; CLASS IV, inverted filled triangles and CLASS V, open circles. Stratigraphic correlation of pyroclastic beds I and J with the Shoestring Road Lava is indicated by solid black lines. FG = Fossil Gulch Ash, PG = Peters Gulch Ash, and SP = Sand Point Ash. With the exception of the Bruneau and Jackass Butte sections, the lithostratigraphy for each locality is based on Malde (1972).

Paleomagnetic sampling of the formation was extended westward into beds at Sand Point, south of the town of Hammett, and a reversely magnetized section 40 m thick was recorded. Two reversely magnetized lava sites from Clover Creek represent the oldest samples from the formation. Deposits from Jackass Butte corresponding to the uppermost portion of the Glenns Ferry Formation are characterized by a 75 m thick zone of reversed polarity.

Finally, a magnetic stratigraphy was delineated for Glenns Ferry sediments that crop out southeast of Bruneau. This exposure measured 46 m in thickness and contained three distinct ash units. The lower 16 m of sediments were reversely magnetized and were overlain by 30 m of normally magnetized deposits. As the Glenns Ferry Formation near Bruneau has not as yet been correlated into the established stratigraphy of Malde (1972), the results from this locality cannot be incorporated into the final interpretation.

INTERPRETATION OF DATA

A magnetic polarity sequence corresponding to the composite geologic section for the Glenns Ferry Formation is pictured in figure 9. Evidence presented here indicates that the Glenns Ferry Formation spans the magnetic polarity time scale from the late Gilbert to early Matuyama epochs.

The lower part of the Glenns Ferry Formation exposed at the four individual localities near Hagerman encompasses the magnetic polarity time scale from the base of the Cochiti event of the Gilbert epoch to the base of the Mammoth event of the Gausss epoch. Independent age controls on this interpretation are provided by radiometric dates for lava flows, pyroclastic beds, and ash units from the formation in the Hagerman area. In their determination of the age of the Hagerman local fauna, Evernden and others (1964) made initial radiometric measurements on the Deer Gulch Lava Flow and two ash units (KA 831 and KA 832). The Fossil Gulch Ash (KA 831), which was sampled approx 18 m below Bed I (the stratigraphic equivalent of the Shoestring Road Lava) in Fossil Gulch, yielded an age of 3.3 mybp. A second, unnamed ash (KA 832) correlating to a position slightly below the Hagerman Horse Quarry has been dated at 3.2 mybp. Evernden and others (1964) also calculated an age of 3.48 ± 0.27 mybp for the Deer Gulch Lava Flow and accepted this age as more reliable than those obtained from glass shards in the ashes KA 831 and KA 832. Obradovich (personal commun.) conducted K–Ar age determinations on plagioclase separates from three basaltic samples from the Shoestring Road Lava Flow and Bed I and calculated a mean age of 3.57 ± 0.21 mybp, which closely parallels the results of Evernden and others (1964).

Conflicting data for the age of the Shoestring Road and Deer Gulch Lava Flows are presented by Armstrong, Leeman, and Malde (1975). As a result of K–Ar dating of whole rock samples, these authors suggest an age of 5.9 ± 1.0 mybp for the Deer Gulch Lava and 6.2 ± 0.7 mybp for the Shoestring Road Lava. Since the age determinations provided by Armstrong, Leeman, and Malde (1975) are not concordant with existing paleontological interpretations and are anomalously older than those of Evernden and others (1964) and Obradovich (personal commun.), we feel that the results of our paleomagnetic investigations in the Hagerman area would be better interpreted by adhering to the younger radiometric ages presented by Evernden and others (1964) and confirmed by Obradovich (personal commun.). The K–Ar dates of 3.48 ± 0.27 mybp for the Deer Gulch Lava (Evernden and others, 1964) and 3.57 ± 0.21 mybp for samples of the contemporaneous Shoestring Road Lava and Bed I (Obradovich, personal commun.) support the interpretation of the polarity transition occurring above the lava flow as the Gauss/Gilbert boundary. The two reversely magnetized samples from the Clover Creek Lava flow are stratigraphically older than the Hagerman deposits and probably represent a portion at the Gilbert epoch below the Cochiti event.

The magnetic stratigraphy developed for the lacustrine beds at Sugar Bowl may be correlated to the Hagerman area via the relationship between Beds I and J discussed previously. Therefore, the transition from

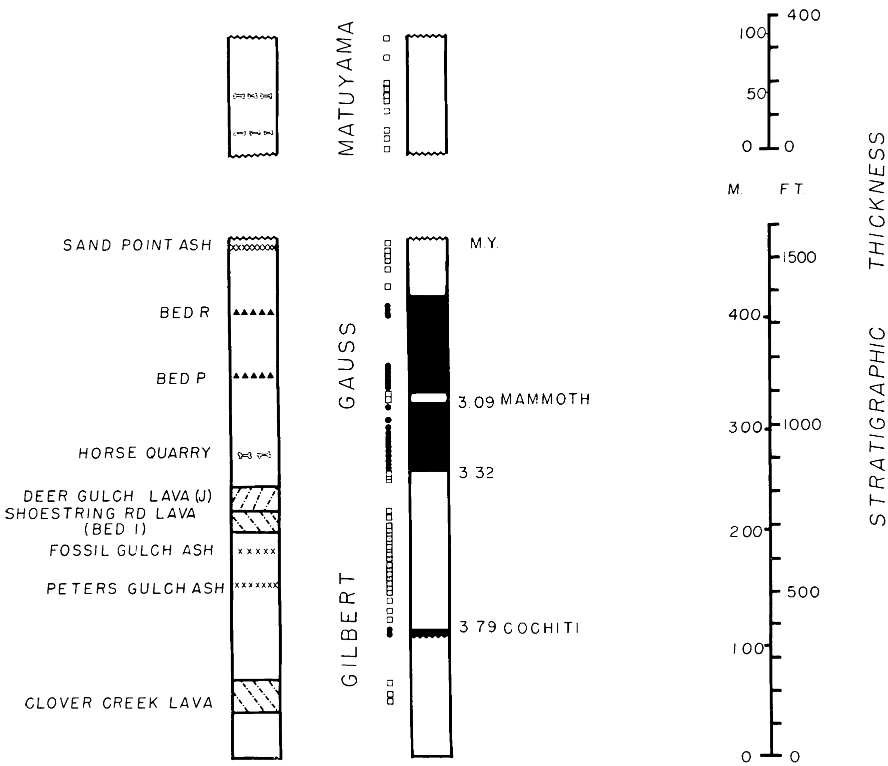


Fig. 9. Composite stratigraphic section for the Glenns Ferry Formation and its corresponding magnetostratigraphy.

reversed to normal polarity, which overlies Bed J, also corresponds to the Gauss/Gilbert boundary. The prolonged normal zone exhibited by the stratigraphically younger sites on Highway 30 is believed to comprise part of the middle to late Gauss epoch. It is probable that the Kaena event, which has not been recognized in the sedimentary sequence, may be present in the present sampling gap between Beds P and R.

Reversely magnetized deposits from Sand Point may represent either the earliest Matuyama or one of the two normal events of the Gauss, although further stratigraphic and paleontological work is necessary before the Sand Point section may be definitively placed into the framework of the magnetic time scale. A radiometric age of ~1.4 mybp for a lava from the overlying Bruneau Formation places the upper limit of the Glenns Ferry Formation in the early Matuyama epoch.

VERTEBRATE PALEONTOLOGY

The Glenns Ferry Formation has produced a rich and diverse fauna of both vertebrate and invertebrate fossils. Three geographically distinct vertebrate faunas — the Hagerman local fauna, the Sand Point local fauna, and the Grand View local fauna are recognized in the Glenns Ferry Formation. Vertebrate paleontologists (Gazin, 1936; Hibbard, 1959; Zakrzewski, 1969; Shotwell, 1970; and Bjork, 1970) usually assign a late Pliocene to early Pleistocene age to the Glenns Ferry Formation, based on the vertebrate faunal assemblages.

The Horse Quarry at Fossil Gulch near Hagerman is one of the best known fossil sites in the Glenns Ferry Formation and is a principal reference for the Hagerman local fauna. More than 100 fossil horse skulls and 15 complete horse skeletons were collected from the Horse Quarry in the early 1930's by paleontologists from the U.S. National Museum. More recently, paleontological studies of rodents (Hibbard and Zakrzewski, 1967; and Zakrzewski, 1969), rabbits (Hibbard, 1969), insectivores (Hibbard and Bjork, 1971), and carnivores (Bjork, 1970) have added to our knowledge of the Hagerman fauna. As defined by the above authors, the Hagerman local fauna is based primarily on about 100 localities in a 10 km area on the west bank of the Snake River near Hagerman. Those sites span a stratigraphic interval of about 150 m (elevation 880-1030 m), with the Horse Quarry near the upper limit of that stratigraphic interval. A complete and up-to-date faunal list for the Hagerman local fauna is given by Skinner and Hibbard (1972, p. 125-130).

The Sand Point local fauna is based on fossils from three sites (USGS loc. 19128, USGS loc. 19129, and UO loc. 1405) on a promontory south of the Snake River south of the town of Hammett, Owyhee County. Hibbard (1959, p. 19-20) gives a faunal list for the Sand Point local fauna, with the emendation that *Pliophenacomys idahoensis* is now known as *Ophiomys taylori*. Hibbard and Zakrzewski (1967) showed that progressive dental characters seen in *Ophiomys taylori* from Sand Point suggest the Sand Point fauna might be younger than the Hagerman fauna. The absence of two rodent genera, *Cosomys* and *Synaptomys*, from the Sand

Point fauna might be significant. *Cosomys* occurs in reversely magnetized deposits of the lower Glenns Ferry Formation which have yielded the Hagerman fauna. *Synaptomys* occurs in reversely magnetized deposits of the upper Glenns Ferry Formation within the Grand View fauna. Repenning (personal commun.) concluded after a thorough review of microtine rodents from the Glenns Ferry Formation that *Pliopotamys* specimens from Sand Point are most like those from the presumed younger Sand Draw fauna of Nebraska and *Ondatra idahoensis* from the Grand View fauna.

Geological mapping by Malde and Powers (1962) indicates the Sand Point fauna should be stratigraphically higher than the Hagerman fauna, but this stratigraphic relationship is tenuous due to marked facies changes and limited marker beds. Both the Hagerman and Sand Point faunas are Blancan Land Mammal Age.

The Grand View local fauna is from the vicinity of Jackass Butte on the south side of the Snake River about 112 km west and north of the Hagerman sites. Fossils from Grand View were described by Wilson (1933), with later additions by Schultz (1936), Hibbard (1959), and Shotwell (1970). The most recent comprehensive list of the Grand View local fauna is given by Shotwell (1970, p. 12), with the emendation that *Pliopotamys idahoensis* is commonly known as *Ondatra idahoensis*. Both Shotwell (1970) and Bjork (1970) consider the Grand View local fauna Blancan Land Mammal Age. Shotwell believed the Grand View and Hagerman faunas were about contemporaneous, while Bjork believed the Grand View fauna was late Blancan, the Hagerman fauna being early Blancan. Stratigraphic and paleontologic data indicate a late Blancan age for the Grand View fauna. Recent work by J. A. White and his students indicates the youngest part of the Glenns Ferry Formation at Jackass Butte contains the genus *Mammuthus* and is therefore Irvingtonian Land Mammal Age. (J. A. White, personal commun.).

The Tuana Gravels that overlie the Glenns Ferry Formation west of Hagerman are practically unfossiliferous. Until recently, the only vertebrate fossils known from the Tuana Gravels are indistinctive leg bones of a proboscidean (Malde and Powers, 1962, p. 1210). During June, 1978 a tooth of the proboscidean *Stegomastadon* was collected about 3.5 m above the base of the Tuana Gravel at USGS loc. M1342, directly above the Hagerman Horse Quarry (Repenning, personal commun.). The Bruneau Formation overlies the Glenns Ferry Formation farther to the west and has produced a number of scattered vertebrate fossils, the most significant of which is *Mammuthus*. A radiometrically dated lava (1.36 mybp) occurs in the Bruneau Formation. The gravel bed that yielded the *Mammuthus* remains is too coarse and poorly indurated to provide magnetic polarity information. Vertebrate fauna from the Bruneau Formation is considered Irvingtonian Land Mammal Age, based primarily on the record of *Mammuthus*.

Stratigraphic ranges of 17 genera recorded from the Glenns Ferry Formation are shown in figure 10. These ranges are plotted relative to elevations in the cliffs near Hagerman and the stratigraphic sections of Bjork (1970) and Malde (1972). The Peters Gulch ash is placed at an elevation of approx 910 m, the Fossil Gulch ash at about 940 m, and the Horse Quarry at about 1000 m. Magnetic polarity of the stratigraphic sequence is shown to afford comparison with magnetic polarity sequences elsewhere. Some of the stratigraphic ranges were already determined by Zakrzewski (1969). Other ranges were plotted with the help of locality

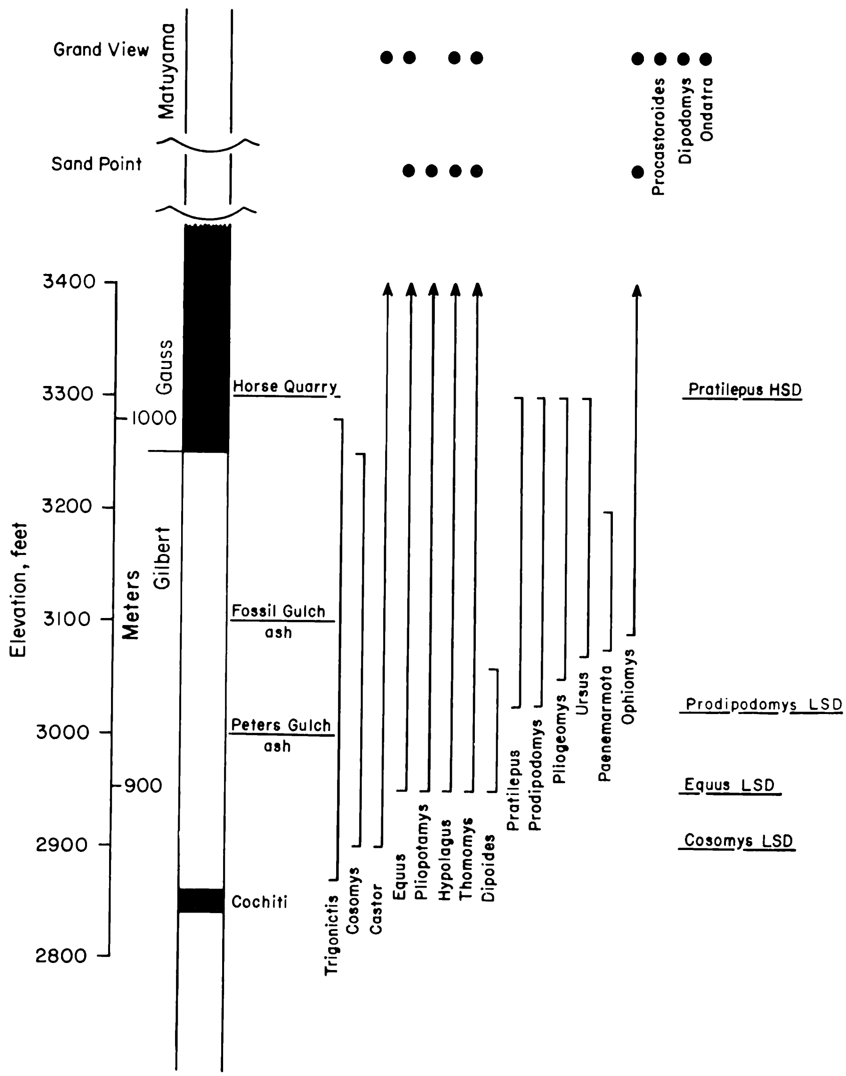


Fig. 10. Correlation of vertebrate biostratigraphy of the Glenns Ferry Formation with the composite magnetic stratigraphy. Four distinct faunal datum planes characterizing the formation are labelled to the right of the figure.

information in the literature or provided by the U.S. Geological Survey, Denver, and the University of Michigan Museum of Paleontology.

From these stratigraphic ranges, four genera are selected to define significant faunal events that we name faunal datum planes. These faunal events are subject to the same limitations specified in Opdyke and others (1977), that is, they mark the lowest or highest stratigraphic occurrences of a taxon within this stratified sequence. The faunal datum planes are given an age by extrapolation from dated magnetic polarity reversals (Cochiti event and Gauss/Gilbert boundary) within the same section. The lowest stratigraphic occurrence and highest stratigraphic occurrence of the named taxon are designated LSD and HSD, respectively.

We emphasize that our use of LSD and HSD differ from the use of FAD and LAD by Berggren and Van Couvering (and others). Our designation of *lowest stratigraphic datum* (LSD) rather than *first appearance datum* (FAD) and highest stratigraphic datum (HSD) rather than *last appearance datum* (LAD) indicates a local stratigraphic event rather than a widespread temporal event. The lowest (or highest) stratigraphic datum is explicably a biostratigraphic event, restricted to that local section. Other faunas with the same taxon may be younger or older than the LSD taxon, where it was designated. The first appearance (or last appearance) datum is explicitly a biochronological event with extraordinary geographical limits (Berggren and Van Couvering, 1974). An FAD event is recognized as a significant biological and chronological event prior to evaluating its chronologic limits. All records of that taxon are then evaluated biostratigraphically and/or radiometrically to limit the taxon in a precise time frame (Van Couvering and Berggren, 1977, p. 284). All faunas with that same taxon (for example, *Hipparion*) are implicitly no older than the FAD and the fauna with the FAD. LSD events evaluate dispersal and evolution of an individual taxon (for example, *Equus* of the Glenns Ferry Formation, the Palm Springs Formation, Calif., and the St. David Formation, Ariz.) but say little about the relative age of other faunas with that taxon. Age of the faunas with LSD events are evaluated independent of the fossils, by comparison with the polarity time scale.

The *Cosomys* LSD (~3.75 mybp) marks the lowest stratigraphic occurrence of the microtine rodent *Cosomys* in the Glenns Ferry Formation. *Cosomys* appears to be related to the well-known European genus *Mimomys* (Wilson, 1933; Hibbard, 1964) which occurs in late Ruscinian and Villafranchian faunas of Europe (Mein, 1975). Ancestry of both *Cosomys* and *Mimomys* is probably in the genus *Promimomys*, which is known from Hemphillian deposits of Oregon, and in early Ruscinian deposits of Europe. *Cosomys* may be derived from North American *Promimomys* or it may be an immigrant from Eurasia, other workers are presently evaluating its ancestry. Either way, the Glenns Ferry *Cosomys* LSD may record the earliest occurrence of this taxon in North America. *Cosomys* is also recorded from the Coso fauna of southern California.

The mustelid *Trigonictis* occurs in the lower part of the Glenns Ferry Formation, ranging from an elevation of about 865 m (below the

Cosomys LSD) to about 990 m. *Trigonictis* differs slightly from the late Ruscinian and Villafranchian mustelid of Europe, *Enhydrictis* (including *Pannonictis*). Pilgrim (1933) and Bjork (1970) consider the European Miocene mustelid *Trochictis* ancestral to both *Trigonictis* and *Enhydrictis*. Hence, *Trigonictis* is probably a Eurasian immigrant (Repenning, 1967), and its earliest record in the Glenns Ferry Formation appears to be slightly earlier than *Cosomys* LSD. The beaver *Castor* appears in the Glenns Ferry Formation approximately at the *Cosomys* LSD. *Castor* is a member of the subfamily Castorinae (in contrast to *Dipoides* which is in the subfamily Castoroidinae), whose known Miocene and Pliocene record is primarily in the Old World. Probably *Castor* was derived from an Old World genus and immigrated to North America during the Pliocene. Repenning (1967) lists *Castor* as a Hemphillian immigrant to North America but its Hemphillian record is not well documented.

The *Equus* (=*Plesippus* of some authors) LSD (~3.7 mybp) marks the lowest stratigraphic occurrence of the horse *Equus* in the Glenns Ferry Formation. *Equus* evolved from a North American Hemphillian horse (probably *Dinohippus*), and its appearance is considered a diagnostic criterion for recognition of Blancan Land Mammal Age. The appearance of *Equus* in deposits of the San Pedro Valley (Johnson, Opdyke and Lindsay, 1975) and the Anza-Borrego Desert (Opdyke and others, 1977) is later, in the Gauss magnetic epoch. The Glenns Ferry *Equus* LSD may be the earliest record of *Equus*. Other taxa that appear in the Glenns Ferry sequence at about the level of the *Equus* LSD are *Pliopotamys, Hypolagus, Dipoides,* and *Thomomys*. *Pliopotamys* is a microtine rodent believed near the ancestry of the *Ondatra* and possibly *Neofiber* by Zakrzewski (1974). *Ondatra* occurs higher in the Glenns Ferry Formation, in the Grand View fauna. *Hypolagus* and *Dipoides* are both known from Hemphillian deposits. *Thomomys* is a geomyid rodent whose earliest record is Blancan. The *Equus* LSD may represent the earliest record of *Thomomys* as well as *Equus*. Genera associated with the *Equus* LSD are all autochthonous, whereas those associated with the *Cosomys* LSD are questionably allochthonous.

Prodipodomys LSD (~3.6 mybp) marks the lowest stratigraphic record of the kangaroo rat in the Glenns Ferry Formation. *Prodipodomys* is recorded from earlier (Hemphillian) deposits at Redington, Arizona (Jacobs, 1977) and Edson, Kansas (Hibbard, 1939). It is well represented in North American Blancan deposits but is absent from the Grand View and Sand Point faunas of the Glenns Ferry Formation. *Prodipodomys* gave rise to *Dipodomys* in Irvingtonian Land Mammal Age; *Dipodomys* is a common rodent in modern mammal faunas of western North America.

The lowest record of the rabbit *Pratilepus* in the Glenns Ferry Formation is also at the level of the *Prodipodomys* LSD. *Pratilepus* is a primitive and early member of the Leporinae (following Dawson, 1958), which include the common North American rabbits, *Lepus* and *Sylvilagus*. *Pratilepus* is well represented in the Rexroad fauna of Kansas and is similar, if not identical, to *Aluralagus* of the Benson fauna of Arizona.

The lowest record of *Pliogeomys, Ursus, Paenemarmota,* and *Ophiomys* occurs slightly higher than the *Prodipodomys* LSD in the Glenns Ferry Formation. *Pliogeomys* is also recorded from the late Hemphillian Buis Ranch fauna of Oklahoma and from the late Hemphillian Rincon fauna of Chihuahua. *Ursus* is believed derived from the European genus *Ursavus* according to Kurtén (1968) and was probably a Blancan immigrant to North America (Repenning, 1967, p. 296). *Ursus* is known from several other Blancan faunas, for example, Cita Canyon, Texas and Ringold, Wash. *Paenemarmota* is a large ground squirrel recorded from both late Hemphillian (Rincon, Chihuahua, and Goleta, Michoacan) and Blancan (Rexroad and Fox Canyon, Kans.; Mt. Blanco, Tex.; Broadwater-Lisco, Nebr.; Comosi Wash, Ariz.; Minaca, Chihuahua; and possibly the Ringold fauna, Wash.) faunas (Repenning, 1962). *Ophiomys* is a small and primitive microtine rodent that may be derived from *Cosomys (*Zakrzewski, 1969) whose record it overlaps in the Glenns Ferry Formation. The *Prodipodomys* LSD approximates the last record of *Dipoides* in the Glenns Ferry Formation.

Pratilepus HSD (~3.2 mybp) marks the highest stratigraphic occurrence of the rabbit *Pratilepus* in the Glenns Ferry Formation. *Pratilepus* (including *Aluralagus* Downey, 1968 from the San Pedro Valley, Ariz.) is restricted to Blancan deposits of North America. It is advanced in dental morphology relative to *Hypolagus* and primitive relative to *Nekrolagus, Sylvilagus,* and *Lepus.* A thorough review of these North American Pliocene and Pleistocene rabbits is needed to interpret adequately phyletic relationships. Other genera whose highest stratigraphic record in the Glenns Ferry Formation occurs near the *Pratilepus* HSD are *Trigonictis, Ursus, Pliogeomys, Prodipodomys, Cosomys.* The reduction in the number of taxa above the *Pratilepus* HSD reflects a reduction in fossiliferous exposures and intensity of collecting above that level.

The Grand View fauna with *Procastoroides, Dipodomys,* and *Ondatra* represents a later stage of evolution than seen in the Hagerman and Sand Point faunas. *Procastorides* is believed derived from *Dipoides, Dipodomys* from *Prodipodomys,* and *Ondatra* from *Pliopotamys.*

The Hagerman fauna characterizes early Blancan, the Grand View fanua characterizes late Blancan. The Sand Point fauna is too poorly represented to characterize middle Blancan.

SUMMARY

In conclusion, fine-grained sediments of the Glenns Ferry Formation utilized in conjunction with several intercalated basaltic lava samples yield a magnetostratigraphic sequence from the upper Gilbert to the lower Matuyama epochs. More than half the weakly magnetized sediment sites are statistically significant and are in good agreement with the lava sites. Mineral analyses indicate that the primary magnetic remanence in the sediments is carried by detrital titanomagnetite grains. Independent age controls are imposed upon the interpretation of the magnetic stratigraphy by several radiometric investigations of lava flows and ash units

within the Glenns Ferry Formation and stratigraphically younger formations.

The established magnetic stratigraphy now permits efforts to date the three Blancan local faunas within the framework of the magnetic polarity time scale. Four distinct faunal events have been discerned in the vertebrate fossil record of the formation: *Cosomys* LSD (~3.75 mybp), *Equus* LSD (~3.7 mybp), *Prodipodomys* LSD (~3.6 mybp), and *Pratilepus* HSD (~3.2 mybp). Ages have been assigned to each faunal datum plane by extrapolation from the magnetic reversal sequence for the formation. The *Equus* LSD datum plane is particularly important since it marks an early record for this Blancan and younger genus, which may prove to be the earliest record in North America. The relationship between the magnetostratigraphy and the vertebrate biostratigraphy for the Glenns Ferry Formation shows excellent agreement with similar studies reported by Lindsay, Johnson, and Opdyke (1975) in which they determined that the Blancan Land Mammal Age corresponded to the magnetic polarity time scale from the upper Gilbert to the lower Matuyama.

This study illustrates that it is possible to compile a cogent magnetostratigraphy for an area characterized by short, discontinuous exposures of unlithified fossil-bearing sediments. Further stratigraphic and chronologic investigations will be required before the paleomagnetic results of the Glenns Ferry Formation in the vicinity of Bruneau and Sand Point may be correlated into the overall magnetostratigraphy of the formation.

ACKNOWLEDGMENTS

We are especially grateful to H. E. Malde for providing valuable stratigraphic information in the field which enhanced our understanding of the Glenns Ferry Formation. We also thank P. R. Bjork and R. J. Zakrzewski for the comments on the paleontological interpretations presented in this paper. D. V. Kent, G. Kukla, J. C. Liddicoat, and R. A. Schweickert critically reviewed the manuscript. Discussions with J. A. White and G. Conrad were also helpful. The assistance of P. A. Larson in sample collection is appreciated.

This research was supported by National Science Foundation Grant EAR74-13860.

REFERENCES

Anderson, N. R., ms, 1965, Upper Cenozoic Stratigraphy of the Oreana 15′ Quadrangle: Ph.D. thesis, Univ. Utah, 212 p.

Armstrong, R. L., Leeman, W. P., and Malde, H. E., 1975, K–Ar dating, Quaternary and Neogene volcanic rocks of the Snake River Plain, Idaho: Am. Jour. Sci., v. 275, p. 225-251.

Berggren, W. A., and Van Couvering, J. A., 1974, The Late Neogene: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 16, p. 1-216.

Bjork, P. R., 1970, The Carnivora of the Hagerman local fauna (late Pliocene) of southwestern Idaho: Am. Philos. Soc. Trans., n.s., v. 60, no. 7, p. 1-54.

Cope, E. D., 1884, On the fishes of the Recent and Pliocene lakes of the western part of the Great Basin, and of the Idaho Pliocene lake: Philadelphia Acad. Nat. Sci. Proc. 1883, v. 35, p. 134-166.

Dawson, M. R., 1958, Later Tertiary Leporidae of North America: Univ. Kansas Paleont. Contr. Vertebrata, v. 6, p. 1-75.

Downey, J. S., 1968, Late Pliocene lagomorphs of the San Pedro Valley, Arizona: U.S. Geol. Survey Prof. Paper 600 D, D169-173.

Dunlop, D. J., 1972, Magnetic mineralogy of unheated and heated red sediments by coercivity spectrum analysis: Royal Soc. Geophys. Jour., v. 27, p. 37-55.

Evernden, J. F., Savage, D. E., Curtis, G. H., and James, G. T., 1964, Potassium-argon dates and the Cenozoic Mammalian Chronology of North America: Am. Jour. Sci., v. 262, p. 145-198.

Gazin, C. L., 1936, A study of the fossil horse remains from the upper Pliocene of Idaho: U.S. Natl. Mus. Proc., v. 83 (2985), p. 281-320.

Gustafson, E. P., 1978, The vertebrate faunas of the Pliocene Ringold Formation, south-central Washington: Univ. Oregon, Mus. Nat. Hist. Bull. 23, p. 1-62.

Haggerty, S. E., 1976, Oxidation of opaque mineral oxides in basalts, *in* Rumble, D., ed., Oxide Minerals: Mineralog. Soc. America Short Course Notes, v. 3, p. 1-100.

Hibbard, C. W., 1939, Notes on additional fauna of Edson Quarry of the middle Pliocene of Kansas: Kansas Acad. Sci. Trans., v. 42, p. 457-463.

——— 1959, Late Cenozoic microtine rodents from Wyoming and Idaho: Michigan Acad. Sci., Letters, v. 44, p. 3-40.

——— 1964, A contribution to the San Rock Canyon local fauna of Kansas: Michigan Acad. Sci. Papers, v. 49, p. 115-127.

——— 1969, The rabbits (*Hypolagus* and *Pratilepus*) from the upper Pliocene Hagerman local fauna of Idaho: Michigan Academician, v. 1 (1), p. 81-97.

Hibbard, C. W., and Bjork, P. R., 1971, The insectivores of the Hagerman local fauna, upper Pliocene of Idaho: Univ. Michigan Contr. Mus. Paleontology, v. 23 (9), p. 171-180.

Hibbard, C. W., and Zakrzewski, R. J., 1967, Phyletic trends in the late Cenozoic microtine Ophiomys, gen. nov., from Idaho: Univ. Michigan Contr. Mus. Paleontology, v. 21, p. 255-271.

Jacobs, L. L., 1977, Rodent of the Hemphillian age Redington local fauna, San Pedro Valley, Arizona: Jour. Paleontology, v. 51, p. 505-519.

Johnson, N. M., Opdyke, N. D., and Lindsay, E. H., 1975, Magnetic polarity stratigraphy of Pliocene-Pleistocene terrestrial deposits and vetrebrate faunas, San Pedro Valley, Arizona: Geol. Soc. America Bull., v. 86, p. 5-12.

Kent, D. V., and Lowrie, W., 1974, Origin of magnetic instability in sediment cores from the central North Pacific: Jour. Geophys. Research, v. 79, p. 2987-3000.

Khramov, A. N. (Irving, E., ed.), 1958, Paleomagnetism and stratigraphic correlation (English trans.): Canberra, Australian Natl. Univ., 204 p.

Kowalski, K., 1977, Fossil lemmings (Mammalia, Rodentia) from the Pliocene and early Pleistocene of Poland: Acta Zoologica Cracoviensia, v. 22, p. 297-318.

Kurtén, Bjorn, 1968, Pleistocene Mammals of Europe: Chicago, Ill., Aldine Pub. Co., 317 p.

Lindgren, W., 1900, The gold and silver veins of Siver City, De Lamai and other mining districts in Idaho: U.S. Geol. Survey 20th Ann. Rept., pt. 3, p. 65-256.

Lindsay, E. H., Johnson, N. M., and Opdyke, N. D., 1975, Preliminary correlation of North American Land Mammal Ages and Geomagnetic Chronology: Univ. Michigan Papers on Paleontology #12, Studies on Cenozoic Paleontology and Stratigraphy in honor of C. W. Hibbard, p. 111-119.

Løvlie, R., Lowrie, W., Jacobs, M., 1971, Magnetic properties and mineralogy of four deep-sea cores: Earth Planetary Sci. Letters, v. 15, p. 157-168.

Malde, H. E., 1965, Snake River Plain, *in* Wright, H. E. and Frey, D. G., eds., The Quaternary of the United States: Princeton, N. J., Princeton Univ. Press, p. 255-263.

——— 1971, History of Snake River Canyon indicated by revised stratigraphy of Snake River Group near Hagerman and King Hill, Idaho, with a section on paleomagnetism by A. Cox: U.S. Geol. Survey Bull. 644-F, 21 p.

——— 1972, Stratigraphy of the Glenns Ferry Formation from Hammett to Hagerman, Idaho: U.S. Geol. Survey Bull. 1331-D, 19 p.

——— 1972, Geologic map of the Glenns Ferry-Hagerman area, west-central Snake River Plain, Idaho: U.S. Geol. Survey Misc. Geol. Inv. Map 1-696.

Malde, H. E., and Powers, H. A., 1962, Upper Cenozoic stratigraphy of western Snake River Plain, Idaho: Geol. Soc. America Bull., v. 73, p. 1197-1220.

Malde, H. E., Powers, H. A., and Marshall, C. H., 1963, Reconnaissance Geologic Map of the West Central Snake River Plain, Idaho: U.S. Geol. Survey Misc. Geol. Inv. Map 1-373.

Mein, Pierre, 1975, Results in report of the committee on Mediterranean Neogene Stratigraphy, working groups (1974-75): Cong. Mediterranean Neogene, VI, Bratislava, p. 78-81.

Merriam, J. C., 1918, New mammalia from the Idaho Formation: California Univ. Pub. Geol. Sci., v. 10, no. 26, p. 523-530.

Molyneux, L., 1971, A complete result magnetometer for measuring the remanent magnetization of rocks: Royal Astron. Soc. Geophys. Jour., v. 24, p. 1-5.

Opdyke, N. D., Lindsay, E. H., Johnson, N. M., and Down, T., 1977, The paleomagnetism and magnetic polarity stratigraphy of the mammal-bearing section of Anza Borrego State Park, California: Quaternary Research, v. 7, p. 316-329.

Pilgrim, G. E., 1933, The genera *Trochictis, Enhydrictis,* and *Trocharion,* with remarks on the taxonomy of the Mustelidae: London Zool. Soc. Proc. 1932, p. 845-867.

Repenning, C. A., 1962, The giant ground squirrel *Paenemarmota*: Jour. Paleontology, v. 36, p. 540-556.

——————— 1967, Palearctic-Nearctic mammalian dispersal in the late Cenozoic, *in* Hopkins, D. M., ed., The Bering Land Bridge: Stanford, Calif., Stanford Univ. Press, p. 288-311.

Schultz, J. R., 1936, *Plesippus francescana* (Frick) from the late Pliocene Coso Mountains, California: Carnegie Inst. Washington Pub. 473, p. 1-13.

Shotwell, J. A., 1970, Pliocene mammals of southeast Oregon and adjacent Idaho: Univ. Oregon Nat. History Mus. Bull. 17, p. 1-103.

Skinner, M. F., and Hibbard, C. W., 1972, Early Pleistocene pre-glacial and glacial rocks and faunas of north-central Nebraska: Am. Mus. Nat. History Bull. 148 (1), p. 1-148.

Stearns, H. T., 1936, Origin of the large springs and their alcoves along the Snake River in southern Idaho: Jour. Geology, v. 44, p. 429-450.

Van Couvering, J. A., and Berggren, W. A., 1977, Biostratigraphical basis of the Neogene time scale, *in* Kauffman, E. G., and Hazel, J. E., eds., Concepts and Methods of Biostratigraphy: Stroudsberg, Pa., Dowden, Hutchinson and Ross, p. 283-306.

van Montfrans, H. M., and Hospers, J., 1969, A preliminary report on the stratigraphical position of the Matuyama-Brunhes geomagnetic field reversal in the Quaternary sediments of the Netherlands: Geol. Mijnb., v. 48, p. 565-572.

Watson, G. S., 1956, A test for randomness of directions: Royal Astron. Soc. Monthly Notices, Geophys. Suppl., v. 7, p. 160-161.

Wensink, H., 1972, A note on the paleomagnetism of the Lower Siwaliks near Choa Saiden Shah, Potwar Plateau, west Pakistan: Pakistan Jour. Sci. and Indus. Research, v. 15, p. 89-91.

Wilson, R. W., 1933, A rodent fauna from later Cenozoic beds of south-western Idaho: Carnegie Inst. Washington Pub. 440, p. 117-135.

Zakrzewski, R. J., 1969, The rodents from the Hagerman local fauna, upper Pliocene of Idaho: Univ. Mich. Mus. Paleontology Cont., v. 23, p. 1-36.

——————— 1974, Fossil Ondatrini from western North America: Jour. Mammalogy, v. 55, p. 284-292.