Stratigraphy of the Glenns Ferry Formation from Hammett to Hagerman, Idaho

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By HAROLD E. MALDE

CONTRIBUTIONS TO GENERAL GEOLOGY

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Correlation of volcanic markers in
fossiliferous lake and stream deposits
along 50 miles of the Snake River has
established the stratigraphy of a
thick sequence of late Pliocene age

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STRATIGRAPHY OF THE GLENNS FERRY FORMATION FROM HAMMETT TO HAGERMAN, IDAHO

By Harold E. Malde

ABSTRACT

Lava flows, beds of basaltic pyroclastic material, and layers of silicic volcanic ash that are interbedded in the lake and stream deposits of the Glenns Ferry Formation provide a means for correlating individual stratigraphic sections along the Snake River between Hammett and Hagerman, Idaho. The sequence thus established, composing the lower part of the formation, is more than 1,700 feet thick. A set of columnar diagrams of 60 measured sections graphically shows the lithology of the sections and the positions of petrographic samples and fossil collections. Because the lithology of particular stratigraphic intervals is commonly uniform enough to be assigned to a single sedimentary environment, the set of columnar diagrams shows how the various sedimentary facies overlap and intertongue. Thick sections of lacustrine deposits, for example, were accumulating while flood-plain and fluviatile deposits of an entirely different nature were being deposited nearby. A review of recent reports on the very large and diverse fauna and flora from the Glenns Ferry Formation, particularly the vertebrate fossils, indicates that the stratigraphic sequence described here is late Pliocene. This age is supported by a potassium-argon date of about 3.5 million years.

INTRODUCTION

The Glenns Ferry Formation is a complex assemblage of lake and stream deposits interbedded with local lava flows of olivine basalt that occupies an area of several thousand square miles in the western Snake River Plain (fig. 1). As originally described (Malde and

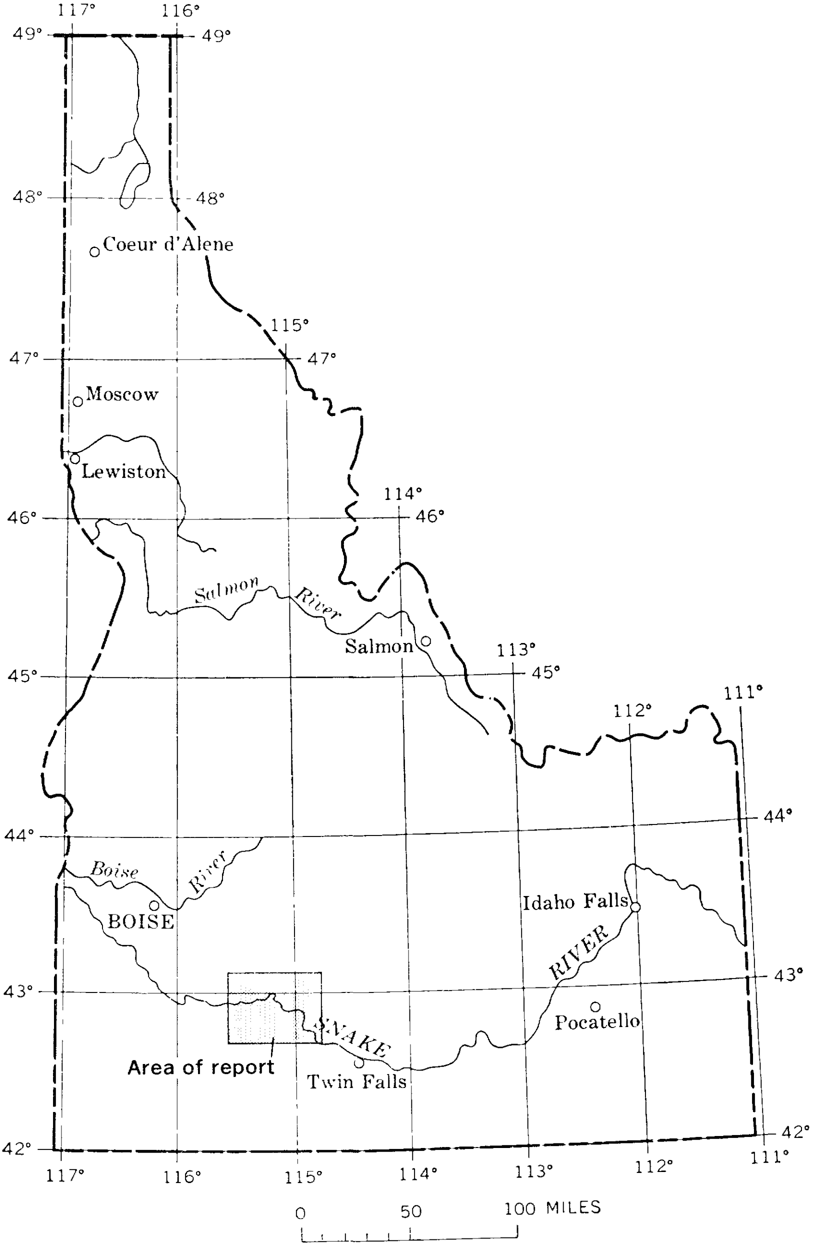


Figure 1.—Index map of southern Idaho showing location of area of report (stippled).

Powers, 1962, p. 1206), the typical exposures "begin 11 miles east of Glenns Ferry * * * and extend * * * 14 miles west of Glenns Ferry." A sequence of outcrops that represent these typical exposures extends west from measured section 29 on Clover Creek to measured section 56 a short distance upstream from Indian Cove. (See fig. 2 and table 1.) This sequence embraces the full thickness of the Glenns Ferry Formation in this area and provides a graphic display of its lithology. However, because of complex facies changes, and because of the local limits of certain marker beds, not all aspects of the Glenns Ferry Formation are represented in the type area. For these reasons, the correlation of outcrops of the Glenns Ferry is here extended upstream along the Snake River to include the exposures in the canyon wall west of Hagerman, as represented between Fossil Gulch and Peters Gulch. This report describes the correlation of the measured sections and identifies the various sedimentary facies. The paleontology given in some recent reports is also briefly discussed.

CORRELATION

The correlation of sections of the Glenns Ferry Formation depends partly on the tracing of recognizable marker beds, as established by geologic mapping (Malde and Powers, 1972), and partly on the petrographic identification of other marker beds in isolated outcrops. The principal correlations are shown on the adjoining diagram of measured sections (pl. 1) by lines that connect the sections and by names that are applied to marker beds. All the marker beds that are useful for correlation are volcanic units: lava flows, beds of basaltic pyroclastic material, and layers of silicic volcanic ash. In a few places the correlation of volcanic units is strengthened by the matching of lithologic sequences in associated sedimentary deposits.

The petrographic studies used here to identify the layers of silicic volcanic ash were done by Howard A. Powers. He worked intermittently with numerous samples for more than a decade before his retirement from the U.S. Geological Survey in 1970; even so, he was unable to complete this petrographic work to his satisfaction, and some of the correlations are necessarily still provisional. The field relations, however, suggest that his correlations of the volcanic ash layers are probably correct. The kinds of uncertainties that remain for correlating the ash layers, and their significance for comprehending the stratigraphy of the Glenns Ferry Formation, are explained in the discussion that follows.

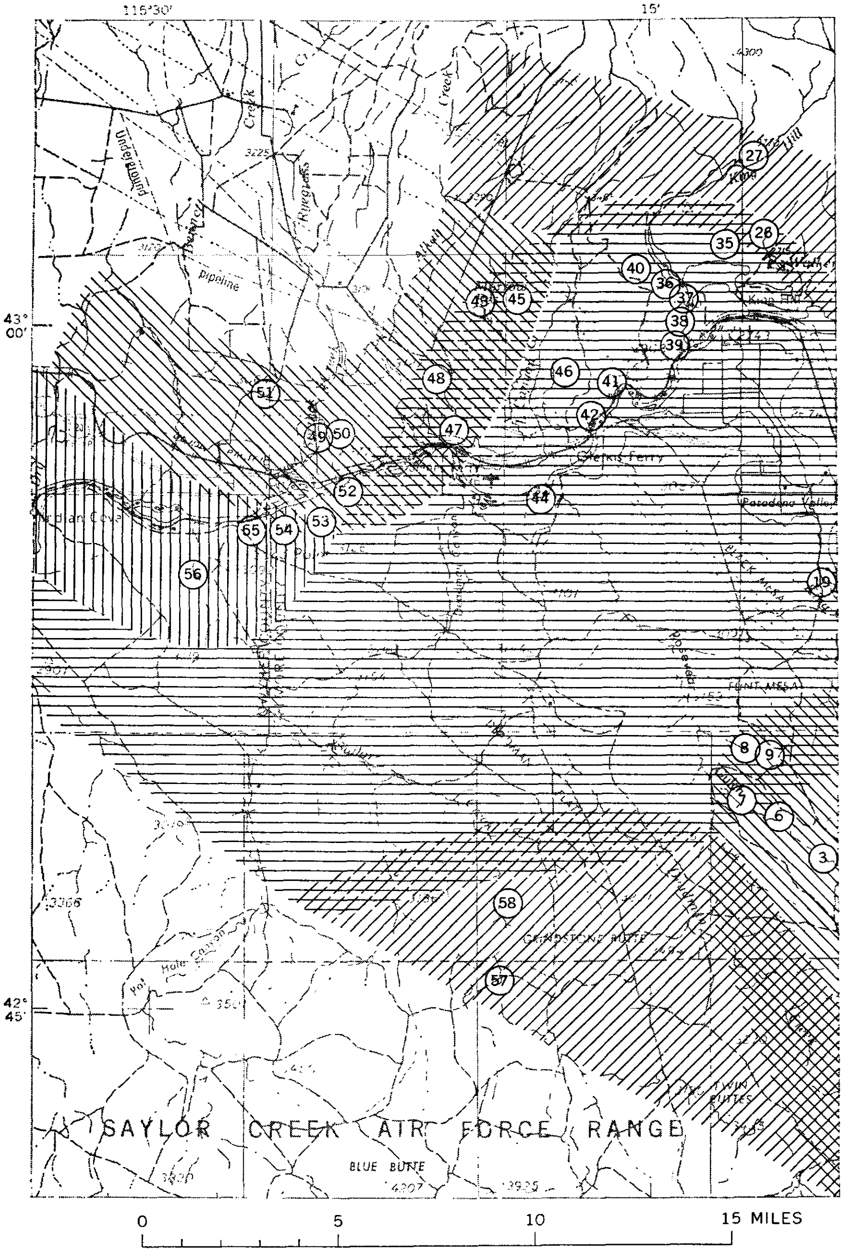
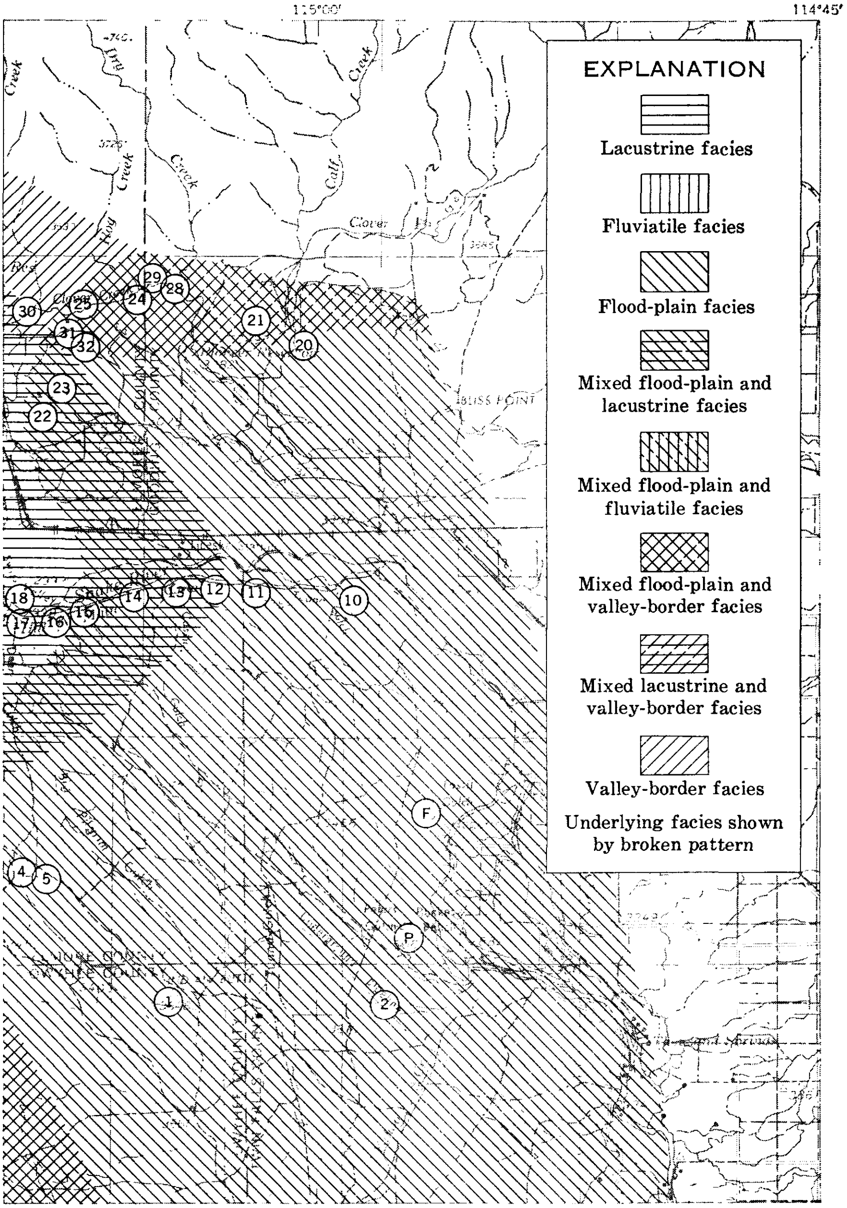


FIGURE 2.—Localities of measured sections (circled numbers) and distribu Hammet-Hagerman area. Base from U.S. Geological Survey topographic



tion of exposed sedimentary facies of the Glenns Ferry Formation in the maps of Twin Falls and Hailey quadrangles, 1955–62, scale 1: 250,000.

TABLE 1.—*Localities of measured sections*

[See pl. 1 for stratigraphy of measured sections]

Measured section		Locality			
No. or letter	Name	Quadrangle	Sec.	T.S.	R.E.
Measured by Howard A. Powers and Dwight W. Taylor, 1955					
P	Peters Gulch	Hagerman	NW¼ 33, NE¼ 32	7	13
F	Fossil Gulch	do	NW¼ 16	7	13
Measured by Harold E. Malde, assisted by Kennard R. Harper, 1960					
1	Indian Butte	Pasadena Valley	SE¼ 5	8	12
2	Crowsnest Road	Hagerman	SE¼ 6	8	13
3	Twentymile Butte	Pasadena Valley	SW¼ 22	7	11
4	do	do	SE¼ 22	7	11
5	do	do	SW¼ 23	7	11
6	Rosevear Gulch	do	SW¼ 16	7	11
7	do	do	NW¼ 17	7	11
8	do	do	SE¼ 6	7	11
9	do	do	SW¼ 5	7	11
10	Tuana Gulch	Bliss	NW¼ 13	6	12
11	Shoestring Road	Pasadena Valley	NE¼ 16	6	12
12	do	do	NE¼ 17	6	12
13	Cassia Gulch	do	NE¼ 18	6	12
14	Shoestring Road	do	NE¼ 13	6	11
15	Pilgrim Gulch	do	SE¼ 14	6	11
16	Pilgrim Spring	do	SE¼ 15	6	11
17	Deer Gulch	do	SE¼ 16	6	11
18	do	do	SW¼ 16	6	11
19	Swiss Valley	do	NW¼ 16	6	11
20	Clover Creek	do	NW¼ 14	5	12
21	do	King Hill	NW¼ 10	5	12
22	Highway 30	Pasadena Valley	SW¼ 22	5	11
23	Jolly Flat	do	NE¼ 22	5	11
24	Clover Creek	King Hill	NE¼ 12	5	11
25	do	do	NW¼ 11	5	11
26	Buckbrush Draw	do	NW¼ 31	4	11
27	King Hill Creek	do	SW¼ 19	4	11
28	Clover Creek	do	SE¼ 6	5	12
29	do	do	SW¼ 6	5	12
30	do	do	NE¼ 9	5	11
31	Burnt Ridge	Pasadena Valley	SW¼ 11	5	11
32	do*W*	do	NE¼ 14	5	11
35	Walker Ditch	King Hill	SE¼ 36	4	10
36	King Hill Creek	do	SW¼ 2	5	10
37	do	do	NW¼ 11	5	10
38	Sugar Bowl	Pasadena Valley	SW¼ 11	5	10
39	do	do	NW¼ 14	5	10
40	Cedar Spring	Bennett Mountain	W½ 3	5	10
41	Highway 30	Glenns Ferry	E½ 21	5	10
42	Glenns Ferry	do	NW¼ 28	5	10
	do	do	NE¼ 29	5	10
43	Morrow Reservoir	Bennett Mountain	NW¼ 12	5	9
44	Three Island Crossing	Glenns Ferry	NE¼ 6	6	10
45	Morrow Reservoir	Bennett Mountain	NW¼ 7	5	10

TABLE 1.—*Localities of measured sections*—Continued

[See pl. 1 for stratigraphy of measured sections]

Measured section		Locality			
No. or letter	Name	Quadrangle	Sec.	T.S.	R.E.
46	Little Canyon Creek	Glenns Ferry	SE¼ 17	5	10
47	Slick Bridge	do	N½ 26	5	9
48	Alkali Creek	do	SW¼ 14	5	9
49	Cold Springs Creek	do	SE¼ 29	5	9
50	do	do	SE¼ 29	5	9
51	Hammett	do	NE¼ 24	5	8
52	The Narrows	do	SE¼ 32	5	9
53	Schoffs Island	do	SW¼ 5	6	9
54	do	do	NW¼ 7	6	9
55	Sand Point	do	SW¼ 1	6	8
56	Sailor Creek	do	NW¼ 14	6	8
	do	do	SE¼ 10	6	8
57	Dove Spring	do	NE¼ 7	8	10
	do	do	Center 6	8	10
	do	do	NE¼ 31	7	10
58	do	do	E½ 30	7	10
	do	do	SE¼ 19	7	10

Beginning near the base of the Glenns Ferry Formation, in the eastern part of the area, the stratigraphy is nearly continuous from Peters Gulch to measured section 30 on Clover Creek. The principal marker beds (fig 3) are the Shoestring Road lava flow, the nearly contemporaneous Deer Gulch lava flow, and the underlying Peters Gulch ash layer (Powers and Malde, 1961) and Clover Creek lava flow. Several beds of basaltic pyroclastic material and an interval rich in pumiceous lapilli along Clover Creek, here informally named the lower lapilli, strengthen the correlation from section to section. Furthermore, preliminary study by H. A. Powers (written commun., Aug. 18, 1960) of the physical properties of samples 58M40 and 60M87 from silicic volcanic ash in measured sections 22 and 23 shows a close similarity of these samples to sample 55P232 from volcanic ash at Fossil Gulch. The bed of silicic volcanic ash at Fossil Gulch was traced by Powers to Peters Gulch during geologic mapping and is here informally named the Fossil Gulch ash layer.

The Glenns Ferry Formation in the area from Clover Creek to measured sections 27 and 26 is poorly exposed, but the stratigraphy is not in doubt. The correlation is based on two marker beds: (1) The Peters Gulch ash layer, which is identified in Peters Gulch, Fossil Gulch, and in measured section 20, is also found in section 26 (Powers and Malde, 1961); (2) a conspicuous layer of basaltic pyroclastic material, bed J, is reasonably correlated with the nearby Deer Gulch lava flow. (See pl. 2.)

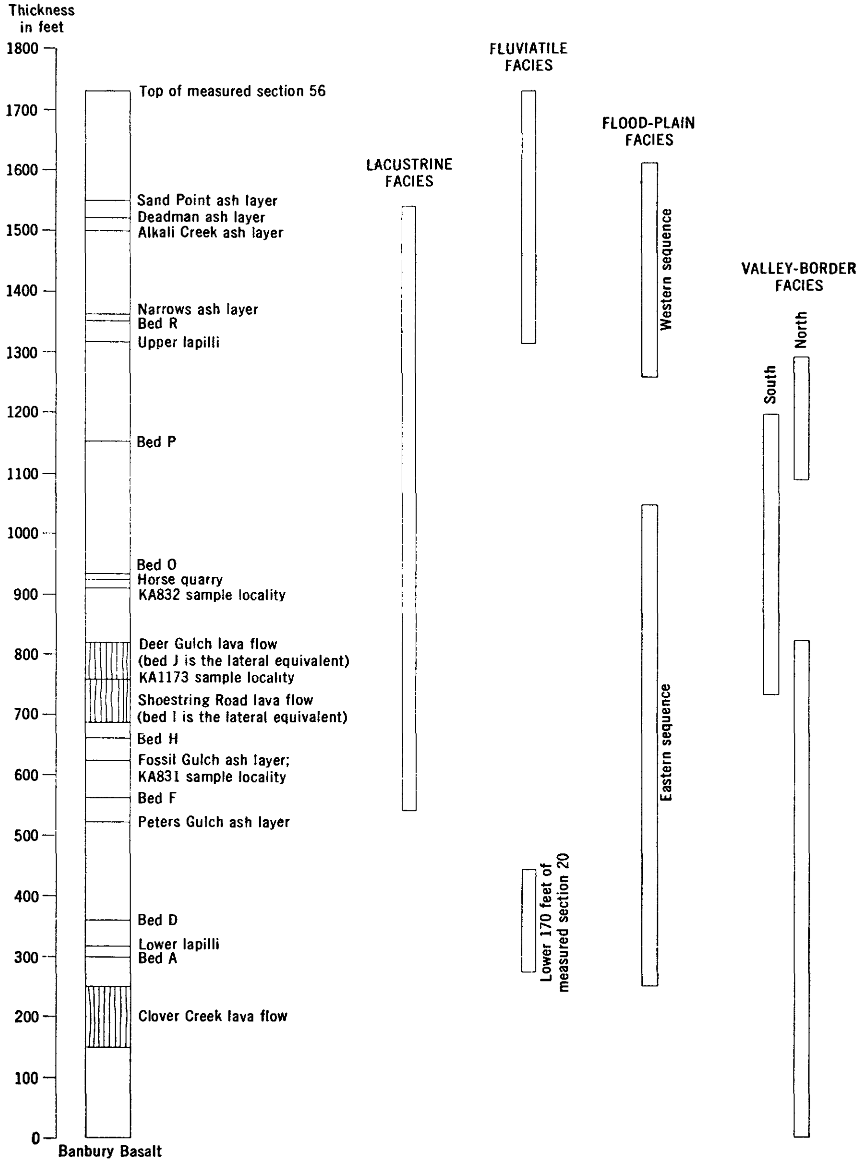


FIGURE 3.—Principal marker beds in the Glenns Ferry Formation and stratigraphic distribution of outcropping facies.

From measured section 26 to measured section 44, the correlation is based on continuous exposures of marker beds of basaltic pyroclastic material, which show a general southwest dip. Structure contours (pl.

2) drawn on beds J, P, and R indicate that gentle deformation accompanied the deposition of this sedimentary sequence. The structural movement, however, was not enough to interrupt the general sequence of beds.

The weakest link in the correlation of these measured sections is from section 44 to section 45. The correlation is based on a preliminary study by H. A. Powers (written commun., August 1970) of samples 58M10 and GF79 from outcrops close to a bed of silicic volcanic ash in section 44, sample 58M30 from an outcrop near an ash bed in section 45, and sample 60M262 from an ash bed in section 48. Similar chemical properties and the mutual presence of pale-green hornblende and fine white granular glass shards in these samples indicate that they represent the same ash fall. This bed of silicic volcanic ash is here informally named the Deadman ash layer; the name comes from its conspicuous outcrop in Deadman Canyon southwest of Glenns Ferry. The assignment of these samples to a single ash layer, though provisional, is in accord with the field relations. Between measured sections 45 and 48, the tracing of lithologic sequences indicates that the Deadman ash layer lies about 200 feet above a thin interval marked by pumiceous lapilli, which is here informally named the upper lapilli. This interval of lapilli is stratigraphically close to bed R, as indicated by the altitude of its outcrops a short distance west of Glenns Ferry. Bed R is 140 feet below the Deadman ash layer in measured section 44. A possible correlative of bed R is found in measured section 43, about 30 feet above the upper lapilli and about 170 feet below the projected position of the Deadman ash layer.

Westward from measured section 45, an important link is provided by the Narrows ash layer, which occurs in sections 43 and 52 (Powers and Malde, 1961). Another, but weaker, link is suggested by sample 60M256 from a bed of silicic volcanic ash in section 48 and by sample 60M330 from an ash bed in section 52. H. A. Powers commented (written commun., August 1970) that these samples have similar chemical and physical properties. This bed of silicic volcanic ash is here informally named the Alkali Creek ash layer. The position of the Deadman ash layer is measured section 52, if present, is still unknown.

From measured section 52 westward to section 56, several layers of silicic volcanic ash are present, but only one of these has so far been useful for correlation. This volcanic ash, here informally named the Sand Point ash layer, is believed to extend from section 52 to section 56. The name is taken from a place known locally as Sand Point where this ash bed forms a conspicuous outcrop. (See section 55.) H. A. Powers (written commun., Mar. 27, 1967) distinguished two kinds of volcanic ash in the Sand Point ash layer: ash in the lower part marked by phenocrysts of orthopyroxene, clinopyroxene, and apatite; and ash in the upper part marked by phenocrysts of hornblende. The lower part is represented by samples 59P82, 59P299, and 60M379 from section 56 and by sample 59P304 from section 55. The upper part is represented by sample 59P298 from section 56 and by samples 58M2, 60M370, and 59P306 from section 55. Farther east, the physical and chemical properties of samples 59P89 and 60M368 from section 54, sample 59P97 from section 53, and sample 59P101 from section 52 very closely match several of those properties of the Sand Point ash layer at sections 55 and 56. Powers commented that "the magnetic susceptibility of the glass shards, the dominance of fragile shards, the array of phenocryst minerals, and the spectrographic analyses of the minor elements are so close that all the samples could be from the same composite ash." This correlation, therefore, seems to be fairly firm, even though the necessary petrographic work on the optical properties of the glass shards and phenocrysts has not yet been done.

The deposits of the Glenns Ferry Formation that are exposed in the measured sections 5, 4, 3, 6, 7, 9, and 8 are correlated with the sequence just described by assigning the basalt at the base of section 3 to the Deer Gulch lava flow. The significance of these sections and of measured sections 57 and 58 for understanding the sedimentary facies of the Glenns Ferry Formation is explained in the remarks that follow.

SEDIMENTARY FACIES

The intertonguing lake stream deposits of the Glenns Ferry Formation vary considerably in lithology. At particular stratigraphic sections, however, the lithology of intervals as much as several hundred feet thick is commonly uniform enough to be assigned to a single sedimentary environment. (See Malde and Powers, 1962, p. 1206–1207, for a description of the various lithologies and their environmental significance.) Moreover, by tracing marker beds, these lithologic units can be identified over areas several miles wide. Such lithologic units, of course, eventually merge into others that are indicative of a different environment. The varieties of lithologies are conveniently classified as sedimentary facies. In the discussion that follows, the facies are broadly considered to represent three principal environments: lacustrine, fluviatile, and flood-plain (fig. 2). In addition to these principal facies, sedimentary processes near the margins of the Snake River Plain during deposition of the Glenns Ferry Formation produced distinctive deposits that are here classified as the valley-border facies. Because all these facies complexly overlap and intertongue, depending on the changing distribution of sedimentary environments when the

Glenns Ferry Formation was being deposited, the various facies can be found in more than a single stratigraphic interval. The examples given here of the intertonguing and repetition of sedimentary facies in the type area of the Glenns Ferry Formation are representative of the kinds of lithologic variability found throughout the extent of this formation in the western Snake River Plain. Unresolved problems in understanding the paleoenvironment of the Glenns Ferry Formation, as interpreted from these sedimentary facies, are briefly mentioned after the following remarks on the relations of particular sedimentary facies.

The lacustrine facies is distinguished by massive layers of tan silt and fine sand; these layers form monotonous outcrops faintly marked by diffuse gray bands spaced several feet apart. As thus recognized, the lacustrine facies, though its outcrops are distributed in disconnected areas, has a very wide extent in the western Snake River Plain (Malde and Powers, 1962, p. 1206). In the area of these measured sections, the facies is represented in a continuous stratigraphic interval about 1,000 feet thick that crops out over much of the central part of the basin. This lacustrine facies is found (pl. 1) in the lower parts of sections 12 through 15 (below bed H), thence westward to include all of section 16 below the Deer Gulch lava flow and all of sections 17 through 19 below the Bruneau Formation, and still westward in sections 36, 37, 38, 39, 40, and 41 (except the upper 180 feet), and 42, 46, and 44. This sequence thus reaches from 150 feet below the Deer Gulch lava flow to at least 20 feet above the Deadman ash layer (fig. 3). In the transition to the valley-border facies on the north, the lacustrine facies forms the beds of the upper 75 feet of section 35, and these beds are part of a tongue of the lacustrine facies bracketed by coarse-textured deposits of the valley-border facies of section 26 in the 265 feet of deposits above bed J. The relations of the lacustrine facies to deposits assigned to the flood-plain facies are described in the subsequent discussion of the flood-plain facies. The interval of transition to the fluviatile facies is not well exposed.

The fluviatile facies is characterized by thick beds of brownish-gray sand, some of which are crossbedded and ripple marked. In the area of these measured sections, the facies forms a continuous sequence 380 feet thick in sections 54, 55, and 56. A detached outcrop of the fluviatile facies, of undetermined lateral extent but probably equal to the beds exposed in the lower part of section 54, is found in the upper 180 feet of section 41. The lower 170 feet of section 20 is possibly still another example of the fluviatile facies. The merging of the fluviatile facies with the flood-plain facies is explained in the following description of the flood-plain facies.

The flood-plain facies consists mainly of thin beds of calcareous pale-olive silt and dark clay. Intermittent layers of sand, which apparently fill shallow channels, and layers of carbonaceous shale are also present. Such deposits occupy two stratigraphic intervals in the area of these measured sections, a lower sequence in the eastern part and an upper sequence in the western part.

The eastern sequence of the flood-plain facies, about 800 feet thick, is almost completely represented by the section at Peters Gulch. From Peters Gulch the facies is recognizable downstream to the beds above the Deer Gulch lava flow in measured section 14. The beds below the Deer Gulch lava flow in this vicinity (measured sections 12, 13, and 15) show a transition from the flood-plain facies to the lacustrine facies. Furthermore, as the Deer Gulch lava flow is traced westward, it changes from a subaerial flow in measured section 15 to pillow lava of a subaqueous flow in the lacustrine deposits of measured section 17. This eastern sequence of the flood-plain facies also extends north to measured sections 20 and 21 on Clover Creek where the facies is recognizable as low as the Clover Creek lava flow. Westward down Clover Creek, this flood-plain facies is expressed by the beds above the Clover Creek lava flow, as shown in measured sections 24 and 25. As the area of the lacustrine facies is approached, measured sections 22, 23, 31, and 32 show that massive layers of silt and sand typical of the lacustrine facies mingle with beds of the flood-plain facies. Similarly, in an upland area west of Peters Gulch, sections 5, 4, and 3, which have typical aspects of the flood-plain facies, pass westward into deposits that are more characteristic of the lacustrine facies, as seen in measured sections 6, 7, 9, and 8.

The western sequence of the flood-plain facies, about 350 feet thick, is exemplified by measured section 52 at The Narrows. From section 52, which includes several of the identifiable marker beds used for correlation, the flood-plain facies extends downstream to section 53. Farther west, continuity of the Sand Point ash layer shows that the flood-plain facies passes rather abruptly into the fluviatile facies. Northward from section 52, this flood-plain facies extends through sections 49, 50, 51, 47 (except the lower 100 feet), 48, and 43 (except the lower 85 feet) to section 45. In sections 47 and 43, beds of the flood-plain facies rest on massive beds of fine sand and silt of the lacustrine facies. In section 45, several thick layers of coarse sand and fine gravel suggest a transition to a valley-border facies on the north.

The valley-border facies north of the Snake River in the area of these measured sections is identified by massive layers of arkosic sand and fine granitic gravel. Locally, a few granitic cobbles can be found.

Such deposits were undoubtedly derived from granitic outcrops in hills north of the Snake River Plain. The arkosic debris rests directly on Banbury Basalt in measured sections 28 and 29, extends upward to the Clover Creek lava flow in sections 24 and 30, and then makes up most of sections 26 and 27, except for a tongue of the lacustrine facies above bed J. The interval embraced by the northern valley-border facies is, therefore, about 1,300 feet thick.

The valley-border facies on the south is also distinguished by deposits of coarse-textured sand and gravel, especially in its lower part. (See measured sections 57 and 58, pl. 1.) These deposits are locally cemented and form resistant ledges of sandstone and conglomerate. Much of this debris could have been derived from nearby outcrops of the Idavada Volcanics on the south, but sources as distant as the mountains along the Nevada-Idaho boundary are indicated by scattered cobbles and scarce boulders of quartzite. The upper part of the sequence given by sections 57 and 58 has some aspects of both the flood-plain facies and the lacustrine facies, but beds of coarse sand and gravel are also present. As inferred by mapping (Malde and Powers, 1972), the upper reach of this sequence is placed approximately at a position above bed O.

The distribution of sedimentary facies in the Glenns Ferry Formation (fig. 2) illustrates the interplay of sedimentary environments that existed concurrently. An area of flood-plain deposition that extended from Peters Gulch to Clover Creek gave way westward to a lacustrine area, which in turn merged into valley-border areas that received coarse detritus from the north and south. Toward the end of the sedimentary episode that is represented by the lacustrine deposits, a new area of flood-plain deposition became established on the west, and these flood-plain deposits graded into an area of fluviatile deposits.

Such patterns of sedimentary facies tell much about the terrain of the ancestral Snake River and its tributaries during Glenns Ferry time. Evidently, the river flowed in a wide valley marked by temporary lakes and by broad stretches that were seasonally flooded. As the river shifted its course, the sedimentary environments changed correspondingly. Even so, the persistence of rather uniform environments in certain areas is shown by surprisingly thick sequences of fairly uniform deposits.

This implied persistence of sedimentary environments presents difficult problems about the paleogeography that are still unresolved. The great thickness of the lacustrine facies in a wide area around Glenns Ferry is particularly perplexing, especially because a considerable part of it evidently accumulated while flood-plain sediments were being deposited nearby. Nearly all these lacustrine deposits consist of wellsorted silt and fine sand that apparently were laid down in deep water, mainly beyond the reach of waves. The interbedded pillow lava, mentioned above, cooled in water at least 80 feet deep, and the numerous beds of basaltic pyroclastic material (which represent glassy debris from this and other lavas that entered the lake) were spread widely over the smooth lake floor. The surprising circumstance is that such a lake basin could have existed long enough in a single area to account for a thousand feet of uniform silt and sand while sediments of an entirely different nature were accumulating only a few miles away. To resolve such problems in paleogeography, a stratigraphic knowledge of the Glenns Ferry Formation over a wider region is required, as well as the accurate recognition and mapping of the various sedimentary environments. The same mingling of sedimentary facies that is described here is repeated many times in outcrops of the Glenns Ferry Formation farther west, as suggested by reconnaissance and mapping (Malde and Powers, 1962; Malde and others, 1963), but these outcrops have not been studied in detail. The paleogeography will be better understood when these details are learned.

FOSSILS AND AGE

Fossils from the Glenns Ferry Formation consist of a very large and diverse fauna and flora. Collections from deposits now assigned to this formation have been made for more than a century, and the reports by paleontologists are widely scattered among numerous journals. Taylor (1966, p. 73–75) gives a comprehensive list of the published fauna, together with a bibliography of 75 pertinent reports published through the year 1964. The faunal list includes clams, snails, crustaceans, fishes, amphibians, reptiles, birds, and mammals. The flora, which has been interpreted from pollen records, was briefly discussed by E. B. Leopold (p. 456 in Weber, 1965), and her data on the abundance of genera in the Glenns Ferry Formation relative to living natives are summarized in another paper on plant extinction (Leopold, 1967, p. 227).

The fossil collection localities that are listed here by stratigraphic placement beside the measured sections are further shown geographically on a geologic map by Malde and Powers (1972). Fossils from several of these localities have been described in published reports, but most of the collection numbers identify collections in U.S. Geological Survey laboratories that are still unpublished. Reports on the Glenns Ferry fauna that have been published since 1964 are briefly reviewed in the remarks that follow.

Paleontologists refer to some of the assemblages of fossils from the Glenns Ferry Formation in terms of particular areas. Fossils from an interval along the cliffs west of Hagerman between Peters Gulch and Fossil Gulch that extends upward approximately from the Peters Gulch ash layer to about 50 feet above the U.S. National Museum horse quarry (a locality famous among vertebrate paleontologists since 1929) are known as the Hagerman local fauna. Fossils from the area of Sand Point as represented in measured section 55, especially from USGS Cenozoic locality 19128 to locality 19129, are known as the Sand Point local fauna. Collections from the Glenns Ferry Formation at Jackass Butte, Wildhorse Butte, and Castle Butte, an area about 50 miles west of Glenns Ferry, are known as the Grand View local fauna.

Taylor (1966, p. 70–78) reviewed the previous work on the mollusks and gave valuable discussions of their type localities; several of these type localities are in the area of these measured sections. One of these, the first collection of fossil fresh-water mollusks described from North America, was found by J. C. Frémont in 1843; it has been traced to a place in Deer Gulch about 1 mile south of measured section 18. Taylor commented that the molluscan fossils of the lacustrine facies are, in general, different from those of the flood-plain facies and show little mingling of species between facies. The fauna of the lacustrine facies, more than 80 species, is virtually extinct and mostly endemic, whereas the fauna of the flood-plain facies, more than 30 species, is sharply distinct and is dominated by species still living (D. W. Taylor, written commun., June 24, 1964). The stratigraphic relations of facies in the Glenns Ferry, as now understood, were not known to Taylor in 1966, and his statement that "virtually all" the abundant mollusks from the lacustrine facies are below the horizon of the Deer Gulch lava flow is incorrect. Instead, the greater part of the molluscan fauna from the lacustrine facies is stratigraphically higher, extending upward at least as high as bed R. Taylor also commented that mollusks of the flood-plain facies had been collected mostly from deposits below the Deer Gulch horizon (below bed I between Fossil Gulch and Peters Gulch); the same mollusk assemblage, however, is found 500–900 feet stratigrapically higher in the western sequence of the flood-plain facies. In short, the distinctive faunas of the lacustrine and flood-plain facies do not differ significantly in stratigraphic range. Taylor argued that the sedimentary basin could have subsided differentially, and he, therefore, mistakenly assumed that the fluviatile facies represented by the outcrop at Sand Point (measured section 55) might be little different in age from the flood-plain facies at the U.S. National Museum horse quarry (section at Fossil Gulch). As now understood, his interpretation of the stratigraphic relations was wrong, even though his inference that differential subsidence occurred may be correct; according to the stratigraphy given here, the fauna at Sand Point is stratigraphically more than 600 feet above the fossils of the horse quarry. The molluscan fauna of the fluviatile facies, about 40 species, is composed of a mixture of forms also found in the lacustrine and flood-plain facies (D. W. Taylor, written commun., June 24, 1964). Taylor assigned an age range for the Glenns Ferry of late Pliocene through middle Pleistocene, although he said that most of the mollusks were Pliocene.

Mammals from the Grand View local fauna of the Glenns Ferry Formation were listed in a review of North America Quaternary mammals by Hibbard, Ray, Savage, Taylor, and Guilday (1965), but mammals from the Hagerman and Sand Point local faunas (namely, those of the area of these measured sections) were considered by them to be late Pliocene and therefore were excluded from their discussion. Repenning (1967, p. 294), however, placed the Hagerman local fauna in the late Blancan (that is, Quaternary) "because * * * several forms * * * appear to be more advanced than those listed from early Blancan faunas."

Zakrzewski's (1967) discussion on the systematic position of two species of mustelids was based on newly discovered skeletal remains and teeth from the Hagerman local fauna.

In an evaluation of the stratigraphic range of the Glenns Ferry Formation, Hibbard and Zakrzewski (1967) analyzed the evolutionary changes in the microtine genus *Ophiomys*, as demonstrated by specimens from the Hagerman, Sand Point, and Grand View local faunas. They decided that *O. taylori* from the Hagerman fauna had given rise to a somewhat more advanced form of this species at Sand Point, and that both were late Pliocene in age. This species in turn had given rise to *O. parvus* in the Grand View local fauna; they assigned *O. parvus* to the early Pleistocene. The evolutionary trend is shown by changes in the teeth. Zakrzewski (1969a, p. 20) provided further statistical data on this trend, although this later report deals primarily with a detailed review of the rodents. On the other hand, Shotwell (1970, p. 7–16), who was unaware of the stratigraphic relations shown by the measured sections given here, expressed doubt that the Sand Point local fauna is younger than the Hagerman local fauna, and he concluded that the age difference between the Hagerman and the Grand View local faunas is very small. Shotwell's conclusions were based on the study of his large collections from the Glenns Ferry Formation in the Grand View area; he considered these collections to be Pliocene in age. He also analyzed the fossil horses from the Hagerman and Grand View local faunas; these horses had been a basis for previous estimates of a presumed difference in age. Other recent reports that deal with the mammals are by Campbell (1969), Zakrzewski (1969b), Hibbard (1969), Bjork (1970), and Hibbard and Bjork (1971).

Miller and Smith (1967) described seven new species of fishes from the Glenns Ferry Formation, thereby increasing the number of known species to about 20. At least five of these seven species are now extinct in the area. Zoogeographically, two or three of the species are closely related to modern forms in the Great Valley of California, and two species show relatively distant relationships to two species found in the Klamath drainage of Oregon and California. These drainage connections that are suggested by the fishes reinforce the connections indicated by the range of a small clam (Taylor, 1960)—namely, former links between the Snake River and northern California via the Klamath system.

The paleontology of snakes from the Glenns Ferry Formation is reviewed by Holman (1968). Two turtles are described by Zug (1969).

New species of birds from the Glenns Ferry are described in several recent reports (Feduccia, 1967; Ford and Murray, 1967; Murray, 1967). Selander (1965, p. 528) briefly discussed birds from the Hagerman local fauna; he asssigned them to the early Pleistocene by adopting the age assignment of Hibbard (1958). Brodkorb's (1958) estimate on the extinction rate of birds, based partly on the Hagerman avifauna, was rigorously criticized by Moreau (1966).

Zakrzewski (1969a, p. 31–34) has provided the most recent and thorough discussion of the age of the Hagerman local fauna; he places it "definitely" in the late Pliocene. He considered intrafaunal aspects as well as interfaunal comparisons with the Rexroad fauna of southwestern Kansas. Because several mammals from the Hagerman are more advanced than their counterparts in the Rexroad, the Hagerman local fauna is considered to be "post-Rexroad and pre-Pleistocene in age."

This age assignment for fossils from the Hagerman local fauna is supported by a potassium-argon date of 3.48 plus or minus 0.27 m.y. (million years) for basalt from the Deer Gulch lava flow (sample KA 1173 near measured section 16), as determined by Evernden, Savage, Curtis, and James (1964, p. 191). They accepted this date as the "best estimate of age" for the Hagerman fauna. By assuming that dates for hydrated volcanic glass are less reliable than those for basalt, they considered their dates of 3.2 m.y. for volcanic ash above the Shoestring Road lava flow (sample KA 832 at measured section 11) and of 3.3 m.y. for volcanic ash below this lava flow (sample KA 831 at Fossil Gulch) to be too young.

The stratigraphically higher Sand Point local fauna is also considered to be late Pliocene (Hibbard, 1959, p. 20–22; Hibbard and Zakrzewski, 1967). Thus, by present understanding of the fossils, all the sections given here belong to the late Pliocene.

Paleontologists differ on the age of the Grand View local fauna from the Glenns Ferry Formation farther west. From comparisons of published descriptions of mammals, Hibbard (1959, p. 32–38) considered the Grand View local fauna to be younger than the Hagerman, probably dating from an early Pleistocene interglacial stage. This conclusion was supported by later study of phyletic trends in the vole, *Ophiomys* (Hibbard and Zakrzewski, 1967). Shotwell (1970, p. 86–94), on the other hand, from study of very large recent collections from the Grand View local fauna (especially by statistical comparison of large numbers of horses from the Grand View and Hagerman local faunas) concluded that the comparisons provided no basis for inferring a difference in age. The small differences between some representatives of the Grand View local fauna and some of the Hagerman were suggested by Shotwell (1970, p. 15–16) to be typical of "differences seen in contemporaneous species occupying a variety of local habitats." He thus regarded the Grand View local fauna of the Glenns Ferry Formation as late Pliocene.

In summary, paleontologists now agree that the lower part of the Glenns Ferry Formation is late Pliocene, and this conclusion is supported by a potassium-argon date of about 3.5 m.y. To resolve conflicting ideas on the age of the upper part, whether late Pliocene or early Pleistocene, detailed studies are needed of the stratigraphy and paleontology of the Glenns Ferry Formation westward from the area of these sections to the Grand View area. Such studies might show that the Glenns Ferry Formation spans the Pliocene-Pleistocene boundary.

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