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Snake River Plain*

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GEOGRAPHY

Curving in a great arc, 500 km long and 80-110 km wide, across the southern part of Idaho, the Snake River Plain is an incongruous physiographic feature among the rugged highlands of the northern Rocky Mountains. It is, for the most part, a lava plain, ranging in altitude from 2,000 m at the east to less than 700 m at the west. Around the perimeter are mountains and uplands composed of folded Paleozoic sedimentary rocks, granite of the Idaho batholith, and faulted Cenozoic volcanics (Fig. 1). From this envelope of surrounding highlands the Snake River gains an outlet by plunging northward through the precipitous Hells Canyon, one of the deepest gorges in North America.

At first glance, the Snake River Plain appears as a drab, monotonous lowland built of endless lava flows, dispersed from subdued eruptive centers. Closer scrutiny, however, reveals a multiplicity of Quaternary geology, not only in the clarity of volcanic processes, but also in a sedimentary record represented by thick sections of fossiliferous clastic deposits, and in erosional events expressed by ancient canyons and upland pediments. Indeed, the Quaternary features of the Snake River Plain are so enormous that their study takes on the attributes of bedrock geology—not merely the appraisal of landforms. The rocks of Quaternary age comprise a section about 1,500 m thick (although, as in other areas of continental deposits, not fully represented at any single locality), and comprehension of their origin must involve the interplay of volcanism, sedimentation, and tectonism, as well as the vagaries of erosion along a major river. The Quaternary record is especially complete in the western Snake River Plain, notably for what it tells about early and middle Pleistocene events (Malde and Powers, 1962). The eastern part is almost completely covered by late Pleistocene and Recent basalt, and exposures of older Pleistocene deposits are scanty (Stearns *et al.*, 1938).

In geographic descriptions (Freeman *et al.*, 1945), the Snake River Plain is commonly discussed in connection

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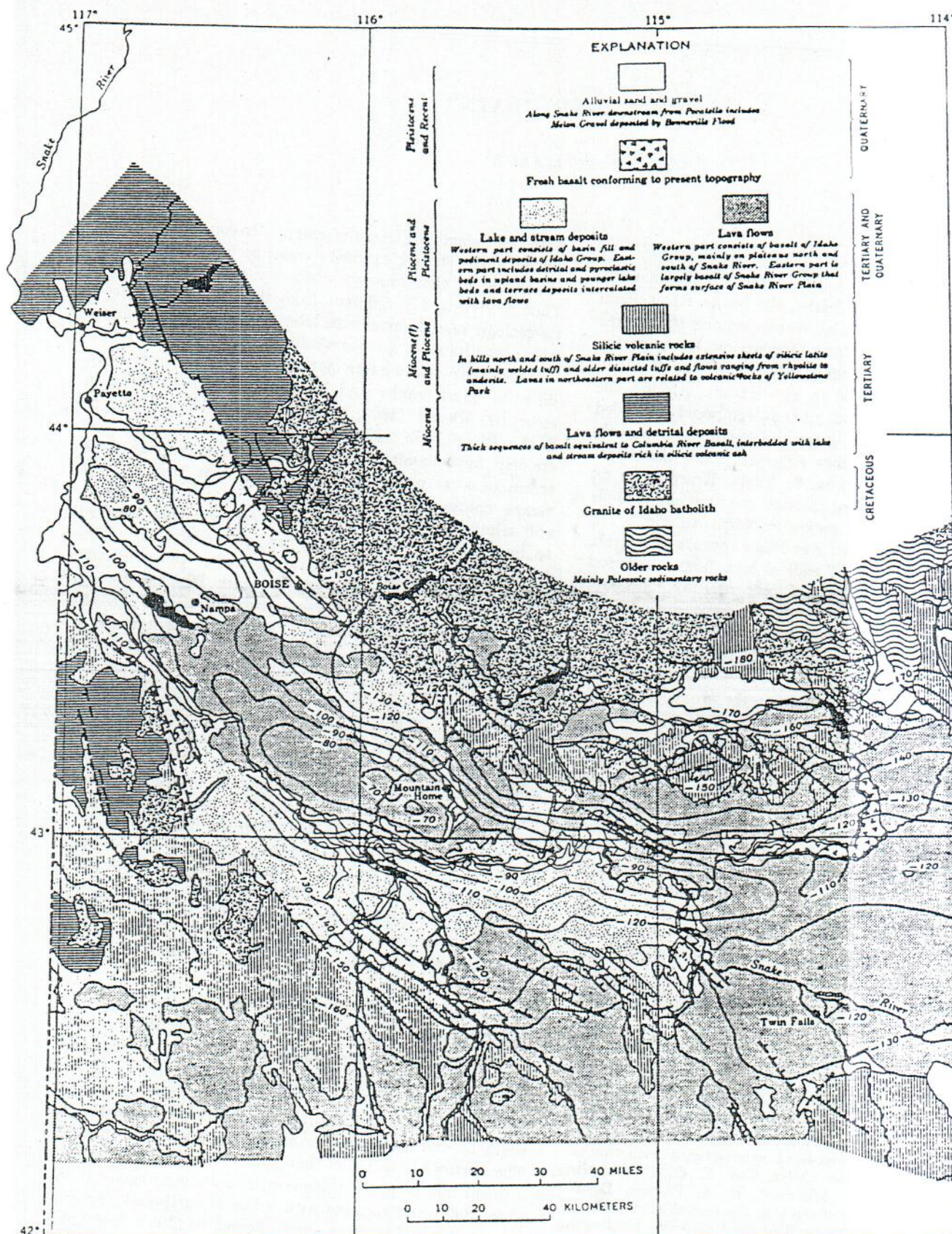
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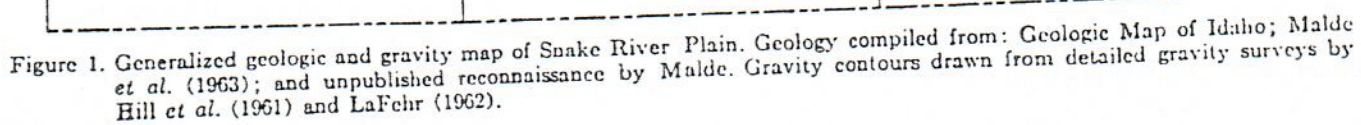
with the Columbia Plateau of eastern Oregon and Washington as if (by sharing extensive tracts of basalt) it were an appendage of that province; but in fact the Snake River Plain is structurally different from the Columbia Plateau, its geologic record pertains to later events (mainly Quaternary), and its lavas are chemically distinct (Powers, 1960).

The eastern and western parts of the Snake River Plain differ in physiography and, as will be discussed later, in structure. Russell (1902, p. 61-66) described the eastern Snake River Plain as constructed by vast floods of extremely fluid basalt that poured in all directions from scores of local vents—so low in relief that they at first escape notice—thus building a broad, nearly level plain, still relatively little dissected. All these vents are believed to be Quaternary in age. They are marked on the "Tectonic Map of the United States." A few of the vents are associated with lava so fresh that they indicate Recent volcanic activity. The western Snake River Plain is much more diversified. Its controlling physiographic feature is the Snake River canyon, which begins a few miles above Twin Falls at a series of cataracts and rapidly becomes entrenched to a depth greater than 150 m. Numerous tributary canyons, absent in the eastern part, here join the Snake and thus dissect the region further. Although the first 30 km of canyon below Twin Falls is cut in basalt, the river thereafter enters a thick mass of detrital deposits, more or less protected from erosion on the north by plateaus of basalt, but intricately dissected into a wide belt of badlands on the south. Considerable parts of the badlands are carved in Quaternary deposits. A few miles from the Oregon state line, the basalt plateaus disappear, the eroded topography becomes subdued, and the Snake River flows on bottomlands of a broad valley. It then enters a mountainous stretch that leads to Hells Canyon.

TECTONIC FRAMEWORK

The Quaternary features of the Snake River Plain express the latest stages of tectonic and depositional events that began in late Tertiary time. The principal structural feature in the western Snake River Plain is a northwest-trending graben about 50 km broad, bounded on the north and south by volcanic highlands of early Pliocene age (Fig. 1). The northwesterly faults that bound the plain project into a broad zone of parallel, high-angle faults in Oregon (Hamilton, 1962) and coincide with a line of earthquake epicenters that stretches from Puget Sound to Great Salt Lake (Malde, 1959). At the bend in the central part of the plain, near the 115th meridian, conjugate northeasterly faults give shape to bordering mountain blocks on the north, and related faults seem to be expressed on the south by saw-





tooth outlines of blocks of siliceous volcanics. If such north-easterly faults continue into the eastern Snake River Plain, even with small throw, they may account for the abrupt termination of mountain ranges at the borders, but inward dips of Tertiary beds at the edges of the eastern Snake River Plain suggest that it may be structurally more like a downwarp than a graben (Kirkham, 1931).

Gravity data also emphasize the structural contrast between the western and eastern Snake River Plain. In the western graben, three well-defined elongated areas of high gravity are nearly parallel to bordering faults, and the southernmost area of high gravity matches a niche formed by the faulted outline of lower Pliocene volcanic rocks. Thus the graben and the concealed heavy rocks that presumably account for the gravity highs seem to have formed concurrently, mainly before middle-Pliocene time. The areas of high gravity are plausibly explained as distended fissure fillings of material injected from the mantle (Hill, 1963), an hypothesis that implies crustal stretching, even though such fissures are not reflected in magnetic data. On the other hand, the eastern Snake River Plain, although also a broad region of high gravity, is characterized by alternating areas of subdued gravity relief that trend across the plain (LaFehr, 1962).

Within the western graben, beginning in the early Pliocene, various clastic beds and intercalated basalt flows that comprise the formations of the Idaho Group were deposited—a sequence that aggregates nearly 1,500 m in thickness. The clastics generally range in texture from sand to clay but include some gravel, siliceous volcanic ash, and diatomite. Nearly all the volcanic ash is in the lower part. The beds form light-colored sequences hundreds of meters thick that erode as badlands. Because of continued subsidence, the Tertiary and lower Quaternary formations of the group occupy successively lower positions topographically, usually in troughs bounded in part by faulted outlines of the next older unit, but the position of later Quaternary deposits was controlled by physiographic factors: pedimentation, canyon cutting, alluviation, and lava damming.

The subsidence that began in the western Snake River Plain in the Pliocene lasted into early-Pleistocene time, but (as shown by level lake beds) the middle-Pleistocene and younger rocks are not perceptibly deformed. Because of the sinking basin, continental deposits extend below sea level (Youngquist and Kiilsgaard, 1951). The eruption of voluminous lavas in the eastern Snake River Plain may also have been accompanied by subsidence as material from the mantle erupted, but the surface flows are not visibly deformed. This evident lack of deformation in later Quaternary time is puzzling, especially in the western part where unloading by late Pleistocene erosion should have caused isostatic rebound.

DETRITAL DEPOSITS OF WESTERN SNAKE RIVER PLAIN

GLENN'S FERRY FORMATION

The outcrops of clastic deposits in the western Snake River Plain display an eastward enlargement of this structural

basin until Blancan time (Wood *et al.*, 1941)—an episode marked by the spread of intertonguing lake and stream deposits over the whole region. Known as the Glenn's Ferry Formation (Table 1), the beds of Blancan provincial age mark an important change in the volume and extent of detrital material. The basin appears to have been extensively and deeply aggraded. Low-angle unconformities within the Glenn's Ferry show that subsidence continued, although perhaps at a slower rate. Because chemically precipitated material is scarce in the Glenn's Ferry, consisting only of local beds of algal limestone and oolite at the base, the lakes and streams of this period apparently were kept fresh by exterior drainage. Biogeographic considerations (Cook and Larrison, 1954; Taylor, 1960) point to an outlet in southern Oregon, probably via the Klamath-Pit River system.

Although the older clastic deposits of the western Snake River Plain contain large amounts of siliceous volcanic ash (chemically related to provincial sources), the Glenn's Ferry Formation has only a few beds of ash. These include ash derived from eruptions in the Cascade Mountains of Oregon and Washington. Because the ash beds are distinctive physically and chemically, they are useful for local correlation (Powers and Malde, 1961).

The lakes and streams of the Glenn's Ferry nourished an extraordinarily large and diverse molluscan fauna, comparable in variety and in degree of endemism to the fossil mollusks from the former Pontian, Dacian, and Levantine basins of southeastern Europe. Dwight W. Taylor (*in* Malde and Powers, 1962, p. 1208) reports: "Most of the mollusks from the lacustrine facies are prosobranch gastropods of the families Hydrobiidae, Pleuroceridae and Thiaridae, but *Payettia*, *Vorticifex*, and the peculiar *Orygoceras* are common (Dall, 1924). Nearly all these lacustrine species are extinct (94 percent)." The Glenn's Ferry Formation is also notable for its fossil fish (Uyeno, 1961) and mammals (Gazin, 1936; Wilson, 1934; Hibbard, 1958).

Evernden *et al.* (1964, p. 184, samples KA 831 and KA 832) have determined potassium/argon ages of 3.3 million and 3.2 million years for two samples of volcanic ash from the Glenn's Ferry Formation. Associated basalt, considered by them to be better for dating, is dated 3.5 million years (KA 1173).

TUANA GRAVEL

After Glenn's Ferry time perceptible deformation ceased, and the basin deposits were broadly beveled by a layer of sand and gravel as much as 60 m thick—the Tuana Gravel. The Tuana rises gradually southward from plateau remnants near the Snake River between the 115th and 116th meridians, and most of its constituents are from hills of siliceous volcanics to the south. However, the regularity of bedding and the presence of a few constituents from the north suggest that the sand and gravel were spread and sorted by the ancestral Snake River. Thus, with deposition of the Tuana Gravel, the buildup of fine-grained detritus that had characterized the Pliocene and earliest Pleistocene came to a close. The basin probably was then largely covered with coarse debris graded to marginal erosion surfaces.

BRUNEAU FORMATION

The earliest signs of canyon cutting are traced by the Bruneau Formation, a complex of lake beds and lava flows that fills a narrow trench roughly parallel to the present Snake River but lying a few kilometers south. The trench is cut in Glens Ferry beds capped by remnants of Tuana Gravel and reaches a depth of 250 m at the mouth of the Bruneau River (116th meridian). In considerable part the sedimentary beds consist of clay, silt, and diatomite deposited in lakes impounded by lava dams, but these fine-grained materials are interbedded with several layers of beach gravel that represent temporary stages of equilibrium in lake level. The gravel was derived by reworking of the Tuana during shore erosion and rests on buried benches along the margins of the ancient canyon.

Part of the lava that impounded the lakes spilled into the ancient canyon from vents on upland erosion surfaces around Mountain Home, but dams were also erected by volcanoes along a remarkable string of vents that reaches 65 km northwestward along the Snake River from the mouth of the Bruneau River. This chain of volcanoes suggests that fractures formed by regional tectonism existed in Bruneau time. Several of these ancient volcanoes have been gutted by the modern canyon of the Snake.

In lowlands farther downstream, beyond these volcanoes, the Bruneau Formation has not been recognized, but the highest lake beds (980 m altitude) suggest that the ultimate dam may have been at the Oxbow on the Snake River (also 980 m altitude—at northwest corner of area of Figure 1). The Oxbow is the presumed site of capture of Snake River drainage by an ancestral tributary of the Salmon River that cut Hells Canyon (Wheeler and Cook, 1954). Spillover at the Oxbow in Bruneau time may have established the present connection of the Snake with the Columbia River system. If so, some other outlet of earlier age, contemporaneous with the stage of Bruneau canyon cutting, must be assumed.

The molluscan fossils from the Bruneau Formation represent almost entirely living species. Dwight W. Taylor (in Malde and Powers, 1962, p. 1211) reports that "only one of the species is extinct, and most of the others are living in southwestern Idaho. The abundant species of the Snake River today, such as *Gonidea angulata* (Lea), *Valvata utahensis* (Call), *Lithoglyphus fuscus* (Haldeman), and *Vorticifex effusus* (Lea), appear first in the Bruneau Formation." The vertebrate fossils, although few, represent typically Pleistocene forms. (See summary in Malde and Powers, 1962.)

On the basis of ages assigned to the mammalian and molluscan fossils, the Bruneau is dated as middle Pleistocene. A potassium/argon age of 1.4 million years (Evernden *et al.*, 1964, p. 191, sample KA 1188) for the youngest basalt suggests that the Bruneau is preglacial.

BLACK MESA GRAVEL

South of the Snake River the Bruneau Formation and older basin deposits are beveled by a pediment deposit of locally derived sand and gravel about 8 m thick that extends

discontinuously about 110 km westward from the 115th meridian. Accordant remnants of this deposit, known as the Black Mesa Gravel, define a gravelly swath about 16 km wide that lies 170 m above the Snake River. This broad pediment displays no geometrical symmetry with respect to tributary canyons of the Snake and clearly antedates the modern canyon. A cap of hard caliche on its surface indicates prolonged weathering and implies that the Black Mesa is rather old, but it cannot be accurately dated. Because the Black Mesa Gravel is older than entrenchment of the present canyon, it is regarded as middle Pleistocene in age.

LAVA FLOWS OF EASTERN SNAKE RIVER PLAIN

Russell (1902), in his pioneer study of the Snake River Plain, surmised that the extensive basalt flows of the eastern plain intertongue with clastic deposits in the western basin—a conclusion confirmed by recent mapping (Malde *et al.*, 1963). Faulted Pliocene basalt that forms upland plateaus on silicic volcanic rocks intertongues with sediments near the Snake River at the 114th meridian and thickens eastward in outcrops along the canyon as far upstream as Twin Falls. Lava flows in Glens Ferry deposits near the 115th meridian also thicken upstream. Much of the basalt of Bruneau age was erupted from sources near the Snake River within a few kilometers of the 114th meridian, where it intertongues with lake beds, although other sources are known in hills north of the Snake farther east. All of these rather ancient lava flows are more or less weathered. Fresh basalt of younger age, known as the Snake River Group, was erupted during entrenchment of the present canyon—almost entirely from sources east of the 115th meridian. Basalt of the Snake River Group came from numerous vents and covered nearly all the eastern plain. The eruption of these younger lavas apparently forced the Snake River into its course along the southern margin of the plain, from which it does not depart until reaching the head of the sedimentary basin near the 115th meridian. In places, therefore, basalt of the Snake River Group is interbedded with stream deposits (mainly gravel), but detrital material is only a minor component.

The relation of lavas of the Snake River Group to entrenchment of the present canyon is particularly well displayed near the 115th meridian. (See the stratigraphic sequence outlined in Table 1.) Here, successive lava flows fill a series of former canyons, each deeper than its predecessor, and each pursuing westward paths that lie successively farther south. This series of lavas culminates in basalt that partly fills the present canyon.

At times between lava eruptions the ancestral Snake River built terraces of gravel, which were formed at progressively lower heights as cutting continued. The oldest, the Sugar Bowl Gravel, is preserved on knobs 120 m above the river in wide places along the canyon that coincide with tributary junctions. Evidently it was deposited after the present system of tributary streams had been established. Abundant pebbles of porphyry, quartzite, and granite from glaciated mountains of central Idaho in the Sugar Bowl

TABLE 1

Sequence of Quaternary Deposition and Erosion in Western Snake River Plain (Based on Malde and Powers, 1962)

AGE		STRATIGRAPHIC UNIT	DESCRIPTION
Pleistocene	Recent	Lava flows	Fresh basalt largely unmodified by surficial deposits.
		Older alluvium	Pebble and cobble gravel on terrace 8-30 m above Snake River.
	Late	TERRACE CUTTING	
		Melon Gravel	Rounded boulders and cobbles of local basalt in matrix of basaltic sand. In Snake River canyon, forms huge bars up to 90 m high--commonly veneered with boulders ("melon patches"). Deposited 30,000 years ago by catastrophic outflow from Lake Bonneville in Utah.
		EROSION OF CANYON-FILLING LAVA FLOWS	
		Lava flows	Fresh basalt and pillow lava filling or cascading into former canyon of Snake River. Upland surfaces partly mantled with eolian material.
		CANYON CUT TO PRESENT DEPTH	
		Crowsnest Gravel	Mainly outwash of cobble and pebble gravel from glaciated mountains of central Idaho. Forms terrace about 60 m above Snake River.
		Thousand Springs Basalt	Succession of lava flows that filled ancient canyons and deflected Snake River toward southern margin of Snake River Plain. Smooth mantle of alluvial and eolian deposits yields cold-climate mollusks.
		CANYON CUTTING	
		Sugar Bowl Gravel	Outwash of pebble gravel from glaciated mountains of central Idaho. Dissected remnants define a terrace 120 m above Snake River.
		TERRACE CUTTING	
		Madson Basalt	Columnar lava filling a former canyon of Snake River 90 m deep.
		PARTIAL ENTRENCHMENT OF SNAKE RIVER	
Pliocene	Middle	Black Mesa Gravel	Gravel and sand on broad remnants of pediment widely preserved south of Snake River and 170 m higher. Hard caliche cap 2 m thick.
		BROAD VALLEY EROSION	
	Early	Bruneau Formation	Canyon fill of undeformed, unconsolidated lake beds (chiefly clay, diatomite, and beach gravel) and interbedded basalt (partly fragmental material altered locally to palagonite). Sequence interrupted by several local disconformities caused by breaching of lava dams. Fill about 250 m thick, but associated marginal deposits of fan gravel and basalt rise 90 m higher. Fossils include <i>Mammoth</i> , <i>Equus</i> , <i>Gigantocamelus</i> , and <i>Paranylodon</i> , and a large molluscan fauna of modern character. Youngest basalt dated 1.4 million years by K-A.
		CANYON CUTTING	
	Late	Tuana Gravel	Pebble and cobble gravel interbedded with sand and silt on dissected erosion surface south of Snake River and 180-250 m higher. Mainly debris from highlands farther south. Locally 60 m thick. Hard caliche cap about 2 m thick. Fossils include proboscidean remains.
		PLANATION OF BASIN DEPOSITS; MINOR FAULTING	
		Glenns Ferry Formation	Basin fill of poorly consolidated detrital material and minor lava flows of basalt. Abrupt lateral changes in sedimentary facies 100-200 m thick represent adjoining environments of lakes (massive silt), river channels (thick beds of sand), and swampy flood plains (thinly bedded dark clay, olive silt, and carbonaceous shale). Bedding interrupted by numerous minor unconformities resulting from contemporaneous subsidence. About 600 m of beds exposed. Fossils include numerous vertebrates of Blancan provincial age (Wood and others, 1941), an extraordinarily large molluscan fauna consisting almost entirely of extinct forms, and abundant remains of pollen, algae, and diatoms. Basalt dated 3.5 million years by K-A.

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gravel—the earliest recognized sign of such material in the Snake River Plain—suggest that this gravel may be mainly glacial outwash. The Crowsnest Gravel, which forms a terrace about 60 m lower, is also rich in these constituents and may represent another stage of alpine glaciation. Neither the Sugar Bowl nor the Crowsnest is strongly weathered, but both have moderately well-developed calcareous soils. A still younger gravel on the canyon floor (the Melon Gravel, to be discussed later) is dated about 30,000 years old by radiocarbon. Stream deposits of probable Wisconsin age are represented by terraces of cobble and pebble gravel 8-30 m above the Snake River.

The fresh lavas near the 115th meridian that are related to entrenchment of the present canyon are only local flows in the great body of basalt that stretches 300 km north-eastward. Buildup of this basalt formed a subdued crest along the axis of the plain, where most of the vents are concentrated. Although the surface flows are not deformed, alignment of vents along northeasterly and northwesterly trends suggests that eruptive centers have been structurally controlled. For example, vents at Craters of the Moon, a picturesque area of exceptionally fresh lavas and cinder cones (Stearns, 1928), lie along a southeast-trending rift that projects to an area of Recent basalt near the Snake River. Basalt at the extreme northeastern end of the plain intertongues with rhyolite tuff related to silicic volcanics of Yellowstone Park, and eruption of the rhyolite apparently coincided with a caldera collapse (Hamilton, in press), shown as a ring fault on Figure 1.

The thickness of basalt in the eastern Snake River Plain is not accurately known, but seismic data between Craters of the Moon and Idaho Falls indicate a local thickness of at least 1,300 m (Perkins *et al.*, 1947). Gravity data suggest that the basalt may fill broad troughs (areas of high gravity) that trend across the plain (Fig. 1), roughly parallel to the structure of basins and ranges to the north and south, although more widely spaced. Hence, if such basalt-filled troughs are a reality, they are probably of tectonic origin.

The great thickness of the basalt in the eastern Snake River Plain prompts questions about the age of the deeply buried part. If the lower part is Pliocene and early Pleistocene, equivalent to weathered basalt exposed west of Twin Falls, the ancestral Snake River must have crossed long stretches of basalt while transporting elastic debris to the western basin. Nevertheless, basaltic constituents are not identifiable in the basin deposits—unless a few layers of dark clay represent reworked basaltic soils. Presumably the old basalt of the western basin does not extend very far eastward, and the lavas of the eastern plains (in spite of their great thickness) are mainly younger than the basin deposits—that is, late Pleistocene.

MELON GRAVEL AND BONNEVILLE FLOOD

Gilbert (1890, p. 177) discovered that Pleistocene Lake Bonneville overflowed at Red Rock Pass (near 42°20' N., 112° W.) and rapidly discharged a vast amount of water into the Snake River. Only recently, however, have effects of the sudden outflow been reported along the Snake River. These consist of scabland paths between Pocatello and Twin

Falls and of gigantic bars of locally derived boulder gravel along the canyon downstream (Malde, 1960; Trimble and Carr, 1961; Stearns, 1962). On the Snake River Plain at Pocatello, the floodwater entered an existing Pleistocene lake and deposited coarse deltaic debris named the Michaud Gravel (Trimble and Carr, 1961). The flood debris below Twin Falls is known as the Melon Gravel, a name that evokes an image of its most conspicuous feature: broad straths strewn with melon-sized boulders.

The scabland shows that some floodwater was diverted into upland channels, which lead to marginal cataracts along the canyon rim some distance downstream. Scabland and abandoned cataracts are particularly noteworthy near American Falls (48 km downstream from Pocatello) and at Twin Falls. The bars of Melon Gravel below Twin Falls show that the canyon was flooded in places to a depth of 90 m. Relatively tranquil flow of floodwater through wide segments that occur here and there along the canyon caused flood debris to be dumped in enormous piles, and the volume of Melon Gravel thus trapped (about 2.4 billion m³) corresponds approximately with the estimated volume of erosion at the canyon head near Twin Falls.

A constriction south of Boise in the Snake River canyon, which acted as a huge hydraulic flume, gives a basis for calculating the maximum discharge—estimated by Clifford T. Jenkins, U.S. Geological Survey, to have been 15 million ft³/sec (0.42 million m³/sec). At this rate the volume of water drained from Lake Bonneville would have provided floodwater for about six weeks; but discharge probably was attenuated as overflow continued, and the Bonneville flood may have lasted several months or years.

The time of the Bonneville flood is approximately dated at 30,000 years ago by radiocarbon. One date, 29,700 ± 1,000 years (Trimble and Carr, 1961, sample W-731), comes from shells in a terrace deposit southwest of Pocatello that is somewhat younger than the peak flood. Two other radiocarbon dates, 33,000 ± 1,600 years and 35,000 ± 3,000 years (Ives *et al.*, 1964, p. 54, samples W-1121 and W-1177), for organic soil baked by a lava flow in the path of the flood downstream from Red Rock Pass, are discussed by Bright (1963) in the light of his stratigraphic studies of the history of the Bear River, which indicate that diversion of the Bear River into the Bonneville basin may have caused Lake Bonneville to overflow. Furthermore, certain high levels of Lake Bonneville correspond with glacial episodes near Salt Lake City (Richmond, 1964). Thus, because of the link between the Melon Gravel and Lake Bonneville, a small part of the history of the Snake River Plain may be tied to knowledge of glacial events gained elsewhere.

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SUMMARY

The vast lowland, known as the Snake River Plain, that stretches across southern Idaho is a Pliocene structural trough filled with a complex sequence of basaltic lava and intercalated detrital deposits more than a kilometer in thickness, much of which is of Quaternary age. The trough at the western end is outlined by a northwest-trending graben 50 km broad, the site of a basin fill of lake and stream deposits rich in molluscan and vertebrate fossils. The eastern plain, on the other hand, a monotonous tract of lava diversified only by numerous subdued volcanic vents, is structurally more like a downwarp.

Canyon cutting in the western basin to a depth of 150-300 m gives excellent exposures of the Quaternary deposits and their physiographic relations. A widespread unit of Blancan provincial age at least 600 m thick, characterized by moderately faulted fine-grained sedimentary facies indicative of adjoining environments of lakes, river channels, and swampy flood plains, is beveled by undeformed lower Pleistocene sand and gravel 180-250 m above the present Snake River. A subsequent canyon 250 m deep was filled in middle Pleistocene time by lava flows and by sediments trapped in lakes behind lava dams. These deposits were then beveled by pediment gravel 170 m above the river.

Entrenchment of the present Snake River canyon, regarded as a late Pleistocene event, coincided with eruption of the surface lava flows in the eastern plain, which apparently forced the Snake River into its course along the southern margin. Two gravel terraces 120 m and 60 m above the river, which were built between lava eruptions as cutting progressed, include abundant constituents from glaciated mountains in central Idaho and possibly represent glacial outwash. Still younger gravel on the canyon floor, distinguished by enormous boulders heaped in huge bars as much as 90 m high, is attributed to catastrophic overflow of Lake Bonneville about 30,000 years ago.

