PRELIMINARY REPORT ON THE GEOLOGY OF PART OF THE LOWER SNAKE RIVER CANYON, WASHINGTON

By

HOWARD H. WALDRON AND LEONARD M. GARD, JR.

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Prepared in cooperation with the
Corps of Engineers, U.S. Army Walla Walla District

Denver, Colorado

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Abstract

The lower Snake River, throughout its length, flows within the Columbia Plateau physiographic province and has cut a deep canyon into the eastern part of the plateau. This report describes the geology of a three mile wide strip of the canyon between river miles 43 and 102 in southeastern Washington.

The formations of the area are readily divisible into two groups. The older group, comprising the bedrock of the entire area, consists of over 1,000 feet of Columbia River lavas, some interbedded sediments and pyroclastics of Miocene age, and some younger canyon lava flows of Pliocene or early Pleistocene age. The second group comprises the surficial deposits and consists of unconsolidated Pleistocene eolian and fluvio-glacial deposits, and Recent sediments.

In general, the basalt flows and the plateau surface controlled by them are tilted gently westward with dips of less than one or two degrees. Some minor folding, faulting, and fracturing probably accompanied this westward tilting, as the present courses of the Snake River and many of its tributaries strongly suggest control by regional lines of weakness.

The geologic history of the area is very incompletely known but records successive periods of pre-Pleistocene volcanism and canyon cutting, accompanied by some minor deformation. The Pleistocene and Recent epochs record several periods of aggradation, degradation and ponding.

Geologically, the lower Snake River canyon is ideally suited, in many ways, for the construction of dams. Excellent foundations and copious quantities of easily excavated construction materials exist at many places throughout the length of the canyon. Geologic structures are simple, and no seismic activity has been recorded in the area. Existing slopes are relatively stable, and no evidence was observed of large landslides.

Introduction

The U. S. Geological Survey in 1949 and 1950, at the request of Col. W. M. Whipple, District Engineer, and in cooperation with the Corps of Engineers, U. S. Army, Walla Walla District, Washington, mapped the geology of part of the lower Snake River Canyon in southeastern Washington. The purpose of the mapping is to provide the Corps of Engineers with basic geologic data and a geologic map of the canyon between river mile 43 and 102, as an aid to planning future projects located upon the river.

The field work upon which this report is based was begun June 18, 1949 and continued to October 15, 1949. During this time the writers were assisted by G. Ray Arnett and Dale Roberts. The mapping was completed by the writers during the period of April 18 to May 31, 1950. Investigations were confined to surface exposures, supplemented where available by Corps of Engineers records of preliminary drilling and seismic exploration. The geology was plotted on aerial photographs and transferred to topographic base maps by sketchmaster. Base maps are U. S. Geological Survey topographic compilation sheets, at a scale of 1:24,000, of the Haas, Starbuck, Hay, and Penawawa 15 minute quadrangles.

The geologic map (plates 1 - 7) is the base of the report. The map explanation includes a description of the materials found in the various deposits, together with their distinctive topographic and lithologic characteristics. Most of the data on engineering geology are presented in tabular form and accompany the geologic map to facilitate the selection of specific kinds of information. The general geology is presented in preliminary form in this report.

Acknowledgements

The Corps of Engineers very kindly furnished geologic maps and reports of their numerous investigations along the Snake River, including records of drilling and seismic explorations, and supplied a boat and motor for river transportation.

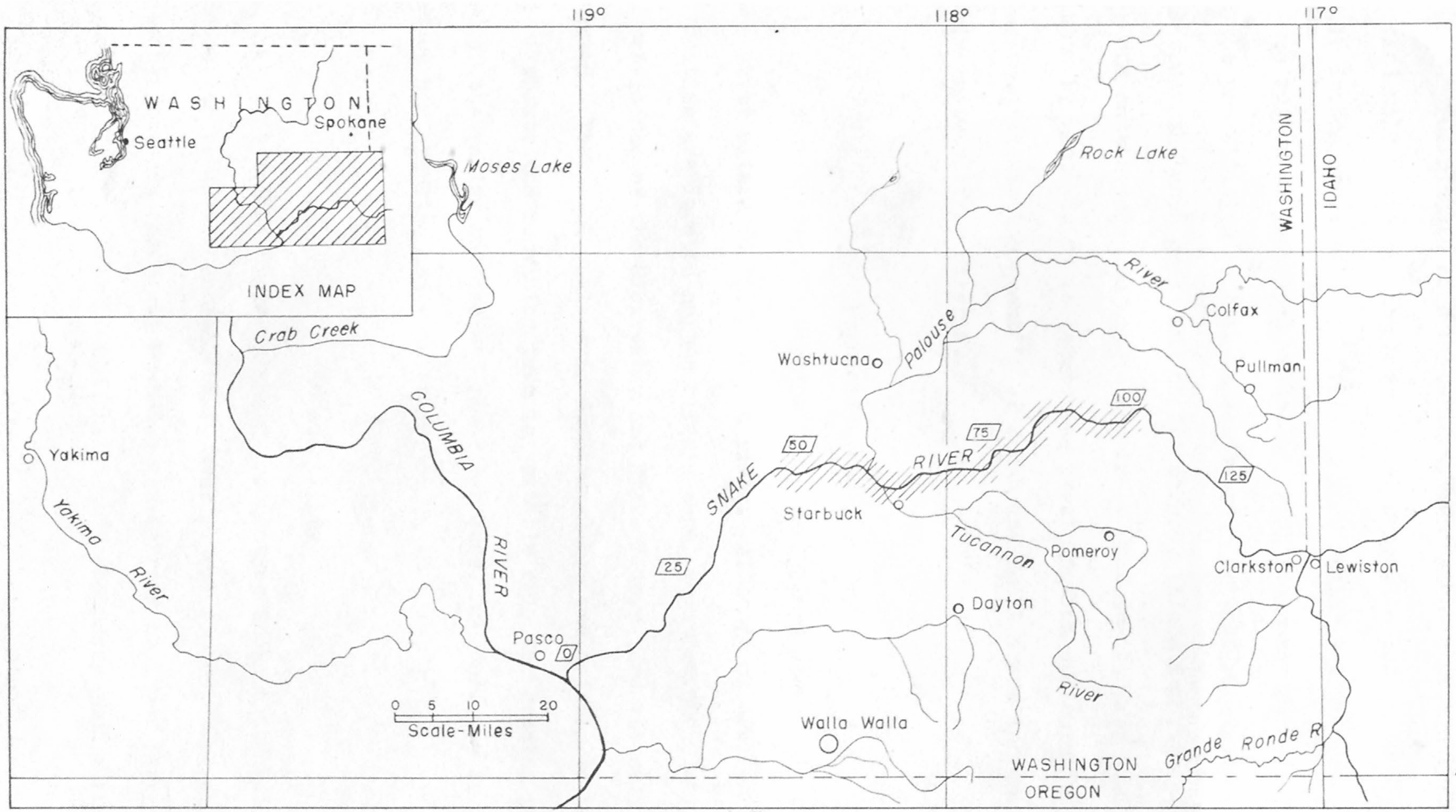
The assistance and cooperation of the following members of the Corps of Engineers, Walla Walla staff, is sincerely appreciated: Engineer Bart G. Long, Chief, Foundations and Materials Branch; Engineering Geologist Thomas F. Thompson, Head, Section of Geology and Exploration; Engineering Geologist Charles J. Monahan, Head, Geology Subsection; and Engineering Geologist Delbert L. Snyder. Mr. Snyder's suggestions and discussions in the field during part of the 1949 field season very materially aided the investigation.

Mr. Fred O. Jones of the Survey took most of the photographs and contributed much to the report by his helpful discussions during frequent visits in the field and during the preparation of the manuscript.

Geography

Location

The Lower Snake River is that part of the river flowing through southeastern Washington between Lewiston, Idaho, near river mile 140, and its confluence with the Columbia River, near Pasco, Washington (fig. 1.). The area mapped includes a strip along the river about 3 miles wide and 60 miles long between river miles 43 and 102 in Franklin, Whitman, Columbia, Garfield, and Walla Walla counties. The canyon traverses the new Haas, Starbuck, Hay and Penawawa 15 minute topographic quadrangle maps which lie between longitudes 117° 30' W. and 118° 30' W., and latitudes 46° 30' N. to 46° 45' N.



25 River Miles

Area Mapped

FIGURE I.-REFERENCE MAP OF LOWER SNAKE RIVER, WASHINGTON

Climate and vegetation

The climate of southeastern Washington is marked by hot, dry summers and mild winters. The mean annual precipitation is low, between 8 and 16 inches, most of which falls as snow during the winter. The winds of this region are somewhat variable, owing to topographic irregularities, but the prevailing direction is southwest. Natural vegetation is restricted largely to bunch grass and desert shrubs. Along the river are some willows and cottonwoods, but few other trees grow in the area except those planted by man. Owing to increasing precipitation and more favorable ground-water conditions, the quantity of brush and small trees increases progressively eastward from Riparia.

Population and industry

Southeastern Washington is sparsely populated; only a few small towns exist within 50 miles of the river. Although several small railroad communities are located on the river's edge, Lewiston and Clarkston, at the confluence of the Clearwater and Snake Rivers, are the only town so situated. The arable upland is devoted almost exclusively to the dry farming of wheat; the remaining land is suitable only for grazing purposes. Some of the valley bottoms and river terraces, however, are irrigated and produce hay, fruits, and vegetables.

Accessibility

The Inland Empire highway, connecting Spokane and Walla Walla, crosses the river at Central Ferry, near river mile 83. The only other crossings between Pasco and Lewiston are ferries at Lyons Ferry (river mile 59), and at Wawawai (river mile 111). Many secondary county and private roads, however, lead to the river, so that almost all of the terraces along the river are accessible by automobile during dry weather, but in the winter months and after heavy rains these roads are nearly impassable unless gravelled. The access road to Lower Monumental dam site is a partly gravelled county road from Clyde and generally is in good condition. Access to Little Goose Island dam site is via an unsurfaced, poorly maintained road which joins the Starbuck-Delaney road near Starbuck.

The maximum altitudes are in the eastern part of the area mapped. Here the tops of the steep-sided loess hills, at an altitude of about 2,000 feet, are remarkably concordant. Hill-top altitudes gradually decrease westward to 1,600 feet or less in the Haas quadrangle, and as the elevation decreases the diversity of relief becomes less pronounced. To the east the valleys and tributary draws are short and numerous, the slopes are short and moderately steep to steep, and the divides are narrow. To the west a series of long coulees, having westerly to southerly trends, receive many tributaries from each side. Here the slopes are generally longer and less steep, the valleys wider, and the divides broader than farther east. From the vicinity of the Palouse River to the western edge of the area mapped, the rolling and maturely dissected "Palouse topography", which has a maximum relief of about 300 feet, is replaced over large areas by "scabland". The term "scabland" is used herein to denote areas from which the surficial cover has been stripped, leaving a rough, ragged, and nearly barren surface of basalt. Relief in the scabland area, exclusive of the deep canyons, is 400 to 500 feet.

The Snake River canyon is nearly 1,500 feet deep at the eastern edge of the area mapped, but it decreases to about 1,000 feet in depth at the western edge. In most places the canyon walls are precipitous and consist of a series of narrow talus covered benches, separated by vertical faces of basalt. The valleys opening toward the Snake River, although commonly short and steep are graded to the river. The floors of the larger canyons are wider than their watercourses and commonly are occupied by sand and gravel or silt terraces. (See pl. 8)

Only a few lakes exist on the plateau and none occur within the mapped area. Although most of the streams are intermittent and flow only during the wet season, drainage on the plateau is well-integrated. Within the mapped area, the Palouse River on the north and the Tucannon River on the south are the only major tributaries. No perennial streams occur west of the Palouse River, but eastward from it a general increase in the number of small perennial streams is noticeable.

The pattern of stream flow of the Snake River and its tributaries is characteristic of snow-melt run-off; i. e., high flow between March and July and low flow between August and February. The average fall of the river is less than 3 feet per mile. The rate of flow, however, ranges from less than 2 to more than 15 miles per hour, averaging about 4 miles per hour. During low water, some of the channel is barely covered; in other places soundings reveal depths as great at 70 feet. During flood stages, however, the river may rise as much as 30 feet or more above low water.

As a rule the bed of the stream is covered by a thin veneer of Recent river alluvium; locally however, the alluvium may be as much as 50 feet thick. There are no falls in the lower Snake River, but there are numerous rapids caused by basalt cropping out in the bed of the stream. Because of the physical character of the basalt, the erosional processes seem to be largely plucking rather than abrasion.

Geology

The geology of the lower Snake River canyon is shown on plates 1 to 7. The formations of the area are readily divisible into two sharply defined groups. The older group, comprising the bedrock of the entire area, consists of a thick series of Miocene and younger canyon lavas, and some minor interbedded sediments and pyroclastics. The second group comprises the surficial deposits that consist of unconsolidated Pleistocene eolion and fluvio-glacial deposits, and Recent sediments.

Rocks older than the Columbia River lavas do not crop out within the area mapped. The occurrence, however, of older igneous and metamorphic rocks in surrounding areas, such as the Blue Mountains, Kamiak Butte, Steptoe Butte, and Granite Point (Russell, 1897, p. 30-40; Huntting, 1942) suggests that these older rocks probably underlie, at varying depths, a large part of the lower Snake River Basin.

The lower Snake River, throughout its length, flows within the Columbia Plateau physiographic province and has cut a deep canyon into the eastern part of the Plateau. In general, the basalt flows, and the plateau surface controlled by them, are tilted gently westward with dips of less than one or two degrees. Faulting occurs in the lavas but apparently only to a minor degree. The geologic history of the area is varied and complex, including records of repeated volcanism, diastrophism, erosion, and deposition.

Igneous Rocks

Columbia River basalt

Within the area mapped, the lower Snake River canyon is cut into a thick succession of basaltic lava flows. These lava flows, part of the

Columbia River basalts, are believed to be chiefly of Miocene age, but may be early Pliocene in part.

The lava erupted from centers as yet unknown and spread out widely over the land, inundating an older topography of considerable relief. Within the area mapped, successive flows, ranging in thickness from 15 to over 150 feet, are exposed in a section nearly 1,500 feet thick. Although the maximum thickness of the lava is not known, it is at least 5,000 feet thick (Culver and Lupher, 1937, p. 72).

In general, the basalts are dark gray to black where fresh, dark brown on weathered surfaces, hard except where weathered or altered, and slightly vesicular. As seen in hand specimen their texture varies from aphanitic to porphyritic, but most of the flows are aphanitic and none of the constituent minerals are visible. In the porphyritic varieties the phenocrysts are feldspar, mostly small, but in some flows may be one-half inch or more in length. As no lava is ever quite homogeneous during and immediately after extrusion, layers and patches differ slightly in composition, gas-content, viscosity, and degree of crystallization, and upon flowage produce the parallel lenses, streaks, bands, and lines manifested in the solidified rock by differences in color and texture.

In thin section the texture of the basalts is generally intersertal, and shows tabular feldspars, augite, olivine and magnetite in a glassy base. The plagioclase feldspar is labradorite; it shows little or no zoning and has an average length of about 1.0 mm. The pyroxene is monoclinic and normally occurs as finely granular or tabular masses of augite scattered throughout the glassy base. Olivine is nearly always present, but is not abundant; normally it is altered to iddingsite and antigorite. Magnetite is abundant as subhedral crystals and as dust. The glassy base, which constitutes 50 percent or more of the rock, is a typical brown basaltic glass. Secondary products are principally vesicle fillings and alteration products. Calcite, opal, and zeolites (?) are the most common vesicle fillings; antigorite, chlorite and iddingsite, are the common alteration products.

The form of a lava flow depends chiefly on the fluidity of the magma, which in turn depends on the composition and temperature. The surface of a flow chills rapidly upon contact with air to form a crust. In some flows the chilled surface is comprised of a mass of rough, jagged, angular blocks of all dimensions; in others the surface is smoother, in many places highly glazed, and exhibits wrinkled, ropy, or corded forms. Both of these forms, however, are considered to be but end-members of a transitional series of lava forms for which all gradations between the two may occur in any one flow.

In general, vesiculation, produced by the escape of gas as the pressure diminishes, is most pronounced in the upper part of a flow, generally in a zone several feet thick, but it may extend to a lesser degree throughout the central part of a flow. A somewhat thinner, less conspicuous vesicular zone, in most places less than 6 inches thick, is commonly present at the base of a flow. The vesicles may be spherical, elliptical, cylindrical, or irregular in shape. Extreme vesiculation produces zones of scoria at the tops and bottoms of the flows. Another surface feature of some flows is an altered breccia, produced by the breaking up and abrasion of the lava and subsequent alteration by gases. The upper part of many of the flows is oxidized to a reddish color for a depth of several feet.

Tension joints resulting from change in volume of the lava during cooling produce the platy features and the familiar vertical polygonal columns which are present in the central and lower portion of most of the flows. In some of the flows the basal vertical columns change abruptly upward into a pseudo-columnar or hackly-massive basalt.

Few large open spaces, caverns or tunnels were observed at contacts between flows. Contact zones, however, because of vesiculation and brecciation, generally are much more pervious than the central portions of the flows, and consequently springs and seeps are more common along these contact zones.

Decay of the basalt is negligible The low humidity and rainfall permit the formation of only a thin weathered zone on the exposed surfaces. The extreme temperatures, however, facilitate disintegration of the well-jointed rock into a loose, blocky surficial rubble.

The age of at least part of the Columbia River basalt is fixed by its relationship to the Latah sediments, which occur interbedded with it along the eastern and northern margins of the plateau. These sediments have been assigned to the middle or upper Miocene (Knowlton, 1926, p. 21; Berry, 1929, p. 234; Kirkham and Johnson, 1929; Berry, 1931, p. 32; and Brown, 1937, p. 163). Berry, (1934, p. 101), Beck (1940), and Chaney (1944, p. 289) have suggested, however, that some of the upper basalt flows may be Pliocene.

Intracanyon basalt

Small discontinous masses of basaltic lava, which disrupt the continuity of the Columbia River basalt flows, occur intermittently throughout the length of the canyon in the area mapped. Evidence as to the mode of origin of these lava masses is not conclusive, but field relations suggest that they are probably remnants of flows that filled former drainage features cut into the main mass of the Columbia River basalt. For that reason they are called "intracanyon basalt".

The intracanyon basalt in most places occurs as small masses less than 100 feet thick, 1,000 feet long, and a few hundred feet broad.

Megascopically they differ but little from the main bulk of the Columbia River basalt. They are similarly dark gray or black, but are characteristically finely porphyritic, containing small needle-like feldspar phenocrysts. Because the rocks are unaltered and weathering is negligible, they also appear much fresher than the older lavas. Their salient characteristic however, is their columnar structure. (See pl. 9.) Generally the columns of the intracanyon flows are of smaller diameter, better developed and more irregular in attitude than those of the older lavas. They range in diameter from 6 inches to 4 feet, but average 12 to 18 inches. In general the columns conform to a fan-shaped pattern, but many of them are irregularly disposed and may be inclined in any direction from horizontal to vertical.

Cross sections of the masses suggest canyon filling. Where exposed on the walls of the Snake River canyon and at the mouths of tributary valleys they exhibit roughly semi-circular or parabolic shapes, discordant with the nearly horizontal older lavas with which they are in contact. Generally the floor of the old canyon is not exposed; at only one locality (NE¼, Sec. 1, T. 12 N., R. 37 E., near river mile 64) were gravels exposed at the base of an intracanyon flow. Other localities, at the east end of Rice Bar (near river mile 94) and at the west end of Three Springs Bar (near river mile 47), showed the intracanyon lavas in sharp contact with rock surfaces of Columbia River basalt, along what is presumed to have been the old canyon wall. At both of these localities the intracanyon lava, near the floor of the old canyon, is in contact with a few inches to as much as several feet of an altered and baked, claylike, dull yellowish soil with included basalt fragments. The implied mode of origin by canyon filling is further borne out by the attitude of the columnar jointing. Columnar jointing normally develops at right angles to the cooling surfaces; hence, in localities where contacts are not exposed, the patterns of the columns, which in general resemble large inverted fans, also suggest canyon filling.

Similar features in the Lewiston basin were interpreted by Fuller (1928) as cross sections of volcanic vents of an unusual type. He named them "Asotin craters". Later work by Lupher and Warren (1942) proved these so-called "craters" to be lava-fillings in a former river canyon. Graham (1948) also has mapped and described intracanyon flows along the Snake River just northwest of the Lewiston basin. Although the intracanyon basalts in the vicinity of Lewiston have not been examined in detail by the writers, their characteristics, as described by the above authors, further substantiates the belief that the anomalous lava masses occurring within the area mapped are intracanyon basalts rather than intrusive bodies.

A longitudinal profile drawn on the bases of the intracanyon flow remnants for 60 miles reveals a remarkably uniform gradient of approximately 3 feet per mile for the postulated ancient stream course. In the vicinity of Palouse Canyon, however, the bases of two of the remnants are approximately 150 feet below the general profile. Two possible explanations may account for this anomaly. First is that these are not intracanyon flow remnants, but are intrusive bodies. This is questioned, however, in view of the evidence just presented, and because of the uniformity of gradient for the remainder of the remnants. The other more likely explanation suggests that there is local deformation of approximately 150 feet in the vicinity of Palouse Canyon. As this suggested deformation takes place over a distance of 20 miles, it is not possible to detect it in the Columbia River lavas. That the intracanyon flows have been deformed in this area is also in keeping with evidence in the Lewiston basin, where intracanyon flow remnants have been warped with the Columbia River basalt (Lupher and Warren, 1942, p. 869).

The age of the intracanyon basalts can not be determined accurately, but because of their relationship to the upper flows of Columbia River basalt, they must be Pliocene or younger. If, as postulated, the basaltic masses are filling old canyons in the Columbia River basalt, then alluvial gravels and sands can be expected to occur at their bases. None of these intracanyon lavas, however, occur at elevations low enough to affect the reservoirs as now conceived.

Dikes

Near the eastern edge of the Penawawa quadrangle, between river miles 98 and 103, several basalt dikes are exposed in the canyon walls. (See pl. 10.) The differential erosion of the almost vertical, wall-like masses of horizontal columns is about all that distinguishes the dikes from the nearly horizontal basalt flows with their vertical columns.

Megascopically, the dikes are similar to the Columbia River basalt. They are dark gray to black, usually porphyritic in texture, and dense or slightly vesicular. Chilled borders, where they exist, are one-fourth inch or less in thickness. The dikes range in strike from N. 25° W. to N. 40° W. and have almost vertical dips generally inclined slightly to the West. Most of the dikes range in thickness from 4 to 15 feet, but one of them is 70 feet thick and two are 40 feet thick. The largest of the group lies just east of the Penawawa quadrangle, on the north side of the river at about river mile 102.5. It appears to be a multiple intrusive, for it exhibits chilled borders within the outer contacts.

Although the dikes are exposed on both sides of the river, none of them can be correlated across the river. On the south side of the river two small intracanyon flow remnants overlie some of the dikes. Talus and soil cover, however, prevent determination of whether or not the dikes occur as feeders for either intracanyon or Columbia River lavas.

Although it is generally believed that the lava flows of the Columbia plateau are fissure type eruptions, notably few dikes have been found. It is not known yet whether only a few fissures fed the flows or whether erosion has exposed only a few of the fissures. Other dikes are reported to occur in the Lower Snake River canyon at river miles 14 and 33, and volcanic cones or feeders at miles 8.5, 18.5, and 38_/.

_/ D. L. Snyder, oral communication, July 1949.

Sedimentary rocks

The sedimentary rocks of the area are unconsolidated and, with the exception of the Miocene inter-basalt formations, are believed to be Pleistocene or younger in age. They consist of loessial silts, ash and proglacial and Recent sands, gravels and silts.

Inter-basalt sediments

Sediments or pyroclastics, probably of Miocene age, occur interbedded with the basalt flows in several places. Most of them are thin seams of claylike material, silt, or ash, but in some places they are beds of gravel or sand. At no observed horizon, however, is any interbedded material continuous enough to serve as a marker bed. In some places, the claylike material and ash have been baked by the overlying flows. This claylike material may represent an embryonic soil development, but more likely, is windblown material.

The largest interbed occurs in the NE$\frac{1}{4}$, sec. 26, T. 13 N., R. 36 E., Haas quadrangle (near river mile 56.5). It is exposed in a cut on the Union Pacific Railroad at an elevation of about 650 feet, on the south cliff of

Snake River canyon, just east of Fields Gulch. Here, for about 1,000 feet along the railroad track, a poorly consolidated gravel is interbedded with the basalt (See pl. 11). It is nearly 30 feet thick at the east end of the exposure, but it lenses rapidly westward to less than 1 foot thick near the mouth of Fields Gulch. The gravels are well-rounded, poorly sorted, and range from pebbles _/ less than one inch to cobbles 10 inches in diameter.

_/ Grade-size terms used here are those of Wentworth's classification (1922).

Interstitial material is coarse, angular, poorly cemented, quartz sand. About 20 percent of the gravel is non-basaltic and consists of granite, porphyry, and quartzite, similar to that now being carried by the Snake River from Idaho. Stratification is nearly horizontal though poorly defined. The gravel lies on an altered scoriaceous flow top and is in turn capped by a thick hackly flow. The top of the interbed shows very little baking and no recognizable disturbance by the capping flow.

Other smaller interbeds of similar composition were found in the Starbuck and Hay quadrangles. One occurs in the NE$\frac{1}{4}$, sec. 1, T. 12 N., R. 37 E., Starbuck quadrangle (near river mile 64) at the base of a columnar intracanyon flow, on the south side of the river, about 100 feet above the Union Pacific Railroad track. This interbed is thinner than the one in the Haas quadrangle, but it is similarly lenticular, pinching out in less than 50 feet. The interbed consists of gravel about 4 feet thick, overlain at the western end of the exposure by white, finely-laminated ash 6 to 15 inches thick that grades upward into a zone of baked ash or tuff about 1$\frac{1}{4}$ feet thick directly underlying the columnar lava. The gravel is well-rounded, ranges in size from less than one inch to twelve inches in diameter, and is poorly cemented by a ferruginous, very coarse, muscovite-quartz sand.

Only 10 to 20 percent of the gravel is non-basaltic and consists predominantly of fine-grained moderate pink granite, white quartzite, and grayish purple porphyry. The bedding in the gravel, although poorly defined, is nearly horizontal.

A third interbed is exposed at an altitude of approximately 950 feet on the south cliff of the Snake River canyon, just west of Central Ferry, near river mile 82.5. Here, the interbedded material consists of gravel $4\frac{1}{2}$ to 5 feet thick overlain by calcareous silt about 4 feet thick and calcareous tuff more than 7 feet thick. Although a small outcrop of calcareous silt is found in a gully about 500 feet to the west, neither its vertical nor lateral extent can be determined accurately because of soil cover. The occurrence at intervals throughout the canyon, of the interbeds just described and of other interbedded sediments at numerous localities throughout the surrounding region, as reported by Russell (1904, p. 32-42) and the Corps of Engineers (1947), indicates that other such deposits undoubtedly exist in the area mapped, but because of colluvium and soil cover are not exposed.

"Older" gravel

Isolated remnants of an older gravel fill are found at scattered intervals along the canyon. The age of the gravel is not definitely known but is presumed to be Pleistocene. It may or may not be related to a glacial stage.

The deposits are small and poorly exposed. They occur up to an altitude of approximately 950 feet, principally as float. In many places, because of the extensive reworking of this older gravel, it is difficult to distinguish from the younger Snake River gravel. The older gravels are exposed best along the road, just south of the ranch at Magallon (near river mile 45), and just above the road on Miller Bar, near Williams Ranch (river mile 87). Other exposures occur on Davin Bar (near river miles 54.5 and 56.5), near Fields Gulch (river mile 56.5), on Goose Island Bar (near river miles 70 and 75), and possible on Central Ferry (river mile 86.5), Swift (near river mile 96), and Indian (near river mile 100) Bars.

The gravel is characterized by flat and elongated, well-rounded and polished stream pebbles and cobbles. Interstitial material is coarse micaceous quartz sand. The gravel is stained and locally is partly cemented by iron oxide, in contrast with the unconsolidated and caliche-coated younger deposits. The gravel is poorly sorted and poorly bedded. It contains Tertiary basalts and resistant pre-Tertiary igneous and metamorphic rocks in nearly equal amounts. The abundance of white and purple quartzite, greenstone, and porphyry is especially characteristic.

The deposits are similar to the inter-basalt gravel at Fields Gulch and also to the Clarkston gravels in the Lewiston Basin, as described by Lupher (1945, p. 337-348). In some places the gravel could be a remnant of a large inter-basalt deposit; however, it is more likely that the gravel represents an older valley fill, such as the Clarkston gravels. Lupher (1945, p. 347) believed the Clarkston gravels to have represented a glacial stage that occurred well within Pleistocene time but prior to the Wisconsin stage. Like the Clarkston gravels, these "older" gravels are undoubtedly pre-Wisconsin in age, but no evidence was seen that suggests they are related to a glacial stage. It seems more likely that they may be the correlative of the Ringold formation in the Pasco basin.

Palouse formation

The Palouse formation (Treasher, 1925, p. 469) or "Palouse soil" (Bryan, 1927, p. 22), believed to be Pleistocene, is a widespread mantle of wind-borne silt or loess overlying the basalt of the Columbia Plateau. Although the topography of the loess varies, in general the surface is maturely dissected and characterized by rounded rolling hills.

In the Lower Snake River area the Palouse formation is a massive, unconsolidated, buff to light brown silt. Owing to differences in quantity of included organic material, however, it varies somewhat in color throughout the plateau. It is a light brown in the western part of the plateau and a deep brown, almost black, in the Palouse country and farther east in Idaho. For the most part it is composed of angular to sub-angular grains of quartz, feldspar, mica, hornblende, and traces of other minerals. The most striking characteristic of the material is its homogeneity. It is extremely well-sorted; more than 90 percent of it passes a No. 200 (U.S.) sieve. Lime enriched or caliche zones, in which the silt is firmly cemented and contains seams, threads, and nodules of calcium carbonate, occur in many places at depth of 18 inches to ten or more feet below the surface (Strahorn, 1929, p. 28). Although the material is predominantly non-stratified, some laminated silts are exposed in the basal portions of the formation in the eastern part of the plateau (Treasher, 1926, p. 312). Waters (1935) has recognized distinct lithologic units in the deposit, but has not published any details on his findings.

The maximum thickness, age, and origin of the Palouse formation is still a matter of conjecture. Bretz (1928b, p. 449) reports thicknesses of 100 to 300 feet in the eastern part of the plateau. Similar thicknesses in the vicinity of Snake River may be inferred from topographic evidence. (See pl. 12), although sections rarely expose more than 40 feet of the material. As little fossil evidence is available, the formation can be assigned only a tentative age of early or middle Pleistocene. (Bryan, 1927, p. 35; Scheid, 1940, p. 57). The material is generally considered to be eolian, and at least in part, may be derived by deflation of the Ringold formation of post-basalt sediments centering in the Pasco basin (Culver, 1937a, b, p. 60; Flint, 1938a, p. 228).

Snake River gravel

Deposits of gravel, silt, and sand occur on the inside of river bends as non-paired, low-level, terrace remnants, locally known as "bars". These remnants occur discontinuously along the floor of the canyon throughout the Penawawa and Hay quadrangles and the eastern half of the Starbuck quadrangle. Similar deposits are reported to occur in the Snake River canyon downstream from the western limits of the channeled scabland tract almost to the mouth of the river _/. The name "Snake River" gravel is tentatively assigned to these deposits. The maximum thickness of these deposits is not known but 150 feet is recorded by seismic lines at Little Goose Island damsite (Corps of Engineers, 1947). Where exposed above river level, the deposits range in thickness from a few feet to a maximum of about 100 feet, and in length from a few hundred feet to about 6½ miles. In a few places they have a characteristic flat-topped terrace shape, but in most places their shape is that of a large, flattish half-mound.

The deposits are composed of silt, sand, and well-worn stream pebbles and cobbles. In general the gravel is poorly sorted and ranges from fine pebbles to boulders; the sand and silt lenses, on the other hand, are usually well-sorted. The maximum diameter of most of the cobbles is about 5 or 6 inches, but large boulders, 2 to 4 feet in maximum diameter, mostly basalt, are scattered throughout the deposits. Judging from pebble

_/ D. L. Snyder, Oral Communication, July 1949.

counts in the larger terraces, the composition of the pebbles and cobbles varies from 40 to 60 percent basalt; the remainder consists of other igneous and metamorphic rocks from Idaho. A typical pebble count is illustrated by a sample of 100 pebbles, one-half to 3 inches in diameter, taken from the west end of the Ridpath Bar (river mile 76):

Rock Type	Percent
Columbia River basalt	48
Coarse-grained salic igneous rocks	15
Andesites and other mafic lavas	14
Quartzites	10
Rhyolites and other salic lavas	8
Other metamorphic rocks	5
	100

In general, although the pebbles and cobbles are well-rounded and fresh, the larger basaltic stones, especially the boulders, tend to be more angular than the non-basaltic material, and stones larger than ½ inch in diameter are commonly elongated. The gravel contains a high percentage, by volume, of interstitial fine silt and coarse sand. It is estimated that the volume of silt may run as high as 25 percent or more of the total. Interstitial coarse sands are composed mostly of angular basalt and/or quartz grains. Clean gravel and sand was observed only at the west end of Young Bar in the Penawawa quadrangle (near river mile 97.5), and the only open-work gravel seen was a lens a few feet thick at the east end of Upper Riparia Bar (near river mile 69.5). The Snake River gravel deposits also contain numerous layers and lenses of silt, silty sands, and coarse sand or fine gravel. (See pl. 13.) The coarse sand lenses are mostly dark colored, basaltic in composition, and rarely exceed 2 or 3 feet in thickness.

The fine sands and silty sands, on the other hand, are mostly buff to cream colored, siliceous in composition, and may be as much as 15 to 20 feet thick. Some rectangular blocks of silt also occur in the gravels and sands and may have a maximum dimension, usually paralleling the bedding, of as much as 2 feet. Bedding of the Snake River gravel, although generally apparent, is extremely variable. Stratification in the silty sands is commonly irregular showing rhythmic deposition by alternating thin beds or lenses of fine sand and silt; the fine sands in many places are minutely cross-bedded. Locally, repeated scouring and filling has resulted in irregular contacts that give a crenulated appearance to the stratification. Because of these irregularities, the thickness of the individual beds also varies greatly. Stratification in the coarser materials is less marked than in the finer deposits and in some places is only slightly apparent. Local unconformities, largely cut and fill structures caused by the scouring out and back-filling of channels cut into the underlying materials, are numerous throughout the deposits.

The most inexplicable character of the bedding is its attitude. Much of the bedding is horizontal, but a large part of it is in the form of truncated foreset strata whose direction of forsetting is not only downstream but also up the Snake River valley. This upstream attitude of many of the foresets is shared not only by the fine gravels and the sands in the deposit but also by the coarse gravels, and extends from Riparia at least as far up the Snake River as Asotin (Bretz, 1929, p. 505-509).

The age of the Snake River gravel is not definitely known. The occurrence of a few large basaltic and non-basaltic boulders, although it does not preclude the possibility of ice rafting by normal streams, suggests that the aggradation was related to a glacial stage. The Snake River gravels apparently are the correlative of similar gravels in the Lewiston basin. Lupher (1945, p. 345) believed these gravels to be intermediate in age between his middle Pleistocene, or Clarkston gravels, and the latest Pleistocene, or scabland-touchet deposits. This same general age relationship is also true of the Snake River gravels in the area mapped. The gravels are, therefore, assigned a tentative age of early Wisconsin.

Scabland deposits

Extensive deposits of basaltic sand and gravel occur in the Snake River canyon and scabland area. These sands and gravels are believed to be the dissected remnants of a once nearly continuous fill deposited by proglacial streams draining through the scablands from ice lobes which occupied the northern edge of the plateau during Wisconsin time. Although the deposits show an apparent general, though irregular, decrease in grain size upward, they have been subdivided, principally on the basis of topography but partly on the basis of particle size, for the purpose of this report, into "lower" and "upper" scabland deposits. (See pl. 14.)

Lower scabland deposits

The lower scabland deposits occur on the inside of river bends as non-paired, low-level, fill terrace remnants, similar to those of the Snake River gravels. These remnants occur discontinuously along the floor of the Snake River canyon in the Haas quadrangle and the western half of the Starbuck quadrangle. They range in thickness above river level from a few feet to a maximum of about 250 feet, and in length from a few hundred feet to about 5 miles. Almost without exception their shape is not terrace-like but resembles a large, flattish half-mound.

The deposits are composed predominantly of pebbles and cobbles of basalt, but also contain numerous large angular blocks of basalt, a few lenses of sand and silt, and a considerable amount of interstitial silt and coarse basaltic sand. Near the surface of the deposits, caliche coatings on pebbles, cobbles, and boulders are common. In general the gravels are poorly sorted. Stones range in size from small pebbles less than one-fourth of an inch in diameter to boulders 10 feet or more in diameter. The average diameter is estimated to be approximately 3 inches. Pebble counts show that 90 to 98 percent of the material is basalt, while the remainder is composed predominantly of metamorphic rocks, chiefly quartzite. The larger boulders almost invariably are angular blocks of basalt. The non-basaltic pebbles and cobbles all are well-rounded and generally elongated, whereas the basaltic material shows considerable variety in degree of rounding. In the terrace remnants at and near the mouths of scabland coulees, such as Davin Coulee and Palouse Canyon, many of the basalt cobbles and boulders are but very little worn. In other terrace remnants farther downstream, rounding of the basalt pebbles and cobbles is much more pronounced. (See pl. 15.) Although open-work gravels were not seen, the gravels probably are quite permeable.

Bedding of the lower scabland deposits is poorly defined, but where apparent it is nearly horizontal or crudely foreset in a downstream direction. The Riparia and Tucannon Bars, near the mouth of Palouse River differ from the other terraces, however, in that the material comprising them, where not horizontal, is foreset predominantly upstream. In addition, although the composition of the gravel in the Riparia Bar is mostly basaltic, the deposit contains several large beds of silt and basaltic sand.

Upper scabland deposits

The upper scabland deposits consist chiefly of unconsolidated angular granule basalt fragments derived from the Columbia Plateau. Generally less than one percent of the material is composed of fragments other than basalt, but locally, non-basaltic material may comprise as much as 4 or 5 percent. This non-basaltic material for the most part, consists of glacial erratics and quartz sand derived from crystalline rocks north of the plateau. Within the scabland tract and downstream from it, the bulk of the upper scabland deposits is very well sorted. Sixty to seventy percent of the fragments occur within the size limits of coarse and very coarse sand (0.5 to 2 mm). The remainder consists largely of fine gravel but includes minor amounts of medium and fine sand and less than 1 or 2 percent silt. The beds of silt and fine sand generally occur as thin interbeds in the coarser sands and gravels; rarely do they exceed a few inches in thickness. Numerous pebble size fragments are scattered throughout the deposits and in some places occur as small lenses. Intraformational silt blocks also are common locally. East of the scabland tract, however, lenses and beds of fine sand and silt are not only more numerous (See pl. 16) but are thicker and much more extensive, sorting is poorer, and the percentage of non-basaltic material is greater than in the scabland deposits occurring within the scabland tract and farther downstream.

Weathering of the upper scabland deposits appears to be restricted to caliche coatings on the surfaces of pebbles, cobbles and boulders near the surface.

Individual fragments vary in shape from angular to rounded, but are predominantly subangular. Locally, especially in some of the smaller tributaries, considerable coarse angular basaltic rubble and silt is mixed with the upper scabland deposits. For the most part this rubbly material was not derived from the north, but was derived locally from colluvial and alluvial deposits existing in the tributaries at the time of flooding by the sand and gravel charged glacial waters. In the ravine back of the old Penawawa High School, near river mile 91, a considerable amount of opal also is admixed with the scabland deposits.

The stratification of the scabland deposits is characterized by lenticular foresets, typical of the cut-and-fill bedding of outwash and other fluvial deposits built by streams carrying considerable loads of detritus. Foresetting normally dips down-valley and laterally away from the main channels. Bedding is usually manifested by abrupt changes in grain size and commonly is quite thin, but because the deposits are unconsolidated, rapid slumping and slopewash in many places nearly obliterates the very thin silty partings and gives a false impression of massive bedding.

The upper scabland deposits occur principally in the form of terrace remnants preserved in protected positions below an altitude of 1300 feet, such as tributary entrants, or in the lee of island-like remnants of basalt or loess. Individual remnants range from small patches, too small to show on the map, to large areas of several square miles. Thickness of the deposits varies correspondingly but may be several hundred feet thick. The deposits are typically mounded in shape, rather free of dissection, and have gently rounded upper surfaces and relatively steep and smooth side slopes. Two factors probably responsible for the slight dissection are the low regional precipitation and the high permeability of the material composing the deposits. In a few places the surfaces of the deposits are marked by faint ridges up to several hundred feet long, 20 feet or more broad, and a few feet high. The origin of these ridges is not known, but they are thought to be constructional.

Pebbly silts

Light tan to gray silts, probably of late Pleistocene age, occur in tributary valleys east of the scabland tract below an altitude of about 1,300 feet (Bretz, 1929). These silts have been mapped only where they occur on the valley floors. Their genetic relationship to the proglacial deposits is not completely known, but at least in part, they are considered to be a fine-grained, ponding facies of the scabland deposits, perhaps the correlative of the "Touchet beds" of the Pasco basin (Flint, 1938b, p. 493-505; Allison, 1941). The silts are characterized by numerous included pebbles and angular rock fragments, and in order to distinguish them from other silt deposits in the area, are referred to as "pebbly silts".

Reworked loessial silt comprises the bulk of these pebbly silts, and ranges from 60 to 90 percent of the total (Bretz, 1929), in contrast to undisturbed loess which is 99 percent silt. The basalt fragments are nearly all angular and vary in degree of weathering from fresh to thoroughly decomposed fragments. The non-basaltic fragments vary in shape from angular grains to smooth rounded pebbles. Quartz is the most abundant of these foreign fragments, but metamorphic and igneous rocks are also common. In a few places cobbles and boulders of various kinds of non-basaltic berg-rafter rocks are also found. Locally, small lenses of basaltic sand and rubble may be present.

In some places the silts display rhythmic stratification, but generally they are imperfectly stratified, poorly sorted, and nowhere do they show development of a soil profile or weathered zone. The pebbly silt occurs on the floors of the valleys as terrace remnants, mostly less than 10 feet thick, and also extends part way up the slopes as a veneer. Apparently the silts are reworked remnants of a deposit that originally mantled the valley floors and lower portions of the walls as a result of waters which were ponded to a maximum altitude of about 1,300 feet.

Terrace silts

Unmapped buff and tan silts cap several low-level gravel terrace remnants of both the Snake River gravels and the lower scabland deposits.

These silts range in thickness from a barely appreciable veneer to a maximum of approximately 25 feet. The original thickness is not known but is presumed to have been little more than the present thickness. The bulk of the material is massive but the basal portion is commonly stratified, and in some places the stratification conforms generally with the pre-silt topography of the underlying gravels. The stratification is manifested by an alternation of thin beds of silt and sand; locally the bedding is smoothly crenulated, and some of the sands are minutely cross bedded. Small basalt pebbles and angular basaltic grains of coarse sand size are scattered throughout the deposit. The material is presumed to have been deposited by the Snake River during stages of flooding or ponding that occurred after degradation of the scabland deposits. The silts are probably partly lacustrine, partly eolian and partly alluvial. They may be related to the "Touchet beds" of the Pasco basin (Flint, 1938 b, p. 493-505; Allison, 1941), but their character and position suggests post-Touchet deposition.

Recent eolian deposits

Three types of unmapped Recent deposits, almost entirely eolian in origin, are local sand dunes, small volcanic ash deposits, and a widespread thin mantle of silt.

The windblown sands occur principally in the form of longitudinal dunes, localized on the surfaces of some of the low level gravel terrace remnants. In places the sand laps up onto the walls of the canyon, especially in protected pockets on benches at the mouths of small draws. The sand consists predominantly of well-sorted unconsolidated angular quartz grains, but also contains a considerable admixture of silt. The dunes range in thickness from a few feet to about 60 feet. For the most part they are semistabilized, but some are still active.

Small, dirty, volcanic ash deposits are scattered throughout the area. Characteristic examples occur on the west wall of the Tucannon Valley near its mouth (near river mile 62), and on the downstream end of New York Bar (near river mile78). The ash is composed almost entirely of very fine, angular, cellular fragments of glass, 90 percent of which will pass a No. 200 (U. S.) sieve. A considerable amount of silt, commonly mixed with the ash, imparts a dirty buff color to the deposits. The ash occurs as small surface deposits, normally only a few tens of square feet in areal extent, mostly on the lee or northeastern side of hills or bluffs, and especially at the lower extremities of small, usually dry gulches. The deposits range from a few inches to a few feet in thickness and are massive or poorly stratified. For the most part the ash is unconsolidated, but where stratified, some zones are partly consolidated. The fineness of the ash and its occurrence principally on lee slopes suggest that the material originated as a post-glacial light shower of volcanic dust from volcanic centers a considerable distance away, presumably to the southwest, and has since been washed and blown into its present positions.

The Recent silt occurs as a thin cover mantling all other deposits in the area. Primarily it consists of wind-deposited, and in part, slope-washed silt derived from the Palouse formation, but it also includes some wind-deposited silt derived from the erosion of the glacial deposits. Lithologically it is indistinguishable from, and in many places merges with, the Palouse formation. It is buff colored, massive, contains organic material throughout, but shows little evidence of any weathering. It ranges in thickness from a barely perceptible veneer to a maximum of several feet.

Recent alluvium

Recent alluvium mantles the floor of the Snake River canyon and tributary valleys. At present this material forms flood plains which are inundated during high water stages. The material consists of stream deposited silt, sand and gravel. As a rule the surface of a flood plain is composed of fine silt and sand; beneath this, at a depth of a few inches to a few feet, the material commonly changes to a gravel. The gravel normally may be at least as thick as the depth of the present channel.

The Snake River alluvial gravel is similar in composition to the Snake River gravel, i. e., 40 to 50 percent basalt and the remainder largely granitic, metamorphic, and other lava rock types from Idaho. As most of the tributary streams are intermittent, and only carry water during spring runoff or following heavy rains, their deposits differ from the normal flood plain deposits of the more perennial streams. The tributary alluvial deposits in general are poorly sorted, and as the only source of non-basaltic material in most of the tributary valleys is from the erosion of the glacial deposits or the Palouse formation, the alluvium in tributary valleys is composed predominantly of a crudely stratified mixture of silt and coarse, angular basaltic rubble. Recent overbank silts occur in the lower extremities of larger tributary valleys.

Structural geology

Preliminary studies indicate that deformation of the basalt in the area is restricted to very gentle westward tilting, possibly some minor folding, and associated faulting and fracturing. No deformation other than local slumping was observed in the post-basalt sediments.

The basalts, almost without exception, have westward regional dips of 1 or 2 degrees toward a major structural basin centering near Pasco, Washington. Flint (1938 a, p. 225) and Trimble (1948, p. 6) report that the canyon of the Snake River, between Palouse Canyon and Devils Canyon, follows a gentle synclinal depression. Their conclusions, although based on the inconclusive assumption that the present surface of the basalt underlying the Palouse formation is essentially an original surface, do not seem entirely unwarranted as the present courses of the Snake River and many of its tributaries strongly suggest control by regional faults and folds.

The inability to trace individual flows for any appreciable distance, the complete lack of marker horizons, and the very gentle dips make the recognition of structural features extremely difficult. Consequently, although several brecciated and sheared zones occur in the basalt and suggest faulting, normally no displacement can be detected. Only in the NE$\frac{1}{4}$, sec. 6, T. 12 N., R. 38 E., Starbuck quadrangle (near river mile 65.5), on the south side of the river, was any displacement measureable. Here a small normal fault, with a vertical displacement of about 15 feet, occupies a zone approximately 25 feet wide of brecciated and altered basalt, gouge, and secondary opal. The fault zone strikes approximately S. 47° E. and dips 84° to the west. The occurrence of other similar brecciated and sheared zones throughout the area which, however, have no apparent vertical displacement suggests possible horizontal or strike-slip movement.

A joint system also exists in the Columbia River basalts. It is not related to the cooling joints but probably is related to the gentle folding and associated fracturing that occurred during the times of regional deformation of the plateau. (See pls. 17 and 18.) This regional jointing is not apparent except within the scabland tracts where numerous dry coulees show a remarkable linear trend. These coulees are narrow, trench-like channels that have steep walls and talus-covered floors; many are closed depressions with rock-defended lips. They range from a few feet in depth and width to 100 feet or more in depth, several hundred feet in width, and several miles in length. Although several of the coulees have an arcuate trend, most of them are relatively straight. Two general trends are common, one N. 30° - 40° W., the other N. 60° - 70° W. These two intersecting sets are especially conspicuous because they are transverse to the trend of the scabland tract.

The floors of the coulees are covered by talus, but a detailed examination of the coulee walls and rock lips shows no evidence of faulting. Following a detailed study of numerous linear channels in the scabland tract bordering the Snake River, Trimble (1950) concluded that the coulees are water-eroded channels controlled by regional lines of weakness. It may be significant that most of these features occur within the area of deformation suggested by the two anomalous intracanyon lava remnants.

Geologic history

The geologic history of the lower Snake River canyon is full of uncertainties, and will remain so until a large part of the Cenozoic geology of over half of the states of Idaho, Washington, and Oregon has been adequately mapped. Consequently, any statement of the geologic evolution of the area, based on a study of only a narrow strip of the canyon, is open to more questions than can be appropriately discussed in this report.

The decipherable history open in mid-Miocene time with the extrusion of tremendous volumes of lava from centers as yet unknown. The lava erupted at successive intervals throughout mid-Miocene and late Miocene times, gradually inundating an older topography of considerable relief. Following the deposition of the first flows, and continuing long after the cessation of volcanism, isostatic adjustment of the earth's crust gradually took place, resulting in the formation of a major structural basin centered near Pasco, in south-central Washington. Some very gentle folding and fracturing probably occurred contemporaneously with this downwarping, as the present courses of the Snake River and its tributaries appear to have been determined largely by regional lines of weakness developed along faults and folds that have northeasterly, northwesterly, and westerly trends. The lines of weakness are thought to have resulted from repeated regional stresses during the several crustal disturbances to which the region has been subjected since ancient times. Some of the fractures that have controlled the drainage are definitely known to be faults in which appreciable displacement is evident; in most places, however, there is no direct evidence of displacement great enough to have been detected in studies so far.

Both the subsidence of the area and its flooding with great quantities of lava profoundly disrupted whatever drainage existed prior to the eruption of the Columbia River basalt. Subsequently the uplands east and southeast of the area of subsidence were uplifted, apparently somewhat unevenly and intermittently, and as a result, the streams that had initially spilled over onto the plateau and followed natural depressions and slopes westward, now rapidly incised themselves, they followed the lines of weakness just referred to and excavated deep canyons in the plateau in what are approximately their present courses.

In late Pliocene or early Pleistocene time, volcanism was renewed locally, and lava flowed into and filled parts of the Snake River Canyon. These intracanyon lavas were subsequently folded and finally dissected by the Snake River as it cut a new canyon, approximately following its former course. The apparent smaller size of this ancient stream, as compared to the present river, suggests that the Snake River drainage system may not have been as fully integrated then as it is today (Lindgren, 1901, p. 597; Livingston, 1928, p. 706-708; Lupher and Warren, 1942, p. 880-88; and Anderson, 1947).

When the canyons were cut again nearly to their present depths, a gravel fill began to accumulate along the Snake River and eventually reached a thickness of more than 400 feet (Lupher, 1945, p. 340), burying the lower portions of the youthful canyons. It is believed that the fill remained at or near its maximum depth for a long time and, meanwhile, that normal lowering of slopes and stream gradients continued on the exposed slopes above the fill. Subsequent erosion has removed most of the fill and the canyons now show a cyclic or two-story effect; i. e., steep inner canyon walls and gentler upper slopes. (See pl. 19.) It is possible, of course, that this two-story effect could have resulted from the intra-canyon lavas temporarily damming the stream, or from the rejuvenation after an earlier valley stage. Evidence in the Lewiston basin, however, favors the aggradation hypothesis (Lupher, 1945, p. 347).

The cause of this aggradation is not known. It may have been related to an early Pleistocene proglacial aggradation in the Columbia River valley at the mouth of the Snake, or more likely it was associated with the deposition of the Ringold formation. The Ringold formation is a sedimentary deposit which overlies the Columbia River lavas in the Pasco basin and contains vertebrate fossils that have been referred to the late Pliocene or early Pleistocene (Merriam and Buwalda, 1917). Because of its position and fossil content, it is of importance in dating the deformation of the Columbia River lavas and in dating the younger non-fossiliferous deposits in the adjacent areas. Unfortunately, however, neither its areal nor vertical extents are definitely known at the present time and consequently its usefulness is limited. Merriam and Buwalda (1917) and Flint (1938 a, p. 226) believed that the Ringold was deposited in structural basins after the deformation of the Columbia River basalts. Culver (1937 b), Lupher and Warren (1942, p. 879), and Lupher (1945, p. 338) believed that the Ringold sediments were deposited on the Columbia River basalt prior to the major deformation. Warren (1941, p. 221-223) concluded that deposition of the Ringold formation was contemporaneous with the deformation. If, however, the afore-mentioned older fill is related to the Ringold formation, the Ringold of necessity must postdate deformation. It is obvious from this brief descussion, that the accurate dating of events in southeastern Washington must await further and more complete studies of the Ringold formation and related sediments.

Another early episode in the Pleistocene is recorded by the deposition of the "Palouse soil" or "Palouse formation". Over much of its areal extent the loess rests upon basalt, but it is underlain in places by sediments that may be Ringold (Culver, 1937). Little is known of its age or time range, other than that the upper part is Pleistocene (Bryan, 1927, p. 22; Scheid, 1940, p. 57). It is believed to have been, at least in part, derived from the Ringold formation (Culver, 1937 b; Flint, 1938 a, p. 228). Tullis (1944, p. 135) has further complicated the dating issue by suggesting that the "Palouse formation" was deposited and maturely dissected before folding of the Clearwater escarpment took place, but he gives no supporting evidence for this statement.

In the Pleistocene epoch, northeastern Washington was partly covered by continental glaciers. Ice covered all except the highest parts of the northern highlands and, in part, encroached upon the plateau. The number of ice sheets, their maximum extent onto the plateau, and their relations to the scablands and scabland deposits have long been controversial subjects.

Although a complete review of the glacial and scabland problems is beyond the scope of this report, the following paragraphs will briefly outline the major controversies and summarize the hypotheses that have been proposed for these features. For more detailed descussions of the subject the reader is referred especially to papers by Bretz (1919, et seq.), Allison (1933; 1941), Flint (1935, et seq.) and Hobbs (1947).

The presence of at least three separate bodies of drift on the plateau, representing as many glacial advances, has been suggested (Bretz, 1923 a; Hodge, 1934; and Bryan, 1927). Anderson (1927) presents evidence for two Pleistocene ice advances in northern Idaho and eastern Washington, the later much less extensive than the earlier. Flint (1937, p. 220-226) concluded, however, that the deposits attributed to the various ice advances were more likely of a single age, namely Wisconsin, but suggests from evidence beyond the drift border zone that there was possibly more than one glacial stage.

Most of the workers in the area have drawn the limits of glaciation north of the position as delineated by Flint (1937). A few individuals, however, have regarded the limits of Pleistocene ice as extending much farther south (Pardee, 1922; Hodge, 1934; and Hobbs, 1947).

At least four hypotheses have been proposed to explain the origin of the scablands and the scabland deposits. Bretz (1923, et seq.) regarded the scabland tract and deposits as features left by an enormous, though short-lived, proglacial rush of water, which he termed the "Spokane flood". At first Bretz (1919) attributed the large lake, named Lake Lewis by Symons (1882, p. 108), and the silt beds associated with it in the Pasco basin to an arm of the sea; later (1925), he considered the deposits to be part of the "Spokane flood". Allison (1933) questioned the sudden liberation of large quantities of water and believed instead that the deposits and erosion were produced by ice-jams, that, over an extended period of time, repeatedly blocked the proglacial channels and diverted the flood-waters into new courses. Hodge (1934) proposed a complex history for the scablands, involving several glacial advances, ice-jams, ponding, ice-rafting, and various other factors, but did not present evidence to support his views. Flint (1938 b) regarded the scabland deposits as remnants of a thick continuous fill aggraded by normal proglacial streams to the level of Lake Lewis. The erosional features were attributed by him to repeated superposition of streams on bedrock as they dissected the fill. Allison (1941) and Lupher (1944, p. 1437-1439) disagreed with the fill hypothesis, as advocated by Flint, on several lines of evidence. They principally contended that Flint misinterpreted the ages of the scabland deposits relative to that of the Touchet beds. Finding both the "Spokane flood" of Bretz and the fill hypothesis of Flint to be untenable, they reiterated the ice-jam concept as originally presented by Allison (1933). Hobbs (1947) believed that the scablands were covered by a lobe of the Pleistocene Cordilleran glacier, and that the surrounding broad apron of outwash gravels and loess were associated with this lobe. The evidence offered in proof of this hypothesis, however, is vague and incomplete.

Many of the ideas and concepts of these four hypotheses are applicable within the writers' area, but no one hypothesis as yet presented is capable of fitting all the facts. Consequently, the writers are neither able to accept any of the aforementioned hypotheses _in toto_, nor unfortunately, are they yet able to offer a satisfactory alternative hypothesis. Although considerably more detailed work will be necessary throughout the scabland and adjacent areas before an adequate solution of events will be forthcoming, the following very tentative outline of events is suggested by the post-basalt sediments in the area mapped:

1) An early Pleistocene period of prolonged aggradation and degradation by the Snake River and tributaries, probably during Ringold time.

Subsequent degradation removed nearly all but a few remnants of this ancient fill. Presumably the Palouse formation, or at least a part of it, was deposited during this time by deflation of the ancient fill.

2) A protracted period of erosion followed, during which time the Palouse formation was maturely dissected, and considerable colluvium accumulated in the coulees and tributaries.

3) Later in the Pleistocene glacier advances to the north resulted in an increased load in the Columbia River, which in turn caused the Snake River to aggrade and deposit the Snake River gravels.

4) Further advances of these glacier lobes, probably during Wisconsin time, dammed the waters to the north and resulted in spill-over of the ponded waters onto the plateau.

5) The flood waters initially occupied existing valleys. Subsequent damming of the lower Columbia River, to form Lake Lewis, however, provided a rising base-level for the scabland streams, so that they aggraded and eventually spilled over existing divides, such as the Washtucna Coulee-Snake River divide. It is suggested that at this time, the waters removed not only part of the Snake River gravels, but also the coarse and angular colluvium and alluvium from the coulees and tributaries and redeposited it on the floor of the Snake River canyon. Continued aggradation by the streams resulted in the accumulation of a thick fill of finer scabland materials and in ponding of the Snake River above Riparia to an altitude of about 1,300 feet.

6) Retreat of the glacier lobes and decline of Lake Lewis was accompanied by excavation of a large part of the upper scabland deposits, including the dam near Lyons Ferry, and by terracing of the lower scabland deposits and Snake River gravels.

7) The draining of the Lake Lewis was followed by a period of relative quiescence during which time normal erosion and slope wash modified

the fill and terrace remnants.

8) When the streams were apparently at or near their present level, ponding in the Snake River was renewed and a layer of silt was deposited in the Snake River canyon and tributary valleys.

9) Reversion of drainage to normal conditions permitted the Snake River to re-excavate through the silts and form the present day features.

10) Intermittent volcanism during Quaternary time is recorded in the area by showers of volcanic ash incorporated in the deposits.

11) The final episode is represented by the deposition of local and regional eolian sands and silts.

General Engineering Geology

Summary of proposed engineering projects

The development of the lower Snake River by the Corps of Engineers in the interests of navigation, irrigation, and power was authorized by Congress in 1945. The law approved the plan of development whereby such dams as are necessary to provide slack-water navigation and irrigation would be constructed. Two of the four dams proposed for the lower Snake River are within the area mapped: Dam No. 2, Lower Monumental, at river mile 44.7, and Dam No. 3, Little Goose, at river mile 72.2.

As now conceived, the dams will be of combined concrete and earth embankment construction; each will include single lift navigation locks, power generating installations, and fishways.

Lower Monumental Dam, under present concepts, will have an overall length of 2,040 feet and a maximum height from low point of foundation to crest, of 128 feet. Effective head under low flow conditions will be 93 feet. The top of the dam will be at an elevation of 554 feet, normal pool elevation will be 533 feet, and maximum pool elevation 542 feet. The spillway will be of the overflow type, located near the center of the structure, and will have a crest elevation of 484 feet. Two fish ladders 30 feet wide will be constructed, one on each side of the dam. A single lock of 93 feet lift, located to the right of the spillway, will have dimensions of 86 by 540 feet and a 14 foot depth over the sills. A power plant comprising 5 units, to be located on the left side of the spillway, will ultimately have an installed capacity of 300,000 kw.

Little Goose Dam, as now conceived, will have an overall length of 3,560 feet and a maximum height from low point of foundation to crest of 159 feet. Effective head under low flow conditions will be 99.8 feet. The top of the dam will be at an elevation of 654 feet, normal pool elevation will be 633 feet, and maximum pool elevation 642 feet. An overflow spillway will be located near mid-channel and will have a crest elevation of 584 feet. Two fish ladders 30 feet wide, one on each side of the dam, also will be constructed. The power plant, situated at the left side of the spillway, will ultimately have an installed capacity of 325,000 kw. in 5 units. A single lock of 100 feet lift, located to the right of the spillway, will have dimensions of 86 by 540 feet and a 14 foot depth over the sills.

Construction of the dams will require the relocation, within the mapped area, of approximately 65 miles of railroad, many miles of state and county roads, and the construction of several miles of access roads.

Geologic Feasibility of Engineering Developments

The engineering geology of the lower Snake River canyon, as presented in the following paragraphs, is confined to generalities only and is without reference to specific engineering sites. For more detailed information pertaining to the geology of engineering sites on the Snake River, the reader is referred to the special reports and investigations prepared by the Sections of Geology and Exploration, Corps of Engineers, Walla Walla District, Walla Walla, Washington, and Portland District, Portland, Oregon.

Geologically the lower Snake River canyon is in many ways ideally suited for the construction of dams, either as presently conceived for irrigation and navigation purposes, or as larger dams for the development of power. Excellent foundations and copious quantities of easily excavated construction materials occur at many places throughout the length of the canyon. Geologic structures are simple, and no seismic activity has been recorded in the area. Existing slopes are relatively stable, and no evidence was seen of large landslides.

Topography

The Snake River has cut a deep canyon into the Columbia River Plateau in southeastern Washington, The canyon is nearly 1,500 feet in depth at the eastern edge of the area mapped, decreasing to about a 1,000 feet in depth at the western edge. The canyon walls are generally steep and rugged and have good rock exposures. The bottom of the canyon, in most places, is considerably wider than the river channel, and the inside of practically every curve is occupied by a large gravel terrace, the surface of which is 30 to 250 feet or more above the river.

Foundations

Nearly flat-lying basalt flows comprise the foundation rocks within the area mapped. Individual flows range in thickness from 15 to over 150 feet, but may vary considerably in thickness laterally. The rock is generally hard and strong and will provide an excellent foundation in most places. Zones of vesiculation and brecciation, mostly accompanied by some alteration, are common, however, at contacts between flows and may be as much as 30 feet thick. In some places interbedded sedimentary or pyroclastic materials occur between the basalt flows. These are composed of gravel, sandy-silt, and claylike material or volcanic ash, in places soft and in other places compacted or baked. In most places the beds are thin, but locally they may be as thick as 30 feet or more. Where these contact zones or interbedded materials occur at critical elevations in the foundation area, additional excavation to sound rock may be necessary, and grouting of contact zones at other elevations also may be required.

Although individual flows vary considerably in permeability, a series of flows is generally considered to be pervious and capable of absorbing considerable water at the surface and transmitting it readily in the zone of saturation. The depth to the water table depends on the extent to which the lava is drained by deep canyons and the existence of less pervious material, such as unfractured flows, dikes or sills, and interstratified layers of tuff, clay, or soil. Factors affecting permeability of basalts, in their probable decreasing order of importance, are as follows: (1) scoriaceous and fragmental zones at the tops and bottoms of successive flows; (2) large open spaces at the contact of one flow with another; (3) open joints, formed by shrinkage during cooling; (4) caverns formed in flows by the draining away of subsurface streams of liquid lava from beneath hardened crusts; (5) vesicles and cavities resulting from the expansion and escape of gases during cooling; and (6) fissures produced by faulting and fracturing after the flows have cooled. Some leakage through the basalt members along reservoir walls can be expected, but it should not be serious enough to endanger the safety or feasibility of the proposed engineering structures.

Structure

Although no major geologic structures were observed within the area mapped, the present courses of the Snake River and many of its tributaries appear to have been determined largely by regional lines of weakness developed along faults and folds that have northeasterly, northwesterly, and westerly trends. In most places, however, there is no direct evidence of any displacement appreciable enough to have been detected in studies so far. Tension joints and other minor fractures occur almost everywhere throughout the lavas, and some small faults and sheared and brecciated zones also occur at scattered intervals throughout the canyon. These sheared and brecciated zones range in width from a few inches to 30 feet or more and commonly show no measurable vertical displacement. No seismic activity has been recorded in the immediate vicinity of the Snake River canyon within historic times, and the field evidence suggests relative stability since early Pleistocene time.

Construction materials

With the exception of clay, construction materials are abundant throughout the canyon but may be in deficient quantities at a specific construction site. Almost unlimited quantities of basalt are available for crushed rock and riprap of nearly all sizes. Numerous joints and fractures in the basalt facilitate blasting and crushing. Large unconsolidated fluvio-glacial and alluvial deposits insure adequate quantities of sand and gravel of nearly all sizes. Screening and washing, however, will probably be necessary for most of the deposits. Tests for deleterious materials should be made in any deposits to be used for aggregate. Although nearly unlimited quantities of silt are available for impervious fill, moisture control and the addition of other materials probably willbe required for proper compaction. The fluvio-glacial and alluvial deposits are unconsolidated, and although varying in permeability from place-to-place, probably all are quite permeable.

Stability of slopes

Present slopes appear to be stable, and no evidence was observed of landslides in the area. Recent talus deposits mantle benches and the lower slopes of the cliffs nearly everywhere throughout the canyon, but they are relatively small in magnitude by comparison with similar deposits flanking the Columbia River, and consequently they will not present the problems that have been encountered there. Where unconsolidated materials comprise the reservoir walls, some slumping probably will result from erosion by the reservoir waters, but it is not expected to be serious.

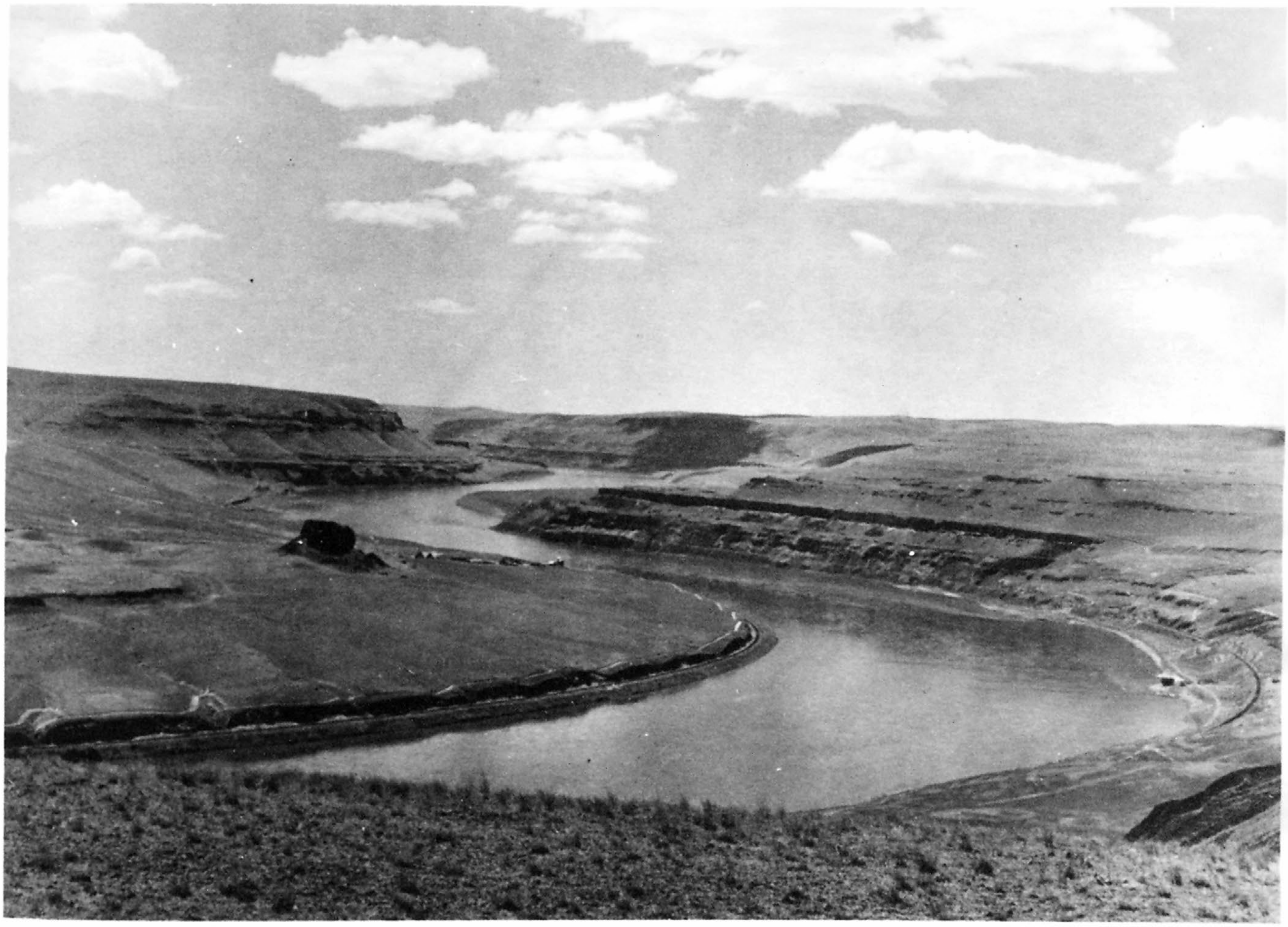


Plate 3

LOWER MONUMENTAL DAMSITE AREA

View looking west down the Snake River. The monument is an island of basalt surrounded by a terrace of lower scabland deposits. Right abutment of dam will be located in basalt cliffs opposite monument. Left abutment will be in scabland deposits.

Plate 4

INTRACANYON FLOW REMNANT NEAR RIVER MILE 85.5

(Photo by: Fred O. Jones)

Plate 5

BASALT DIKE IN NORTH CANYON WALL NEAR RIVER MILE 98.5

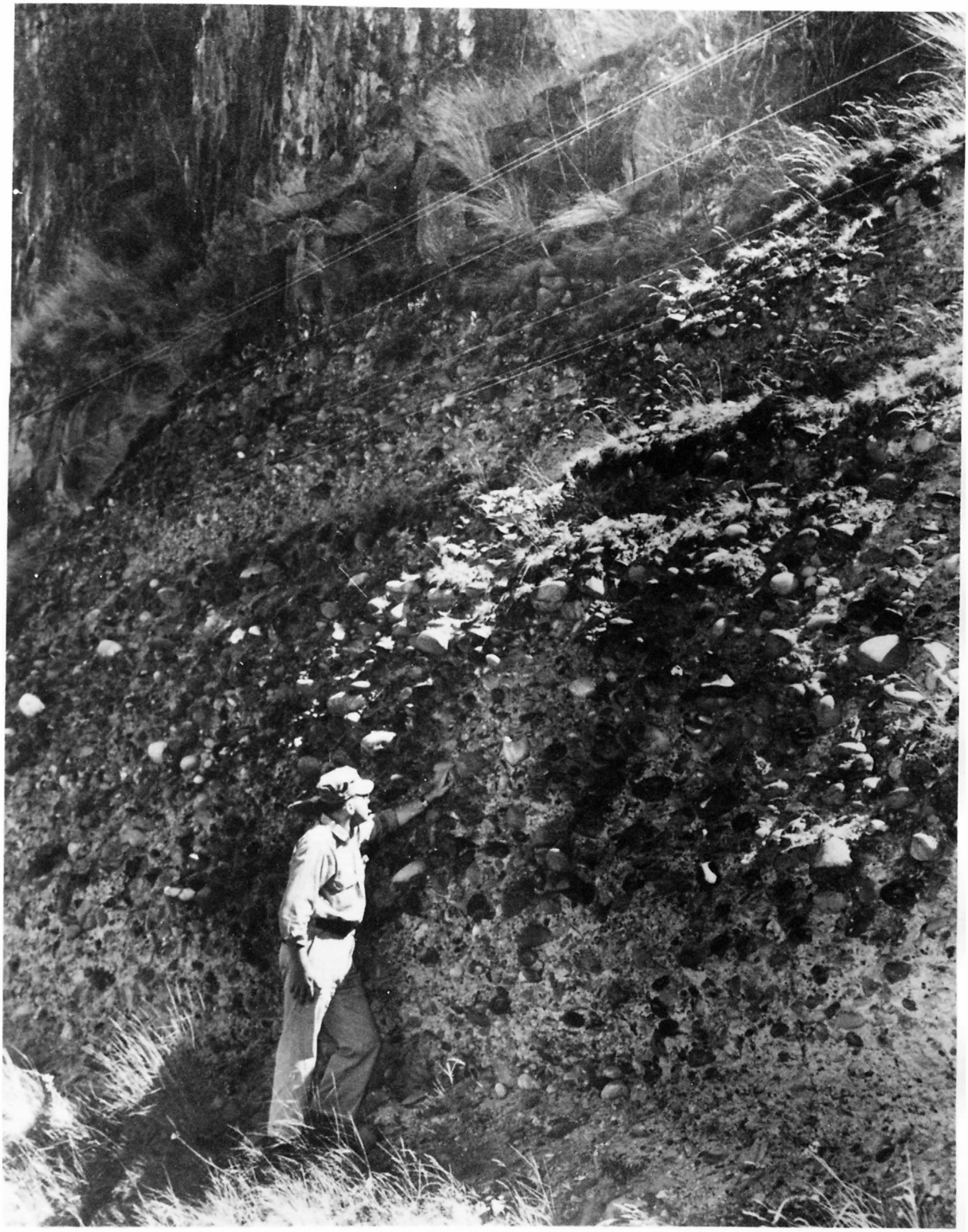


Plate 6

GRAVEL INTERBEDDED WITH COLUMBIA RIVER BASALT NEAR RIVER MILE 56.5

(Photo by: Fred O. Jones)

Plate 7

PALOUSE "ISLAND"

An erosional remnant of the Palouse loess rising more than 120 feet above the scoured basalt surface of the scabland channel. The basalt surface is now covered in most places by a thin sheet of post-scabland loess (Photo by: Fred O. Jones)

Plate 8

SNAKE RIVER GRAVELS

Silt lens in Ridpath "bar" near river mile 75.5. Downstream is to the left in the picture, note upstream attitude of the foresetting in the gravels.

(Photo by: Fred O. Jones)

Plate 9

LEFT ABUTMENT AREA, LOWER MONUMENTAL DAMSITE

Left foreground shows lower scabland deposits capped by silt. Background shows high terrace of upper scabland deposits lying against basalt cliffs

(Photo by: Fred O. Jones)

Plate 10

DETAIL OF LOWER SCABLAND DEPOSITS NEAR LOWER MONUMENTAL DAMSITE
Note compacted interstitial silt. Sloughing of fresh faces will occur as silt loses its moisture. (Photo by: Fred O. Jones)

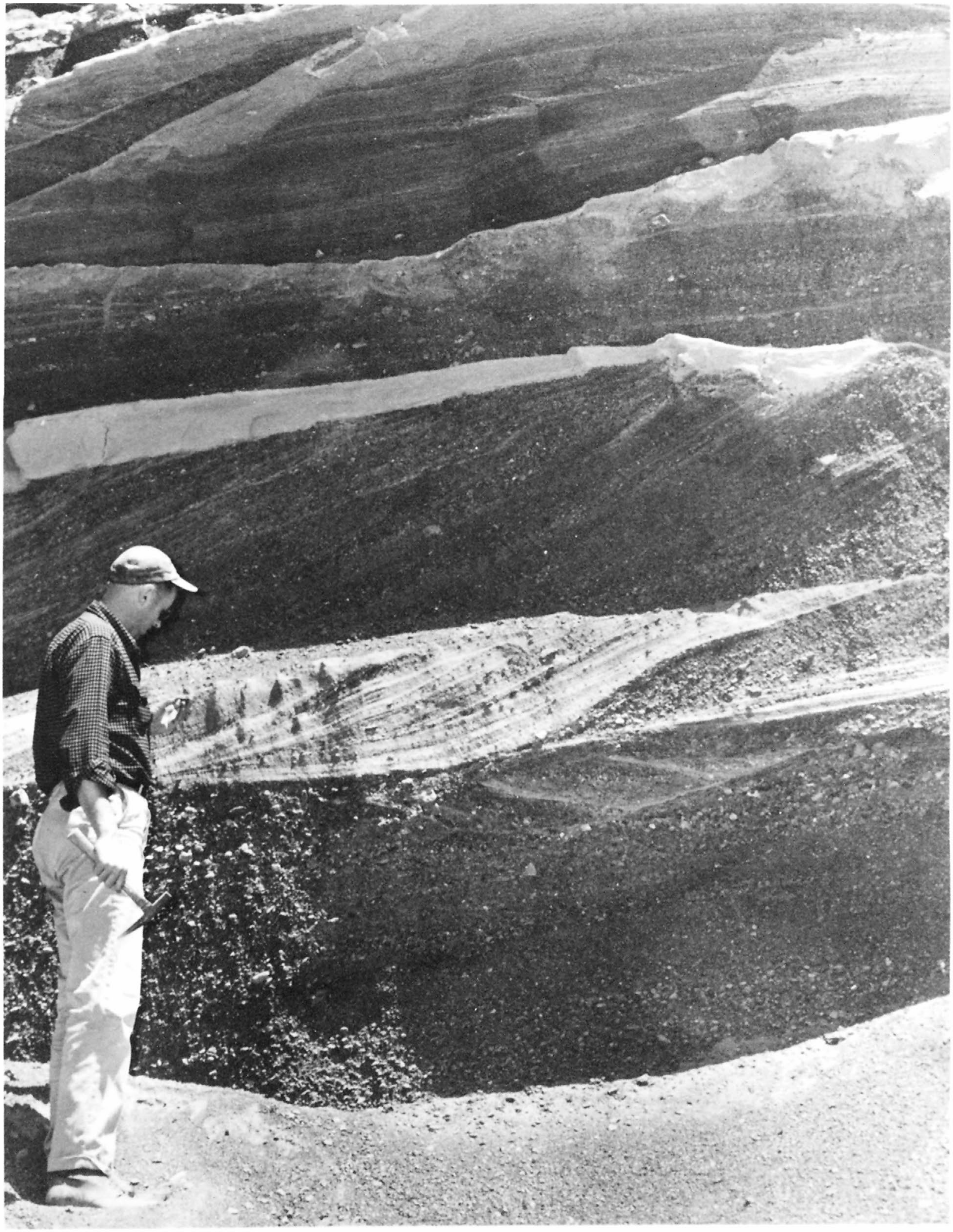


Plate 11

UPPER SCABLAND DEPOSITS IN TUCANNON VALLEY
The material is predominantly subangular basalt granule fragments; lesser amounts of sand, silt, and fine gravel. (Photo by: ~~Fred~~ O. Jones)

Plate 12

PALOUSE CANYON

View looking downstream from Palouse falls. Note joint control of canyon.

(Photo by: Fred O. Jones)

Plate 13

DEEPLY INCISED CREVICE ON WALLS OF PALOUSE RIVER CANYON
Narrow crevice below Palouse falls. Note probable extension on opposite rim. On crevice floor is a foot wide zone of close jointing and shearing.
(Photo by: Fred O. Jones)

Plate 14

SNAKE RIVER CANYON WALL

View of the north canyon wall showing steep inner canyon and gentler outer canyon walls. Wide, flat Goose Island terrace in foreground is cut on Snake River gravels. (Photo by: Fred O. Jones)

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