SUMMARY OF LATE-CENOZOIC GEOLOGY OF SOUTHEASTERN WASHINGTON.

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The preparation of a paper (Flint, 1938) on the genesis of scabland in southeastern Washington emphasized to the writer the lack of a summary of existing data on the late-Cenozoic geology of that region. As the information thus far published is widely scattered, an essential part of it is presented here, together with some hitherto unpublished observations by the writer, as a temporary document which may prove useful pending the appearance of more detailed studies.

COLUMBIA RIVER LAVA.

Southeastern Washington includes the northern part of the Columbia Plateau, which consists of a great thickness of basalt flows,[1] the margins of the upper flows in eastern Washington overlapping upon the crystalline rocks of highlands that inclose the plateau on the east and north, and in part on the west. The basalt, believed to be chiefly of Miocene date, on evidence furnished by related fossiliferous sediments, was termed by Russell (1901, p. 28) the Columbia River lava.[2] Russell's papers are still the best source of published information on the basalt in this region.

In general, the basalt flows, and the plateau surface controlled by them, slope inward centripetally from the eastern, northern, and western margins of the plateau in Washington, with an average descent not far from 25 feet per mile. The centripetal slope is interrupted by gentle folds in the basalt which form subparallel ridges and depressions, trending generally east-west. Prominent among these are Frenchman Hills, Saddle Mountain, and Yakima Ridge, with their continuations eastward, and Rattlesnake Hills. The centripetal dip culminates at the north base of a still more conspicuous faulted fold which forms the Horse Heaven Hills, a massive ridge

[1] A boring in the Rattlesnake Hills penetrated gently dipping basalt to a depth of 2212 feet without encountering the pre-basalt floor (Culver 1926, p. 3). More than 4000 feet of basalt are exposed along the Snake River (Russell, 1897, p. 42).

[2] As this term is more inclusive than the name Yakima basalt (Smith, 1903B) currently used by the U. S. Geological Survey, it seems advisable to retain it until definite correlations have been established.

1000 to 1500 feet high. The basin at the north base of this ridge extends northwest to Saddle Mountain, north into Esquatzel Coulee and Snake River canyon, and east to the vicinity of Walla Walla. As thus broadly defined, it will here be termed the Pasco basin, from the town of Pasco near its center.

SEDIMENTS INTERBEDDED WITH THE BASALT.

Ellensburg formation.

Andesitic sandstones, shales, and conglomerates carrying a late-Miocene flora are interbedded in places with the upper part of the basalt sequence. These sediments, chiefly fluvial, have been named the *Ellensburg formation* (Smith, 1903A, p. 17), in the region west of the one under discussion. They have been recognized north of the type locality by Waters (1932, p. 607), along the lower Yakima River by Shedd (Culver, 1926, p. 1), and northwest of Pasco by Jenkins (1922, p. 15).

Latah formation.

A great thickness of lacustrine and fluvial siltstone and shale, carrying plant fossils of Miocene date, occurs in many valleys along the eastern and northern margins of this part of the plateau. The name *Latah formation* has been applied to these deposits (Pardee and Bryan, 1926; see also Anderson, 1927, p. 11; Kirkham and Johnson, 1929; Berry, 1931) which occupy valleys cut into the pre-basalt rocks before the basalt accumulated, and are in places interbedded with the basalt. These sediments were deposited in lakes and streams at the margins of the encroaching basalt flows.

There is no essential difference in general conditions of origin between the Latah sediments and the Ellensburg sediments.

Other interbedded sediments.

Borings made in the Rattlesnake Hills have shown that thin zones of sediments are intercalated between some of the basalt flows (Culver, 1926, p. 2, 3, 4). A conspicuous exposure of interbasalt sediments was found by the writer in 1936 in the NE 1/4 Sec. 26, T13N, R36E, Willamette P. M., in a cut on the Union Pacific Railroad, at an elevation of about 650 feet, on the south cliff of Snake River canyon just west of Lyons

Ferry. Here about eight feet of poorly consolidated conglomerate is interbedded with the basalt, occurring at least 700 feet below the top of the basalt section. The stones are well rounded, and range from pebbles less than one inch, to cobbles 12 inches in diameter. They are slighly imbricated though not well size sorted, and are surely of stream origin. Their most striking feature is their composition, which includes quantities of porphyries and foliates similar to those now being carried by the Snake River from regions in Idaho east of the plateau. This strongly suggests that the river was already in existence at this early date, and the presence of a west-flowing stream indicates some warping in order to permit flow from the margin toward the center of the region of basalt accumulation.

DRAINAGE PATTERN.

With short and local exceptions, the drainage pattern of this part of the plateau is of preglacial date. The main drainage routes came into existence at various times and in various ways. The principal groups of streams are indicated below.

1. *Streams consequent on long dip slopes.* There are many of these, the longest being the Palouse River-Rock Creek-Cow Creek system, which extends from near Spokane to the Snake River, a distance of 75 miles.

2. *Streams marginal to the basalt field.* The Spokane River and its continuation in the Columbia River skirt the northern margin of the basalt through a distance of nearly 200 miles, from Spokane to Wenatchee. This course, as first suggested by Willis (1887, p. 7), was undoubtedly assumed at least as early as the date of the uppermost basalt flows.

3. *Streams consequent on synclinal depressions.* Many of the east-west streams of the plateau are of this character, although nearly all of the structures are inconspicuous. Examples are Snake River between Palouse Canyon and Devils Canyon, Washtucna Coulee (now largely dry), Lind, Bowers, and Rocky coulees, and Crab Creek. These drainage lines probably came into existence later than the basalt-margin streams.

4. *Cross-axial streams.* The Columbia River downstream from Wenatchee, where it abandons its basalt-margin course, and less conspicuously upstream as well, has this character. It crosses the Frenchman Hills and Saddle Mountain anticlinal ridges through great water gaps, and crossing the Pasco basin, transects the Horse Heaven Hills uplift via the enormous

Wallula Gap, one mile wide, eight miles long, and in places 1000 feet deep. The Columbia may be antecedent to the Frenchman Hills and Saddle Mountain uplifts, but the origin of the Wallula Gap may be somewhat different. The Columbia parallels the strike of the Horse Heaven Hills uplift for many miles before turning to cross its axis, and the crossing takes place at the lowest point on the crest of the uplift. This suggests that the Columbia may have been defeated by this uplift or by its continuation northwest, and slackened or ponded for a time until its water rose high enough to spill over a low part of the barrier. The character and date of the Ringold formation fit this view.

POST-BASALT SEDIMENTS.

Ringold formation.

Centering in the Pasco basin, underlying several hundred square miles of territory, and extending north at least to the vicinity of Frenchman Hills, there is a deposit of partly consolidated silt, sand, gravel, and clay, at least 500 feet thick, known as the Ringold formation. It rests on the basalt, and is flat-lying, apparently postdating the warping that formed the Pasco basin. The material is in part fluvially crossbedded and in part parallel bedded, much like the White River formation of the Great Plains. It carries a fossil vertebrate fauna which has been referred to the early Pleistocene (Merriam and Buwalda, 1917). The constructional upper surface of this formation is probably nowhere preserved, so that its vertical relationship to the Horse Heaven Hills is not known. It may well represent a deposit built jointly by the Columbia and Snake rivers at a time when the Horse Heaven structure was undergoing uplift. As indicated above, there is reason for believing that the Snake River was in existence here long prior to Ringold time.

The altitudes of the dissection remnants of the Ringold formation indicate that this deposit once filled the Pasco basin up to an elevation of at least 1000 feet. Extensive post-Ringold stream erosion is recorded not only by the dissection of the Ringold formation itself, but possibly also by superposed stream channels at 900 to 1000 ft. A.T., cut obliquely across the summit of Gable Mountain, an island-like anticlinal basalt remnant five miles west of Hanford. The channels, each hanging at both ends, may have been cut when the Columbia was temporarily superposed from the Ringold formation, across the underlying basalt. Less probably, superposition may have taken place from a fill of glacial outwash which formerly occupied the Pasco basin.

"Palouse soil."

The surface of the basalt on the plateau is covered with a conspicuous mantle of buff to reddish silt, which is absent only along drainage lines from which streams have removed it. Although predominantly silt, it includes also fine sand (especially along the northeast margin of the Pasco basin) and a small proportion of clay. The average grain size decreases conspicuously from the Pasco basin northeastward toward Spokane and the "Palouse country" around Pullman and Colfax, and the deposit as a whole apparently thickens somewhat in the same direction. The material is predominantly nonstratified, although in some exposures in the eastern part of the plateau, zones of conspicuous subhorizontal lamination are present. Considerable accumulations of caliche (secondary calcium carbonate) occur in thin zones parallel with the surface, giving a false impression of stratification. One exposure near Connell (NW 1/4 NW 1/4 Sec. 9, T13N, R32E) shows a 24-inch zone of almost pure caliche, which must have required considerable time for its development, as the superficial postglacial material in the same district shows no such accumulations.

Although it overlies the basalt, the relation of the silt to the Ringold formation is obscure. This is because the contact between the two deposits has never been seen, as the surface in the critical zone is covered with a thick mantle of windblown sand. Although sections exposing 40 to 60 feet of this material exist, and although thicknesses of 100 to 150 feet can be commonly inferred from topographic evidence, its true thickness over most of the plateau is a matter of conjecture.

This body of sediment has been termed "Palouse soil" by Bryan (1927) who showed that its date is preglacial. It has been generally considered an eolian deposit. As the winds now prevailing are southwesterly, the progressive decrease in grain size to the northeast fits in with the eolian interpretation. Microscopic examination of the "Palouse soil" has shown that the sediment consists partly of detrital grains and partly of volcanic ash (Bryan, 1927; Krynine, 1937). It seems possible that the "Palouse soil" is at least in part the reworked eolian equivalent of the Ringold sediments, winnowed out of the growing fluvial plain in the Pasco basin, and blown to leeward during Ringold and post-Ringold preglacial time. Some of the sediment may have settled in small bodies of standing water, giving rise to the lamination locally observed. Waters (1935, p. 135) has recognized stratigraphic zones in the deposit. The final solution of the Ringold-"Palouse soil" relationship awaits intensive field and microscopic study.

The topography of the "Palouse soil" is not uniform. Near the northeast margin of the Pasco basin it is a faintly undulating plain with broad interfluves between widely spaced drainage lines with gentle sideslopes. Farther north and east it is maturely dissected into a systematic plexus of steep-sided hills controlled by a fine-textured dendritic drainage pattern. The one topographic type grades into the other without abrupt change. Near the Pasco basin the annual precipitation scarcely exceeds seven inches, and in addition, the "Palouse soil" is sandy and readily permeable to water. This results in coarse-textured topography with little-dissected interfluves and gentle slopes. Farther northeast the precipitation increases to 20 inches, and the "Palouse soil" is predominantly silty and much less permeable, giving absolutely more runoff, and in addition a greater proportion of surface runoff to total precipitation. This appears to be a complete explanation of the topographic differences observed. In addition, the steep-sided dissection hills near the eastern margin of the plateau have systematically asymmetric profiles, a fact attributed by Kirkham (1931) and Rockie (1934) to a combination of eolian accumulation, and nivation-steepening by winter snowbanks.

Glacial sediments.

The northern margin of the plateau carries discontinuous till and other deposits related to Pleistocene glacier ice (Flint, 1937, and references therein given). South of this drift, the "Palouse soil" and basalt are cut by valleys and channels, well shown on a map by Bretz (1928, Pl. 5). These denuded basalt areas are locally termed *scabland.* Most of these valleys are part of the preglacial valley system of the plateau, later modified by meltwater streams from the glaciers. Remnants, some of them very extensive, of at least two fluvial fills of sand and gravel, distinct in time, have been recognized in this valley system, and the development of much of the scabland is believed to have resulted from the accumulation and later dissection of these fills (Flint, 1938, and references therein given).

Postscabland eolian deposits.

A veneer of wind-blown sand and silt including volcanic ash, the whole usually only a few feet in thickness, covers the surface generally. It conforms with the dissected surface of the "Palouse soil," and rests on the eroded surface of the Ringold formation, but is less conspicuous on the basalt. Probably it postdates the scabland, and is less well developed there because it does not readily find lodgment on bare basalt.

The wind-blown veneer, like the "Palouse soil," is dominantly fine sand in the vicinity of the Pasco basin, and to leeward (northeast), becomes a true loess, including increasing amounts of silt, with considerable volcanic ash. In many places nearly pure fine white volcanic ash forms distinct beds in sections of tawny-buff loess and fine sand, probably recording ash falls sharply localized in time.

In some parts of the Pasco basin the sand lies in pronounced dunes. In the region between Pasco and White Bluffs, the dunes are thin and sparse, and are generally elongate northeast, parallel with the prevailing wind. Locally the sand forms thick, sharply localized complexes, like the Saharan *ergs*. The most conspicuous complex covers many square miles, centering in the southwest quarter of T11N, R32E, about 15 miles northeast of Pasco. The individual dunes are closely spaced ridges 30 to 40 feet high, trending approximately at right angles to the prevailing wind direction, and are at present actively moving.

Exposed bluffs of "Palouse soil" and Ringold silt in the Pasco region are commonly abraded by the wind so as to show small concave-outward facets resembling the marks of hand-adzing on a wooden beam. Deflation of flat-lying surfaces of stratified deposits of glacial date has removed enough fines from some areas to develop conspicuous lag concentrates of pebbles, some of them polished and faintly faceted by wind-driven sand.

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