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INTERRELATIONSHIPS
OF GEOLOGIC FORMATIONS AND PROCESSES
AFFECTING ECOLOGY AS EXPOSED
AT RATTLESNAKE SPRINGS
HANFORD PROJECT

MAY 1970

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INTERRELATIONSHIPS OF GEOLOGIC FORMATIONS
AND PROCESSES AFFECTING ECOLOGY AS EXPOSED AT RATTLESNAKE SPRINGS

HANFORD PROJECT

By

Randall E. Brown

Earth Sciences
Water and Land Resources

Arid Land Ecology Program
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PACIFIC NORTHWEST LABORATORY
RICHLAND, WASHINGTON

PREFACE

This is the third of a series of reports describing pertinent results from research on the Arid Land Ecology Reserve and associated areas of the AEC Hanford Reservation. The purpose of these preliminary reports is to provide current information on the various ecosystems under study in the Arid Land Ecology Program (ALE Program). Final results and conclusions will normally be published in the open literature. The research was conducted for the AEC by a member of the Water and Land Resources Department, Battelle-Northwest Laboratories.

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INTRODUCTION

The Rattlesnake Springs are the largest permanent springs on the Hanford Project. They lie about 690 feet above sea level near the southwest corner of the Project in Dry Creek Valley, 3.5 miles upstream from its junction with Cold Creek Valley. The springs lie adjacent to the east end of Yakima Ridge which there separates the two valleys, and at the northern edge of a large alluvial fan heading in Snively Canyon.

The Rattlesnake Springs area is a geologically complex and key part of the larger Arid Land Ecology (ALE) Reserve. All the late Miocene to Holocene (Recent) geological formations known in the Pasco Basin are exposed there or lie at shallow depth. Late Pleistocene to Holocene deposits (less than about 12,000 years old) that elsewhere were not deposited, were eroded or covered, are excellently exposed at or near the site and constitute the principal geologic units of interest. Moreover, most geologic processes that have been active in the Hanford Project area are in evidence in the small Rattlesnake Springs area. Hence the site is particularly attractive for studying geologic-ecologic relationships because it represents a condensed but accurate replica of a much larger area.

PURPOSE

This was a study to (1) obtain data in a key area typical of many eastern Washington arid-land areas, (2) characterize the geologic units, processes and problems expected in the ALE Reserve, and (3) begin to develop a geologic and paleoecologic base that will result in a better understanding of the geologic events, processes and causes that bear on and have influenced the development of the current ecology on ALE Reserve lands.

Knowledge of the geologic history of the area in the last 12,000 years provides evidence of some events that might recur in the at least long-time future. Such information is applicable and necessary to understand future ecologic changes.

PREVIOUS WORK

The geology of the Hanford Project was studied by various workers over many years. Most studies dealt with the Pleistocene and Holocene sediments, however, only where radioactive wastes were discharged to ground or where they were moving in those sediments.

The geologic events related to deposition of those sediments were first discussed by Bretz between 1919⁽¹⁾ and 1959⁽²⁾. Grolier⁽³⁾, Grolier and Bingham⁽⁴⁾, Fryxell and Cook⁽⁵⁾, Richmond, et al.⁽⁶⁾ more recently studied them.

Bretz⁽²⁾ recognized evidence of seven floods. Five of them traversed the basalt plateau and created the Channeled Scabland, and two were restricted to the river valley. They resulted dominantly from rapid drainage of glacial Lake Missoula and related lakes in late Pleistocene and early Holocene times. Bretz dealt mostly with the Channeled Scabland and did not initially study the Pasco Basin because of the thick basin fill. When he recognized the origin of the basin fill

sediments, security restrictions at Hanford permitted only casual glances at key features.

Bretz's basic concepts were not accepted for many years because they required events difficult to visualize. Only since 1956⁽⁷⁾ have they generally been accepted. Identification of many flood-formed features and appreciation of the magnitude of the floods in the Pasco Basin remain to be achieved. Grolier⁽³⁾, Brown⁽⁸⁾ and others only recently recognized that some slides and scarps attributed by others to earthquakes and faults respectively were more probably flood-caused.

SUMMARY AND CONCLUSIONS

Rattlesnake Springs are the result of a highly fortuitous association of four factors, each one of which is peculiarly dependent on the geographical location of the site. These are (1) a nearly flat-lying bed of compact, nearly impermeable floodplain silt that perches ground water, (2) a large synclinal drainage basin that recharges the perched aquifer, (3) tectonic deformation that created a shallow basin in the perching bed, and (4) deflation that lowered the base level of Dry Creek.

Rattlesnake Springs lie close to 700 feet in altitude. That is the level at which ephemeral and periodic glacial Lake Lewis stood during the latter part of the Pleistocene epoch. It is the level of much of the basin fill following the glacial Lake Missoula floods. Floodplain silts were laid down as the final deposits of those floods in the sheltered backwaters between the Rattlesnake Hills and Yakima Ridge, from Rattlesnake Springs westward. Tectonic deformation, recognized elsewhere in the Pasco Basin as slowly continuing today, helped create a broad, shallow saucer with the edges of the floodplain

silt lapping upon or over the rising anticlinal ridges.

A warming, drying climate in Altithermal period times, 8000 to 4000 years ago, permitted the beginning of deflation of lower Dry Creek valley. Winds, sweeping over the Rattlesnake Hills, at times funnelled down Dry Creek valley and impacted the ground east of Rattlesnake Springs, just as they do today. Runoff again became effective and responded to the deflated base level by incising a canyon to the perching bed. Water, charged to the perched aquifer from upper Dry Creek and Black Rock valleys to the west, then appeared as springs where the perching bed was exposed in the canyon bottom.

Eastward the perching bed probably was never deposited in areas subjected to the stronger flood currents. Additionally, its east edge was eroded where it was uplifted beneath lower Dry Creek above the buried anticlinal ridges that helped create the basin or saucer. Consequently the waters of Dry Creek, once they reach the slit in the rim of the basin, seep downward through the more permeable Touchet Beds sands to the regional unconfined water table, more than 100 feet deeper.

Sodium-rich sediments in the Rattlesnake Springs area support a lush stand of greasewood, a sodium-tolerant plant. The sodium evidently was leached from sediments in the hills to the south and west, and precipitated on the poorly drained floodplain roughly 8000 to 10,000 years ago. The base level of Dry Creek then was lowered, first by drainage of the Pasco Basin as the Columbia River cut its channel deeper, then by deflation of lower Dry Creek Valley, probably in Altithermal times. Precipitation of sodium salts ceased. Incisement of Dry Creek canyon lowered the perched water so that subsurface leaching of the salts was not possible. Insufficient rain falls today to leach the salts, especially when the greasewood concentrates sodium in its

leaves, then sheds the leaves on the ground surface. Hence the sodium-rich area evidently reflects an ancient saline floodplain or near-playa lake evaporite.

Many large grazing mammals occupied the region to 8000 or 10,000 years ago, then became extinct. Early man coexisted with the mammals and by hunting may have contributed to their extinction as the environment changed. Rattlesnake Springs probably is a recent feature and thus cannot be an ancient camp site, particularly during or following the glacial floods or when the saline area was developing. More optimum campsites and hunting sites probably existed at the 900 to 1200-foot altitudes such as those occupied in the Horse Heaven Hills.

Figure 1 Index map showing the general setting and key geological features of the Rattlesnake Springs Radioecology Facility.

STRATIGRAPHY

The Yakima Basalt Formation and the Ellensburg Formation - The area is underlain by the basalt flows of the Yakima Basalt Formation of the uppermost part of the Columbia River Group, as described by Raymond and Tillson⁽⁹⁾ from the Rattlesnake No. 1 well seven miles southwest of Rattlesnake Springs. Interbedded with those flows in the upper part of the Formation are various sedimentary rock units including the Beverly Member of the Ellensburg Formation. Those flows and sedimentary beds, not exposed in the study area, crop out a half mile to the west and northwest in Yakima Ridge, and three miles to the south in the Rattlesnake Hills. In the immediate area the basalts and interbedded sediments were explored by the Benson Ranch well, drilled in 1929 to a depth of 2000 feet, and by the Rattlesnake No. 11 well, drilled in 1922 to a depth of 1003 feet at the mouth of Snively Canyon. The individual basalt flows and interbeds thus are known to underlie the Rattlesnake Springs site in a known section beginning more than about 100 feet below the ground surface.

Ringold Formation - Sediments of the Ringold Formation overlie the basalts. They are known locally from the Benson Ranch well, well 699-19-88, and isolated exposures in the bed of lower Dry Creek. Fanglomerates evidently correlative with that Formation are exposed along the flanks of the Rattlesnake Hills immediately to the south. They are equivalent and comparable to those described by Laval⁽¹⁰⁾ in the Horse Heaven Hills and Grolier⁽³⁾ in the Saddle Mountains. They were shed from the Rattlesnake Hills northward toward Rattlesnake Springs, grade into finer sediments in that direction, and probably extend to within a mile of the Springs. At well 699-17-93, they are 30 feet thick. Farther southeast fanglomerates are thin and even rare

along the flanks of the Rattlesnake Hills, and basalt crops out in the gullies and canyons. Runoff was appreciably less there than in the Snively Canyon area, for the canyons drain smaller areas. Additionally, such fanglomerates as developed to the southeast evidently were removed by the glacial Lake Missoula and related floods, because insufficient talus and alluvial fans are present today to account for the missing and eroded flows. These floods were not able to erode the fanglomerates south of the Rattlesnake Springs site because of the protecting Yakima Ridge.

The remainder of the Ringold Formation sediments appear to be normal Ringold Formation gravels, sands and silts of mixed composition, frequently highly cemented by caliche. They interfinger with and underlie the fanglomerate deposits, particularly west and south.

Directly above basalt, as indicated by the Benson Ranch well and well 699-19-88, is a bed of silt and clayey silt 40 feet thick. Similar material crops out two miles due south of Rattlesnake Springs, east of the mouth of Snively Canyon, and suggests continuity of the bed. Well 699-17-93 encountered only fanglomerates above basalt, however. Possibly runoff from the Snively Ranch area eroded the silt prior to deposition of the fanglomerate, and left the silt outcrop in a protected site. The Snively Canyon alluvial fan is dominantly Ringold Formation (largely Pliocene) fanglomerates, veneered with later fanglomerates, Touchet Beds, eolian silt and ash. Its presence requires more runoff than now to create such a large fan. Previously greater runoff is indicated by (1) the presence of the Glacier Peak and Mazama ash beds high in the fans with little fanglomerate cover, (2) the absence of much runoff even during the optimum conditions of frozen ground, extensive snow cover, and rapid melting that prevailed in February 1969, (3) markedly underfit

streams throughout canyons in the anticlinal ridges and (4) canyons largely choked with eolian sediments that contain the Mazama and Glacier Peak ash beds.

The fanglomerates of the Ringold Formation probably grade upward into younger fanglomerates of Pleistocene and early Holocene age so that the upper boundary of the Ringold Formation in the fanglomerates is not identifiable as it is to the east beneath the main part of the Hanford Project. Elsewhere deposition of the Formation ceased once the Columbia River began to lower its base level through the Horse Heaven Hills at Wallula Gap, probably in early Pleistocene time. Then the river began to erode the Ringold Formation sediments. Some of the fanglomerates south of Rattlesnake Springs thus must bridge the time gap between the Ringold Formation exposed in the White Bluffs and the overlying Touchet Beds and Pasco Gravels (the glaciofluvial sediments).

Glaciofluvial Deposits - The Touchet Beds unconformably overlie the Ringold Formation beneath the Hanford Project area. They overlie the Ringold fanglomerates in the Rattlesnake Springs area and form a veneer on the higher slopes. In the Rattlesnake Springs area they grade upward into more massive silts and fine sands which locally interfinger with recent fanglomerates. The Touchet Beds and associated Pasco Gravels are the deposits in glacial Lake Lewis, which formed by sudden drainage of glacial Lake Missoula and comparable ice-marginal lakes. The torrential to catastrophic floods resulting from the drainage ponded in the Pasco Basin apparently in response to hydraulic damming in Wallula Gap and downstream constrictions. Bretz⁽²⁾ identified seven floods, five of which Fryxell and others⁽⁶⁾ have confirmed and at least roughly dated. They range in age from more than 50,000 years to probably

EPOCH	AGE YRS BP	GEOLOGIC UNITS	GEOLOGIC AND RELATED EVENTS	CLIMATIC TRENDS
HOLOCENE	MODERN	LANDSLIDES	IRRIGATION-INDUCED LANDSLIDING	COOLER, MOISTER
		ASH DEPOSITS	ERUPTION OF MT. ST. HELENS	
	4,000	PALOUSE SOILS AND DUNES	DEFLATION OF COLD CREEK VALLEY, DUNE CREATION. MINIMAL MASS WASTING	
			COLUMBIA RIVER AT LOW FLOW RATE	
	6,600	MAZAMA ASH BED	ERUPTION OF MT. MAZAMA	<u>ALTI THERMAL PERIOD</u>
	8,000	PALOUSE SOILS AND EOLIAN SEDIMENTS		
			EXTINCTION OF MANY LARGE MAMMALS EARLY MAN KNOWN IN BASIN	
	10,000	TOUCHET BEDS LANDSLIDES	FLOODS TO AT LEAST 850 FEET ALTITUDE EXTENSIVE LANDSLIDING	
		GLACIER PEAK ASH BED	ERUPTION OF GLACIER PEAK EARLY MAN KNOWN AT MARMES ROCKSHELTER	PLUVIAL CLIMATE BECOMING WARMER AND DRIER
	12,000			
PLEISTOCENE		FLOOD DEPOSITS	CONTINUED ANTICLINAL UPLIFT AND BASINING. FLOODS. DOMINANTLY GRAZING ANIMALS IN REGION	
	18 - 20,000	TOUCHET BEDS AND PASCO GRAVELS	CATASTROPHIC FLOODS FROM GLACIAL LAKE MISSOULA, POSSIBLY TO 1250 FEET ALTITUDE. EXTENSIVE EROSION, LANDSLIDING, SEDIMENT DEPOSITION	
		FLOOD DEPOSITS	FLOODS FROM GLACIAL LAKE MISSOULA AND LAKES TO THE WEST	
	50,000	EARLY FLOOD DEPOSITS	GLACIAL LAKE MISSOULA FLOODS	ONSET OF THE ICE AGE WITH COOL CLIMATE AND AT LEAST LOCALLY INCREASED MOISTURE. REVERSALS IN INTER- GLACIAL PERIODS
		FANGLOMERATES	PLANING OF THE RINGOLD FORMATION BENEATH THE HANFORD PROJECT	
PLIOCENE	1-2 MILLION			
		EARLY PALOUSE SOILS	CONTINUED ANTICLINAL UPLIFT AND BASINING	
		RINGOLD FORMATION AND ASSOCIATED FANGLOMERATES	DOMINANTLY BROWSING ANIMALS IN THE REGION	
	10 MILLION	THE YOUNGEST BASALT FLOWS (POMONA, ELEPHANT MOUNTAIN AND WARD GAP)	TERMINATION OF THE BASALT FLOODS BEGINNING OF ANTICLINAL UPLIFT AND INCREASING VOLCANIC ACTIVITY IN THE CASCADE RANGE	DRYING AND COOLING

FIGURE 2. TIME AND GEOLOGIC EVENTS, PLIOCENE TO HOLOCENE EPOCHS, PASCO BASIN. (DERIVED IN PART FROM FRYXELL AND COOK (5); RICHMOND ET AL. (6))

about 10,000 years old. Currently the deposits and floods in the Pasco Basin are only in part distinguishable from each other.

The Touchet Beds are fine-grained sands and silts that are distinctly and finely bedded. They were first described by Flint⁽¹¹⁾ from Touchet, Washington, in the Walla Walla River Valley. Ripple marks, characteristically wavy bedding, local convolutions and even involutions are common. Pebbles, cobbles, boulders and even blocks of ice-rafted exotic rock types indicate shallow lake and floodplain deposition where rafting bergs and floes ran aground and melted, dropping their rock loads. Toward the basin center the Touchet Beds grade and interfinger with progressively coarser sands and gravels (the Pasco Gravels) that also show many characteristics of flood-type deposits. Those include deltaic foreset beds, cut and fill beds, cross beds and related features in quite unsorted materials.

The Touchet Beds thus represent the shallow and quiet water phase of the glaciofluvial deposits, with the Pasco Gravels representing contemporaneous deposits in the areas of more rapid water flow.

The above picture is greatly simplified. The floods entered the Pasco Basin from the northwest down the Columbia River, from the north down Othello Channels, from the northeast down Esquatzel Coulee, and from the northeast to east down the Snake River. Which channels were used by each flood were in part a function of the flood magnitude as well as the source of the water. Thus, a quiet water area for one was a channel for another. Separate floods, flood pulses, and fluctuating lake levels and base levels resulted in a complex sequence of sediments. Each flood also

eroded some of the deposits of earlier floods. Moreover, tentative data suggest more than the seven floods recognized by Bretz farther north. Some probably were relatively minor sheet floods, possibly originating in the Cascades or up the Snake River, and hence not identified by Bretz in areas he studied.

Clastic dikes are common to the Touchet Beds and are less common though present in the Pasco Gravels. Their origin has been controversial ever since Jenkins' ⁽¹²⁾work in 1925. They appear occasionally in older materials ⁽¹³⁾but not in significantly younger deposits. They thus appear related to the floods and flood-caused events. Several processes currently are believed to have contributed to the dike formation, with one process dominant at one site and time, and another process elsewhere at a different time or under different conditions.

The topmost five feet of the Touchet Beds at Rattlesnake Springs are finely laminated sands and silts in which the dikes terminate or are absent. Cycles of deposition are indicated, with sand forming the base of a deposit, and grading upward into finer sand, then into silt over a vertical distance of a foot to a foot and a half. The sequence is repeated higher. A comparison with the deposits on Gable Mountain, at the same altitude of 700 feet, indicates that each deposit or cycle records probably a sheet flood sweeping across a basin fill standing about at the 700-foot level. At Rattlesnake Springs the sediments represent the shallow and quiet water deposits in a protected area.

The laminated sands and silts form the floor of Dry Creek Valley upstream from the 646 Building. They evidently perch the stream, because eastward the stream loses water

where it flows over the stratigraphically lower and coarser-grained Touchet Beds. Persistent dampness of the laminated silts well above creek level, in contrast to the sandier and dry Touchet Beds, indicates their lower permeability, their higher water-retaining capacity and perching capability.

Few dikes in the laminated silt, compared to the sandy Touchet Beds, suggest either the improper environment for dike formation, or that the beds were deposited after the dike-making events. Certainly the laminated silts were laid down well after the major floods had inundated the area. A regional study of the dike distribution with respect to the various types of sediments, their ages, and the environment, may solve the problem.

The Glacier Peak Ash

A thin but widespread and oftentimes continuous bed of white ash of dacitic composition occurs in the uppermost part of the Touchet Beds and the Pasco Gravels throughout the Pasco Basin. It ranges up to two inches thick and is bifurcated, with up to two inches of water-deposited sediments between the layers. Clastic dikes commonly cut the ash. In the Horse Heaven Hills above an altitude of between 850 and 900 feet it lies within massive, compact silts and fine sands that are eolian deposits evidently reworked from the earlier Touchet Beds. Brown⁽⁸⁾ concluded that the ash was derived from Glacier Peak on the basis of its stratigraphic position and geologic occurrence, a conclusion concurred in by Fryxell⁽¹⁴⁾.

Radiocarbon dates on peat deposits associated with the Glacier Peak ash near its source indicate its age to be about 12,000 years. The latest Touchet Beds overlying the ash thus may be 11,000 to 12,000 years old. Their occurrence to nearly 900 feet above sea level thus records a flood to at least that altitude at that time. The persistence and recognizability of the ash make it invaluable in dating late Pleistocene and early Holocene geological events, and paleontological and archeological finds.

The full significance of the bifurcation is not yet known. It may represent two separate eruptions with an unknown time interval between them. Alternatively it may represent a sudden change in wind direction for a short period and/or a flood pulse during its deposition.

Eastward from Rattlesnake Springs the ash bed is progressively closer to the ground surface until at Benson Ranch it lies at that surface. That indicates erosion to the east of the once-present Touchet Beds and later sediments as later discussed.

Early Eolian Silts and Associated Fanglomerates

The classical Touchet Beds and the overlying laminated silt at Rattlesnake Springs are in turn overlain by massive, compact and indurated fine sand and silt comparable to the Touchet Beds in composition, but deposited under different conditions. Similar material occurs in the Horse Heaven Hills, on Wahluke Slope, and elsewhere above the highest levels reached by any glacial Lake Missoula flood. Its nature, distribution, and lack of bedding indicate eolian deposition

Figure 3 Geological profile along part of Dry Creek Canyon, showing the detailed structural and stratigraphic relationships.

subsequent to the last floods. Some reworking by runoff occurred in local sites in the Horse Heaven Hills and elsewhere.

The degree of compaction and consolidation of the eolian deposits compared to distinctly later ones probably reflects greater time for consolidation and induration and a moister climate than now, as concluded from other data.

Significant amounts of runoff from the Rattlesnake Hills and Dry Creek still occurred, for the Touchet Beds upstream from the 646 Building are cut by a north-trending channel at least four feet deep (see Fig. 3). It is filled with eolian and water-deposited silts and sands identical to those overlying the Touchet Beds.

Westward, up Dry Creek Canyon, the eolian silts and sands interfinger with basaltic sands that are highly iron-stained but not cemented by caliche. Numerous north-south channels also cut the eolian sediments, terminate some beds, and are filled with iron-stained silts, sands and gravels. They represent the downstream phase of fan conglomerates that were deposited closer to the mountain front. They are younger than the Ringold fan conglomerates, as indicated in part by the absence of caliche, and by their truncation of the Touchet Beds and even later deposits. Although they well may have originated to the south in the Snively Canyon area, reconnaissance studies up Dry Creek show abundant evidence of interlacing stream channels there. Probably the north-south-trending channel segments are the downstream portions of ancient Dry Creek, shifting about as it encountered the Snively Canyon fan.

The early compact silts in the Horse Heaven Hills contain many bones of mammoth, bison, horses, and other grazing species⁽¹⁵⁾. By

reference to the Glacier Peak ash, those finds appear to be about 10,000 years old. No bones yet have been noted in comparable deposits at Rattlesnake Springs. Possibly this is because of the limited exposures. The Rattlesnake Springs site and the Snively Ranch area now are ecologically favored areas for mammals. Indications are that they were even more so 10,000 years ago. Consequently the prospect of finding paleontological materials appears excellent. That appears particularly true along the flanks of the Rattlesnake Hills above 1000 feet altitude where conditions probably were comparable to these in the Horse Heaven Hills.

Recent Eolian Sediments and the Mazama Ash

Recent, unconsolidated eolian sediments partly interbedded with the old Dry Creek deposits, the fanglomeratic sands and volcanic ash beds are exposed westward from the main canyon area to and beyond the west fence of the Radioecology Facility. High in those eolian sediments is a bed of volcanic ash six inches thick and intermittently traceable for more than two miles up Dry Creek. Its thickness, stratigraphic position, association with eolian silt, and comparability to the Mazama ash described by Richmond et al.⁽⁶⁾ strongly indicate that it is the Mazama ash. It accordingly was deposited 6400 - 6900 years ago. It is overlain in the Rattlesnake Springs site by up to two feet of eolian silt and then by an impure and diffused ash bed about a foot thick that extends nearly to the ground surface. The uppermost ash probably is from Mt. St. Helens which erupted 3200 years ago and 500 years ago, and spread ash at least as far as the Canadian border⁽¹⁶⁾. Less likely sources are Mt. Rainier and Newberry volcano in central Oregon, which erupted in comparable times.

The bench, terrace or flat west-southwest of the 646 Building, liberally covered with greasewood, represents the level of the Touchet floodplain, fanglomerate and eolian fill there prior to canyon cutting. A comparable altitude of similar benches or terraces to the northeast, the terrace from the saddle of Gable Mountain to the east end of the mountain, the floors of coulees east of the Columbia River, and terraces in the White Bluffs indicate that the 700-foot level is probably a long-standing water level and probably a continuous or nearly continuous basin-fill surface. Probably that surface extended and sloped gently eastward and southeastward from the Rattlesnake Springs site. Its gradient must have been less than that of Dry Creek now (30 feet per mile), for the old creek, as indicated by the gravels, lay above the floodplain fill level. Eastward from the Springs the surface was that of floodplain deposition. Probably the fill surface sloped between five and ten feet per mile to the area west of West Richland which is a comparable depositional surface 20 miles away but 100 to 150 feet lower in altitude.

The increase in gradient of Dry Creek Valley eastward from Rattlesnake Springs from 30 feet per mile to about 60 feet per mile suggests considerable erosion in that direction and indicates that the bench or terrace is only a remnant of the more extensive earlier deposits.

Dry Creek continues eastward to Benson Ranch where the stream channel ends on a floodplain or playa-like surface. Upper Cold Creek Valley ends less than a mile northeast of Benson Ranch at an altitude of 620 feet in what approaches a hanging valley on the side of Dry Creek Valley. No stream channel exists in upper Cold Creek Valley nearer than four miles to the northwest. Brown⁽¹⁷⁾ determined in 1963 that Cold Creek Valley downstream from the Rattlesnake Springs

is largely a wind-deflation valley traversed by short and totally unconnected segments of stream gullies. Those segments migrate upvalley whenever and wherever local runoff is concentrated sufficiently to form a stream. Within a mile or less, those channels terminate as the water percolates into the ground and the streams lose both erosive and transporting power. The difference in the altitude of lower Dry Creek and upper Cold Creek Valleys at their junction is due to deflation of the mid-Cold Creek Valley area. Its deflation, and not that of upper or lower Cold Creek Valley or Dry Creek Valley, results from the position and orientation of the Rattlesnake Hills with respect to the prevailing winds that sweep over it in part as described by D. J. Brown⁽¹⁸⁾.

Deflation of the valley probably began shortly after deposition of the latest Touchet Beds sediments about 10,000 years ago and continued at least periodically or intermittently to current times. As base level lowered near the junction of Dry and Cold Creek Valleys, runoff down Dry Creek incised a canyon in the sediments just upstream from the deflated area. That incisement clearly is recent because the Dry Creek canyon cuts through the Mazama ash and the later ash, which appear on both sides of the canyon. Probably maximum deflation occurred during the Altithermal period for reasons later discussed.

Lowering of base level was too far removed from runoff in upper Cold Creek Valley to result in downcutting of that valley. Consequently the large flat or playa immediately east of the Yakima Ridge is aggradational in origin. This is suggested by samples of material from the upper 45 feet in wells 699-34-88, 699-36-93 and 699-26-89, which suggest reworked sediments derived from the Touchet Beds, the Ringold Formation and Ellensburg Formation (Beverly Member) in upper Cold Creek Valley,

rather than Touchet Beds in place.

GEOLOGIC STRUCTURE

The Rattlesnake Springs Radioecology Facility lies above the eastward and underground continuation of Yakima Ridge, and across the lower end of Dry Creek Valley west of its junction with Cold Creek Valley.

Yakima Ridge consists of two converging anticlines that, due north of the 646 Building, lie only about 1500 feet apart⁽¹⁹⁾. Their subsurface position is inferred but farther east the presence and location of both are known from scattered outcrops, wells and geophysical data^(20, 21). Probably both anticlines are discontinuous but with low, elongate domes or doubly terminated anticlines at periodic intervals along the axes. That is comparable with the Rattlesnake Hills Anticline Southeast between the Yakima River water gap at the southeast end of the Rattlesnake Hills and the Horse Heaven Hills at Wallula Gap⁽⁸⁾.

The southernmost anticline of the Yakima Ridge, the Yakima Ridge Anticline South, evidently passes beneath the Radioecology Facility about 300 feet north of the 646 Building. That conclusion is based upon the known southerly swing of the Cold Creek Anticline, and because the Glacier Peak ash and Touchet Beds, including the laminated silts, show a change in dip at that point. The ash bed, which slowly rises from an altitude of about 620 feet at the east edge of the Radioecology Facility to 760 feet at the west edge in about two miles (about 1.5° east dip), north of the 646 Building dips westward for more than 200 feet at an angle up to 4°. The enclosing Touchet Beds and the overlying laminated silts, although not traceable as individual thin beds over comparable distances, consistently show dips paralleling the ash bed and show no signs that the dip changes are depositional. We conclude

that the dip change probably reflects uplift of the adjoining anticlines and downwarping of the syncline comparable to that noted by Brown⁽⁸⁾ at Finley quarry. There, neither the dip angle nor dip direction of the Touchet Beds appears wholly explainable as depositional dip. However in the Dry Creek area depositional dip and differential compaction in a westward-thickening sedimentary section may have contributed to the dip reversal. Logically the dip reversal, for whatever reason, evidently created a shallow basin in which perched water accumulates and from which it escapes through the gap cut by Dry Creek Canyon.

The Dry Creek synclinal axis lies south of the valley floor, about a half mile south of Dry Creek at its northernmost reach. The syncline parallels the more northerly anticlines and probably trends eastward from the middle of section 30 toward Benson Ranch. The greasewood covered bench or terrace west of the 646 Building thus lies immediately north of the synclinal axis.

Emplacement of Dry Creek across the projected anticlinal axis is the result of initial depositional surfaces of the Snively Canyon fan sloping northward, lowering of the ground surface to and beyond Benson Ranch by deflation, and northward spread of fan conglomerates from Snively Canyon, particularly in the western part of the facility. Little runoff has occurred from the steep south face of Yakima Ridge to counter the runoff from Snively Canyon and resulting northward offset of the valley. That is indicated by the small alluvial fans at the mouths of canyons in Yakima Ridge. In turn, the contrast between the Yakima Ridge fans and the Snively Canyon fan indicates the importance and probable magnitude of runoff from the Snively Ranch basin. It heads at the crest of the Rattlesnake Hills where greater amounts of precipitation fall than at lower altitudes. Evidence earlier cited,

however, indicates that little runoff has occurred since latest Pleistocene and early Holocene time.

POSTULATED FAULTS

Some persons postulate that faults exist in the western part of the Hanford Project. As proposed, they lie along two zones: (1) the north-south zone from the east end of Umtanum Ridge past the nose of Yakima Ridge into the Rattlesnake Hills, and (2) a northwest-trending hypothesized "Olympic-Wallowa Lineament"⁽²²⁾ or a "Rattlesnake Hills - Wallula - Milton-Freewater Fault Zone"⁽²³⁾. Both zones, if projected, intersect south of the Rattlesnake Springs Facility in the Snively Ranch area.

Evidence for the north-south zone of faults consists of (1) a north-south topographic lineation from the front of Umtanum Ridge to Yakima Ridge, (2) suggested offset of the eastward extension of Umtanum Ridge, (3) a change in trend of the Rattlesnake Hills from southeast to east-west, (4) the occurrence of what was considered to be a large landslide covering the entire Snively Ranch area (in turn suggesting faulting there), (5) the presence of an artesian well field in upper Cold Creek valley west of the supposed fault, and (6) a high water table at Rattlesnake Springs in a position comparable to the artesian well field. No one however has identified a fault in surface exposures along that zone, nor demonstrated offset of individual basalt flows or interbeds.

Bedrock contours, compiled by Brown (shown as Plate 4 by Jones and Deacon⁽²³⁾), show a steepening plunge of the anticlines and synclines eastward instead of indications of a fault. A fault or faults may be present but major offset is not suggested by the contours; and the topographic lineation, based upon the ends of the two ridges, easily

can be explained as downwarping along a north-south axis along the west side of the Pasco Basin comparable to Mackin's Hog Ranch axis⁽²⁴⁾. The trend change of the Rattlesnake Hills at the south end of the zone was shown by Brown⁽⁸⁾ to result from overlapping of anticlinal axes trending in different directions. Similarly, the suggested periodic offset of the Gable Mountain-Gable Butte-Umtanum Ridge structure is the result of overlapping en echelon anticlines also suggested by the bedrock contour map and demonstrated by Laval⁽¹⁰⁾ and Stradling⁽²⁵⁾ for the Horse Heaven Hills. The lateral offset supposedly due to faulting in the Umtanum Ridge structure is not duplicated in the continuation of the Yakima Ridge structures. Brown⁽⁸⁾ also showed that the Snively Ranch "landslide" as mapped by Newcomb and Strand⁽²⁶⁾ does not exist, and cannot be cited as evidence for a fault or for earthquakes associated with that or other faults.

Newcomb⁽²⁷⁾ attributes the formation of the upper Cold Creek artesian reservoir to a fault or sharp fold and indicates that the artesian reservoir "terminates abruptly in alinement with the sharp east edge of the Yakima Ridges to the north and south of the syncline." He pinpoints the site by "The easternmost well, the McGee, is about a quarter of a mile upslope from the inferred location of the barrier."

Newcomb cites no specific evidence for the fault location, and in fact neither in 1953⁽²⁶⁾ nor in 1966⁽²⁸⁾ did he indicate either a fault or an adequately sharp fold on his cross sections A-A'. If a fault is present it must be small in significance for it does not appear in Umtanum Ridge nor Yakima Ridge where exposures are continuous for a mile east of the inferred position of the barrier. Well data do not suggest a sharp fold, and positive evidence of a sharp fold or fault is absent to the south in Yakima Ridge. Magnetometric data,

reported by Raymond and McGhan⁽²¹⁾, fail to show an anomaly that can be ascribed to a fault rather than plunging anticlines.

The artesian wells west of the McGee well produce most of their water, and presumably head, from the Squaw Creek diatomite bed or its equivalent and the Vantage Sandstone Member and associated basalt flows. The McGee well, the second deepest of all the artesian wells at 1110 feet, lies sufficiently east of the other wells so that it penetrates only the Ringold Formation, a thick Beverly Member and the Priest Rapids Member. Consequently it terminates far above the Vantage Sandstone Member. Wells to the east penetrating to the Vantage Sandstone are the Benson Ranch well and the Haynes and Culver stock well, 7 1/2 and 13 miles away, respectively. Termination of the artesian field thus is not demonstrated, the termination cannot yet be ascribed to a fault or sharp fold, nor can the barrier site pinpointed by Newcomb be shown without vastly more stratigraphic data and the comparability of piezometric heads clearly measured in the same aquifers.

The hypothesized "Olympic-Wallowa Lineament" of Skehan and the "Rattlesnake Hills-- Wallulla - Milton-Freewater Fault Zone" of Jones and Deacon are features yet unsubstantiated by adequately detailed mapping. If either are shallow-seated major fault zones of the magnitude postulated by Skehan or Jones and Deacon, they should appear to the south or west of Rattlesnake Springs. Neither Jones and Deacon nor Newcomb mapped or even suggested possible faults in that area nor has field work leading to this report yet indicated any faults of significance there.

Faults consistently have proved to be secondary features of minor significance where adequately detailed field work was done. Faults cannot arbitrarily be excluded from the Rattlesnake Springs area; however,

only indirect evidence even suggests them. Moreover, at or near the Springs, bonafide fault gouge, slickensided surfaces, fault breccia and shear zones are not visible and have not been reported. Such evidence for faults as are cited above consequently are equally or more indicative of other conditions.

The reversed dip of the Touchet Beds and Glacier Peak ash contained therein could be the result of fault offset in the basaltic rocks below the Springs with accompanying adjustment of the unconsolidated sediments above the fault without rupture. If that adjustment were in response to north-south faulting related to the ground-water barrier, however, the upward movement on the eastern side of the fault is opposite to that expected in a subsiding basin bordered by rising anticlines. Movement in the other direction (east side down) would more likely drain the springs by positioning stratigraphically higher and more permeable sediments east of the hypothesized fault at the water level. Faults were not mapped by Newcomb in 1952 in Yakima Ridge west of the Springs, even where dips reach 74° . Hence, we can conclude that dip reversal in the ash bed probably reflects largely anticlinal uplift without evidence of faulting.

THE SOURCE OF THE SPRING WATER

The Rattlesnake Springs appear over about one-half mile as seeps along both sides of the canyon bottom. The absence of riparian vegetation westward up Dry Creek indicates a deeper water table that probably results from a land surface increasing in altitude faster than the water table. Eastward, the terminus of the Springs is not well defined because vegetation is watered by the surface stream until, in the eastern part of the Radioecology Facility, the stream disappears because of influent seepage. Well 699-19-88, at the southeast corner of the facility,

indicates that the depth to water is about 130 feet and consequently that the stream and springs must be perched.

The springs occur along the northwest edge of the fan that heads in Snively Canyon where a surface stream in at least some places flows the year around. Numerous subsurface and surface channels radiate from the canyon and attest to appreciable drainage and runoff from the Canyon and the large drainage basin behind it. However the almost complete lack of runoff from Snively Canyon to the end of the fan during favorable conditions in February 1969 questions that area as a major source of the water. Instead, in February 1969 abundant floodwaters coursed down Dry Creek from Black Rock Valley more than 10 miles away. The primary reason for that runoff clearly was due to frozen ground that inhibited downward percolation of the runoff water.

If the winter of 1968-69 had been colder and wetter than it was, and possibly comparable to that inferred at the close of the Pleistocene epoch, the permeable fanglomerates of the Snively Canyon fan may have been rendered insufficiently permeable so that greater runoff would have reached Dry Creek. Currently, the Dry Creek channel consistently exhibits signs of more recent runoff than the Snively fan distributary channels and must be considered as the major water source.

THE DISTRIBUTION OF GREASEWOOD

The kinds and density of vegetation recognizably vary from site to site on the Hanford Project and often reflect differences in soil types and in the accessibility of water. Greasewood (Sarcobatus vermiculatus) occurs on the Hanford Project only in the Rattlesnake Springs area.

It is generally considered a phreatophyte which tolerates or requires a sodium-enriched habitat (see, for instance Rickard⁽²⁹⁾) and may even perpetuate such conditions⁽³⁰⁾. Hence, an appraisal of the occurrence

of sodic soils at Rattlesnake Springs is warranted.

The Touchet Beds commonly contain leachable sodium, but salt crusts on canyon walls indicate either that the old eolian silts at the Springs contain greater quantities than the Touchet Beds, or that sodium was concentrated in them. Because the eolian silts were derived at least partly by eolian reworking of earlier Touchet Beds, concentration of the sodium brought in from external sources and deposited in those eolian sediments is most likely. This is also indicated by the fact that the Springs contain about 7 PPM of sodium, or about one third to one fourth that of normal Hanford ground waters. Conditions unique on the Hanford Project must have prevailed at the Springs.

The Ellensburg Formation sediments commonly contain leachable alkali (potassium, sodium, magnesium) as recognized as early as 1913 by Waring⁽³¹⁾. Where ground waters occur close to the ground surface in the Yakima Valley, underlain by the Ellensburg Formation, evaporation has concentrated sodium salts to the point where crops do not grow. Elsewhere, such as in the Ringold Formation, derived largely from northern Washington rock types rather than Cascade volcanic rocks, calcium carbonate (caliche) was deposited under similar conditions. Hence chemical study of the leachable constituents of the two formations seems warranted.

The bench or terrace, adjacent to the 646 Building, lies at an altitude of about 700 feet and represents the remnant of an old land surface or surface of the Pasco Basin fill about 10,000 years ago. Surface runoff, from Snively Canyon and Black Rock Valley, removed leachable sodium from Ellensburg Formation beds and Touchet beds and transported it to the Springs site. There, where the land surface was flat, drainage poor, and evaporation rates high, the sodium was concentrated. As the Columbia River lowered its base level at Wallula

Gap, the ground water table, discharging into the Columbia River, increased its gradient and hence its depth from the ground surface. Perching of the ground water occurred. Changing climates, as later discussed, resulted in increased evaporation and concentration of the sodium, but the drying climate had not yet resulted in appreciable deflation of the downstream portion of Dry Creek Valley. Consequently, the perched water lay close to the ground surface. Following deflation of lower Dry Creek Valley and the beginning of canyon incisement, the perched water body probably became partly drained. The lack of sufficient rainfall or surface runoff across the old land surface following canyon incisement, however, has precluded leaching of the concentrated sodium into the stream and subsequent removal of salts from the Rattlesnake Springs area. Consequently, the area of the old basin-fill surface remains and will remain a sodium-rich area.

Elsewhere sodium has not concentrated in the sediments, indicating (1) the absence of the old basin-fill surface on which sodium once may have been concentrated, or (2) the lack of an area where ground waters could have been long maintained near the ground surface where evaporation could have concentrated that sodium, or (3) the lack of leachable sodium in rocks through which ground waters flow.

The uniqueness of the Rattlesnake Springs site is again emphasized.

PALEOCLIMATES AND GEOLOGIC HISTORY

Jakway⁽³²⁾ as the result of his collection and study of a large faunal assemblage from the Ringold Formation, is reviewing the age, environmental and climatic conditions represented by that Formation. The fauna are believed to indicate a late Pliocene to possibly earliest Pleistocene (probably Blancan) age for the upper part of the Formation. The mammals found are largely browsing species with some aquatic forms,

indicating moderately humid conditions on the Ringold floodplain. Eolian sediments (the Palouse Formation and Palouse soils) in eastern Washington in the stratigraphic position of the Ringold Formation suggest at least intermittently dry conditions or at least dry conditions by the close of Ringold time. Then, of course, the Columbia River lowered its base level in Wallula Gap, terminated deposition of the Formation in the central part of the Pasco Basin and exposed the floodplain to wind erosion. This is further indicated by the extensive beds of caliche which cap the Ringold Formation⁽³³⁾ in and to the east of the Basin center, and by eolian soils overlying the latter of two caliche beds⁽³⁴⁾.

The Cascade Range was rising in Pliocene time, concurrently with the uplift of the anticlinal ridges of south-central Washington. By late Pliocene or earliest Pleistocene times they had risen sufficiently to intercept many of the moisture-laden winds from the Pacific Ocean. Consequently, exposure of the Ringold floodplain sediments roughly coincided with a marked change to a dryer climate that resulted in extensive eolian reworking of those sediments.

Effective if not total precipitation periodically may have increased in Pleistocene time to result in the repeated glacial advances of the epoch. An alternative possibility in the Pasco Basin is that the lower temperatures of the epoch resulted in the accumulation of much of the precipitation as snow. Snow-melt floods over frozen ground then could have caused runoff sufficient to flow the length of and to add to the huge alluvial fans. Probably total precipitation periodically increased and temperatures decreased. Fanglomerates flanking the Rattlesnake and Horse Heaven Hills were deposited as the result of greater runoff. The Columbia River meanwhile was eroding

still further downward at Wallula Gap and simultaneously eroding the Ringold Formation sediments beneath the Hanford Project. Possibly its erosive ability was increased by the greater precipitation, or meltwater runoff during interglacial periods. Accordingly, positive Pleistocene deposits in the Pasco Basin are restricted to fanglomerates and loess deposits, laid down above the Columbia River.

In late Pleistocene and early Holocene time, the Pasco Basin was inundated by a series of floods from glacial Lake Missoula, Columbia, Spokane and similar ice-marginal lakes, and by glacial meltwaters. Those floods further scoured the Ringold Formation, excavated the Channeled Scablands, induced many landslides, and stripped basalt from the north faces of the anticlinal ridges and even from their crests where those crests were inundated. Touchet Beds sediments and Pasco Gravels were laid down in a complex sequence of deposits. Between floods, winds reworked the fine-grained Touchet Beds sediments, deposited some in local sites and transported some as far as Idaho.

The faunal species known from the Touchet Beds and early eolian sediments indicate extensive grasslands. Mammoth, bison, horses, deer and some yet unidentified species⁽¹⁵⁾ indicate an important change from the browsing animals of Ringold time and probably a long time period as already suggested by the unconformities capped by caliche. Effective precipitation was greater then than now, in order to support the vegetation upon which the population of large grazing animals fed. Fanglomerates exposed at Rattlesnake Springs apparently accumulated at a much greater rate than they do today, reflecting greater runoff as already indicated.

The mammoth, bison and horses that then existed are believed to have become extinct between 8,000 and 10,000 years ago⁽³⁵⁾, thus

disappearing shortly after the time of the last glacial Lake Missoula floods. If so, the indurated and compact eolian deposits in which most of the bones have been found in the Horse Heaven Hills, identical in appearance to the early eolian sediments at Rattlesnake Springs, may represent the time of last occurrence of those species in the Pasco Basin. Careful dating of the sediments thus is desirable.

The period from about 8,000 to 4,000 years ago (the Altithermal period) is recognized throughout the Pacific Northwest as a time of warmer temperatures and less effective precipitation, as summarized by Brown⁽⁸⁾. Fryxell⁽³⁶⁾ at Marmes Rockshelter has determined the existence of the Altithermal period and its order of magnitude and effects there. The Altithermal period is similarly indicated in the Pasco Basin by extensive unconsolidated eolian deposits that include the indicated Mazama ash bed. However, fanglomerate deposits associated with the Mazama ash indicate some periodic flood runoff during that period and suggest that total precipitation may not have been greatly different from that of today, but perhaps concentrated in intense storms.

Deflation of lower Dry Creek Valley presumably began in the Altithermal period. Movement of the sands and silts northeastward with the prevailing winds and in directions evidenced by the linear ridges (dune trails) suggests that active dunes south of the Hanford townsite originated in the area at the junction of Cold and Dry Creek Valleys.

The extensive dunes present near the Hanford townsite required a large source of uniform, fine-grained sediment. Nowhere else than in the Dry Creek - Cold Creek junction area was and is a sufficient source available to create those dunes. If the crest of Goose Egg

Hill, comparable in altitude to that of the Separations area terrace farther north, be considered as the original surface of Cold Creek Valley at that point, about 120 feet of the valley was there deflated. Additionally 20 feet of silt was deposited on the deflated valley floor by periodic floods, as indicated by well 699-12-64. Hence up to 150 feet or more of Touchet and reworked Touchet Beds sediment may have been deflated from the valley, providing abundant material for the dunes. In part, however, the valley was an old fosse, as postulated by Bretz⁽⁷⁾, and in which case less deflation has probably occurred.

Dry Creek is actively cutting its channel deeper near Rattlesnake Springs, in an effort to keep pace with deflation that continues to remove the deposited sediment from the Benson Ranch area.

The Mazama ash bed also reinforces the concept of deflation of lower Dry Creek Valley. In several West Richland and North Richland sites, the ash is overlain by stream-deposited sands at altitudes of roughly 400 to 500 feet. Above 500 feet altitude the Mazama ash is overlain by eolian sediments indicating that in post-Mazama ash time the Columbia River surface lay between 400 and 500 feet altitude and west of its current course. In that subsequent 5,000 to 6,000-year period it migrated roughly five miles eastward and lowered its channel about 100 feet. The dunes south of Hanford townsite then lie east of the probable course between North Richland and the Gable Mountain area as well as lower than the grade was then. Accordingly, the dunes were emplaced after the river reached its current course and altitude. Deflation of the valley to produce the dunes could have begun sometime earlier, however.

ARCHEOLOGICAL IMPLICATIONS

Recent and even historical cutting of Dry Creek canyon suggests that Rattlesnake Springs may have existed for only a hundred years or less. Its age lies between the age of the youngest ash bed, a maximum, and the age of the oldest trees at the Springs, a minimum. The Spring site thus cannot be considered to offer the potential of very old cultural materials or fossil mammal bones in amounts greater than those which probably occur throughout the ALE Reserve at sites only randomly occupied.

The old alluvial fan heading in Snively Canyon indicates that abundant water periodically flowed down the canyon toward Dry Creek. Its apparent sporadic flow in pre-Altithermal period times was greater than today; hence, the area probably was a somewhat unusual site for both plants and animals just as it is today.

The route over the Rattlesnake Hills from the current site of Rattlesnake Springs past Snively Ranch and to the crest of the Hills well could have been a favored route for early Americans. Its lower hill crest, gentler grade, abundant game and water and, following the Indians' adoption of the horse, better pasture than elsewhere on the Rattlesnake Hills indicate this. Geological evidence indicates that Rattlesnake Springs did not exist long ago, but the geological features that cause the spring to flow may well have formed a favorable path over the mountain. The general area may be one of the more favorable early archeological sites on the Hanford Project as indicated by Rice⁽³⁷⁾. Rice⁽³⁸⁾ also points out that the Horse Heaven Hills, by far most of which lie above the highest floods from glacial Lake Missoula, would have been a favored habitat of early man. In addition those Hills, providing easy access to the river waters, probably

were favored by the large grazing mammals found by Fry. The sites then could have been excellent hunting locales. The Rattlesnake Springs area and adjacent parts of ALE Reserve were comparable. Hence the older archeological materials can be expected above the 700 foot level of the long-standing basin fill and river level, with the oldest materials above the 900 to 1,200 foot altitudes.

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