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Holocene eolian modification of Pleistocene glacial outburst flood deposits on the Hanford Site, Washington

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ABSTRACT

Petrographic and geostatistical analysis of linear dune forms on the Hanford Site, south-central Washington, have resulted in data supporting reinterpretation of depositional environments from eolian to primary glaciofluvial with post-depositional eolian modification. Miocene basalt flows of the Columbia River Basalt Group form the bedrock across the region overlain by Pliocene fluvial deposits from the preglacial Columbia River. Between ~21,000 and 12,000 YBP, glacial outburst floods scoured eastern Washington forming the Channeled Scablands. In the Pasco Basin, floodwaters were ponded behind flow restrictions resulting in deposition of coarse-grained gravel and sand sheets capped by fine-grained cyclic Touchet beds in higher elevation peripheral canyons. Outflow of ponded water mobilized the upper few meters of sediment forming a series of giant current ripples or megaripples. Modification of the surfaces of the megaripples under the influence of the Holocene wind regime has produced an eolian surficial signature. Subsurface excavations in these dune forms revealed the primary glaciofluvial provenance. Sedimentologic and petrographic evidence supports a general winnowing of fine-grained sediments from west to east under the current wind regime and includes both quartz and heavy minerals. These processes have resulted in the formation of an active dune field along the western bank of the Columbia River that overlies flood deposits locally.

1. Introduction

The Hanford Site in south-central Washington State (Fig. 1) has been successfully transformed from a plutonium-generating site to an active nuclear waste repository (Gee et al., 2007; McKinley et al., 2007; DOE-RL, 2016; Energy.gov) and is one of the largest environmental cleanup sites in the United States. Part of the restoration included the Hanford Barriers Program (Cadwell et al., 1993) and was designed to reduce environmental and human risk from potential radionuclide contamination by isolating or permanently reducing toxicity, mobility, or volume of contaminants (DOE-RL, 1992). Barriers were to provide a stable designed surface that would function maintenance free in a semiarid to subhumid climate for ~1000 years with minimal erosion (water and wind) potential (DOE-RL, 2016).

This research was focused on determining provenance of the extensive active and inactive sand dunes that cover the site to aid in assessing surface stability and functionality for use in the Barriers Program. The research objective was to define provenance and observe trends in sediment mobility that could provide answers regarding uncertainty in future potential mobility pathways for contaminated sediment mobilized by wind.

Field and laboratory analysis utilized during the foregoing research has resulted in additional data supporting a glaciofluvial provenance for the surficial deposits that have been significantly modified by Holocene eolian processes. Sedimentologic lithofacies defined by Gaylord and Stetler (1994) are fully described and petrographically analyzed resulting in detailed evidence supporting a reinterpretation of provenance from eolian to primary glacio-fluvial.

2. Regional setting

The Hanford Site is located in the Pasco Basin, a structural and topographic basin within the Yakima Fold Belt (YFB) subprovince of the Columbia River Plateau Physiographic Province (Fig. 1) (Liverman, 1975; Kasper and Glantz, 1987; Ebinghaus et al., 2014). A series of WNW- to ESE-trending anticlinal ridges rising to 1200 m formed between 17 and 4 Ma (Plescia and Golombek, 1986) and define the northern (Saddle Mountains), western (Umtanum and Yakima Ridges), and southern (Rattlesnake Mountain) margins of the Pasco Basin (Liverman, 1975; Meyers et al., 1979; Tallman et al., 1981; Reidel, 1982; Plescia and Golombek, 1986; USDOE, 1986; Ebinghaus et al., 2014). These basalt ridges, except for Saddle Mountain, have their eastern termination at the western margin of the Hanford Site. To the east of the Columbia River, the boundary is formed by the Jackass Flats monocline and White Bluffs, a relatively low (300 m) region of rolling hills. Land caught

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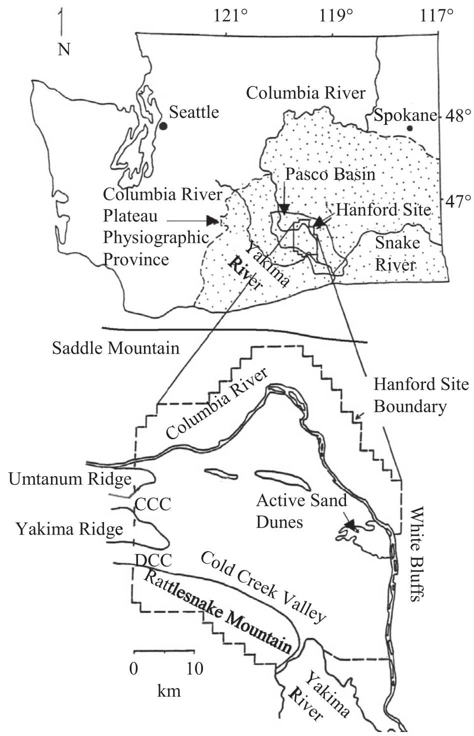

Fig. 1. Location map for the Hanford Site showing major geomorphic features of central and eastern Washington State. All mountains and ridges in the inset map consist of Columbia River Basalt Group rocks.

Epoch	Ma	Formation/Group		Stratigraphy
Holocene	0.01	Surficial Deposits		Alluvial & Eolian Deposits
Pleistocene	2.6	Hanford Formation (Glacio-Fluvial)		Touchet Beds / Pasco Gravels
Pliocene		Ringold Formation (Fluvial/Alluvial)	Upper	Sandstones & Siltstones
			Middle	Conglomerates
	5.3		Lower	Blue-Green Silts
Miocene	5.5	Columbia River Basalt Group	Saddle Mts Basalt	Tholeiitic Basalt Flows Intercalated with Sedimentary & Volcaniclastic Interbeds (Ellensburg Formation)
	14.0		Wanapum Basalt	
	15.6		Grande Ronde Basalt	
	16		Imnaha & Steens Basalt	
	16.7			

Fig. 2. Stratigraphic column for bedrock and overlying fluvial and glaciofluvial deposits for the central Pasco Basin.

between the deforming basalt ridges on the west and the monocline on the east slowly subsided over the period of basalt emplacement forming the structural low that presently defines the site.

The Hanford Site, located in the center of the Pasco Basin, is dominated topographically by Rattlesnake Mountain in the west-southwest and the Yakima and Umtanum Ridges in the northwest. Broad, low-lying (~150 m) synclinal valleys (Cold Creek Canyon, CCC, and Dry Creek Canyon, DCC) between the prominent ridges form major drainages leading into the center of the site, which is generally flat, river terrace topology. To the east, the White Bluffs rise 100 m above the Columbia River. Local relief is ~1000 m ranging from 1100 m on Rattlesnake Mountain to 122 m in the basin center. Two major rivers flow through the site, the larger southward-flowing Columbia River (northern and eastern boundary) and the eastward flowing Yakima River (southern boundary).

Stratigraphy of the central Pasco Basin (Hanford Site) is dominated by Miocene and younger units and in ascending order are: Miocene Columbia River Basalt Group (CRBG), classified as a large igneous province (Ebinghaus et al., 2014), Pliocene Ringold Formation, Pleistocene Hanford Formation, and Holocene alluvial and eolian sedimentary units (Fig. 2).

Contemporaneous volcanism in the Cascade Range accompanied by north-south tectonic compression produced continuous deformation of the CRBG Ma that formed the anticlinal ridges across the Columbia Plateau (Plescia and Golombek, 1986). These ridges controlled later depositional processes and the development of Pleistocene glaciofluvial forms.

Pleistocene Wisconsin glacial outburst flooding on the Columbia Plateau correlates to marine Oxygen Isotope Stages (OIS) 4 (~71–61 ka) and 2 (~25–11 ka). These OIS occurred during low stands of sea level that were 80 and 120 m below present respectively and represent advances of the Cordilleran ice sheet. The early Wisconsin floods (OIS 4) scoured into preexisting sediments resulting in glaciofluvial gravel deposits and associated fine-grained slackwater deposits. These slackwater deposits were subsequently winnowed by a wind transport regime, similar to that operating today, to produce thick eolian loess deposits extending across the Columbia Plateau (McDonald et al., 2012). During late Wisconsin glaciation (OIS 2), ~100 catastrophic floods resulting from a series of ice dam failures in western Montana and northern Idaho (Missoula Floods) ravaged the region and scoured eastern Washington, including the Pasco Basin (Bretz, 1923, 1969; Pardee, 1942; Waitt Jr., 1980, 1985; Clague et al., 2003; Lopes and Mix, 2009; Hanson et al., 2012). At least two of the floods were gigantic by any measure in that ~2085 km^3 of water flowed across the Columbia Plateau at rates between 37.5 and 62.5 km^3/h (Baker, 1973). The first of these megafloods occurred ~18,000 YBP and scoured most of the scabland topography during a period of a few days (Bretz, 1969). Simultaneously, several large channels were incised into the underlying Ringold Formation across the Pasco Basin (R.E. Brown, 1960b; Liverman, 1975). Similar channeling took place during the second megaflood, which occurred ~12,000 YBP (Brown, 1970; Mullineaux et al., 1977). Aggradation of sediment throughout the time of glacial outburst flooding (>18,000–12,000 YBP) occurred in primary braided channels, on surrounding braided terraces, and on higher elevation slopes and peripheral canyons resulting in the deposits of the Hanford Formation.

Two time-correlative and interfingering depositional facies have been recognized: the Pasco gravels (Brown, 1975) and Touchet beds (Flint, 1938; D.J. Brown, 1960a). Total thickness of the Hanford Formation approaches 120 m (Liverman, 1975). Both facies grade vertically and horizontally, reflecting a decrease in flow energy as they were deposited.

The Pasco gravels (Fig. 3) occupy the northern and central basin (including the Hanford Site) and consist of between 30 and 60 m of quartzo-feldspathic and volcanic boulder and cobble conglomerates interbedded in a coarse-grained glaciofluvial gravel and sand matrix (Brown, 1975; Meyers et al., 1979; RHO, 1979).

Touchet beds interfinger with the Pasco gravels in basin-marginal canyons and toward higher elevation slopes (Flint, 1938; Meyers et al., 1979). Touchet beds consist of up to 7+ m thick, sand- to silt-rich cyclic varve-like sequences of distinctly thin-bedded quartz- to basalt-rich detritus (Fig. 4). Sedimentary structures range from horizontal- to cross-laminations and climbing ripples. Depositional sequences record upslope followed by downslope current action (Brown, 1970). Deposition was mainly from slackwater processes resulting from ponded floodwater that developed behind hydraulic dams (Bretz, 1969; Brown, 1970; Waitt Jr., 1980, 1985).