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The Moxee City (Washington) mammoth: Morphostratigraphic, taphonomic, and taxonomic considerations

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THE MOXEE CITY (WASHINGTON) MAMMOTH: MORPHOSTRATIGRAPHIC, TAPHONOMIC, AND TAXONOMIC CONSIDERATIONS

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ABSTRACT.—A nearly complete, but highly fractured, proboscidean tusk was unearthed during parking lot construction near Moxee City in central Washington in May 2001. Schreger angle analysis revealed that the tusk was from a mammoth. AMS radiocarbon dating of the tusk established that the mammoth died 14,570 ^{14}C yr BP. The age, combined with the biogeography of proboscidean finds in the Pacific Northwest, suggests the tusk is from a Columbian mammoth (*Mammuthus columbi*). The condition of the tusk and its association with basalt and crystalline erratics suggest that a locally derived tusk was swept up in the advancing flood and transported to ~320 m elevation, where it was deposited in the sediments of the 3rd of 3 Missoula Floods that are preserved in the area. The tusk's weathering indicates subaerial exposure prior to burial in the slackwater sediments. Slackwater deposits at the site are pale, ~30–100 cm thick, calcareous, fine-textured strata that include occasional coarse basalt and crystalline sand and gravel. They are intruded by numerous clastic dikes. The sediments encapsulating the tusk lack rhythmites because of their deposition in the nearshore zone of an ephemeral slackwater lake. The first 2 floods inundated the site between 15,300 ^{14}C yr BP and 14,570 ^{14}C yr BP, stripping the A horizon from a well-developed soil formed in alluvial fan sediments sitting above an Ellensburg Formation pediment. The last flood to reach the site occurred later than 14,570 ^{14}C yr BP, as indicated by the presence of the dated tusk. Post-flood and post-MSH S tephra loess derived from the Yakima River floodplain mantles these slackwater deposits. The Warden soil is forming in the now-stable loess parent material.

Key words: Columbian mammoths, Yakima River valley, Missoula Floods, slackwater deposits.

Five members of the elephant family roamed North America during the Quaternary—*Mammuthus meridionalis* (southern mammoth) in the early Pleistocene; *Mammuthus imperator* (imperial mammoth) in the middle Pleistocene; and *Mammuthus columbi* (Columbian mammoth), *Mammuthus primigenius* (woolly mammoth), and *Mammuthus exilis* (dwarf mammoth) during the late Pleistocene (Maglio 1973, Graham 1986, Lister and Bahn 1994, Roth 1996). Mammoth remains are found throughout western North America in areas that were predominantly Pleistocene parkland or grassland, ranging from northern Alaska to southern Mexico (Lister and Bahn 1994).

Most mammoth remains found in Washington State that are identifiable to species are from Columbian mammoths and consist of single elements, typically a molar or tusk (Barton 1998, 1999). Less common are sites with multiple associated skeletal elements. In eastern Washington most mammoth sites are found within Missoula Flood slackwater deposits south of Cordilleran ice sheet end moraines (Barton 1999; Fig. 1). During the late Pleistocene these mammoths inhabited low parklands and grasslands of the Columbia Plateau, feeding on grasses and herbaceous plants (Barton 1998).

Glacial Lake Missoula floodwater surges across Idaho, Washington, and Oregon occurred from after 19,000 ^{14}C yr BP until after 12,700 ^{14}C yr BP (Waitt 1985, Benito and O'Conner 2003). These floods were temporarily ponded in tributary valleys as they encountered hydraulic constrictions. Wallula Gap, one such constriction (Fig. 1), caused backflooding of the Walla Walla, Snake, Yakima, and Columbia River valleys (Symons 1882, Russell 1893, Bretz 1919). Backfloods up the tributary valleys carried loads of silt, sand, and ice-rafted basalt and crystalline boulders (Bretz 1969). The resulting slackwater deposits were termed the "Touchet Beds" after the type locality in the Walla Walla River valley (Flint 1938; Fig. 1). These slackwater deposits are massive to rhythmically laminated, typically upward fining beds

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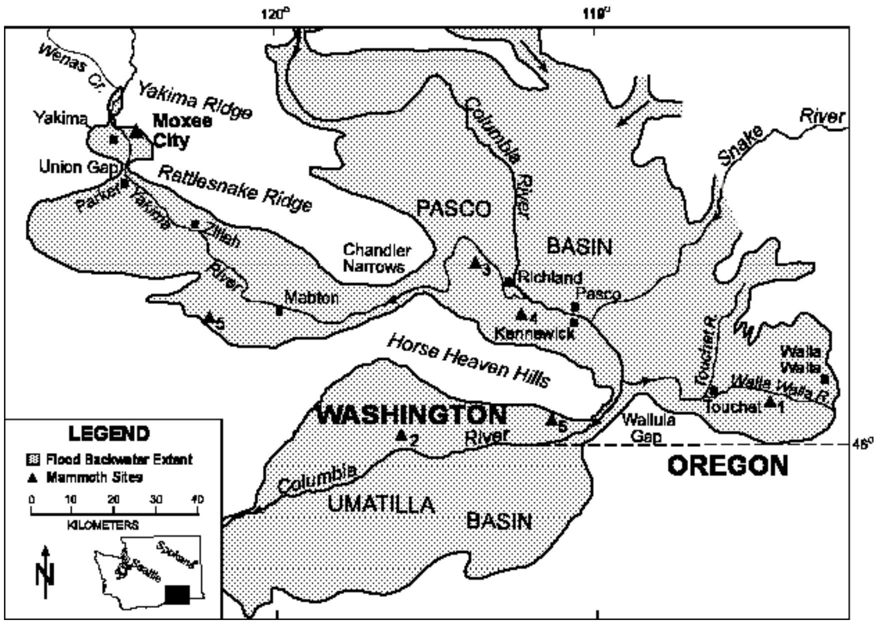

Fig. 1. Extent of Missoula Flood backwater flooding to 350 m elevation in south central Washington (adapted from Waitt 1980). Mammoth sites include (1) Walla Walla/Gardena, *Mammuthus columbi* (Scott and Clem 1967); (2) Artesian Coulee/Dead Canyon, *Mammuthus* spp. (Newcomb and Repenning 1970); (3) west Richland, *Mammuthus* spp. (Waitt 1980, Martin et al. 1982); (4) western Pasco Basin, *Mammuthus* spp. (Waitt 1980); (5) Yakima Valley, *Mammuthus* spp. (Waitt 1980); and (6) Umatilla, *Mammuthus* spp. (Gilbow 1981).

of silt and sand (Flint 1938, Carson et al. 1978). Bedding commonly encloses the 13,000 ^{14}C yr BP Mount St. Helens (MSH) S tephra couplet (Mullineaux et al. 1978, Waitt 1980). Grain size and deposit thickness of these beds decrease upvalley in the tributaries (Bretz 1928). Erratics, as well as folds, faults, and clastic dikes, are common in the strata (Flint 1938).

In May 2001 parking lot construction uncovered a nearly complete, but highly fractured, tusk (Fig. 2) near Moxee City in the middle Yakima River valley of central Washington State (Figs. 1, 3). Initial excavation revealed the tusk of a proboscidean, presumably that of a Columbian mammoth (*Mammuthus* cf. *columbi;* Greg McDonald, National Park Service, written communication, November 2002), encased within generally fine-grained sediments. Subsequent excavation disclosed more detail on the site's stratigraphy and geomorphology than was originally ascertained. The purpose of this study was to (1) identify the tusk and briefly discuss its taphonomy and (2) place this tusk in local and regional morphostratigraphic contexts.

STUDY SITE

The site is located in the Moxee Valley about 6 km southeast of Yakima and 1 km northwest of Moxee City (Fig. 1). The tusk was found at about 320 m elevation, approximately 24 m above and 5 km east of the Yakima River on the southwest-facing footslope of a southwest-trending hill (Fig. 3). The broad Moxee Valley is bounded by Yakima Ridge and the Rattlesnake Hills. A mid-latitude, continental, semiarid climate consisting of cool, moist winters and hot, dry summers characterizes the setting. Today, deep and well-drained soils are found in lower portions of the Moxee Valley (Lenfesty and Reedy 1985). Irrigated fruit orchards, hop fields, hayfields, and associated farmsteads dominate land use of the valley. Historical air photos reveal that the study site was irrigated and farmed prior to being converted to a parking lot in 2001.

METHODS

We examined the site and surrounding area between July 2001 and July 2002. The stratigraphy of the west face of a 5-m-long trench

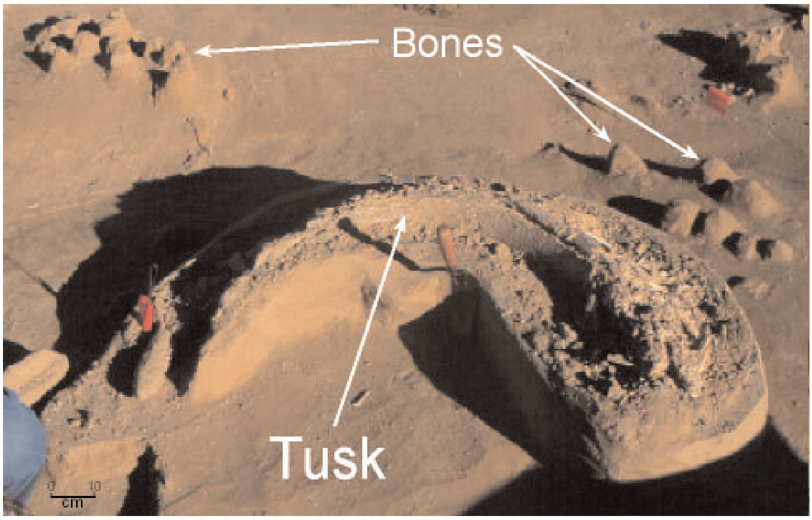

Fig. 2. The Moxee City Mammoth tusk and associated bones in situ in the Alexandria Moulding, Inc., parking lot, near Moxee City, Washington. Note taxonomically unrecognizable bone remnants adjacent to the tusk (see arrows).

adjacent to the tusk was described after establishing a 25 × 25-cm grid network from a level line datum. Sedimentary structures, bone, gravel, and unit boundaries were assessed within each grid square. Samples were taken from the trench wall at 10-cm intervals. Stratigraphy was also described on the north face of a 3-m-long trench adjacent to the tusk. The west face of the parking lot excavation was described and sampled unit by unit. Stratigraphic units across the study area were geometrically correlated using a geodetic total station. We assessed sediment colors with a Munsell Soil Color Chart, texture following Gee and Bauder (1979), and general calcium carbonate content of these samples via reaction with hydrochloric acid to discern different stratigraphic units and structures. The geomorphology of the area was analyzed on topographic maps, on air photo stereopairs, and in the field.

We examined exposed sections of the plaster-jacketed tusk at the Yakima Valley Museum in December 2002 and June 2003. Using metric tapes and forestry calipers, we measured tusk length, basal diameter, and overall curvature. We then compared these data with detailed field drawings from the tusk excavation. We analyzed Schreger angles on a large, unattached portion of the tusk in June 2003 following the methods of Espinoza and Mann (1991). Schreger angles form at the intersection of dextral and sinistral arching lines that radiate outward from the central axis of the tusk. These lines and their resultant angles and patterning are unique to proboscidean dentine. The range of angles produced in the tusks of any given genus of proboscidean (e.g., *Elephas*) is probably unique to that genus, although the ranges of such angles in various proboscidean genera often show considerable overlap with other members of the order. Fortunately, the overlap in the range of these angles for North American mammoths (*Mammuthus* spp.) and American mastodons (*Mammut americanum*) is minimal (Fisher et al. 1998, Barton and Kester 2001, Trapani and Fisher 2003). This allows suitably dated and preserved tusks from North America to be assigned to a genus with some confidence.

RESULTS

Tusk

The Moxee City mammoth find consists of a single, relatively complete proboscidean tusk and numerous small, nearby bone fragments. The tusk is a right tusk measuring 210 cm in length along its outer curve, with a chord length of 120 cm measured directly from the base to the tip. The basal portion of the tusk is heavily damaged, but a partial profile of the remaining section suggests a basal diameter of approximately 15 cm, with a reconstructed basal circumference of 45 ± 3 cm. The basal

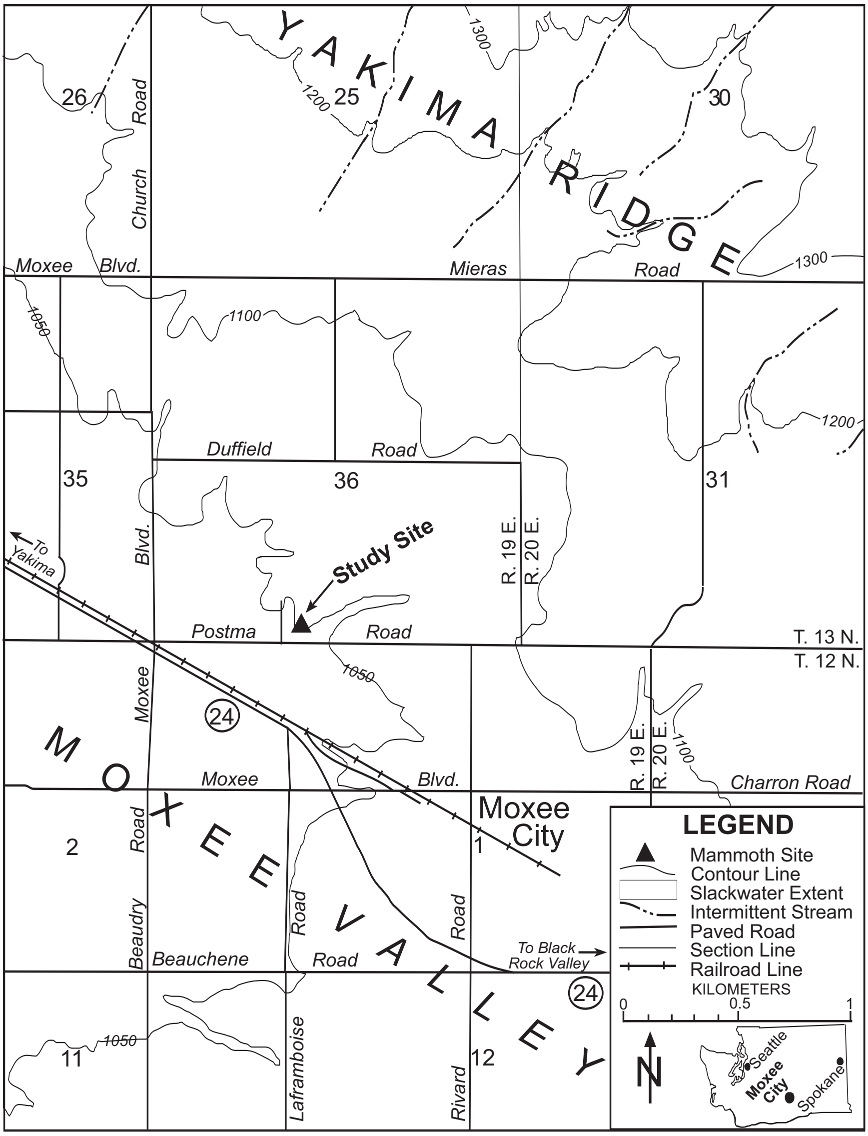

Fig. 3. Moxee City Mammoth site, Moxee Valley, Washington (adapted from the Yakima East, Washington 7.5′ U.S. Geological Survey quadrangle). Note upper extent of Touchet Beds at 320 m (1050 feet) as identified by Bentley et al. (1993).

diameter was calculated by fitting a circumference to a traced curved section of the tusk, which was then compared with field drawings from the excavation. One hundred eight Schreger angles measured on the polished section of the tusk range from 55° to 94°, with a mean of 78°. Multiple transverse and longitudinal cracks and areas of exfoliation are present on the proximal 180 cm of the tusk. Cracks and exfoliated patches are edge rounded and filled with sediment. The distal 30 cm of tusk, including the tip, shows little evidence of such alteration. Multiple recent transverse/radial compression fractures divided the tusk laterally into segments, many of which broke into individual fragments that were scattered around the tusk at the site.

Site Stratigraphy

We identified 5 stratigraphic units in the trenches immediately east and north of the mammoth tusk and in the wall of the parking

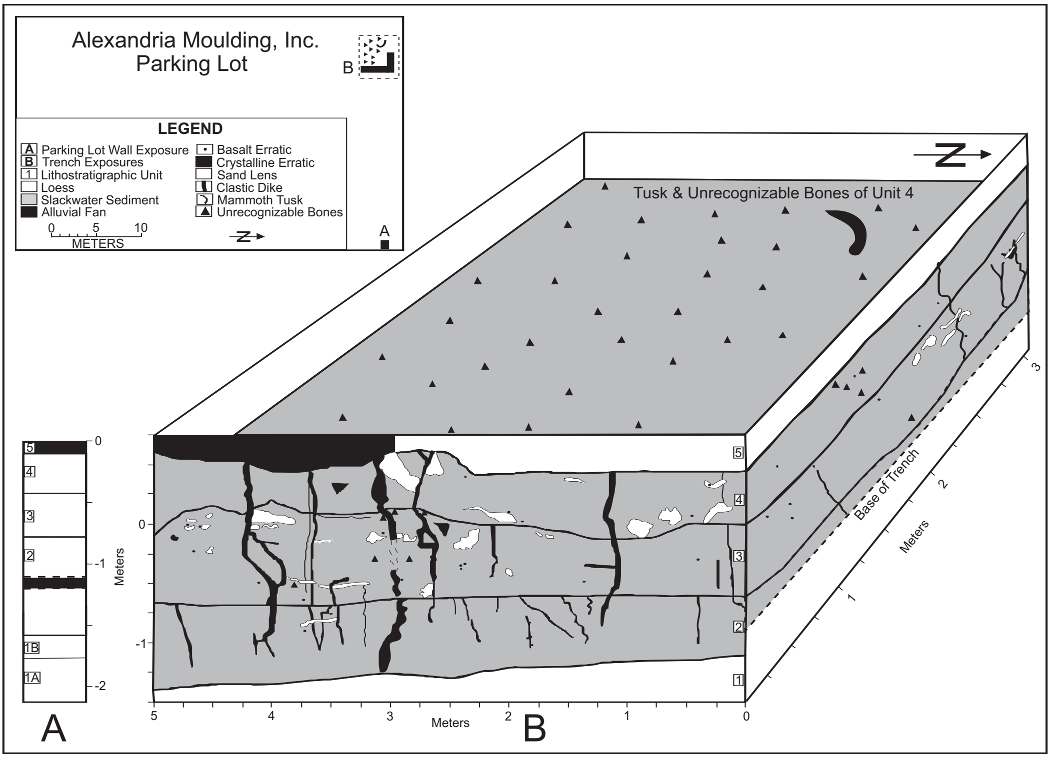

Fig. 4. Detailed stratigraphy of wall of the parking lot excavation ~50 m east of the trench (A) and trenches immediately east and north of mammoth tusk (B), Moxee City Mammoth site. Note the inset map showing locations of measured sections. Also note the position of tusk in Unit 4 relative to bones in Units 3 and 4.

lot excavation ~50 m east of the trench. The tusk was located in the 4th unit from the bottom (Unit 4).

UNIT 1.—The lowest deposit, Unit 1, consists of poorly sorted, nonstratified, round to subangular basalt pebbles and cobbles in a clay to sandy loam matrix (Fig. 4; Tables 1, 2). The >40-cm-thick unit exposed in the wall of the parking lot excavation is composed of 2 subunits: 1A and 1B. The lower subunit, 1A, is a gravelly, sandy loam cemented and indurated by calcium carbonate. Unit 1B, a gravelly clay, displays a medium prismatic pedogenic structure and clay skins on ped faces. Basalt gravels in both subunits are generally unweathered.

UNIT 2.—Unit 2 unconformably overlies Unit 1, with a gently undulating lower boundary. This light gray unit ranges from 50 cm to 100 cm in thickness, includes a range of textures, and is intruded by clastic dikes (Fig. 4; Tables 1, 2). Textures include sandy loam, loam, and silt loam. This unit lacks grading and stratification. However, a 10-cm-thick lens of round to subangular basalt and assorted crystalline pebbles mixed with coarse sand is present in the wall of the parking lot excavation. This lens occurs approximately midway in the unit. Clastic dikes are 3–60 mm wide, straight to sinuous to branching, and sandy loam to silt loam in texture, and they commonly display vertical stratification parallel to their walls. They are often lighter or darker than the surrounding deposits. Some clastic dikes truncate abruptly at the upper boundary of Unit 2 while others continue upward into Unit 3.

UNIT 3.—Unit 3 is conformably separated from Unit 2 by a gradational, gently undulating contact. This unit ranges from 40 cm to 70 cm in thickness and is characterized by a silt loam texture (Fig. 4; Tables 1, 2). Like Unit 2, this unit lacks grading and stratification. Basalt pebbles and irregularly shaped sand lenses are scattered throughout this light gray unit. Clastic dikes also dissect the unit but are less numerous than those in Unit 2. As in Unit 2, several of the clastic dikes end at the top of the unit while

TABLE 1. Characteristics of sediment exposed in trench immediately east of tusk, Moxee City mammoth site.

Unit	Sample depth (cm)	Texture	Color	React w/ HCl	Clastic dike	Sand lens	Gravel	Bone
5	+70	clay loam	5Y 7/2 (light gray)	yes	no	no	no	no
4	+60	silt loam	2.5Y 7/2 (lt. gray)	yes				
4	+50	silt loam	2.5Y 7/2 (lt. gray)	yes				
4	+40	silt loam	2.5Y 7/2 (lt. gray)	yes	yes	yes	yes	no
4	+30	silty clay	2.5Y 7/2 (lt. gray)	yes				
4	+20	silt loam	2.5Y 7/2 (lt. gray)	yes				
3	+10	silt loam	2.5Y 7/2 (lt. gray)	yes				
3	0	silt loam	2.5Y 7/2 (lt. gray)	yes				
3	–10	silt loam	2.5Y 7/2 (lt. gray)	yes				
3	–20	silt loam	2.5Y 7/2 (lt. gray)	yes	yes	yes	yes	yes
3	–30	silt loam	2.5Y 7/2 (lt. gray)	yes				
3	–40	silt loam	2.5Y 7/2 (lt. gray)	yes				
3	–50	silt loam	2.5Y 7/2 (lt. gray)	yes				
2	–60	silt loam	2.5Y 7/2 (lt. gray)	yes				
2	–70	loam	2.5Y 7/2 (lt. gray)	yes				
2	–80	silt loam	2.5Y 7/2 (lt. gray)	yes				
2	–90	silt loam	2.5Y 7/2 (lt. gray)	yes	yes	yes	yes	no
2	–100	silt loam	2.5Y 7/2 (lt. gray)	no				
2	–110	loam	2.5Y 7/2 (lt. gray)	no				
2	–120	sand loam	2.5Y 7/2 (lt. gray)	no				
1	–130	sand loam	2.5Y 7/3 (pale yellow)	yes	no	no	no	no

TABLE 2. Characteristics of sediments exposed in wall of parking lot excavation ~50 m east of trench, Moxee City Mammoth site.

Unit	Unit depth (cm)	Texture	Color	React w/HCl	Clastic dike	Sand lens	Gravel	Bone
5	0–10	silt loam	2.5Y 7/2 (light gray)	yes	no	no	no	no
4	10–44	silt loam	2.5Y 7/2 (light gray)	yes	no	no	no	no
3	44–76	silt loam	5Y 7/2 (light gray)	yes	no	no	no	no
2	76–158	silt to silty clay loam	2.5Y 6/3 (light yellowish brown) to 2.5Y 7/2 (light gray)	yes	yes	no	yes	no
1B	158–178	clay	10 YR 5/3 (brown)	yes	no	no	no	no
1A	178–>200	sandy loam	10YR 8/2 (very pale brown)	yes	no	no	no	no

others extend into Unit 4. Dike widths, composition, stratification, and texture are similar to those of Unit 2. Highly decomposed and taxonomically undiagnostic <4-cm-diameter bone remnants (Andrew Granitto and Michael Siebol, Yakima Valley Museum, written communication, June 2002) appear as resistant knobs exposed on the trench walls in this unit.

UNIT 4.—Unit 4 is conformably separated from Unit 3 by a gradational, moderately undulating contact. This unit, like Units 2 and 3, consists primarily of silt loam and lacks grading and stratification (Fig. 4; Tables 1, 2). It ranges from 30 cm to 70 cm in thickness and includes scattered basalt gravels and numerous irregularly shaped sand lenses. Unit 4 includes fewer clastic dikes and gravels than Unit 3. The tusk was located near the base of this unit. An AMS radiocarbon date on tusk collagen indicated that the Columbian mammoth died 14,570 ± 50 ^{14}C yr BP (CAMS 79942; Granitto and Siebol, written communication, January 2002). Like Unit 3, numerous taxonomically unrecognizable, small bone remnants were observed in Unit 4.

UNIT 5.—Unit 5 unconformably overlies Unit 4 along a gradational, gently undulating contact. This unit ranges from 10 cm to 50 cm thick. While the light gray color and clay loam/silt loam texture are similar to underlying units (Fig. 4; Tables 1, 2), this stratum lacks clastic dikes, irregularly shaped sand lenses, erratics, bone remnants, and tusk.

DISCUSSION

Mammoth

TAXONOMY.—Fisher et al. (1998:106) measured Schreger angles on 82 prehistoric proboscidean tusks—38 American mastodon tusks and 44 mammoth tusks of various species (including *Mammuthus primigenius* and *M. columbi*). All were tusks "independently identified by dental or skeletal evidence." They found that mastodon Schreger angle values, with a mean of 124.7° and a range of 113°–149°, "differed significantly ($P < 0.001$) from mammoth values" with a mean of 87.1° and a range of 62°–105°. Our examination indicates that the 78° mean and the 94° upper range values for Schreger angles on the Moxee City tusk are well below those reported for American mastodons. Instead, they fit well into the range of previously reported results for mammoths (Fisher et al. 1998). Based on these results, and lacking any mitigating or conflicting data, the Moxee City tusk is herein assigned to the genus *Mammuthus.*

The only evidence that may be used to assign the mammoth tusk to species is circumstantial. Columbian mammoth and American mastodon have been reported from Pacific Northwest sites during the period coincident with the latest Missoula floods. Currently, no reliably documented evidence exists for other late Pleistocene mammoths (specifically woolly mammoths), or for other Proboscidea, such as gomphotheres (Barton 1999), in the Pacific Northwest. Further, the absence of an enamel band on the tusk precludes a gomphothere diagnosis. Given the Schreger angle analysis indicating the genus of the tusk, and its 14,570 ^{14}C yr BP AMS date, we conclude that the tusk is most likely from a Columbian mammoth. The length and girth of the Moxee City tusk are analogous to those of an African elephant (*Loxodonta africana*) tusk of at least 15 ± 3 years of age, a late subadult or early prime adult life stage (Sikes 1971, Lister and Bahn 1994).

TAPHONOMY.—Surface features on the tusk reveal direct evidence of at least 2 taphonomic events. The multiple transverse and longitudinal cracks and areas of exfoliation suggest a bone weathered to taphonomic weathering stage 2 or 3 (on a scale of 1–5; Behrensmeyer 1978, Lyman 1994). This weathering indicates initial exposure, hence weathering, of the tusk following the death of the mammoth. Cracks with well-rounded edges, filled cracks, and exfoliated patches on the proximal end also suggest that the tusk was initially exposed and weathered prior to burial. However, the lack of similar weathering on the distal portion of the tusk indicates that the tip was not exposed to the same degree of weathering as the rest of the tusk. All of this suggests initial partial burial of the tusk on a pre-flood landscape prior to its entrainment and final deposition within Unit 4 sediments.

The multiple fresh transverse/radial compression fractures on the tusk's uppermost surface likely occurred during construction excavation of the site. Additional torsional cracking was caused by exposure and desiccation of the tusk after discovery.

Morphostratigraphic Context of the Tusk

The tusk is part of a dynamic morphostratigraphic environment that has been impacted over the past 10 million years by (1) tectonic- and climate-driven fluvial erosion and deposition, (2) pedogenic development, (3) slackwater deposition, (4) eolian deflation, and (5) loess deposition (Fig. 5).

EROSION AND DEPOSITION.—Folding and faulting of the Columbia River Basalt Group (CRBG) and associated interbeds (e.g., Ellensburg Formation) resulted in the formation of Yakima Ridge, Moxee Valley, and Rattlesnake Hills after deposition of the Saddle Mountains Basalts $<$10.4 million yr BP (Reidel et al. 1994). The uplift of Yakima Ridge relative to the Moxee Valley enhanced sheetflow and stream erosion of the Ellensburg Formation in the Pliocene and early Pleistocene (Fig. 5A). Ultimately, sheetflow and stream erosion stripped much of the Ellensburg Formation on Yakima Ridge, thus creating valleys between basinward sloping, stepped, erosional remnant (i.e., pediments) ridges and hills (Fig. 5B; Waters 1955). Mapped outcrops of Ellensburg Formation pediment project stratigraphically and topographically from the south flank of Yakima Ridge (Campbell 1979, Bentley et al. 1993, Schuster 1994)

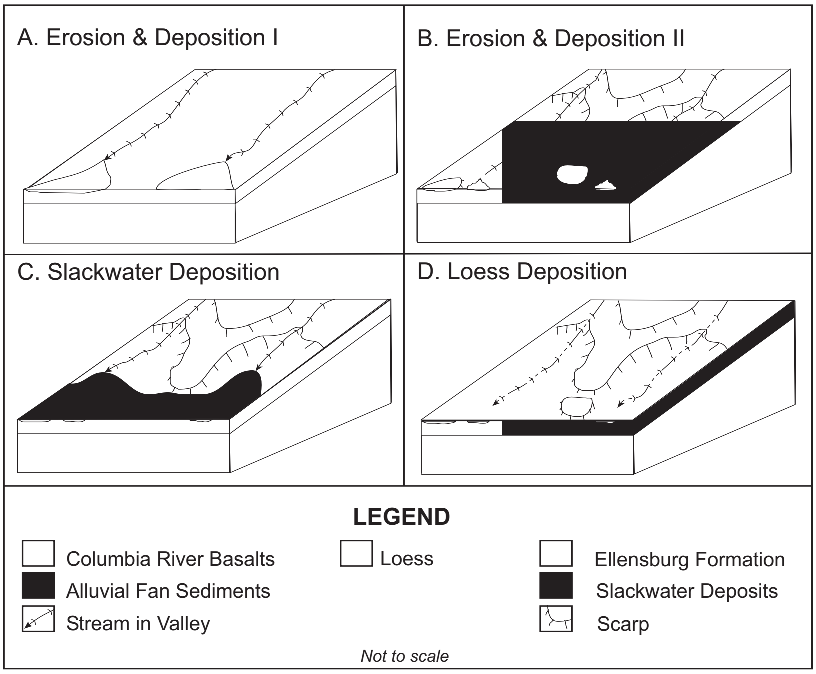

Fig. 5. Morphostratigraphic context and landscape evolution of the Moxee City Mammoth site and surrounding environs.

1.5 km downslope to the hill on which the tusk was located (Fig. 3).

As incision continued, alluvial fans composed of CRBG gravels were deposited on the footslopes and toeslopes of Yakima Ridge, often burying portions of the Ellensburg Formation pediment (Fig. 5B). An alluvial fan origin for the sediments draped over the pediment remnant hill is supported by the deposit's breadth (>50 m), slope (dipping to the south and west), and footslope location and the presence of generally subangular to subrounded basalt clasts seen in Unit 1. This fan originated near the terminus of a stream flowing from Yakima Ridge.

LANDSCAPE STABILITY I.—The indurated and laminated, carbonate-rich subunit 1A soil Bkm horizon and the clay-rich subunit 1B soil Bt horizon of the alluvial fan deposits of the parking lot excavation (Fig. 4) indicate (1) a setting that was sufficiently stable for a soil to develop following the erosional/depositional episodes and (2) that this period of pedogenesis occurred over a significant time period. The Bkm horizon displays indurated and laminated stage IV (on a scale of I–VI) soil carbonate development similar to that of the Table Grounds surface in the Beaver, Utah, area that has been dated as early to middle Pleistocene (Machette 1985). The similarity of the Beaver climate to that of the middle Yakima River valley suggests that the Moxee City Bkm horizon represents a soil that began to form at least several hundred thousand years ago.

MISSOULA FLOOD SLACKWATER DEPOSITION.—The initial pulse of slackwater flow stripped the A horizon from the well-developed Unit 1 soil, thus ending the lengthy period of landscape stability. The 3 floods recorded at the site resulted in the deposition of slackwater strata (Units 2, 3, and 4) to an elevation of ~320 m in Moxee Valley (Figs. 3, 5C). The lack of rhythmites at the mammoth site, compared to nearby Union Gap (Allison 1933), Zillah, and Mabton (Waitt 1980; Fig. 1), is due to (1) relatively few floods reaching the middle Yakima River valley (Waitt 1980) and (2) its high-energy, nearshore location, which provided a poor sorting environment for fine-grained sediments when the temporary slackwater lakes were present in the middle Yakima River valley.

Clastic dikes are present in each of the 3 Missoula Flood slackwater units. The cross-sectional and planimetric characteristics of the dikes generally match previous descriptions by Jenkins (1925), Flint (1938), Lupher (1944), Alwin (1970), and Black (1979). Clastic dikes confined to Units 2 and 3 suggest formation during or soon after the deposition of each of these units, and before the deposition of subsequent units. Conversely, clastic dikes that extend across 1 or 2 unit boundaries may have formed (1) during or following the deposition of subsequent units or (2) by reactivation of dikes in lower units during or following deposition of subsequent slackwater sediments. Clastic dikes at the site did not extend into the Unit 5 loess, suggesting that the process(es) creating the dikes ended before deposition of loess.

Individual gravel clasts, gravel lenses, and sand lenses within Units 2, 3, and 4 were deposited when sediment-laden icebergs grounded on the slackwater lake margin. These gravel and sand lenses are similar to clusters of sand- to boulder-sized ice-rafted erratics found elsewhere in Yakima River valley slackwater deposits (Russell 1893, Smith 1903, Bretz 1930, Allison 1933, Flint 1938). The mixed-clast lithologies noted at the site are consistent with those identified by Waitt (1980), who attributed CRBG gravels to the Okanogan lobe and crystalline rocks to the Pend Oreille lobe of the Cordilleran ice sheet.

The relationship of the taxonomically undiagnostic, small bone remnants of Unit 3 to similar bones and tusk of Unit 4 (Fig. 4) is problematic. Barring further information about the bone remnants of each unit, we assume that they are unrelated to each other or to the tusk. The total inclusion of the tusk within Unit 4, combined with taphonomic information suggesting earlier partial weathering of the tusk and its association with mixed-lithology sand and gravel, suggests that the mammoth died away from the site and below 320 m elevation. Following death, the tip of the mammoth's right tusk was partially buried, exposing the remaining portion to weathering. Subsequently, the tusk and surrounding sediments were entrained in and ultimately redeposited by the last of 3 Missoula Floods to surge up the Yakima Valley to an elevation of ~320 m. The scope of the study did not permit the determination of the geographic origin of the tusk or the associated basalt and crystalline rocks; however, the overall condition of the tusk suggests a local origin (perhaps the lower Yakima River valley?) and rather limited exposure to the turbulence of the flood. The crystalline rocks may have originated as primary clasts as near as north central Washington. Alternatively, the tusk and erratics could have been entrained quite close to the site, having been picked up from previously flooded surfaces. The moderately undulating boundary separating Unit 3 from Unit 4 may reflect the melting of an ice-raft and subsequent deformation of the bed.

The presence of the 13,000 ^{14}C yr BP Mount St. Helens (MSH) S tephra couplet (Mullineaux et al. 1978, Waitt 1980) at the Moxee Drain southwest of the study area (Campbell and Reidel 1999), as well as its known trajectory from Mount St. Helens to the Spokane area (Stradling and Kiver 1986), suggests that this tephra was initially deposited at the site but was subsequently eroded by fluvial or eolian action. Given its absence from the mammoth site, the timing of middle Yakima River valley slackwater flooding can be best determined by the position of the 14,570 ± 50 ^{14}C yr BP tusk within the slackwater deposits. Accepting Benito and O'Conner's (2003) post-19,000 ^{14}C yr BP date for the initiation of late Pleistocene Missoula Floods suggests that the first 2 Missoula Flood strata (Units 2 and 3) were deposited at the site later than 19,000 ^{14}C yr BP and prior to 14,570 ^{14}C yr BP. The tusk age and degree of weathering suggest that the subsequent slackwater stratum (Unit 4) was deposited soon after 14,570 ^{14}C yr BP. The AMS date, combined with few slackwater deposits at the site, supports Waitt's (1980) assertion that earlier Missoula Floods were larger than subsequent floods, and that later Missoula Flood slackwaters generally did not flow as far upstream as the Moxee City Mammoth site.

LOESS DEPOSITION.—The Unit 5 loess has a clay loam and silt loam texture and lacks erratic sands, gravels, and clastic dikes. Late Pleistocene (<13,000 ^{14}C yr BP) and Holocene winds likely deflated nearby poorly vegetated portions of the Yakima River floodplain, transported these sediments downwind, and deposited them as the Unit 5 loess atop the older slackwater deposits (Fig. 5D). Loess thicknesses vary because of landscape position. Unit thickness may have been 50 cm at the footslope position of the tusk. The heavy equipment operator who discovered the tusk removed

~1.30 m of combined overburden (Unit 5 and much of Unit 4) before encountering the tusk (Granitto and Siebol, written communication, June 2002). Conversely, only ~10 cm of loess is present in the excavation of the shoulder slope of the wall of the parking lot. The loess of the site likely corresponds to the post-MSH S tephra, L1 loess identified by Busacca and McDonald (1994). With slackwater deposits and a presumably sediment-charged Yakima River located upwind on the nearby floodplain, it is surprising that the L1 loess at the site is so thin compared with >400 cm loess accumulations at locations northeast of the Pasco Basin. Busacca and McDonald (1994) attribute these thickness differences to the poor potential for loess preservation on steep anticlinal slopes due to water erosion. The relatively thin loess combined with the site's location at the base of Yakima Ridge suggests that the upwind source areas for the loess may have been more spatially limited and/or deficient in deflatable sediments than originally thought.

LANDSCAPE STABILITY II.—The Warden soil formed in the Missoula Flood slackwater deposits and the overlying loess mantle (Lenfesty and Reedy 1985) during the Holocene. This Xerollic Camborthid reflects the relatively short pedogenic development time since loess deposition and the semiarid climate of the Moxee Valley. The position of the site above the Yakima River floodplain and away from any present-day streams draining Yakima Ridge has enhanced site stability. However, irrigated agriculture in the past century has likely enhanced eluviation, soil weathering, and tusk decomposition.

CONCLUSIONS

Remains of at least 6 mammoths have been found previously in the Missoula Flood slackwater deposits of south central Washington (Scott and Clem 1967, Newcomb and Repenning 1970, Waitt 1980, Gilbow 1981, Martin et al. 1982, Barton 1999). This study is unique in central Washington proboscidean finds in its detail of tusk analysis and its focus on the morphostratigraphic context of the find. The tusk is significant because it represents the 1st application of Schreger angle analysis to an otherwise undiagnostic proboscidean tusk from central Washington. Further, the Moxee City mammoth is the 1st AMS-dated mammoth in the Yakima River drainage. At 14,570 ± 50 ^{14}C yr BP, the tusk is currently the oldest radiometrically dated Columbian mammoth in the Missoula Flood slackwater deposits in central Washington. This well-dated tusk provides temporal control on late Quaternary events where the MSH S tephra is missing, thus enhancing understanding of a complex morphostratigraphic environment characterized by fluvial erosion and deposition, pedogenic development, slackwater deposition, eolian deflation, and loess deposition.

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