
**Short-term fluctuations in small mammals
of the late Pleistocene
from eastern Washington**

JOHN M. RENSBERGER AND ANTHONY D. BARNOSKY

A sustained local presence of terrestrial vertebrates, followed by burial and preservation, over an interval sufficiently long to record a population's evolution is an uncommon occurrence. In this chapter we describe a deposit that has preserved a relatively continuous faunal record of small land mammals from the late Pleistocene and early Holocene. In 1981 and 1982, field parties from the Burke Museum at the University of Washington collected approximately 15,000 bones and stratigraphic data from a roadside outcrop southwest of Kennewick in eastern Washington (Figure 13.1). Small vertebrates were obtained from the base of the exposed deposits to the uppermost beds. This report describes the depositional setting, the faunal composition and its changes, and the morphological changes in several local populations through the stratigraphic section.

Stratigraphy

General characteristics

The Kennewick Road Cut exposure is located approximately 11 km (7 miles) southwest of Kennewick, on highway 82, in the southwest quarter of Section 4, T. 7 N., R. 29 E., Pasco quadrangle. The exposure extends more than 140 m in a north-south direction along the west side of the highway (Figure 13.2). The locality lies at an elevation of 389 m in the southeast-trending Horse Heaven Hills.

The deposits consist of generally massive, tan-colored, poorly to moderately indurated silt ranging from 21 to 24 m in exposed thickness.

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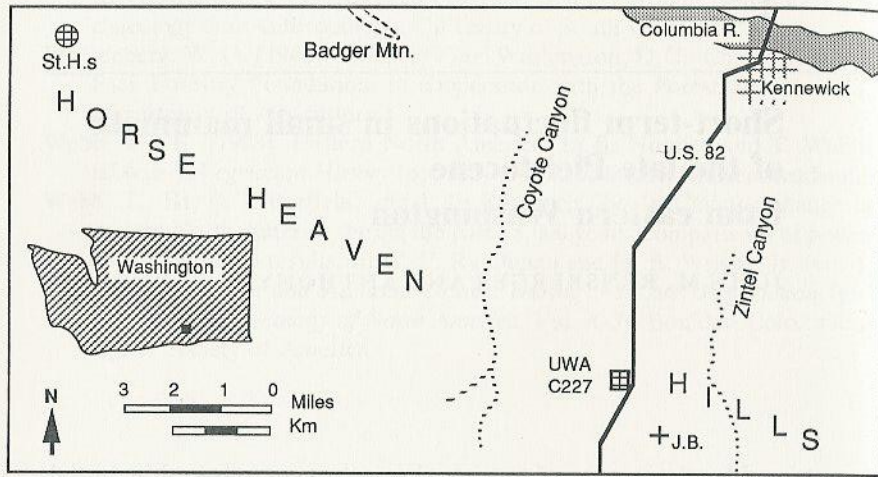


Figure 13.1. Map of the Kennewick Road Cut locality (UWA C227). Abbreviations: J.B., Johnson Butte; St.H.s, exposure of St. Helens S ash. From Waitt (1980).

Variations in thickness result from the north-south rise of the highway bed and the sloping surfaces of the hill. The most prominent sedimentary structures are a series of calcite-cemented layers (calcrete) that are typically less than 2 m in thickness. The calcrete layers provided the primary basis for correlating the fossil samples across most of the outcrop. The massive siltstone units separating the calcrete layers range in thickness from 1 m at the south end of the exposure to as much as 21 m at the northern end, where no calcrete is present. Where calcrete layers are present, the intercalated silt units average 2 m thick. Zones of filamentous calcite, animal burrows, and tephra layers are sometimes present in the otherwise massive silt units. Bedding other than that resulting from the alternating uncemented and cemented units and tephra is rare.

Silt units

The nonbedded units separating the calcrete layers consist of brown to gray-brown silt or sandy silt. When calcite and iron oxides are removed by treatment in HCl, the color becomes light gray.

Sediment grain-size parameters. Grain-size analyses performed on 21 samples distributed vertically and horizontally through the exposed sec-

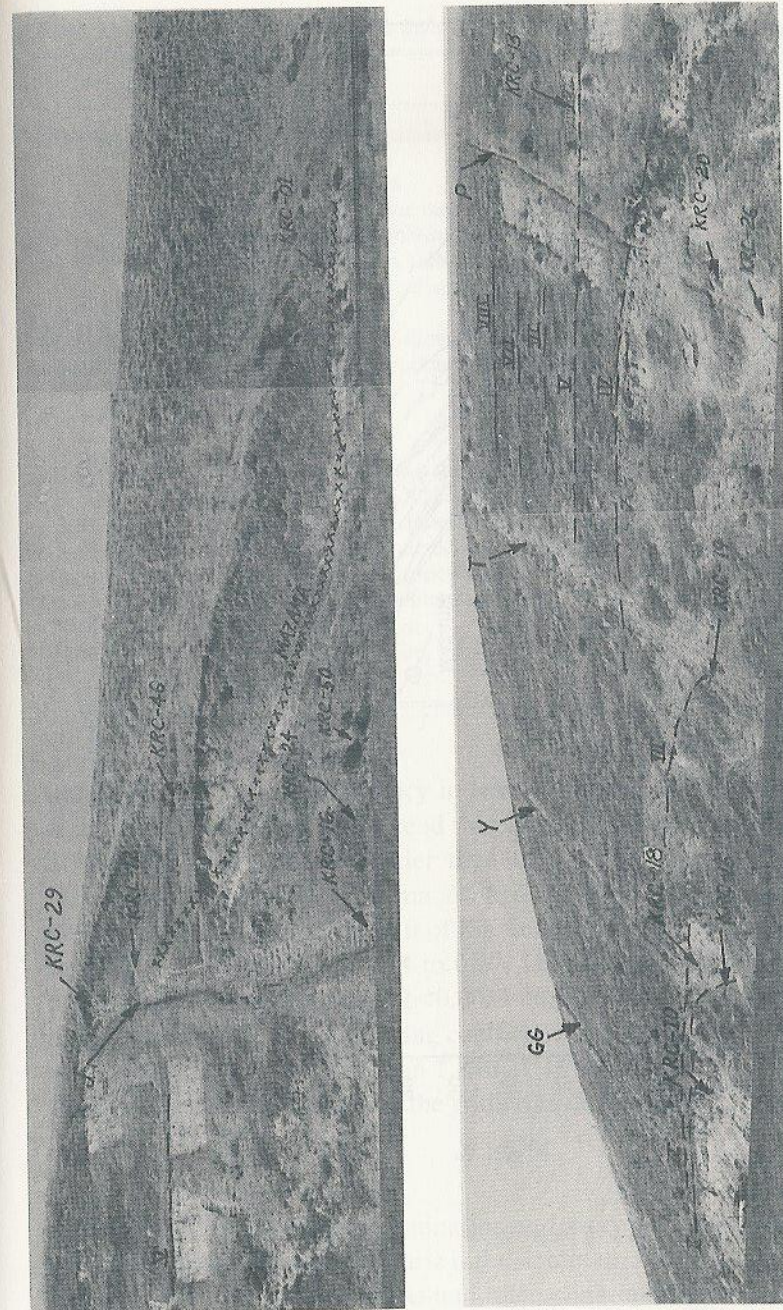


Figure 13.2. Views of the Kennewick Road Cut locality. Northern half of exposure above, and southern below. KRC numbers indicate several collecting sites. X indicates exposed Mazama ash. Dashed lines and Roman numerals show calcrete beds associated with paleosols. GG, trench 1; Y, trench 2; T, trench 3; P, trench 4; J, trench 5.

Table 13.2. Heavy-mineral separates

| Sample | Weight of sample | Weight of heavies | Weight of lights | Percentage of heavies |
|--------|------------------|-------------------|------------------|-----------------------|
| S-16 | 2.3782 | 0.1382 | 2.2400 | 5.81 |
| S-42 | 1.7020 | 0.0765 | 1.6255 | 4.49 |
| S-16 | 2.0503 | 0.0793 | 1.9710 | 3.87 |
| S-51 | 2.2416 | 0.0950 | 2.1466 | 4.24 |
| S-85 | 1.6957 | 0.0940 | 1.6017 | 5.54 |
| S-106 | 2.0645 | 0.1255 | 1.9390 | 6.08 |
| S-91 | 2.3528 | 0.1396 | 2.2132 | 5.93 |
| S-59 | 2.5875 | 0.1106 | 2.4769 | 4.27 |
| S-25 | 2.3350 | 0.0895 | 2.2455 | 3.83 |
| S-98 | 2.5039 | 0.0743 | 2.4296 | 2.97 |
| Mazama | 2.4857 | 0.0294 | 2.4562 | 1.18 |

Quartz-grain surface textures. Quartz grains sampled vertically and horizontally through the section were examined by scanning electron microscopy for surface features characteristic of specific depositional environments. The samples were cleaned by boiling in concentrated HCl to remove the calcite and iron oxide.

The grains typically are quite angular, but have edges subdued by silica solution and precipitation and have flat precipitation surfaces (Figure 13.4). Cleavage planes and adhesive particles are common. The textures closely resemble those in samples of Pleistocene loess at Kaiserstuhl, West Germany (Krinsley and Doornkamp, 1973), and Waltherheim, West Germany (Pye, 1983). Impact V's characteristic of subaqueous environments are absent from the quartz surfaces. Grains with razor-sharp edges, extreme angularity, and conchoidal fractures characteristic of unmodified grains from glacial environments are rare.

The eolian nature of loess is accepted by most workers (Smalley, 1975). The distributions of the deposits in Germany and Poland indicate derivation from ice-marginal areas and fluvio-glacial outwash channels during glacial phases of the late Pleistocene (Fink and Kukla, 1977; Maruszczak, 1980). We conclude that the sediments throughout the section at Kennewick represent airborne dust deposited over vegetated surfaces that held the particles and allowed accumulation of the observed unit thicknesses. The absence of bedding resulted from the relatively homogeneous particle sizes of the sediment and bioturbation by soil-forming processes as discussed later.

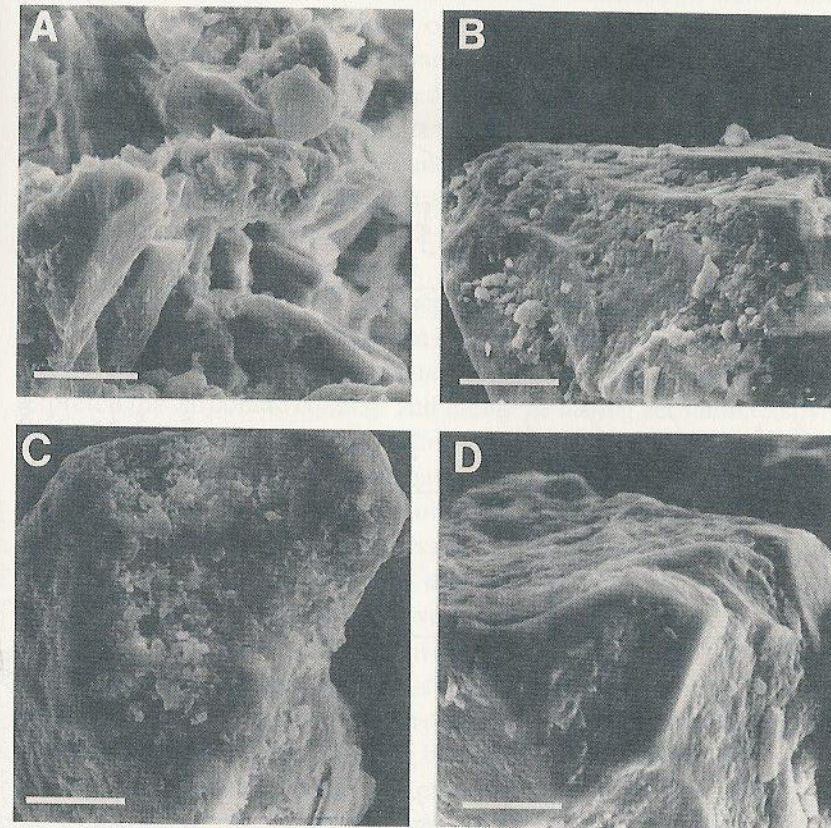


Figure 13.4. Scanning electron micrographs of quartz grains. (A) Compound grain from sediment sample S-31. S-31 is of normal size for the deposit, but is composed of cemented particles smaller than normal, indicating cementation prior to deposition. (B, C, D) Single grains showing silica solution, silica precipitation, and adhering fine particles characteristic of loess: B, sample S-100; C, S-15; D, S-100. Scale = 10 μ m.

Pedogenic calcrete zones. Eight calcrete layers are distinguishable (Figures 13.2 and 13.5). These zones are characterized by a high calcium carbonate content that ranges from coatings on particles to a pervasive medium engulfing the grains to form reddish, weakly cemented nodules 2–10 cm in diameter. The calcrete zones often grade upward into sets of faint carbonate filaments.

The calcrete deposits are similar to K-horizon pedogenic carbonate accumulations observed on desert alluvial fans, plains, and grasslands along the Rio Grande of southern New Mexico near Las Cruces (Gile,

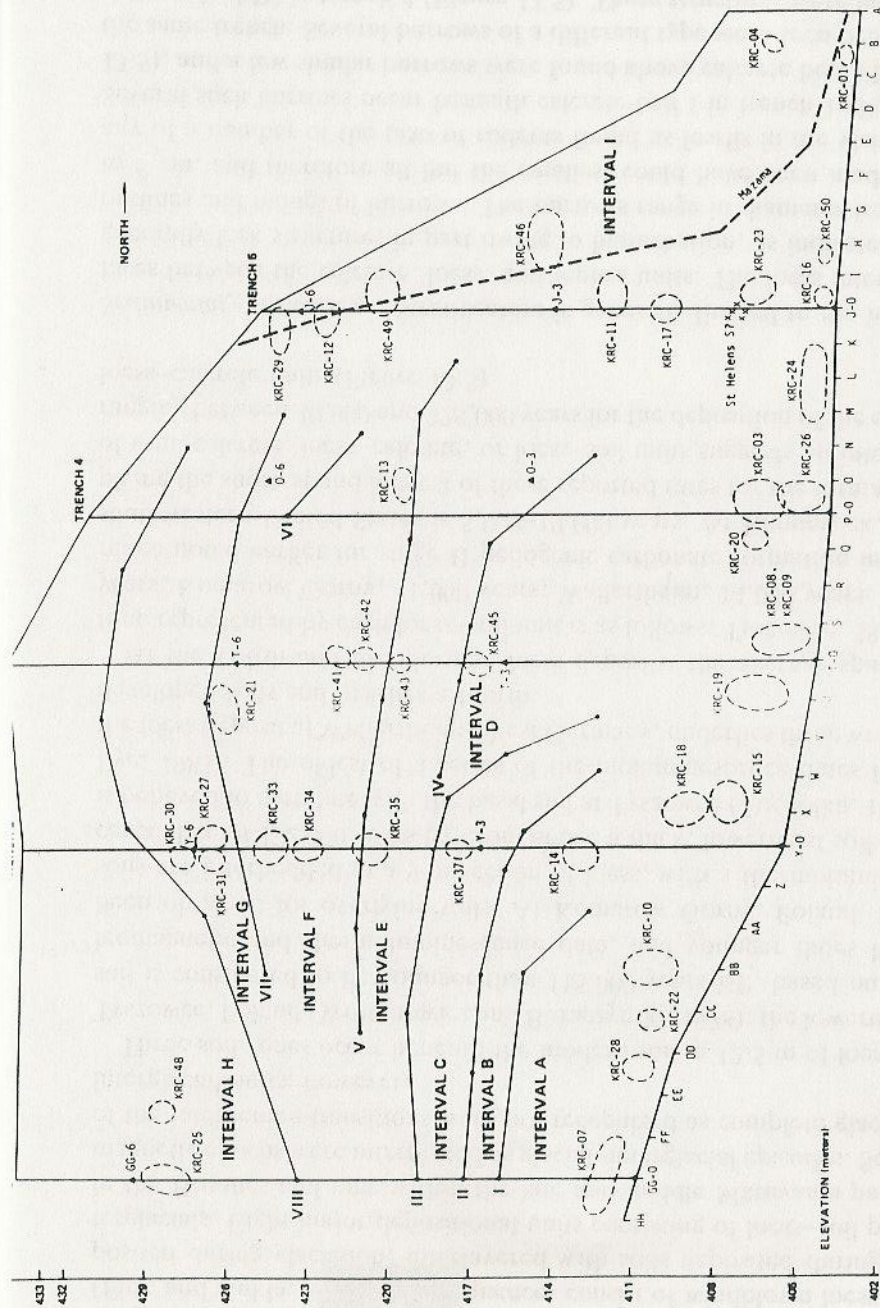


Figure 13.5. Vertical section through Kennewick Road Cut along plane of exposure, showing spatial relations of collecting sites (KRC) to trenches, grid lines, calcrete beds I–VIII, and ash layers.

Peterson, and Grossman, 1965, 1966). Those soils are in thick, well-drained alluvium of either pebbly or fine grained matrix, and the carbonate structures differ in the coarse and fine sediments. Gile et al. (1966) found that in the fine-grained sediments, stage I is characterized by filaments, stage II by rare-to-common nodules, stage III by many nodules and internodule fillings, and stage IV by laminar, heavily impregnated beds. The distinct calcrete zones at the Kennewick Road Cut resemble the fine-sediment stage II or early stage III. The filamentous calcite probably represents stage I.

The youngest geomorphic surfaces on which these stages were observed in New Mexico were (I) from less than 2,600 up to 5,000 years and (II) from less than 5,000 years to latest Pleistocene. Gile et al. (1966) interpreted the carbonate coatings and fillings as having accumulated over long periods of downward percolation of water falling on the surface of porous soils. The water took carbonate into solution from calcareous dust and precipitated the carbonate below the surface. Although eolian dust did not accumulate in large thicknesses in the New Mexico deposits, nor were dunes common, they inferred that the dust deposited by one storm was wetted and then largely removed by the next storm. However, at Kennewick, where coarse clastics are absent, the fineness of the deposit and the apparent relative stability of the structure suggest that the vegetation cover was thick enough much of the time to prevent significant portions of the preceding deposit being blown away during storms.

Even where sediment consists of over 90% calcite, as in coastal dunes, the formation of calcrete is observed to have extended over a lengthy interval of time, commencing soon after stabilization of the dune by vegetation.

Uncemented (up to 6,000 years BP) and cemented, calcreted (up to 80,000 years BP or older) Pleistocene coastal dunes occur on the South Australian coast (Warren, 1983). The stages are analogous in development to those described by Gile et al. (1966) for southern New Mexico: The unconsolidated sand passes in stages from a free-flowing sand to nodular calcrete to massive nodular calcrete to laminar calcrete (Warren, 1983).

The cliff faces of the South Australian Pleistocene dunes show cross-bedded dune intervals separated by calcrete zones. Warren interpreted each sandy unit as a pulse of dune sand deposited during an interglacial and capped by calcrete before the next interglacial. By similar reasoning it is probable that at least some of the loess-calcrete sequences at Kennewick represent glacial-interglacial units.

Seventeen glacial–interglacial episodes are recognized as loess–paleosol units in deposits near Krems, Austria, and Brno, Czechoslovakia (Fink and Kukla, 1977). The sequences consist of windblown loess deposited during glaciation, interlayered with soils deposited during interglacials. Eight major depositional units consisting of loess–soil pairs in the Brunhes and nine within the late and middle Matuyama paleomagnetic epochs were interpreted as glacial–interglacial episodes. Some of the intervening transitions were not recognized as complete glacial–interglacial units, however.

Three soil zones occur beneath the modern soil in 12.5 m of loess at Tyszowce, Poland (Wojtanowicz and Buraczynski, 1978); the lowermost soil is considered to be younger than 115,000 years BP, based on paleomagnetic and thermoluminescence data, and younger dates have been obtained for overlying soils. At Komarow Gorny, Poland, four soils are interbedded in a 9-m section of loess, with a thermoluminescence date of 122,000 years BP from above a thick, lowermost soil that is believed to correlate with the basal soil at Tyszowce (Tucholka, 1977; Pye, 1983). The oldest of a series of thermoluminescence dates from the loess deposit at Wallertheim, West Germany, underlies three weakly developed soils and overlies a fourth.

At the Polish and the German loess deposits, the average span of time represented by each loess–soil unit is as follows: Tyszowce, 38,000 years; Komarow Gorny, 41,000 years; Wallertheim, 14,000 years. The range noted earlier for stage II pedogenic carbonate formation in the southwestern United States is 5,000–10,000 years. At Kennewick, applying the shortest and longest of these reported rates for the formation of sand-calcrete, loess-calcrete, or loess–soil units suggests an interval ranging between 40,000 and 328,000 years for the deposition of the eight loess–calcrete units (Figure 13.5).

Sedimentary structures. Stratification is generally limited to the interfaces between the calcrete, loess, and tephra units. The loess intervals generally lack structure, in part owing to bioturbation, as indicated by outlines and fillings of burrows. The burrows range in diameter from 2 to 5 cm, and therefore all but the smallest could have been made by any of a number of the taxa of rodents found as fossils in the vicinity. Several such burrows occur beneath calcrete bed I in trench 1 (Figure 13.5), and a few similar burrows were found above calcrete bed VIII in the same trench. Several burrows of a different type were seen beneath calcrete bed IV in trench 4 (Figure 13.5). These structures were larger,

up to 1/3 m in diameter, and were filled with stratified sediments containing fossil bone material. Except for the presence of laminations, the fillings resemble the overlying sediment. These larger burrows may have been the dens of small carnivores or possibly rabbits. The fine texture of the loess made digging easy, which may account for the abundance of small mammals that build burrows.

Taphonomy. The presence of carnivore dens and of some concentrations of bones that may be attributable to carnivore scat suggest that animals commonly hunted by predators may be overrepresented with respect to their abundance in the living community. However, rodent teeth that under SEM magnifications show no signs of digestion also are present. Because many of the fossil rodents burrowed and the carnivores dug dens, a sampling site should not be regarded as an “instant” in time. Rather, bioturbation may have caused some of the sites to combine mammals that lived up to a few hundred years apart. More pronounced mixing seems to have been unlikely, because living representatives of these animals seldom dig deeper than 2 m (usually less than 1 m), and most sites show no obvious evidence of bioturbation.

Tephra. The stratigraphically highest of two tephra units dips to the northeast in the upper part of trench 5 (Figures 13.2 and 13.5). This tephra is 10 cm thick at the higher end, but thickens to about 30 cm a few meters to the north, suggesting deposition on a slope. The indices of refraction for the majority of the glass shards range between 1.506 and 1.510 and average slightly above 1.508, which is not distinguishable from samples of Mazama ash, but is higher than indices for Glacier Peak pumices (Powers and Wilcox, 1964). The chemical composition of the glass resembles that of Mazama pumice (Powers and Wilcox, 1964) in the percentages of silica, soda, and titanium oxide (Table 13.3). The higher percentages of iron oxides and lime in the Kennewick tephra may be due to contamination from the surrounding loess. These characteristics, together with the high stratigraphic position of this unit above the uppermost calcrete layer, indicate that it represents the Mazama ash (6,600 years BP).

The stratigraphically lower tephra is poorly preserved near the base of trench 5 (Figure 13.5). It was also found between calcrete units V and VI in trench 4, above KRC-13, the *Mammuthus* site. This tephra occurs as an indistinct couplet of units a few centimeters thick and badly contaminated from adjacent sediment. Because of the diffuse nature

Table 13.3. Compositional comparison of upper tephra, Kennedwick Road Cut

| Compound | Kennewick | Mazama ^a | Glacier Peak ^a |
|--------------------------------|-----------|---------------------|---------------------------|
| SiO ₂ | 71.95 | 72.39 | 73.01 |
| Al ₂ O ₃ | 14.75 | 14.79 | 15.08 |
| FeO's | 2.40 | 1.85 | 1.79 |
| MgO | 0.06 | 0.52 | 0.73 |
| CaO | 2.13 | 1.58 | 2.30 |
| MnO | 0.05 | 0.05 | 0.05 |
| TiO ₂ | 0.44 | 0.43 | 0.30 |
| K ₂ O | 2.75 | 2.77 | 2.89 |
| Na ₂ O | 5.27 | 5.21 | 3.72 |
| P ₂ O ₅ | 0.19 | 0.09 | 0.13 |

^aData from Powers and Wilcox (1964).

and poor exposure of this unit, determination of the chemistry was not attempted. Waitt (1980, p. 664) found a white silt-tephra couplet of 2.5-cm- and 0.7-cm-thick layers commonly associated with eolian silt in scores of exposures of the Touchet Formation in south-central Washington a short distance (e.g., 6 m) beneath the Mazama ash. Waitt (1980, Table 1) found that samples of this couplet from Badger Coulee, a locality about 24 km (15 miles) northwest of the Kennewick Road Cut, match the St. Helens set S ash in trace-element quantities. This widespread distribution of the St. Helens set S as a couplet suggests that the Kennewick Road Cut couplet may represent that set.

The St. Helens set S is dated at approximately 13,000 years BP, which is younger than expected for this inferred position in interval F, judging from the estimated time for calcrete formation. There are several possible reasons for this discrepancy: (1) The tephra is not the St. Helens set S. (2) The placement of the tephra with respect to the calcrete units is incorrect. (3) The time for formation of the three upper calcrete units averages slightly less than 5,000 years each. This tephra is seen only at the north end of the exposure, where the calcrete units disappear, and one (unit VI) is short and discontinuous.

Discontinuities and bedding structures. The discontinuities and dips of the calcrete zones and tephra (Figure 13.5) suggest that deposition proceeded northward. The dipping northern ends of these layers roughly parallel the present topographic surface, which dips prominently at the northern end of the exposure. Calcrete zones I through V successively

extend farther northward. The Mazama ash (Figures 13.2 and 13.5) lies in a plane almost parallel to the northern topographic surface.

The southern end of the section (trench 1) lacks recognizable calcrete layers IV, V, VI, and VII, whereas trench 4 is missing layers I, II, and III. These relationships are consistent with erosion, apparently through deflation, occurring at the southern end of the hill after development of paleosol III and prior to development of paleosol VIII, with deposition progressively filling at the northern margin of the deposit. The fine particle size and the fact that the quartz grains do not have features characteristic of saltation indicate that the deposit did not migrate to the north in the fashion of a sand dune. The foreset effect and the antiquity of the calcrete-silt cycles suggest a consistency in storm wind from a southerly direction over a long period of time.

Relationship to neighboring deposits. Neighboring deposits of silt, sand, and conglomerate of late Pleistocene to Holocene age have been called Touchet beds since the use of that term by Flint (1938). Most of the Touchet Formation along river drainages and in coulees is waterlaid, consisting of bar, channel, and slackwater deposits. Rhythmic slackwater deposits comprising up to 39 rhythmite layers are exposed in the Walla Walla and Yakima valleys (Waitt, 1980) and in Badger Coulee, a few kilometers to the northwest of the Kennewick Road Cut fossil locality (Waitt, 1980; Bunker, 1982). The individual rhythmite typically consists of a 0.5–1-m-thick unit that grades upward from sand to silt. The silt and calcrete deposits of the Kennewick Road Cut section lack graded bedding, in most cases lack the bimodal grain size characteristic Waitt (1980, p. 664) noted for the massive rhythmite layers, lack SEM-visible quartz-grain textures characteristic of waterlaid deposits, and are located topographically above the boundary of the neighboring waterlaid beds as mapped by Waitt (1980, Figure 2). The Kennewick Road Cut deposit more closely resembles the Palouse Formation, which is characteristically a brownish loess and has at least three moderately cemented calcareous horizons (Newcomb, 1961).

Faunal composition

Faunal list

Amphibia
Order Anura (sp. indet.)

- Reptilia
 Order Squamata
 Suborder Serpentes (sp. indet.)
 Suborder Lacertilia (sp. indet.)
 Aves (sp. indet.)
 Mammalia
 Order Chiroptera
 Myotis (sp. indet.)
 Order Insectivora
 Sorex palustris
 Sorex sp.
 Insectivora (sp. indet.)
 Order Lagomorpha
 Family Leporidae
 Sylvilagus idahoensis
 Sylvilagus nuttallii
 Lepus (sp. indet.)
 Order Rodentia
 Family Sciuridae
 Spermophilus townsendii
 Eutamias (sp. indet.)
 Family Heteromyidae
 Dipodomys microps
 Dipodomys ordii
 Perognathus parvus
 Family Geomyidae
 Thomomys talpoides
 Family Cricetidae
 Neotoma lepida
 Neotoma cinerea
 Peromyscus maniculatus
 Lagurus curtatus
 Phenacomys intermedius or *Arborimus longicaudus*
 Synaptomys cf. *S. borealis* (or closely related species)
 Microtus (Pitymys) meadensis
 Microtus sp.
 Order Proboscidea
 Family Elephantidae
 Mammuthus (sp. indet.)
 Order Carnivora

Family Canidae (sp. indet.)
 Order Artiodactyla (sp. indet.)

Systematic description

The identifications of most of the mammalian species are based on teeth or jaws from tens to hundreds of specimens. Avian, reptilian, and amphibian fossils are sparse and fragmentary and have not been identified to lower taxonomic levels. Large samples of postcranial elements have not been studied. The following brief descriptions give the critical characteristics of the taxa that are identified to the level of species or genera:

Myotis (sp. indet.): Remains: two jaws, one humerus fragment, three premolars present, anteroposteriorly expanded (esp. P₄); P₄ with incipient talonid.

Sorex palustris (northern water shrew): Upper molars wider than in *S. trowbridgei*, *S. merriami*, *S. cinereus*, or *S. obscurus* (Figure 13.6). P₄ less bladelike than in *S. bendirii* or *S. vagrans*. Smaller than *S. bendirii*. Resembles *S. prebla* (Ingles, 1965, pp. 87–8) in size.

Sorex sp.: Smaller than *S. palustris*.

Sylvilagus idahoensis (pygmy rabbit): Anterior premolars lacking complex anterior borders. Anterior enamel of P² with only one inflection, and P₂ with none. Enamel separating anterior and posterior lophs of upper molariform teeth lacking crenulation of *S. idahoensis* (Orr, 1940), but with mild undulation in some individuals. Labial margins of protoconid and hypoconid more angular than in *S. nuttallii*. Talonid of lower molariform teeth one-half to two-thirds width of trigonid.

Sylvilagus nuttallii (mountain cottontail): P² with three inflections of anterior enamel, and P₂ with one. Single anterior inflection of P₂ lacking crenulation characteristic of *S. auduboni*. Talonid of lower molariform teeth one-half to two-thirds the width of trigonid (in other *Sylvilagus*, except *S. idahoensis*, the talonid is four-fifths the width of the trigonid) (Orr, 1940).

Spermophilus townsendii (Townsend ground squirrel): M₃ longer (Figure 13.7) than in *S. washingtoni*, lacking metaloph. Cheek teeth higher-crowned, with less bulbous cusps than in *S. beecheyi*, *S. saturatus*, or *S. lateralis*. Teeth smaller than in *S. columbianus* and *S. richardsonii*. M₃ and M³ relatively shorter; P₄ lacking prominent anterior cingulum; upper molars with more rounded lingual margins than in *S. columbianus* and *S. beldingi*.

Eutamias sp. (chipmunk): Within range of variation in dentitions of

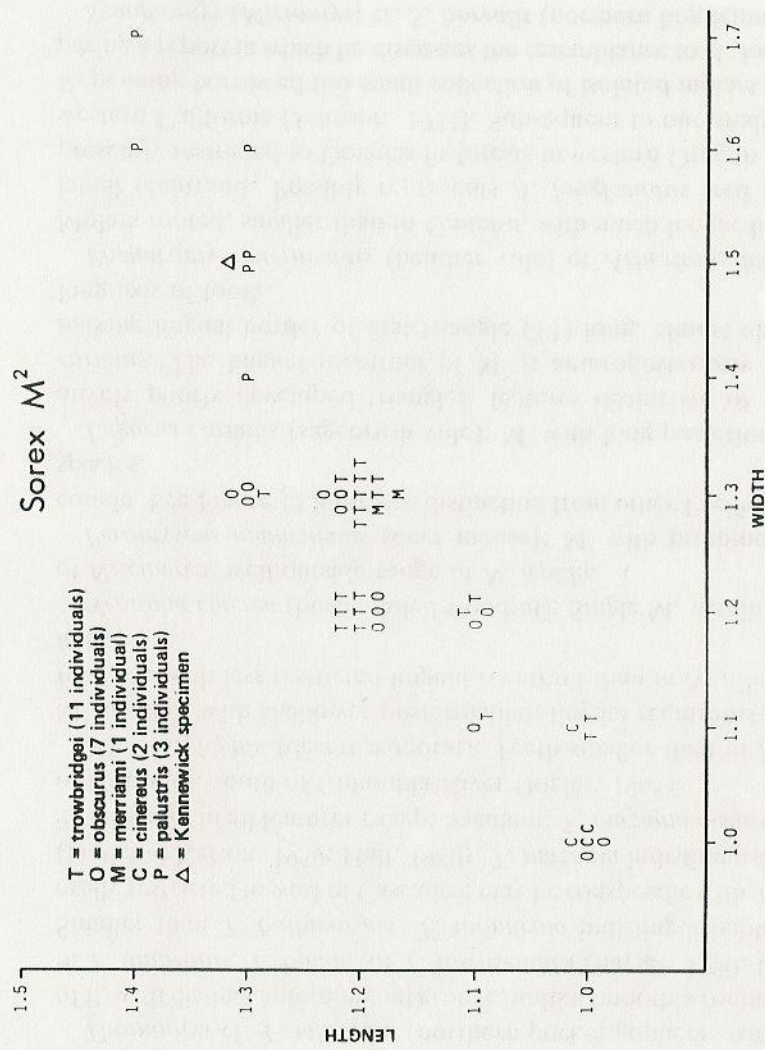


Figure 13.6. Size relationships between fossil *Sorex* from Kennewick Road Cut and several extant species, based on length and width of M_2 . Measurements in millimeters. The Recent specimens are from the Burke Museum, and most of those for which locality data are known are from Washington: *S. cinereus* (Lewis and Pierce counties, WA); *S. bendirii* (Pierce and Whatcom counties, WA); *S. palustris* (Pierce and Ferry counties, WA); *S. obscurus* (Pierce and Whatcom counties, WA); *S. trowbridgei* (King, Pierce, and Whatcom counties, WA); *S. vagrans* (Lincoln, Pierce, King Skagit, Lewis, and Yakima counties, WA, and Glacier Bay, AK).

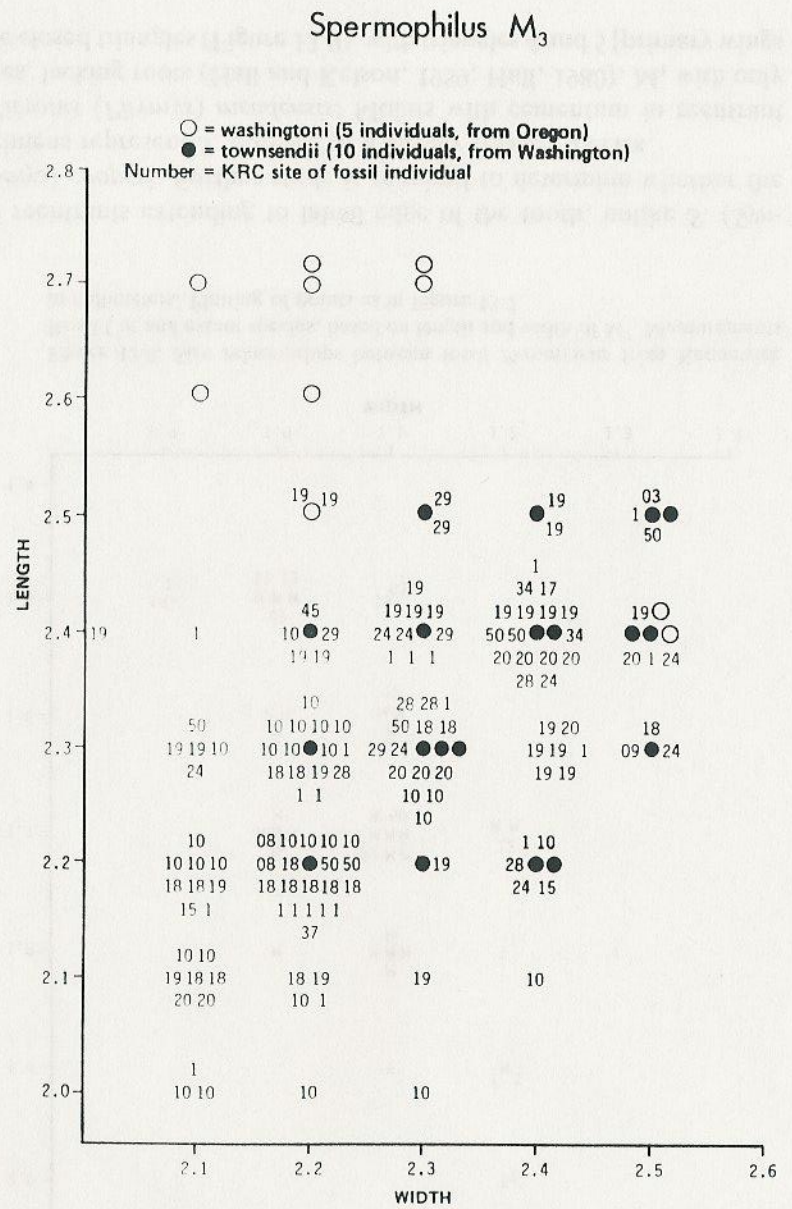


Figure 13.7. Size relationships between fossil *Spermophilus* from Kennewick Road Cut and extant species, based on length and width of M_3 . Measurements in millimeters. Measurements were taken to the nearest 0.1 mm; clusters of points all have the same measurement, but are offset for graphic feasibility.

species inhabiting area today (*E. minimus*) and species (*E. amoenus*) ranging nearby (Hall and Kelson, 1959).

Perognathus parvus (Great Basin pocket mouse): Hypolophid bulging anteriorly in all stages of wear. Larger than *P. apache* or *P. longimembris* (Hall and Kelson, 1959; Ingles, 1965).

Dipodomys microps (Great Basin kangaroo rat): Anterior margin of P_4 rounded; dentinal tracts almost reaching unworn occlusal surface.

Dipodomys ordii (Ord kangaroo rat): Anterior lophid of P_4 anteriorly flat to concave; dentinal tracts reaching occlusal surface only in well-worn teeth.

Thomomys cf. *T. talpoides* (northern pocket gopher): Anterior lobe of P_4 with distinct anterolingual groove, unlike smoothly rounded surface in *T. umbrinus*, *T. bottae*, or *T. townsendii* (Thaeler, 1980, Figure 2b). Smaller than *T. bulbivorous*. *T. monticola* indistinguishable but generally restricted to west of Cascades; may be conspecific with *T. talpoides* (Hall and Kelson, 1959; Hall, 1980). *T. mazama* indistinguishable from *T. talpoides* in all features except baculum; *T. mazama* occurs only west of Cascades, south of Columbia River (Ingles, 1965).

Neotoma lepida (desert woodrat): Teeth smaller than in *N. cinerea*. M^3 smaller, with shallower posterolabial, lingual reentrants than in *N. fuscipes*; with less restricted lingual reentrant than in *N. albigula* or *N. lepida*.

Neotoma cinerea (bushy-tailed woodrat): Single M_1 within size range of *N. cinerea*, well outside range of *N. lepida*.

Peromyscus maniculatus (deer mouse): M^1 with prominent anteroconule. See Figure 13.8 for size distinction from other Pacific Northwest species.

Lagurus curtatus (sagebrush vole): M^3 with long posterior loop, relatively poorly developed triangles, features distinctive of Recent *L. curtatus*. The lingual reentrant of M^2 is anteroposteriorly expanded, making lingual border of first triangle (T1) long, almost aligned with long axis of tooth.

Phenacomys intermedius (heather vole) or *Arborimus longicaudus*: Molars rooted, smaller than in *Ondatra*, with much longer lingual than labial reentrants. Possibly represents *A. longicaudus* (red tree vole), presently restricted to Douglas fir forests in western Oregon and northwestern California (Johnson, 1973). Subsequent to our analysis, C. A. Repenning borrowed this small collection of isolated molars and is preparing a report in which he discusses the resemblance to *A. longicaudus*.

Synaptomys (Mictomys) cf. *S. borealis* (northern bog lemming): Lin-

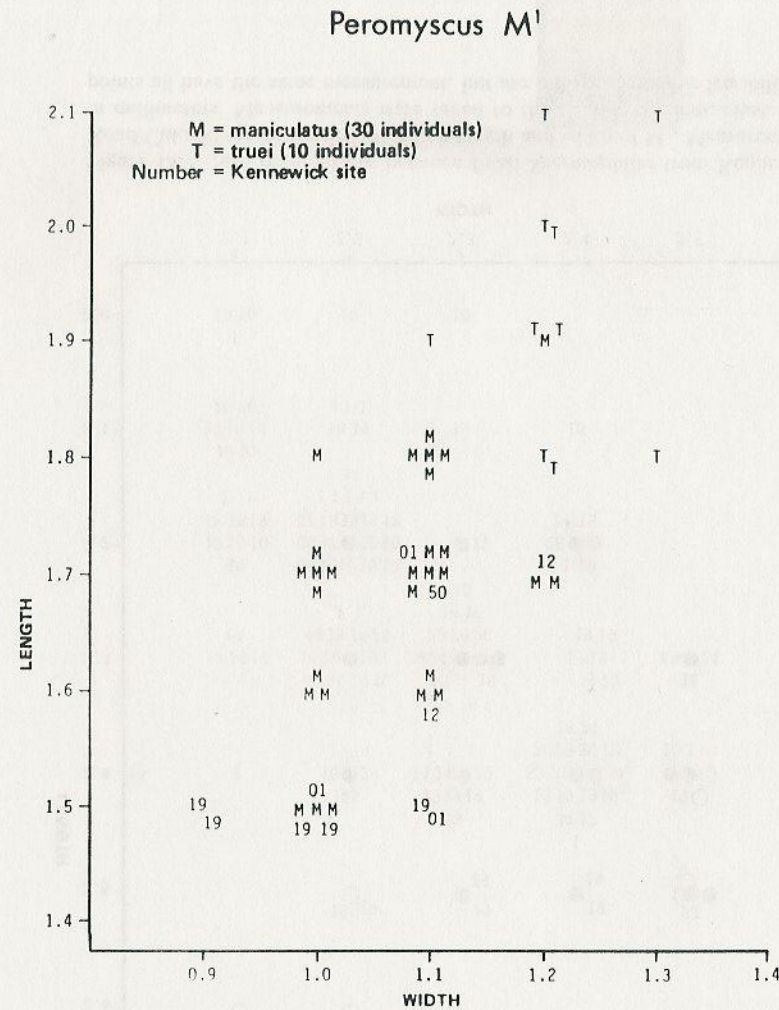
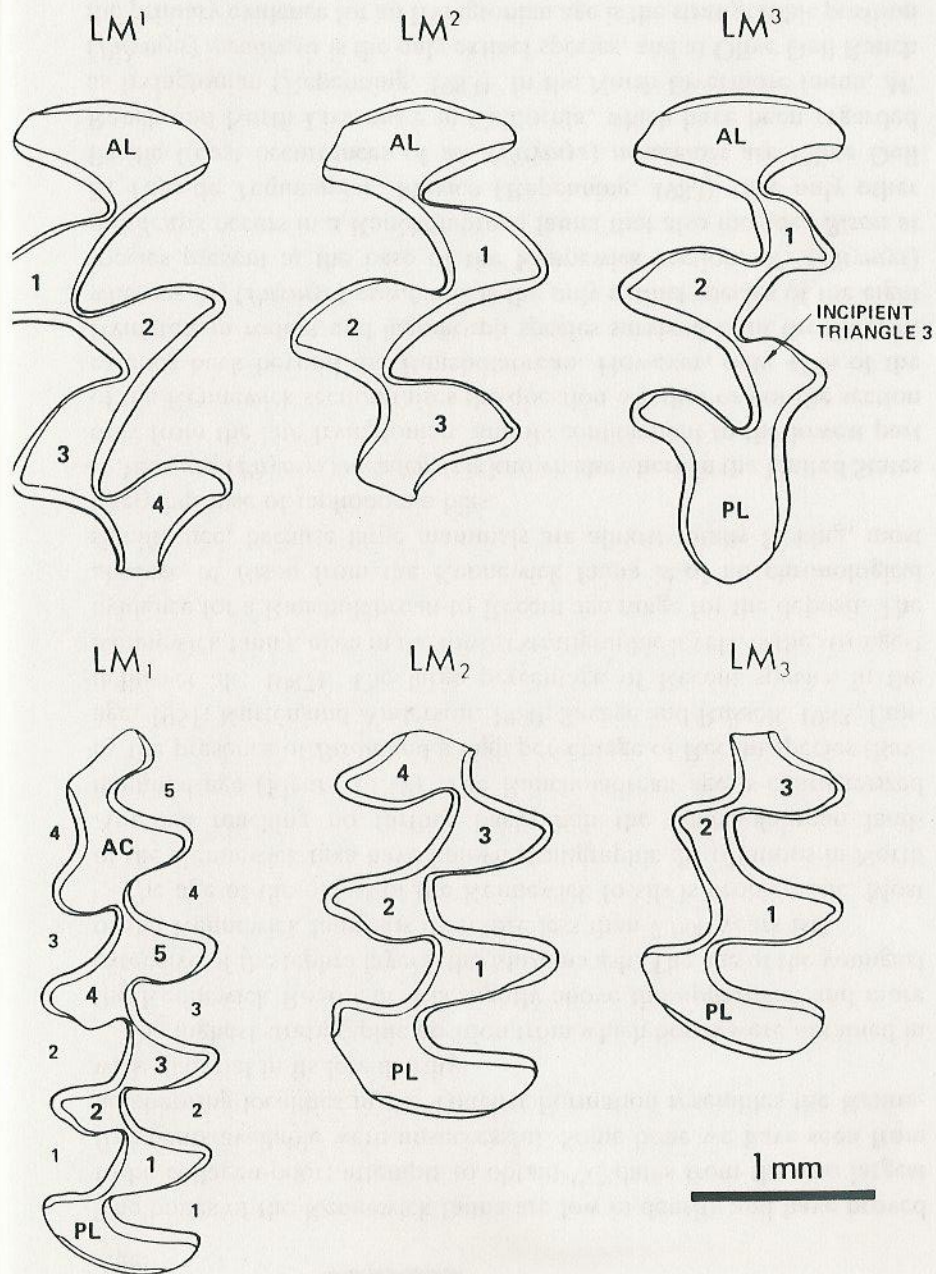


Figure 13.8. Size relationships between fossil *Peromyscus* from Kennewick Road Cut and extant species, based on length and width of M^1 . Measurements in millimeters. Plotting of points as in Figure 13.7.

qual reentrants extending to labial edge of the tooth, unlike *S. (Synaptomys) cooperi*. Further study is required to determine whether the specimens represent *S. borealis* or a closely related species.

Microtus (Pitymys) meadensis: Molars with cementum in reentrant angles, lacking roots (Hall and Kelson, 1959; Hall, 1980). M_1 with only three closed triangles (Figure 13.9), with triangles 4 and 5 [primary wings

Table 13.4. Dimensions (mm) of teeth in Kennewick M. (*Pitymys*) meadensis (KRC-10)

| Parameter | LM/1 | WM/1 | LM/3 | WM/3 |
|-----------|---------|---------|---------|---------|
| Mean | 3.14 | 1.17 | 1.97 | 1.02 |
| SD | 0.192 | 0.088 | 0.134 | 0.100 |
| OR | 2.9-3.5 | 1.0-1.4 | 1.7-2.3 | 0.8-1.2 |
| N | 50 | 53 | 43 | 42 |

of Repenning (1983)] broadly confluent; M³ with two closed triangles, simple posterior loop, unlike the condition in following subgenera and species of *Microtus*: (*Microtus*) *pennsylvanicus*, (*M.*) *breweri*, (*M.*) *nophilus*, (*M.*) *montanus*, (*M.*) *californicus*, (*M.*) *townsendii*, (*M.*) *oeconomus*, (*M.*) *longicaudus*, (*M.*) *coronarius*, (*M.*) *mexicanus*, (*M.*) *fulviventris*, (*M.*) *chrotorrhinus*, (*M.*) *xanthognathus*, (*Aulacomys*) *richardsonii*, (*Chilotus*) *oregoni*, (*Stenocranius*) *miurus*, (*S.*) *abbreviatus*. M₁ in (*Herpetomys*) *guatemalensis* somewhat similar, but M³ with three closed triangles, and M₁ with four triangles.

Prominent closure of anterior two triangles (T3 and T4) of M₂ in *M.* (*Pitymys*) *meadensis*, unlike remaining extant North American species: *M.* (*Pedomys*) *ochrogaster*, *M.* (*Pedomys*) *ludovicianus*, *M.* (*Pedomys*) *parvulus*, *M.* (*Pitymys*) *pinetorum*, *M.* (*Pedomys*) *quasiater*, *M.* (*Orthiomys*) *umbrosus*.

M² with three triangles in addition to anterior loop, unlike *M.* (*Pitymys*) *nemorialis* (Repenning, 1983, p. 479).

Prominent constriction separating triangles 4 and 5 from anterior cap in M₁, unlike (*Allophaiomys*) and *Microtus* *guildayi* (Martin, 1975, van der Meulen, 1978). Lingual reentrant angle 3 almost opposite labial reentrant angle 2, unlike *M.* *deceitensis* (Guthrie and Matthews, 1971) and *M.* *paroperarius* (Hibbard, 1944; Paulson, 1961; van der Meulen, 1978). Posterior loop of M³ less complex than in *M.* *paroperarius*.

Triangles 3 and 4 on M₂ closed or almost closed, unlike condition in *M.* *guildayi* (Hibbard, 1955; van der Meulen, 1978), *M.* (*Pitymys*) *mcnowni* (Hibbard, 1937), typical *M.* (*P.*) *aratai* (Martin, 1974, 1987), *M.* (*P.*) *hibbardi* (Holman, 1959), *M.* (*P.*) *cumberlandensis* (van der Meulen, 1978), and *M.* (*P.*) *llanensis* (Hibbard, 1944; Paulson, 1961).

Thinned enamel, as in other samples of *M.* (*Pitymys*) *meadensis*, especially on trailing edges of lower molars. Slightly larger than previously described specimens of *M.* (*Pitymys*) *meadensis* (Hibbard, 1944; Paulson, 1961): mean length of M₁ is 3.1 mm (Table 13.4), compared

with 2.9 mm; however, variability of combined samples similar to that in other conspecific samples of arvicolines (Kowalski, 1970, p. 155).

Age

The bones of the Kennewick fauna are low in density and have proved to be collagen-poor; attempts to obtain ^{14}C dates from the two largest fragments available were unsuccessful. Some bone we have seen from neighboring localities in the Touchet Formation resembles the Kennewick material in its low density.

The highest stratigraphic position from which bones were obtained in the Kennewick Road Cut was slightly above the uppermost and more extensive of the tephra layers, the Mazama ash. The age of the youngest of the Kennewick faunas is therefore less than 7,000 years BP.

The age of the oldest of the Kennewick fossils is problematic. Most of the Kennewick taxa have known stratigraphic distributions in North America reaching no further back than the Rancholabrean land-mammal age (Figure 13.10). The Rancholabrean age is characterized by the presence of *Bison* and a high percentage of Recent species (Savage, 1951; Kurtén and Anderson, 1980; Savage and Russell, 1983; Lundelius et al., 1987). The large percentage of Recent species in the Kennewick fauna, even in the lowest stratigraphic levels, is the strongest evidence for a Rancholabrean-to-Recent age range for the deposit. The absence of *Bison* from the Kennewick fauna is of no chronological significance, because large mammals are almost totally lacking, most likely because of taphonomic bias.

Microtus (Pitymys) meadensis is known elsewhere in the United States only from the late Irvingtonian, and its confinement to the lowest part of the Kennewick section raises the question whether or not the section extends back beyond the Rancholabrean. However, only 41% of the Irvingtonian rodent and lagomorph species survived until the Recent, whereas *M. (Pitymys) meadensis* is the only extinct species of the eight species present at the base of the Kennewick section. *M. (Pitymys) meadensis* occurs in a Rancholabrean fauna that also includes *Bison* at El Tajo de Tequiquiac, Mexico (Repenning, 1983). The only other Pacific Coast occurrences of *M. (Pitymys) meadensis* are Olive Dell Ranch and North Livermore in California, which have been regarded as Irvingtonian (Repenning, 1983). In the North Livermore fauna, *M. (Pitymys) meadensis* is the only extinct species, and at Olive Dell Ranch the primary evidence for an Irvingtonian age is the stratigraphic position

| TAXON / AGE | <i>Sorex palustris</i> | <i>Sylvilagus idahoensis</i> | <i>Sylvilagus nuttallii</i> | <i>Spermophilus townsendii</i> | <i>Perognathus parvus</i> | <i>Thomomys talpoides</i> | <i>Dipodomys microps</i> | <i>Dipodomys ordii</i> | <i>Neotoma lepida</i> | <i>Neotoma cinerea</i> | <i>Peromyscus maniculatus</i> | <i>Phenacomys intermedius</i> | <i>Lagurus curtatus</i> | <i>Synaptomys cf. borealis</i> | <i>Microtus (Pitymys) meadensis</i> | <i>Mammuthus sp.</i> | LAND MAMMAL AGE | |
|-----------------------|------------------------|------------------------------|-----------------------------|--------------------------------|---------------------------|---------------------------|--------------------------|------------------------|-----------------------|------------------------|-------------------------------|-------------------------------|-------------------------|--------------------------------|-------------------------------------|----------------------|-----------------|--------------|
| RECENT | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| WISCONSINAN | | | | | | | | | | | | | | | | | | |
| SANGAMONIAN | | | | | | | | | | | | | | | | | | |
| ILLINDIAN ~300,000 | | | | | | | | | | | | | | | | | | |
| PRE-ILLINDIAN | | | | | | | | | | | | | ? | | | | | |
| | | | | | | | | | | | | | | ? | | | | |
| | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | ~450,000 | |
| | | | | | | | | | | | | | | | | | | LATE |
| | | | | | | | | | | | | | | | | | | MIDDLE |
| | | | | | | | | | | | | | | | | | | EARLY |
| | | | | | | | | | | | | | | | | | | IRVINGTONIAN |

Figure 13.10. North American stratigraphic ranges of Kennewick Road Cut species [dates from Kurtén and Anderson (1980), except that *Lagurus curtatus* is extended as discussed by Barnosky and Rasmussen (1988)].

of the fauna above the late Irvingtonian El Casco fauna. Therefore it is possible that the California faunas containing *M. (Pitymys) meadensis* correlate with the lower part of the Kennewick section. In the Rocky Mountains of Colorado, *M. (Pitymys) meadensis* occurs with *Lagurus curtatus*, as it does at Kennewick. Barnosky and Rasmussen (1988) suggested that this association indicates an age of around 400 ka, because at all other localities *M. (Pitymys) meadensis* disappears by 400 ka, and *L. curtatus* does not appear until after 400 ka.

The age of the Irvingtonian–Rancholabrean boundary has been estimated to be close to 600 ka BP (Lindsay, Johnson, and Opdyke, 1975),

based on evidence that the Irvingtonian-age sediments range across the Matuyama-Brunhes magnetic-epoch boundary, as well as the stratigraphic proximity of the Pearlette type O ash to the Irvingtonian Cudahy fauna of the Great Plains, at about 450 ka BP, based on Repenning's (1987) microtine rodent biochronology. The calcrete chronology at Kennewick suggests that the bottom of the section is not much older than 328 ka and at minimum only 40 ka; hence it probably does not extend back into the Irvingtonian.

Some of the pedogenic calcrete-loess sequences may represent interglacial-glacial cycles, which is the interpretation given to paleosol-loess sets in Europe, where 17 major paleosols are believed to have formed during the past 1.7 my. However, the eight Kennewick calcrete zones would represent all of Rancholabrean time if fitted to a similar scale, which seems to be too great a magnitude of time, judging from the poor representation of extinct species, even in the lower part of the section. Nevertheless, this possibility should not be ruled out in the absence of independent dates, which conceivably could be obtained by such techniques as thermoluminescence.

Two parts of the Kennewick section, intervals A through B and the part from the middle of interval D through E, may have accumulated during glacial stages, judging from the presence of boreal species in those intervals and the presence of desert species in the intervening and superjacent intervals (see the later section on habitat changes). The faunules above interval E, which lack boreal species and approach the composition of the modern fauna, also indicate an interglacial environment.

If the two colder intervals indeed represent glacial stages and the maximum rate of calcrete formation applies, then the younger of the two may have been deposited during the Fraser glaciation (25,000–10,000 years BP), and the older during the Salmon Springs glaciation (>36,000 years BP). These Pacific Northwest stages appear to correlate with the Pinedale glaciation and the Bull Lake glaciation, respectively, in the Rocky Mountain region (Richmond et al., 1965). Correlation of the younger cold interval at interval D in the Kennewick section with the youngest glacial stage yields an average of 5,000 years for each of the succeeding five pedogenic calcrete units to form, which is at the low end of the rates observed in other regions. An alternative hypothesis is that the two cold intervals at Kennewick are older and correlate with the Salmon Springs and Stuck glaciations, with the Fraser being unrecognized in the upper part of the section where the fauna is more poorly

represented. If the basal part of the Kennewick section is pre-Salmon Springs glaciation, the loess there differs from the pre-Salmon Springs loess as it has been described in other areas of southeastern Washington and Idaho, where it is characterized by mature weathering zones more than 3 m thick and thicker calcified layers (Richmond et al., 1965; Baker, 1978).

At the top of the section, dated at approximately 7,000 years BP because of its association with the Mazama ash, is a faunule with *Dipodomys microps*, a group 4 species (see the later section on habitat changes) that has a more southern distribution today. This occurrence is consistent with conclusions reached by Lyman and Livingston (1983) and C. Barnosky (1984, 1985), based on faunal and floral data, that from about 8,500 to 4,000 years BP a regime of less effective moisture and warmer temperatures prevailed in the Columbia Basin than after 4,000 years BP.

Faunal and phyletic changes

Almost all of the microfauna was collected by passing sediment through $\frac{1}{16}$ -inch mesh screens. Because the same procedure was used throughout the fieldwork, differences in relative abundances of taxa sampled from site to site and through the stratigraphic section should reflect differences in abundances in the deposit.

Changes in distribution

In order to analyze the vertical ranges, the taxa are grouped according to stratigraphic intervals from A at the base of the section through I at the top, with some intervals subdivided into low and high, or low, middle, and high parts, depending upon our ability to relate sites to key beds (Figure 13.5). The most abundant taxon (Table 13.5) is *Spermophilus townsendii*, which ranges throughout the section (Figure 13.11). Other taxa have more restricted stratal ranges whose endpoints have the potential to allow correlation beyond the limits of the Kennewick locality, or reconstruction of the biogeographic history of the species, or inference of climatic change.

An early faunal change occurred between intervals A and B, when the extinct vole *Microtus (Pitymys) meadensis* was replaced by an extant but undifferentiable species of *Microtus* (Figure 13.11), and *Sylvilagus nuttallii* appeared for the first time.

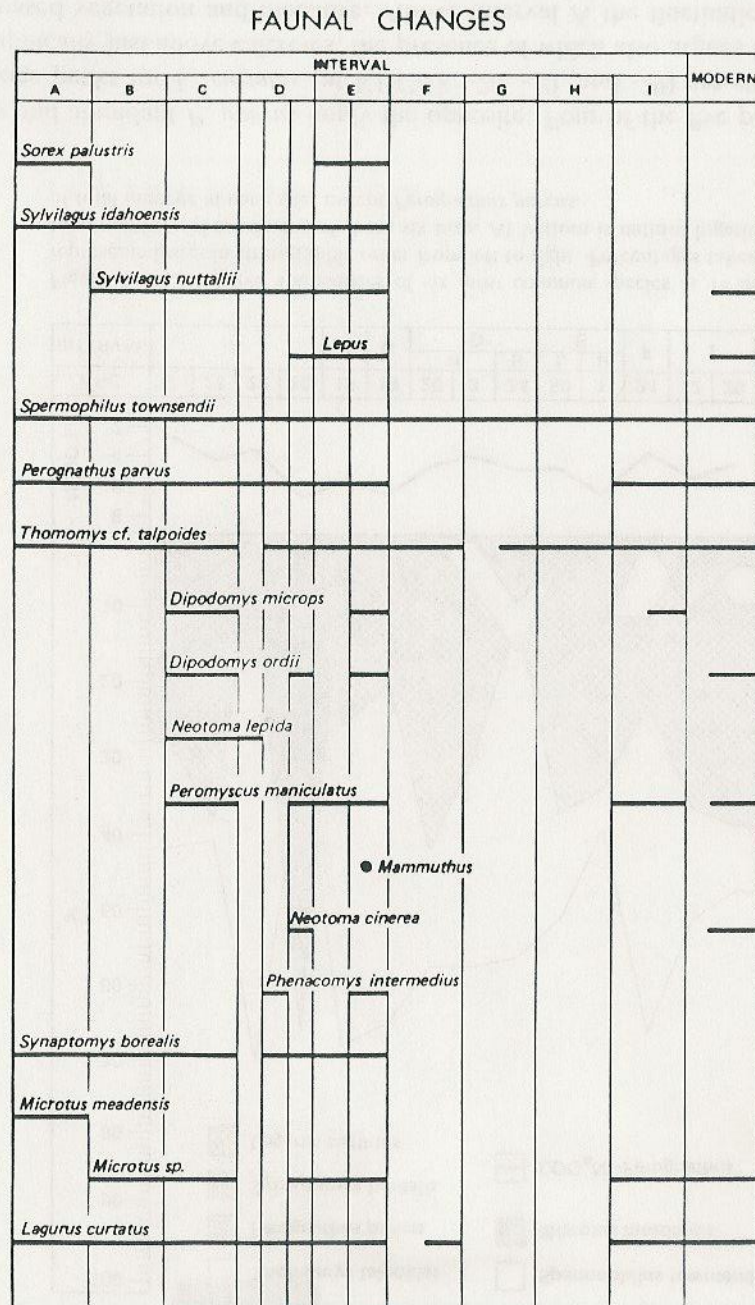


Figure 13.11. Stratigraphic ranges of certain species in Kennewick Road Cut showing changes in faunal composition. Stratigraphic divisions A-I based on positions of collecting sites with respect to key beds (see Figure 13.5).

is sparsely represented (Table 13.5), and only the normally abundant taxa with long ranges were found, it is difficult to determine exactly when the actual disappearances of these taxa occurred. At interval I, *D. microps* makes its last appearance, but only by a single specimen in several large samples.

Habitat changes

Indications of habitat changes are seen when the taxa are grouped according to preferred habitats based on physiographic distributions and ecological studies of modern representatives. See Hall and Kelson (1959), Hall (1946, 1981), Dalquest (1948), Ingles (1965), Baker (1968), Bailey (1936), Beatley (1976), and Finley (1958) for range maps and summaries of habitat preferences.

Group 1. Taxa whose current distributions are restricted to arid habitats like that of the area today: *Spermophilus townsendii*, *Perognathus parvus*, and *Lagurus curtatus*. Beginning with interval C, *S. townsendii* and *L. curtatus* are the most abundant species in most samples. Therefore, arid habitats like those of the area today must have predominated in this region through most of the time spanned by the deposit. There are, however, fluctuations in the relative abundances of group 1 species (Figure 13.12). The percentages of *Lagurus* fluctuate extensively, with increases in abundance relative to the abundances of other common taxa at chronologically sequential sites KRC-28, -18, -20, and -50, and decreases at KRC-22, -19, -3, and -24 (probabilities for no change <0.003).

The relative abundance of *Perognathus* also changed in an episodic fashion, with increases at KRC-19, -24, and -1, and decreases at KRC-10, -20, and -21 ($p < 0.001$), with perhaps a decrease at KRC-50 ($p = 0.008$). The directions of the fluctuations in *Perognathus* are the reverse of those in *Lagurus* at seven positions: KRC-28, -22, -19, -20, -24, -50, and -1.

The nocturnal, seed-eating *P. parvus* prefers habitats with little shrub cover. These pocket mice are restricted to the loose, dry soils of the desert floor (Scheffer, 1983; Kritzman, 1974, p. 176). The diurnal, grass-eating *L. curtatus* prefers habitats within stands of sagebrush, other shrubs, or at least thick grass cover, although it is still limited to arid regions; see Carroll and Genoways (1980) and the references therein. Times of abundant *L. curtatus* and scarce *P. parvus* therefore suggest a relative increase in vegetation, probably shrub cover. Scarce *L. cur-*

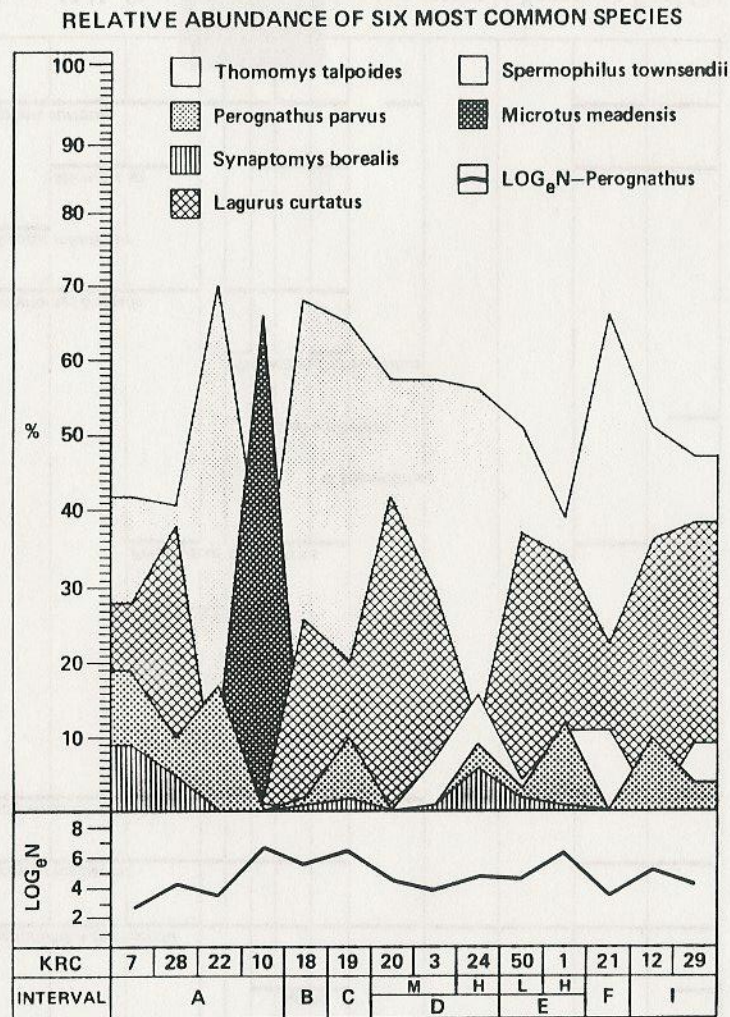


Figure 13.12. Relative abundances of six most common species at 14 best-represented sites in stratigraphic order from left to right. Percentages taken of total numbers of specimens of these six taxa. At bottom is natural logarithm of total number at each site, except *Perognathus parvus*.

tatus and abundant *P. parvus* imply the opposite. Four of the five percentage peaks for *L. curtatus* (at KRC-18, -20, -50, and -29) are stratigraphically just above calcretes, the presence of which also argues for increased vegetation and moisture. Above interval A the fluctuations in the percentage of *P. parvus* seem to correspond with short-term

fluctuations in the absolute abundance of the other taxa taken together, as indicated by the graph at the bottom of Figure 13.12.

Group 2. Taxa whose current habitats are diverse and distributions very broad: *Thomomys talpoides*, *Peromyscus maniculatus*, and *Neotoma cinerea*. Except for *N. cinerea*, these species have long, relatively continuous stratigraphic ranges in the Kennewick section (Figure 13.11). *T. cf. T. talpoides* ranges from the base to the top of the section. *P. maniculatus* has a relatively continuous range after its appearance in interval C. *N. cinerea* is found only in the upper part of interval D and in the modern fauna; its poor representation in the stratigraphic section is consistent with its usually sparse representation in the modern fauna (Bailey, 1936, p. 171).

Group 3. Taxa whose current climatic distributions are more boreal or more humid than the Kennewick region today: *Phenacomys cf. P. intermedius*, *Synaptomys borealis*, and *Sorex palustris*. *P. intermedius* inhabits mountaintops in open grass parks (Dalquest, 1948, p. 339; Guilday and Parmalee, 1972). *P. cf. P. intermedius* has also been reported from the Wisconsinan and mid-Holocene of the currently arid Great Basin of Nevada (Grayson, 1981). If this vole represents the related taxon *Arborimus longicaudus*, its preference today is for humid forests (Johnson, 1973). *Synaptomys borealis*, the bog lemming, is confined to alpine environments in Washington today (Dalquest, 1948; Ingles, 1965), and as its name implies, it prefers moist habitats. Presumably, other closely related congeners had similar general preferences. *Sorex palustris* prefers clear, cold streams of alpine cirques and mountainsides (Dalquest, 1948). The restriction of these taxa to the intervals beneath E suggests that the climate during deposition of the lower part of the section was cooler and wetter than at Kennewick today.

Group 4. Taxa whose current distributions are more southern than southeast Washington: *Neotoma lepida*, *Dipodomys ordii*, and *Dipodomys microps*. *D. microps* and *N. lepida* today occur only as far north as southeastern Oregon. *D. ordii* occurs in this region today, but this is its northernmost range for Washington, Idaho, and western Montana (it reaches the Canadian border and beyond in eastern Montana). None of these taxa is represented in the large collections from the two lowest intervals A and B. Their simultaneous appearances in the samples of interval C may reflect increasing aridity, because all are desert animals

(Bailey, 1936; Dalquest, 1948; Finley, 1958; Cameron and Rainey, 1972; Beatley, 1976).

Group 5. A taxon (*Sylvilagus idahoensis*) whose current distribution (Bailey, 1936, p. 110; Orr, 1940; Green and Flinders, 1980) is restricted to habitats with denser vegetation than exists in the area today (sagebrush, *Artemisia tridentata*, or rabbitbush, *Chrysothamnus*). *S. idahoensis* disappears after interval E, together with group 3 species that prefer cool, wet habitats.

To summarize:

1. The climate in general appears to have been arid in eastern Washington for as long as the section represents – at least 40,000 years and possibly as long as 328,000 years. Within this context there are indications of fluctuations in effective moisture.
2. During intervals A and B, conditions were wetter and cooler than those in that area today.
3. A major decrease in effective moisture occurred between intervals B and C, when desert species appear for the first time.
4. A second decrease in effective moisture and perhaps an increase in temperature occurred between intervals E and I, but the scarcity of fossils above interval E prevents determination of exactly when this event occurred.
5. There are indications of shorter-term fluctuations superimposed on the long-term drying trend. The simultaneous disappearance of *Neotoma lepida* and appearance of *Phenacomys intermedius* (or *Arborimus longicaudus*) and the slightly later appearance of *Neotoma cinerea* may reflect wetter and cooler conditions late in interval D than occurred in interval C. Two taxa with longer records, *Lagurus curtatus* and *Perognathus parvus*, show fluctuations in an inverse abundance relationship that are repeated in intervals A, C, D, E, and I, implying changes in shrub cover and the moisture that controls it.
6. There was a coexistence in intervals C through E of boreal (group 3) and southern desert (group 4) species that do not live together today.

Sympatry of currently allopatric species is common in late Quaternary sites of the northeastern and midwestern United States, where the assemblages have been termed “disharmonious” faunas or “no-analogue” faunas and explained by postulating a less strongly seasonal climate than today; see Graham and Lundelius (1984) and Lundelius

et al. (1983) and the references therein. Presumably winters in north-eastern and midwestern United States lacked extremely cold temperatures, perhaps because the Laurentide ice sheet restricted Arctic air to the polar region and split the jet stream (Wright, 1983; Kutzbach and Wright, 1985; Graham and Mead, 1987), and summers were cooler than today. Thus, species limited by winter extremes could have expanded their ranges to the north, and those limited by hot summers could have ranged farther south and to lower elevations. The northern migration of the group 4 species supports the idea of milder winters than we have today, because extremely low winter temperatures seem to limit both *Dipodomys microps* in Nevada (Beatley, 1976) and *Neotoma lepida* in Colorado (Finley, 1958). In addition, and perhaps alternatively, physical displacement by Cordilleran ice could explain the presence of boreal species (group 3), whose only option would be southward migration along suitable microhabitats in the Columbia River drainage. Although we cannot rule out minor stratigraphic mixing (see the earlier section on taphonomy), the observed amounts of bioturbation at most of the collecting sites are insufficient to support a contention that stratigraphic mixing by itself produced the no-analogue species associations.

Morphological changes within species

Recognition of local evolutionary changes in terrestrial species at the population level usually is hampered by discontinuities of preservation. Depositions in lowlands (where most thick sections accumulate) are intermittently reworked by braiding streams. The Kennewick deposit is unusual in that it was deposited at a high elevation, so that the stream activity at the lower elevations, even floods, apparently left it undisturbed.

Changes in the morphology of teeth are recognizable in the Kennewick species that are long-ranging and abundant. Some of the changes involve size, but others represent modifications of the shapes of occlusal structures.

Spermophilus townsendii. The sizes of the M^3 and P_4 in *S. townsendii* change through the stratigraphic section (Figures 13.13 and 13.14). The M^3 increases in width at interval B (Fisher's exact test gives a null probability of 0.037), with probably a further increase at interval C

Spermophilus townsendii

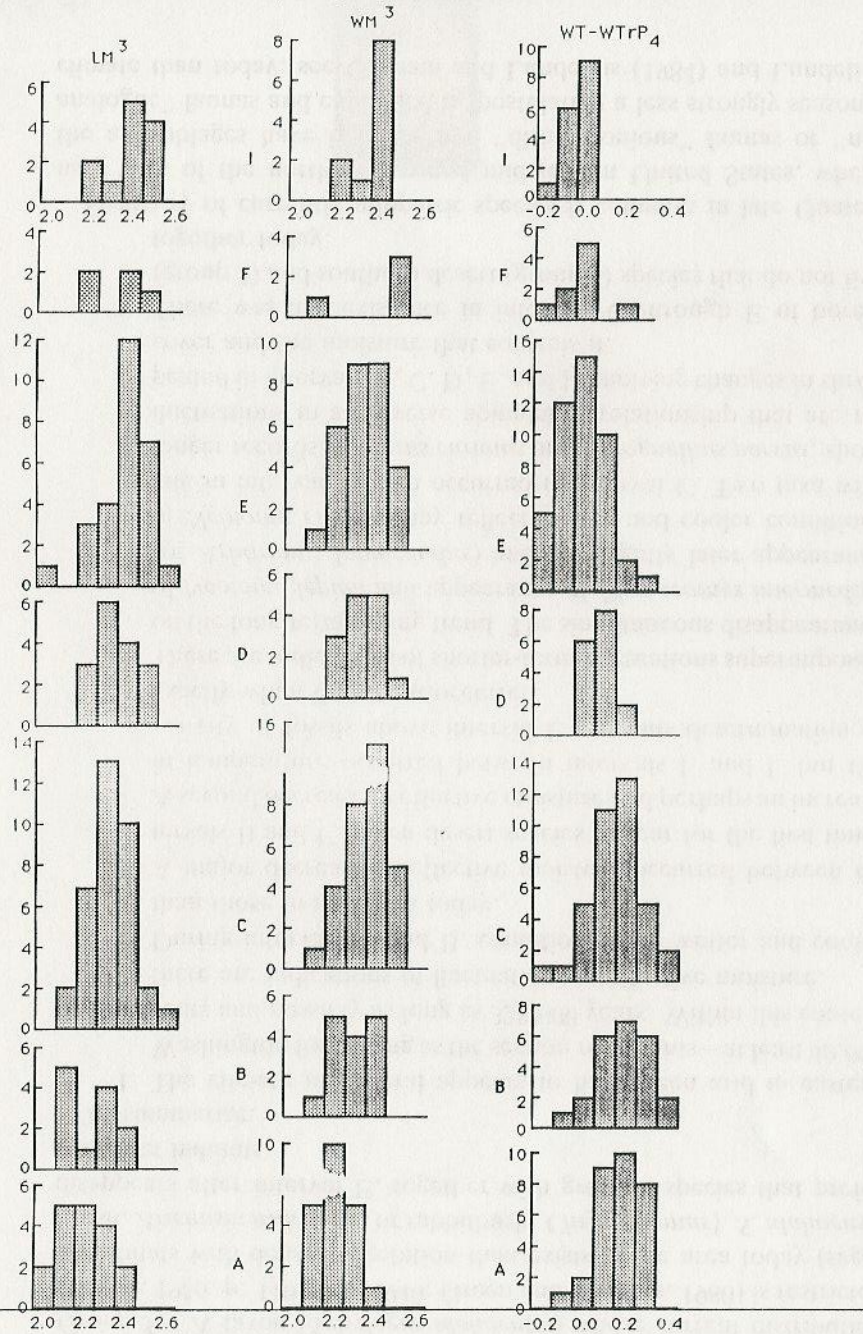
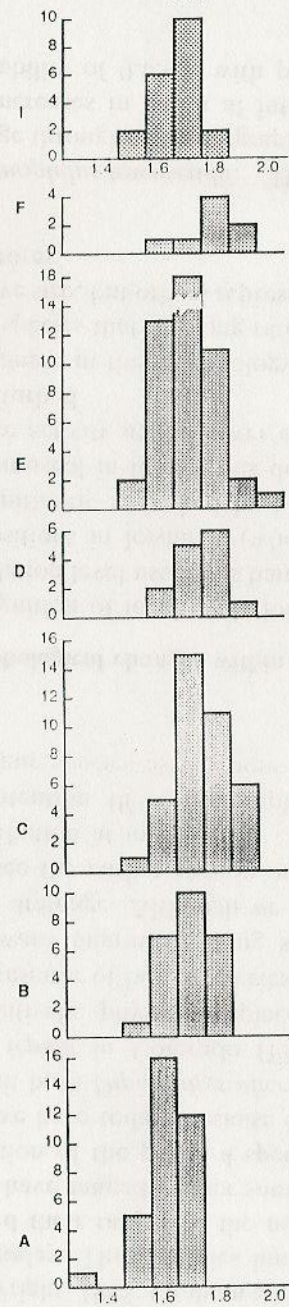


Figure 13.13. Frequency distributions of length and width of M³ and of difference in width of talonid and trigonid of P₄ (talonid minus trigonid) in *Spermophilus townsendii* at stratigraphic intervals A-I.

Spermophilus townsendii
LP/4



Lagurus curtatus
LM/1

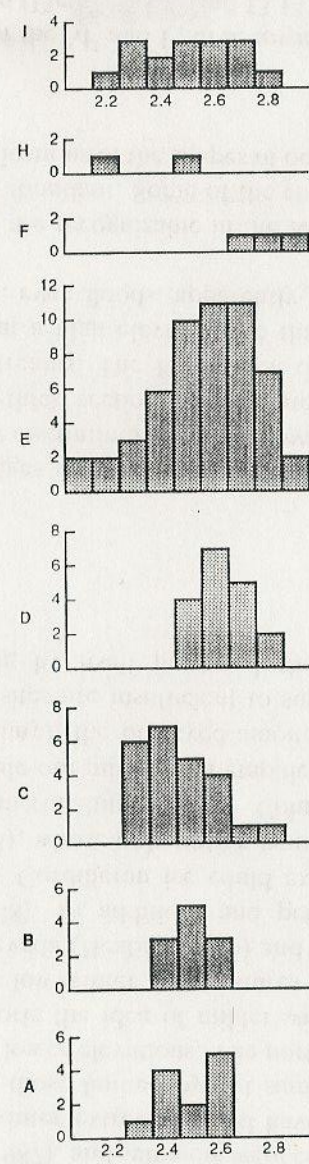


Figure 13.14. Frequency distributions of length of P₄ in *Spermophilus townsendii* (LP₄) and length of M₁ in *Lagurus curtatus* (LM₁) at stratigraphic intervals A-I.

($p = 0.074$). However, the ratio of width to length remains more or less constant throughout the section (Barnosky, 1987, p. 124).

The length of P_4 (Figure 13.14) increases from interval A to interval B ($p = 0.005$) and may again increase slightly at interval C ($p = 0.14$). Another increase seems to occur between intervals E and F ($p = 0.024$), but at interval I the size decreases ($p = 0.002$).

The talonid of P_4 is transversely wider than the trigonid (Figure 13.13) at intervals A through C, but becomes subequal to the trigonid at interval D (null probability for a change at C: 0.002) and increasingly narrower than the trigonid at KRC-01 of interval E ($p = 0.004$) and upward. The absolute width of the talonid increases from interval A to interval C ($p = 0.004$), but does not change above interval C.

Most of these changes represent variable-rate phyletic change, that is, the change continues through more than one superjacent interval, but in none of the characters do the changes continue in the same rate throughout the section. In LM^3 , WM^3 , and $WT-WTrP_4$ (Figure 13.13) there are net changes from bottom to top, but the changes occur in the lower three to four intervals. In three characters the population then reverts to true stasis (no change) in the upper three or four intervals, but in the upper four intervals the LP_4 mean appears to decline, increase, and then decline (i.e., stasis in the sense of "random" fluctuation around a mean).

Lagurus curtatus. The cheek teeth of *L. curtatus* increase in size at interval D. The size change is most pronounced in M_1 between intervals C and D (Figure 13.14), in which the length increases ($p = 0.002$). At interval E, the same modal values present at D persist, but the distribution is skewed and contains smaller individuals than are present anywhere in the lower intervals. It is possible that a less abundant population of smaller individuals is present at E. The small samples of intervals F and H further suggest two discrete populations of larger and smaller individuals. The bimodality of the larger sample in the overlying interval I is consistent with this interpretation. A reduction in size occurs between interval F and intervals H and I ($p = 0.018$).

The number of closed triangles on M_1 (Figure 13.15A) varies from four to five among the specimens of most intervals, but the percentage with five triangles increases upward through the section (Figure 13.16). At the top of the section, a few individuals have six closed triangles. At intervals A through C, about 35% of the specimens have five closed triangles, whereas more than 75% from interval D have five closed

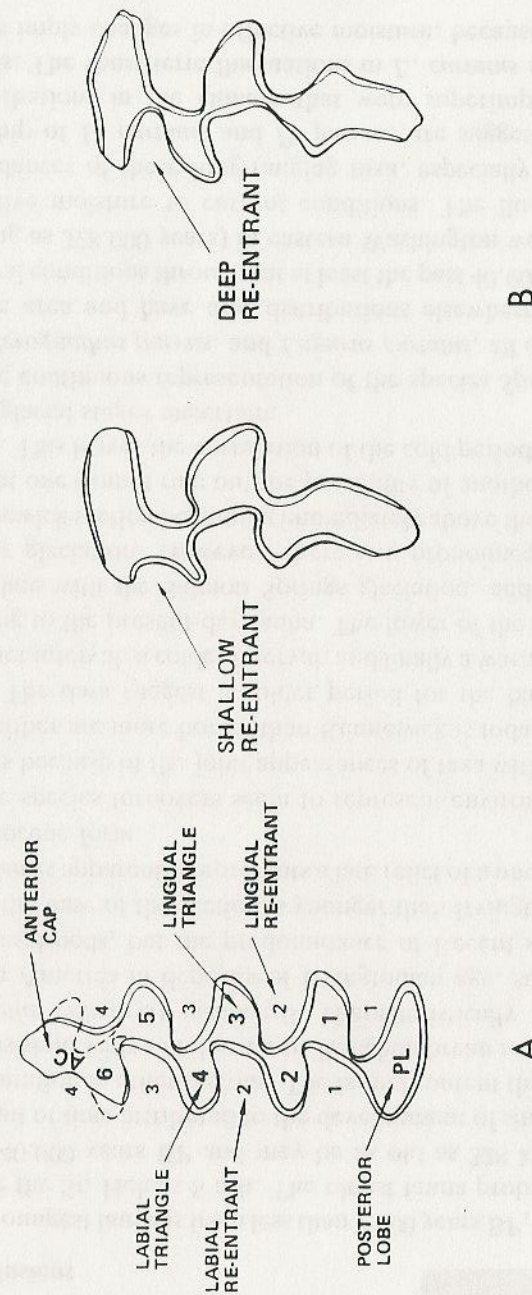


Figure 13.15. Molar structures in *Lagurus curtatus*. (A) Left M_1 with five closed triangles (solid line) and six closed triangles (dashed line). (B) Structure of M_3 showing shallow versus deep labial reentrant variants.

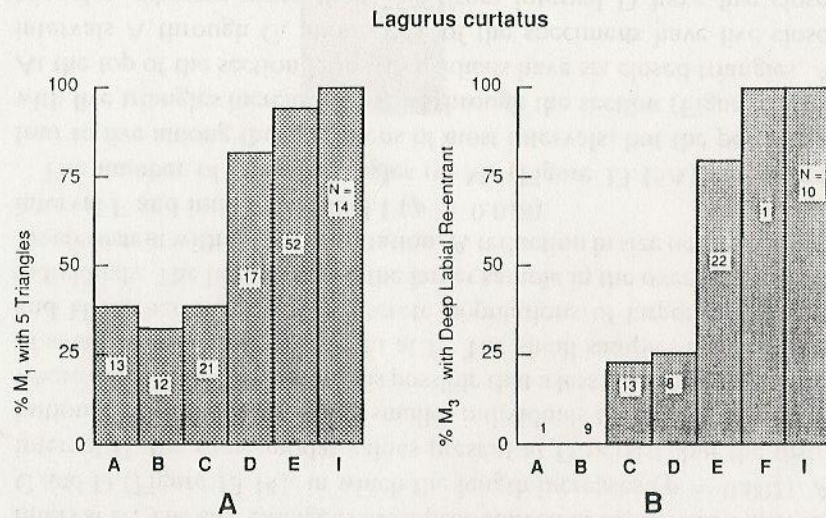


Figure 13.16. Vertical changes in molar structure in *Lagurus curtatus* through stratigraphic intervals A-I. (A) Frequencies of specimens with five triangles in M₁. (B) Frequencies of specimens with deep labial re-entrant in M₃.

triangles, and the difference is significant. From interval E upward, at least 90% of the teeth have five closed triangles. In the very large collection of interval E, one specimen has six closed triangles; in the smaller sample of interval I, two specimens have six closed triangles.

Another type of change in occlusal shape occurred in this species. The percentage of specimens with a deep labial reentrant on M₃ (Figure 13.15B) increased from the bottom of the section to the top. The frequency varied from zero at intervals A and B to almost 25% at intervals C and D, to more than 75% at interval E, and to more than 90% at intervals F and I (Figure 13.16).

The increase in size in *Lagurus* seems to have been confined to one interval (D) and presents a pattern suggestive of staircase evolution. Although some size differences exist in the higher intervals, these may reflect the existence in the region of more than one population or sub-population. Changes in occlusal shape involving increasing invagination of enamel reentrants appear more like variable-rate phyletic change and occurred (1) before the change in size occurred, (2) in the same interval that the size change occurred, and (3) in later intervals (E-I). It is possible that this pattern of change in occlusal shape (involving different positions changing at different times), like the size changes, is related

to the possibility that more than one subpopulation contributed to the fossil sample.

Conclusions

The youngest fauna is from less than 7,000 years BP, based on its position above the St. Helens S ash. The oldest fauna probably is from not less than 40,000 years BP and may be as old as 328 ka, judging from the amount of time attributed to the development of similar stages of calcite cementation in other regions. The faunal content throughout the section is consistent with a Holocene-to-Rancholabrean range. The extinct vole *Microtus (Pitymys) meadensis*, characteristically found elsewhere in North America in deposits of Irvingtonian age, suggests antiquity for the basal beds, but the predominance of Recent species suggests that even the base of the section is younger than Irvingtonian. *M. (Pitymys) meadensis* apparently represents a late relict of a once widespread earlier Pleistocene form.

The species turnovers seem to represent environmentally controlled events because of the joint appearances of taxa with present-day ranges that either are more boreal than Kennewick is today or are more southerly. The data suggest a colder period for the base of the section, a warmer interval, a colder interval, and finally a warmer interval probably leading to the present-day fauna. The lower of the colder intervals may correlate with the Salmon Springs glaciation, and the upper with the Fraser glaciation. However, there is a pronounced faunal gap in the Kennewick section beginning immediately above the second cold period, so that one cannot rule out the possibility of another unseen fluctuation there. This leaves the correlation of the cold periods with Pacific Northwest glacial stages uncertain.

The continuous representation of the species *Spermophilus townsendii*, *Perognathus parvus*, and *Lagurus curtatus*, all of which occur today in the area and have arid distributions elsewhere, indicates that the general conditions throughout at least the past 40,000 years (and possibly as long as 328,000 years) in eastern Washington were grossly similar in effective moisture to current conditions. The fluctuations in relative abundances of these long-ranging taxa, especially the reciprocal relationship of *L. curtatus* and *P. parvus*, are suggestive of shorter-term perturbations in the climate that were superimposed on the longer trends. The short-term fluctuations in *L. curtatus* and *P. parvus* themselves imply changes in effective moisture, because *L. curtatus* prefers

substantial stands of low vegetation, whereas *P. parvus* prefers dry desert soils.

Most of the within-species changes in morphology appear to have been independent events in each lineage. The main changes in *S. townsendii* involved the size of the teeth and are explainable as variable-rate phyletic evolution. Changes in relative dimensions of both the P_4 and M^1 exhibit stasis. Several of the changes in *L. curtatus* happen to have corresponded to times of immigration of other taxa, but whether these apparent morphological changes reflect immigration of allopatric demes or evolution within one deme cannot be determined without the availability of similar morphological data about *Lagurus* from other regions. The changes in occlusal crests in *L. curtatus* represent long-term evolutionary changes in the population, whether or not the speed of change was influenced by immigrants interbreeding with the previously established deme. These variable-rate phyletic changes include (1) the proportion of specimens with five closed enamel triangles increasing upward through the section, from 50% at the base to over 90% at the top, with a few specimens at the top even having six triangles, and (2) the proportion of specimens with a deep labial enamel reentrant on M^1 increasing from zero at the base of the section to more than 90% at the top.

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