

The Enterprise Gravel: The Ancestral Wallowa River and Neotectonism in Northeastern Oregon.

Abstract

The Enterprise Gravel includes silt, sand, gravel, diamict, two paleosols, and the Chief Joseph tephra. It includes a well-preserved assemblage of vertebrate fossils in exposures in the Joseph Upland north of Wallowa Lake, northeastern Oregon. Based on fission-track age and magnetic polarity, the Enterprise Gravel is late Pliocene to middle Pleistocene in age. Sedimentologic criteria suggest that exposures of the Enterprise Gravel represent deposits of the ancestral Wallowa River flowing northward across the Joseph Upland. Modern drainage patterns indicate that the region underwent deformation after deposition of the Enterprise Gravel, which caused drainage reversal and realignment of the course of the Wallowa River.

The Enterprise Gravel is unique in that it preserves the previously unknown Chief Joseph tephra, and one of few vertebrate fossil assemblages of late Pliocene to mid-Pleistocene age in the Pacific Northwest. Study of the deformation of the Enterprise Gravel adds to the existing knowledge of the neotectonic history of the region.

Introduction

Location and Previous Work

The study area extending from a moraine complex at Wallowa Lake to the valley of Trout Creek some 15 km north of Enterprise, along the northeast face of the Wallowa Mountains (Figure 1) includes sediments that overlie the Miocene Columbia River Basalt Group. These sediments comprise a sequence of Quaternary fluvial and glaciofluvial sand, silt, and gravel (Crandell, 1967). Newcomb (1969) briefly described the geology and physiography of the region north of Enterprise, which he termed the Joseph Upland.

The bedrock and sediment cover of the region was mapped by Walker (1977, 1979); he included the Enterprise Gravel of this report with the Pliocene McKay gravels, the bulk of which are exposed to the northwest in the Pendleton region (Baldwin, 1986).

Significance of Study

In this study we define and characterize the Enterprise Gravel, and propose mechanisms by which it was deposited. The interpretation of the origin, age, and significance of the Enterprise Gravel involved integration of geomorphology, sedimentology, paleontology, and structural geology, plus various methods of age-determination. This interdisciplinary approach to problem solving resulted in a better understanding of the late Cenozoic geologic history of the Wallowa Lake region.

The Enterprise Gravel

Definition and Type Locality

The Enterprise Gravel is here defined as a sequence of silt, sand, diamict, and gravel exposed between the town of Joseph and the drainage divide between the Grande Ronde and Wallowa Valleys (Figure 1). The name is derived from the town of Enterprise, Oregon, and a type locality (indicated as site 5 on Figure 1) is designated at outcrops along Highway 82 west of Enterprise. The type locality is in the NW 1/4 of sec. 2 and the NE 1/4 of sec. 3, T.2S., R.44E. Between the Chief Joseph Monument and downtown Enterprise are about 0.5 km of outcrops of the Enterprise Gravel on the north side of Highway 82.

Distribution and Topographic Expression

The Enterprise Gravel is exposed in terrace segments north of Joseph and also flanking the valley of Trout Creek north of Enterprise (Figure 1). The best exposures are in a roadcut west of Enterprise and in about a dozen gravel pits scattered across the study area.

The Enterprise Gravel is easily distinguishable on the basis of topographic expression, from the gravel, sand, and silt of the youngest outwash plains and the modern floodplains along Hurricane Creek and the Wallowa River. Figure 2a (section A-A', Figure 1) shows a topographic cross-section from moraines at Wallowa Lake north to Enterprise; Figure 2b (Section B-B', Figure 1) is from Sheep Ridge in the Wallowa Mountains northeastward to Enterprise. The outwash plain is graded from the outlet

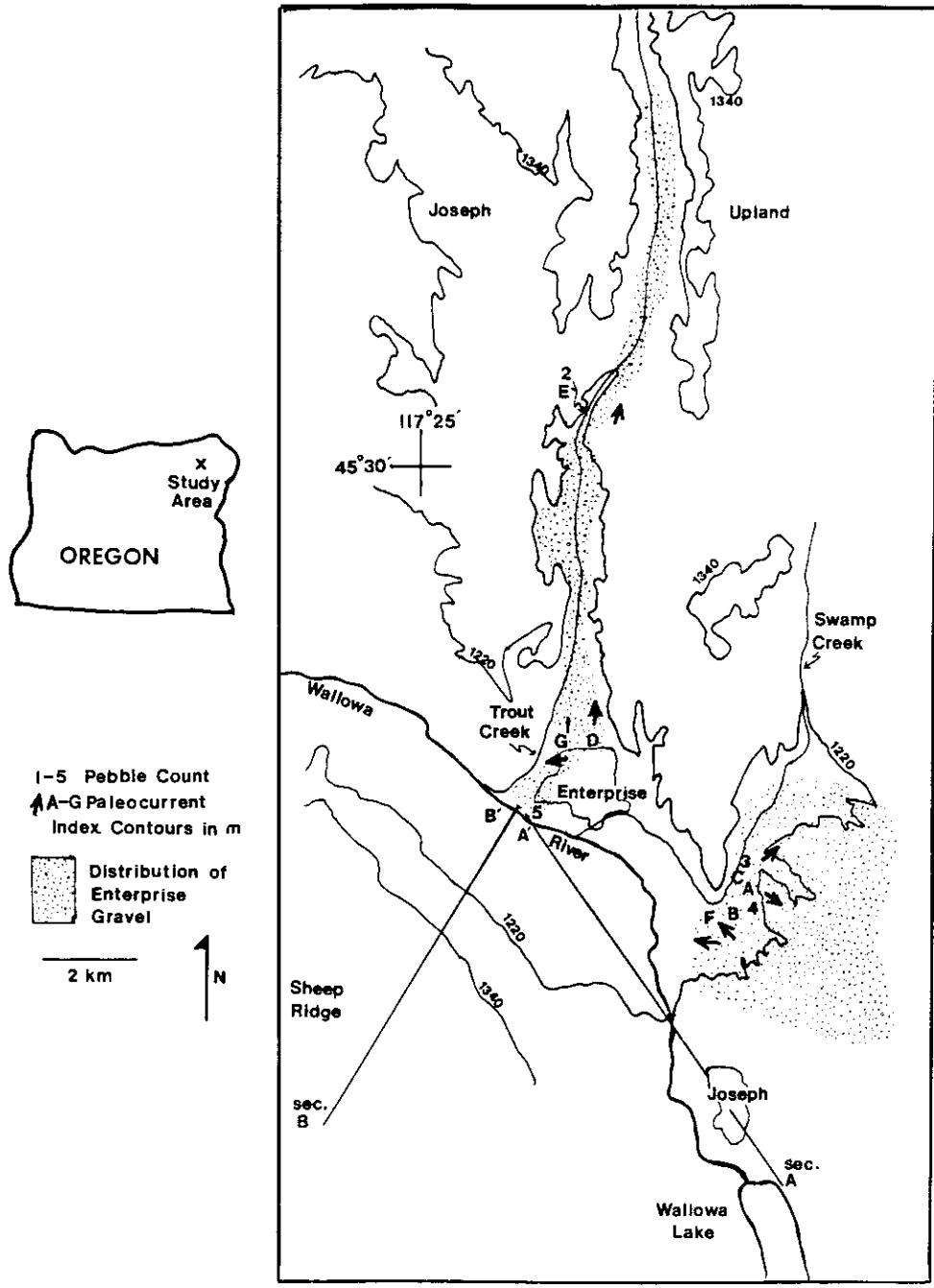


Figure 1. Index map of the Wallowa Lake-Joseph Upland region showing approximate distribution of the Enterprise Gravel (shaded pattern); pebble count locations (1-5); paleocurrent locations (A-G; arrows indicate approximate average paleocurrent for each site); and cross-section lines.

for Wallowa Lake to the modern floodplains of Hurricane Creek and the Wallowa River. Alluvial fans of Alder Slope flanking the study area to the west and southwest are also graded to the modern rivers. Terrace segments and outcrops of the Enterprise Gravel stand topographically above the modern floodplain surfaces and appear to be erosional remnants of a more ancient topographic surface.

Measurements with a surveying altimeter of surface altitude of terraces composed of Enterprise Gravel show that the upper surface of the Enterprise Gravel at the type locality is 30 meters above Hurricane Creek (Figure 2a). Between Joseph and Enterprise the upper surface of the Enterprise Gravel decreases in elevation in a northwesterly direction, consistent with the gradient of the Holocene floodplain and defining the slope of the ancient topographic surface. In the Trout Creek valley the surface of the Enterprise Gravel increases from 1174 meters at the type locality (Loc. 5, Figure 1) to a maximum of 1250 meters at a point 15 km north of Enterprise. The south-sloping gradient is 5.6 m/km.

Sedimentology and Facies

The Enterprise Gravel comprises a sequence of massive to well-stratified silt, sand, diamict, and gravel with complex facies associations. In addition, a tephra horizon is preserved, along with a B-horizon paleosol. At the type locality, the facies used to define the Enterprise Gravel are well-developed. Exposures at other localities are less variable, but can be linked to the type locality based on criteria such as terrace-surface elevation, soils, clast lithology, sedimentary structures, and sedimentary textures. Figure 3 shows idealized facies relationships in a composite stratigraphic column.

Facies Units

Silt Facies: At the type section silt facies generally occur as localized lenses bounded by erosional surfaces. Silts are massive, moderately well-sorted, and poorly indurated. This facies also contains caliche-coated root casts. At other localities, silts occur as rip-up clasts.

Sand Facies: Sand occurs primarily as lenses bounded by erosional lower contacts and either erosional or gradational upper contacts. This

facies displays poor sorting, with significant proportions of silt and fine gravel in most lenses. Planar and trough cross-stratification is common.

Gravel Facies: Gravel is abundant at the type locality and is the dominant textural component of other localities. Nearly all of the gravel is sandy, clast supported, and silt-poor. Lower contacts are erosional and commonly trough shaped; the scale of troughs is about 0.5 meter and they display cross-stratification. Upper contacts are erosional or gradational with sandy intervals.

Diamict Facies: In addition to the silt, sand, and gravel, the Enterprise Gravel includes massive, very poorly sorted diamict exposed at the type and other localities. Diamicts are matrix-supported and contain angular clasts.

Palcosol Facies: A well-developed, purplish, clayey B-horizon palcosol is persistent across the exposed section at the type locality. This unit is present at other outcrops of the Enterprise Gravel as rip-up clasts but has not been recognized in place.

Additionally, the Enterprise Gravel is capped by a well-developed pedocal. This facies is not exposed at the type locality, but is present at the top of most of the remnant terrace segments in the study area. The stage of development of this soil suggests that it is associated with the Enterprise Gravel rather than with the Holocene soil, and that it represents a period of soil development preceding dissection of the ancient surface of the Enterprise Gravel.

Tephra Facies: Associated with the B-horizon soil is a tephra, here named the Chief Joseph tephra (CJt). The CJt is discontinuous at the type locality, and has not been recognized at any other exposure of the Enterprise Gravel. It ranges in thickness from one to about ten centimeters and is preserved as a horizon in the silt facies.

Vertebrate Fossil Facies: Near the top of the type section vertebrate fossils comprise a diverse, well-preserved suite of large and small mammals, including a *Perissodactyl* (horse), a suid (wild pig), a canid (wolf or coyote), and at least one bird. Fossils have been recovered in other parts of the type locality and at other localities, but these are rare and in poor condition. Spencer and Barnosky (1986) studied some of the taphonomic aspects of the fauna and proposed several explanations for the excellent preservation.

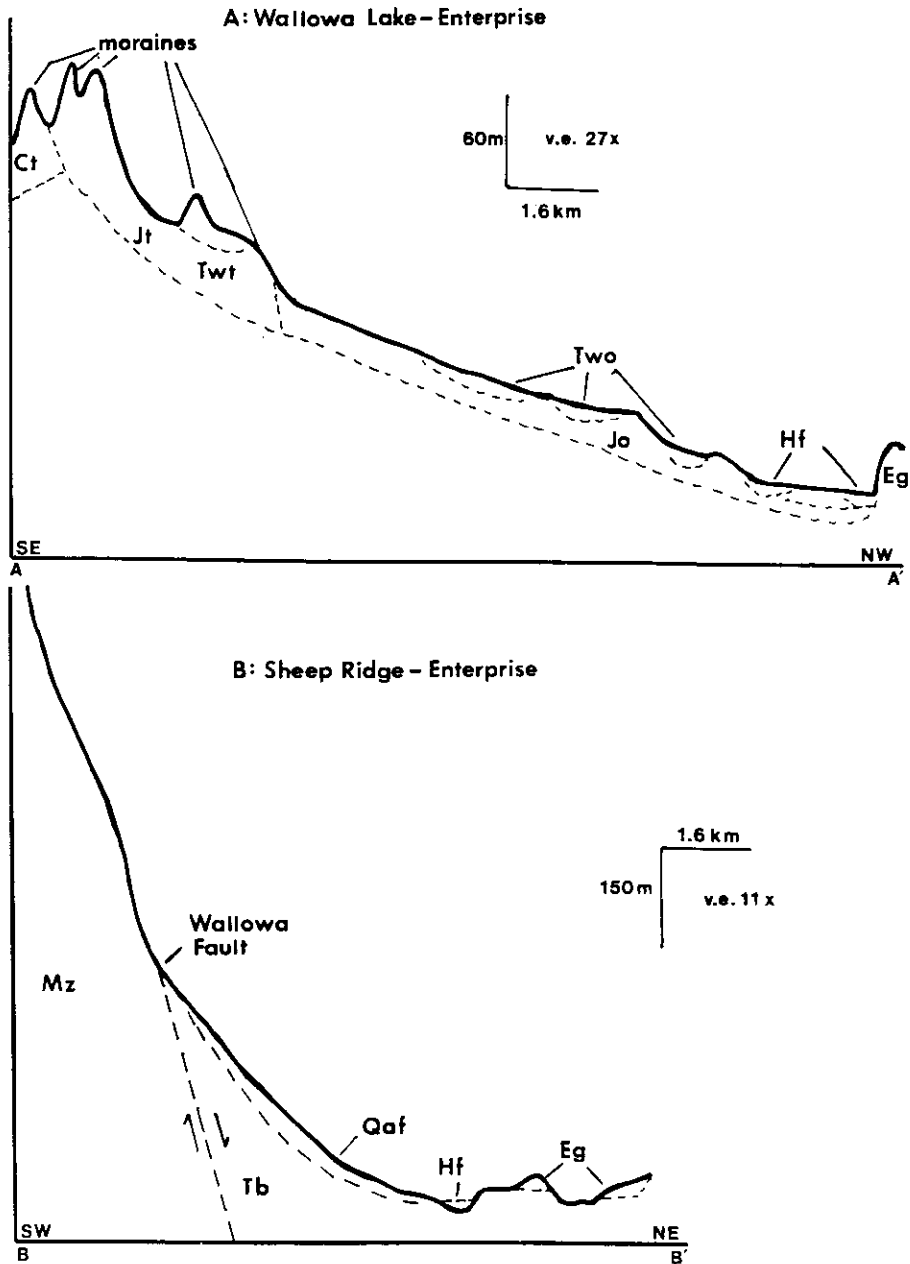


Figure 2. Cross-sections showing topographic relationships between the Enterprise Gravel and surrounding region. 2A (section A-A', Figure 1): From moraine complex at Wallowa Lake to type locality of Enterprise Gravel (drift units those of Crandell, 1967; EG-Enterprise Gravel; HF-Holocene floodplain). 2B (section B-B', Figure 1): From Sheep Ridge, Wallowa Mountains, to north of type locality of Enterprise Gravel (EG-Enterprise Gravel; HF-Holocene floodplain; Qaf-Quaternary alluvial fans; Tb-Columbia River Basalt Group; Mz-Mesozoic rocks).

Sedimentary Structures

Sedimentary structures in the Enterprise Gravel are numerous and diverse, the variety reaching a maximum at the type locality. Scour and fill features are abundant and associated with every depositional unit. Cross-stratification is common in the sandy intervals and present in some of the gravelly units. Parallel stratification is also well-developed in some of the sandy and gravelly units. Many of the gravel, diamict, and silt beds are massive.

At other localities, variability in the types of structures represented is minimal. Generally these supplementary sections display massive gravel beds, with scour and fill features well-developed, and massive diamicts. Cross-stratification is developed in the sandy intervals. Rip-up clasts of silt and fine sand are present in most sections.

Sedimentary Textures

Grain Size and Sorting: Except for the CJt and the paleosol, facies of the Enterprise Gravel are poorly sorted. Gravel units range in grain size from pebbles to cobbles with a coarse sandy matrix. Sandy intervals range from medium sand to granules and pebbles commonly with silt. Silty units range from medium and fine silt to medium sand. The diamicts contain pebbles and cobbles and are matrix-supported.

Grain Shape: The granular facies of the Enterprise Gravel exhibit well-rounded clasts. Diamict facies exhibit both angular and rounded clasts.

Contacts

The Enterprise Gravel rests unconformably upon the Miocene Columbia River Basalt Group. This contact can be observed at the type locality west of Enterprise. At other localities the basal contact cannot be observed, but can be inferred by the presence in close proximity of exposures of Enterprise Gravel and Columbia River Basalt.

The upper contact, marked by a well-developed pedocal, represents a period of non-deposition and soil formation. At the type and other localities, this soil is overlain by late Quaternary loess.

Clast Lithology

Clast counts of Enterprise Gravel were conducted at five gravel pits (Pinney *et al.*, 1986) to determine the provenance, whether the Wallowa Moun-

tains to the southwest, or the exposed basalt in the Joseph Upland to the north. At each pit, multiple beds were sampled. Data are summarized in Figure 4.

Three categories reflect lithologic types that predominate in the region: basalt, metamorphic and metasedimentary, and intrusive. Basalt is exposed north of the study area and capping the high peaks of the northern Wallowa Mountains (Walker, 1977, 1979). Also exposed in the Wallowa Mountains are late Mesozoic intrusive rocks, and a diverse suite of older Mesozoic and Palaeozoic metamorphic (mostly greenstone and marble) and sedimentary rocks (mostly sandstone, siltstone, shale, and limestone) (Walker, 1977, 1979; Armstrong *et al.*, 1977; Armstrong, 1978; Brooks and Vallier, 1978).

Pebble count data shows a predominance of basalt and metasedimentary clasts in most exposures of the Enterprise Gravel, and an anomalously low proportion of intrusive rocks. Although this could reflect the fact that the intrusives were relatively recently unroofed by fluvial and glacial processes, it is more likely a reflection of the widely-spaced joint sets developed in the intrusive rocks, which would produce clasts too large to be transported as outwash.

Paleocurrent Indicators

The azimuth of inclination of cross strata was measured at seven different localities in the Enterprise Gravel (A-G, Figure 1). Localities A, B, C, and F, representing terrace remnants adjacent to the late Pleistocene outwash plain, show the most variation in paleocurrent direction, and suggest a depositional mode of constantly and randomly shifting current directions. Those localities along the modern Trout Creek valley (D, G, and E) indicate a variable-direction current, but preferentially to the north.

These data are consistent with pebble count data suggesting a source area in the Wallowa Mountains, with sediment spread northward from Wallowa Lake, and additional sediment from the Wallows distributed via the alluvial fans at the foot of Sheep Ridge across the area in various directions. Sediment found in the Trout Creek valley was confined to the valley and shows north paleocurrent dominance along the valley axis.

The paleocurrent data is consistent with modern drainage patterns on the late Pleistocene

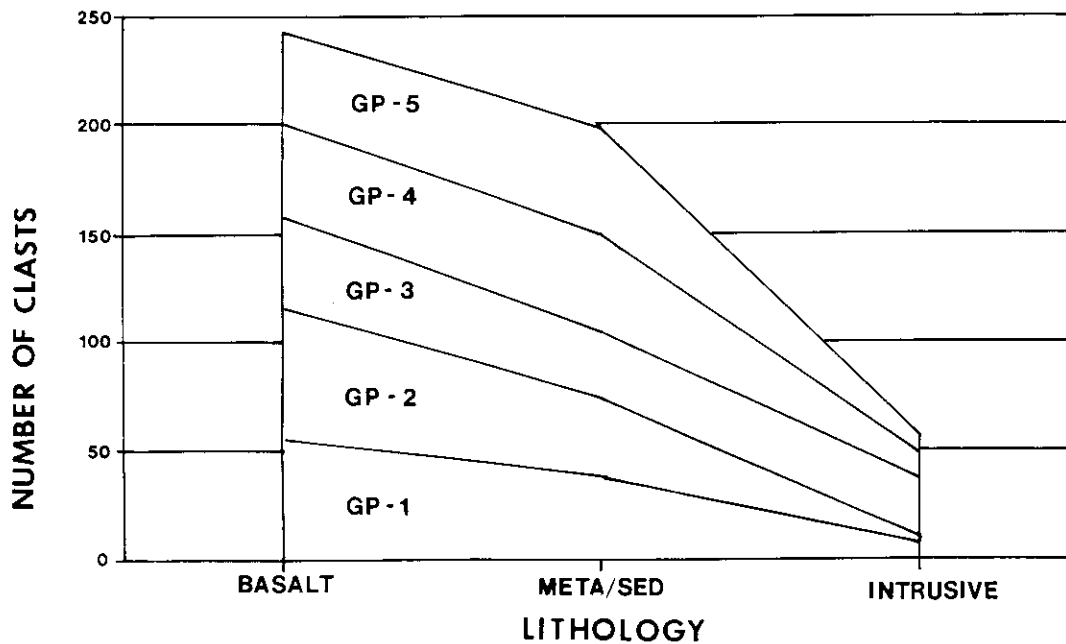


Figure 4. Summary of pebble count data (GP-1 through GP-5; gravel pits). Locations shown on Figure 1 (1-5).

outwash plain and alluvial fans. But Trout Creek presently drains the Joseph Upland in a southwestward direction to the west of Enterprise, where it joins the Wallowa River and flows northwestward. The paleocurrent data, with a predominant northerly component along Trout Creek, opposes the modern drainage and suggests that since deposition of the Enterprise Gravel, drainage in the Trout Creek valley has reversed. This relation was mentioned by Newcomb (1969); he attributed the reversal in drainage direction to downwarping of the syncline in which the modern Wallowa River flows, resulting in capture of the drainages of formerly north-flowing streams.

Depositional Mode of the Enterprise Gravel

Grain-size distribution of the sediment of the Enterprise Gravel, varying from silt through cobbles, suggests a depositional system characterized by variable energy conditions from relatively high (minimum transport velocity 1 m/sec) to nearly zero for fine-grained units. The absence of clay in the samples suggests that while energy was low at times, there was enough current to keep the finest material in suspension. The dominance of coarser sediments at most localities suggests that overall,

the depositional mechanism of the Enterprise Gravel was characterized by high energy.

Variation in paleocurrents suggests randomly and constantly shifting current direction: highly variable where unconfined by topography south of Enterprise but less variable where confined by topography in the Trout Creek valley.

Massive beds, trough cross-stratification, rip-up clasts, and abundant scour and fill features suggest rapid deposition of sediments as well as active erosion. Diamicts at many exposures of the Enterprise Gravel reflect periodic contribution of catastrophic events of rapid deposition, probably mudflows. These could have been introduced into the Enterprise Gravel via the alluvial fans of the Alder Slope, or as sediment derived from moraine bursts or jökulhlaups at Wallowa Lake.

The Enterprise Gravel represents a braided stream complex associated with a glaciofluvial environment. The subenvironments represented at the type locality are those of coarse-grained channel bars (gravel and sand), inactive channels and backwaters (silt), and exposed interchannel areas (B-horizon soil and root casts). At other localities, subenvironments represented include channels and channel-bars.

We propose that the Enterprise Gravel represents the deposits laid down by the ancestral

Wallowa River flowing northward from Wallowa Lake across the Joseph Upland to the Grande Ronde River.

Age of the Enterprise Gravel

Relative Age Criteria

Weathering rind thickness was measured on 79 clasts of basaltic composition from the terrace surface at the type locality. The mean weathering rind thickness is 0.3 mm ($\sigma = \pm 0.3$ mm). Comparison of this mean with results obtained by Colman and Pierce (1981) suggests an age of 20,000 to 40,000 years. Colman and Pierce (1981, p. 14) suggest that "the development of rinds is inhibited in dry, continental climates, especially where calcium carbonate accumulates within the soil." The age of the Enterprise Gravel is probably greater than indicated by data from the basalt weathering rinds.

Absolute Age Criteria

Magnetic Polarity

The CJt was analyzed in the field using a portable specimen magnetometer. In addition, a sample was excavated and laboratory paleomagnetic analysis was performed (Easterbrook, pers. comm.). Both field and laboratory analyses yielded a reversed magnetic signature (Spencer *et al.*, 1989). The most recent reversed polarity epoch was from 2.43 to 0.7 Ma; therefore the CJt is probably at least 700 Ka.

Fission Track

The CJt was processed for zircon grains to obtain a fission track age. The CJt is zircon poor, but enough grains were extracted to obtain a reasonable age.

The total age range of zircons from the CJt was from >8 Ma to about 1.8 Ma. The oldest grains were most likely accidental, and were disregarded. Fission track analysis of seven grains presumed to be primary give an age of 3.0 Ma (± 0.9 , 2 σ). Figure 5a, showing the individual curves for seven grains, shows two clusters of curves; one of these centers on an age of 3.65 Ma, the second on 1.9 Ma. Two possibilities can explain these data: first, that there was a major volcanic eruption at about 3.0 Ma; second, that there were two eruptions, one at 3.65 Ma that provided accessory grains for a second eruption at 1.9 Ma.

The youngest cluster of essential grains indicates a minimum age for the Chief Joseph tephra and thus the Enterprise Gravel, of 1.9 Ma (± 1.1 , 2 σ), or late Pliocene to middle Pleistocene (Spencer *et al.*, 1989). Paleomagnetic data further constrain the age to a reversed polarity interval, most likely the Matuyama Reversed Polarity Epoch (ca. 2.43-0.7 Ma) (Figure 6).

Fauna

At the type locality of the Enterprise Gravel, a diverse and well-preserved vertebrate fauna has been recovered (Spencer *et al.*, 1985). Aspects of its preservation were discussed by Spencer and Barnosky (1986).

The fauna comprises an assemblage of large and small vertebrates, including partial remains of a perissodactyl (*Equus*), a suiid (wild pig), at least one carnivore tooth (*Canis?*), numerous small mammal bones, and at least one bird bone. Other localities in the Enterprise Gravel have not produced fossils, except for locality G (Figure 1) where a large scapula was recovered; based on its size, it is probably a mammoth or mastodon.

The fossils, particularly the perissodactyl, are in exceedingly good condition, despite the fact that they were recovered from diamicts overlying gravel. Many of the individual fossil elements display no evidence for post-mortem transport or abrasion, or post-burial dissolution or weathering (Spencer and Barnosky, 1986).

The primary significance of the fauna of the Enterprise Gravel is that it represents the first well-documented vertebrate fauna in the region, and thus may establish a standard for correlation with similar-aged deposits elsewhere in the West. Fission-track and paleomagnetic data on the CJt establishes the age of the Enterprise Gravel as late Pliocene to middle Pleistocene; the fauna may thus be assigned to the late Blancan to early Irvingtonian land mammal stages. Based on data in Kurtén and Anderson (1980), the Enterprise fauna represents the only vertebrate fauna of Blancan or Irvingtonian age in the state of Oregon, and one of few in the greater Pacific Northwest region.

Tectonic History of the Enterprise Gravel

The Enterprise Gravel was deposited by the ancestral Wallowa River flowing north along Trout Creek valley. The gradient of the modern Wallowa River is 9 m/km from Enterprise 15 km northwest

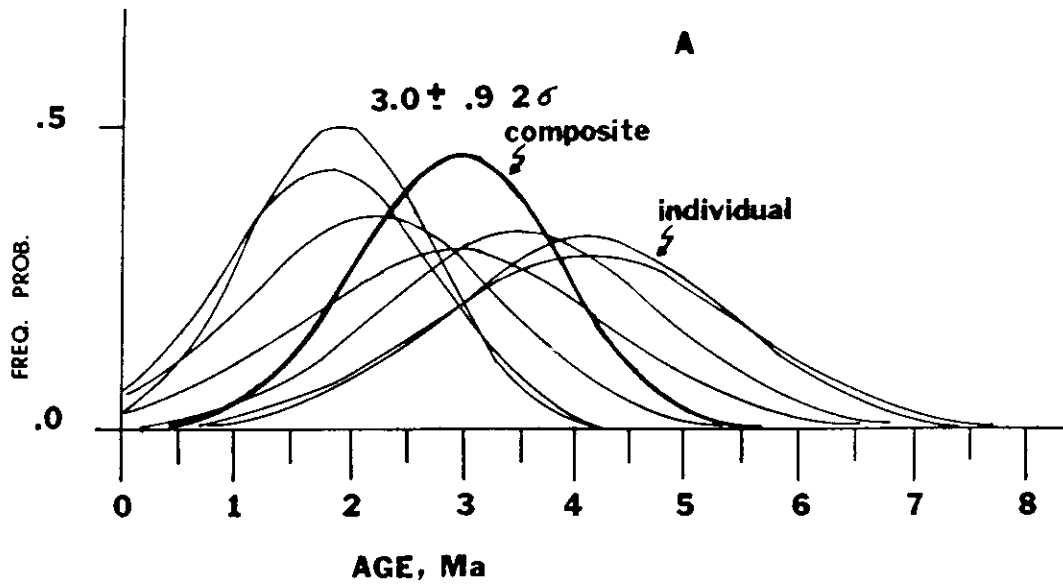


Figure 5. Summary of fission track data from the Chief Joseph tephra at the type locality of the Enterprise Gravel. 5A: Frequency probability curves for seven grains with composite curve and indicated age-range. 5B: Frequency probability curves for three grains clustered at low end of age-range, indicating minimum age for Enterprise Gravel of mid-Pleistocene.

to Lostine—approximately the gradient expected for the Enterprise Gravel between the type locality at Enterprise and gravel pit E (Figure 1). The slope of the upper surface (paleosol) of the Enter-

prise Gravel is 5.6 m/km southward along Trout Creek valley. The slope of the contact between the basalt and the Enterprise Gravel was not observed. If the original grade of the ancestral Willowa River

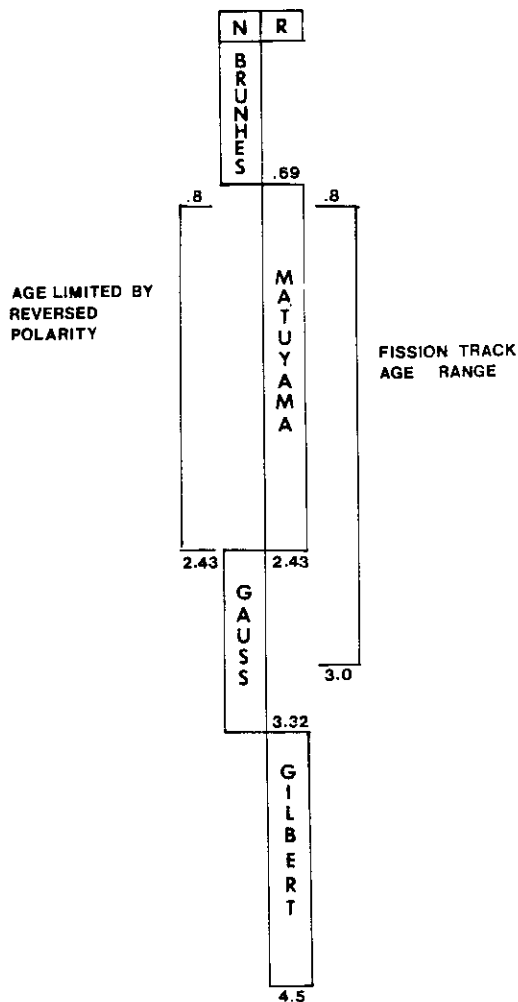


Figure 6. Summary of fission track and magnetic polarity data from the Chief Joseph tephra at the type locality of the Enterprise Gravel. Age of 2.43-0.8 Ma suggested by minimum fission track age and reversed magnetic polarity.

was 9 m/km northward, the Enterprise Gravel (and therefore the northern part of the Joseph Upland) has been tilted southward about 15 m/km since the late Pliocene or early Pleistocene. The northward paleocurrent indicators of the Enterprise Gravel contrast with the southward flow of the modern Trout Creek.

There was considerable tectonism in the Wallowa Mountains during the Cenozoic. Well to the north of Enterprise the antinodal uplift of the Blue Mountains occurred, and just south of Enterprise,

the Wallowa Mountains rose along the Wallowa Fault. The Wallowa Fault runs along the base of the northeast side of the Wallowa Mountains, and flanks the study area on the southwest. This fault is part of the Olympic-Wallowa lineament (as defined by Raisz, 1945), which extends northwest from the Wallawas across Washington.

The altitude of the top of the Columbia River Basalt Group atop Sheep Ridge compared to that on the adjacent Joseph Upland, indicates movement along the Wallowa Fault of at least 1500 m vertically since Miocene time. But Imnaha Basalt flows (c. 17 Ma) are exposed atop the Wallowa Mountains, whereas Grande Ronde Basalt flows (c. 16 Ma; stratigraphically above the Imnaha) crop out in the Joseph Upland (Steve Reidel, pers. comm.). Vertical displacement may be closer to 2 km.

According to Newcomb (1969), deformation of the south part of the Joseph Upland was a result of downwarping of a suspected syncline, whose axis trends northwest along the course of the Wallowa River. There are, however, several possible explanations for the drainage reversal of the ancestral Wallowa River.

- A. Synclinal downwarping of the Wallowa Valley and anticlinal uplift of the Joseph Upland (Newcomb, 1969).
- B. Graben development in the Wallowa Valley. The Wallowa Fault forms the southwest border of the graben. According to Steve Reidel (pers. comm.), digital photography suggests the presence of an east-west trending, down-to-the-south fault between Enterprise and the Joseph Upland, which may be a splay of the Olympic-Wallowa Lineament.
- C. Down-to-the-south step faulting between the Wallowa Valley and the Joseph Upland.
- D. Listric faulting along the Wallowa Fault resulting in rotation (southward tilt) of the Joseph Upland.

It is unclear which relationship exists. Any combination of tilting, folding, and faulting resulting in the relative uplift of the Joseph Upland would have reduced the gradient of the ancestral Wallowa River and increased the likelihood of stream capture and drainage reversal. The canyon of the Grande Ronde River with its well-developed incised meanders indicates substantial late Cenozoic uplift of the Joseph Upland.

Within the area of the terrace segments and exposures of the Enterprise Gravel there is no field evidence for down-to-the-south faulting. Elevations of the carbonate-capped terrace segments indicate down-to-the-south tilting. As the north flow of the ancestral Wallowa River was being defeated by whatever mechanism, it was captured by a tributary of the Grande Ronde River located in the depression just northeast of the Wallowa Fault. Once the Grande Ronde tributary captured the ancestral Wallowa River, it became the modern Wallowa River.

Summary

The Enterprise Gravel, as newly defined in this report, comprises a sequence of sediments including sand, silt, gravel, diamict, two ancient soils, and a tephra. The environment of deposition of these sediments seems to be that of a braided-stream complex derived from the glaciers which once occupied the Wallowa Lake area, and alluvial fans on the Alder Slope to the southwest of the study area. Transport of the sediments was northward. Reversal of drainage direction was caused by tilting that was likely related to faulting associated with the Olympic-Wallowa Lineament. The distribution of the Enterprise Gravel defines the course of the ancestral Wallowa River, which moved to its present course probably in the Pleistocene, resulting in capture of the predominantly northward-flowing streams.

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The diamicts in the Enterprise Gravel indicate that catastrophic events of sedimentation, possibly related to moraine bursts or jökulhlaups at Wallowa Lake or mudflows from the humid alluvial fans to the west, periodically discharged large volumes of sediment instantaneously.

Fission track and paleomagnetic data loosely constrain the Enterprise Gravel to an age of late Pliocene to middle Pleistocene. The fauna of the Enterprise Gravel represents the first recorded occurrence of Blancan or Irvingtonian vertebrates in the state of Oregon, and one of few such sites in the greater Pacific Northwest region.

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