NW mocpit

Geomorphology, Stratigraphy, and Soil Interpretations, Willamette Valley, Oregon

Frank Reckendorf [1]

Abstract

This paper presents a chronological sequence of geomorphic surfaces and associated soils for the Willamette Valley. The oldest surfaces described are Middle Pleistocene (about 200 ka yrs.) Eola surfaces, with soils that vary from Xeric Haplohumults to Andic Fragiumbrepts. When devoid of vegetation the sloping Haplohumults tend to have high sheet and rill and ephemeral gully erosion. The sloping Andic Fragiumbrepts, although not as erosive as the Haplohumults, tend to yield high levels of soluble phosphorous in runoff.

The next lowest geomorphic surface in the Willamette Valley is the Dolph, with an estimated age of 125 ka yrs. This surface has a thin overlay of side valley alluvium or eolian material over paleosols classified as Ultic Haploxeralfs. On sloping surfaces, these soils also can have high sheet and rill and ephemeral gully erosion if there is a sparse vegetated cover.

Below the Dolph are two Brateng surfaces. These surfaces also have Ultic Haploxeralfs paleosols, but these are overlain by deposits derived from glacial Lake Missoula Floods. The pediments and paleosols of the High and Low Brateng have an estimated age of 105 ka yrs. However, the overlying flood sediments are interpreted to be derived from "Bretz Floods" with estimated ages between 15 ka and 12.8 ka yrs.

The sequence of surfaces below the Brateng are the Bethel, Senecal, and Calapooyia surfaces. The Bethel varies from rounded hills topography to a swell and swale topography similar to the Senecal. The Senecal topography represents a drainage development on the geomorphic flat Calapooyia surface. Stratigraphically, these surfaces are underlain by various members of the Willamette and Roland formations, but in general they all have an overlying gray silty Greenback Member that is a depositional unit of the Bretz Floods (15 ka - 12 ka yrs.). The A and E horizons of Dayton (Fine, montmorillonitic, mesic Typic Albaqualf) soils are developed in the Greenback Member. Below the Greenback is the Malpass Member, in which the 2Bt of Dayton soils has developed.

Below the Malpass is the Irish Bend Member, which corresponds to the 3C of Dayton soils. The Irish Bend overlies the Diamond Hill Paleosol or the Linn Member of the Rowland Formation. The Linn Member has been dated to be beyond reach of C-14 dating (>40 ka yrs). The overlying Irish Bend sediments should therefore be younger, but not as young as the Greenback Member.

The Irish Bend Member is interpreted in this study to be associated with earlier stages of glacial Lake Missoula floods that occurred between 50 ka and 60 ka yrs. or earlier, as dated by paleosols in the loess in southeastern Washington.

The Malpass Member that overlies the Irish Bend Member is younger than the Irish Bend but older than the Greenback Member, which is considered here to be between about 15 ka and 12.8 ka yrs. The material in the Malpass Member is considered by the author to be derived from multiple sources, with the predominant source being commingled "Bonneville Flood" (15 ka to 14 ka) and "Bretz Flood" (15 ka to 12.8 ka) sediment.

Below the Calapooyia and Senecal surfaces are the Winkle and Ingram and Horseshoe surfaces which represent the primary geomorphic surfaces of the Willamette Valley associated with the present drainage system. The Winkle surface is the natural high flood plain prior to reservoir construction, which has an age that in general varies from about 12.20 ka yrs., in deep vertical accretion deposits under the Winkle to 5.2 ka yrs. in the 2Bt horizon of the Malabon (Pachic Ultic Argixeroll) soil profile.

Large areas of the Winkle surface are lake deposits. These Winkle areas, and the flood plain of the Tualatin River that is predominantly a Winkle surface which receives annual flood deposition, have served as sediment and nutrient sinks for the last 12.2 ka years. Therefore, these areas have high natural background levels of organics and phosphorus and have associated water quality problems.

The Ingram surfaces are the dominant current flood plains of the Willamette River with flood frequencies that vary from frequent to rare. Fine textured soils and stratigraphy occur beneath both the Winkle and Ingram surfaces in the Willamette Valley and in tributary valleys such as the Long Tom, Calapooyia, Muddy, Luckiamute, Yamhill, Pudding, and Tualatin.

The youngest of the flood plains are the Horseshoe surfaces, which are dated younger than 0.5 ka yrs. The soils on these young floodplains have no diagnostic soil horizons.

[1]Sedimentation Geologist, Soil Conservation Service, West National Technical Center, 511 N.W. Broadway, Room 248, Portland, Oregon 97209.

Introduction

The Willamette Basin is in northwestern Oregon between the Cascade Mountains on the east and the Coast Range on the west. The basin is 200 km long from Eugene to Portland and averages about 40 km wide between the foothills. The major tributaries to the Willamette River on the south end of the valley are the Coast Fork and Middle Fork of the Willamette River.

On the Cascade Range side of the valley, entering from south to north, the tributaries to the Willamette River are the McKenzie, Calapooyia, South Santiam, North Santiam, Pudding, Molalla, and Clackamas Rivers. On the Coast Range side of the valley, entering from south to north, the tributaries of the Willamette River are the Long Tom, Marys, Luckiamute, Yamhill, and Tualatin Rivers. The Willamette Basin drains an area of about 29,785 sq km.

Precipitation

The Willamette Valley is one of the few areas in the continental United States that is characterized by heavy rains in the winter and near drought throughout the summer. Floods can occur at any time between October and April but usually occur during December and January. Soils tend to be saturated between November and April and therefore are subject to excess runoff. The average annual precipitation varies from 102 cm on the valley floor to about 381 cm in the Cascade and Coast Range Mountains (Reckendorf, 1973).

Historic Forest

Historically, the Willamette Valley was generally forested, but portions of the valley were covered with grasslands and scattered stands of Oregon white oak (Habeck, 1961). The flood plain areas tended to be dense forest, some of which were predominantly Douglas fir.

Geologic Setting

Almost two-thirds of the Willamette Basin lies within the volcanic terrain of the Cascade Range, with rock units that are predominantly mafic (basalt) and intermediate (andesitic) volcaniclastics (volcanic breccias and tuffs) and flows of Late Eocene to Pliocene age (Peck, et al., 1964). Minor glacial deposits of Pleistocene age have been recognized in the Cascades, but these occur only along tributaries to the Willamette River, such as the Santiam.

On the Coast Range side of the Willamette Basin, the rock units are predominantly basalt, sandstone, and shale of early Tertiary age, but some Oligocene, Miocene, and Pliocene units are present (Vokes et al., 1954). In a few places, the valley floor is interrupted by basalt-capped ridges that were more resistant to erosion than the surrounding Eocene to Miocene sandstones, siltstones, and claystones that underlay the valley unconsolidated units. An example of this is the north-south trending Salem Hills-Eola Hills at Salem.

Geologic History

The Willamette valley has been described as the southern end of a structural depression that extends as far north as the Straits of Georgia, British Columbia (Roberts and Whitehead, 1984). As summarized in Orr et al. (1992), the geologic history of the Willamette Valley starts with the volcanic foundation rocks. These volcanics erupted as part of a submarine oceanic island archipelago.

The archipelago accreted to the western margin of North America, and a forarc basin filled with marine deposits from Eocene through Pliocene. Fossils and sediments that have accumulated in the basin during the Oligocene and Miocene reflect a shallowing and filling of the basin, while a sea was withdrawing from the basin. This was occurring with a slow uplift of the Coast Range.

In the middle and late Miocene, lavas of the Columbia River Basalt covered the marine sediments of the Oligocene seaway at various locations and reached as far south as Salem. In northern Marion and Clackamas counties, about 1,000 feet of Miocene clastic sediments, mudflows, and volcanic tuffs of the Molalla formation reflect the first terrestial sediments after withdrawal of the Oligocene seaway.

During the Pliocene and Pleistocene, filling of the basin continued with sediment from the surrounding landscape and the Columbia River. The northern basin was a large lake in the Pliocene when the Boring lavas erupted from over 100 small volcanoes near Portland. LaButte, southwest of Wilsonville, is at about the southern extent of the Boring lava.

Up to 300 feet of Pleistocene riverine sands and gravels covered the rugged erosional surfaces on top of the Columbia River Basalts and older tertiary units in the Willamette Valley. This is overlain in the Southern Willamette Valley by up to 150 feet of Pleistocene Roland Formation coarse gravels and sand, considered to be of glacial and alluvial fan in origin. The Roland Formation is overlain by the Willamette Formation in the main valley. However, in the northern Willamette Valleys, the Pliocene Boring lavas are overlain by the Portland Hills Silt, the Troutdale gravels, and the Willamette Silts of the Willamette Formation.

Geomorphology

Balster and Parsons Studies

Balster and Parsons (1968, 1969) geomorphically separated the Willamette Valley into two units separated by the Salem Hills-Eola Hills topographic high area. The area to the south was characterized by very low relief and slightly incised valleys. The area to the north was characterized as being more completely dissected with streams that have incised their valleys several times deeper than those of the southern valley. They separated a stepped sequence of geomorphic surfaces (episodes of landscape development) in which each mapped geomorphic unit was assigned a name, based on a type locality where that unit was well expressed in the Willamette Valley.

The Balster and Parsons (1968, 1969), Parsons (1969), and Parsons, Balster, and Ness (1970) geomorphic surfaces are shown from oldest to youngest in Table 1. In general, the geomorphic surfaces fit a time sequence, but as set up by Balster and Parsons (1968, 1969) there are exceptions, as Table 1 shows. It is important to view the chronological listing of geomorphic surfaces in

Table 1 with the understanding that external depositional units on some of the geomorphic surfaces have modified the morphology and time sequence of particular surfaces, as well as the associated soils.

This author's present evaluation in the field of the geomorphic sequence presented by Balster and Parsons (1968,1969) shows that the basic sequence is still applicable for broad scale evaluation, with only minor modifications needed within specific geomorphic surfaces to reflect the past 20 years' research and this author's hundreds of transect observations. Interpretations of the stratigraphy are different, however, and reflect the author's evaluations in the valley over the past 30 years.

Eola

Variations from the Balster and Parsons (1968) chronology of surfaces are apparent for both Eola and Dolph surfaces. A larger scale of mapping than used by Balster and Parsons (1968) could show that there are stepped geomorphic surfaces within the broadly defined Eola surface, as Figure 1 shows. However, since there is no research information about the soil differences across these surfaces, I will not attempt to describe the different episodes of Eola landscape development.

Dolph

I have observed three separable Dolph equivalent geomorphic surfaces in the Willamette Valley. This is consistent with Balster and Parsons' observations of three Dolph surfaces that were first published in 1968 but were mapped as one surface.

This author's unpublished studies in the Willamette Valley, along stream valleys on the Oregon coast, in central Oregon, in southwestern Oregon, and in central Washington have found enough geomorphic, stratigraphic, and soil differences across the apparent equivalent Dolph surfaces to make a mappable distinction between the three Dolph units. These have been called High Dolph, Middle Dolph, and Low Dolph, or the equivalent coastal terrace, for my coast work.

The Dolph relationships in the Willamette Valley are complicated because of deposition that mantles the three surfaces. On two of the three, these deposits are thought to have been derived from an external glacial melt water runoff source (Glassman and Kling, 1980) (See discussion in the Stratigraphy Section). However, I have correlated the age of the high Dolph landscape at the coast (based on observation of the same step sequence of geomorphic surfaces from the rivers to the uplands) without the glacial meltwater deposits (i.e., with the paleosol over saprolite) as equivalent to the Silver Butte coastal terrace, along the Oregon Coast. In Curry County, Silver Butte has been assigned an estimated age of 125,000 years before present (Kelsey, 1990).

Glassman and Kling (1980) and Glassman, Kling, and Brown (1980) describe eolian deposits over a high Dolph paleosol that overlies saprolite in south central Willamette Valley. They consider this high Dolph surface to best fit the original Balster and Parsons (1968) concept of a Dolph middle Pleistocene surface. However, the Dolph of Balster and Parsons (1968) was defined specifically to contain erratics as well as the correlated Lacomb and Leffler gravels of Allison (1953), and Glassman, Kling, and Brown (1980) state that erratics are absent from the Dolph (i.e., High Dolph of Reckendorf).

Glassman and Kling (1980) redefined the Dolph of Balster and Parsons (1968) to restrict it only to that part of the Dolph in their study area above 122 m. This higher Dolph is equivalent to this author's High Dolph. This author believes that the Glassman and Kling (1980) separation of the highest Dolph is the reasonable interpretation for the oldest part of the Dolph landscape, that part that is not modified by the glacially derived lacustrine deposits (Bretz

Table 1. Willamette Valley Geomorphic Surfaces
(Balster and Parsons, 1968, 1969, and Parsons, Balster, and Ness, 1970)

Geomorphic Surface	Type Locations	Geomorphic Expression	Stratigraphy	Age
Eola	Salem Hills, Waldo Hills, Eola Hills, Red Hills of Dundee, Hills near Lacomb	Crest and upper parts of hills.	Weathered soils and deeply weathered gravels.	Middle Pleistocene
Dolph	Three miles north of Dallas, OR Dolph Corners. Also, near Alvadore.	Variable but as many as three dissected flats. Numerous small pediments.	Extensive flats underlain by weathered gravels, sand and clays and surface erratics.	Middle Pleistocene
Quad	Quadrangle on campus of Oregon State University	Terrace flat that is similar to next lower Calapooyia unit.	Essentially the Willamette silts in an upfaulted position.	Late Pleistocene
Calapooyia	Southern part of Willamette Valley particularly along the eastern part of Calapooyia River.	Flat main valley floor, little relief, light colored areas on photos are poorly drained depressions separated by intervening, slightly higher and better drained dark colored areas.	Greenback Member and Malpass or Irish Bend Members. Or, Greenback and/or Malpass over buried paleosol or weathered gravels.	Late Pleistocene
Senecal	Area around Senecal Creek near Woodburn.	Modification of the Calapooyia surface and development of drainage. Locally appears like drainage organization produced by overland flooding of major streams shortly after Greenback Member deposited.	Greenback Member and Malpass or Irish Bend Members. Or, Greenback and/or Malpass over buried paleosol or weathered gravels.	Late Pleistocene
Champoeg	Two miles southwest of Newberg near Champoeg Park.	Modification of Calapooyia and Senecal surfaces. Small pediment-like landforms make up the greater part of the Champoeg.	Torrentially, cross-bedded sands or gravel, probably of Glacial Lake Missoula flood origin.	Late Pleistocene
Winkle	Winkle Butte, 10 miles south of Corvallis.	Broad abandoned flood plain in the Willamette Valley and oldest surface related to present drainage system. Also, old lake beds like Lake Labish.	Fine textured sediment, over gravel. Lake beds of peat and muck.	Late Pleistocene to Holocene

(continues on next page)

Table 1, cont. Willamette Valley Geomorphic Surfaces
(Balster and Parsons, 1968, 1969, and Parsons, Balster, and Ness, 1970)

Geomorphic Surface	Type Locations	Geomorphic Expression	Stratigraphy	Age
Ingram	Ingram Island along the Willamette River northeast of Harrisburg.	The higher of two flood plains of the Willamette River and its tributaries.	Flood plain sediments.	Late Holocene
Horseshoe	Horseshoe Island near Corvallis, OR.	The lower flood plain of the Willamette River and tributaries.	River channel bars, point bars and channel fillings. Usually sandy alluvium and gravel.	Predominantly Post Settlement
Looney	The southern margin of the Salem Hills near Looney Butte.	The geomorphic surface is a complex of valleys, and ridges that make up the dissected steeply sloping landscape.	Side valley alluvium of mixed lithology.	Of Any Age
Luckiamute	Luckiamute River Valley near town of Pedee	Flood plains of streams that flow out of terrains composed of Eola, Dolph, and Looney surface, and associated alluvial fans.	Flood plain and alluvial fan deposits of tributary streams too small to map as Horseshoe or Ingram.	Of Any Age
Mass Movement	No formal location.	Hilly areas of the Willamette Valley with mass movement, slump blocks and mud flows. Frequently hummocky, irregular topography with poorly drained depressions.	Mixed side valley alluvium, and slumped materials.	Of Any Age

Flood deposits 15 ka to 12.8 ka yrs.). The remainder of this discussion will use this concept.

Brateng

Glassman and Kling (1980) and Glassman, Kling, and Brown (1980) redefine the two lower Dolph surfaces in the south central Willamette Valley that were included in the Dolph by Balster and Parsons (1968). The separation was based on stratigraphy, mineralogy, and soil discontinuities, that will be discussed in the Stratigraphy Section. Two surfaces called Brateng were defined, between elevation 80 m and 122 m in the Glassman and Kling (1980) study area. The name Brateng was assigned to represent the area where Brateng Road crosses the Brateng surfaces at Elkins Road in Polk County.

These surfaces are similar to the equivalent Middle and Low Dolph surfaces that I previously studied in the Airlie Hills in Polk County in the Willamette Valley. The Airlie Hills are about 9.6 km south of the Brateng type locality. I also consider the Brateng surfaces to be the Middle Dolph and Low Dolph that I previously identified in the Willamette Valley and elsewhere in Oregon and Washington.

The complex depositional history of the unconsolidated materials that lie beneath the Brateng surface will be discussed later under the Stratigraphy and Age section. However, to keep the chronology in perspective, the Brateng should be thought of as a middle to late Pleistocene landscape that has been modified by late Pleistocene erosion and associated glacial lacustrine deposits.

Quad and Bethel

The Quad surface (Table 1), as Balster and Parsons (1968) defined it, was not considered extensive enough to map much beyond the type locality area, at the field scale of one inch per mile. However, later work by Gelderman (1970), established the Bethel surface near McCoy in the Willamette Valley. Gelderman considered the rounded hills near McCoy as similar in relief and age to the Quad surface, yet different in configuration. Gelderman and Parsons (1972) characterized the Bethel surface as rounded hills having moderate relief and gently sloping sides that were graded to the next lower Calapooyia and Senecal Surfaces. Gelderman (1970) originally thought that the Bethel units had limited extent and might be restricted to the Yamhill and Tualatin River Valleys.

This author initially observed some of the Bethel surface in Yamhill and Polk Counties well beyond the range of the Yamhill and Tualatin Valleys. The Bethel surface was expressed as a swell and swale topography similar to that found on the lower lying Senecal Surface. This author later found that the geomorphic step surface equivalent to the Bethel surface occurs within essentially all Willamette Valley counties, along the Oregon Coast in central Oregon, in southwest Oregon, and in central Washington.

There is little need to maintain correlations to both the Quad surface of Balster and Parsons (1968) and the Bethel of Gelderman and Parsons (1972). Because the Bethel surface is the better defined of the two and has greater extent, the Quad surface should be considered as a local geomorphic inclusion of the Bethel surface. Mapping and the literature should reference the Bethel surface as the distinctive geomorphic surface that lies next above (i.e., slightly older than) the Senecal surface with similar soils to those on the Senecal surface.

Senecal

The Senecal and Calapooyia surfaces are characterized adequately by the data in Table l. However, the relationship of the Senecal to the Winkle surface needs some additional explanation. Balster and Parsons (1968) recognized that, in the area south of the Salem, a very small scarp break occurs between the Winkle surface and the Senecal surface. This scarp is less than 1.5 m at the Winkle Butte type locality.

The scarp difference increases rapidly northward until it exceeds 7.5 m at Lake Labish and attains a maximum of about 21 m near Canby. The scarp difference between the Winkle surface and the next lower Ingram surface remains nearly the same throughout the valley. The difference in scarp break height between the Winkle and Senecal surfaces from the southern to the northern parts of the valley may indicate major tectonic events in the lower Willamette Valley (Balster and Parsons, 1968; Parsons, 1969).

Champoeg

In the northern Willamette valley is a geomorphic surface named Champoeg (Balster and Parsons, 1968) that occurs between Senecal and Winkle. This consists of torrentially cross-bedded gravels and cobbles derived from flood waters of Glacial Lake Missoula. This author has not been able to find evidence of Champoeg outside the area where it was mapped by Balster and Parsons (1968).

Winkle and Ingram

The next lower surfaces beneath Senecal, Calapooyia, or Champoeg are Winkle and Ingram, whose geomorphic surfaces vary as Reckendorf (1973) and Parsons and Herriman (1969) have discussed. Detailed mapping and cross sections have shown both Low Ingram and High Ingram geomorphic surfaces, as well as Low Winkle and High Winkle geomorphic surfaces. Differences include geomorphic features present, such as meander scrolls, oxbows, oxbow lakes, natural levees, old channels, and the degree of bar and channel topography, in progressing from the Low Ingram (i.e., frequently flooded areas) to High Winkle (i.e., rarely flooded, such as in 100-year or 500-year flood events). The High Winkle surface is essentially devoid of geomorphic features, except for natural levies and sand splays.

The largest known flood in the Willamette Valley occurred in 1861, before the advent of structural controls (Reckendorf, 1973). This flood inundated 513,000 acres in the main Willamette Valley, probably flooding the High Winkle and all surfaces below, and establishes the natural flooded riparian area of the main Willamette Valley. However, the woody vegetated riparian area is better represented by only the Ingram and the Horseshoe geomorphic surfaces.

Horseshoe

The Horseshoe geomorphic surfaces consists primarily of channel bars, point bars and meander scrolls. Two Horseshoe geomorphic surfaces occur along the Willamette River at some locations, and the difference in the surfaces may reflect pre-dam verses post-dam flood deposition. In addition, some recent, coarse textured, super-elevated flood deposition on the Ingram surfaces occurs along the outside of curves of the river and can be mistaken for Horseshoe surfaces. These sand splay or other deposits are higher than the surrounding landscape and have a stratigraphy similar to the Horseshoe surface.

Stratigraphy and Age

Eola Surface

Balster and Parsons (1968) found saprolite, and the Lacomb and Leffler gravels established by Allison (1953), beneath the Eola sequence of surfaces. Both of these gravels are deeply weathered, and are considered middle Pleistocene (Balster and Parsons, 1968). This author correlated, by observation (the upland surfaces along the river valley were graded to various upland coastal terraces), the coastal terraces identified as Seven Devils (or Indian Creek) and Metcalf (or Poverty Ridge) in Curry County, Oregon as being the terrace equivalent to the Eola upland surfaces along the rivers in that area. The Metcalf has been assigned a minimum estimated age of 200 ka years before present (McInelly and Kelsey, 1990).

Dolph, Brateng, Bethel, Senecal, and Calapooyia Surfaces

Common Upper Stratigraphy

The stratigraphy underlying the Dolph surface varies in characteristics and age, as stated earlier, because of different erosional and depositional histories expressed by the redefined Dolph (i.e., High Dolph) and Brateng surfaces. In other words, the surface does not show a simple chronological sequence of geomorphic surfaces but a complex sequence of a chronological landscape development, with superimposed later deposition from external sources (Table 2, and Figure 1). The higher surfaces on the landscape do not necessarily reflect that they are older, because they have quite young deposition and associated soils. The last external deposition crosses the landscape units to provide a common upper stratigraphy.

Dolph Paleosol

The Dolph surface in the Glassman and King (1980) and the Glassman, Brown, and Kling (1980) studies is stratigraphically underlain by a paleosol developed on the Eocene Spencer formation that was overlain by about a 30-cm deposit of material interpreted to be eolian. Although their study was much more limited in scope than the Balster and Parsons (1968, 1969) work, the author's independent confirmation of the approximate equivalent condition (High Dolph with thin silts over reddish brown paleosol over sandstone) in the Airlie Hills is sufficient for this author to ascribe to the Glassman and Kling interpretation as the correct general interpretation for the highest of the Dolph units. The exception is the interpretation that weathered gravels can be part of the stratigraphy on the High Dolph, overlying the paleosol.

Dolph Interpretive Problems

Balster and Parsons (1968, 1969) and Glassman, Brown, and Kling (1980), interpret the elevation of the Dolph type locality (i.e., Dolph Corners) and the presence of the Greenback Member and the associated glacial erratics very differently. At Dolph Corners an erratic surface is underlain by weathered gravels. This location appears to be the highest part of the Dolph landscape in the area, but it does not appear to be the High Dolph in the Willamette Valley. This relationship needs further study and mapping in the field, but on an elevation basis the 76 m Dolph type locality more closely fits the Low Brateng surface, which has its type locality only about 19 km to the southwest.

The Greenback Member and the erratics pose an additional interpretation problem. The Greenback Member as described by Balster and Parsons (1969) in the southern Willamette Valley is composed predominantly of silt-sized quartz and feldspar, with significant contents of coarse sand-sized iron manganese oxide concretions near the base of the surface. This member is essentially coextensive with the Calapooyia, Senecal, and Bethel geomorphic surfaces (Balster and Parsons, 1969, and Gelderman and Parsons, 1972). Previously, Allison (1953) and Glen (1965) suggested that these higher silts (i.e., above the Bethel surface) were derived from glacial Lake Missoula floods. The Glassman, Brown, and Kling (1980), and Glassman and Kling (1980) work extends the Greenback member to overlap the Brateng surfaces; it also interprets the material as derived from late Pleistocene glacial Lake Missoula floods.

Based on electron micrographs, the quartz-sand grains in the Greenback Member have surface morphologies similar to the underlying Irish Bend Member. At elevations below 80 m, the grains are said to have (Glassman and Kling, 1980) surface morphologies suggesting glacial flood transport. However, at higher elevations (above 80 m) more euhedral sand grains appear, suggesting that much of the material

Table 2. Willamette Valley Geomorphic Surfaces, Representative Soils and Stratigraphy

Geomorphic Surface	Series	Subgroup	Particle Size Class	Stratigraphy and Other	Special Interpretation
Eola	Bellpine	Xeric Halplohumult	Clayey	Side valley alluvium over paleosol, and weathered soils over saprolite.	Erosion
	Bacona	Typic Halpohumult	Fine-silty	Side valley alluvium over paleosol and weathered soils over saprolite. Erratic pebbles.	Erosion
	Olyic	Typic Haplohumult	Fine-loamy	Side valley alluvium over paleosol, and weathered soils over saprolite.	Erosion
	Jory	Xeric Haplohumult	Clayey	Side valley alluvium over paleosol, and weathered soils over saprolite.	Erosion
	Cascade	Typic Fragiumbrept	Fine-silty	External depositional silt over reddish paleosol. Erratic pebbles & cobbles in depositional unit.	Erosion
	Goble	Andic Fragiumbrept	Medial	Volcanic ash & upland silt over fragipan paleosol.	Erosion Phosphorus in runoff
	Melby	Umbric Dystrochrept	Fine	Side valley alluvium.	Erosion
Dolph	Cornelius	Mollic Fraglxeralf	Fine-silty	Fragipan	Erosion
	Willakenzie	Ultic Haploxeralf	Fine-silty	Side valley alluvium over brownish paleosol	Erosion
	Salkum	Xeric Haploxeralf	Clayey	Side valley alluvium over weathered gravels. Lacomb & Leffler weathered gravels	Erosion
High Brateng Low Brateng	Willakenzie variant, deep	Ultic Haploxeralf	Fine-silty	Depositional glacial silts on brownish paleosol. Erratics	Generally the highest glacial flood level. Variable shape on the landscape.
	Helmick variant, moderately deep	Aquic Xerochrept	Very-fine	Side valley alluvium over depositional clay over Cr. Associated with the upslope claystones, siltstones, & tuff sources of clay.	Commonly in swale shape. One source for lower lying depositional clay. Variable shape on the landscape.
Bethel	Willamette variant	Pachic Ultic Argixeroll	Fine-silty	Greenback over Irish Bend Members. Abundant erratics.	Stratified soils, well drained, wide crop variety.

(continues on next page)

Table 2, cont. Willamette Valley Geomorphic Surfaces, Representative Soils and Stratigraphy

Geomorphic Surface	Series	Subgroup	Particle Size Class	Stratigraphy and Other	Special Interpretation
Calapooyia	Dayton	Typic Albaqualf	Fine	Greenback in Dayton soil is A & E, 2BT is Malpass & 3C is the Irish Bend.	Drainage problem limits crop varietys and stratified soils.
Senecal	Willamette	Pachic Ultic Argixeroll	Fine-silty	Derived from minor incision of Calapooyia	Stratified soils, well drained, wide crop variety.
Champoeg	Multnomah	Dystic Xerochrept	Fine-loamy	Torrentially cross-bedded gravels and sands. Reflects Glacial Lake Missoula flooding.	Well drained coarse soils.
Winkle	Malabon	Pachic Ultic Argixeroll	Fine	Primarily vertical accretion deposits. Associated with modern drainage.	Rarely flooded, well drained, wide crop variety.
	Sifton	Andic Xerumbrept	Medial over sandy	Gravelly alluvium and volcanic ash.	Andic properties
	Labish	Cumulic Humaquept	Fine	Muck and peat in ponded areas. Phosphorus sink.	High organics and phosphorus
Ingram	Chehalis	Cumulic Ultic Haploxeroll	Fine-silty	Vertical & lateral accretion deposits. Infrequent flooding. Lacks Bt soil horizon.	Flooding
Horseshoe	Camas	Fluventic Haploxeroll	Sandy-skeletal	Essentially lateral accretion deposits. Lacks diagnostic soil horizon.	Frequent flooding

may be locally derived from the Paléosol and the saprolite of the Spencer Formation, underlying the High Dolph. Thickness of the Greenback member on the Brateng surfaces was reported to vary from 90 cm at lower elevations to less than 30 cm near the upper boundary. In the Airlie Hills, the author, using soil pits auger transects and mapping, correlated the Greenback Member to occur on the Lower Brateng surface with an average thickness of about 38 cm. It contains erratics.

The Dolph Corner erratics, therefore, are not consistent with the Glassman, Brown, and King (1980) and Glassman and King (1980) interpretations. Further investigations are needed to determine if the true High Dolph occurs at the Dolph type locality and if the erratics at that locality are older than the Greenback surface. Perhaps the Dolph type locality should be redefined as the Brateng surface, which is characterized by the presence of late Pleistocene erratics and the Greenback Member, both of which are associated with Glacial Lake Missoula flooding. Because of the elevation (76 m), the presence of a Greenback like onlap, and the erratics, this author believes that the Dolph type locality is what Glassman, Kling, and Brown (1980) include in the Brateng, and it probably represents the Low Brateng.

Understanding the Erratics

Understanding the age of the erratics in the Willamette Valley would greatly help in our understanding of the age of the associated deposits like the Greenback Member. The erratics have been reported in Balster and Parsons (1968) to occur mostly above 76 m in elevation, such as those that occur at Dolph Corners. However, many erratics are as high as 122 m, as described by Allison (1953), or with the

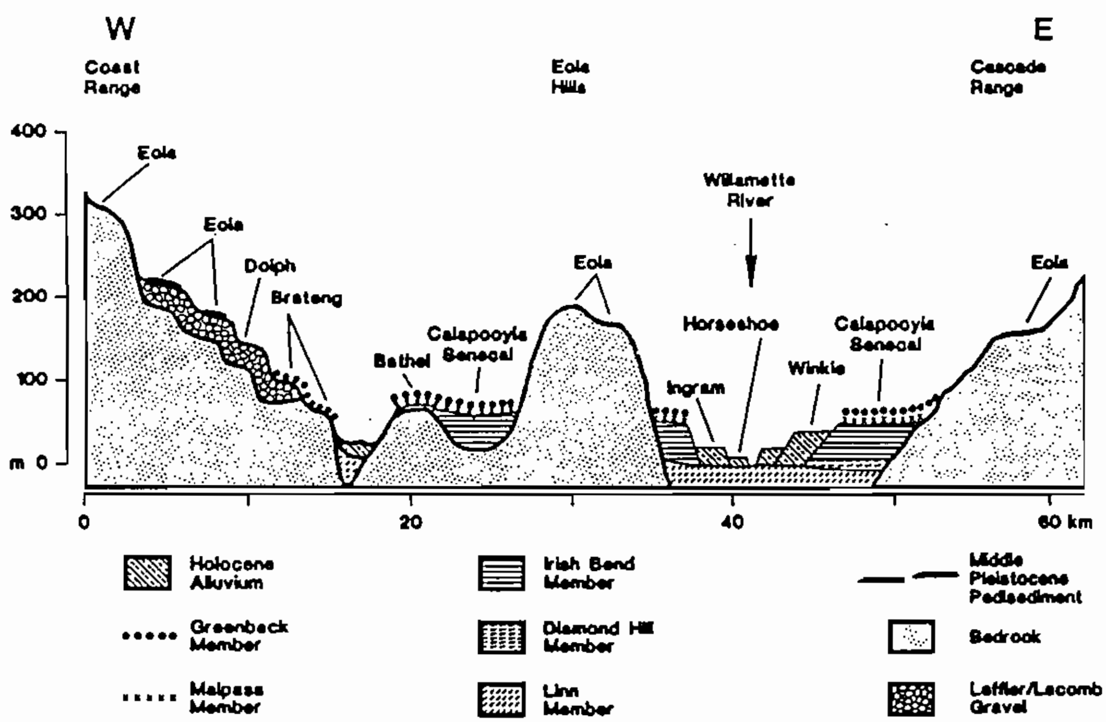

Figure 1. Generalized cross section of geomorphic surfaces at about the 45° latitude of Salem, Oregon. Subsurface distribution of Linn and Leffler/Lacomb Gravels shown here is speculative. Modified from McDowell (1991).

associated Greenback Member as described by Glassman and Kling (1980). Allison's (1935) original work reported no erratics lower than 30 m in the main valley but some as low as 10.5 m in the Portland area. Dozens of erratics locations are shown below 76 m and only rarely are erratics described at the maximum elevation of 122 m.

According to Allen et al. (1986), one small group of six boulders on Judkins Point east of Eugene occurs at an elevation of 198 m. It is assumed that these particular erratics are on the Eola surfaces rather than on Dolph Surfaces. Allen et al. (1986), attribute these high erratics to Indian transport, but an old Lake Missoula flood origin is also a possibility. Taken collectively, the data shows that erratics occur at various elevations above 30 m in the main valley, and they could be represent several different glacial Lake Missoula floods, rather than just the highest flood.

In general, the erratics range in size from small pebbles to boulders. They are composed of granites, granodiorites, gneisses, quartzites, schist, argillites, and phyllites. Allison (1935, 1936) noted at least 300 occurrences of erratics in the Willamette Valley. According to Allen et al. (1986), probably fewer than 50 of the erratic boulders still exist today.

The erratic rocks all require some outside source. Since the Willamette Valley lacks late Pleistocene continental till and associated outwash, and areas to the north show the definite presence of unmodified (by glaciers) Pleistocene non-glacial soil, it seems unlikely that the erratics were brought in by glaciers from the north. Allison (1935) related the erratics and the Willamette Silts, to be discussed later, to surges of glacial meltwater. This happened when the ice dams at the mouth of the Clark Fork River in Montana failed on different occasions, releasing the flow of Glacial Lake Missoula, to create the "Spokane Floods," between about 15 ka and 12.8 ka years before present (Allen et al., 1986).

The "Spokane Flood" (Bretz, 1919) was later named the "Missoula Flood," when the Montana Lake source for the flood water was discovered. It is commonly published (Allen et al., 1986) that, between 15 ka and 12.8 ka years ago, there were as many as 40 "Missoula Floods", so the term "floods" is now the common reference to these events. The floods between 15 ka to 12.8 ka years ago have been renamed the "Bretz Floods" (Allen, et al., 1986). The rest of this paper uses the term

"Bretz Floods" for those between about 15 ka and 12.8 ka, years ago and "Ancient Missoula Floods" (Burns and Cordio, 1992) for the earlier glacial meltwater events.

"Bretz Floods" Phases

Allison (1978) believed that the "Bretz Floods" caused backflooding into the Willamette Valley in two ways. First, an aggradation of "Bretz Floods" sediments along the Columbia River in the Portland Basin (i.e., essentially at the mouth of the Willamette River and downstream) caused diversion of the Columbia River flood flows into the Willamette Valley and tributaries. This early phase was attributed mainly to repeated failure of the glacier dam at Pend Oreil, Idaho, and many evacuations of Glacial Lake Missoula, and was estimated to take place over a long period of time (Allison 1978). These floods resulted in 75 m of deposition, called the Portland Gravels and later the Portland Sands (McDowell, 1991).

In a later part of the first phase of flooding, the Columbia River was to have transported mostly sand and silts, when the flood flows were diverted into the Willamette Valley, crossing the Portland Sands and depositing sands and coarse silts in the lower Willamette Valley and progressively finer silts to the south in the upper valley.

Allison (1978) believed a second phase of "Bretz Floods" was short lived. Hydraulic or ice damming on the Columbia River downstream from Portland allowed slackwater in the Willamette Valley to reach 122 m. The flood flows in this short event are to have caused extensive scour of the aggradation delta at the mouth of the Willamette River and created new bouldery gravel and plane-bedded sand beds where the glacial flood flows entered the northern Willamette and Tualatin Valleys.

This author believes that these coarse-textured deposits are the materials in the Champoeg surface described by Balster and Parsons (1986).

"Bretz Floods" Backwater

Allen et al. (1986) noted that the cross section of the Columbia River to transport the "Bretz Floods" at Kalama Gap, downstream from Portland, is 76 percent of that at Crown Point, upstream from Portland. They concluded that the reduced cross section, the significant elevation drop and gradient change from Crown Point to Portland, the time span of flow, and the velocity of the "Bretz Floods" flows were sufficient to produce a hydraulic backwater effect at Kalama Gap and force the "Bretz Floods" into the Willamette Valley.

An hydraulic dam interpretation certainly seems reasonable for diverting Glacial Lake Missoula floodwaters into the Willamette Valley, especially if viewed in context with evidence for the large amount of aggradation in the Portland Basin at the mouth of the Willamette River. Since several "floods" were associated with the failure of the glacial dam at Pend Oreil, Idaho, even the first-phase floods of Allison (1978) are likely to have carried icebergs and river ice to jam up the Columbia River (i.e., reduced capacity) and to divert glacial floodwaters into the Willamette Valley.

In other words, aggradation (along the Columbia River in the Portland Basin) is not the only method to reduce river capacity and cause the glacial floodwaters to be diverted into the Willamette Valley. Reduced capacity, due to the ice either at the main aggraded area near the mouth of the Willamette Valley, or further down the Columbia at Kalama Gap, could give rise to numerous and extended backwater ponded periods, and the ice effect would be to increase aggradation and associated periods of ponding.

Because the one cause (aggradation) leads to the other (river ice and ice jams) and vice versa, a two-stage concept is unnecessary to explain the different floods, even to explain the different textured units such as the Irish Bend and Malpass Members which I discuss later. Obviously some flood backwater was higher than at other times, and quite probably the latest flooding that put the Greenback Member type sediments up on the Brateng geomorphic surface represents the highest events. It also seems reasonable that the icebergs are the likely source to transport the erratics into the Willamette Valley, at various times, and up across geomorphic surfaces to the High Brateng.

"Bretz Floods" Duration

Allen et al. (1986) assumed that each lake created in the Willamette Valley by a "Bretz Flood" only lasted a few days or weeks. This conclusion is based on their concern that there needed to be hundreds of icebergs transporting erratics to the over 300 localities, and those that had to float the one hundred or more kilometers up the valley to reach their destinations, must have been carried on the first surge or they would have melted. A reasonable alternative conclusion is that the erratics were brought by a variety of different "floods" of different magnitude (i.e., flood height), age, and length of ponding, and a first-surge concept to account of all erratics at the same time is unnecessary.

Recognizing "Ancient Missoula Floods"

Bretz (1969) who did most of the pioneering work studying the Lake Missoula created "floods" and the channeled scablands, suggested that there were seven or eight floods but that the last was the most distinct, with water surface elevations up to about 122 meters, based on the erratics. Recent work by Busacca (1991) noted that many giant floods in the Columbia Basin predate the traditional dates (given as between 17 ka and 12 ka) for the last episode of scabland flooding.

Busacca (1989, 1991) indicates that the loess, paleosols, and tephras in the Palouse area of eastern Washington, rather than the flood deposits themselves, may have the most complete record of the history of flooding on the Columbia Plateau caused by Glacial Lake Missoula. The Palouse is downwind of the channel scablands and contains numerous paleosols and buried ash deposits.

Foley (1982) has developed a concept that loess deposition and the associated soil development were controlled by episodes of flooding (i.e., like the glacial Lake Missoula "floods") and that the times of glacial recession and interglaciation were times of sediment supply with rapid loess deposition. Conversely, times of glacial advance and glacial maxima were times of relative stability and soil development. According to Busacca (1991), the record in the loess fits this two-phase model for at least the last 36,000 years.

More recent work by Busacca (Personal Communication, February 1992), pushes the two-phase model concept back to about 50 ka to 60 ka years. This is based on Mount St. Helens, Set C tephra being this old. The Cordilleron glaciation occurring after the 50 ka to 60 ka yrs. interstadial associated with the "Ancient Missoula Floods" is the Bull Lake Glaciation, estimated to be greater than 32 ka years (Richmond, 1965). Recent studies reported by Moody (1989) of mineralogy and tephra chronology (especially Mount St. Helens Set C tephra) in the Willamette Valley suggest that the Greenback Member correlates with the larger (17 ka - 12 ka yrs.) flood sediments, and the Irish Bend Member in the Willamette Valley is similar to the "Ancient Missoula Flood" sediments of the Channeled Scablands of Washington. This author generally agrees with this interpretation.

The loess records of the earlier floods should have comparable deposits and paleosols in the Willamette Valley. This author has observed as many as three palesols in the Irish Bend Member, but none have been dated. Understanding the age and distribution of Mount St. Helens Set C tephra (36 - 37.6 ka in Sarna-Wojcicki and others, 1991 or 50 ka to 60 ka yrs. Busacca, Personal Communication, February 1992) in the Willamette Valley will help explain this issue. A tephra in the Irish Bend Member at the type locality may fit Mount St. Helens Set C, based on stratigraphic position.

Willamette Formation

The Willamette Formation includes the Greenback, Malpass, Irish Bend and Wyatt Members. Understanding the stratigraphy of the Greenback Member and underlying deposits will help us to place the earlier flood events in perspective. McDowell (1991) covers the work of Trimble (1963), Schlicker and Deacon (1967), Roberts (1984), and Waitt (1985) on the lower stratigraphic units and I will not repeat it here. However, I will describe for the Willamette Valley the stratigraphy of the deposits, called Willamette silts and later redefined as the Willamette Formation.

Allison (1953) redefined the Willamette Silts (previously defined by Treasher, 1942) to apply to parallel bedded sheets of silt and associated materials that cover most of the Willamette Valley lowland. Allison noted that erratic particles from chips to boulders were included in the silt. Balster and Parsons (1969), primarily using studies in the upper Willamette Valley, proposed that the Willamette Silts be renamed the Willamette Formation and consist of four units which, from top to bottom, are called Greenback Member, Malpass Member, Irish Bend Member, and Wyatt Member. With the exception of the Wyatt Member, the units have a type section along the Willamette River at Irish Bend in Benton County.

Greenback Member

The Greenback Member (Figure 1) is a surficial deposit predominantly of silt-sized quartz and feldspars and sand-sized, iron-manganese oxide concretions (Balster and Parsons, 1969). Also common near the base of the unit are pyroclastic materials, interpreted by petrographic study to be Mount Mazama tephra (Norgren, 1962). The Greenback Member includes the A and E horizons of the Dayton soil profile. In addition, it includes the topsoil of the Amity, Woodburn, and Willamette soils and the topsoil of all soils on the Brateng Surfaces.

Association of the Greenback Member with the "Bretz Floods" (15 ka to 12.8 ka yrs.) deposits places the Greenback at about the same time that volcanic ash was being deposited from Mount St. Helens Set S tephra as well as tephra from Glacier Peak. The ash plume from Glacier Peak, however, probably had less influence than Mount St. Helens Set S (Porter, 1978). Mt. St. Helens Set S has a date of 13 ka yrs. (Busacca, 1991), and Glacier Peak, 12 ka yrs. (Fryxell, 1965). Both of these ash falls could have occurred when a ponded water body remained from glacial meltwater.

However, even if the ash fall occurred after ponding, deposition of ash on the valley floor could be expected from watershed runoff. Either of these alternatives could be significant enough to reflect the ash influence in the Greenback Member. The much later Mount Mazama tephras (about 6.6 ka Fryxell 1965; or 7.0 ka, Bacon 1983) also should be reflected in the A horizon of the Greenback Member, as the edge of the Mount Mazama plume would have crossed the Willamette Valley (Fryxell, 1965).

Malpass Member Characteristics

The light gray silty Greenback Member unconformably overlies the massive gray clay Malpass Member (Figure 1) in large areas of the Calapooyia, Senecal, and Bethel Surfaces, but either member is locally absent from the sequence. The Malpass Member has an irregular thickness and in many locations appears to have been deposited in depressions and drainageways. It is the 2Bt horizon of the Dayton soil profile. The upper part of the Malpass Member, in general, is very flat lying, but, in local areas, scour channels are apparent on top of it.

The Malpass unconformably overlies the Irish Bend Member (Figure 1), as evidenced by its broad extent beyond the limits of the Irish Bend Member, to also overlie the sandy Wyatt Member of the Willamette Formation, or the lower lying Diamond Hill or Linn Members of the Rowland Formation. In other words, the lake area to deposit the Malpass Member was broader and required higher flood height than the lake that existed when the underlying Irish Bend Member was deposited. In addition, remnants of illuviated clay commonly occur in the upper few feet of the underlying Irish Bend Member, suggesting that earlier development of a soil profile. This soil profile was removed partly before deposition of the Malpass and Greenback Members.

Malpass Member Origin

The gray clay Malpass Member has been argued to be an estuarine deposit (Condon, 1871, and Balster and Parsons, 1968, 1969) or to represent glacial meltwater deposits (Allison, 1953, 1978, and Allen et al., 1986). This author agrees that its origin is from the glacial meltwater or other flood sediments and considers the Malpass Member texture, thickness, and extent as evidence of slow deposition of fines in a flooded (ponded) Willamette Valley.

It is reasonable to assume that scour of the Irish Bend Member and its soil profile, which occurred when glacial meltwaters entered the valley, caused high sediment concentrations in the lake water. The lake deposits (i.e., Malpass Member) thus should represent a fine-textured unit even without the contribution of fine-textured particles from other sources.

Where the Malpass Member is found in the tributary valleys in the Willamette Valley, the lake sediments are likely to reflect a large organic rich phosphorus sink, because of the sediment contributions from the surrounding landscape to the lake. This is quite apparent in the Tualatin Basin, as will be explained later.

Erosion of the fine-textured soils on the Brateng, High Dolph, and Eola surfaces, along with erosion of claystones and siltstones and Tuffs of the Spencer formation, could have added large quantities of locally derived fine-textured sediment to form the Malpass Member. For example, the gray clays commonly associated with Helmick (very-fine, mixed, mesic Aquic Xerochrepts) and Hazelair (very-fine, mixed, mesic Aquic Haploxerolls) soils, found on High Dolph and High and Low Brateng surfaces, could have been a major source for the Malpass Member in the upper Willamette Valley. The landscapes where these soils occur have been extensively eroded and truncated, and the finer textured soils frequently occur as elongate side-valley alluvial channels.

In the lower Willamette valley, the Mayger (clayey, mixed, mesic Aquic Haplohumults) soil on the Eola landscape, eroded in shale, also could be a partial source for the clay in the Malpass Member. The thickness of the Malpass Member may reflect a long period of high runoff conditions, as well as an extended period of ponding.

One other possible source of fine-textured sediment is little researched: the fine-textured sediment from a "Bonneville Flood" that could have come into the Willamette Valley in Late Pleistocene time. A "Bonneville Flood" resulted from a catastrophic outflow from Pleistocene Lake Bonneville, when the Lake overtopped its rim at Red Rock Pass in Southeastern Idaho and discharged down the Snake River, and eventually the Columbia River. Jarrett and Malde (1987) estimate the volume of water released was 4,700 Km^3, and the paleodischarge peak at mile

460 on the Snake River was 935,000 m^3/s. This discharge is higher than modern flood records (1927, 70,010 m^3/s, Mississippi River) but small compared to the largest discharge at the Lake Missoula breakout estimate (about 21,300,000 m^3/s).

Research has not considered what should be expected as a discharge and sediment load from a commingled "Bonneville Flood" and "Missoula Floods" at the mouth of the Willamette Valley. The time of the "Bonneville Flood" varies from 18 ka to 14 ka yrs. (Morrison, 1991). This coincides with early "Bretz Floods," when ice jams or other sediment obstructions could have caused backflooding into the Willamette valley, or commingled "Bretz Floods" and a "Bonneville Flood."

By the time the "Bonneville Flood" passed down through the Snake and Columbia rivers, most sediment particle sizes would have dropped out, so high concentration of fine-textured particles would be expected in the suspended sediment discharge. The mineralogy of the Malpass should reflect the combination of sediment from "Bretz Floods," "Bonneville Flood," and eroded fine-textured soils and rocks in the Willamette Valley.

Irish Bend Member

Balster and Parsons (1969) describe the Irish Bend Member as including only the faintly bedded micaceous silts part of the Willamette Silts. These overlie the Wyatt Member, which is described (Balster & Parsons, 1969) as brown to yellowish brown sands to clayey silts that occur as elongate lenses (possibly filled old channels) from zero to 3 m (10 ft) thick.

Disagreement exists about the origin and age of the Willamette Silts or the associated Irish Bend and Wyatt Members. The Irish Bend represents the typical Willamette Silts, as Allison (1953) described. However, texture varies from coarser, more distinctly bedded facies in the lower Willamette Valley, to finer in the upper Willamette Valley. Disagreement also occurs over whether each rhythmite bed reflects a separate flood event on the Columbia River (Glenn, 1965; Allison, 1978) or whether several beds could be emplaced during a single flood by hydraulic surges (Baker and Bunker, 1985).

Part of the debate centers around similarities of the Irish Bend to the Touchet Beds in southeastern Washington, and how to interpret the meltwater deposition of the Touchet Beds. Waitt (1985) discusses this relationship. When Waitt's Touchet deposition sequence and time frame is applied to the Willamette Valley, not enough time (2,000 to 3,000 years for the entire Willamette Formation) exists for the multiple events of deposition and soil development found in the Willamette Valley (McDowell, 1991). However, using the multiple flood concepts presented in Busacca (1989, 1991), the Willamette Formation is consistent with the multiple floods apparent in the Touchet and other flood-deposited beds in southeastern Washington.

The time frame of the earlier catastrophic flooding in the Willamette Valley (50 ka to 60 ka, Personal Communication, Busacca, 1991), does not exactly fit the Irish Bend in the Willamette Valley, based on some correlated radio carbon dates. Dates from Roberts, reported in McDowell (1991) correlated a paleosol studied to the Diamond Hill Member (which directly underlies the Wyatt Member). The paleosol was dated 28.5 ka and 34.3 ka yrs. (near top) and 36 ka yrs. (near bottom), making the Irish Bend and Wyatt Members younger.

This author believes that at least part of the Irish Bend is older than the Roberts dates, because his dates are in conflict with the Balster and Parsons (1969) dates for the Diamond Hill Member, which they stated to be beyond reach of C-14 dating at that time (>40 Ka yrs.). In other words, the correlation by Roberts to the Diamond Hill paleosol is incorrect.

Wyatt Member

No exposures of the Wyatt Member have been found in the Willamette Valley. It is composed of sandy and silty alluvium, considered by Balster and Parsons (1969) to be of local origin. The coarse grains are predominantly basalt and the unit is weakly cemented.

Diamond Hill Member

The Diamond Hill and the lower lying Linn Member (Figure 1) make up the Roland Formation. These are uncomformable, separated from the Willamette Formation. The Diamond Hill Member is 2 to 3 meters thick and varies from sand to clay. Pebbles typically are coated with clay. A clayey paleosol commonly occurs in the upper part of the Diamond Hill. Parsons and Balster (1969) dated wood from the Diamond Hill Member and found the samples to be beyond reach of C- 14 dating at the time (i.e., about 40,000). Glassman, Brown, and Kling (1980) state the Diamond Hill Paleosol extends, beyond the boundaries of the Calapooyia, Senecal, and Bethel surfaces, crosses the Brateng, and is equivalent to the paleosol on the High Dolph previously described.

Linn Member

The Linn Member underlies the Diamond Hill Member. It consists of a cross-bedded gravel composed predominantly of intermediate and mafic igneous rock pebbles and cobbles. It ranges in thickness from 5 to 70 m (Mc Dowell, 1991). These cross-bedded gravels, with locally cross-bedded sand lenses and pumice grains, are a redefinition (Balster and Parsons, 1969) of the Linn Gravel (Allison, 1953).

Glenn (1965) reported a date of 34.4 ka yrs. on a gravel deposit near River Bend. McDowell (1991) discusses this date as being from the Linn Member. However, Parsons, Balster, and Ness, (1970) report the Glenn site to be in gravels beneath the Winkle surface, rather than beneath the Senecal or Calapooyia surface. As will be explained later, I consider Glenn's (1965) gravels to be reworked Linn age (pre 34.5 ka) gravels rather than gravels associated with incision and deposition in Winkle time.

The Linn Member gravels are generally mapped (Bela, 1979; Gray and Throop, 1981) as part of the Quaternary middle terrace deposits (Qtm) in the Willamette Valley. However, occasionally these gravels are mapped as a separate unit (Qlg) in the Stayton, Turner, Salem area, where they are called Linn gravel and are characterized as stratified fine to coarse fan gravels (Bela, 1981).

Lacomb Leffler Gravels

The Linn gravels are not the oldest gravels in the Willamette Valley, as reported earlier. The Leffler gravels are older, and they overlie the Lacomb gravels. As previously mentioned, the Lacomb and Leffler gravels occur high in the landscape beneath Dolph and Eola surfaces. These weathered gravels described by Allison (1953) and by Piper (1942), Volkes (1954), and Balster and Parsons (1968), occur up to an elevation of about 112 m (Allison, 1953) in the central Willamette Valley. The Lacomb and Leffler units commonly are referred to as High terrace deposits (Qth) (Bela, 1979, 1981; and Gray and Throop, 1981).

Age of Dolph and Brateng Surfaces

I have found the same step sequence and visually correlated river valley surfaces equivalent to the Willamette Valley three Dolph surfaces (High Dolph and High and Low Brateng) in Tillamook, Curry, Deschutes, and Douglas Counties in Oregon and in Kittitas County Washington. I consider the Silver Butte, Pioneer, and Cape Blanco coastal marine terrace levels in Tillamook and Curry Counties to be equivalent to the High Dolph and High and Low Brateng surfaces found in the river valleys in those respective areas.

The Silver Butte marine terrace near Cape Blanco in Curry County has an estimated age of 125 ka years (Kelsey, 1990). The Pioneer surface at Cape Blanco (Kelsey, 1990) and at Cape Arago (McInelly and Kelsey, 1990) in Curry County, Oregon, has been dated 105 ka years before present (McInelly and Kelsey, 1990). In other words, based on gross correlations of riverine geomorphic surfaces and coastal marine terraces, the High Brateng without the external glacial meltwater deposits has an estimated age of 105 ka yrs.

Winkle

Geomorphic Surface

The stratigraphy of the alluvial stream terraces named Winkle (Figure 1) reflect the main stem and tributary drainage systems in the Willamette Valley. Before construction of flood control dams in the upper Willamette Valley, both High and Low Winkle components probably were flooded by the 100-year to 500-year flood events (Reckendorf, 1973).

As an old flood plain surface, the Winkle stratigraphy reflects gravelly to sandy vertical accretion deposits, that are overlain by silty vertical accretion deposits. Little geomorphic surface evidence exists of an old flood plain on the High Winkle; but an old bar and old channel topography is common on the Low Winkle, in the Willamette Valley. This author has observed a similar topography in other areas in the western United States where the equivalent to the Winkle surface can be found.

The Linn gravel is common beneath the Winkle surface because of lateral scour during Winkle time. However, the Linn gravel is much older and does not reflect the lateral accretion deposits of Winkle time.

Truncation of Linn Gravels

After the last episode of "Bretz Floods," represented by deposition of the Greenback Member, extensive downcutting by streams in the Willamette Valley occurred as the drainage channels that we see today were developing. The upland, and primarily the capping Greenback Member, was being severely eroded as base level dropped. This downcutting in the Willamette and its tributaries truncated the Greenback, Malpass, Irish Bend, Wyatt, and Diamond Hill Members and cut into the Linn Member. This truncation is younger than the deposits it crosses.

Parsons and Balster (1969) noted that Diamond Hill Member above the Linn Member was beyond reach of radiocarbon dating (about 40 ka yrs.). Therefore, the upper gravel at the Glenn (1965) site, which was called Linn Member gravels and was dated 34.5 ka yrs., probably represents Linn Member gravels that were reworked during the episode of downcutting, truncation, and redeposition, as the stratigraphy of these gravels cannot be younger than the Diamond Hill member.

The Linn Member certainly was reworked by lateral cutting of the Winkle channel and therefore commonly occurs beneath the Winkle surface. However, the true Winkle gravels, as will be explained, are only about 12 to 13 ka yrs. old. Traditionally, the true Winkle gravels are not separated in mapping but, instead, lumped (Bela, 1979; and Gray and Throop, 1981) with the Linn Member and mapped as part of the Quaternary middle terrace deposits (Qtm) in the Willamette Valley.

Age and Winkle Gravels

Work along the Luckiamute River in Polk County (Reckendorf and Parsons, 1966) determined that the argillic horizon of the Malabon soil profile under the Winkle surface has an age of 5,280 ± 270 yr. Wood fragments in sandy clay loam sediments that are 543 cm deeper dated 10,850 ± 240 yr. (Date by Isotopes Inc. I-1564). Organic rich sediments from about the same level also have been dated 10,490 ± 240 yrs. (Date by Isotopes Inc. I-1563).

The sandy clay loam sediments extended to a depth of 772 cm. Below this deep sequence of fine textured vertical accretion deposits, the lateral accretion deposits of the true Winkle gravel are encountered at 813 cm. These Winkle gravels along the Luckiamute or in the main valley are not exposed to any great extent, so they are not well characterized. The Winkle gravels along the Luckiamute Valley were observed by this author, at the dated site, to have a median size of about 1.9 cm (0.75 inch).

Fine-Textured Character

We should expect the Winkle deposits to be primarily fine textured. After the last "Bretz Flood", the downcutting and erosion of the upland mantle of the Greenback Member, along with associated erosion of the Malpass and Irish Bend Members on the Senecal surface, produced large volumes of clay, silt, and sand-sized sediments for vertical accretion deposition on the flood plain.

In addition, this was happening over a time frame of tephra deposition from Glacier Peak, Mount Saint Helens Set S, and Crater Lake eruptions. It is not uncommon to find tephra from Crater Lake, Mount Mazama (6.7 ka - 6.8 ka, Sarna-Wojcicki et al., 1991) in Winkle soils (Green, 1983; Smythe. 1986; Langridge. 1987). In other words, the fine-textured nature of High Winkle and Low Winkle surface soils is made even more fine by the pyroclastic deposition of fines that were probably silt-sized.

Lake Beds

Some of the Winkle surface consists of old lake beds. Lake Labish in the central Willamette Valley and Jackson Bottom and Onion Flat, along the Tualatin Valley, are such areas. Peat near the base of the bog (about 640 cm) at Lake Labish has an age of 11,000 ± 230 yrs. (Glenn, 1965). Peat from 490 cm below Onion Flat (4.8 km west of Tualatin) has been dated 12,240 ± 330 yrs. (Glenn, 1965). Organic materials associated with the Tualatin mastodon, taken from beneath the Winkle surface (as correlated by this author) in the city of Tualatin, have been dated 11,300 yrs. (Tualatin Times, 1992).

As Glenn (1962) stated, Lake Labish is a former northeastern flowing channel of the Willamette River, that was diverted because of deposition of a thick wedge of sand (about 550 cm) near the center of the abandoned channel. This former Willamette Channel was considered (Allison, 1978) to be cut off by the "Bretz Floods" and forced to move west into its present northerly route. This diversion has also been described as caused by a natural dam of sand from Silver, Abiqua, and Butte Creeks that blocked the original Willamette channel (Orr et al., 1992)

Tualatin Hanging Valley

The Onion Flat and Jackson Bottom Winkle surfaces have a different ponded history related to a restricted outlet of the Tualatin Valley in post Senecal time (Parsons, 1969; Reckendorf, 1973). A drainage change occurred at the mouth of the Tualatin River at the time of formation of the Champoeg surface (Parsons, 1969). Baldwin (1957) and Parsons (1969) discuss alternative ways for the channel changes and associated timing.

Regardless of which interpretation is used, the Tualatin Valley can be interpreted as a hanging valley from about 6.5 km above its mouth. The Tualatin Channel above the knickpoint has a wide Winkle surface (there are some Ingram remnants) that is frequently flooded. The Tualatin in general did not widen to form a lower lying Ingram surface above the 6.5 km point, but instead the Tualatin formed a flood plain of thick vertical accretion deposits.

The continual overbank flooding and ponding associated with the frequent flooding has prevented the development of soils typical of the Winkle surface in other areas. With the continual renewal of additional alluvium since the start of Winkle time

(12.2 ka yrs.), an alluvium high in organic matter and nutrients (phosphorus, nitrogen, etc.) has accumulated, and soil development has been retarded. During early Winkle time, essentially complete ponding (i.e. a lake) occurred, as evidenced by the muck and peats dated 12.2 ka yrs. at Onion Flats.

Gravelly Components

In contrast to the predominantly fine-textured nature of the common Winkle surface in the Willamette Valley, representative areas of Winkle surface show gravelly material as the primary stratigraphic unit. These deposits are interpreted as alluvial fans of Winkle age or deposits of braided streams. They are common in Linn and Marion Counties (Williams, 1972; Langridge, 1987).

Ingram

Stratigraphy and Geomorphic Features

The stratigraphy of the High Ingram and Low Ingram surfaces is a mixture of lateral and vertical accretion deposits of variable thickness. These deposits vary from loamy sand to silt loam. These tend to reflect channels, longitudinal bars, point bars, meander scrolls, sand splays, and natural levees (Reckendorf, 1973). Vertical accretion deposits tend to occur in old channels, oxbows, oxbow lakes, and backswamp areas.

Sometimes super-elevated flows (flows well above the channel flood flows that occur on the outsides of the river curve or in old channels away from the river bank) produce deposits above the normal level of the flood plain. These are common along the Ingram surfaces and could be interpreted as a higher geomorphic surfaces, if not viewed in the context of superelevated flow.

The High Ingram is older and shows fewer of the geomorphic features listed, than occur on the Low Ingram. The High Ingram also has more of the well drained silty soils, because of thicker and broader vertical accretion deposits over the lateral accretion deposits.

Mineralogy and Age

According to Balster and Parsons (1968), the mineralogy of the Ingram sediments reflects more of the sedimentary rocks of the Coast Range and Cascade Mountains. In other words, there is less influence of the reworked Greenback Member that is the common source for the Winkle sediments. The Ingram surface in the Willamette Valley has been assigned and age by direct correlation to the Luckiamute surface. It has been radiocarbon dated ranging from 3,290 ± 120 yrs. to 555 ± 100 yrs. (Balster and Parsons, 1968).

Horseshoe

Geomorphic Features

The Horseshoe surface is made up primarily of channel bars, point bars, and meander scroll lateral accretion deposits. There may be as many as two Horseshoe levels, but much of the difference may be related to superelevated flow deposits previously discussed or to pre-dam versus post-dam flood deposition.

Stratigraphy and Age

Horseshoe stratigraphy varies from gravel to silt loam in texture, and annual flooding of most of the surface results in continual alteration. Dam construction probably has altered the flood height and duration of flooding on the Horseshoe, as well as the texture of the deposition. This has contributed to increased growth of riparian vegetation if not cleared for streamside activities. Metallic artifacts are found in the surface alluvium, so the geomorphic surface is thought to have formed in post-settlement time (Parsons, Balster and Ness, 1970).

Soils Characteristics and Interpretation

Summary of Typical Soils

Table 2 shows typical soils representative of different geomorphic surfaces in the Willamette Valley. It also shows an abbreviated stratigraphy for the surface, relative age, and abbreviated soil interpretations. For all of the surfaces to be discussed, understanding the geomorphic history of the surface, and its deposit, helps in identifying appropriate soils differences between geomorphic surfaces. This understanding then aids in mapping and in making associated soil interpretations.

Eola

Soils on stable upland pediments and ridgetops on the Eola geomorphic surfaces are usually red or yellowish red Haplohumults (Green, 1983, Smythe, 1986, Langridge, 1987) (Table 2). These Ultisols exhibit the most advanced stages of weathering and leaching of bases in the Willamette Valley. They are relict paleosols that have been stated to be equivalent to the Diamond Hill Paleosol (Smythe, 1986).

The Jory, Nekia, and Bellpine soils occur at elevations below 366 M and have a xeric moisture regime. Honeygrove and Peavine soils occur above 366 M and have a udic moisture regime. These upland soils may have upslope contributions of side valley alluvium or of external eolian deposition.

Occasionally, as in Multnomah County, there is evidence of glacial meltwater deposition over the Haplohumults on Eola, so that the Haplohumult is found as a paleosol (Green, 1983). This unusual situation probably occurred because of very high backwater associated with hydraulic damming and ice dams during the "Bretz Floods" and possibly during the earlier "Ancient Missoula Floods." These high backwater levels would have dropped rapidly once flood waters entered the Willamette Valley and tributaries, so comparable Eola surfaces immediately south of Washington and Clackamas County are not known to have the glacial erratics and probable flood water deposits on Eola surfaces.

The rolling topography of the Eola surfaces, whose pediments and ridge tops are characterized by fine textured Haplohumult soils (Bacona, Bellpine, Jory, Nekia, and Honeygrove), provides the setting for the most erosive conditions in the Willamette Valley. Sheet and rill and ephemeral gully erosion are common if the vegetative cover is removed or is sparse. The associated Fragiumbrepts (Cascade and Goble) in the northern Willamette Valley also have a high potential for sheet, rill, and ephemeral gully erosion because of the impermeable fragipan and proximity to steep side slopes.

Andic properties of the Goble (Medial, mixed, mesic Andic Fragiumbrept) soil cause the runoff waters to be higher in soluble phosphorus than non andic soils such as Melby (Fine, mixed, mesic Umbric Dystrochrept) and Olyic (Fine-loamy, mixed, mesic, Typic Haplohumult) (Personnel Communication, Dr. Mary Abrams and Dr. Wesley Jarrett, Oregon Graduate School, 1992). The sediment associated with the runoff from soils with andic properties also is expected to be higher in sediment-bound phosphates. This creates downstream water quality problems in the slow moving and ponded areas like the Tualatin River and its flood plain.

Because of the history of ponding throughout Winkle time, and earlier during Malpass time, areas like the Tualatin Valley have become large phosphate sinks. Consistent with research evaluation of the effects of land use on phosphorus transport (Vaithiyanathan and Correll, 1992), soils with andic properties and higher soluble phosphorus in runoff are expected to have even higher soluble phosphorus in runoff if they are cultivated or logged and left bare (i.e., higher runoff and erosion).

High Dolph

Soils on the redefined High Dolph pediments, ridgetops, and saddles have a sequence of soils on saprolite, bedrock, or weathered gravels (Table 2 and Figure 1). Side valley alluvium or other external depositional units may overlie the reddish to brownish paleosol of the Fragixeralfs or Haploxeralfs, which is similar to the deposition on the Eola surface.

The weathered loamy gravel that underlies the Dolph surface in Multnomah County (Green, 1983) is derived from the Troutdale Formation, whereas further south in Linn County (Langridge, 1987) the deposits below the discontinuity are Lacomb and Leffler gravels mapped as Salkum soil (Clayey, Kaolinitic, misic, Xeric Haplohumult). Soil interpretations given for the Eola unit apply to a lesser extent to the true High Dolph unit. The area of concern is much smaller, and the slopes are less steep.

Brateng

On the Brateng pediments (Table 2 and Figure 1), glacial flood sediments overlie a reddish to brownish paleosol over saprolite or bedrock. The soils are classified as variants because of the thickness of the Greenback Member over the paleosol for both the Willakenzie (Fine-silty, mixed, mesic, Ultic Haploxeralf) and Helmick (Very-fine, mixed, mesic, Aquic Xerochrept) soils. Helmick soil can be found in a channel shaped cross-section with an elongate surface expression.

The soil variability is great on the High and Low Brateng, reflecting the complexity of the landscape development. The flood sediments can occur on the residual soil profile, or side valley alluvium can occur over the paleosol (i.e., the flood sediments were eroded off), or the paleosol can be absent because of erosion, and flood sediments or side valley alluvium may rest on saprolite or bedrock. Soil-forming processes have proceeded under all these circumstances. Therefore, separating the Brateng landscape from landscapes above and below it can help to expedite mapping, by acknowledging the potential complexity of the landscape.

Bethel

As discussed in the Geomorphic Section, the Bethel surface is defined to include the Quad surface, so only the Bethel surface will be discussed in this section.

The Bethel is made up of depositional units of the Willamette Formation in which the Malpass and Wyatt Members tend to be absent. The primary unit therefore is the Greenback, overlying the Irish Bend

Members. When this occurs, the resulting soils are the Willamette Variant and Woodburn. Where the intervening Malpass member is present, which usually occurs on opposing side slopes of rounded hills, then soils with drainage problems such as Dayton, Concord, or Woodburn can be found. These differ in depth to and thickness of the Malpass clay and in landscape position.

Recognization of the Bethel surface can aid in soil mapping and interpretation because the Bethel surface implies specific relict soils and their potential distribution. The agrillic horizons in the profiles of the Willamette, Woodburn, Willamette-variant, Amity, Concord, and Dayton soils are products of late Pleistocene rather than Holocene time (Gelderman, 1970). Therefore, soil profiles are considered relict.

Calapooyla and Senecal

The Calapooyia and Senecal (Table 2 and Figure 1) geomorphic surfaces are the next lower depositional surfaces in the Willamette Valley. If the Greenback and Malpass Members are present, which is the common situation on the Calapooyia surface, then Dayton (Fine, montmorillonitic, mesic Typic Albaqualf) soil are mapped. The A and E horizons of the Dayton are the Greenback Member, the 2Bt is the Malpass Member, and the 3C is the Irish Bend Member. However, Dayton soils have sola that overlie the Diamond Hill Paleosol and bedrock, as well as the Irish Bend Member. On the Calapooyia surface where the Malpass Member pinches out, the combination of Greenback and Irish Bend Members usually results in Amity (Fine-silty, mixed, mesic Argiaquic Xeric Argialboll) soils.

The Calapooyia surface lacks relief and surface drainage compared to the Senecal surface. When there is slight drainage development downvalley on the Calapooyia surface, the Malpass (i.e., 2Bt of Dayton) will likely be thickest near the bottom of the swale. As the Malpass Member thins going up the side of the swale, then Concord (Fine, montmorillonitic, mesic Typic Argiaquolls) soils tend to occur. However, out of the swale and on the ridge the Amity soil tends to occur.

With further drainage development, the Senecal surface forms. Willamette (Fine-silty, mixed, mesic Pachic Ultic Argixerolls) soil is well represented on the Senecal surface where there is moderate relief. Where there is less drainage development, Amity and Woodburn (Fine-silty, mixed, mesic Aquultic Argixeroll) soils tend to occur. Amity soils on Senecal are common on ridges with Greenback over Irish Bend Member, with Malpass along the flank on each side of the ridges. Even though Amity soil has a winter water table, the soil has sufficient permeability that tile drainage is very effective. Therefore, Amity soil can support a wider diversity of agriculture and less limitation for urban development than Dayton soil.

Champoeg

The geomorphic episode that formed the Champoeg surface had only limited extent in the Willamette Valley. The deposits associated with the Champoeg surface consist of torrentially cross-bedded gravel and cobbles and associated boulders. These deposits are thought to have been formed by flood waters from Glacial Lake Missoula. Multnomah (Fine-loamy, mixed, mesic Dystic Xerochrept) soil has formed in these materials.

Winkle

The soils on the Winkle geomorphic surface (Table 2 and Figure 1) represent the oldest soil associated with the present drainage system in the Willamette Valley. Most soils on the surface are typical of flood plain vertical accretion deposits of meandering streams. These vary from the well drained Malabon (Fine, mixed mesic Pachic Ultic Argixeroll), to the moderately well drained Coburg (Fine, mixed mesic Pachic Ultic Argixeroll), to poorly drained Awbrig (Fine, montmorillonitic, mesic Vertic Albaqualf).

The Winkle terrace has been stable long enough for the soils like Malabon to develop a mollic epipedon and have an organic matter and clay distribution resulting from pedogenic activity rather than deposition. The fine texture of the depositional material has facilitated the eluviation of clay from the surface to form a fine-textured argillic horizon, and bases have been depleted to less than 75 percent of base saturation (Langridge, 1987).

In some areas the depositional alluvium in Winkle time was quite gravelly. Under these circumstances, soils such as Clackamas (Fine-loamy, mixed, mesic Typic Argiaquoll) or Courtney ((Fine, monmorillonitic, mesic Abruptic Argiaquoll) have formed. The gravelly depositional materials may represent aggradation as braided streams rather than as meandering streams, and in some areas they may occur as alluvial fans.

In other areas, the Winkle surface is an old lake beds or an old channel where peat and muck have accumulated. Soils such as Labish (Fine, mixed, mesic Cumulic Humaquept) and Semiahmoo (Euic, Mesic Typic Medisaprist) have formed under these conditions. On some areas of Winkle surface where primary pyroclastic material of Mt. Mazama age has accumulated, Sifton (Medial over sandy, mixed, mesic Andic Xerumbrept) soil is common (Smythe, 1986).

As previously noted, the Winkle soils are Late Pleistocene to Holocene in age (about 12.2 ka to 5.3 ka yrs.). At that time, fine-textured materials were being transported by the meandering streams and depositing in the flood plains. Also during that time period, there were several tephra events, especially during the later part of Winkle time when Mt. Mazama was erupting.

Pyroclastic material from these eruptions may have added fine- textured material to the Winkle age deposits. This happened to both the vertical accretion deposits of meandering streams and to the lateral accretion deposits along the meandering stream as well as to the lateral accretion deposits of braided streams. In other words, the gravel deposits could obtain fine-textured additions to fill the intersticies because of ash deposition, both from primary ashfall and as reworked ash in the watershed runoff.

During Winkle time and later several areas were ponded to form sinks for sediment and nutrients. Substantial complete ponding has occurred on the Tualatin area Winkle surface, as evidenced by the presence of extensive areas of peat (Schlicker and Deacon, 1967) and Labish mucky soils (Reckendorf, 1973).

The Tualatin River flood plain appears to have a long history from about 12.2 ka yrs. to present of accumulating fine-textured sediment and associated nutrients. These materials are likely to form a phosphate sink, and soil sampling and testing has confirmed the high phosphorus levels. Any erosion or reworking of these particular materials would add high natural phosphorus contributions to the Tualatin River.

Due to the continual renewal of additional alluvium on the Tualatin flood plain over essentially the last 12.2 ka years, soil development was retarded. As a result, the Chehalis (Fine-silty, mixed, mesic Cumulic Ultic Haploxeroll) soil lacking B horizons with clay illuviation formed rather than the equivalent Malabon or Coburg soils that occur on Winkle in other locations in the Willamette Valley.

Ingram

Other than along the Tualatin River, the Ingram surface has the oldest flood plain soils in the Willamette Valley without a Bt horizon. Common soils include Chehalis (Fine-silty, mixed, mesic Cumulic Ultic Haploxeroll), Cloquato (Coarse-silty, mixed, mesic, Cumulic Ultic Haploxeroll), McBee (Fine-silty, mixed, mesic, Cumulic Ultic Haploxeroll) and Wapato (Fine-silty, mixed, mesic, Fluvaquentic Haplaquoll).

Soils such as Wapato are poorly drained and formed mostly in old channel sloughs and backswamp areas. As such, they accumulate sediment and are also phosphorus sinks associated with sediment deposition. They also provide phosphorus to the river system through streambank erosion and therefore become a phosphorus source. The Ingram soils have characteristics that reflect their flood history.

Horseshoe

The soils on the Horseshoe surface include Camas (Sandy-skeletal, mixed, mesic, Fluventic Haploxeroll) and Newberg (Coarse-loamy, mixed, mesic Fluventic Haploxeroll). These soils are forming flood plain deposits and have no diagnostic horizons. Aggradation is primarily by lateral accretion.

Conclusion

Eola

This paper has used the basic steps sequence of geomorphic surfaces developed in the late 1960s by Balster and Parsons (1968) and updated the chronology, stratigraphy, and ages using the additional research of the past 29 years. High surfaces such as Eola have been described with their relict paleosols Haplohumults that have been assigned an estimated age of about 200 ka yrs. These highly weathered Haplohumults and the associated Fragiumbrepts are both highly susceptible to sheet and rill and ephemeral gully erosion if the vegetated cover is removed or is sparse. The Fragiumbrepts with andic properties also are considered to yield runoff that is high in soluble and sediment bound phosphorus.

Dolph

A High Dolph surface has been defined below the Eola, that has side valley alluvium or eolian deposits over Haploxeralfs, Haploxerolls, and Xerochrepts. These soils also have high potential for sheet and rill and ephemeral gully erosion if the vegetated cover is removed or sparse. The High Dolph has an estimated age of 125 ka yrs.

Brateng

The High and Low Brateng geomorphic surface also have relict palesols, but these are overlain by late Pleistocene "Bretz Flood" deposits. The High

Brateng with the paleosol has an estimated age of 105 ka yrs., but the overlying glacial Lake Missoula Flood deposits have an estimated age between 15 ka and 12.8 ka yrs. Side valley alluvium is mixed with the "Bretz Flood" deposits in a unit described as the Greenback Member. Associated with the Greenback Member on the High and Low Brateng are glacial meltwater derived erratics. Soil variability is great on the Highland Low Brateng, reflecting the complexity of the landscape development.

Bethel, Senecal, and Calapooyla

Below the Brateng surface lie the Bethel, Senecal, and Calapooyia geomorphic surfaces. The Bethel surface consists primarily of the Greenback Member over the Irish Bend Member, with soils such as the Willamette variant. The lower lying Senecal geomorphic surface, which is a drainage modification of the Calapooyia surface, is underlain by a variety of soils depending on the combination of Greenback, Malpass, Irish Bend, Wyatt, Diamond Hill, or Linn Members that are present.

On the Calapooyia surface, the A and E horizons of the Dayton soil are the Greenback Member. The underlying Malpass Member is the 2Bt of the Dayton soil, and the underlying Irish Bend Member is the 3C of the Dayton soil. The Malpass Member has not been dated specifically but is estimated to be older than 12.2 ka yrs. (oldest sediments under Winkle surface) but younger than 50 ka yrs. (estimated minimum age for Mt. St. Helens Set C tephra).

The origin of the Malpass is interpreted to be a lacustrine deposit of mixed origin. The possible sources for the fine-textured Malpass are (1) erosion of the Irish Bend paleosol and the Irish Bend Member; (2) erosion of specific fine-textured, soils, saprolite, and bedrock beneath the Brateng, High Dolph, and Eola surfaces during periods of high rainfall and runoff; (3) tephra from various volcanic eruptions in the area; and (4) "Bonneville Flood" deposits, commingled with "Ancient Missoula Flood" deposits. The author considers the commingled flood source to be the predominant source.

The Irish Bend Member beneath the Malpass and the lower lying Wyatt Member are interpreted as being derived from earlier (pre 15 ka yrs.) "Ancient Missoula Floods," with limited associated additions of tephra from volcanic eruptions. Woodburn and Willamette soils therefore are interpreted to be partly derived from late Pleistocene "Bretz Floods" (15 ka - 12.8 ka) and partly derived from "Ancient Missoula Floods" (50 ka - 60 ka).

Beneath the Wyatt in stratigraphic sequence is the Diamond Hill Paleosol. This unit is believed to be beyond reach of radiocarbon dating (>40 ka). Some authors have correlated the upland paleosols on the Eola and Brateng to the Diamond Hill Paleosol. The author does not believe that the Diamond Hill is as old as the estimated dates given for Brateng through Eola (i.e., 105 ka to 200 ka yrs.). The Linn Member occurs stratigraphically beneath the Diamond Hill Paleosol and also is expected to be beyond reach of radiocarbon dating.

Winkle

The Winkle geomorphic surface is the next lower surface below the Senecal surface and is the primary geomorphic surface in the Willamette Valley associated with the present drainage system. The argillic horizon of a soil profile on the Winkle surface has been dated 5.2 ka yrs. Snady clay loam sediments 543 cm deeper dated about 10.8 ka yrs. In general, the Winkle surface is composed of thick, fine-textured, vertical accretion deposits. Some of the Winkle surface is represented by lacustrine deposits where peat and mucks are common. Dates from several of these deposits help to establish an age-range for the Winkle deposits and surface of 12.2 ka to 5.2 ka yrs.

The Winkle lacustrine deposit areas and the flood plain of the Tualatin River have served as sediment and phosphate sinks for the last 12.2 ka yrs. As such, these areas contribute a high organic and phosphate load that affects the water quality of the specific areas.

Ingram & Horseshoe

The flood plains below the Winkle high flood plain are the Ingram and Horseshoe geomorphic units. Both of these units have multiple flood plain surfaces and soils that reflect their flooded condition. Ingram deposits vary in age from 3.3 ka to 0.555 ka yrs. The younger Horseshoe flood plains have been dated as younger than 0.555 ka yrs., up to the present time. These Horseshoe low floodplains have soils that lack diagnostic horizons.

Acknowledgement

The manuscript benefited from the review of Herb Huddleston, Professor of Soils, Oregon State University, and Scott Burns, Associate Professor of Geology, Portland State University.

The support and tolerance during the preparation of this manuscript of my wife Elisa, and the patience, persistence, and diligence of secretaries Phyllis Paradise and Patricia Schwerin, along with

James Light, Civil Engineering Technician, were greatly appreciated and are very worthy of acknowledgement.

Literature Cited

Allison, I.S. 1935. Glacial erratics in Willamette Valley, Oregon. Geol. Soc. Amer. Bull., 46:615-632.

Allison, I.S. 1936. Pleistocene alluvial stages in north-western Oregon. Sci., 83:441-443

Allison, I. S. 1953. Geology of the Albany Quadrangle, Oregon. Dept. Geol. and Mineral Resources Bull. 37, pp 1-18.

Allison, I. S. 1978. Late Pleistocene sediments and floods in the Willamette Valley. The Ore Bin, 40:177-191 and 193-202

Allen, J. E., M. Burns, and S.C. Sargent 1986. Cataclysms on the Columbia. Timber Press. Portland, Oregon. 221p.

Bacon, C. R. 1983. Eruptive history of Mount Mazama and Crater Lake caldera, Cascade Ranges. Journal of Volcanology and Geothermal Research 18:57-115.

Baker, V. R., and R. C. Bunker. 1985. Cataclysmic late Pleistocene flooding from glacial Lake Missoula: A Review. Quaternary Science Reviews 4:1-41.

Baldwin, E. M. 1964. Geology of the Dallas and Valsetz Quadrangles, Oregon. Dept. of Geol. Miner. Industries Bull 35 (revised).

Baldwin, E. M. 1957. Drainage changes of the Willamette River at Oregon City, and Oswego, Oregon. Northwest Science 31:109-117.

Balster, C. A., and R. B. Parsons. 1968. Geomorphology and soils, Willamette Valley Oregon. Oregon Agr. Exp. Sta. Special Report 265.

Balster, C. A., and R. B. Parsons. 1969. Late Pleistocene stratigraphy, Southern Willamette Valley, Oregon. Northwest Science 43:116-129.

Bela, J. K. 1979. Geologic hazards of eastern Benton County, Oregon. Dept. of Geol. Miner. Industries Bull. 98.

Bela, J. L. 1981. Geology of the Rickreall, Salem West, Monmouth and Sidney 7.5 Quadrangles, Marion, Polk, and Linn Counties, Oregon. Dept. Geol. Miner. Industries GMS-18.

Bretz, J.H. 1919. The Pleistocene submergence in the Columbia Valley of Oregon and Washington. Jour. of Geol. 27:489-506.

Bretz, J.H. 1925. The Spokane Flood beyond the Channel Scablands. Jour. Geol. 33:97-115 and 236-259.

Bretz, J.H. 1969. The Lake Missoula floods and the channel scablands. Jour. Geol. 77:505-543.

Burns, S.F. and D.I. Cordio. 1992. "Ancient Missoula Floods" Proceedings of the Oregon Academy of Science Abstract V.29, p.38.

Busacca, A. J. 1989. Long Quaternary record in eastern Washington, U.S.A., interpreted from multiple buried paleosols in loess. Geoderma 45:105-122.

Busacca, A. J. 1991. Loess deposits and soils of the Palouse and vicinity, p. 216-228. *In* geology of North America Vol K-2 Quaternary nonglacial geology. Chapter 8. Quaternary geology of the Columbia Plateau.

Condon, T. 1871. The Willamette Sound: Overland monthly, 7:393-398.

Foley, L.L. 1982. Quaternary chronology of the Palouse loess near Washtucna, eastern Washington. Masters thesis, Western Washington Univ. Bellingham, Washington. 137 numb. leaves.

Fryxell, R. 1965. Mazama and Glacier Peak volcanic ash layers; relative ages. Science 147:1288-1290.

Gelderman, F. W. 1970. Willamette and associated soils of late Pleistocene geomorphic surfaces, Polk County, Oregon. Masters thesis. Oregon State University Corvallis, Oregon. 181 numb. leaves.

Gelderman, F.W., and R. B. Parsons. 1972. Argixerolls on Late Pleistocene surfaces in northwestern Oregon. Soil Sci. Soc. of Am. Proc. 36:335-341

Glassman, J. R., and G. F. Kling. 1980. Origin of Soil Materials in foothill soils of Willamette Valley, Oregon. Soil Sci. Soc. Am. Proc. 44: 123-130.

Glassman, J. R., Brown, R. B., and G. F. Kling. 1980. Soil-Geomorphic Relationships in the Western Margin of the Willamette Valley, Oregon. Soil Sci. Soc. Am. Proc. 44:1045-1052.

Glenn, J. T. 1962. Gravel deposits in the Willamette Valley between Salem and Oregon City, Oregon. The Ore Bin 24:33-47.

Glenn, J. T. 1965. Late Quaternary sedimentation and geologic history of the northern Willamette Valley, Oregon. Ph.D thesis. Oregon State University, Corvallis, Oregon. 231 numb. leaves.

Gray, J. J., and A. H. Throop. 1981. Rock material resources of Marion, Polk, Yamhill, and Linn Counties, Oregon. Dept. Geol. Miner. Industries Open File Report 0-81-7. 47p.

Green G. L. 1983. Soil survey of Multnomah County area, Oregon. USDA, 244pp., illus.

Habeck, J. R. 1961. The original vegetation of the Willamette Valley, Oregon. Northwest Science 35:65-71.

Jarrett, R.D., and H.E. Malde. 1987. Paleodischarge of the late pleistocene Bonneville Flood, Snake River, Idaho, computed from new evidence. Geol. Soc. Amer. Bull. 99:127-134.

Kelsey, H.M. 1990. Late Quaternary deformation of marine terraces on the Cascadia subduction zone near Cape Blanco, Oregon. Tectonics 9:983-1014.

Langridge, R. W. 1987. Soil survey of Linn County area, Oregon. USDA, 344pp., illus.

McDonald, E.V., and A. J. Busacca. 1988. Record of pre-late Wisconsin giant floods in the Channeled Scabland interpreted from loess deposits. Geology 16:728-731.

McInelly, G.W., and H. M. Kelsey. 1990. Late Quaternary tectonic deformation in the Cape Arago-Bandon region of Coastal Oregon as deduced from wave-cut platforms. Jour. Geophys. Res. 95:6699-6713.

McDowell, P. F. 1991. Quaternary stratigraphy and geomorphic surfaces of the Willamette Valley, Oregon, p156-164. *In* Geology of North America Vol K-2. Quaternary nonglacial geology. Chapter 7, Quaternary geology of the pacific margin.

Moody, U. L. 1989. Preliminary correlation between the Willamette Silts of Oregon and the Channeled Scablands of eastern Washington. GSA Abstracts with programs v. 21, p119.

Morrison, R. B. 1991. Quaternary stratigraphic, hydrologic and climatic history of the Great Basin, with emphasis on Lake Lahonton, Bonneville and Tecopa, p 283-320. *In* Geology of North America Vol. K-2. Quaternary non-glacial geology. Chapter 10.

Norgren, J. A. 1962. Thin-section micromorphology of eight Oregon soils. Masters thesis. Oregon State University, Corvallis, Oregon. 122 numb. leaves.

Orr, E.L., W.N. Orr, and E.M. Baldwin. 1992. Geology of Oregon. Kendall Hunt Publishing, Dubuque, Iowa. 254pp.

Parsons, R. B. 1969. Geomorphology of the Lake Oswego area, Oregon. The Ore Bin 31:187-192.

Parsons, R.B., and R.C. Herriman. 1969. Huploxerolls and Agrixerolls developed in recent alluvium, southern Willamette Valley, Oregon. Soil Sci. 109:299-309.

Parsons, R. B., and G. L.Green. 1982. Geomorphic surfaces and soils in Multnomah County. Soil Conservation Service, West Technical Service Center, Portland, Oregon. 16pp., illus.

Parsons, R. B., C. A. Balster, and A. O. Ness. 1970. Soil development and geomorphic surfaces, Willamette Valley, Oregon. Soil Sci. Soc. Amer. Proc. 34:485-491.

Peck, D. L., A. B. Griggs, H. G. Schlicker, F. G. Wells, and H. M. Dole. 1964. Geology of the central and northern parts of the western Cascade Range in Oregon. USGS Professional Paper 449. 56pp.

Piper, A. M. 1942. Ground water resources of the Willamette Valley, Oregon. USGS Water Supply Paper 890. 194p.

Porter, S. C. 1978. Glacier peak-tephra in the North Cascade Range, Washington: stratigraphy, distribution and relationships to late-glacial events. Quaternary Research 10:30-41.

Reckendorf, F.F. 1973. Techniques for identifying flood plains in Oregon. Ph.D thesis. Corvallis, Oregon, Oregon State University. 344 numb. leaves.

Reckendorf, F. F., and R. B. Parsons. 1966. Soil development over a hearth in Willamette Valley, Oregon. Northwest Science 40:46-55.

Richmond, G.M. 1965. Glaciation of the Rocky Mountains, P. 211-230. *In* The Quaternary of the United States, Wright, H.E., and D.G. Frey, eds. Princeton University Press. Princeton, New Jersey.

Roberts, M. C. 1984. The late Cenozoic history of an alluvial fill; The southern Willamette Valley, Oregon. p491-504. *In* MaHaney, W. C., ed. Correlation of quaternary chronologies: Norwich England. Geo. Books.

Roberts, M. C., and D. W. Whitehead. 1984. The palynology of a nonmarine Neogene deposit in the Willamette Valley, Oregon. Review of Palaeobotany and Palynology 41:1-12.

Sarna-Wojcicki, A.M., K.R. Lajoie, C.E. Meyers, and D.P. Adam. 1991 Tephrochronologic correlation of upper Neogene sediments along the Pacific Margin, coterminous United States, p 117-140. *In* The Geology of North America. Vol K-2. Quaternary non-glacial geology. Chapter 6.

Schlicker, H. G., and R. G. Deacon. 1967. Engineering geology of the Tualatin Valley region, Oregon: Dept. Geol. Miner. Industries Bull. 60. 103p.

Smythe, R.T. 1986. Soil survey of Columbia County area, Oregon. USDA. 198pp., illus.

Snavely, P. D., and H. C. Wagner. 1963. Tertiary geologic history of western Oregon and Washington. Wash. Div. Mines Geol., Rep. Invest. Rept. 22. 25pp.

Snavely, P. D., R. D. Brown, A. E. Roberts, and W.W. Rau. 1958. Geology and coal resources of the Centralia - Chehalis district, Washington. USGS Bull. 1053. 159pp.

Treasher, R.C. 1942. Geologiuc history of the Portland area: Dept. Geol. Miner. Industries GMI Short Paper 7, 17p.

Trimble, D.E. 1963. Geology of Portland Oregon and adjacent areas. USGS Bull. 1119. 119p.

Tualatin Times Newspaper. 1992. Photograph caption dated 4/9/92. Tualatin, Oregon.

Williams, L.H. 1972. Soil survey of Marion County area, Oregon. USDA. 132 pp., illus.

Vaithiyanathan, P., and D. L. Correl. 1992. The Rhode River Watershed: Phosphorus distributions and export in forest and agricultural soils. J. Environ. Qual. 21:280-288.

Volkes, H. E., D. A. Myers, and L. Hoover. 1954. Geology of the west central border area of the Willamette Valley, Oregon. USGS Oil and Gas Investigations Map OM 150.

Waitt, R. B. 1985. Case for periodic colossal jokulhlaups from Pleistocene glacial Lake Missoula: Geo. Soc. Am. Bull. 96:1271-1286.