AN ABSTRACT OF THE THESIS OF

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Title: Valley Fill and Channel Incision in Meyer's Canyon, Northcentral Oregon

Abstract approved: Robert L. Beschta

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Meyer's Canyon, a tributary of Bridge Creek in the John Day Basin, is a deeply incised valley fill in northcentral Oregon. The current channel is incised to the Cretaceous and Tertiary bedrock. To determine the precedence of the current incision and the variation and timing of depositional sequences, the sediments exposed by incision were examined for clues. The incision evaluated in this study occurs along the length of the lower valley fill, approximately 2300 meters, with a maximum depth of about 22 meters near the medial section of the valley. The incision occurred near the beginning of the 20th century and widened from 1951 to 1979, after which tributary headward cutting only is occurring at one location. Colluvial aprons and aggradation within and at the margins of alluvial fans indicate depositional processes again dominate.

Fill sediments date from the early Holocene. Volume of the fill prior to incision was estimated to be about 10.8 mcm (million cubic meters), of which 1.2 mcm (11%) was removed by the incision. Fill sediments are contributed by coalescing alluvial fans and alluvial plain sedimentation. The Upper Drainage and Permian Tributary could potentially donate 67% of the Lower Valley fill sediments though these portions of the drainage were not studied. Early sedimentation is dominated by coarse-grained fluvial transport, followed by numerous thick fine-grained sequences, topped by debris

flow/mud drape couplets where proximal fan processes dominate. Sediment size decreases and sorting increases toward the fan margins. Valley plain deposition is currently and was, within the Holocene, enhanced and influenced by thick vegetation due to perennial groundwater saturation. Aggradation throughout the Lower Valley fill has dominated over the course of the Holocene, with only one previous episode of incision coincident with the Mt. Mazama eruption, about 6900 yrs BP.

Rates of accumulation have changed over the course of the Holocene. Volume rate of accumulation was 140 m^3/yr prior to the Mazama eruption and 210 m^3/yr following the eruption at a proximal fan location. Within the alluvial fans and plains, sediment characteristics change with distance from source of sediment. At more distal fan and alluvial plain locations, an average volume accumulation rate of 260 m^3/yr was estimated prior to the Mazama eruption, and 130 m^3/yr following the eruption. These rates indicate that input at the proximal locations has been increasing in the late Holocene and that aggradation may again be dominating Meyer's Canyon sedimentation.

Recurrence intervals of debris flows (proximal locations) or events capable of transporting matrix-supported gravels (distal and alluvial plain locations) show an average recurrence interval of 600 yrs pre-Mazama and 1500 yrs post-Mazama. At proximal locations, the shortest interval is after about 1200 yrs before present (BP) when debris flows occurred about every 500 years. Shorter intervals also generally occurred in all pre-Mazama locations when coarse-sediment input was rapid, probably from the Pleistocene-Holocene climate shift from cool/wet to warmer/drier. Following the Mazama eruption, the medial section of the Lower Valley fill had rapid input of coarse debris, while proximal fan locations had massive fine-grained input. This is interpreted as a complex response, i.e., rapid runoff reworked previously deposited sediments at proximal locations and sediments were deposited at more distal locations. Fine-grained sediment accumulation followed this period until about 1200 yrs BP.

The strongest evidence for a causal mechanism for incision is a complex response at the previously saturated wet-meadow, medial portion of the Lower Valley fill due to loss of riparian vegetation which maintained an oversteepend alluvial slope. The previously saturated portion of the Lower Valley fill shows an increasing transportation slope over time. This slope was probably maintained by the hydrophytic vegetation, but loss of that vegetation due to Euroamerican influence could have led to a geomorphic threshold being crossed on the oversteepened slope and channel incision ensued. The incision is widest at this point and, if width is used as a surrogate for length of time of exposure, it is likely that incision began here.

Valley Fill and Channel Incision
in
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by

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VALLEY FILL AND CHANNEL INCISION IN MEYER'S CANYON, NORTHCENTRAL OREGON

INTRODUCTION

Valley fills are depositional landforms resulting from a complex set of alluvial processes (Chorley et al. 1985). Although formed over thousands of years by persistent, incremental and episodic deposition, these landforms experience erosional episodes as well. Whereas, most of the research on channel incision has been accomplished in the American Southwest, little is known about the controls and timing of valley alluviation and subsequent incision particular to the semiarid Pacific Northwest.

There are several spatial and temporal scales which may influence valley fill history. To be considered are the climate regime over the course of valley filling (e.g., Holocene aggradational episode), which affects the region of study (e.g., the Great Basin), and the effects of processes which dominate individual landforms such as alluvial fans.

Gully erosion, or stream incision, changes drainage basin hydrology, produces and transports large quantities of sediment, affects water quality, alters floodplain functions, and can fill reservoirs (Patton and Schumm 1975). Some investigators have identified incision of valley fills as an important feature of streams in eastern Oregon (e.g., Elmore and Beschta 1987). Incision seems to be dominating valley fill processes in semiarid eastern Oregon currently, and it appears to be somewhat coincident with Euroamerican settlement in the West. Because of this coincidence, the study of historical information (i.e., the last 100 years) can perhaps determine when the incision occurred. The study of depositional sequences can be used to determine the age of the sediments, i.e., over what period sediments have been added to valley fill, the dominant depositional processes, and if the current incision cycle has precedence. By combining when the incision occurred and the depositional and erosional characteristics of the watershed prior to incision, causal mechanisms may perhaps be inferred.

Throughout the geomorphic literature, investigators have made distinctions between incised channels based on comparisons in the geometry, morphology, geography, and cause. Distinctions such as "gully", "arroyo", "incision", "trench", "wadi" are used (e.g., Antevs 1952, Patton and Schumm 1975, Schumm et al. 1984). All cases refer to an alteration of drainage pathway (Schumm et al. 1984). The incised channel evaluated in this study (Meyer's Canyon) is one such altered pathway and "incision" is used throughout. Meyer's Canyon, in north-central Oregon (Figure 1), is a deeply-incised valley fill and serves as a vehicle for attempting to document and understand valley fill processes and the current episode of stream incision associated with Northwest rangelands.

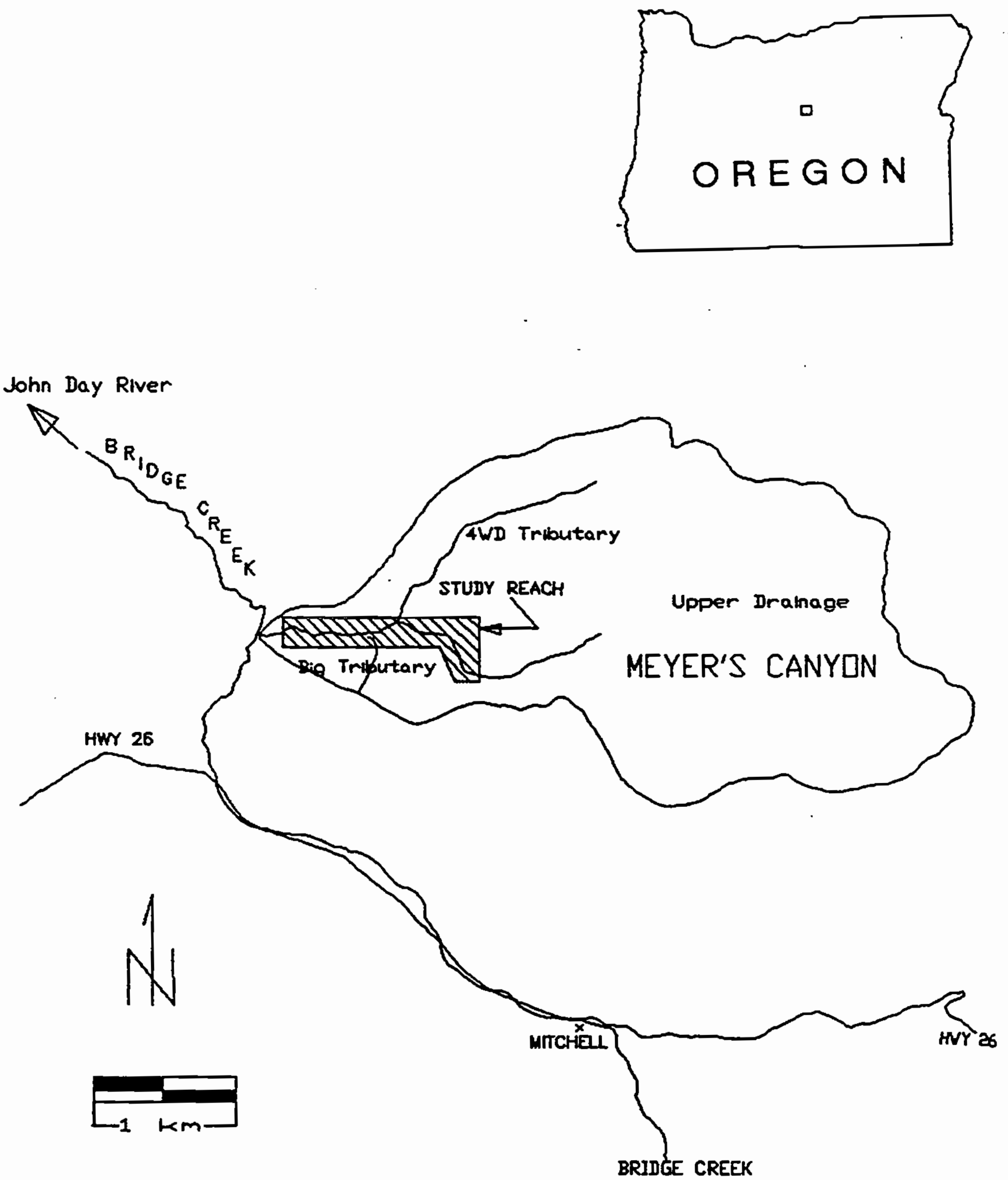


Figure 1. Location map of Meyer's Canyon drainage and study reach.

STUDY OBJECTIVES

The overall goal of the study was to better understand factors and processes affecting valley fill deposition and what those elements would tell us about channel incision in a semiarid drainage of eastern Oregon. Specific objectives of this study are as follows:

1. Determine land use and incision history of Meyer's Canyon.

2. Determine rates and processes of valley alluviation, and frequency and magnitude of cut-and-fill cycles within Meyer's Canyon.

3. Discuss geomorphic, climatic, vegetative, and anthropogenic controls on alluviation and incision within the context of Meyer's Canyon.

LITERATURE REVIEW

Depositional sequences within Meyer's Canyon were used to search for precedence, i.e., whether the current incision is a regularly occurring phenomenon in the history of the valley fill. Stratigraphy is a tool to study and classify depositional sequences. Alluvial fan processes are believed to strongly influence the character of the deposits in the study section of the valley fill. In the case of Meyer's Canyon, channel incision is a landform response, possibly due to geomorphic threshold exceedance. Channel incision can occur from different initial conditions and proceed in different ways (Cooke and Reeves 1976). Climate, vegetation, and human land use, both as interacting variables and individually, are often invoked as explanatory mechanisms. These mechanisms can influence both deposition and incision.

The following literature review discusses deposition in semiarid valley fills, the tools to study depositional sequences, and the elements important in initiation and maintenance of channel incision. Paleoclimate may have affected both deposition and incision over the course of the Holocene. Paleoclimate for the northern Great Basin, eastern Oregon, and southwestern Washington are synthesized to provide an opinion of climate elements which may have influenced the character of the deposits and the timing of incision.

Ephemeral channels in semiarid areas can carry several hundred times more coarse material as perennial streams in humid areas and are effective as sediment transport agents (Laronne and Reid 1993). This is probably because of poor armor development and availability of coarse sediment as less size-selective transport prevents the selective transport of fine-grained sediment. High sediment loads therefore make predictive sediment transport equations inadequate as most equations were developed in humid, perennial streams (Laronne and Reid 1993). These high sediment concentrations may cause significant overestimates of discharge using indirect methods such as the slope-area method. Because of the problems with using indirect methods and the lack of stream gaging on small, ephemeral streams, depositional sequences and the study of the geomorphology of a valley fill in a semiarid region, over time, may fill the knowledge gap as to how these systems operate.

Alluvial Fans and Plains

Alluvial fans form in depositional semiarid and arid mountain environments where local sediment availability is high in relation to transport capacity (Bull 1977, Harvey 1989). Fans occur where confined drainages emerge into zones of reduced stream power (Harvey 1989) and where there are changes in the hydraulic geometry of flow (Bull 1977). Sediments within fans can be separated into three sections based on distance from debris source: proximal (near source), medial (mid-fan), and distal (farthest from source, near fan toe). Debris flows and reworked coarse sediments often comprise alluvial fan sediments at proximal fan locations; sediment size decreases and sorting increases toward the fan margins. Rust (1978) classified fans as a gravel lithotype characterized by framework supported gravel with no upper size limit. Distal coalescence of alluvial fans create alluvial plains (Rust 1978) characterized by finer-grained, reworked deposits downslope. Fans do, however, have differing lithologies, from organic soils to boulder-size materials. Differences in runoff characteristics, sediment availability and transportability vary greatly and are reflected in individual beds preserved in the fan (Bull 1977). Ford and Wells (1986) found Pleistocene alluvial fans formed primarily by sheetflood deposition, whereas Blackwelder (1928) found fans strewn with large, isolated boulders and unsorted, unstratified heterogeneous mixture placed by mudflows. Ultimately, the proportions of water-laid and debris flow deposits can vary greatly within and between fans (Bull 1977).

The study of alluvial fan sediment sequences led to inferences and understanding of depositional processes, short- and long-term fan behavior, and the depositional basin setting (Heward 1978). These sequences can be generalized into models, against which future studies can be evaluated. Heward's (1978) synthesis of published vertical fan sequence descriptions is complete with the character and interpretation of depositional processes. Heward (1978) emphasizes the importance of detailed analysis of individual fan sequences to establish a local model, rather than distillation of models created by others. To illustrate problems of using others' models, Blair and McPherson (1992) revised the Trollheim fan analysis in Death Valley, upon which many alluvial fan models are based. They found the fan to be built almost exclusively by mass-wasting events, rather than sheetflow and sieve deposits as previously believed. Their interpretation was based on: 1) ubiquitous matrix-supported gravels, 2) levee and lobe morphology, 3) total absence of stratification indicative of bedload transport.

Fluvial sedimentology has evolved from studies of modern sedimentary processes and of ancient deposits. Fluvial sedimentology is a combination of descriptive fluvial geomorphology, channel hydraulics, sediment transport and textural studies, bedforms and paleocurrents, facies studies, and paleohydraulics (Miall 1978). The Miall (1977) system of sediment assemblage classification can be adapted to the systems and objectives of a particular project (Rust 1978).

Use of Stratigraphy

The net results of alluviation are recorded in the structure and composition of the deposited material (Bailey 1935).

Reconstruction of past fluvial activity based on stratigraphic evidence must recognize the limitations of such evidence (McDowell 1983). For example, because so much geomorphic work of fluvial systems is erosional, as well as depositional, much of the "evidence" may have been previously removed (Schumm and Brackenridge 1987). Additionally, geomorphic activity can be episodic, or, over spans of 100 to 1000 years, continuous but with varying intensity (McDowell 1983). Haynes (1968) used stratigraphic mapping to determine the chronology of alluviation, soil formation, and erosion, the rates of these processes, and to determine how sequences are temporally and spatially related to other late Quaternary events.

Rust (1978) established lithotypes in braided alluvial deposits based on sorting, support, bedding (or lamination), stratification, texture, and vertical and lateral succession to develop a depositional model. Miall (1977, 1978) reviewed all the main lithofacies and sedimentary structure assemblages associated with modern braided rivers, and developed a lithofacies code. By using buried deposits and current surface deposits, one can use lithotypes to describe depositional structures and, by interpretation, process. For example, channel bars are characterized by trough- and low-angle cross stratification as well as horizontal stratification, whereas flood-plain alluvium is generally finer grained with sediment structures indicative of less stream power (Hereford 1984). Miall (1977, 1978) and Rust (1978) and others adapted techniques used to evaluate hard rock stratigraphy for modern alluvial systems. Important considerations in the evaluation of hard rock stratigraphy are to determine original horizontality, original continuity, and the principle of superposition (Steno's Laws, Prothero 1990). In Holocene-age sediments, sediments are in the position in which they were deposited (original horizontality), longitudinal and vertical continuity is often still evident (original continuity), and oldest sediments are lowest in the profile and layers upward are progressively younger (superposition).

Thresholds

A geomorphic threshold occurs when the stability of a landform is exceeded by either a change of the landform, which may involve a change in the strength of the material involved (intrinsic variable), or by a change of an external variable such as climate, base level (Schumm et al. 1984), or land use. A progressive change of external variables can sometimes trigger an abrupt response in the landform. In semiarid regions where sediment production and transport capability are high, sediment storage on the valley floor can progressively increase the slope of the valley floor until an erosion cycle occurs (Schumm et al. 1984). Patton and Schumm (1975) measured gullied and ungullied valley floors in the Piceance Creek Basin in Colorado, and found that for a given drainage area, a valley slope exists above which the valley floor is unstable when they plot the tangent of the slope angle against the drainage area which contributed to that portion of the valley floor (Figure 2, p. 89, in Patton and Schumm 1975). Critical threshold slope can be exceeded at steep, narrow portions of a valley fill slope (Schumm and Hadley 1957, Patton and Schumm 1975, Schumm et al. 1984). Stream incision could occur at the site closest to the geomorphic threshold of incision, as defined by Schumm et al. (1984) where stream power is greatest (Prosser 1991). Total stream power is represented by the equation:

$$\text{Power} = \gamma Q S$$

γ = fluid density
Q = discharge
S = channel slope (surrogate for energy slope)

Channel incision can be inherent in the depositional/erosional features of a valley fill and occurs when geomorphic thresholds are exceeded (Schumm et al. 1984). Thus an important element in the study of incision causation is what may be affecting that threshold, and where the threshold might be located in time and space.

Channel Incision

Incised channels are created by the excavation of valley floor alluvial deposits via channel erosion (Graf 1983). Essentially, a channel is formed because the eroding force exerted by flowing water exceeds the resistance of valley fill materials over which it flows (Schumm et al. 1984). Because surface materials and vegetation resist flood flow force (Graf 1979), disruption of the vegetation or surface materials, or an increase in runoff or peak discharge, can initiate incision (Graf 1979, Schumm et al. 1984). Flow erosiveness can be increased by changing hydraulic variables such as an increase in slope, hydraulic radius, or a decrease in surface roughness. These changes can occur without changing available water or by a change in discharge (Cooke and Reeves 1976). Models created by LaGasse et al. (1990) emphasize unified upland and valley-floor processes; namely, channel incision and valley filling responds to flow and sediment supplied from the uplands.

Channel incisions are distinctive landforms that can occur over a very short period of time in response to various internal and external variables of exceedingly variable time frames. Whereas geologic processes which produce landforms and streams are measured in thousands and millions of years, changes in plant associations occur over tens and hundreds of years (Platts 1991), essentially over a human lifetime. Therefore, humans can create and observe dramatic change within a plant community. Alluvial cycles (aggradation and degradation) reflect complex ecological readjustments to rainfall seasonality and intensity, ground cover, runoff, etc. Because climate and human activity affect each of these elements, they are the ultimate variables (Butzer 1980).

Effects of Vegetation

Valley slopes as well as riparian or valley floor slopes are affected by vegetation. Vegetated slopes can be as steep as 60°, whereas bare talus slopes are generally less than 35° (Bailey 1941, in Antevs 1952). Thus, vegetation serves to allow slope development at a steeper angle than the internal strength of the soil or slope material alone would allow. Vegetation can influence flood magnitude and sediment concentration within a basin, and sediment yield from a basin because it enhances infiltration capacity and reduces surface runoff velocity (Knox 1983). On surface slopes, increasing plant cover from 16 to 40% reduced surface runoff 64%, and soil removal by 54% on an 4-ha watershed on the Colorado Plateau (Bailey 1935).

In semiarid areas, upland vegetation is sparse and has less effect than riparian vegetation upon channel processes. Schumm et al. (1984; Table 2.1, p. 12) provide a listing of various agents of channel incision. A decrease or change in vegetation cover owing to increased agricultural activity, overgrazing, or drought can act as such a geomorphic agent. The spatial distribution of vegetation (both mean and valley floor biomass) can be an important factor influencing stream incision (Graf 1979). Vegetation within a stream channel provides a resistance to erosion which prevents incision (Antevs 1952). Loss of vegetative cover increases the erosive power of streams (Bryan 1928b, Bailey 1935, Peterson 1950, Montgomery 1991). Riparian vegetation seems to have been relatively ignored as a geomorphic agent compared to the evaluation of physical parameters such as shear stress and Froude numbers in fluvial systems. Some authors, however, have identified the importance of vegetation as a source of resistance to erosion and sediment transport (e.g., Bryan

1928a, Bailey 1935, Antevs 1952, Cooke and Reeves 1976, Bull 1979, Graf 1979). Reid (1989), Dietrich et al. (1993) and others assume that channel instability occurs where critical boundary shear stress is reduced due to disturbance of vegetative cover. However, extreme climatic events can affect major morphological responses within a stream system without a change in vegetation because vegetation represents average rather than extreme climatic conditions (Knox 1983).

Within the riparian zone, Manning et al. (1989) found that the high root density of hydrophytes has superior site-stabilizing characteristics. Because increased moisture enhances vegetative growth, streamside vegetation provides a resiliency that allows riparian systems to withstand a variety of environmental conditions (Elmore and Beschta 1987). Prosser (University of New South Wales, Australia, personal communication, 1993) estimated shear stresses required for incision through dense tussock grass or sedge of the order of 3000 dynes/cm^2 (300 N/m^2), much greater than those for sparse or unvegetated surfaces. Reid (1989) estimated critical boundary shear stress of 160-320 dynes/cm^2 for disturbed, poorly-vegetated surfaces. Surface material affected by roots, stems, and decayed organic material is highly resistant to erosion, much more so than the immediate subsurface (Dietrich et al. 1993). Once incision has begun with significant erosion below the root mass, it is unlikely that original valley-floor vegetation will arrest arroyo development (Graf 1979). The success of an initial incision depends upon the relative rates of further excavation and vegetative/depositional recovery processes (Reid 1989). Thus, it may not be the initiation of channel incision but the maintenance of the incision which determines the extent of the incision.

Effects of Grazing

The lack of ground cover on the uplands of semiarid systems, both from initially sparse cover and grazing pressure, make these areas susceptible to high erosion rates (Branson et al. 1972), which translates to high sediment availability. Reducing plant cover and changing the species composition of valley slopes through grazing from fibrous-rooted perennials to shallow-rooted annuals or tap-rooted perennials (Bailey 1935, Platts 1991) can strongly affect the ability of slopes to hold sediment. Degraded uplands potentially concentrate and accelerate runoff, and increase sediment input to streams causing aggradation (Chaney et al. 1990) in tributaries and in valley fills. USDA (in Chaney et al. 1990) rated rangelands based on the ecological potential of the site compared to the land's present vegetation, and found vegetation cover significantly less than its potential on up to 85% of all rangelands.

During periods of lower than normal flow, riparian areas become more attractive to grazers due to relatively nutritious and palatable herbage, moderate slope gradient, more reliable water supply and more favorable microclimate (Gillen et al. 1985). Thus, livestock grazing in riparian areas can: 1) remove vegetation, 2) compact moist soils which reduces infiltration and plant growth, 3) trample streambanks initiating mechanical breakdown and increased sediment loads, and 4) create gullies because a lack of stream vegetation which provides a resistance to erosion increases the erosive potential of a stream (Chaney et al. 1990). The effects of grazing are accentuated in semiarid drainages underlain by fine-grained sediments (Bull 1979). Dietrich et al. (1993) suggest low gradient valleys in northern coastal California were discontinuous and only incised following intensive cattle grazing. A more complete discussion of the effects of livestock grazing is contained in Skovlin (1984) and Platts (1991).

Paleoclimate

The disintegration of ice sheets at the end of the Pleistocene marked the beginning of the Holocene (Barnosky 1985). Following the glacial retreat prior to the beginning of the Holocene 10,000 years before present (BP), a warming trend began with attendant decrease in effective precipitation (i.e., moisture available for plant growth) until about 8000 years BP (e.g., Mehringer 1986, Barnosky 1985). Nonetheless, even during this warming period, temperatures were cooler than present (Miller in press).

The most significant vegetation adjustment within the Holocene occurred in response to the Pleistocene-Holocene transition; subsequent vegetation changes have been modest in comparison (Knox 1983). During the early Holocene, Great Basin and Northwestern Sagebrush Steppe-type (of which Meyer's Canyon is a part) vegetation would have shifted from grassland to steppe. Knox (1983) suggests that this transition may have enhanced mean annual sediment yield and sediment concentration in rivers, favoring valley alluviation. According to Knox (1983), 7000 years BP marks a transition from a period in which adjustments of water and sediment yield occurred in response to global climate and vegetation changes, to the current period in which river responses are directly related to regional and individual climatic events. These responses are not necessarily globally synchronous. However, Miller (in press) states that intermountain sagebrush steppe vegetation has essentially remained unchanged over the past 10,000 years except for a change in species abundance.

According to Schumm (1993), a change from humid to semiarid climate would produce the greatest increase in sediment accumulation, as opposed to a change from humid to sub or superhumid conditions. Fans in the Mohave desert aggraded during the Pleistocene-Holocene transition (Ritter and Wells 1987). The authors noted little, if any, soil development indicating few periods of quiescence or perhaps temperature and precipitation levels that were not conducive to growth of vegetation and soil development.

Miller (in press) states that in the intermountain sagebrush region, of which Meyer's Canyon is a part, the period 7000 to 4500 yrs BP was a warmer and/or drier period than today, with little soil formation. This period continued beyond the Mazama eruption (6845 ± 50 yrs ^{14}C BP), until perhaps 3000 yrs BP (Bedwell 1973). Aridity and drought prevailed during this period (Bedwell 1973, Barnosky 1987, Wigand 1987). Mehringer (1986) reports less effective moisture from 8750 to 6550 yrs BP than before or since at Fish Lake near Steens Mountain in southeastern Oregon in sagebrush steppe country.

It is generally agreed that conditions for eastern Oregon and the northern Great Basin were wetter and cooler than the previous warm/dry period, for the period about 5000 to 2000 yrs BP (Bedwell 1973, Knox 1983, Barnosky 1985, Welcher 1993), with an attendant decrease in aridity (Knox 1983). However, authors do not agree on the exact timing of transition and shifts from cool-moist to warm-dry climates, or vice-versa, and these shifts are not necessarily contemporaneous over the entire intermountain region (Miller in press). Climate is inferred from vegetation and archaeologic information and the quality of such information varies from basin to basin.

Eastern Oregon seems to have gone through a period of reduced effective moisture between 2000 and 1400 yrs BP, followed by returning greater effective moisture between 1400 and 900 yrs BP (Wigand 1987). Mehringer (1986) agrees with a slight warming and drying trend beginning about 2000 yrs BP, but he does not recognize an increase in effective moisture and states the drying trend continued until 450 yrs BP (1500 AD). Wigand (1987) does agree this same approximate period (500 yrs BP) was a drought period. The Little Ice Age began about 450 yrs BP (1500 AD) and culminated about 150 yrs BP (1800 AD) (Miller in press). Wigand (1987) similarly identifies moister conditions 300 to 150 yrs BP. Since about 3000 yrs BP, Miller (in press) indicates that the overall climatic trend was one of increasing aridity; conditions since the 1800's also seem to suggest an intensification of this arid trend (Wigand 1987). Significant droughts have occurred in 1889 (Graumlich 1987) and 1920 through 1940 (Keen 1937).

Sediment deposits within Meyer's Canyon may reflect the watershed's adjustment to climate change. Increases in aridity may result in increased rates of aggradation and/or charcoal layers from more frequent watershed fires. Soil development can indicate increasing moisture availability for plant growth, and result in iron and aluminum oxide and clay translocation. Shifts of fluvial activity can favor soil development on the non-active portion of an alluvial fan. Examination of the sediments at various locations within Meyer's Canyon are expected to provide important clues regarding changing environmental conditions.

SITE DESCRIPTION

Among examples of stream incision in eastern Oregon, Meyer's Canyon represents perhaps an extreme example due to the depth of incision, the nature of the deposits, and the deep vertical exposure following incision. The geometry of the incision ranges from sloping walls of about one meter above the incision floor, to vertical walls of up to 22 m. The Canyon was chosen as a research site because of the extent of exposure, the historical and climatic information available for the area, and the presence of a distinctive ash layer exposed in many locations throughout the canyon which has been attributed to the climactic eruption of Crater Lake (Mt. Mazama) about 6900 yrs (^{14}C) BP. The Mazama origin of the ash exposed within Meyer's Canyon was established through mineralogical analysis by Dr. Brittain Hill (OSU Department of Geology). His report is contained in Appendix D.

Location

Meyer's Canyon (also known as Alkali Flat, Myer's Gulch, Myers Ranch) is located on Bureau of Land Management (BLM) land in north-central Oregon, about five kilometers north of Mitchell (Figure 1). The name "Meyer's Canyon" refers to the main valley floor of the entire drainage, as written on USGS maps of the area. It is southeast of the John Day Fossil Beds National Monument, on the edge of the Blue Mountain highlands (Loy and Patton 1976). The drainage is a tributary to Bridge Creek, in the John Day River Basin.

Precipitation and Streamflow

Because there are no flow records for Meyer's Canyon, other hydrograph and regional information must be used as a surrogate to provide an index of hydrologic elements influencing streamflow and subsequent incision in Meyer's Canyon. Average annual precipitation was 294 mm for the period 1961-1990 at the Mitchell Station (Sta. No. 48517; Figure 2). Air temperatures average 9.9°C (Oregon Climate Service 1993). Monthly averages of precipitation from the Mitchell and Fossil (Sta. No. 30387) stations within John Day Basin, and streamflow from McDonalds Ferry gaging station (Station #1404800) near the mouth of the John Day Basin, are illustrated in Figure 3. From February through May, the John Day Basin hydrograph generally responds to snowmelt from the headwater portions of the basin. Flows at the mouth of the John Day Basin do not respond to convectional storms during the hot, dry summer months because of the small area covered by thundershowers compared to the large area drained by the John Day River. Basin discharge does not respond to late summer/early fall frontal storms until about November, probably as a result of soil storage being recharged.

From the late 1920's to the mid 1940's, eastern Oregon experienced a severe drought. Keen (1937) called it the worst drought of the past 650 years, based on tree ring data. Judging from the cumulative departure from the mean in Figure 4, the John Day Basin was significantly affected, as Meyer's Canyon might have been affected. A wet period in the early to mid-1980's caused a rapid return to average conditions.

Mountain Creek is a small (52 km^2) basin near Mitchell which has had an Oregon Water Resources Department and then a U.S. Geological Survey gage (Station #14040600; Figure 2) from 1966 through 1991 (discontinued in 1991). The Mountain Creek gaging station is the closest to Meyer's Canyon within the John Day Basin. Precipitation stations have been maintained near and in Meyer's Canyon since 1948. However, there is no obvious relationship between total 24-hour

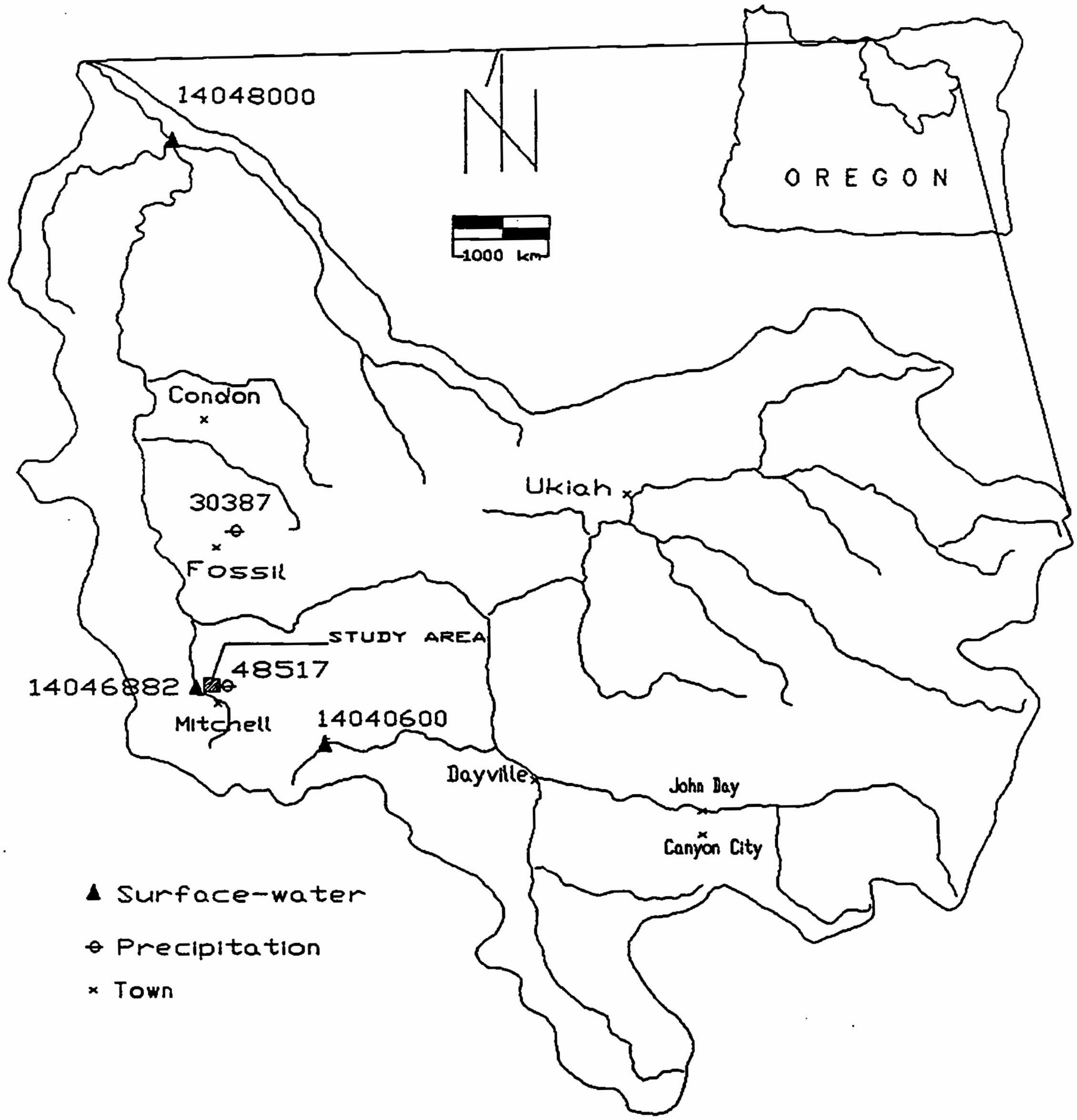


Figure 2. Location of surface-water and precipitation stations in the John Day River Basin.

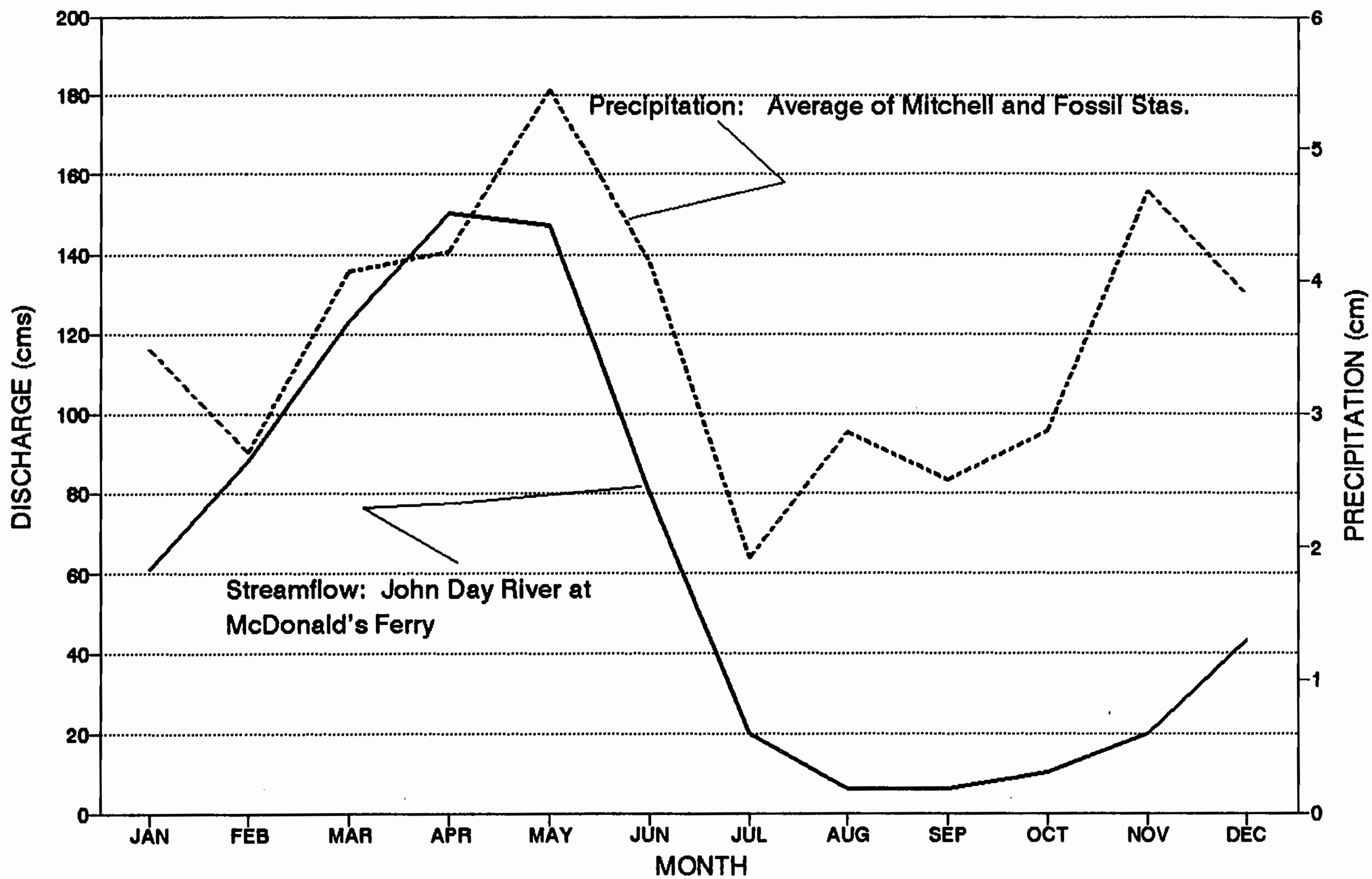


Figure 3. Monthly precipitation and streamflow (cms = cubic meters per second) patterns for the John Day Basin (based on 1961-1990 monthly averages, from USGS data).

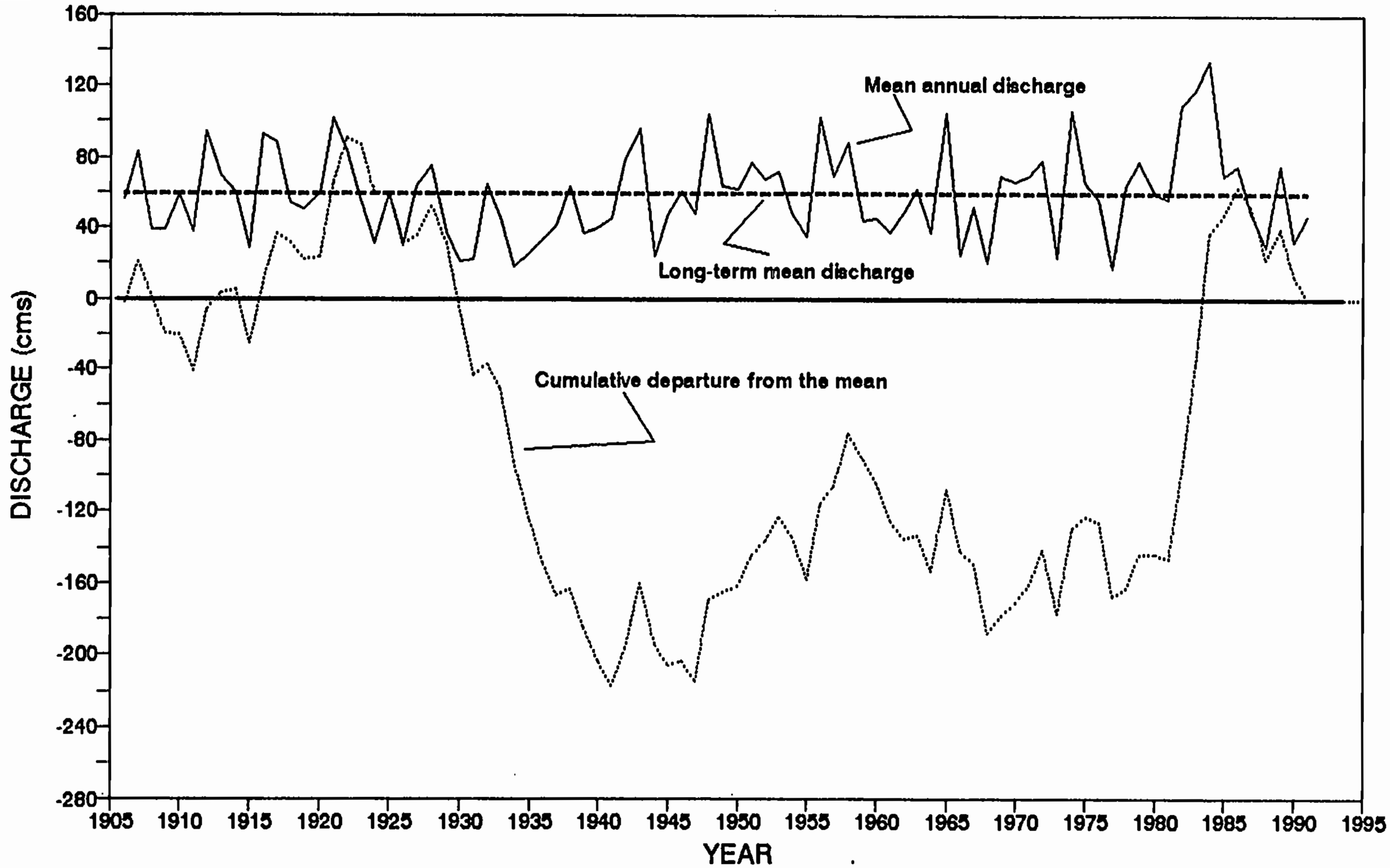


Figure 4. Mean annual, long-term mean, and cumulative departure from the mean discharge for John Day River Basin at McDonald's Ferry (for period 1906-1991, from USGS data).

precipitation measured in Meyer's Canyon and average daily streamflow measured in Mountain Creek a short distance away (Figure 5). This lack of correspondence between rainfall in Meyer's Canyon and Mountain Creek streamflow may be due to: a) Meyer's Canyon drainage is at a lower elevation than Mountain Creek drainage and has little or no snowmelt (maximum/minimum elevation in Meyer's Canyon is 1290/670 m and is 1400/1200 m in Mountain Creek); b) convectional storms are localized and may or may not occur simultaneously at both Meyer's Canyon and Mountain Creek; c) during hot, dry periods, infiltration and soil moisture storage may preclude stream response. The effects of convectional storms cannot be overemphasized, however, as these storms can do much geomorphic work in a very short time. The result of convectional storms is rapid sediment transport from steep, narrow canyons to deposition of lobes of debris where hydraulic conditions change to flat, wide valleys.

Basin Characteristics

The basin is approximately 3460 ha, and is separated into four major tributaries on Figure 6: Upper Drainage (1620 ha, 47%), Permian Tributary (710 ha, 20%), 4WD Tributary (440 ha, 13%), and Big Tributary (200 ha, 6%). For discussion purposes, the drainage has been separated into Upper Drainage, Narrows, and Lower Valley Fill (Figure 7 and Figure 8). Most of the research and discussion focuses on the Lower Valley Fill. Big Tributary and 4WD Tributary contribute solely to the Lower Valley fill sediments. The Upper Drainage and Permian Tributary could conceivably provide 67% of the total input to the Lower Valley fill based solely on areal percentages of these portions of the watershed.

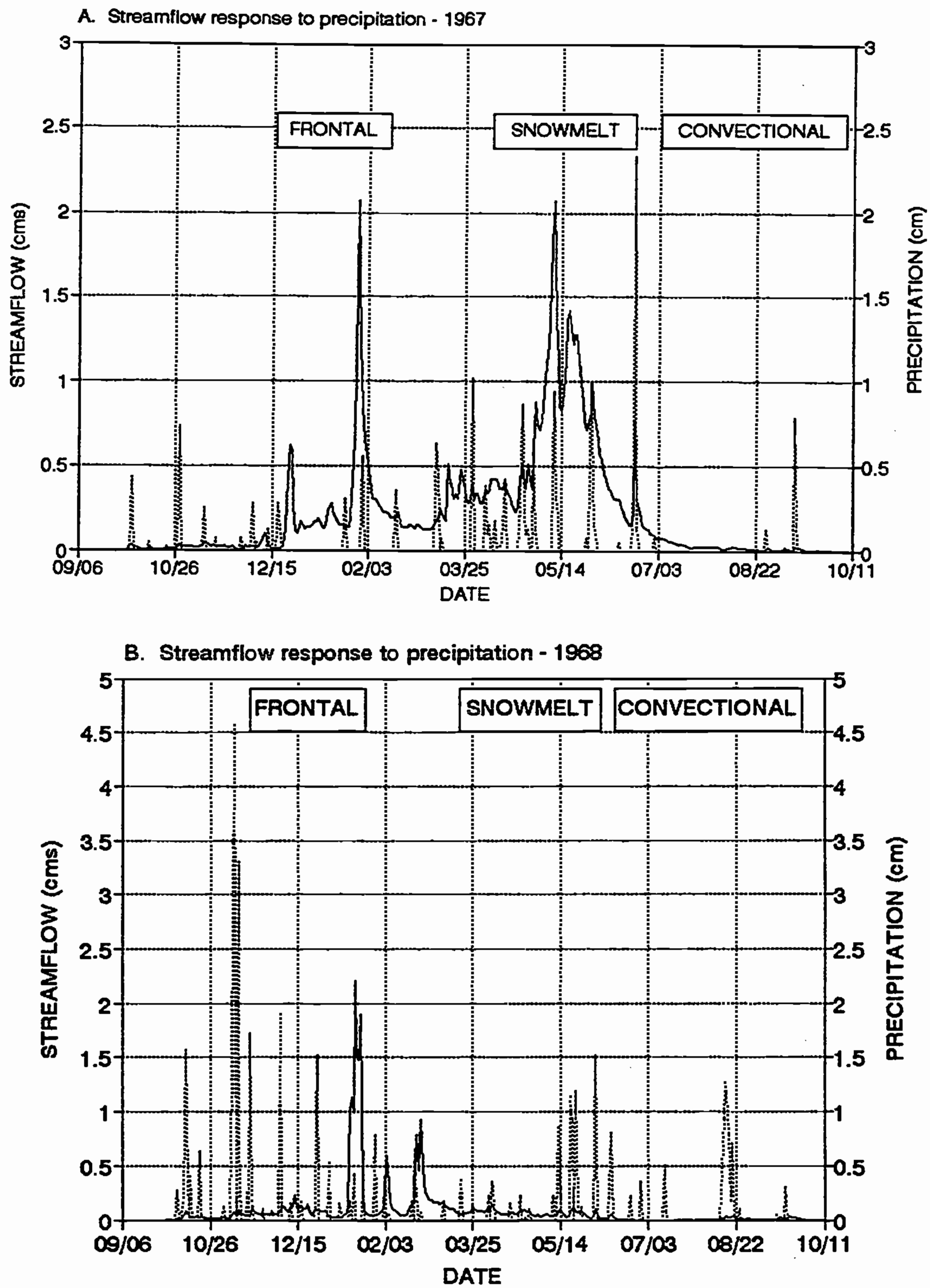


Figure 5. Mountain Creek average daily streamflow (Sta. 14040600) and Mitchell (Sta. 48517) 24-hour precipitation, Meyer's Canyon and vicinity, for 1967 (A) and 1968 (B).

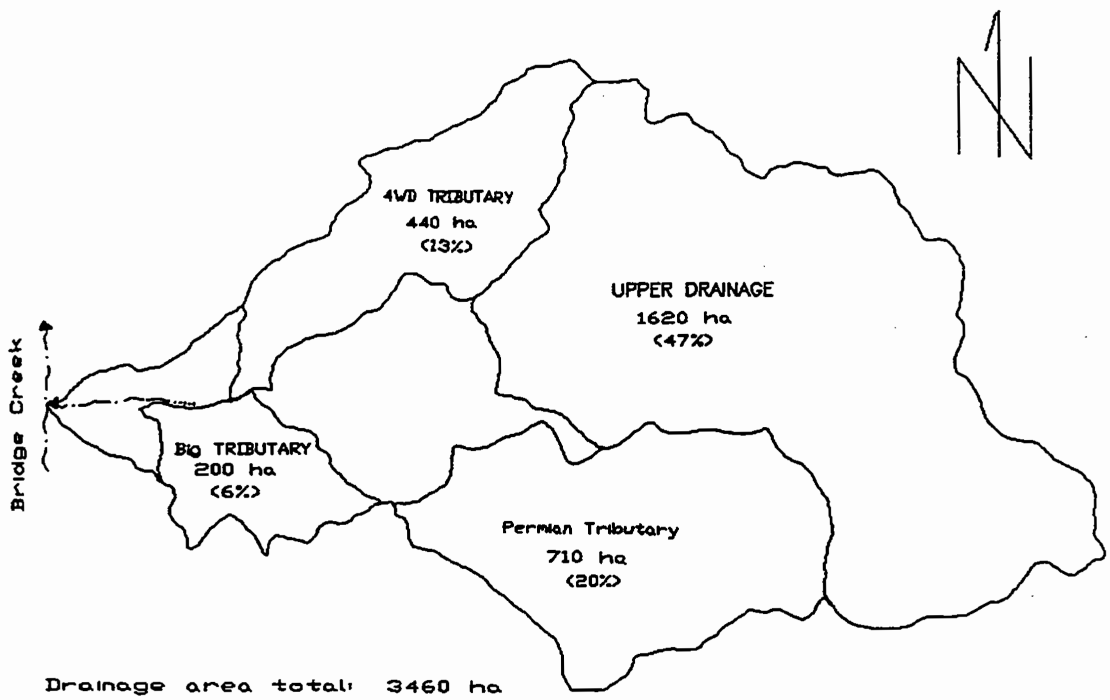


Figure 6. Meyer's Canyon drainage and tributary drainage areas.

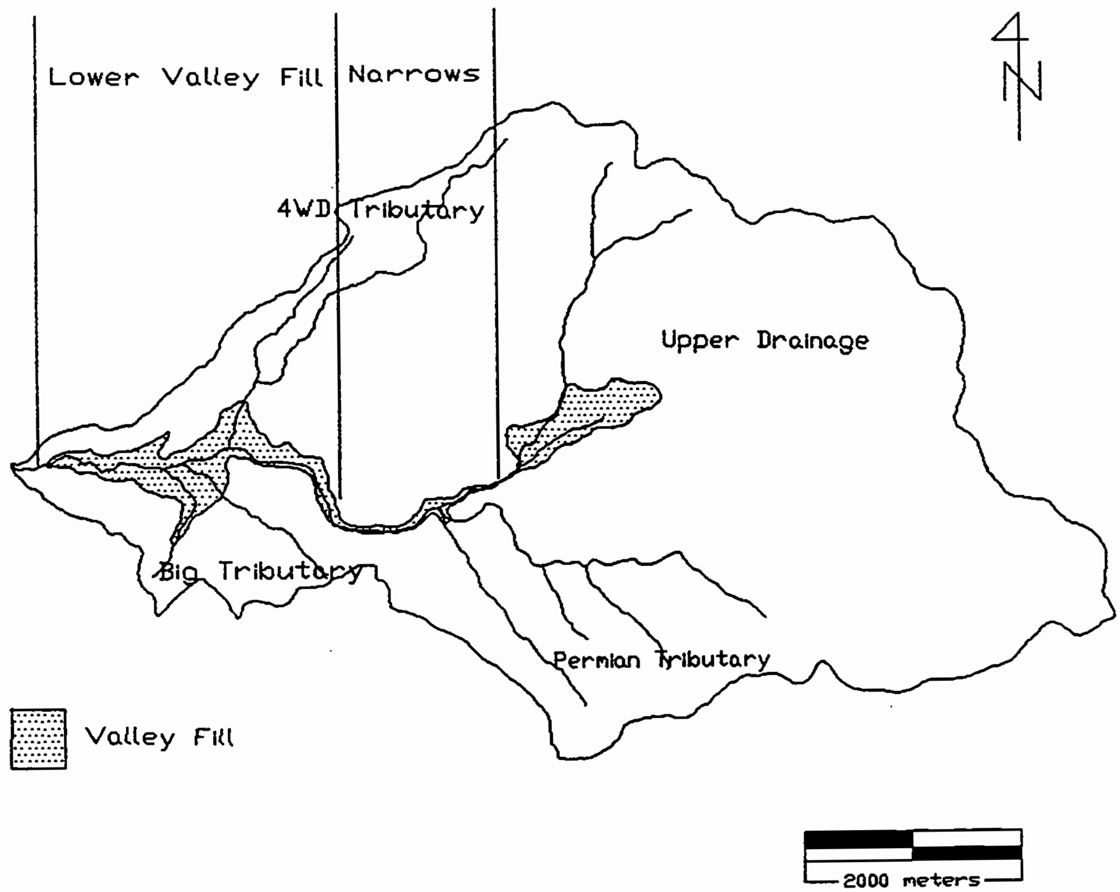


Figure 7. Meyer's Canyon drainage sections and valley fill.

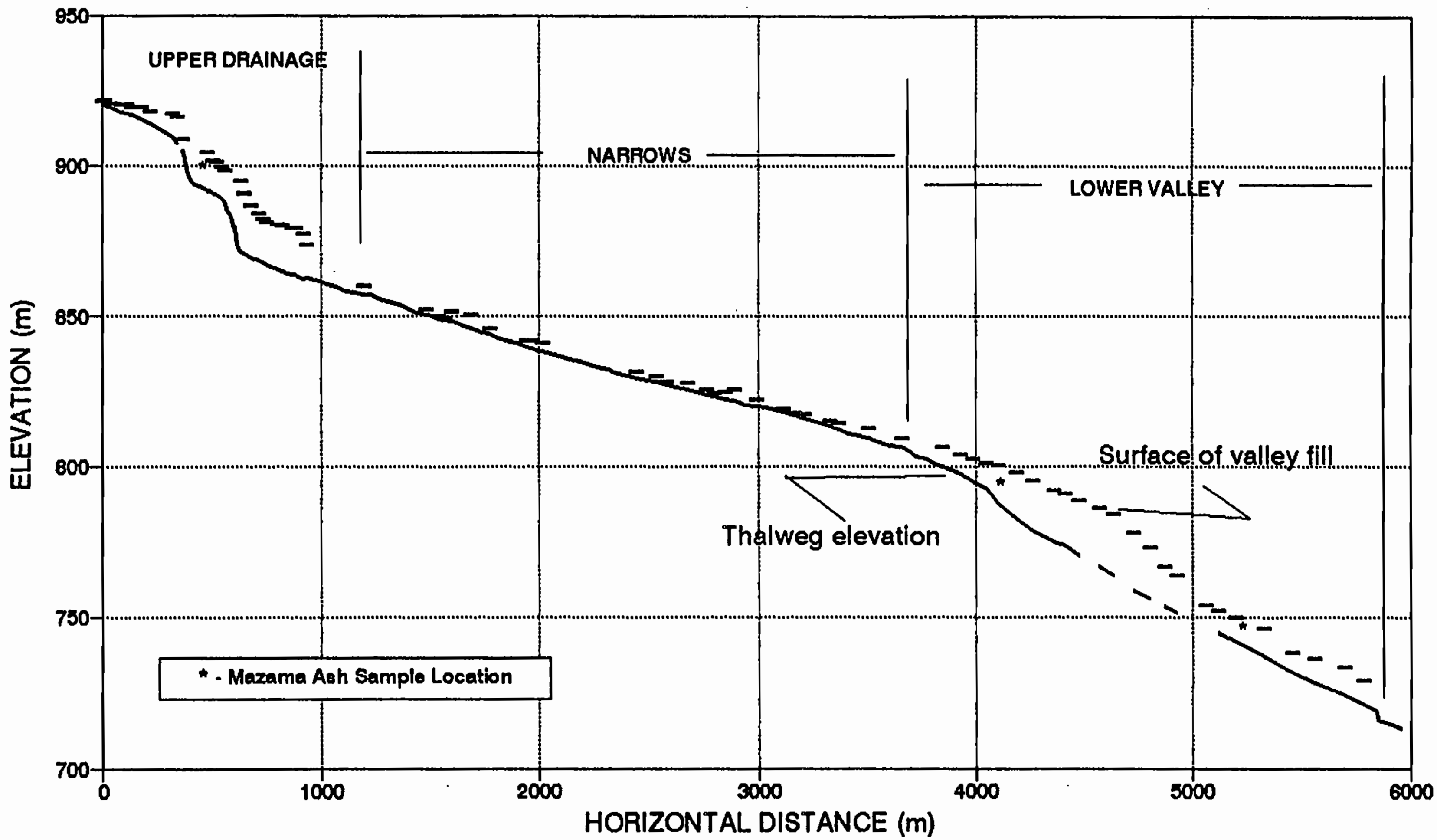


Figure 8. Profile of Meyer's Canyon valley fill surface and incision thalweg.

Geology

Exposed rocks and surficial units within the Meyer's Canyon watershed are Permian, Cretaceous, Tertiary, and Quaternary in age (Figure 9). Permian metasediments are exposed within Permian Tributary and are the oldest rock units within Meyer's Canyon. They represent the oldest rock unit, and are relatively resistant to erosion.

Among the Cretaceous rocks, the Hudspeth Formation is the oldest unit and occurs as a widespread and thick sequence of marine mudstones having subordinate siltstones and sandstones. The Gable Creek Formation is a series of conglomerate and sandstone beds which intertongue intricately with the Hudspeth (Oles and Enslows 1971). The Hudspeth and Gable Creek formations compose a significant portion of the valley fill as evidenced by rounded black pebbles found only in the Gable Creek conglomerate, by the high sand content of portions of the fill derived from the Hudspeth and Gable Creek formations within the drainage above 4WD Tributary and Big Tributary, and by extensive fracturing and subsequent erosion into exposed mudstone in Permian Tributary, Upper Drainage, and Big Tributary. Hudspeth mudstone form topographic lows within the Big Tributary drainage (E. Taylor, OSU Department of Geology, personal communication, 1992).

Another major component of the valley fill below 4WD Tributary is the Tertiary Clarno Group. The Lower Clarno andesite flows compose the resistant, ridge-forming elements of the drainage. Large boulders of andesite are transported during high magnitude events and typically comprise the coarse-grained (cobble/boulder) fraction of debris/mud flows. The Clarno andesite is the "abundant bedrock exposed" and is the parent material for the "thin regolith" of the slopes of the basin referred to by Costa (1987). Also, within the Lower Clarno group are tuffaceous sediments closely aligned with the andesite flows. These Clarno rocks are very similar to the

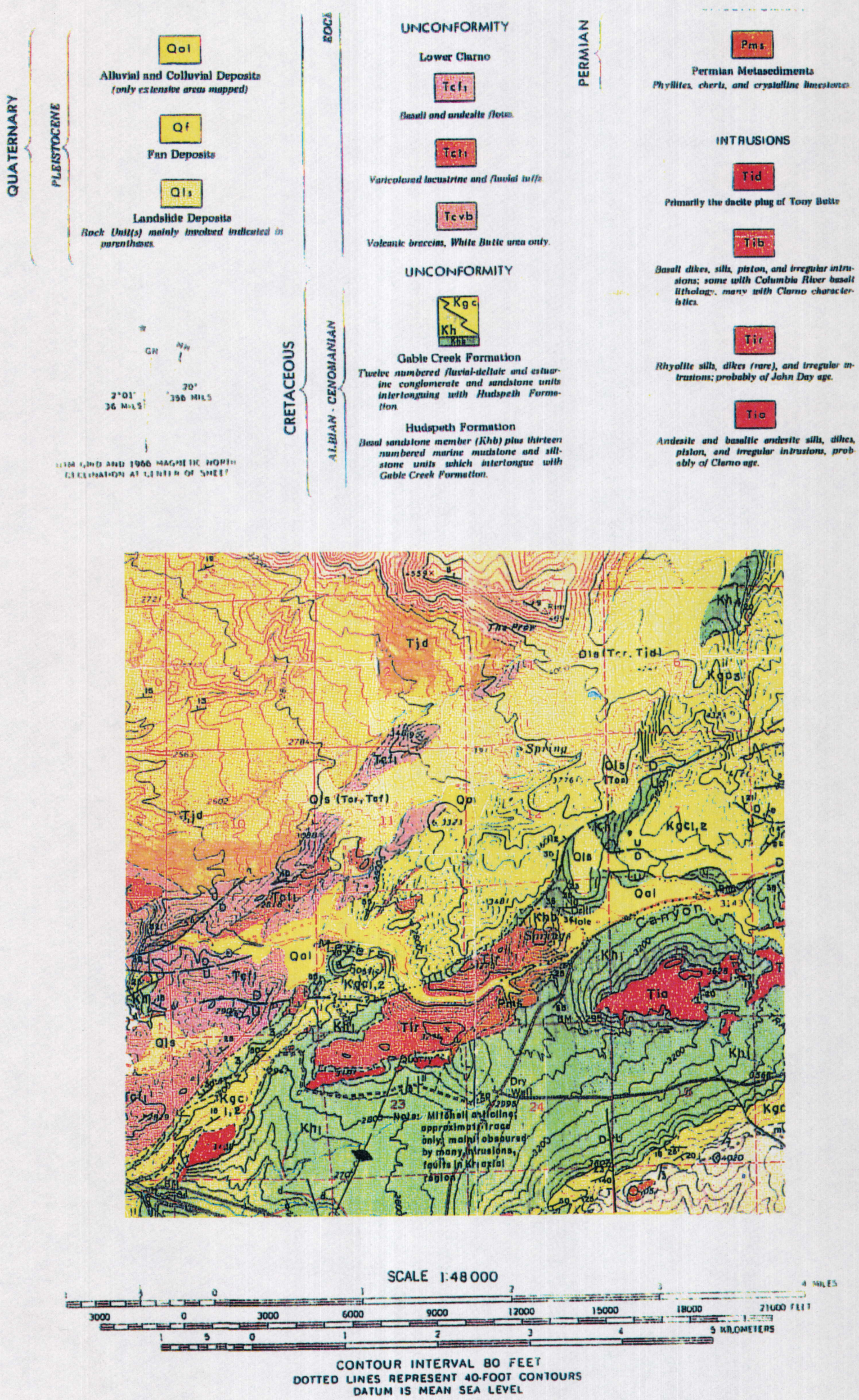


Figure 9. Geologic map of Meyer's Canyon and vicinity (from Oles and Enslows 1971).

distinctive John Day Fossil Beds formation but are separated from the younger John Day Formation by Clarno andesite. These red, green, and yellow rocks weather to a very fine, montmorillonitic (2:1 expandable clay) sediment (E. Taylor, OSU Department of Geology, personal communication, 1992). The resulting sediment has a characteristic deep brick-red color when deposited within the valley and was used to distinguish 4WD Tributary sediments from Upper Drainage sediments.

A minor Tertiary unit is represented by the rhyolite intrusions, probably of John Day age (Oles and Enslows 1971). Rhyolite gravels and cobbles comprise a significant portion of the coarse sediments in alluvial fans at the mouths of small tributaries feeding directly into the Narrows, and channel and terrace fill material until below the end of the Narrows (Figure 7), where the valley widens and Clarno tuffaceous sediments influence the valley fill material.

Youngest known orogeny in the area was during the Oligocene and was along the Mitchell fault to the south (J.Dilles, OSU Department of Geology, Corvallis, Oregon, personal communication, 1992). A northeast-trending Meyer's Canyon Fault follows the axis of the valley and thus may have determined the pre-depositional topography of the valley. Throughout the valley are throughgoing discontinuities of the bedrock units, with slopes dipping towards the northwest (E. Taylor, OSU Department of Geology, personal communication, 1993). These discontinuities could have a dramatic influence upon the groundwater in the Lower Valley fill.

Soils

Surface soils generally characteristic of the grass-shrub uplands of eastern Oregon are broadly classified as xeric/aridic mesic soils of soil order Mollisol, suborder xerolls (USDA-SCS 1986). Detailed soils mapping has been completed by the Prineville district of the BLM (unpublished data). The soils in the upper portions of the Lower Valley fill and through the Narrows are classified as Hack loam on 3-7% slopes with taxonomic class of fine loamy, mixed, mesic, Calcic Argixerolls. The soils of the lower three-quarters of the Lower Valley fill are classified as Courtrock loam, 3-15% slopes with taxonomic class as coarse-loamy, mixed, mesic Calciorthidic Haploxerolls.

Vegetation

Native vegetation of the area is bluebunch wheatgrass (*Agropyron spicatum*), western juniper (*Juniperus occidentalis*) and Sandberg bluegrass (*Poa sandbergii*) (SCS 1986). Also common are various species of sagebrush (*Artemisia spp.*), rabbitbrush (*Chrysothamnus nauseosus*), an introduced variety of cheatgrass (*Bromus tectorum*), and various species of salt-tolerant herbs, shrubs, and grasses (e.g., *Atriplex spp.*). Knox (1983) states, based on the work of others, that this area is a part of the Northern West Sagebrush Steppe which did not emerge until approximately 7000 yrs BP. There is one Russian olive tree (*Elaeagnus augustifolia*) approximately 21 years old within the incised portion of the canyon. Also within the perennially saturated areas of the incision are horsetail (*Equisetum sp.*), watercress (*Radicula Nasturtium-aquaticum*), various sedges and rushes (e.g., *Scirpus spp.*), cattail (*Typha augustifolia*), and teasel (*Dipsacus sylvestris*). A more complete riparian habitat survey was completed in 1989 by Prineville district of the BLM (unpublished data).

METHODS

Meyer's Canyon History and Environment

To determine when the incision occurred, it was necessary to review historical information. Such records may contain references to the Canyon before it was incised or events leading to the incision. If the time of the incision can be determined, the conditions of the watershed leading up to incision may be inferred, thus perhaps gaining insight into causal mechanisms of incision. However, historical reconstructions may ultimately provide anecdotal information only.

Since Meyer's Canyon was settled by the first permanent settler in Wheeler County, and the stage line through the Canyon was run by the county namesake, H. H. Wheeler, the canyon is referred to frequently in historical papers. Mary Cottingim (deceased January 1993, age 93), was interviewed regarding her memories of the Canyon. Her father, L. L. Jones, owned the canyon from the early 1920's until his death in 1942. Crook and Wheeler County Historical Societies' documents mentioning events concerning Meyer's Canyon were reviewed as well as University of Oregon microfilm of the Mitchell Sentinel newspaper from February 11, 1915 to September 3, 1925. The Oregon Historical Society, in Portland, has microfilm of H.H. Wheeler's personal log book (largely illegible), military diaries, and original letters describing early Oregon history which were examined for any mention of Meyer's Canyon, Meyer's Ranch, Alkali Flat, or the town of Mitchell. For landownership records, the Wheeler County Clerk's office allowed access to deeds and transactions from 1895 to present. These deeds were helpful in finding names of people who owned land within the Canyon; these names were then used to check for additional information at the Oregon Historical Society. General Land Office maps for 1873 established north/south section lines, Wheeler stage line location, and Meyer's Ranch location.

Vegetation: The vegetation in the area was used as indicators of land surface age and debris flow events. Juniper (*Juniperus occidentalis*) and sagebrush (*Artemisia spp.*) both have annual growth rings. Tree ages represent the minimum age (years before 1992) that a particular land surface was established. Dating of stem scars is useful for dating non-lethal debris flow events. Increment cores of junipers were taken near the root collar, total number of rings counted, and ten years were added to estimate a time of tree establishment (R. Miller, OSU Experiment Station, Burns, Oregon, personal communication, 1992). Location of aged junipers are included as Figure 10.

Precipitation and Streamflow: Rainfall records for the Mitchell station #56417 (Lat. 44°55'67", Long. 120°16'67", Elev. 808 m) were obtained from the State Climatologist's office for the period of 1948 to August, 1993. However, there is much missing data. Precipitation data is of limited value because of the variability of streamflow response to rainfall in these semiarid systems (e.g., Figure 5).

There are no long-term stream flow records for Meyer's Canyon. As part of an irrigation study, the Oregon State Water Resources Department (OWRD) measured flow using a staff gage and 2-foot weir from June 22 to September 13, 1929 (OWRD station No. 2520; USGS station No. 14046662); station location corresponds to the outlet of Meyer's Canyon (Sec. 16, T11S, R21E). Mountain Creek (Lat. 44°32'06", Long. 120°01'45", Elev. 1262 m) was gaged by OWRD and U.S. Geological Survey (USGS Sta. No. 14040600) from 1967 to 1991. The John Day River at McDonalds' Ferry has been gaged by USGS (USGS Sta.

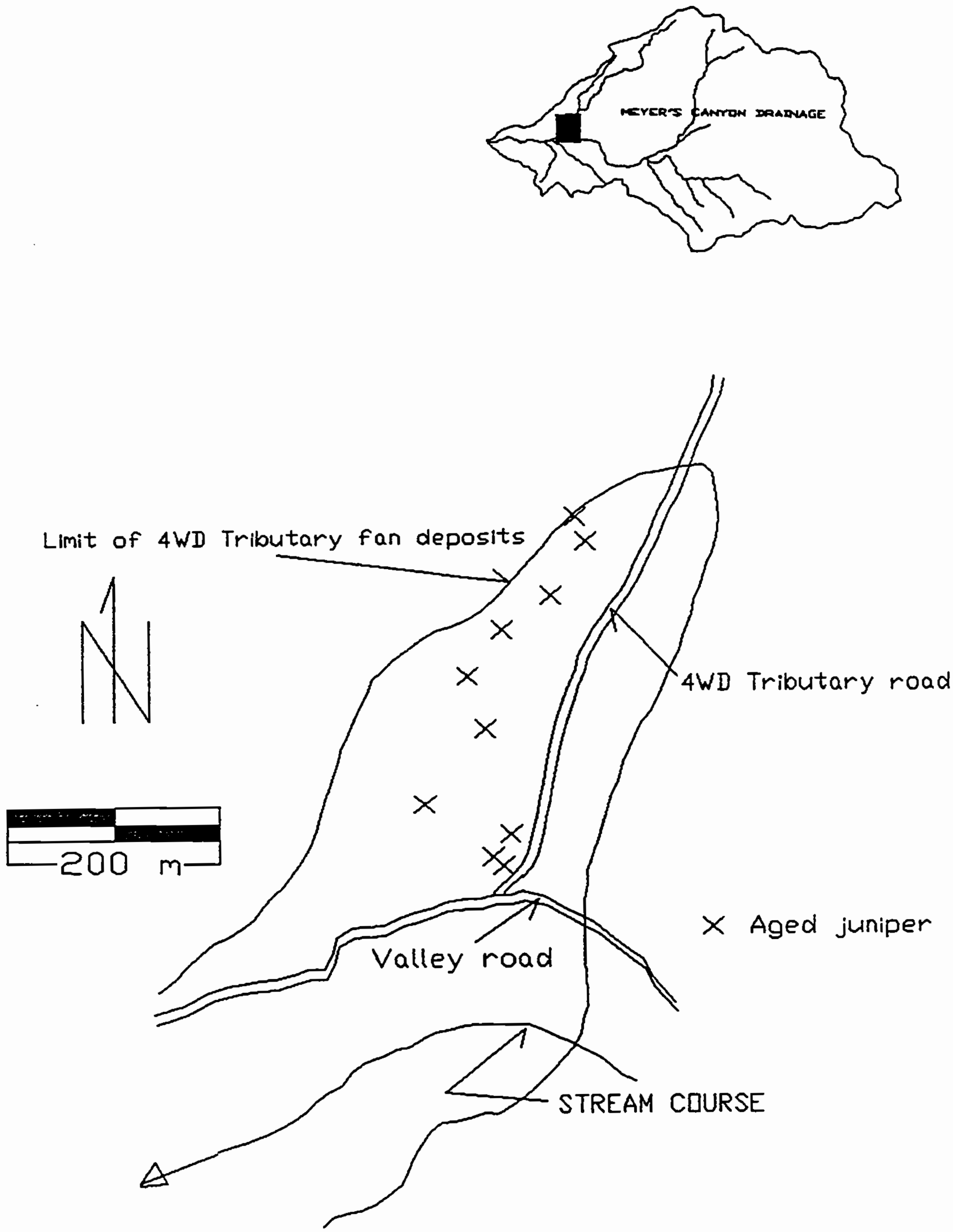


Figure 10. Approximate location of aged junipers within 4WD Tributary fan deposits.

No. 14048000) from 1906 to present (Figure 2). Using available records, a log-log relationship was established between the discharge of Mountain Creek and the John Day River at McDonald's Ferry (significant at $\alpha = 0.05$, $r^2 = 0.85$) and was used to extend the flow values of Mountain Creek. This relation is (std. dev. of coefficients in parentheses):

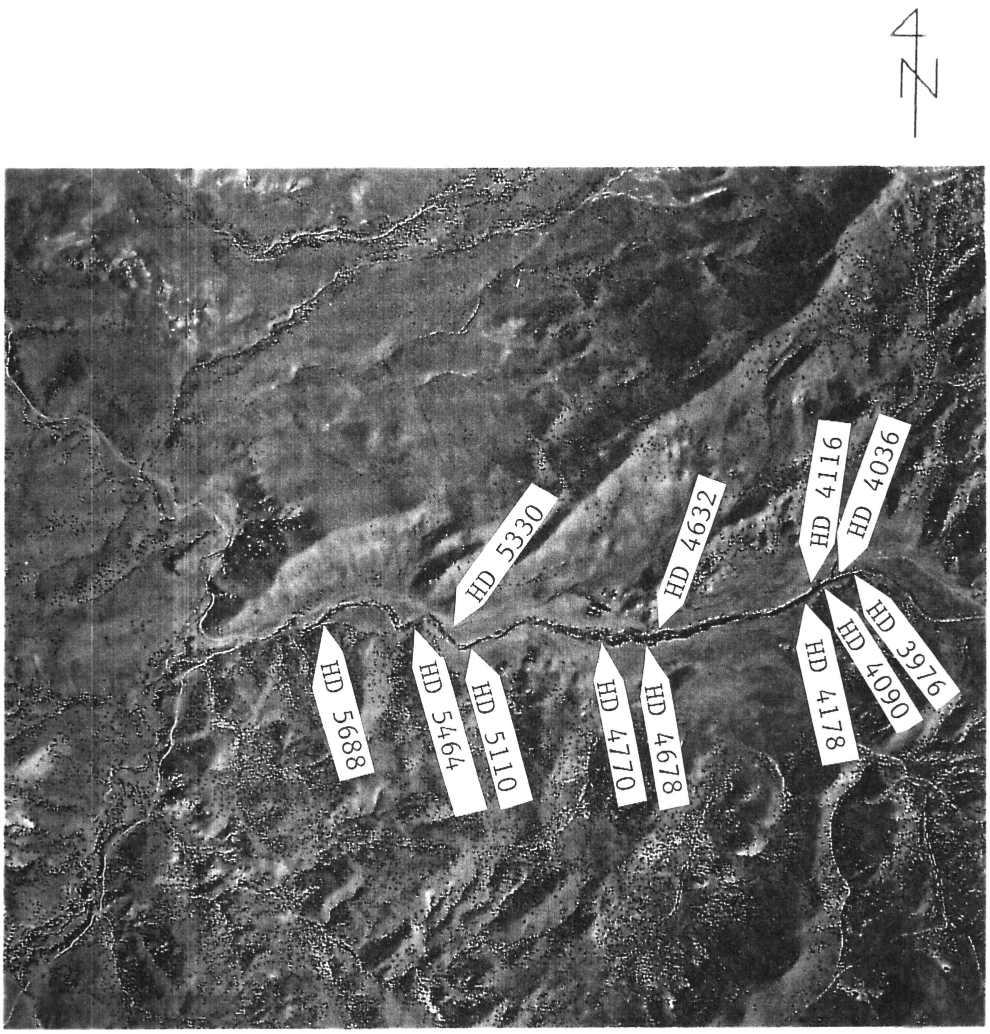
$$\mathrm{LOG_{10}(Mtn\ Ck\ Flow)} = -2.49 + 1.05 * \mathrm{LOG_{10}(John\ Day\ Flow)}$$
$$(0.34)\quad(0.10)$$

This relation indicates the drought associated with the John Day Basin from the 1920's to the 1940's also probably affected the upper drainage and thus Meyer's Canyon.

Costa (1987) and Hubbard (1991) indicated that a 1956 flood from Meyer's Canyon was one of the twelve largest flash floods in the nation. Using the indirect slope-area method, Costa (1987) calculated a maximum flood event of 1547 m^3/s; Hubbard (1991) estimated that peak discharge of the Meyer's Canyon flood exceeded 44 $m^3/s/km^2$ (4,000 csm). However, the slope-area method can significantly overestimate sediment-rich flood flows because of sediment bulking (Blood and Humphrey 1990), or localized channel adjustments.

Exposure

Changes in rates of sediment accumulation over the course of the Holocene may be indicative of extrinsic changes (e.g., climate) or intrinsic (e.g., distance from sediment source). The volume of valley fill and amount of material removed by incision was calculated using data obtained from 1986 aerial photos and survey data. Historical changes in the areal extent of the incision were evaluated using four series of aerial photos and incision width at 12 locations. Figure 11 is a photo copy of the 1951 aerial photograph



<u>Scale</u> : 1:22823

Figure 11. Location of measurements of incision width from aerial photographs of Meyer's Canyon for the years 1951, 1968, 1979, and 1986.

of the Canyon. Jim Kiser (Oregon State University College of Forestry Photo Lab) established ground control points and measured cross section dimensions:

Year	Scale of Aerial Photos
1951	1:22823
1968	1:21746
1979	1:41923
1986	1:36487

Horizontal distances (HD) from survey data were used to spatially locate exposures, cross-sections, paleochannels, and carbon-14 sample sites along the incised channel (Appendix A contains the cross references of numbers used for field descriptions to numbers used in this document). The "zero point" for these measurements was within the Upper Drainage where incision first begins (Figure 12). The field descriptions (exposures), cross-sections, paleochannels, and carbon-14 collection sites are referenced by the horizontal distance from the zero point, preceded by an "X", "CS", "PC", and "^{14}C", respectively.

The channel cross sections used for aerial photogrametry measurements coincide approximately with exposures X3852, X4170, X4678, and X5060. An additional cross section was added at HD 4210 m (Figure 12). The cross sections provided the measure of the distance between hillslopes and the incision edge, and the hillslope angle needed to extrapolate to the base of the sediments (e.g., Figure 13). Cross section data was supplemented by surveying data for depth and width of current incision.

The cross-sectional geometry of valley fill and incision at five locations (Figure 12) were used to determine volumes of fill and sediment removed by channel incision. The cross-section surveys included valley slopes so hillslope gradients could be extrapolated to below the valley fill and a depth to the base of the alluvial sediments could be estimated, as in the Figure 13 schematic.

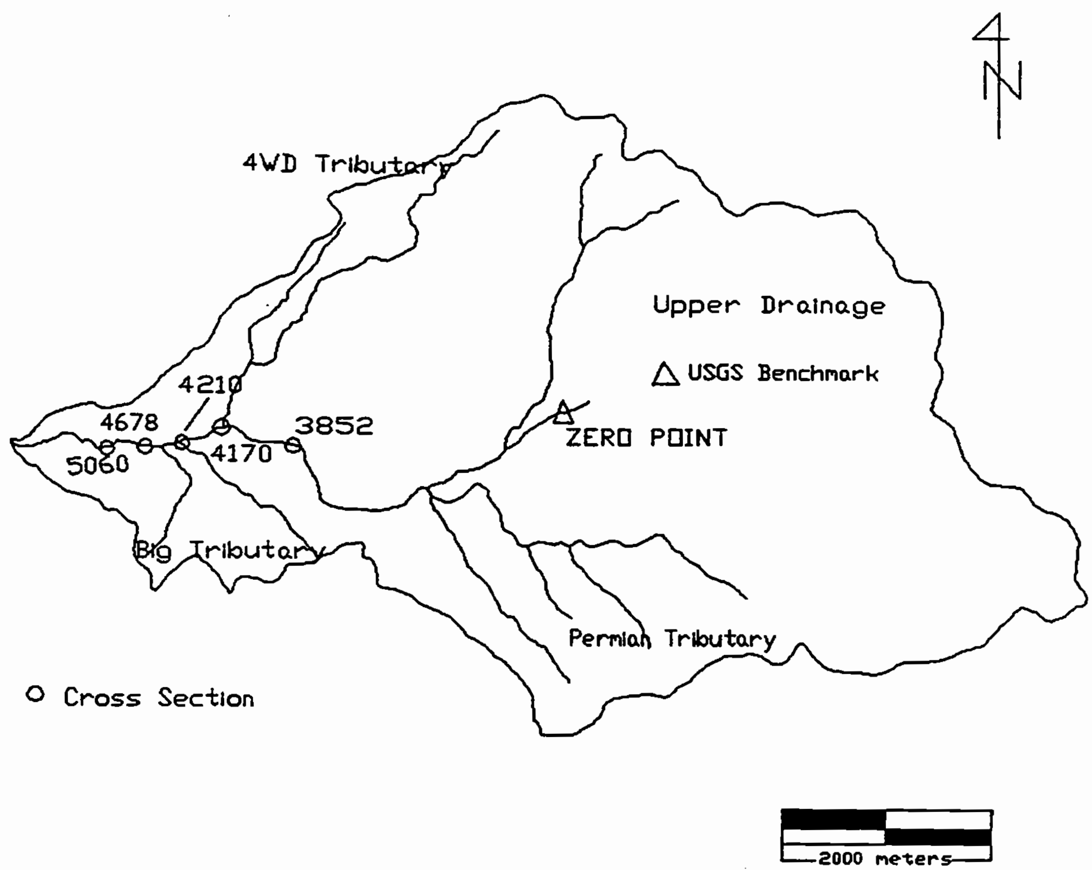


Figure 12. Meyer's Canyon drainage and cross section locations. Numbers indicate horizontal distances from "zero point" in the Upper Drainage.

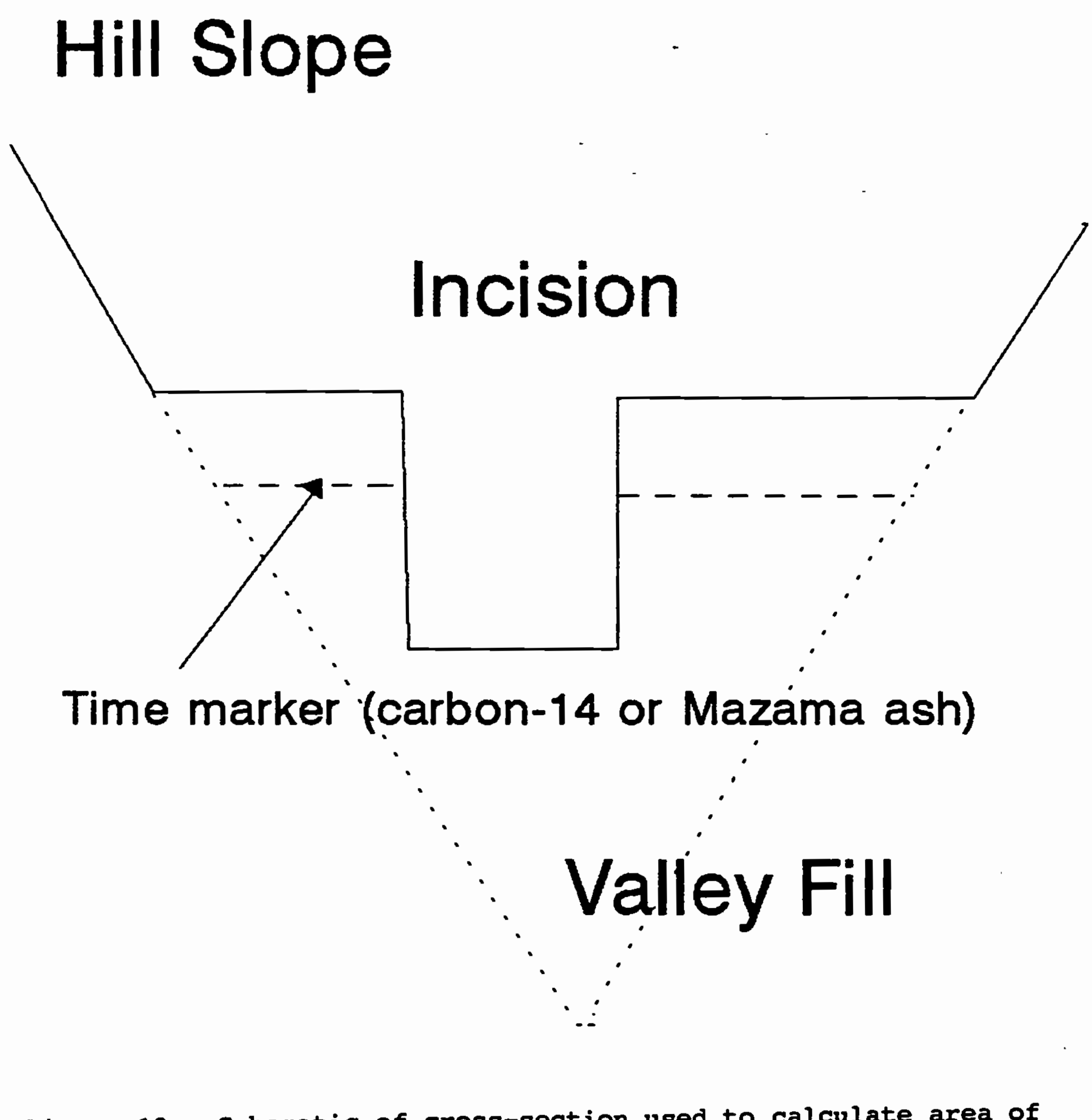


Figure 13. Schematic of cross-section used to calculate area of valley fill and incision.

Paleochannels were determined by erosional unconformities which extended vertically through at least three layers of sediments and horizontally at least 5 meters. Often, paleochannels are backfilled with coarser or different colored sediments than the sediments into which the channel is inserted. These paleochannels were numbered based on the horizontal location within the Lower Valley fill.

Carbon-14 dates were used to further segregate the deposits to determine rates of sediment accumulation during certain periods. Other than the Mazama ash, dates were not continuous between exposures and the sediments were assumed to "pinch out" upstream and downstream before reaching the next exposure (this is for purposes of volume calculations). Since the Mazama ash layer is longitudinally extensive, fill rates could be estimated for before and following the Mazama eruption and compared between exposures. The total fill rate was estimated using 10,000 years as total filling time for convenience. Many authors (e.g., Knox 1983, Barnosky 1985, Bull 1991) suggest 10,000 years ago as the beginning of the Holocene when alluviation dominated (Knox 1983). Carbon-14 dates indicate the current aggradational sequence is within the Holocene.

Vertical and Longitudinal Alluviation

One of the reasons Meyer's Canyon was chosen to investigate the timing and controls of depositional and erosional processes was the excellent exposure provided by stream incision along a longitudinal gradient. The incision is about 22 meters deep at the deepest portion, and depositional sequences are well exposed in the lower valley for approximately 2000 meters. Much of the oldest sediment within the vertical exposure have been covered in recent years by colluvial aprons resulting from bank collapse of the incision edges.

Five sites were chosen for detailed examination and description; these are, from upstream to downstream, Exposures X3664, X3852, X4170, X4678, and X5060 (Figures 14 and 15). The sites for description were chosen based on key features of the fill such as changes in grain size from bottom to top of sediments, longitudinal continuity of layers from upstream to downstream locations, the color of the sediments, and the accessibility for field observations. Stratigraphic and soils descriptions included depth (from valley fill surface), thickness, texture, color, structure, consistency, cementation, roots, carbonate (using 1N solution HCl), and boundary characteristics of each designated layer. Layers were separated based on texture, boundary condition (e.g., abrupt boundary from clay-sized particles to gravel was always separated), color, and lateral continuity. Field methods and terms of description are from Definitions and Abbreviations for Soil Descriptions (USDA-SCS 1974), Soil Taxonomy (USDA-SCS 1975), Geomorphological Field Manual (Gardiner and Dackombe 1983), and The Field Description of Sedimentary Rocks (Tucker 1982). Structure and texture codes are derived from Definitions and Abbreviations for Soil Descriptions (USDA-SCS 1974); color values are from Munsell Soil Color Charts® (1975). Soil descriptions were used to provide evidence for periods of quiescence, e.g., the longer the soil is undisturbed, the greater the clay movement as shown by structure and thickness and orientation of clay skins on individual soil peds. Each identifiable layer at a site was drawn to scale in a field notebook in conjunction with a physical description; synthesis of the field data is included for each description in Appendix B. The lines in Tables B-1 through B-5 separating certain units represent erosional unconformities (EUCs). Erosional unconformities were determined by abrupt changes in the structure and texture of the sediments.

Depth and thickness of layers were measured from the surface of the valley fill. Offsets were often necessary because of the depth of the canyon and accessibility of an exposure. Usually a coarse

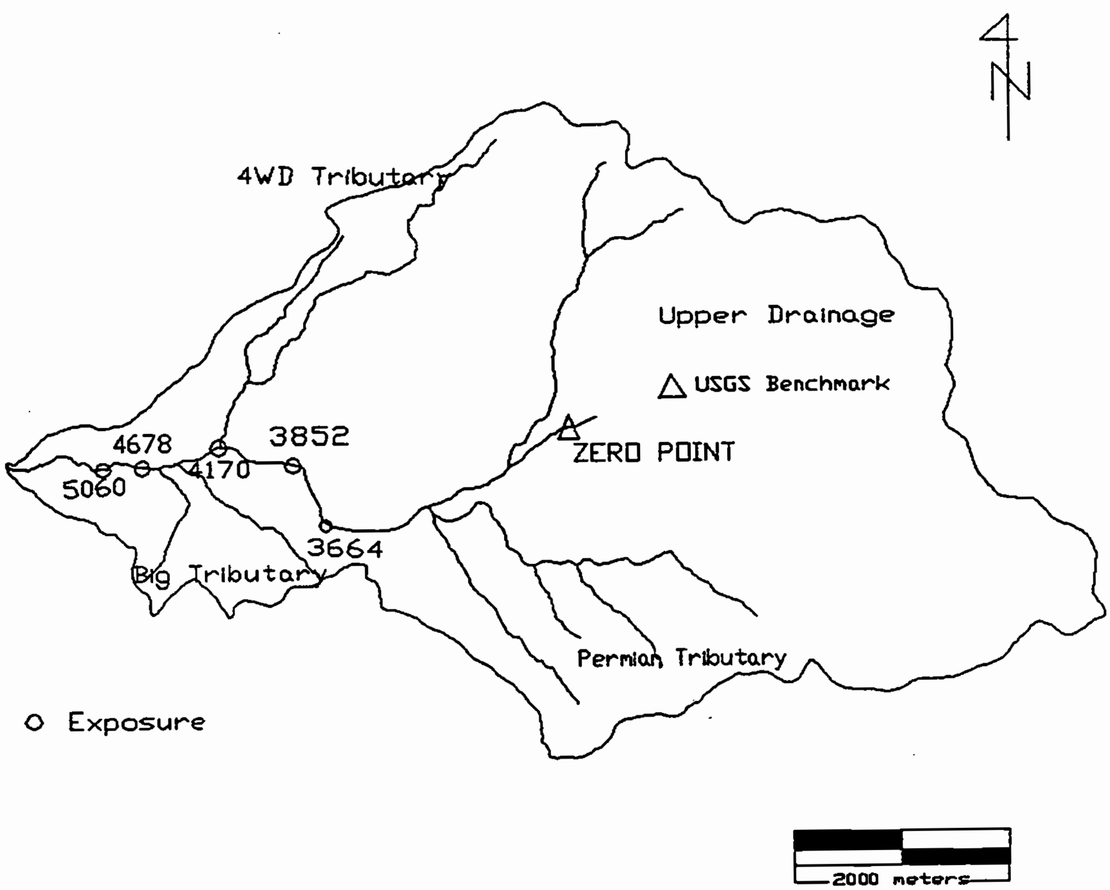


Figure 14. Meyer's Canyon drainage and exposure locations. Numbers indicate horizontal distance from "zero point" in Upper Drainage.

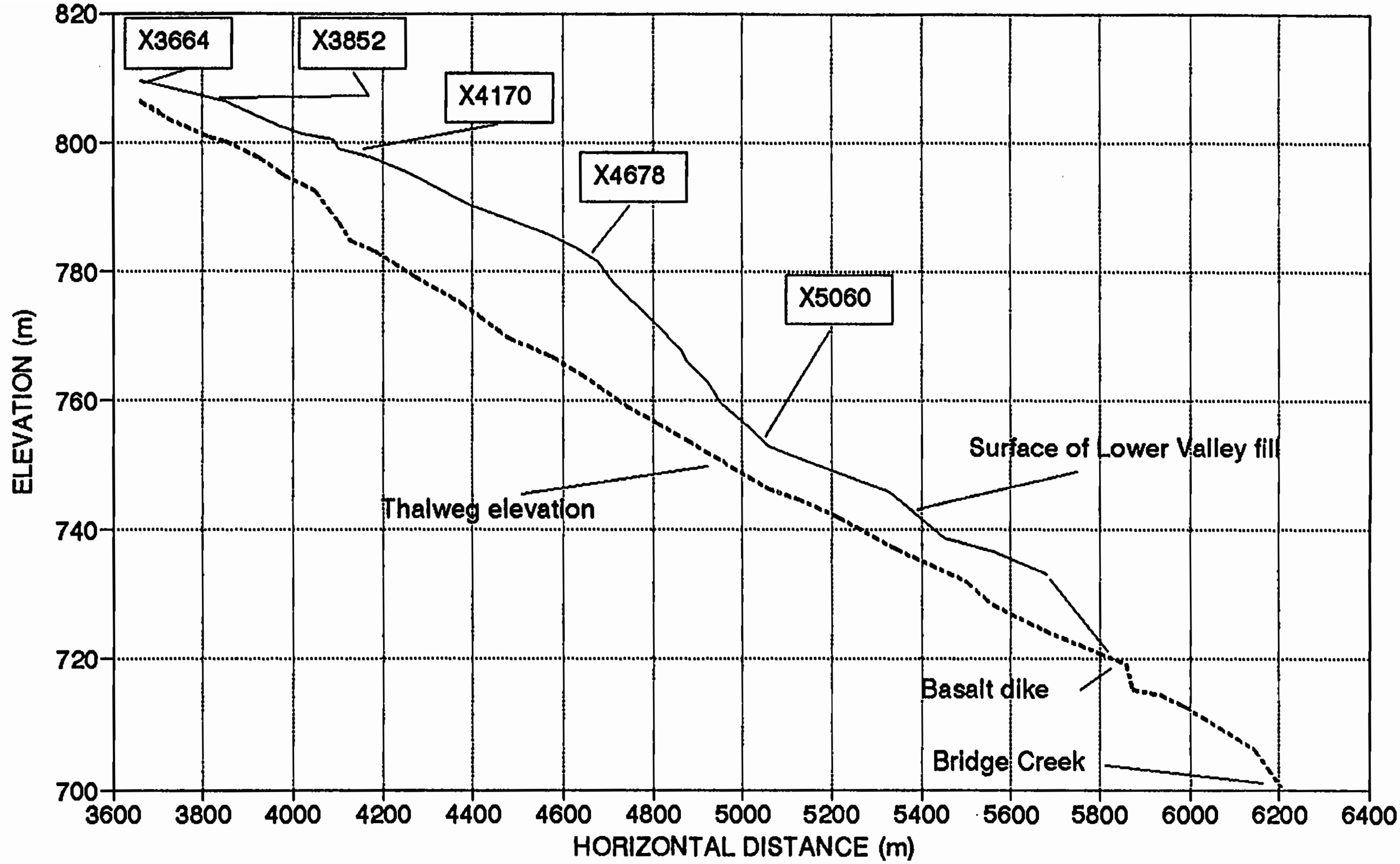


Figure 15. Longitudinal profile of surface and thalweg elevations for Meyer's Canyon Lower Valley fill. Numbered exposure locations are also shown.

layer (cobbles or gravels) extended from one section to the next. If no coarse layer was available, a sand or well-developed soil horizon was traced. If a layer or series of layers were continuous from one exposure description to the next, the continuity was noted. The continuity of the layers, or lack thereof, is relevant in the interpretation of the alluvial processes.

Each described layer was given a sequential number from the surface in combination with the exposure description, e.g., X3852-1, X3852-2, X3852-3 are the first three layers within X3852. Samples of each layer were obtained with a trowel by cutting a vertical swath from the top of the layer to the bottom with the sediments falling directly into a heavy-duty polyethylene ziplock bag. Samples were labeled and stored for analysis.

Within the sediments are numerous coarse-grained layers (gravel and larger). The frequency and character of these layers change from upstream to downstream and from oldest to newest deposits. There may be a change in frequency of these deposits based on climate change over the course of the aggradational cycle, the position of the exposure within the watershed, and the influence of individual landform features such as an alluvial fan. Alluvial fans can be separated in proximal, medial, and distal locations, which separation is based on distance from the source of the sediment. Sediment characteristics change due to the hydraulic changes which occur over that distance.

Within alluvial fans, layers are often separated into debris flows, mudflows, mud drapes, and channel deposits. Debris flows are characterized by coarse-grained, poorly-sorted, clast-supported debris. Mudflows are somewhat heterogeneous mixtures of gravel through clay-sized material, the gravel often is within a sandy or "muddy" matrix, and there are sand, silt and clay lenses throughout the deposit indicating reworking of the original mass. The mudflow is often very thick, longitudinally continuous, and may have a coarse debris layer which precedes the bulk of the heterogeneous mass. Events/layers are separated based on the distinctness of the boundary between the layer and the preceding layer, e.g., an abrupt, smooth boundary between coarse gravel and underlying silt-size material indicates an "event" and an erosional unconformity would be noted (EUC). Additional information, such as clay movement suggesting a "B" horizon in the preceding layer, but without the darker, organic rich "A" horizon, can add support to the identification of an EUC. Mud drapes are thinner than mudflows and less heterogeneous, based on field descriptions. Channel deposits are marked by well-sorted, clast-supported sand- through cobble-size material, often with imbrication which suggests direction of flow. Channel gravel and sand deposits may still retain lamination or bedding structures.

As distance from the source increases, sediments are sorted by fluvial action and fine material increasingly dominates the depositional profile. Downfan and downstream (alluvial plain) locations are characterized by integration of sediment from many sources by streamflow, as opposed to one source within a fan, and coarse deposits are within a fine-grained matrix.

Discrete depositional layers are classified as lithofacies based on numerous properties such as bedding characteristics, grain size, and longitudinal continuity, after Miall (1977, 1978) and Rust (1978). A facies, originally defined for rocks (Reading 1978) was adapted herein for physical descriptions of depositional sequences. A facies is a sequence of sediments with specific characteristics and is defined on the basis of color, texture, bedding, composition, erosional unconformities, and lateral continuity. Many layers deposited under similar conditions can be reduced to one lithofacies, e.g., laminated sand, silt or clay layers deposited by waning flood deposits are classified as Fl. Definitions and descriptions of lithofacies used herein are contained in Appendix C as Table C-1. Lithofacies schematics which correspond to given layers are also contained in Appendix C. Many walking-traverses of the canyon were undertaken in an attempt to understand the broader alluvial context of the individual layers and to determine down-valley changes in these lithotypes.

The location and quantity of calcium carbonate, common in semiarid soils, is a function of rainfall amount, temperature, depth and texture of soil, and parent material. Because layers have been consistently subjected to deposition, erosion, and climatic change over the Holocene, percent calcium carbonate outside a context of known soil horizonation is meaningless and has been discarded.

Percent organic matter (% OM) is used primarily to compare between exposures. Organic carbon (organic carbon is only about 58% of the organic matter in soils (Horneck et al. 1989)) is one of the soil properties which changes rapidly in response to changes in species composition, moisture and temperature, on the order of 10^2 to 10^3 years (Birkeland, 1984), and it also oxidizes readily. Texture and exposure to oxygen can influence amount of organic matter remaining in paleosols and paleodeposits. Thus, with rapidly changing conditions, such as occurred in Meyer's Canyon, absolute organic matter has limited usefulness without other controls such as extensive dating and correlation with known climate and soil chemical analysis. To determine within and between exposure variation of organic matter content, several layers were analyzed using the Walkley-Black method of organic matter analysis (Horneck et al. 1989). Layers analyzed were chosen based on texture, depth, structure, and color to give an idea of the variability of organic matter accumulation and preservation within the deposits. Organic matter data are included in Tables B-1 through B-5 in Appendix B.

The entire valley was surveyed to determine physical parameters such as slopes of fill material, incision thalweg and bottom of the Mazama ash deposit, and depth and width of incision. Certain critical portions such as location from a USGS bench mark at an upvalley location within the Upper Drainage to the beginning of the channel incision (Figure 12), and X3852 to the end of the Lower Valley Fill (Figure 15), were surveyed using a Wild Level and stadia rod. Otherwise, portions of the Upper Drainage, Narrows, and the downstream end of the Lower Valley fill to the end of live stream were rapidly surveyed using a clinometer and 30 m cloth tape. Slopes were calculated based on the surveying data; there was variation between fill slopes surveyed on the north and south sides of the incision, but differences were nonsignificant (α = 0.05, 46 df) and slopes were averaged.

The survey data were reduced to xyz coordinates using TRAVERSE PC software, ver. 1.2 (John Balcom/Ward Northwest, Inc., Florence, Oregon), a coordinate geometry program in which horizontal distances were calculated. Distances to bottom of the ash and the top of certain soils or coarse layers which could be traced longitudinally were measured. The slopes of portions of the stream incision thalweg, certain paleosols (ones which were longitudinally continuous), the bottom of the Mazama ash layer, and the current valley fill surface were compared to see if the transportation slope of the surface was changing over time. The assumption is that a layer which is longitudinally continuous would probably reflect the valley fill surface prior to subsequent deposition.

Volume Rates of Accumulation

To establish rates of sediment accumulation, changes in types of sediment accumulation over what period of time, and temporal relations between sediments from upstream to downstream locations, it was necessary to date the sediments. Charcoal samples were gathered from several locations within the sediments for Carbon-14 (^{14}C) analysis (Figure 16). The samples were collected onto aluminum foil then transported to Corvallis. The main charcoal chunks were separated with needle and tweezers, placed in aluminum foil, and sent to Beta Analytic, Inc., in Miami, Florida for analysis. Some the charcoal accumulations were very small and as such required Accelerator Mass Spectrophotometer (AMS) analysis to estimate ^{14}C concentrations and provide a date estimate. The ^{14}C dates were converted to years before present (years (cal) BP) using methodology and software developed by Stuiver and Reimer (1993). Years BP represent years before 1950 AD. By comparing measured carbon-14 contents (yrs (^{14}C) BP) of unknown age materials with carbon-14 accumulations with known ages, the age of the unknown material can be calculated (yrs (cal) BP). Dates are kept in years ^{14}C BP for comparison to other literature, but are used in years (cal) BP to compare within the study. The Mazama ash layer exposed in the incision sidewalls is a time-stratigraphic marker and as such offered further opportunity for establishing a dated control point in the valley fill. Ash samples were taken from three locations within the Canyon (Figure 8) and evaluated (Appendix D).

Recurrence intervals can be established using dated controls within a vertical sequence. The intervals are separated by the number of erosional unconformities (EUCs) within an exposure as in X3852, or by number of debris flow/mud drape couplets (X4170), or layer with sorted coarse particles (X4678 and X5060). The midpoint of the calibrated date (yrs (cal) BP) for the charcoal samples and the Mazama ash marker layer, and 10,000 years (for convenience) as the beginning of valley fill accumulation were used to separate the intervals. The age of the sediments (midpoint of years (cal) BP for

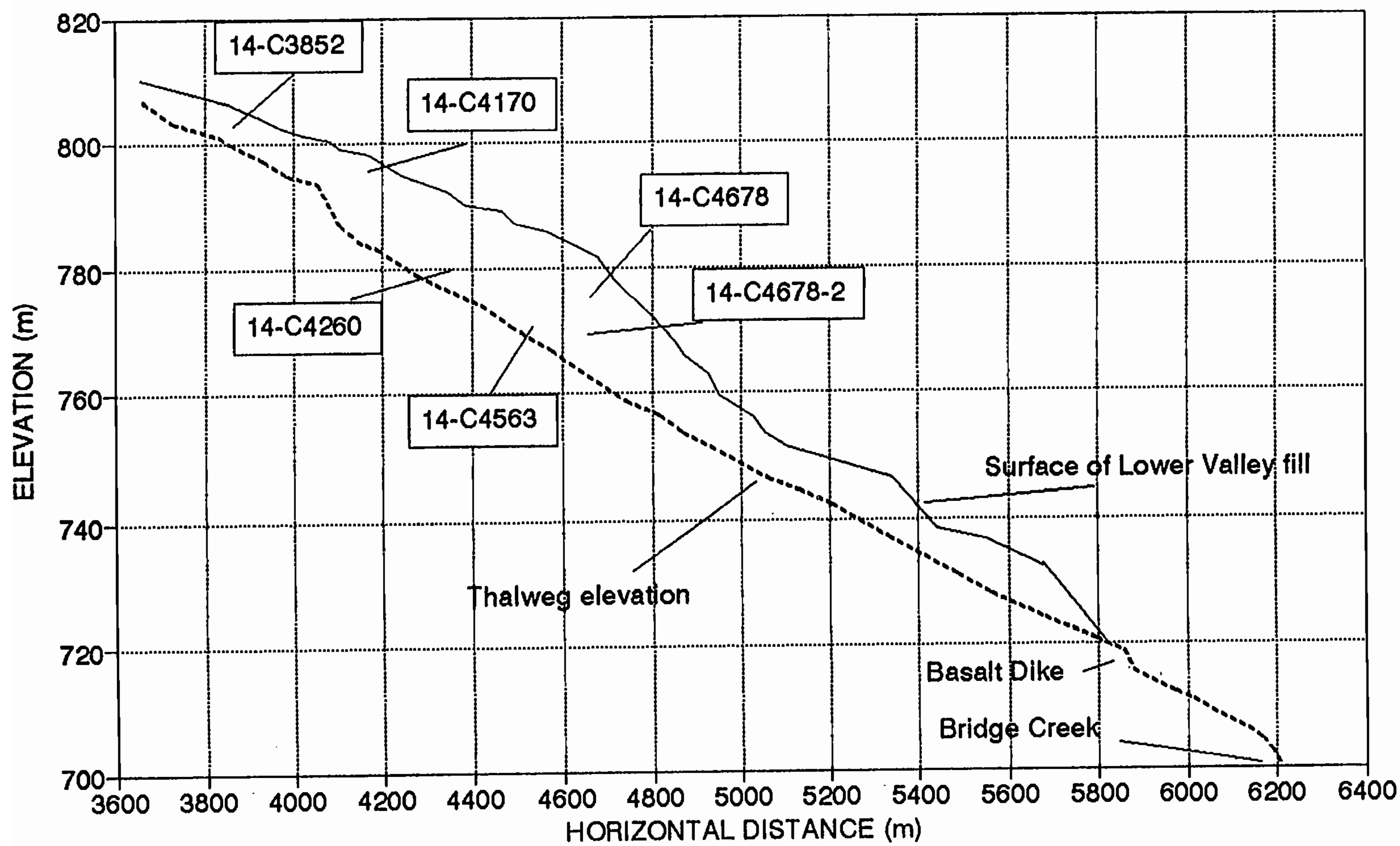


Figure 16. Longitudinal profile of surface and thalweg elevations Meyer's Canyon Lower Valley fill. Locations of carbon-14 samples are also shown.

sample sent from that location) divided by number of "events" equals the recurrence interval.

RESULTS AND DISCUSSION

Channel Incision Initiation

Though many sources were checked, no information was found as to the timing of the current incision or where it began. There is, however, historical information regarding lack of an incision prior to the beginning of the 20th century. Vegetation established on the incision floor and vegetation subjected to recent debris flows may indicate time of incision or time of debris flow, respectively. Only precipitation information is available for the canyon; geomorphic evidence of major flood events (e.g., surface cobbles) is all that might provide evidence of stormflow. Additionally, by measuring the changes in the incision over time (1951-1986, from aerial photos available for the Canyon), extrapolation of the rate of increase of incision width back to zero width may lend support to a hypothesized "time of beginning."

Historical: According to historical records and an eyewitness account, the channel incision which currently exists within Meyer's Canyon occurred between 1899 and 1951, probably after 1920. No evidence was found which suggested a deep incision bisected Meyer's Canyon prior to 1873. Cristian W. Meyer (aka Myers), first settled in the valley in 1867, along with Frank C. Huot (also known as "Alkali" Frank Hewett, Hewot, Hewott, and Huat). They established one of the first irrigated orchards and truck gardens, and managed the Alkali Flat stage station for H.H. Wheeler from 1864 to 1868 on the Dalles-Canyon City Military Road (Shaver 1905) (see Figure 17). In 1873, the General Land Office surveyed the north/south sections lines of T11S, R20E, between sections 15/16, 14/15, and 13/14 (see Appendix E for GLO map). No mention was made of a deep canyon bisecting the survey path, though a spring was noted in the

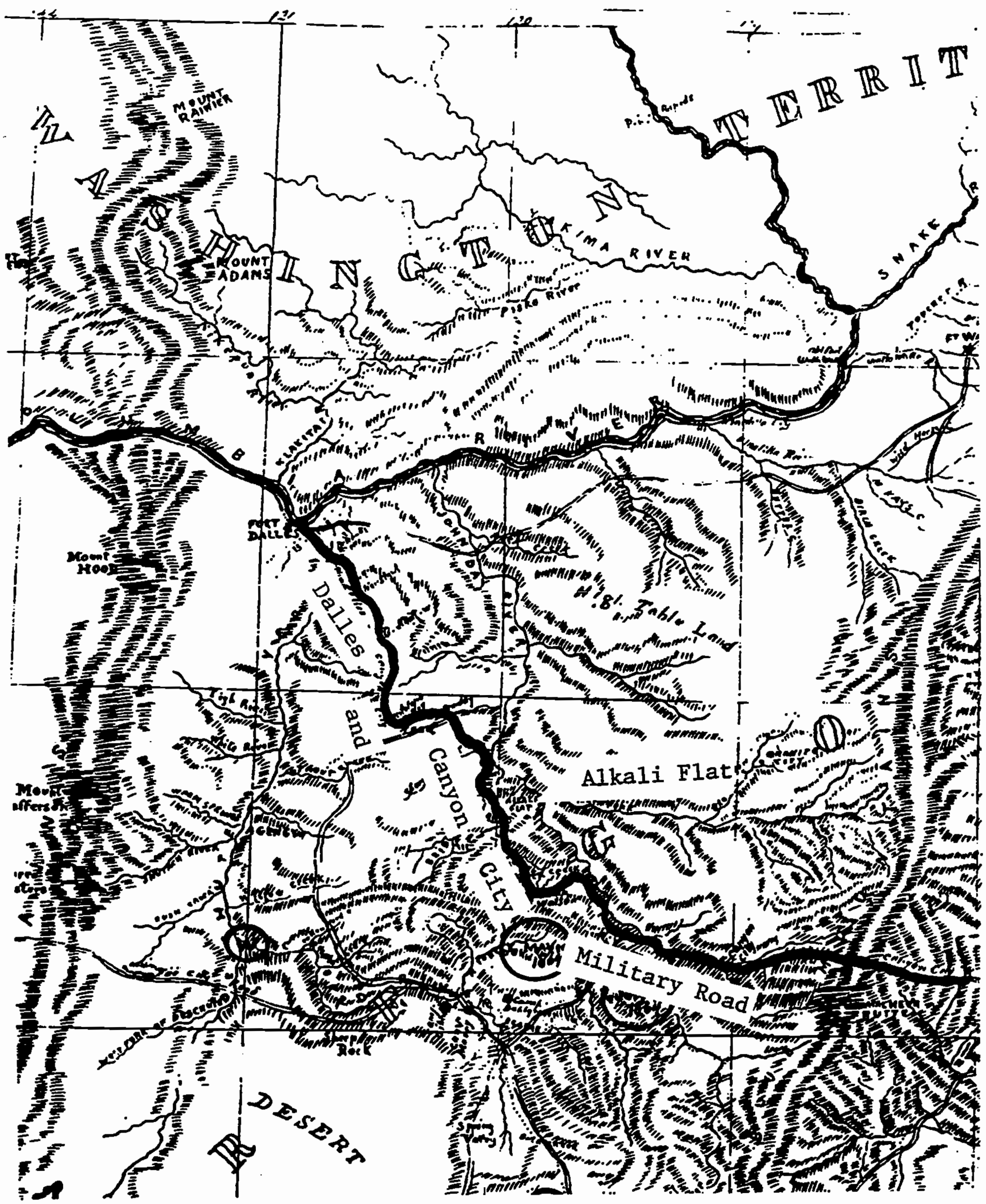


Figure 17. Early map of Oregon showing the Dalles-Canyon City Military Road (Preston 1972).

approximate location of the current "waterfall" just below the downstream end of the Lower Valley fill over the bedrock dike.

In 1899, a geologic team from the University of California traveled on a field trip to the John Day Beds (Miller 1899). They camped at "the broad flat upper end of the valley", which is probably just below the Meyer's Canyon junction with Bridge Creek. They made a trip to Mitchell "up a side canyon onto an alkali flat, crossing a low divide" and came to Mitchell from a downstream location on Bridge Creek. Prior to road construction, Bridge Creek was impassable at the Meyer's Canyon junction, thus the stage line and others detoured through the Canyon to reach Mitchell.

L.L. Jones began buying up portions of the drainage beginning in 1918. By 1942, at the time of his death, he owned the entire drainage. According to his daughter, Mary Cottingim, Mr. Jones was one of the largest sheep farmers in the area and the drainage was used only as sheep range, with a sheep cabin and tank about 3 km up 4WD Tributary. Jones had between 4800 and 7200 head of sheep but owned significant acreage in and around Mitchell outside of Meyer's Canyon so the intensity of use within Meyer's Canyon is unknown.

Mary Cottingim indicates the major incision occurred sometime after 1920 due to a major intense convectional thunderstorm. She is the only source for this information. The timing of the events are ambiguous as Mrs. Cottingim's memory of dates was not as good as her memory of events. To add credence, however, the Oregon Department of Water Resources completed an irrigation study of the John Day Basin in the summer of 1929 and they listed this site as Meyer's Gulch. Other significant floods which affected Mitchell and could have initiated the incision occurred in 1884 (when a "wall of water" hit Mitchell), 1904, and 1956 (Stinchfield 1983). All these storms occurred in the summer as a result of intense convectional storm activity. It is known that the 1956 storm created a large flash flood in Meyer's Canyon (Costa 1987), but it cannot be assumed that all intense storm activity which affected Mitchell would automatically affect Meyer's Canyon. Brogan (1972) notes that the 1884 flood killed members of the Carroll family; the Carroll family was located downstream of the Meyer's Canyon junction on Bridge Creek near the current visitor's center of John Day Fossil Beds Painted Hills Unit. Brogan (1972) also calls Meyer's Canyon "Alkali Flat" and "Meyer's Gulch" with no transition or explanation as to when the name change occurred. Nielsen et al. (1985) attributed the recent deep gully to severe floods in 1964; aerial photos from 1951 show this to be incorrect as the incision was well-established at this time (Figure 11). The entire drainage is called Meyer's Canyon on all published maps and is listed in Oregon Geographical Names as such (McArthur 1974).

<u>Vegetation</u>: Sagebrush *(Artemisia spp.)* and juniper *(Juniperus occidentalis)* growing on the arroyo floor and colluvial aprons near HD 4170 m were 7-19 years old, to greater than 60 years old. The 60-year old juniper upon the colluvial apron dates the incision at this point to at least before the 1930's. A Russian olive (*Elaeagnus augustifolia*) at below Exposure X5060 at HD 5100 m was estimated at 21 years old.

The sediments/fan from 4WD Tributary have experienced recent (i.e., within the last 100 years) debris flows; the junipers' age within the 4WD Tributary gave an idea as to when certain of the sediments may have been deposited, but also the time when the most recent debris flow occurred. The most recent event happened about 43 to 30 years ago, as shown by aging debris scars. Older trees were from 65 to 115 years old. Tree ages do not necessarily date the soil surface since significant time may have passed and subsequent depositional events may have occurred before the tree was established. Tree ages only show the minimum age of the material upon which it is growing. Neither does the lack of trees older than 115 years indicate a maximum date for subsurface deposits. While catastrophic events may have removed all juniper on the alluvial fan, there is evidence that juniper densities have been increasing in eastern Oregon (Miller in press) and may not have been present in Meyer's Canyon more than a century ago.

<u>Precipitation and Streamflow</u>: While streamflow is the integrator of precipitation events, there are no streamflow records for the drainage. Geomorphic evidence such as the debris flow mentioned earlier and transport and deposition which occurred during the field study, however, suggests that summer convectional storms have a significant effect on the deposition and transport of sediment within the valley. Between May and September of 1993, the incision into 4WD Tributary at HD 4170 m headcut about three meters and deepened and widened significantly. The material was moved into the main canyon and moved downstream to approximately HD 4620 m by at least two events. These same events also created additional incision of about 1 meter into arroyo floor sediments upstream of HD 4170 m. The maximum precipitation recorded during the May-August period was 30 mm in 24 hours on August 20 (Mitchell Sta. No. 48517); this was likely a convectional storm and probably occurred over less than a two-hour period.

Costa (1987) reported a 102 mm/two-hour storm intensity for a July 13, 1956, flood. However, the Oregon Climate Service reported a 24-hour precipitation of 21.5 mm. Costa estimates that a discharge of 1540 m^3s^{-1} (4000 csm) was generated by this storm. He cites information provided by Hendricks (1964) in his analysis of discharge. Hendricks (1964) had data from a convectional storm in north-central Washington which dropped 38 mm in a few minutes and led to a maximum peak of 6640 csm. A peak of 1540 m^3s^{-1} translates to a rainfall intensity of 157 mm/hr, which is greater than any measured 5 minute intensity for eastern Oregon stations (Beschta, OSU Department of Forest Engineering, personal communication, 1993). Since Costa used the slope area method to estimate discharge, sediment bulking or temporary channel aggradation is suspected. When Costa measured the high flow mark and water surface elevation using the slope-area method, he calculated much more discharge than could have occurred resulting in a significant overestimate. The timing of the event (1956) coincides with that most recent debris flow event coming from 4WD Tributary which was dated using tree scars. This debris flow cut into upstream reaches to depths of three meters and moved boulders up to a meter in diameter. Surface cobbles were deposited as far as the edge of the current incision.

Volume of Incision: The volume of incision (i.e., the volume of valley fill removed by incision) calculated from cross sections of the Canyon is shown in Table 1. Out of 11.8 million cubic meters (mcm), 1.2 mcm (11%) of the valley fill was removed by incision. Figure 18 shows the five cross sections within the context of the entire valley. The greatest percentage of volume lost is in the upper portion of the Lower Valley fill in the proximal to medial section of the Narrows fan. This percentage supports a hypothesis that this area was strongly influenced by braiding and repositioning of channels on the alluvial fan and a greater proportion of the valley fill is in channels at any one time. Downstream, where sediments are influenced by the fine-grained sediment of 4WD Tributary, valley fill sediments are more cohesive and potential

Table 1. Volume of Lower Valley fill removed from Meyer's Canyon by incision.

Cross Section	Location HD (m)	Volume Fill (1000 m^3)	Volume Incision (1000 m^3)	Percent Removed (%)
Beginning	3375	0	0	
		1164	211	18
CS3852	3852			
		2940	185	6
CS4170				
		2132	174	8
CS4260	4260			
		2111	238	11
CS4678	4678			
		1685	282	17
CS5160	5160			
		765	119	16
End	5701			
TOTAL		10797	1209	11%

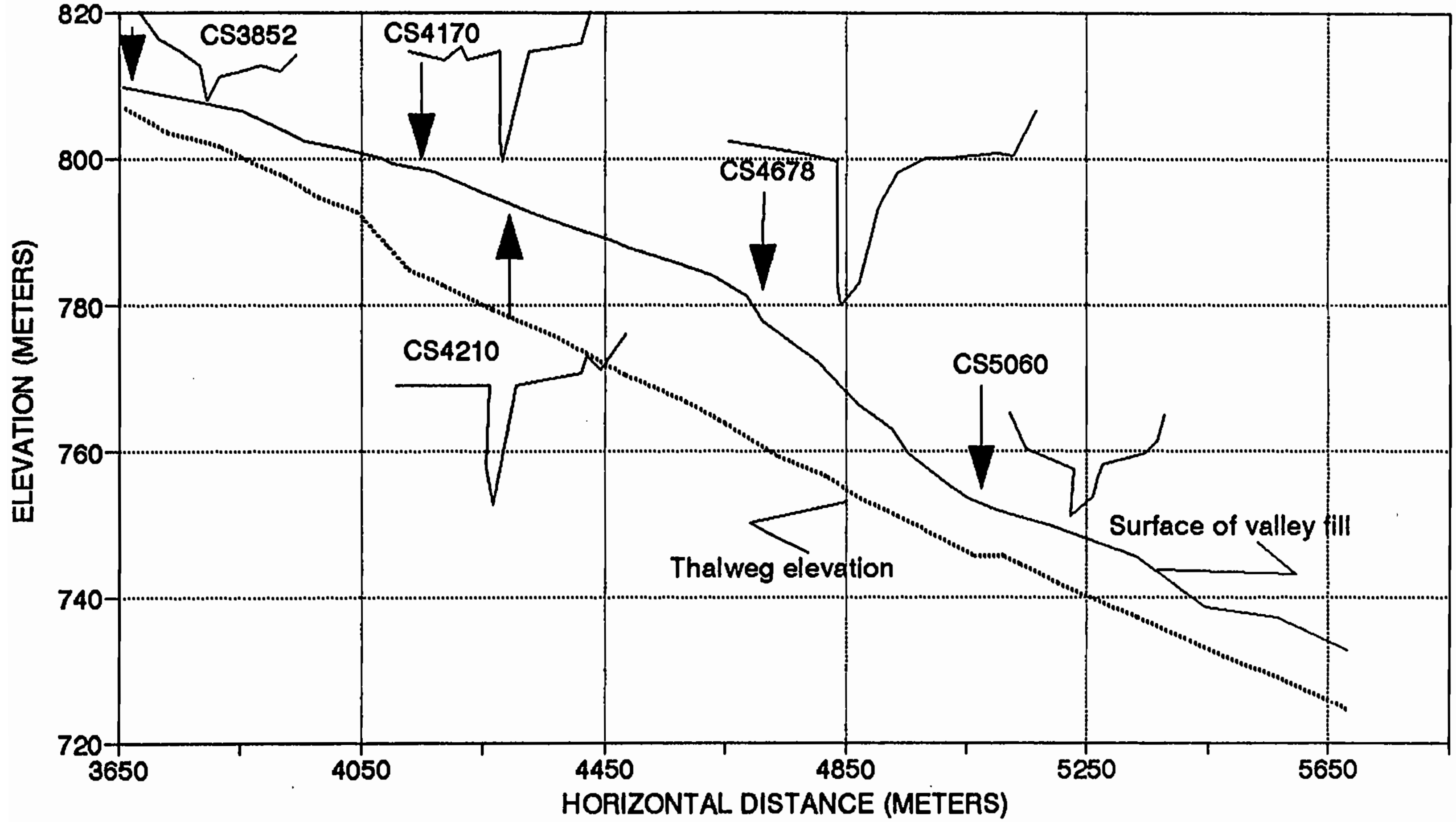


Figure 18. Valley fill, incision thalweg, and incision cross-sections at five locations within Meyer's Canyon Lower Valley fill.

stream banks are perhaps more resistant to lateral movement and channel shifting and widening (i.e., channel adjustments are vertical rather than lateral). Once incision begins, flow is concentrated and increased depth of flow increases shear stress on valley floor, which propagates the incision. Wider valley fill means less percentage of the total volume is removed by the same size of channel. Eleven percent of the Lower Valley fill was removed at HD 4678 m. This could be because a) the incision began here and fill sediments have been exposed to more sapping and erosion from the banks, and/or b) the sediments are prone to sapping and erosion regardless of length of time of exposure. Large sapping holes (about the size a Volkswagon bug) which exit at the arroyo wall were evident within the south-side valley fill sediments, in addition to large cracks which parallel the incision. The arroyo edges are unstable and the incision is wider at HD 4678 m than at other locations; incision width may be a surrogate for length of time of exposure.

Based on aerial photography and field measurements, the width of the incision has increased over the 40-year period of record. Figure 19 shows the width of the incision over time (measurements are located in Appendix F). The last 15 years show a decrease in width expansion. Over what period of time the current width was attained is unknown. However, simple linear extrapolation of the rate of increase from 1951 to 1979 indicates the incision could have occurred about the year 1900. An earlier date of about 1880, or later date of 1930, is indicated by extrapolating from the standard deviation of the width. Note that all extrapolated "times of beginning" post-date Euroamerican settlement of the canyon. The increase in incision width over time is consistent with the extent of colluvial aprons and evidence of planar block failures from the walls of the canyon. The greatest increase in incision width was around X4678. This is where the surface cracks and sapping holes exist, but also where the

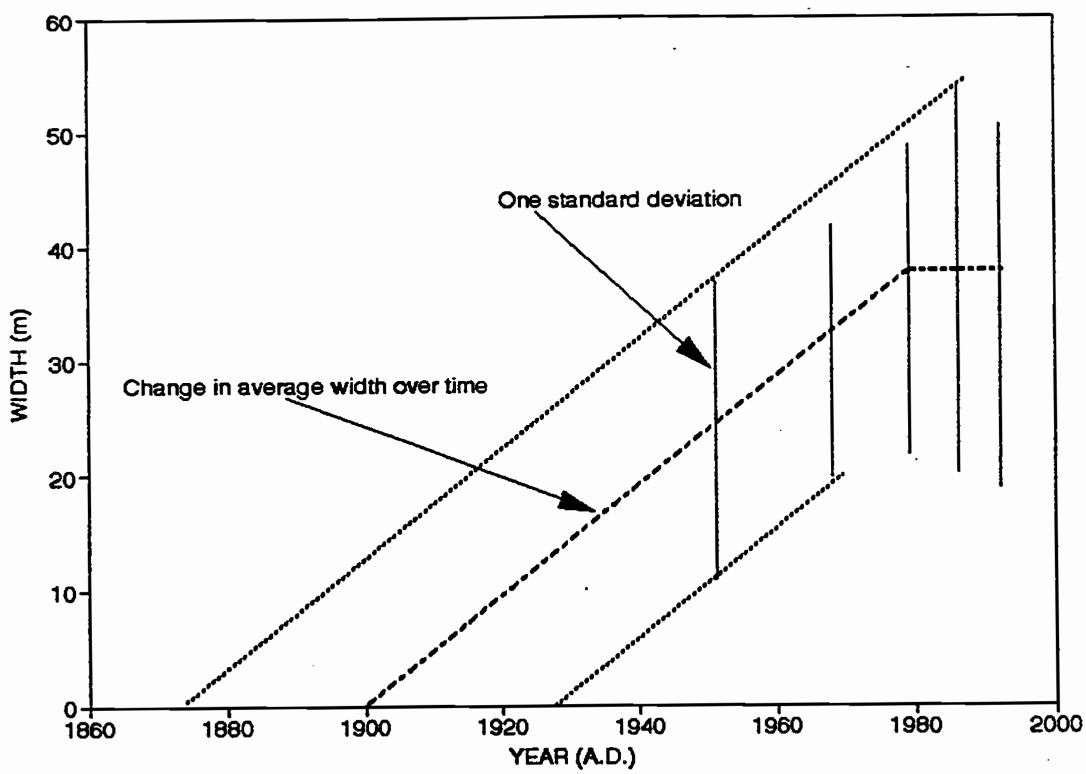


Figure 19. Average change in width of incision from 1951 through 1986 based on aerial photograph measurements. Error bars are extended one standard deviation above and below the mean width of the incision. Dashed line indicates possible rate of incision increase. Dotted lines are extrapolated from one standard deviation to indicate possible earliest and latest time of incision initiation.

largest colluvial aprons lie so that much of the sediment was not actually removed. There appears to be no increase in width after 1979; general incision width expansion may have been replaced by headcutting up 4WD Tributary. Aerial photo interpretation shows that headward cutting has been occurring up 4WD Tributary at the rate of 8 m per year since 1979.

Characteristics of Sediment Accumulation

Each exposure has attributes of deposition which separate it from other exposures. However, there are also recurring depositional sequences which are consistent throughout the valley fill. The synthesis of the field description notes, comments, interpretations, and observations is contained in Appendix B. The interpretation of the vertical exposures follows, and are succeeded by a summary of the features of the exposures relevant to position within an alluvial fan, and their position within the drainage.

X3664 Interpretation: Site X3664 is located at the downstream end of the Narrows section and upstream end of the Lower Valley fill. It is near the valley wall and as such is influenced both by colluvial and alluvial action. Colluvial sediments confound the upper layers though they are still classified as Fm (Figure C-1). Because there is a filled channel (PC3774) which truncates some of the units and is still evident on the surface nearer the center of the valley, the main fluvial action was away from this portion of the valley in more recent times. However, stratified gravels, parallel laminated sands, and the current incision indicate that fluvial action often occurs near this valley sidewall, perhaps concurrently as with a braided channel system; or "a network of braided distributary channels" (Bull 1977). Water-laid deposits which dominate this section of the Lower Valley fill may be well-sorted, cross-bedded, laminated, or massive, also as Bull (1977) describes for alluvial fan sediments.

This portion of the Lower Valley fill is interpreted as a proximal to medial portion of a valley-fill alluvial fan ("Narrows fan"). Flows experience decreased valley wall confinement and the stream is unable to transport the sediment load due to energy loss. Where there is a change in stream confinement and subsequent changes in erosional and depositional processes is essentially where alluvial fans occur (Bull 1977, Harvey 1989, Fischer and Harvey 1990). Subsequent flood events, or the waning portion of the event which mobilized the sediments, reworks the deposited sediments removing fines and creating stratified sand and gravel channel deposits. These channel sediments and mudflow deposits are subject to waning flood clay and silt drapes. However, there were periods of soil formation of sufficient duration, prior to subsequent erosion or deposition, for clay movement to occur within the soil profile. These periods of soil formation often followed a mudflow event, possibly due to shifting of channel action to other portions of the fan.

X3852 Interpretation: The upper portions of X3852 (top three meters) show influence from much the same mechanisms as X3664, or sheetflow with braided distributary channels. Sediments from various tributaries influence the depositional sequences. Heward (1978) has developed a model for alluvial fans developing in response to initial topography. In this model, proximal (or high-energy) processes increase toward the surface of fan deposits, which seems to be occurring at this location within Meyer's Canyon. Generally, there is a downfan decrease in clast size and vertical changes in clast size would be a result of influence from different sources areas (i.e., proximal to medial to distal locations within a fan, based on distance from sediment source), or by channel sorting and winnowing. However, numerous fine-grained layers of similar interpreted genesis are thicker below three meters (lithofacies "Fl", Figure C-2). A pattern of coarse debris flow material deposition followed immediately by fine-grained mudflow deposits, or mud drapes, is apparent in exposures after about 4500 years ^{14}C BP (5400 years (cal) BP). Fischer and Harvey (1990) investigating an alluvial fan in southern Utah found the same paired system of "coarse-fine couplets" of which the fine was interpreted as a mud drape generated by shallow flow depths. Their coarse layer was sand size, however, as they did not recognize the same pattern in more proximal portions of the fan where debris flow and sheetfloods dominate. Their stratigraphic sections (Figure 4, p. 606) show the same couplets with cobbles/boulders as the coarse layer but were not noted as a "couplet".

Within Meyer's Canyon Narrows fan, soils often develop on fine-grained mudflow sediments, probably when alluvial fan activity shifted to other portions of the fan, only to be truncated or eroded completely by subsequent debris flow events when activity shifted back. Recurrence interval for flows which were sufficient in energy to truncate a previously deposited layer was 600 years for the period 5435 years (cal) BP to present. Because coarse layers used to calculate the recurrence interval may have been completely eroded, the recurrence interval estimate is a maximum and events may have occurred more frequently.

Prior to about 5400 BP (below four meters), thick sequences of fine-grained sediments were being deposited ("Fm" lithofacies, Figure C-2). No flow structures are evident; sheetflood deposits with high sediment:water ratio are suggested. The sediment:water ratio, along with availability of fine-grained sediments control the amount of sediment transported (Harvey 1989) and, ultimately, the amount of sediment deposited. Decreasing the sediment:water ratio while decreasing the amount of fine material can lead to traction flow of coarse material and the formation of bar and sheet structures (Wells and Harvey in Harvey, 1989). High energy flow was either nonexistent, or at other portions of the valley during this period. Another hypothesis is that this is the distal end of an early alluvial fan (from further up the valley); more recent sediments are the proximal and medial portions, or near-source, of valley fill fans. Since alluviation within Meyer's Canyon began approximately 10,000 years ago, and orogeny is unlikely in this area (J. Dilles, E. Taylor, OSU Department of Geology, personal communication, 1992), alluvial fans are probably in response to initial topography. The fine-grained deposits are classified as Fm due to the complete lack of flow structures; otherwise, they resemble Fl and Sp.

X4170 Interpretation: Exposure X4170 is strongly influenced by a high rate of deposition generated from mud drapes and debris flows from 4WD Tributary. Figure C-3 shows the lithofacies synopsis. This is the medial to distal end of a valley alluvial fan associated with this tributary which has a high sediment availability and transport capability. Fine-grained mud drapes follow the coarse-grained debris flows, which debris flows act as erosive agents. The high clay content enhances the strength of the soil structure and, probably to some extent, resistance to erosion. Fine material also increases the internal strength of the material so it can support larger clasts thus allowing debris flow movement by plastic flow to occur (Pierson 1981, in Harvey 1989). Hyperconcentrated mud and debris flows increase the transporting capacity of streams and alters streamflow mechanics (Krone and Bradley 1989). The addition of fines to water increases its bed material transport capacity (Glancy 1969) by reducing fall velocity of bed material grains (Krone and Bradley 1989).

The coarse-grained debris flows were only common after about 1200 years BP. It should be noted, however, that the upper portions of Exposure X4170 were in more proximal locations within the 4WD Tributary fan because of accessibility, thus the increase in proximal processes in near-surface location and more proximal location. After the Mazama eruption 6845 ± 50 yrs ^{14}C BP (7630 yrs (cal) BP) and before 1200 yrs BP, units were primarily depositional, composed mostly of sand to clay-sized material. Prior to the Mazama eruption, high energy channel flow transported and sorted cobble to sand-sized material to the main valley axis. Mud drape/debris flow couplets were replaced with channel deposits. This was probably a more distal portion of the fan early in its history.

X4678 Interpretation: These are fine-grained, distal valley fan and valley plain deposits with vegetative growth influenced by saturated field conditions. The high water table probably enhanced vegetative growth, which promoted deposition and limited erosion. Most of the coarse-grained sediments dropped upvalley of this site, likely due to waning flood energy as flows spread (Bull 1979) and from increasing vegetation resistance (Bailey 1935). Streamflow at this location apparently did not have sufficient energy to create erosional unconformities (the lines which separate certain units in Table B-4 are representative of periods which began with coarse-grained input rather than erosional unconformities as with upstream exposures). Fines are deposited frequently (e.g., annually) because vegetation slows flow and creates an optimal depositional environment. The sediments are dominated by numerous fine-grained, thin layers ("Fl" and "Fsc" lithofacies, Table C-3). Fischer and

Harvey (1990) also showed layers to be thinner and finer grained in distal fan locations, and more so beyond the toe of the fan. Exposure X4678 may be beyond true fan influence and may instead be more of an alluvial plain (Rust 1978), or secondary fan which occurs at the toe of a primary accumulation (Heward 1978) where sediments are better sorted and finer grained.

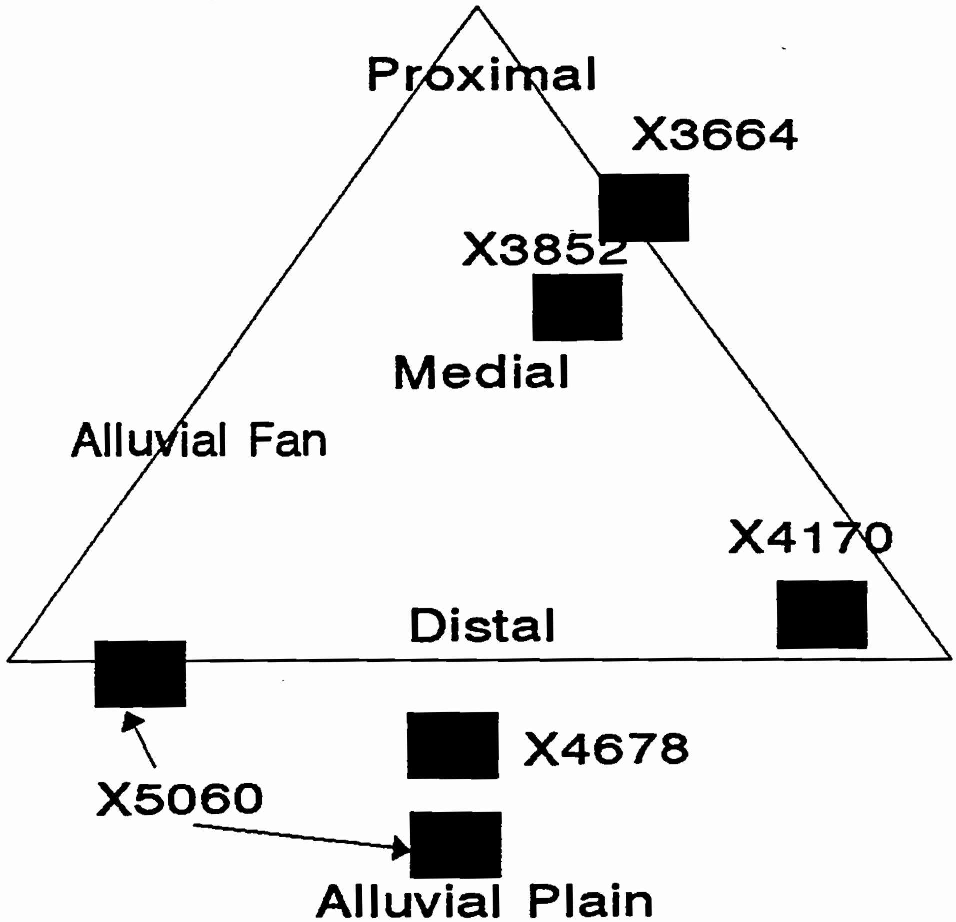
Just above the Mazama ash deposit are significant coarse-grained channel deposits which are not evident in upstream locations. Sequences near fan toes can be "inverted", or coarser deposits are located within lower portions of the exposure than upfan locations because coarse material from the source area has been redistributed (Heward 1983). High energy flow coincident or shortly following the Mazama eruption could have redistributed large material from upstream locations.

X5060 Interpretation: This portion of the valley fill has a lack of sediment accumulation above the ash, compared to other valley fill exposures. This is either due to effective storage at upstream locations, or very effective transport at this location. This portion of the valley fill appears to have been subjected to numerous channel erosion events after the eruption of Mt. Mazama as seen by numerous paleochannels identified above the ash layer. Deposits above the ash layer are derived from adjacent north-wall tributaries. Following the eruption, mudflows and debris flows from adjacent small tributary fans dominate the deposits. Prior to the Mazama ash deposition, character of deposits indicate sediments were derived from upstream locations and the site acted as an alluvial plain, with the earliest deposits being channel and lag deposits. Water and sediment must proceed through a narrow pass between bedrock ridges at this location. Flow was probably concentrated here and more of a channelized valley system was maintained than at upstream, unconfined reaches. Additionally, effective sediment storage upstream may have changed the sediment:water ratio, favoring channelization (transport) rather than deposition.

Bryan (1928a) notes more stable channel locations where large tributaries enter, or where the valley floor narrows. Bailey (1935) also found previous epicycles of erosion to be concentrated at narrow parts of the valley or where tributaries which drain steep country enter. Where ephemeral channels are near the water table (as is the case upstream a short distance) flow can occur in direct response to rainfall (Bull 1964). Bull (1979) showed downcutting reaches have stream width equal to canyon width which is possible at the narrow section of the Lower Valley fill at high discharge.

Figure 20 shows the exposures in relation to position within and adjacent to an alluvial fan. The difference in the character of the sediments between exposures is largely dependent upon distance from the source of the material, sorting by fluvial action, vegetation within the alluvial plain which enhances deposition, and valley width in relation to channel width. Alluvial fans are effective sediment storage features; as flows spread over the valley floor, sediment is deposited. Vegetation enhanced by perennial groundwater source enhances further deposition of fine grained material. Downstream, transport is perhaps favored where valley floor width approaches channel width and sediment:water ratio declines. Exposure X5060 is shown at two locations within Figure 20 because it seems to have been influenced by channel and sorting action prior to the Mazama eruption, and by alluvial fan processes following the eruption.

<u>Longitudinal Profile</u>: Figure 21 shows the longitudinal profile of the lower valley sediments and current incision thalweg. Thalweg slope is fairly consistent at an average of 4.3% overall. A maximum



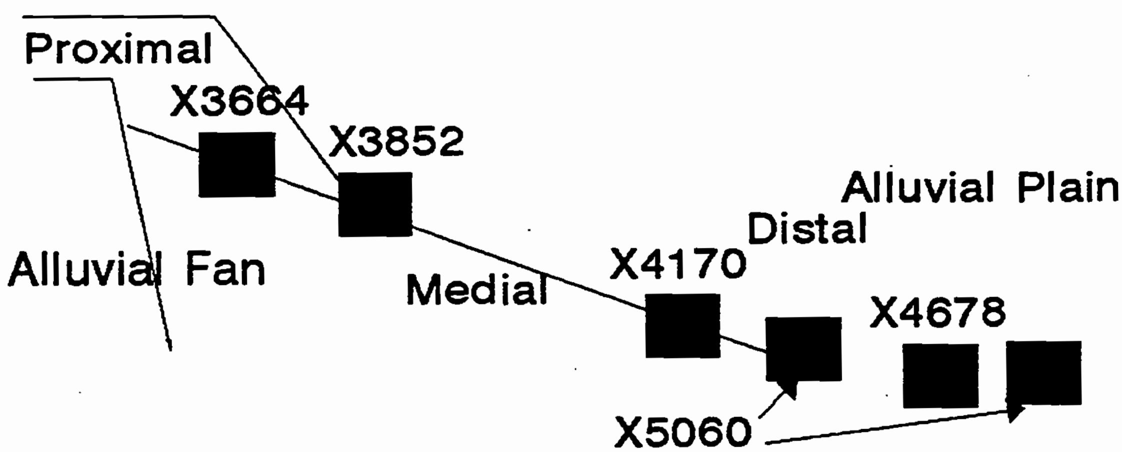


Figure 20. Exposure locations in relation to alluvial fan, planear map (A) and cross section (B).

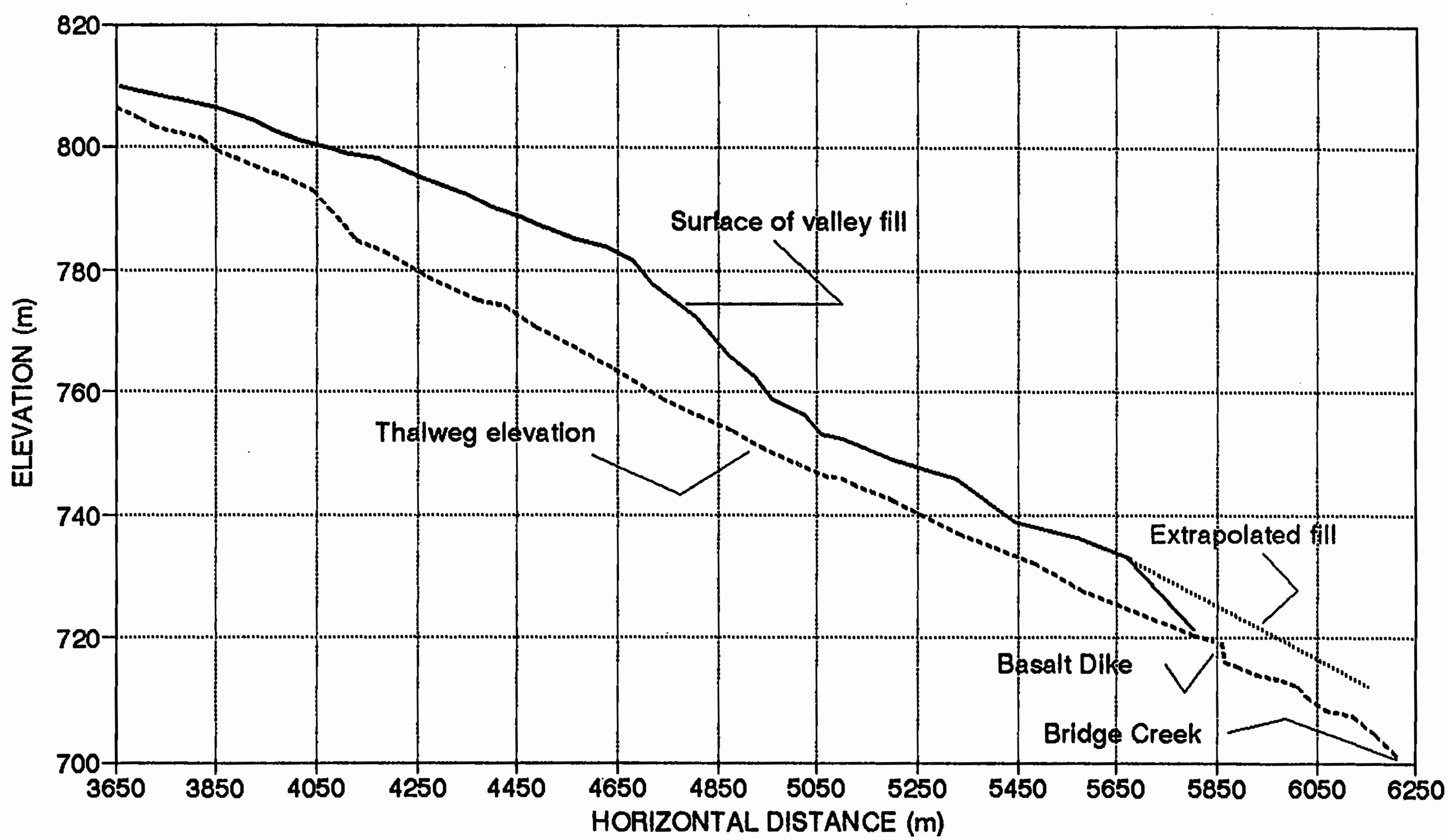


Figure 21. Meyer's Canyon Lower Valley fill profile with base level influences of basalt dike and Bridge Creek.

slope of 10% occurs near HD 4060 where the incision hugs a bedrock ridge near the valley sidewalls and bedrock is exposed. Melton (1965) showed deposited sediment from a tributary fan (e.g., 4WD Tributary fan) can increase transverse gradient of a valley floor (e.g., Meyer's Canyon main valley floor axis) which serves to concentrate flow along the longitudinal axis.

The distinct break just after HD 5860 m is the basalt dike exposed, at which the valley fill essentially stops (Figure 21). Clues which may have led to hypotheses about where and how the fill was removed below this point, or what the junction of Meyer's Canyon stream with Bridge Creek may have looked like, have been removed by road construction of the Bridge Creek road and access road into Meyer's Canyon. Aerial photos show both roads were constructed prior to 1951 (Figure 11, page 35).

Slopes of the valley fill surface have discontinuities not evident in the thalweg slopes. Figure 21 shows the thalweg slopes are much higher nearer the source of the sediment derived from Upper Drainage or 4WD Tributary, and where bedrock influences the channel directly. Fill slopes are steep (up to 17%) between HD 4800 and 5050 m. Table 2 shows the slopes for the valley fill taken from data used to develop Figure 21. If the slope of the valley fill above HD 4700 m were to be extrapolated at the same angle to Bridge Creek, it would be 40 meters above the current Bridge Creek. The slope discontinuity of the valley fill surface below HD 4700 m could be a result of:

a) Throughgoing bedrock discontinuities sloping to the northwest could influence groundwater (E. Taylor, OSU Department of Geology, Corvallis, Oregon, personal communication, 1993). It is obvious from the gleyed sediments that water was very close to the surface up until the time of incision. This near-surface groundwater may have created

Table 2. Average slopes for certain sections of Lower Valley fill, Meyer's Canyon.

Section	Average Slope (%)
HD 3664 - 4170 m	2.7
HD 4170 - 4678 m	3.3
HD 4678 - 4850 m	7.7
HD 4850 - 5050 m	9.7
HD 5050 m - end	3.0

saturated conditions, which enhances vegetative growth, especially of phreatophytes, or plants which derive water from ground water rather than rainfall. Enhanced vegetative growth may have created a higher rate of deposition that extended upvalley. This effect was seen in the summer of 1993 when convectional storm activity created incision and reworking of deposits from HD 4170. Coarse deposits were transported to HD 4550 m where thick marsh vegetation inhibited transport due to increased roughness, and coarse-grained material was deposited in a matrix of fine silt and mud.

b) The survey of the valley fill surface shows that downstream of approximately HD 4850, other short, steep sections of valley fill occur. Paleosols intersect the ground surface and there is surface evidence for recent (i.e., the last 100 years) small tributary headcuts from the incision wall into valley fill sediments. These features may be small tributary headcuts, or previous valley floor depressions prior to incision. While the Mazama ash and paleosols generally parallel the valley fill slope (Figure 22), recent surface channels are evident and depositional layers are truncated.

The valley fill slope decreases over time above HD 4678 m, and increases over time below HD 4678 m. The changes in slope over time are shown in Figure 23 where slopes of the current incision thalweg are compared to the slope of the base of the Mazama ash, longitudinally continuous paleosols, and the current valley fill surface. An increase in slope over time suggests the transportation slope is increasing over time below HD 4678 m, and decreasing above, which indicates effective storage upstream, and potential threshold exceedance downstream by an increase in stream power from increasing slope.

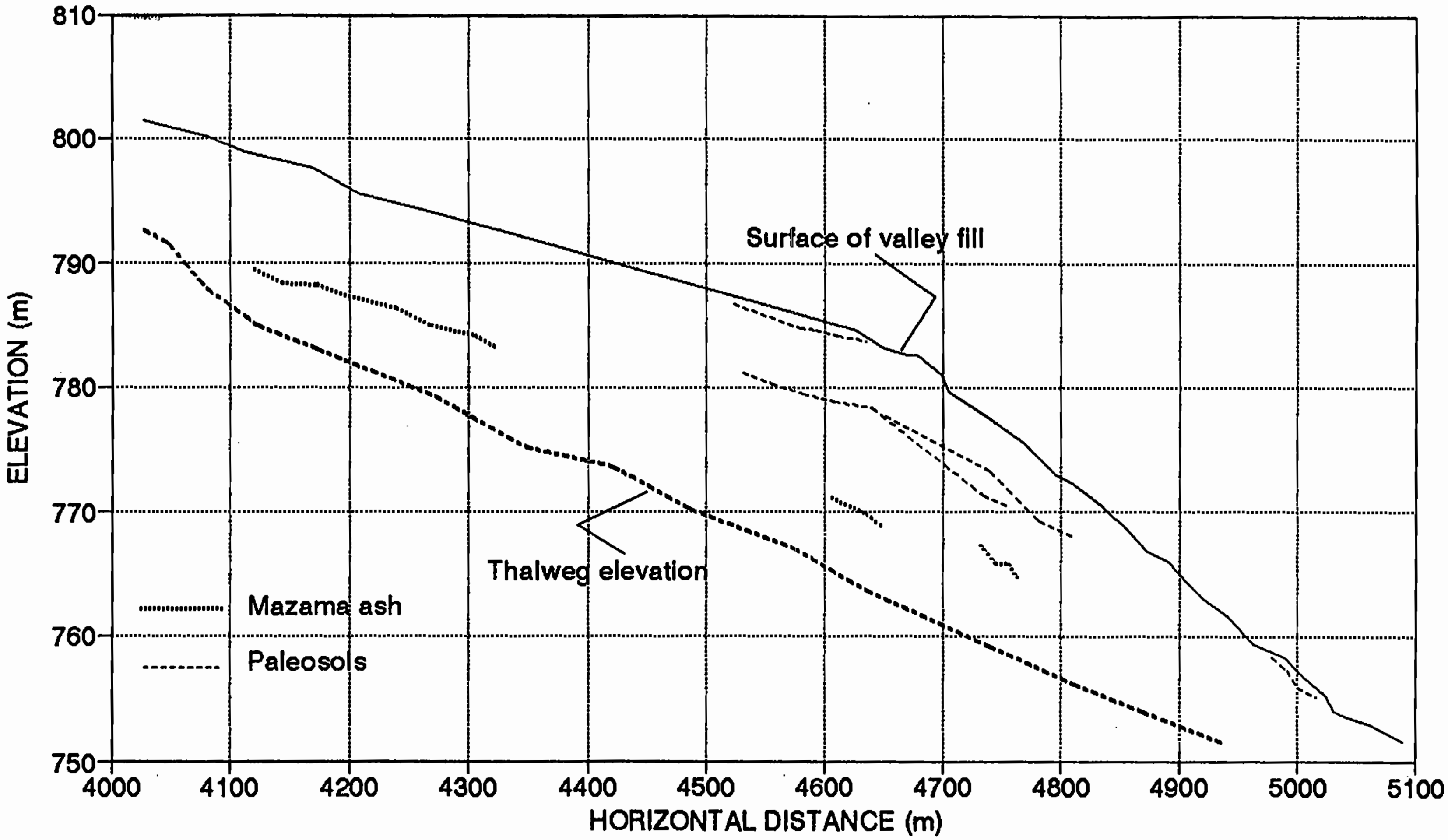


Figure 22. Longitudinal profiles of surface, Mazama ash, and paleosols exposed within Meyer's Canyon Lower Valley fill (from EDM data).

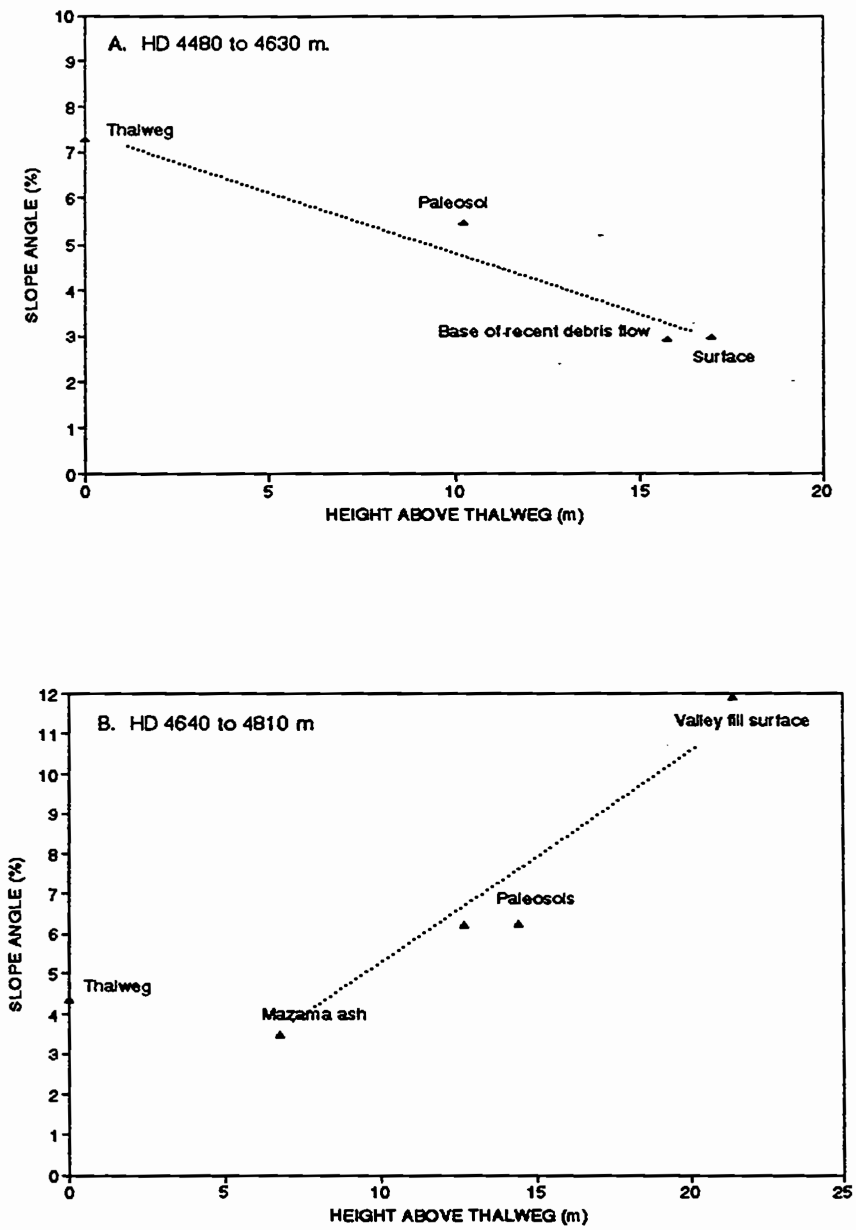


Figure 23. Comparison of slopes of thalweg, Mazama ash, two paleosols, and Lower Valley fill surface in Meyer's Canyon, HD 4480 to HD 4630 m (A) and HD 4640 to HD 4810 m (B).

Patton and Schumm (Fig. 2, p. 89; 1973) established a relation between valley slope and drainage area for Piceance Creek basin in Colorado. A threshold of valley slope (tangent) to drainage area ratio was determined above which all valley fills were incised. Figure 24 is a reproduction of the threshold line, with data points from Meyer's Canyon. Though this threshold was empirically derived for one basin, it is interesting to note that each location measured in this study falls above the line except X3664, which is the beginning of the Lower Valley incision. Basically, as valley floor slope increases, valley floor instability increases (Patton and Schumm 1973). To validate the threshold, this sort of study should be conducted for the semiarid Pacific Northwest. In Meyer's Canyon as slopes increase, valley floor instability may be inherent and the causes for valley floor steepness may not be obvious. Patton and Schumm's (1973) threshold may be shifted by vegetation because of the rooting characteristics and above-ground roughness provided by sedge/rush species. If the vegetation is removed or dies, or channelization occurs below the root zone, failure or incision is likely. In fact, Patton and Schumm (1973) state the statistical significance of their threshold relation falls apart in small drainages with significant vegetation influence.

Sorted channel deposits occur on an exposed cutbank of the Bridge Creek Road at the mouth of Meyer's Canyon. There is some evidence that Bridge Creek high water mark was as much as 11 m above its current channel, probably within the last century. Rounded cobbles formed an EUC over fine deposits, which deposits appear to be controlled by a downstream narrowing of bedrock on Bridge Creek, essentially a back-water effect. The back-water effect could be from a high flow or sediment plug from Meyer's Canyon. Across Bridge Creek is a linear feature at the same elevation as the base of the rounded cobbles, below which fine colluvium has been scoured from the

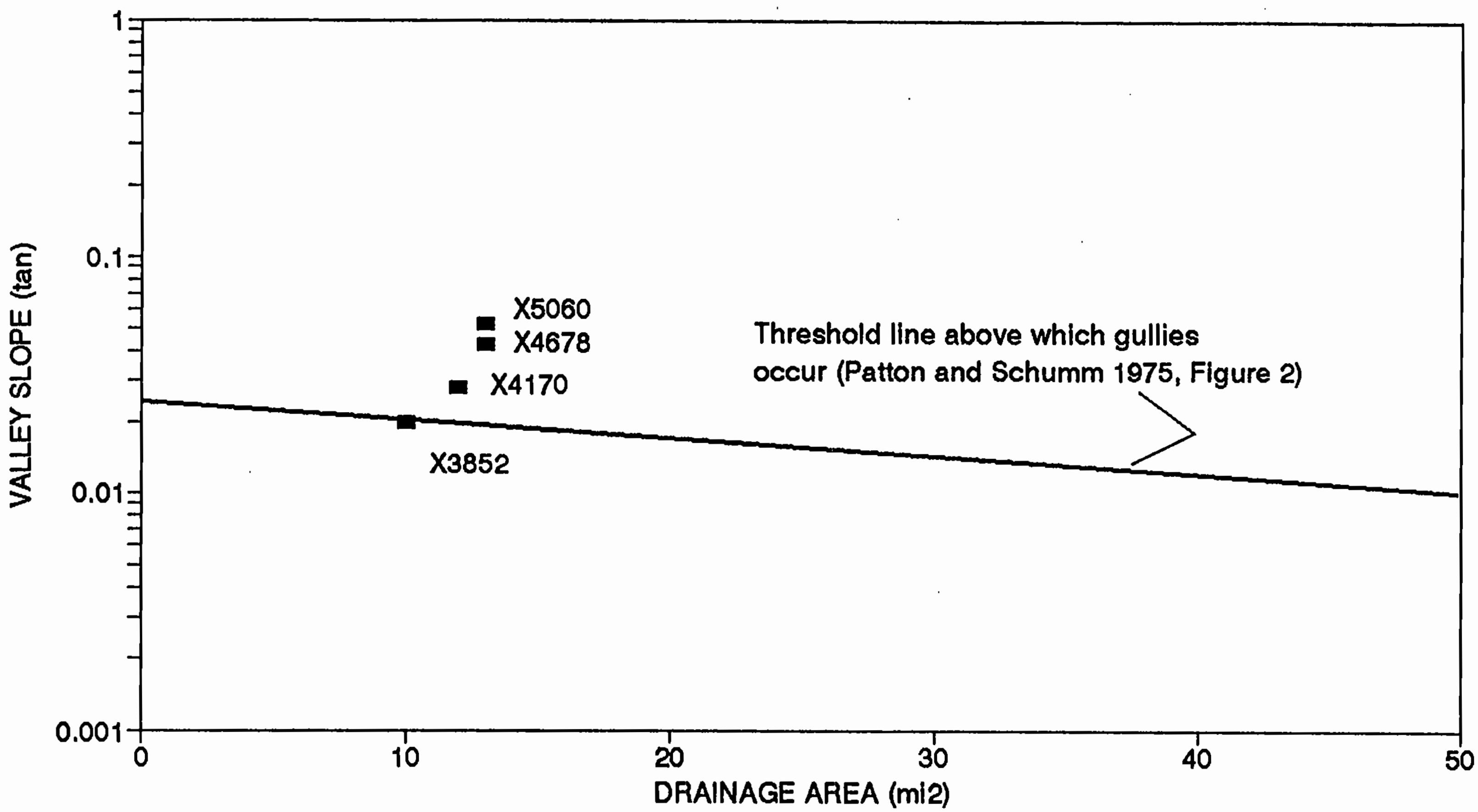


Figure 24. Tangent (tan) of valley slope versus drainage area (mi^2) in Lower Valley fill of Meyer's Canyon for Exposures X3852, X4170, X4678, and X5060. Area is cumulative; threshold line is derived from Piceance Creek, Colorado, data (Patton and Schumm 1975).

slopes. This scour/deposition may have occurred during the floods of the late 1800's when a "wall of water" was reported to have flowed through Bridge Creek (Stinchfield 1983). Several unpaired terraces occur at various locations along Bridge Creek. Meyer's Canyon does not exhibit terrace features, indicating a different fluvial history. Extrapolated fill from the end of Meyer's Canyon fill to the base of the coarse cobbles deposited 11 m above the current Bridge Creek showed a reasonably consistent slope (Figure 21).

<u>Paleochannels</u>: The uniqueness of the current incision is under investigation. The paleochannels preserved in the sediments could indicate previous cut-and-fill cycles. Several paleochannels (PC's) were found within the exposed valley fill sediments. Characteristics of paleochannels are described and reproduced in Table 3. Paleochannels are placed within the context of the valley fill profile on Figure 25. The paleochannel sketches represent <u>exposed</u> channels, not necessarily a cross section as the current incision may have cut the paleochannel obliquely. Not all the observed channels within the exposed fill are measured or noted because of their small sizes. In addition to PC3774 and PC3800 near the surface, there are small channels filled with coarse material above X3852 within the braided stream/medial portion of the Narrows fan section. Opposite the mouth of 4WD Tributary at HD 4186 m, PC4186 is 23 m wide and 3 m deep filled with sorted channel gravels (classified as Gm) and is concurrent with the valley fill surface.

Downstream of HD 4186 m, paleochannels PC4428, PC4563, PC4810, and PC5078 are larger and sediments which filled the channels were sediments derived from the layer just above the Mazama ash layer. Stratigraphic position of these paleochannels exposed in the middle and lower portion of the Lower Valley Fill suggests that they are the same channel, and occurred coincident with the Mazama eruption. This

Table 3. Dimensions and locations of paleochannels (PCs).

PC I.D. #	Location H.D.* (m)	Width (m)	Elev. (surface) (m)	Depth in fill (m)	Elev. (PC) (m)	Depth (PC) (m)	Elev. (PC thalweg) (m)	Elev. (incision thalweg) (m)
PC3774	3774	10.5	807	0.0	807	1.5	806	802
PC3800	3800	13.8	807	0.0	807	1.7	805	802
PC4186	4186	22.9	798	0.0	798	3.1	795	783
PC4428	4428	33.9	790	8.4	782	4.8	777	772
PC4586	4563	42.1	785	8.6	776	5.0	771	767
PC4810	4810	9.4	772	12.0	760	3.9	756	753
PC5016	5016	24.0	754	3.0	751	0.7	750	747
PC5017	5017	10.1	754	1.5	753	--	--	747
PC5063	5063	29.8	752	3.2	749	1.9	747	746
PC5078	5078	75.4	752	3.0	749	3.9	745	745

* H.D. = Horizontal distance

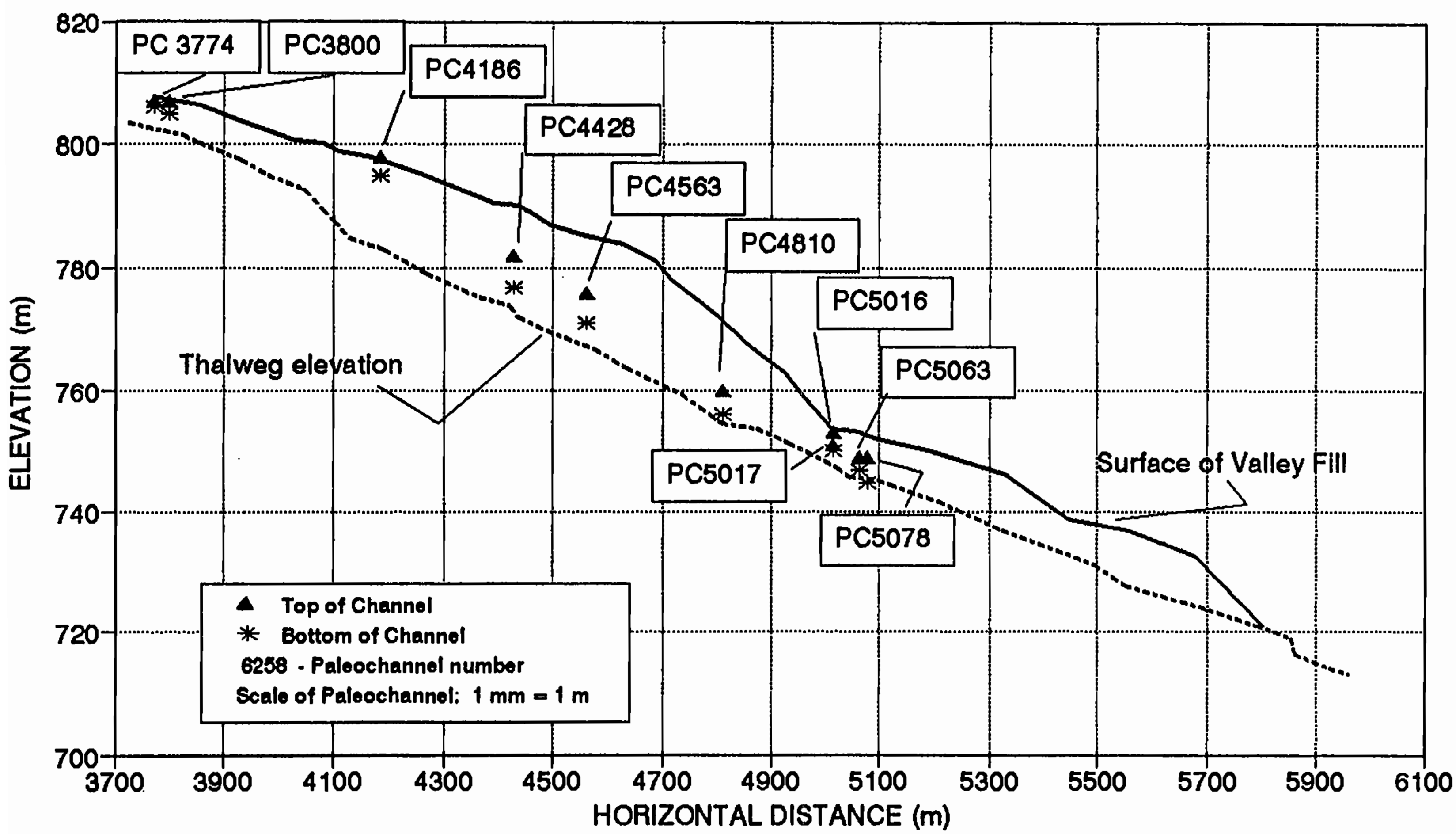


Figure 25. Location, width, and depth of paleochannels within the Lower Valley fill of Meyer's Canyon.

channel may have been almost as longitudinally continuous as the current incision, though not as deep. Only in PC5078 does the thalweg of the paleochannel occupy the same location as the current incision thalweg. The thalwegs of PC4186, PC4488, and PC4810 are three to five meters above the current incision thalweg. The base of PC4563 is ambiguous because it is inserted into sorted gravels very similar to that material which fills the channel. A ^{14}C sample taken near the base at about three meters above the current incision, however, indicates that these sediments were deposited 8080 ± 70 yrs ^{14}C BP (8935 yrs (cal) BP), well before the Mazama climactic eruption 6845 ± 50 yrs ^{14}C BP (7630 ± 80 yrs (cal) BP). Since the edge of PC4563 truncate the Mazama ash, this paleochannel has been inserted into these older sediments. The lack of terraces within the valley suggests that no higher stages of valley filling have occurred (Bailey 1935).

PC5016, PC5017, and PC5063 are the most evident paleochannels clustered about HD 5000 m. A paleosol exists at the upstream edge of PC5063, which indicates the channel bank was in place long enough to have organic matter incorporation and soil development prior to subsequent channel filling. The bases of PC5063 and PC5016 are inserted into older sediments similar in character to X5060-4 through 18. It is difficult to tell whether these paleochannels actually truncate the ash and are related to the paleoincision indicated by PC4428, PC4563, PC4810, and PC5078. Other smaller paleochannels near the valley fill surface were noted at HD 5000 m, but not documented.

<u>Paleochannel Summary and Interpretation</u>: The minor paleochannels above HD 4170 m represent portions of the braided distributary channels common in this portion of the fill. PC4186 at the fill surface is a channel derived from within the 4WD Tributary

fan. The 4WD Tributary fan appears to be regularly entrenched under current conditions. Entrenchment of fans is important in the redistribution of material on a fan surface (Buwalda 1951). Toward the distal end of the fans, a drop in sediment load by deposition in the proximal and medial portions of the fan can create conditions favorable for temporary channel incision (Bull 1977). The current headcut migration began after 1979 and therefore has been moving upvalley at approximately 8 m/year.

The incision that apparently occurred near the time of the Mazama eruption, as indicated by PC4428, PC4563 PC4810, and PC5078, has significant implications in the analysis of causal mechanisms for the current incision. The Mazama ash was actually erupted over a 3 - 100 year period (Sarna-Wojcicki et al. 1983) but the date used herein is the date attributed to the climactic eruption 6845 ± 50 yrs ^{14}C BP.

The paleoincision implied by the paleochannels preserved in the valley fill sediments in Meyer's Canyon may be time-correlative with a large paleochannel found in Camp Creek, a drainage to the south, a tributary to the Crooked River in the Deschutes basin (Welcher 1993). Welcher (1993) dated the soil which developed upon the surface of the material filling the paleochannel which truncated the ash about 3300 yrs BP. It is possible that the incision was coincident with the Mazama eruption, but further erosive or depositional action did not occur for another 3300 years. It is also possible for sediment to have filled the channel over most of the period, and evidence to separate layers over the 3300 year period, such as soil development or erosion, were not noted.

Lidstrom (1972) provides an isopach map of Mazama ash depths. Based on this map, as much as 30 cm of ash covered the valley slopes in Meyer's Canyon, 246 km away from Mt. Mazama. Both Cressman and Mehringer in Miller (in press) stated eastern Oregon landscape lay buried following both the eruption of Mt. Mazama and Newberry Crater (about 2000 years BP). Within the valley fill sediments of Meyer's Canyon, Mazama ash is 40 to 60 cm thick; reworking and accumulation of upland ash deposits in valley fill deposits is to be expected (Lidstrom 1972). This much ash covering the slopes would have significant hydrologic and ecologic implications within the drainage, in addition to regional and global climatic effects:

1) Accelerated runoff and erosion may result from decreased permeability due to surface crust on deposited ash, and ash-charged runoff may increase stream competence (Malde 1964). Ash can potentially decrease infiltration rates by one-fifth to one-tenth that of undisturbed forest sites (Leavesley et al. 1989). Infiltration into 3-30 cm deep undisturbed ash cover from Mt. St. Helens ash fall averaged less than 2-10 mm/hr, when rainfall intensity was 6.6 to 9.4 mm/hr (Fiksdal 1981).

2) Vegetation damage may occur through smothering, mechanical overloading and chemical attack (Malde 1964) such as acid rain (Bedwell 1973) from volcanic fumes which may increase the acidity of the atmosphere.

3) Fine textured ash can lower surface soil temperatures. Cooler soils may slow plant transpiration. This can decrease effective precipitation (or moisture used by plants) and increase runoff (Gardner, in Mack 1981). Cooler soils also reduce evaporative loss of moisture.

4) LaMarche et al. (1984) suggest that climate change from stratospheric veil of ash and aerosols with 2-3 year decay

period may have led to widespread surface cooling with the following three responses ("Krakatoa effect"):

a. circulation response - increased intensity of upper level trough over western North America in January. Mehringer and Blinman (in Kittleman 1979) estimate that the climactic eruption began in the fall and lasted three years with nearly two thirds in the first five months. Often large floods are clustered in time and associated with large scale, upper atmosphere regimes of weak westerly circulation and meridional regime prevails. Therefore, this leads to polar air mass at a low latitude and tropical air mass in high latitudes leading to intense cyclones and storms in mid latitudes and thus more frequent and more intense flooding (Knox 1983).

b. July weather resembles May.

c. Increased frequency of extreme and unusual weather situations.

LaMarche et al. (1984) based their analysis of this so-called "Krakatoa effect" (Mazama put out three to four times the volume of ash than Krakatoa) on the increase in occurrence of frost rings less than two years after volcanic eruptions.

According to pollen records, conditions at the time of the Mazama eruption were similar to historical conditions, though perhaps slightly wetter and cooler (Sarna-Wojcicki et al. 1983), though most authors consider the period as more arid (e.g., Bedwell 1973). It is unknown whether this is a limited or worldwide climatic response to the Mazama eruption, though short-term climatic variations and neoglacial advances coincide with increases in volcanic activity. Bailey (1935) suggests previous epicycles of erosion within the Colorado Plateau were a result of short-term variations in climate, rather than a gradual climatic change.

The relevance of the Mazama eruption for Meyer's Canyon is that the changes in runoff characteristics and short-term climate change believed to have occurred in response to ashfall on the drainage and to ash in the atmosphere created an incision perhaps similar in characteristics to the present incision. Incisions can occur from different initial conditions and along different pathways but the incisions in Meyer's Canyon may be in response to similar triggering mechanisms. Similarities are due to the potential loss of riparian vegetation due to human influence rather than mortality due to ashfall and overgrazing on the hillslopes which may change runoff characteristics rather than ashfall which may decrease infiltration. These changes are combined with intense convectional storm activity to provide the energy for erosion. The storm activity is not unusual, but the response within the watershed has changed.

<u>Volume Rates of Sediment Accumulation</u>: Sediment accumulation rates may change over the course of the Holocene in response to climate change or merely due to the geometry of the fill. To calculate rates of accumulation, several samples of charcoal taken from various locations in the valley fill were dated using Carbon-14 methodology. The age of these samples and their location within the fill provide the means with which to calculate volume rates of accumulation by using simple geometric calculations (e.g., Figure 10). The Mazama ash layer was longitudinally continuous thus allowing comparison between sites. Table 4 lists the sample

Table 4. Carbon-14 (^{14}C) and calibrated dates of samples from Meyer's Canyon Lower Valley fill.

Sample No.	Depth (m)	Location (H.D.) (m)	Carbon-14 Age (yrs ^{14}C BP)	Calibrated Age* yrs (cal) BP	Midpoint yrs (cal) BP	Confidence Interval yrs (cal) BP
$^{14}C3852$	4	3852	4680 ± 60	5435 ± 145	5435	5290-5580
$^{14}C4170$	2	4170	1300 ± 90	1170 ± 180	1170	990-1350
$^{14}C4260$	12	4260	7810 ± 70	8690 ± 225	8690	8440-8940
$^{14}C4563$	15	4563	8080 ± 70	8935 ± 275	8635	8660-9210
$^{14}C4678$	6	4678	5430 ± 60	6175 ± 135	6175	6040-6310
$^{14}C4678-2$	15	4678	7900 ± 70	8720 ± 260	8720	8460-8960
Mazama	var.**	var.***	6845 ± 50	7630 ± 80	7630	7550-7710

* Using software developed by Stuvier and Reimer (1993).
** 2 - 12 m
*** At various locations within fill sediments.

location, ^{14}C age, and calibrated age. Figure 26 shows that vertical accumulation rates are decreasing over time. This is not surprising because non-glaciated valleys often form a "V" shape and vertical rates of accumulation within a profile are misleading. Less area is initially available for the same amount of sediment, leading to an increased depth though not necessarily a greater volumetric rate of accumulation. A channel (or V-notch) must fill before sediment can spread over the entire valley floor, therefore valley filling (as opposed to channel filling) takes considerably more time (Schumm 1993). The outlier at HD 5060 m is based on the depth of the Mazama ash layer. There is little accumulation over the ash at this location compared to other locations, most likely due to effective transport at this location as seen by numerous paleochannels which removed material, or by increasing effective storage at upstream locations.

Table 5 shows the volume rate of sediment accumulation before and after the Mazama eruption. It is believed the influence of 4WD Tributary resulted in the highest rate of sedimentation between Exposure X3852 and X4170, with a higher input rate after the Mazama eruption. This higher rate may be a result of the increased number of thick debris flows above the ash layer as noted in the discussion of Exposure X4170. The lowest volume rate of accumulation was below X5060 for the same reason as stated for vertical rate of accumulation.

Figure 27 shows the cumulative volume of sediment for each exposure, with slope representing rate. The estimated beginning of the aggrading period is 10,000 years. The absolute numbers are less important than the rates, which is the slope of the lines. CS4210 and CS4678 have the same rate after about 3800 years; their physical location is close, and because the valley is widest between these two

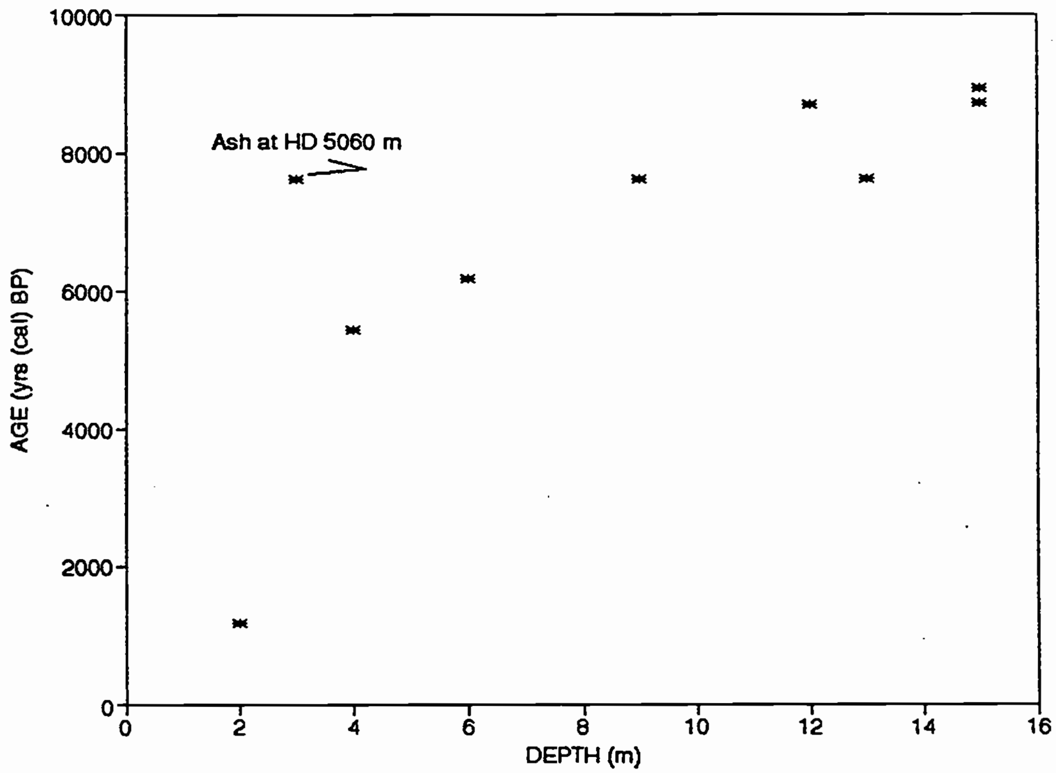


Figure 26. Vertical accumulation of sediments based on calibrated carbon-14 ages of charcoal samples and depth within Lower Valley fill of Meyer's Canyon.

Table 5. Volume rate of sediment accumulation and estimates of incision volume within Meyer's Canyon Lower Valley fill.

Cross Section	Location H.D. (m)	Volume Fill 1000 m^3	Rate of Accumulation - Volume		
			Total (m^3/yr)	Pre-Mazama (m^3/yr)	Post-Mazama (m^3/yr)
Beginning	3375	0			
		1164	120		120
CS3852	3852				
		2940	290	140	208
CS4170	4170				
		2132	210	260	210
CS4260	4260				
		2111	170	260	150
CS4678	4678				
		1685	170	290	130
CS5060	5060				
		765	80	210	40
End	5701				
TOTAL		10797			

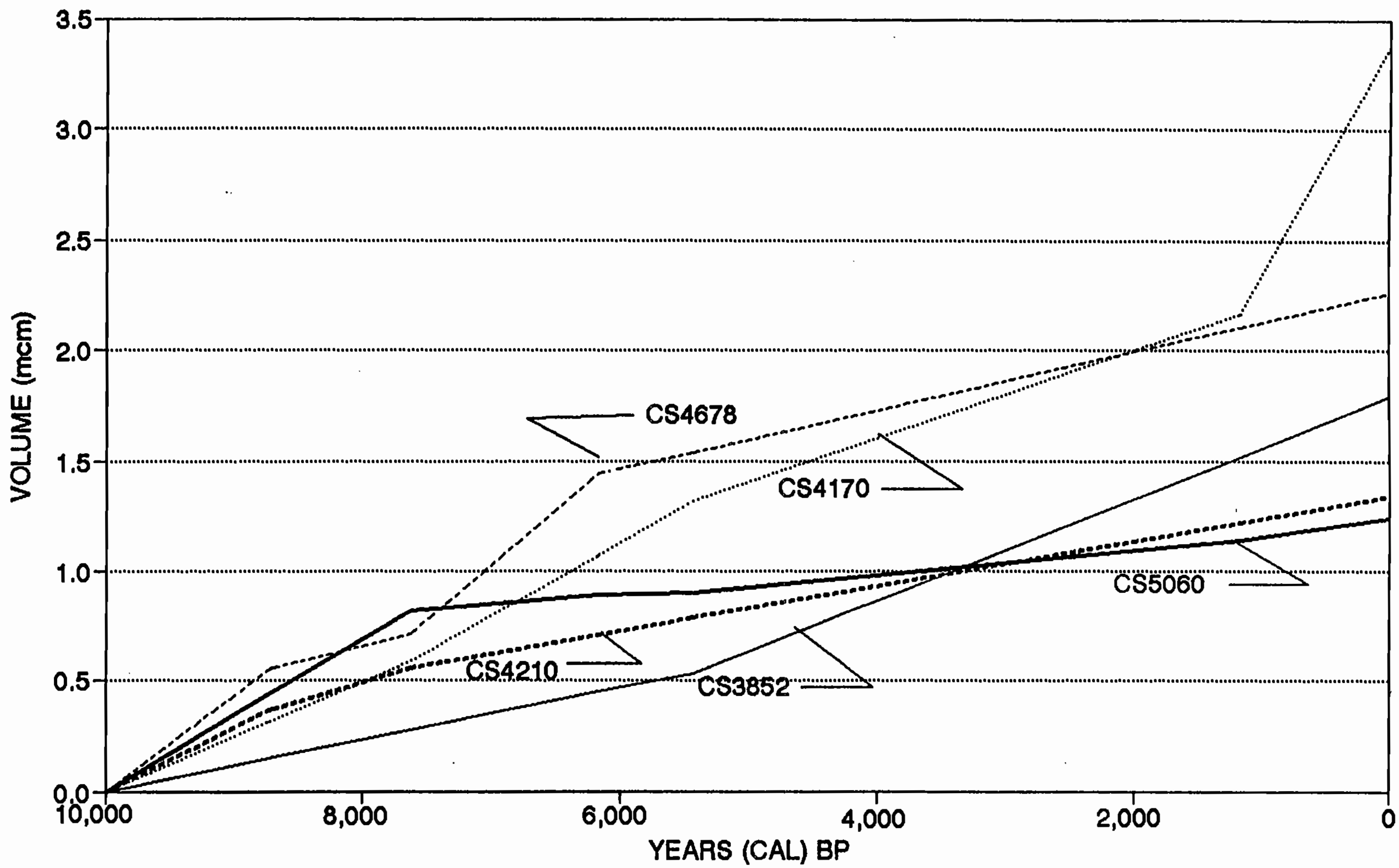


Figure 27. Estimated volume rate of sediment accumulation (million cubic meters) using five cross sections within Meyer's Canyon Lower Valley fill.

points, these rates should be fairly consistent. Before 3800 yrs BP, fill was shallow and individual fans could influence various portions of the fill separately. CS4170 had a very high rate of input after about 8500 years of filling as a result of large inputs from the debris flows in 4WD Tributary. At CS3852, the rate of input increased after 4500 years and this higher rate may also be due to increased debris flow activity. Both CS3852 and CS4170 are in more proximal locations and as such would be more affected by a recent increase in aggradation. One would expect sediments from debris flows (e.g., at proximal locations) to move to downstream locations (distal location) gradually, thus more steady state and gradual input at downstream locations, as shown by accumulation rates at CS4210, CS4678 and CS5060. The increase in debris flow sediments in X4170 and X3852, and the increase in rates of accumulation in CS4170 and CS3852 are evidence to suggest that Meyer's Canyon may be in a period of aggradation. This is consistent with Emmett (1974) who suggests that the region encompassed by the Vigil Network sites from Montana to New Mexico is in a period of aggradation, and by Gellis et al. (1991) in the Colorado Plateau. Emmett (1974) indicates the aggradation phase late in the Holocene is confounded by a current period of incision which may not be climatically related.

Recurrence Intervals: Using the Mazama ash layer within the Lower Valley fill as a time-stratigraphic marker layer, it is possible to evaluate changes in recurrence intervals over time. Pre-Mazama is the period from 10,000 years BP to 7630 yrs (cal) BP; Post-Mazama is the period from 7630 yrs (cal) BP to present. The Mazama ash layer is the only "date" available at more than one site and is used to compare between sites.

Table 6 shows that pre-Mazama, events were less frequent as one moves downstream to more distal fan locations, and to more of an

Table 6. Recurrence intervals of coarse deposits or mudflows within the sediments of the Lower Valley Fill of Meyer's Canyon.

Exposure X3852:

Interval (Yrs (cal) BP)	Events	Rec.Int.
5435 - present	9	600

Exposure X4170:

Interval	Events	Rec.Int.
Pre-Mazama	5	470
Mazama-1170	6	1080
1170-present	5	470
Post-Mazama	11	690

Exposure X4678:

Interval	Events	Rec.Int.
10000-8720	2	640
8720-7630	1	1090
7630-6175	5	290
6175-present	3	2060
Pre-Mazama	3	790
Post-Mazama	8	950

Exposure X5060:

Interval	Events	Rec.Int.
Pre-Mazama	5	470
Post-Mazama	2	3820

Recurrence Interval, All Exposures, Pre and Post-Mazama:

	X3852	X4170	X4678	X5060
Pre-Mazama	--	470	790	470
Post-Mazama	600	690	950	3820

alluvial plain. Once the more narrow portion of the valley is encountered at X5060, the recurrence intervals match that of the more proximal fan location at X4170. Post-Mazama events were most frequent in the two proximal fan locations, X3852 and X4170, but these events decreased in frequency in a downvalley direction to X5060. The long recurrence interval post-Mazama at X5060 may be due to lack of input, but may also be due to erosion having removed the evidence. Exposure X4170 also shows a long recurrence interval post-Mazama, when thick sequences of fine-grained deposition occurred.

Exposure X4678 had both the shortest and longest recurrence interval. The approximately 1500 years following the Mazama eruption had five coarse-grained events, and then only three for the next 6200 years. This coarse-grained debris is believed to have been added due to erosion of upstream alluvial fan sediments, essentially a complex response. The dating (^{14}C and ash) resolution was the best at this site with three available dates. Therefore, the number of events following the Mazama eruption can be quantified. The other exposures suffer from averaging over much longer periods, though it is evident that recurrence intervals were much longer following the Mazama eruption. Proximal locations (X4170 and X3852) mark a decrease in recurrence interval length after about 1200 yrs BP, with frequent debris flow and coarse debris input. These recurrence intervals show changes of coarse debris input based on location within a watershed, essentially downstream fining. However, there are exceptions due to complex response, sediment storage and fill erosion. The intervals also indicate large events capable of transporting coarse debris do not always result in incision.

Possible Causes of Incision

Possible hypotheses for stream incision initiation include: complex response, base level response, alluvial fan dynamics, and channel perturbation effects.

Geomorphic threshold exceedance: The valley fill surface between HD 4879 m and 4953 m have slopes as much as 16-17% and have been increasing over time. These slopes exceed any other alluvial slopes within this valley. They could have been created and maintained by the dense vegetation encouraged by the high water table set up by perennial groundwater. However, once that vegetation was removed, stream power may have been sufficient to locally remove fine grained sediments and initiate channel downcutting. Mazama ash deposition in Meyer's Canyon may have led to increased runoff and less resistance to erosion. The current watershed conditions may be producing similar results. Several authors indicate that intensive grazing on watershed slopes leads to increased runoff (e.g., Bailey 1935, Chaney 1990), and grazing in riparian areas reduces stream resistance (e.g., Cooke and Reeves 1976, Graf 1979). However, no data is available for changes in vegetation in Meyer's Canyon, either in the uplands or in the riparian area for the last 100 years.

Baselevel lowering: On Figure 21 (page 68), the extrapolated valley fill line shows the line between the last point measured on the valley fill slope to the coarse channel sediments deposited by Bridge Creek, probably early in this century, or late in the previous century. Bridge Creek experienced severe floods and "walls of water" during this period (Stinchfield 1983). These floods may have left a high water mark still visible today above Bridge Creek, and deposited coarse material 11 m above the current Bridge Creek stream course. The high water mark could of course be a backwater profile due to channel constriction. A survey shows where the fill would be if it was tied to this level of Bridge Creek. Baselevel lowering can rejuvenate a drainage network (Schumm 1993); if Bridge Creek had been incised, Meyer's Canyon may have responded by an adjustment in gradient through rapid headward cutting to match that of the new, lower baselevel set up by Bridge Creek. If the baselevel change had been large, incision would have been likely, especially if the change occurred rapidly. There would be lateral migration with small, gradual change (Schumm 1993). It is suspected, however, that the high water mark 11 m above the current channel was flood action and not a channel. Unpaired terraces on Bridge Creek suggest that Bridge Creek was at a higher elevation, probably within the Holocene (though these terraces have not been dated) but not during the last 100 years. Bridge Creek does show evidence of incision also, but usually where significant valley fill sediments occur, not in narrow canyons.

Alluvial fan dynamics: Meyer's Canyon may be in a current period of aggradation. However, entrenched streams are a natural feature of alluvial fans (Bull 1964). A recent, back-filled channel exists at the distal location of 4WD Tributary fan at the junction with the main Meyer's Canyon channel. It is unlikely that headwalls would migrate downstream (Montgomery, Center for Quaternary Research, University of Washington, Seattle, Washington, personal communication 1993), but concentrating flow by alluvial fan entrenchment could conceivably create downstream incision if the downstream system were already close to a geomorphic threshold due to removal of riparian vegetation. This same effect could occur if water were concentrated by roads, pack trails, or drainage ditches.

Channel perturbation effects: At about HD 5000 m, several paleochannels are evident. If channels existed here consistently in the past, the channel which existed prior to incision could have been widened or deepened (e.g., human enlargement, bank destruction by grazing or watering hoofed animals, increase in discharge, reduction in sediment availability) which could propagate upstream. Channelization concentrates floodwaters, thus increasing shear stress on channel material, incision ensues and propagates upstream, especially in cohesive sediments (Schumm 1993).

On balancing the evidence, it is believed that a complex response occurred below HD 4700 m due to changes in vegetation and possibly channelization. The incision is widest in this section; if width is used as a surrogate for length of time of exposure, it may indicate incision began here. This site is also next to Meyer's Ranch location making channelization to control saturation of the "front yard" likely.

Paleoclimate

The sediments stored within Meyer's Canyon date from the Pleistocene-Holocene transition period. Rapid aggradation with significant channel action marked the shift from cool/wet conditions to warmer/drier conditions, as suggested by Schumm (1993). Carbon-14 samples ^{14}C4678, ^{14}C4260, and ^{14}C4563 show that the sediments below the Mazama ash at 15, 15, and 12 m depth (respectively) represent the period prior to 8000 years BP (see Table 4). These sediments are characterized by fairly coarse deposits (sand and larger), with common sorting and flow structures.

After 8000 yrs BP to about 4500 yrs BP, aridity increased to maximum Holocene aridity. Aridity may be reflected in the rate of fine-grained sediment accumulation, and lack of soil development. The sediments show periods of rapid, fine-grained aggradation with numerous charcoal layers perhaps caused by increased watershed fire frequency, which may reflect increased summer drought.

The Mazama eruption (about 6900 yrs BP) coincided with a deep paleoincision; physical effects such as enhanced rapid runoff from slopes and short-term climatic effects could be implicated in affecting watershed conditions, perhaps leading to the paleoincision.

The period of 4500 yrs BP to about 1300 yrs BP exhibited the existence and structure of soils on the Narrows and 4WD Tributary fan deposits which indicate long periods of surface stability following deposition, without flow events of sufficient magnitude to completely remove previously existing layers/soils. The paleosol discovered within the Narrows fan (X3852-20 at 3.5 m depth, as dated by ^{14}C3852) corresponds to a soil-forming period at 4600 yrs BP (aka 2600 BC) reported by Mehringer (1986). Sample ^{14}C4678 (5430 yrs ^{14}C BP, 6175 yrs (cal) BP) marks the end of numerous charcoal layers and the beginning of numerous fluvents. The interpretation is an increase in high frequency, low magnitude events redistributed available sediment. Soil development was enhanced by favorable climate and vegetative interactions.

A period of more intense fluvial activity is indicated for the last 1300 years BP shown by increased coarse debris flow deposits within 4WD Tributary and the Narrows fan. Numerous debris flow events from 4WD Tributary and the Narrows fan, and recent paleochannels near HD 5060 m indicate that the increased effective precipitation suggested by Wigand in Welcher (1993) may have led to higher debris flow/fluvial activity, but also to greater soil development.

Keen's (1935) tree ring data indicate that the 1920'-40's represented the most severe period of drought within the last 650 years, though Graumlich (1987) indicates the most severe drought year occurred in 1889. The incision of Meyer's Canyon appears to have been initiated during the 1920's, but could be as early as the 1880's. One would expect incision to occur during the latter part of drought periods due to potential cumulative pressure on the riparian vegetation. Welcher (1993) found two incisions of Camp Creek, over the course of the Holocene, followed drought periods in conjunction with significant precipitation events. Not only would upland vegetation be affected by drought, thus changing runoff characteristics, lack of riparian vegetation through possible increased grazing pressure in ephemeral stream systems could initiate incision. Riparian vegetation increases shear strength of channel material and resistance to erosion, and encourages sediment deposition. Overall, vegetation species composition on valley floors would not change substantially with short-term climate variations such as drought, due to the subsurface water sources. Grazing and human influence most likely would work to reduce surface roughness (Cooke and Reeves 1976) and change valley floor interactions with stream discharges.

SUMMARY AND CONCLUSIONS

Incision

The current incision occurred within the early part of the 20th or late 19th century, and has removed approximately eleven percent of Lower Valley fill volume. It is not possible to state unequivocally where incision began but three locations are likely: 1) Medial to distal location of 4WD Tributary fan due to alluvial fan entrenchment, 2) Slopes exceeding 10% between HD 4700 and 5000 m due to vegetation removal, channelization, and/or grazing, or 3) HD 5017 m where existing channel could have been enlarged or perturbed by channelization. Exceedance of a geomorphic threshold on the oversteepened portion between HD 4700 and 5000 m is considered the most likely mechanism.

Deposition

The Meyer's Canyon valley fill is a series of coalescing alluvial fans which grade to an alluvial plain. Sediment availability is very high from well-weathered Tertiary and Cretaceous parent material in this semiarid region. The upper Lower Valley deposits (primarily sand and larger) are characterized by debris flow and braided distributary channel flow. The valley fill immediately below the Narrows is considered alluvial fan deposits but because sediments are derived from several fans, each fan may have contributed various portions of the fill at various times, some of which are proximal, medial, or distal to the fan source. Channel entrenchment, or erosion, is common in alluvial fans and is an important element in the movement of coarse material to lower portions of the fan by mudflow or water flood (Buwalda 1951), each fan having different portions affected at different times. The 4WD Tributary fan is currently experiencing headward migration of channel incision from the main channel into the mouth of the Tributary. Headcut migration, a form of accelerated vertical erosion (Bull 1979), began after 1979 (as seen from aerial photos) and is progressing at a rate of 8 m/yr. Because coarse-grained debris flow activity has increased in the last approximately 1200 years at both the Narrows fan and 4WD Tributary fan, proximal processes are increasing near the surface of the alluvial fans, and/or aggradation rates are increasing.

Moving downstream from the mouth of the Narrows fan, sediment size decreases and has a high clay fraction, and influence of 4WD Tributary fan becomes evident. The fine-grained fraction creates cohesive stream banks which may lead to a vertical incision rather than lateral movement.

Further downvalley, Big Tributary sediment influence is added to 4WD Tributary influence and Upper Drainage sediments, and the cumulative sediment input is high albeit spread over a relatively wide portion of the valley. The high water table beginning upstream of HD 4700 m appears to have enhanced vegetative growth and established a depositional environment. This situation could create a feedback mechanism whereby vegetation spreads and reduces streamflow velocity which causes additional deposition, prolonged infiltration, and additional vegetative growth (Bull 1979). Additionally, effective sediment storage upstream of HD 4700 m is indicated by decreasing transportation slope. Coarse-grained material rarely moves beyond this point and is well-sorted and stratified or within a thick fine grained matrix when it does. Although fine sediment availability is high at this location, the transport capability is low due to roughness from vegetation. Increasing transport slope downstream of HD 4700 m indicates a slope where stream power could be sufficient to create incision once vegetation is removed.

Paleoclimate

The sediments stored within Meyer's Canyon date from the Pleistocene-Holocene transition period. Rapid aggradation, with significant coarse-debris sorting by channel action, marked the shift from cool/wet to warmer/drier. The Mazama eruption coincided with a deep paleoincision; physical effects such as enhanced rapid runoff from slopes due to a surface crust on ash and regional rapid climate shift to intensification of storm activity could have created the paleoincision. Following the eruption, high rates of fine-grained sediment accumulation, with little soil development, marked a period of increasing aridity and decreasing effective precipitation, with potentially increased summer drought. A return to cooler, moister conditions in recent times, with short-term drought periods, is marked by numerous debris flow/mud drape events, with soils developing rapidly on clay-rich material in favorable moisture and temperature regimes.

Given the long history of aggradation with only one previous large-scale incision, it is unlikely that incision is an inherent response to naturally high rates of aggradation and/or climate change. It is believed the paleoincision required a severe watershed perturbation to occur, namely, the Mt. Mazama eruption and its attendant thick ash fall in the drainage basin. Had conditions in the valley remained unchanged, changes in aggradation and climate alone probably would not have created the current incision. Since the only change that has occurred in the last 100 years is Euroamerican settlement, human perturbation is believed to be the triggering mechanism.

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APPENDICES

APPENDIX A

APPENDIX A

Master list of numbers used in field descriptions for exposures, paleochannels, ^{14}C samples, and cross sections cross referenced to numbers used in thesis.

Category	Field No.	Thesis No.
Exposures	7011	X3664
	7021	X3852
	8191	X4170
	8211	X4678
	8221	X5060
Paleochannels	6251	PC3774
	6252	PC3800
	6253	PC4186
	6254	PC4428
	6255	PC4563
	8141	PC4810
	6258	PC5016
	6258B	PC5017
	6256	PC5063
	6257	PC5078
Carbon-14 Samples	7021-25	$^{14}C3852$
	8191-11	$^{14}C4170$
	50793C-1	$^{14}C4260$
	50793C-12	$^{14}C4563$
	8211-15	$^{14}C4678$
	8211-38	$^{14}C4678-2$
Cross sections	7021	CS3852
	8191	CS4170
	TP4	CS4210
	8211	CS4678
	8221	CS5060

APPENDIX B

APPENDIX B

Exposure X3664

Units X3664-1 and 2 are probably genetically related as there are no alluvial flow structures and there is clay movement from 1 to 2 along root traces. Bioperturbation may have removed the evidence of fluvial input. There is no obvious erosional unconformity (EUC) between units 2 and 3, thus the top two layers are believed to be colluvial.

Because of platy structure remaining in X3664-3, this may be clay drape deposited on the waning limb of the mudflow which deposited X3664-4. However, because of the appearance of an EUC between 3 and 4, the surface of X3664-4 could have been smoothed by flowing water, and X3664-3 is a clay drape which closely conforms to the smoothed surface. X3664-4 is a coarsening upward, fairly coarse-grained (sand) mudflow with an erosional disconformity under the base (X3664-5). The parallel lamination and sorting of coarse sand near the top indicates sediments may have been sorted and fines removed by fluvial action within a lower sediment:water ratio than the main mudflow event. There is no distinct EUC between the finer-grained material near the base and the coarser, sorted deposits at the top of the unit so the sequence is interpreted as related. X3664-5 may be the mobile, fine-grained mudplaster upon which X3664-4 mudflow rode in. There is a distinct EUC between X3664-5 and X3664-6 which leads to the interpretation that X3664-5 was the bottom of the significant erosional event OR that X3664-5 was a pulse/clay drape following a significant erosional event which preceded the main action, the evidence of the erosional event having been removed.

Units X3664-6/7 are a fining-upwards sequence of channel deposits longitudinally continuous to HD 3925 where Lower Valley sediments become more influenced by 4WD Tributary sedimentation.

Imbrication at the base (290°, parallel to current flow direction), well-sorted, rounded gravels support the interpretation of channel deposits. These deposits (X3664-6/7) overlie a distinct EUC with X3664-8/9, though it also overlies an EUC with units X3664-10-13 downstream at site X3852 (HD 3852 m), which means 8/9 is discontinuous and irregular.

Units X3664-8/9 are not longitudinally continuous but do appear in other downstream locations. The base is composed of a poorly sorted, clast-supported cobble/gravel layer (X3664-9) overlain by a silt/mud matrix (X3664-8). A soil developed upon X3664-8 (subsequently eroded by X3664-6/7), of which only an incipient "B" horizon remains. This sequence (X3664-8/9) is interpreted to be a mudflow event which truncates (forms an EUC with) units X3664-10-13 below.

X3664-10 through 13 form a continuous, extensive fining-upwards mudflow deposit evident in the deposits above HD 3925 m. This sequence becomes X3852-12 downvalley. The stratigraphy of this sequence is highly variable; there are portions which have inclusions of discrete, fairly well-sorted, laminated sand deposits. This is not unusual with a highly mobile, widely-dispersed mudflow event. Units below X3664-10-13 are covered by a colluvial apron but because this mudflow can be traced to X3852, the assumption is made that units underlying this mudflow will be fairly similar to those underlying X3852-12, though it seems likely that the sediments are not as deep in the more upstream location. Paleochannel PC3774 truncates units X3664-5 through 13.

Table B-1. Exposure X3664 field synopsis.

Descr.#	Depth (m)	Structure			Texture	Color (Munsell)	% OM	Genesis
		Grade	Size	Type				
X3664-1	0.00-0.03	sg	vf	gr	ls	10YR 3/4	2.3	Fairly recent deposition, some recent fine root growth.
X3664-2	0.03-0.07	1	f	gr	l	10YR 2/2	1.5	Some clay along root traces. Co-evolved with X3664-1.
X3664-3	0.07-0.12	2	m	pl	sc	--	1.1	First buried soil.
X3664-4	0.12-0.62	na	na	na	s	--	--	Parallel lamination near top of mudflow (4/5); coarsening
X3664-5	0.62-0.66	sg	c	sbk	ls	--	--	upwards.
X3664-6	0.66-0.78	na	na	na	vcos	--	--	Parallel lamination. Fining upwards with X3664-7.
X3664-7	0.78-1.02	na	na	na	g	--	--	Rounded gravel, well-sorted, imbrication 290 degrees (parallel to current channel); extends 250 m d/s where pinches out at surface.
X3664-8	1.02-1.05	2	c	sbk	scl	--	0.8	Eroded by X3664-6/7. Root casts preserved, clay transported; strongest B horizon so far.
X3664-9	1.05-1.16	na	na	na	g/cob	--	--	Coarse lens; fining upwards; mudflow event with X3664-8.
X3664-10	1.16-1.28	1	c	sbk	l	--	--	Soil developed on top of mudflow (X3664-10-13).
X3664-11	1.28-1.35	sg	na	na	ls	--	--	Sand content variable and noncontinuous throughout
X3664-12	1.35-1.49	sg	c	sbk	lfs	--	--	mudflow. Continuous to below X3852.
X3664-13	1.49-??	sg	c	sbk	vfsl	--	--	

NOTES: Three buried soils, with four erosional unconformities preserved. Lower portion of deposits are dominated by a large mudflow (10-13). Mudflow was fairly extensive longitudinally to below X3852. X3664-6 and 7 are also longitudinally continuous and represent sorted, reworked channel deposits. Units 5-13 are truncated by PC3774. Because X3664 is close to the valley walls, it escaped recent fluvial action which influenced downstream exposures; soils developed on X3664-3 which do not exist near PC3774.

Exposure X3852

Table B-2 shows the synthesis of the field notes, laboratory analysis, and ^{14}C dates from X3852. X3852-1-3 is a fining-upwards sequence (one-event) upon which the current surface soil is forming. Maximum root development occurs in X3852-1, clay movement into X3852-2, and there is a downward decrease in soil organic matter. The base (X3852-3) is composed of rhyolite and andesite gravels which are poorly-sorted in a matrix of silt and mud. X3852-1 through 3 corresponds to the top half meter of PC3800, which is clearly a fining-upwards sequence of cobbles within a gravel/sand matrix (clast-supported, poorly sorted), and forms an abrupt boundary (EUC) over laminated sand.

Unit X3852-4 is a fairly continuous sand layer, portions of which are laminated. These bedding structures are not always evident or obvious. However, the sand lens is continuous to PC3800, where parallel and low-angle lamination is evident. There are also discontinuous gravel and cobble lens which grade to coarse sand lens, which are subsequently truncated. This sand lens truncates a mudflow, which is composed of units X3852-5 through X3852-8. There was a soil developing upon X3852-5, which was eroded by X3852-4.

Units X3852-5 through 8 have a high degree of variability but, though the individual units are discontinuous and irregular, the sequence (5-8) as a whole is fairly consistent and continuous and forms a portion of the upper fill within PC3800. X3852-8 is a clast-supported, poorly sorted cobble/gravel layer which truncates the previous mudflow of X3852-9/10. X3852-5 through 7 is mudflow material with lens, or portions, of sorted sand. This change in sand/silt/clay indicate many pulses and reworking of sediment, and perhaps with temporally and spatially varying ratios of sediment to water over the course of deposition.

Units X3852-9/10 follow the same pattern as X3852-5 through 7/8 and indicate evidence of a recurring depositional sequence: A coarse, debris-flow event truncates previous fine-grained deposits, depositing clast-supported cobbles and gravels, followed by thick fine-grained, fairly homogeneous deposits. The coarse events vary from fairly well-sorted gravels to poorly-sorted cobbles and can change longitudinally. The degree of sorting depends upon the material transported and, ultimately, the magnitude of the event initiating transport and the changes in hydraulics downstream. The fine-grained deposits which follow the coarse deposit often have fairly strong structure and clay translocation, indicating that soils often form on the mudflows. Soils are favored to form during periods of "geomorphological quiescence", periods of greater effective precipitation, higher temperatures, and/or under undisturbed vegetation. This pattern is hereafter referred to as the Fm/Gms sequence (see Table C-1 for definitions of lithofacies).

The sorted channel gravels which compose X3852-11 are the same channel gravels which compose X3664-6/7. Gravels are finer, though still well-sorted, than upstream exposures of this facies.

Units X3852-12/13, 14, 15/16, and 18/19 form the Fm/Gms pattern. Unit X3852-14 has been eroded significantly by 12/13 and the Fm unit is less obvious. Unit X3852-16 forms the coarse Gms portion of the pattern but the gravels are better sorted and finer than those within Gms unit X3852-13. Unit X3852-16 also forms an EUC with previously deposited X3852-17. Units X3852-18/19 are finer grained members of the Fm/Gms sequence; Gms is actually trending towards Gm (finer grained, increased sorting).

X3852-17 is a sand layer which grades to a sorted gravel layer and truncates X3852-18. This sand/gravel channel-type deposit has no remaining flow structures such as cross bedding or parallel lamination. However, because of the sorting, it is interpreted to be channel fill material.

Below X3852-19, deposits are fine grained, without obvious erosional unconformities. X3852-20 capped a period of deposition and is the strongest paleosol developed in these upper Lower Valley sediments; the 5 YR color (Munsell) designation may be an indication of "B" horizon clay illuviation. Below X3852-24, which is one of the last coarse layers exposed, a date of 4680 ± 60 ^{14}C yrs BP (5435 ± 145 yrs (cal) BP) was established for unit X3852-25. Events prior to this transported and deposited primarily fine-grained sediments without sufficient energy to erode previous deposits.

Within these fine-grained sediments, shell fragments (X3852-31) and carbonates along root traces suggest an increase in effective precipitation, sufficient to allow $CaCO_3$ coalescence and to support fresh water mollusks. Fine charcoal fragments were common in X3852-30, 32, and 35; this may be due to increased transport of sediments made available by previous fires within the drainage.

Table B-2. Exposure X3852 field synopsis.

Descr.#	Depth (m)	Structure Grade	Structure Size	Structure Type	Texture	Color	OM (%)	Genesis
X3852-1	0.00-0.04	3	vf	gr	l	10YR 3/4	3.3	Soil developing in surface deposits. Many fine roots, weak structure.
X3852-2	0.04-0.08	3	m	sbk	l	10YR 3/3	1.8	Some clay movement; organic matter incorporation.
X3852-3	0.08-0.22	3	m	pl/abk	scl	7.5YR 3/4	1.1	Poorly-sorted rhyolite/andesite pebbles; fining-upward clay/mud mix.
X3852-4	0.22-0.40	na	na	na	fs	7.5YR 3/4	--	X3852-4 through X3852-8 is a mudflow event; fining upwards sequence with fine lens and flasers of silt, clay, and gravel. I am interpreting that the clay in the layers is fluvial deposition.
X3852-5	0.40-0.46	m	na	na	lfs	7.5YR 3/4	--	
X3852-6	0.46-0.60	na	na	na	s	10YR 3/4	--	
X3852-7	0.60-0.72	3	vf	sbk	lfs	10YR 3/3	--	
X3852-8	0.72-0.81	na	na	na	g/cob	10YR 4/4	--	
X3852-9	0.81-0.92	m	na	na	sil	10YR 4/2	--	Soil developing on X3852-9/10 mudflow. Moderate structure, root traces. Truncated by X3852-8.
X3852-10	0.92-1.18	na	na	na	g/cob	10YR 3/3	--	
X3852-11	1.18-1.51	na	na	na	g	10YR 3/3	--	Sorted channel gravels. Imbricated at base (parallel to current channel direction). Fining upwards.
X3852-12	1.51-2.46	2	f	sbk	sl/s	10YR 4/4	--	Sand with low angle cross bedding at top of layer. Some structure, root traces, charcoal flecks.
X3852-13	2.46-2.69	na	na	na	g/cob	10YR 3/2	--	Pulse of coarse debris with some channel reworking, followed by fines. X3852-13 fills a small u/s (approximately 10 m) paleochannel.
X3852-14	2.69-2.76	na	na	na	g	10YR 3/2	--	Fines capping gravel largely eroded but some evidence remains d/s.
X3852-15	2.76-2.86	na	na	na	fs	10YR 3/4	--	Some structure, little organic matter; calcium

Table B-2. Exposure X3852 (continued).

Descr.#	Depth (m)	Structure			Texture	Color	OM (%)	Genesis
		Grade	Size	Type				
X3852-16	2.86-3.01	na	na	na	g	--	--	carbonate along root traces which increases as move down in profile.
X3852-17	3.01-3.06	na	na	na	fs	10YR 3/4	--	Sand lens, no structure; reworked channel material. Truncates preceding deposit.
X3852-18	3.06-3.26	1	f	sbk	sil	10YR 3/3	--	Root traces, some structure. Soil developed on mudflow (18/19).
X3852-19	3.26-3.36	na	na	na	vcos/g	10YR 3/3	--	Coarse mudflow base, fining upwards. Erodes previous deposit.
X3852-20	3.36-3.53	3	f	sbk	sicl	5YR 3/4	--	Soil developing on top of mudflow (20-24)
X3852-21	3.53-3.77	2	m/c	sbk	l	10YR 3/4	0.9	truncated by subsequent event. Fining
X3852-22	3.77-3.83	na	na	na	fs	10YR 3/4	--	upwards with silt and clay flasers.
X3852-23	3.83-3.89	2	f	sbk	l	10YR 3/4	--	
X3852-24	3.89-3.94	na	na	na	vcos/g	10YR 3/4	--	Fining upwards.
X3852-25	3.94-4.07	3	m	abk	sil	10YR 3/4	--	Soil developed on top of mudflow (25/26);
X3852-26	4.07-4.17	na	na	na	ls	10YR 3/4	--	truncated by subsequent event. Fining upwards.
X3852-27	4.17-4.29	2	m	sbk	sicl	10YR 3/4	--	Soil developed on top of mudflow (27/28).
X3852-28	4.29-4.45	na	na	na	ls	10YR 3/4	--	Fining upwards.
X3852-29	4.45-4.69	2	f	sbk	l	10YR 4/4	--	No soil developed on surface of mudflow (29-37).
X3852-30	4.69-4.73	na	na	na	sil	10YR 3/4	--	Quiet water clay deposits; charcoal chunks.
X3852-31	4.73-4.81	na	na	na	lfs	10YR 3/3	--	Shell fragments.
X3852-32	4.81-4.91	2	f	sbk	sil	10YR 4/3	--	Carbonates along root traces; charcoal chunks.
X3852-33	4.91-5.01	na	na	na	ls	10YR 3/4	--	

Table B-2. Exposure X3852 (continued).

Descr.#	Depth (m)	Structure			Texture	Color	OM (%)	Genesis
		Grade	Size	Type				
X3852-34	5.01-5.11	1	f	sbk	vfsl	10YR 3/4	--	Carbonates along root traces.
X3852-35	5.11-5.15	1	f	sbk	vfsl	10YR 4/4	--	Very fine charcoal fragments; carbonates along root traces.
X3852-36	5.15-5.19	2	vf	pl	lfs	10YR 3/4	0.5	Carbonates along root traces.
X3852-37	5.19-5.25	na	na	na	s/g	10YR 3/3	--	Clast-supported gravel in sand matrix.
X3852-38	5.25-5.30	na	na	na	vfs	10YR 3/4	--	No soil developed on surface of mudflow (38/39).
X3852-39	5.30-5.33	na	na	na	fs	10YR 3/4	--	
X3852-40	5.33-5.42	2	f	sbk	l	10YR 4/4	--	Charcoal fragments. Mudflow 40/41.
X3852-41	5.42-5.47	na	na	na	fs	10YR 3/4	--	
X3852-42	5.47-5.56	2	m	sbk	lfs	10YR 3/6	0.4	Carbonates along root traces.
X3852-43	5.56-5.79	na	na	na	g	10YR 3/4	--	Clast-supported, sorted gravels. Base of mudflow (42/43).
X3852-44	5.79-6.19	1	vf	gr	sl	10YR 3/6	--	Matrix-supported fine gravel.
??								

NOTES: Numerous depositional events confound diagnosis because of sequencing within the event. Seems that usually coarse deposits precede massive input of silt and clay material. Within the mudflow, textures can be sand, silt, or clay dominated. There are periods of reworking and quiet water deposition within the flow.

Soils often develop on the mudflow surface only to be subsequently eroded by the next major event. There There are sorted and stratified deposits indicating channel action, but these only compose a small fraction of the total, and are only preserved above about 2.5 m from the surface. Below 3.5 m, fine-grained sediments dominate with no flow structures remaining.

Exposure X4170

Table B-3 is the field description synopsis of X4170. This site is at the mouth of 4WD Tributary, and as such is heavily influenced by sediments derived from Clarno tuffaceous material. The color (5 YR) in upper three meters is primarily due to these sediments.

There are eight Fm/Gms sequences similar to those referred to in X3852: X4170-1 (without the subsequence Fm unit, Gms only), 2/3, 4/top of 5, bottom of 5/6-8, 9/10, 11/12, 13/14, and 15/16. X4170-bottom of 5/6-8, while a mud drape/debris flow event like the others, had significant channel reworking of the deposits and so has a coarse-fine-coarse sequence, with the coarse deposits being well-sorted. These Fm/Gms units are much thicker than in exposure X3852. The structure of the Fm units is generally a higher grade, larger size, and more blocky type, probably as a result of higher clay content in the parent material. Many of the paleosols and coarse layers extend downfan to the junction of 4WD Tributary with the main canyon, but end at the junction or slightly downstream.

Within this top three meters, percent organic matter (%OM) averages 0.9%, in Fm units X4170-2, 4, 9, 11, 13, and 15. The highest %OM is in the lower units 11 and 13, then drops off sharply within 15. This can be due to several factors: a) effectiveness of erosional events which truncate soil horizons, b) length of time unit is unperturbed varies, allowing greater organic matter incorporation with increasing time, c) vegetation and/or effective moisture is more conducive to greater organic matter incorporation (especially X4170-11 and X4170-13), and/or d) coarser texture (clay loam versus clay) is more favorable for organic matter oxidation. The lower portion of X4170-11 has large charcoal chunks dated at 1300 ± 90 yrs ^{14}C BP (1170 ± 180 yrs (cal) BP). These large charcoal chunks within a thick matrix of fine-grained sediment indicate a lot of sediment moved rapidly, perhaps in response to watershed burning. Because the chunks do not exist in the underlying debris flow material, the source material could be separated temporally or spatially. A possible hypothesis is that coarse debris flow scour cut a "channel-like feature" (Dietrich et al. 1993) after which fine sediment was rapidly added to the new "channel" via overland and sheetflow from the hillslopes.

Below X4170-16 (beyond three meters) to X4170-E (about nine meters), units are finer grained depositional units without the erosive cobble/gravel Gms units which were an element of the top three meters (except for X4170-32). Paleosol X4170-23, topped by X4170-22, was still evident at the 4WD Tributary junction; X4170-32 was evident 20 meters downstream of the junction. Fine grained units are often separated by units rich with charcoal fragments, such as X4170-25, 27, 29 and 30. There are some coarse sand layers (X4170-31 and 36) but no remaining flow structures which would indicate high velocity channel flow.

Under (prior to) the Mazama ash deposition (at a depth of 8.3-8.9 m), units are coarse grained and therefore higher energy units. Particle size is larger than upper units (sands, gravels and cobbles), with obvious sorting and bedding structures. Clay drapes maintain the platy structure particular to quiet water deposition, or deposition during the waning portion of high flow events.

Table B-3. Exposure X4170 field synopsis.

Descr.#	Depth (m)	Structure Grade	Structure Size	Structure Type	Texture	Color (Munsell)	OM (%)	Genesis
X4170-1	0-0.09	na	na	na	vcos/g	5YR 3/3	0.2	Recent surface deposition. Discontinuous gravels and cobbles, followed by deposition of fine material.
X4170-2	0.09-0.20	2	f	sbk	sil	7.5YR 3/2	0.8	Material added by X4170-1 while soil forming; near stream environment, ebbing without scour.
X4170-3	0.20-0.29	na	na	na	cob	5YR 3/3	--	Base of mudflow (X4170-2/3); clast-supported, poorly sorted.
X4170-4	0.29-0.34	3	f	sbk	cl	5YR 3/3	0.7	Eroded by subsequent mudflow (2/3); fines deposited following
X4170-5	0.34-0.55	na	na	na	g/cob	5YR 3/3	--	coarse mudflow base (5); coarsens upward within X4170-5.
X4170-6	0.55-0.67	na	na	na	g	5YR 3/2	--	Clast-supported channel deposit gravels; fining upwards until capped by fine sand.
X4170-7	0.67-0.83	m	sh	sbk	s	5YR 3/3	--	Low angle lamination.
X4170-8	0.83-1.02	1	vf	sbk	g	5YR 3/2	--	Clast-supported gravels with cobble lag deposits. X4170-8 is base of mud/debris flow event; cobble lag deposits which interfinger with sand, sorted gravel channel deposits.
X4170-9	1.02-1.42	3	m	pr	cl	5YR 3/3	0.8	Well-developed, large aggregates.
X4170-10	1.42-1.69	na	na	na	g/cob	5YR 3/2	--	Clast-supported gravels with cobble lag deposits. Fining upwards mudflow (9/10).
X4170-11	1.69-2.00	3	vf	gr	c	5YR 3/4	1.1	Clay movement along root traces.
X4170-12	2.00-2.17	na	na	na	cob	5YR 3/3	--	Clast-supported, poorly sorted mudflow base (10-11).
X4170-13	2.17-2.50	3	vf-c	abk	c	5YR 3/4	1.2	Soil developed on mudflow surface; truncated by 12.
X4170-14	2.50-2.75	na	na	na	g/cob	5YR 3/2	--	Clast-supported, poorly sorted mudflow base (13/14)
X4170-15	2.75-2.96	2	f-m	sbk	cl	5YR 3/4	0.5	Mud drape on debris flow/drape couplet (15/16).
X4170-16	2.96-3.05	na	na	na	g/cob	7.5YR 3/4	--	Discontinuous, clast-supported, poorly sorted mudflow base.
X4170-17	3.05-3.36	2	f-m	pr	sil	7.5YR 4/4	--	Series of 3 fluvents; discontinuous and irregular.

Table B-3. Exposure X4170 (continued).

Descr.#	Depth (m)	Structure Grade	Structure Size	Structure Type	Texture	Color (Munsell)	OM (%)	Genesis
X4170-18	3.36-3.62	2	c	sbk	c	7.5YR 4/4	--	A/B (soil horizons) combined.
X4170-19	3.62-3.72	3	c	pr	c	5YR 3/4	0.8	A/B combined. Fines deposited during mudflow (19/20).
X4170-20	3.72-3.95	3	f	cr	ls	5YR 3/4	--	Matrix-supported gravels, fining upwards w/in lower portion of mudflow (19/20).
X4170-21	3.95-4.97	2	m	pr	c	5YR 3/4	--	Massive fine-grained mudflow on which soil developed and was subsequently eroded by 20.
X4170-22	4.97-5.05	2	vf	abk	ls	7.5YR 4/4	--	G/cob in weakly-cemented sand matrix; somewhat discontinuous base of mudflow (21/22).
X4170-23	5.05-5.33	3	vf	abk	--	--	--	Bioperturbation, little OM.
X4170-24	5.33-5.35	3	vf	pl	--	--	--	Silt/clay quiet water or waning flood depostion.
X4170-25	5.35-5.38	3	vf	sbk	--	--	--	
X4170-26	5.38-5.63	3	f	sbk	sil	7.5YR 4/4	--	
X4170-27	5.63-5.81	2	f	abk	--	--	--	
X4170-28	5.81-6.08	1	f	abk	cl	10YR 4/4	0.2	X4170-23 through X4170-32 are a series of fine mudflow deposits
X4170-29	6.08-6.25	1	--	--	--	--	--	with some soils developing between depostional/
X4170-30	6.25-6.32	2	vf	abk	--	--	0.3	erosional events. Reworking of deposits common.
X4170-31	6.32-6.48	m	na	na	vfs	10YR 4/4	--	Waning flood deposits followed by 30.
X4170-32	6.48-6.63	na	na	na	g/cob	7.5YR 3/4	--	Cobble lag/mudflow base followed by 31.
X4170-33	6.63-6.87	2	f	sbk	sil	7.5YR 4/6	--	Quiet water, lapping edge of stream.
X4170-34	6.87-7.09	2	f	sbk	sil	5&10YR 4/4	--	Clay flasers, nonpedogenic.
X4170-35	7.09-7.48	2	f	sbk	sil	7.5YR 4/4	0.1	
X4170-36	7.48-7.71	na	na	na	sl	2.5YR 4/4	--	Sand composes base; precedes fines in mudflows (33-36).
X4170-37	7.71-8.02	2	c	sbk	sil	10YR 4/4	--	Fine deposits topping reworked ash (38). Finest of

Table B-3. Exposure X4170 (continued).

Descr.#	Depth (m)	Structure Grade	Structure Size	Structure Type	Texture	Color (Munsell)	OM (%)	Genesis
X4170-38	8.02-8.32	na	na	na	ls	10YR 3/4	--	fining upwards sequence 37-H.
ASH	8.32-8.92	na	na	na	ash	na	na	Mazama ash layer; parallel lamination at base.
X4170-E	8.92-10.07	na	na	na	sil-s	na	na	Parallel lamination of sand and silt deposits.
X4170-F	10.07-10.8	na	na	na	s-g	na	na	Gravel/cobble lag and bar deposits; parallel and cross laminated samd; matrix-supported pebbles with lenses and lag deposits of fine-coarse gravels; gravels sorted indicating cahnnel action.
X4170-G	10.82-11.2	na	na	na	s-g	na	na	Parallel and cross-laminated sand with some sorted gravel lenses.
X4170-H	11.22-13.3	na	na	na	s-cob	na	na	Clast-supported, poorly sorted gravels and cobbles; some homogeneous sands.

NOTES: Numerous depositional events which also acted as erosional events. A and B horizons often truncated by coarse deposits of next depositional event. Coarse deposits followed by thick fine-grained deposits. Fine-grained deposits may or may not be reworked; some are massive and are in obvious "layers", indicating fluvial action. Above Mazama ash, there are many fine grained deposits; below the Mazama ash, material is primarily coarse cobble and gravel channel and lag deposits, with some channel sediments of sand-sized material.

Exposure X4678

Exposure X4678 is located at the deepest part of the valley fill. Sediments are contributed by 4WD Tributary, main channel sediments, and Big Tributary. The sediments have been saturated; gleyed layers are often classified as 2.5 Y. Table B-4 has the field synopsis of X4678.

There are few erosional unconformities and transitions between layers are subtle. Layers with a coarse fraction from the valley fill surface to 9.6 m, and from 11.6 m to 16.5 m are few and usually matrix- rather than clast-supported. Charcoal-rich layers are common; charcoal is often embedded in a thin, fine-grained layer which is also carbonate-rich (stage II+, Birkeland 1984). Miller (in press) estimated that in eastern Oregon, the range of recurrence intervals for presettlement fires was 50-100 years; on more productive sagebrush sites, as frequently as once every 17 years. Root traces, calcium carbonate concretions, and clay translocation are common. Most of the sediments are very sticky, very plastic. Exposure is gleyed (2.5 Y) to about 14.5 m, but portions are better oxidized than others and thus have a 10 YR color.

Coarse layers (X4678-14, 26-30, and 43) are poorly to well-sorted, rounded gravels with some cobble lag deposits, and silt/sand lens associations. There are only two coarse-grain dominated deposits before and two after the Mazama ash deposition. Silica cementation in the deposit under the ash layer (X4678-32) has created a massive, erosion-resistant layer which is traceable to above PC5016.

Organic matter content, while variable (i.e., no distinct trend from surface to depth), was higher in this downstream location to greater depths than in upstream locations (judging from both field observations and laboratory analysis). This may be because oxidation of organic matter within fine-grained material is slower than in coarse-grained material. Extensive paleoroot channels throughout this exposure (less evident at upstream exposures) indicate that vegetation may have been more abundant here than elsewhere.

Table B-4. Exposure X4678 field synopsis.

Descr.#	Depth (m)	Structure Grade	Structure Size	Structure Type	Texture	Color (Munsell)	OM (%)	Genesis
X4678-1	0.0-0.12	2	vf	cr	sil	10YR 3/3	2.3	Bioperturbation; many very fine roots;
X4678-2	0.12-0.16	2	m	sbk	si-cl	2.5Y 3/2	--	increasing CaCO3 twds bottom. Surface soil on recent deposits.
X4678-3	0.16-0.97	3	f-m	sbk	si-cl	2.5 3/2	1.6	Concretions of CaCO3; may be separate horizons within but very indistinct.
X4678-4	0.97-1.15	3	m	sbk	c	2.5Y&10YR	2.3	CaCO3 concentrated in concretions only; soil essentially noncalcic; clay skins on ped faces.
X4678-5	1.15-1.32	3	m	sbk	c	10YR 3/3	--	CaCO3 concentrated in small concretions or larger amorphous "pods"; soil barely calcic. Concretions resistant to dissolution with water. Amorphous iron oxide stains.
X4678-6	1.32-1.56	3	c	abk	c	10YR 3/3	--	Resistent concretions; clay skins on ped faces.
X4678-7	1.56-1.78	3	m	abk	c	10YR 3/3	0.5	Resistent concretions; matrix-supported cobbles and coarse gravel. Lower portion of mudflow 6/7.
X4678-8	1.78-3.18	3	m	pr	c	10YR 3/3	--	Massive light grey; oxidation of reduced clay creates mottles of iron oxide stain (m 1,2,&3 p); decreases as move down vertically within horizon.
X4678-9	3.18-3.43	3	vf	gr	c	10YR 3/3	--	Numerous depositional fluvents; root casts oxidized; roots occasionally still remaining; clay follows root traces.
X4678-10	3.43-3.82	3	vf	cpr	sc	10YR 3/2	--	Root casts oxidized; red clay mottles; iron oxide rust mottles; 3 weakly developed fluvents.

Table B-4. Exposure X4678 (continued).

Descr.#	Depth (m)	Structure Grade	Structure Size	Structure Type	Texture	Color (Munsell)	OM (%)	Genesis
X4678-11	3.82-4.12	3	m	pr	c	10YR 3/2	--	Mottles 10YR 4/3 m2d
X4678-12	4.12-4.71	3	f	pr	c	10YR 3/2	0.9	mottles 10YR 4/3 m2d; 3 poorly developed fluvents or depositional layers; oxidized root casts.
X4678-13	4.71-4.93	2	c	abk	c	2.5Y 4/2	--	Mottles 10YR 3/3 c1d; matrix of clay supports gravel.
X4678-14	4.93-5.08	1	m	sbk	c/s/g	10YR 5/4	--	Moderately-sorted gravel with significant sand and clay; matrix oxidizing.
X4678-15	5.08-6.42	--	--	--	--	2.5Y 5/2	--	Many individual layers of sand separated by clays and silts. Often separated by .5 cm thick charcoal-rich seams; matrix-supported gravel at base; fining upwards.
X4678-16	6.42-6.61	2	m	sbk	c	2.5Y 5/2	--	Charcoal throughout.
X4678-17	6.61-6.81	1	f	cr	fsl	2.5Y 4/2	--	Sand base of unit 16/17.
X4678-18	6.81-6.95	2	f	sbk	fsl	2.5Y 4/4	--	Sand with clay; separated from 17 by silt with charcoal; fining upwards topped by quiet water deposition.
X4678-19	6.95-7.09	2	c	sbk	c	2.5Y 3/2	2.5	Sand with clay; fining upwards, topped by quiet water deposition; separated from 20 by charcoal seam.
X4678-20	7.09-7.47	2	c	sbk	c	10YR 3/3	--	Pockets of lighter silt within clay matrix.
X4678-21	7.47-7.95	2	c	sbk	c	10YR 4/2	--	Iron oxide stain follows root traces.
X4678-22	7.95-8.20	2	c	sbk	c	10YR 4/3	--	Amorphous CaCO3 separates 3 fluvial deposits.
X4678-23	8.20-8.73	2	m-c	sbk	c	10YR 4/3	--	2mm concretions of CaCO3.
X4678-24	8.73-9.09	2	c	abk	c	10YR 3/3	0.6	Iron oxide cases conform to root zone; silt/ash
X4678-25	9.09-9.60	1	m	sbk	c/s	2.5Y 4/4	--	Thick sand with clay in broken, irregular pockets;

Table B-4. Exposure X4678 (continued).

Descr.#	Depth (m)	Structure Grade	Structure Size	Structure Type	Texture	Color (Munsell)	OM (%)	Genesis
								clay has color 10YR 4/3.
X4678-26	9.60-9.85	1	f	sbk	g/cob	10YR 4/3	--	Clast-supported coarse gravel and fine cobbles; poorly sorted; particles subrounded by fluvial action.
X4678-27	9.85-10.13	1	f	sbk	s-bould	10YR 4/4	--	Cobble/boulders (>15cm) lag deposits (discontinuous) within continuous sand layer.
X4678-28	40.13-10.49	2	m	sbk	s-cob	2.5Y 4/4	--	Clast-supported, poorly-sorted coarse gravel; sand/gravel intermixed with quiet water clay "pods"; clay has color 10YR 4/3; 2mm concretions of CaCO3.
X4678-29	10.49-11.34	1	f-m	sbk-cr	s-cob	2.5YR 4/4	--	Moderately-sorted gravels, discontinuous cobble lag deposits; discontinuous sand lens; some charcoal; coarse deposits resting on clay.
X4678-30	11.34-11.64	na	na	na	g	10YR 3/4	--	Clast-supported gravels, moderately well-sorted; fining upwards.
X4678-31	11.64-12.48	a	m	sbk	c-s	10YR 5/4	--	Reworked fines and ash.
ASH	12.48-13.08	--	--	--	ash	--	--	Mazama ash.
X4678-32	13.08-13.94	m	--	--	?	10YR 4/3&5	--	Clay moved down vertical cracks established in massive silt/sand/clay deposits; silica cementation; CaCO3 concentration increases with increasing depth.
X4678-33	13.94-14.35	na	na	na	g	10YR 3/4	--	CaCO3 decreases with increasing depth; coarsening upwards; clast-supported, mod. well-sorted gravels.
X4678-34	14.35-14.47	m	--	--	c-s	10YR 4/3	--	Clays sandwiched by sands by fluvial action.
X4678-35	14.47-14.77	m	--	--	cs	2.5Y 3/2&4/	1.1	Darker portion may be OM incorporation.

Table B-4. Exposure X4678 (continued).

Descr.#	Depth (m)	Structure Grade	Structure Size	Structure Type	Texture	Color (Munsell)	OM (%)	Genesis
X4678-36	14.77-14.93	3	m	cpr	c-sil	2.5Y 3/2&5/	--	
X4678-37	14.93-15.29	2	m	cpr	cs	2.5Y 4/2&4/	--	Approximately 5 layers of fluvial deposition; base of ash and silt.
X4678-38	15.29-15.53	3	f	pr	c-s	2.5Y 5/2	--	Oxidized sand; 2 layers; sand underlying fines (fining upwards).
X4678-39	15.53-15.87	2	c	sbk	ls	2.5Y 3/2	--	Fining upwards sand; top has some structure.
X4678-40	15.87-16.10	2	c	sbk	c	2.5Y 4/2	--	4 layers; much charcoal in layers.
X4678-41	16.10-16.47	m	--	--	cs	2.5Y 4/4	--	1 layer; amorphous CaCO3; charcoal chuncks.
X4678-42	16.47-16.57	2	f	sbk	c	10YR 3/3	1.9	1 layer; pebbles in clay matrix; fining upwards from 43
X4678-43	16.57-16.94	na	na	na	g/cob	10YR 3/3	--	Clast-supported, poorly-sorted coarse gravel/cobbles (subrounded rhyolite, clasts from Gable Creek).
X4678-44	16.94-????	na	na	na	s/g	2.5Y 4/4	--	S-sil matrix with clast-supported, poorly-sorted gravel lens.

NOTES: Primarily depositional forms. Difficult to discern actual soil horizons; color is often misleading. Coarse layers often precede significant fine deposition. Periods of significant charcoal input at 5-7 meters down; charcoal is preserved in fine silt lenses between depositional layers. Strong gleying being oxidized, especially along root traces; much of the structure is derived from non-pedogenic clay; clay also affects current massiveness of exposure. Under the ash is strong silica cementation.

Exposure X5060

Table B-5 has the field description synopsis of Site X5060. These sediments are also recently influenced by Clarno tuffaceous sediments, but from two adjacent small drainage areas, not from 4WD Tributary. The soil developed upon these recent deposits are weakly developed with pale to dark brown hues with fresh clasts. This location is characterized by several paleochannels (PC5016, PC5017, PC5063, and PC5078). PC5016 "banks" have evidence of soil development, indicating a fairly stable channel for a period of time.

The Mazama ash layer is within 2 m of the surface and reworked ash deposits are found within 1.2 m of the valley fill surface. Layers are numerous below the ash though without obvious erosional unconformities; these layers are interpreted as comparable material being deposited under very similar conditions and therefore were often not separated in the field description. Coarse deposits are only retained on the surface from a recent (within the last 100 years) debris flow generated from the nearby tributaries as seen by deep Clarno-red sediments from adjacent small alluvial fan influence, and coarse deposits below 5.3 m are generated from upstream locations. The coarse deposits at the base are a mixture of cobble and gravel lag deposits, well-sorted fine gravel lens, and matrix supported coarse gravel, closely associated with sand and silt lens and very similar in character and appearance to deposits at upstream locations in the same stratigraphic position.

Table B-5. Exposure X5060 field synopsis.

Descr.#	Depth (m)	Structure Grade	Structure Size	Structure Type	Texture	Color (Munsell)	OM (%)	Genesis
X5060-1	0.0-0.10	1	f	cr	--	2.5YR 3/4	1.6	Soil developing in surface deposits of clast-supported angular gravel; fining upwards.
X5060-2	0.10-0.15	2	m	pl	--	5YR 3/3	1.7	Matrix supported angular gravel.
X5060-3	0.15-1.20	1	f	abk	--	2.5 YR 3/4	0.8	Strong structure, possibly argillic horizon; severely dried condition masks deposition/soil development.
PREASH	1.20-1.95	na	na	na	ash mix	--	--	Ash reworked with Clarno sediments.
ASH	1.95-2.55	na	na	na	ash	--	--	Mazama ash.
X5060-4	2.55-2.80	2	m	sbk	--	10YR 5/4	0.6	Fine root casts; small charcoal pieces.
X5060-5	2.80-2.92	2	f-m	sbk	--	10YR 4/4	--	
X5060-6	2.90-3.11	2	m	sbk	--	10YR 4/4	--	
X5060-7	3.11-3.82	3	f-m	sbk/pr	--	7.5YR 3/2	--	14 broken, discontinuous, irregular layers; clay movement and oxidation of iron-rich material obvious; charcoal chunks in dense clay/silt matrix at base.
X5060-8	3.82-3.86	3	vf	cpr	--	5YR 3/4	--	Root casts, clay, but no humus.
X5060-9	3.86-4.01	3	f	pr	--	10YR 4/3	0.4	At least 2 broken, discontinuous, irregular layers. Similar to 7 but less layers.
						2.5YR 4/4		At least three broken, irregular layers; humus, clay movement, root casts.
X5060-10	4.01-4.50	3	m	pr	--	10YR	--	Organic matter and roots, but residual fluvial structures; various hues and chromas on 10YR page.

Table B-5. Exposure X5060 (continued).

Descr.#	Depth (m)	Structure Grade	Structure Size	Structure Type	Texture	Color (Munsell)	OM (%)	Genesis
X5060-11	4.50-5.03	3	c	abk	--	10YR	--	At least 5 layers; various hues and chromas on 10YR page in the Munsell color chart.
X5060-12	5.03-5.11	2	m	sbk	ash	10YR 4/3	--	
X5060-13	5.11-5.14	m	na	na	ash	10YR 8/1	--	Thin, white ash/silt layer.
X5060-14	5.14-5.33	2	m	sbk	--	10YR 4/3&3/4	0.4	Humus, root casts.
X5060-15	5.33-6.16	m	na	na	g	10YR 5/4	--	Matrix-supported coarse gravel with cobble lag deposits; gravel with coarse gravel lens (moderately well-sorted at base of layer).
X5060-16	6.16-6.54	na	na	na	s/g	10YR 4/4	--	Sand with clast-supported fine gravel, well-sorted lens.
X5060-17	6.54-6.61	2	f	sbk	sil	10YR 4/4	--	Dark red layer; structure from clay and CaCO3.
X5060-18	6.61-????	m	na	na	s/g	10YR 4/3	--	Well-sorted gravel associated with sand; cannot tell which is lens and which might be matrix.

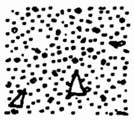
NOTES: Strong influence by Clamo clays above ash (strong brick red color). Prior to Mazama ash, older deposits very much like those underlying ash at X4170 but more sorted, overall finer grained. Numerous thin deposits which are very difficult to separate or discuss individually.

APPENDIX C

Table C-1. Lithofacies definition and description (after Miall 1977, 1978, and Rust 1978).

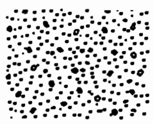
Gravelly facies - Individual clasts may reach more than 20 cm in diameter but mean size is within the gravel to cobble range.

Gms



Massive, clast-supported gravel and cobbles, often within a clay/mud matrix. This is a coarse facies with angular megaclasts and poorly-sorted matrix ranging in size from gravel to clay. Clast orientation is random. Base is commonly erosional. It is distinguished from Gm by its lack of bedding and imbrication. Interpreted to be debris flow, and lag deposits where laterally discontinuous.

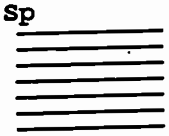
Gm



Massive or crudely bedded gravel. This facies comprises gravel or cobbles where crude horizontal stratification may or may not be present (somewhat sorted). Most gravels are clast-supported, indicating sand and silt matrix filtered into interstices following deposition. Impersistent lenses of clay, silt or sand may be interbedded with the gravels. Lateral variation in grain size is common. Base is erosive. Interpreted to be channel fills, longitudinal bars, slightly reworked and sorted debris flow material.

Sandy facies - Deposits ranging from very fine to very coarse sand. The coarser beds commonly are gravelly. Sorting and bedding are variable.

Sp



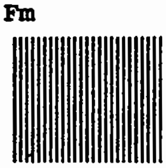
Parallel and horizontally laminated sand. At times, low-angle lamination exists (less than 5 degrees). Very small scale ripple marks may be present. Interpreted to be reworked channel deposits separated from Fl because sand is major component, indicating higher energy depositional environment.

Sc

Channel fill sand-size material. Base is commonly erosional, but no lamination, bedding or stratification is evident.

Fine-grained facies - Silt and clay compose a large fraction of the Meyer's Canyon deposits due to the geologic source areas. The clay is predominantly of geologic origin, rather than pedogenic. Base is rarely erosional and fine material conforms to previous deposit so closely, it is often difficult to say if the deposits were generated during different events.

Fm



Massive fine sandy mud (clay, silt, sand mixture). The mud can be massive or laminated with lenticles a few millimeters to a few centimeters in thickness. This can occur as a drape over underlying beds, its lower surface conforming to the shape of the underlying bedform. In Meyer's Canyon, this unit also represents the common thick mudflows which often overlie debris flow deposits. As a whole, the mudflow deposit is unsorted and unstratified earthy material (Blackwelder, 1928). The Fm/Gms combination is common, especially within 4WD tributary alluvial fan.

Table C-1 (continued).

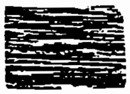
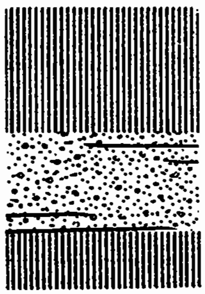
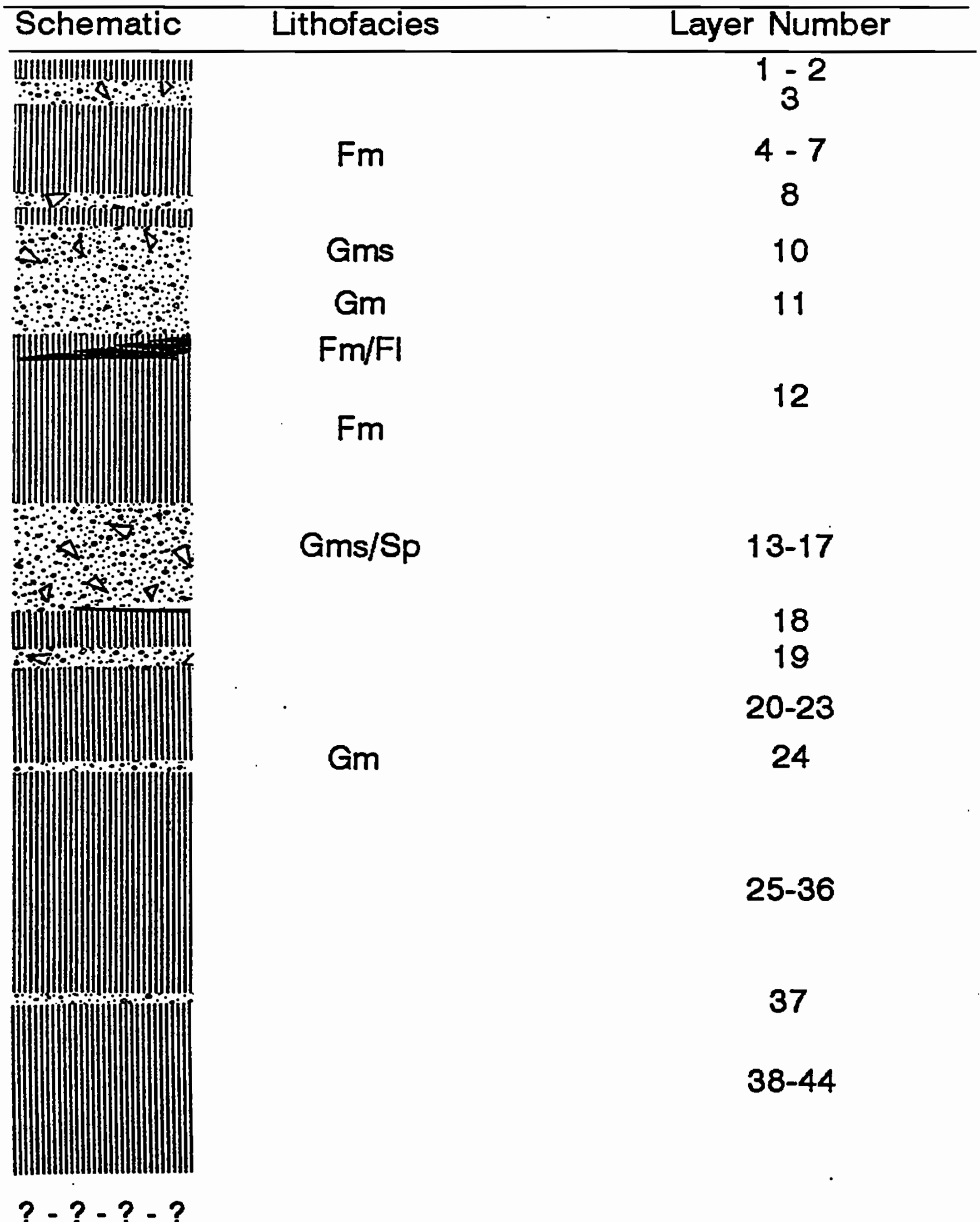
Fl		Laminated sand, silt, or clay. Interbedding of sand, silt and clay is common. Thickness and lateral extent is variable. Interpreted to be waning and stream-reworked flood deposits.
Fsc		Silt, clay, or loam, horizontally laminated to massive. Often lamination is no longer evident. Interpreted to be wet meadow or backswamp deposits. Deposits are thick due to vegetative cover which restricts flow action and enhances deposition. Freshwater molluscs can be present.
V	VVVVV VVVVV	Ash derived from climactic eruption of Mt. Mazama.

Figure C-1. Schematic of Lithofacies Exposure X3664.

Schematic	Lithofacies	Layer Number
	Fm	1 - 5
	Gm/Sp	6 - 9
		10 - 13
? - ? - ? - ?		

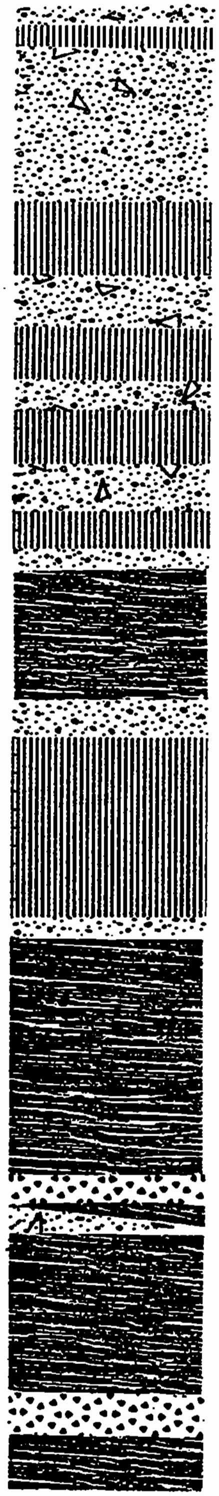
Vertical scale 1:40

Figure C-2. Schematic of Lithofacies Exposure X3852.



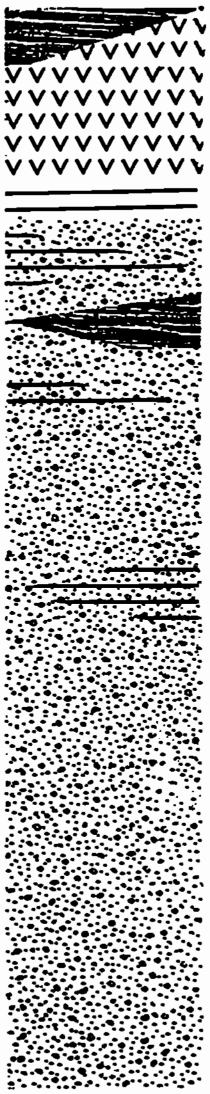
Vertical scale: 1:40

Figure C-3. Schematic of Lithofacies Exposure X4170.

Schematic	Lithofacies	Layer Number
	Gms	1
	Fm	2
	Gms	3-5
	Gm	8-6
	Fm	9
	Gms	10
		11
		12
		13
		14
		15
	Gm	16
	Fl	17-19
	Gm	20
		21
		22
		23-30
	Sc	31
	Gms/Fl	32
		33-35
		36
		37

Vertical scale: 1:40

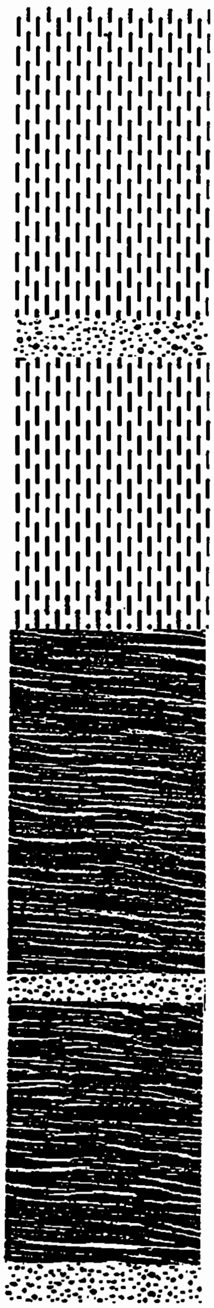
Figure C-3 (continued).

Schematic	Lithofacies	Layer Number
	Fl/V	38
	V	Mazama Ash
	Sp	E
	Sp/Gm/Fl	E2
	Gm	F
	Sp/Gm/Fl	G
		H

? - ? - ? - ?

Vertical scale: 1:40

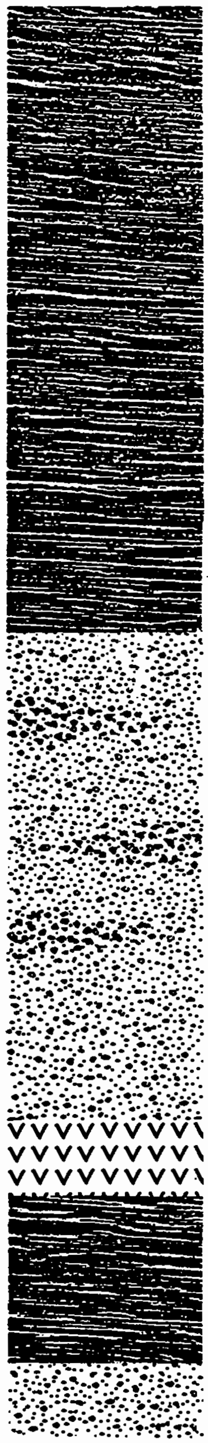
Figure C-4. Schematic of Lithofacies Exposure X4678.



Schematic	Lithofacies	Layer Number
	Fsc	1-6
	Gm	7
		8
	Fl	9-13
		14
		15
		15

Vertical scale 1:40

Figure C-4 (continued).



Schematic	Lithofacies	Layer Number
	Fl	16-25
	Gm/Sc	26-30
	V	Mazama Ash
		32
	Gm	33

Vertical scale 1:40

Figure C-4 (continued).

Schematic	Lithofacies	Layer Number
	Fl	34-41
	Gm	42-43
	Sc/Gm	44

? - ? - ? - ?

Vertical scale 1:40

Figure C-5. Schematic of Lithofacies Exposure X5060.

Schematic	Lithofacies	Layer Number
	Gms	1-2
	Fm	3
	Sc/V	Preash
	V	Mazama Ash
	Fl	4-14
	Gm	14-18

? - ? - ? - ?

Vertical scale 1:40

APPENDIX D

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June 2, 1992

To: Kathi Peacock, Oregon State University

From: Brittain Hill

Subject: Mineralogic analysis of tuffaceous sediments from Meyers Canyon, Wheeler Co., Oregon.

Summary: The abundances of the minerals plagioclase, orthopyroxene, hornblende (amphibole), and clinopyroxene in the Meyers Canyon tuffaceous sediments are consistent with derivation from the 6845 ± 50 yrs.B.P. climactic eruption of Mt. Mazama (Crater Lake).

Methods: Three samples of unconsolidated tuffaceous sediments were collected and provided by Kathi Peacock on 5/27/92. Samples were labeled "Lower Meyers", "Head wall", and "Just below Narrows". Representative sample splits were manually sieved to separate the >1 mm, 0.5-1 mm, and 0.18-0.5 mm size fractions. The constituents from each size fraction were visually identified, and abundances estimated. The 0.18-0.5 mm fraction from the "Head wall" sample was passed through a Franz Magnetic separator, to concentrate the magnetic (opx, hb, cpx) minerals. The "Narrows" and "Lower Meyers" samples were not separated magnetically.

The 0.18-0.5 mm fractions were allowed to settle through a heavy liquid ($\rho = 2.68$ g/cm^3), in order to separate the minerals ($\rho > 2.68$) from pumice and rock fragments ($\rho < 2.68$). After cleaning with ethanol, the mineral concentrates were visually examined to determine the mineralogy and mineral abundances within each sample.

Results: Sieving data for each sample:

	Size Range	Abundance(%)	Compositions
Head Wall	>1 mm	40	Fresh, rounded white pumice
		60	Angular, weathered volcanic and metamorphic rock fragments
	1-0.5 mm	20	Angular, weathered volcanic and metamorphic rock fragments
		80	Fresh, rounded white pumice
	0.18-0.5 mm	10	Angular to sub-angular, weathered volcanic and metamorphic rock fragments
		30	Angular crystals & crystal fragments: Plag >> Opx ≈ Hb > Cpx.
		60	Fresh, rounded white pumice
Narrows	>1 mm	20	Fresh, rounded white pumice
		60	Angular, weathered volcanic and sedimentary rock fragments
	1-0.5 mm	5	Plagioclase crystals and crystal fragments
		10	Angular to sub-angular, weathered volcanic and sedimentary rock fragments
		20	Flocculated clay balls
		65	Fresh, rounded white pumice

	Size Range	Abundance(%)	Compositions
Narrows (cont.)	0.18-0.5 mm	1	Angular to sub-angular, weathered volcanic and metamorphic rock fragments
		30	Angular crystals & crystal fragments: Plag >> Opx ≈ Hb > Cpx.
		30	Flocculated clay balls
		40	Fresh, rounded white pumice
Lower Meyers	>1 mm	10	Rounded white pumice to ≈1 cm, highly altered to clays.
		90	Flocculated clay balls.
	1-0.5 mm	Trace	Sub-rounded volcanic rock fragments + plag crystals
		5	Flocculated clay balls
		95	Moderately fresh (≈50% clays) sub-angular to round, white pumice
	0.18-0.5	5	Flocculated clay balls
		5	Angular crystals & crystal fragments: Plag >> Opx ≈ Hb > Cpx.
		90	Fresh to moderately fresh white pumice

Mineralogical data:

"Head Wall": 40% Plagioclase (variety: andesine), 30% orthopyroxene, 20% Hornblende, 5% Clinopyroxene, 5% miscellaneous weathered & rounded rock fragments, highly oxidized mineral fragments.

"Narrows": 90% Plagioclase (variety: andesine), 4% orthopyroxene, 3% Hornblende, 1% Clinopyroxene, 5% miscellaneous weathered & rounded rock fragments, highly oxidized mineral fragments.

"Lower Meyers": 87% Plagioclase (variety: andesine), 4% orthopyroxene, 3% Hornblende, 1% Clinopyroxene, 5% miscellaneous weathered & rounded rock fragments, highly oxidized mineral fragments.

Additional Data & Analysis:

All of the major mineral phases above have large amounts of clear, volcanic glass adhering to the mineral faces, indicating that these minerals were derived from the pumice and are not the result of erosion and sedimentary transport from the surrounding rocks. The pyroxenes contain a significant amount of Fe-Ti oxide inclusions. All the major phases are very angular, and are fragmented in a manner characteristic of primary volcanic fallout deposits.

The climactic eruption of Mt. Mazama (Crater Lake) at 6845 ± 50 yrs. B.P. produced large volumes of silicic pumice and ash. These fallout deposits were at least 30 cm thick in the Meyers Canyon area, based on the work of Lidstrom (1972). The mineralogy of these deposits is Plagioclase (andesine) >> orthopyroxene ≈ hornblende > clinopyroxene >>> magnetite ≈ ilmenite ± apatite (Druitt and Bacon, 1989). The mineral compositions and relative proportions of each phase in the Meyers Canyon samples are consistent with mineralogy of the climactic Mt. Mazama eruption.

Another potential source of young (i.e., <10,000 yr.) silicic eruptions in the Pacific Northwest is located at Newberry Volcano (≈1300 yrs.). However, the Newberry pumice had a limited distribution and only traveled as far as ≈60 km NNE from the source (MacLeod & Sherrod, 1988). Newberry pumice also lacks crystals (≤1%); Mazama pumice has ≈11% crystals, which is consistent with the observed amounts in the Meyers Canyon samples. Young eruptions at Mt. St. Helens (35,000-10 yrs B.P.) are generally less silicic than Mazama, and contain greater proportions of clinopyroxene relative to orthopyroxene and hornblende. Mt.St. Helens eruptions commonly contain biotite or cummingtonite, which are not observed in the Meyers Canyon tephra. Holocene eruptions at the Yellowstone caldera are characterized by abundant quartz and sanidine, which are also not observed in the Mazama or Meyers Canyon deposits.

Conclusion:

The mineralogy of the Meyers Canyon tuffaceous sedimentary samples is consistent with local reworking of primary pumice + ash + crystals from the 6845 ± 50 y.B.P. climactic eruption of Mt. Mazama. Other well-studied Holocene tephras in the Pacific Northwest are either of limited volume, or of incorrect mineralogy, to have produced the Meyers Canyon deposits. Although the mineralogical data in this study strongly support the Meyers Canyon-Mazama correlation, this relationship has not been unequivocally proven. Studies of the mineral, pumice, and ash chemistry should be completed to rigorously test this apparent correlation.

References cited:

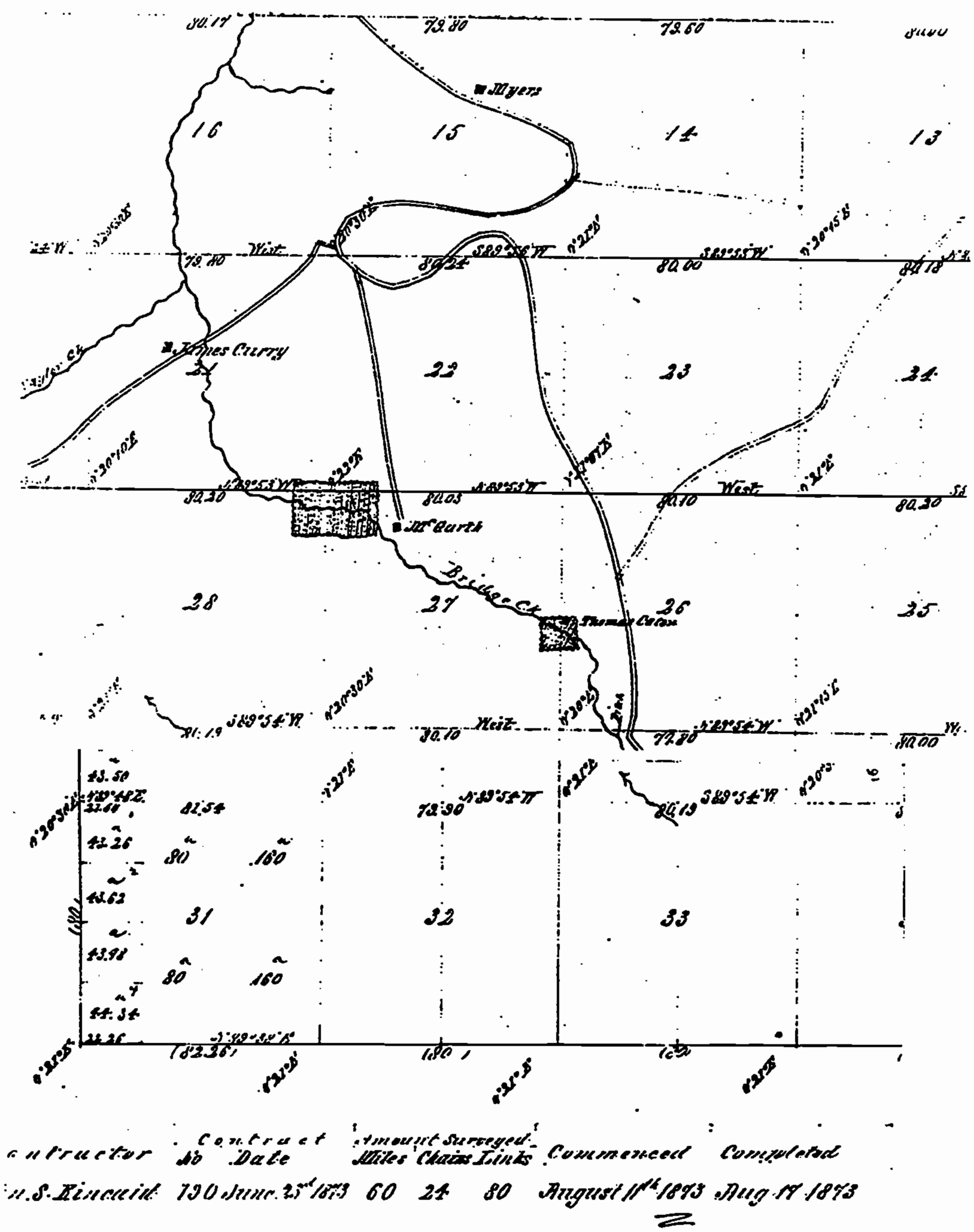
Druitt, T.H., Bacon, C.R., 1989. Petrology of the zoned calcalkaline magma chamber of Mount Mazama, Crater Lake, Oregon. Contrib. Mineralogy & Petrology, 101:245-259.

Lidstrom, J.W., 1972. A new model for the formation of Crater Lake Caldera, Oregon. Ph.D. thesis, Oregon State University, 85 p.

MacLeod, N.S., Sherrod, D.R., 1988. Geologic evidence for a magma chamber beneath Newberry Volcano, Oregon. J. Geophysical Res., 93-B9:10067-10079.

APPENDIX E

Appendix E. General Land Office map of Meyer's Canyon, completed August 17, 1873.



18

41

Township 11 South Range 20 East

North between secs. 14 and 15.

26.50 Dalles Wagon Road-course N.E. and S.W.

37.40 Dalles Wagon Road-course N.W. and S.E.

40.00 Set stone, 15x9x7, for 1/4 sec. cor.

50.00 Set Stone, 40x16x5, for cor. to secs. 10, 11, 14 and 15.

Land hilly; 3rd rate.

Scattering Juniper.

Bunch grass.

29

Willamette Meridian.

North between secs. 15 and 16.

2.25 Wagon road; course N.E. and S.W.

40.00 Set Stone, 14x4x7, for 1/4 sec. cor., from which,

A Juniper, 12 in. diam. bears North 75° E., 114 lks. dist.

54.25 Spring runs West.

65.50 Myers' house bears South 79° East.

80.00 Set Stone, 14x10x7, for cor. to secs. 9, 10, 15 and 16.

Land hilly; 3rd rate.

Scattering Juniper.

Bunch grass.

APPENDIX F

Appendix F. Station, location, and azimuth of incision width measurements based on aerial photography, and field measurements (1992 only).

Station	Location H.D. (m)	Azimuth (degrees)	Year 1951 (m)	1968 (m)	1979 (m)	1986 (m)	1992 (m)
TP1	3976	175	11	22	21	19	19
5	4036	165	15	22	28	33	29
TP2	4090	163	15	30	30	32	29
6	4116	112	17	23	30	26	30
TP3	4178	163	17	33	38	37	39
TP7	4632	179	52	51	66	57	55
13	4678	194	46	52	64	76	76*
TP9	4770	200	36	44	58	54	46
18	5110	133	14	21	23	24	22
TP15	5330	234	26	25	30	30	28
TP17	5464	161	20	23	23	26	26
TP19	5688	295	23	31	30	26	26*
Average			24	31	37	37	35
(Std.Dev.)			(13.4)	(11.4)	(16.3)	(16.9)	(16.4)

* - Estimated