HOLOCENE CHANNEL CHANGES OF CAMP CREEK;

AN ARROYO IN EASTERN OREGON

by

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In the stratigraphic record of Camp Creek are episodes of fluvial scour and fill thousands of years old. Radiocarbon dates and the Mazama tephra, which serves as a stratigraphic time line, temporally bracket episodes of vertical aggradation and incision. Before 9000 years B.P. the valley floor was scoured to the Tertiary bedrock. Aggradation dominated since that time. Large cut-and-fill structures indicate that two periods of erosion occurred prior to incision of the modern arroyo. The first occurred before 6800 yr B.P. and the second occurred approximately 3000 years ago. The modern arroyo-channel flows at or near the Tertiary bedrock, is entrenched as much as nine meters in the valley-fill alluvium and is thought to have originated during the late 19th century.

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CHAPTER I

INTRODUCTION

Studies of Late Quaternary alluvial deposits in arroyos furnish information about the timing of late Pleistocene and Holocene geomorphic processes. They make possible the reconstruction of fluvial responses to past climate changes. The present study is an attempt at reconstructing the alluvial history of a deeply incised creek where it flows through a broad flat valley in arid eastern Oregon. Understanding processes that govern arroyos--climate change and culturally-induced landscape changes--may facilitate prediction and mitigation of future channel trenching.

Few stratigraphic investigations of alluvium have been carried out in the semi-arid Pacific Northwest, and no such investigation of arroyos has been done in eastern Oregon. Comparison of results from this area with those from elsewhere in the northwestern and the southwestern United States may lead to insights about the history of arroyo development and its causes.

The Spanish term "arroyo" means river or streambed. In the American southwest it refers to a trench of rectangular cross-section that has been excavated in alluvium and in the floor of which runs a stream channel (Graf, 1988). Initially coined by R.E. Dodge in 1902 (Tuan, 1966), the word "arroyo" became synonomous with "gully" and "wash." The frequent use of these terms interchangeably in the literature has led to some confusion. According to Hodges (1974), an arroyo is characterized as a deeply entrenched channel in alluvial fill with vertical walls developed on both sides of the channel. A gully is smaller than an arroyo, but larger than a rill; it is more than two feet in depth but less than ten feet in width and must have vertical walls on both sides of the channel. A wash is typically shallow and characterized by less spectacular channel forms than the arroyo. A wash may have some vertical wall development, but it is commonly less than five feet high with a large width to depth ratio.

In the southwestern United States, arroyos have been of interest to the scientific community for over ninety years (Bryan, 1925; Bailey, 1935; Leopold et al., 1954; Tuan, 1966; Balling and Wells, 1990). Valley floors once covered by shallow stream beds and covered by grasses and clumps of trees were suddenly transformed into sagebrush covered flats with deeply incised stream channels (Bryan, 1928; Bailey, 1935; Peterson, 1950; Schumm and Hadley, 1957; Graf, 1988). Sediment losses were greatly increased. Interest in arroyo formation developed out of the negative effects of gullying and associated soil erosion and sedimentation. Fertile, irrigated valley floors, the most desireable sites for human settlement and economic activities, suddenly became less inhabitable. Livestock production, the backbone of the rural economy, suffered from the loss of meadows of grass and sedge. The loss of riparian vegetation caused the water tables to drop. The organic matter needed to retain water and draw it up from the water table below gradually disappeared.

Early hypotheses for arroyo cutting implicated thoughtless human action because of the coincidence of white settlement and arroyo formation. In time, researchers broadened their point of view and hypothesized that historical climate changes, such as variation in rainfall intensity, might lead to entrenchment. Cooke and Reeves (1976) developed a model of arroyo formation that divided causation of arroyos into three categories: random frequency-magnitude variations of climate, secular climatic changes, and human land-use changes. Their model holds that arroyos may be formed in a multitude of ways and isolating a single mechanism of causation is difficult and most probably impossible. Investigators tended to over-simplify the complex processes and conditions that influence arroyo development.

To develop an explanation of arroyo formation, a complete historical record of the local and regional phenomena is needed. The goal of this study is to reconstruct the history of alluviation and degradation of the alluvial fill of Camp Creek and to reconstruct the past morphology of the channels and wet meadows of the creek. The stratigraphy of Camp Creek, Oregon, gives evidence of cut-and-fill cycles, which provide evidence for the timing and nature of fluvial adjustment and its relationship to regional climatic shifts. The present channel is sinuous, and it is entrenched within vertical walls as much as nine meters into the valley-fill alluvium. Data collected during this investigation have permitted evaluation of several working hypotheses as to possible climatic, vegetational, and human influences on landscape evolution. They have led to a formulation of a chronology of evolution of the arroyo at Camp Creek. The results of this stratigraphic study are, nevertheless, only the beginning of much needed research at this site.

Research Questions

This study of the stratigraphy of Late Quaternary alluvium in the banks of Camp Creek was undertaken to gain evidence about two topics: one, the history of the processes of alluviation and degradation of the alluvial fill; and, two, the history of the morphology of the channels and wet meadows of the creek where it flows through Price Valley.

To understand the history of deposition, erosion, and stable soil forming periods, the following questions were asked:

1. What are the major sediment and soil stratigraphic units in the alluvium of Camp Creek?

2. What depositional sedimentary facies are visible within the stratigraphic units?

3. What type of boundaries exist between stratigraphic units? Do they represent deposition, erosion or periods of stability and soil development?

4. If soil development is present, what are its characteristics?

5. When did deposition of stratigraphic units occur and when did soils develop in the sediment?

6. What is the history of channel incision and floodplain development during the formation of the stratigraphic units and soil development in this valley?

7. How does the stratigraphic record compare to available data of vegetation succession and climate history, which regionally expresses climatic variations that occurred during the Holocene?

To understand the history of the morphology of the channels and wet meadows, the following questions were asked:

1. How does the modern morphology of the creek compare to the arroyo and the paleochannels evident in the stratigraphy?

2. Do cross-sections of channels indicate a change in width or depth over time, and is there evidence of deep incision prior to the modern arroyo?

3. What is the evolutionary history of wet meadows found in the alluvial soils of the valley?

Thesis Contents

The first chapter in this thesis includes the introduction with the goals of the study stated and an outline of research questions asked during the course of the study. The chapter ends with previous studies on arroyos, alluviation and climate. The second chapter contains a description of the study site and the research methods used during the course of the study. Chapter three presents the results of the identification of stratigraphic units. Chapter four presents the results of the wet meadow organic matter content of the soils and paleosols, as well as the results of the geometry of the channels and mean annual discharge calculations. Finally, chapter five begins with an interpretation of climate history in relation to the fluvial behavior of Camp Creek, and ends with the conclusions.

Previous Studies

An enormous amount of research and literature has been devoted to the study of arroyos, particularly in the southwestern part of the United States. Much research has also been done on Holocene climate change and the resulting responses of fluvial systems throughout the western United States. These studies show that streams experience alluviation, degradation and stability in response to climate change. Research and literature on past climate change in the Pacific Northwest include glacier, vegetation succession and lake level fluctuations, and tree-ring records. These three areas of research are discussed below and set the stage for the analysis of the geomorphological aspects covered in this study.

Arroyos: Climate, Livestock and Beaver

During the early twentieth century investigations of arroyo down-cutting in the southwest saw differing theories of causation begin to emerge. Some investigators postulated that human misuse and abuse of the land and destruction of plant cover through the introduction of livestock, farming, timber cutting, mining, and roadways were responsible for the entrenchment of arroyos at their research sites (Bailey, 1935; Antevs, 1951). Impressed with the evidence of arroyo cutting and filling in prehistoric times before major alterations by man, other researchers suspected a climatic cause for the cut-and-fill cycles of arroyos (Bryan, 1928; Peterson, 1950; Miller, 1957; Love, 1980). One theory suggested a change to drier climate (Bryan, 1925); the other theory postulated by Dutton in 1882 and Huntington in 1914 was that a shift to wetter climate would set the stage for streams to erode. Richardson in 1945 proposed a third theory, that a change either to the drier or to the wetter would initiate incision (Cooke and Reeves, 1976). Finally, Leopold (1954), Miller (1957) and Schumm and Hadley (1957) theorized that a change in rainfall intensities, such as an increased frequency of heavy rains, could initiate arroyo cutting. Within the Zuni River drainage basin, New Mexico, Balling and Wells (1990) observed changes in arroyo activity which appeared to be synchronous with statistically significant changes in local and regional climate. Their study showed that arroyo "infilling and stability occur as precipitation patterns change to fewer intense summer storms and less annual rainfall." High-intensity summer storms and increased runoff enhanced channel erosion.

In general, erosion by geologic uplift with increased gradient of the streams was rejected as a cause of arroyo cutting because erosion of equal magnitude affected streams of different drainage systems flowing in all possible directions (Bryan, 1925; Bailey, 1935).

Since climatic variations and human land use change both occurred in the period of arroyo initiation in many studies, the causation of arroyo formation remains controversial to this day. There is general agreement that large numbers of livestock were introduced around 1870 (Peterson, 1950), and that the 1880s were especially important as entrenchment years (Cooke and Reeves, 1976). Yet, the complexity of the problem is underlined by the discovery of arroyos in areas that had never been grazed and the absence of arroyos in some areas that were heavily grazed (Peterson, 1950). It is generally accepted that overgrazing may be a factor, but that climate plays an important role in the aggradation or degradation of a stream system.

Another modification of the environment gaining the attention of investigators was the removal of beaver by fur trapping in the 1800s (Nagle, 1993). Beaver build dams which reduce a stream's ability to transport sediment by reducing the slope of the stream channel. A beaver dam spreads out the stream flow across a wider area of the floodplain thereby reducing its velocity and its ability to erode. Sedimentation occurs, vegetation stabilizes the streambanks and the water table rises. With beaver removal the sediments stored by the beaver dams are downcut by streams and a narrow, deep channel forms.

The trapping of beaver began in earnest by 1818 and extended until 1839, in what is known as the Snake Country of Oregon. This area includes the southeastern part of Oregon, and the drainage of Camp Creek. The Hudson's Bay Company deliberately and systematically sought to trap all of the beaver in the territory surrounding their most productive trapping country. Their aim was to make it unprofitable for their competitors to trap near their valuable country. By 1831, the Snake Country was exhausted of beaver, leading to virtual extinction of the beaver in this region (Rusco, 1976). In 1825-26, Peter Skene Ogden returned from an expedition up the Crooked River in the vicinity of Camp Creek, and made references to plentiful beaver along different Forks of the river. In 1858, a gold prospector, Andrew S. McClure, took note of the considerable number of beaver on Camp Creek. Beaver dams were prevalent and mentioned in the journals of military personnel into the 1860s particularly along the Crooked River (Buckley, 1992). Although beaver appeared to be plentiful into the mid-1800s in the vicinity of Camp Creek, today evidence of only two beaver dams exist within the 6.4 km (4 mi) study site.

Buckley (1992), through historical analysis of diaries and journals of the mid-nineteenth century, has narrowed the dates of initiation of incision of Camp Creek to between 1876 and 1903, and possibly 1885 and 1903. This coincides with the timing of entrenchment found in the American southwest, where the 1880s were particularly important years.

Alluvial History

Researchers agree that streams respond to climate change. Changes in rainfall and temperature as well as variations in distribution, frequency, magnitude, intensity, and duration of storms affect stream hydrology and its corresponding gradational regime (i.e., aggradation, degradation or stability) (Bryan 1925; Melton, 1965; Brice, 1966; Hodges, 1974; Schumm, 1977, 1987). Many hypotheses and theories have been developed to explain relationships between stream aggradation, degradation, and conditions of relative stability. However, researchers do not always agree on what gradational response results from what set of climatic conditions.

Studies show that climatic variations have resulted in adjustments that involve periods of both deposition and erosion in streams (Knox, 1972; Baker and Penteado-Orellana, 1977; Brakenridge, 1980, 1984; Patton, 1981; McDowell, 1983; Martin, 1992; May, 1992). They attribute the gradational response of streams in the southwestern and midwestern United States to climatic changes which occurred in the Holocene.

Schumm and Brakenridge (1984) recognized four difficulties in explaining gradational responses to climate change: 1) different types of rivers have different responses; 2) effects of similar climate or hydrologic change differ among drainages; 3) river sensitivity greatly influences how a river adjusts to external influences; and 4) once change has been initiated, the response of the river will be complex. However, even given these four difficulties in identifying causality, if the type of a river can be identified, its response can be estimated.

Hereford and Webb (1992), studying the historic variation of warm-season rainfall in the southern Colorado Plateau, related the sediment load of the Colorado River to climate change. Results indicate that the frequency and amount of rainfall were larger during the period of high sediment load, while lower frequency and lower rainfall were associated with periods of low sediment load and floodplain reconstruction.

In the Pacific Northwest, near Vantage, Washington, and the Columbia River, gully sections were examined and values of sediment yield, sediment concentration and runoff were estimated, providing a history of aggradation, degradation and stability at Bock Spring Gully and Rye Grass Coulee (Pavish, 1973). Relationships between climate and sediment yield show erosion occurred during the Late Pleistocene glacial period (14,000 to 10,000 years ago) and aggradation dominated during the early and mid-Holocene (8000 to 3000 years ago). The Neoglaciation (3000 years ago to present) was characterized by minor erosion, but increased moisture promoted vegetation cover and alluviation.

A study in the upper Kootenai River Valley of northwestern Montana, Clearwater Valley of north central Idaho, and in the upper Ladd Creek drainage of northeastern Oregon (Cochran, 1988) developed a regional history of the gradational processes and events in the Pacific Northwest interior. Climatic variations of the Holocene influenced gradational responses of streams during four major alluvial cycles. The first aggradational episode occurred after ca 11,000 yr B.P., but before 8100 yr B.P., followed by an aggradational period which began before 8100 yr B.P. and ended before 6700 yr B.P. The second aggradational phase began before 6700 yr B.P. and ended ca. 4200 yr B.P. The third aggradational phase is dated between 4200 and 2000 yr B.P. The fourth aggradational phase dates between 2000 yr B.P. and the present. The author was unable to determine direct causal relationships of climate and gradational responses to streams, however he used paleoenvironmental data (alpine glaciations and vegetation succession) to infer that floodplain stability occurs during periods of cooler temperatures and more effective precipitation, while erosion occurs at the beginning of warm-dry periods.

Although little literature is available on alluvial studies in eastern Oregon, alluvial studies indicate that the alluvial record can be compared to past climate changes and that fluvial response to past climate change indicates that aggradation has dominated during the Holocene in the Pacific Northwest. Between aggradational periods are sporadically spaced erosional episodes.

Climate History

Various lobes of the Cordilleran ice sheet expanded south of the Canadian border of today, to approximately the 48th parallel, between ca. 17,000 and ca. 12,000 yr B.P. (Waitt and Thorson, 1983). The maximum extent of ice was reached at ca. 15,000 yr B.P. although minor advances and episodes of ice stagnations occurred until ca. 13,000 yr B.P. The Cascade Range experienced alpine and valley glaciations in Washington (Miller, 1969; Porter, 1976) and Oregon (Scott, 1977) during this time. The Wallowa Mountains in north eastern Oregon (Crandell, 1967) also had mountain glaciers expanding into major valleys.

The Cordilleran ice sheet began to disappear rapidly after 13,000 yr B.P. By ca. 11,000 yr B.P., the Pacific Northwest began to experience a general warming trend as inferred from pollen records (Mack et al., 1978ab; Heusser et al., 1980; Mehringer, 1985). However, between ca. 10,000 and ca. 7000 yr B.P., a brief episode of alpine glaciation occurred at Glacier Peak and Dome Peak, Washington (Miller, 1969; Beget, 1983) and in the Wallowa Mountains of Oregon

(Crandell, 1967). Porter et al. (1983) believed this indicated a cool and moist early Holocene. This interpretation, however, conflicts with evidence for warming during the early Holocene in the pollen records of the southwestern Columbia basin (Barnosky, 1985) and pronounced aridity and drought in Okanogan Highland sites of eastern Washington (Mack et al., 1978).

Between ca. 9000 yr B.P. and today, the Holocene pollen record indicates that minor climate variations occurred, with a warm and dry period dating between ca. 7000 and ca. 4000 yr B.P. Coolness and moistness increased between ca. 4000 and ca. 2000 yr B.P. The pollen record of the last 2000 years is characterized by pollen spectra comparable to modern vegetation (Mack et al., 1978ab; Heusser et al., 1980; Mehringer, 1985).

Porter and Denton (1967) determined that a Neoglacial advance in the North American Cordillera followed the warmer "Hypsithermal" approximately 4600 years ago. A major ice advance culminated 2600 to 2800 years ago which was followed by a long period of milder climate. Marked advances of glaciers occurred again during the last several centuries, perhaps attaining their maximum Neoglacial positions during the period commonly known as the "Little Ice Age."

Eastern Oregon has only one pollen record close to Camp Creek. At Diamond Pond, Harney County, a vegetation history of the last 6000 years was reconstructed using the varying abundance of juniper, grass, sagebrush, and greasewood pollen, as well as aquatic and littoral plant macrofossils found in silts and sands (Wigand, 1987). This record showed that between 6000 to 5400 yr B.P. greasewood and saltbush pollen dominated. This indicated a shadscale desert. Accumulation of alternating silts and sands lacking aquatic plant macrofossils and pollen reflected ephemeral ponds with a water table 17 m below present level, along with considerable erosion of maar slopes. At 5400 to 4000 yr B.P., sagebrush expanded, and finely laminated clayey silts indicated a perennial pond existed. Abundant juniper and grass pollen dominated the record from 4000 to 2000 yr B.P., reflecting an extensive juniper grassland. The deepest late-Holocene pond occurred ca. 3700 yr B.P. From 2000 to 1400 yr B.P., increased sagebrush pollen reflected reduced effective moisture and reexpanding sagebrush steppe, and macrofossils suggested a shallow pond. Between 1400 and 900 yr B.P. grass pollen was more abundant. This suggested a return to greater effective moisture, which resulted in a higher lake level. At 500 yr B.P., increased greasewood and saltbush pollen indicated drought, with shallow, brackish water. Moister conditions, with abundant juniper and grass pollen, are reflected between 300 and 150 yr B.P., along with deeper, fresher water in Diamond Pond. By the mid 1800s, sagebrush had expanded again, and macrofossils indicated that the water was shallower.

L.T. Jessup (1935) related precipitation and tree growth in the Harney Basin. Using juniper trees, despite their inherent tendency to grow unpredictably, Jessup constructed a tree-ring chronology using four trees, and compared it to precipitation data going back to 1898. He examined the period 1760 to 1930 using the variation of each ring from the mean and expressed it as a percentage. His results showed precipitation was greatest during the years of 1785-90, early 1800s, 1810, 1860-1870, 1885 and 1905.

Keen (1937) studied 265 stump sections of Ponderosa Pine in eastern Oregon. His work contributed to the discussion of the influence of climate on tree growth. Keen arrived at an index of climate history going back to 1268 A.D. The chronology showed periods of lower than average tree growth or drier conditions occurred from 1739 to 1743, 1755 to 1760 and 1840 to 1852. Higher than average tree growth or wetter conditions occurred from 1745 to 1755, 1765 to 1777, 1800 to 1820, and 1855 to 1870.

More accurate statistical methods have been applied by Graumlich (1987, 1986) and Fritts and Shao (1992). Graumlich (1987) contrasted three drought sensitive regions defined in her study of Washington, Oregon and northern California, over the period 1675 to 1975. Reconstructing climate in the Columbia Basin (which includes Camp Creek), Graumlich found drought to have occurred around 1680, 1750s, 1780s, 1790s, 1840s, 1865 to 1895 and the 1920s and 30s. Wet periods occurred from 1810 to 1835, 1740 to 1760, and 1695 to 1715. The most severe drought time, according to tree-ring records for the Columbia Basin, was 1889. Of the twenty most severe drought years, the 1929 year ranked seventh.

Fritts and Shao (1992) reconstructed seasonal and annual temperature, precipitation and sea-level pressure by mapping tree-ring width indices using computer programs and models. They reconstructed the 17th-19th century anomalies in sea-level pressure, temperature and precipitation expressed as departures from instrumental 1901-1970 mean values. Their results show that the Pacific Northwest experienced enhanced precipitation during the Little Ice Age, suggesting that storms moved through the area more frequently than during 1901-1970.

Conclusions drawn from analysis of tree rings, lake levels, instrumental records, and descriptions in southeastern Oregon, by Hatton (1989), show large variability of the climate for the past several centuries. No evidence was found of extensive humid periods that resulted in high lake levels such as those evident during the Pleistocene Period, which etched lake terraces and wave-cut benches into the landscape over 200 feet (62 m) higher than the present day lake beds. However, instrumental records and descriptions do indicate considerable water existed in the lakes during short spans in the last 100 years, and at other times dried up almost completely exposing wagon ruts made in the 1840s.

Hatton described severe winters which resulted in large livestock losses in 1874-75, and 1880-81. A severe drought between 1885 and 1889 was followed by heavy snow and extreme cold in 1889-90, and heavy livestock loss resulted again. By the turn of the century a return to a more humid climate in the region may have lured agricultural settlement to eastern Oregon. An above-average precipitation (nearly 150 percent of a long-term average) resulted in misleading claims of availability of moisture for farming.

In summary, Pacific Northwest glacier records, pollen records, lake-level records, tree-ring records, and historical analyses indicate that the early to mid-Holocene in the Pacific Northwest was a warm and dry period. Between 4000 and 3000 yr B.P. the Neo-glaciation brought a cooler and wetter climate. Pollen records indicate that a dry period occurred in eastern Oregon 2000 to 1400 yr B.P. followed by a wetter period 1400 to 900 yr B.P. Drier conditions prevailed from 900 to 500 yr B.P. and moister conditions returned ca. 300 to 150 yr B.P.

CHAPTER II

DESCRIPTION OF STUDY SITE, METHODS

Study Site

The Setting

Camp Creek is located in central Oregon in Price Valley (Figure 2-1). The mouth of the creek is approximately 71 km (43 mi) southeast of Prineville, Oregon, and is a left bank fourth order tributary of Crooked River (Hydrology and Hydraulics Committee, 1976). Price Valley lies at the foot of the Maury Mountains, which rise abruptly to the north. Among the streams that flow into Camp Creek from the south are the Middle Fork, which drains from Logan Butte and points southwest, and the South Fork, which drains the northern slopes of Hampton Butte and the uplands that separate Price Valley from the plateau to the south. The drainage area of Camp Creek is 300 sq km (180 sq mi).

The study site is 20 km (12 mi) upstream from the mouth of Camp Creek. It spans a four mile long reach from the confluence of Parrish and Indian Creeks downstream to a point

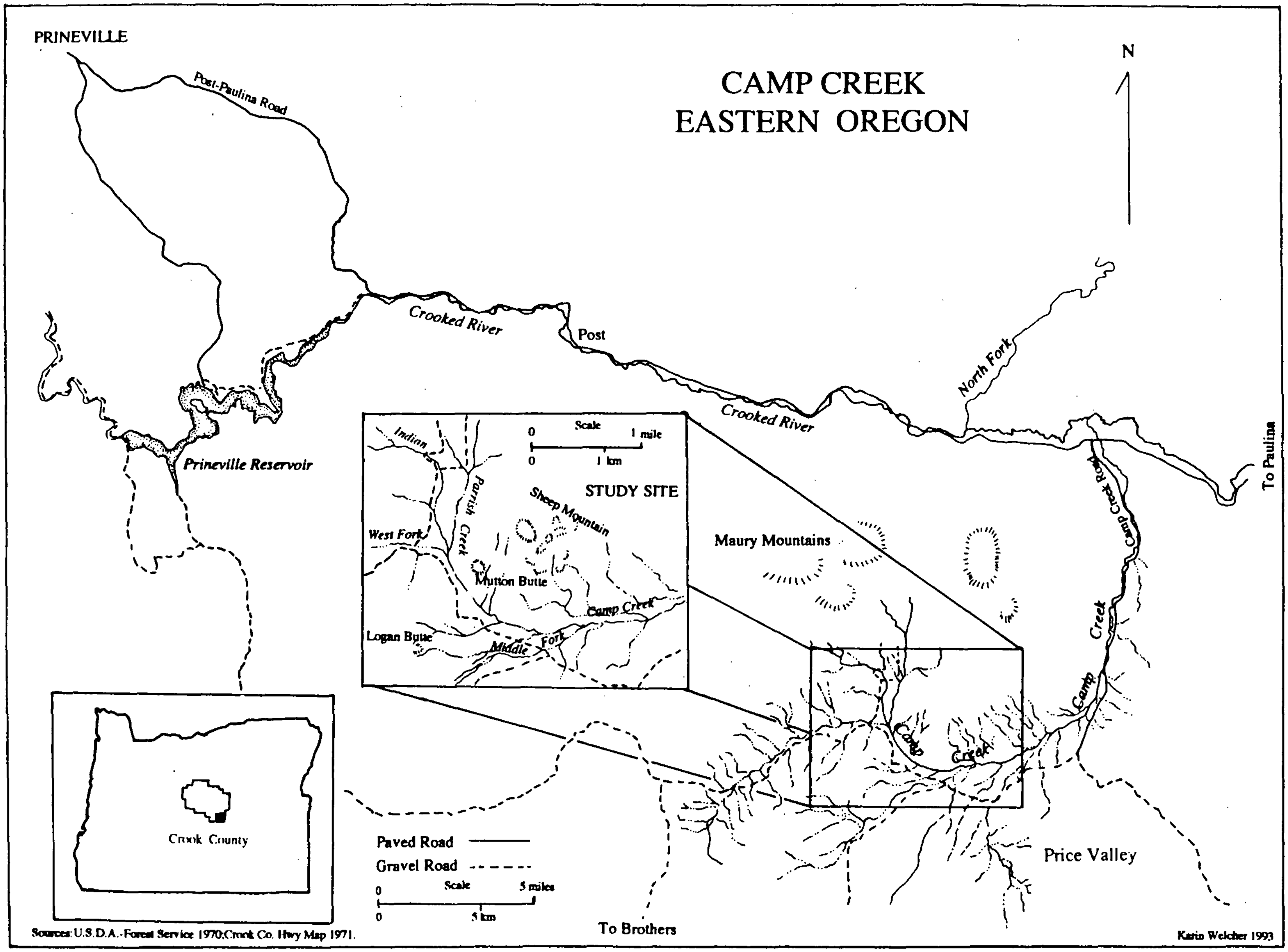


FIGURE 2-1. Study Site Location.

several hundred yards above the confluence of Middle Fork Camp Creek (Pole Creek) and Camp Creek. Included in the study site are the private properties of two ranchers and BLM land. Elevation within the study area ranges from 1234 to 1270 m (4060 to 4180 ft) above sea level.

This site was selected for several reasons. The deep vertical incision of the arroyo made by Camp Creek provides an excellent opportunity to map the stratigraphy and cut-and-fill cycles. Also, several studies have focused on Camp Creek. An exclosure was built by the BLM in 1966 and 1974 to exclude cattle from the riparian zone (Winegar, 1977; Elmore and Beschta, 1987). There are now about 6 km (4 mi) of fenced channel in Price Valley. The upper portion of the fenced exclosure has accumulated 2 to 3 m (6 ft) of sediment (Oral communication, W. Elmore, 1992) but is upstream of a roadway built with large boulders by the BLM and which crosses the arroyo within the exclosure. The roadway is effectively acting as a dam. Downstream of the roadway, the amount of sediment accumulation decreases. No quantitative data have been analyzed on groundwater levels in or near the stream channel, although government personnel observed that stream base flow is higher inside the exclosure than above or below it. However, no flow measurements are available prior to the building of the exclosure and no data are available from which to judge changes before and after construction of the exclosure.

Barber (1988) researched and mapped the groundwater system near the exclosure. His findings indicate that the water table contour lines run perpendicular to the creek through most of Price Valley and subsurface flow runs parallel with the creek. Near the base of the exclosure the subsurface water flow bends toward and drains into the creek.

Another study was done by Buckley (1992) reconstructing the history of the basin from 1826 to 1905. Through historical documentation Buckley determined that the initial downcutting of the modern arroyo occurred in the early 1890s.

Geology

The Camp Creek watershed is underlain by the mid-Eocene and Oligocene aged Clarno Formation which is composed of andesitic and rhyolitic lavas. Lying above the Clarno Formation are the Oligocene John Day Formation, the Miocene Picture Gorge Basalt of the Columbia River Basalts, and a capping of mid-Pliocene and Pleistocene tuffaceous Rattlesnake Formation (Walker et al., 1991).

Price Valley is cut through soft, easily eroded John Day sediments (Bowman, 1940). Picturesque John Day beds surround the study site with outcroppings of banded red, green, and cream colored tuffs. The John Day Formation is composed largely of andesitic to dacitic tuffaceous claystone and air-fall tuff. Interlayered in this material are ash-flow tuffs, silicic lava flows, and mafic lava flows. These Oligocene age deposits range in age from 37 to 19 m.y. and are thought to have been derived from vents within or beneath the Cascade Range. The thickness of the formation varies considerably. It is up to 1,300 m (4,276 ft) thick in its western most facies (Robinson, 1984). At Logan Butte, total thickness of the John Day beds is given at approximately 912 to 1,216 m (3,000 to 4,000 ft) (Mote, 1940). This variation in thickness for the most part is due to Oligocene erosion.

The alluvial sediments of Price Valley are composed of John Day Formation material. John Day parent material has weathered and diagenetically altered to montmorillonite and clinoptilotite clays (Robinson et al., 1984). Therefore, any developed soils inherit a clay texture from the parent material. Soil cores collected on Camp Creek in 1985 indicate that Price Valley fill is underlain by a sedimentary claystone at a depth of 9 m (30 ft). The claystone acts as an aquiclude, which forms a perched water table (Barber, 1988). Camp Creek has incised to this resistant Tertiary bedrock. Samples of the bedrock have been positively identified as part of the John Day Formation (E. Bestland, oral communication, 1992).

Geomorphology

Price Valley lies at the southern foot of the Maury

Mountains which rise abruptly to the north. The valley has been excavated approximately 304 m (1000 ft) deep and 3.2 km (2 mi) wide through John Day sediments. In between the hills and ridges along the valley walls, erosion has produced outcrops characterized by a badland topography with brilliant and varied colors. Logan Butte is a prominant landmark which lies on the west end of the valley and displays the red, green and cream colors of the John Day sediments and in which well-preserved bones of extinct animals have been found.

On the northern side of the valley are a series of alluvial fans which issue from Sheep Mountain which rises more than 425 m (1400 ft) off the valley floor. Camp Creek has dissected the bases of these alluvial fans and this stratigraphy is visible in the exposures of the channel walls of the creek. A series of east-west trending abandoned floodplain terraces follow the northern edge of the valley and mirror the gentle slope of the valley, which does not exceed 2%. Remnant terraces which rise as much as 42 m (140 ft) off the valley floor represent a much older period of alluvial development.

The floor of Price Valley presents the look of a smooth sagebrush covered plain. However, when traversing the valley the valley floor gives way to a surface intersected by arroyos. The main arroyo known as Camp Creek follows the longer axis of the valley and is incised as much as 9 m (30 ft) and is measured to more than 26 m (85 ft) in width. Camp

Creek is joined by side tributaries which also are deeply incised. Soil piping is a widespread occurrence in the mid-channel section of Camp Creek. The creek itself is confined within the vertical walls of the arroyo. The Tertiary John Day Formation bedrock intermittently crops out of the bottom of the arroyo.

The arroyo walls are composed of stratigraphic units which represent different episodes of deposition and erosion. Cut-and-fill cycles are visible throughout the study site. The arroyo walls are made up predominantly of silts and clays and reveal laminae and beds of alluvium derived from the John Day Formation. One distinct stratigraphic unit is a white Mazama ash bed. This unit lies between 1.5 and 3.8 m (5 and 12 ft) from the surface of the valley floor and is clearly visible within the arroyo incision. On the north bank the creek has dissected alluvial fans. Here a sheet of cobbles as much as 1 m (3 ft) in height underlies finer silts and sands. At the base of other reaches along the vertical wall are discontinuous beds of larger gravels. Stratigraphic units show that soil development was spatially variable. In the exposures upstream, dark soils indicate a wet-meadow existed, while downstream these stratigraphic units show no wet-meadow soil characteristics.

Soils

Soils on the basin floor of Price Valley are identified as Mollisols on terraces and floodplains of eastern Oregon. These include the Dayville, Kimberly and Powder series (S.C.S., 1986).

The Dayville Series soils are fine-silty over sandy or sandy-skeletal, mixed, mesic Cumulic Haplaquolls. They are somewhat poorly drained soils that formed in recent alluvium on bottom lands and low alluvial fans. They occur on slopes of 0 to 2 percent and elevations of 669 to 1216 m (2200 to 4000 ft). These soils have very dark brown to very dark grayish brown A horizons that overlie very dark grayish brown C horizons (S.C.S., 1981). The process of melanization--darkening of the soil by addition of organic matter--is the dominant process in Mollisols. The aquolls have characteristics associated with wetness. They are characterized by extensive iron reduction and loss due to prolonged periods of water saturation in the presence of large amounts of organic matter. They are commonly gray with olive hues in their subsoils under a black epipedon (Buol et al., 1989).

Because of the montmorillonite parent material and its 2:1 shrink-swell characteristics, another soil, a Vertisol, appears in the wet-meadow section of the study site found in the upstream reaches. Vertisols are classified as soils over

50 cm deep to lithic or paralithic contact that have cracks at least 1 cm wide at a depth of 50 cm during part of most years (Buol et al., 1989). Such soils at Camp Creek have the following properties: a clay texture; a dark color with a low chroma; no evidence of illuviation; a strong granular structure in the upper 15 to 50 cm; calcareous; a high coeficient of expansion; extremely sticky when wet; montmorillonite as the dominant clay mineral; and little weathering.

Vegetation

The vegetation of Price Valley varies with altitude. Above 1,216 m (4000 ft), junipers, sage and grasses are abundant. Below 1,216 m (4000 ft), Price Valley is an abandoned floodplain covered in sagebrush, rabbit brush, and grasses. Confined within the Camp Creek arroyo is a riparian plant community consisting of grasses, rushes, sedges, aster, buttercup, dandelions, common plaintain, dock, flax, thistle, peppermint, wild rye, cattail, wild rose, current, and willow. Mean annual precipitation for the watershed ranges between 275 to 575 mm (11 to 23 in) per year. The climate is characterized by hot, dry summers, and cold winters.

Study Design and Methods

Field study, laboratory study, and information from previous works were sources of the data for this investigation of the history of alluviation and history of the morphology of the channels and wet meadows.

The depositional environments or circumstances of formation of the major sedimentary units were determined from the following characteristics: stratigraphic position in sequence, sedimentary facies, topographic position in the Camp Creek drainage, and the evidence of paleosol development. Deposits exposed in stratigraphic sections were correlated within the study site by tracing continuous exposures. Discontinuous sedimentary units were correlated by reference to a volcanic ash marker bed, soil (paleosol) stratigraphic units, repeating sedimentary sequences, and radiocarbon dating.

Compilations of evidence from previous work include tree-ring indices and pollen records for the area surrounding Camp Creek and literature related to the reconstruction of past environments in the northwest. This information was used to determine whether a relationship exists between climate and channel behavior.

Field Study

Field work was accomplished during the summer and fall of 1992. Downstream of the confluence of the West Fork Camp Creek and Camp Creek, exposure walls were selected based on local stream conditions. A well-exposed bank that revealed the time-stratigraphic marker of volcanic ash was the main criterion for selecting a profile. The exposed channel wall was cleaned with a trowel. A section of the selected profile was gridded with string. The wall was then sketched, sampled and photographed. Detailed notes and descriptions were taken. Cross-sectional measurements were taken of the modern channel and arroyo and of the paleochannels found on the exposed walls.

This detailed mapping and sampling of sediments made it possible to define the geometry of geomorphic and sedimentary features and to laterally trace the stratigraphic units. Evidence came from describing soils and alluviated stream sediments. Sediments were described by reference to Munsell color designations, textures, bed and lamina thickness and orientation, degree of sorting and rounding, and the character of the boundaries between major depositional units. Soils were described using procedures of Soil Taxonomy (Soil Survey Staff, 1975): Munsell color designations (Munsell, 1975), texture, structure (pedologic), degree of biogenic disturbance, and the nature of the boundary of sedimentary units and soil horizons.

Defining Stratigraphic Units

Stratigraphic units were identified along the creek's vertically exposed walls. Stratigraphic information used in defining stratigraphic units included the following:

1. Abrupt horizon boundaries indicated temporally distinct episodes of deposition or erosion.

2. Less well-defined boundaries were considered indicative of continuous deposition.

3. Laterally continuous units found from one profile to another profile were considered more likely to be major stratigraphic units.

4. Soil texture helped in the interpretation of defining stratigraphic units. A pause in deposition or a change in depositional environment would be reflected in a change in soil texture. Layers of contasting soil texture were commonly associated with a buried soil.

5. Color, soil structure and the presence of roots, charcoal, and carbonates also delineated the stratigraphic units.

6. The relative position of the stratigraphic units in relation to the Mazama tephra determined their chronology. Using this ash unit as a time-stratigraphic time marker, the

relative position of stratigraphic units could be ascertained and easily traced laterally.

Cross-section Measurement

At each sampled profile, survey sites were established for cross-section measurements. A straight reach of the creek was selected adjacent or near to the study profile. The channel cross section was then surveyed perpendicular to the thalweg using a level and a measuring tape. The active channel was identified from banktop and vegetation boundaries.

Each paleochannel found at a profile along the channel exposure was measured horizontally from highest margin to highest margin of the stratigraphic unit it cut and vertically at its deepest point. The width of the arroyo was measured at each profile. If surface channels were evident on the abandoned floodplain above the confined arroyo they were measured with the same techniques.

Facies Identification

Recognizable facies were identified through the determination of the distribution of bedforms and the presence of sedimentary structures, including cross-bedding and fining upwards sequences. Vertical accretion deposits are formed on the floodplain, primarily as a result of overbank floods (Allen, 1964). These deposits or topstratum deposits were identified in the field as being finer in texture than lateral accretion deposits, and if present were identified as floodplain deposits. Lateral accretion deposits are coarse in texture and are considered channel or substatum deposits. When these deposits were present they were considered to be bar or point bar and channel lag deposits.

Tephra Identification

A major difficulty was posed by the presence of other beds of volcanic ash other than Mazama found in the stratigraphy. In the field, Tertiary air-fall ashes within the John Day Formation parent material bore a great similarity to late Quaternary ash-falls. To overcome this problem, great care was taken to locate and identify the Mazama ash unit from a Mazama ash bed which was then traced laterally.

The following criteria were found useful for determining the position of the Mazama ash unit:

1. The ash is relatively pure and qualitatively homogeneous in color.

2. It is of a consistent texture with little internal sorting or bedding.

3. A primary ash bed underlies less pure deposits of mixed ash and pumice and locally-derived sediment.

There was always the possibility of misidentification or redeposition of the ash into later and earlier sediments. Therefore, whenever possible, the tephra identification was independently supported by a stratigraphic sequence and radiocarbon dates.

Physical and Chemical Analysis

Relatively little material suitable for radiocarbon dating was found, but four samples were collected. The four included charcoal, a piece of wood, and two organic-rich soils. The samples were picked from the sediment with a trowel and immediately packaged in plastic bags. The charcoal and wood were later wrapped in foil. These samples were sent to Beta Analytic, Inc. in Miami, Florida for radiocarbon testing. The charcoal was given a normal counting time; the wood was given an extended counting time due to its small size; and the two soils were processed as bulk soil samples.

Ten soil samples were collected and sent to Central Analytical Lab, Oregon State University, for a Walkley-Black analysis of organic matter content. Details and analyses of the procedure are described in Allison (1976). The soils were not arbitrarily selected, but chosen because of their chronologic sequence and topographic position in the watershed. Soils that were representative of other soil units and that would best answer the question of what environmental changes had occurred in the alluvial history of the creek were selected for analysis. The content of organic matter of the soils of Camp Creek was compared to a modern "wet-meadow" analog found in the S.C.S. published soil surveys of eastern Oregon. The modern analog was selected on the basis of topography and if possible, parent material.

The single tephra found in the course of the study, which was used as a time stratigraphic marker, was carefully collected in a plastic ziplock bag. One sample was sent to Washington State University for a glass microprobe analysis. Details of the procedure and results of this analysis are given in the Appendix.

CHAPTER III

RESULTS AND SUMMARY: STRATIGRAPHY, TEPHRA, SOILS, DEPOSITIONAL FACIES, RADIOCARBON DATES, AND DESCRIPTION OF STRATIGRAPHIC UNITS

This chapter describes the stratigraphy, tephra, soils, depositional facies, and radiocarbon dates of the study site. Results are presented first and the chapter concludes with a summary.

Stratigraphy

In this study the most important aspects of stratigraphy deal with the age relationships of the strata, the successions of beds, local correlation of strata, and the chronological arrangement of beds in the alluvial column. At Camp Creek each stratigraphic unit is a body of sediment that can be traced laterally along the valley floor. Each stratigraphic unit may be composed of several facies and was laid down during a discrete period of time.

Seventeen profiles were sampled along a four mile stretch of Camp Creek. These profiles were identified as CC-1A, CC-1B, CC-2, CC-3A, CC-3B, CC-4, CC-5, CC-6A, CC-6B, CC-

7, CC-8, CC-9, CC-10, CC-11, CC-12, CC-13, and CC-14 (See Figure 3-1). Eight stratigraphic units were identified. The units were labeled, from oldest to youngest, Unit I, Unit II, Unit III, Unit IV, Unit V, Unit VI, Unit VII, and Unit VIII (See Figure 3-2). Four units contained buried soils, with A/C horizons and weak soil development, on their upper surfaces. One unit is identified as a Mazama ash unit. Detailed stratigraphic and soil descriptions are given in Appendix A. A summary of each stratigraphic unit, type of deposit and sediment and soil characteristics is provided in Table 3-1.

The stratigraphic units are laterally discontinuous, as a result of cutting and filling and interaction of multiple depositional media issuing from different tributaries within the basin. Several units which pinch out reestablish their chronological relationship farther downstream. Generally, the preservation of sedimentary units and deposits is good. Mass wasting along many reaches of the channel walls covered exposures which might otherwise have defined cut-and-fill cycles and did not allow continuous lateral tracing of units.

Tephra

Ash from Mt. Mazama is widespread throughout the northwest. It can easily be identified by its uniform petrographic and chemical characteristics and has been traced

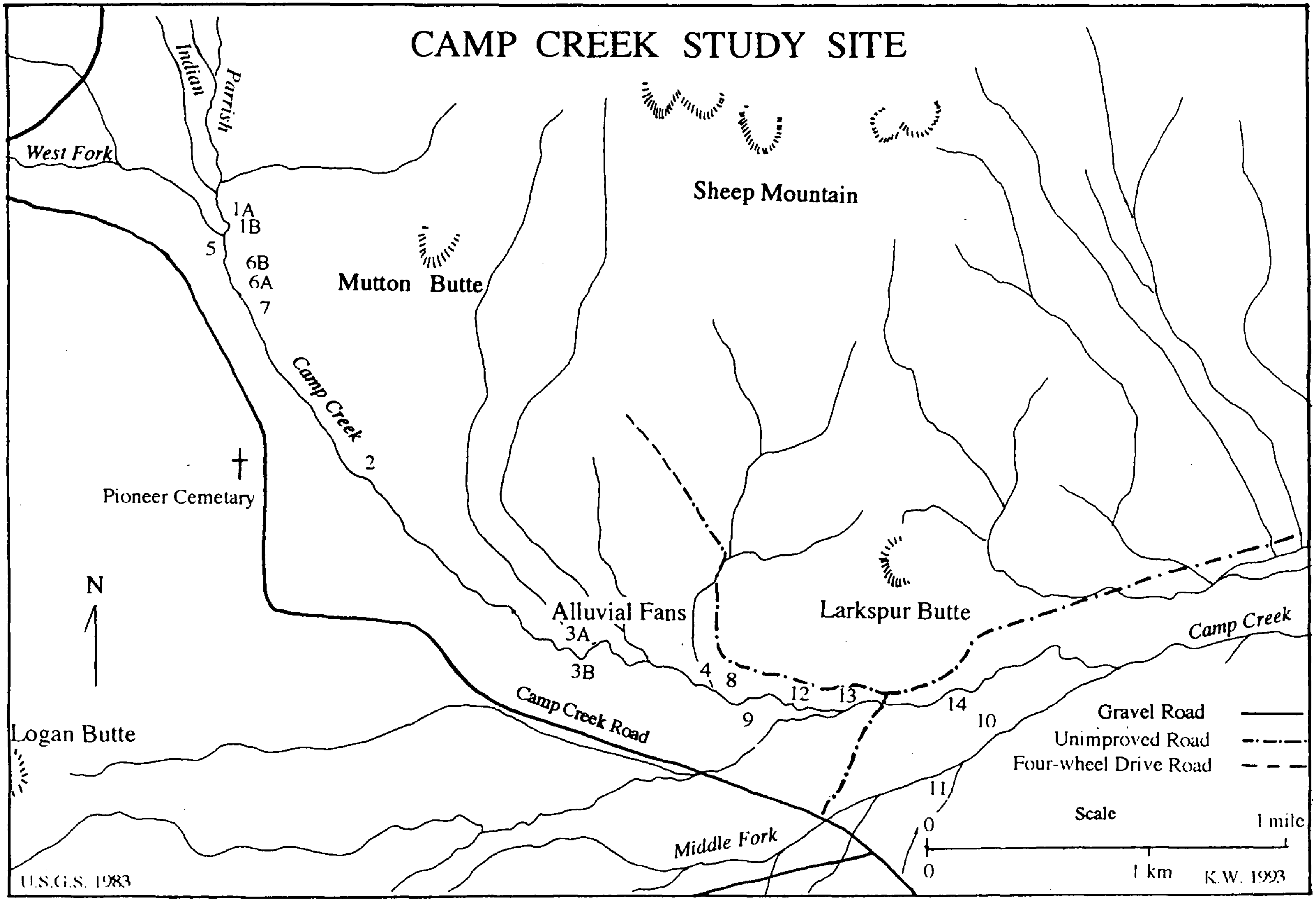


FIGURE 3-1. Location of Profiles on Camp Creek (1A to14).

STRATIGRAPHIC UNITS AND RADIOCARBON DATES

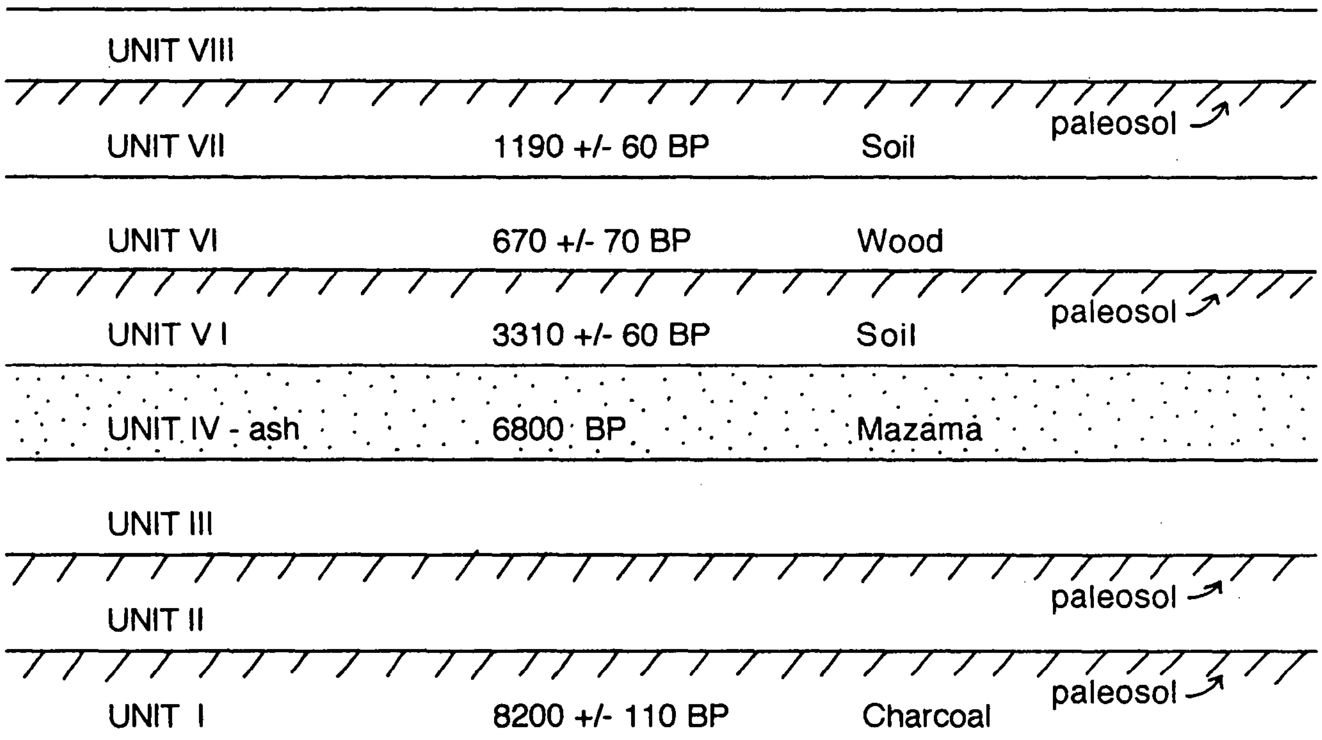


FIGURE 3-2. Stratigraphic Units and Radiocarbon Dates.

TABLE 3-1

STRATIGRAPHIC UNITS PRESENT IN CAMP CREEK

Stratigraphic Unit	Type of Deposit	Sediment and Soil Characteristics
Unit I	Vertical accretion floodplain facies	Brown to dark brown clay; medium prismatic structure; A horizon present, charcoal; horizontal lamination
Unit II	Vertical accretion floodplain facies	Brown to dark brown clay to silty clay loam; coarse prismatic structure; A horizon present; horizontal lamination
SubUnit IIa at CC-14	Lateral accretion point bar	John Day Formation sediments and ashes; very thinly bedded ash units
SubUnit IIb at CC-14	Channel fill	Brown to pale brown silty clay loam; fine angular structure; channel lag, A horizon present
Unit III	Vertical floodplain accretion	Extensively eroded, brown to olive silty clay to clay--John Day Formation sediments; no soil development; some horizontal lamination
Unit IV	Mazama Ash	Structureless sandy loam or silt loam; some horizontal bedding at some sites; massive bed; no soil development

Unit V	Vertical floodplain accretion	Dark gray, gray, to olive gray clay to silty clay; fine to coarse prismatic structure, A horizon present
	Transitional channel fill	Silt and clay; numerous cut -and-fill channels; eroded by Unit VI; lenticular and wavy bedding
Unit VI	Vertical floodplain accretion	Pale olive to very dark grayish brown silt loam to clay, fine granular to medium prismatic structure; no soil development; no sediment structure
	Lateral accretion point bar deposits	Basal gravels fining upwards to sand and silt; wavy bedding
Unit VII	Vertical accretion floodplain deposit	Very dark grayish brown or black silt loam to clay loam; granular to medium prismatic structure, A horizon present; horizontal lamination
Unit VIII	Vertical accretion floodplain deposit	Very dark grayish brown to black silt loam to clay loam; very fine granular structure; no sediment structure

to its source vent at Crater Lake (Kittleman, 1973). The climactic eruption is thought to have occurred ca. 6700 ^{14}C yr B.P. (Powers and Wilcox, 1964; Fryxell, 1965; Mack et al., 1979). There is a considerable range of variation in the radiocarbon ages of the Mazama eruption, from 6020 +/- 90 to

7610 +/- 120 ^{14}C yr B.P. (Skinner and Radosevich, 1991). The most common date associated with the climactic eruption is 6845 +/- 50 ^{14}C yr B.P. (Bacon, 1983). For the purposes of this study, the 6800 ^{14}C yr B.P. date will be used.

The primary ashfall from Mt. Mazama created the thickest known late Pleistocene and Holocene tephra in Oregon. It is widely used as a time stratigraphic marker to correlate discontinuous sedimentary sequences across hundreds of kilometers in the Pacific Northwest. At Camp Creek, Mazama ash and pumice form a bed up to 170 cm thick. The ash occurs as fluvially reworked and redeposited ash. It was traced laterally to provide a datum for determining the chronology of each of the stratigraphic units.

Soils

Soil development occurs during periods of stability in the landscape. Long stable periods result in well developed horizons, while shorter periods of stability result in weakly developed horizons. The alluvial deposits of Camp Creek have formed Mollisols at the surface of the units. There are no B horizons. The length of time required for soil formation of Mollisols under prairie vegetation is estimated to be 400 years for the genesis of mollic epipedons (Buol, 1989). Favorable moisture conditions enhance soil formation so that soil development may require even shorter periods of time.

At Camp Creek, alluvial soil development has been frequently interrupted by erosional or depositional events.

On the valley floor the vertical exposures of the soil profiles show weakly developed but pedogenically altered sediment. The parent material of the soil is derived from varicolored claystones and interlayered air-fall tuffs of the John Day Formation.

Buried Soils

Stratigraphic units were delineated based on abrupt contacts, and soil development within stratigraphic units was described. Soil forming episodes are visible in the stratigraphy of Camp Creek. Four stratigraphic units are capped with soil development (See Figure 3-2). These buried soils vary in the development of thin A horizons, but all show weak development with no B horizon present. A soil is considered to be a buried soil if it has between 30 to 50 cm of sediment overlying it (USDA, 1990). The uppermost buried soil, Unit VII, does not always have 30 cm of sediment overlying it, but for purposes of this study it is referred to as a buried soil because its characteristics resemble the other three buried soils, and because topographically it is situated at the top of the arroyo, but below a surface soil, and not within the modern floodplain of Camp Creek.

Depositional Facies

Each stratigraphic unit is composed of one or more depositional facies. Depositional facies were identified to interpret what type of depositional processes operated during the deposition of each unit. Lateral facies include point bars, channel bars and alluvial islands which are the result of the sideways migration of the channel. Vertical facies occur when accretion of suspended load after overbank flow leads to construction of levees, crevasse-splays, and floodbasin deposits on top of lateral accretion deposits (Allen, 1964). At Camp Creek both lateral and vertical accretion facies have been identified.

Floodplain vertical accretion dominates the facies. This is evident as topstratum deposits where suspended load materials are dominant and no channel lag deposits are present. Some alluvial sequences show sedimentary fill of alternating sequences of sand, silt and clay, fining upwards.

Lateral accretion facies identified in the paleochannels include sediments deposited in the higher energy mid-channel flow regime and in the channel fill draped over the edges of the cut channels onto the floodplain topstratum. This facies is identified as a transitional channel-fill facies (Allen, 1964) and includes lenses of sand and gravel. Also evident are lateral point bar facies which include trough cross-bedding structures, with coarser sands and gravel.

There are also lateral accretion facies deposits in the bedforms of braided channels within the alluvial fan vicinity where Camp Creek has dissected the bases of the fans at CC-4, CC-8, CC-9, CC-12, and CC-13 (See Figure 3-1).

Radiocarbon Dates

Four radiocarbon dates were obtained. Conventional ages were converted to calibrated ages at one standard deviation (68%) by a computer calibration program by Stuiver and Reimer (1986). Unit I was dated at profile CC-1B on charcoal from the C horizon (8,200 +/- 110 ^{14}C yr B.P.). Unit V was dated at profile CC-4A on a bulk-carbon soil sample (3310 +/- 60 ^{14}C yr B.P). Unit VI was dated at profile CC-14 on silty-wood and was collected at the boundary of Unit VII and Unit VI (670 +/- 70 ^{14}C yr B.P.). Although this date suggests that the chronology of stratigraphic units was misinterpreted by the author, it is the author's opinion that the alluvial chronology is correctly identified and that the spurious age may be the result of dating a sagebrush root which may have grown down from an upper unit during a later time. Unit VII was dated at profile CC-4A on a bulk-carbon soil sample (1190 +/-60 ^{14}C yr B.P) (See Table 3-2).

TABLE 3-2

RADIOCARBON DATES OF SAMPLES FROM CAMP CREEK

Lab #	Unit	Depth	Dating Material	^{14}C age (yr B.P.)	Calibrated age (1st Deviation) (cal yr B.P.)
Beta-59314	(VI)	220 cm	woody-silt	670 +/-70	730-540
Beta-60205	(VII)	70 cm	soil	1190 +/-60	1217-1010
Beta-60206	(V)	180 cm	soil	3310 +/-60	3639-3440
Beta-59313	(I)	400 cm	charcoal	8200 +/-110	9159-9009

Radiocarbon analysis done by Beta Analytic, Inc, Florida
Calibrated using CALIB 3.0 (Stuiver and Reimer, 1986)

Description of Stratigraphic Units

Unit I

Unit I is the oldest identifiable unit. When this unit is present, it is located at the base of the profile. Underlying this unit are poorly exposed, unidentifiable sediments, and channel lag gravels which are made up of sands, gravels and boulders at two profiles, CC-1B and CC-10. These basal unit stream deposits are not recognizable as an individual unit as they are discontinuous and grade laterally into and sometimes out of the unit overlying them. Erosional materials which have sloughed off the banks cover the bottom vertical edges of the arroyo making determination of possible lower stratigraphic units impossible within the confines of this study.

Identification of Unit I was made primarily by texture, color and stratigraphic position. Unit I is found at seven profiles: CC-1B, CC-3A, CC-3B, CC-5, CC-7, CC-10, and CC-14. Unit I is a brown to dark-brown clay which has a medium prismatic structure and ranges in thickness from 50 to 100 cm. The contact with the underlying sediments is not observable since material eroded from the banks concealed the length of the unit.

Soil development in Unit I is weak but clearly indicates a period of stability and time enough for a soil to begin to develop. This unit is capped by a buried soil with an A horizon. Flecks or laminae of charcoal exist in the buried paleosol at sites CC-1B, CC-3, CC-5, and CC-10.

Only one facies is apparent in Unit I. The unit is composed of very fine clay, with no sand or gravel present, and it is interpreted as a vertical accretion floodplain facies. The upper boundary of the unit runs parallel with the modern channel and no sedimentary structures are visible.

Unit II

Unit II is found at nine of the sites: CC-1A, CC-1B, CC-3B, CC-5, CC-7, CC-10, CC-11, CC-13, and CC-14. Unit II consists of a brown to dark-brown clay to silty clay loam which has a fine to coarse prismatic structure and ranges in thickness from 50 to 254 cm. At CC-14 Unit II consists of two subunits, an upper dark yellowish brown clay loam and a lower bedded sand, gravel and ash unit. The abrupt contact with the underlying unit is conformable (See Figure 3-3).

Soil development is weak, and the color indicates that an A horizon began to develop on top of the unit before being buried. Where the unit is thick, the basal part, designated a C horizon, generally has an olive-gray color and is characteristic of the John Day parent material.

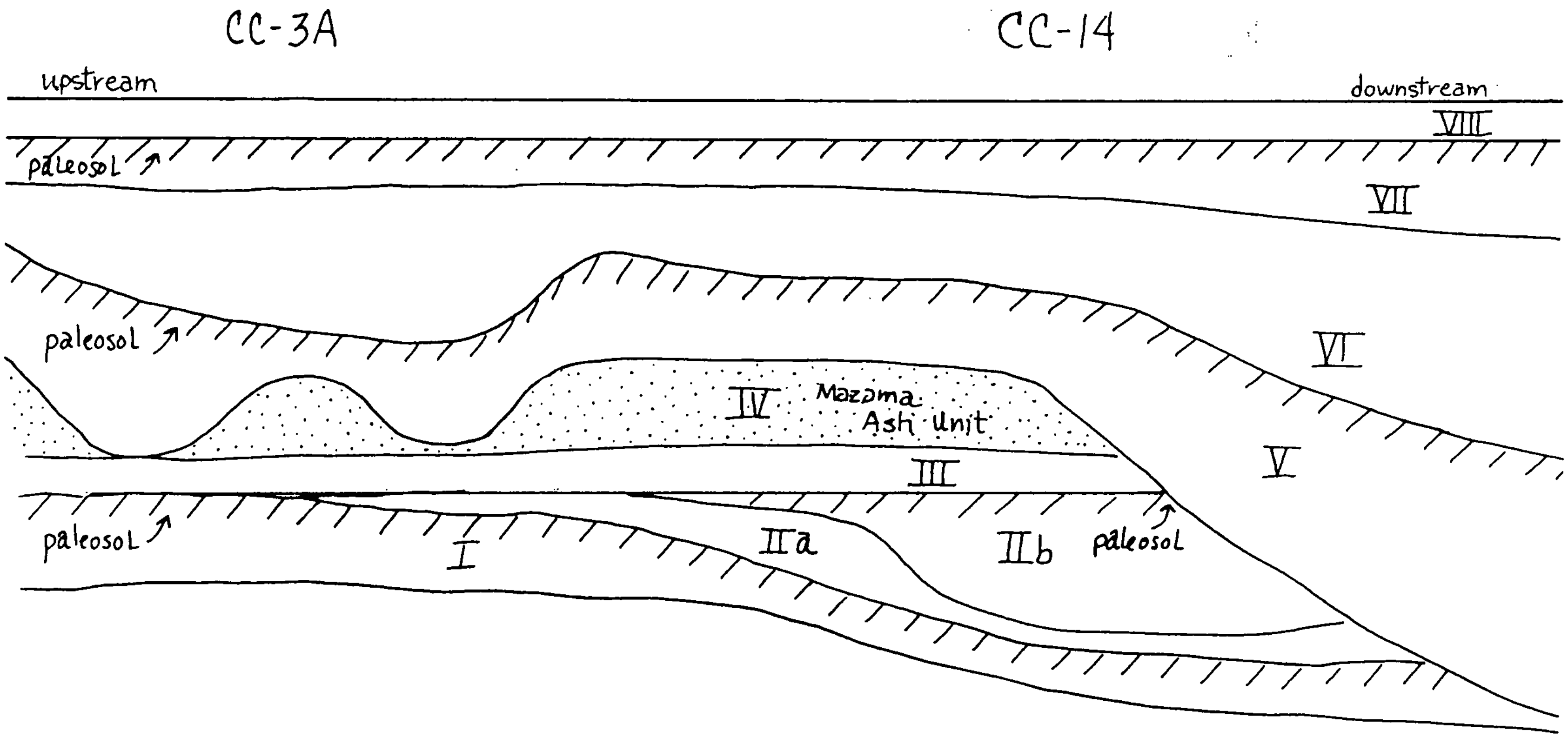


FIGURE 3-3. Composite Stratigraphic Diagram of Cut-and-Fill Units IIb and V at 3A and 14.

Where the unit is thin and no sedimentary structures are present, a vertical accretion floodplain facies is indicated. At CC-10, CC-11, and CC-14, sand, gravel, and beds of John Day Formation ash are the dominant sedimentary feature seen in the basal part of the unit. The discontinuosly laminated sands and gravels occur in lenses as channel lag deposits with some trough cross-bedding. The trough cross-bedding is commonly sandwiched between laminated ash deposits. These sedimentary structures indicate that these were possible areas of point bar lateral accretion.

Unit III

Unit III is found at five profiles: CC-1A, CC-3A, CC-7, CC-11, and CC-14. Unit III is a brown to olive silty clay loam to clay, with a medium to coarse prismatic structure, ranging in thickness from 7 to 125 cm. There is no soil development and it has the general characteristic olive color of the surrounding outcrops of the John Day Formation parent material. When present, this unit has an abrupt contact which lies unconformably on Unit II. It is overlain by the Mazama ash unit.

This unit is interpreted as a vertical accretion floodplain deposit in the downstream profiles. Horizontal lamination is evident at many of the locations. The unit occurs in isolated bodies, is discontinuous and appears to have been extensively eroded.

Unit IV

Unit IV is a Mazama ash unit and is the tephra time-stratigraphic marker used to place the stratigraphic units in chronological order throughout the length of the study site. The ash is found in fourteen of the profiles: CC-1A, CC-1B, CC-2, CC-3A, CC-3B, CC-5, CC-6B, CC-7, CC-10, CC-11, CC-12, CC-13, CC-14. It can be traced laterally over 80% of the study area length.

Unit IV is a white to light gray or olive pumice and ash unit. It is a massive and structureless sandy loam or silt loam unit except at CC-1A. Unit IV has no soil development. The thickness of the unit ranges from 11 to 235 cm. In several profiles, CC-1A, CC-1B, CC-5, CC-6B, CC-9, CC-11, and CC-13, a 2 cm bed of a white very fine ash underlay the thicker pumice and ash unit. The purity of this ash bed indicates that this is most likely a primary airfall tephra layer (WSU, 1993). The contact with the underlying unit is abrupt and conformable.

At CC-1A, the Mazama unit is 235 cm thick and exhibits characteristics not found elsewhere in the selected profiles of the study site. The same bedding sequence was found in one other location, not selected as a profile for this study.

At CC-1A a basal 2 cm bed of very fine silt ash is overlain by alternating very fine tephra beds and cross-bedded pumice beds. Each very fine tephra bed is approximately 2 cm in thickness. In all, six beds are visible. Between each very fine tephra bed lies a bed of very thin crossbedded pumice. The pumice beds are 4 to 5 cm in thickness. The tephra fragments are poorly sorted, and grain-size varies from fine ash to coarse ash with lapilli (pumice) as large as 2 mm. These beds clearly indicate that the ash and pumice was deposited in a fluvial system and that reworked pumice and ash dominate Unit IV. Why six beds of finer ash are interstratified between episodes of more poorly sorted, larger pumice is not known. Two scenarios are likely. Pulses of fine ash may have been fluvially washed off surrounding hillslopes in a series of floods separated by normal fluvial deposition. Alternatively, there may have been a sequence of eruptive pulses from Mt. Mazama which may have left this imprint in the stratigraphy. These alternatives could not be adequately tested in this study, although it is the author's opinion that the former rather than the latter explains these bedding characteristics.

Unit IV is considered a single event which recorded a relatively short-lived geologic episode, although the pumice and ash may have been introduced to the valley floor in a post-eruptive depositional environment. Airfall distribution of Mazama is estimated to have been one-third meter in the Price Valley region (Kittleman, 1979).

Unit V

Unit V is individually distinguishable at eleven profiles: CC-1B, CC-3A, CC-3B, CC-6B, CC-7, CC-9, CC-10, CC-11, CC-12, CC-13, and CC-14. It is a very dark gray, gray, to olive gray clay to silty clay, which has a moderately fine to coarse prismatic structure, and ranges in thickness from 29 to 95 cm. The base of unit V has an erosional abrupt contact.

This unit has a weakly developed buried soil, its color indicating that the soil began to develop an A horizon before being buried. Color varies markedly from locality to locality within the study site within each of stratigraphic Units V, VI, VII and VIII. At CC-3A and CC-3b, unit V separates units IV and VI with a large contrast in color and texture. Unit IV is the Mazama silt ash unit, Unit V is very dark gray Vertisol, and Unit VI is a John Day Formation parent material mudflow which is olive in color. CC-2 and CC-5 have the same dark, organic rich soil development and characteristics of a Vertisol, but the stratigraphic boundaries separating Units V, VI, VII, and VIII are overprinted by soil development and are not distinguishable.

At CC-1B, CC-6B, CC-7, CC-9, CC-11, CC-12, CC-13, and CC-14, Unit V is distinguishable by weak soil development and its stratigraphic position. It is a discontinuous stratigraphic unit. An A horizon is present in the upper part, while the basal part of the unit is made up of a C horizon parent material. Frequently the unit has been truncated by an erosional contact and sediment from the unit above it, Unit VI. Beneath Unit V rests the Mazama ash Unit IV.

At CC-10 and CC-14, Unit V has filled an arroyo paleochannel which was cut before or synchronously during Unit V time. This paleochannel is found at two different locations but in the same topographic position within the valley floor. Located at the lower end of the study site, CC-14 was taken from the main stem of Camp Creek while the CC-10 was taken from the Middle Fork of Camp Creek. The depth of the alluvial fill generally increases downstream within the study area and these cut-and-fill paleochannels exhibit enormous infilling and healing of the system. The channel fill consists of beds of rounded gravels alternating with clays which extends over the channel margin to the upper part of the unit. At CC-10 over three meters of channel fill occur. Such a large channel fill furnishes evidence that the stream was laterally migrating and filling topographically lower areas during a period of aggradation.

Just upstream of CC-10 is CC-11. Unit V occurs here as a relatively thin lens of dark soil and is truncated by an erosional contact and sediment from an upper unit. Commonly throughout the reaches, Unit V is discontinuous and appears in lenses.

A complex pattern of sedimentary facies that reflects the meandering of the channel of Camp Creek begins with Unit V and continues through Unit VIII. Infilling of buried channels becomes prevalent with Unit V and are one of the unit's more distinguishable characteristics. CC-1B, CC-6B, CC-7, CC-3A, CC-3B, CC-13, and CC-14 also have buried channels exposed in the arroyo wall. These channels are cut into Unit IV and are filled with cross-bedded clay, silt and sand of Unit V. Thin gravel lenses are present at the base of several of the channel fills. With the abandonment of these channels came alluvial infilling events. Allen (1964) describes transitional deposits of channel fill being built over successive periods of flow, in beds at first discordant and then concordant upon the channel sides. Beds of the youngest fill then drape over the edges of the initial channel onto floodplain topstratum. This transitional channel-fill facies is clearly recognizable in these exposures.

Alluvial fans issue from the north slopes of Sheep Mountain into Camp Creek between CC-4 and CC-14 (Figure 3-1). Here the stratigraphy becomes difficult to discern. Units become discontinuous and difficult to distinguish. John Day Formation ashes resembling the Mazama tephra are deceiving, and identification of the ash unit, Unit IV, is problematic. Stratigraphic units and the Mazama tephra are not recognizable in segments of the alluvial fan reach. The Mazama ash unit was identified downstream and retraced upstream to reestablish the stratigraphic chronology. At CC-12, Unit V sits unconformably above Unit IV. Unit V is wedged within a point bar deposit. Whether Unit V is part of an abandoned channel could not be determined. Depositional features such as cross-bedding could not be seen in Unit V. These features may be blurred or erased by soil forming processes.

Unit VI

Unit VI is represented in eleven profiles: CC-1A, CC-1B, CC-3A, CC-3B, CC-6B, CC-7, CC-9, CC-10, CC-11, CC-12, and CC-14. This unit varies in color from profile to profile, similarly to unit V, depending on its location within the study site. It is a pale olive to very dark grayish brown silt loam to clay with a fine granular to medium prismatic structure. Unit VI ranges in thickness from 30 to 310 cm. The contact underlying unit VI is erosional and abrupt.

The stratigraphic sequence of units V, VI, VII and VIII and contrasts between them and Unit VI were important in identifying Unit VI. Unit VI has little or no soil development in the upper part of the unit. At CC-1A, CC-1B, CC-7, CC-9, CC-10, and CC-14, a very weak A horizon is present at the top of Unit VI. At all sites, Unit VI sediment bears great similarity to the John Day parent material. Pumice less than 2 mm in diameter is present in Unit VI in all the profiles.

Unit VI exhibits alternating fining upwards sequences within beds of the unit. On the Middle Fork of Camp Creek, Unit VI at CC-11 represents a large aggradational episode. The sediment appears as a sequence of horizontal lamination. It consists of a 310 cm thick channel fill. Although there are definite sedimentary depositional subenvironments in this unit, the sedimentary features are similar and adjacent to each other so they are considered together as a sedimentation package. Channel gravels are found at the base of the unit and as irregularly spaced layers occurring upward toward the mid portion of this unit. Alternating lenses and beds of subrounded to rounded channel gravels, sands and pumice are expressed in the channel fill. Mud cracks are evident at the base of several filled channels.

At CC-9, Unit VI consists of transitional channel-fill deposits where clay sediment is built upward until beds of the youngest fill drape over the edges of the initial channel onto the floodplain topstratum. Beds of John Day Formation ashes and sediment form channel fill overlying channel lag deposits of sand and gravel at the base of the unit.

Unit VI at CC-6B, CC-7, CC-12 and CC-13, is expressed as a point bar facies. Basal gravels grade upward to beds of sand and silt in alternating fining upwards sequences. The presence of alternating fining upward sequences within beds suggests alternating energy levels of flow during the rise and fall of the water level. CC-12 has large trough cross-bedded clay, silt and sand which overlie alluvial fan cobbles and a discontinuous unit of Mazama ash. The trough cross-bedding indicates this may be a braided channel bedform from the streams issuing from the alluvial fan.

Unit VII

Unit VII is clearly represented in six profiles: CC-3A, CC-3B, CC-6B, CC-9, CC-10, and CC-14. This unit varies in color and texture among locations. At CC-3A, CC-3B and CC-6B, it is a very dark grayish brown and black, silt loam to clay loam soil, with granular to medium prismatic structure from top to bottom of the unit. At CC-9, CC-10 and CC-14, this unit is an olive to olive gray, silt clay to clay loam with fine angular structure. Unit VII generally represents a vertical floodplain facies. At CC-9, Unit VII is a clay filled buried channel with no soil development. Its thickness ranges from 60 to 110 cm and its lower contact is abrupt and conformable.

At CC-3A, CC-3B, and CC-6B, the soil formed in this unit is interpreted as representing wet meadow conditions and is identified as a Vertisol soil. At CC-10 and CC-14, this unit has no indication of soil development.

Unit VIII

Unit VIII is the surface stratigraphic unit. Samples were taken at CC-1A, CC-1B, CC-2, CC-3A, CC-3B, CC-4, CC-5, CC-6A, CC-6B, CC-7, CC-8, CC-9, CC-10, CC-11, CC-12, CC-13 and CC-14. This unit is a very dark grayish brown to black silt loam to clay loam, with very fine granular structure. It ranges in thickness from 6 to 30 cm. This unit represents a vertical accretion facies.

Summary

Eight alluvial stratigraphic units have been identified and laterally traced. A Mt. Mazama time-stratigraphic ash marker dated at ca. 6800 ^{14}C yr B.P. was used to constrain the stratigraphic relationships. Some stratigraphic relationships remain unclear and some interpretations were chosen because they were only slightly more desirable than others in terms of the available evidence on which they were based.

Stratigraphic units underlying Unit I are discontinuous and poorly exposed. These sediments appear to include much coarser bedload material, sand, gravel, and cobbles. Unit I is dated at 8200 +/- 110 ^{14}C yr B.P. (9159-9009 cal yr B.P.). and is identified as a vertical floodplain facies.

Unit II is buried by Unit III and is interpreted as a vertically accreted floodplain deposit. Similar to Unit I, this determination was made on the basis of its laterally continuous position, fine texture of the sediment and lack of sedimentary structures.

Unit III is eroded away in much of the study site. The Mt. Mazama ash unit overlies Unit III. Unit III is a vertical accretion floodplain facies with horizontal lamination and resembles the fine texture of the John Day Formation parent material of the valley. No soil development is present.

Unit IV is the Mt. Mazama ash unit dated at 6800 ^{14}C yr B.P. This is an extremely hard, massive pumice unit which varies in thickness from profile to profile. This unit is found throughout most of the study site. Heavy erosion of Unit IV occurred in the vicinity of the alluvial fans issuing off of Sheep Mountain. When the Mt. Mazama ash fell, it covered the landscape with a third of a meter of ash and pumice. This would have effectively denuded the region of vegetation and stream power undoubtedly increased due to the increased runoff from the hill slopes. This erosive period explains the absense of Unit III in much of the study area.

Unit V has a date of 3310 +/- 60 ^{14}C yr B.P. (3639-3440 cal yr B.P.) and fills numerous channels which were cut into the Mazama unit which underlies it. The channels are filled in with transitional channel fill facies. Other facies in Unit V include lateral point bar facies. Evidence suggests that Unit V occurred during an aggradational episode but was subject to erosion. Unit V commonly occurs as a thick lens of dark soil, truncated by an overlying unit. The soils of Unit V are quite variable from upstream to downstream locations. The soils at upstream locations are much darker and indicate moister floodplain conditions. Along the alluvial fans Unit V is much sandier. Downstream of the alluvial fan reach Unit V is commonly much lighter in color, reflects the clay John Day Formation parent material, and fills an arroyo channel cut before or synchronously with deposition of Unit V.

Unit VI is radiocarbon dated to 670 +/- 70 ^{14}C yr B.P. (674-560 cal yr B.P.). There was a period of erosion prior to deposition of Unit VI. Unit V is truncated by Unit VI repeatedly along the study site. Unit VI was a period of aggradation of John Day Formation sediments with vertical accretion floodplain deposits.

Unit VII is dated at 1190 yr B.P. +/- 60 ^{14}C yr B.P. (1217-1010 cal yr B.P.). and represents vertical accretion floodplain deposits. The soil of this unit is very dark and exhibits wet-meadow conditions in the upper reaches where the arroyo walls are 2 to 3 meters in height. In the lower reaches Unit VII has no indication of soil development, but is located 5 to 6 meters off the arroyo floor, high in the profile.

Unit VIII is a vertical accretion floodplain surface layer not more than 30 cm in thickness, which lies on the floor of Price Valley. Camp Creek has incised from 2 to 6 meters below this surface layer within the study site.

CHAPTER IV

RESULTS AND SUMMARY: ORGANIC MATTER, GEOMORPHIC CHANNEL OBSERVATIONS AND MEASUREMENTS

This chapter presents the results of the organic matter analysis of the buried paleosols and the results of cross-section measurements and calculations of average discharge in acre-ft/year of paleochannels and modern channels. The organic matter contents of four modern eastern Oregon wet-meadow Mollisols and one Vertisol are used as examples of modern wet-meadow organic matter contents found regionally and were compared to the organic matter content of buried paleosols at the study site. Channel cross-section measurements and calculations gave the average discharge in acre-ft/year for the study site. These amounts were compared to the modern streamflow data of three Oregon streams located nearby. These analyses provide information which will help reconstruct the paleoenvironment of Camp Creek. They are used to understand the history of the morphology of the channels and wet-meadows. Summaries are provided at the end of each section.

Organic Matter

Wet-meadows are valley bottom sites underlain by stratified alluvial and organic accumulations which have shallow water supporting a wet-meadow plant community. Typical wet-meadow vegetation associations in the Ochoco Mountains region are wooly sedge, small-fruit bulrush, beaked sedge, inflated sedge, and Nebraska sedge (Kovalchik, 1987).

There are at least three possible explanations for the presence or absence of wet-meadows at Camp Creek. 1) Wet-meadows develop when the stream channel is shallow and unincised, helping to maintain a high water table. Surface water may flow across a meadow either in retarded overland flow through meadow foliage, or it may collect in shallow well defined channels. Incision of the channel to > 1 m depth allows the water table to drop, and the wet-meadow is converted to drier vegetation. 2) Wet-meadows develop under wetter climatic conditions when streamflow is higher and a higher water table is maintained. A shift to drier climate reduces streamflow, lowers the water table, and converts the wet-meadow to a drier vegetation. 3) Bedrock constrictions along the valley floor bring groundwater closer to the surface and local springs issuing from the uplands contribute water to the valley bottom. Wet-meadows can survive in these favorable sites despite climate changes and arroyo-cutting.

These three explanations for the occurrence of wet-meadows may not be mutually exclusive. For example, conversion of wet-meadows to drier floodplains may have been caused by climatic drying, stream incision, or both factors acting together. Furthermore, within a single valley some wet-meadows may be lost due to environmental change, while other wet-meadows related to bedrock constrictions and springs survive.

Modern Wet-Meadow Soils

Riparian wet-meadow soils are those that are distinguished by characteristics of saturation by groundwater during much of the growing season. Pedogenic development typically occurs rapidly in a wet environment and surface horizons are darkened by an accumulation of organic matter (Bouma, 1983). Using soil color and topographic location, four modern soils were chosen to represent wet-meadow soils in eastern Oregon.

In Umatilla County the Silvies-Winom complex soils occur on 0 to 3 percent slopes at elevations of 3300 to 4300 feet. Precipitation is 20 to 25 inches and average air temperature is 40 to 45 degrees F. The Silvies soil series is classified as fine, montmorillonitic Cumulic Cryaquaolls (Mollisols) and the Winom series is classified as fine, montmorillonitic, frigid Chromic Pelloxererts (Vertisols). Both soils form in old alluvium from lacustrine sediments and are typically black. The Silvies series has a 10YR or neutral 1 to 2/0 to 1 (moist) and the Winom series has a 10YR 2/0 to 1 (moist) Munsell color. They are silty clay loams with A/C horizons. The organic matter content of the A horizon ranges between 3 and 5 %, and the soils have high shrink-swell potential (S.C.S., 1988).

The Catherine soil series in Union County occurs on slopes 0 to 3 percent at elevations from 2200 to 4000 feet. Mean annual precipitation is 17 inches and annual air temperature is 48 degrees F. The Catherine soils are classified as fine-silty, mixed, mesic Cumulic Haplaquolls (Mollisols). These soils develop on floodplains which formed in mixed alluvium. The soils are black to very dark gray. The upper ten inches of the A horizon are designated as 10YR or 2.5Y 1 to 3/0 to 2 (moist) color. The lower A and AC horizons are a 10YR or 2.5Y 2 to 3/0 to 2 (moist) color. They have A/C profiles. Organic matter content of A horizons range between 4 and 10 percent (S.C.S., 1985).

The Veazie series in Union County occurs on slopes of 0 to 3 percent in elevations ranging between 2500 and 4000 feet. Mean annual precipitation is 12 to 25 inches and the average annual air temperature is 45 to 52 degrees F. The Veazie series is coarse-loamy over sandy or sandy-skeletal, mixed, mesic Cumulic Haploxerolls (Mollisols). These soils develop in mixed alluvium on floodplains. The soils are very dark brown 10YR 1 to 2/2 (moist), and organic matter content ranges between 2 and 3 percent (S.C.S., 1985).

The Wingville soil series occurs on slopes 0 to 2 percent at elevations 2200 to 3600 feet. Precipitation is 11 to 14 inches and annual air temperature is 47 to 51 degrees F. The Wingville soils are classified as fine-silty, mixed (calcareous), mesic Cumulic Haplaquolls (Mollisols). These soils develop on alluvium of alluvial fans and floodplains. The soils are black to very dark brown 10YR 2 to 3/ 1 to 2 (moist) with A/C profiles. Organic matter percentages range between 2 and 4 percent (S.C.S., 1985).

Modern soils of eastern Oregon indicate that alluvial floodplain Mollisols which exhibit dark colored organic rich surface horizons have organic matter contents ranging between 2 and 5 percent or higher. Their A horizons range between 10YR or 2.5Y 1 to 3/0 to 2 (moist) in Munsell color. These soils may or may not indicate a wet-meadow, but seasonal high water tables and flooding are characteristic of the soils. According to Mitsch and Gosselink (1986), the organic content of bottomland soils in the western United States ranges between 2 % and 5 %, while upland soils range between 0.4 % and 1.5 % (highly organic peats range between 20 % and 60%).

Nagle (1993) did a comparison of organic carbon levels in A horizons of floodplain soils in the area of Shoestring Creek in the Fremont National Forest of southeastern Oregon. In trying to determine where former riparian areas existed, he found that soil organic carbon levels showed too much variation to be a reliable indicator of past hydrology in itself. He suggested, however that soil profiles, the development of an A horizon and degree of mottling could possibly be used to determine a former riparian area. Other studies show that patterns of organic carbon accumlation are valuable indicators of the geomorphic history of a site (Yorker, 1988).

Buried Wet-Meadow Soils

The percent of organic matter present in A horizons of buried paleosols was measured at three sites within the study area to determine when a riparian wet-meadow existed on the valley floor. The indicators used in this study to determine the presence of a former riparian area or wetland soil were 1) the color of the soil, and 2) the percent of organic matter content.

Historical records of Camp Creek are available which describe and map sections of the valley bottom in the 1870s (Buckley, 1992). Surveyors' notes and maps indicate that "swamps" existed in several reaches of Camp Creek. The survey maps do not show "swamps" within the boundary of the study site (U.S. General Land Office, 1876) although one "swamp" is mapped just north of the study site.

Thirteen samples were analyzed for organic matter using the Walkley-Black method at the Central Analytical Laboratory, Corvallis, Oregon. Samples were taken from the A horizons of four buried paleosols identified within the stratigraphic columns, and samples were taken at three separate locations within the study site. The three profiles represented are CC-3A, CC-3B, CC-5, and CC-14 (Table 4-1).

The profiles at CC-3A and CC-3B are found on opposite banks of one another and were used together in order to develop a complete record of chronological units. At CC-5 Units V and VII are not indistinguishable as individual units and are overprinted by soil development. Unit V was chosen on the basis of its position at the base of the unit while Unit VII is near the top of the profile.

Summary of Organic Matter Analysis

A strong indication of a wet riparian meadow is the presence of a thick, very dark A horizon which suggests high moisture levels and high biomass production, and organic matter contents over 2 percent. Modern analogs of bottomland soils in eastern Oregon indicate that modern wet-meadows have organic matter contents ranging between 2 and 10 percent.

Darker colored units occur at profiles CC-2, CC-5, CC-3A and CC-3B. Organic matter content of Units V and VII at CC-

TABLE 4-1

ORGANIC MATTER CONTENT

Site #	Unit #	% Organic Matter	Color (moist)
CC-3A	VII	2.48	very dark gray (5Y 4/1)
CC-3A	V	2.16	black (5Y 2.5/1)
CC-3B	II	.70	dark grayish brown (10YR 3/2)
CC-3B	I	.32	dark brown (10YR 3/4)
CC-5	VIII	1.51	very dark gray (10YR 3/1)
CC-5	VII	2.97	very dark gray brown (10YR 3/2)
CC-5	V	2.11	very dark gray (10 YR 3/1)
CC-5	II	.65	dark brown (10YR 3/3)
CC-5	I	.43	dark yellowish brown (10YR 3/2)
CC-14	VII	.76	olive gray (5Y 4/2)
CC-14	V	.38	olive gray (5Y 2/2)
CC-14	II	.05	brown (10YR 5/3)
CC-14	I	.11	dark yellowish brown (10YR 4/4)

5, CC-3A and CC-3B verify that these soils could possibly have been wet-meadow soils. Profile CC-14 is located downstream and does not appear to be associated with wet -meadow soils in any of the analyses of the units, nor are any of the soils a darker color.

Given the constricted nature of the topography of the valley in the upper end of the study site where buried wet-meadow soils are evident, it is likely that the buried soils reflected local water recharge from springs and subsurface flow. Downstream at Profile CC-14, the valley is very broad, and apparently it is difficult to develop wet-meadows under any climatic or channel conditions. At the favorable upstream sites, wet-meadows have formed and disappeared as environmental conditions changed. Since Camp Creek's deep modern incision the local elevated water table has been drained into the stream. No wet-meadow is presently evident within the reaches which are identified as past wet-meadows along the channel wall exposures. The geologic controls of the valley have not changed over the Holocene. Therefore wet-meadow development at the upstream sites is controlled either by climate change or channel incision.

There are no wet-meadow soils evident in Units I, II or III. Unit I lies on the Tertiary bedrock of the valley floor, so it is unlikely that the channel was incised at this time. No channels in Unit I are evident in the arroyo wall exposures. Unit II and Unit III have channels but the valley fill during that time period (pre-Mazama) is not very deep and channels are shallow. Units I, II and III date from the early Holocene, thought to be a dry period (Barnosky, 1985; Mack et al., 1978 ab). If the climate had been wet, then darker wet-meadow soils likely would have developed. In contrast, wet-meadow paleosols are associated with Units V (3310 +/- 60 ^{14}C yr B.P.) and VII (1190 +/-60 ^{14}C yr B.P.). The late Holocene was a time of wetter climate (Mack et al., 1978 ab; Mehringer, 1985). There are no black wet-meadow soils evident in either Units I, II or III.

It can therefore be assumed that an increase or decrease in effective precipitation is reflected in the organic matter content of each of the stratigraphic units. Effective precipitation appears to have determined the degree of development and amount of organic matter found in the soils on the floodplain. It can therefore be inferred that past development of wet-meadows in Camp Creek is related to local geologic controls and to favorable cool/wet climate conditions.

Channel Morphology

Channel-geometry measurements can be used to estimate the stream-flow characteristics of ungaged streams (Hedman and Osterkamp, 1982). Computation of mean annual runoff is given by equations using different criteria for individual watersheds based on flow frequency, runoff, and channel-material characteristics. According to Hedman and Osterkamp (1982) discharge of intermittent streams in the western United States, north of latitude 39 degrees N., with silt-clay channel material, can be calculated using the following equation: $Q = 40W^{1.80}$, where Q = mean annual discharge in acre ft/yr, and W = width of the active channel in feet.

Streamflow Data in Oregon

Statistical summaries of streamflow data at three eastern Oregon stream-gaging sites are presented to aid in appraising discharge values calculated on Camp Creek in this study. Camp Creek does not have a gaging station located on it. Beaver Creek near Paulina has a drainage area of approximately 450 mi^2. The average discharge is 64,550 acre-ft/yr. The North Fork Beaver Creek near Paulina has a drainage area of approximately 64 mi^2 and an average discharge of 19,690 acre-ft/yr. Fox Creek at Gorge near Fox has a drainage of approximately 90.2 mi^2 and an average discharge of 18,750 acre-ft/yr (Moffatt et al, 1990).

The entire Camp Creek drainage area is approximately 180 mi^2. The study site has an estimated drainage area of 90 mi^2. Given the average discharges of streams located nearby, Camp Creek at the study site would have an average discharge of approximately 19,000 acre-ft/yr within the study site.

Cross-Section Measurements

Cross-section measurements were taken of the arroyo (Table 4-2), relict surface channels (Table 4-3), the paleochannels (Table 4-4) and modern channels (Table 4-5). A total of forty four cross-sections were measured. To compare the paleochannels with the modern and relict surface channels, discharge was calculated according to the equation of Hedman and Osterkamp (1982) for thirty-two of these channels. Each paleochannel is identified by the stratigraphic unit that fills it. The channel therefore represents either the time just prior to or synchronous with deposition of the unit. The other twelve cross-sections were measured in the modern arroyo for future reference. Dimensions of the arroyo do not represent an active channel level and therefore meaningful discharge cannot be calculated from these dimensions.

Within the exclosure, sedimentation of approximately six feet has occurred above the road crossing located south of Larkspur Butte, which the BLM maintains and which may be acting as a dam (Wayne Elmore, oral communication; 1992). The sediment has obscured lower units upstream of the road crossing making identification of the ash unit nearly impossible and lateral tracing difficult. Paleochannels found within this section of the study site have therefore been omitted from measurement. Field observations indicate that dirt roads play an important role as local or temporary base levels where they have been constructed across arroyo beds, particularly within the exclosure. The compacted alluvium and boulders act as a bedrock lip and cause high sedimentation rates upstream.

TABLE 4-2

MODERN ARROYO CROSS-SECTION MEASUREMENTS

Site #	Width (m)	Depth (m)
CC-1A	19.6	5.6
CC-2	25.0	2.0
CC-3A	20.3	4.3
CC-6B	25.6	5.0
CC-7	26.1	4.1
CC-4	11.4	3.2
CC-9	18.1	3.0
CC-12	16.8	4.5
CC-11	12.5	5.3
CC-10	10.5	6.9
CC-13	26.9	3.9
CC-14	20.8	5.9

TABLE 4-3

RELICT SURFACE CHANNEL CROSS-SECTION MEASUREMENTS

Site #	Width(m)	Width(ft)	Depth(m)	W/D ratio	Q(ac-ft)
CC-5	3.6	11.81	0.35	10.3	3405
CC-4	6.5	21.33	0.55	11.8	9864
CC-9	7.4	24.28	1.0	7.4	12458

TABLE 4-4

PALEOCHANNEL CROSS-SECTION MEASUREMENTS

Site # (Unit)	Width(m)	Width(ft)	Depth(m)	W/D ratio	Q(ac-ft)
CC-1B (IV)	8.8	28.87	1.5	5.9	17017
CC-1B (V)	9.1	29.86	1.2	7.6	18076
CC-3A (V)	2.0	6.56	0.5	4.0	1182
CC-3A (V)	1.6	5.25	0.5	3.2	791
CC-3B (V)	8.8	28.87	1.0	8.8	17017
CC-3B (V)	5.8	19.03	0.2	29.0	8035
CC-3B (V)	2.2	7.22	0.8	2.8	1403
CC-3B (V)	11.6	38.06	1.0	11.6	27980
CC-3B (V)	8.3	27.23	0.7	11.9	15317
CC-9 (VI)	7.6	24.93	1.3	5.8	13070
CC-7 (III)	16.0	52.49	1.8	8.9	49916
CC-7 (V)	11.7	38.39	1.2	9.8	28416
CC-10 (V)	16.6	54.46	3.0	5.5	53336
CC-13 (IV)	1.9	6.23	0.5	3.8	1078
CC-14 (II)	4.0	13.12	1.0	4.0	4117
CC-14 (V)	11.0	36.09	3.0	3.7	25429
CC-14(VII)	8.0	26.25	1.5	8.0	14335

There are numerous buried channels in the alluvial fill of Camp Creek. Presently exposed sections of the buried channels do not necessarily represent the older stratigraphic units since undoubtedly, younger channels were superimposed

TABLE 4-5

MODERN CHANNEL CROSS-SECTION MEASUREMENTS

Site #	Width(m)	Width(ft)	Depth(m)	W/D ratio	Q(ac-ft)
CC-1A	3.4	11.15	0.26	13.1	3072
CC-2	3.1	10.17	0.30	10.3	2602
CC-3A	4.9	16.08	0.32	15.3	5932
CC-3A	5.1	16.73	0.73	7.0	6375
CC-4	3.9	12.80	0.70	5.6	3933
CC-6B	3.3	10.83	0.20	16.5	2912
CC-7	3.2	10.50	0.25	12.8	2755
CC-9	3.2	10.50	0.45	7.1	2755
CC-10	4.6	15.09	0.49	9.4	5294
CC-12	3.6	11.81	0.40	9.0	3405
CC-11	4.3	14.11	0.35	12.3	4689
CC-13	2.1	6.89	0.30	7.0	1291
CC-13	3.6	11.81	0.38	9.5	3405
CC-13	4.0	13.12	0.55	7.3	4117
CC-14	5.5	18.04	0.61	9.0	7303

over the older. In some places younger channels could not be identified because of clay-wash and erosion off of the vertical arroyo walls.

The calculation used to determine estimated discharge in acre feet/year does not take depth into consideration and in some instances estimated discharge values may not be realistic. For instance, in the upper part of the study site at CC-3B (Unit V) where evidence of a wet-meadow is present, the channel becomes very wide and shallow. The estimated discharge value is very large, 27,980 acre-ft/yr. At CC-7, Unit III has an estimated discharge rate of 49,916 acre-ft/yr, yet the geometry of the exposed channel indicates that it was a very wide and shallow channel.

Two buried arroyo channels were identified at CC-10 and CC-14 at the lower end of the study site. The walls are not vertical and appear to be u-shaped, but the channel width and depth rival the modern arroyo. This width is measured from the margin of where it cuts the top of the uppermost underlying stratigraphic unit, Unit IV. At CC-10 the base of the filled arroyo channel is obscured by slumping but has incised to, if not below, Unit I. If calculated using the upper margins of the channel, the estimated discharge would be 53,336 acre-ft/yr at CC-10 and 25,429 acre-ft/yr at CC-14. These discharges indicate the presence of an arroyo when contrasted with the estimated 19,000 acre-ft/year estimated discharge of the modern channel.

Three relict surface channels which can be associated with historical time, probably from just before the modern arroyo cutting, are similar in size to the modern channels but are slightly wider and deeper. The estimated discharge of the channels is also larger.

The modern channels have an estimated discharge rate of 751 and 860 acre-ft/yr. This is much lower than the estimated 19,000 acre-ft/year. The active channel measurements were taken during the summer when precipitation was light. The modern channel appears small. It is probably aggrading in a system in disequilibrium which is experiencing frequent overbank flows.

Width-depth ratios were calculated to determine whether channels were aggrading or degrading. It is generally recognized that aggrading channels have a higher width-depth ratio, whereas degrading channels have a lower width-depth ratio (Schumm, 1960). According to Schumm (1960), a channel width-depth ratio of about 10 or less would be expected in a high silt-clay content (> 50%) watershed such as Camp Creek. At Camp Creek the modern channels' and the relict surface channels' width-depth ratios are slightly less than, or only slightly above, a width-depth ratio of 10. Those above 10 are very shallow channels which indicates an aggrading stream system.

The width-depth ratios of the paleochannels are generally less than 10, indicating incision of the stream occurred. The width-depth ratios of the buried arroyos of CC-10 and CC-14 are 5.5 and 3.7 respectively.

Paleochannels and deposits suggest that the floodplain within the study site aggraded to progressively higher levels interspersed with episodes of cut-and-fill until incision of the modern arroyo. A disproportionately high number of cut-and-fill buried channels occur before or during Unit V, where

Unit V has filled the channels. Of the seventeen paleochannels identified, ten are associated with a cut-and-fill episode which occurred during the Unit V interval.

Summary of Cross-Section Measurements

In order to establish patterns of channel morphology and their changes over time, comparison of the modern channel was made with the paleochannels, relict surface floodplain channels, the arroyo channel and streamflow data from three gaging stations in close proximity to Camp Creek. Since aggradation of the valley floor first began approximately 9000 cal yr B.P., cut-and-fill cycles have periodically occurred and are visible in the valley fill alluvium.

The estimated discharge rate of one paleochannel found in Unit II (pre-Mazama time) is 4117 acre-ft/yr. The Mazama ash unit (ca. 6800 ^{14}C yr B.P.), Unit IV, has two buried channels identified with average discharge rates of 1078 and 17,017 acre-ft/yr. The channel with the 1078 discharge rate is related to the alluvial fan tributaries and may not represent the main channel stem. Unit V (ca. 3300 ^{14}C yr B.P.) is associated with numerous cut-and-fill cycles. Nine paleochannels are identified with estimated discharge rates ranging between 791 and 28,416 acre-ft/yr. Two other channels of Unit V are identified as buried arroyos. One paleochannel of Unit VI (older than ca. 1200 ^{14}C yr B.P.) shows an estimated discharge rate of 13,070 acre-ft/yr.

Using not only the estimated discharge, but geometric shape and size, it appears that before ca. 3300 ^{14}C yr B.P. an arroyo existed in the Camp Creek watershed. The headcut appears to have been at the lower end of the study site within deepening valley fill and did not extend upstream.

Modern channel estimated discharge rates range between 1291 and 7303 acre-ft/yr, while relict surface floodplain channels have average discharge rates of 3405 to 12,458 acre-ft/yr. Modern channel cross-section measurements were taken during the summer and probably do not accurately reflect the true average discharge values of the watershed.

Few channels are evident in the exposures during the early Holocene. Indications are that average discharge rates increased during post-Mazama times before ca. 3300 ^{14}C yr B.P. cutting a large arroyo in the lower end of the study but creating wide and shallow channels in the wet-meadow reaches upstream. These channels were filled with Unit V. The valley floor continued to aggrade until the modern arroyo formed and a modern channel was established within it. The modern channel's estimated discharge figures are much lower than the paleochannels occurring since Mazama time ca. 6800 ^{14}C yr. B.P.

CHAPTER V

DISCUSSION AND CONCLUSIONS

Environmental conditions that may have affected the relationships between floodplain stability, aggradation and degradation of arroyos include climate and human land use change (Cooke and Reeves, 1976). Coinciding with climate change in the mid to late-nineteenth century was the introduction of livestock and the removal of beaver by fur trapping. This coincidence of recent climate change and Euroamerican settlement makes it difficult to unravel the cause and effect relationships of arroyo formation.

Exact identification of causes of fluvial adjustments is also not possible since causal relationships between specific climatic variations and specific gradational responses (i.e., aggradation, degradation or stability) remain unclear (Knox, 1972; Baker and Penteado-Orellana, 1977; Brakenridge, 1980, 1984; McDowell, 1983; Patton, 1981; Martin, 1992; May, 1992). Changes in climate lead to changes in vegetation, but the initial fluvial response of a change to drier conditions may be the same for a change to wetter conditions. It is this transitional period which presents theoretical problems in developing a model for the relationship between fluvial change and the direction of climate change (McDowell, 1983).

This chapter contains a discussion of the climate interpretation of the floodplain. It ends with a summary of conclusions that are drawn from the study.

Discussion

Climate Interpretation of Floodplain History

Paleoclimatic information from a variety of sources in the Pacific Northwest, including Cascade Range alpine glacier fluctuations, vegetation successions, tree ring records, lake levels, and historical data, provides a climate history with which the gradational response of Camp Creek can be compared.

Following glacial ice advances during the late Pleistocene (Crandell, 1967; Miller, 1969; Porter, 1976; Scott, 1977) alpine glaciers retreated before the beginning of the Holocene, ca. 10,000 yr B.P. This would have required a time of a mild and warm climate. Late Quaternary pollen records and lake levels of the northwest generally reflect the glacial record. Pollen records show a warming trend into the early Holocene. Increased summer drought began between ca. 10,600 and 9000 yr B.P. (Mack et al., 1978; Mehringer, 1985; Barnosky, 1987).

The first aggradational period documented at Camp Creek occurred at the radiocarbon age of 8200 +/- 110 ^{14}C yr B.P. (9159-9009 cal yr B.P.) during a general warming trend of the early Holocene characterized by reduced effective precipitation and increased temperatures. No buried channels were identified at any of the reaches within stratigraphic Unit I. The only facies identifiable is a vertical accretion floodplain facies. Given that the John Day Formation parent material is a cohesive clay which lends itself to becoming a single thread meandering stream, similar to the modern channel, I infer that Camp Creek probably was a single thread channel during Unit I. This unit lies upon a bedrock Tertiary claystone in much of the study site. In some places cobbles and gravels lie beneath Unit I. These were evidently laid down and scoured by high energy waters of the glacial or late glacial period. These features and the characteristics of stratigraphic Unit I support the conclusion that Unit I formed in a period of drier climate and diminished energy of run-off water.

Aggradation of Unit I was followed by an episode of surface stability on Unit I, which can be inferred from weak soil development on this Unit. Lower organic matter contents (< 1%) reflect a drier pre-Mazama time in contrast to higher organic matter content found in post-Mazama alluvial soils (> 2%). The radiocarbon dating material is a 0.5 cm thick bed of charcoal which is traceable throughout the study site in Unit I. The charcoal may possibly reflect drier conditions with increased fires in the watershed or uplands. The characteristics of stratigraphic Unit I correspond to a period of drier time.

Dry conditions continued in eastern Oregon throughout the mid-Holocene. Pollen records indicate aridity and drought prevailed in eastern Washington (Barnosky, 1987). Before 5400 yr B.P. eastern Oregon data from Diamond Pond suggest that the climate was extremely dry with a water table 17 m below the present level (Wigand, 1987).

At Camp Creek the first interval of aggradation is followed by a second interval (Unit II) of aggradation that occurred between 8200 and 6800 ^{14}C yr B.P. There does not appear to be an erosive period between the two episodes of aggradation. Facies are primarily identified as vertically accreted floodplain deposits. It appears that Camp Creek continued to be a single thread channel during this pre-Mazama time. On Unit II is a weak soil which reflects a second episode of relative surface stability. Organic matter content in Unit II soil is less than 1%. Riparian wet-meadows likely did not exist in the study area during this time. One buried channel of unit II has a mean annual discharge rate comparable to the modern channel.

Climatic stability was followed by a third aggradational period and the deposition of unit III. Unit III was severely eroded in many of the study's reaches before or during the deposition of Unit IV (the Mazama ash unit dated at ca. 6800 ^{14}C yr B.P.). Unit III is absent in some spots along the exposure walls. Unit III shows no soil development on its surface but does have horizontal lamination present indicating it was a vertically accreted floodplain deposit.

The fourth aggradational interval, Unit IV, followed immediately after the eruption of Mt. Mazama at ca. 6800 ^{14}C yr B.P. (Bacon, 1983). This unit was preceded or accompanied by an intense erosional period. Ash and pumice from Mt. Mazama may have partially denuded the watershed of vegetation. The intense erosion of Unit III may be explained by a thick blanket of Mazama ash and pumice falling on the watershed and upland slopes and possibly leading to increased runoff and increased stream power. Increased stream power may have led to deeper incision and widening of the creek channel. Increased runoff concentrated the Mazama ash in fluvial deposits on the valley floor. There is no soil development on Unit IV. Generally, Unit IV is a structureless unit, although some bedding structures indicate that the ash was redeposited having been fluvially laid down on the valley floor.

Glacial expansion occurred during the last 5000 years, during a period known collectively as the Neoglaciation (Beget, 1983). Mid to late Holocene glacial advances in the Cascade Range occurred about 3400 yr B.P. (Porter, 1976) and between 3500 and 2040 yr B.P. (Crandell and Miller, 1964). A reversal of climate conditions ca.4000 to 2000 yr B.P. is recorded by a return to a wetter pollen assemblage (Mack et al., 1978; Mehringer, 1985; Wigand, 1987). This climate change to cooler and wetter conditions corresponds to Unit V at Camp Creek which is radiocarbon dated at ca. 3310 +/- 60 ^{14}C yr B.P (3639-3440 cal yr B.P). This aggradational period was preceded by an erosional phase which cut numerous channels into the Mazama ash unit, but the Mazama ash unit does not appear to have been severely eroded by Unit V. This may be due to the resistance of silica cementation of the Mazama ash. Estimated discharge rates of paleochannels show discharge rates were much higher than modern day average discharge rates. An arroyo channel existed at the downstream end of the study site and was buried. The presence of many cut-and-fill channels along the channel exposure walls indicates an increase in stream power accompanied by a higher sinuosity. Facies that were identified include vertical accretion floodplain and lateral accretion point bar and transitional channel fills. There was an interval of surface stability when some weak soil development occurred. Organic matter content is more than 2% indicating a wet bottomland existed on some parts of the study site (Mitsch and Gosselink, 1986). A wet-meadow appears to have existed at profiles CC-2, CC-3A and CC-3B and CC-5. At these profiles dark black and brown Vertisols overlie the Mazama ash unit. Unit V is cut into the Mazama ash unit. Stratigraphic Unit V corresponds to a period of increased effective precipitation and aggradation.

The neoglacial advance at ca. 3500 yr B.P. was followed by a long period of milder climate during which time the glaciers diminished in size. Between 2000 and 1400 yr B.P. pollen spectra indicate drier conditions in eastern Oregon (Wigand, 1987). At Camp Creek an erosional episode occurred which eroded Unit V, followed by aggradation of Unit VI. The age of this unit is between ca. 3300 and 1200 ^{14}C yr B.P. Unit VI appears as a clay rich vertical accretion floodplain facies and as sandier sediments from the braided channels of the alluvial fans coming off of Sheep Mountain. Facies also include channel fill deposits and point bar deposits. At the time of Unit VI Camp Creek still remained dominantly a single thread channel but during times of flood, it is possible that the erosional power of water might cause temporary braided channels to form because of an overload of sediment delivered into the system.

According to pollen and lake level records, between 1400 to 900 yr B.P. more effective moisture had returned to eastern Oregon (Wigand, 1987). At Camp Creek, this interval corresponds to the aggradation of Unit VII, which is dated at ca. 1190 +/- 60 ^{14}C yr B.P. (1217-1010 cal yr B.P.). Soil organic matter content greater than 2% indicates that this was a period of wet bottomlands with increased effective precipitation. Unit VII is also represented by black to dark brown Vertisols at CC-2, CC-3A, CC-3B and CC-5. These profiles are located at the upstream end of the study area and indicate a wet meadow existed at these profiles. Field observations show that this was one continuous wet meadow which extended for approximately 3 km (1.8 mi) along the stream. At the downstream end of the sample area, Unit VII is an aggradational unit which has a weakly developed soil on its surface but which shows no evidence of a wet-meadow soil. It has retained much of the characteristics of the John Day parent material. The facies of Unit VII are vertical accretion floodplain deposits.

Marked glacial advances occurred during the last several centuries, with many glaciers attaining their maximum Neoglacial positions during this time (Porter and Denton, 1967). Glacial advances occurred in the Cascade Range at 450 years (Porter, 1976) and 500 to 400 yr B.P. (Crandall and Miller, 1964). Many authors refer to this period as "the Little Ice-Age." In eastern Oregon by 500 yr B.P. drought was reflected in an increase in greasewood and saltbush. Moister conditions returned 300 to 150 yr B.P. Since the mid-1800s drier conditions, and perhaps human impact, have caused the expansion of sagebrush (Wigand, 1987). Tree-ring records indicated that the most severe drought year was 1889 (Graumlich, 1987). The relict surface channels are associated with historical times and indicate a higher average discharge than the modern arroyo. The modern arroyo incision at Camp Creek appears to have occurred in the early 1890s (Buckley, 1992). This incision occurred after a three year drought and after an extremely severe winter (Hatton, 1989).

The incision of the 1890s coincides with a pattern of severe droughts followed by heavier than average winter snowfall. This precedes a modern warm-dry period. Average discharge rates of the modern channel are much lower than paleochannel discharge rates.

Of particular note is the development and healing of an arroyo channel in the lower reaches of the study site. The channel occurred prior to or during Unit V time (3310 +/- 60 ^{14}C yr B.P.) which is associated with a period of wetter climate. The study site is located below the head-cut of the modern arroyo. It is possible that the head-cut of the buried arroyo channel exists near the lower end of the study site and this accounts for the lack of evidence of its existence further upstream.

Regional Synchrony of Fluvial Activity

Pavish (1973) in eastern Washington provided a history of aggradation, degradation and stability in which relationships between climate and sediment yield show that erosion occurred during the late Pleistocene, aggradation dominated during the mid-Holocene and the Neo-glacial period was characterized by minor erosion, but increased alluviation. Cochran (1988) in northeastern Oregon used paleoenvironmental data to infer that floodplain stability occurs during periods of cool and wet climate, while erosion occurs at the transition toward warm-dry periods. Which transition leads to which response could not be determined at Camp Creek. The complexity of the system and the need for more detailed research barred a detailed reconstruction of the floodplain history, and I could not identify the fluvial response associated with a specific climatic change in one direction or another.

It appears that at Camp Creek aggradation has dominated during the Holocene which was warmer and drier than the late Pleistocene. Minor erosional episodes occur throughout the Holocene but the system appears to have healed itself throughout this aggradational period. A major erosional period occurred ca. 3300 ^{14}C yr B.P. which is associated with a wetter climate and an arroyo channel which was filled with Unit V sediments.

Conclusions

The fluvial behavior of Camp Creek has been inferred by the characteristics of its stratigraphy and chronology. This fluvial behavior can, in turn, be correlated to regional climatic trends. Camp Creek has responded in the following way to climatic fluctuations:

1. Before 8200 ^{14}C yr B.P., the valley floor was scoured to the Tertiary claystone the modern channel flows on today.
2. Between 8200 and 6800 ^{14}C yr B.P., aggradation dominated. It was drier than post-Mazama times. Two episodes of stability and soil formation occurred on Units I and II.
3. Just before the eruption of Mt. Mazama ca. 6800 ^{14}C yr B.P., an erosional period occurred which was associated with wetter conditions than pre-Mazama time.
4. Associated with the Mt. Mazama eruption ca. 6800 ^{14}C yr B.P., an episode of fluvial adjustment deposited ash and pumice on the valley floor.
5. A major episode of erosion resulting in the cutting of a highly sinuous channel and an arroyo channel was followed by aggradation, healing of the system, stability and soil development at ca. 3300 ^{14}C yr B.P. Wet climate conditions existed in eastern Oregon. Wet-meadows existed in the watershed.
6. Before 1200 ^{14}C yr B.P. it was a drier and warmer period of time in eastern Oregon, and aggradation dominated. One episode of stability and soil development is evident.
7. From 1200 ^{14}C yr B.P. to present, there was a period of aggradation. Alternating moist and dry conditions have existed in eastern Oregon. Wet meadows existed in the watershed.

8. It was drier in the early 1800s, and severe droughts from 1885 to 1889 were followed by a severe winter of 1889-90. The modern arroyo incised in the 1890s.

Water runs off a surface when vegetation, soil surface and slope together do not allow it to penetrate and percolate down. Hillslope and channel erosion occurs. Reduction of vegetational cover by humans plays a role, but may not be the primary cause of entrenchment. Relationships between climate and fluvial activity may be studied by looking at the exposed channel walls of Camp Creek. A buried arroyo channel found at Camp Creek that predates Euroamerican settlement indicates that arroyo cutting may be climatically influenced in the watershed. Many hypotheses can be offered to explain the fluvial response of streams and the associated floodplain construction, destruction or reconstruction. Ascribing a given fluvial process to a regional climatic change can locally be done. Determining a given fluvial response to a particular direction of climate change proves to be more difficult. At Camp Creek it was possible to link the alluvial chronologies, channel morphology and soil development to regional climate change.

Much has been learned from this investigation, yet much remains to be learned. Larger samples of exposures along the whole length of the arroyo need to be studied. More dates are needed to get answers about rates of cutting and filling. We need clearer evidences for the processes of erosion and what accounts for the unconformities between units. We need better maintained experiments examining the effects of humans and other agents on aggradation and erosion. Amidst all these outstanding questions, this study has shown that analysis of fluvial sediments of arid lands can lead to a better understanding of the evolution of the landscape.

APPENDIX A

SOIL PROFILES

SOIL PROFILES

Each section is measured from the top of the bank (0 cm) downward. The first Munsell color stated is moist.

Locality CC-1A

NW 1/4, SE 1/4, NW 1/4, SE 1/4, Sec. 26, T.18S, R.20E. East Bank, 150 meters downstream of the confluence of Parrish Creek and Indian Creek.

Unit ? A1 horizon--0 to 10 cm; very dark brown (10YR 2/2) clay loam, dark grayish brown (10YR 4/2) dry; weak, very fine granular structure; slightly sticky, slightly plastic, very friable, loose; many fine rootlets, non calcareous; clear smooth boundary.

Unit ? A2 horizon--10 to 30 cm; very dark grayish brown (10YR 3/2) clay loam, gray (10 YR 6/1) dry; moderately weak, medium granular structure; slightly sticky, plastic, very firm, hard; few roots, non calcareous; clear abrupt boundary.

Unit V A1 horizon--30-65 cm; gray (10YR 5/1) clay loam, light gray (10YR 6/1) dry; strong, medium angular blocky structure; sticky, plastic, extremely firm, extremely hard; non calcareous; smooth gradual boundary.

Unit V A2 horizon--65-150 cm; gray (10YR 5/1) silty clay, light gray (10YR 7/1) dry; strong medium angular blocky structure; sticky, plastic, extremely firm, extremely hard; 15% white carbonate mottles, calcareous; smooth abrupt boundary.

Unit IV C--150-215 cm; olive gray (5Y 5/2) silty clay, light gray (5Y 7/2) dry; strong, medium angular blocky structure; slightly sticky, slightly plastic, firm, very hard; 40% white carbonate mottling, single grain pumice <1mm in diameter, calcareous; smooth abrupt boundary.

Unit IV C--215-310 cm; light olive gray (5Y 6/2) pumice and ash, white (5Y 8/2) dry; structureless, many single grain pumice <1mm in diameter; slightly sticky, slightly plastic, loose, extremely hard-strongly cemented when dry; non calcareous; smooth abrupt boundary.

Unit IV--310-383 cm; light olive gray (5Y 6/2) sandy ash and pumice, white (5Y 8/1) dry; structureless, many single grain pumice < 3mm in diameter, sand and ash; six well defined finer sorted ash beds 2 to 3 cm thick throughout, non calcareous; smooth abrupt boundary.

Unit IV--383-385 cm; light gray (5Y 8/1) ash, white (5Y 7/1) dry; structureless, single grain, very fine granular structure; slightly sticky, slightly plastic, loose, very hard; fine ash bed underlying pumice unit, non calcareous; smooth abrupt boundary.

Unit III A--385-470 cm; olive gray (5Y 4/2) silty clay loam, light gray (5Y 7/2) dry; strong, medium prismatic structure; slightly sticky, slightly plastic, very firm, extremely hard; non calcareous; clear smooth boundary.

Unit III C--470-510 cm; olive (5Y 4/3) clay loam, pale yellow (5Y 7/3) dry; strong, medium prismatic structure; slightly sticky, plastic, very firm, extremely hard; non calcareous, few charcoal flecks; abrupt smooth boundary.

Unit II A horizon--510-560 cm; dark brown (10YR 3/3) clay, brown (10YR 5/3) dry; strong, medium prismatic structure; slightly sticky, very plastic, firm, extremely hard; non calcareous, few flecks of charcoal.

560 cm--water level.

Locality CC-1B

NW 1/4, SE 1/4, NW 1/4, SE 1/4, Sec. 26, T.18S, R. 20E. East Bank, 25 meters downstream from CC-1A.

Unit VIII A horizon--0-12 cm; very dark grayish brown (10YR 2/2) silty clay, very dark brown (10YR 2/2) dry; weak, very fine granular structure; slightly sticky, slightly plastic, friable, loose; many fine rootlets, non calcareous; clear smooth boundary.

Unit VI A horizon--12-100 cm; very dark grayish brown (2.5Y 3/2) silt loam, pale yellow (2.5 Y 7/4) dry; moderately weak, fine granular structure; sticky, plastic, very firm, hard; few rootlets, <10% gravels, gravels horizontally sorted into a lens, few white carbonate mottles, slightly calcareous; clear smooth boundary.

Unit V A1 horizon--100-120 cm; dark grayish brown (10YR 4/2) silty clay loam, light gray (10YR 6/1) dry; moderately strong, very fine angular blocky structure; sticky, plastic, very firm, very hard; few distinct white carbonate mottles, moderately calcareous, few flecks of charcoal; clear broken boundary.

Unit V A2 horizon--120-205 cm; very dark grayish brown (2.5Y 3/2) silty clay, light gray (2.5Y 7/2) dry; moderately strong, fine angular blocky structure; slightly sticky, plastic, very firm, very hard; many fine white carbonate mottles, calcareous; abrupt wavy boundary.

Unit IV C--205-290 cm; olive (5Y 4/3) silty loam (ash and pumice), pale yellow (5Y 8/3) dry; structureless, many single grain pumice; slightly sticky, non plastic, loose, soft; non calcareous, reworked ash unit; abrupt wavy boundary.

Unit II A1 horizon--290-320 cm; dark grayish brown (2.5Y 4/2) clay, light brownish gray (2.5Y 6/2) dry; strong, medium prismatic structure; sticky, plastic, extremely firm, extremely hard; prominent common green mottling (5Y 7/2) in root vesicles, few rootlets, few flecks of charcoal, slightly calcareous; clear wavy boundary.

Unit II A2 horizon--320-360 cm; olive brown (2.5Y 4/4) clay, grayish brown (2.5Y 5/2) dry; strong, medium prismatic structure; slightly sticky, slightly plastic, firm, extremely hard; prominent many medium pale olive (5Y 6/3) mottles in root vesicles, thin lens of charcoal with few flecks, non calcareous; clear wavy boundary.

Unit I A horizon--360-420 cm; dark brown (10YR 3/3) clay, pale brown (10YR 6/3) dry; strong, fine prismatic structure; sticky, plastic, very firm, extremely hard; prominent common fine pale olive (5Y 6/3) mottles in root vesicles, few charcoal flecks, non calcareous; clear wavy boundary.

Unit ?--420-540 cm; very dark grayish brown (2.5Y 3/2) clay, sand and gravels; weak, very fine granular structure; sticky, slightly plastic, noncoherent, loose; very gravelly, rounded, discoidal, very fine to coarse pebbles; average diameter is 10mm, range is 2 to 30mm; gravels content is about 50% of volume, gravels coated with black manganese; thin charcoal lens present <2mm in diameter, non calcareous.

540 cm--water level.

Locality CC-2

NE 1/4, NE 1/4, SE 1/4, NE 1/4, Sec. 35, T.18S, R.20E. Northeast Bank of Camp Creek, due east of Pioneer Cemetary.

Unit ? A1 horizon--0-2 cm; dark brown (10YR 3/1) loam, gray (10YR 6/1) dry; very weak, very fine granular structure; sticky, non plastic, friable, soft; organic matt, non calcareous; smooth abrupt boundary.

Unit ? A2 horizon--2-6 cm; black (10YR 2/1) silt loam, gray (10YR 5/1) dry; moderately strong, very fine granular structure; sticky, plastic, friable, soft; common roots, non calcareous; clear smooth boundary.

Unit ? A3 horizon--6-45 cm; very dark gray (10YR 3/1) silty clay, gray (10YR 6/1) dry; strong, very fine angular blocky structure; sticky, very plastic, firm, hard; many fine rootlets, common white carbonate mottles, moderately calcareous; clear smooth boundary.

Unit ? A4 horizon--45-64 cm; very dark gray (10YR 3/1) clay loam, gray (10YR 6/1) dry; strong, very fine angular blocky structure; sticky, plastic, very friable, hard; common white carbonate mottles; clear smooth boundary.

Unit ? A5 horizon--64-88 cm; very dark grayish brown (10YR 3/2) sandy loam, light brownish gray (10YR 6/2) dry; weak fine granular structure; sticky, slightly plastic, very friable, slightly hard; few roots, calcareous; smooth abrupt boundary.

Unit IV C1--88-115 cm; very dark grayish brown (10YR 3/2) silty loam ash and pumice unit, gray (10YR 6/1) dry; very weak, very fine granular structure; sticky, slightly plastic, very friable, soft; moderately calcareous; clear smooth boundary.

Unit IV C2--115-125 cm; dark grayish brown (10YR 4/2) silty loam ash and pumice unit, light gray (10YR 7/2) dry; moderately weak, very fine granular strucutre; slightly sticky, nonplastic, loose, soft; many <2mm pumice, few rootlets, moderately calcareous; smooth abrupt boundary.

Unit ? C--125-160 cm; dark brown (10YR 7/4) sandy loam, very pale brown (10YR 7/4) dry; structureless, single grain, to very fine granular structure; slightly sticky, nonp[lastic, very friable, soft; few roots, few gravels, calcareous; clear smooth boundary.

Unit ? A horizon--160 cm to 210; dark yellowish brown (10YR 4/4) silty clay, light yellowish brown (10YR 6/4) dry; moderately weak, very fine granular structure; sticky, slightly plastic, very friable, hard; common well rounded, prismoidal, small to large cobbles, average diameter 10 cm, range is 5 to 20 cm; common well rounded, very fine to very coarse pebbles, average diameter is 3 to 4 mm, range is 2 to 60mm; gravels content is more than 50% of volume, calcareous.

210 cm--water level.

Locality CC-3A

SE 1/4, SW 1/4, NE 1/4, SW 1/4, Sec.36, T.18S, R.20E. Northeast Bank of Camp Creek, due south of Sheep Mountain, 250 meters east of the westernmost BLM exclosure fence line.

Unit VIII A1 horizon--0-30 cm; dark brown (10YR 3/3) loam, dark brown (10YR 4/3) dry; weak, very fine granular structure; sticky, plastic, very friable, soft; few fine rootlets, moderately calcareous; smooth clear boundary.

Unit VII A1 horizon--30-55 cm; very dark gray (5Y 3/1) silt loam, light gray (5Y 6/1) dry; moderate, fine angular blocky structure; slightly sticky, plastic, friable, hard; few small rootlets, non calcareous; smooth abrupt boundary.

Unit VII A2 horizon--55-110 cm; very dark gray (5Y 4/1) clay loam, dark gray (5Y3/1) dry; strong, medium prismatic structure; slightly sticky, plastic; very firm, very hard; few white carbonate mottles, moderately calcareous; wavy abrupt boundary.

Unit VI C horizon--110-140 cm; olive (5Y 4/3) silty clay, white (5Y 8/2) dry; moderate, fine angular blocky structure; slightly sticky, plastic, friable, hard; few white carbonate mottles, calcareous; wavy abrupt boundary.

Unit V A horizon--140-210 cm; black (5Y 2.5/1) silty clay, dark gray (5Y 4/1) dry; strong, medium prismatic structure; sticky, plastic, very firm, very hard; prominent, many white carbonate mottles, very calcareous; wavy abrupt boundary.

Unit IV C--210-235 cm; dark grayish brown (2.5Y 4/2) silt loam ash and pumice unit, light gray (2.5Y 7/2) dry; structureless, single grain very fine granular; nonsticky, slightly plastic, firm, very hard; common pumice <2mm in diameter, non calcareous; smooth abrupt boundary.

Unit III C--235-340 cm; olive (5Y 4/3) clay, light gray (5Y 7/2) dry; strong, medium prismatic structure; sticky, plastic, very firm, hard; few pale olive (5Y 6/3) mottles in root vesicles, common white carbonate mottles, slightly calcareous; smooth abrupt bounday.

Unit I A--340-430 cm; dark brown (10YR 3/3) clay, brown (10YR 5/3) dry; strong, medium prismatic structure; slightly sticky, plastic, firm, hard; few olive (5Y 4/3) mottles in root vesicles, non calcareous.

430 cm--water level.

Locality CC-3B

SE 1/4, SW 1/4, NE 1/4, NW 1/4, Sec. 31, T.18S, R.20E.
South Bank-50 meters downstream from CC-3A.

Unit VIII A horizon--0-20 cm; very dark brown (10YR 2/2) loam, dark brown (10YR 3/3) dry; weak, very fine granular structure; slightly sticky, slightly plastic, noncoherent, loose; few fine rootlets, calcareous; clear smooth boundary.

Unit VII A1 horizon--20-40 cm; black (10YR 2/1) silt loam, gray (10YR 5/1) dry; strong, fine angular blocky structure; sticky, plastic, firm, hard; non calcareous; clear smooth boundary.

Unit VII A2 horizon--40-130 cm; very dark gray (10YR 3/1) silty clay, gray (10YR 5/1)dry; strong, medium prismatic structure; slightly sticky, very plastic, firm, extremely hard; prominent many white carbonate mottles, very calcareous; smooth abrupt boundary.

Unit VI A horizon--130-200 cm; very dark gray (5Y 3/1) silt loam, gray (5Y 6/1) dry; weak, very fine granular structure; slightly sticky, slightly plastic, very friable, slightly hard; few very fine gravels present, moderately calcareous; wavy abrupt boundary.

Unit V A horizon--200-295 cm; very dark gray (10YR 3/1) silt clay, gray (10YR 6/1) dry; strong, medium prismatic structure; sticky, plastic, very firm, extremely hard; few white carbonate mottles, slightly calcareous; wavy abrupt boundary.

Unit IV C--220-250 cm;(out of profile sequence) very dark gray (10YR 8/1) loam, pumice and ash unit, light gray (10YR 7/1) dry; moderate, medium prismatic structure; slightly sticky, slightly plastic, very firm, extremely hard; prominant many white carbonate mottles, common single grain pumice <2mm, very calcareous; wavy abrupt and broken boundary.

Unit II A horizon--295-340 cm; very dark grayish brown (10YR 3/2) clay loam, brown (10YR 5/3) dry; moderate, fine prismatic structure; sticky, plastic, friable, hard; slightly calcareous, smooth abrupt boundary.

Unit I A horizon--340-390 cm; dark yellowish brown (10YR 3/4) clay, yellowish brown (10YR 5/4) dry; strong, medium prismatic structure; sticky, plastic, friable, hard; few charcoal flecks, non calcareous.

390 cm--water level.

Locality CC-4

SW 1/4, SW 1/4, SW 1/4, NW 1/4, Sec. 31, T.18S, R.21E. North Bank, alluvial fan originating from Sheep Mountain.

Unit ? A1--0-25 cm; very pale brown (10YR 7/4) silty clay loam, white (10YR 8/2) dry; weak, fine granular structure; sticky, slightly plastic; friable, hard; common pumice <2mm in diameter, few rootlets, calcareous; gradual smooth boundary.

Unit ? A2--25-150 cm; light yellowish brown (10YR 6/4) silty loam, very pale brown (10YR 8/3) dry; weak, very fine granular structure; slightly sticky, slightly plastic, very friable, slightly hard; faint few white carbonate mottles, calcareous; clear smooth boundary.

Unit ? A3--150-300 cm; brown (10YR 4/3) clay loam, very pale brown (10YR 8/3) dry; moderate, medium subangular blocky structure; sticky, slightly plastic, firm, very hard; faint few white carbonate mottles, calcareous; abrupt smooth boundary.

Unit ? B--300-320 cm; dark yellowish brown (10YR 4/4) clay loam, brown (10YR 5/3) dry; weak subangular blocky structure; slightly sticky, slightly plastic, very friable, hard; calcareous.

Gravels: clast supported pebbles and cobbles.
Geomorphic position: found along the base of Sheep Mountain where Camp Creek has dissected the alluvial fan of locality CC-4. Well-rounded, prismoidal, medium to very coarse pebbles; average diameter is 10mm, range is 8 to 30 mm; pebble content is about 20% of volume; well-rounded, prismoidal, large cobbles; average diameter is 6cm, range is 15 to 25cm; cobble content is about 70% of volume.

320 cm--water level.

Locality CC-5

NW 1/4, SE 1/4, NW 1/4, SE 1/4, Sec. 26, T.18S, R.20E. South Bank, south wall of the West Fork of Camp Creek at the confluence of Parrish/Indian Creeks.

Unit ? A1 horizon--0-33 cm; very dark gray (10YR 3/1) silty clay loam, very dark grayish brown (10YR 3/2) dry; strong, fine granular structure; slightly sticky, plastic, very friable, very hard; common rootlets and roots, calcareous; clear smooth boundary.

Unit ? A2 horizon--33-50 cm; very dark grayish brown (10YR 3/2) silty clay, gray (10YR 6/1) dry; strong fine angular blocky structure; very sticky, very plastic, friable, very hard; few rootlets, common medium roots, prominent many white carbonate mottles, very calcareous; clear smooth boundary.

Unit ? A3 horizon--50-95 cm; very dark gray (10YR 3/1) silty clay, dark gray (10YR 4/1) dry; strong very fine angular blocky; very sticky, very plastic, friable, very hard; few rootlets, common medium roots, prominent many white carbonate mottles, very calcareous; smooth abrupt boundary.

Unit IV C--95-153 cm; dark yellowish brown (10YR 4/4) silt loam, pumice and ash unit, white (10YR 8/1) dry; massive, single grain, very fine granular structure; non sticky, non plastic, loose, soft; common pumice <2mm in diameter, few gravels <5mm, root vesicles, 2 cm fine ash layer at base of unit, non calcareous; smooth abrupt boundary.

Unit II A horizon--153-270 cm; dark brown (10YR 3/3) clay, gray (10YR 6/1) dry; strong coarse prismatic, very sticky, very plastic, extremely firm, extremely hard; common root vesicles with distinct many orange mottling, few flecks of charcoal, few white carbonate mottles, calcareous; clear smooth boundary.

Unit I A1 horizon--270-295 cm; dark yellowish brown (10YR 3/4) clay, gray (10YR 5/1) dry; strong coarse angular blocky structure; very sticky, very plastic, firm, extremely hard; prominent common orange root vesicle mottles, 2 cm charcoal bed, pominent many white carbonate mottles, very calcareous; clear smooth boundary.

Unit I A2 horizon--295-345 cm; very dark grayish brown (10YR 3/2) clay, dark brown (10YR 3/3) dry; moderately strong, medium prismatic breaking to fine angular blocky structure; very sticky, very plastic, firm, very hard; many common root vesicles, few orange stained rootlet vesicles, few white carbonate mottles, calcareous.

345 cm--water level.

Locality CC-6A

SW 1/4, NE 1/4, SW 1/4, SE 1/4, Sec. 26, T.18S, R.20E. North Bank, east wall, profile taken from the historical terrace which formed within Camp Creek.

Unit ? A1 horizon--0-40 cm; very dark grayish brown (10YR 3/2) silt loam, gray (10YR 5/1) dry; weak very fine granular structure; slightly sticky, slightly plastic, friable, slightly hard; common gravels < 2mm, many roots and rootlets, slightly calcareous; clear wavy boundary.

Unit ? A2 horizon--40-100 cm; very dark grayish brown (10YR 3/2) silt loam, light brownish gray (10YR 6/2) dry; moderate angular blocky breaking to fine granular structure; slightly sticky, slightly plastic, very friable, extremely hard; light colored laminae 1 to 2 cm thick, crossbedded sand and pumice, many gravels <5mm, very fine to fine pebbles, average size 3mm, gravels content is about 20-40% of volume, slightly calcareous; wavy abrupt boundary.

Unit ? A1 horizon--100-110 cm; very dark grayish brown (10YR 3/2) loam, dark grayish brown (10YR 4/2) dry; weak very fine granular to single grain structure; slightly sticky, slightly plastic, very friable, loose; many sand, common gravels <2mm, gravels content is about 10% of volume, slightly calcareous; wavy abrupt boundary.

Unit ? A2 horizon--110-130 cm; dark brown (10YR 3/3) clay loam, pale brown (10YR 6/3) dry; strong fine angular blocky breaking to fine granular strucutre; sticky, plastic, friable, hard; few roots, common gravels <2mm, gravels content is about 10% of volume, slightly calcareous; smooth abrupt boundary.

Unit ? C--130--160 cm; very dark brown, (10YR 2/2) silt, sand and gravels, very dark grayish brown (10YR 3/2) dry; non sticky, non plastic, loose, loose; common roots, clast supported, few cobbles <50mm; subrounded, subprismoidal, fine to medium pebbles, average diameter 8mm, range is 2 to 20 mm, gravels content is 60 to 80% of volume.

160 cm--water level.

Locality CC-6B

NW 1/4, NE 1/4, SW 1/4, SE 1/4, Sec. 26, T.18S, R.20E. East Bank, 10 meters upstream on Camp Creek from locality CC-6A; west southwest of Mutton Butte.

Unit VII A horizon--0-60 cm; very dark grayish brown (10YR 3/2) silt loam, light brownish gray (10YR 6/2) dry; strong very fine granular structure; slightly sticky, slightly plastic, friable, slightly hard; common rootlets, few gravels <2mm, moderately calcareous; clear smooth boundary.

Unit VI A horizon--60-130 cm; dark grayish brown (10YR 4/2) clay loam, gray (10YR 5/1) dry; strong medium prismatic; slightly sticky, plastic, firm, extremely hard; few roots and rootlets, many pumice <2mm, slightly calcareous; wavy abrupt boundary.

Unit V A horizon--130-207 cm; grayish brown (10YR 5/2) silty clay, light gray (10YR 7/1) dry; strong medium prismatic; very sticky, very plastic, extremely firm, extremely hard; many pumice <2mm, very slightly calcareous; wavy abrupt boundary.

Unit IV C--207-300 cm; dark yellowish brown (10YR 4/4) silt loam, ash and pumice unit, white (10YR 8/2) dry; massive very fine granular structure; non sticky, non plastic, very friable, hard; crossbedded common sand and few gravel <5mm in diameter, many pumice <2mm in diameter, common root vesicles, non calcareous; broken beds <2cm thick of fine ash, lowest 2 cm of profile is a fine ash, non calcareous; gradual smooth boundary.

Unit ? C horizon--300-450 cm; dark brown (10YR 3/3) sand, brown (10YR 5/3) dry; weak, single grain, very fine granular structure; non sticky, non plastic, loose, loose; sand and pumice <2mm content is more than 80% of volume, slightly calcareous; clear smooth boundary.

Unit ? A horizon--450-500cm; brown (10YR 5/3), clay loam; slightly sticky, plastic, very friable; common pumice <2mm in diameter, few orange root vesicles.

500 cm--water level.

Locality CC-7

NE 1/4, SE 1/4, SW 1/4, SE 1/4, Sec.26, T.18S., R.20E. North Bank, east wall, 120 meters downstream from locality CC-6A, southwest of Mutton Butte.

Unit VIII A horizon--0-13 cm; very dark brown (10YR 2/2) loam, dark grayish brown (10YR 4/2) dry; strong very fine granular structure; slightly sticky, slightly plastic, very friable, soft; common roots and many rootlets, non calcareous; clear smooth boundary.

Unit ? A1 horizon--13-54 cm; dark grayish brown (10YR 4/2) clay loam, light brownish gray (10YR 6/2) dry; strong fine angular blocky structure; sticky, plastic, friable, hard; few roots and rootlets, few white carbonate mottles, slightly calcareous; gradual wavy boundary.

Unit ? A2 horizon--54-88 cm; very dark grayish brown (10YR 3/2) clay loam, light brownish gray (10YR 6/2) dry; strong fine granular structure; slightly sticky, plastic, friable, hard; few roots and rootlets, few charcoal in root vesicles, common pumice <2mm in diameter, few gravels <50mm, non calcareous; gradual wavy boundary.

Unit ? A3 horizon--88-130 cm; dark brown (10YR 3/3) silty clay loam, brown (10YR 5/3) strong coarse angular blocky breaking to fine angular blocky, slightly sticky, plastic, friable, hard; few roots and rootlets, few charcoal in root vesicles, non calcareous; wavy abrupt boundary.

Unit ? A4 horizon--130-140 cm; very dark grayish brown (10YR 3/2) silty clay loam, gravel, light brownish gray

(10YR 6/2) dry; clast supported, single grain structure; sticky, slightly plastic, friable, slightly hard; subrounded, subdiscoidal pebbles, average diameter is 2mm, range is 2 to 10mm, gravels content is about 75% of volume, non calcareous; wavy abrupt boundary.

Unit V A1 horizon--140-155 cm; very dark grayish brown (10YR 3/2) silty clay, grayish brown prismatic (10YR 5/2) dry; strong coarse prismatic structure; slightly sticky, plastic, friable, very hard; few root vesicles, few roots, < 2cm broken gravel lens with <5mm in diameter pebbles, non calcareous; wavy abrupt boundary.

Unit V A2 horizon--155-179 cm; dark grayish brown (10YR 4/2) silty clay, light gray (10YR 7/1) dry; strong coarse prismatic breaking to fine and medium prismatic structure; slightly sticky, plastic, friable, very hard; broken gravel lens with <5mm in diameter pebbles, non calcareous; wavy abrupt boundary.

Unit IV C--179-253 cm; very pale brown (10YR 7/4) silt loam, pumice and ash, white (10YR 8/1) dry; massive, coarse granular breaking to single grain structure; slightly sticky, slightly plastic, loose, very hard; many root vesicles, flecks of charcoal, non calcareous; wavy abrupt boundary.

Unit III C--253-315 cm; very pale brown (10YR 7/4) clay, white (10YR 8/1) dry; strong very coarse angular structure; sticky, plastic, friable, extremely hard; few flecks of charcoal, broken 3 to 5 cm gravel lens <5mm in diameter, non calcareous; wavy abrupt boundary.

Unit II A1 horizon--315-330 cm; very dark brown (10YR 2/2) clay, dark grayish brown (10YR 4/2) dry; strong medium prismatic structure; sticky, plastic, extremely firm, extremely hard; few root vesicles with few olive (5Y 4/4) staining, many reddish yellow (7.5YR 6/8) staining, few charcoal flecks, non calcareous; clear wavy boundary.

Unit II A2 horizon--330-360 cm; dark grayish brown (10YR 4/2) clay, light brownish gray (10 YR 6/2) dry; strong medium prismatic structure; sticky, plastic, friable, extremely hard; few root vesicles with few olive (5Y 4/4) staining, many reddish yellow (7.5YR 6/8) staining, few charcoal flecks, non calcareous; wavy abrupt boundary.

Unit I A horizon--360-410 cm; brown (10YR 5/3) clay, pale brown (10YR 6/3) dry; moderate fine angular blocky structure; very sticky, very plastic, friable, extremely hard; few root vesicles with reddish yellow (7.5YR 6/8) staining, few gravels <2mm in diameter, slightly calcareous.

410 cm--water level.

Locality CC-8

SW 1/4, SW 1/4, SW 1/4, SW 1/4, Sec. 31, T.18S, R.21E.

South Bank of tributary entering Camp Creek off of alluvial fan issuing from Sheep Mountain.

Unit ? A1 horizon--0-10 cm; dark grayish brown (10YR 4/2) silt loam, grayish brown (10YR 5/2) dry; strong very fine granular structure; slightly sticky, slightly plastic, friable, slightly hard; many rootlets, few roots, non calcareous; clear smooth boundary.

Unit ? A2 horizon--10-50 cm; dark grayish brown (10YR 4/2) silty clay, gray (10YR 5/1) dry; moderate fine granular structure; sticky, plastic, firm, hard; few rootlets, few roots, slightly calcareous; gradual wavy boundary.

Unit ? A1 horizon--50-80 cm; brown (10YR 5/3) clay loam, light brownish gray (10YR 6/2) dry; moderate very fine angular breaking to very fine granular structure; sticky, plastic, very friable, hard; few white carbonate mottles, common <2mm pumice, very slightly calcareous; clear smooth boundary.

Unit ? A2 horizon--80-180 cm; brown (10YR 5/3) loam, light brownish gray (10YR 6/2) dry; massive fine granular structure; slightly sticky, slighty plastic, very friable, hard; few root vesicles, many pumice <2mm in diameter, broken beds of sand and gravels <5mm in diameter, very slightly calcareous; smooth abrupt boundary.

Unit ? A1 horizon--180-203 cm; strong brown (7.5YR 5/6) silty clay loam, brown (7.5YR 5/4) dry; strong fine prismatic structure; sticky, plastic, friable, hard; common white carbonate mottles, moderately calcareous; smooth abrupt boundary.

Unit ? B2 horizon--203-223 cm; light yellowish brown (10YR 6/4) clay loam, very pale brown (10YR 8/4) dry; moderate very fine angular blocky structure; slightly sticky, slightly plastic, friable, slightly hard; prominant many white carbonate mottles, faint clay skins; many well rounded, prismoidal, fine to very coarse pebbles, average size is 10mm, range is 5 to 50mm, gravels content is 50% of volume; calcareous; smooth abrupt boundary.

Unit ? C--223-345 cm; dark yellowish brown (10YR 4/6) sandy loam, pale brown (10YR 6/3) dry; soil supported gravels, weak very fine granular structure; slightly sticky, slighty plastic, very friable, hard; well rounded, pismoidal pebbles and cobbles ranging from 2mm to 15cm, average diameter is 10mm, gravels content is 70% of volume; prominent many white carbonate mottles, very calcareous; smooth abrupt boundary.

Unit ? B horizon--345-350 cm; yellow (10YR 7/6) clay loam, very pale brown (10YR 8/4) dry; strong thin platy structure; slightly sticky, slightly plastic, very friable, slightly hard; few mangans, distinct many clay skins, prominent common white carbonate mottles, slightly calareous.

Locality CC-9

SE 1/4, SW 1/4, SW 1/4, SW 1/4, Sec. 31, T.18S, R.21E. Southwest Bank, 90 meters downstream from locality CC-8, south of Sheep Mountain, north of the Price Valley Well.

Unit VIII A horizon--0-29 cm; dark brown (10YR 3/3) clay loam, grayish brown (10YR 5/2) dry; moderate fine angular blocky structure; sticky, slightly plastic, friable, hard; few rootlets, few pumice <2mm in diameter, non calcareous; clear smooth boundary.

Unit VII A horizon--29-75 cm; grayish brown (10YR 5/2) silty clay loam, light gray (10YR 7/2) dry; moderate medium granular structure; sticky, plastic, firm, extremely hard; common pumice <2mm in diameter, few roots, few root vesicles, slightly calcareous; wavy abrupt boundary.

Unit VI A1 horizon--75-145 cm; very dark grayish brown (10YR 3/1) silty clay loam, gray (10YR 5/1) dry; strong fine prismatic structure; sticky, plastic, very firm, hard; few pumice <2mm in diameter, few roots, distinct common white carbonate mottles, slightly calcareous; wavy clear boundary.

Unit VI A2 horizon--145-200 cm; olive (5Y 5/3) silty clay loam, light gray (5Y 7/2) dry; moderate fine angular blocky structure; sticky, plastic firm, very hard; few rootlets, few root vesicles, few pumice <2mm in diameter, slightly calcareous; wavy clear boundary.

Unit VI A3 horizon--200-230 cm; olive gray (5Y 4/2) silty clay, light gray (5Y 7/1) dry; moderate fine angular blocky structure; sticky, plastic, firm, hard; broken and wavy beds of fine gravels, sand and pumice <2mm in diameter, few roots, non calcareous; wavy abrupt boundary.

Unit V A horizon--230-259 cm; dark gray (5Y4/1) clay, light gray (5Y 7/1) dry; strong medium prismatic breaking to fine angular blocky structure; sticky, plastic, firm, very hard; few roots, few root vesicles, non calcareous; broken abrupt boundary.

Unit IV C--259-270 cm; pale yellow (5Y 7/3) sandy loam, pumice and ash, pale yellow (5Y 8/3) dry; massive, single grain pumice structure; non sticky, non plastic, loose, very hard; few roots, few root vesicles, many pumice <2mm in diameter, non calcareous; broken abrupt boundary.

Unit ? A horizon--270-300 cm; pale olive (5Y 6/3) silty clay loam, pale yellow (5Y 7/3) dry; moderate medium prismatic breaking to fine granular structure; sticky, plastic, firm, extremely hard; few roots, few root vesicles with green and orange staining, slightly calcareous.

300 cm--water level.

Locality CC-10

SE 1/4, NW 1/4, NE 1/4, NE 1/4, Sec. 6, T.19S, R.21E. Northwest Bank, southeast of Larkspur Butte on Middle Fork Camp Creek.

Unit VIII A horizon--0-10 cm; grayish brown (10YR 5/2) loam, light gray (10YR 7/1) dry; strong very fine granular structure; slightly sticky, slightly plastic, loose, soft; few rootlets, non calcareous; clear smooth boundary.

Unit VII C horizon--10-70 cm; olive (5Y 5/3) clay loam, light gray (5Y 7/2) dry; moderate very fine angular blocky structure; sticky, slightly plastic, firm, hard; slightly calcareous; smooth abrupt boundary.

Unit VI A horizon--70-150 cm; olive gray (5Y 5/2) clay, light gray (5Y 7/2) moderate fine angular blocky structure; sticky, plastic, firm, hard; moderately calcareous; smooth broken abrupt boundary.

Unit VI C horizon--150-290 cm; olive gray (5Y 5/2) clay, light gray (5Y 7/2) dry; moderate medium angular blocky; sticky, plastic, firm, extremely hard; common pumice <2mm in diameter, few white carbonate mottles, moderately calcareous; smooth broken abrupt boundary.

Unit IV C--290-316 cm; olive gray (5Y 5/2) silt loam, pumice and ash, white (5Y 8/2) dry; massive single grain pumice and ash structure; sticky, plastic, friable, hard; many pumice <2mm in diameter, calcareous; smooth broken abrupt boundary.

Unit II A1 horizon--316-395 cm; dark brown (10YR 3/3) clay loam, very pale brown (10YR 7/3) dry; strong medium angular blocky structure; sticky, plastic, firm, hard; prominent common white carbonate mottles, common root vesicles with olive gray (5Y 5/2) staining, few very fine gravels, moderately calareous; clear smooth broken boundary.

Unit II A2 horizon--395-480 cm; dark brown (10YR 4/3) silty clay loam, pale brown (10YR 6/3) dry; strong fine angular blocky structure; sticky, plastic, friable, hard; prominent common white carbonate mottles, few root vesicles with olive gray (5Y 5/2) staining, moderately calcareous; smooth broken abrupt boundary.

Unit II C horizon--480-570 cm; olive gray (5Y 5/2) clay, light olive gray (5Y 6/2) dry; moderate fine prismatic breaking to fine angular blocky structure; sticky, plastic, firm, hard; green and white broken beds of very fine sands and ashes intermixed with few gravels <5mm in diameter, few white carbonate mottles, moderately calcareous; broken wavy abrupt boundary.

Unit I A horizon--570-620 cm; very dark grayish brown (10YR 3/2) clay loam, light brownish gray (10YR 6/2) dry; strong fine prismatic breaking to fine angular structure; sticky, plastic, friable, hard; few root vesicles with green staining, fine charcoal bed, common white carbonate mottles, moderately calcareous; smooth abrupt boundary.

Unit ? C horizon-620-640 cm; dark brown (10YR 3/3) sand, brown (10YR 5/3) dry; structureless, single grain; non sticky, non plastic, loose, loose; non calcareous; smooth abrupt boundary.

Unit ? A horizon--640-690 cm; dark brown (10YR 3/3) clay, pale brown (10YR 6/3) dry; moderate fine angular blocky structure; sticky, plastic, firm, hard; few root vesicles stained green.

690 cm--water level.

Locality CC-11

SW 1/4, SE 1/4, NW 1/4, NE 1/4, Sec. 6, T.19s, R.21E. South Bank, south of Larkspur Butte on Middle Fork Camp Creek, upstream from locality CC-10.

Unit VIII A horizon--0-10 cm; dark grayish brown (10YR 4/2) sandy loam, light brownish gray (10 YR 6/2) dry; weak very fine granular structure; slightly sticky, slightly plastic, very friable, loose; many rootlets, very slightly calcareous; clear smooth boundary.

Unit VI C horizon--10-320 cm; pale olive (5Y 7/2) clay loam, light gray (5Y 7/2) dry; moderate coarse angular blocky structure; slightly sticky, slightly plastic, extremely firm, extremely hard; multitude of beds of sand and gravels < 3mm in diameter, few root vesicles, very calcareous; smooth abrupt boundary.

Unit V A horizon--320-350 cm; olive (5Y 4/3) silty clay, light olive gray (5Y 6/2) dry; strong large prismatic structure; sticky, plastic, extremely firm, extremely hard; slickenslides, prominent common white carbonate mottles, very calcareous; broken wavy abrupt boundary.

Unit IV C--350-386 cm; olive (5Y 5/6) silt loam, pumice and ash, light gray (5Y 7/2) dry; massive single grain granular structure; slightly sticky, slightly plastic, very friable, loose; ash and pumice <2mm in diameter interbedded with sand and very fine gravels, calcareous; smooth abrupt boundary.

Unit III A horizon--386-440 cm; olive (5Y 5/3) silty clay, light gray (5Y 7/2) dry; strong coarse prismatic structure; sticky, plastic, extremely firm, extremely hard; few roots and rootlets, few white carbonate mottles, very calcareous; wavy abrupt boundary.

Unit II A horizon--440-480 cm; brown (10YR 4/3) silty clay, brown (10YR 4/3) dry; moderate medium angular blocky structure; sticky, plastic, friable, very hard; few gravels <3mm in diameter, few roots, prominent common white carbonate mottles, calcareous; smooth abrupt boundary.

Unit II C horizon--480-530 cm; olive (5Y 5/4) clay, light olive gray (5Y 6/2) dry; moderate fine angular blocky structure; sticky, plastic, firm, hard; few white carbonate mottles, calcareous.

530 cm--water level.

Locality CC-12

SE 1/4, SE 1/4, SW 1/4, SW 1/4, Sec. 31, T.18S, R.21E. North Bank, east wall, south of Sheep Mountain, north of Price Valley Well.

Unit VIII A1 horizon--0-20 cm; dark grayish brown (10YR 4/2) silt loam, gray (10YR 5/1) dry; moderate very fine granular structure; slightly sticky, slightly plastic, very friable, soft; common rootlets, very slightly calcareous; clear smooth boundary.

Unit VI A2 horizon--20-69 cm; very dark grayish brown (10YR 4/2) silt loam, grayish brown (10YR 5/2) dry; moderate very fine granular structure; slightly sticky, slightly plastic, very friable, soft; few rootlets, 2 cm sand and gravel bed <2mm in diameter at base of profile, very slightly calcareous; clear smooth boundary.

Unit VI A3 horizon--69-196 cm; dark grayish brown (10YR 4/2) clay loam, light gray (10YR 7/1) dry; weak fine angular blocky structure; slightly sticky, plastic, friable, slightly hard; few root vesicles stained reddish-brown, few thin beds of sand, non calcareous; wavy abrupt boundary.

Unit V A horizon--196-225 cm; gray (10YR 5/1) silty clay loam, gray (10YR 6/1) dry; moderate medium prismatic structure; very sticky, plastic, hard; common root vesicles stained reddish-brown, non calcareous; wavy abrupt boundary.

Unit ? C horizon--225-248 cm; yellowish brown (10YR 5/4) sandy loam, light gray (10YR 7/1) dry; weak coarse angular blocky breaking to very fine granular structure; non sticky, non plastic, friable, slightly hard; many pumice <2mm in diameter, few root vesicles, slightly calcareous, wavy abrupt boundary.

Unit IV C--248-310 cm; light yellowish brown (10YR 6/4) sandy loam, pumice and ash, very pale brown (10YR 8/3) dry; massive single grain structure; non sticky, non plastic, friable, loose; few root vesicles few beds and laminae of pumice <2mm in diameter, few white carbonate mottles, non calcareous; smooth broken abrupt boundary.

Unit ? B horizon--310-330 cm; dark yellowish brown (10YR 4/6) clay loam, pale brown (10YR 6/3) dry; strong fine angular blocky structure; slightly sticky, plastic, friable, hard; few very coarse pebbles, average 30mm in diameter; many very fine to medium pebbles; prominent common white carbonate mottles; wavy abrupt boundary.

Unit ? C--330-400 cm; dark yellowish brown (10YR 3/6) sandy loam, light yellowish brown (10YR 6/4) dry; gravels almost clast supporting; non sticky, non plastic, very friable, hard; well rounded, prismoidal, large cobbles and pebbles, range 2mm to 12 cm, average size is about 10mm; gravels content is about 80% of volume; many white carbonate mottling on gravels, calcareous; smooth abrupt boundary.

Unit ? B horizon--400-450 cm; brown (10YR 4/3) sandy loam, very pale brown (10YR 8/4) dry; weak very fine granular, single grain structure; non sticky, non plastic, very friable, slightly hard; thin parallel sand laminae, distinct many white carbonate mottles, calcareous; point bar facie.

Unit ? B horizon--400-450 cm; yellowish brown (10YR 5/8) silty clay, yellow (10YR 8/6) dry; strong medium platy structure; sticky, plastic, friable, hard; few prominent black manganese specks, distinct common brownish yellow (10YR 6/8) color between plates, few iron nodules <4mm in diameter, prominent white carbonate mottles, calcareous.

450 cm--water level.

Locality CC-13

NE 1/4, NE 1/4, NE 1/4, NW 1/4, Sec. 6, T.19S, R.21E. North Bank, southwest of Larkspur Butte 30 meters west of the BLM road crossing Camp Creek.

Unit VIII A horizon--0-30 cm; black (10YR 5/1) silt loam, gray (10YR 5/1) gray, dry; weak very fine granular structure; slightly sticky, plastic, very friable, soft; many roots and rootlets, non calcareous; clear smooth boundary.

Unit ? A horizon--30-60 cm; very dark gray (10YR 3/1) clay loam, light gray (10YR 7/1) dry; weak fine angular blocky structure; slightly sticky, slightly plastic, firm, very hard; many rootlets, thin lens of sand and pebbles, few white carbonate mottles, slightly calcareous; wavy abrupt boundary.

Unit V A1 horizon--60-120 cm; very dark grayish brown (10YR 3/2) silty clay loam, gray (10YR 6/1) dry; moderate very fine prismatic structure; sticky, plastic, firable, very hard; common rootlets, many white carbonate mottles, slightly calcareous; clear wavy boundary.

Unit V A2 horizon--120-200 cm; olive gray (5Y 5/2) clay loam, light gray (5Y 7/2) dry; moderate fine prismatic structure; slightly sticky, slifhtly plastic, friable, very hard; sand layer at base 10 cm thick, few white carbonate mottles, moderately calcareous; wavy abrupt boundary.

Unit IV C--200-335 cm; brown (10YR 5/3) silt loam, pumice and ash, white (10YR 8/1) dry; massive; non sticky, non plastic, very friable, soft; common pumice <2mm in diamter, few root vesicles, fine white thick ash lens in pool at base of unit, slightly calcareous; wavy abrupt boundary.

Unit II A horizon--335-385 cm; brown (10YR 5/3) silty clay loam, pale brown (10YR 6/3) dry; moderate fine prismatic breaking to fine angular blocky structure; sticky, plastic, friable, very hard; common white carbonate mottles, calcareous.

385 cm--water level.

Locality CC-14

SE 1/4, SE 1/4, SW 1/4, SE 1/4, Sec. 31, T.18S, R.21E.
East Bank, south wall.

Unit VIII A1 horizon--0-30 cm; very dark grayish brown (10YR 3/2) silt loam, gray (10YR 6/1) dry; weak very fine granular structure; slightly sticky, slightly plastic, very friable, soft; common roots and rootlets, non calcareous; clear smooth boundary.

Unit VIII A2 horizon--30-55 cm; brown (10YR 5/3) clay, light gray (10YR 7/1) dry; weak fine granualar blocky structure; sticky, plastic, extremely hard, firm; common roots and rootlets, few charcoal flecks, moderately calcareous; clear abrupt boundary.

Unit VII C horizon--55-150 cm; olive gray (5Y 4/2) silty clay loam, light gray (5Y 7/2) dry; weak fine angular blocky breaking to very fine granular structure; sticky, plastic, firm, hard; few roots and rootlets, few root vesicles, many pumice <2mm in diameter, moderately calcareous; smooth abrupt boundary.

Unit VI C1 horizon--150-200 cm; olive gray (5Y 4/2) silty clay, light gray (5Y 7/2) dry; weak fine granular breaking to fine angular blocky structure; sticky, plastic, friable, hard; many pumice <2mm in diameter, few sand and pebbles <4mm in diameter intermixed, slightly calcareous; wavy abrupt boundary.

Unit VI C2 horizon--200-225 cm; olive gray (5Y 4/2) clay loam, gray (5Y 6/1) dry; weak medium prismatic structure; slightly sticky, slightly plastic, friable, hard; few roots and rootlets, many sands and pebbles, few white carbonate mottles, slightly calcareous; wavy broken abrupt boundary.

Unit V A horizon--225-290 cm; olive gray (5Y 2/2) clay, light olive gray (5Y 6/2) dry; weak fine angular blocky structure; sticky, plastic, very firm, hard; few rootlets, many pumice <2mm in diameter, common white carbonate mottles, black discoloration on top of individual peds, moderately calcareous; wavy abrupt boundary.

Unit IV C--290-385 cm; light olive gray (5Y 6/2) silt loam, pumice and ash, white (5Y 8/1) dry; massive single grain; non sticky, non plastic, friable, hard; common root vesicles, many pumice <2mm in diameter, common white carbonate mottles, non calcareous; smooth abrupt boundary.

Unit III C horizon--385-392 cm; brown (10YR 5/3) clay loam, light brownish gray (10YR 6/2) dry; moderate coarse angular blocky structure; sticky, plastic, friable, very hard; common root vesicles, common white carbonate mottles, calcareous; smooth abrupt boundary.

Unit II A1 horizon--392-420 cm; brown (10YR 5/3) silty clay loam, pale brown (10YR 6/3) moderate fine angular blocky structure; sticky, plastic, firm, very hard; few root vesicles stained olive gray (5Y 5/2), common white carbonate mottles, calcareous; wavy abrupt boundary.

Unit II A2 horizon--420-470 cm; olive (5Y 4/4) clay, light gray (5Y 7/2) dry; weak medium granular structure; sticky, plastic, firm, extremely hard; few root vesicles stained with pale olive (5Y 6/3), very fine charcoal lens, few white carbonate mottles, moderately calcareous; smooth abrupt boundary.

Unit II A3 horizon--470-475 cm; dark yellowish brown (10YR 4/4) clay loam, pale brown (10YR 6/3) dry; weak fine granular structure; slightly plastic, plastic, firm, hard; few root vesicles, common sand, moderately calcareous; smooth abrupt boundary.

Unit II A4 horizon--475-540 cm; olive (5Y 4/3) silty clay, light olive gray (5Y 6/2) dry; weak very fine granular structure; sticky, plastic, firm, very hard; few root vesicles stained with pale olive (5Y 6/3), up to 8 beds of fine ash up to 3 cm thick, interbedded with sand, moderately calcareous; smooth abrupt boundary.

Unit I A horizon--540-590 cm; dark yellowish brown (10YR 4/4) clay, brown (10YR 5/3) dry; moderate fine prismatic breaking to fine angular blocky structure; very sticky, very plastic, friable, hard; few roots, many white carbonate mottles, calcareous.

59cm--water level.

APPENDIX B

ELECTRONMICRO PROBE ANALYSIS OF MOUNT MAZAMA

ELECTRONMICRO PROBE ANALYSIS OF MOUNT MAZAMA

Tephra beds constitute ideal chronostratigraphic marker horizons because they record relatively short-lived geologic events. The tephra bed at Camp Creek was identified as ash from the Mount Mazama eruption of 6850 ^{14}C yr B.P. using the Electronmicro Probe (EPM) technique. This technique is grain specific and was used on 17 volcanic glass shards from the tephra bed at Camp Creek to determine the major element chemistry of individual glass particles (Mehringer et al, 1984). The EPM technique provides an analysis of the major elements iron, sodium, potassium, magnesium, calcium, titanium, aluminum, silicon and chlorine (Table B-1). The major elements were normalized to 100 percent. The EMP elemental analysis was conducted by Washington State University, Department of Geology, Pullman, Washington.

TABLE B-1

GLASS CHEMISTRY OF TEPHRA SAMPLE

Oxide	Weight %	SD*
Fe2O3	2.22	0.12
Na2O	5.02	0.09
K2O	2.75	0.07
MgO	0.43	0.03
CaO	1.57	0.05
TiO2	0.42	0.04
Al2O3	14.23	0.18
SiO2	73.19	0.24
Cl	0.17	0.03
Total	100**	
# of shards analyzed	17	

Identity	Mazama
Age	6850 BP
Similarity Coeffficient	0.99

* standard deviation

** analyses normalized to 100 weight percent

APPENDIX C

STRATIGRAPHIC DIAGRAMS

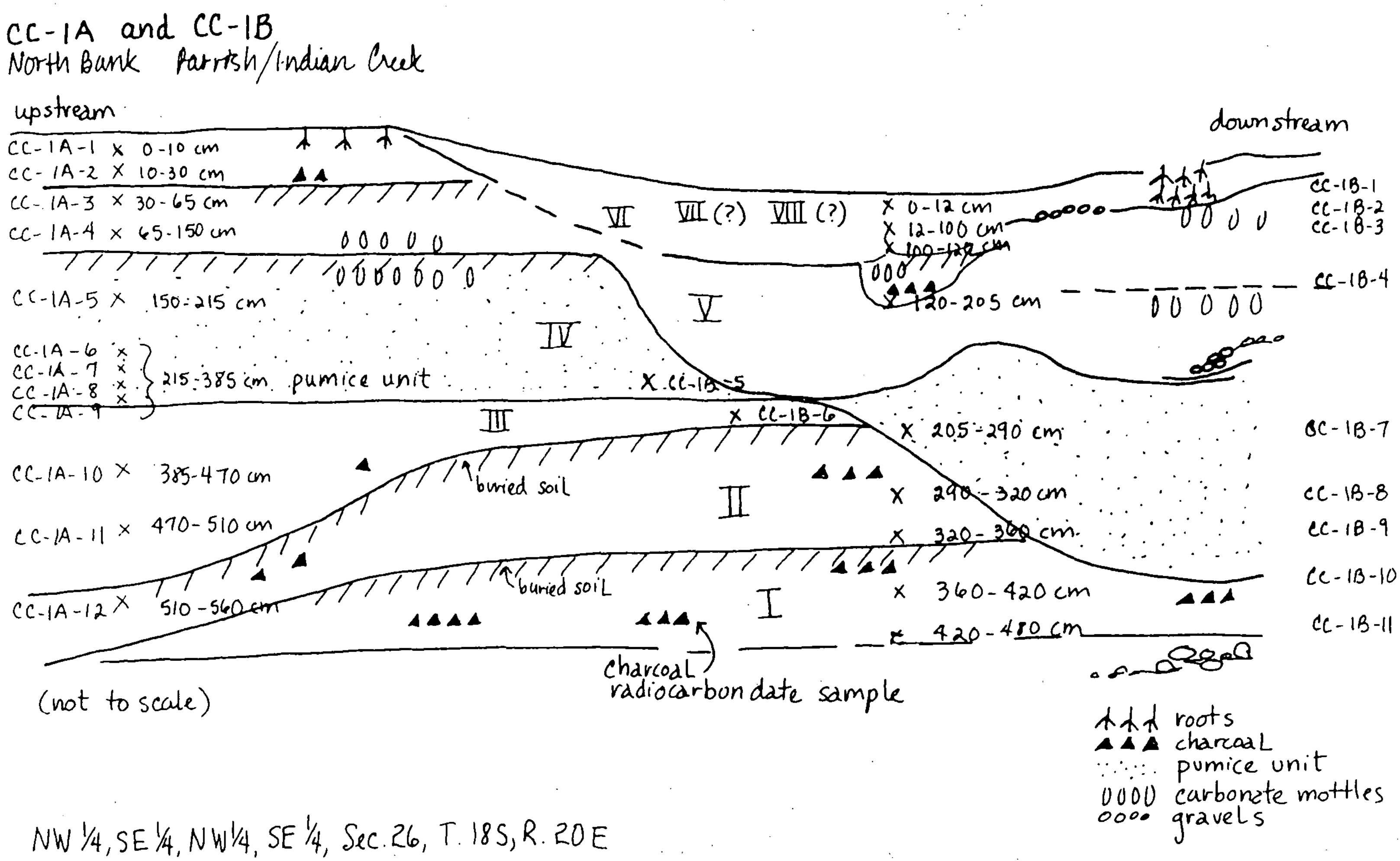


Figure C-1. Stratigraphic Diagram CC-1A and CC-1B

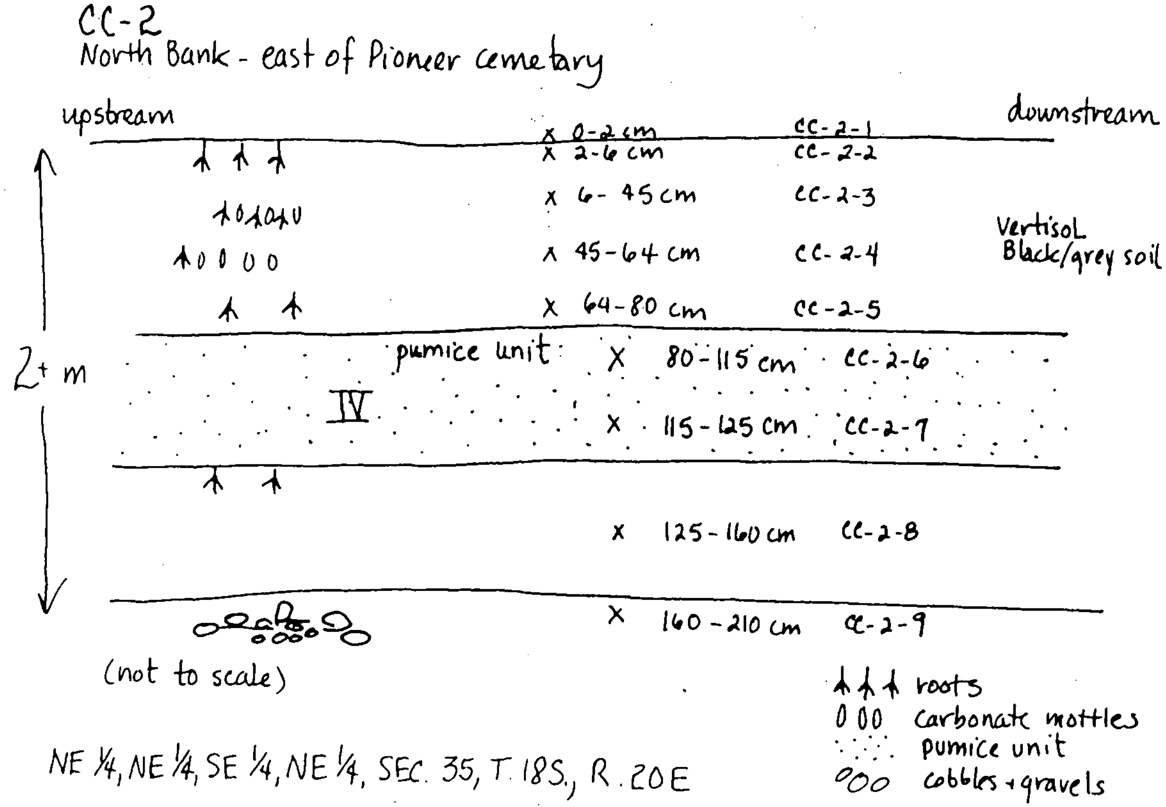


Figure C-2. Stratigraphic Diagram CC-2

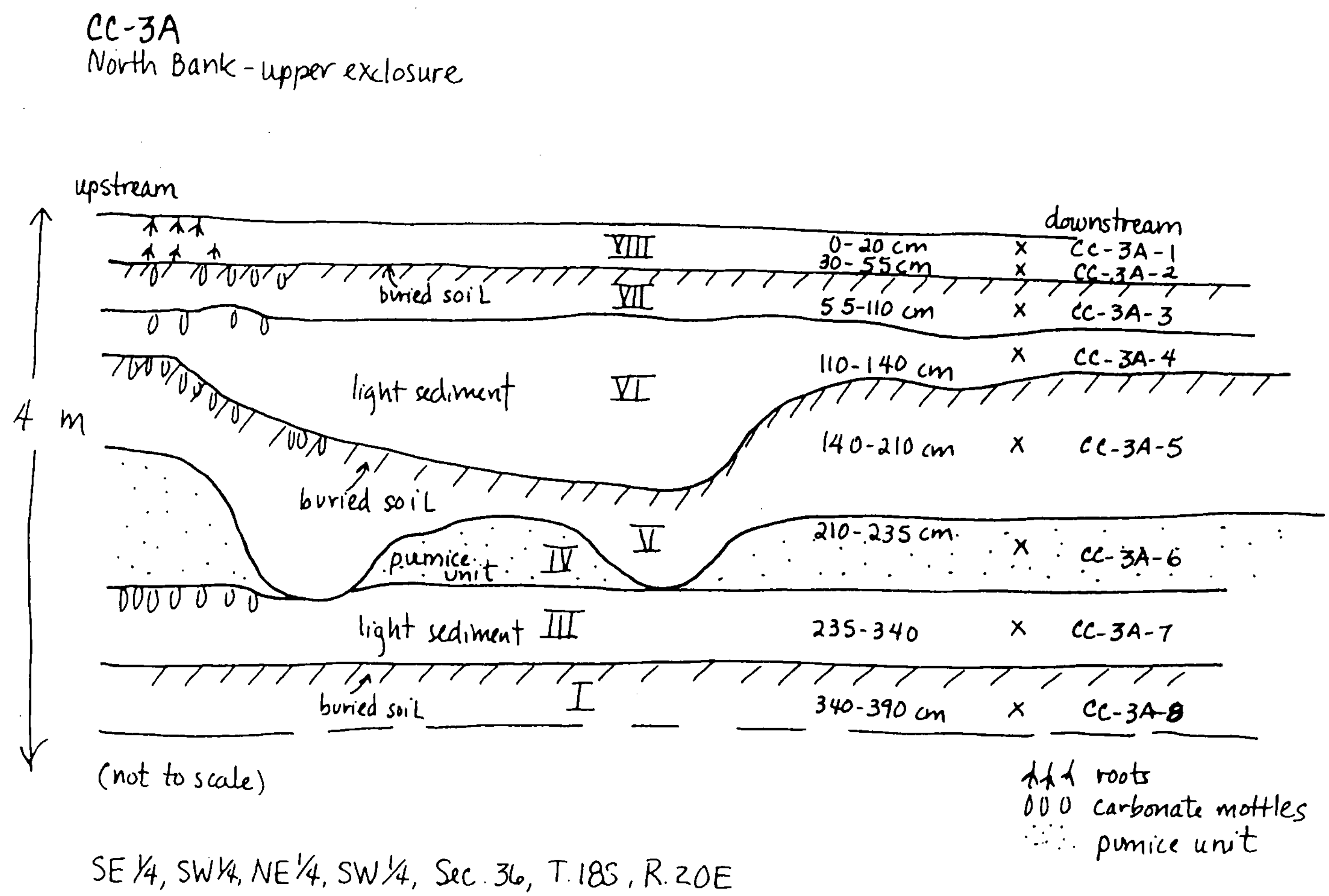


Figure C-3. Stratigraphic Diagram CC-3A

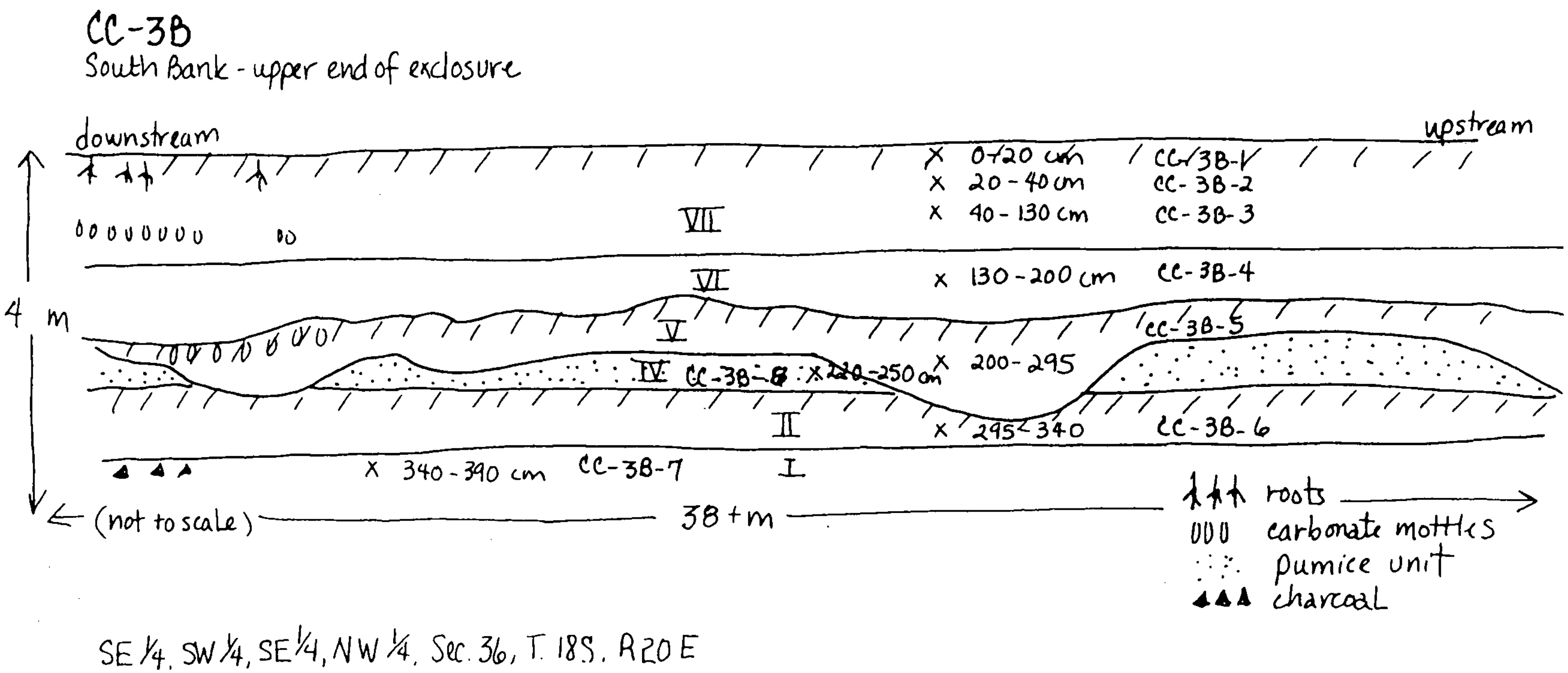


Figure C-4. Stratigraphic Diagram CC-3B

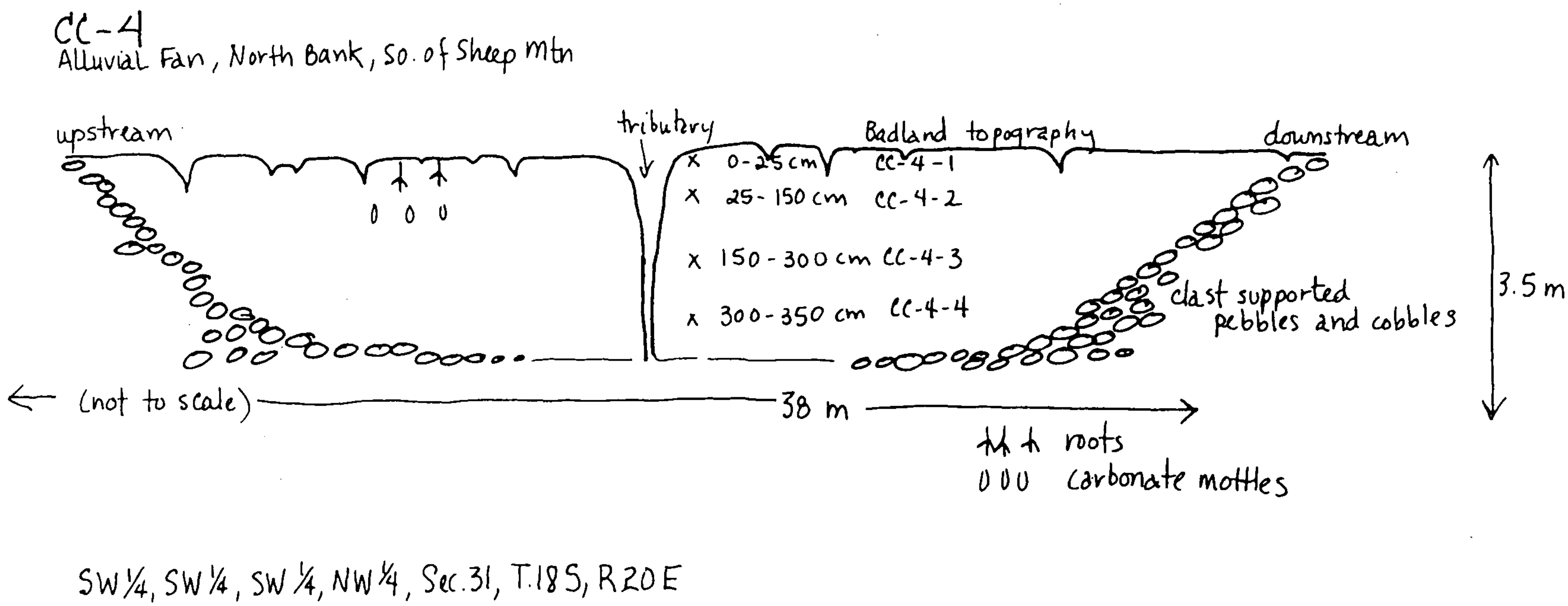


Figure C-5. Stratigraphic Diagram CC-4

CC-5
South Bank at confluence of Parrish/Indian Creek

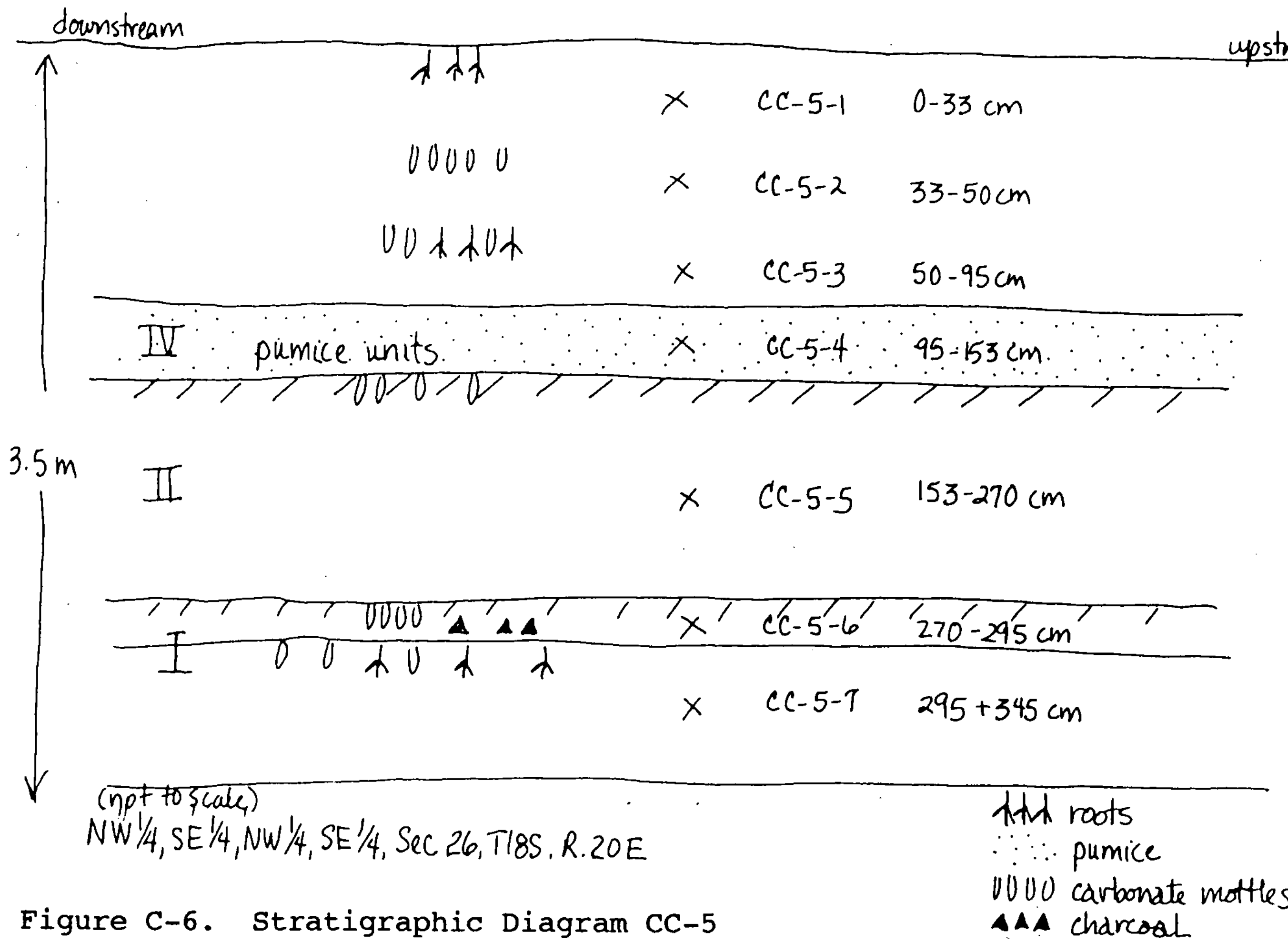


Figure C-6. Stratigraphic Diagram CC-5

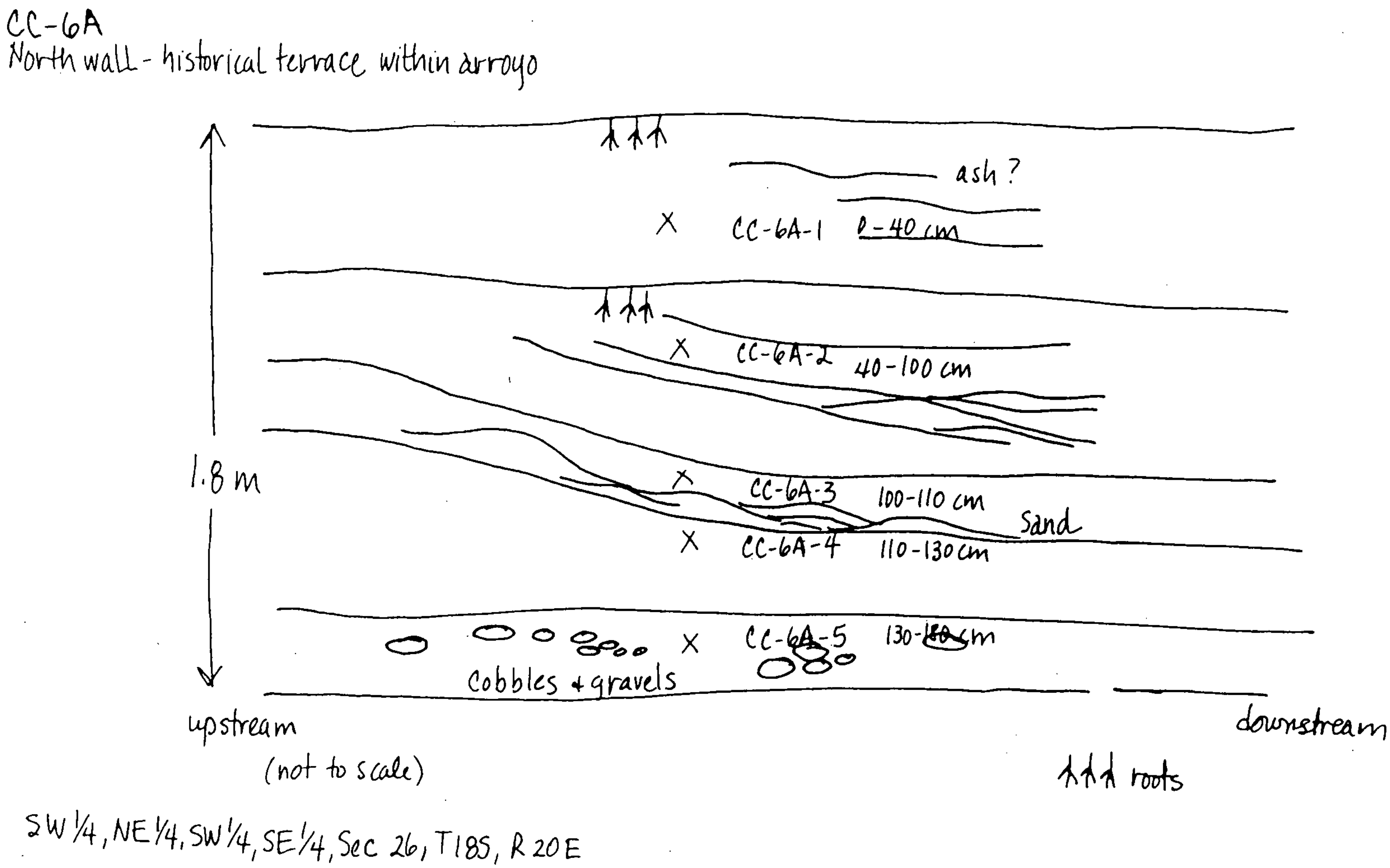


Figure C-7. Stratigraphic Diagram CC-6A

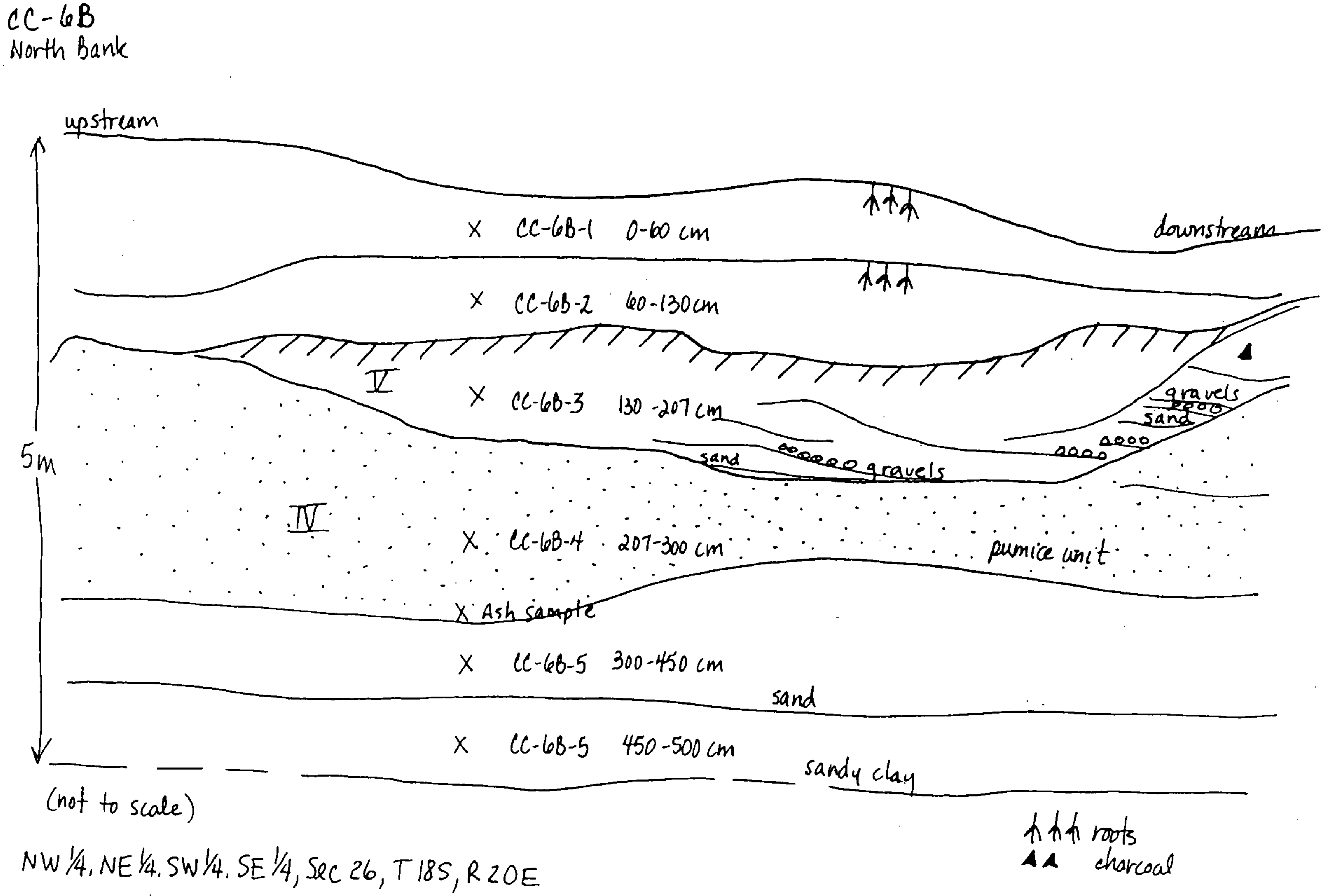


Figure C-8. Stratigraphic Diagram CC-6B

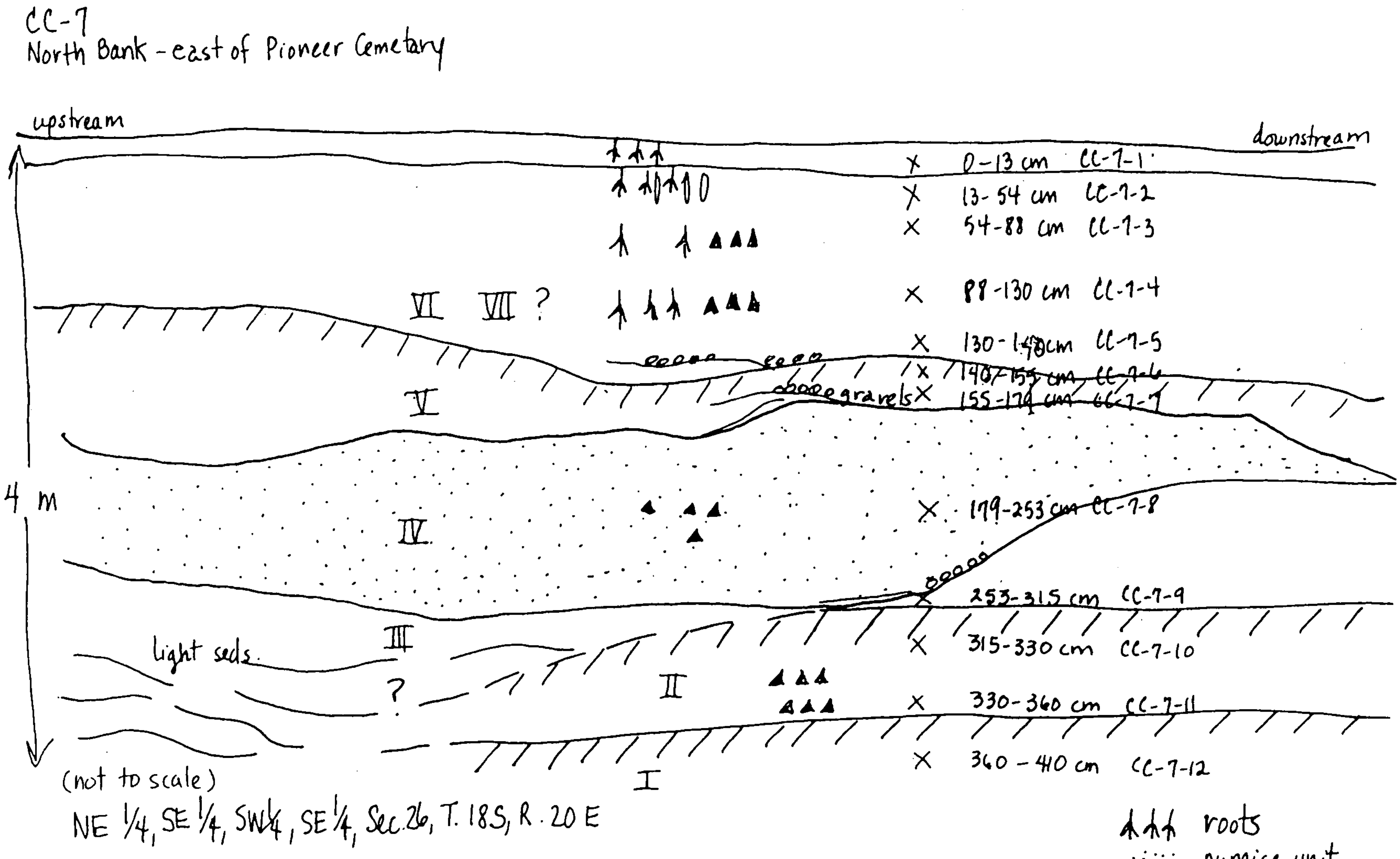
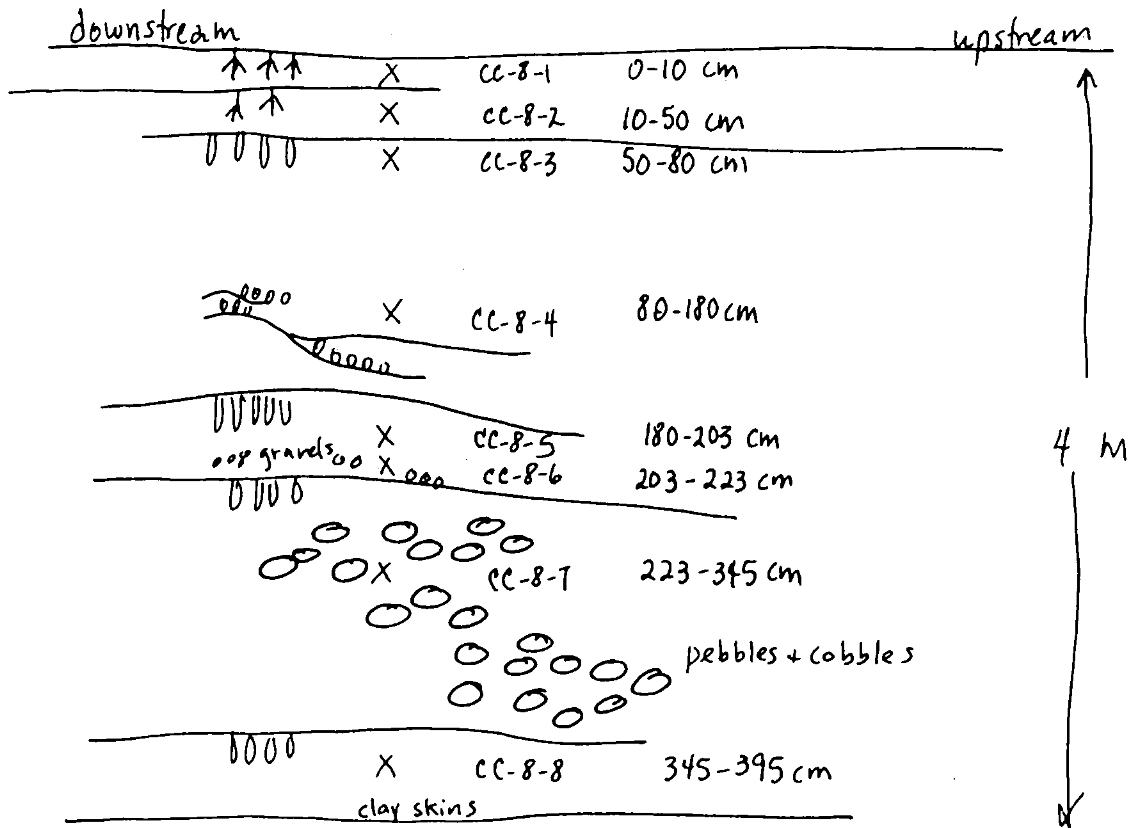


Figure C-9. Stratigraphic Diagram CC-7

CC-8

South Bank of tributary entering Camp Creek off alluvial fan



(not to scale)

SW 1/4, SW 1/4, SW 1/4, SW 1/4, Sec. 31, T 18 S, R 21 E

Figure C-10 Stratigraphic Diagram CC-8

roots

Carbonate mottles

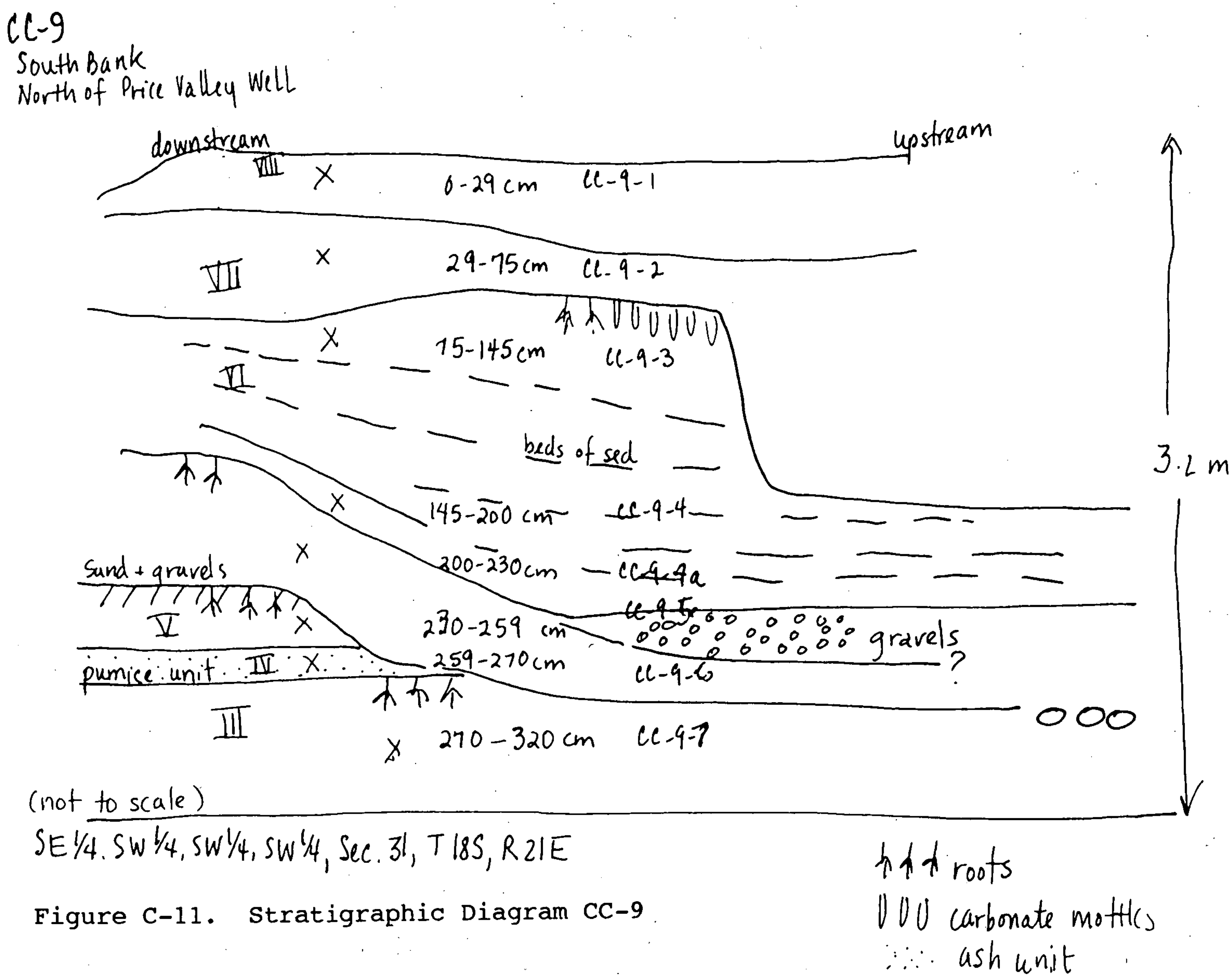


Figure C-11. Stratigraphic Diagram CC-9

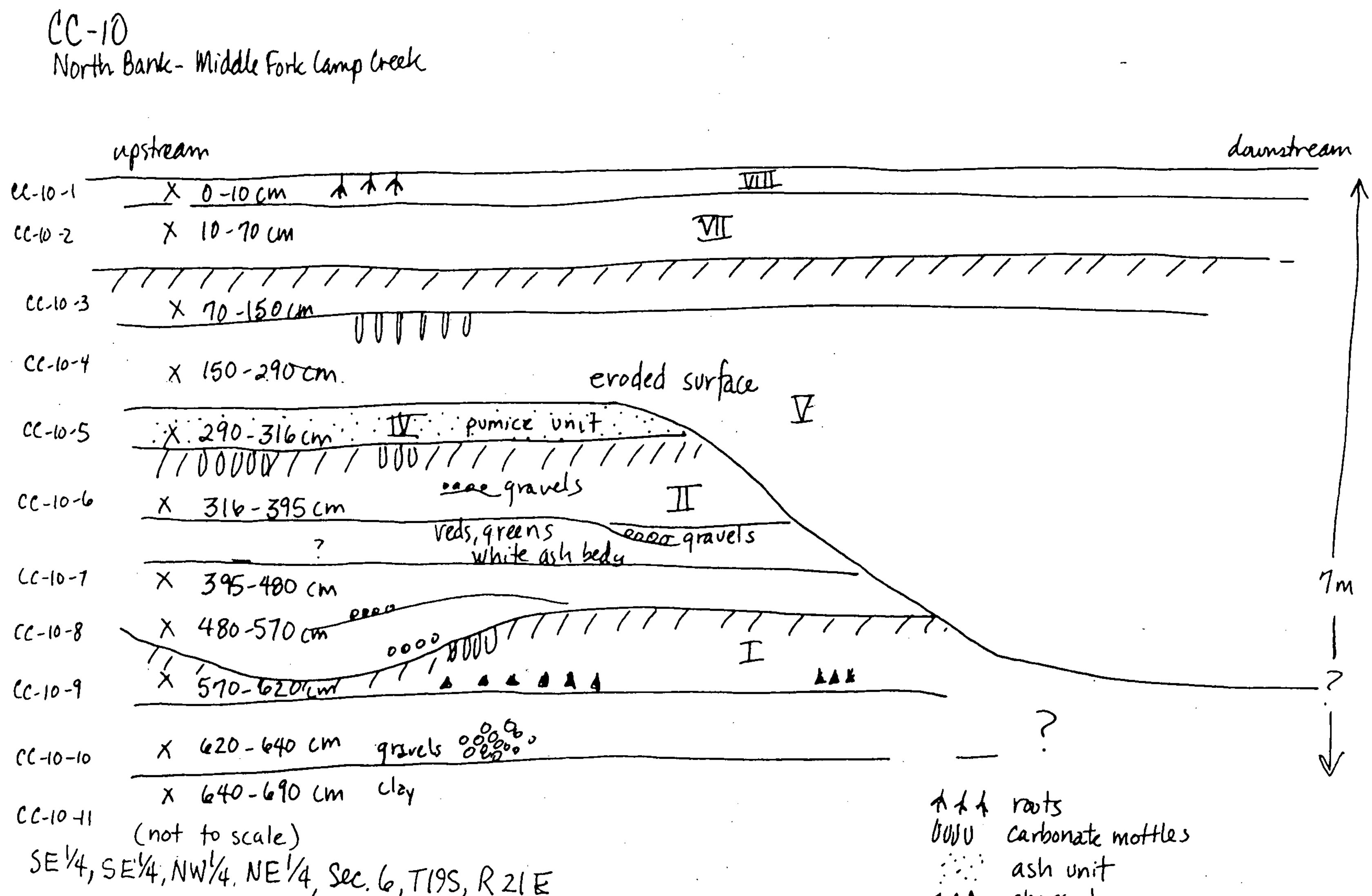


Figure C-12. Stratigraphic Diagram CC-10

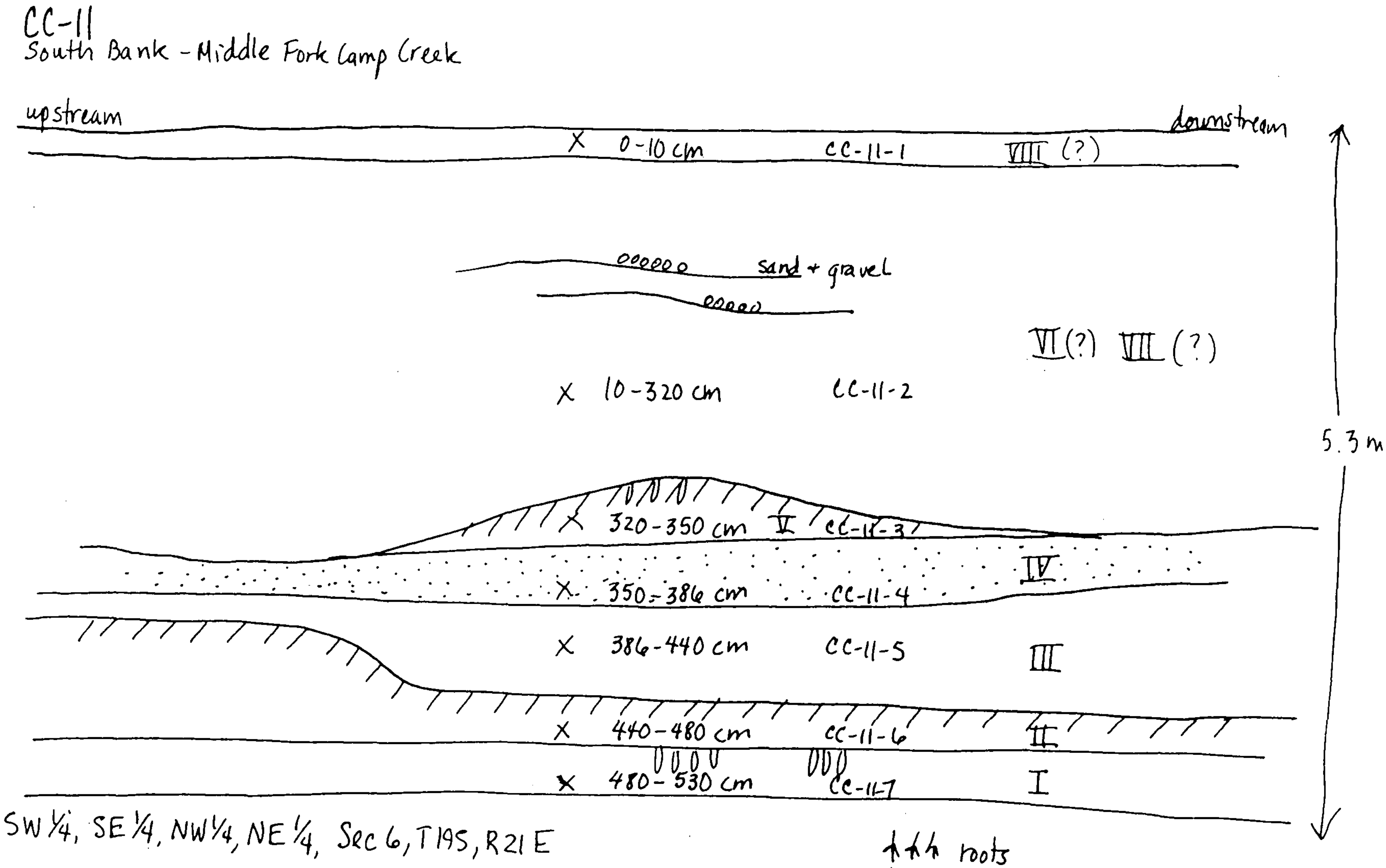


Figure C-13. Stratigraphic Diagram CC-11

CC-12
North Bank, alluvial fans off of Sheep Mtn.

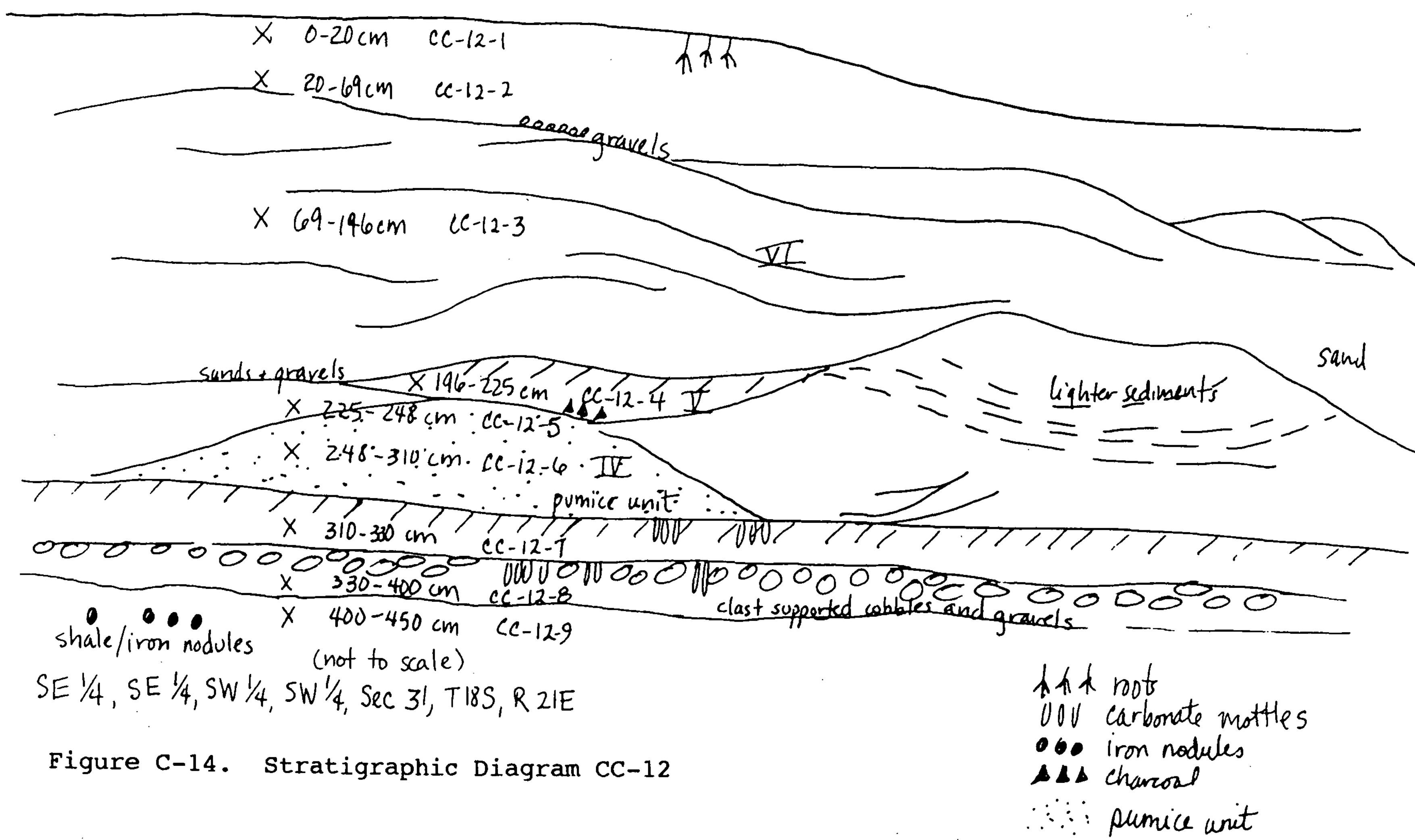


Figure C-14. Stratigraphic Diagram CC-12

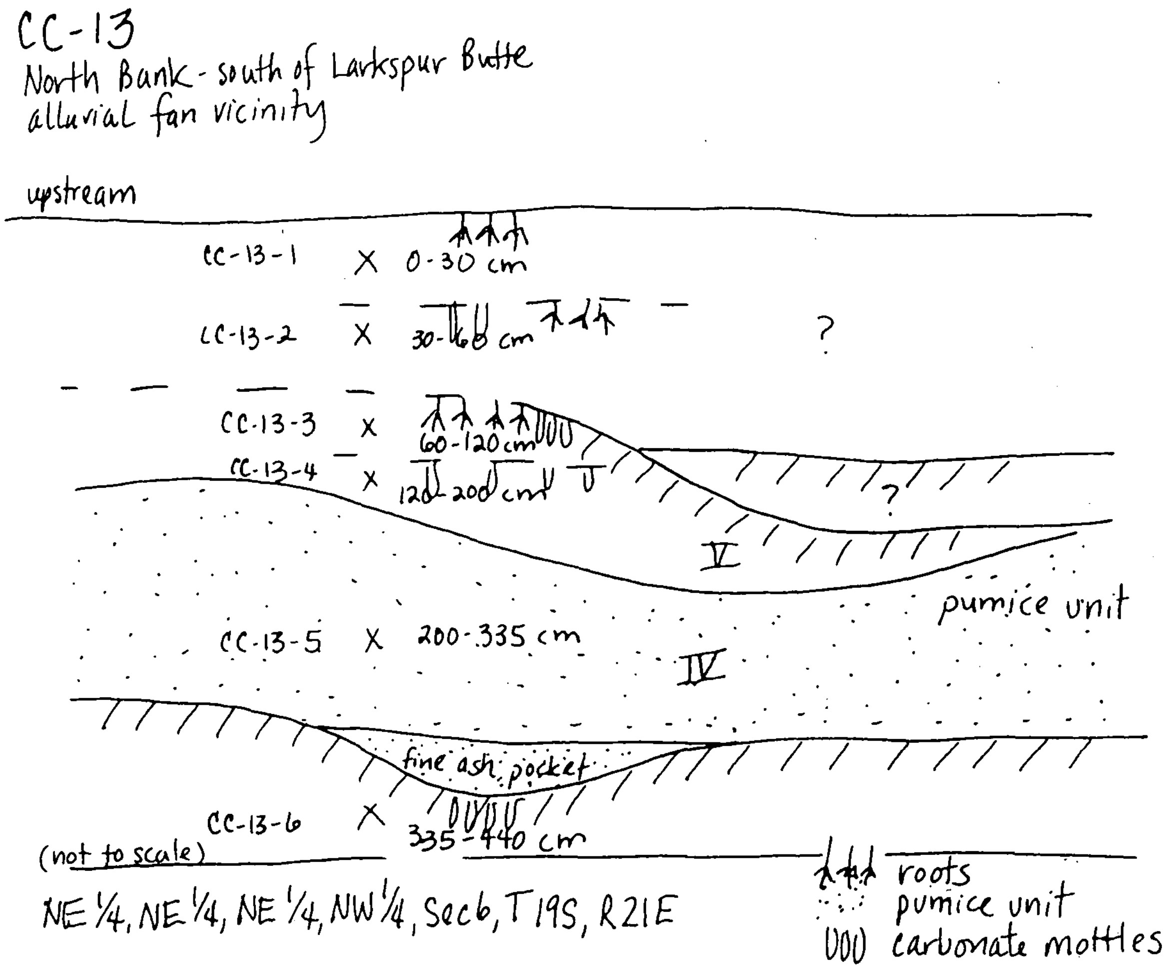


Figure C-15. Stratigraphic Diagram CC-13

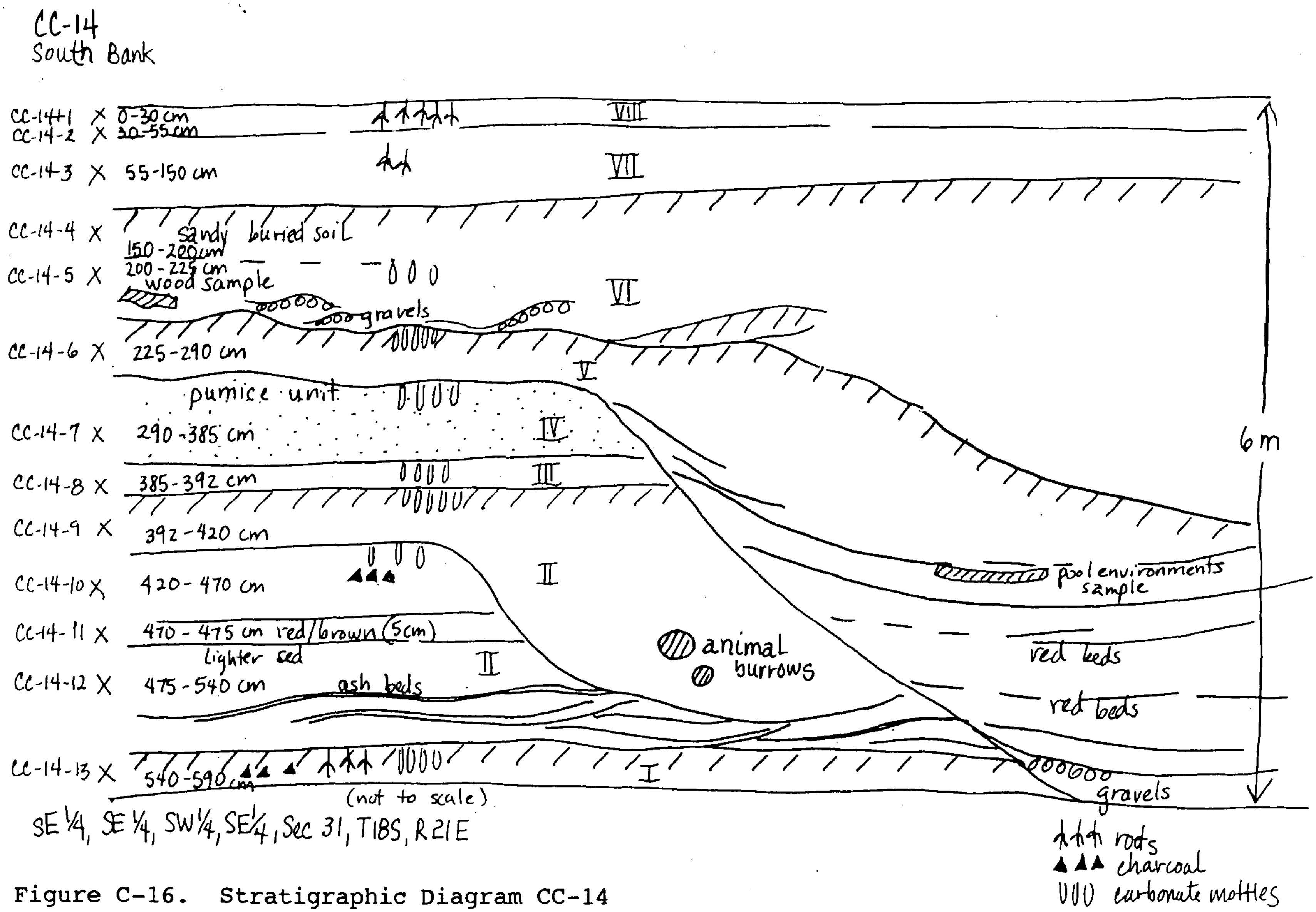


Figure C-16. Stratigraphic Diagram CC-14

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