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Ancient Cataclysmic Floods in the Pacific Northwest:

Ancestors to the Missoula Floods

by

Erica Medley

A thesis submitted in partial fulfillment of the
requirements for the degree of

Master of Science
in
Geology

Thesis Committee:
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Portland State University
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Abstract

Ancient Cataclysmic Floods were the Ice Age Floods that left erosional and depositional features and preceded the Missoula Floods (15-18,000 ka) in the Pacific Northwest of the United States (Allen et al., 2009). All previously studied ancient sites were visited (14) and new sites (11) were found; four Missoula Flood quarries were also visited; a total of 29 sites were studied in this thesis.

The use of calcrete paleosols to provide relative age dates for flood deposits was analyzed in this thesis. Missoula Flood gravel pits were sampled in order to examine the degree of calcrete development in flood deposits of known ages. All of the Missoula Flood deposits tested contain Stage 1 calcrete soil development.

Calcrete paleosols at sites with evidence for older floods were all analyzed. Eight sites have paleosols with Stage II development (3-12% CaCO_3): Rulo Outcrop, Potholes Coulee, Leslie Road, Bengé, E. Callaway Road, Collier Coulee, Palouse, and Connell. Five sites have paleosols with Stage II+ development (12-17% CaCO_3): Brown Road, Leslie Road, Bengé, Reese Coulee, and Connell. Fourteen sites have paleosols with Stage III development (17-35% CaCO_3): The Dalles, Rulo Outcrop, Winans Road 1, Poplar Heights, Yakima Bluffs, Canal Outcrop, Othello Canal, Reese Coulee, Potholes Coulee, E. Callaway Road, Frenchmen Coulee, Macall, Ritzville, and East Connell. One site has a paleosol with Stage III+ development (35-50% CaCO_3): Othello Canal.

Ancient Cataclysmic flooding initiated in the Early Pleistocene, at least 1.5 Myr. Sixteen field sites show evidence for Early Pleistocene flooding, preserved in all

six provinces: Othello Channels, Columbia River Gorge, Cheney-Palouse Scabland, Quincy Basin, Pasco Basin, and the Walla Walla Valley. There are 26 field sites with evidence for Middle Pleistocene flooding, present all regions except Othello Channels. Eleven of those 26 sites also show evidence for Early Pleistocene floods. Evidence for ancient flooding is present over dis. Evidence for Early and Middle Pleistocene floods is present over a wide distribution of elevations from 117 to 524 meters.

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Chapter 1: Introduction

The Ice Age Floods include all the floods occurring in the Pleistocene; the Missoula Floods from 15 – 18 ka and the Ancient Cataclysmic Floods from 2.6 Ma to 18 ka. The Missoula Floods are well studied but there is a need to put together all of the information available about the Ancient Cataclysmic Floods. The National Park Service has recognized the importance of the Ice Age Floods and has proposed that the Ice Age Floods National Geologic Trail be established (Figure 1). It formally became a national park in 2011 (Ice Age Flood Institute, 2011). The trail is “the largest, most systematic, and most cooperative effort yet proposed to bring the dramatic story of the Ice Age Floods to the public’s attention, and this has the potential to bring significant economic and cultural benefits to communities throughout the Northwest” (Ice Age Flood Institute, 2011).

Figure 1 The Ice Age Floods National Geologic Trail. (Ice Age Flood Institute, 2011)

The Missoula Floods have been the main focus of the trail and the most studied floods. However, researchers on the Missoula Floods all mention bits and pieces of evidence for older flood events. No one has put together the complete story of these Ancient Cataclysmic Floods (Allen et al., 2009).

1.1 Missoula Floods

The Missoula Floods were one of the greatest sets of geologic events in Earth's recent history. The floods lasted 3,000 years from 15 to 18 thousand calendar years ago (Allen et al., 2009). J Harlen Bretz (1923; 1928) was the first to propose that flooding created the channeled scablands in eastern Washington and Oregon. In 1980, Waitt described rhythmite near Touchet, Washington to propose multiple flooding episodes rather than one large flood. He estimated 40 floods by counting rhythmite sequences; Atwater (1984) expanded that number to about 89 floods in the 3,000-year period. Forty of the floods reached the Wallula Gap and Portland (Waitt, 1980).

The Missoula Floods affected 41,440 square kilometers in Washington and Oregon (Allen et al., 2009). The floods initiated at the end of the last ice age when an ice dam filled the Pend Oreille Valley and blocked the Clark Fork River from flowing from western Montana into the Columbia River Basin. Flows from Glacial Lake Missoula when the ice dam broke had estimated velocities up to 27.4 meters per second (Baker et al., 1991). Eventually, the ice dam reformed and Glacial Lake Missoula was created again until the next ice dam breached (Baker et al., 1991). Layers of loess, animal burrows, and Mt. St. Helens tephra in between layers of

rhythmite flood deposits provide the evidence for the draining of Glacial Lake Missoula in between flooding events (Waitt, 1980). The catastrophically large floods left a lot of evidence behind in the form of erosional and depositional features (Figure 1) in the Channeled Scablands of eastern Washington.

Figure 2. Glacial Lake Missoula (blue) and the extent of the Missoula Floods (gray). (Parfit, 1995)

1.2 Ancient Cataclysmic Floods

The Missoula Floods eroded away much of the evidence of older flooding that may have occurred before the first Missoula Flood 18,000 calendar years ago. However, many geologists who have studied the Missoula Floods have documented evidence of much older flood deposits at certain localities in the channeled scablands of Eastern Washington and Oregon. These old floods, termed the Ancient

Cataclysmic Floods by Allen et al. (2009), are thought to have occurred throughout the Quaternary.

There are several criteria used for determining if a flood is older than the Missoula Floods. One method is by dating organic material present in flood deposits that produces dates > 18,000 years B.P. and shows a clear stratigraphic relationship to the “younger” Missoula Flood deposits and paleosols. Geologists have also found evidence of magnetic reversals in paleosols and older flood deposits (Bjornstad, 2006). The last magnetic reversal was 790,000 years before present (Johnson, 1982); therefore, those deposits are much older in age than the Missoula Floods. Another criteria for distinguishing the Ancient Cataclysmic Floods from the Missoula Floods is by determining the stage of calcrete development in the soils developed on the flood deposits. Stages I through IV of CaCO_3 development take certain amounts of time (Birkeland, 1999). “In most cases Stages II, III, and IV carbonate take more time to develop than possible since the last Missoula Flood 15,000 years ago” (Allen et al., 2009). Exotic clasts may also be used as indicators of Ancient Cataclysmic Floods, especially when used in conjunction with other criteria. The Columbia Plateau is composed of thick basalt sequences; therefore, any non-basalt clasts found in a deposit imply that the deposit has been transported from a different source.

1.3 Aims and Objectives

There are many known Missoula Flood deposits in the Channeled Scablands of Eastern Washington and Oregon. There is stratigraphic evidence at certain

localities for floods that are older. My objectives are to determine where the Ancient Cataclysmic Flood deposits are located, how widely distributed they are, and how many separate flood events there were that preceded the Missoula Floods.

1. A complete literature review of every paper that cites evidence of Ancient Cataclysmic Flood deposits.
2. Visit all the sites mentioned in literature. At each site, do the following:
 - a. Take photos,
 - b. Record GPS location and elevation,
 - c. Take samples of flood deposits and calcrete paleosols, and
 - d. Analyze the stratigraphy.
3. Find new sites with evidence of Ancient Cataclysmic Flood deposits. Evidence of these sites exhibit:
 - a. Significant calcrete development,
 - b. Flood gravels with exotic clasts, and/or
 - c. Rhythmites with calcrete layers above them.
4. Collect samples of Missoula Flood deposits at gravel pits and quarries that are younger than Ancient Cataclysmic Flood deposits.
5. Lab work on sediment samples:
 - a. Percentage of CaCO_3 ,
 - b. Stage of CaCO_3 development, and
 - c. Particle size and color in some cases.

6. Develop chronosequence for Missoula Floods and Ancient Cataclysmic Floods.
7. Compare all sites in study through chronosequences and geographic positions and determine relationships

Chapter 2: Background

2.1 Cenozoic Geologic History of the Study Area

The main bedrock across eastern Washington and Oregon is Columbia River Basalt (CRB). CRB was formed during the Miocene 17-6 Ma from lava that flowed from vents on the eastern edge of Washington and Oregon. The Imnaha and Grande Ronde Formations make up 90 percent of the CRB, and flowed/cooled from 16.6 to 15 Ma (Reidel and Hooper, 1989). Some sedimentation happened concurrently with the basalt flows; the Ellensburg Formation is composed of silt, sand, and graded lahar beds several meters thick interbedded with basalt flows at the eastern edge of the Cascade Mountains (Carson and Pogue, 1996).

The Palouse Formation, deposited throughout the Pleistocene, is extensive in eastern Washington, especially in the Pasco Basin near the tri-cities of Richland, Pasco, and Kennewick. The Palouse Formation is composed of blankets of loess and paleosols formed during times of intermittent deposition.

2.2 Pleistocene Ice Age History

Glacial advances and retreats are important for sediment supply. Interglacial stages represent a time of abundant sediment supply and rapid loess deposition; whereas, glacial maximums are a time of relatively stable soil development (Smiley et al., 1991). The series of glacial advances and retreats began at the beginning of the Pleistocene 2.6 Ma and lasted until 10,000 years ago. Four major advances were originally recognized on land in North America: the Nebraskan 2 to 1.65 Ma, Kansan

900 to 750 ka, Illinoisan 400 to 250 ka, and most recently the Wisconsinan from 100 to 11 ka (Smiley et al., 1991).

Figure 3 Deep sea curve showing Oxygen Isotope Stage and Magnetic Polarity, July temperatures based on pollen analysis (Berendsen 2004).

Based on the deep-sea curve (Figure 3) there probably were actually over 50 advances and retreats, and there could be as many as 44 interglacial cycles in the Pleistocene (Morrison, 1991).

It is difficult to estimate the number of ice age floods in eastern Washington because of the unknown amounts of erosion between cycles, and perhaps only the largest advances resulted in flooding. The number of ice age floods could be in the hundreds. The Cordilleran Ice Sheet had three lobes that extended southward from Canada into Washington, Idaho and Montana (DeGrey and Link, 1999). The three lobes from west to east were the Puget, Okanogan, and Purcell (Figure 4).

Figure 4 Cordilleran Ice Sheet with three lobes (DeGrey and Link, 1999).

2.3 Missoula Floods-Most Famous of the Ice Age Floods

The Missoula Floods occurred during the late-Wisconsin glaciation, 15-18ka in calendar years (Allen et al., 2009). Bretz (1923, 1928) was the first to recognize that a flood had created the depositional and erosional features in the Channeled Scablands and termed it the “Spokane Flood.” In 1961, Bretz modified the flood title to “Missoula Flood.” Baker (1973) made quantitative descriptions of the Missoula

Flood. Waitt (1980) used rhythmite sequences to propose a multiple flood hypothesis, estimating 40 floods. In 1984, Atwater expanded that number to 89 floods in the 3,000 year period.

“Preceding the Wisconsin glaciation, mostly interglacial conditions existed for ~50,000 years during the Sangamon (80-130 ka) (oxygen isotope stage 5)” (Bjornstad et al., 2001). According to Clague et al. (1980), Glacial Lake Missoula could only have existed between 18.9 to 14 ka based on radiocarbon dating and estimates of the length of time the Purcell lobe of the Cordilleran Ice Sheet would take to advance. Clague et al. (1980) also used lake varves that indicate it was only in existence for 2,500 years.

The pre-late Wisconsin Ancient Cataclysmic Floods occurred throughout the Pleistocene, approximately the last 2.6 Ma. Glacial Lake Missoula formed behind an ice dam from a finger of the Purcell Lobe. It is possible that the Ancient Cataclysmic Floods had sources in addition to ancient Glacial Lake Missoula, which could have included the ice-dammed lakes from the Okanogan and Purcell lobes of the Cordilleran Ice Sheet (Figure 4) (Allen et al., 2009; Shaw et al., 1999).

2.4 Ancient Cataclysmic Floods

Several authors cite evidence for flooding episodes prior to the Missoula Floods (Figure 5, 6), called the “Ancient Cataclysmic Floods” by Allen et al. (2009). Most of these Ancient Cataclysmic Flood deposits have been eroded away by the powerful subsequent Missoula Floods. However, evidence exists at certain localities referenced by geologists who studied the scablands. Baker and Nummedal (1978)

found successions of coarse-grained flood gravels, fine-grained flood sediments, and loess overlain by paleosols near Marengo, Washington. Three of the loess units are overlain by calcareous paleosols, which could not have developed in 18,000 years. Baker and Nummedal (1978) correlated the gravels at Marengo to other exposures at Revere, Macall, and Old Maid Coulee. Old Maid Coulee was also shown by Bjornstad (2006) as having reversed magnetic polarity, an age of at least 790 ka.

Figure 5 Overview map of Washington and Oregon with field sites of Ancient Cataclysmic Flood deposits represented as yellow squares. The red square shows the location of Figure 6.

Figure 6 Eastern Washington and Oregon with field sites labeled.

Baker et al. (1991) found evidence of ancient flood deposits at multiple localities in the Pasco Basin in Washington. At some sites they found deposits that had a reversed magnetic polarity. There were also multiple sites in the Pasco Basin where Bjornstad et al. (2001) found paleosols with well developed CaCO_3 overlain by Missoula Flood deposits. At one site locality, FMEF (Fuels Material and Examination Facility), they were able to date wood pieces in a clastic dike that truncated two flow deposits. The dike was dated 32,000 radiocarbon years before present, 37.3 ka calendar years before present. The dike must be younger than the two sandy flood deposits it truncates, which means the floods are older than 37.3 years. The sites referenced by Baker et al. (1991) are: Poplar Heights, Yakima Bluffs,

Kiona Quarry, South Bombing Range Road, Leslie Road, FMEF, Cummings Bridge, Macall, Marengo, Revere, and Washtucna.

In 2001, Bjornstad et al. wrote one of the first articles to compile some of the “Pre-Wisconsin” Ice Age Floods, now termed Ancient Cataclysmic Floods (Allen et al., 2009). The following sites were included and dated using radiometric dating: Kiona Quarry, Leslie Road, Macall, Marengo, Old Maid Coulee, and Yakima Bluffs.

In 2006, Bjornstad wrote an updated field guide to the Columbia Basin. At a site he termed “Evergreen and Babcock Ridges”, near Frenchman Coulee, he found evidence for a very old flood with a thick caliche soil overlying very weathered flood gravels. He sites this flood as having an eastward water movement, which is in the opposite direction of the Missoula Floods. At two other sites, Badger Coulee and Cold Creek Bar, he found further evidence of a magnetic reversal, dating the paleosols older than 790,000 years before present.

Kiver et al. (1991) found evidence of episodic flooding along Latah Creek near Spokane, Washington. He dated tephras that show a clear stratigraphic relationship to flood gravels between 30 and 40 thousand radiocarbon years ago. The flood gravels are overlain by Missoula Flood deposits. Kiver correlated these deposits to deposits at the Malden Gravel Pit, Willow Creek, and the Tuscan River Valley.

Most recently, Gastineau (2011) studied the Rulo Outcrop near Walla Walla, Washington. The outcrop has several layers of silt and calcrete development and two tephras dated at 165-210 ka and >200ka.

Spencer and Gilk (1999) and Spencer and Jaffee (2002) documented some of the same sites as others but also discovered new sites: Winans Road 1 and 2 also near Walla Walla, Washington.

Evidence of pre-Missoula Floods also reaches into Oregon at one known site. Dave Cordero and Scott Burns studied a roadcut on Oregon Highway 197, three kilometers southeast of The Dalles that contained five paleosols with well developed CaCO_3 (Cordero, 1997). The deposits overlie volcanoclastic sediments of The Dalles Formation (Cordero, 1997) and overlain by Missoula Flood rhythmites.

Lastly, workers that have done studies on loess in eastern Washington have found the loess to be interbedded with paleosols, some with magnetic pole reversal evidence. Thick loess deposits that are adjacent to flood coulees provide evidence for flood events. Evidence includes unconformities cut by floods, fining upward sequences in separate loess strata, formation of calcrete horizons in the loess, and slackwater sediment (McDonald and Busacca, 1988a). Baker et al. (1991) found sections of these loess and paleosol beds near Connell, Dusty, Winona, and 7.4 km west of Washtucna. McDonald and Busacca (1988a) found similar deposits, depicting six different episodes of flooding and some of which have reversed magnetic polarity. In the Pasco Basin, Baker et al. (1991) divided the loess into five different units, three of which they interpreted to be older than the Missoula Floods. Bjornstad (2006) also found a site at Palouse in the Pasco Basin that has loess, reverse magnetic polarity evidence, and Mt. St. Helens “set C” tephra (40 to 36 ka years ago).

2.5 Soil Development

Calcrete is a term used to describe both pedogenic CaCO_3 accumulation and CaCO_3 accumulation from groundwater genesis (Birkeland, 1999). The carbonate for a pedogenic calcrete is derived from loess and Ca^{2+} dissolved in rainwater. Eastern Washington is moisture limited so the influx of Ca^{++} is not the limiting factor. During periods of more rainfall, more Ca^{++} is leached into the soil. "Groundwater carbonate tends to be more coarsely grained than pedogenic carbonate, fills only the original pore spaces, and because of overburden pressure, has not forced the original grains apart" (Laity, 2008). Quaternary soils in eastern Washington display pedogenic CaCO_3 accumulation typical of soils in arid to semiarid climates (Baker, 1973; Baker and Nummedal, 1978; Patton and Baker, 1978; Busacca et al., 1989; Baker et al., 1991; Bjornstad et al., 2001).

Figure 7 Stages of carbonate morphology for gravelly parent material on top and fine-grained soil on the bottom (Birkeland, 1999; based on Gile et al., 1981)

Stage	Gravelly Parent Material	Nongravelly Parent Material
I	Discontinuous clast coatings, about 4% CaCO ₃	Few coatings on sand grains, <10% CaCO ₃
I+	All clast coatings thin and continuous	Filaments are common
II	Continuous clast coatings	Few to common nodules, 10-15% CaCO ₃
II+	Carbonate more pervasive	Common nodules, ~15% CaCO ₃
III	Carbonate forming continuous medium, 20-25% CaCO ₃	Many nodules, 20% CaCO ₃
III+	Clasts have thick coats and matrix particles continuously coated or plugged by CaCO ₃	Most grains coated and most pores plugged by CaCO ₃ , >40%
Partly or entirely cemented		
IV	Upper K horizon nearly cemented with weak platy structure, >50% CaCO ₃	
V	Laminar layer and platy structure are strongly expressed; incipient brecciation and pisolith formation	
VI	Brecciation and recementation, as well as pisoliths, common	

Figure 8 Stages of Carbonate Morphology. Taken from Birkeland (1999). (Gile et al., 1981; modification by R.R. Shroba, 1982; Machette, 1985)

Birkeland (1999) and Gile et al. (1981) mention four stages of development of calcrete morphology (Figure 7). Machette (1985) expanded these stages of development to six stages (Figure 8). I will use Machette (1985) for stages of development in this thesis. The stage of soil development is useful for determining the relative age of the flood deposits. Each stage of soil development takes a certain amount of time to form; using the percentage of CaCO₃ and paleosol morphology, the relative age of underlying flood deposits can be determined. "Soil development atop the last cataclysmic (late Wisconsin) flood deposits (~15 ka) [is] weak (Stage I or less), alteration [is] limited to calcareous filaments and/or nodules in fine grained soils, and thin carbonate [is] found on the undercoatings of gravel clasts within coarser-textured soils. In contrast, pre-Wisconsin (i.e., >130 ka) flood deposits are

typically capped with a >1-m-thick pedogenic calcrete (Stages III-IV), consisting of one or more platy, well-cemented, calcic horizons with massive to laminar secondary CaCO_3 completely filling the matrix” (Bjornstad et al., 2001). Pedogenic calcrete with more than 50% CaCO_3 requiring hundreds of thousands to millions of years to develop (Machette, 1985).

2.6 Unconformities

An unconformity is a buried erosion surface and represents missing time between the underlying and overlying deposits. Several “loess islands” located in depositional areas in the Channeled Scablands are adjacent to erosional areas that have been scoured by floods. Several unconformities truncate loess layers and are interpreted as being cut by floods (McDonald and Busacca, 1988a). Loess and gravel sites that have multiple paleosols separated by unconformities provide evidence for missing time periods. By determining the stage of soil development of each paleosols, minimum ages for the exposure of each surface can be determined.

2.7 Exotic Clasts

A thick layer of Columbia River Basalt underlies most of the Channeled Scablands in eastern Washington and Oregon (Allen et al., 2009). Therefore, clasts of other lithologies are of particular importance. Granites and low-grade metamorphic rocks and other exotic clasts of pebble to boulder size are found within the Touchet Beds and suggest a different mode of transport, possibly ice-rafting (Fecht and Tallman, 1978).

2.8 Truncated Clastic Dikes

Clastic dikes that truncate older flood deposits are present at several sites. "The dikes signify soft-sediment deformation during or soon after flooding, perhaps associated with flood-induced seismicity (Bjornstad et al., 2001)." The dikes do not provide proof for pre-Wisconsin flooding because the timing relative to the flood deposits is unknown. However, they help support other stratigraphic evidence depending on the degree of weathering along the youngest truncated horizon. The dikes often truncate advanced stages of paleosol development and reversed magnetic polarity horizons.

2.9 Reversed Magnetic Polarity

Many flood deposits and loess deposits have been analyzed for magnetic polarity. The Brunhes-Matuyama magnetic reversal is dated at 790 ka (+/- 20) (Johnson, 1982); therefore, sediments with reversed magnetic polarity were deposited at least 790 ka. It is a good method at distinguishing Early Pleistocene from Middle Pleistocene and for relative dating because reversed magnetism means the deposit as well as the underlying deposits are at least 790,000 years old.

Chapter 3: Methods

3.1 Literature Review

All previous publications on the Missoula Floods and potentially older flood deposits were compiled. The literature was searched for specific site localities where older flood deposits might exist. The sites were added to a spreadsheet with their precise location and a brief summary of the geology. The sites were then added to a topographic map using Google Earth.

3.2 Field Data Collection

Each site mentioned in literature was visited, except sites in the northeast part of the Channeled Scablands, the sites of Kiver et al. (1991). At each site the following were collected: photographs, Global Positioning System (GPS) coordinates, and samples. Samples were collected from each stratigraphic horizon at each site, which could include Missoula Flood sediments, calcrete paleosols, ancient flood gravels, loess, and rhythmites.

In addition to visiting most of the sites mentioned by other workers, new sites were searched for by driving through as many roadcuts as possible in the Channeled Scablands. The criteria for finding a new site were elevation and the presence of a calcrete paleosol. Several modern gravel pits and quarries with presumed “Missoula Flood” gravels were also sampled as a basis of comparison for the ancient flood gravels.

3.3 Laboratory Methods

All samples were tested for their CaCO_3 content using the Chittick Apparatus (Figure 9). The method, first implemented by Dreimanis (1962) then modified by Machette (1986), is based on the volumetric evolution of carbon dioxide when carbonates react with dilute hydrochloric acid. Five splits of each sample were analyzed. The average of the splits with calculated standard mean error is shown in the Results. A more detailed methodology of the Chittick Apparatus procedures performed for this thesis is in Appendix A.

Figure 9 Chittick apparatus.

The results from the Chittick apparatus were calculated by converting amount of carbon dioxide to CaCO_3 using the formula in Appendix A. The percentage of CaCO_3 was assigned a stage of calcrete soil development based on the classification system of Machette (1985) (Figure 8). After determining the stage of soil development, the relative ages of paleosols and flood deposits were determined.

Table 1 Stages of carbonate morphology (modified from Machette (1985)).

Stage	Percent CaCO_3
Stage I	0.0 - 2.9
Stage II	3.0 - 11.9
Stage II+	12.0 - 16.9
Stage III	17.0 - 34.9
Stage III+	35.0 - 49.9
Stage IV	50.0 - 74.9
Stage V	> 75.0

The Pleistocene is broken up into three age ranges: Early Pleistocene from 2.58 Ma – 781 ka, Middle Pleistocene from 781-126 ka, and Late Pleistocene from 126 ka to 11,700 (Morrison, 1991). However, all pre-Missoula Flood (15 – 18 ka) deposits were termed “Middle Pleistocene” in this thesis to differentiate them from the Late Pleistocene Missoula Flood deposits. Early to Middle Pleistocene deposits ranged from Stage II to III+ soil development. Late Pleistocene Missoula Flood deposits contained only Stage I CaCO_3 .

Two samples of slackwater deposits and loess deposits were analyzed for grain size analysis using the pipette method (Gee and Bauder, 1986). The detailed methodology I used for this thesis is explained in Appendix B. The results were analyzed to determine the percentages of sand, silt, and clay for each sample.

Slackwater flood deposits should have more sand and gravel in them than loess deposits.

All field notes are listed in Appendix C.

Chapter 4: Results

The field sites mentioned in literature as well as newly discovered field sites (Figure 6) are described in more detail below. Google maps with a close-up of the field site location as well as the precise GPS coordinates are given for each site. Each site description includes relevant pictures of the outcrop with sample locations labeled. Layers are separated by blue lines and unconformities are labeled as red lines. If the samples collected were tested for the amount of CaCO_3 , the results and stage of the calcrete development are given in a table based on carbonate morphology (Figure 8) and percent CaCO_3 in the sample (Table 1). Each sample is described: calcrete paleosols should have high CaCO_3 values whereas the underlying slackwater deposits, fluvial gravels and loess, should be much lower. If the sites are not newly discovered, the findings of previous scientists are discussed.

A total of 29 field sites are studied in this thesis. Four of the sites are Missoula Flood-aged gravel pits, studied for a basis of comparison of “Missoula Flood” deposits to “Ancient Cataclysmic Flood” deposits. Eleven of the sites are newly discovered possible Ancient Cataclysmic Flood sites.

The sites are divided into Missoula Flood gravel pits, loess outcrops, and flood deposits. The loess outcrops are adjacent to flood scoured channels and contain evidence that correlates to Ancient Cataclysmic Floods. Flood deposits record high energy floods at sites that have flood gravels and low energy floods at places with slackwater flood deposits and rhythmites. Table 2 summarizes the GPS location in decimal degrees, elevation, and references for each field site.

Table 2 Complete list of field sites from west to east with GPS location, elevation, and reference.

Field Site	Latitude (degree decimal)	Longitude (decimal degree)	Elevation (m)	Reference
The Dalles	45.578519	-121.104914	284.0	Cordero (1997)
St. Petersburg Bar	45.617268	-121.074666	120.7	Missoula Flood gravel pit
Avery Gravel Pit	45.662232	-121.018684	80.0	Missoula Flood gravel pit
Fairbanks Farm	45.626514	-121.005139	158.5	Missoula Flood gravel pit
Arlington	45.712292	-120.192113	164.0	Missoula Flood gravel pit
Silica Road	47.046525	-119.976711	402.0	NEW
Frenchmen Coulee	47.042778	-119.970768	413.0	Bjornstad 2006
Potholes Coulee	47.160043	-119.901514	388.0	Bjornstad 2006
Cold Creek Bar	46.611200	-119.764714	313.9	Bjornstad 2006
Field Rd.	46.245089	-119.467444	165.2	NEW
FMEF	46.421036	-119.372827	158.5	Baker et al. 1991
South Bombing Range Rd.	46.269697	-119.342790	174.7	Baker et al. 1991
Yakima Bluffs	46.265312	-119.313353	148.7	Baker et al. 1991, Fecht et al. 1999
Canal Outcrop	46.738063	-119.303453	301.0	NEW
Leslie Road	46.239699	-119.259859	118.0	Baker et al. 1991
Othello Canal	46.811680	-119.131982	329.0	NEW
Poplar Heights	46.168759	-119.098520	146.0	Bjornstad 2006
Old Maid Coulee	46.568056	-118.952637	277.0	Bjornstad
Cummins Bridge	46.037963	-118.768358	117.0	Bjornstad et al. 1980, Moody 1987

Reese Coulee	46.067093	-118.759732	193.0	Bjornstad
Connell	46.631671	-118.752708	349.0	Busacca
East Connell	46.621870	-118.659126	384.0	NEW
Rulo Outcrop	46.165369	-118.502400	299.9	Gastineau 2011
Winans Road 1	46.166671	-118.432645	286.2	Spencer and Jaffee 2002
Winans Road 2	46.188467	-118.391303	291.1	Spencer and Jaffee 2002
Palouse	46.677697	-118.378030	394.0	NEW
HW125	46.234457	-118.372790	302.7	NEW
Brown Road	46.237280	-118.369293	311.2	NEW
Washtucna	46.834753	-118.328585	501.0	McDonald and Busacca 1988
Ritzville	46.769984	-118.288106	341.0	Busacca
Marengo	47.020214	-118.200967	493.5	Baker 1978
Benge	46.932452	-118.142050	506.6	Busacca 1988, McDonald and Busacca 1988
Macall	46.932391	-118.141931	507.2	Baker 1978, Patton and Baker 1978, Baker et al 1991
Callaway Rd.	46.986710	-118.078691	524.9	NEW
Revere	47.064726	-117.939204	512.0	Baker 1978, Patton and Baker 1978, Baker et al. 1991

4.1 Missoula Flood Gravel Pits

Missoula Flood gravel pits were sampled in order to examine the degree of calcrete development in flood deposits of known ages. Several different gravel pits throughout the Columbia River Gorge were sampled at different elevations to see the range of CaCO_3 values for Missoula Flood deposits of various ages.

4.1.1 Avery Gravel Pit (Wishram, Washington)

Figure 10 Location of the Avery Gravel Pit field site.

Figure 11 Overview of Avery Gravel Pit showing the lower and upper section sampled.

Avery gravel pit, owned by Tripco, Inc., located 16 km east of The Dalles, Oregon, on the Washington side of the Columbia River (Figure 10) is an actively mined pit for sands and gravels. The GPS coordinates for this site are N 46.662232 latitude and W -121.018684 longitude; the elevation is 80 m. Each sample was collected from a stratigraphically higher location from A1 (bottom of the pit) to A8 (top of the pit) (Figure 11). The flood gravels are composed of mainly basalt clasts, but exotics are present. Samples AV1-AV6 collected at Avery Gravel Pit measured between $1.0\% \pm 0.0$ and $1.9\% \pm 0.3$ CaCO_3 , placing them all at Stage I development. AV7 and AV8 contain significantly less calcrete development ($0.6 - 0.5\%$, Stage 1). The gravelly flood deposits are all Missoula Flood deposits, Late Wisconsin in age.

Figure 12 Lower flood gravel section at Avery Gravel Pit with sample locations labeled.

Figure 13 Upper flood gravel section at Avery Gravel Pit with sample locations labeled.

Table 3 Chittick results for Avery Gravel Pit site.

Sample ID	Average CaCO ₃ Percent	Stage of Development
AV1 Missoula Flood gravels	1.3 ± 0.0	Stage I
AV2 Missoula Flood gravels	1.6 ± 0.0	Stage I
AV3 Missoula Flood gravels	1.0 ± 0.1	Stage I
AV4 Missoula Flood gravels	1.0 ± 0.1	Stage I
AV5 Missoula Flood gravels	1.9 ± 0.3	Stage I
AV6 Missoula Flood gravels	1.2 ± 0.1	Stage I
AV7 Missoula Flood gravels	0.6 ± 0.1	Stage I
AV8 Missoula Flood gravels	0.5 ± 0.0	Stage I

4.1.2 St. Petersburg Bar (The Dalles, Oregon)

Figure 14 Location of the St. Petersburg Bar field site.

Figure 15 West end of St. Petersburg Bar gravel pit with sample locations labeled.

Figure 16 East end of St. Petersburg Bar gravel pit with sample location labeled.

One thick gravel unit is present, with gravels composed of basalt, pumice, and exotics. Benito and O'Connor (2003) dated St. Petersburg Bar in two locations yielding dates of $14,480 \pm 145$ and $16,720 \pm 210$. There is a weak development of CaCO_3 , Stage I, with coatings on the underside of clasts (Birkeland, 1999). Samples SP1 and SP2 were collected from the west end of the gravel pit; SP2 is approximately 12 meters upsection from SP1 (Figure 15). SP3 was collected from the east end of the outcrop (Figure 16). Each of the three samples contained approximately the same amount of CaCO_3 : $1.7\% \pm 0.2$, $1.7\% \pm 0.1$, $1.8\% \pm 0.2$ (Table 4).

Table 4 Chittick results for St. Petersburg Bar site.

Sample ID	Average CaCO_3 Percent	Stage of Development
SP1 Missoula Flood gravels	1.7 ± 0.2	Stage I
SP2 Missoula Flood gravels	1.7 ± 0.1	Stage I
SP3 Missoula Flood gravels	1.8 ± 0.2	Stage I

4.1.3 Fairbanks Farm (The Dalles, Oregon)

Fairbanks Farm is another Missoula Flood gravel pit field site. It is located east of St. Petersburg bar along 15 Mile Road at its intersection with Company Hollow Road (Figure 17). The GPS coordinates for this site are N 45.626514 latitude and W -121.005139 longitude; the elevation is 158.5 m. The samples were taken from the sample gravel unit composed of primarily basalt gravels, and FF2 is 20 meters east of FF1 (Figure 18). Sample FF1 measured $1.7\% \pm 0.2$ CaCO_3 and FF2 measured $0.8\% \pm 0.7$ (Table 5).

Figure 17 Location of the Fairbanks Farm field site near The Dalles, Oregon.

Figure 18 Fairbanks Farm outcrop with sample locations labeled.

Table 5 Chittick results for Fairbanks Farm site.

Sample ID	Average CaCO ₃ Percent	Stage of Development
FF1 Missoula Flood gravels	1.7 ± 0.2	Stage I
FF2 Missoula Flood gravels	0.8 ± 0.7	Stage I

4.1.4 Arlington (Arlington, Oregon)

Figure 19 Location of the Arlington field site.

Figure 20 Arlington roadcut with sample location labeled.

The Arlington roadcut is located at milepost 1 along Highway 19 south of downtown Arlington, Oregon (Figure 19). The GPS coordinates for this site are N 45.71229237 latitude and W -120.1921135 longitude; the elevation is 164 m. The roadcut contains Missoula Flood sediments. The sample collected, HW19 (Figure 20), contains $2.0\% \pm 0.1$ CaCO_3 (Table 6).

Table 6 Chittick results for Arlington site.

Sample ID	Average CaCO_3 Percent	Stage of Development
HW19 Missoula Flood gravels	2.0 ± 0.1	Stage I

4.2 Loess Sites

4.2.1 Washtucna (Washtucna, Washington)

Figure 21 Location of the Washtucna field site near Washtucna, Washington.

The Washtucna outcrop is located 6.4 km northwest of Washtucna, Washington along SR 261 (Figure 21). The GPS coordinates for this site are N 46.834753 latitude and W -118.328585 longitude; the elevation is 501 m. Two samples were taken from two loess layers.

Figure 22 Washtucna outcrop with sample locations labeled.

Figure 23 Washtucna stratigraphy, "Line-and stipple pattern marks approximate position of prominent paleosol B horizons. Dashed lines are tephras; those correlated are : M=Mazama; MSH S=Mount St. Helens set S; MSH C= Mount St. Helens set C. Heavy lines are flood-cut unconformities and are labeled alphabetically" (McDonald and Busacca, 1988a).

The Washtucna field site is the most famous loess stratigraphy site in eastern Washington (Figure 22) and has been interpreted by many previous workers including: McDonald and Busacca (1988a), Baker et al. (1991), Bjornstad et al. (2001), and Bjornstad (2006). There are a total of five angular unconformities and one disconformity in the section (McDonald and Busacca, 1988a). The outcrop is interpreted as predominately loess deposits separated by unconformities and

paleosols (Figure 23). There are also tephra layers, two of which have been dated, both of which overlie the sampled layers (Figure 23). The youngest, Mount St. Helen's "S" is 15,500 calendar years old and fell during the Missoula Flood times. The oldest is the Mount St. Helens set C ash dated at approximately 36 ka. The unconformities cut below the "S" ash were produced at the times of floods older than the Missoula Floods.

There are no flood deposits present at the site, but the presence of loess cut by unconformities is evidence for earlier flooding events. McDonald and Busacca (1988a) interpret that each unconformity was caused by flood scouring and count four episodes of floods older than 36 ka. The calcrete paleosols at the tops of the loess sequences are evidence for time in between the deposits. The surfaces are all irregular because deposition occurred on flood-scoured sequences. Two samples were taken, WCC and WCC1 (Figure 22), near the top of two loess layers. Sample WCC measures 4.08 ± 0.16 percent CaCO_3 and WCC1 measures 9.55 ± 0.20 percent; both are Stage II in calcrete development (Table 7). The WCC1 loess layer was tested for particle size analysis and contains 13.3% sand, 82.8% silt, and 3.9% clay. The sand contains quartz.

The floods that cut unconformities below the ash are at least 36,000 years old. The calcrete formation on loess layers between the unconformities provides evidence for at least 20,000 years between flood scouring events. There is evidence for four floods, probably all Middle Pleistocene.

Table 7 Chittick results for Washtucna field site.

Sample ID	Average CaCO ₃ Percent	Stage of Development
WCC loess	4.08 ± 0.16	Stage II
WCC1 calcrete in loess	9.55 ± 0.20	Stage II

4.2.2 Benge (Benge, Washington)

Figure 24 Location of the Benge field site.

The Benge site is located 6 km from Benge, Washington along the Benge-Ralston Road (Figure 24) The GPS coordinates for this site are N 46.9324525 latitude and W -118.14205 longitude; the elevation is 506.6 m. Four flood-cut unconformities are present with three calcrete paleosols (Figure 25) (McDonald and

Busacca, 1988a). Samples B1 and B2 are in the lowermost paleosol, capped by a calcrete horizon, B3. The calcrete horizon along B3 is the lowermost unconformity at the site. B1 was taken from the reddish Bt soil horizon, B2 is taken from the B horizon. Sample B4 was taken from the B horizon that is capped by another thin calcrete layer. The sediments from B4A that overlie the lowest unconformity, B4, have reversed magnetic polarity (Baker et al., 1991), representing at least one Early Pleistocene flood. No flood gravels are present at the site, but McDonald and Busacca (1988a) interpret layers B1-B4A as old loesses associated unconformities cut by floods.

Figure 25 Benge Outcrop with sample locations labeled B1-B5.

Figure 26 Benge stratigraphy, "Line-and stipple pattern marks approximate position of prominent paleosol B horizons. Dashed lines are tephras; those correlated are : M=Mazama; MSH S=Mount St. Helens set S; MSH C= Mount St. Helens set C. Heavy lines are flood-cut unconformities and are labeled alphabetically" (McDonald and Busacca, 1988a).

All of these older paleosols are truncated by a loess deposit B5 with normal magnetic polarity interpreted as Late Wisconsin (McDonald and Busacca, 1988a).

Another Missoula Flood age loess deposit, B6, overlies B5, with a layer modern soil development, B7, covering the outcrop.

The amount of CaCO_3 in the paleosols (Table 8) and flood-cut unconformities provide evidence for large amounts between each paleosol, at least 20,000 years. B1-B3 have 10.9-13.9% CaCO_3 and Stage II – II+ calcrete development. They are interpreted as Early Pleistocene in age. B4, in the B soil horizon of the overlying paleosol, contains 3 percent CaCO_3 . It is probably Middle Pleistocene in age, as interpreted by Bjornstad et al. (2001). The large, approximately 10 m thick, loess deposit B5 contains less than one percent CaCO_3 and is Late Wisconsin in age. Another loess deposit (not sampled), B6, also Late Wisconsin, overlies B5.

Table 8 Chittick results for Benge site.

Sample ID	Average CaCO ₃ Percent	Stage of Development
B1 calcrete in loess	13.3 ± 1.0	Stage II+
B2 calcrete in loess	10.9 ± 0.3	Stage II
B3 calcrete paleosol in loess	13.9 ± 0.4	Stage II+
B4 loess	3.1 ± 0.1	Stage II
B5 loess	0.8 ± 0.1	Stage I

4.2.3 E. Callaway Road (Benge, Washington)

The Calloway Road outcrop is located along E Calloway Road 0.7 km east of the E Calloway Road and the Ritzville-Benge Road intersection (Figure 27) The GPS coordinates for this site are N 46.98671 latitude and W -118.078691 longitude; the elevation is 524.9 m. I discovered the outcrop.

Figure 27 Location of the E. Callaway Road field site near Benge, Washington.

Figure 28 E. Callaway Road outcrop, the red box indicates the location of Error!
Reference source not found.Error! Reference source not found..

Figure 29 E. Callaway Road close-up with sample locations labeled.

Figure 30 Stratigraphy of E. Callaway Road outcrop.

The outcrop contains layers of loess and paleosols in the loess (Figure 28). GB1 and GB3 are both layers of loess, measuring $11.1\% \pm 0.6$ and $14.3\% \pm 0.1$ CaCO_3 , Stage II and II+ development (Table 9). Sample GB2, another loess deposit, was collected in between the two layers of loess in a potential calcrete paleosol and measured $29.2\% \pm 0.6$ CaCO_3 , Stage III development. No flood deposits are present, but the layers of loess with late stage CaCO_3 paleosols implies that there is considerable time between the deposition events and the unconformities were probably produced by floods in the Middle Pleistocene.

Table 9 Chittick results for E. Callaway Road site.

Sample ID	Average CaCO_3 Percent	Stage of Development
GB1 loess	11.1 ± 0.6	Stage II
GB2 calcrete paleosol in loess	29.2 ± 0.6	Stage III
GB3 loess	14.3 ± 0.1	Stage II+

4.2.4 Rulo Outcrop (Walla Walla, Washington)

Figure 31 Location of the Rulo Outcrop field site near Walla Walla, Washington.

The Rulo outcrop was studied by Karen Gastineau (2011) at Whitman College for an undergraduate thesis project. The outcrop is located 8 km northwest of Walla Walla, Washington along Sudbury Road (Figure 31). The GPS coordinates for this site are N 46.16536944 latitude and W -118.5024 longitude; the elevation is 299.9 m. The site contains several units of silt and calcrete development (Figure 32).

Figure 32 Rulo outcrop with sample locations labeled, red lines are unconformities and the yellow line is a clastic dike.

Layer R01 is a layer of quartz sand at the base of the section with basalt fragments and mica present in the silt to fine sand, with a few basalt pebbles (Gastineau, 2011). Sample R01 measured $5.9\% \pm 0.2$ CaCO_3 (Table 10). The second unit, sample R02, is truncated by two flood-cut unconformities in red (Figure 32). R02 was taken from a rigid calcrete horizon, a Bk soil horizon below a Bt. Mica is present throughout R02, which infers either paleoflood or loess origin. Sample R02 measured $21.7\% \pm 0.7$ CaCO_3 , Stage III. A clastic dike, shown in yellow, also truncates these layers down to the first unit. Above the unconformity and dipping to the north, lie layers R03 through R06. Layers R03 and R04 are poorly consolidated silt layers that grade into a prominent calcrete horizon at the top (Gastineau, 2011).

The samples measure $0.7\% \pm 0.2$ CaCO_3 for R03 and $12.2\% \pm 0.4$ for R04. The two layers above, R05 and R06, are structureless silt units and measure $15.3\% \pm 0.5$ and $14.0\% \pm 0.2$ CaCO_3 , Stage II+. Dipping in the north direction above the other unconformity are layers R07 and R08. Layers R07 contains at Bt over Bk soil horizons and measures $6.4\% \pm 0.4$ CaCO_3 . Above these calcrete layers is a massive silt layer, R08, which contains two tephra layers. The two tephras are dated at 165-210 ka and >200ka. Another unconformity lies above R08, and the top two units are made up of coarse silt with a basal unit of calcrete (Gastineau, 2011). These loess units point to evidence for at least four ancient floods that are older than 200 ka. They are probably all Middle Pleistocene in age.

Table 10 Chittick results for Rulo Outcrop site.

Sample ID	Average CaCO_3 Percent	Stage of Development
R01 flood gravels	5.9 ± 0.2	Stage II
R02 calcrete paleosol in loess	21.7 ± 0.7	Stage III
R03 loess	0.7 ± 0.2	Stage I
R04 calcrete paleosol in loess	12.2 ± 0.4	Stage II+
R05 calcrete paleosol in loess	15.3 ± 0.5	Stage II+
R06 calcrete paleosol in loess	14.0 ± 0.2	Stage II+
R07 calcrete paleosol in loess	6.4 ± 0.4	Stage II
R08 calcrete paleosol in loess	4.9 ± 0.1	Stage II

4.3 Flood deposits

4.3.1 Poplar Heights (Highland, Washington)

Poplar Heights is located along E 45th Avenue approximately 240 meters west of South Oak St., Highland, in the Pasco Basin (Figure 33). The Global Positioning System (GPS) coordinates for this site are N 46.168759 latitude and W - 119.09852 longitude; the elevation is 44.5 m. Stratigraphic layers are described (Figure 34), and each was sampled.

Figure 33 Location of Poplar Heights field site in Highland, Washington.

PH1 is from the lowest layer, the gravel-dominated flood deposit. Baker et al. (1991) measured reversed magnetic polarity in a sand lens in this gravel deposit, dating the flood deposit to Early Pleistocene. Figure 36 shows a close-up of the PH1

flood deposit which contains exotic, non-basalt, clasts of granites, quartzites, and some schists. Sample PH2 was taken from the overlying calcrete paleosol which formed in the same sediments of PH1. The paleosol contains $32.4\% \pm 4.6 \text{ CaCO}_3$, Stage III development (Table 11). The third sample, PH3, was taken above an unconformity in Missoula Flood sediments (Baker et al., 1991). Based on the presence of exotic clasts, reversed magnetic polarity, and Stage III calcrete development in the paleosol, the underlying flood deposit PH1 is at least Early Pleistocene in age.

Figure 34 Poplar Heights outcrop with sample locations labeled.

Figure 35 Stratigraphy of Poplar Heights outcrop.

Figure 36 Close-up on exotic clasts present in the gravel-dominated PH1 flood deposit at Poplar Heights.

Table 11 Chittick results for Poplar Heights site.

Sample ID	Average CaCO ₃ Percent	Stage of Development
PH1 flood gravels	0.1 ± 0.3	Stage I
PH2 calcrete paleosol in flood gravels	32.4 ± 4.6	Stage III
PH3 Missoula Flood sediments	3.5 ± 0.4	Stage II

4.3.2 Old Maid Coulee (Mesa, Washington)

Figure 37 Location of Old Maid Coulee field site near Mesa, Washington.

Old Maid Coulee is located 4.3 km east of Mesa, Washington and U.S. 395 along Pepiot Road (Figure 37, 14). The GPS coordinates for this site are N 46.568056 latitude and W -118.952637 longitude; the elevation is 277 m. Two stratigraphic

layers are present at this site; a younger loess (OM1) over a calcrete formed in flood gravels (OM2) (Figure 39).

Figure 38 Old Maid Coulee outcrop.

The Old Maid Coulee site has been visited and interpreted by many other workers including: Baker (1973), Baker and Nummedal (1978), Baker et al. (1991), Patton and Baker (1978), Bjornstad et al. (2001), and Bjornstad (2006). All workers interpreted one Early Pleistocene flood deposit at the site. The Ancient Cataclysmic Flood deposit OM2 consists of highly weathered basalt and scoria clasts cemented by CaCO_3 . Bjornstad (2006) has reported, “...reversed magnetic polarity has been measured in the fine-grained loess just above the flood gravels and below the caliche.”

Figure 39 Old Maid Coulee outcrop with sample locations labeled.

The top of the outcrop has been removed since Bjornstad (2006) last visited the site, and therefore there is no longer a calcrete paleosol present above the loess. However, the remaining loess above the flood gravels does not appear to be re-worked and contains $1.2\% \pm 0.4$ CaCO_3 (Table 12). The flood gravels, OM2, are continuously coated with CaCO_3 with some cementation between clasts, placing the gravels in at least Stage II carbonate morphology (Machette, 1985). The flood deposit contains $4.3\% \pm 0.9$ percent CaCO_3 , Stage II calcrete development, and is

interpreted as Early Pleistocene in age based on reversed magnetic polarity. Layer

OM1 is interpreted as loess deposited since Missoula Flood times.

Table 12 Chittick results for Old Maid Coulee site.

Sample ID	Average CaCO ₃ Percent	Stage of Development
OM1 loess	1.2 ± 0.4	Stage I
OM2 flood gravels	4.3 ± 0.9	Stage II

4.3.3 Potholes Coulee (George, Washington)

Figure 40 Location of Potholes Coulee field site, north of George, Washington.

Figure 41 Potholes Coulee outcrop with sample locations labeled.

Figure 42 Highly weathered basalt clast (sample PC5) found in layer PC4 at Potholes Coulee outcrop.

Figure 43 Stratigraphy of Potholes Coulee outcrop.

The Potholes Coulee field site is located along White Trail Road approximately 10 km north of George, Washington (Figure 40). The GPS coordinates for this site are N 47.160043 latitude and W -119.901514 longitude; the elevation is 388 m. There are four stratigraphic layers: PC1 calcrete paleosol, PC2 flood gravels, PC3 calcrete paleosol, PC4 ancient flood slackwater deposit. The site has been analyzed by Bjornstad (2006) who describes evidence of a “...very old, large Ice Age flood spilling over Evergreen and Babcock ridges from west to east-opposite that of Scabland floods.” His evidence is the east-dipping calcrete paleosols near the George landfill and Frenchmen Coulee.

The total section of the outcrop measures 356 cm thick (Figure 41). The top layer, PC1, from 0 to 89 cm is a thick calcrete paleosol, with $22.5\% \pm 5.9 \text{ CaCO}_3$ and

Stage III development (Table 13). The lower part of the PC1 gravel deposit, PC2, below the upper paleosol is a flood deposit composed of sand and basalt pebbles and measures $6.6\% \pm 1.4 \text{ CaCO}_3$. The second calcrete paleosol, PC3, is much thinner, from 188 to 193 cm, contains basalt pebbles and measures $11.0\% \pm 0.5 \text{ CaCO}_3$, Stage II development. Layer PC4 is another potential ancient flood deposit with a fine-grained matrix and gravel pieces, possibly a slackwater deposit. Sample PC5 was collected from the flood deposit in layer PC4; the coatings around highly weathered basalt clasts (Figure 42) measured $18.8\% \pm 1.2 \text{ CaCO}_3$, Stage III development.

It takes hundreds of thousands of years for basalt to weather to this degree. Based on the degree of weathering and the advanced stages of CaCO_3 development, the lower flood deposit, PC4, is probably Early Pleistocene in age and the upper flood deposit, PC2, is probably Early-Middle Pleistocene.

Table 13 Chittick results for Potholes Coulee site.

Sample ID	Average CaCO_3 Percent	Stage of Development
PC1 calcrete paleosol in flood gravels	22.5 ± 5.9	Stage III
PC2 flood gravels	6.6 ± 1.4	Stage II
PC3 calcrete paleosol in slackwater deposit	11.0 ± 0.5	Stage II
PC4 slackwater deposit	1.0 ± 0.1	Stage I
PC5 calcrete coating on boulder in PC4	18.8 ± 1.2	Stage III

4.3.4 Frenchmen Coulee (George, Washington)

Figure 44 Location of the Frenchmen Coulee field site near George, Washington.

Frenchmen Coulee is located 9.6 km southwest of George, Washington along Silica Road (exit 143 from I-90) (Figure 44). The GPS coordinates for this site are N 47.042778 latitude and W -119.970768 longitude; the elevation is 413.0 m.

Frenchmen Coulee has “evidence for a very old, large Ice Age Flood” that originated from the west (as opposed to Glacial Lake Missoula to the east) (Bjornstad, 2006). These stratigraphic layers were described here: an upper A horizon of the soil; FC1, a calcrete paleosol; and FC2, highly weathered basalt (Figure 45).

Figure 45 Frenchmen Coulee outcrop with sample locations labeled.

The “A” soil horizon comprises the upper 46 cm of the outcrop and seems to have formed in recent loess. An unconformity separates the soil horizon from the calcrete paleosol layer FC1. The calcrete is formed in mostly silt with scattered basalt gravels. The paleosol is 104 cm thick and measures $27.9\% \pm 5.2 \text{ CaCO}_3$, Stage III development (Table 14). The paleosol overlies highly weathered basalt bedrock, FC2 (Figure 47). I interpret the paleosol to be at least Middle Pleistocene in age.

Stratigraphy		
SCALE (m)	NOTES	LITHOLOGY
1	FC1 calcrete paleosol formed in slackwater deposit
	FC2 weathered basalt bedrock

Figure 46 Stratigraphy of Frenchmen Coulee outcrop.

Figure 47 Close-up of the contact between weathered basalt bedrock and calcrete paleosol at Frenchmen Coulee.

Table 14 Chittick results for Frenchmen Coulee site.

Sample ID	Average CaCO ₃ Percent	Stage of Development
FC1 calcrete paleosol in slackwater deposit	27.9 ± 5.2	Stage III

4.3.5 Silica Road (George, Washington)

Figure 48 Location of the Silica Road field sites near George, Washington.

The Silica Road outcrops are located approximately 3.6 km northwest of I-90, just north of the Frenchmen Coulee outcrop (Figure 48). I discovered the outcrops doing field work in the summer of 2010. The GPS coordinates for Silica Road 1 are N 47.046525 latitude and W -119.976711 longitude; the elevation is 402 m. The GPS coordinates for Silica Road 2 are N 47.050727 latitude and W -119.9976364

longitude; the elevation is 415 m. The GPS coordinates for Silica Road 3 are N 47.053686 latitude and W -119.982361 longitude; the elevation is 427 m. No samples were taken because the sites are on private property. Each site contained a prominent calcrete paleosol in slackwater deposits with a gravelly flood deposit below, composed of basalt gravels (Figure 49). Further north along Silica Road there is a more discontinuous calcrete layer with weathered basalt bedrock below (Figure 50). The outcrop appears to have Stage II-III soil development and I suggest that it is Middle Pleistocene in age; however, the outcrop needs to be sampled and tested.

Figure 49 Silica Road 1 outcrop.

Figure 50 Silica Road 2 outcrop.

4.3.6 Reese Coulee (Touchet, Washington)

Figure 51 Location of the Reese Coulee field site, west of Wallula, Washington.

Reese Coulee is located along U.S. 12, 11.6 km west of Wallula Junction (Figure 51). The GPS coordinates for this site are N 46.067093 latitude and W - 118.759532 longitude; the elevation is 193 m. Many stratigraphic layers of calcrete paleosols are found here. I sampled four places at the bottom of the stratigraphic section: RC1, RC2, RC3 and RC4.

The outcrop was previously interpreted by Bjornstad et al. (2001), Jaffee and Spencer (2000), and Bjornstad (2006). Bjornstad (2006) found ice-rafted, highly weathered granite boulders at the base of the section. “The exact age of the flood(s) that carved the coulee and deposited the erratic is uncertain, but a minimum age of 770,000 (or 790,000) years ago is based on the reversed magnetic polarity, measured in the fine-grained sediments that enclose the erratic” (Bjornstad, 2006).

Figure 52 Reese Coulee outcrop with sample locations labeled. Photo by Kat Barnard

Figure 53 Basalt boulder covered in calcrete, sample locations labeled.

Figure 54 Clastic silt dike at Reese Coulee outcrop. Photo Kat Barnard

At least eight separate calcrete paleosols in flood gravels are counted at the outcrop, each of which overlies a sandy to gravelly flood deposit (Figure 52). The calcrete covering the weathered basalt boulder (Figure 53), sample RC4, measured $17.9\% \pm 0.7\text{CaCO}_3$, Stage III development. Sample RC1, $1.2\% \pm 0.4 \text{ CaCO}_3$ was collected in the flood deposit adjacent to the basalt boulder. RC3 was collected below the flood deposit and contained $0.5\% \pm 0.2 \text{ CaCO}_3$. Sample RC2 was collected in the calcrete paleosol overlying the flood deposit and contained $14.7\% \pm 0.3 \text{ CaCO}_3$, Stage II+ calcrete development. Many clastic injection dikes are present at the outcrop (Figure 54). Based on reversed magnetic polarity, there is at least one Early Pleistocene flood deposit and many more Early-Middle Pleistocene deposits separated by calcrete paleosols.

Table 15 Chittick results for Reese Coulee site.

Sample ID	Average CaCO_3 Percent	Stage of Development
RC1 flood gravels	1.2 ± 0.4	Stage I
RC2 calcrete in flood gravels	14.7 ± 0.3	Stage II+
RC3 flood gravels	0.5 ± 0.2	Stage I
RC4 calcrete rind on boulder in RC3	17.9 ± 0.7	Stage III

4.3.7 Cummins Bridge (Touchet, Washington)

Figure 55 Location of the Cummins Bridge field site near Touchet, Washington.

The Cummins Bridge outcrop is located off of Byrnes Road 3.5 km southeast of U.S. 12 (Figure 55). The GPS coordinates for this site are N 46.0379625 latitude and W -118.7683583 longitude; the elevation is 117 m. Two stratigraphic layers are described, CB1, Missoula Flood rhythmites, and CB2 Ancient Cataclysmic gravels. Burns and Medley estimate approximately 30 meters of Missoula Flood rhythmites (layer CB1) ranging in thickness, from 20 cm to several meters thick. No samples were collected because of the inaccessibility of the outcrop.

Figure 56 Cummins Bridge outcrop.

Approximately 1.5 m of old gravels (layer CB2) underlie the rhythmites, separated by an unconformity. Another unconformity below the gravels separates an old rhythmite sequence that is approximately 0.6 m thick, which unconformably overlies basalt bedrock or possibly more old gravels. This site is unique because there is evidence for strong flood waters (gravels) and low energy slackwater deposits (rhythmites) (Figure 56). Bjornstad (2006) measured the older slackwater rhythmites beneath the gravels to have normal magnetic polarity placing the

deposit younger than 790,000 years ago. The deposits are probably Middle Pleistocene, between 130,000 and 790,000 thousand years ago.

4.3.8 Connell (Connell, Washington)

Figure 57 Connell field site location.

The Connell field site is located along Highway 260 approximately 8.2 km west of U.S. 395 (Figure 57). The GPS coordinates for this site are N 46.631671 latitude and W -118.752708 longitude; the elevation is 349 m. Two stratigraphic layers were sampled, CON2 and CON3.

Figure 58 Connell outcrop with sample locations labeled.

The section appears to be entirely composed of calcrete with more and less resistant layers. The more resistant layers are marked in (Figure 58). Baker et al. (1991) hypothesized that there is evidence for one Middle Pleistocene flood at this location based on Mount St. Helens set C tephra that “fills a flood-scoured depression cut into underlying paleosols and loess; thus, the flood that cut the unconformity occurred just prior to 36 ka.” Sample CON2 was collected just below the uppermost resistant ledge, and CON3 is from the thickest and most strongly lithified calcrete layer at the base. Both layers consist of fine sand to silt containing

quartz and basalt sand. Based on the high amounts of CaCO_3 in the paleosol samples, $16.6\% \pm 1.8$ and $25.0\% \pm 5.3$ Stages II+ and III calcrete development, any flood deposits that were subsequently scoured are at least 36 ka (Table 16).

Table 16 Chittick results for Connell site.

Sample ID	Average CaCO_3 Percent	Stage of Development
CON2 calcrete in slackwater deposit	16.6 ± 1.8	Stage II+
CON3 calcrete in slackwater deposit	25.0 ± 5.3	Stage III

4.3.9 East Connell (Kahlotus, Washington)

Figure 59 Location of the East Connell field site, west of Kahlotus, Washington.

Figure 60 East Connell field site with sample locations labeled.

The East Connell site is located approximately 8 km east of the Connell site along Highway 260 and 9.2 km west of Kahlotus, Washington (Figure 59). The GPS coordinates for this site are N 46.62187 latitude and W -118.659126 longitude; the elevation is 384 m. Two samples were taken from the upper and lower part of the calcrete formed in basalt gravels at the site (Figure 60).

Figure 61 Stratigraphy of East Connell outcrop.

This is a new site that most likely correlates to the Connell site based on proximity. The calcrete paleosol with basalt gravels is 230 cm thick and is bounded by unconformities. Weathered basalt bedrock lies below the lower unconformity. The two samples were taken in the upper resistant calcrete, E.CON1, and the lower resistant calcrete layer, E.CON2. The percent of CaCO_3 in the samples, $18.1\% \pm 0.6$ and $25.2\% \pm 5.8$ and Stage III development, correlates closely with the Connell samples (Table 17). Any scoured away flood deposits are in the same age range as those at the Connell site, at least 36 ka.

Table 17 Chittick results for East Connell site.

Sample ID	Average CaCO_3 Percent	Stage of Development
E.CON1 calcrete in flood gravels	18.1 ± 0.6	Stage III
E.CON2 calcrete in flood gravels	25.2 ± 5.8	Stage III

4.3.10 Marengo (Ritzville, Washington)

Figure 62 Location of the Marengo field site near Ritzville, Washington.

Figure 63 Marengo railroad cut. Only weathered basalt was found here.

The Marengo site is located off Marengo Road 0.14 km north of its intersection with Cow Creek Road (Figure 62). The GPS coordinates for this site are N 47.02021389 latitude and W -118.2009667 longitude; the elevation is 493.5 m. The site was referenced by Baker and Nummedal (1978) as having an exposure of two older flood gravel sequences separated by layers of loess. Burns and Medley visited the site and found highly weathered basalt bedrock but no gravels (Figure 63).

4.3.11 Macall (Benge, Washington)

The Macall outcrop is located 4.5 km east of Harder Road, northwest of Benge, Washington (Figure 64). The GPS coordinates for this site are N 46.9323907 latitude and W -118.141931 longitude; the elevation is 507.2 m.

Figure 64 Location of the Macall field site, northwest of Benge, Washington.

Figure 65 Macall outcrop with sample location labeled.

The site has one gravely flood deposit overlain by a calcrete paleosol (Figure 65). Sample M2 was collected in the top layer of the outcrop from the calcrete paleosol and measures $28.60\% \pm 1.65$ CaCO_3 , Stage III development (Table 18). Below the paleosol lies a gravel-dominated flood deposit composed of basalt gravels, sample M1. Bjornstad et al. (2001) measured “reversed-polarity soil over flood gravels capped by calcrete dated at >350 ka.” The flood deposit is at least 790,000 years old, Early Pleistocene.

Table 18 Chittick results for Macall site.

Sample ID	Average CaCO_3 Percent	Stage of Development
M2 calcrete paleosol in flood gravels	28.60 ± 1.65	Stage III

4.3.12 Revere (Benge, Washington)

Figure 66 Location of the Revere field site near Benge, Washington.

Revere is located at the intersection of Breedon Road (also called Gering Road) and Revere Road. The GPS coordinates for this site are N 47.0647264 latitude and W -117.939204 longitude; the elevation is 512 m. Four layers are described here: RV1 gravel flood deposit, RV2 calcrete paleosol in flood gravels, RV2A loess, RV3 calcrete paleosol formed in loess.

Baker and Nummedal (1978), Patton and Baker (1978), and Bjornstad et al. (2001) interpret two flood-scoured unconformities in Palouse Loess with reversed magnetic polarity measured in layer RV2A. Layer RV1 is a gravelly flood deposit with primarily basalt clasts.

Figure 67 Revere outcrop with sample locations labels.

Figure 68 Stratigraphy of Revere outcrop.

A thin calcrete paleosol, RV2, caps the gravel layer. Sample RV3 was taken in the upper calcrete paleosol layer containing basalt pebbles. Lenses of fine-grained silt are also present in RV3. A layer of loess, RV2A, is located between the two calcrete paleosols, separated by two unconformities. I interpret RV1 to be an Early Pleistocene flood deposit and the flood cut unconformities as Middle Pleistocene.

4.3.13 Leslie Road (Richland, Washington)

Figure 69 Location of the Leslie Road field site, near Richland, Washington.

Leslie Road is located 3.7 km southeast from Highway 12 off of Columbia Park Trail (Figure 69). The GPS coordinates for this site are N 46.23969907 latitude and W -119.2598591 longitude; the elevation is 118 m. Two prominent calcrete paleosols in two gravelly flood deposits are present at the outcrop (Figure 70).

Figure 70 Leslie Road outcrop with sample locations labeled.

Stratigraphy		
SCALE (m)	NOTES	LITHOLOGY
1	LR1 calcrete formed in gravels	
2	LR2 flood gravels	
3	LR3 calcrete paleosol formed in gravels	

Figure 71 Stratigraphy at Leslie Road outcrop.

Baker et al. (1991) dated the upper calcrete paleosol horizon where LR1 was sampled at a maximum age date of >400 ka. LR1 contains $6.4\% \pm 0.3$ percent CaCO_3 , Stage II development. Th/U dating at or near this locality from the eastern end of Badger Coulee gives a minimum age of 0.2 Ma for the calcrete cap (Baker et al., 1991). The gravelly flood deposit that underlies the upper calcrete cap, sample LR2, contains many exotic clasts including granites, schists, and quartzites (Figure 72). I interpret LR2 as a Middle Pleistocene Flood deposit. Another much thinner discontinuous calcrete paleosol, sample LR2, lies approximately 4.6 to 6 meters below LR1. Sample LR3 measured $16.5\% \pm 1.1$ CaCO_3 , Stage II+ development (Table 19). More flood gravels containing exotic clasts lie below the lower paleosol, and I interpret them as Early Pleistocene in age.

Figure 72 Exotic clasts from the gravelly flood deposit LR2 at Leslie Road outcrop.

Table 19 Chittick results for Leslie Road site.

Sample ID	Average CaCO_3 Percent	Stage of Development
LR1 calcrete paleosol in flood gravels	6.4 ± 0.3	Stage II
LR2 flood gravels	0.1 ± 0.3	Stage I
LR3 calcrete paleosol in flood gravels	16.5 ± 1.1	Stage II+

4.3.14 Fuels Materials and Examination Facility (FMEF) (Richland, Washington)

The Fuels Materials and Examination Facility site was not visited due to its prohibited access on the Hanford site in Washington (Figure 73). Baker et al. (1991) found three plane-laminated sand sequences that “...possibly correlate with Early, Middle, and Late Pleistocene flood episodes, discussed above for coarse-grained flood deposits.

Figure 73 Location of the FMEF field site, north of Richland, Washington.

The uppermost unit contains the Mount St. Helens set S tephra couplet dated at about 15.4 ka calendar years (Mullineaux et al., 1978). The two lower plane-laminated sand sequences bear paleosols with weakly developed and bioturbated B horizons, suggesting distinctly different ages. Additional evidence for three separate

flood episodes includes clastic dikes in the lower and middle units which are truncated at their upper contacts (Baker et al., 1991).

4.3.15 South Bombing Range Road (West Richland, Washington)

The South Bombing Range Road field site is located along Bombing Range Road approximately 0.8 km north of Keene Road (Figure 74). The GPS coordinates for this site are N 46.26969907 latitude and W -119.34279 longitude; the elevation is 174.7 m. Bjornstad et al. (2001) found “normally magnetized soil over flood gravel with a calcrete cap.” Scott Burns and I did not find the field site described. We believe this field site has been turned into a park, and the visible features have been covered with fill.

Figure 74 Location of the South Bombing Range Road field site.

4.3.16 Yakima Bluffs (Richland, Washington)

The Yakima Bluffs field site is located above the present day Yakima River on private property at the north end of Truman Road where the road dead ends (Figure 75). Truman Road can be accessed from Exit 3 on Highway 182. The GPS coordinates for this site are N 46.26531216 latitude and W -119.3133526 longitude; the elevation is 148.7 m. The site contains a minimum of 12 ancient flood rhythmites (Figure 79) capped by old flood gravels (Figure 76).

Figure 75 Location of the Yakima Bluffs field site near Richland, Washington.

Yakima Bluffs has been studied by Baker et al. (1991), Fecht et al. (1999), Bjornstad et al. (2001), and Bjornstad (2006). Bjornstad (2006) found “at least two layers of gravel-dominated flood deposits...[15.24 m] or more below the

surface...Fine-grained sediments sampled from the lower layer exhibit reversed magnetic polarity, while the younger layers above show normal magnetic polarity.” High energy floods coming through this area eventually jammed the coulee and caused the Yakima River to be diverted north (Bjornstad, 2006). The subsequent deposits overlying the gravels are low energy slackwater rhythmites. However, more gravels unconformably overlie the sequence of at least 12 thick rhythmites at the site (Figure 78).

Figure 76 Yakima Bluffs outcrop, upper gravels; sample locations labeled.

Figure 77 Exotic clasts in the gravel-dominated flood deposits at Yakima Bluffs outcrop.

Figure 78 Unconformable contact between flood gravels and slackwater rhythmites at Yakima Bluffs outcrop.

Sample YB1, containing $21.3\% \pm 2.6 \text{ CaCO}_3$ and Stage III calcrete development, was collected from the uppermost gravelly calcrete paleosol (Figure 76) (Table 20). YB2 was collected from the gravel-dominated flood deposit underlying the paleosol and contains $8.7\% \pm 0.4 \text{ CaCO}_3$, Stage II development. YB3 was collected from a thin, very fine-grained calcrete deposit in the flood gravels and contained $22.6\% \pm 1.6 \text{ CaCO}_3$, Stage III development. YB4 ($1.2\% \pm 0.2 \text{ CaCO}_3$, Stage I)

was collected below layer YB3 in flood gravels containing little or no sand, silt, or clay.

Figure 79 Yakima Bluffs outcrop with sample locations labeled.

Figure 80 Clastic dikes in rhythmites at Yakima Bluffs outcrop.

The gravels from these deposits contain many exotic clasts including granite, quartzite, and schists (Figure 77).

Samples YB7 and YB6 were taken from one of the lowermost rhythmite layers at the outcrop (Figure 79). Each rhythmite gradually coarsens upward from coarse-grained sand to silt. Sample YB5 was taken from an extremely hard, calcified silt layer at the top of the rhythmite and contains $24.9\% \pm 2.3 \text{ CaCO}_3$. The lower sandy parts of these ancient rhythmites contain low amounts of CaCO_3 (1.6 – 1.8%, YB6 and YB7, Table 20). The rhythmites are probably Middle Pleistocene in age. Truncated clastic silt dikes are found throughout the section (Figure 80).

Table 20 Chittick results for Yakima Bluffs site.

Sample ID	Average CaCO_3 Percent	Stage of Development
YB1 calcrete paleosol in flood gravels	21.3 ± 2.6	Stage III
YB2 flood gravels	8.7 ± 0.4	Stage II
YB3 calcrete paleosol in flood gravels	22.6 ± 1.6	Stage III
YB4 flood gravels	1.2 ± 0.2	Stage I
YB5 calcified silt layer rhythmites	24.9 ± 2.3	Stage III
YB6 sand layer in rhythmites	1.8 ± 0.2	Stage I
YB7 sand layer in rhythmites	1.6 ± 0.1	Stage I

4.3.17 Field Road (Benton City, Washington)

Figure 81 Location of the Field Road field site near Benton City, Washington.

Figure 82 Field Road outcrop with sample locations labeled.

The Field Road site is located along Field Road (Figure 81). Heading north on Highway 82, take exit 96 and then head east on Webber Road. The GPS coordinates for this site are N 46.24508872 latitude and W -119.4674443 longitude; the elevation is 165.2 m.

The Field Road outcrop is adjacent to the “Kiona Quarry” site referenced by Baker et al (1991), Fecht et al. (1999), and Bjornstad et al. (2001). The quarry is now named “A & B Asphalt” and could not be visited due to safety codes. Bjornstad et al. (2001) found “normally magnetized flood gravel with calcrete cap (calcrete dated at >210 and >400ka); oxidized flood gravels at depth.” They hypothesize that there is one Middle and possibly one Early Pleistocene flood deposit at depth.

The gravel-dominated flood deposit sample collected adjacent to the quarry, FRS (Figure 82), is composed subrounded basalt gravels and measures $16.5\% \pm 0.5$ CaCO_3 , Stage II+ calcrete development. It is probably Middle Pleistocene in age (Table 21).

Table 21 Chittick results for Field Rdoad site.

Sample ID	Average CaCO_3 Percent	Stage of Development
FRS calcrete paleosol in flood gravels	16.5 ± 0.5	Stage II+

4.3.18 Winans Road 1 (Walla Walla, Washington)

The Winans Road 1 field site is located on Winans Road approximately 0.17 km east of Harvey Shaw Road (also called Cochran Road) (Figure 83). The GPS

coordinates for this site are N 46.16667092 latitude and W -118.432645 longitude; the elevation is 286.2 m.

Figure 83 Location of the Winans Road 1 field site near Walla Walla, Washington.

Both Spencer and Gilk (1999) and Spencer and Jaffee (2002) interpret two pre-late Wisconsinan outburst flood deposits at this site. Three layers are described at this outcrop: WR11 slackwater deposit, WR12 calcrete paleosol in the slackwater deposit, WR12A loess layer, and WR13 diamict with calcrete paleosol.

The younger flood event, recorded by the diamict WR13, contains basaltic, granitic, and metamorphic clasts and contains $13.7\% \pm 0.4 \text{ CaCO}_3$, Stage II+ soil development (Figure 84) (Table 22). The older flood is recorded by a slackwater deposit, WR11. Weathered basalt bedrock lies below the lower slackwater deposit.

Sample WR11 contains $12.6\% \pm 0.4 \text{ CaCO}_3$ and is capped by a calcrete paleosol,

sample WR12 (Table 22). The paleosol contains $20.1\% \pm 0.6 \text{ CaCO}_3$, Stage III calcrete development. A thick layer of loess, WR12A separates the calcrete paleosol and the younger diamict, separated by two unconformities. Three generations of clastic dikes are also present in all units at the outcrop. There is evidence for two floods at this site, both Middle Pleistocene.

Figure 84 Winans Road 1 outcrop with sample locations labeled.

Figure 85 Stratigraphy of Winans Road 1 outcrop.

Table 22 Chittick results for Winans Road 1 site.

Sample ID	Average CaCO ₃ Percent	Stage of Development
WR11 slackwater deposit	12.6 ± 0.4	Stage II+
WR12 calcrete paleosol in slackwater deposit	20.1 ± 0.6	Stage III
WR13 calcrete paleosol in flood gravels	13.7 ± 0.4	Stage II+

4.3.19 Winans Road 2 (Walla Walla, Washington)

Figure 86 Location of the Winans Road 2 field site.

The Winans Road 2 field site is located 4.8 km northeast of Winans Road 1 along Winans Road (Figure 84). The GPS coordinates for this site are N 46.18846746 latitude and W -118.432645 longitude; the elevation is 291.1 m. No samples were taken; the site has the same stratigraphic units as the outcrop at Winans Road 1. The lower slackwater deposit layer (WR11) overlies basalt bedrock. A rigid calcrete layer is formed on top of the slackwater deposit (WR12) We found this site, (Figure 81), when exploring in the area near Winans Road 1. I interpret the deposits as Middle Pleistocene in age.

Figure 87 Winans Road 2 outcrop.

4.3.20 Palouse Falls (Washtucna, Washington)

The Palouse Falls field site is located along Highway 261 approximately 4 km southeast of Highway 260 (Figure 88). The GPS coordinates for this site are N 46.677697 latitude and W -118.37803 longitude; the elevation is 394 m.

Figure 88 Location of the Palouse Falls field site.

Figure 89 Palouse Falls outcrop.

Figure 90 Palouse Falls outcrop with sample locations labeled.

Figure 91 Stratigraphy of Palouse Falls outcrop.

Sample PF1 is taken from a prominent and continuous calcrete layer with a lot of basalt and pumice clasts (Figure 89). Sample PF1 measured $11.43\% \pm 0.69$ CaCO_3 , Stage II calcrete development (Table 23). Below the calcrete layer is a stratum of gravels with a sandy matrix. Sample PF2 was collected in these gravels underlying the calcrete and contains $1.1\% \pm 0.1$ CaCO_3 (Figure 90). I discovered this site, and I interpret it as being Middle Pleistocene in age.

Table 23 Chittick results for Palouse Falls site.

Sample ID	Average CaCO_3 Percent	Stage of Development
PF1 calcrete paleosol in flood gravels	11.4 ± 0.7	Stage II
PF2 flood gravels	1.1 ± 0.1	Stage I

4.3.21 Canal Outcrop (Othello, Washington)

Figure 92 Location of the Canal Outcrop field site.

The Canal Outcrop is located along SR 24 also called West Muse Road 13.5 km from Othello, Washington (Figure 92). The outcrop is approximately 15.4 km directly southwest of the Othello Canal outcrop. I discovered the outcrop with Barnard in 2010. The GPS coordinates for this site are N 46.738063 latitude and W - 119.303453 longitude; the elevation is 301 m. The outcrop has one calcrete paleosol and one slackwater flood deposit (Figure 93).

Figure 93 Canal Outcrop with sample locations labeled. Photograph by Kathryn Barnard.

Figure 94 Stratigraphy of Canal Outcrop.

Sample CO2 was taken in the prominent calcrete paleosol layer and measures $28.5\% \pm 1.3$, Stage III calcrete development (Table 24). Sample CO1 is in the upper part of the calcrete and measures $5.4\% \pm 0.3$ CaCO₃, Stage II.

Table 24 Chittick results for Canal Outcrop site.

Sample ID	Average CaCO ₃ Percent	Stage of Development
CO1 calcrete paleosol	5.4 ± 0.3	Stage II
CO2 calcrete paleosol in slackwater deposit	28.5 ± 1.3	Stage III
CO3 slackwater deposit	0.6 ± 0.0	Stage I
CO3.5 slackwater deposit	0.4 ± 0.1	Stage I

4.3.22 Othello Canal (Othello, Washington)

Figure 95 Location of the Othello Canal field site, southeast of Othello, Washington.

The Othello Canal outcrop is located along HW26 just 100 m east of the HW17 and HW26 intersection (Figure 95). I discovered the outcrop with Barnard in 2010. The GPS coordinates for this site are N 46.81168 latitude and W -119.131982 longitude; the elevation is 329 m. A calcrete paleosol that is two meters thick in places overlies a slackwater deposit at the outcrop.

Sample OC3 was collected from the massive calcrete paleosol and measures $38.3\% \pm 4.79$ CaCO_3 , Stage III+ calcrete development (Figure 96). However, based on the massive and platy morphology and thickness of the paleosol, it qualifies for Stage V soil development.

Figure 96 Othello Canal outcrop with sample locations labeled.

Figure 97 Othello Canal close-up with sample locations labeled.

Figure 98 Stratigraphy of Othello Canal outcrop.

Sample OC2, collected below OC3, is in the platy calcrete and measures 28.27 ± 1.33 percent CaCO_3 , Stage III development (Table 25). A slackwater deposit, OC1, lies below the paleosol. OC1 was tested for particle size analysis and contains 29.1% sand, 67.5% silt, and 3.5% clay. The sand contains quartz.

The soil development in the paleosol takes hundreds of thousands of years to form. The underlying slackwater flood deposit, OC1, is probably Early Pleistocene in age and possibly of the oldest preserved Ancient Cataclysmic Flood deposits (Figure 97). The Othello Canal site correlates with the Canal Outcrop site, which is 15.4 km southwest and has the same stratigraphy. Based on morphology, this is a Stage V calcrete (Machette, 1985).

Table 25 Chittick results for Othello Canal site.

Sample ID	Average CaCO ₃ Percent	Stage of Development
OC1 slackwater deposit	0.8 ± 0.5	Stage I
OC2 calcrete paleosol in slackwater deposit	28.3 ± 1.3	Stage III
OC3 calcrete paleosol in slackwater deposit	38.3 ± 4.8	Stage III+

4.3.23 Ritzville (Washtucna, Washington)

Figure 99 Location of the Ritzville field site.

Figure 100 Ritzville field sites, described by McDonald and Busacca (1988a). Samples were not collected from this outcrop but correlate to the adjacent section that was sampled. Photograph by Kathryn Barnard.

Figure 101 HW260 Field site adjacent to the Ritzville site, samples collected in marked layers.

Figure 102 Stratigraphy of HW260 outcrop.

The Ritzville site is located along Highway 261, north of Washtucna (Figure 99). The GPS coordinates for this site are N 46.769984 latitude and W -118.288106 longitude; the elevation is 341 m. The samples were collected from an outcropping paleosol (Figure 101) adjacent to the Ritzville outcrop (Figure 100) studied by McDonald and Busacca (1988a). The Ritzville outcrop has three unconformities, shown in red. One unconformity is below the lowermost sample collected, HW2603.

HW2603 was taken in a flood deposit layer containing basalt gravel clasts with $10.0\% \pm 1.2$ CaCO_3 Stage II development, coatings on the underside of clasts, in

a quartz sand matrix. A continuous calcrete paleosol containing basalt pebbles overlies the flood deposit, layer HW2602, which contains $20.4\% \pm 1.3$ CaCO_3 , Stage III development. Layer HW2601 is a sandy deposit with scattered basalt pebbles that overlies HW2602, separated by an unconformity. At the Ritzville outcrop, an angular unconformity cuts the two paleosols. The material above the unconformity is comprised of “lenses of basaltic sand and fragments of paleosols” (McDonald and Busacca, 1988a). Above the unconformity there is also evidence of Mount St. Helen’s set C tephra, which provides a minimum age of 36 Ka (Mullineaux et al., 1978) for the paleosol. Based on the tephra and amount of soil development, I interpret ages of the floods here as Middle Pleistocene.

Table 26 Chittick results for Ritzville site.

Sample ID	Average CaCO_3 Percent	Stage of Development
HW2601 slackwater flood deposit	3.8 ± 0.2	Stage II
HW2602 calcrete paleosol in flood gravels	20.4 ± 1.3	Stage III
HW2603 flood gravels	10.0 ± 1.2	Stage II

4.3.24 HW125 (Prescott, Washington)

The HW125 outcrop is located at milepost 19 along HW125 (Figure 103). The GPS coordinates for this site are N 46.23445707 latitude and W -118.3727899 longitude; the elevation is 302.7 m. The outcrop correlates to the Winans Road sites and has the same stratigraphy, a calcrete paleosol developed in loess overlying a slackwater deposit, with basalt bedrock below (Figure 104). No samples were

collected at this site. I interpret the slackwater deposit to correlate to the floods at Winans Road, Middle Pleistocene in age.

Figure 103 Location of the HW125 field site near Prescott, Washington.

Figure 104 HW125 outcrop.

4.3.25 Brown Road (Prescott, Washington)

Figure 105 Location of the Brown Road field site near Prescott, Washington.

Figure 106 Brown Road outcrop with sample locations labeled.

The Brown Road site is located 0.4 km north of the HW125 site along HW125 (Figure 105). The GPS coordinates for this site are N 46.23728007 latitude and W - 118.3692935 longitude; the elevation is 311.2 m. The site is newly discovered. The BR1 sample was taken in the lower part of the diamict in the Bk horizon, the section is mostly massive and contains a few basalt gravels (Figure 106). BR1 measured $12.4\% \pm 0.3$ percent CaCO_3 , Stage II+ development (Table 27). The flood deposit is probably Middle Pleistocene.

Table 27 Chittick results for Brown Road site.

Sample ID	Average CaCO_3 Percent	Stage of Development
BR1 calcrete paleosol in slackwater deposit	12.4 ± 0.3	Stage II+

4.3.26 The Dalles (The Dalles, Oregon)

Cordero (1997) studied a roadcut on Oregon Highway 197, three kilometers southeast of The Dalles (Figure 107). The GPS coordinates for this site are N 45.57851944 latitude and W -121.1049139 longitude; the elevation is 284 m. The site contains five paleosols, with carbonate formation, scattered gravel of “varied lithologies, including granite” is present throughout the section (Cordero, 1997). Missoula Flood slackwater deposits and loess overlie the older calcrete capped flood deposits at the north end of the section. Cordero (1997) suggests that the carbonate development ranges from Stage II to IV (Table 28). Of the samples I collected, only OR3 contained Stage III calcrete development in the Chittick analysis (Table 28).

Figure 107 Location of The Dalles field site near The Dalles, Oregon.

Cordero (1997) sampled every soil horizon of each of the five paleosols; the given percentages are for the B_K soil horizon in each paleosol (Paleosol 1-5 in Table 28). I collected and measured samples just below each paleosol in every layer (OR1-5 in Table 28). The pumice, located in OR3, has been correlated to the Dibekulewe tuff of Nevada, 600 ka (Cordero, 1997). The deposits overlie volcanoclastic sediments of The Dalles Formation (Cordero, 1997). Paleosols 4 and 5 (layer OR4.5 and 5) could have reversed magnetic polarity and needs to be measured.

Figure 108 The Dalles outcrop with sample locations labeled; samples P1-P5 correlate to Cordero (1997). Yellow line is a reverse fault.

Figure 109 Schematic of The Dalles field site with sample locations labeled (Cordero, 1997).

Table 28 Chittick results for The Dalles site, samples OR1-OR5 were sampled and analyzed by me; Loess-Paleosol 5 were sampled and analyzed by Cordero (1997).

Sample ID	Average CaCO ₃ Percent	Stage of Development
OR1 slackwater deposit	0.9 ± 0.2	Stage I
OR2 slackwater deposit	1.4 ± 0.1	Stage I
OR3 calcrete paleosol in slackwater deposit	17.9 ± 2.0	Stage III
OR4 slackwater deposit	1.2 ± 0.1	Stage I
OR4.5 slackwater deposit	0.3 ± 0.3	Stage I
OR5 slackwater deposit	1.8 ± 0.5	Stage I
Loess	0.2	Stage I
Paleosol 1 (calcrete in slackwater deposit)	27.3	Stage III
Paleosol 2 (calcrete in slackwater deposit)	30.6	Stage III
Paleosol 3 (calcrete in slackwater deposit)	10.9	Stage II
Paleosol 4 (calcrete in slackwater deposit)	23.4	Stage III
Paleosol 5 (calcrete in slackwater deposit)	46.5	Stage III+

Three paleosols lie below Paleosol 2 with the following amounts of calcrete: Paleosol 3 has 10.9% (Stage II), Paleosol 4 has 23.4 (Stage III), and Paleosol 5 has 46.5 (Stage III+) (Cordero, 1997). Paleosol 1 overlies Paleosol 2 and contains 27.3% CaCO₃, Stage III. I interpret two Early Pleistocene and three Early-Middle Pleistocene floods here.

4.4 Subsurface Sites

4.4.1 Cold Creek Bar (Desert Aire, Washington)

Cold Creek bar has been previously studied by Reidel et al. (1998) and Bjornstad (2001, 2006). The giant flood bar is located along SR 24 near Vernita Rest Area and

the intersection of SR 240, north of the Hanford site (Figure 110). The GPS coordinates for this site are N 46.6112 latitude and W -119.7647139 longitude; the elevation is 313.9 m. The bar is located on the Hanford Site and is mostly inaccessible, but the subsurface stratigraphy has been analyzed with hundreds of boreholes. “Because of the expansion of the floodwaters here and their slower speed, they couldn’t carry as much sediment, which resulted in deposition” (Bjornstad, 2006). This depositional area grew to 90 meters in thickness and 19 km long. The lower half of the flood bar sediments have reversed magnetic polarity (Bjornstad, 2006). The site has at least one Early Pleistocene flood deposit.

Figure 110 Location of the Cold Creek Bar field site.

Chapter 5: Discussion

A total of 29 field sites are studied in this thesis. Four of the sites are Missoula Flood gravel pits, studied for a basis of comparison of “Missoula Flood” deposits to “Ancient Cataclysmic” flood deposits. I discovered 11 possible Ancient Cataclysmic Flood field sites. I visited most of the field sites that were analyzed by other workers including: Baker and Nummedal (1978), Patton and Baker (1978), Busacca et al.(1989), Baker et al. (1991), Kiver et al. (1991), Fecht et al. (1999), Bjornstad et al. (2001), Spencer and Jaffee (2002), Bjornstad (2006), Cordero (1997), and Gastineau (2011).

Figure 111 Overview of field sites with geographical zones colored: Columbia River Gorge (blue), Pasco Basin (teal), Walla Walla Valley (green), Othello Channels (fuchsia), Quincy Basin (red), and Cheney-Palouse (yellow).

The sites have been broken up into six geographical areas for further analysis:

Columbia River Gorge (blue), Pasco Basin (teal), Walla Walla Valley (green), Othello Channels (fuchsia), Quincy Basin (red), and Cheney-Palouse (yellow) (Figure 111).

5.1 Columbia River Gorge

Figure 112 The Columbia River Gorge region with field sites labeled.

The Columbia River Gorge region contains the following field sites that are Missoula Flood gravel pits: St. Petersburg Bar, Avery Gravel Pit, Fairbanks Farm, and Arlington (Figure 112). The Missoula Flood sediments were sampled in order to examine the amount of calcrete soil development is present in deposits of known ages. The elevation of the sites range from 80 to 284 meters. The flood gravel samples all contained Stage I calcrete development. Many of the Ancient Cataclysmic

Flood deposits also contain Stage I or II calcrete development because most of the CaCO_3 is leached into the “B” soil horizon. It is taking 15,000 calendar years to develop Stage I calcrete deposits.

The Dalles field site is also in the Columbia River Gorge region. The site has five paleosols and Missoula Flood deposits at the north end. One of the paleosols contains Stage III CaCO_3 development and pumice clasts dated to 600,000 years before present (Cordero, 1997). Three paleosols with calcrete development ranging from Stage II to III+ lie below the dated paleosol. One paleosol with Stage III CaCO_3 overlies the dated paleosol. At least two of the floods are interpreted as Early Pleistocene and three Early-Middle Pleistocene.

5.2 Pasco Basin

Figure 113 The Pasco Basin region with field sites labeled.

The Pasco Basin region was a major erosional and depositional area for the Missoula Floods. Evidence for Ancient Cataclysmic Floods exists at several localities (Figure 113). The field sites (Poplar Heights, Leslie Road, Yakima Bluffs, and Field Road) range in elevation between 118 and 313.9 meters. Evidence of high-energy flood gravels and low energy slackwater rhythmites is preserved at Yakima Bluffs. High energy floods coming through this area eventually jammed the coulee and caused the Yakima River to be diverted north (Bjornstad, 2006). At least 12 Early-Middle Pleistocene floods are recorded in rhythmites with reversed magnetic polarity measured at the base of the sequence at Yakima Bluffs. There are also two Middle Pleistocene gravelly flood deposits that overlie the rhytmite sequence at Yakima Bluffs. Field Road contains one Middle Pleistocene flood deposit with Stage III calcrete development. Just next to Field Road is Kiona Quarry, which has two thick sequences of normal magnetic polarity gravels from Middle Pleistocene (Baker et al., 1991). Leslie Road has evidence for one Early Pleistocene and one Middle/Late Pleistocene flood. The Poplar Heights site has evidence for one Early Pleistocene flood. Cold Creek Bar, in the northern region of Pasco Basin, has reversed magnetic polarity sediments and at least one Early Pleistocene flood deposit. The FMEF site was not sampled, but contains flood deposits that Baker et al. (1991) interpret as one Early Pleistocene and one Middle Pleistocene. South Bombing Range Road, although no longer exists, was documented by Bjornstad et al. (2001) as having one Middle Pleistocene flood.

5.3 Walla Walla Valley

Figure 114 The Walla Walla Valley region with field sites labeled.

The Walla Walla Valley region has several field sites that contain evidence for multiple Ancient Cataclysmic Floods (Figure 114). The sites range in elevation from 117 to 311.2 meters. The Reese Coulee site has evidence for at least eight floods; one is at least Early Pleistocene in age based on reversed magnetic polarity. The other floods range from Early-Middle Pleistocene. Rulo loess outcrop has evidence for at least four Ancient Cataclysmic Floods that are probably Early-Middle Pleistocene in age, based on the presence of tephra dated to >200 ka and Stage II+ and III calcrete development. Winans Road 1, Winans Road 2, Brown Road, and HW125 are all closely located and stratigraphically correlated. They all have evidence of one

Middle Pleistocene flood, and one Early Pleistocene flood is also evidenced at Winans Road 1. Cummings Bridge site has evidence for at least one Middle Pleistocene flood.

5.4 Othello Channels

Figure 115 The Othello Channels region with field sites labeled.

The two new field sites discovered in the Othello Channels region, Othello Canal and Canal Outcrop, are important (Figure 115). The elevations are 301 and 325 meters. Based on the similarity of elevations, proximity, and stratigraphy, these two sites are correlated to one another. These sites contain an extremely well developed calcrete paleosol, Stage III to III+ based on CaCO_3 percentages, but Stage V based on morphology. They have one slackwater flood deposit below the paleosol, interpreted as Early Pleistocene in age and possibly one of the oldest preserved

Ancient Cataclysmic Flood deposits. These slackwater deposits will be tested for magnetic reversals in the winter of 2012-2013. Flood waters may have gotten diverted into these channels, lowered in energy, and deposited finer-grained sediments.

5.5 Quincy Basin

Figure 116 The Quincy Basin region with field sites labeled.

Ancient Cataclysmic Flood deposits in the Quincy Basin region are scarce (Figure 114). Potholes Coulee, Frenchmen Coulee, and Silica Road all contain late stage (Stages 2 and 3) calcrete paleosol development. The elevation ranges from 388 to 413 meters. Potholes Coulee has evidence for one Early Pleistocene and one Early-Middle Pleistocene, based on the late stage soil development. Flood deposits

are not present at Frenchmen Coulee or Silica Road, but they both contain late stage paleosols that could correlate to those present at Potholes Coulee, mainly Middle Pleistocene.

5.6 Cheney-Palouse Scabland

Figure 117 The Cheney-Palouse region with field sites labeled.

The Cheney-Palouse Scabland is one of the most highly eroded regions in the Channeled Scablands (Figure 117). It is the closest area to Glacial Lake Missoula, and floods were probably high velocity when they scoured this area. Evidence of Ancient Cataclysmic Floods in this area should be preserved at higher elevations. Field sites in the northeastern section of the region (Marengo, Benge, Macall, Revere, and E. Callaway Road) are located at elevations between 493.5 and 524.9 meters. The sites

(except Marengo, which contained no evidence) contained paleosols with Stage II, II+, and III calcrete development. Benge has evidence for three Early Pleistocene floods and reversed magnetic polarity, as well as one Middle Pleistocene flood. Evidence for one Early Pleistocene flood and reversed magnetic polarity in sediments at Macall correlates to the deposits at Benge. Revere has one gravelly Early Pleistocene flood deposit and evidence for two more Middle Pleistocene floods; the Early Pleistocene flood correlates to Macall and Benge. The outcrop on East E. Callaway Road contains evidence in the loess for one Middle Pleistocene flood which, based on proximity and elevation, probably correlates to Benge also.

The field sites in the middle and lower sections of the Cheney-Palouse region are much lower in elevation, between 277 and 501 meters. The sites contain Stage II-IV calcrete development in paleosols. Three of the sites have preserved ash layers with Mount St. Helens set "C" tephra, dated to 36 ka calendar years. Evidence suggests one Middle Pleistocene flood deposit that is probably correlated at the sites: Washtucna, Ritzville, Palouse Falls, Connell, and East Connell.

Elevation of field sites in the region decreases from northeast to southwest. The Old Maid Coulee site, at the very southwestern edge of the region is the lowest in elevation, at 81.7 meters. Reversed magnetic polarity has been measured in sediments at the site, and there is one preserved Ancient Flood Deposit (Bjornstad, 2001).

5.7 Age Correlation

The earliest loess strata in the Palouse Formation was deposited in the Early Pleistocene, >1.5 Ma (Bjornstad, 2001). Table 29 lists the field sites according to their evidence for Early, Middle, or Late Pleistocene Missoula Flood deposits. Sixteen field sites show evidence for Early Pleistocene flooding (Figure 118).

Table 29 Field sites with evidence for flooding throughout the Pleistocene. If more than one event is displayed at the site, the number is in parentheses. The highlighted sites have evidence for both Early and Middle Pleistocene floods.

Site	Early Pleistocene	Middle Pleistocene	Late Pleistocene	Deposit Type
Avery Gravel Pit			x	high energy gravels
St. Petersburg Bar			x	high energy gravels
Fairbanks Farm			x	high energy gravels
Arlington			x	high energy gravels
The Dalles	x	x		low energy slackwater deposit
Cummins Bridge		x		high energy gravels
Reese Coulee	x	x		high energy gravels
Rulo Outcrop		x		loess
Winans Road 1	x	x		low energy slackwater deposit
Winans Road 2		x		low energy slackwater deposit
HW125		x		low energy slackwater deposit
Brown Road		x		low energy slackwater deposit
Cold Creek Bar	x	x		high energy gravels
Poplar Heights	x			high energy gravels
Leslie Road	x	x		high energy gravels
South Bombing Range Rd.		x		high energy gravels
Yakima Bluffs	x	x		high energy gravels and low energy rhythmites
Field Rd.		x		high energy gravels
FMEF	x	x		high energy gravels
Canal Outcrop	x			low energy slackwater deposit
Othello Canal	x			low energy slackwater deposit
Potholes Coulee	x	x		high energy gravels and

				low energy slackwater deposits
Frenchmen Coulee		x		low energy slackwater deposit
Silica Road		x		low energy slackwater deposit
Benge	x	x		loess
Macall	x			high energy gravels
Revere	x			high energy gravels
Callaway Rd.		x		loess
Washtucna		x		loess
Ritzville		x		high energy gravels
Palouse		x		high energy gravels
Connell		x		low energy slackwater deposit
East Connell		x		high energy gravels
Old Maid Coulee	x			high energy gravels

Evidence for Early Pleistocene flooding is preserved at lower elevations where the typical stratigraphy is a massive late stage calcrete paleosol overlying a slackwater flood deposit. Some more gravel dominated flood deposits are also preserved at much higher elevations, where subsequent floodwaters could not have scoured all the evidence. The stratigraphy at multiple flood bars is Late Wisconsin deposits over Early Pleistocene deposits with reversed magnetic polarity. These flooding cycles have been slowly contributing to the build up of loess islands and gravel bars for at least 1.5 Myr.

Figure 118 Field sites with evidence for Early Pleistocene flooding are in red and all other sites are yellow.

Bjornstad et al. (2001) suggests, “...on the basis of the number of pre-Wisconsin flood localities that lie at or near the base of flood channels and bars, it is possible that the major flood features were established early in the Pleistocene, and later floods simply routed through the preexistent anastomosis.” Sediment cores from Cold Creek bar show evidence of the slow aggradation of flood deposits starting in the Early Pleistocene on the basis of a thick sequence of reversed polarity over normal polarity deposits.

Ancient Cataclysmic Floods initiated in the Early Pleistocene and continued at unknown intervals until the Late Wisconsin. There are twenty-six field sites with evidence for Middle Pleistocene flooding (Figure 119). Evidence for Early

Pleistocene Floods is also found at eleven of those twenty-six sites. Evidence for Early and Middle Pleistocene floods is found at wide distribution of elevations from 117 to 524.

According to McDonald and Busacca (1988a), at least one secondary cycle (oxygen isotope stage 4) produced cataclysmic floods between 65 and 80 ka. Morrison (1991) estimated that there were as many as 44 major interglacial cycles during the Pleistocene. However, ice-dammed lakes and subsequent flooding were not necessarily associated with each glacial advance, so that perhaps only the largest advances resulted in cataclysmic flooding. Depending on the interpretation of the number of floods associated with each glacial cycle, the total number of individual cataclysmic flood episodes could be in the hundreds.

Figure 119 Field sites with evidence for Middle Pleistocene flooding are in aqua and all other sites are yellow.

The lack of Mount St. Helens tephra and flood cut unconformities provides evidence for flood scouring between major deposition episodes. Due to the erosion, the time between flooding events and the total number of floods is unknown.

5.8 Geographical Distribution of Floods

Evidence for Early Pleistocene floods is present in all six geographical provinces. Most of the evidence is in the Pasco Basin (6 sites), Cheney Palouse Scabland (3), Walla Walla Valley (2), Othello Channels (2), Quincy Basin (1), and Columbia River Gorge (1). Evidence for Middle Pleistocene floods is present in all provinces except for Othello Channels. Most of the evidence is in the Cheney-Palouse Scablands province (10 sites), Walla Walla Valley (7), Pasco Basin (6), Quincy Basin (3), and Columbia River Gorge (1). It is noted that no Early or Middle Pleistocene deposits have been found in the Yakima Valley to the west, which has many Missoula Flood deposits.

Previous workers cite evidence for different origins for some of the Late Wisconsin Floods. Allen et al. (2009) hypothesizes that Moses Coulee and Grand Coulee (both located north of Quincy Basin) formed from the advance of the Okanogan Lobe of the Cordilleran Ice sheet. The Okanogan Lobe was thought to have dammed the Columbia River Channel. "The overflow from Glacial Lake Columbia was forced to the south, forming Moses Coulee. When the ice advanced further, the overflow was then moved into the next drainage to the east forming the Grand Coulee" (Allen et al., 2009). Both coulees were later modified by the Missoula

Floods. Moses Coulee and Grand Coulee could have been formed much earlier in the Pleistocene than even suggested by Allen et al. (2009).

Waitt (1977) cites evidence for cataclysmic flooding coming from the Columbia River in the form of ice-rafted erratics and upvalley-dipping crossbeds in gravels. However, Waitt states that the Okanogan lobe was blocking the Columbia River until the Late Wisconsin. If some of the interglacial retreats were large enough and glacial advances small enough, this could have been a source for floods much earlier in the Pleistocene. Floods could also have originated as outbursts from beneath the Cordilleran ice sheet itself (Shaw et al., 1999).

Figure 120 Graph showing elevations flood deposits of different ages, the triangles represent field sites.

Evidence for Early and Middle Pleistocene floods is present over a wide distribution of elevations from 117 to 524 meters (Figure 120). The deposits are present at various elevations, however; most of the Early Plesitocene deposits are present at either the lowest or highest elevations (in places where subsequent floods could not have eroded them or have only eroded away overlying Middle Pleistocene deposits. Middle Pleistocene deposits are found at all elevations.

Chapter 6: Conclusions

The Missoula Floods were one of the greatest sets of geologic events in Earth's recent history. The Floods occurred during the late-Wisconsin glaciation, 15-18 ka in calendar years (Allen et al., 2009). The Missoula Floods eroded much of the evidence of previous floods. However, many geologists who have studied the Missoula Floods have documented evidence of much older flood deposits at certain localities in the channeled scablands of Eastern Washington and Oregon. These old floods are termed the Ancient Cataclysmic Floods by Allen et al. (2009). The pre-late Wisconsin Ancient Cataclysmic floods occurred during the Illinoian glaciation (oxygen isotope stage 6) and throughout the Pleistocene, approximately the last 2.6 Ma. I visited most of the field sites that were analyzed by other workers including: Baker and Nummedal (1978), Patton and Baker (1978), Busacca et al. (1989), Baker et al. (1991), Kiver et al. (1991), Fecht et al. (1999), Bjornstad et al. (2001), Spencer and Jaffee (2002), Bjornstad (2006), Cordero (1997), and Gastineau (2011). There are a total of 29 field sites studied in this thesis. Four of the sites are modern gravel pits, studied for a basis of comparison of "Missoula Flood" deposits to "Ancient Cataclysmic" flood deposits. Eleven of the sites are newly discovered possible Ancient Cataclysmic Flood sites. Fourteen sites were previously described in literature.

6.1 Calcrete Paleosols

Calcrete paleosols are a major criteria used for the relative age dating of Ancient Cataclysmic Floods. There is a direct correlation with the amount of soil

development in an overlying paleosol and the age of the flood deposit below. According to a personal communication with Busacca (1997) cited in Cordero's thesis (1997) carbonate development Stage II to IV takes between 20,000 to 100,000 years to form; therefore, paleosols with $\geq$ Stage II development are older than the Missoula Floods. A total of 19 sites have calcrete paleosols, many with multiple paleosols, which were analyzed to determine the stage of CaCO_3 development Table 31). Eight sites have paleosols with Stage II development (3.0-11.9% CaCO_3): Rulo Outcrop, Potholes Coulee, Leslie Road, Benge, E. Callaway Road, Collier Coulee, Plaouse, and Connell. Five sites have paleosols with Stage II+ development (12.0-16.9% CaCO_3): Brown Road, Leslie Road, Benge, Reese Coulee, and Connell. Fourteen sites have paleosols with Stage III development (17.0-34.9% CaCO_3): The Dalles, Rulo Outcrop, Winans Road 1, Poplar Heights, Yakima Bluffs, Canal Outcrop, Othello Canal, Reese Coulee, Potholes Coulee, E. Callaway Road, Frenchmen Coulee, Macall, Ritzville, and East Connell. One site has a paleosol with Stage III+ development (35.0-49.9% CaCO_3): Othello Canal. Based on morphology, Othello Canal might be classified as Stage V calcrete development, I interpret Othello Canal and Canal Outcrop to be two of the oldest preserved flood deposits.

6.2 Early Pleistocene deposits

Ancient Cataclysmic Flooding initiated in the Early Pleistocene at least as early as 1.5 Ma and continued at unknown intervals until the Late Wisconsin. Sixteen field sites show evidence for Early Pleistocene flooding. Evidence for Early Pleistocene floods is present in all six geographical provinces. Most of the evidence

is in the Pasco Basin (6 sites), Cheney Palouse Scabland (3), Walla Walla Valley (2), Othello Channels (2), Quincy Basin (1), and Columbia River Gorge (1). The main basis of distinction for Early Pleistocene versus Middle Pleistocene is reversed magnetic polarity, measured in slackwater deposits and loess. However, some sites that have not been tested for reversed magnetic polarity are still classified as Early Pleistocene, such as Othello Canal, Canal Outcrop, and the lower Dalles paleosols. They will be tested for paleomagnetic reversals in the winter of 2012-2013. The sites were classified on the basis of very thick and massive calcrete paleosols with Stage III and III+ soil development. Most of the Early Pleistocene deposits are at very low elevations, below 150 m. The typical stratigraphy is a massive late stage calcrete paleosol overlying a slackwater flood deposit. Gravel dominated flood deposits are preserved at much higher elevations, where subsequent floodwaters could not have scoured all the evidence. No Early Pleistocene deposits were found in the Yakima Valley.

6.3 Middle Pleistocene deposits

There are twenty-six field sites with evidence for Middle Pleistocene flooding (Figure 119). Eleven of those twenty-six sites also show evidence for Early Pleistocene Floods. Evidence for Middle Pleistocene floods is present in all provinces except for Othello Channels and the Yakima Valley. Most of the evidence is in the Cheney-Palouse Scablands province (10 sites), Walla Walla Valley (7), Pasco Basin (6), Quincy Basin (3), and Columbia River Gorge (1).

Sites that have been tested in this grouping exhibit normal magnetic polarity. There are fewer preserved Middle Pleistocene deposits in the lowest elevation regions of Pasco Basin and Othello Channels because only the Early Pleistocene flood deposits have remained in those valleys. The Middle Pleistocene deposits are not present in the lower elevations; due to subsequent erosion, only the earliest flood deposits have remained in those valleys.

6.4 Calcrete formation in Missoula Flood gravel deposits in quarries

The Missoula Flood deposits were sampled at a few quarries and gravel pits in the Columbia River Gorge region. Multiple samples were collected at varying elevations at each quarry. The samples from Avery Gravel Pit ranged from 0.5-1.9% CaCO_3 , or Stage I carbonate development. St. Petersburg bar samples contained 1.7-1.8% carbonate, Stage I. Fairbanks Farm samples contained 0.8-1.7% CaCO_3 , Stage I. The sample from Arlington, which is highest in elevation and the furthest east of the modern sites, contained 2.0% CaCO_3 , Stage I development. Therefore, we do have calcrete formation in Missoula Flood deposits, contain a maximum of 2.0% CaCO_3 and only Stage I development. Much more time is necessary to develop Stage II-IV.

6.5 Big Picture of Calcrete Formation

The Ancient Cataclysmic flood deposits at all the other field sites range from Stage I-III of CaCO_3 development. Some of the field sites determined to be the earliest in age with the most overlying soil development (Stage III+), such as Othello Canal and Canal Outcrop, have accompanying flood deposits with the least amounts

of CaCO_3 . Othello Canal and Canal Outcrop flood deposits contain 0.6-0.8% CaCO_3 , Stage I development. At most sites with a prominent CaCO_3 paleosol present, the underlying flood deposit is extremely leached of CaCO_3 , which is collected in the “B” soil horizon.

In the opposing case, where an Ancient Flood deposit remains but the overlying paleosol has either been removed by man or eroded, the stage of CaCO_3 development in the flood deposit is much higher. Such is the case at Field Road Site, Old Maid Coulee, and Winans Road 1, where the once existing overlying paleosols have been removed at some point. The flood deposit at Field Road contains 16.5% CaCO_3 , Stage III development and the diamict at Winans Road 1 contains 13.7% CaCO_3 , Stage III development. The flood deposit at Old Maid Coulee is thought to have been more recently exposed based on recent literature (Bjornstad 2001, 2006) mentioning the presence of a paleosol. The flood deposit contains only 4.25% CaCO_3 today.

Flooding occurred throughout the Pleistocene which is broken up into three age ranges: Early Pleistocene from 2.58 Ma – 781 ka, Middle Pleistocene from 126-781 ka, and Late Pleistocene from 126 ka to 11,700 (Morrison, 1991). However, all pre-Missoula Flood (15 – 18 ka) deposits were termed “Middle Pleistocene” in this thesis to differentiate them from the Late Pleistocene Missoula Flood deposits. Early to Middle Pleistocene deposits ranged from Stage II to III+ soil development. Late Pleistocene Missoula Flood deposits contained only Stage I CaCO_3 . Stage I development of CaCO_3 in paleosols takes 15,000 years to form; therefore, paleosols with $\geq$ Stage II development are older than the Missoula Floods.

6.6 Particle size grading curve for a loess vs. flood deposit

Many paleosols are formed in fine-grained deposits where little to no gravels, which could be slackwater flood deposits or windblown loess. Slackwater flood deposits should have more quartz sand and less overall silt. Particle size analysis was conducted on two samples using the pipette method (Gee and Bauder, 1986). The slackwater deposit tested for grain size is from Othello Canal (OC1), which lies below a Stage V calcrete paleosol. The loess deposit tested is from the most famous loess site, Washtucna (WCC1). The slackwater deposit contains much more quartz sand (26.1%) than the loess deposit (13.3%). The WCC1 loess deposit also contains 15.4% more silt than OC1 slackwater deposit.

Table 30 Particle size results of a slackwater deposit (OC1) and a loess deposit (WCC1).

	OC1 slackwater	WCC1 loess
sand	29.1%	13.3%
silt	67.5%	82.8%
clay	3.5%	3.9%

Table 31 Summary of elevation and calcrete development for each field site.

Site	Elevation (m)	Flood deposit	Loess	Calcrete paleosol	Interpretation
<i>Columbia River Gorge</i>					
Avery Gravel Pit	80.0	Eight Stage I			Missoula Flood deposits
St. Petersburg Bar	120.7	Three Stage I			Missoula Flood deposits
Fairbanks Farm	158.5	Two Stage I			Missoula Flood deposits
Arlington	164.0	One Stage I			
The Dalles	284.0			One Stage II, Three Stage III, One Stage III+	Two Early Pleistocene, three Early-Middle Pleistocene
<i>Walla Walla Valley</i>					
Cummins Bridge	117.0				one Middle Pleistocene
Reese Coulee	193.0	One Stage I		One Stage II+, One Stage III	at least eight separate calcrete paleosols (each overlies flood deposit), at least one Early Pleistocene and many more Early- Middle Pleistocene
Rulo Outcrop	299.9		One Stage I, Three Stage II+	One Stage III, One Stage II	multiple middle Pleistocene
Winans Road 1	286.2	Two Stage III		One Stage III	one Early Pleistocene and one Middle Pleistocene
Winans Road 2	291.1				one Middle Pleistocene
HW125	302.7				one Middle Pleistocene

Brown Road	311.2			One Stage II+	one Middle Pleistocene
<i>Pasco Basin</i>					
Cold Creek Bar	313.9				at least one Early Pleistocene, more Early-middle Pleistocene
Poplar Heights	146.0	One Stage I		One Stage III	one Early Pleistocene
Leslie Road	118.0	Two Stage I		One Stage II, One Stage II+	one Early Pleistocene, one Middle/Late Pleistocene
South Bombing Range Rd.	174.7				one Middle Pleistocene
Yakima Bluffs	148.7	One Stage I, One Stage II	Two Stage I	Three Stage III	12 Early-Middle Pleistocene rhythmites, and two Middle Pleistocene gravelly flood deposits
Field Rd.	165.2	One Stage III			one Middle Pleistocene gravelly flood deposit
FMEF	158.5				one Middle Pleistocene
<i>Othello Channels</i>					
Canal Outcrop	301.0	One Stage I		One Stage III	one Early Pleistocene (correlates to Othello)
Othello Canal	329.0	One Stage I		One Stage III, One Stage III+	one Early Pleistocene slackwater below
<i>Quincy Basin</i>					
Potholes Coulee	388.0	One Stage I, One Stage II		One Stage II, One Stage III	one Early Pleistocene and one Early-Middle Pleistocene

Frenchmen Coulee	413.0		One Stage III	no flood deposit, weathered bedrock below paleosol
Silica Road	402.0			one Middle Pleistocene
<i>Cheney-Palouse Scabland</i>				
Marengo	493.5			no deposit
Revere	507.2			one Early Pleistocene, one Middle Pleistocene
Benge	506.6		One Stage I	Two Stage II, Two Stage II+ three Early Pleistocene, one Middle Pleistocene
Macall	507.2			One Stage III one Early Pleistocene
Revere	507.2			
E. Callaway Rd.	524.9		One Stage II+	One Stage II, One Stage III one Middle Pleistocene
Washtucna	501.0		Two Stage II	one Middle Pleistocene
Ritzville	341.0	Two Stage II		One Stage III one Middle Pleistocene
Palouse	394.0	One Stage I		One Stage II one Middle Pleistocene
Connell	349.0			One Stage II, One Stage III one Middle Pleistocene
East Connell	384.0			Two Stage III one Middle Pleistocene
Old Maid Coulee	277.0	One Stage II		one Early Pleistocene

Chapter 7: Future Work

Although many scientists have studied the Missoula Floods extensively, it has only been in the last century that they have been known about. Most workers of the Missoula Floods have mentioned much older flood deposits. I have only begun to put together the story of the Ancient Cataclysmic Floods. More flood deposits, referenced by Kiver (1991), exist in the Northern part of the Scablands in the Spokane area. These deposits need to be studied, added to the database of existing flood deposits, and correlated to as many other deposits as possible. Once all known Ancient Flood deposits are accounted for, further investigations constraining the ages and origins of these flood deposits can be made. Additionally, more new sites need to be searched for along the Columbia Gorge and Willamette Valley as well as the Channeled Scablands and the Yakima Valley.

The use of soil development as an age indicator has proved useful. The percentage of CaCO_3 in sample replicates, determined using the Chittick method, shows extremely low amounts of error. However, the accuracy of determining the age based on this percentage is unknown. A study in another arid environment using calcrete paleosols of known ages should be conducted. U-series dating of all of the calcretes would also be useful to test the stage of development to age correlation.

Only a few sites have been tested for reversed magnetic polarity. The remaining Early Pleistocene and some of the early-Middle Pleistocene deposits need tested; especially the Othello Canal, Canal Outcrop, and The Dalles sites.

Also, only a few sites have been run for particle size analysis, some by me and some by others. The remaining sites with slackwater deposits should be tested to differentiate them from loess, especially the Yakima Bluffs rhythmites. Specifically, the following slackwater deposit and rhythmite samples should all be tested for particle size: PC4, YB5, YB6, YB7, WR11, WR13, C03, C03.5, HW2603, R01.

The Ice Age Floods National Geologic Trail was first established in 2011 (Ice Age Flood Institute, 2011). The trail is culturally important in the Northwest and brings together evidence of the Missoula Floods. The trail should be updated in order to include the history of the Ancient Cataclysmic Floods. The trail spans four states and is a great way to educate the public about the Missoula and Ancient Cataclysmic Floods.

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Appendices

Appendix A: CaCO₃ analysis, Chittick methods

The Chittick Apparatus was first implemented by Dreimanis (1962) then modified by Machette in 1986. The method based on the volumetric evolution of carbon dioxide when carbonates react with dilute hydrochloric acid. First, samples were dried and the gravel was removed with a number 10 sieve. If the material collected on the sieve contained aggregates, the sample was disaggregated in a mortar and pestle. The remaining fine-grained material was split into small amounts to be analyzed in the Chittick, five splits of each sample were analyzed. The amount of sample was dependent on the amount of carbonate contained in the sample. For non-carbonate samples, more sediment was needed, between 1 and 2 grams. Samples containing more CaCO₃ were digested by the acid much more readily so less sample was needed, between 0.75 and 1 grams (Dreimanis, 1962). An individual sample was placed into a flat-bottomed flask and connected to the Chittick apparatus, where 10ml of 6N hydrochloric acid was added, in order to digest the carbonate. Each sample is stirred with a magnetic stir-bar under a closed system for five minutes to allow for digestion of the entire sample and equilibrium of the displacement solution to be reached. The digestion process produces CO₂ gas, which displaces the solution in the Chittick. Under observed atmospheric and barometric conditions, the volume of CO₂ is converted to percent of CaCO₃ with use of the formula:

Equation 1

$$\%CaCO_3 = \frac{\left[(CO_2 \text{ volume (ml)}) \cdot \left(\frac{\text{Pressure (ml)}}{\text{Temperature (K)}} \right) \cdot (0.16) \right]}{\text{Sample Weight (g)}}$$

The use of different sample sizes based on CaCO₃ content increases the accuracy of the results. According to Dreimanis (1962), “the probable error of the results, which is expressed as percentages of carbonates from the total sample analyzed, does not exceed ± 0.3 in carefully done analyses.”

Appendix B: Grain size analysis, pipette methods

The following method is based on the methods of Gee and Bauder (1986) but it is significantly modified. About 100 grams of sample was weighed out. If gravel was present, it was removed with a 2.0 mm opening sieve and weighed. The rest of the sample is placed in a 600ml beaker and 50ml of the dispersant Sodium Hexametaphosphate (50g/l). Enough water to make a slurry was also added to the beaker. The sample was stirred in order to break up all aggregates/peds (especially if a lot of clay is present).

The slurry was then poured onto a pre-wetted #230 sieve. The sieve was placed in a large funnel inside of a large steel container to catch the sediment and water. More water was added to the sieve and aggregates were gently broken up on top of the sieve until no more sediment passes the sieve (the water runs clear). If possible, no more than 1000ml of water should be used. Add the “dirty” water (water plus sediment) to a hydrometer column. (If additional water was used, the extra water and sediment that does not fit into the 1000ml hydrometer column must be dried in an oven so the sample can be added before analysis.)

The sediment left on top of the #230 sieve was placed in an oven. When it was completely dried, the sample was dry-seived with a #230 sieve. The passing material was added to the hydrometer column and the remaining sediment was weighed.

The hydrometer column was filled to exactly 1000ml of water if not already at that level. The column was then stirred with a wooden stirring rod for five minutes or until all the sediment was in suspension. A stopwatch timer was started immediately.

Samples were collected in six labeled beakers using a 20ml pipette. Sample depth and time varies for a given temperature, the temperature of the lab room I used was 21 degrees Celcius and the corresponding depths and times are shown in the table below. The results were analyzed for the amount of sand, silt, and clay in each sample.

Withdrawal depths and times used for a 21 degree Celcius room.

Withdrawal Depth (cm)	Grain Size Equivalent (mm)	Time
20	0.063	0:00:20
10	0.031	0:01:51
10	0.016	0:07:25
10	0.008	0:29:41
5	0.004	0:59:23
5	0.002	3:58:00

Appendix C: Field Notes

Wiens, Donald

8/3/10

Poplar Heights Stop 2 (The Diller #1)

GPS standing // to paleosol

P: alt. 146m
ITE 0338007
N 5114941

T: alt. 140m
ITE 0338005
N 5114938

Waypoint 2 (Waypoint 1 = Tracy's house)
is at outcrop paleosol layer

Waypoint 3 Road at PH outcrop
ITE 0338003
N 5114962

2 45th Avenue to 3 Oak St.

8/3/10 2:50 PM

Old Maid Couler

EPS

11T E 0350358

N 5159016

268 m elev.

Loess OM1

OM2

Caliche
cemented
Floor
deposited with
highly
weathered
basaltic scoria

8/5/10

Old Maid revisited with Scott

105°F!!

Waypoint 12

on SPI-7 by Ochello, near outcrop? Looks like Caliche but
could be ~~distomaceous~~

8/4/10

Potholes Creek

Waypoint 5

Elev. 386.8m

ITE 0280076

N 5227034

8/4/10 Franchman Coulee FC

Waypoint 6

elev. 410.2

11T E0274333

N 5214201

138°
8m
Slope

Waypoint 7 → a little further N on Silica Road
caliche overlying highly weathered Basalt Bedrock
elev. 396.5m

11T E 0273897

N 5214635

Waypoint 8 → Trespassing off Silica Road

Looking at ridge top
caliche layer w/ weathered Basalt below
elev. 401.1m

11T E 0273941

N 5215102

Waypoint 9 → N. of Trespassing place on Silica Rd

elev. 418.2m

11T E 0273499

N 5215446

W

W

N 8/6/10
Roose Coulted
elev. 179.6m
11T 0363906
5103008

looking for granite boulders
covered in caliche
at least 8 old floodplain

weathered
Basalt

caliche
around
the big
Basalt
Boulder

RC2
RC1 Flood Dep.
RC3
" → lower, below RC1

Dark brown deposit
looks like deposit
from Otterello

Silt dikes → injecting layers
→ fine grained material
more to the top

8/10 Canal Outcrop HW 24, located 10 mi East of mile 68
 on HW 24 on our way to Verrito
 Waypoint 10
 elev. 297.4 m
 E 0324028
 N 5178633

8/6/10 Oshelle Canal
 B Outcrop off of HW 17 #26
 Waypoint 12
 elev. 327.4 m
 IT 0337342
 5186397

Waypoint 12
 Oshelle Canal

plates
 40cm massive
 12cm platy - 18cm
 2m

OC1
 blackwater?
 well?

caliche
 10% small pebbles
 Magic Fingers
 not sticky, sandy
 brown, some black
 gravel pieces (Basalt)

Old
 Flood Deposit

if its 2000 680ish
 if it has more sand
 then we can say its
 blackwater & this is an
 old flood deposit

At a higher elevation, blackwater
 deposit

8/10/10
Connell Side

East Connell Road Cut slightly 0.2 mi West of
Bellevue Rd.

Waypoint 15
IT 0372978
5164482

8/10/2010 Wasktuna, Collier County

Waypoint 16

11T 0394470

5181904

elev 449.7

We don't see all the fossils discussed by Busacca & Bjornstad it all looks like the same loess. We collected what looks like ash on the opposite side of the road. Baffling!

8/10/2010

On the way to Palouse Falls SP

Ron Munamakers 2700 S260

Waypoint 17

elev. 452 m

11T E 0394613

N 5170269

0.4 — PF1 rounded basalt to pumice
0.8 — PF2 cobbles in Stage 1 caliche
gravelly all gravel

8/11/10 HW260

On HW260 on the way to Ridgville

Waypoint 18

elev. 49.3m

IT E 0401680

N 5180450

HW2601 sand with pebbles

0.2m

caliche with basalt
pebbles

HW2602

0.6m

HW2603 sand with
basalt pebbles

Also, outcrop here a little beyond the road, past a fence, lots of
caliche pebbles outcropping

Further North along HW260

Waypoint 19

elev. 50.3

IT 0386083

S187068

19M 182h

971 673 0447

8/11/10 E Callaway Road
Grand Ridge
grand road near bridge?

Waypoint 21
elev. 524.5
UTM 0417901
5204250

scarp face 0.4m
601 / 0.25m
602
603
massive
less
electro
caliche layer
not continuous
layers of
Potential
Paleosols
beds

7/24/11 Leslie Road 200 yards S of HWY 12
 LR Outcrop Waypt 1
 11T 0325773 387ft
 5123165
 200 yards from HWY 12
 Columbia
 Park Trail
 (off Leslie Rd)

lat 46.2396990660739
 long -119.211088
 .25989140222

1/24/11
 Park / School
 Church
 WP 3
 11 T @ 0319240 }
 5127196 }
 557 ft
 Trying to find
 South Bombing site
 Along road picked
 up some Stone
 Calcrete clasts

WP4
 "Park" No Swimming
 0319478
 5126684 573'

Ref

7/28/11

Yakima Bluffs

YB

WP 5

11T 0321732
5126130

Alt. 488 ft

Page 2

7/25/11

Rhyolite, North end of Truman Road until
it dead ends then turn
Rt. onto Pvt. Property
12 ft. Moll

all rhyolite fizz
So rhyolite probably from one flood event
travel from north location

Exit 96 off E2 (headed N)
Babylon Rd

7/28/11

A+B Asphalt - "Korea Quarry"
on Field Rd

AJ crushing + concrete

486'

WP 7

0310042
5124071

Road cut on Field Rd not to quarry!

WP 8

0309788
5124242

Field L1 Site
FRS

542'

caliche
gravels
Stage II

7/28/11 Ardington - Modern gravel stop

Mile Post 1 on HW 19

538'

WR 9

10x 0718543

5065923

Sample HW 19

8/22/11
 Cummins Bridge
 11.1 0325702
 5123105
 WP 1
 476ft

100ft {
 Missed
 Rhyolite (m.c.)
 2d Granite } 5ft
 old Rhyolite } 2ft
 more 2d } 5ft +
 granite or
 Basalt

8/23/11

Pine Creek 2:51 PM

Along State Line Road

Overshown veg. & sediments sloughed in

WP 2

0325768

5123178

496 ft.

No samples or GPS, only

8/23/11

5:13 PM

8.7

WR1

Located 1.5 mi N of Conely Rd on Harvey Shaw +.

Basaltic, granitic, melatrophic
class
WR13 ← Diarnid (looking for
spotted-clasts) Cochran Rd
new name for Rd

WR12 Coes
WR11 Rhyolite OK in Rhyolite
Basalt

Spencer calling these silt-clay instead of sand-silt
like the young

WP4 0389401
5113564

939 ft

8/23/11

Rulo Outcrop

WP 3 0319241
5127196

984 ft.

~~Outcrop~~ located

5.3 mi N of
Lonely Rd to Sudbury Rd
on Sudbury

Cichada benroa in the Be,
Belsen the K- to
in unit one is, to
very fine-grained sand
with ~~lots~~ of Mica,
Mica throughout K and Be
too

8/23/11

WR2

5:44 PM

Located 3.0 mi from WR1 outcrop along Cochran Rd.
Cochran

0.4 Miles west of HW125

WP5 0392636
5115929

955 ft.

HW125 → site correlates to WR2,
↳ mile 19 on HW125 same stratigraphy

WP6 0394152
5121014

993 ft

0.2 miles S of Brown Road

Brown Road

WP7 0394427
5121323

1021 ft

BR1 Samp
Bk (lower part of Diamict)

↳ if any clasts than same as
above 2 sites
in entire size range.

8/24/11 Berge

2.5
6.2

Located 3.7 mi from Berge along Berge-Ralston Rd.

WP 8 04/30/06
5198291

1662 ft.

2 older flood deposits overlain by series of loess dep.
↓
fluvial w/rel. mag.

colored

Red B loess

B loess B4

terrace

B3

terrace

B2

B1

B loess

loess

loess B5

8/24/11

12:07 PM

Rever

intersection of Lakin Rd + Rever Rd.
or
Boring
3585 E Boring Mailbox

WP 9 0428683
5215785
1664 ft.

caliche AB

Coess

caliche R12

gravel R11
caliche
covering
bottoms of slots

8/24/11
Macell

53.7
09.9

From Bangs 10.2 miles to intersection along Berger Rd. 2.8 ^{East} more miles to outcrop Harder Rd.

6.7 gravel

71.1

Harder Highway

4.3 miles from Macell along Macell / Bangs into Harder Rd.

WP9

16644#

0413615

5198284

M2

K

calcrete

BK

old
M1

Gravels !, look for textures

(can't really tell if it's from a flood b/c
we couldn't really find spores - but
we do know it's fluvial and old)