WILLAMETTE GEOLOGICAL SERVICE

Dr. J. Reed Glasmann
31191 Peterson Rd.
Philomath, OR 97370
(541) 929-3607 PH/FAX

PETROLEUM EXPLORATION CONSULTING CLAY MINERALOGY SEDIMENTARY PETROLOGY

Stream Turbidity and Suspended Sediment Mineralogy During the 1998/1999 and 1999/2000 Winter Rainy Seasons, Marys River Watershed.

An OWEB Funded Project Report.

Dr. J. Reed Glasmann
Willamette Geological Service

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Marys River Watershed Suspended Sediment Characterization Project

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PROJECT BACKGROUND AND INTRODUCTION

Stream turbidity during periodic high winter runoff in the Marys River Watershed commonly exceeds the established limits listed in the Oregon Administrative Rules 340.41 (i.e., >10% above background). Turbidity, which is a measure of the light scattering properties of water, is a commonly used parameter to evaluate suspended particle concentration in streams. Suspended particles in stream runoff may originate from a variety of sources including stream bank erosion, urban/agricultural runoff, road-related sediment, and a host of other natural and management-related causes. Understanding the source of high turbidity is an essential first step in designing programs to improve water quality. Turbidity monitoring on a subwatershed basis during winter storm events is one means of identifying sediment-sensitive areas of the watershed. In addition, the nature of the suspended sediment in the Marys River Watershed may provide clues to the origin of the sediment or point to specific landscapes with high sensitivity to erosion.

This project seeks to measure storm-related stream turbidity and identify the mineralogical nature of suspended sediment within sub-watersheds of the Marys River drainage. This information will be used to establish which, if any, sub-watersheds are most prominent in the sediment budget of the watershed. It is hoped that the combination of both turbidity and mineralogy data will help identify the geologic sources of fine sediment entering the river system during high discharge episodes and potentially assist in developing plans to improve water quality within the Marys River watershed.

The Marys River Watershed encompasses a geomorphically complex region that includes mountainous areas of the eastern Oregon Coast Range and extensive flats of the floor of the Willamette Valley (Balster & Parsons, 1968). Landuse patterns are also closely linked to watershed landscapes, with extensive agricultural activity concentrated on valley floor and valley-margin foothills. Steeper mountain slopes are commonly used for timber production or recreation. These different watershed regions have developed in different geologic parent materials, ranging from ancient sea floor basalts and marine sediments to more recent lake and river channel sediments (Figure 1). The soils of the watershed developed in response to differences in landscape age, parent material, topography, climate, and vegetation. On the subwatershed level, these basin-defining geologic/landuse characteristics may strongly influence the nature of sediments that are eroded and ultimately delivered to the Marys River. Soil mineralogy, which evolves in response to soil formation factors, may offer a means of fingerprinting the sediment eroded from different landscapes in the watershed.

The sediment in streams includes material of a wide range in grain size, from coarse sand and gravel to fine clay. Coarse sediment tends to roll along the bottom of stream channels (bed load) and generally does not contribute to stream turbidity; however, clay-size particles are concentrated in the suspended portion of stream sediment and are a dominant component of

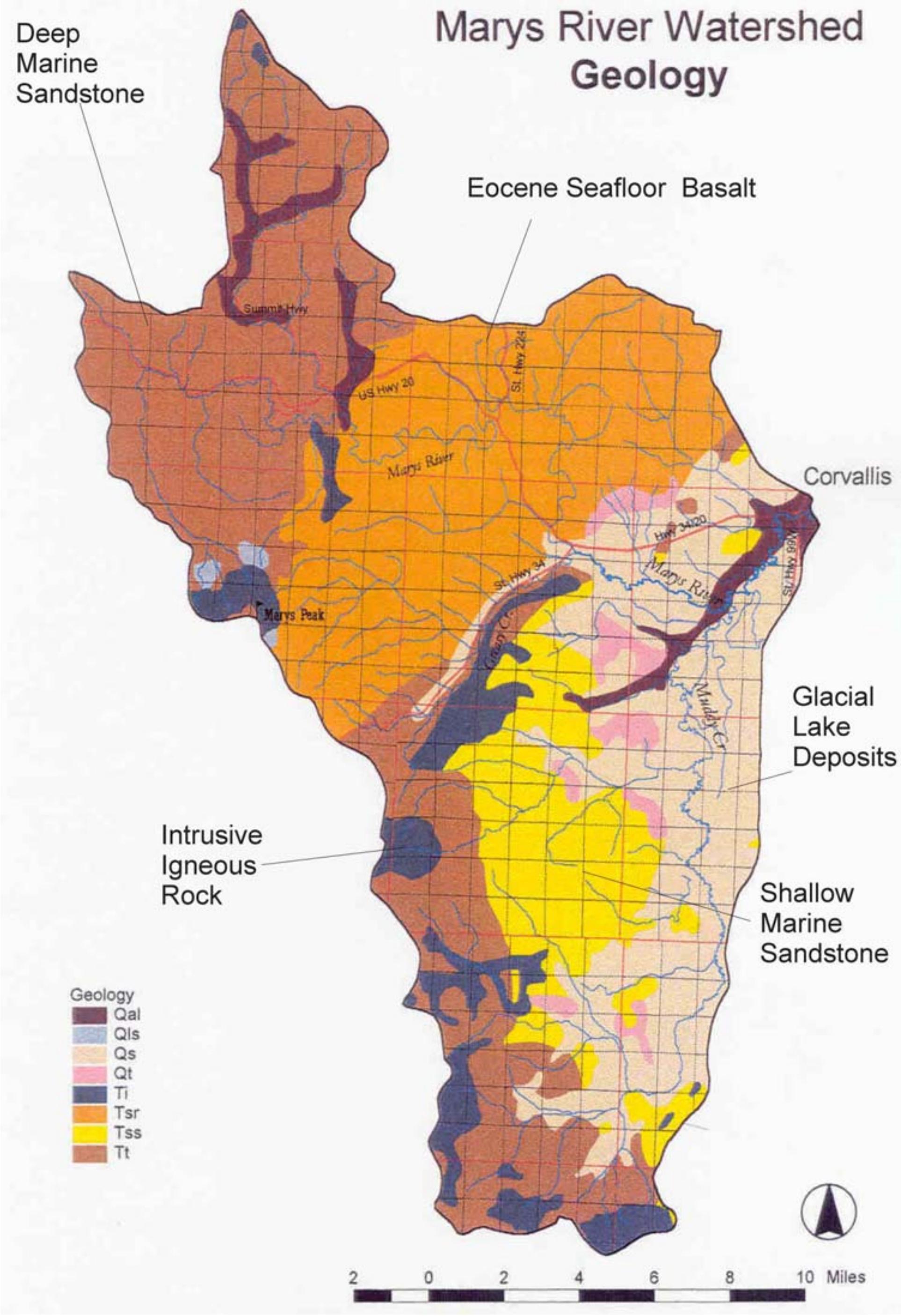

Figure 1. Generalized geology of the Marys River Watershed (from Marys River Watershed Assessment, 1999).

stream turbidity. Other components of degraded water quality (e.g., pesticides, heavy metals, and fertilizer) are often adsorbed on clay surfaces and may find their way into streams during erosional events.

Clay particles are generally developed during the chemical breakdown of other mineral grains such as feldspar or mica. Though extremely small (<0.002 mm) and invisible to the naked eye, clay particles have unique mineralogical properties that often provide important genetic or environmental information. The mineralogy of clay particles may be inherited from the underlying bedrock or reflect the weathering history of soils on a landscape. Thus, clay minerals are closely linked to watershed geomorphology and soil development. In many western Oregon soils, soil clay mineralogy shows important depth-related variation that may be used to distinguish the origin of a particular sample in the weathering zone. These geomorphologicly related mineralogical differences make possible the identification of sediment contributing landscape elements through comparative analysis of suspended sediment and soil mineralogy. If, for example, surficial gully erosion of an agricultural field was the dominant mechanism contributing to stream turbidity, the mineralogy of suspended fines in the stream should compare closely with that of the shallow eroded soil surface (A horizon). A low-relief sub-watershed developed within old weathered sediments would be expected to contribute suspended sediments of different character than a sub-watershed dominated by steep slopes and erosion of freshly exposed bedrock. Thus, mineralogical analysis of suspended sediments within the Marys River watershed may provide insights into the dynamics of sediment production and transport and help characterize the erosion sensitivity of different watershed elements.

The technique of mineralogical “fingerprinting” of landscape elements has been used with some success in watershed studies in the Western Cascades (Ambers, 1998; Bates, et al., 1998; Glasmann, 1998; Pearch, 2000) as well as other river systems (Klages & Hsieh, 1975; Walling & Woodward, 1995; Collins, et al., 1998). The major flooding that resulted from the February 1996, storm in the Willamette Valley resulted in long-term turbidity in the North Santiam River and seriously affected drinking water quality for the city of Salem. Clay mineral analysis of suspended sediment at the city water intake, at Detroit Reservoir, and in various soils and sediments helped identify the nature of persistent turbidity and erosion-sensitive landscape elements within the North Santiam River watershed (Bates, et al., 1998). With such data in hand, watershed management plans can be intelligently formulated to minimize sediment production and better regulate water quality. With increasing governmental focus on water quality and watershed management, it is imperative that basic geomorphic and sedimentologic information be acquired to determine the geologic “pulse” of the watershed. What areas of a watershed are prone to sediment production? What storm intensity is required to cause significant sediment production? What is the nature of the suspended sediment in the watershed? If sensitive watershed elements can be identified, what can be done to better manage these areas and improve water quality? This project will provide primary background mineralogical data on the soils and suspended sediments of many sub-basins within the Marys River Watershed that will assist in answering many of these questions.

Proposal

I propose to conduct a preliminary investigation of suspended sediments within the Marys River watershed with the goal of identifying fine sediment character on the sub-basin level based on mineralogical analysis of the suspended fraction. These data, combined with peak flow stream turbidity measurement, will be used to identify sediment-prone sub-basins and infer the dominant process of sediment delivery within these basins. The watershed data will be gathered over several winter storm cycles to include a range of runoff events. I will measure stream turbidity within different segments of several sub-basins during periods of peak flow and during intervening periods of low flow to identify trends in sediment production within different watershed elements. I will also determine the mineralogy of the fine suspended sediment (<15-2- and <2-μm size range) and compare this to the clay mineralogy of soils within related sub-basins. These data will be used to help determine which parts of the Marys River watershed are most sensitive to sediment production and reduced water quality (sediment-related, exclusive of other water quality parameters such as temperature, dissolved oxygen, bacteria, etc.). This proposal does not include quantitative evaluation of sediment yield, as the equipment for such an analysis necessitates permanent stream monitoring installations (e.g., the Marys River gauging station at Bellfountain Road operated by the Army Corp. of Engineers); however, the reconnaissance information provided by this study may point to sensitive watershed elements that should receive more careful attention in the future.

Project Volunteers

Many people assisted in the successful completion of this project (Table 1). Several volunteers assisted with field measurement of stream turbidity and collection of water samples for mineralogical analysis. Additional help was obtained to concentrate the suspended sediment and separate the various particle size fractions used for mineralogical analysis. Subsequent X-ray diffraction analysis of the clay minerals was carried out using non-volunteer staff that was qualified to operate radiation-generating instrumentation.

Table 1. List of Volunteers and Other Participants, Marys River Turbidity/Suspended Sediment Monitoring Project.

Person	Activity	Status	Time Involved
J. Reed Glasmann	Turbidity measurement, water collection, sample preparation, XRD analysis	Volunteer/Project Coordinator/Staff	320 hours
Kathy Verble	Sample preparation, XRD analysis	Staff	120 hours
John Pearch	XRD analysis	Staff/Volunteer	10 hours
Jessica Glasmann	Sample preparation	Volunteer	24 hours
Jacklyn Glasmann	Water collection, sample preparation	Volunteer	32 hours
Josh Glasmann	Water collection	Volunteer	8 hours
Margaret Glasmann	Sample preparation	Volunteer	32 hours

MATERIALS AND METHODS

The Marys River watershed includes 24 major sub-watersheds that reflect various tributaries or major segments of the river (Figure 2). Turbidity monitoring sites were established at 30 locations within the watershed (Table 2). Sampling each of these locations during episodes of

Figure 2. Subwatersheds of the Marys River Watershed (from Marys River Watershed Assessment, 1999).

Table 2. List of Turbidity Monitoring Sites and Storm Events Sampled, Marys River Turbidity Assessment Project.

Sample Information		Storm Events Sampled									
Site	**Location**	**11/25/98**	**12/2/98**	**12/28/98**	**1/5/99***	**1/18/99**	**2/25/99**	**2/27/99**	**11/26/99**	**12/16/99**	**1/13/00**
1	Marys R. @ Avery Park		x	x	x				x	x	
2	Marys R. @ Borden Rd.		x						x	x	
3	Marys R. @ Fern Rd.	x					x		x	x	x
4	Marys R. @ HWY 34			x	x	x		x			x
5	Marys R. @ Wren		x	x	x				x		
6	Marys R. @ Summit		x								
7	Evergreen Cr @ Fern Rd.	x								x	
8	Bull Run Cr @ Peterson Rd.			x							x
9	Beaver Cr @ Saxton Rd.					x			x		x
10	Beaver Cr @ Bellfountain Rd.			x		x			x		x
11	Starr Cr @ Wills Dr.					x					
12	Muddy Cr @ Greenberry Rd.								x		x
13	Muddy Cr @ Llewellyn Rd.					x			x		x
14	Muddy Cr @ Dawson Rd.						x				
15	Reese Cr @ Foster Rd.					x	x				
16	Oliver Cr @ Foster Rd.					x	x				
17	Oliver Cr 1/2 mi above mill						x				
18	Rickard Cr @ Oliver Cr						x				
19	Oak Cr @ Western Blvd.		x								
20	Oak Cr @ 30th St.						x			x	
21	Oak Cr @ Bald Hill Park	x				x	x			x	
22	Greasy Cr @ Grange Hall Rd.						x	x	x	x	x
23	Greasy Cr @ Fircrest Rd.	x		x	x	x					
24	Rock Cr @ HWY 34		x	x	x	x			x		x
25	Greasy Cr @ Decker Rd.			x		x	x		x		x
26	Wells Cr @ Botkin Rd.			x							
27	Greasy Cr @ Botkin Rd.		x	x							
28	Wood's Cr @ Wood's Ck Rd.	x		x			x	x	x		x
29	Tum Tum River @ Harris Rd.							x	x		
30	Shotpouch Cr @ Burnt Woods							x			

peak storm runoff was desirable, but beyond the means of the principal investigator due to the great distances between subwatersheds and limited access during major flooding. Local stream monitoring by residents within a particular sub-basin would greatly facilitate sample collection, but was hindered by volunteer availability during major storm events, which may occur at any time of day or night (e.g., university student volunteers were away on winter vacation during the major 12/28/98 storm event, the 11/26/99 storm occurred on Thanksgiving Day – another holiday!). For these reasons, monitoring measurements were not obtained at each location for every storm event. However, repeated sediment sampling was generally performed at various sites to evaluate storm or time related differences in sediment character and stream turbidity.

Turbidity Measurement:

Stream turbidity was measured using a Hach model 2100P portable turbidimeter at periods of peak stream flow. Flow conditions in tributary subwatersheds were estimated visually by reference to the amount of exposed stream bank. The overall flood intensity or the lower Marys River was estimated using Marys River discharge information posted on the internet by the Army Corp. of Engineers (AEC). The turbidimeter was calibrated and samples analyzed according to the manufacturer's standards as outlined in the Oregon Water Quality Monitoring Technical Guidebook (July 1999). Each day of sampling the unit calibration was checked hourly against Gelex standards. Turbidity was measured using grab samples obtained using a 2-gallon bucket attached to a long rope. The bucket was lowered into the center part of the stream channel and filled and rinsed 3 times before retrieving a sample for turbidity characterization. Enough liquid was obtained to fill a 5-gallon bucket, the contents of which were later used for sediment mineralogical characterization. The water in the bucket was stirred with a large plastic spoon and a small sub-sample was immediately obtained for turbidity measurement. Fogging of the turbidity bottles was eliminated by placing the bottles in a stream of hot air for 30 seconds prior to measurement. The bottles were carefully wiped clean and slowly tipped several times to ensure uniform mixing of sediment prior to analysis. Additional information that was recorded at the time of turbidity measurement included time of day, stream flow in relation to bank morphology (i.e., bank full, over bank, ½ bank full, etc.), weather conditions, and daily rainfall (measured at Philomath and Corvallis). Published discharge information for the Marys River is recorded at the Bellfountain Rd gauging station. This information is continuously updated on the internet and was used as a guide to sampling, especially for the lower segment of the Marys River.

Sediment Mineralogy:

Since clay particles are too small to study with the naked eye, the technique of X-Ray diffraction (XRD) is used to determine the crystalline nature of fine sediments. Clay minerals differ from one another primarily on the geometric arrangement of sheet-like layers of atoms. The distance between similar structural sheets is of the same order as the wavelength of X-radiation. Therefore, when a tightly focused beam of X-Rays is shined on a clay sample, the radiation is bent or diffracted by interaction with the structural layers in the clay particles. By carefully measuring the intensity and angular position of the diffracted X-Ray beam, a pattern can be generated that defines the various clay minerals in a particular specimen. All that needs to be done is to collect enough clay and carefully control the conditions of XRD analysis to fully characterize the crystalline phases in a sample.

To get enough clay from suspended sediment samples water was collected in 5-gallon buckets during episodes of peak stream flow/high turbidity (Figure 3). The suspended sediment was concentrated into 250 ml bottles by centrifuging after adding a few ml 0.5 M $MgCl_2$ to promote flocculation of the clay. The concentrated sediment was then separated into several size fractions: >15-μm, 15-2-μm, and <2-μm (the symbol "μm" signifies a micron, which equals 0.001-mm). The mineralogy of the silt and clay fractions (15-2-, <2-μm) was characterized by XRD analysis using the treatments outlined by Glasmann & Simonson (1985). This procedure uses several chemical treatments to achieve uniform cationic saturation of the clays and careful control of their shrink/swell properties. No attempt was made to remove organic material from the sediment. Once treated, oriented mounts of the clays were prepared on glass slides (Theissen and Harward, 1962) and mineralogy was determined by X-ray powder diffraction (XRD). Mineralogical analyses were performed using a computer automated Phillips 3100G X-ray Diffractometer equipped with compensating slits and a focusing monochromator. This device collects digital X-Ray angular/intensity data that are used to determine sample mineralogy based on comparison with intensity data from minerals of known composition. All samples were step scanned using copper Kα radiation (step size =0.04 degrees 2-theta, count time = 2 sec., beam current 40 KV/35ma, quartz reference intensity = 35,000 counts/sec.). The primary purpose of project funding was to pay for operation of the X-ray Diffractometer.

For several samples, the amount of suspended sediment in the 5-gallon bucket was so small after concentration that special slides had to be prepared for mineralogical analysis (common where turbidity values <25 ntu were encountered). This special treatment involved the use of specially cut quartz slides that produce a flat background during XRD analysis. For these very small samples, the count time of the step scan was increased to 4 seconds to improve data collection statistics. Semi-quantitative determination of sample mineralogy was accomplished by comparison of sample XRD patterns with computer-generated patterns (NEWMOD, R.C. Reynolds, Jr., 1996). In addition, the depth-related soil mineralogy of soils from major geomorphic surfaces within the watershed was evaluated for comparison against subwatershed suspended sediment mineralogy. These soil samples were collected using a bucket auger or from road cut exposures. In each case, the location and depth of the sample were recorded and the samples were sealed in plastic bags to prevent drying. Soil material was dispersed in distilled water using mild ultrasonic treatment and the suspended component was used to obtain a silt and clay fraction through the same techniques applied to the river sediments.

RESULTS

Stream Turbidity

Stream turbidity data were collected for several storm events during the 1998-1999 and 1999-2000 water years (Table 3). Sample collection coincided with major runoff events; however, storm intensity varied significantly between the 2 water years studied (Figure 3). The year of project funding (1999-2000) was characterized by moderately low intensity storms that resulted in much lower stream flow than observed during the prior water year.

Table 3. Stream turbidity (NTU) at various locations sampled at peak discharge, Marys River Watershed.

Sample Information		Storm Event Turbidity (NTU)									
		1998-1999 Water Year							1999-2000 Water Year		
Site	Location	11/25/98	12/2/98	12/28/98	1/5/99	1/18/99	2/25/99	2/27/99	11/26/99	12/16/99	1/13/00
1	Marys R. @ Avery Park		63.5	303	24.1				178	65.8	
2	Marys R. @ Borden Rd.		87.2						102	57	
3	Marys R. @ Fern Rd.	x					39.2		94.4	57.1/41.2	29.2
4	Marys R. @ HWY 34			250	11.7	91.1		103			26.4
5	Marys R. @ Wren		32.3	135	11.2				85.5		
6	Marys R. @ Summit		12.9								
7	Evergreen Cr @ Fern Rd.	x								28.7	
8	Bull Run Cr @ Peterson Rd.			145							24.6
9	Beaver Cr @ Saxton Rd.					320			>1000		74.4
10	Beaver Cr @ Bellfountain Rd.			500		140.2			820		78.2
11	Starr Cr @ Wills Dr.					66.6					
12	Muddy Cr @ Greenberry Rd.								18.9		27.9
13	Muddy Cr @ Llewellyn Rd.					74.8			456		40.8
14	Muddy Cr @ Dawson Rd.						29.2				
15	Reese Cr @ Foster Rd.					121	47				
16	Oliver Cr @ Foster Rd.					61.6	31.6				
17	Oliver Cr 1/2 mi above mill						18.7				
18	Rickard Cr @ Oliver Cr						27.5				
19	Oak Cr @ Western Blvd.		152								
20	Oak Cr @ 30th St.						99.6			243	
21	Oak Cr @ Bald Hill Park	x				151	87.9			183/81.7	
22	Greasy Cr @ Grange Hall Rd.						46.4	170	91.1	48.3	32.4
23	Greasy Cr @ Fircrest Rd.	x		460	9.8	132					
24	Rock Cr @ HWY 34		76.9	191	29.1	67.8			38.4		9.74
25	Greasy Cr @ Decker Rd.			797		144	41		91		24.8
26	Wells Cr @ Botkin Rd.			590							
27	Greasy Cr @ Botkin Rd.		56.5	960							
28	Wood's Cr @ Wood's Ck Rd.	x		236			37.1	306	46		24.3
29	Tum Tum River @ Harris Rd.							29	62.4		
30	Shotpouch Cr @ Burnt Woods							55			

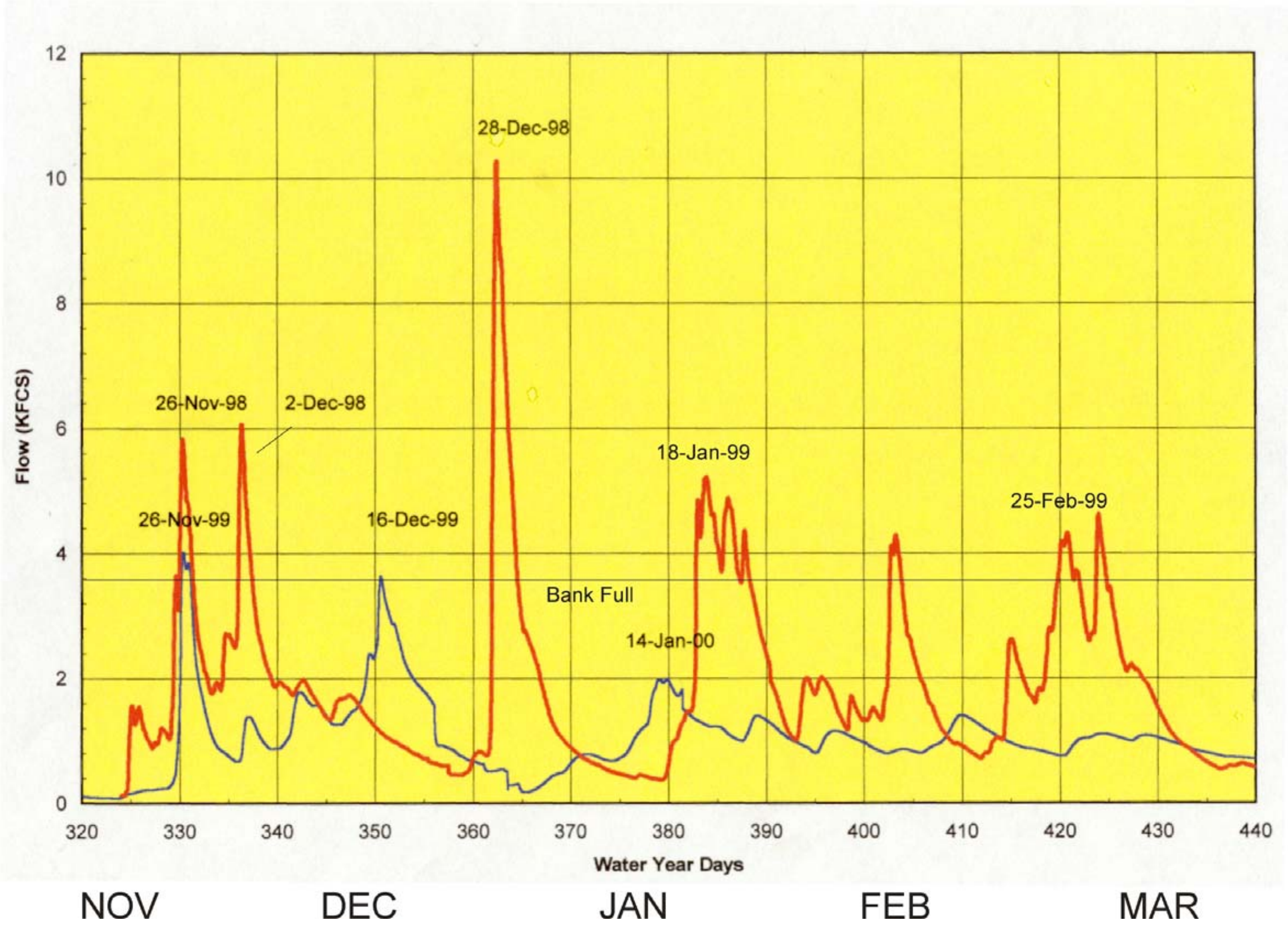

Figure 3. Comparison of Stream Discharge Measured at the Bellfountain Rd. Gauging Station for the 1998/1999 (red) and 1999/2000 (blue) Water Years, Marys River, Benton County, Oregon. (Army Corp. Eng. Data).

The 1998-1999 water year was associated with numerous episodes of overbank flooding on the lower Marys River as well as overbank flooding in the Tum Tum drainage and upper Marys near Summit. The major storm event on December 28, 1998, affected the entire watershed and was associated with record 24 hour rainfall totals that contributed to high stream turbidity. The recorded peak discharge during this event exceeded the maximum flow of the Marys River during the February 1996 storm (ca 10.2 KCFS vs. 5.3 KCFS, Army Corp. Eng. Data); however, flood duration was much longer during the 1996 event and resulted in more significant channel scour and bank erosion than the 12/28/98 event. In contrast, the 11/26/99 storm event that caused major flooding along the Oregon coast skirted the western reaches of the watershed and had only moderate impact on stream discharge and turbidity (excluding the Beaver Creek subwatershed, Table 3). Discharge records indicate that the 3 years preceding the 1999-2000 water year were characterized by above normal storm intensity and peak stream flow (USGS data). Such climatic variation may strongly affect stream turbidity, especially if above average stream flow initiates changes in stream channel morphology through accelerated bank erosion, channel avulsion, or reworking of sediment stored in bars or behind unstable log jams.

Stream turbidity shows a clear correlation to maximum stream flow, with peak measured turbidity coinciding with the major 12/28/98 flood event (Table 3). The one exception to this relationship is the extremely high turbidity measured in the Beaver Creek drainage during the moderate 11/26/99 flood event (Table 3). This high turbidity episode was influenced by prior channel conditions related to catastrophic flooding caused by failure of an upstream dam in June 1999. The debris flow associated with this dam failure left the channel choked with fine sediment that was readily eroded by subsequent early winter storm runoff. Later winter flow was much less turbid, suggesting that the stream had substantially cleaned itself of much of the debris (Table 3, compare 11/26/99 and 1/13/00 turbidity).

The measured high flow turbidity values for 4 different storm events are schematically illustrated in Figure 4. Of these 4 events, the 12-28-98 storm was one of the most significant events of the last decade, surpassing even the February 1996 storm for peak discharge. This storm was focused in the Flat Mountain/southern Marys Peak area of the watershed and resulted in very high flow in Greasy Creek and other tributaries draining Flat Mountain (Beaver Creek system). The highest turbidity measured during this storm was from the upper Greasy Creek drainage at the Botkin Road culvert (960 ntu, Table 3; Fig. 4). Wells Creek, which merges with the upper Greasy drainage just below Botkin Road, was substantially less turbid (590 ntu), although still suffering a high turbidity event. (This storm was also associated with a major debris flow that destroyed a local residence on the other side of the ridge along Alsea Highway.) Turbidity in Greasy Creek measured at the Decker Road crossing was somewhat lower than the Botkin site (797 ntu), probably due to dilution from the addition of the lower turbidity Wells Creek flow. Further dilution is evident at the Fircrest Rd site (460 ntu) that lies below the junction of Greasy and Rock Creeks. Rock Creek is the most significant tributary to Greasy Creek and had significantly lower turbidity during the 12/28/98 flood than the upper Greasy drainage (191 ntu). The influx of much less turbid water had a significant impact on turbidity measured in the lower Greasy, suggesting that most of the suspended sediment in the lower reaches of the Greasy was derived from upstream sources (possibly a debris avalanche or storm-related road failure above the Botkin Road site).

Beaver Creek also drains Flat Mountain and experienced a high turbidity event during the 12/28/98 storm (500 ntu). Beaver Creek was significantly more turbid than the Bull Run

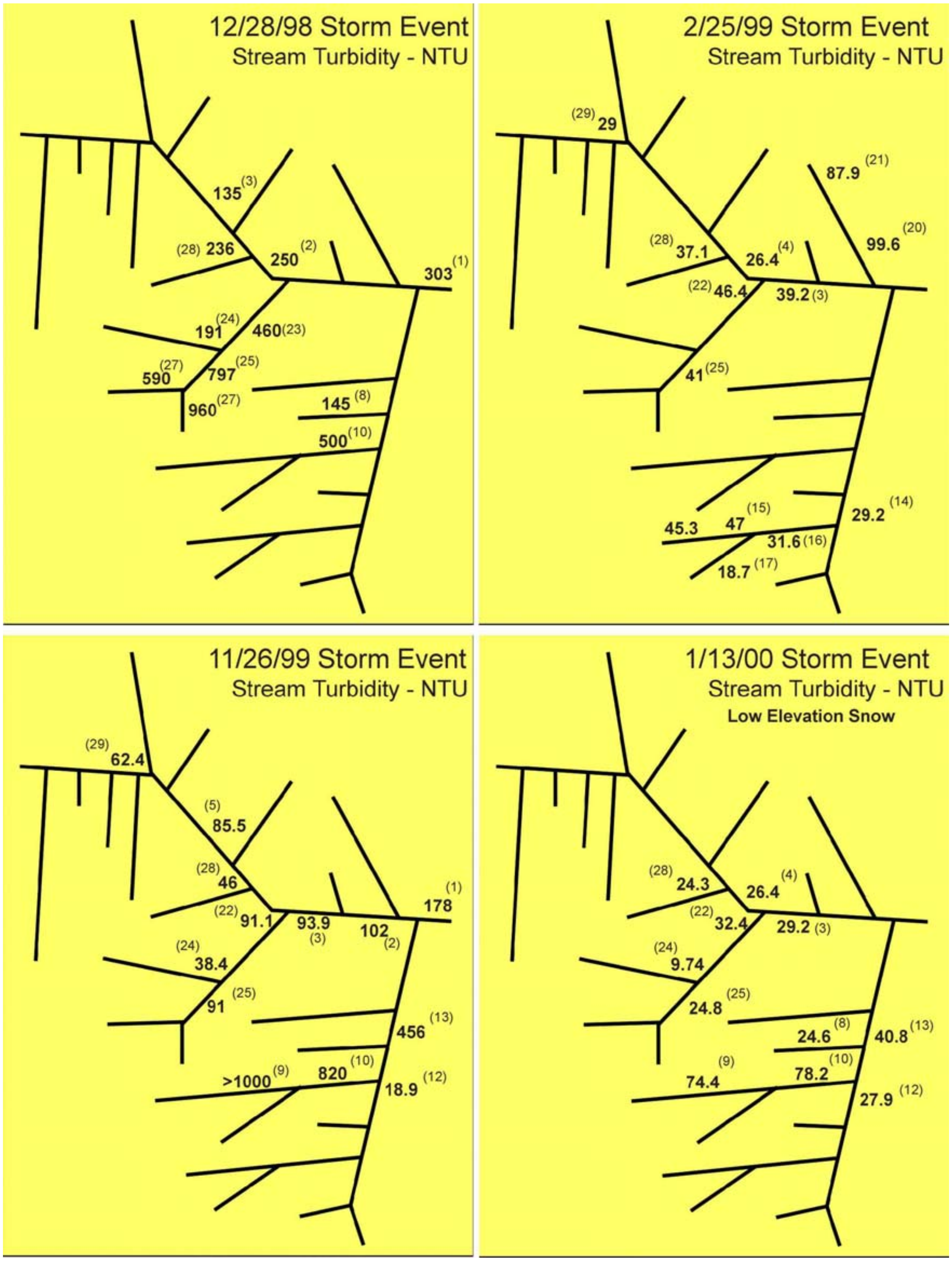

Figure 4. Schematic drainage network of major tributaries of the Marys River watershed showing storm-related turbidity at different locations (locations given by numbers in parentheses and correspond to site numbers in Table 3).

Creek, which heads in the low-relief foothills east of Decker Ridge. The 24 hour rainfall total for this storm was nearly 10 inches (Peterson Rd. rain gauge, Appendix 1) and resulted in major overbank flooding of Bull Run that eroded portions of Peterson Road. Rainfall at the higher elevations of Flat Mountain may have been at least twice that measured at the Peterson Road rain gauge and resulted in major overbank flooding along Beaver Creek.

In contrast to the very high turbidities measured in the Greasy and Beaver Creek drainages, turbidity in the upper and middle portions of the Marys River was not abnormally high (135 ntu at Harris Road bridge near Wren, Table 3). Turbidity significantly increased in the Marys at the Highway 34 bridge crossing (250 ntu), in part due to influx of very turbid water from Woods Creek (236 ntu). There was a noticeable mud plume originating from Woods Creek at the confluence of the Marys and Woods Creek during this storm. Turbidity continued to increase in a downstream direction in the Marys River, reaching a maximum of 303 ntu at the Avery Park bridge. At this location, turbidity is influenced by contributions from the entire watershed, including the Muddy Creek drainage (influenced by Beaver, Starr, Reese, Oliver, Hammer, Bull Run, and Evergreen Creeks; Figure 2). Access to the Muddy Creek sampling sites was inhibited by severe flooding during the 12/28/98 storm.

The 12/28/98 storm was truly a major event in the watershed (probably into the category of a 100 yr flood event). In contrast, the early December 1998 storm (12-2-98) produced significant overbank flooding along the Mary' River near Summit, but less significant flooding below Wren through Avery Park. In spite of overbank flooding at Summit, turbidity in the upper Marys was very low (12.9 ntu vs. 87.2 ntu at Borden Rd bridge, Table 3, 12/2/98). Similar low turbidity was recorded during overbank flooding on the Tum Tum during a later February flood event in 1999 (29 ntu, 2/27/99, Table 3). A more significant flood event on the Tum Tum during the Thanksgiving Day storm of 1999 (11/26/99) resulted in slightly higher turbidity (62.4 ntu). This storm was the first major runoff event of the water year and turbidity may have been affected by accumulation of fines in the channel during low summer flows. In general, a pattern exists that indicates that the upper and middle Marys River subwatersheds are low turbidity segments of the basin, even during above average flood events.

The maximum storm turbidity measured in the lower Marys River watershed exceeds the published maximum values reported in the Marys River Watershed Preliminary Assessment (1999) (53 vs. 303 ntu). The wide variation in reported maximum values underscores the need for the establishment of continuous turbidity monitoring stations to eliminate operator selectivity and timing biases in relation to peak runoff events.

Management Influences on Stream Turbidity

During June 1999, a culvert was replaced at the outlet of a small dam in the upper Beaver Creek subwatershed. Problems with culvert installation led to catastrophic failure of the dam and the ensuing flood made the local news headlines as chocolate brown water could be traced from the mouth of the Marys River up to the Muddy, then up the Muddy to the confluence with Beaver Creek. This was clearly a 1-stream turbidity episode that was repeated several weeks later as the replaced culvert again failed. The 11/26/99 storm event was the first major runoff episode of the 1999-2000 water year, and though not associated with significant overbank flooding or abnormally high turbidity in most of the Marys River watershed, was a major turbidity event in areas affected by Beaver Creek (Table 3). Turbidity during the morning of 11/26/99 was off scale at the Saxton Rd. bridge along Beaver Creek (>1000 ntu). Lower down the subwatershed, turbidity was 820 ntu at Bellfountain Rd.

bridge. At this point, turbidity of Beaver Creek is diluted by mixing with runoff from Starr and Decker Creeks. A more interesting pattern was noted along Muddy Creek. Upstream of the Beaver Creek confluence, the Muddy was flowing just below bank full with low turbidity (18.9 ntu). Just below the Beaver Creek confluence, turbidity in the Muddy increased to 456 ntu. Beaver Creek sediment also impacted the lower Marys River at Avery Park, almost doubling stream turbidity in comparison with the Borden Rd. site (178 ntu vs. 102 ntu, Table 3).

In contrast to the 11/26/99 high turbidity episode on Beaver Creek, upper Greasy Creek experienced an order of magnitude lower turbidity for similar flow conditions during this same storm (91 ntu vs. >1000 ntu, Table 3). The upper Greasy also drains Flat Mountain and is influenced by similar geology, soils, and rainfall as Beaver Creek watershed. Clearly, the 11/26/99 discharge of extremely turbid water from Beaver Creek was an unusual event that was influenced by the prior summer's debris flow. Subsequent winter runoff was much less turbid (74 – 78 ntu, 1/13/00, Table 3), suggesting that much of the fine debris was cleaned from the subwatershed by early winter runoff.

It is important to exercise caution in the interpretation of spot turbidity data. Turbidity is intimately linked to stream flow and may vary dramatically on opposite sides of a peak discharge event. For example, samples obtained 6 hours apart from Oak Creek during the 12/16/99 storm event differed in turbidity by over 100 ntu (183 vs. 81.7 ntu, Table 3; sampling on this date resulted in a police investigation when a jogger on Bald Hill reported seeing a suspicious person pouring a brown liquid into Oak Creek from a 5-gallon bucket!). A similar, but less dramatic, decrease in turbidity was associated with decreasing flow on the Marys at Fern Rd. bridge during the same storm (57.1 vs. 41.2 ntu). The difference in the 2 streams reflects the extremely flashy discharge character of Oak Creek compared to the slower storm response of the lower Marys River. Thus, turbidity data derived from grab samples suffer from uncertainties related to passage of the flood crest at a given location. It is impossible to demonstrate that any of the data reported in Table 3 are maximum values for a given storm event. Discharge data are only available for the lower Marys River at the Bellfountain Rd. gauging station, but the bridge at this location is unsafe for spot sampling due to the high volume (and speed) of vehicular traffic using Bellfountain Rd. Continuous turbidity monitoring using automated sampling equipment is the only way to ensure collection of sediment discharge information that fully characterizes storm runoff.

Clay Mineralogy of Soils and Suspended Sediments

The suspended sediment load of the Marys River consists predominantly of silt and clay-sized mineral particles. The mineralogical composition of suspended sediments is primarily controlled by the geologic character and weathering history of rocks that occur in a given subwatershed. For example, the Woods Creek, Rock Creek, and Oak Creek drainages are underlain primarily by ancient submarine basalt of the Siletz River Group. These submarine basaltic flows and breccias generally do not contain quartz. The silt and clay components of suspended sediment in streams draining basaltic landscapes are therefore quartz deficient relative to subwatersheds developed in quartz-rich sedimentary rocks (e.g., Tum Tum, upper Marys, Muddy Creek; Appendix 2). Furthermore, since basalt is an igneous rock (cooled from a very high temperature lava), it generally does not contain micaceous clays that are common in muddy sedimentary rocks. The clays that occur in watersheds underlain by the Siletz River Basalt developed through post-eruptive alteration in response to ancient interaction with ocean water and more recent interaction with fresh water during subaerial weathering and soil formation.

Deciphering the watershed significance of the mineral composition of suspended sediments requires some background in watershed geology and basic clay mineralogy. With the geological and mineralogical framework of the landscape established, one can begin to interpret the environmental significance of suspended sediment character in the various subwatersheds. Clay minerals are classified on the basis of their crystalline structure and chemical composition. There are at least 7 major types of clay minerals that are common in the watershed:

1. Smectite – This group of clays is typically composed of extremely fine particles (<0.2-μm) with true colloidal character. These clays are often associated with wetland soils that exhibit shrink/swell character upon wetting and drying. They typify wet soils and the lower part of deep weathering profiles where the ground remains wet throughout the year. Smectitic clays are especially common in association with weathered basalt, but also occur in moderate amounts in wet soils developed from sedimentary rocks. Smectite is often associated with persistent turbidity that resists removal by filtration unless coagulating agents are added (Bates et al., 1998).

2. Chlorite – The chlorite group of clays does not exhibit shrink/swell properties and tends to occur in association with sedimentary rocks or altered intrusive rocks in the watershed (especially around Green and Flat Mountains). Chlorite is also common in sedimentary rocks that were cooked by the intrusion of molten rock along faults that occur along Decker Ridge. Chlorite particles tend to be larger than smectite and are readily removed by most filtration techniques. There is also a family of minerals sometimes called "soil chlorite" or chloritic intergrade. These clays are most often associated with the surface layers of old soils and form by conversion of smectite or vermiculite to chlorite. This conversion may also be associated with the formation of other clays that characterize highly weathered soils.

3. Mica – The mica group includes platy minerals such as muscovite, biotite, and illite that are common components of sedimentary rocks in the watershed, especially the Tyee Formation that underlies the western area of the watershed (Tum Tum and upper Marys subwatersheds). Weathering of biotite in soils may result in the transformation of this mineral to chlorite or smectite, whereas muscovite commonly transforms to vermiculite. Mica is not only found in the clay fraction of suspended sediments, but large flakes may occur in association with silt and fine sandy sediment. Both illite and chlorite are very abundant in the silty lake deposits that floor the Willamette Valley. The presence of these clays is one of the primary means for distinguishing these lake sediments from underlying buried soils (paleosols) and local volcanically derived sediments. Micaceous clays are readily removed during water filtration and are not a component of persistent turbidity; however, they are important clay in the degradation of fish habitat, since they tend to settle rapidly from suspension, forming mud drapes on gravel bars that hinder oxygen flow to embryonic fish.

4. Kaolin – Kaolin group clays form as a result of prolonged weathering under acid leaching conditions. These clays are most common in the red hill soils that occur on the low foothills surrounding the Willamette Valley. Kaolin typically forms during weathering of feldspar, but may also form after prolonged weathering of smectite or mica. In some deep soils the soil mineralogy shows a transition from kaolin and chloritic intergrade at the surface, to smectite and mica at depth, reflecting a downward decrease in the intensity of weathering in the soil profile. The low hills in the southernmost Muddy Creek drainage are underlain by highly pure kaolin deposits that are locally mined by the Monroe Brick Company to produce specialty brick products.

5. Vermiculite – Vermiculitic clays commonly form by weathering of mica in the soil. These clays have some of the shrink/swell properties of smectite and are often a component of soil chlorite. Vermiculite is often concentrated in the fine silt fraction of micaceous soils and tends to be associated with soils developed from glacial lake deposits on the floor of the Willamette Valley and in illitic soils on Flat Mountain.

6. Halloysite – This mineral group is a special component of the kaolin group. It has the same chemistry and similar crystal structure, except that halloysite often contains water. Halloysite is very common in the upper portion of deeply weathered basalts and in highly weathered volcanic sediments that occur in the foothills of the watershed.

7. Gibbsite – Gibbsite is an end product of intense weathering. The mineral is basically aluminum hydroxide and develops by the complete leaching of silica and other elements (e.g., calcium, potassium, magnesium) from the soil. Gibbsitic soils are common on stable upland surfaces on Flat Mountain and associated with remnants of very old geomorphic surfaces in the Corvallis Watershed. Gibbsite is generally not found in deeper parts of the soil profile, where kaolin or smectite are chemically more stable.

These are the dominant components of the fine fraction (<2-μm) of soils and suspended sediments of the Marys River watershed. Rarely will a sediment sample consist of only one mineral, but instead will be composed of an assemblage of clays that reflects complex soil mineralogy or homogenization of many sediment sources within the watershed. Another class of materials that may contribute to measured turbidity in natural waters is para- or non-crystalline compounds that cannot be readily characterized by X-Ray Diffraction. This study did not attempt to identify or characterize the amount of non-crystalline phases in suspended sediments.

Soil Mineralogy and Watershed Landscapes

Soil mineralogy in the Marys River Watershed is intimately linked to the landscape and underlying geologic materials. For example, broad areas of the valley floor are underlain by silty sediments that originated as cataclysmic floods inundated the Willamette Valley at the end of the last glacial period (Glasmann & Kling, 1981). These floods originated in the upper Columbia River drainage and poured out across what is now the channeled scabland of eastern Washington, scouring the wind-blown silts and clays of this region as the floods poured down towards the Pacific Ocean. The shear volume of water associated with these floods is difficult to comprehend, but geologic evidence indicates that the Willamette Valley was filled to the 400 ft elevation as recently as 13,000 years ago by the last of these great floods. The bedded character of the silt deposits suggests that as many as 20-30 floods affected the southern Willamette Valley. The lake deposits buried an older valley landscape that developed during a warmer interglacial climate prior to the last glaciation. Surrounding foothill soils that lay above the flood-induced lake received a thin cover of wind blown silt as the lake drained and the muddy, non-vegetated surface dried and was eroded by storm winds. Local rivers entering the Willamette Valley from the Coast Range found their former stream channels choked with lake silts and had to establish new channels. The glacial silts were easily eroded by large streams and the Marys River carved a broad floodplain where it entered the valley near Philomath. The prominent scarp that crosses the highway going north on Bellfountain Road just after passing over the Marys River resulted from erosion of the glacial silts during the last 13,000 years (Photo 1). Standing on this scarp and looking to the south reveals the great width of the modern Marys River floodplain – a fact often painful to travelers on Bellfountain Road who find the road submerged during severe winter floods. The mineralogical character of the glacial silt deposits is very different from that of the older valley-margin soils that were buried beneath the silts (compare Figures 5 and 6). The clay mineral assemblage of the glacial silts in very illitic and includes minor amounts of smectite, vermiculite, chlorite, and kaolinite (Figure 5). The silts also contain quartz, K-feldspar, and plagioclase. In contrast, the mineralogy of older soils buried beneath the glacial silts is generally non-illitic and contains disordered kaolinite and smectite (Figure 6). In addition, the long weathering history of the old buried soil resulted in the destruction of feldspar. The

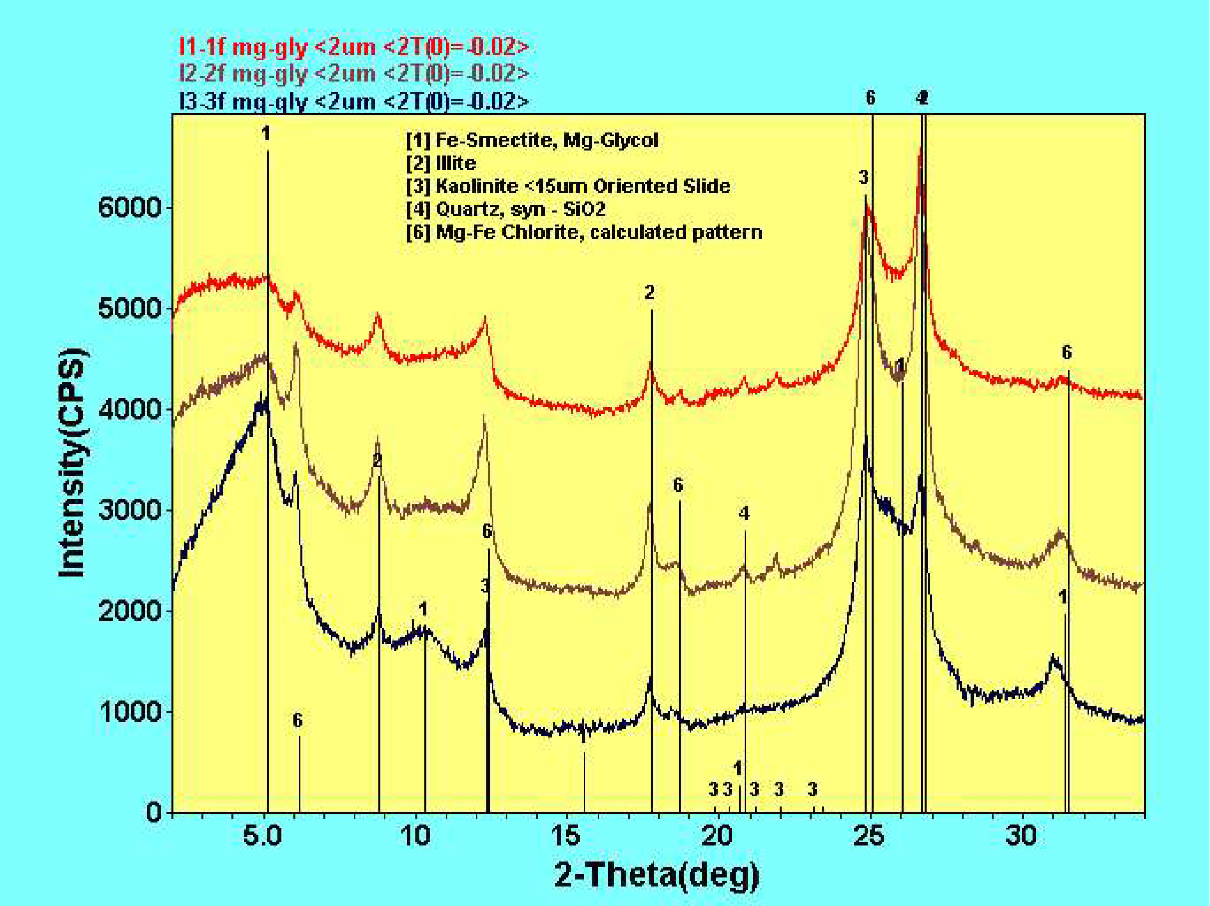

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Figure 5. The clay mineral assemblage of glacial lake deposits that underlie broad flats of the lower Mary's River Watershed is highly illitic. The flattened peak character of the Fe-smectite phase at about 5 degrees 2-Theta reflects a decreases in expansive character in the surface soil layer due to recent weathering and formation of chloritic intergrade clay. These samples represent an Amity soil from the OSU Poultry Farm approximately 200 yards north of Harrison Blvd. in the Oak Creek drainage. Sample I1-1f = 5-10 in deep, Sample I2-2f = 25-30 in deep, Sample I3-3f = 40-45 in deep.

illitic/feldspathic character of the surficial soil layer of the low foothill soils coincides with the geologically recent addition of a thin layer of glacial silt. The 2 soil layers are very different in their mineralogical character, even though they occur within the same soil profile. These clear differences in depth-related soil mineralogy may help in identifying the source of eroded sediments in streams draining low foothill landscapes.

Photo 1. View from Bellfountain Road Bridge at the Marys River Crossing looking northwest showing the prominent scarp that separates older glacial silts of the high valley terrace (background) from modern Marys River floodplain sediments (foreground). These 2 sedimentary deposits have very different mineralogy. The scarp represents the former cutbank of the Marys River at a time when the river channel lay about 100 yards further north. The smectite-rich clayey sediments of the modern Marys River floodplain at this location accumulated as the river channel migrated southward to its present location.

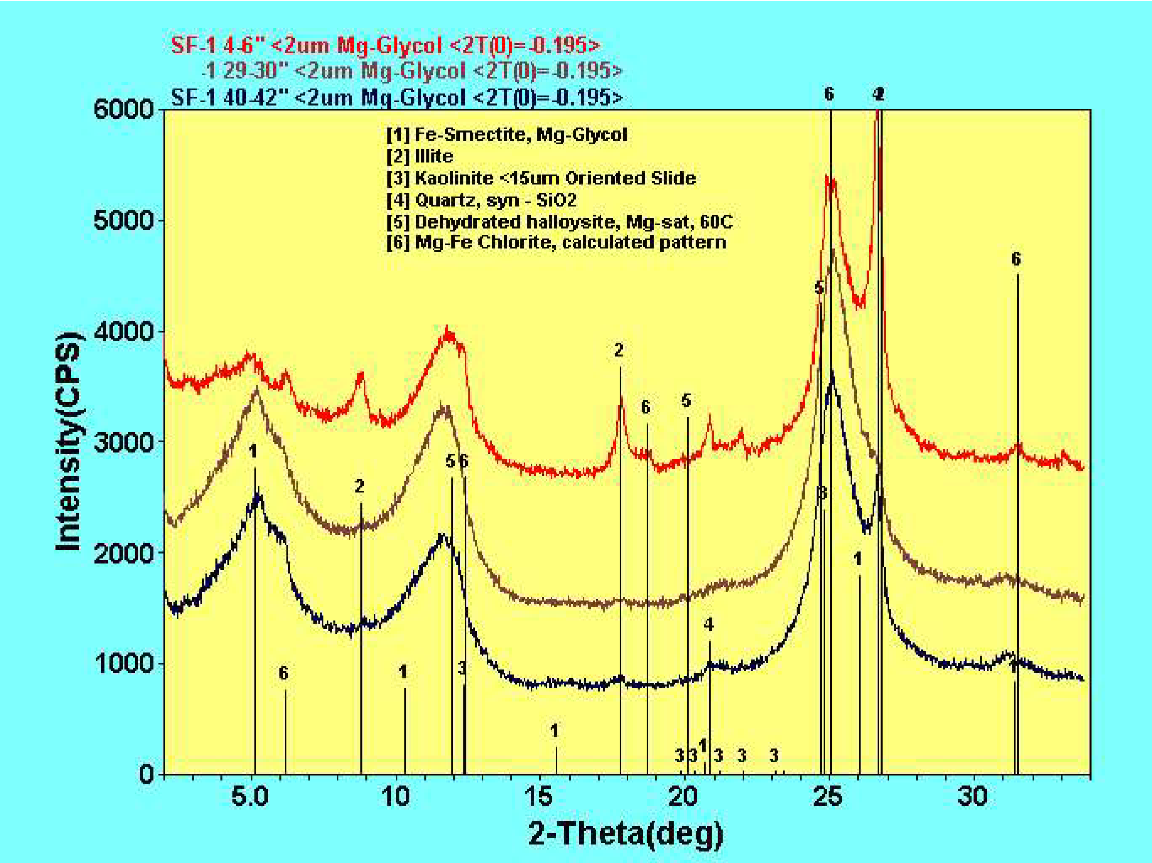

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Figure 6. The clay mineral assemblage of a Hazelair soil (OSU swine farm ¼ mile east of 53rd St) that occupies low foothill landscapes underlain by sedimentary bedrock exhibits a dramatic change in mineralogy in the upper soil horizons. Deeper soil layers are non-illitic and show broad peaks for smectite and kaolinite (dehydrated halloysite). In contrast, the shallow soil is strongly illitic and chloritic – minerals found in the glacial silts depicted in Figure 5. This mineralogical character resulted from burial of old highly weathered soil material beneath more recent, less weathered glacial silt. Some mixing of the old weathered material has occurred in the surface layer, indicated by the presence of halloysite (halloysite is absent in the surface layer of the Amity soil in Figure 5).

At slightly higher foothill elevations, the surficial glacial silt layer is absent and soil mineralogy is dominated by clays that indicate intense or prolonged weathering (Figure 7). Soils with this intensely weathered character include the Jory and Bellpine series. These soils have a very long period of development that may extend back well over 100,000 years. Because of this prolonged weathering, only the most stable mineral phases persist (e.g., quartz, kaolinite, gibbsite, soil chlorite, iron oxide). There is almost no depth-related variation in clay mineralogy because of the homogenizing effects of deep weathering. In addition, many of the soils are “colluvial” in nature, meaning that the earth material in which the soil developed originated from erosion, mixing, and down-slope transport of much older

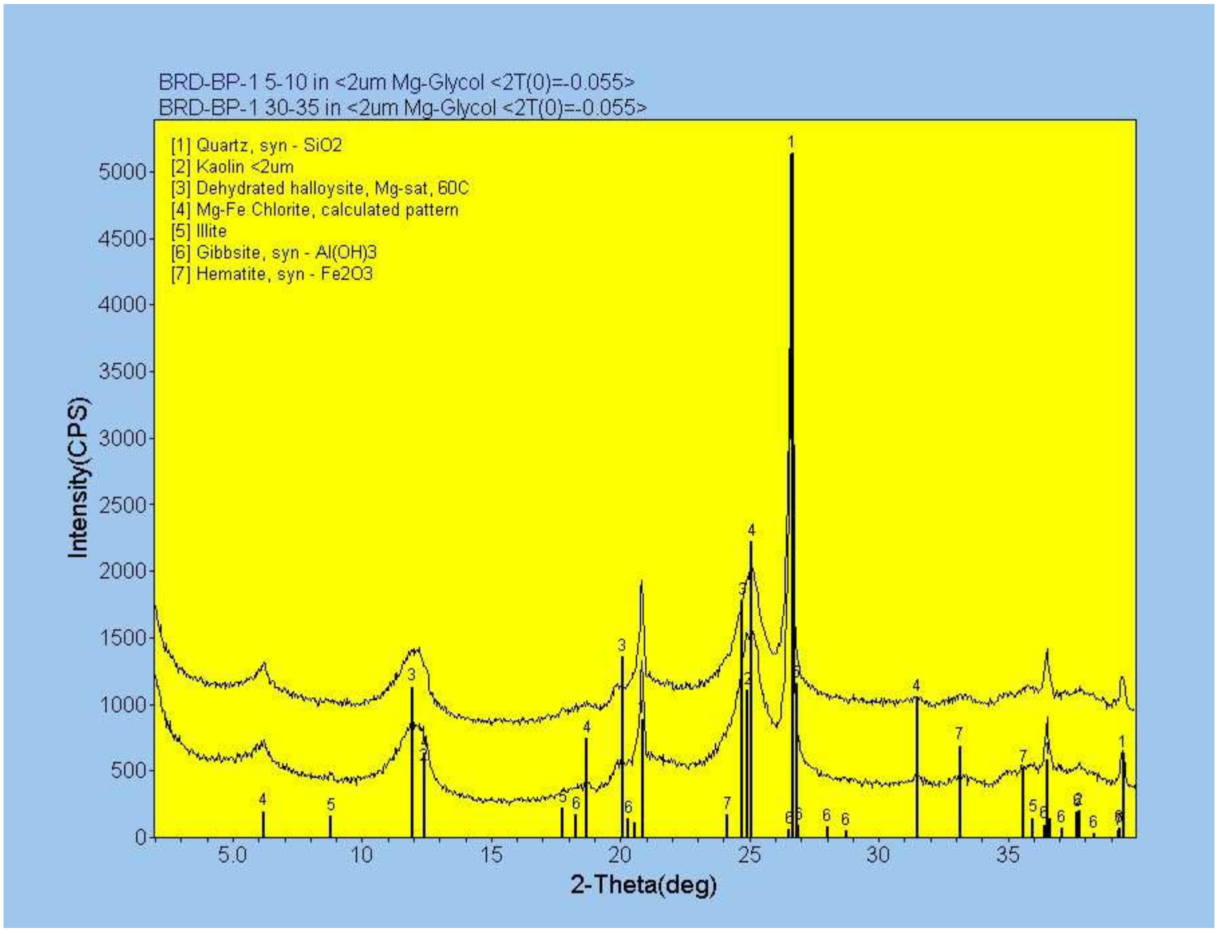

Figure 7. The clay mineral assemblage of Bellpine soils found along Ervin Rd in the upper reaches of the Bull Run Creek watershed shows almost no variation with soil depth. These soils formed in ancient colluvial material that had a prior history of weathering. Only the most chemically stable minerals survived this long weathering history (quartz, kaolin, chlorite, gibbsite, and hematite). Although the underlying sedimentary bedrock is micaceous, the mica component was destroyed in the soil by the intense weathering history of the soil.

soil material. Most of the red-colored foothill soils in the Marys River Watershed share this colluvial nature and indicate that the watershed has been subjected to prehistoric cycles of severe erosion, perhaps in response to global climate change, landslides, or effects of episodic wild fires.

Remnants of very old, highly weathered soils persist into high elevation landscapes on Marys Peak and Flat Mountain (Figure 8). Some of these soils are 10-20 ft deep and consist of red-colored clay with soil features that suggest similarities to modern tropical soils (so-called laterites or oxisols). The gibbsitic and strongly chloritic nature of these soils distinguishes them from lower elevation kaolinitic red soils. The differences in soil mineralogy of these old stable landscapes may arise from differences in annual

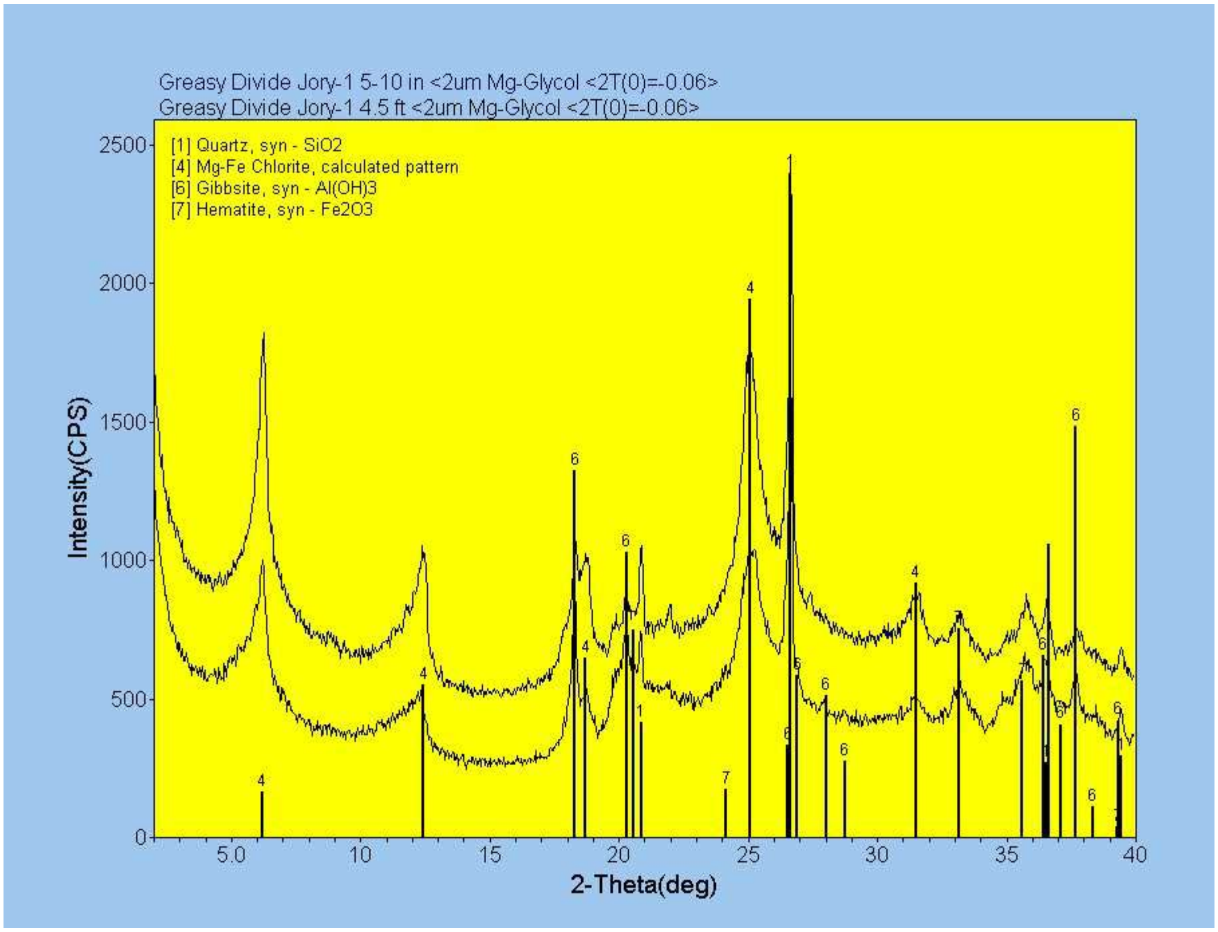

Figure 8. Deep red soils on flat upland surfaces on Flat Mountain in the Greasy and Beaver Creek watersheds are characterized by the presence of Al-and Fe-rich clays (soil chlorite, gibbsite, and hematite). These minerals develop as the end products of prolonged and intense weathering in a strongly leaching environment. The underlying sedimentary bedrock is highly illitic (see Figure 9).

precipitation, with strongly leached, gibbsitic soils occurring in the wetter high elevation sites. Below the zone of intense soil weathering, the clay mineral assemblage of moderately weathered sedimentary bedrock has a completely different character (Figure 9). Instead of gibbsite and soil chlorite, the clay assemblage shows a complex association of illitic, smectitic, and mixed-layered clays that formed from geologic baking of the sediments by intrusion of molten igneous rock (Figure 1). The mixed-layer clays are unique to high temperature contact metamorphic alteration of sedimentary bedrock in the Marys River Watershed and are not found in the overlying highly weathered soils. The presence of mica and mixed layer clay in the Greasy-Beaver Divide road runoff reflects cutting of the road bed below the soil into weathered bedrock. Surface runoff focused into the roadside ditch carries suspended clays derived from freshly exposed bedrock, not the overlying soil. The presence of regular interstratified mixed-layer clays in stream suspended sediments is a good indicator of deep erosional processes in the Flat Mountain area.

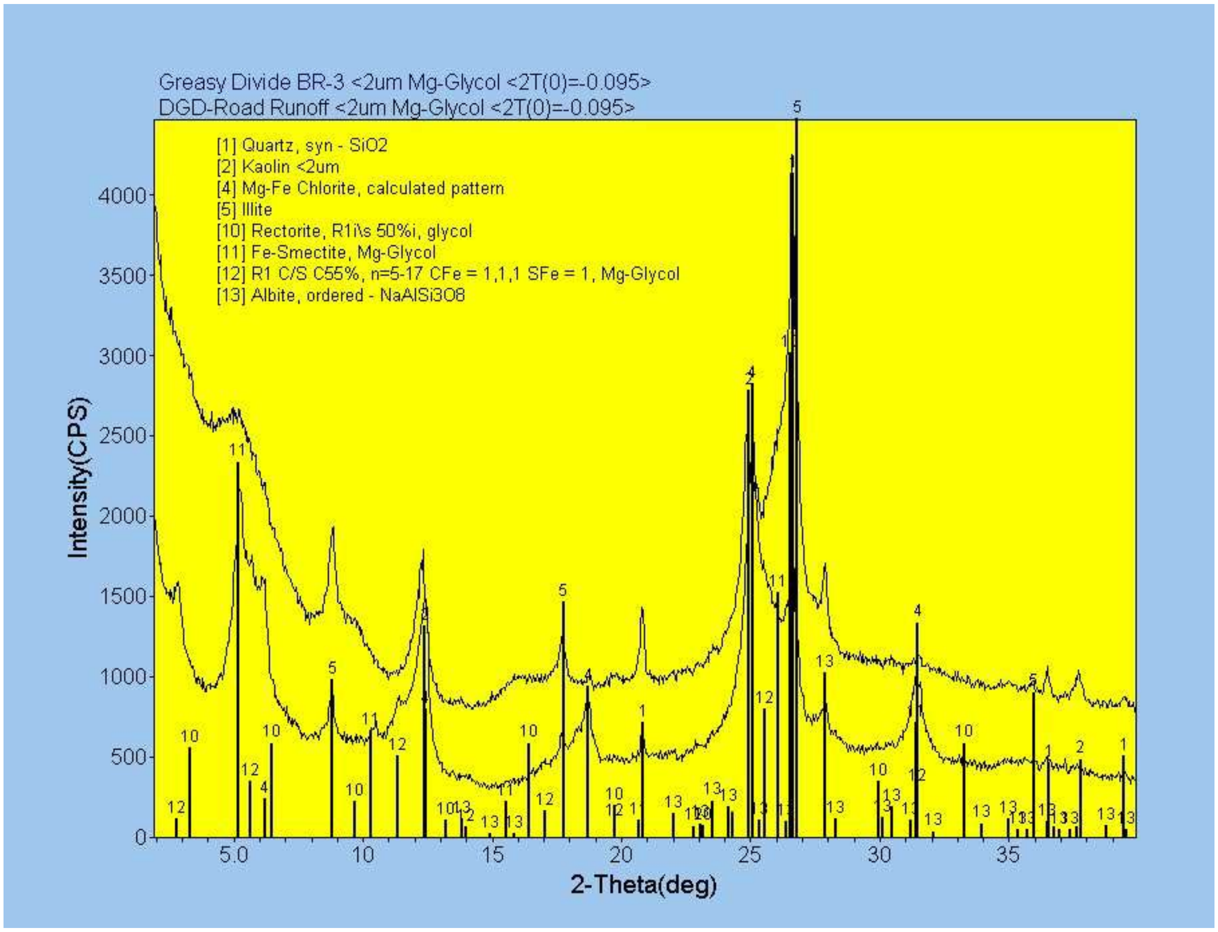

Figure 9. Exposed weathered sedimentary bedrock in the Greasy-Beaver Creek headwaters on Flat Mountain yields a clay assemblage that includes illite and complex mixed-layer clays (illite/smectite and chlorite/smectite). This clay assemblage probably formed as a result of contact metamorphism as the igneous rock that forms the core of Flat Mountain was emplaced.

Downstream Changes in the Mineralogy of Suspended Sediment

The foregoing discussion has focused on the nature of clay minerals found in soils from different kinds of landscapes in the Marys River Watershed. While soil-clay mineral relations are fairly simple on low elevation landscapes, greater variability occurs in the steep, unstable landscapes of the Coast Range. In spite of the potential for major site-to-site variability in clay mineralogy in the Marys River Watershed, the suspended sediment mineralogy of the Marys River shows regular downstream variations that reflect important sediment delivery processes in the watershed (Figure 10).

The mineralogy of the suspended clay fraction in the Marys River changes dramatically from the upper watershed near Summit to the lower watershed near Avery Park (Figure 10). The clay mineral assemblage of the 12/2/98 flood discharge at Summit was composed of a

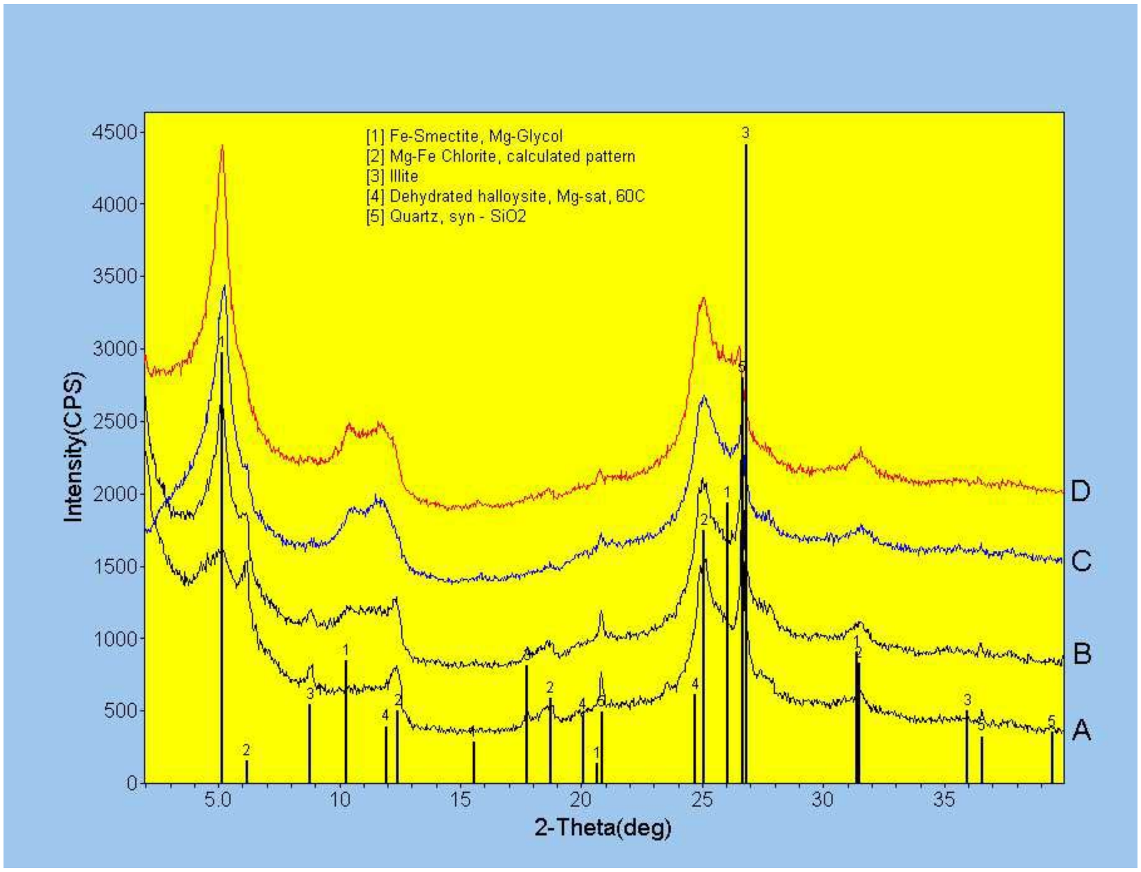

Figure 10. Downstream changes in the clay mineralogy of suspended sediments from Marys River. A. Summit location, B., Wren location, C., Fern Road location, D., Borden Road location. All XRD patterns represent the Mg-saturated, ethylene glycol solvated treatment of the <2-μm fraction obtained from the 12-2-98 storm event. Sediments from the lower Marys watershed are enriched in smectite relative to the upper Marys watershed.

mixture of mica, chlorite, smectite, and kaolinite, with minor amounts of quartz and feldspar. At Wren, the suspended clay fraction shows slight enrichment in smectite relative to the Summit sample. The trend of increasing smectite content continues downstream such that sediment from the Fern and Borden Rd. bridges is smectite dominated. In addition, the suspended sediments from the lower Marys River contain much less mica, chlorite, and quartz than suspended sediment from the upper Marys River watershed. This dramatic change in suspended sediment composition coincides with a significant downstream increase in stream turbidity between the Wren and Fern Rd. sites (Table 3) as well as a change in the underlying geology from sandstone upstream from Wren to basalt between Wren and Philomath (Figure 1).

It is interesting to note the similarities between the clay mineralogy of suspended sediment from the upper Marys near Summit and glacial silts from the floor of the Willamette Valley (compare with Figure 5). The reason for this similarity is that the Tyee Formation underling the central Coast Range was also sourced by sediments eroded from granitic or metamorphic rocks that lie east of the Cascade Mountains. Prior to eruption of the Western Cascades, rivers draining granitic mountains in present-day Idaho flowed into the Pacific and left the sediments that formed portions of the Tyee Sandstone. Although the glacial silts are separated in age by tens of millions of years from the Tyee Formation, the clay mineralogy of the 2 deposits is similar. This mineralogical similarity could only be preserved if the upper Marys River eroded “fresh” bedrock, as soil weathering would destroy the mineralogical nature of the deposits.

The changes in suspended sediment composition within the lower reach of the Marys River occur independent of erosive processes that are associated with the Muddy Creek drainage, which intersects the Marys River near the junction with the Willamette (Figure 2). Clearly, the factors that contribute to the downstream change in suspended sediment composition between the upper and lower Marys watersheds must be at work in the interval between the Wren location and Philomath. This indicates that significant sediment contributions must occur from the Greasy, Woods, Wren, and Blakesley drainages. No samples were obtained from the Wren and Blakesley Creek subwatersheds, but the small size and relatively low elevation of these areas suggests that they are not major sediment sources relative to the other 2 subwatersheds. In the Greasy Creek subwatershed, the majority of the basin is drained by Rock Creek and Wells Creek – streams that head in steep mountainous terrain that is underlain by basalt. Runoff from these basaltic subwatersheds is mineralogically distinct from runoff from the Flat Mountain portion of the upper Greasy Creek drainage (Figure 11). Whereas runoff from the upper Greasy sampled at Botkin Rd exhibits the quartz, illite, chlorite, and mixed-layer clay assemblage of thermally altered sandstone, runoff from the Wells Creek and Rock Creek drainages is highly smectitic. Greasy Creek runoff becomes increasingly smectitic downstream, reflecting dilution of the illitic sediment from the upper Greasy by the more voluminous smectitic runoff from Rock Creek (Figure 12) and other minor streams draining the east side of Marys Peak. The suspended sediment mineralogy of basalt-influenced subwatersheds (Rock, Woods, and Oak Creeks) is dominated by smectite, with variable amounts of halloysite and traces of mica (Figure 12). Halloysite is most abundant in the Oak Creek subwatershed and probably reflects the somewhat drier environment of this lower elevation drainage. Quartz is generally absent, reflecting the basaltic parent material of these sediments.

The mineralogical composition of suspended sediments in the Philomath area of the lower Marys River watershed also shows minor variation with storm location and intensity. During the major 12-28-98 storm, the most intense rainfall was centered over the Greasy Creek drainage around Marys Peak. Suspended sediment mineralogy at the Fern Rd. site was strongly influenced by smectite and halloysite during this event. In contrast, the 11/26/99 storm was centered in the western Coast Range and the Tum Tum subwatershed received the greatest precipitation. Suspended sediment mineralogy at the same location is enriched in quartz, mica, chlorite, and kaolinite relative to the 12-28-98 event (Figure 13). These subtle differences in suspended sediment mineralogical composition clearly indicate the general geographic area of the most significant storm runoff.

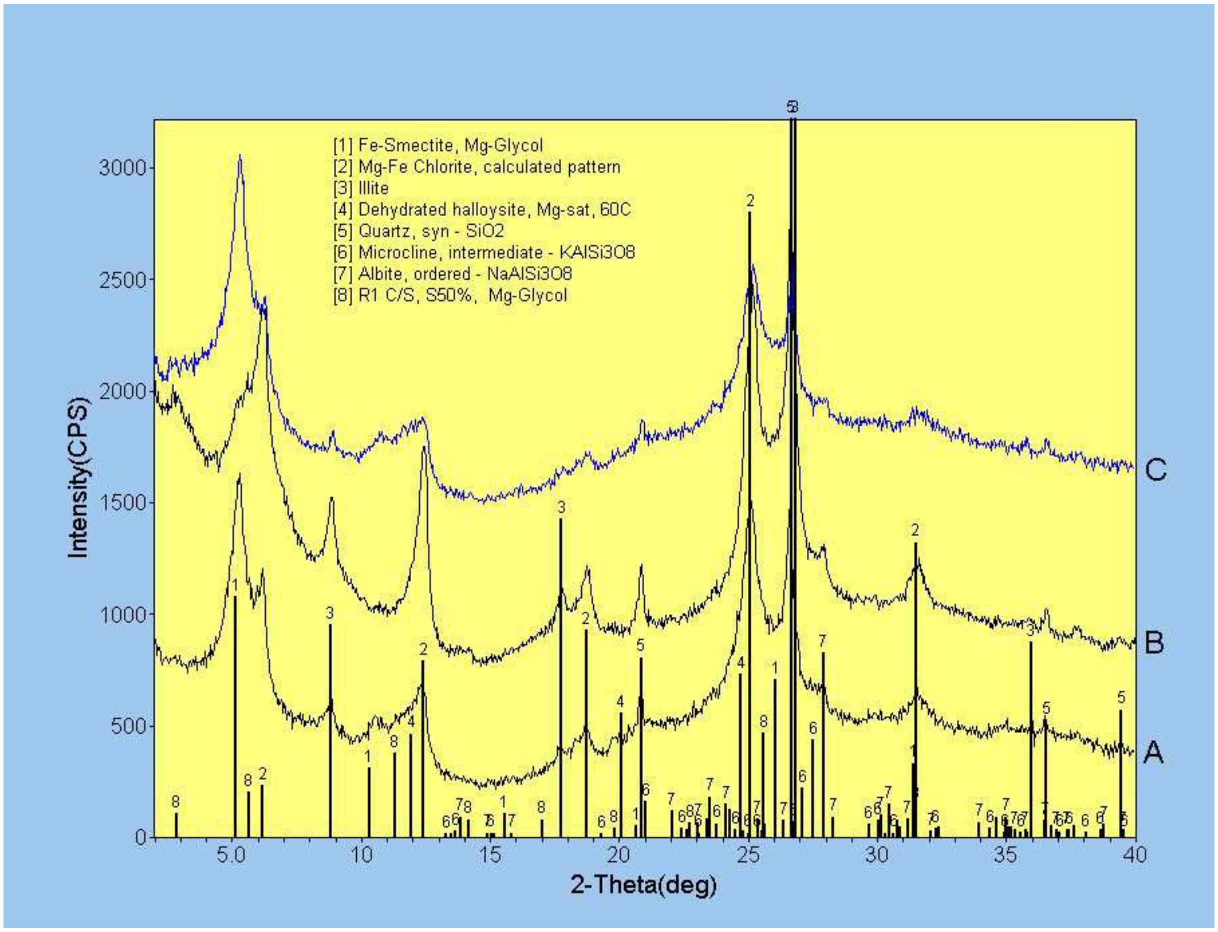

Figure 11. Variations in suspended sediment mineralogy within the Greasy Creek subwatershed during the 12/28/98 storm. Sample A represents runoff from Wells Creek sampled at Botkin Rd. This sample has a mixed clay assemblage that includes smectite, chlorite, illite, and halloysite. In contrast, runoff from the upper Greasy drainage at Botkin Rd. is dominated by chlorite, illite, quartz, and regular interstratified clays (illite/smectite and chlorite/smectite) – clays that reflect deep erosive processes. At Grange Hall Rd., the mineralogical character of Greasy Creek is more strongly smectitic and illite, chlorite, and quartz are much less abundant relative to the upper Greasy. This reflects dilution of the sandstone-sourced sediment from the upper Greasy subwatershed by basaltic sediments from Wells and Rock Creek (see Figure 12 for XRD pattern of Rock Creek suspended sediment).

In contrast to the storm-related variations in suspended sediment mineralogy that appear common in the lower Marys River watershed, the suspended sediment mineralogy in the mid- and upper portions of the watershed shows greater storm-related homogeneity (Figure 14). Three different storm events sampled at the Wren location on the middle Marys River exhibit insignificant variation in clay mineralogy, even though significant variations in river stage and storm location occurred between the 3 storms. This mineralogical homogeneity indicates that the middle and upper Marys have a consistent sediment source that was not overly influenced by storm intensity during the sampling period. The quartz-mica-chlorite-smectite character of the clay mineral assemblage is consistent with erosion of sedimentary bedrock of the Tyee Formation with minor contribution from basaltic components of Shotpouch and Mulkey Creek watersheds.

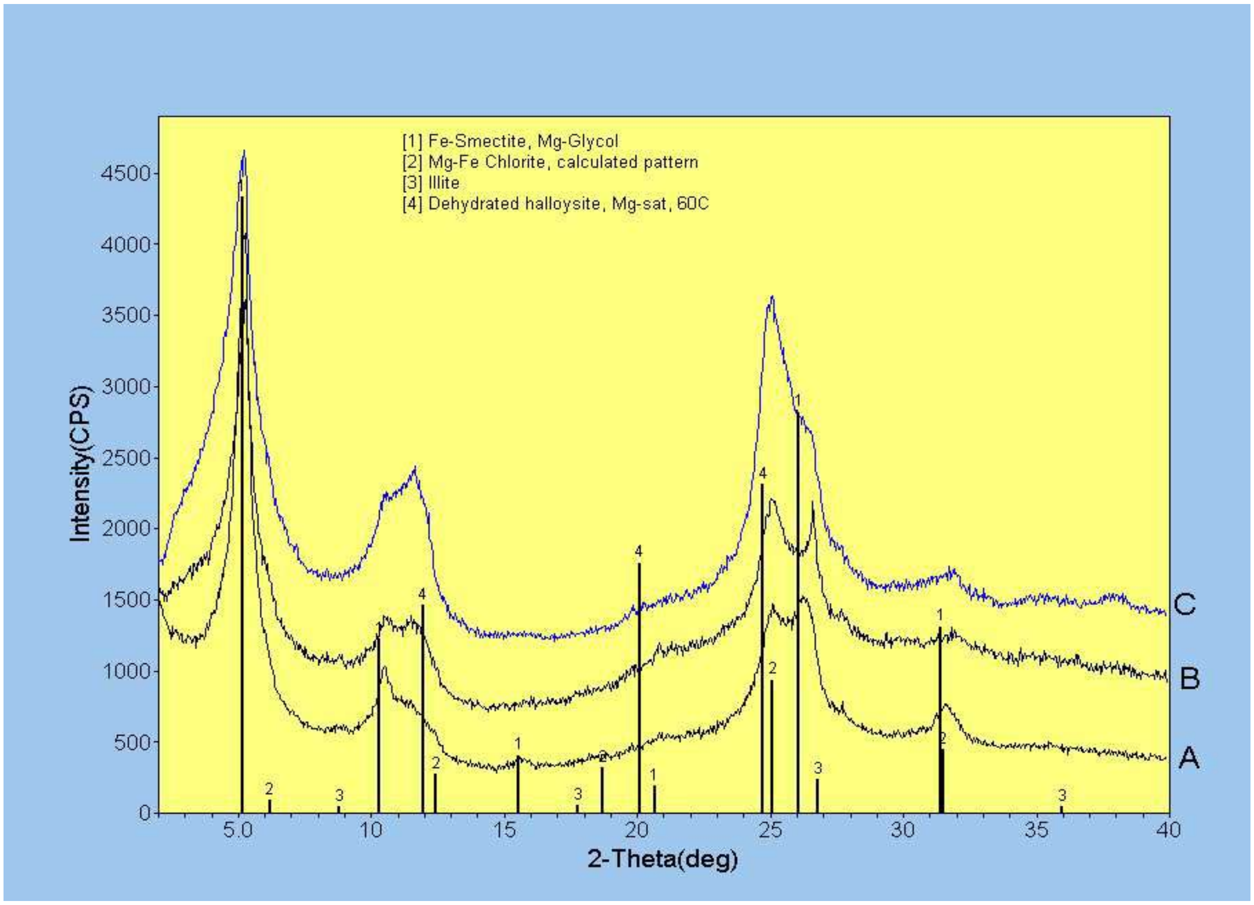

Figure 12. Comparison of XRD patterns of the <2-µm fraction of suspended sediment from Rock Creek @ HWY 34 (A), Wood's Creek @ HWY 20 (B), and Oak Creek @ Bald Hill Park (C). These samples are dominated by iron-rich smectite and dehydrated halloysite and contain only traces of quartz. The illite, chlorite, and quartz components that occurred in the upper Marys watershed do not occur in streams draining basaltic landscapes.

The Oak Creek subwatershed heads in basaltic terrain that was uplifted long ago along the Corvallis fault. The upper reached of the Oak Creek drainage exhibit hummocky topography associated with ancient landslides. Oak Creek has cut a narrow incised channel in its upper reach, but meanders across an incised floodplain below the confluence with Mulkey Creek (Figure 2). The clay mineralogy of suspended sediment from various locations along Oak Creek exhibits a strong smectitic character with moderate occurrence of dehydrated halloysite (Figure 15). Halloysite is common in deeply weathered basalts (Glasmann & Simonson, 1985) and often exhibits a transition from dehydrated to hydrated halloysite with depth (hydrated halloysite is common in deeply weathered basalts in the Corvallis Municipal Watershed – Glasmann, 1982). The absence of hydrated halloysite in suspended sediments of Oak Creek suggests that sediment is derived from soil zones

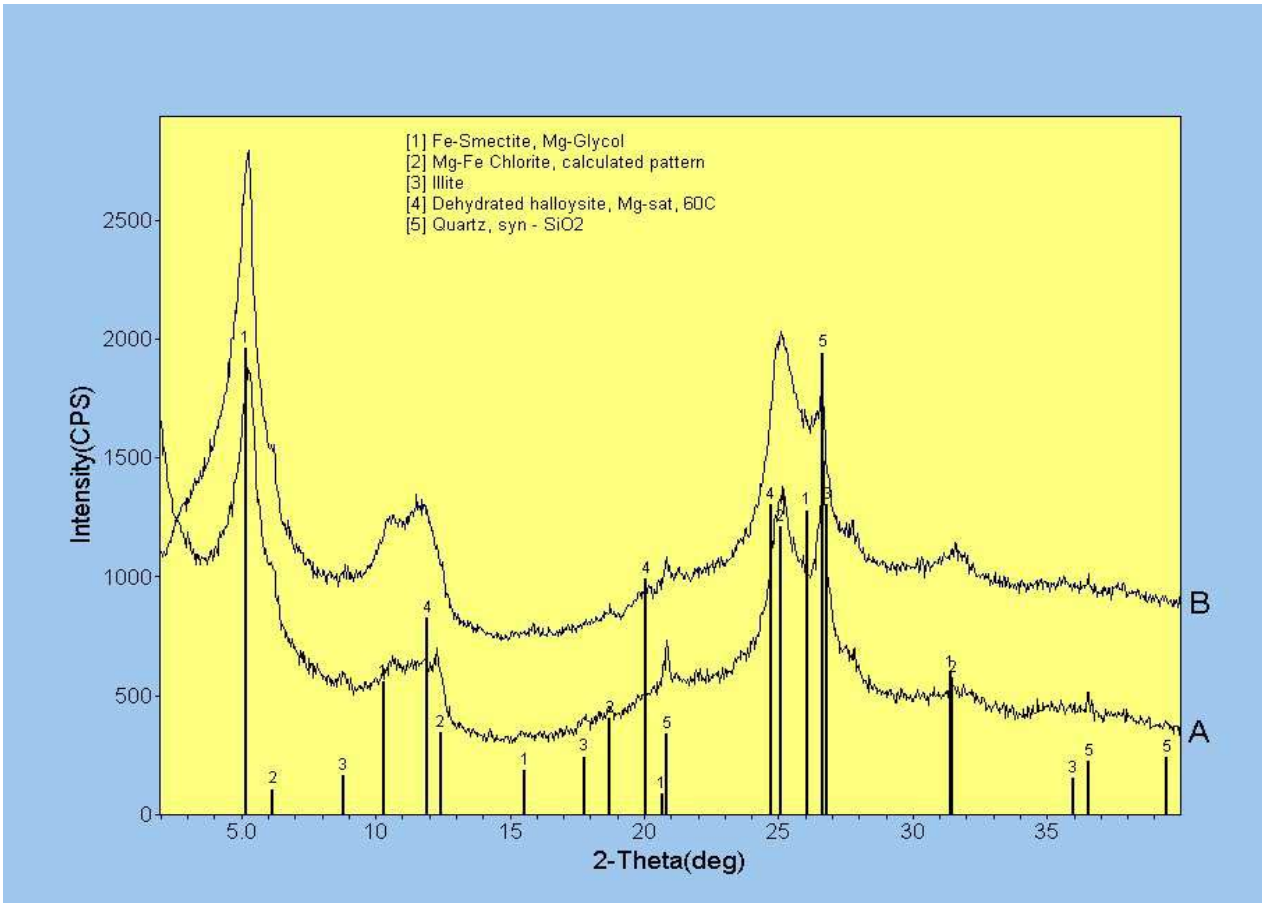

Figure 13. Storm location/intensity effect on suspended sediment mineralogy at the Fern Rd. site of the lower Marys River subwatershed. Pattern A represents the 11/26/99 storm that was centered in the Tum Tum subwatershed. Pattern B represents the 12-28-98 storm that was centered on Marys Peak. The clay fraction of suspended sediments associated with the 11-26-99 storm is enriched in quartz, mica, and chlorite relative to the smectite-halloysite clays associated with the 12-28-98 storm. Runoff from the 12-28-98 storm was dominantly influenced by erosion of basaltic materials, whereas the 11-26-99 sediments were dominantly derived from erosion of Tyee sandstone material. Mg-Glycol patterns.

subjected to periodic drying; however, the absence of chloritic intergrade clays, which commonly occur in the surficial soil layer of basaltic soils in Oak Creek drainage, indicates an absence of surface runoff (rilling, gullying, or sheet wash). Furthermore, the absence of illite, chlorite, and quartz indicates that glacial silts mantling lower watershed landscapes do not contribute to stream sediments. This implies that Oak Creek flows within deposits eroded from upland basaltic sources and is continually reworking these clays, rather than eroding surrounding glacial silts. The smectite-rich mineralogy of Waldo and Bashaw soils that occur on the wetland floodplain of Oak Creek mimics the mineralogy of suspended sediment and suggests that these soils developed in response to overbank flooding and deposition of fine clays (a wetland alluvial fan setting similar to what has been described at Jackson-Frazier creek; D’Amore, 1996, OSU M.S. thesis, Crops & Soils Department).

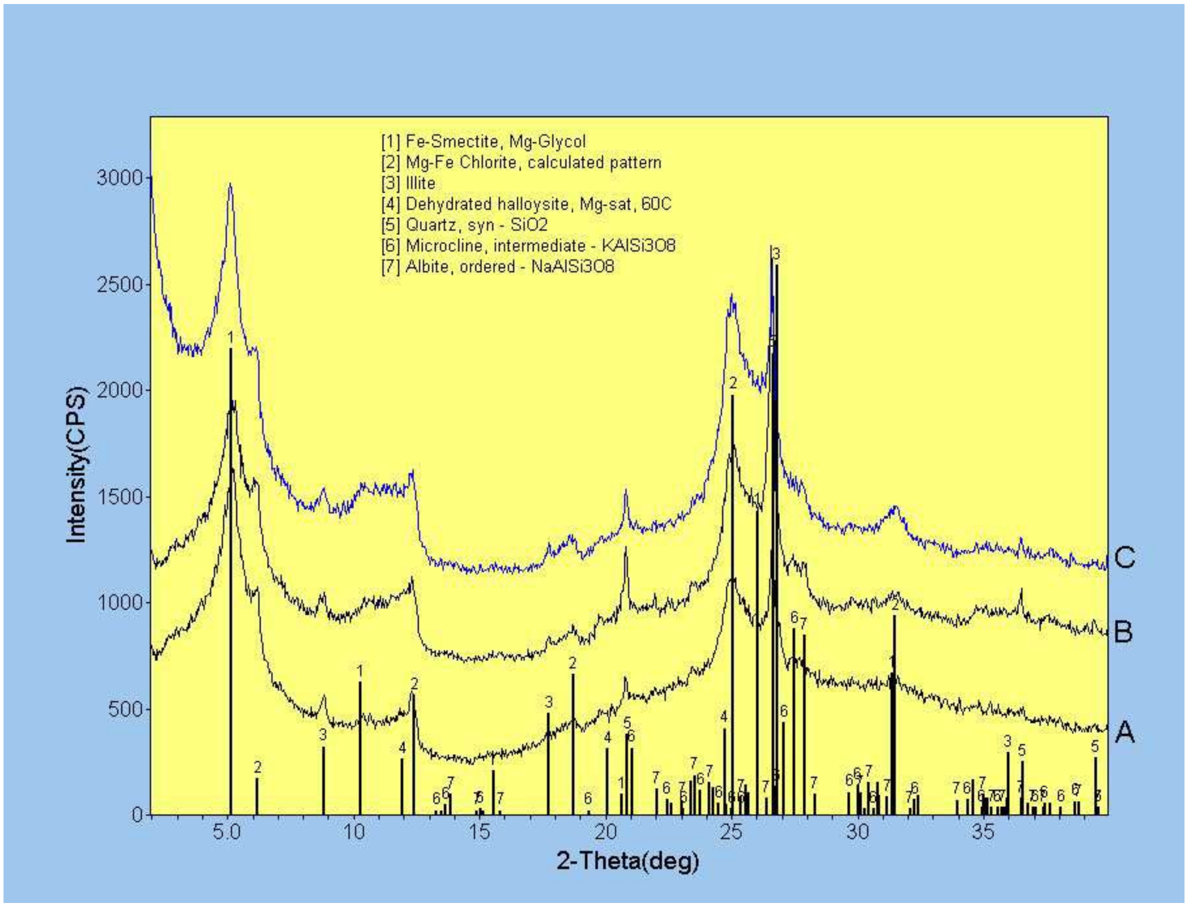

Figure 14. Suspended sediment mineralogy at the Wren location on the middle Marys River subwatershed during 3 storm events. The lower pattern represents the 12-2-98 storm event (A), the middle pattern represents the 12-28-98 storm (B), and the upper pattern represents the 11-26-99 storm (C). All three samples exhibit very similar mineralogy, which consists of a mixture of smectite, chlorite, mica, quartz, and feldspar. <2-μm fraction, Mg-Glycol pattern.

Muddy Creek Subwatershed

The Muddy Creek drainage accounts for about half the area of Marys River Watershed (Figure 2). Heading in the southeastern part of the watershed near the town of Bellfountain, the Muddy flows northward as a low gradient stream that roughly parallels the track of the Willamette River. Muddy Creek is unusual. Why didn't its eastward flowing tributaries continue across the valley to the Willamette River? The most likely explanation is that deposition of glacial silt and subsequent Willamette River levee deposits in the center of the valley built a slight mound that deflected eastward-flowing tributaries to the north. In order for these east flowing streams to access the Willamette River they must fill in the low area behind this natural levee to re-establish their former courses across the valley. Ongoing stream deposition results in a broad swamp land region along the course of Muddy Creek. During high winter flow, the Muddy consists of a broad depositional wetland where stream flow is generally not confined to any major channel. Muddy Creek is appropriately named –

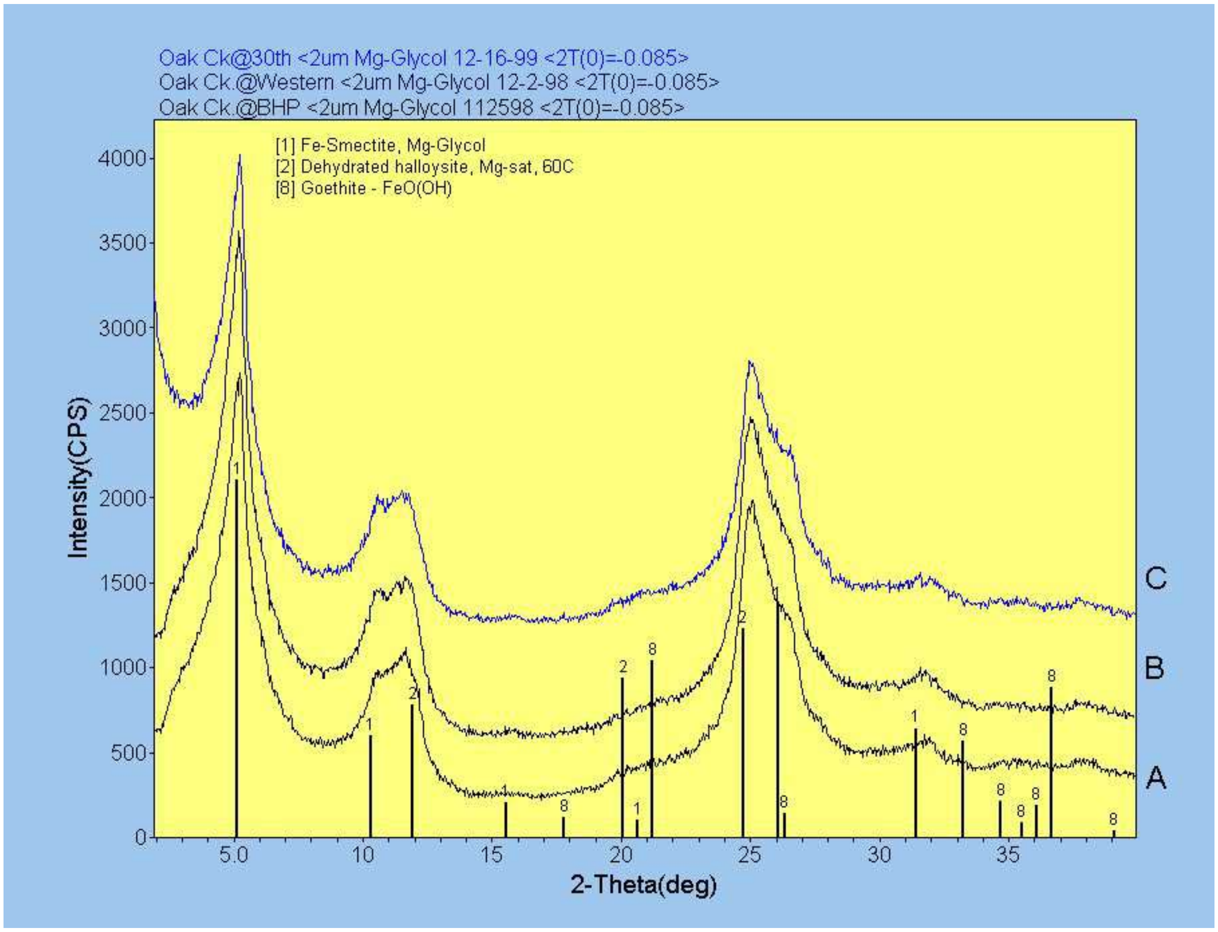

Figure 15. Suspended sediments from Oak Creek show essentially no downstream variation in clay mineralogy. The smectite-dehydrated halloysite-goethite assemblage is common at Bald Hill Park (A), 30th St (B), and at Western Blvd (C). The absence of quartz reflects the basaltic source material of the suspended sediment and further indicates an absence of eroded contribution from glacial silts that border the lower reaches of Oak Creek.

its geological framework has forced it to become an extensive wetland where coarser sediments rapidly settle out, leaving fine mud in suspension.

Major tributaries to Muddy Creek include the Evergreen, Bull Run, Beaver, Gray, Oliver, Reese, and Hammer Creeks. These subwatersheds lie in the easternmost Coast Range and associated low foothills that are underlain by sedimentary rocks (Figure 1). The higher topographic features of the area (Flat Mountain, Green Mountain, Decker Ridge) are “held up” by igneous intrusive rock. These rocks squeezed up through the sandstone and mudstone while in a hot, molten form and cooked the adjacent sediments. The predominant landform of these valley-fringing mountains is hummocky slump topography produced by ancient (and ongoing) large rotational landslides (Photo 2).

Photo 2. Hummocky topography on Flat Mountain results from ancient rotational landslides. The steep slope at the right of this photo is the exposed slump failure surface. The relatively flat segment in the center of the photo is the current top of the rotated soil block. The steep slope in the distance is another slump scarp. These steep scarps expose relatively unweathered sedimentary bedrock.

The suspended sediment mineralogy of tributary subwatersheds can be grouped on the basis of subwatershed geomorphology. Runoff from low elevation subwatersheds (Evergreen, Bull Run, Starr, and Gray Creeks) with low rounded hills exhibits a clay mineral assemblage that is dominated by chloritic intergrade and kaolinitic clay with abundant fine quartz (Figure 16). Most samples contain a trace amount of illite. Smectitic clay are generally absent. The features of the XRD patterns of these suspended sediment samples are very similar to those obtained from the red soils that occur on low foothill landscapes (Figure 7). The general absence of illite and smectite in the suspended sediment from these low elevation foothill watersheds reflects the erosion of intensely weathered old soils. As noted earlier, the prolonged weathering that affected low foothill landscapes mantled by Jory and Bellpine soils resulted in destruction of illitic and smectitic clays and formation of kaolinitic and chloritic soils. Streams have not cut through the strongly weathered zone into “fresh” sedimentary bedrock, where illitic and smectitic mudstones occur. Because of the lack of depth-related mineralogical variation in the soil, it is hard to relate suspended sediment mineralogy to a particular source, although the stronger indication of smectite in Evergreen Creek suggests a component of deep erosion.

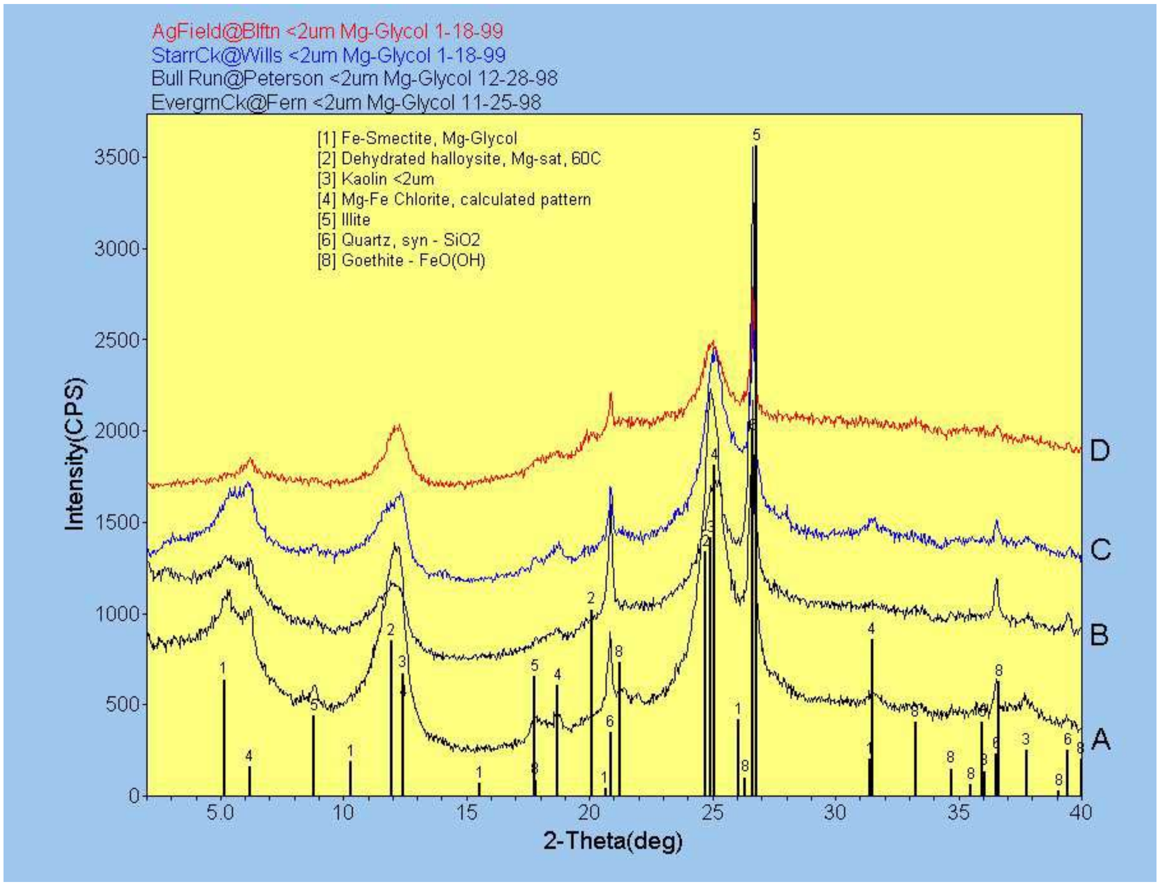

Figure 16. The clay mineralogy of suspended sediment from low elevation subwatersheds draining into Muddy Creek is dominated by chloritic intergrade and kaolinitic (halloysitic) clays that indicate prolonged weathering. Compare these patterns with clays shown in Figure 7. A. Evergreen Creek @ Fern Rd., B., Bull Run Creek @ Peterson Rd., C., Starr Creek @ Wills Drive, D., Gray Creek @ Bellfountain Rd. <2-μm Mg-Glycol patterns.

In contrast to the chloritic intergrade-kaolinitic mineral assemblage of the low foothill watersheds, streams draining higher elevation landforms exhibit suspended sediments that are highly illitic and contain well crystalline chlorite (not chloritic intergrade – Figure 17). In addition the clay assemblage includes regular interstratified mixed layer clays (illite/smectite and chlorite/smectite) that developed during baking of sedimentary rock during igneous intrusion (see Figure 9). These interstratified clays are not found in shallow soil exposures on Flat Mountain (Figure 8), but do occur in deep exposures (deep road cuts, landslide scarps, deeply incised stream banks). The clay mineral assemblage of suspended sediments in Beaver Creek is almost identical to that identified in the upper Greasy Creek above Botkin Rd (see Figure 11). The upper Greasy heads on the northwest side of Flat Mountain and is influenced by the same baked-rock geology as Beaver Creek. The headwaters of both drainages consist of steep hummocky terrain formed by ancient landslides. The rotational character of these landslides brings deep soil material to the surface and continually feeds sediment to streams through soil creep.

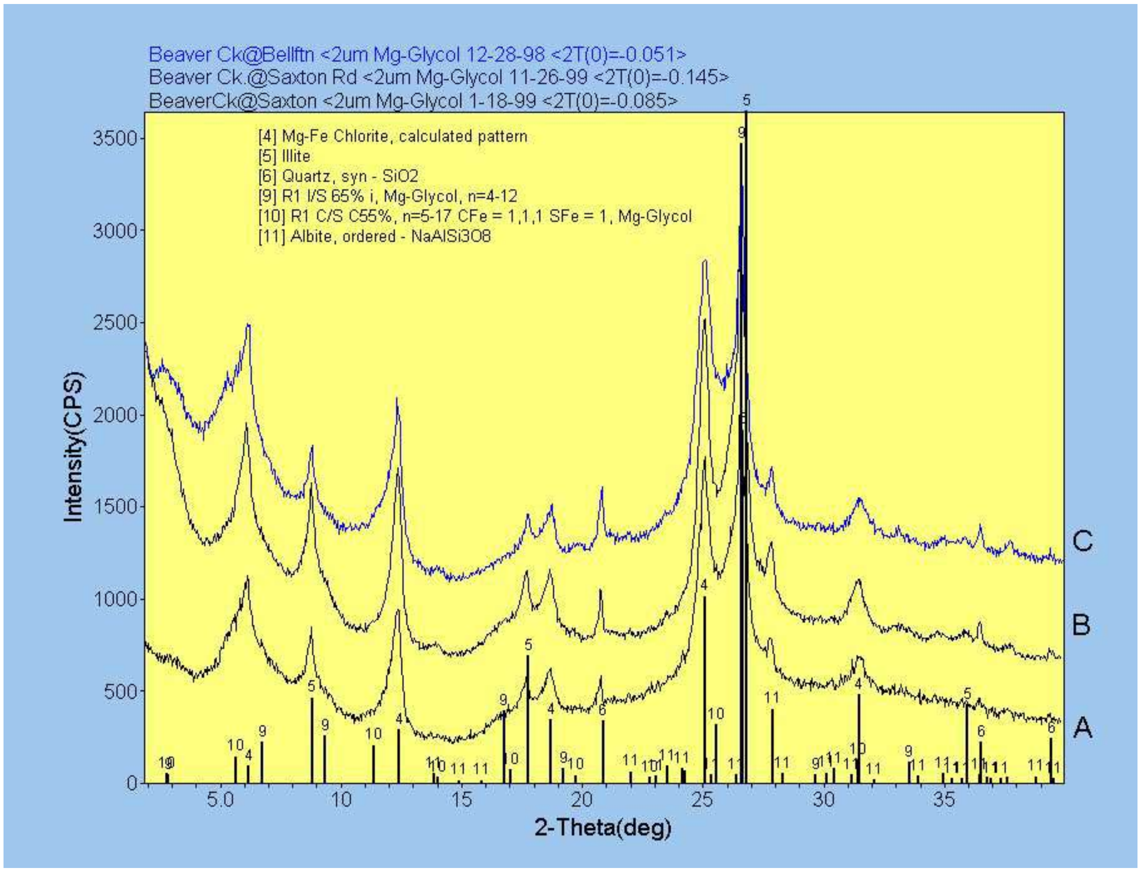

Figure 17. The suspended sediment mineralogy of runoff from Beaver Creek includes abundant illite and chlorite, with associated interstratified clays (illite/smectite and chlorite/smectite). These interstratified clays do not occur in the upper parts of highly weathered soils in the watershed, but are found at depth (see Figures 8 & 9). Note that suspended sediment mineralogy did not appreciably change after the dam failure (11/26/99 event), indicating the continual presence of a deep sediment source (landslides or road sediment).

The suspended sediment mineralogy from Oliver Creek is generally similar to that observed in the Beaver Creek watershed and includes illite, chlorite, and mixed layer illite/smectite clays (Figure 18C). In contrast, red soil material exposed in roadcuts bordering upper reaches of Oliver Creek is non-illitic (Figure 18A) in has the chloritic intergrade-kaolin-gibbsite clay mineral assemblage of deeply weathered Jory-like soils (compare with Figure 8). Similar clays were identified in Oliver Creek roadbed material that was eroded during the 12/28/98 flood (Figure 18B). Roadbed erosion occurred as a result of deflection of Oliver Creek by a debris dam that developed due to rafting of large woody debris in the 12/28/98 floodwaters (Photo 3). While physical evidence of roadbed erosion and shallow soil slumping were common in the Oliver Creek drainage, the suspended sediment mineralogy obtained during a subsequent storm event (1/18/99) did not suggest shallow sediment sources. The highly illitic and chloritic nature of the clays in the 1/18/99 runoff is strongly unlike the clay assemblage of shallow sediment sources adjacent to the stream

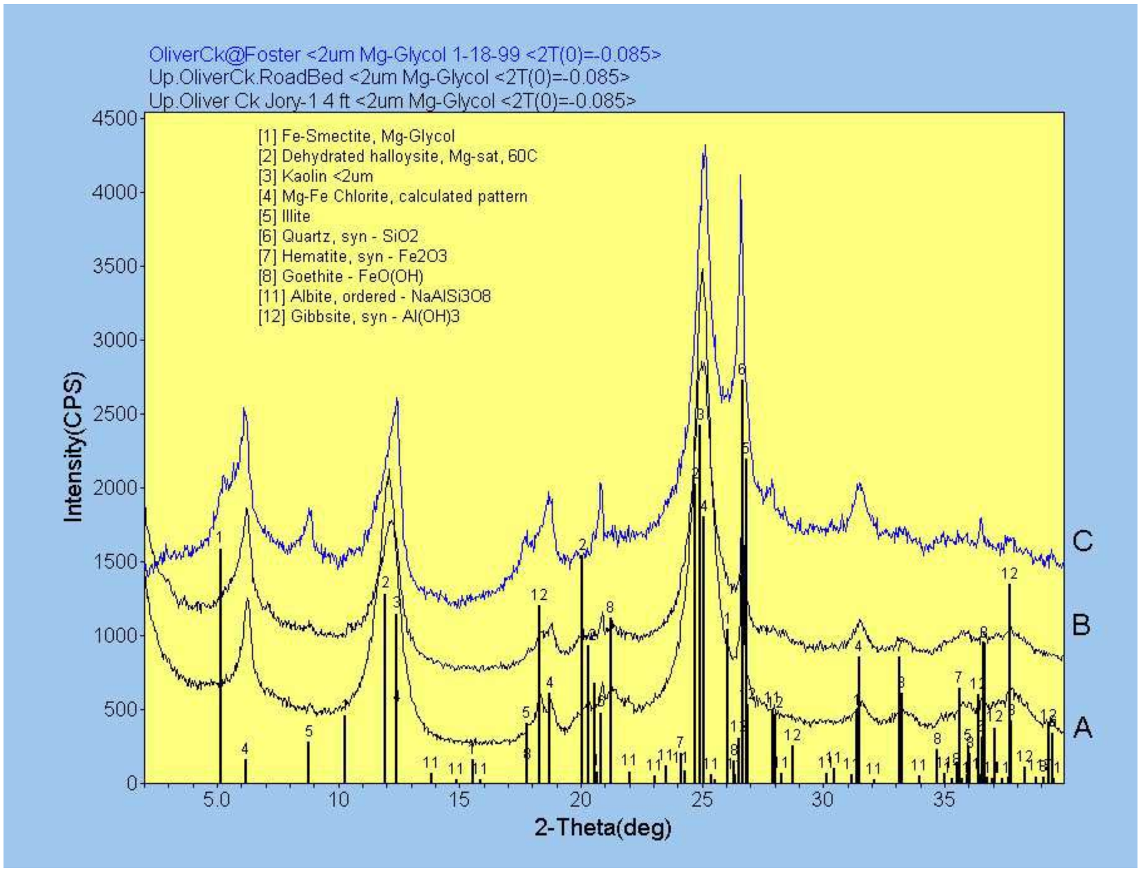

Figure 18. Suspended sediment from Oliver Creek (C) exhibits a very different character than soil material exposed in roadcuts adjacent to the stream (A) or roadbed material eroded during the 12/28/98 storm event (B). Shallow soil material contains chloritic intergrade, kaolinite, and gibbsite, whereas the suspended sediment is illitic, chloritic, and enriched in quartz relative to the highly weathered soil. This difference in mineralogy suggests that sediment associated with the 1/18/99 runoff was not derived from erosion of shallow soils, but tapped deeper, less weathered sedimentary bedrock.

and indicates a dominance of deep sediment sources (deep stream incision, erosion of slump toes, road runoff from deeply incised roadcuts). Unfortunately, the suspended sediment associated with the 12/28/98 flood at this location was not sampled due to restricted access.

DISCUSSION

The clay mineralogy of suspended sediments within the Marys River Watershed clearly defines distinct geologic provinces of the watershed. The upper Marys River area that is underlain by deep marine sandstone and mudstone has a distinctive chlorite-illite-smectite assemblage that is very different from the smectite-dominated clays eroded from basaltic watersheds. Furthermore, low elevation foothill subwatersheds have a distinctive chloritic intergrade-kaolin-quartz assemblage that reflects deep weathering and mineralogical

Photo 3. A debris dam on Oliver Creek formed during the 12/28/98 storm and diverted flood discharge onto Oliver Creek Road, stripping road gravel and eroding part of the compacted road bed. The clay mineralogy of this road bed material is illustrated in Figure 18B. Formation of such dams is a natural occurrence in streams with large woody debris and the associated channel diversion results in significant erosion.

homogenization of soils. This homogenization probably reflects derivation of the modern soil from downslope transport of much older soil material (colluvium). Higher elevation watersheds that drain into Muddy Creek yield suspended sediments with a strong illite-chlorite-mixed layer clay assemblage that originated as a result of geologic “cooking” of the sedimentary rocks by igneous intrusions.

Of greatest interest to this study is the apparent absence of shallow soil material in stream suspended sediments. Shallow soil horizons (generally A horizon material, approximately 0-10 inches deep) usually contain distinctive chloritic intergrade clays, especially where soil drainage permits periodic wetting and drying. In the lower foothills, the surface soil horizon often contains illitic clay related to deposition of glacial or wind-blown silt on older soils (paleosols – Figure 6). In mountainous settings, the stable surface soils contain gibbsite and kaolin-group clays, in addition to strongly developed chloritic intergrade clay. These phases are absent in all sediment samples except those originating from lower elevation foothill drainages (Bull Run, Evergreen, Starr, and Gray Creeks). As shown, the red soils on these foothill watersheds display similar mineralogy over a wide range of soil depth due to colluvial mixing and extreme weathering.

The absence of “shallow” soil clays in suspended sediments from the watershed indicates that most erosion reflect “deep” sediment sources. Deep is here defined as near the rock-soil interface (C horizon or weathered bedrock). On seriously eroded soilscapes, “deep” erosion may translate into a depth of a few feet, whereas in steeply sloping, slumped mountain settings, deep may mean several 10’s of feet. The significant factor in identifying the sediment source as deep is the presence of readily weatherable minerals that are excluded in the modern soil profile (e.g., mica, feldspar, zeolite, smectite, hydrated halloysite, or regular interstratified mixed layer clays). Minerals with a “deep” character may also be found in the surface horizons of young soils, especially if the young soils are developed in material eroded from fresh bedrock. Thus, cutbank erosion of the young floodplain soils bordering the Marys River results in recycling of smectitic clays transported out of steep mountain landscapes.

The clay mineralogical data obtained as a result of this study indicates that episodes of shallow surface erosion are very infrequent in the Marys River Watershed (i.e., rilling, sheet wash, and debris avalanche). The reasons for this lack of shallow erosion reflect a variety of environmental factors, including storm intensity and soil permeability. The Pacific Northwest is characterized by storms of low to moderate rainfall intensity that rarely exceed the infiltration capacity of the soil. Over time, poorly drained soils flood, not because of high rainfall intensity, but because they gradually fill to the brim with water. In contrast, well-drained soils rapidly transmit water downslope as subsurface flow. Where this subsurface flow intercepts the ground surface, stream flow is initiated. On steep hillslopes that are truncated by logging roads, water may often be observed flowing from exposed roadcuts. This artificially “exhumed” soil water then becomes part of the surface flow and carries with it minerals characterizing deep soil environments.

Deep erosional processes include stream bank erosion, logging road runoff, landslide reactivation, and deep gullying. Modern floodplains tend to display mineralogical characteristics similar to the sediments transported by their streams. This results from overbank deposition on floodplains during high flow and subsequent recycling of floodplain sediments by stream channel migration. It is significant that turbidity always increases on the low gradient meandering segments of the Mary’s River (Table 3). This reflects the importance of cutbanks and lateral channel migration in meandering river systems. Meandering stream channels migrate laterally across broad floodplains, continually reworking the sediments stored in floodplain soils. Thus the smectite-halloysite-zeolite character of the soils on the Marys River floodplain near Borden Rd Bridge indicates deep erosion of weathered basalt (the presence of zeolite is particularly significant, since zeolite does not survive surficial acid weathering environments, see Appendix 2).

Since the suspended sediment mineralogy suggest that turbidity is largely related to deep erosional processes, steps to reduce stream turbidity should be focused on areas most sensitive to erosion – the steep basaltic landscapes of Greasy, Woods, and Oak Creeks, and the lower eroding stream banks of the Marys River floodplain below Philomath. Proper management of logging road sediment will reduce an important source of deep erosion. Since road runoff entrains subsoil materials exposed during road grading, it is imperative that road discharge not be allowed to enter streams. Road runoff should be diverted to areas of the landscape where surface water can percolate back into the soil and resume its downslope subsurface flow. Ultimately, a portion of the soil subsurface flow must reach the permanent water table and become part of normal stream flow. In steep mountainous terrain, geologic erosion associated with stream incision and soil mass movement is a fact of life. The smectitic sediments of the mile-wide floodplain of the lower Marys River didn't develop overnight, but represent thousands of years of erosion of Mary's Peak, much of it related to occasional large landslides that are gradually removed by the streams into which they flow. Such geologic erosion can never be eliminated, but short-term management-related additions can be minimized through better road design and maintenance and use of environmentally friendly logging techniques (adequate stream buffers, no skid trails up ephemeral drainages, etc.).

Curtailing stream channel migration on the lower Marys is a more difficult process. Bank protection through addition of rip rap material is a local solution, but almost guarantees accelerated erosion downstream of the protected reach. Channel margin vegetation provides minimal protection from erosion during major runoff events, but may greatly influence stream temperature by providing important shade and snags. Since the lower Marys River flows across a clay-dominated floodplain, there is little in the way of natural rock to stabilize stream banks. During average winter runoff, bank erosion is generally not severe; however, severe floods can greatly perturb river channel morphology, as was the case in the lower Greasy Creek following the February 1996 flood. Channel avulsion and bank erosion associated with this prolonged flood event seriously perturbed channel equilibrium within the lower reach of Greasy Creek. Tree falls and snags rerouted stream flow against formerly stable banks and resulted in significant channel migration and loss of real estate. This portion of he Greasy Creek subwatershed continues to be a sediment-sensitive area that may require artificial restoration to achieve short-term turbidity mitigation.

Other Thoughts About This Project

One problem faced with this project was the large size of the watershed and long distances between sampling stations. Because of this geographical complexity, the timing of peak streamflow varied from location to location. It was not always possible to obtain sediment samples or measure turbidity on the rising limb of the hydrograph or be sure that the maximum discharge event was sampled. To accomplish such sampling would require constant observation of sampling locations by a highly dedicated team of volunteers or remotely controlled automated sampling. Neither of these options was possible given the low budget and preliminary investigative nature of this study. At a time when so much is to be gained from environmental watershed studies, these studies remain financially beyond the means of local watershed councils. The U.S. Geological Survey once had a mandate to perform such studies, but now is limited by budget and manpower to larger watershed studies with strong local funding. As shown by the true cost analysis of this Marys River turbidity project (Table 4), even a limited study of soils and sediments in a watershed can incur large expense.

Another problem facing any kind of monitoring study is normal climatic variability. As shown in the discharge plot for the 1998/1999 and 1999/2000 runoff years (Figure 3), large variations occur in annual, monthly, or daily stream discharge and storm intensity. If a project has a short term focus, it is difficult to ensure collection of representative data. This study, if it had only considered the year of project funding, would have missed the major 12/28/98 storm event and frequent overbank flooding associated with the above normal rainfall that occurred in early 1999. Environmental studies must be based on long term observation, which requires prolonged dedication of volunteers and funding agencies to see to the establishment of permanent monitoring programs.

The technique of X-Ray Diffraction analysis is well suited to the study of fine-grained sediments, but mineralogy is a very dry subject to the average watershed resident. Writing a report based upon highly detailed sediment analysis for public consumption is a difficult task. An appreciation of earth science is fundamental to any watershed monitoring project. I was inspired by the power of the 12/28/98 storm and the great intensity of the runoff it produced. Standing on bridges with a bucket on a rope, trying to avoid trees that were floating down stream, seeing the water boil and stream banks collapse, I gained a great appreciation for the dynamic forces at play during a severe winter storm. I hope to continue to gather watershed data in the coming years and promote scientific study of the Marys River Watershed whenever possible.

CONCLUSIONS

In summary, the Marys River Watershed is a river system that is prone to high turbidity during periods of high winter streamflow. Mineralogical evidence indicates that basaltic landscapes in the middle portion of the watershed are most sensitive to erosion, yield the highest stream turbidity, and historically have dominated stream sedimentation patterns. In contrast, the upper reaches of the watershed are characterized by fairly low turbidity flood events with distinctive illitic sediment character. The mineralogical nature of suspended sediments from the watershed indicates a predominance of deep erosional processes. Such erosion is dominantly of geologic origin, but is accentuated by management activities that destabilize hillslopes or promote erosion of artificially exposed deep soil layers.

The reconnaissance nature of this monitoring study points to a need for more detailed monitoring of turbidity on the subwatershed level. It is difficult to define “background” turbidity in the watershed without continuous turbidity monitoring at several locations. The published “maximum” turbidity for the watershed (53 ntu, Marys River Watershed Assessment) is an example of the poor background data that are available for the watershed. If “background” turbidity was based on the flow weighted average for the winter runoff season, a very different definition of “normal” stream turbidity would result. High stream turbidity in the lower Marys is a normal winter occurrence; however, some excessively high turbidity events are man-made (e.g., Beaver Creek 11/26/99 runoff event). Mineralogical analysis of suspended sediment helps identify the kinds of processes that influence stream turbidity. Though generally incapable of finding a “smoking gun” or point sediment source within a large watershed, such data are essential for distinguishing between shallow versus deep sediment sources and associated erosive processes.

EXPENSE SUMMARY

The major expense associated with this project involved per-sample charges for X-ray diffraction analysis and operator wages. Over the course of the 2 water-years of sediment sampling 70 suspended sediment samples were analyzed (Table 4). In addition, the clay mineralogy of soil from the valley floor, low foothills, and other locations within the watershed was determined, representing over 25 separate analyses. Other expenses included purchase of the Hach 2100P turbidimeter and assorted laboratory chemicals required for preparation of clay samples. Travel mileage was considerable, owing to the large extent of the watershed. As evident, project expenses significantly exceeded the budget amount requested from OWEB. Willamette Geological Service donated the bulk of the extra expense, primarily through in-kind services and free XRD analyses. Some of the chemicals required were purchased with OSU Foundation funds designated for clay mineral research. In addition, many of the soil clay mineral analyses were performed by students enrolled in the graduate clay mineralogy course offered by the Department of Geosciences. The approximate dollar value of these analyses is around $5000 and was considered a donation of in-kind service to the project. Without the nearly $15,000 in donated labor and laboratory expense, this project could not have progressed.

Table 4. Expense summary for the Marys River Watershed Turbidity/Sediment Monitoring Project.

Activity	# Samples	$/Sample	Total $
Clay XRD	70	200	14,000
Soil XRD	25	200	5,000
Turbidimeter			780
Mileage	700	0.35	245
Chemicals			300
Payroll	120	12	1,440
Cascade Pacific Overhead			800
Total Expense			22,565
OWEB Funds			8,000
OSU Funds*			5,300
WGS Funds			9,265

* Value of donated Mineralogy Class XRD analyses.

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Appendix 1.

Turbidity and Environmental Data For Marys River Watershed Turbidity Monitoring Project, 1998-2000

Appendix 2.

Compilation of XRD Patterns of soil and suspended sediment samples from Marys River Watershed.

This section will be provided upon request to persons desiring a detailed look at individual XRD patterns.