Washington State
Department of Transportation

Transportation Building
310 Maple Park Avenue S.E.
P.O. Box 47300
Olympia, WA 98504-7300

360-705-7000
TTY: 1-800-833-6388
www.wsdot.wa.gov

Short synopsis of the SR 530 Milepost 35-41 geotechnical study

In 2014, the Washington State Department of Transportation (WSDOT) and a group of partners from Snohomish County, Washington State Department of Natural Resources, United States Geological Survey and the Tulalip and Stillaguamish Tribes conducted a geotechnical study in the State Route 530 corridor impacted by the May 22, 2014 landslide. WSDOT has a vested interest in conducting this study relative to the safety of the highway in the future.

What is the purpose of this study?

This study consisted of a preliminary "big-picture" examination of the subsurface conditions on the north and south sides of the Stillaguamish River Valley within the SR 530 slide area for the following:

- Geologic conditions (rock and soil layers).
- Hydrogeologic conditions (distribution of underground water in rock and soil layers).
- Geotechnical conditions (behavior of the soil and rock).

This study:

- **Does not** examine or determine the cause(s) of the SR 530 landslide that occurred on March 22, 2014.
- **Does not** establish the groundwater conditions that existed in the hillside prior to the 2014 landslide; those conditions cannot be retroactively determined.
- **Does not** quantify the risk or impact of future landslide activity in the valley.

What methods were used to gather data for this study?

To complete this study, last October, WSDOT geotechnical engineers drilled two 650-foot-deep test borings behind the SR 530 landslide headscarp on Whitman Bench and one 300-foot-deep test boring on the south side of the valley near Skaglund Hill. They also installed ten instruments (piezometers) in the borings to monitor groundwater response to rainfall.

A summary of what we learned

On the north side of SR 530 behind the landslide headscarp on Whitman Bench:

- The SR-530 landslide involved two different landslide masses of near-equal volume:
  1. A comparatively weak landslide deposits that covered the hillside and have been the source of historic landslide activity.
  2. An underlying, 650-ft-thick sequence of undisturbed, comparatively strong, glacial, and possibly non-glacial, deposits. The lower half of this bench consists of mostly compact clay.
- In general, aquifers identified within the intact sequence behind the SR 530 landslide headscarp demonstrated no response to precipitation to a variance of less than 5 feet over this past winter.

On the south side of SR 530 near Skaglund Hill:

- Failure zones near Skaglund Hill within two comparably large, mobile prehistoric landslides are located:
  - Near the bottom of the glacial sequence within compact, layered silts and clays.
  - Are likely flat to shallowly inclined for more than 1,000 feet in length.
- Aquifers were noted in the deposits of two landslides on the south side of valley, and were responsive to precipitation.
- Piezometers installed within the intact glacial and non-glacial deposits generally exhibited no to very limited (less than 5 feet) response to short-term (days to weeks) and longer-term (season) precipitation for the monitoring period between December 2014 and May 2015.

By completing this short study, both WSDOT and our partners learned more about the current geologic, hydrogeologic and geotechnical conditions between mileposts 35-41. The information learned may be useful for future geotechnical work necessary to maintain existing infrastructure or for land use activities within the area.

GEOTECHNICAL REPORT

SR 530 MP 35 to 41 Geotechnical Study

For our partners at Snohomish County, the Washington State Department of Natural Resources, the United States Geological Survey Landslide Hazards Program, and the Tulalip and Stillaguamish Tribes.

State of Washington
Engineering Geologist
114
Licensed Geologist

6/23/15

Thomas C. Badger

Prepared by:
Thomas C. Badger, LEG, LHG, PE
Chief Engineering Geologist

Technical review by:
Tony M. Allen, PE
State Geotechnical Engineer

June 2015

Washington State Department of Transportation
Lynn Peterson
Secretary of Transportation

Construction Division
Geotechnical Office
P.O. Box 47365
Olympia, WA 98504-7365

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EXECUTIVE SUMMARY

As a result of a March 22, 2014 landslide near the town of Oso, Washington (SR 530 landslide), a group that included Snohomish County (SnoCo), the Washington Department of Natural Resources (DNR), the United States Geological Survey Landslide Hazards Program (USGS), the Washington State Department of Transportation Geotechnical Office (WSDOT), the Tulalip Tribes and the Stillaguamish Tribe, initiated a geotechnical study. The objective of this study is to advance current understanding of the geologic, hydrogeologic, and geotechnical conditions that may contribute to landsliding in this portion of the valley, focusing on those having large volume, exhibited high mobility, and, thus, potentially posing the most severe public risks. This study does not quantify the risk and impact of future landslide activity in the valley, nor is it a forensic investigation of the SR 530 landslide. There are five primary study components:

1. Drilling two deep geotechnical borings behind the SR 530 landslide headscarp to define the nature and thickness of the geologic units within the undisturbed sequence of valley fill.
2. Utilizing piezometers installed in the borings to identify the groundwater regimes in the undisturbed sequence immediately behind the SR 530 landslide headscarp and to monitor their short and long-term response to precipitation.
3. Laboratory testing of representative samples recovered from the borings to characterize the basic engineering properties of each geologic unit.
4. Ascertain if the same glacial sequence and groundwater regimes in the vicinity of the SR 530 landslide are present on the south side of the valley. A third deep boring was drilled and instrumented, and other geotechnical data was reviewed, to examine two prehistoric landslides on the south side of the valley with comparably large volume and high mobility.
5. Documentation of field observations and other data regarding the landslide activity at the site of the SR 530 landslide.

The 650-ft-thick undisturbed sequence beneath Whitman Bench near the SR 530 landslide headscarp down to near river level consists of sands, silt and clay derived primarily from the last continental glaciation. Clay dominates the lower half of the sequence. Most of this sequence is very dense/hard, due to several thousand feet of ice-loading. Thick landslide deposits mantle the slope of Whitman Bench and the slopes along much of the north and south sides of the river between SR 530 Mile Post 35 to 41.

The SR 530 landslide involved essentially two distinctly different masses of apparent similar volume:

1. a comparatively weak, dilated mass of prehistoric and historic landslide deposits that mantled the terrace face and that have been the sole source of historic landslide activity at the site, and
2. an underlying, 600-ft-thick sequence of undisturbed, comparatively strong, glacial, and possibly nonglacial, deposits.

In general, aquifers identified within the intact glacial sequence behind the SR 530 landslide headscarp demonstrated no response to precipitation to a variance 5 feet for the monitoring period of December 2014 to mid-May 2015. One of the two borings (H-1vwp-14) encountered extremely pressurized groundwater at 630-ft depth within a sand unit beneath the glacial clay, which produced artesian flow for a short time. An adjacent boring drilled to the same 630-ft depth did not encounter extremely pressurized conditions. The significance to landsliding and areal extent of this pressurized aquifer is not fully known at this time.

Geotechnical borings were also drilled within two comparably large and mobile prehistoric landslides on the south side of the valley as part of this investigation and previous investigations at the Skaglund Hill landslide. The borings indicate that the lower portion of the glacial sequence of valley fill is similar to the north side in the vicinity of the SR 530 landslide. Aquifers were noted in the landslide debris of these two prehistoric landslides on the south side of valley, and they were responsive to precipitation. In addition, the failure zones within these two prehistoric are:

- located near the bottom of the glacial sequence within very hard, laminated/stratified silts and clays (advance glaciolacustrine unit); and
- likely flat to shallowly inclined for more than 1000 feet in length.

Future investigations by others to more fully define landslide hazards may wish to pursue the following:

- Defining the intact sequence of geologic units present on the south side of the valley above SR 530;
- Delineating and characterizing the location, shape, orientation, and geotechnical properties of the failure zone within the SR 530 landslide;
- Performing advanced geotechnical testing to identify potential failure mechanisms;
- Determining the triggering mechanisms, contributing factors, and sequencing of the SR 530 landslide; and,
- Investigating the frequency of occurrence of large volume, high mobility landslides in prehistoric time.

INTRODUCTION

The landslide that occurred on March 22, 2014 near the community of Oso, Washington, referred to herein as the SR 530 landslide, has generated considerable scientific interest, due to its large volume, highly mobile behavior, and the density of large landslides within the surrounding six-mile-reach of the North Fork Stillaguamish River valley.

Following the recovery phase of the disaster, a group that included Snohomish County Public Works (SnoCo), Washington Department of Natural Resources Division of Geology and Earth Resources (DNR), the United States Geological Survey (USGS) Landslide Hazards Program, the Washington State Department of Transportation Geotechnical Office (WSDOT), the Tulalip Tribes, and Stillaguamish Tribe committed resources to acquire more detailed information about the landslides in the valley between the communities of Oso and Darrington (Figure 1). This study focuses on both the north and south valley slopes along SR 530 between Mile Posts (MP) 35 to 41.

The objective of this study is to advance current understanding of the geologic, hydrogeologic, and geotechnical conditions that may contribute to landsliding in this area of the valley, specifically focusing on those having large volume, exhibited high mobility, and, thus, potentially posing the most severe public risks, like the SR 530 landslide. This study does not quantify the risk and impact of future landslide activity in the valley, nor is it a forensic investigation of the SR 530 landslide. There are five primary study components:

- Definition of the nature and thickness of each major geologic unit within the undisturbed stratigraphic sequence of valley fill immediately behind (northwest of) the SR 530 landslide headscarp from the top of Whitman Bench (elevation 890 ft) to below river level (elevation 240 ft).
- Identification of the groundwater regimes in the undisturbed stratigraphic sequence immediately behind the SR 530 landslide headscarp, which may contribute to slope instability, and monitoring of their short and long-term response to precipitation.
- Determination of the general engineering characteristics and behavior of the major geologic units through a basic suite of geotechnical laboratory tests.
- Documentation of other data regarding the landslide activity at the site of the SR 530 landslide to provide context for field observations.
- From previous geologic mapping by others, a similar glacial sequence of valley fill appears to be present on the south side of the valley above SR 530, where comparable large volume, highly mobile landslides also initiate. Therefore, the fifth component is to ascertain if the same generalized stratigraphic sequence and groundwater regimes as the north side of the valley are present on the south side. In addition, two prehistoric landslides on the south side of the valley with comparably large volume and high mobility are examined.

WSDOT's participation in the study included drilling and instrumenting three deep test borings, monitoring the instrumentation, and summarizing the results. SnoCo observed geologic field operations and provided geotechnical input. USGS coordinated the laboratory testing of the samples recovered in the borings, which was performed by the University of California,

Berkeley, Department of Civil and Environmental Engineering. DNR aided in the stratigraphic interpretation of the samples recovered from the borings.

Landslides may be considered to have essentially two phases of development – an initiation and deformation phase. The initiation phase is governed by the geologic, hydrogeologic and geotechnical conditions and characteristics present in the slope and changes in the stress conditions that drive a slope to become unstable and begin to deform. The deformation phase is a mechanically complex suite of interacting processes and physical constraints, such as material strain, breakage and disaggregation; elevation and dissipation of pore pressures; and freedom of movement, which control how fast and how far a landslide might travel (mobility). This study is concerned with the subsurface conditions that may contribute to the initiation of landslides in the valley. Defining how and which landslides within the valley transition from the initiation phase into a highly mobile deformation phase is beyond the scope of this study.

This report provides preliminary results from the study, describing the methods used and summarizing initial results. This report provides factual data and limited fact-based interpretations, and identifies what additional information is needed to more fully characterize the landslide hazards in the valley and manage their respective risks. Interpretation of the study results in this report is limited to:

- geologic characterization of the undisturbed stratigraphic sequence that was involved in and presently exists behind the SR 530 landslide;
- a preliminary delineation of the failure surfaces and undisturbed stratigraphy beneath a prehistoric and several historic landslides that were nested within the limits of the SR 530 landslide;
- a preliminary delineation of the failure surfaces and undisturbed stratigraphy beneath two large prehistoric landslide on the south side of the valley; and,
- a preliminary definition of the groundwater regimes immediately upslope of the SR 530 landslide and within two large prehistoric landslide on the south side of the valley.

Ongoing laboratory testing and instrumentation monitoring associated with this study may result in the production of another report at a later date.

GEOTECHNICAL INVESTIGATION

The results presented in this report were derived from a variety of sources, as described in the subsections that follow.

Literature Review

Geologic references, aerial photography, widely available documentation regarding the historic landslide activity of the site, and recent publications that have investigated various conditions surrounding the SR 530 landslide were reviewed. The documents reviewed are listed in the references at the end of this report.

Remote Mapping and Analyses

Bare earth models from 2003, 2013, and post-event 2014 lidar data and post-event terrestrial laser scanning data were utilized in a GIS platform and within PolyWorks™ to remotely map and interpret geomorphic characteristics of landslides in the valley (Appendix A: Gerstel and Badger, 2014). These data were also used to extract slope profiles through landslide features, locate features of interest, measure orientations of key landslide features, and carry out change analyses to assess surface deformation.

Field Reconnaissance

Some members of the interagency group collectively spent numerous weeks on site performing a variety of field-related tasks that included aerial reconnaissance immediately after the event, ground reconnaissance in the weeks and months following the search and recovery operation, river channel excavation, and highway reconstruction. These observations included:

- the distribution and geologic/geomorphic characteristics of the various landslide domains (referred to as *zones* in the GEER report (Keaton et al., 2014)),
- hydrogeologic conditions,
- geotechnical behavior (i.e., stability, degradation/erosion susceptibility, liquefaction susceptibility of the landslide debris, nature of excavated landslide debris and stability of excavated slopes), and
- geomorphic characteristics of adjacent slopes and landslides features on both sides of the valley.

Subsurface Exploration

Between October 14th and November 20th, 2014, WSDOT drilled three geotechnical borings: two borings (650.5 ft and 635.0 ft in depth) immediately behind the March 22nd landslide headscarp and one 300-ft-deep boring within a large prehistoric landslide exhibiting high mobility located on the south valley above SR 530 (Fig. 2). The borings were primarily advanced by reverse circulation, wet rotary method and an HQ-sized triple-tube, wireline, diamond coring system and bentonite-polymer drilling mud. Lexan tubes were intermittently substituted for the steel split sleeves to retain, preserve and transport relatively undisturbed core samples. Retention of core samples in Lexan tubes inhibited detailed field examination and description. HWT-sized casing was partially advanced into the borehole either ahead of or followed by the HQ coring for the purposes of maintaining drill fluid return, reducing sidewall friction, and preserving borehole stability. HWT-sized casing with a tricone advancer were sometimes used, when sample recovery was not needed. WSDOT utilized a track-mounted CME 850 drill equipped with a calibrated auto hammer for standard penetration testing. Standard Penetration Tests (SPTs) were taken intermittently with a conventional 2-inch-OD sampler, as well as with an oversized sampler, and were generally limited to the upper 200 feet of the boreholes in zones with low core recovery and for the purposes of in situ density and strength correlations. SPTs were generally not taken below this depth, due to the excellent core recovery in the overconsolidated sediments and the high hammer-energy loss with depth.

A WSDOT inspector was present at all times during the drilling of the test borings to convey the sampling protocol, log the retained samples, document groundwater conditions, and inspect

instrumentation installation. A licensed engineering geologist with SnoCo was on site for much of the drilling to observe, advise, and assist with documenting the drilling operation. The drilling operation was closely coordinated and directed by senior-level WSDOT geotechnical personnel.

The inspector described the soil samples from the SPTs in the field using WSDOT protocol. The inspector then placed them into a labeled sample bag, and transported the samples to the WSDOT Headquarters Materials Laboratory for further evaluation. Core samples of soil were similarly described in the field using WSDOT protocol, wrapped with plastic wrap to help preserve moisture contents and placed into core boxes, and then transported to the WSDOT Materials Laboratory for further evaluation. Lexan tubes of cored soil were also sealed to prevent drying, were carefully transported the WSDOT Materials Laboratory, and were stored in a laboratory wet room until further evaluation could be conducted. Senior-level WSDOT geotechnical personnel prepared the final logs for the three geotechnical test borings, which are presented in Appendix B.

Geotechnical Instrumentation

Ten vibrating-wire piezometers (VWPs) were installed in the three borings within zones judged by senior-level geotechnical personnel to be hydrogeologically and geotechnically significant, based on the conditions encountered in the borings. The VWPs had pressure ratings of 100, 250 and 500 psi, which were selected for the anticipated groundwater and grouting pressures to ensure devices were not damaged during installation. The VWPs were saturated prior to installation, inverted and grouted in-place with a cement-bentonite mixture, in general accordance with the approach outlined in Mikkelsen and Green (2003). The devices were taped to the outside of a continuous 1-inch pvc pipe at the requisite depth, which serves as the tremie tube, grouting from the bottom of the hole to the surface in a single operation. The VWPs are monitored near real-time on 2-hr intervals. The results of the groundwater monitoring, from early December 2014 to mid-May 2015, are presented in Appendix C.

Two tipping-bucket rain gages are deployed in the area to monitor precipitation. One was located behind the SR 530 landslide headscarp, and the other was located on the opposite side of the valley above SR 530 (Fig. 2). The rain gages are monitored near real-time on 2-hr intervals. The data record for the rain gage behind the SR 530 landslide headscarp includes frequent interruptions due to accumulating windblown dust from the proximal headscarp and tree litter clogging the instrument. The precipitation data from the gage on the south side of the valley was the most uninterrupted record, and the data from that rain gage are included with the groundwater data in Appendix C.

Six UniMeasure, linear position transducers (extensometers) were deployed by WSDOT during the search and recovery operation to monitor surface deformation behind the SR 530 landslide headscarp. Two devices were installed on each of the three transects – north, south, and west (Fig. 2), approximately 400 to 500 feet behind the headscarp. Steel cable connected to each transducer and housed in ¾-inch pvc pipe was run several hundred feet along the ground to a fixed point proximal to the headscarp. Occasional climate-related device malfunctions, fallen tree litter, and possible animal-related disturbance resulted in replacement of or resetting of devices, and ultimately an interrupted record of monitoring data. The extensometers are presently being monitored near real-time on 2-hr intervals.

Data from the VWPs, extensometers, and rain gages are collected using Campbell Scientific equipment and telemetered via cell phone to an Internet-based monitoring platform hosted by WSDOT.

Other slope deformation monitoring methods have been employed on an as-needed basis. Coaxial cable was grouted full depth in one of the borings located behind the SR 530 landslide headscarp, H-2vwp-14, to monitor for lateral slope deformation with time-domain-reflectometry methods. WSDOT has utilized terrestrial laser scanning on an intermittent basis, with the most recent scan being completed on March 11th, 2015. The latest comparison of scans is presented in Appendix C. Since the landslide occurred, SnoCo has surveyed targets set around the perimeter and on the landslide. The USGS also deployed several GPS units equipped with seismometers (referred to as spiders) during the search and recovery phase of the landslide.

Laboratory Testing

The USGS contracted with UC-Berkeley to perform an initial suite of index tests on samples recovered from test borings H-1vwp-14 and H-2vwp-14. The test results are summarized in a USGS Open File Report, which is included in Appendix D.

WSDOT ran one ring shear test on a sheared fat clay zone recovered in H-3vwp-14 when drilling BA6S landslide on the south side of the valley. The test is performed in general accordance with ASTM D6467 except that the sample preparation has been modified to allow testing of remolded specimens.

SITE CONDITIONS

Physiography

The North Fork Stillaguamish River valley trends westerly from the western slope of the North Cascades (Fig. 1). The watershed heads just west of the community of Darrington and drains steep mountainous terrain that bounds the valley on both sides to elevations approaching 5200 feet on the north side and 6800 feet on the south. The river meanders through the roughly 25-mile-long reach from Darrington at around elevation 400 feet down to the community of Arlington at around elevation 100 feet. Valley bottom width along this reach varies from less than 1 to more than 3 miles. The most constrained portion of the valley lies between Mile Post (MP) 35 and 41. Here, prominent corresponding terraces bound both sides of the valley. These terraces are erosional remnants resulting from river incision into a thick sequence of glacial sediments that once filled the valley. The terrace surfaces grade very gently eastward from around 950 feet elevation around MP 35 to about elevation 750 feet where the valley broadens around MP 41. The terrace on the north side of the valley, above the SR 530 landslide, is locally known as Whitman Bench.

Moisture-laden westerly flow from the Pacific Ocean impacting the western slope of the North Cascades delivers mean annual precipitation totals of 46 inches in Arlington to 79 inches in Darrington, most of which falls as rain in the lower elevations of the valley between October and March (Western Regional Climate Center). Valley slopes are densely forested, dominated by conifers, and historically managed for timber production on an assemblage of private, state, and federal lands. Other land uses include rural residential development and agriculture scattered throughout the valley bottom.

Regional Geology

The North Fork Stillaguamish valley transects a belt of deformed rock assemblages that are juxtaposed along a cluster of west- to northwest-trending faults collectively identified as the Darrington-Devils Mountain fault zone (Tabor et al., 2002, and references within). The fault zone is a major crustal fault system in the Puget Sound region dominated by left-lateral and compressional (transpressional) slip with demonstrated Holocene offset (Personius et al., 2014). Tabor et al. (2002, and references within) interpret a primary concealed strand of the fault zone being subparallel with the valley, and trending beneath Whitman Bench.

On the north side of the valley, the rock assemblages include the Helena-Haystack mélange (metamorphosed intrusive, extrusive, and sedimentary rocks in a serpentinite matrix, including the Darrington Phyllite) and Tertiary sandstone, siltstone and mudstone of the Chuckanut Formation, which underlies Mt. Higgins (Tabor et al., 2002; Dragovich et al., 2003). Bedrock on the south side of the valley consists of deformed and metamorphosed marine rocks (sandstone, volcanic rocks, and chert) of the western and eastern mélange belts. The described bedrock is exposed as prominent ridges and peaks high above both sides of the valley, as well as localized protrusions and promontories within the thick glacial sediments mantling the lower valley walls.

Multiple Pleistocene-age glaciations of both alpine and continental origin shaped the present-day landscape, though evidence for all but the most recent continental glaciation, the Fraser Stade, is absent in the valley. Prior to the Fraser glaciation, perhaps as early as 60,000 years before present (60 ka), the region was dominated by a cool period, referred to as the Olympia Interglaciation (Armstrong et al., 1965). Sediments associated with this period (Qc_o of Dragovich et al., 2003) are mapped near the valley floor and are thought to extend beneath it to tens of feet in depth (Fig. 3). Olympia-age sediments are fluvial in origin, consisting of gravel, sand, silt, clay, and organic material. Armstrong et al. (1965) marked the onset of the Fraser Glaciation in northern Washington by an alpine advance beginning roughly around 25 ka. Its subsequent retreat was shortly followed by a major advance of continental ice, the Vashon Stade, into northern Washington around 18 ka (Porter and Swanson, 1998). The maximum continental ice thickness was on the order of 4000 feet in the vicinity of the Stillaguamish valley (Thorson, 1980; Tabor et al., 2002). The ice advance overtopped much of the ridge north of the valley and flowed east, up-valley, damming river flow and creating a proglacial lake.

During this time, the Skagit River down valley of the present-day community of Rockport (Fig. 1) was similarly dammed by ice, directing drainage from the upper Skagit, Suiattle, and Sauk Rivers into the North Fork Stillaguamish River valley (Heller, 1978). It rapidly deposited a voluminous quantity of silt and clay into the proglacial lake (advance glaciolacustrine deposits; Qgl_v of Dragovich et al., 2003) occupying the North Fork valley. As the lake filled with sediment and the ice advanced eastward, coarser sediment was deposited on top of the glaciolacustrine sediments by shallow meandering rivers and streams draining from the ice. These streams laid down fine- to medium-grained silts and sands (advance outwash; Qga_v of Dragovich et al., 2003).

This sequence of deposits was then overridden by the advancing ice. Unsorted material carried along beneath the Vashon ice was deposited over the advance outwash, leaving behind a highly compact, unsorted, matrix-supported mixture of clay, silt, sand, gravel, cobbles and boulders; this is the till (Qgt_v) of Dragovich et al. (2003).

Cessation of the advance and subsequent melting of the ice, beginning around 13 ka, persisted until around 11ka and defines a brief warm period referred to as the Everson Interstade. During this time, abundant sand and gravel (recessional outwash; $Qgos_e$ and $Qgog_e$ of Dragovich et al., 2003) was deposited on top of the till (Qgt_v). A broad remnant outwash channel is preserved on Whitman Bench from this period. One brief ice advance, the Sumas Stade, between 10 and 11 ka occurred north of the North Fork valley and marks the end of the Fraser Glaciation. Drainage from the upper Skagit, Suiattle and Sauk Rivers into the North Fork valley persisted after deglaciation, likely contributing to significant erosion and incision into the glacial sediments that filled the North Fork valley. Ultimately, post-glacial eruptions of Glacier Peak and associated lahars deposited material in the lower Suiattle and Sauk drainages and diverted flow from these drainages back northward into the Skagit River valley (Vance, 1957). This drainage diversion resulted in a considerable reduction of flow within the North Fork. Despite the reduced flow, the North Fork continued to meander through a broadly excavated valley, frequently encroaching on the base of the steep high terraces and cutting into the glacial sediments. Large-scale landslides ensued into modern times along the terrace faces, and their areal extensiveness in this reach of the valley has been previously mapped (Tabor et al., 1988 and 2002; Dragovich et al., 2003; Haugerud, 2014; Gerstel and Badger, 2014). Haugerud (2014) assessed the relative age differences of landslides in close proximity to the SR 530 landslide, mapping the distribution of these deposits utilizing lidar interpretation. Subsequent remote mapping and geomorphic characterization of 22 landslide basin areas within the six-mile-long constrained reach of the North Fork valley between MP 35 and 41 by Gerstel and Badger (2014; Appendix A) identified considerable complexity in terms of morphology, type, and deformation characteristics (Fig. 4). Including the basin area from which the SR 530 landslide occurred (BA 4N, identified in Figure 4 and Appendix A), two other landslide basin areas (BA 1N and BA 6S) have preserved evidence of comparable large volume and high mobility (Haugerud, 2014; Gerstel and Badger, 2014).

This report presents data on three landslides for which some historic geotechnical information was available or has been generated as part of the scope of this study. The investigated landslides include:

1. the 22 March 2014 SR 530 landslide, referred to herein as the ***SR 530 landslide***;
2. an unnamed, large prehistoric landslide on the south side of the valley with apparent high mobility and large volume, located between MP 37.5 and 38.0, referred to herein as the ***BA6S landslide***; and,
3. a large prehistoric landslide with historic localized activity (Skaglund Hill landslide) on the south side of the valley, located between MP 36.2 and 36.8, referred to herein as the ***BA4S landslide***.

SR 530 Landslide, North Side of Valley

Historic Activity

Earlier reports (i.e., Shannon, 1952; Thorsen, 1970; Benda et al., 1988; Miller and Miller, 1999) document a history of landslide activity at the location of the SR 530 landslide, which include: (1) landslides prior to 1937, (2) a landslide event in December 1951, (3) enlargement of the active landslide limits through 1967, (4) a landslide event in January 1967, (5) gradual enlargement of the landslide through 1970, (6) mudflow activity on east side of the slide area

between 1984 and 1988, (7) a landslide event in November 1988, and (8) a landslide event in January 2006. For the purposes of this report, we refer to all landslide events at this location prior to the 22 March 2014 landslide as the "Hazel Slide". The reports provide useful facts about the geologic units involved and not involved in the landslide, the position of the failure zone at the base of the slope, the potential role river erosion may or may not have contributed, and the nature and mobility of the debris.

Shannon (1952) reported characteristic landslide morphology, widespread weak clayey material and springs, and both sliding (translation?) and flow-type behavior of the slide mass or debris. Scaled dimensions of the active landslide limits were about 1500 feet wide at the river by 900 feet in length. Interpreted factors contributing to the landslide activity included river erosion of the landslide toe due to an adverse channel configuration, low strength clay materials involved, overburden stresses, and rainfall and springs.

Miller and Miller (1999) wrote, "*A berm of alluvium and logs was constructed in the summer of 1960 in an attempt to protect the toe of the landslide. It was eroded away the first winter (Webb and Rees, 1961). A rock revetment was constructed along the eastern (upstream) portion of the slide toe in 1962, which persists to this day.*"

Responding to a large landslide event in January 1967, Thorsen (1970) noted similar conditions and that "*pre-1967 photos show the lower 80 feet or so of the river bank as a steep slope of relatively undisturbed horizontally stratified clays.*" Further, "*it appears that the bulk of the material in the 1967 slide was from the already disturbed upper slope area. Even though completely buried, there appears to remain some topographic expression of the lower steep bank (along the river) that did not fail... The plane of failure for the 1967 slide was at the top of the horizontally stratified bank (about 80 feet above river level) rather than at or below river level.*" Thorsen classified the landslide as a mud flow, "*although blocks of the overlying clayey sand were moved intact.*" Thorsen (1970) is the first geologic/geotechnical reference to assign the name of "Hazel Slide" to the landslide area. Miller and Miller (1999) noted that debris from the 1967 slide event diverted the river nearly 700 feet to the south.

Following the 1967 landslide, the river gradually eroded northward through the debris until 1988 when it reached the former landslide toe (Miller and Miller, 1999). The November 1988 landslide was considerably smaller in volume than the 1967 event, so that while the debris again inundated the river, the river was soon able regain its former channel. Miller and Miller also note that "*The 1962 revetment has been re-exposed, at least since 1996, along the eastern, so-far-inactive, portion of the slide…*", which would indicate that landslide debris overtopped the 1962 rock revetment and thus the 1988 failure surface in the vicinity of the revetment was also above river level.

Lidar from 2003 and an oblique photograph depict the conditions of the slope prior to the 25 January 2006 landslide (Fig. 5). As shown in the figure, a sharp inverted "V"-shaped headscarp is evident, defining the uppermost extent from which previous historic events had initiated. The morphology of the slide mass below is rough and contains discontinuous down-dropped benches. The dimensions of the active landslide limits are about 1500 feet wide near the river and 1200 feet long. The historic landslides are nested within a much larger prehistoric landslide mass that sharply cuts the southeastern corner of Whitman Bench. The topography of the prehistoric landslide mass above the active headscarp is considerably smoother. The river is situated in a tight meander against the base of the slope. At river level, historic landslide debris overlies an

approximately 50-ft-high, 700-ft-long exposure of laterally continuous, horizontally bedded sediments. Dragovich et al. (2003) described these sediments as bedded sands with localized foreset bedding dipping northwest between 15 and 22°. Detrital wood they recovered from these foreset beds was radiocarbon dated, which was a basis for their mapping the deposits as Olympia age.

The 2006 landslide occurred around 2:00pm on a Wednesday (Stillaguamish Tribe, 2006). Like the 1967 event, much of the debris was fluid-like and highly mobile, dispersing 700 to 800 feet beyond the slope toe and diverting the river. The landslide volume was estimated to be on the order of 2 to 3 million cubic yards. Unlike the SR 530 landslide, however, photographs taken shortly after the 2006 event and 2013 lidar show an absence of significant solid hummocks in the dispersed debris. From a comparison of the 2003 and 2013 lidar, the 2006 headscarp retrogressed between 30 and 80 feet from historic limits into the prehistoric landslide mass, but the width of the 2006 landslide did not enlarge appreciably. The location of the landslide surface-rupture toe is indeterminate from the available photography and lidar, as much of the base of the slope was buried in landslide debris.

A search for geotechnical reports that summarized the conditions or eyewitness accounts of the 2006 landslide yielded no records, though photographs and other information were found. An Internet search for eyewitness accounts associated with the event found only a single report of, "*one fisherman wasn't aware of the slide until the water began rising around his waders*" (Stillaguamish Tribe, 2006). In contrast, a very loud noise was heard by eyewitnesses immediately before the SR 530 landslide inundated the valley (various news reports, Keaton et al., 2014; Iverson et al., 2015). A cursory search of available seismic records from the closest short period/high gain and broadband stations for the three hours preceding and two hours following the 2006 landslide revealed no discernable energy release similar to that associated with the SR 530 landslide (K. Allstadt, 2014; personal communication). The event may have been too small to detect above the existing background noise or diffuse in time over the duration that the landslide initiated. Obviously, the absence of eyewitness accounts of associated loud noise or seismic signals related to the failure does not mean they did not occur.

Following the 2006 landslide diversion of the river, a log crib wall was constructed along the right bank of the new channel to reduce erosion and sedimentation into the river. Some river-related damage on the upstream end of the crib wall developed shortly after construction, but the structure was largely intact and the river was in the post-2006-landslide channel at the time of the SR 530 landslide in 2014 (Fig. 6).

Initiation of the 2014 Landslide

Establishing potential failure mechanisms of any landslide requires the definition or estimation of the external and internal conditions preceding failure, which is why landslide investigations typically make considerable effort to document these conditions. Commonly, the pre-failure conditions and the failure itself are not observed and must be inferred through careful study of post-failure conditions. Scientific publications about the SR 530 landslide have documented available climatic, morphologic, seismic, and eyewitness information (Keaton et al., 2014; Iverson et al., 2015; Hibert et al., 2015). From this information, they recognized two or more stages of landslide development. This study provides additional relevant information that could be used to advance the objective of defining the conditions that may contribute to the widespread landsliding in this reach of the valley.

An evaluation of the 2013 lidar did not reveal evidence of a scarp forming on Whitman Bench in the vicinity of the 2014 headscarp to suggest an incipient failure (R. Haugerud, 2014; personal communication). However, given the limitations of imaging the ground surface through the tree canopy and lidar-processing uncertainties, the necessary detectable offset on a scarp would probably need to be 5 feet or more (T. Walsh, 2015; personal communication).

Henn et al. (2015) estimated that between 300 and 400 mm (11.8 and 15.7 inches) of precipitation fell at the site in the 21 days prior to the landslide event, representing a 25 to 88-year return period (based on analysis of available historic data) for a precipitation episode ending on March 22nd, 2014. They further report that for such a 21-day precipitation total to occur sometime throughout a year represents a return period of only 2 to 6 years. In other words, while the cumulative rainfall for a 21-day period ending in late March was exceptional, it would have had a lower return period if it had occurred, for instance, in the preceding winter months. An example of such an event recently occurred between October 11th and November 1st, 2014, when 13.00 inches (330 mm) were recorded during this 21-day period at a WSDOT rain gage located on the south side of the valley across from the landslide. Evaluated return periods of up to 10 years of cumulative precipitation preceding the landslide yielded a 4-year high representing a nearly 10-year return period (Henn et al., 2015).

Approximately two weeks before the March 22nd event, two long-time residents of the valley reported seeing a fresh separation along the 2006 headscarp, visible from their location on the highway at Skaglund Hill. (R. and C. Brewer, 2015; personal communication). They noted more apparent offset on the Rollins Creek (eastern) portion. How much of the slope distress the eyewitnesses observed from their vantage, whether what they observed in fact represented new slope distress, and whether this apparent new distress significantly contributed in some way to the large size and high mobility of the event are indeterminate. If these observations were in fact actual slope movement and they represented the early phase of development of the failure on March 22nd, then the slope distress would have developed during or before the early portion of the 21-day wet period.

Eyewitnesses reported two different phases of very loud noise associated with the event. The first phase of noise was reported by a man who was in his house when he heard the noise. He reported going outside, walking to the river, and standing along the north side of the river off the west flank of the landslide. He had a clear view of the valley but not the landslide. He continued hearing what sounded like a very loud, low-flying airplane lasting tens of seconds. The noise stopped, and as he was about to return to his house, he observed a shimmering near the riverbank followed by extreme turbulence and darkening of the river. This was immediately followed by an enormous and extremely rapid torrent of debris estimated to be 100 feet in height so as to fully obscure his view up valley. The eyewitness stated that he saw no evidence of uplift near the river. Survivors within and on the periphery of the landslide debris field reported what would be a second phase of extreme noise (based on the account of the first eyewitness) associated with the rapid inundation of the valley by the debris avalanche-flow.

Iverson et al. (2015) reported that, *"…detectable landslide motion began at 10:36:33 am local time (17:36:33 UTC) according to our inversion of broadband seismic data.*" The time at which the high-mobility phase of the landslide inundated the valley has been widely reported to have occurred between 10:37 and 10:38 AM local time. The first 911 call was not received until 10:42:39 AM. Given the number of witnesses and those early on the scene, this 4 to 5-minute-period raises uncertainty about the actual time of inundation. The establishment of this 10:37-

10:38 AM time, based on a review of available geotechnical-related documents, seems to have been solely determined from the analysis of seismic signals detected by the regional seismic network (Keaton et al., 2014; Iverson et al., 2015; Hibert et al., 2015). Because these publications relate specific phases from the seismic records to specific landslide stages, first-order verification of the actual times of initiation and inundation are important to support future interpretations of the mechanisms and sequence of initiation and deformation. Snohomish County Public Utilities District confirmed a 10:38 AM automated timestamp on their outage report of their main transmission line along SR 530, presumably from inundation by the landslide debris (B. Holt, 4/1/2015; personal communication). They further discounted the possibility that a localized outage in the Steelhead Drive community, perhaps due to a smaller-sized pulse of landslide debris, would have caused an outage of the main line, because the trunk line serving the community had a circuit-interrupting fuse. The 10:38 AM time of valley inundation was additionally supported by interviewing and verifying cell phone records for one of the early 911 callers, who made several urgent calls to a family member before calling 911 at 10:43:49 AM.

Geomorphology

The slope area from which the SR 530 landslide initiated, referred to by Varnes (1978) as the zone of depletion, included the lower slope area of historic landsliding, much of the prehistoric landslide limits, and an additional 300-ft step-back into Whitman Bench (Fig. 7). The dimensions of the depletion zone are 1600 feet in length and 1500 feet in width near the base of the slope. Upon receipt of the post-failure lidar in late March 2014, and at the request of the Washington Military Department and the Department of Natural Resources, WSDOT estimated the initiating landslide volume to be between 10 and 11 million cubic yards. Varnes (1978) refers to the portion of landslide where debris is transported and deposited as the zone of accumulation. Before and after differencing of the digital terrain models of the debris volume extending from the base of the slope yielded around 5.7 million cubic yards. As landslide depletion zones commonly do not fully evacuate, on the order of 5 million cubic yards of displaced and transported material may remain within the depletion zone of the SR 530 landslide.

The SR 530 landslide can be divided into three primary domains based on landslide characteristics: an upper rotational and/or translational slide mass, an intermediate zone of broadly dispersed hummocks classified as a debris avalanche, and a fluid distal portion characteristic of a debris flow. Iverson et al. (2015) classify the landslide as a debris avalanche-flow (DAF). Hungr (personal communication, 2015) classifies the event as a clay flow slide.

Keaton et al. (2014) divided the landslide into six zones (A-F) based on deformation style, geologic materials, vegetation and geomorphic expression, with zones A, a small portion of B, and the upper portion of C defining the zone of depletion, and much of B, the lower portion of C, and D through F defining the primary zone of accumulation (Fig. 8). They further subdivided Zone A into four sub-zones, A1 through A4.

The upper limit of the depletion zone is prominently defined by an approximately 250-ft-high steep headscarp (Fig. 9). Observations made two days after the landslide noted about 130 feet of recessional outwash (measured from terrestrial lidar) consisting of mostly unsaturated, cross-bedded sands, and gravels exposed at the top of the scarp. Localized perched zones of seepage were evident in the lower 5 to 20 feet of the recessional outwash immediately above a mostly laterally continuous, 60 to 80-ft-thick, near-vertical exposure of Vashon till. The till consists of

compact, poorly sorted (well graded), predominantly non-stratified, clay to boulder-sized sediment. Persistent debris falls and ravel from the oversteepened scarp rapidly accumulated as a thick colluvial apron at the base of the scarp, obscuring the base of the till. One observable exception was a 30-ft-high, localized exposure underlying the till of stratified sands and silts that appeared unsaturated. After completion of the recent borings behind the headscarp, these stratified sediments were later interpreted to be advance outwash. Both the western and eastern lateral margins of the scarp crosscut and expose down-dropped and translated portions of adjacent prehistoric landslides (Fig. 10).

A 300-ft-wide, down-dropped and back-rotated block with back-fallen, mature, second-growth conifers (Zone A2 of Keaton et al. (2014)) was transported 400 to 500 feet downslope and occupies the central portion of the depletion zone (Fig. 11).

The lower portion of the depletion zone consists of what Keaton et al. (2014) referred to as Zone B, the rotational block field (Fig. 12). This zone of extension is defined by a series of transverse ridges and depressions comprised of back-rotated blocks with apparent repeating stratigraphy. They noted, *"…deeper (stratigraphic) units are exposed on the downslope side of blocks, with the tops and uphill sides of high-standing blocks preserving oxidized recessional outwash and patches of forest floor, and the downhill side of blocks being buttressed by till or defined by arcuate scarps in (advance glacio) lacustrine material, some of which preserve failure surfaces with steeply inclined slickensides*." Springs emanate from the landslide debris in the rotational block field along the lower western margin around and below elevation 400 feet. The downslope extent of the depletion zone is approximately located within the middle portion of the rotational block field, near the pre-2006-landslide river channel, which is about 700 feet north of the present channel.

Keaton et al. (2014) defined the eastern margin of the depletion zone as a source of debris flows. Based on lidar interpretation and stratigraphic characteristics and position established from the drilling, the scarp exposes rafted landslide blocks of recessional outwash sands, till, advance outwash sands and silts, and advance glaciolacustrine silts and clays. Groundwater seeps, possibly derived from recharge by Headache Creek, are prevalent within the lateral scarp below roughly the 510-foot contour, generating localized flow slides and debris flows (Fig. 13).

Zone D of Keaton et al. (2014) is fully within the accumulation zone and overlies the former valley floor in the vicinity of the existing river channel. This zone consists of abundant sheared blocks of compact advance glaciolacustrine deposits and debris hummocks to thicknesses of up to 60 feet.

Keaton et al. (2014) described the Zone E block field as an areally extensive zone of debris hummocks with thicknesses up to 40 to 60 feet. Oxidized sand and gravel cover many of the hummocks with localized patches of coniferous and deciduous trees and ferns. They noted, "*Relatively small, deciduous trees are increasingly prevalent toward the middle and distal areas of Zone E where progressively smaller block sizes reflect disintegration of the original ground surface of the 2006 landslide.*" They also noted the presence of sand ejecta and sand boils, indicating the development of porewater pressures within the deposit exceeding total overburden pressures.

Keaton et al. (2014) identify the distal portion and most fluid-like phase of the landslide deposit as debris flow runout of Zone F up to about 20 feet in thickness. The debris consists of a clay-silt-sand matrix with blocks of advance glaciolacustrine and till, trees, and other debris. The

debris included logs from the log revetment structure constructed along the right bank of the river in 2006, as well as sections of asphalt pavement scoured from the highway. Sand boils were also observed within this zone.

Subsurface Conditions

As originally planned, one 650-ft-deep test boring (H-1vwp-14) was to be located immediately behind the headscarp of the SR 530 landslide to define the nature and thickness of each unit within the undisturbed stratigraphic sequence, and to identify groundwater regimes that might be contributing to instability of the slope. Upon completion of the test boring to depth, drill cuttings seized the drill casing and the lowermost 130 feet of the casing was inadvertently twisted off at the bottom of the hole. After spending several days trying to retrieve the lost drill casing, it was decided that it would be less costly and would result in a better piezometer installation to abandon the lower portion of H-1vwp-14 and re-drill the test boring. This resulted in H-2vwp-14 being drilled to a depth of 635 feet about 50 feet to west of H-1vwp-14.

The following are generalized descriptions of the stratigraphic units encountered in H-1vwp-14 and H-2vwp-14, along with the respective depths and elevations below the ground surface of their upper contacts:

Depth / Elev	Stratigraphic Unit Description
0 ft / 892 ft	***Recessional Outwash*** – SAND with gravel and cobbles to silty GRAVEL with sand to silty fine SAND (SW-SM; SM); subrounded to rounded; poorly to well graded; medium dense to dense; grayish brown; moist becoming wet at bottom of unit; cross-bedded to horizontally stratified to homogenous. *Everson outwash sand* ($Qgos_e$) of Dragovich et al. (2003). Abrupt contact with lower till unit.
132 ft / 760 ft	***Till*** – Silty SAND with gravel to sandy SILT with gravel, with cobbles and clay (diamict) (CL on fine-grained fraction from SPT); subrounded; well graded; very dense; grayish brown to gray; moist; homogenous to locally stratified with sand and silt beds; slickensides within silt bed near bottom of unit. *Till (Vashon Stade)* (Qgt_v) of Dragovich et al. (2003). Gradational contact with lower outwash unit, between about 212 and 218 feet in depth.
218 ft / 674 ft	***Advance Outwash*** – Well graded SAND with gravel; by 230 feet, grading to interbedded silty fine SAND to SILT (SM-ML); dense to very dense; gray; moist becoming wet by 245 feet with localized water-bearing layers; laminated (layers <1/4") to stratified (layers >1/4") with variable orientation; slickensides noted in the silt bed at bottom of unit; notable sulfurous smell. *Advance outwash (Vashon Stade)* (Qga_v) of Dragovich et al. (2003). Gradational contact with lower advance glaciolacustrine unit.
293 ft / 599 ft	***Advance Glaciolacustrine*** – SILT to FAT CLAY (CL-CH); nonplastic to high plasticity (PI=20 to 45); clay fraction 26 to 66%; compact; gray to dark gray to greenish gray; moist; above about 500-ft depth, laminated to stratified (commonly rhythmic) to homogenous, occasional fine sand laminae/strata, generally distorted and variable orientation, fissured with silt and fine sand coating, occasional slickensides; below about 500-ft depth, laminated to stratified to homogenous, generally horizontal to

shallowly inclined; possible sparse ash and graphitic laminae. *Advance glaciolacustrine (Vashon Stade) (Qgl_v)* of Dragovich et al. (2003). Abrupt contact with lower nonglacial sand-silt unit.

580 ft / 312 ft ***Nonglacial Deposits*** – Poorly graded SAND to SILT to LEAN CLAY with occasional gravel (SM-SP); nonplastic to moderate plasticity; compact; gray to olive gray to dark gray; moist becoming wet below about 620 feet and locally pressurized with artesian flow originating between 625 and 630-ft depth (noted in H-1vwp-14, but not in H-2vwp-14); horizontally laminated to stratified to homogenous; possibly with organic-rich laminae. *Deposits of Olympia nonglacial interval (Qc_o)* of Dragovich et al. (2003).

650 ft / 242 ft Terminus of deepest boring H-1vwp-14.

The lowermost unit encountered in H-1vwp-14 and H-2vwp-14 appeared compositionally similar and was encountered near the same elevation as the sediments mapped along the early-2000s river bank at the base of the slope by Dragovich et al. (2003). They identified the exposed sediments as Olympia-age nonglacial deposits. For the purposes of this report, the unit encountered in the borings is tentatively correlated to those mapped by Dragovich et al (2003). It is also possible that the deposits encountered in the borings could represent an early Vashon advance outwash or older glacial deposits.

Dragovich et al. (2003) identified a recessional glaciolacustrine unit on the lower eastern margin of the landslide and on the southwestern edge of the Whitman Bench. Deposits of this nature were neither observed in the headscarp nor encountered in the borings located behind the headscarp.

Seven vibrating wire piezometers were installed within test borings H-1vwp-14 and H-2vwp-14 and distributed within stratigraphic units exhibiting potential as water-bearing zones. The installed depths/elevations, stratigraphic units and piezometer response from the two borings are summarized below and graphically presented in Appendix C.

Depth / Elev	Hydrogeologic Description
128 ft / 764 ft	Unconfined, water-bearing zone near the base of the recessional outwash unit identified in the drilling perched on the till unit at 132-ft depth. From the onset of the monitoring period on December 3, 2014 to May 11, 2015, the piezometric surface has risen gradually from about 109-ft depth below ground surface (bgs) to 105 feet bgs. No to only very minor (≈1 ft) discernable response to short-term precipitation events exceeding several inches within several days.
230 ft / 662 ft	From the drilling, apparent water-bearing sand unit near the top of the advance outwash unit confined above by the base of till unit at about 218-ft depth. From the onset of the monitoring period on December 3, 2014 to May 11, 2015, the instrument has recorded negative pore pressures, inferring the zone in which it is installed is unsaturated.
290 ft / 602 ft	Water-bearing sand unit near the base of the advance outwash unit identified in the drilling, confined above by a silt interbed around a depth of 245 feet or by the base of the till unit at about 218-ft depth. From the onset of the monitoring period on December 3, 2014 to May 11, 2015, the piezometric

surface has fluctuated less than 0.7 feet around the mean reading of 256-ft depth with no discernable response to short-term precipitation events exceeding several inches within several days or longer-term seasonal changes.

450 ft / 442 ft Saturated zone within the middle of the advance glaciolacustrine, with no apparent stratigraphic or hydrogeologic significance noted from the drilling. From the onset of the monitoring period on December 3, 2014 to May 11, 2015, the piezometric surface has gradually dropped from a high of 332 feet to around 340 feet in depth with no discernable response to short-term precipitation events exceeding several inches within several days.

570 ft / 322 ft Saturated zone near the base of the advance glaciolacustrine of no apparent stratigraphic or hydrogeologic significance noted from the drilling. From onset of monitoring period on December 3, 2014 to May 11, 2015, the piezometric surface has steadily dropped from a high of 548 feet to around 551 feet in depth with no discernable response to short-term precipitation events exceeding several inches within several days.

585 ft / 307 ft Confined, water-bearing sand unit near the top of the Olympia nonglacial deposits identified from the drilling confined above by base of advanced glaciolacustrine at 585-ft depth. From onset of monitoring period on December 3, 2014 to May 11, 2015, piezometric surface has only fluctuated about 1.5 feet at an approximate depth of 572 feet with no discernable response to short-term precipitation events exceeding several inches within several days or longer-term seasonal changes.

625 ft / 267 ft Upon completing the 5-ft core run from 625.5 ft to 630.5 ft and pulling the core barrel in H-1vwp-14, driller and inspector noted artesian flow from top of drill casing and established head level at 14 feet above ground surface (after correcting for the heavier fluid density of the drilling mud), equating to elevation 906 ft. Flow persisted for at least five minutes before cessation. Unlike previous core runs, no core was recovered between 630 and 635 feet from this apparent water-bearing zone. Subsequently, lowermost portion of drill casing was twisted off at a depth of 650 feet, and the lower portion of boring was abandoned. H-2vwp-14 was drilled approximately 50 feet to the northwest and a similar stratigraphy was encountered, but pressurized flow was not encountered. A piezometer was installed within the saturated zone at same depth/elevation where pressurized conditions were encountered in H-1vwp-14. From the onset of the monitoring period on December 3, 2014 to May 11, 2015, the piezometric surface from H-2vwp-14 has gradually risen from a low of 624 feet to around elevation 610 feet, with no discernable response to short-term precipitation events exceeding several inches within several days.

BA6S Landslide, South Side of Valley

Geomorphology

Situated on the south side of the valley above SR 530 between MP 37.5 and 38.0 is a large prehistoric landslide deposit that extends several thousand feet into the valley (Fig. 4 and Fig. 14). The basin from which it initiated is herein referred to as BA6S, so named by Gerstel and Badger in their 2014 report (Appendix A). The landslide heads at around elevation 900 feet in the terrace directly across the valley from Whitman Bench and the SR 530 landslide. The depletion zone is defined by a deep, uniformly arcuate scarp set back 1500 feet from the terrace edge. Much of the depletion zone has been evacuated. The surface of the remnant landslide deposits exhibits subdued internal scarps and ridges and aggraded depressions. Ponded water occupies two larger depressions in the middle of the deposit. Drainages within the landslide deposits are poorly developed except on the eastern and western margins where the landslide deposit cross-cuts apparently older slope forms. The distal extent of the landslide deposits has been truncated and extensively eroded by the North Fork Stillaguamish River. Localized landsliding is evident along this eroded margin. SR 530 is situated on the distal end of the deposits. Seattle City Light high-voltage transmission towers also cross the entire width of the landslide near the base of the valley.

Subsurface Conditions

One geotechnical boring, H-3vwp-14, was drilled within the outer portion of the depletion zone to define the shape of and depth to the failure surface, controlling geologic unit of the failure zone, hydrogeologic conditions within the landslide deposits, and hydrogeologic conditions beneath the failure zone. The following are generalized descriptions of the stratigraphic units encountered in the boring, along with their respective depths and elevations below ground surface:

Depth / Elev	Stratigraphic Unit Description
0 ft / 580 ft	***Landslide Debris*** – Well graded GRAVEL with sand and cobbles to poorly graded SAND to silty SAND with gravel to SILT to FAT CLAY; fines mostly washed away; subrounded to rounded; poorly to well graded; medium dense to very dense; olive brown to gray with FeO staining; moist; homogenous, blocky, disrupted, and slickensided. Apparent basal failure zone of disrupted and slickensided fat clay (PI=35; CF=58%; φ_r= 13°) encountered between about 183 and 184 feet bgs. *Landslide complexes* (*Qls*) of Dragovich et al. (2003). Abrupt contact with lower advance glaciolacustrine unit.
184 ft / 396 ft	***Advance Glaciolacustrine*** – SILT to FAT CLAY; nonplastic to high plasticity; compact; gray to dark gray; moist; laminated (layers <1/4”) to stratified (layers >1/4”) (commonly rhythmic) to homogenous, generally horizontal to shallowly inclined; possible sparse ash. *Advance glaciolacustrine (Vashon Stade) (Qgl_v)* of Dragovich et al. (2003). Abrupt contact with lower nonglacial sand-silt unit.
252 ft / 328 ft	***Nonglacial Deposits*** – Poorly graded SAND with occasional gravel to SILT; nonplastic to low plasticity; compact; gray; moist; homogenous to

horizontally laminated/stratified. *Deposits of Olympia nonglacial interval (Qc_o)* of Dragovich et al. (2003).

300 ft / 280 ft Terminus of boring H-3vwp-14.

The lowermost unit encountered in H-3vwp-14 appeared compositionally similar to those encountered in the two borings on the north side of the river. In addition, its contact with the upper advance glaciolacustrine unit was encountered within 16 feet of elevation as the north side borings. For the purposes of this study, the lowermost unit encountered in H-3vwp-14 is tentatively correlated with Olympia-age deposits of nonglacial origin. It is also possible that the deposits encountered in the borings on the south side of the valley represent an early Vashon advance outwash or older glacial deposits.

A number of geotechnical borings have been advanced over the past several decades by WSDOT and its contractors into the distal lobe of this landslide debris along the highway. One of the most recent and deepest borings, K-1p-14, was drilled by WSDOT near the crest of the existing highway cut for the design of the SR 530 reconstruction. This boring extends to about 20 feet in depth below the valley floor (WSDOT, 2014a). The boring encountered at least 93 feet of interpreted landslide debris consisting of intermixed zones of medium dense to dense, poorly graded sand, silt to fat clay, and silty gravel with sand. Below 93 feet and to the bottom of the boring at around 110 feet bgs, the boring encountered dense to very dense silty sand with gravel to poorly graded sand. The origin of this denser unit is uncertain and may represent a denser zone of landslide debris or undisturbed sediments buried beneath the landslide debris, such as alluvium, Olympia nonglacial deposits, or older glacial deposits.

Three vibrating wire piezometers were installed within test boring H-3vwp-14 and placed within stratigraphic units exhibiting potential water-bearing zones or of geotechnical interest. The installed depths/elevations, stratigraphic units, and associated piezometer responses are summarized below and graphically presented in Appendix C.

Depth / Elev	Hydrogeologic Description
178 ft / 402 ft	Presumed unconfined, water-bearing zone within the landslide debris unit anticipated from stratigraphy perched on the advance glaciolacustrine unit at a depth of 184 feet. From the onset of the monitoring period on December 2, 2014 to May 11, 2015, the piezometric surface has risen gradually from about a depth of 125 feet to a high of 118 feet. A 5-ft rise in the piezometric surface was noted during the approximately 15 inches of rain that was recorded for the month of December. Leveling or dropping porewater pressures were associated with dry periods. A several-day response lag to rainy periods was noted in pore pressure response.
250 ft / 380 ft	Saturated zone near the base of the advance glaciolacustrine of no apparent stratigraphic or hydrogeologic significance noted from the drilling. From the onset of the monitoring period on December 2, 2014, the instrument has recorded no to possibly slightly negative pressures, inferring the zone in which it is installed was initially unsaturated. In mid-December, gradually increasing porewater pressure equivalent to a 4-ft rise in piezometric surface was noted, stabilizing in mid-January. No subsequent response was noted through May 11, 2015.

290 ft / 290 ft Water-bearing sand unit within the interpreted Olympia nonglacial deposits was identified from the drilling as moist to wet and was confined above by the base of the advanced glaciolacustrine at a depth of 252 feet. From the onset of the monitoring period on December 2, 2014 to mid-January, piezometric surface has dropped from a high of 269 feet bgs to 277 feet bgs. No discernable response to short-term precipitation events exceeding several inches within several days or longer-term seasonal changes.

A preliminary geologic section was developed for this landslide utilizing the two recent test borings (H-3vwp-14 and K-1p-14) and geologic mapping by Dragovich et al. (2003) of an intact sequence of glacial deposits that defines the western limit of the landslide depletion zone (Fig. 14). The unit thicknesses of the intact glacial sequence estimated from the mapped contacts are recognized as being approximate and have been presumed for illustrative purposes only to be horizontal and laterally continuous within the immediate vicinity of the landslide headscarp. Additional borings would be required to confirm their presence, thickness and continuity. The landslide(s) from this basin area cuts through 500 feet of the 600-ft-thick sequence of glacial sediments. An approximately 1-ft-thick zone of disrupted, slickensided, fat clay was retained in H-3vwp-14 overlying undisturbed, compact, horizontally laminated, fat clay (advance glaciolacustrine unit). This disrupted zone of fat clay is interpreted to be the lowermost portion of the basal failure zone of the landslide. Projection of this basal failure zone towards the former terrace face would be represented by a shallowly inclined to near flat-lying failure zone near the base of the advance glaciolacustrine unit. The steepness and shape of the upper portion of the failure zone is uncertain, but likely was steeper than what is depicted. The shape depicted represents the back-wasted configuration of the headscarp.

An evacuated volume of approximately 50 million cubic yards is inferred by a terrace-edge projection between the eastern and western margins of the basin area (Fig. 14). It is possible that the processes responsible for the basin evacuation may not be entirely landslide-related. Significant erosion of the distal terminus of the landslide debris by the river prohibits determination of a total volume associated with the landslide(s) generating this debris. A volume of 30 million cubic yards was estimated by average end-area method for this distribution of remaining landslide debris.

BA4S Landslide, Skaglund Hill Vicinity

Geomorphology

Situated on the south side of the valley above SR 530 between MP 36.2 and 36.8 is a large prehistoric landslide (Fig. 4and Fig. 15), referred to by Gerstel and Badger (2014) as BA4S. Its dimensions are about 2800 feet wide near the highway and 2600 feet long, measured from the headscarp to river. The landslide heads at around elevation 840 feet on the northwestern corner of the terrace directly across the valley from Whitman Bench and the SR 530 landslide. The 200-ft-high headscarp is uniformly arcuate and dissected by numerous small drainages. A broad flat graben about 450 feet across is situated at the base of the headscarp and, based on its smooth appearance, has been filled by back-wasting and erosion of the headscarp. A prominent interior scarp bounds the north side of the graben, with a linear, water-filled graben at its base. Minimal drainage incision of this intermediate scarp, and sharpness and narrowness of the graben, suggest a later stage of internal landsliding of the slope below this intermediate scarp. Overall, this

intermediate to lower portion of the landslide has poorly developed drainage. Landslide deposits and features extend to near highway level in the western portion and to near the river level in the eastern portion. Reconstruction of the pre-failure configuration of this portion of the terrace is complicated by the high density of large coalescing landslides and considerable internal instability within these large landslide complexes.

Several permanent residences are situated above the highway within the lower central limits of this prehistoric landslide. Seattle City Light high-voltage transmission towers also cross the entire width of the landslide just upslope of the highway.

Inset near the base of the larger prehistoric landslide is a historically active landslide that has repeatedly impacted SR 530 since at least the 1960s, which is referred to as the Skaglund Hill landslide (Fig. 15). One notable episode of activity for the Skaglund Hill landslide was February 1, 2006. Pavement cracking developed in the highway followed shortly thereafter by up to several feet of vertical and horizontal movements, before remedial subsurface drainage and grading finally slowed the movement in late spring (Landau Associates, 2009). This episode of reactivation followed a reported month-long-period of above-normal precipitation and initiated within a week of the large 25 January 2006 reactivation of the Hazel Slide. Several geotechnical investigations, which included numerous borings with instrumentation, have been conducted in recent decades within and around this area of active landsliding (Landau Associates, 1993, 2006, 2009, and 2010) and stabilization measures have been constructed to safeguard the highway.

Subsurface Conditions

Several geotechnical borings and instrumentation located near the highway (H-5-06, H-3-06 and H-1-06 from Landau Associates, 2006; logs included in Appendix A) are of sufficient depth and descriptive detail to provide some stratigraphic information on what is likely the toe area of surface rupture for this portion of the prehistoric BA4S landslide (Fig. 15). The stratigraphic assignments by Landau Associates have not been wholly adopted herein. For the purposes of this study, interpreted assignments presented below have considered the characteristics encountered in the intact stratigraphic sequence drilled behind the SR 530 landslide. Further, the distinction made below of disturbed landslide debris from intact deposits is based upon the presence/absence of noted disturbance (i.e., slickensides, fracturing, variably oriented laminae/strata) and the abrupt doubling in SPT values to greater than 60 blows per foot. The following are generalized descriptions of the interpreted stratigraphic units encountered in H-1-06, along with their respective depths and elevations below the ground surface,:

Depth / Elev	Stratigraphic Unit Description
0 ft / 396 ft	***Landslide Debris*** – LEAN to FAT CLAY (CL-CH); plastic (PI=20-33); medium stiff to very stiff (SPT values typically 20s-30s); gray; moist to locally water-bearing; disrupted to horizontal bedding and laminations, slickensides. Depth of active movement from inclinometer at 30 to 32 feet. *Landslide complexes* (*Qls*) of Dragovich et al. (2003).
67 ft / 329 ft	***Advance Glaciolacustrine*** – Silty to clayey fine SAND to clayey SILT (SM-ML); very dense to very hard (SPT values greater than 60); gray to dark gray; moist to wet; horizontally laminated to bedded. *Advance glaciolacustrine (Vashon Stade) (Qgl_v)* of Dragovich et al. (2003).

85 ft / 311 ft ***Advance Outwash*** or ***Nonglacial Deposits*** – Silty fine to medium SAND; very dense (SPT values greater than 60); brown to light brown; moist to wet; homogenous. *Vashon Advance Outwash (Qga_v)* or *Deposits of Olympia nonglacial interval (Qc_o)* of Dragovich et al. (2003).

101 ft / 295 ft Terminus of test boring H-1-06.

Two 100-ft-deep geotechnical borings drilled in 2009 above the highway for Seattle City Light (SCL-4 and SCL-3, Landau Associates, 2009; logs included in Appendix B) terminated within a thick unit described from 5-ft-interval SPT sampling as very stiff to hard, gray, silty clay and noting interbedded fine sand, slickensides and occasional horizontal laminations. Neither boring fully penetrated what was interpreted on the logs as the glaciolacustrine unit to terminate within the very dense sands that were encountered in the deeper borings closer to the highway, for example H-1-06. Based on the distinguishing criteria above for disturbed and intact deposits, these borings may have terminated within landslide debris. (The last sample in SCL-4 at 100-ft depth had an SPT value of 61 though no sample was recovered.) Deeper borings would be needed to delineate the failure zone in this portion of the prehistoric landslide.

Subsurface information on groundwater conditions is only available for the active, Skaglund Hill landslide portion of the prehistoric BA4S landslide. Landau Associates (2009) reported, "*The existing borings in the area and the results of the horizontal drain installation conducted by WSDOT showed that the soil and groundwater conditions are highly variable. Rather than a distinct water-bearing zone, groundwater was present in scattered sandy zones and in fractured soil at discontinuous locations within the landslide mass.*" From piezometers installed within the zone of active landsliding and underlying disturbed glaciolacustrine deposits (which are interpreted herein as prehistoric landslide debris), they observed, "*…water pressures measured in the layers beneath the slide debris* (disturbed glaciolacustrine deposits) *are relatively different than those within the slide debris* (zone of active landsliding)*, it is interpreted that the groundwater table is perched above the slickensided zone of clay."* Further groundwater observations within the slide debris included, *"…a general trend of dropping levels during the late spring to fall months, and rising water levels during the late fall to late spring months…"*.

Three vibrating wire piezometers were installed between late 2006 and early 2007 within the active landslide limits beneath the advance glaciolacustrine deposits near the top of the advance outwash or Olympia nonglacial deposits (H-8p-07, H-10p-07, H-12p-06). These piezometers indicated that the advance outwash/Olympia nonglacial deposits were not fully saturated. In other words, pressurized conditions were not detected beneath the advance glaciolacustrine deposits.

DISCUSSION OF FINDINGS

While the initial findings of this study contribute to improved understanding of the subsurface conditions within and around a few of the large volume, high mobility landslides present on both sides of the valley, more questions of importance have arisen and uncertainties with the available information remain.

Stratigraphy, Hydrogeology, and Geotechnical Characteristics

One of the more important questions this study sought to answer was whether similar subsurface conditions exist on the south side of the valley in the vicinity of SR 530 as are present on the north side of the valley.

Comprehensive geologic mapping and other geologic investigations within the North Fork Stillaguamish River valley and the northern Puget Lowlands (primarily Armstrong et al., 1965; Tabor et al., 2002; and Dragovich et al., 2003) provided the framework for interpreting the intact stratigraphic sequences encountered in the borings. Interpretations of the continuity and orientation of the stratigraphic units relied on a few deep, widely-spaced borings; sparse outcrops; and consideration of their depositional environments. While it is tempting to assume uniform thickness, horizontality, and lateral continuity of units between widely-spaced borings and outcrops, earlier depositional and erosional environments significantly complicate stratigraphic relations, sometimes within very short distances. Younger units inset within older units, lateral facies changes, inter-fingering of units, and mantling of sediments over paleo-topography are likely to be present. The continuity, thickness, and orientation of the units depicted on the geologic sections are intended to provide geologic context for the limited subsurface data that is available. Additional borings would often be required to better define the stratigraphy.

As was originally planned, a deep boring was not completed that would have enabled the definition of the intact stratigraphy and groundwater regimes beneath the south terrace. The absence of this subsurface information limited more accurate definition of the stratigraphic and hydrogeologic controls upslope of the two large landslides that were investigated on the south side, BA4S (Skaglund) and BA6S (MP 38 vicinity). At least one additional deep boring is needed on the south side terrace to relate the stratigraphy across the valley.

The groundwater monitoring period of this study missed the October 2014 onset of winter rains and its corresponding aquifer response. In WSDOT's experience, the wet season onset can result in significant aquifer response, especially for unconfined aquifers. A longer monitoring period is needed through at least the end of the 2015-2016 wet season to more fully establish the ranges of seasonal aquifer response.

Recessional Outwash and Till

The recessional outwash that was encountered in H-1vwp-14 and observed in the SR 530 landslide headscarp (Fig. 9), a distance between of about 300 feet, had very similar thickness (about 130 feet). Till is exposed beneath the recessional outwash and is laterally continuous for over 1000 feet across the headscarp. While the base of the till is mostly obscured by colluvium, in one area its basal contact with underlying bedded sands and silts (advance outwash) is apparent. The thickness of the till in this exposure was estimated from terrestrial laser scans of the headscarp to be about 80 feet, which is similar to the 86-ft-thickness encountered in H-1vwp-14. Based on this limited data, the recessional outwash-till and till-advance outwash contacts appear to be near flat-lying in the immediate vicinity of the headscarp.

It was evident from observations of the headscarp that the till acts as an aquitard and perches a modest groundwater table deep within the recessional outwash, as high as about 105 feet bgs. Observed aquifer response to precipitation in H-1vwp-14 could be described as unremarkable, with no to only very minor (≈1 ft) discernable response to short-term precipitation events

exceeding several inches within several days and only an overall 4-ft seasonal rise through this past wet season. Determination of the orientation and continuity of the recessional outwash-till contact, as well as the aquifer characteristics (i.e., hydraulic conductivity, transmissivity), would be necessary to quantify the contribution of this perched aquifer to downslope instability.

Advance Outwash

The advance outwash encountered in H-1vwp-14 consists of about 75 feet of interbedded silts and fine sands, the latter of which became water-bearing with depth. It is observable beneath the till in a localized area of the SR 530 landslide headscarp (Fig. 9). While Dragovich et al. (2003) mapped localized outcrops of this unit both low along the valley floor and high on the south terrace, the continuity of this unit is not well known elsewhere within the study area.

Piezometer data from H-1vwp-14 suggests that a roughly 30-ft-thick unsaturated zone exists at the top of this unit in the vicinity of the SR 530 landslide. This condition negates the potential for hydraulic connection through the downward transmission of pore pressures from the upper perched aquifer within the recessional outwash. Observed aquifer response to precipitation could be described as nonresponsive, with the piezometric surface having fluctuated less than one foot with no discernable response to short-term precipitation events exceeding several inches within several days or longer-term seasonal trends in precipitation. If the till aquitard is continuous beneath Whitman Bench, recharge of this confined aquifer may be more readily occurring horizontally on its northern margin where it may connect with the unconsolidated deposits mantling the valley wall. On the south and east margins of Whitman Bench, this confined aquifer would be crosscut by pre-existing landslide failure surfaces. Aquifers within landslide deposits that mantle the terrace face would have the potential to be recharged by this confined aquifer. Quantifying the potential contribution of this confined aquifer to downslope instability would require additional deep water wells and aquifer characterization.

Advance Glaciolacustrine

With over 90% core recovery of the advance glaciolacustrine deposits, H-1vwp-14 revealed that the unit was a nearly 300-ft-thick sequence of homogenous laminated or stratified silt and clay. Fine sand laminae or strata were occasionally encountered, as were apparent water-bearing zones, in the upper portion of the unit above about 400-ft elevation. The advance glaciolacustrine unit represents almost the entire lower half of the sequence beneath Whitman Bench. The thickness and characteristics of the entire unit present on the south valley terrace is currently undetermined. Laboratory gradations and hydrometers indicated the sequence to be finer and more clay-rich with depth. In H-1vwp-14, the upper, roughly three-quarters of the deposit characteristically exhibited distorted laminae/bedding with occasional silt-coated fissures and slickensides; this disturbance is attributed to ice-loading and/or syn-sedimentary deformation prior to full consolidation. In roughly the lower quarter of the unit, below about elevation 400 feet, the laminae/strata are characteristically horizontal to shallowly-inclined and generally lack the distortion, fissures, and slickensides observed at higher elevations in this deposit. These same undisturbed characteristics were observed in the south valley terrace below elevation 400 feet in H-3vwp-14 and described in the logs of the few deep borings within the Skaglund Hill landslide that fully penetrated this unit (i.e., H-1p-06). A bottom contact elevation of the advance glaciolacustrine unit was established within or near all three landslides, which are roughly one mile equidistant from each other. Test borings H-3vwp-14 in BA6S and H-1p-06 in BA4S

encountered the contact at nearly identical elevations at about 312 feet. Test boring H-1vwp-14 located behind the SR 530 headscarp encountered the contact at about elevation 328 feet.

Data from the two piezometers within the middle and bottom of this unit beneath Whitman Bench (H-1vwp-14 at 450 and 570 ft depths, respectively) indicate differently pressurized zones are present, but with a lack of hydraulic connection between them. Observed aquifer response to precipitation at the bottom of the advance glaciolacustrine unit on both sides of the valley (H-1vwp-14 at 570 ft depth and H-3vwp-14 at 250 ft depth) could be described as nonresponsive to short-term precipitation and nonresponsive to unremarkable (4-ft rise) to longer-term seasonal trends in precipitation.

Nonglacial Deposits

Within the study area, Dragovich et al. (2003) mapped several exposures along both sides of the channel near river level as Olympia-age nonglacial deposits of fluvial origin. From borings and water wells, they also identified these deposits as underlying recent valley alluvium. They noted the variable nature of the deposits, ranging from gravel, sand, silt, clay and peat. As these represent ancestral (pre-Vashon) river deposits, considerable compositional, lateral, and thickness variability would be expected. The deposits encountered beneath the advance glaciolacustrine deposits in all three borings performed for this study, as well as previous deeper borings for the Skaglund Hill landslide, consisted of stratified sand, silty sand, and silt. These stratified sands and silts are tentatively correlated, for the purposes of this study, with those mapped by Dragovich et al. (2003). It is also possible that the deposits encountered in the borings represent an early Vashon advance outwash or older glacial deposits.

Groundwater regimes are notably complex within the nonglacial deposits beneath the advance glaciolacustrine deposits at Whitman Bench and that underlie the valley floor. According to available water well logs, a number of the deeper water wells (>50 feet) in the valley intersect pressurized aquifers, two of which located near the base of the SR 530 landslide were observed to produce artesian flow. An extremely pressurized aquifer was encountered between elevations 262 and 267 feet (approximately 10 feet below river level) during the drilling of the first boring on Whiteman Bench, H-1vwp-14. After correcting for drill fluid density, the head was established at 14 feet above ground surface (elevation 906 ft), equating to a total head of between 639 to 644 feet or 277 to 279 psi of pressure. Artesian flow persisted for at least five minutes and then dissipated. The measured head establishes a recharge elevation for this pressurized zone above elevation 906 feet. This contour is plotted on Figure 16. Given the likely low hydraulic conductivities and considerable thicknesses of the till and advance glaciolacustrine units, recharge of this confined aquifer may be more readily occurring horizontally on its northern margin where it may connect with the unconsolidated deposits mantling the valley wall. Explanations for H-2vwp-14 not encountering the same pressurized conditions when drilled 50 feet from H-1vwp-14 could include:

- abrupt lateral discontinuity of water-bearing deposits,
- leaking condition and aquifer depressurization from incomplete grouting during the abandonment of the lower portion of H-1vwp-14, and
- artesian flow from H-1vwp-14 was drilling-induced.

The duration of the flow and the absence of any core being recovered within this zone support the conclusion that pressurized conditions were not drilling-induced. Furthermore, it is unlikely that incomplete grouting during abandonment of the lower portion of the adjacent hole could

cause significant depressurization of the aquifer. Therefore, the lateral discontinuity of the water-bearing deposits is the most likely explanation here.

A laterally continuous, highly pressurized aquifer that extends from beneath Whitman Bench near river elevation and that underlies the slope from which the SR 530 landslide occurred could be a major contributor to large-scale landsliding and high mobility. The apparent discontinuity of the aquifer that underlies the valley floor observed from comparison of borings H-1vwp-14 and H-2vwp-14 appears to conflict with this hypothesis. Additional drilling within the landslide limits would be necessary to confirm or refute the existence of this highly pressurized aquifer, and if present, to quantify its potential contribution to slope instability.

With the exception of the apparent localized, highly pressurized aquifer encountered in H-1vwp-14, the remainder of the borings in the three landslides encountered more benign groundwater conditions within the nonglacial deposits. In BA4S and BA6S landslides, unsaturated zones exist near the top of the unit, and no highly pressurized conditions were encountered or noted within these deposits at either landslide on the south side of the valley. A14-ft seasonal rise has been measured in the piezometer at 625 feet in H-2vwp-14; otherwise, the response of the piezometers within this stratigraphic unit on both sides of the valley could be described as nonresponsive to short-term precipitation and longer-term seasonal trends in precipitation.

Landslide Deposits

BA4S (Skaglund) and BA6S (MP 38 vicinity on south side of Valley) landslides have borings that penetrate landslide deposits. No recent borings of significant depth have been drilled within the SR 530 landslide mass that remains on the terrace face.

H-3vwp-14 drilled within the depletion zone of BA6S encountered about 184 feet of landslide deposits, including a portion of the apparent basal failure zone, overlying advance glaciolacustrine deposits. The material recovered from the coring was a heterogeneous mixture of gravel/cobble-rich zones, silty sand, silt and fat clay. Borings in the distal lobe of the BA6S deposit encountered similarly heterogeneous materials. Deep borings drilled in the landslide deposits within the lower active portion of BA4S encountered primarily silt and clay-rich materials derived from the advance glaciolacustrine unit.

Perched groundwater is present within the BA6S landslide deposits, and it is responsive to both short-term precipitation events exceeding several inches within several days and longer-term seasonal trends in precipitation. Though somewhat more complex groundwater conditions were noted within the landslide deposits in BA4S, perched conditions within the landslide deposits were also interpreted from the piezometer data.

Geotechnical Characterization of Units

The geotechnical characterization of the index and strength properties of all the stratigraphic units is a necessary and important task. However, determination of the appropriate type of strength testing to conduct relies on some understanding of how the SR 530 landslide (and those similar in size and behavior) may have developed and the loading conditions (stress history, degree of saturation and drainage paths, rate of deformation) that were present during its various phases of evolution.

The SR 530 landslide involved both comparatively weak landslide deposits and a comparatively strong, intact sequence of glacial, and possibly nonglacial, units, most of which has been highly

overconsolidated from glacial loading. These glacially overconsolidated units include the till, advance outwash and glaciolacustrine units, and the nonglacial deposits.

An initial suite of index tests have been performed on all of the units in the intact sequence of the SR 530 landslide as part of this initial phase of study; the results are included in Appendix D. No index tests have yet been performed on materials recovered from the drilling of BA6S landslide (H-3vwp-14). Extensive geotechnical laboratory testing was completed for remediation of the Skaglund Hill landslide, and those data are summarized in previous reports (Landau Associates, 2006, 2009, and 2010). Initial strength testing of intact units behind the SR 530 headscarp is expected to continue through the remainder of the year. Drilling within the SR 530 landslide limits would be necessary to assess what is needed for more in-depth laboratory testing and to recover additional materials for testing. At that time, testing results could be compared for landslides on both sides of the valley to assess commonality or differences in geotechnical behavior for these areally extensive deposits.

Failure Zones

Deep borings within/near the three landslides established the presence of the advance glaciolacustrine unit in the lower portion of both terraces. The basal contact with the underlying nonglacial deposits (or possibly an older advance outwash at the BA4S (Skaglund Hill vicinity) landslide) within the three landslides is approximately located between elevations 311 and 328 feet.

Boring H-3vwp-14 advanced through 183 feet of landslide debris and penetrated the interpreted, lowermost portion of the basal failure zone of the BA6S (MP 38 vicinity on south side of valley) landslide. This failure zone was located within the advance glaciolacustrine at elevation 396 feet, 68 feet above the contact with the nonglacial deposits (Fig.14). The basal failure zone at elevation 397 feet consisted of disrupted, slickensided fat clay (advance glaciolacustrine deposits) with a plasticity index of 35, a clay fraction of 58%, and residual shear strength of about 13°. The intact glaciolacustrine deposits below the failure zone were laminated (layers <1/4”) to stratified (layers >1/4”), generally horizontal to shallowly inclined, and locally homogenous. The failure zone is situated elevationally low within the depletion zone, which would indicate that the surface rupture toe is near the base of the valley slope (Fig. 14). It further defines the failure zone to be shallowly inclined to near flat-lying for a length of about 1000 feet. Such a failure zone configuration may have produced a very steep headscarp that subsequently back-wasted to a flatter configuration.

In the lower portion of the BA4S (Skaglund Hill vicinity) landslide, boring H-1p-06 penetrated an estimated 67-ft-thick zone of apparent landslide debris described as medium to very stiff, slickensided, lean to fat clay (Fig. 15). At about elevation 329 feet, an 18-ft-thick zone of apparently undisturbed, advance glaciolacustrine deposits was encountered. It was described as very hard, horizontally laminated/bedded, clayey fine sand to clayey silt. Based on the boring logs, the furthest upslope borings, SCL-4 and SCL-3, did not encounter either undisturbed glaciolacustrine deposits or the contact with the underlying advance outwash or nonglacial deposits. It is evident from inspection of the slope profile above these uppermost borings to the prominent internal scarp and prehistoric landslide headscarp that the failure surface(s) must be shallowly inclined (less than 10°) and has an overall length of about 1500 feet (Fig. 15).

While no recent borings of significant depth have been drilled within the SR 530 landslide, other evidence is available that identifies where the failure zones of prehistoric and historic events prior to the January 25, 2006 landslide rupture the surface near the base of the slope. These data are summarized below and presented in Figure 17. Thorsen (1970) noted that the 1967 surface-rupture toe was about 80 feet above the river and an intact sequence of horizontally bedded sediments that formed the right bank of the river beneath the landslide. Dragovich et al. (2003) mapped this same outcrop three decades later as Olympia-age nonglacial deposits. The failure zone of the much larger, prehistoric landslide that cuts into the southeastern edge of Whitman Bench, and into which the historic events of the Hazel Slide are inset, must also lie at or above the intact riverbank sequence. Events (prior to 2006) of the Hazel Slide that remobilized existing landslide debris may have utilized the same basal failure zone created by the prehistoric landslide.

The 25 January 2006 reactivation of the Hazel Slide was similarly inset within the much larger prehistoric landslide as preceding historic events (Fig. 18). The location of the landslide surface-rupture toe (and basal failure zone) is indeterminate from the available photography and lidar, as much of the base of the slope was buried in landslide debris and the river channel was pushed 700 feet to the south. The log crib wall constructed after the landslide prevented the river from significantly eroding the 2006 landslide debris and reoccupying its former channel (Fig. 6).

Delineation of the landslide failure zone and surface rupture toe of the SR 530 landslide is also not possible at this time. Drilling within the SR 530 landslide limits would be needed to locate the failure zone. In the absence of additional drilling, interpretations about the location of the failure zone for the SR 530 landslide will need to account for about 6 million cubic yards of debris in the valley and at least several million cubic yards of landslide debris remaining on the slope. Available information from the current study of the SR 530 landslide is presented in Figure 19.

Available data indicates that the failure zones for both landslides on the south side of the valley (BA4S and BA6S) are located low in the glacial sequence (roughly between elevations 300 and 400 ft) within the lower portion of the advance glaciolacustrine deposits, are nearly flat to shallowly inclined, and exceed 1000 feet in length. The deposits within which these failure zones occur have a prominent sub-horizontal bedding structure. Thus, bedding may have contributed to the development and long lengths of the shallowly inclined failure zones within these two landslides. Strength anisotropy within the undisturbed glaciolacustrine clays should be quantified through laboratory testing to determine the potential contribution bedding has on the development of new landslides within the intact glacial sequences in the valley. While bedding may be a controlling factor, understanding the mechanism through which strength is lost within these undisturbed, highly overconsolidated clays is also important. The phenomenon of creep and strain-softening within overconsolidated clays and their contribution to progressive slope failure is well known (Skempton, 1964; Bjerrum, 1967). Keaton et al. (2014) and Landau (2010) suggested that strain-softening within the advance glaciolacustrine deposits may be a potentially important mechanism for the SR-530 landslide and for landsliding elsewhere in the valley. These behaviors also need to be quantified through laboratory testing. Additional residual strength testing is needed to quantify its contribution to reactivating pre-existing failure zones within landslide deposits.

Initiation of the SR 530 Landslide

The SR 530 landslide involved essentially two distinctly different masses of apparent similar volume:

1. a comparatively weak, dilated mass of prehistoric and historic landslide deposits that mantled the terrace face, and
2. an underlying, 600-ft-thick sequence of undisturbed, comparatively strong, glacial, and possibly nonglacial, deposits.

Accounting for both landslide masses is fundamental to future interpretations made about how precipitation and groundwater may have contributed, the stress conditions that led to failure within these two distinct landslide masses, and how these masses deformed and ultimately became highly mobile.

Much attention has been given to the potential triggering role of the wet-period that preceded the SR 530 landslide. The widespread presence of springs, wet ground, and flow-type slope failures have been historically noted in the landslide deposits mantling the lower half of the terrace face, indicating that the landslide deposits may have often been extensively saturated. Additionally, the large 25 January 2006 reactivation of the Hazel Slide occurred following a month-long-period of above-normal precipitation, as did the Skaglund Hill landslide on the south side of the valley a week later (Landau Associates, 2009). These 2006 events suggest that aquifers within these landslide deposits may have been responsive to precipitation, though instrumentation data is lacking to confirm such a connection. It is reasonable to expect that the various aquifers within the two distinctly different masses identified in the SR 530 landslide could respond quite differently to precipitation. Unconfined perched aquifers that exhibited some responsiveness to precipitation were noted in the landslide deposits of the two large landslides investigated on the south side of the valley. The inherent dilated nature of landslide deposits and the presence of tension cracks and surface depressions that pond water are conditions that predispose aquifers within landslide deposits to be responsive to precipitation. While it is likely that such an unconfined aquifer existed within the landslide deposits prior to the initiation of SR 530 landslide, it is not possible to retroactively establish the porewater pressures associated with such an aquifer at the time failure, especially now that the landslide mass has been fundamentally changed.

As a result of this study, much additional information has been gained regarding the stratigraphy and groundwater conditions within the intact glacial/nonglacial sequence that underlies southeastern corner of Whitman Bench. The uppermost aquifer located within the recessional outwash unit is unconfined and perched on the till unit. Through this past winter, the groundwater level has risen gradually from about 109 feet depth below ground surface (bgs) to 105 feet, and only very minor (≈1 ft) discernable response has been measured to short-term precipitation events exceeding several inches within several days. Two days after the landslide, observations of the headscarp revealed only minor seepage within a 5 to 20-ft-thick zone above the till (Fig. 9). The underlying confined aquifer in the advance outwash and saturated zones within the advance glaciolacustrine have been demonstrably nonresponsive to short-term precipitation and seasonal trends. Their position behind the landslide deposits on the terrace face, however, could make them sources of recharge of the landslide deposits and pore-pressure elevation along landslide failure zones.

SUMMARY

The objective of this study was to advance current understanding of the geologic, hydrogeologic, and geotechnical conditions that may contribute to landslides in this reach of the valley, specifically focusing on those having large volume, exhibited high mobility, and, thus, potentially posing the most severe public risks, like the SR 530 landslide. Based on this investigation, the following factual information has been gained:

- The SR 530 landslide consisted of two distinctly different masses of apparent similar volume: 1) a comparatively weak, dilated mass of prehistoric and historic landslide deposits that mantled the terrace face; and 2) an underlying, 600-ft-thick sequence that comprises Whitman Bench consisting of undisturbed, comparatively strong, glacial, and possibly nonglacial, deposits.
- Highly overconsolidated (compact), glaciolacustrine (glacial lake) clay comprises the lower half of the sequence beneath southeast corner of Whitman Bench, as determined by two deep borings drilled near the SR 530 landslide headscarp.
- Geologic units underlying Whitman Bench generally exhibited very limited (less than 5 feet) to no response to short-term (days to weeks) and longer-term (season) precipitation for the monitoring period between December 2014 and mid-May 2015, based on the performance of seven piezometers installed at varying depths. An extremely pressurized aquifer was encountered around elevation 260 feet (approximately 10 feet below river level) during the drilling of the first boring on Whitman Bench, H-1vwp-14; however, it was not encountered in an adjacent boring, suggesting that the pressurized conditions are not laterally continuous.
- A boring drilled into the prehistoric landslide on the south side of the valley (BA6S) defined the failure zone to be within the lower portion of the sequence in the highly overconsolidated, glaciolacustrine clay. Three piezometers installed within the boring identified an aquifer perched within the overlying landslide deposits, which was responsive to precipitation. Aquifers beneath the landslide failure zone exhibited no to very limited (less than 5 feet) response to short-term (days to weeks) and longer-term (season) precipitation for the monitoring period between December 2014 and mid-May 2015.
- Previous geotechnical investigations made for WSDOT at the Skaglund Hill landslide (BA4S) similarly define the surface-rupture toe area of the prehistoric landslide to be within the lower portion of the sequence in the highly overconsolidated, glaciolacustrine clay.
- The defined failure zones within the two large volume, prehistoric landslides along SR 530 (BA4S and BA6S) indicate they are nearly flat to shallowly inclined for over 1000 feet in length.
- Baseline geotechnical index properties have been established for all of the geologic units comprising the intact sequence near the SR 530 landslide headscarp. One ring shear test provided residual strength results for the failure zone in BA6S landslide.

Future investigations that may be undertaken by others to more fully define landslide hazards and that may aid in the future management of risks posed to infrastructure may wish to pursue the following:

- Defining the intact sequence of geologic units present on the south side of the valley above SR 530;
- Delineating and characterizing the location, shape, orientation, and geotechnical properties of the failure zone within the SR 530 landslide;
- Performing advanced geotechnical laboratory testing to quantify residual strength within landslide deposits, as well as strength anisotropy, creep and strain-softening behavior within the undisturbed, overconsolidated glaciolacustrine clays;
- Determining the triggering mechanisms, contributing factors, and sequencing of the SR 530 landslide; and,
- Investigating the frequency of occurrence of large volume, high mobility prehistoric landslides.

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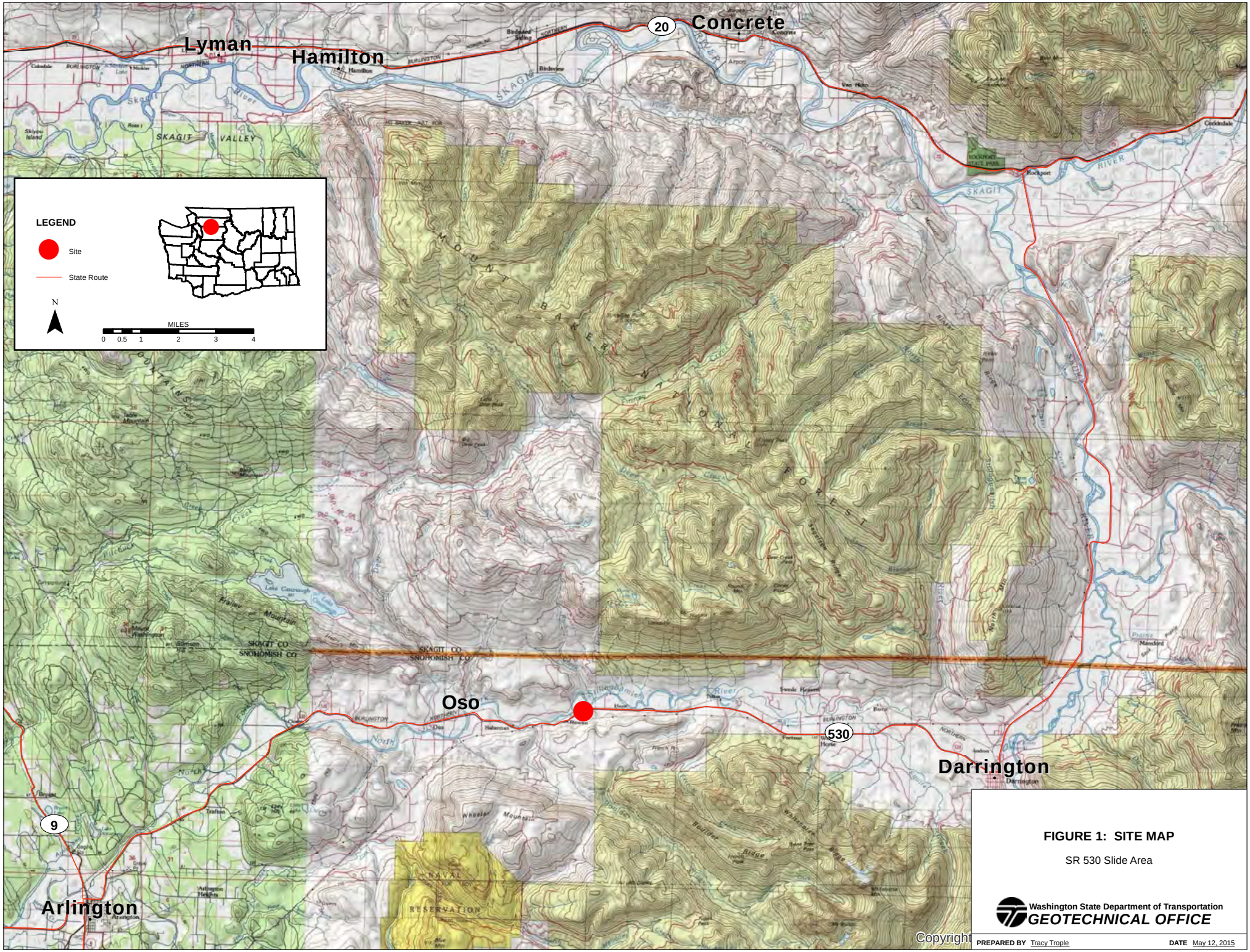


FIGURE 1: SITE MAP

SR 530 Slide Area

Washington State Department of Transportation
GEOTECHNICAL OFFICE

PREPARED BY Tracy Trople **DATE** May 12, 2015

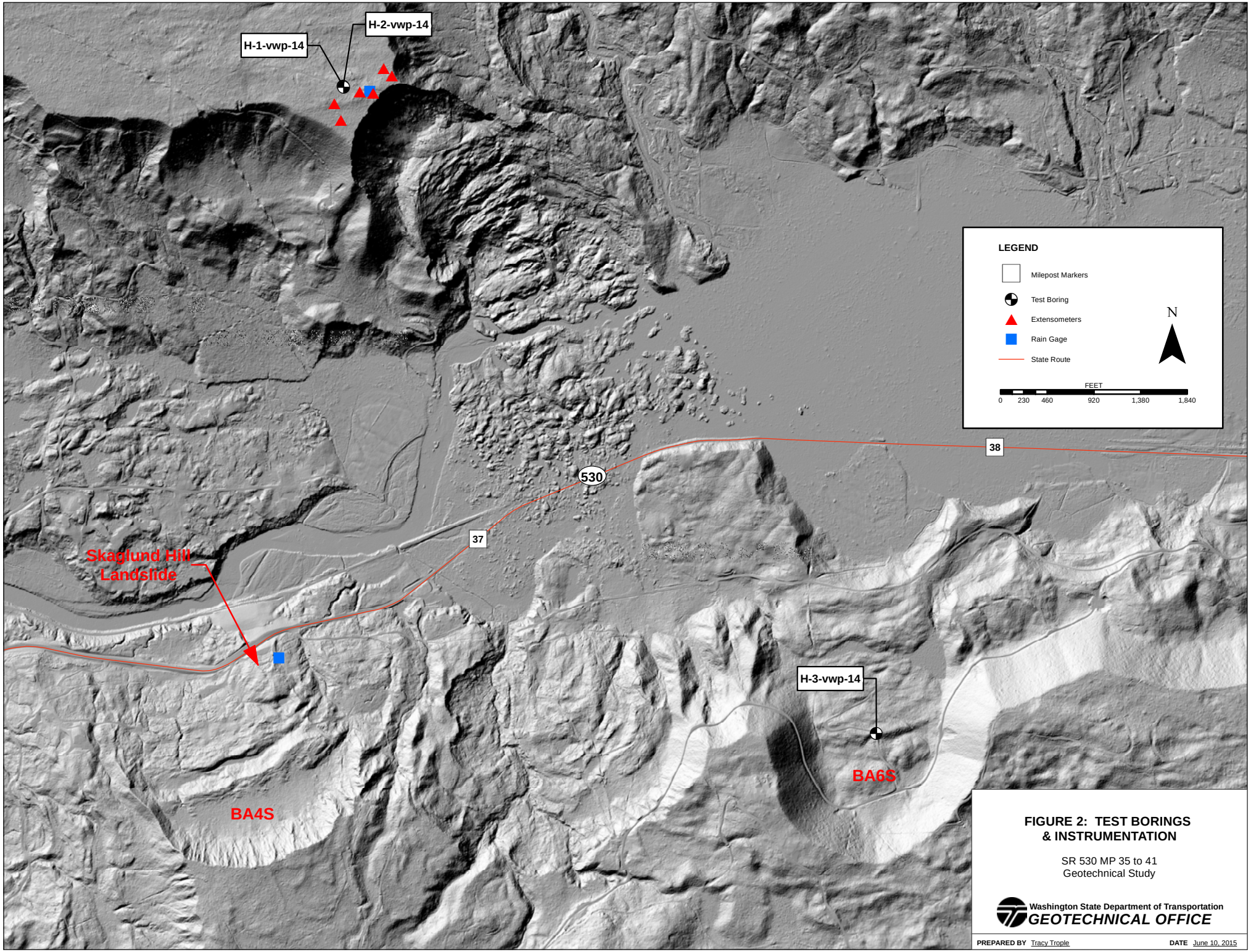


FIGURE 2: TEST BORINGS & INSTRUMENTATION

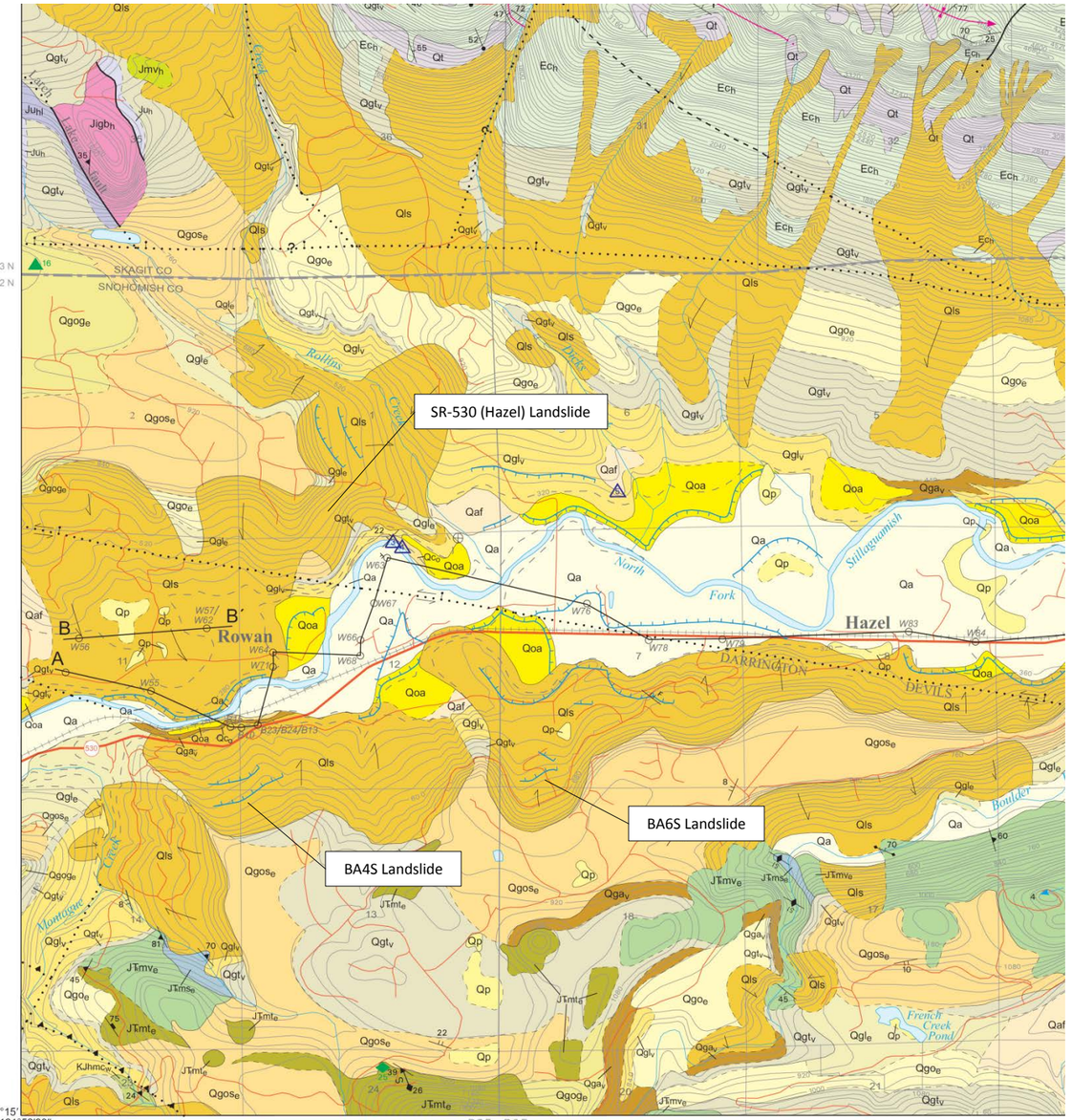
SR 530 MP 35 to 41
Geotechnical Study

Washington State Department of Transportation
GEOTECHNICAL OFFICE

PREPARED BY Tracy Trople **DATE** June 10, 2015

Figure 3. Geologic map

Excerpted from Dragovich, J.D., B.W. Stanton, W.S. Lingley, Jr., G.A. Griesel, and M. Polenz 2003, Geologic Map of Mount Higgins 7.5-minute Quadrangle, Skagit and Snohomish Counties, Washington, Washington Division of Geology and Earth Resources, Open File Report 2003-12



Lambert conformal conic projection
North American Datum of 1927
Base map information from the Washington Department of Natural Resources, Geographic Information System, and from U.S. Geological Survey digital line graphs
Digital cartography by Charles G. Caruthers, Anne C. Heinitz, Donald T. McKay, Jr., and J. Eric Schuster
Edited by Karen D. Meyers and Jaretta M. Roloff

SCALE 1:24 000

1 0.5 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 0.5 0 1 KILOMETER

contour interval 40 feet
supplementary contour interval 20 feet

GEOLOGIC SYMBOLS

- Contact—Dashed where inferred
- Fault, unknown offset—Dashed where inferred; dotted where concealed; queried where uncertain
- Normal fault—Bar and ball on downthrown side; dashed where inferred; dotted where concealed; queried where uncertain
- Oblique-slip fault—Bar and ball on downthrown side; half arrows show apparent relative lateral motion; dashed where inferred; dotted where concealed
- Thrust fault—Sawteeth on upper plate; dotted where concealed
- Anticline—Large arrowhead shows direction of plunge; dashed where inferred; dotted where concealed
- Syncline—Large arrowhead shows direction of plunge; dotted where concealed
- Late Pleistocene to Holocene terrace—Hachures point downslope
- Direction of landslide movement
- Horizontal bedding
- Inclined bedding (or flow banding in volcanic rocks)— Showing strike and dip
- Overturned bedding—Showing strike and dip
- Inclined bedding—Showing strike and dip; top direction of beds known from local features
- Inclined bedding in unconsolidated sedimentary deposits or unconsolidated fragmental deposits of volcanic origin— Showing strike and dip; F near symbol indicates foreset bedding
- Inclined foliation in metamorphic rock—Showing strike and dip
- Inclined foliation parallel to bedding in metamorphic rock—Showing strike and dip
- Vertical or near-vertical first-generation (S1) foliation in metamorphic rock—Showing strike
- Minor inclined fault—Showing strike and dip
- Inclined joint—Showing strike and dip
- Inclined slickensided surface—Showing strike and dip
- Vertical slickensided surface—Showing strike
- Mineral lineation—Showing bearing and plunge
- Slip lineation or slickenside on a fault or shear surface— Showing bearing and plunge of offset
- Stretching lineation—Showing bearing and plunge
- Glacial stria—Showing bearing
- K-Ar radiometric age
- Zircon fission-track age
- Radiocarbon age
- Fossil age (Tabor and others, 2002)
- Approximate center of area of high seismicity within the Darrington seismic zone of Zollweg and Johnson (1989) and this study. See Zollweg and Johnson (1989) for full extent of the Darrington seismic zone
- Other locations referred to in text
- W56 ○ Water well or geotechnical borehole—*W* indicates water well; *B* indicates geotechnical borehole; number is assigned by authors

HOLOCENE NONGLACIAL DEPOSITS

Qs — **Surficial deposits, undivided (Quaternary) (cross sections only)**—Surficial units that are too thin to delineate separately in cross section.

Qa — **Alluvium (Holocene)**—Channel alluvial deposits include sand, gravel, and cobbly gravel; gray; subrounded to rounded clasts; loose, well stratified, and well sorted; planc-bedded sands common. Fine overbank deposits are mostly loose or soft to stiff, gray to brown to olive-gray stratified sand, silt, clay, and peat and muck deposits (similar to unit Qp). Stillaguamish River gravels and cobbles locally contain gray or reddish gray Glacier Peak dacite clasts (5–20%); other clasts are phyllite, slate, other metasediments, greenstone, granite, pegmatite, gneiss, vein quartz, schist, chert, conglomerate, sandstone, and siltstone. Alluvium is generally thin in the study area (<25 ft thick). Peat (unit Qp) is deposited primarily in alluvial settings and is mapped both in conspicuous abandoned channels within floodplains and in poorly drained upland marsh or pond areas. Radiocarbon ages from stinks in peat and organic sediments yield ages of less than 600 yr B.P. and of 2,270 ±60 yr B.P. near the study area (Dragovich and others, 2002a,b, 2003).

Qop — **Older alluvium (Holocene)**—Cobble gravel, sand, and gravel with minor silt and clay interbeds; gray; subrounded to rounded; loose, well stratified, and well sorted; clasts include greenstone, greenschist, granite, gneiss, schist, dacite, pumice, phyllite, slate, vein quartz, chert, quartzite, sandstone, and siltstone; separated from the modern Stillaguamish valley floodplain by distinct topographic scarps (~5–40 ft high); occurs locally as a thin mantle (1–10 ft thick) on Vashon Stade or Everson Interstade glacial deposits exposed in valley bottoms and is separated from the underlying glacial deposits by a scoured surface. Unit Qoa postdates recessional outwash but age relations are ambiguous in some higher elevation localities. Some unit Qoa deposits have dacite clast content (10–15%) suggestive of reworked Glacier Peak volcanic sediments and thus may represent fluvial deposits stranded during incision following volcanic aggradation (this study, Tabor and others, 2002).

Qaf — **Alluvial fan deposits (Holocene)**—Diamicton; massive to weakly stratified; largely angular to subangular, locally derived clasts; mostly poorly sorted debris-flow deposits, locally modified by fluvial processes. The distinction between units Qaf and Qls is at times difficult and differentiation is reliant on the distinct lobate geomorphology of alluvial fan deposits. Alluvial fans occur where upland streams spill out onto valley floors or flat terraces. We obtained a radiocarbon age of 8,040 ±40 yr B.P. from charcoal in flood silt (site 5).

Qls — **Landslide complexes (Holocene)**—Diamicton with soil sand, silt, and (or) clay matrix; contains locally derived, angular to subangular clasts and may contain some rounded clasts from older Quaternary deposits; poorly sorted and unstratified; includes deep-seated (slump-earthflows) and shallow (debris flows and torrents) landslides. Some landslides may have been initiated during removal of ice buttressing during late Pleistocene deglaciation or may be seismically induced (this study, Tabor and others, 2002).

Qt — **Talus deposits (Holocene)**—Nonsorted angular gravel and boulder gravel to diamicton; includes rock-avalanche, rock-fall and rockslide deposits; locally gradational with unit Qaf or Qls and may include Holocene moraine, rock glacier, and proglacial rampart deposits. Talus surfaces are generally unvegetated, however, older rock avalanche run-out areas are sparsely to completely revegetated mostly by slide alder and similar pioneer plant species. Near Mount Higgins, talus deposits typically merge downslope with rock avalanche chutes and (or) depositional aprons containing debris flow deposits. Some avalanche deposits may have resulted from seismic activity associated with the Darrington–Devils Mountain fault zone (DDMFZ).

PLEISTOCENE GLACIAL AND NONGLACIAL DEPOSITS

Deposits of the Fraser Glaciation

EVERSON INTERSTADE

Qgo$_e$ — **Recessional outwash (Pleistocene)**—Sand, gravel, and sandy cobble gravel with rare boulders; loose; clasts are subrounded and commonly polymictic; contains interlayered thin to laminated beds of sandy silt and silt, particularly where grading to unit Qgl$_e$; non- to well stratified; typically contains meter-thick, subhorizontal beds normally crudely defined by variations in cobble, gravel, and sand content. Pebble imbrication, scour, and local low-amplitude trough and other cross-bedding features indicate deposition in braided river and deltaic environments. Some deposits were isolated ice-contact deposits as indicated by the occurrence of rare flow and (or) ablation till lenses and near-ice sedimentary structures. Clast types are dominantly polymictic gravel with a mixed local (phyllite and greenstone) and Canadian to eastern (granite and high-grade metamorphic clasts) provenance. The unit locally contains rip-up clasts of glacial lake silt deposits. Gravel deposits are typically poor in Glacier Peak dacite and (or) pumice clasts (0–5%); however, some of the outwash sands and gravels south of the Stillaguamish River and east-southeast of the study area may locally interfinger with the White Chuck assemblage along the southern margin of the Stillaguamish Valley (Dragovich and others, 2002a,b; J. D. Dragovich, DGER, unpublished data). Locally abundant dacite boulders in the French Creek and Boulder River channels are probably eroded from a nearby (but unobserved) lahar deposit overlying or interbedded with recessional deposits. Locally divided into:

Qgo$_{ge}$ — **Gravel**—Sandy gravel and cobble gravel; locally contains beds of fine sand to silty fine sand typically 1 to 5 ft thick; loose; subangular to subrounded clasts with mixed local and Canadian provenance and minor dacite clasts (typically less than 3%); also includes clasts of greenstone, granite, meta-argillite, metasandstone, chert, sandstone, volcanic rocks, gneiss, vein quartz, phyllite, and rip-up clasts of lake deposits (up to 4 ft long); generally crudely subhorizontally stratified and imbricated.

Qgo$_{se}$ — **Sand**—Sand or pebbly sand; locally contains thin interbeds of silt and silty sand; loose; clasts are subangular to subrounded; generally structureless with some local cross-bedding. Thin-section examination of sand indicates a distinct local clast component (for example, subangular serpentinite, phyllite, and silica-carbonate rock) mixed with far-traveled subrounded detritus (such as granite fragments) probably derived from the North Cascades and (or) the Coast Mountains of British Columbia. Unit Qgo$_{se}$ deposits are typically fluvial but may include shallow deltaic deposits transitional to lake deposits.

Qgo$_{de}$ — **Deltaic outwash**—Sandy gravel and cobbly sandy gravel; loose; moderately to well sorted; contains mostly locally derived, angular to subangular clasts of phyllite, vein quartz, and greenschist. High-amplitude deltaic foreset beds are generally thick, tens of meters high, dip about 30 degrees toward the Deer Creek valley, and are indicative of deltaic deposition into a recessional ice-dammed glacial lake. Facies relations, including fining trends, between deltaic deposits and glacio-fluvial valley-train outwash (units Qgo$_{ge}$, Qgo$_{se}$, and Qgo$_a$) and glacial lake deposits (unit Qgl$_e$) suggest more widespread deltaic deposits than mapped herein.

Qgl$_e$ — **Recessional glaciolacustrine deposits (Pleistocene)**—Clay, silt, sandy silt, and sand with local dropstones; gray to light gray to blue-gray; weathered to shades of brown; well sorted; loose, soft, or stiff; nonstratified to laminated; varve-like rhythmite beds about 0.4 in. thick and laminated beds of silt to sand common; locally contains ball-and-pillow structures; rare sand dikes; common dropstone clast types include granite and greenstone; deposited in glacial lakes impounded by receding glacial ice and locally interfingers with recessional outwash. Note that differentiation between advance and recessional glacio-lacustrine geologic units (units Qgl$_a$ and Qgl$_e$) is difficult where stratigraphic position, sediment density, and other criteria are ambiguous.

VASHON STADE

Qgt$_v$ — **Till (Pleistocene)**—Nonstratified, matrix-supported mixture of clay, silt, sand, and gravel in various proportions with disseminated cobbles and boulders; compact or dense; mottled dark yellowish brown to brownish gray, grayish blue, or very dark gray; matrix commonly consists of silty fine to coarse sand with or without clay; includes Canadian-provenance and locally derived clasts; where overlying bedrock, up to 90 percent of basal clasts are excavated from underlying bedrock; generally a few yards thick, but can range from a discontinuous veneer to several tens of yards; forms a patchy cover over much of the study area; overlies bedrock in elevated alpine settings but forms a conformable layer in glacial-terrace and low valley-bottom settings and thus mantles topography (cross sections A and B); consists largely of lodgment till but may locally include flow till.

Qga$_v$ — **Advance outwash (Pleistocene)**—Medium to coarse sand, pebbly sand, and sandy gravel with scattered lenses and layers of pebble-cobble gravel; locally contains sand, silt, and clay interbeds; well sorted; compact or dense; clasts consist mostly of Canadian-provenance rock types, some locally derived rock types, and little or no Glacier Peak dacite; subhorizontal bedding or cross-stratification prominent; contains localized cut-and-fill structures and trough and ripple cross-beds; commonly overlain by unit Qgl$_v$ along a sharp contact; interfingers with, conformably overlies, or is complexly interlayered with unit Qgl$_v$; composite sections of units Qga$_v$ and Qgl$_v$ are up to 130 ft thick. Deposits are primarily fluvial, but based on stratigraphic relations, some are inferred to be deltaic (cross sections A and B). For example, unit Qga$_v$ in the Deer Creek valley (site 23) contains high-amplitude and planar foreset beds that dip 21 to 29 degrees upvalley. These beds are traceable into mud-sand laminated bottomset beds with some gravelly sands. The sedimentary structures and facies arrangement indicate ice-impounded glaciolacustrine conditions in the Deer Creek valley during up-valley ice advance.

Qgl$_v$ — **Advance glaciolacustrine deposits (Pleistocene)**—Clay, silt, silty clay, and silty fine sand with local dropstones; blue gray or gray, weathered to pale yellowish brown; locally contains thick beds of structureless, clast-rich diamicton that may be flow till or iceberg melt-out contact zones; also locally contains lenses and beds of fine- to medium-grained sand; stiff or dense; well sorted. Bedding varies widely from structureless to thinly bedded to laminated and most commonly consists of 0.4 to 1.6 in. thick rhythmite beds (probable varves) that are normally graded from silty clay to fine sand. Rhythmite bedding is locally interrupted by thin to thick beds of sand or silty fine sand. Soft-sediment and (or) ice-shear deformational features include contorted bedding, overturned folds, and flame structures. Overturned fold geometries are consistent with east-southeast-directed ice shear during ice advance up the major river valleys. This unit is typically underlain by unit Qc$_o$ and locally overlain by and (or) interbedded with unit Qga$_v$ (cross sections A and B). Note that differentiation between advance and recessional glaciolacustrine geologic units (units Qgl$_v$ and Qgl$_e$) is locally difficult where stratigraphic position, sediment density, and other criteria are ambiguous.

Deposits of the Olympia Nonglacial Interval

Qc$_o$ — **Deposits of the Olympia nonglacial interval (Pleistocene)**—Gravel, sand, silt, clay, peat, and rare diamicton; compact to very compact, well-sorted, and very thinly to thickly bedded; disseminated organic material, logs or wood fragments are common (cross section A). The Olympia nonglacial interval occurred from about 20,000 to 60,000 yr B.P. (Mullineaux and others, 1965; Pessl and others, 1989). We obtained ages of 35,040 ±450 yr B.P. and 38,560 ±640 yrs B.P. (sites 3 and 4) from detrital wood fragments in foreset-bedded fluvial sand exposed near the river level (cross section A). Glacier Peak volcanic fragments in the radiocarbon-dated nonglacial sands indicate that Glacier Peak detritus contributed to the Stillaguamish basin during part of the Olympia nonglacial interval. Unit Qc$_o$ consists mostly of fluvial deposits, forms a dissected pre-Vashon stratum in the subsurface, and may be gently warped and uplifted near the main strand of the DDMFZ (cross section A).

SEDIMENTARY ROCKS OF THE CHUCKANUT FORMATION

E$_{cu}$ — **Mount Higgins unit (Eocene)**—Fluvial feldspathic to lithofeldspathic sandstone, siltstone, and mudstone with minor conglomerate, coal (anthracite), and altered tuff (bentonite); sandstone is various shades of bluish gray to greenish gray and weathered to dark gray to brown; minor minerals reported by Cruver (1981) include K-rectorite, illite, siderite, anatase, zircon, and ankerite; some black shale horizons contain siderite concretions; clasts are subangular to subrounded and are moderately sorted in sandstone and pebble conglomerate; sandstone–shale ratio is about 2:1; structures include cross-bedding, laminated mudstone, symmetrical ripple marks, mudcracks, leaf litter layers, sole marks, and paleosols; bentonite beds (primary or reworked volcanic airfall deposits) (sites 18 and 21) are bluish to light gray to white and weathered reddish yellow. Bentonite is rhyolitic (75% SiO_2; site 21) and contains scattered ash-sized fragments of pumice, irregular-shaped (angular and thin) glass shards, a few angular clear fragments of euhedral, broken and embayed volcanic quartz, and minor rounded fragments of very fine-grained sandstone, all in a glass matrix containing secondary smectite or montmorillonite. Cruver (1981) reports some feldspar in bentonites with crystal fragments concentrated in the lower portion of graded beds (this study; Cruver, 1981; Evans and Ristow, 1994).

HELENA–HAYSTACK MÉLANGE

The Helena–Haystack mélange of Tabor (1994) or the Haystack terrane of Whetten and others (1980, 1988) is a serpentinite-matrix mélange. Blocks of greenstone often erode out of mélange matrix as steep resistant hillocks. Regional greenstone geochemistry suggests a mid-oceanic-ridge to oceanic-island-arc origin (Dragovich and others, 1998, 1999, 2000; Tabor, 1994). U-Pb zircon ages obtained from meta-igneous rocks indicate a Jurassic age of about 160 to 170 Ma (Dragovich and others, 1998, 1999, 2000; Whetten and others, 1980, 1988). Mélange formation is probably mid-Cretaceous or younger and may be partially Tertiary (Tabor, 1994; Tabor and others, 2002). Cretaceous to Tertiary faulting within the broad DDMFZ locally imbricates the ultramafic rocks of the Helena–Haystack mélange with Tertiary and other pre-Tertiary rocks.

Jmv$_h$ — **Greenstone (Jurassic)**—Metamorphosed basalt, andesite, dacite, and rare rhyolite occurring as mafic to intermediate flows and intermediate to felsic tuff and lapilli tuff; bluish gray to grayish green and weathered to dark greenish gray to light yellowish brown; flows locally contain amygdules, pillow breccia, and pillows; commonly nonfoliated but locally contains strong spaced cleavage; relict minerals include common augite and saussuritized plagioclase and rare hornblende; metamorphic minerals include albite, chlorite, acicular actinolite, Fe- and Mg-pumpellyite, prehnite, stilpnomelane, aragonite, and calcite (this study; Dragovich and others, 2002a,b, 2003; Reller, 1986; Tabor and others, 2002).

Jg$_h$ — **Metagabbro (Jurassic)**—Medium-grained to rarely coarse-grained and uralitic greenstone; light to dark greenish gray weathered to yellowish or grayish brown; nonfoliated to locally protomylonitic; also includes coarse-grained gneissic quartz diorite and metamorphosed diorite, pegmatitic gabbro, and diabase; relict minerals include saussuritized and albitized plagioclase, augite or pigeonite, brown actinolized hornblende, and minor interstitial quartz; ophitic or subophitic relict igneous textures common; metamorphic minerals include acicular actinolite, tremolite, epidote, chlorite, pumpellyite, white mica, stilpnomelane, calcite, and (or) aragonite; recrystallization partial and typically static. K-Ar ages of 133 ±10 Ma and 164 ±24 Ma west of the study area (Bechtel, 1979) are consistent with Jurassic intrusive U-Pb intrusive ages reported elsewhere (this study; Reller, 1986; Tabor and others, 2002).

Ju$_h$ — **Ultramafite (Jurassic)**—Mostly serpentinite with rare nonserpentinized or partially serpentinized dunite, peridotite, and pyroxenite and minor metasomatic silica-carbonate rock (unit Ju$_{sq}$), rodingite, or talc-tremolite rock; rare amphibolite; serpentinite is greenish gray to greenish black and weathered to a dark yellowish orange and reddish brown; serpentinite composed of serpentine minerals locally with relict pyroxene and (or) olivine and accessory picotite, magnesite, and opaque minerals (this study; Jones, 1959; Tabor and others, 2002).

Ju$_{sq}$ — **Silica-carbonate rocks (Jurassic)**—Silica-carbonate mineralization products (listwaenites) resulting from metasomatism of ultramafites; pods of incompletely altered serpentinite and brecciated silica-carbonate rock locally common; brown to orange-brown weathered to a reddish or brownish yellow; hydrothermal minerals include microcrystalline quartz and magnesite in roughly equal amounts, with magnesite forming granular aggregates and vein swarms; magnetite, pyrite, and marcasite occur as accessory minerals; associated replacement rocks contain talc, tremolite, sphene, and chlorite; vugs contain colorless, euhedral quartz with overgrowths of dolomite; commonly displays compositionally banded veins or replacement bands of micro-crystalline or macrocrystalline quartz, microcrystalline magnesite, fibrous chalcedony, and (or) macrocrystalline dolomite. Where silica-carbonate rocks and serpentinites are tectonically juxtaposed against the Chuckanut Formation (cross section C), silica-carbonate minerals locally replace the Chuckanut sandstone matrix. Structural relations in these areas suggest that the circulation of hydrothermal fluids accompanied deformation across the DDMFZ and may have been driven partly by hydrothermal circulation cells around Eocene volcanic intrusions. Dragovich and others (2002c) suggested that much of the silica-carbonate mineralization was synchronous with major Tertiary transpression and thrusting in the DDMFZ but locally continued after major fault displacement (this study; Graham, 1988; Lovseth, 1975).

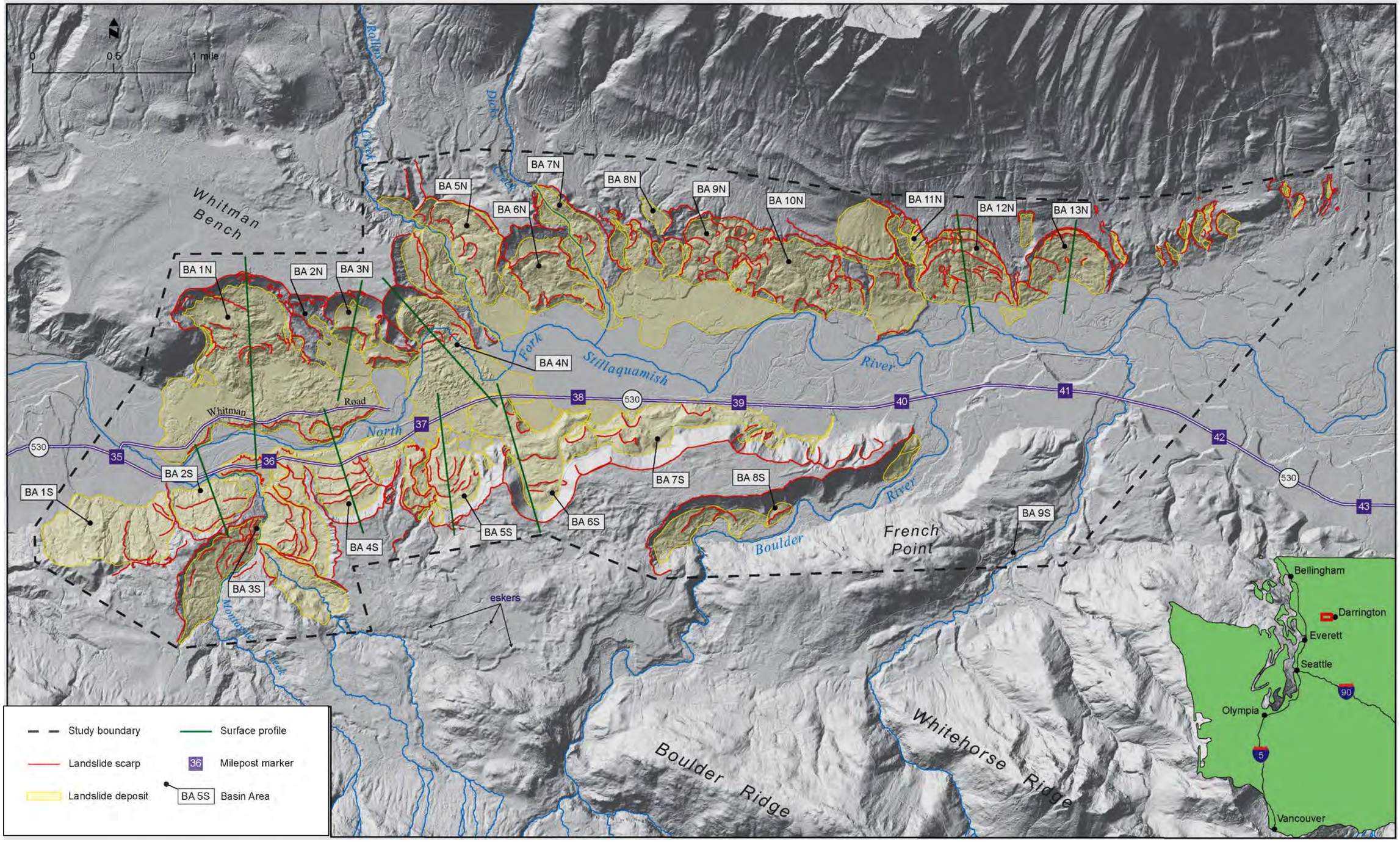
JTmv$_h$ — **Heterogeneous metamorphic rocks, chert bearing (Jurassic)**—Graphite-bearing, medium gray meta-argillite, bluish gray metasandstone to metawacke, and minor metachert; meta-argillite characterized by a strong phyllitic to slaty cleavage; metasandstone and meta-argillite weathered bluish gray and dark greenish gray. Unlike in the Easton suite, cleavage and bedding are locally nonparallel, quartzose metamorphic segregations are generally lacking, and the rocks are less recrystallized.

ROCKS OF THE EASTERN MÉLANGE BELT OF TABOR (1994)

JTmt$_e$ — **Mixed metavolcanic and metasedimentary rocks (Jurassic–Triassic)**—Greenstone with volcanic subquartzose metasandstone, metawacke, meta-argillite, phyllitic argillite, metachert, and minor marble or marl pods; rocks structureless to locally moderately foliated; greenstone contains relict clinopyroxene (some titaniferous) and plagioclase in an altered matrix of chlorite, carbonate, and pumpellyite; prehnite common in veins; deformed pillows are rare. Up to 50 percent of the unit is highly sheared and disrupted greenstone (this study, Tabor and others, 2002).

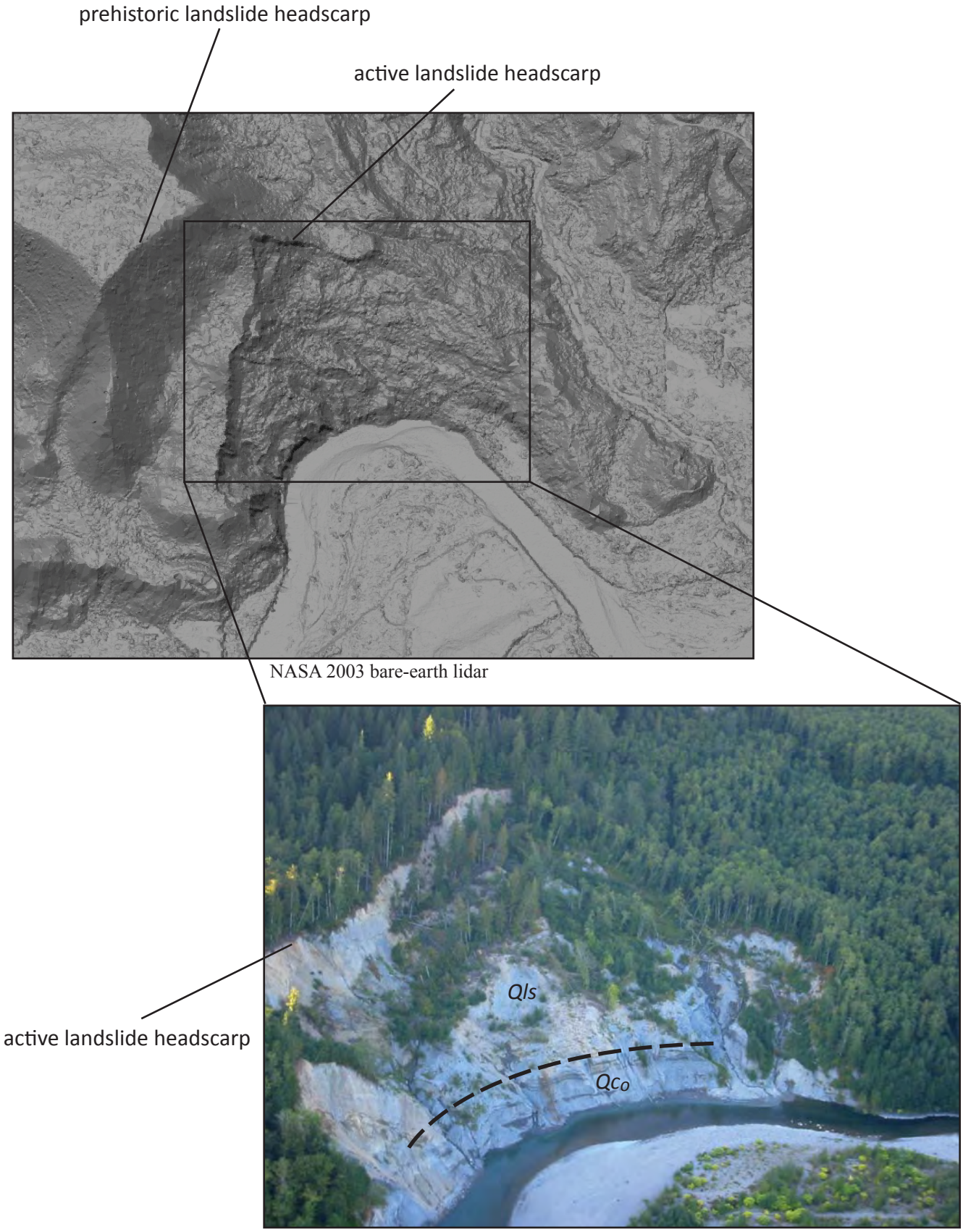
JTmv$_e$ — **Greenstone (Jurassic–Triassic)**—Metamorphosed plagioclase- and augite-phyric basaltic andesite, basalt, andesite, and dacite with minor diabase and gabbro; dark to greenish gray or dusky green weathered dark greenish or bluish gray or brown; thin metasandstone, meta-argillite and metachert interbeds occur locally; mostly thick flows with subordinate thinner beds of breccia or crystal-rich pyroxene-bearing tuff; metamorphic minerals include epidote, pumpellyite, prehnite, and chlorite; local amygdaloidal flow tops; massive to incipiently foliate. At site 25, structureless basaltic greenstone (49.5% SiO_2) contains interlocking plagioclase and augite phenocrysts with disseminated chlorite (this study; Dethier and others, 1980; Tabor and others, 2002).

JTms$_e$ — **Metasedimentary rocks (Jurassic–Triassic)**—Metamorphosed argillite, sandstone, wacke, siltstone with subordinate chert pebble conglomerate, chert, marl, and rare marble; locally contains tuff or greenstone layers and lenses; argillite commonly contains radiolaria and (or) silt-sized grains including angular quartz and plagioclase; sandstone commonly contains large rip-up clasts of argillite; other sandstone clasts include monocrystalline and polycrystalline quartz, chert, plagioclase, sedimentary lithic fragments, quartz mica tectonite, mica, and rare coral fragments; some metasandstones are volcanic lithic to feldspatholithic with a chert-rich provenance; metamorphic minerals include epidote, chlorite, pumpellyite, carbonate, and white mica; prehnite occurs typically in veins; rocks vary from massive to incipiently foliated to rarely strongly cleaved (this study; Dethier and others, 1980; Dragovich and others, 2003; Tabor, 1994; Tabor and others, 2002).



Landslide deposits denoted with yellow shading and prominent scarps in red. From Gerstel and Badger, 2014.

Figure 4. Landslide features in the North Fork Stillaguamish River valley



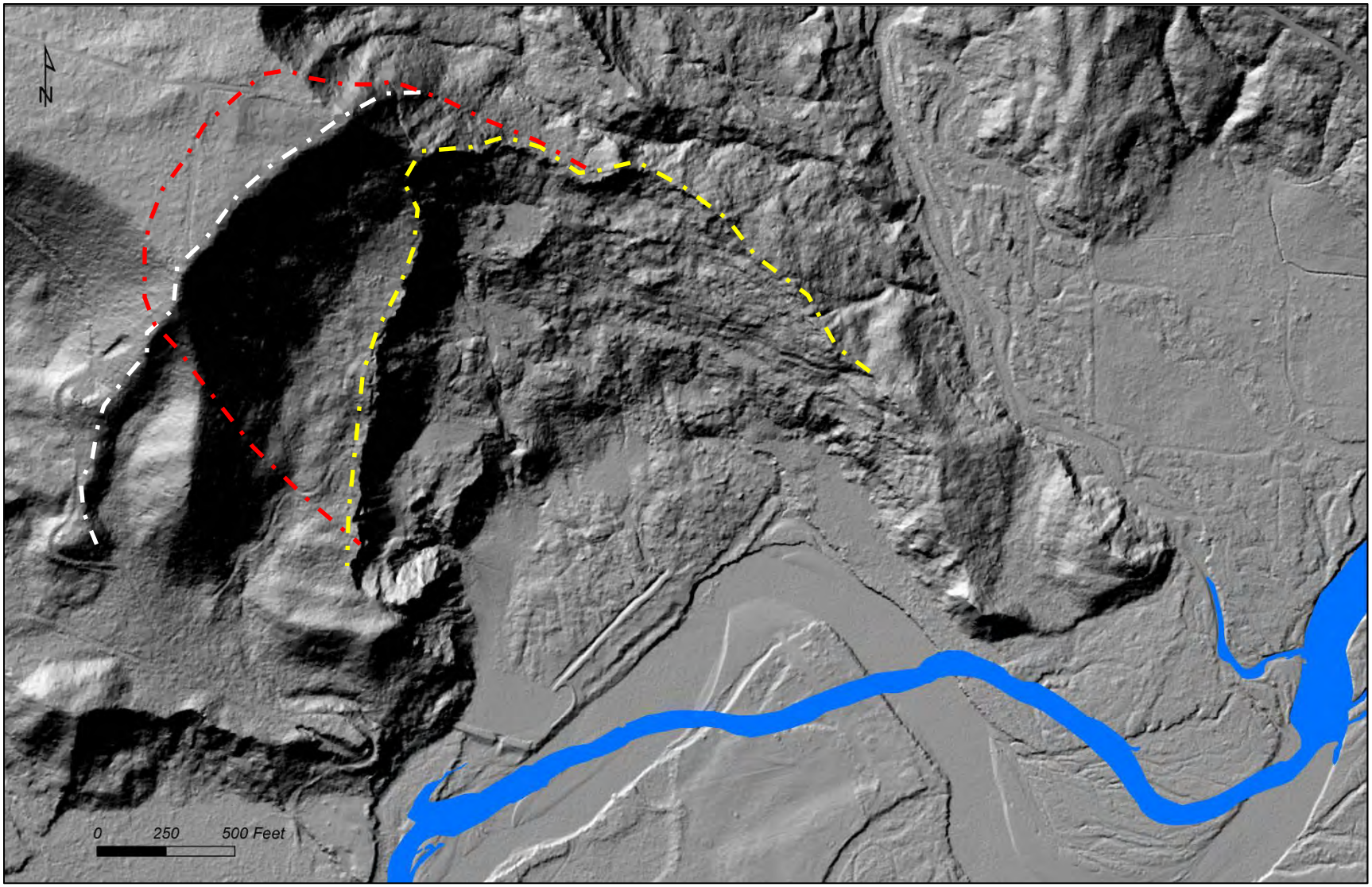
Oblique photograph taken 9/9/2002 shows landslide debris (Qls) over intact bedded unit mapped by Dragovich et al. (2003) as Olympia nonglacial deposits (Qc_O). Photograph courtesy of B. Tart #4247.

Figure 5. Hazel slide (2003)

View looking west. Photograph taken 11/11/2006 (courtesy of B. Tart #4752) of log crib wall construction following the 25 January 2006 Hazel slide.

View looking north of log crib wall, which remained largely intact through at least late November 2013 with exception of minor breach (red dashed polygon). Interpreted landslide toe of the 22 March 2014 SR-530 landslide is hundreds feet northwest of crib wall, indicating that at least through November 2013 the slope from which the landslide initiated was not compromised by river erosion (5/6/2012 photograph courtesy of B. Tart #0313).

Figure 6. Condition of log crib wall

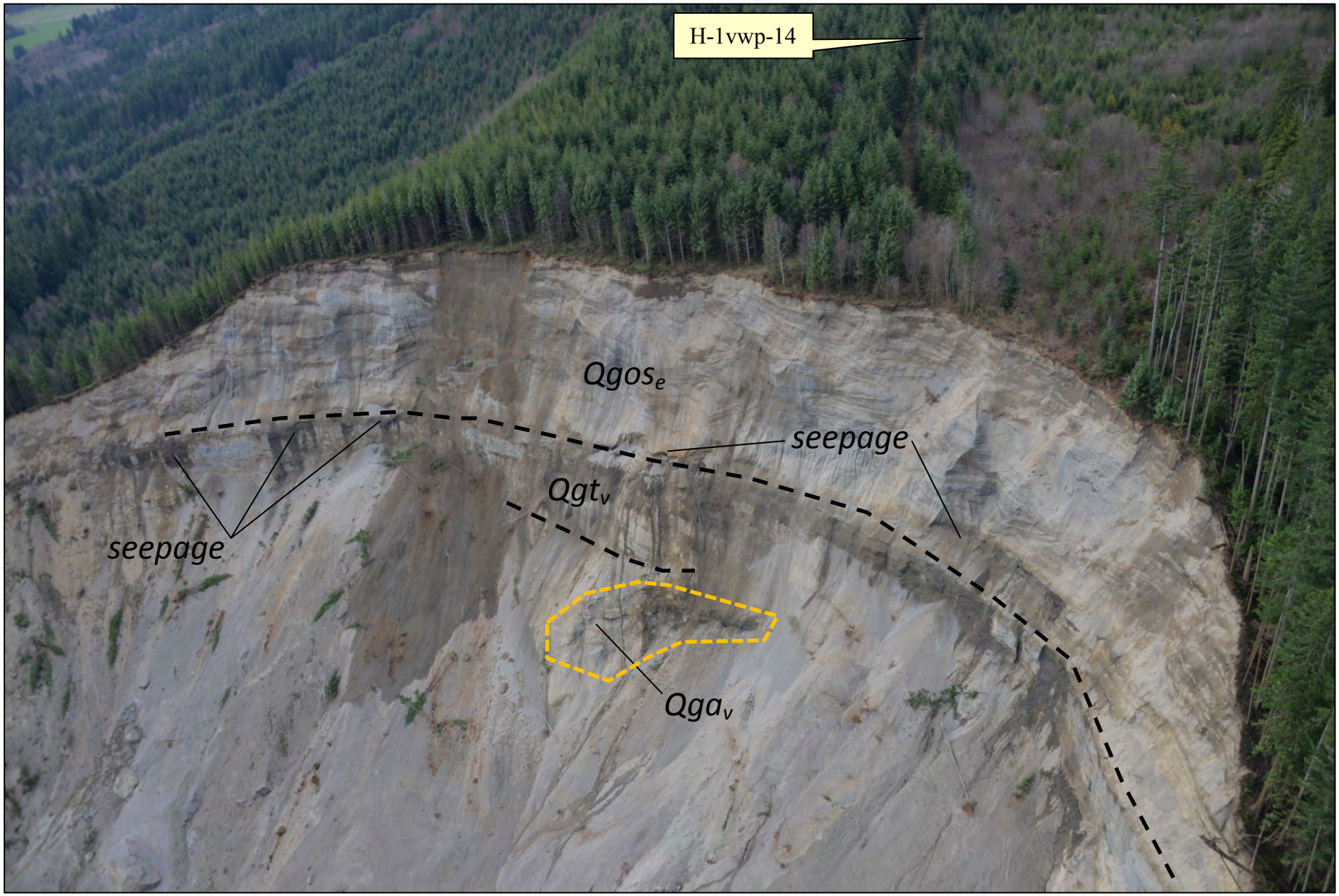


Historic landslides (circa 1930s through 2006) occurred within 2006 landslide limit (yellow dashed line) collectively referred to as the Hazel slide. Historic landslides are inset within a prehistoric landslide (white dashed line). The 22 March 2014 SR-530 landslide (red dashed line) retrogressed approximately 300 feet into the upper terrace referred to as Whitman Bench and its underlying intact sequence of glacial, and possibly nonglacial, deposits. Base image derived from 2013 lidar.

Figure 7. Historic and prehistoric landslide limits

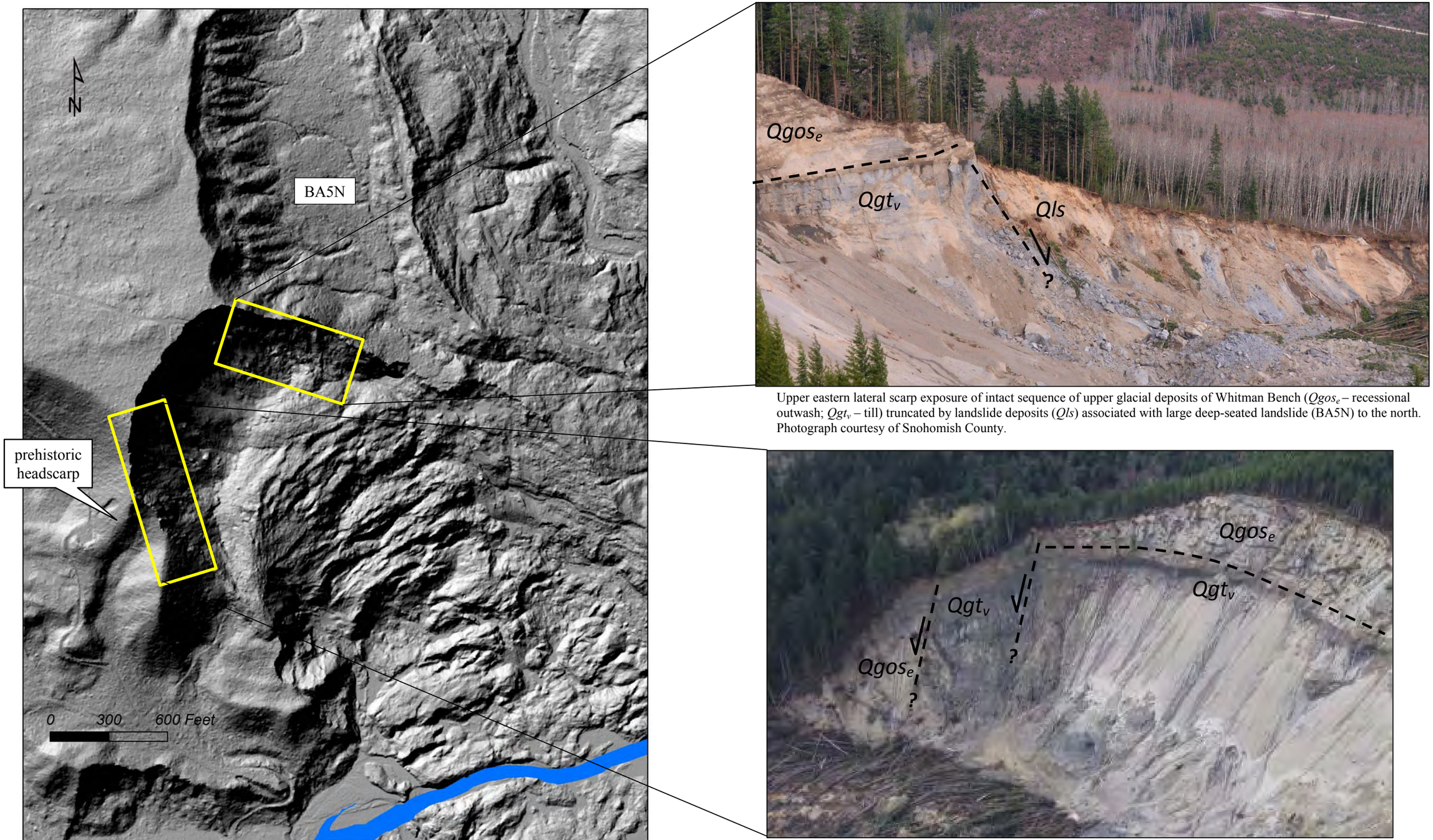
Keaton et al., 2014

Figure 8. Landslide zones identified in 2014 GEER report



Stratigraphic units exposed include recessional outwash ($Qgos_e$), till (Qgt_v), and advance outwash (Qga_v); black dashed lines denote contacts between units. Localized zones of seepage perched within lower portion of recessional outwash. Approximate location of test boring H-1vwp-14 shown. Photograph taken 2 days after landslide; courtesy of E. Jensen, King County Sheriff #2345 3/24/2014.

Figure 9. Headscarp of SR-530 landslide



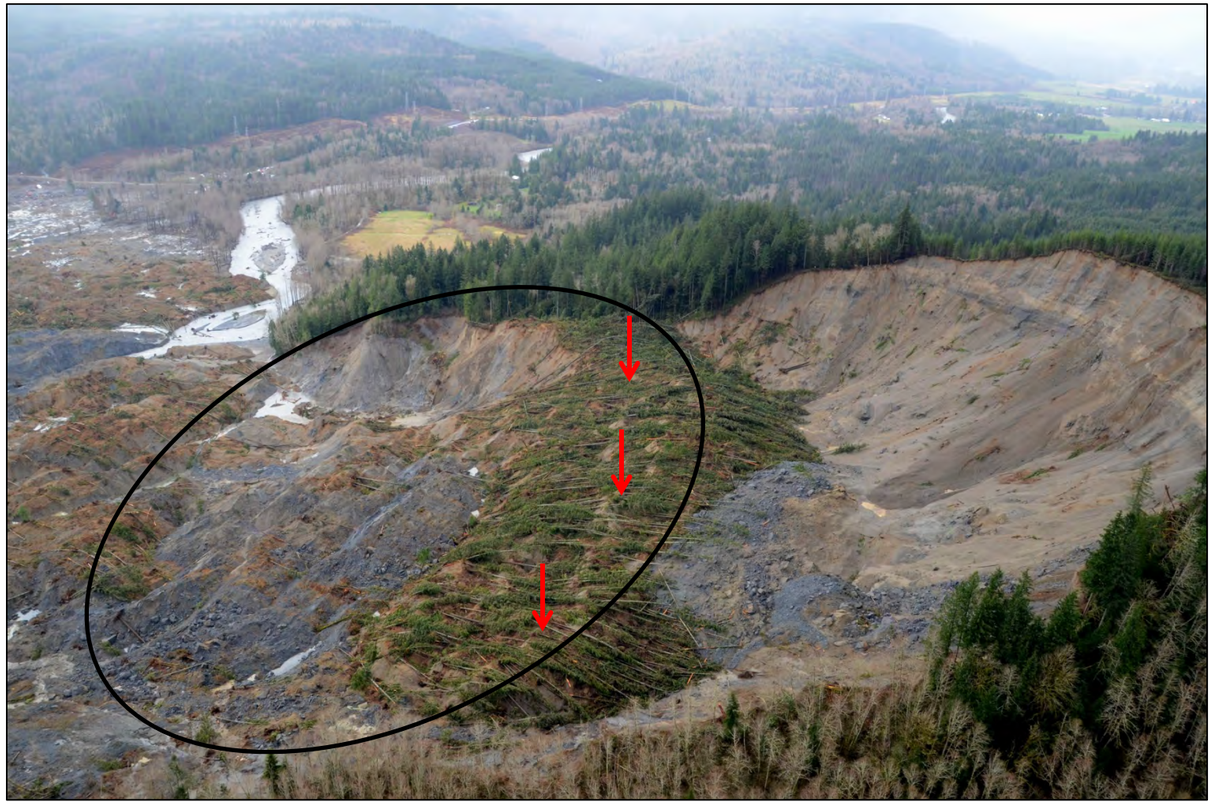
Upper eastern lateral scarp exposure of intact sequence of upper glacial deposits of Whitman Bench ($Qgos_e$ – recessional outwash; Qgt_v – till) truncated by landslide deposits (*Qls*) associated with large deep-seated landslide (BA5N) to the north. Photograph courtesy of Snohomish County.

Headscarp and upper western lateral scarp exposure of intact sequence of upper glacial deposits of Whitman Bench ($Qgos_e$ – recessional outwash; Qgt_v – till) truncated by landslide offset associated with prehistoric event. Photograph courtesy of B. Tart #0223 4/4/2015.

Figure 10. Upper lateral landslide scarps

Upper forested block of Keaton et al. (2014) situated below headscarp is a 300-ft-wide, down-dropped and back-rotated block, which was transported 400 to 500 feet downslope.

Figure 11. Upper forested block



Rotational block field (Zone B of Keaton et al., 2014) consists of a series of back-rotated blocks (black ellipse), with the steep downslope side exposing compact silt and clay (advance glaciolacustrine deposits). Down-dropped portion of upper forested block (red arrows) (Zones A2 of Keaton et al., 2014 – Figures 8 and 11) resembles Zone B characteristics.

Photo shows areal extent of a back-rotated block. Inclinations of downslope surfaces ranged between 36° and 44°. Some surfaces exhibited extensive down-dip striations and slickensides, indicative of shearing between blocks. Diagram below depicts process of internal shearing and back-rotation between blocks.

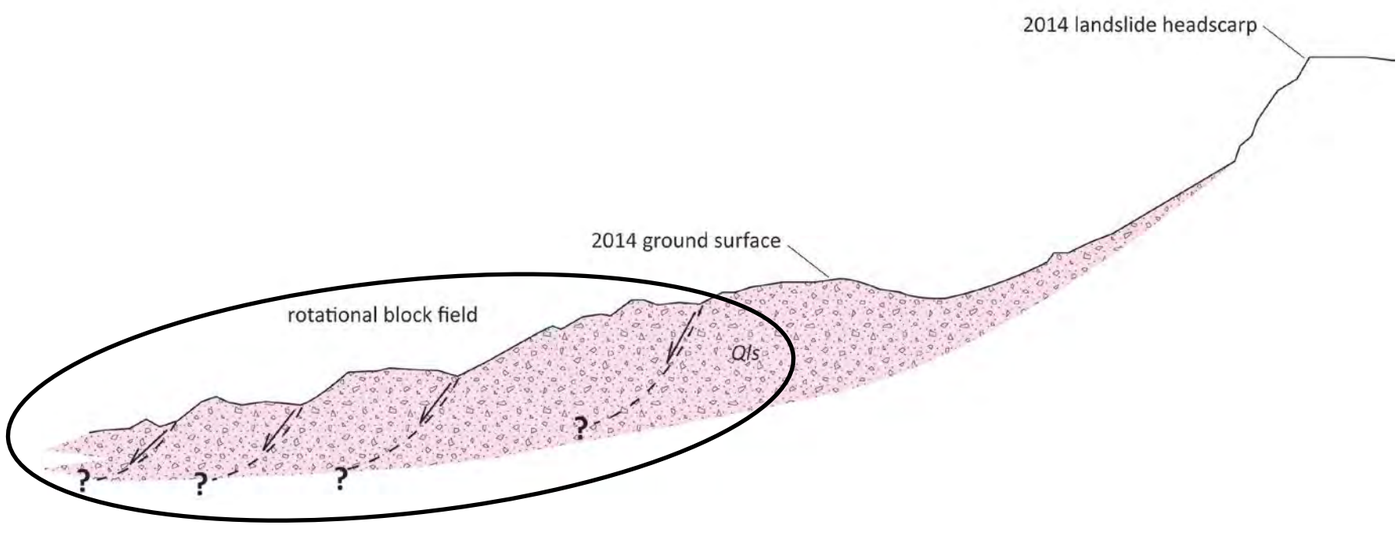


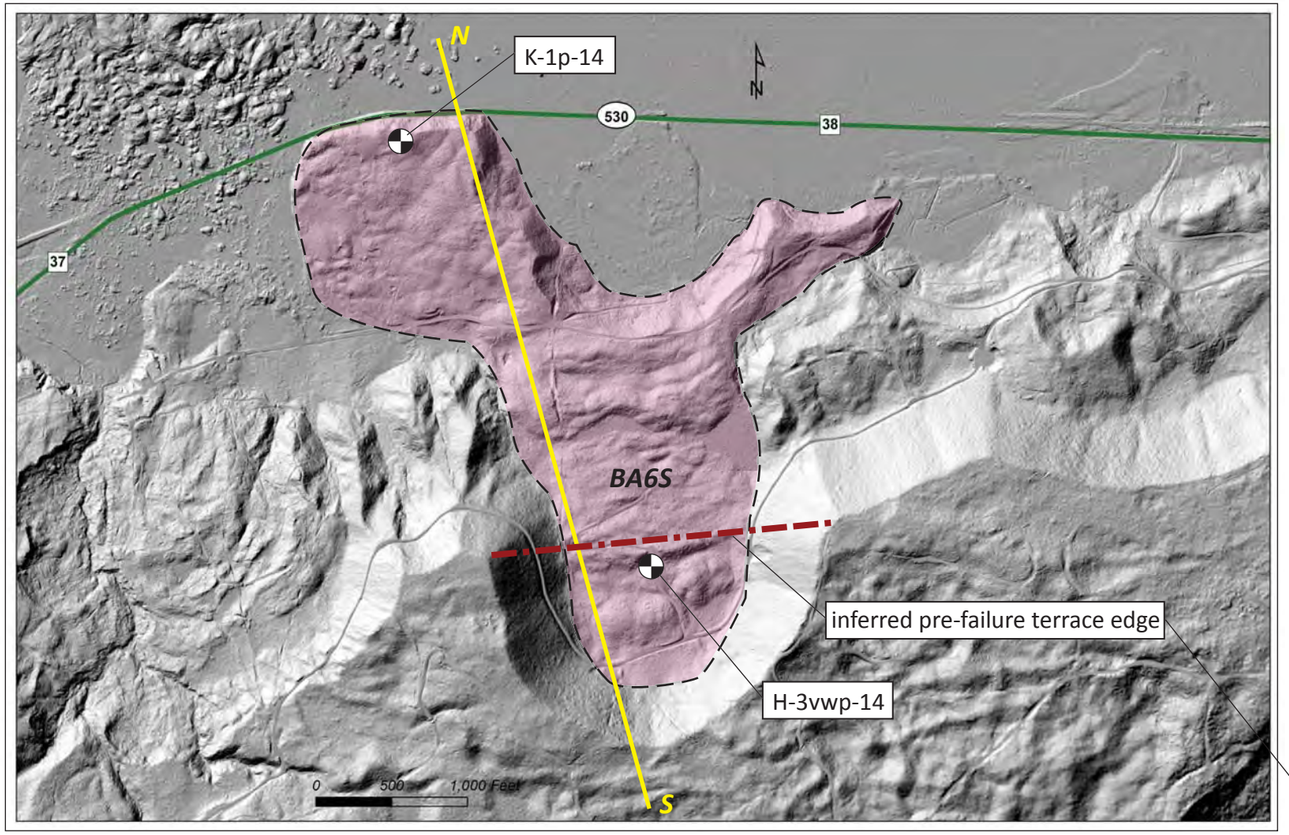
Figure 12. Rotational block field

Keaton et al. (2014) defined Zone C (yellow dashed line) along the eastern margin of the SR-530 landslide as an area of abundant seeps and springs and a source zone for debris flows.

Close-up of an area with standing water and aggraded depressions by flow of saturated debris.

Figure 13. Eastern lateral scarp

Figure 14. BA6S landslide



Clay-SIlt-Sand-Gravel-Cobbles, disrupted (Landslide Debris - *Qls*)

Silt-Sand-Gravel-Cobbles (Alluvium - *Qa*)

Sand-Gravel, stratified and cross-bedded (Everson Recessional Outwash - $Qgos_E$)

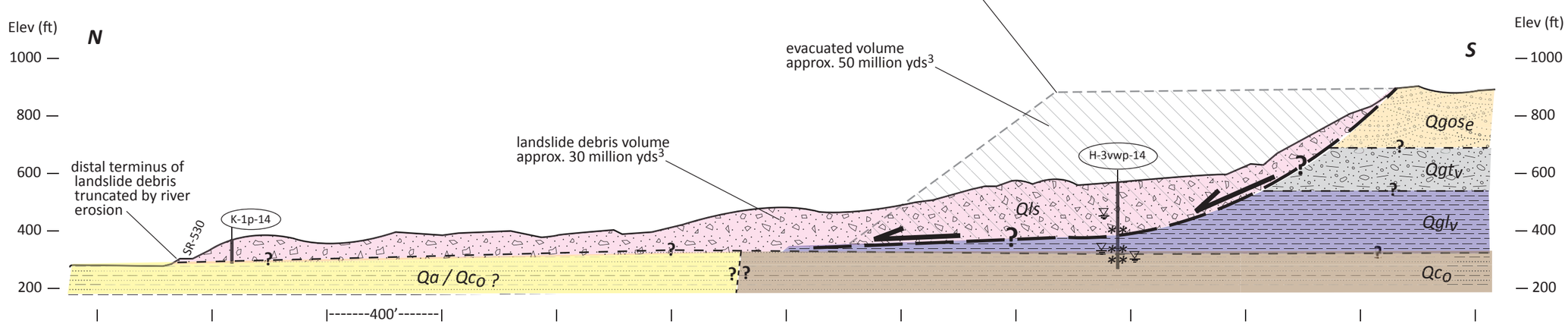
Clay-Silt-Sand-Gravel-Cobbles-Boulders, diamict to stratified, compact (Vashon Till - Qgt_V)

Clay-Silt, laminated to stratifed, compact (Vashon Advance Glaciolacustrine - Qgl_V)

Sand-Silt, stratified, compact (Olympia Nonglacial Deposits - Qc_O)

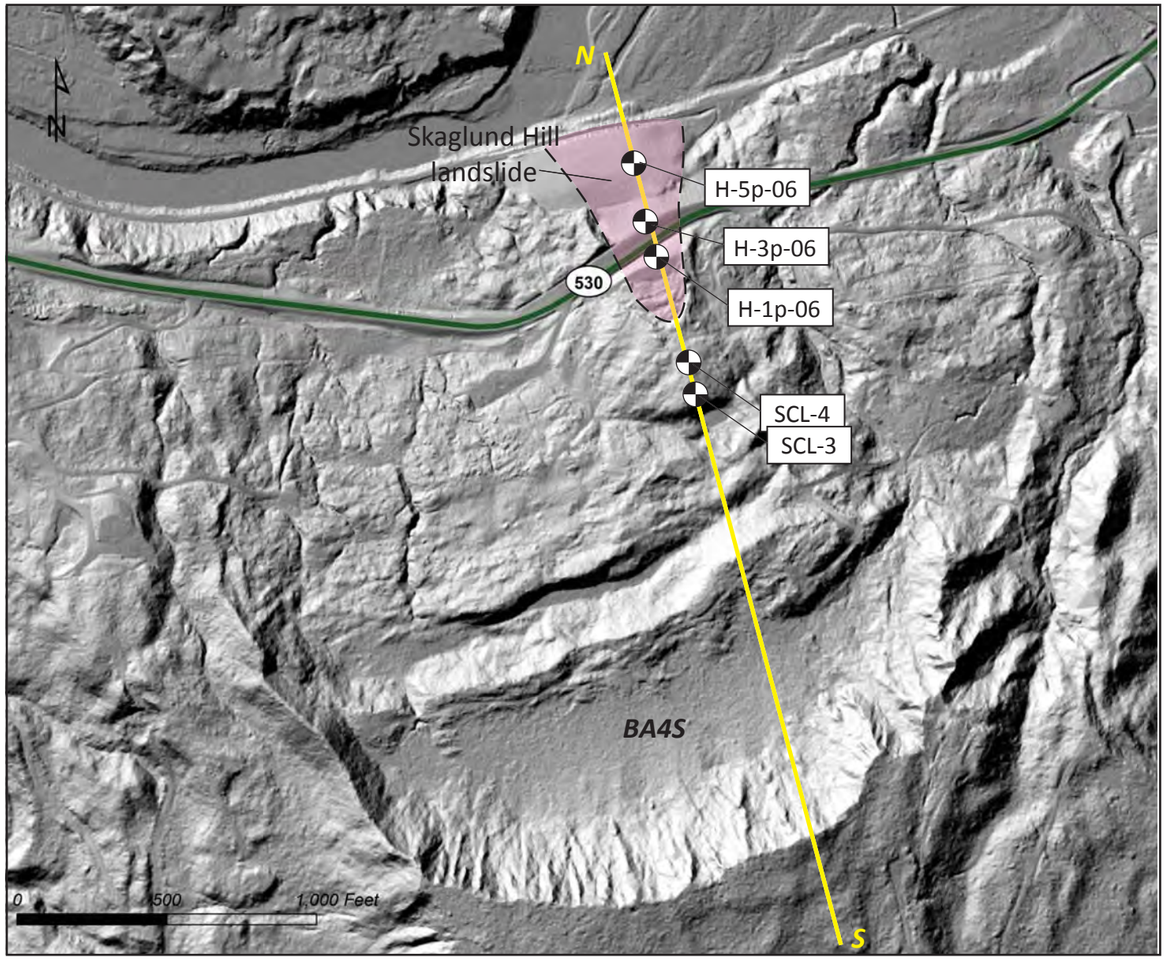
**/ vibrating wire piezometer / piezometric surface

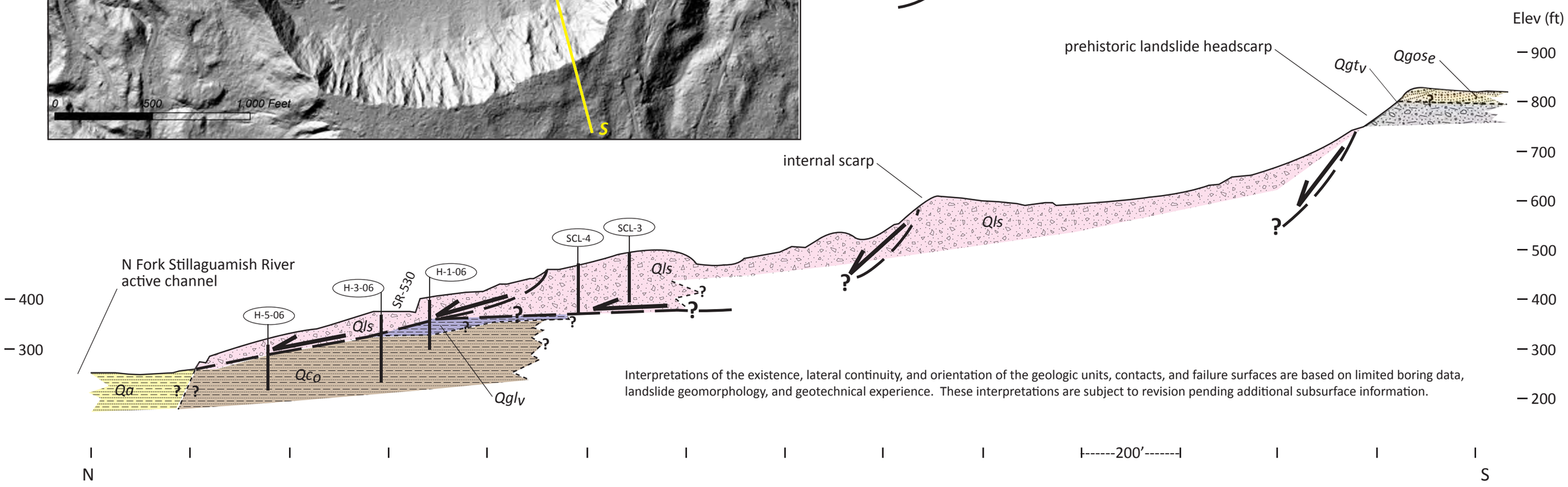
interpreted landslide failure surface

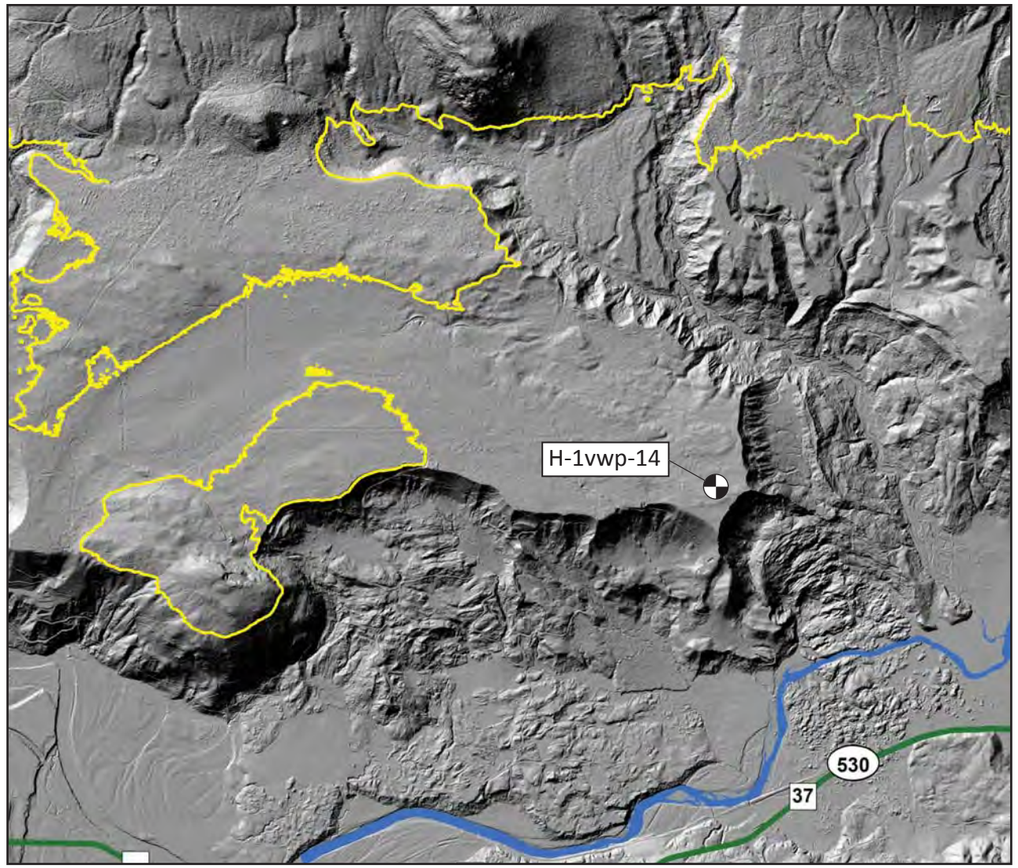


Interpretations of the existence, lateral continuity, and orientation of the geologic units, contacts, and failure surfaces are based on limited boring data, landslide geomorphology, and geotechnical experience. These interpretations are subject to revision pending additional subsurface information.

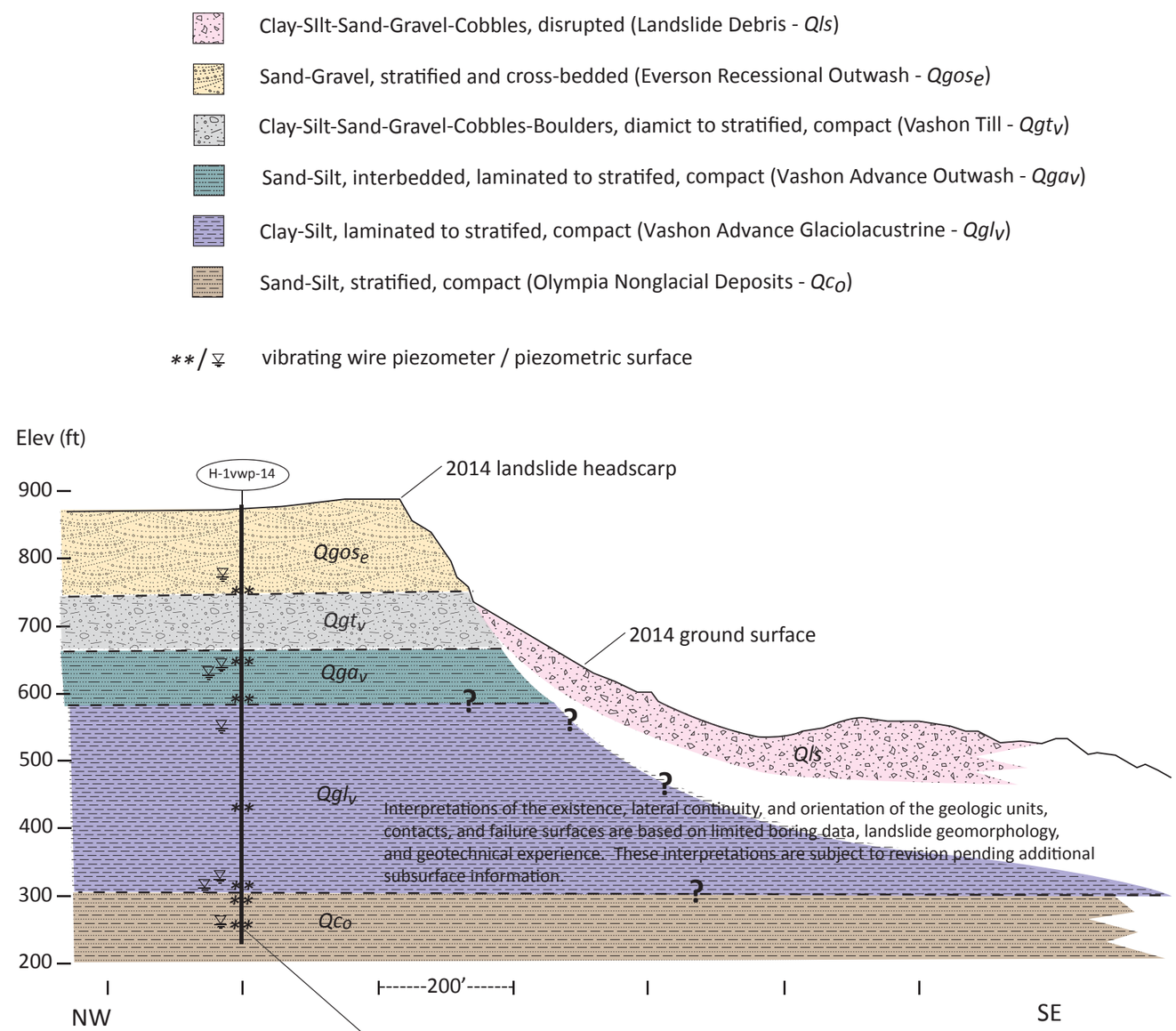
Figure 15. BA4S landslide







Test boring H-1vwp-14, located approximately 300 feet behind the headscarp of the SR-530 landslide, was drilled to a depth of 650.5 ft. Artesian flow from the well was noted at 630-ft depth with a corrected head level of 906 feet elevation. The yellow contours depict the 906-ft contour in the vicinity of the well, above which pressure of the aquifer must originate.

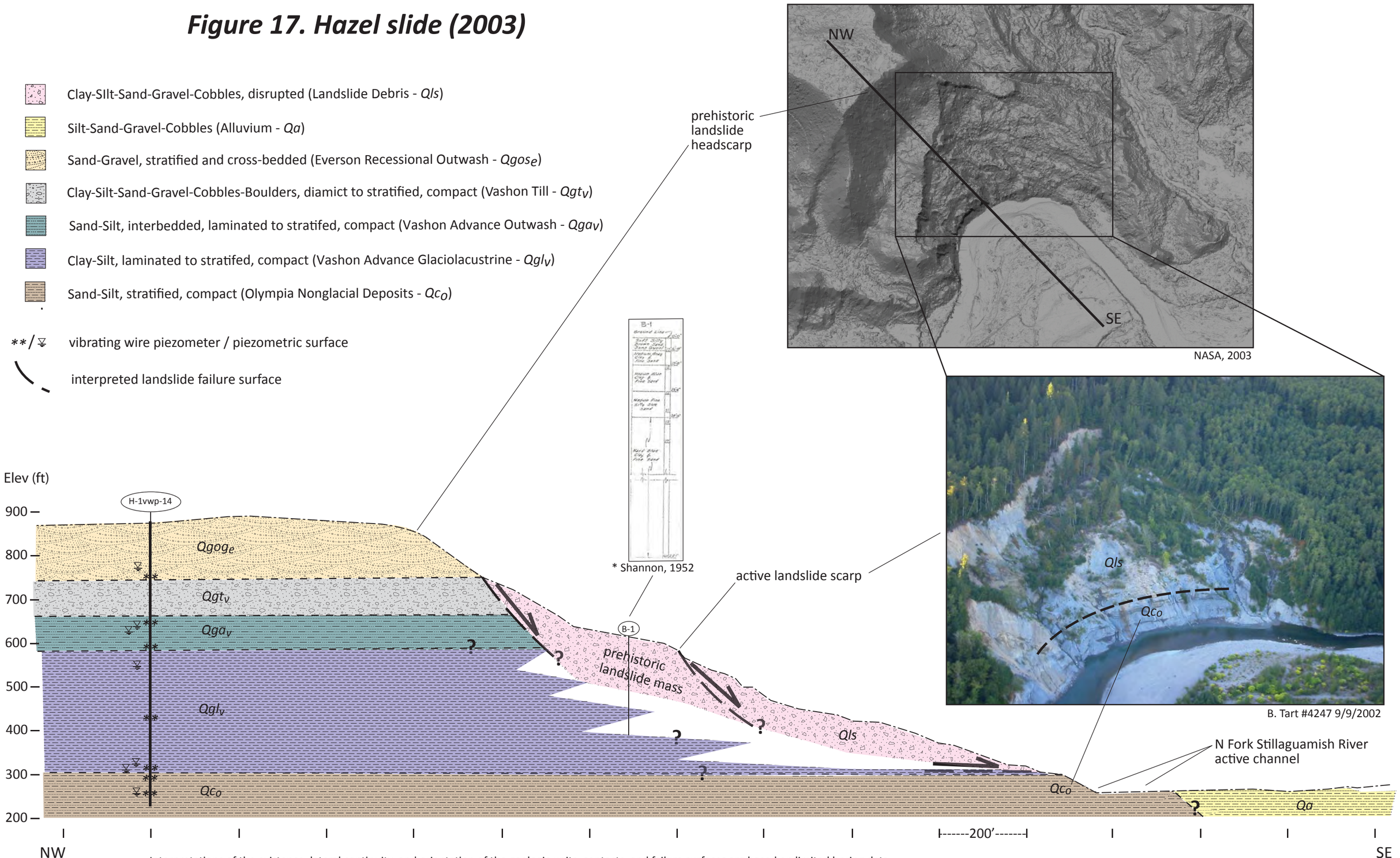


Groundwater response during drilling H-1vwp-14

Ground elev = 892 ft
Water-bearing zone depth / elev = 630 ft / 232 ft elev
Observed fluid level above ground = 8 ft
Uncorrected head / piezometric surface elev = 638 ft / 900 ft elev
Uncorrected pressure = 638 ft x 62.4 lbs/ft^3 = 39,800 lbs/ft^2 (276 psi)
Drilling fluid density = 1.01
Corrected head / piezometric surface elev = 644 ft / 906 ft elev
Corrected pressure = 644 ft x 62.4 lbs/ft^3 = 40,200 lbs/ft^2 (279 psi)

Figure 16. Groundwater conditions in H-1vwp-14

Figure 17. Hazel slide (2003)



Interpretations of the existence, lateral continuity, and orientation of the geologic units, contacts, and failure surfaces are based on limited boring data, landslide geomorphology, and geotechnical experience. These interpretations are subject to revision pending additional subsurface information.

Figure 18. Hazel slide (2013)

Clay-SIlt-Sand-Gravel-Cobbles, disrupted (Landslide Debris - *Qls*)

Silt-Sand-Gravel-Cobbles (Alluvium - *Qa*)

Sand-Gravel, stratified and cross-bedded (Everson Recessional Outwash - $Qgos_e$)

Clay-Silt-Sand-Gravel-Cobbles-Boulders, diamict to stratified, compact (Vashon Till - Qgt_v)

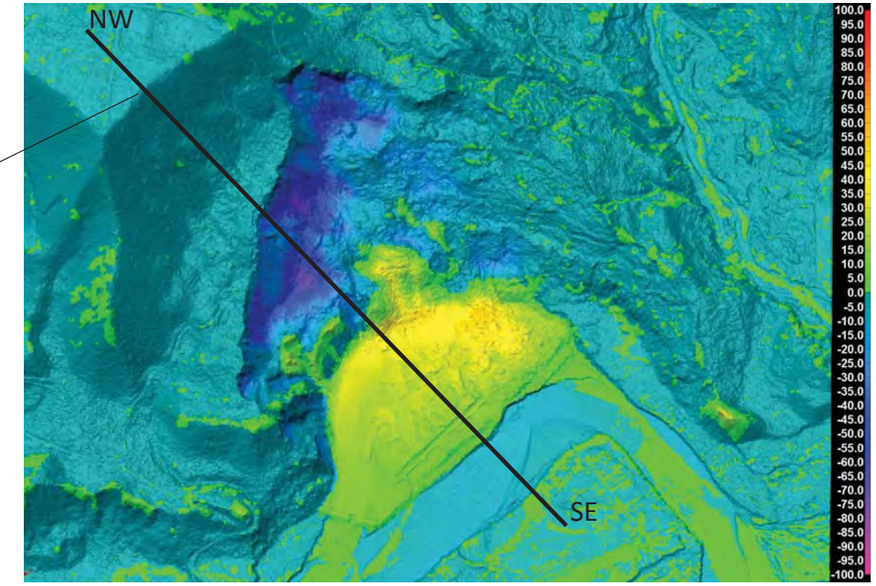
Sand-Silt, interbedded, laminated to stratifed, compact (Vashon Advance Outwash - Qga_v)

Clay-Silt, laminated to stratifed, compact (Vashon Advance Glaciolacustrine - Qgl_v)

Sand-Silt, stratified, compact (Olympia Nonglacial Deposits - Qc_o)

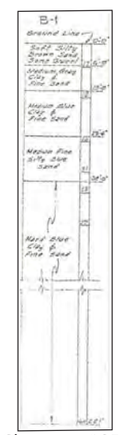
**/ vibrating wire piezometer / piezometric surface

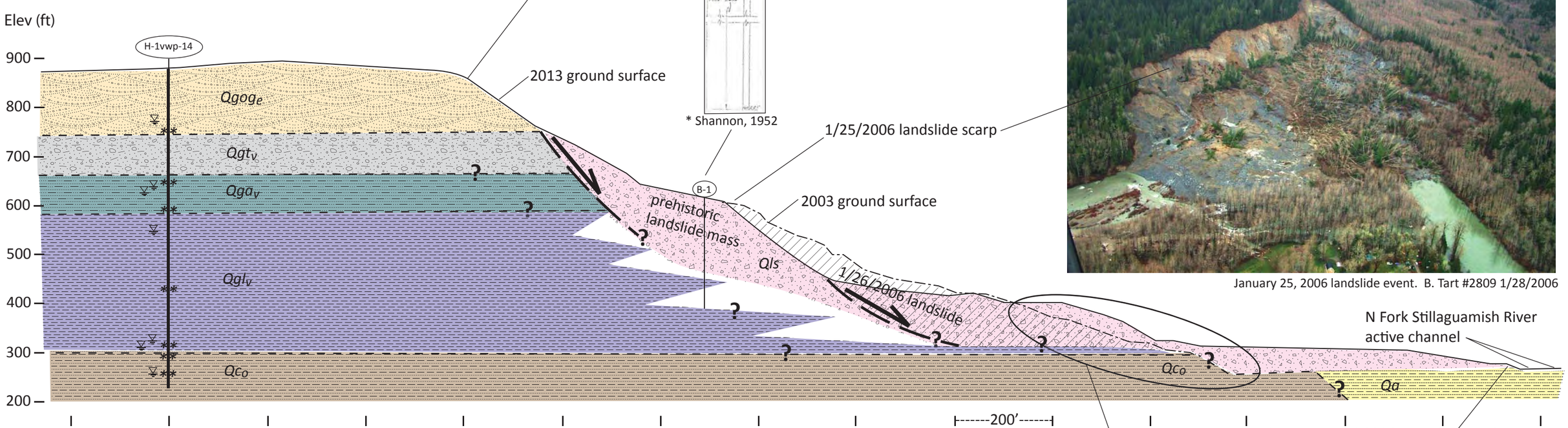
interpreted landslide failure surface



Lidar change analysis 2003 (NASA) and 2013 (PSLC). Warm colors indicate debris accumlation and cold colors indicate depletion; units in feet.

January 25, 2006 landslide event. B. Tart #2809 1/28/2006





Interpretations of the existence, lateral continuity, and orientation of the geologic units, contacts, and failure surfaces are based on limited boring data, landslide geomorphology, and geotechnical experience. These interpretations are subject to revision pending additional subsurface information.

Figure 19. SR-530 landslide (2014)

Clay-SIlt-Sand-Gravel-Cobbles, disrupted (Landslide Debris - *Qls*)

Silt-Sand-Gravel-Cobbles (Alluvium - *Qa*)

Sand-Gravel, stratified and cross-bedded (Everson Recessional Outwash - $Qgos_E$)

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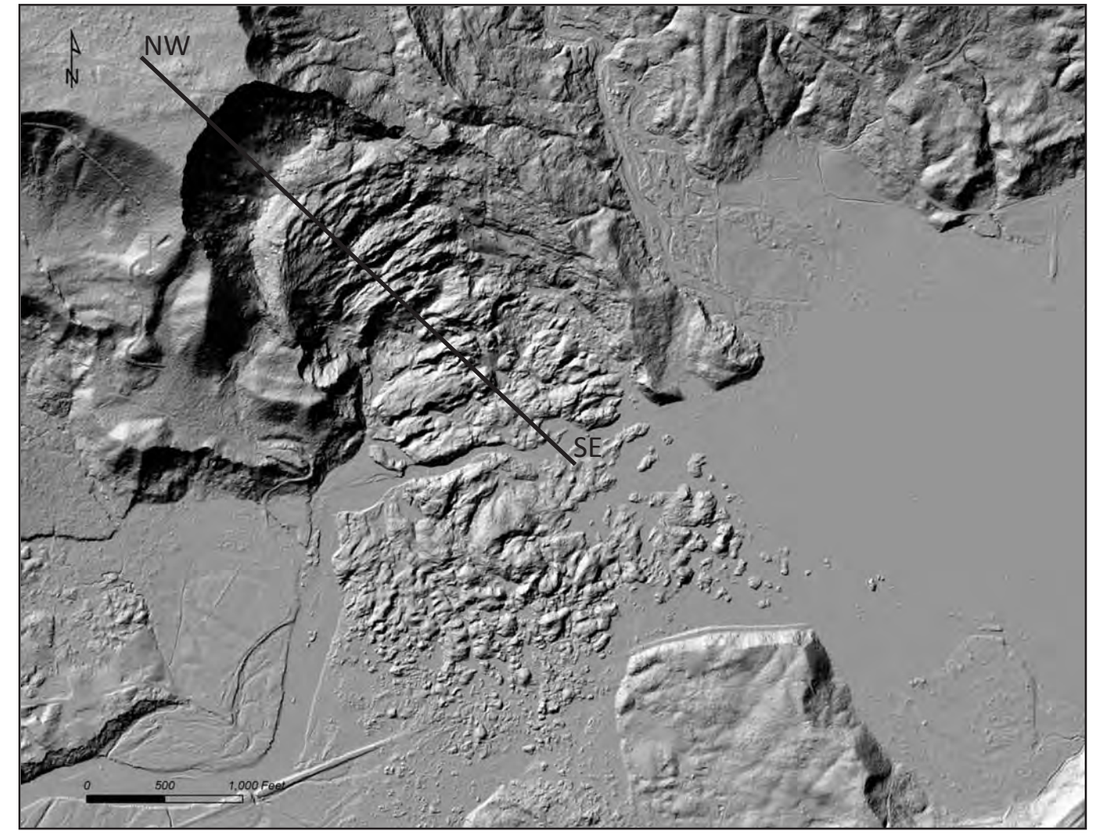
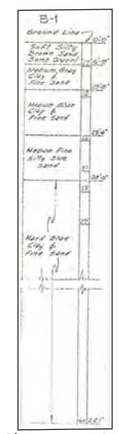
Sand-Silt, stratified, compact (Olympia Nonglacial Deposits - Qc_O)

**/ vibrating wire piezometer / piezometric surface

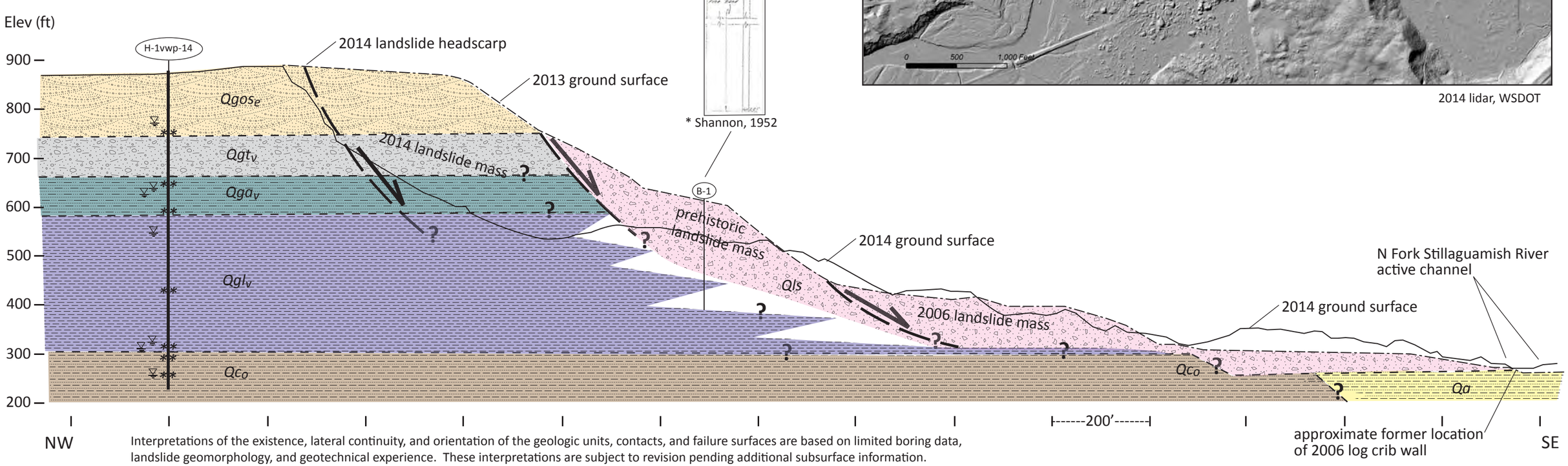
interpreted landslide failure surface



2014 lidar, WSDOT



* Shannon, 1952



Interpretations of the existence, lateral continuity, and orientation of the geologic units, contacts, and failure surfaces are based on limited boring data, landslide geomorphology, and geotechnical experience. These interpretations are subject to revision pending additional subsurface information.

Appendix A
Remote Landslide Mapping Report

RECONNAISSANCE MAPPING AND CHARACTERIZATION OF LANDSLIDES ALONG STATE ROUTE 530 BETWEEN MILEPOSTS 35 AND 41, SNOHOMISH COUNTY, WASHINGTON

by Wendy J. Gerstel and
Thomas C. Badger

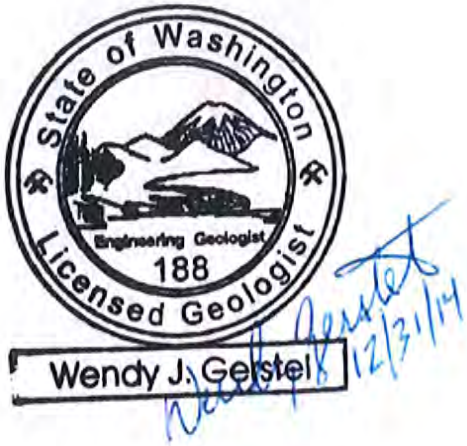
Report to Washington Department of Transportation
Geotechnical Office

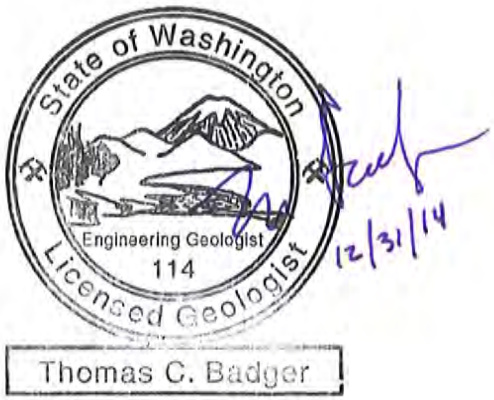
December 2014

Suggested Citation: Gerstel, W. J.; Badger, T. C., 2014, Reconnaissance mapping and characterization of landslides along State Route 530 between mileposts 35 and 41, Snohomish County, Washington: Report to Washington Department of Transportation, Geotechnical Office. 19 p.

ACKNOWLEDGEMENTS

We would like to thank Tracy Trople and Jessica Czajkowski for their GIS work to improve the accuracy and clarity of the figures, Jessica Czajkowski for her editing improvements to the original summary report, Kitty Reed for her last-minute review and corrections, and Joe Dragovich for sharing his insights on the geology of the North Fork Stillaguamish River valley.





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TABLES

Table 1. Key geomorphic attributes of the major landslide basin areas and their condition 8

Reconnaissance Mapping and Characterization of Landslides along State Route 530 between Mileposts 35 and 41, Snohomish County, Washington

by Wendy J. Gerstel[1] and Thomas C. Badger[2]

[1] Qwg Applied Geology
1802 Pine Ave NE
Olympia, WA 98506

[2] Washington State Department of Transportation,
Geotechnical Office
MS 47365; Olympia, WA 98504-7365

STUDY OVERVIEW

The following is a summary of remote and reconnaissance observations made along State Route 530 on both sides of the North Fork Stillaguamish River (hereafter referred to as the North Fork) valley between Mileposts (MP) 35 and 41.5, using 2010, 2013, and March 26, 2014 LiDAR data. This study was requested by and prepared collaboratively with the Geotechnical Office of the Washington State Department of Transportation (WSDOT) for the purposes of identifying, coarsely delineating, and broadly characterizing the nature of the unstable landforms within this reach of the North Fork. The initial application of the study results was to inform highway-related decisions necessary as a consequence of the SR 530 landslide and debris avalanche/flow of March 22, 2014. The study results were submitted as a report (dated August 11, 2014) to the WSDOT (Gerstel and Badger, 2014).

An additional and critical purpose of the mapping was to identify areas that may warrant further field verification and investigation to evaluate how transportation-related activities might affect or be affected by these landforms.

For the purposes of discussion and in referencing specific landslides in the following text, the landslide features are numbered as Basin Areas (BA), followed by an 'N' or 'S', designating the BA location on the north or south side of the North Fork valley, respectively (Figs. 1A and 1B, collectively referred to as 'Fig. 1'). Each basin area usually includes more than one landslide feature.

Although the mapping was done remotely, it benefited from two days of reconnaissance field work on April 1 and 2, 2014, by Gerstel and geologists from the Washington State Department of Natural Resources, Division of Geology and Earth Resources (DGER) in portions of BA 1N and BA 1S through 5S, the purpose of which was to describe and locate using GPS any indicators of active slope instability (tension cracks, raveling steep slopes, displaced or cracking roads, etc.). Additionally, as part of a separate multi-agency effort (WSDOT, U.S. Geological Survey, and Snohomish County), an additional week's worth of reconnaissance field work by Badger focused on the depletion and accumulation zones of the SR 530 landslide (BA 4N). The purpose of this second reconnaissance effort was to assess the geologic, hydrologic, and geotechnical conditions associated with the failure; to develop and deploy an instrumentation monitoring program; and to evaluate residual hazards and risks for reopening the highway; those findings are not discussed in this report.

This report provides some broad context for possible groundwater conditions, but makes no attempt to address the potential effects of surface or groundwater changes resulting from timber harvest or other human activities, nor does it provide any discussion of relative impacts of individual storm events or antecedent groundwater conditions on slope instability. The interpretations offered herein rely strictly on remotely-observed geomorphic conditions of the hillslope and the active river channel, primarily using LiDAR imagery, and are nominally informed by limited field observations.

The map linework delineating scarps and deposits is not intended to infer relative age, relative level of certainty, or runout extent for any of the unstable landforms within the major basin areas, but rather to represent the character of the unstable landforms within the identified reach. In other words, the linework shown in Figure 1A and Appendix A representing the valley bottom deposits as either landslide-derived or alluvium is an artifact of GIS mapping protocol and may not represent the true distal limits of the landslide deposits. Landslides were mapped using hillshades of 2010, 2013, and 2014 bare-earth LiDAR with multiple sun azimuth directions. Furthermore, the

density of minor landslide scarps, and the time constraints and limited scope of the mapping effort prevented their full display at map scale, and therefore not all scarps are shown.

Table 1 summarizes a number of geomorphic attributes remotely interpreted for the major basin areas shown on Figure 1. The stated condition of each attribute is selected to best represent overall conditions of a given basin, even though most basins exhibit a combination of conditions. The attributes used for this study are commonly used to infer relative age, activity, and mobility of landsliding. However, some of the unstable landforms in the valley exhibit apparent inconsistencies that challenge these classifications. In such cases, additional ground information will be particularly critical in assessing the potential hazard posed by—and risk associated with—the landform. We offer these data to inform future studies on risk analysis and age determinations for the range of unstable landforms present in the valley.

Slope profiles along critical sections through some of the major landslides (BA 1N, 3N, 4N, 12N, 13N, 2S, 4S, 5S, and 6S) are included in Appendix A at the end of this report (Figs. A1–A9). The illustrations provide a comparative view of slope profiles of these landslides. Note that scales provided are variable between landslide images.

GENERAL OBSERVATIONS ON LANDSLIDING— NORTH FORK VALLEY AND TRIBUTARY STREAMS

The study reach consists of the constricted portion of the North Fork valley between MP 35 and 37.5 and a slightly wider reach to the east, between MP 37.5 and MP 41.5. East of MP 41.5, the North Fork valley broadens significantly and glacial kame and outwash terraces are narrower and lower in elevation, reflecting the eastward flow of water and sediments coming from the continental ice that once dammed the lower valley (Dragovich and others, 2003).

Large landslides exist along both the north and south side of the valley. Within the study reach, we identify 22 distinct basin areas formed by these landslides; 13 on the north valley wall and 9 on the south. The morphology of the valley walls and cross-cutting relationships indicate several periods of large-scale slope movement occurring primarily as deep-seated rotational slides to debris avalanches, some transitioning distally to debris flows. Large translational landslide complexes are also apparent. Most of the landslides host superimposed smaller slump-earthflows and debris flows, indicating ongoing localized internal instability. Landslide deposits with overall lower slope angles have many closed depressions and sag ponds. There are broad similarities in morphology among the landslides that likely correspond to similarities in the valley-wall stratigraphy and geotechnical properties of the mobilized sediment. However, close inspection of the LiDAR images reveal notable geomorphic differences, both from landslide to landslide, and between the north and south sides of the North Fork valley.

Tributary streams draining from the north and south into the North Fork valley and their respective drainage areas (basins) are characterized by extensive deep-seated landslides along their respective channel hillslopes. This is particularly evident in BA 5N (Rollins Creek) and BA 7N (Dicks Creek) on the north and BA 3S (Montague Creek), BA 5S, and BA 8S (Boulder River) on the south. The opposing landslides within the drainages are thought to periodically block or displace the stream channels, creating small debris dams and resulting in subsequent outburst floods and debris flows. The debris flow deposits can be seen in the lower reaches of the tributary drainages and in some cases on the North Fork valley floor.

An early attempt was made by these authors to assign relative ages to the landslide and debris flow deposits and to evaluate their association with the historic locations of the active North Fork channel. However, the complexity of the channel's migration and sediment reworking and the limitations of aerial photo coverage thwarted this effort. Haugerud (2014) produced a preliminary interpretation of the relative ages of landslide deposits in this vicinity shortly after the SR 530 landslide. Additionally, Keaton and others (2014) were able to suggest some limiting dates for landslide deposits, based on organic material found in BA 5N. Future transportation and other land-use planning efforts in the valley should expand on these efforts to evaluate past, current, and likely future locations of the active North Fork channel and future landslide risks.

The various unstable landform features evident on both valley walls are described in more detail below.

North Valley Wall

The largest areal extent of a landslide deposit discernable from the LiDAR imagery initiates from BA 1N on the north side of the North Fork valley (Figs. 1 and A1). Maximum basin width at the headscarp is about 0.5 mi, with

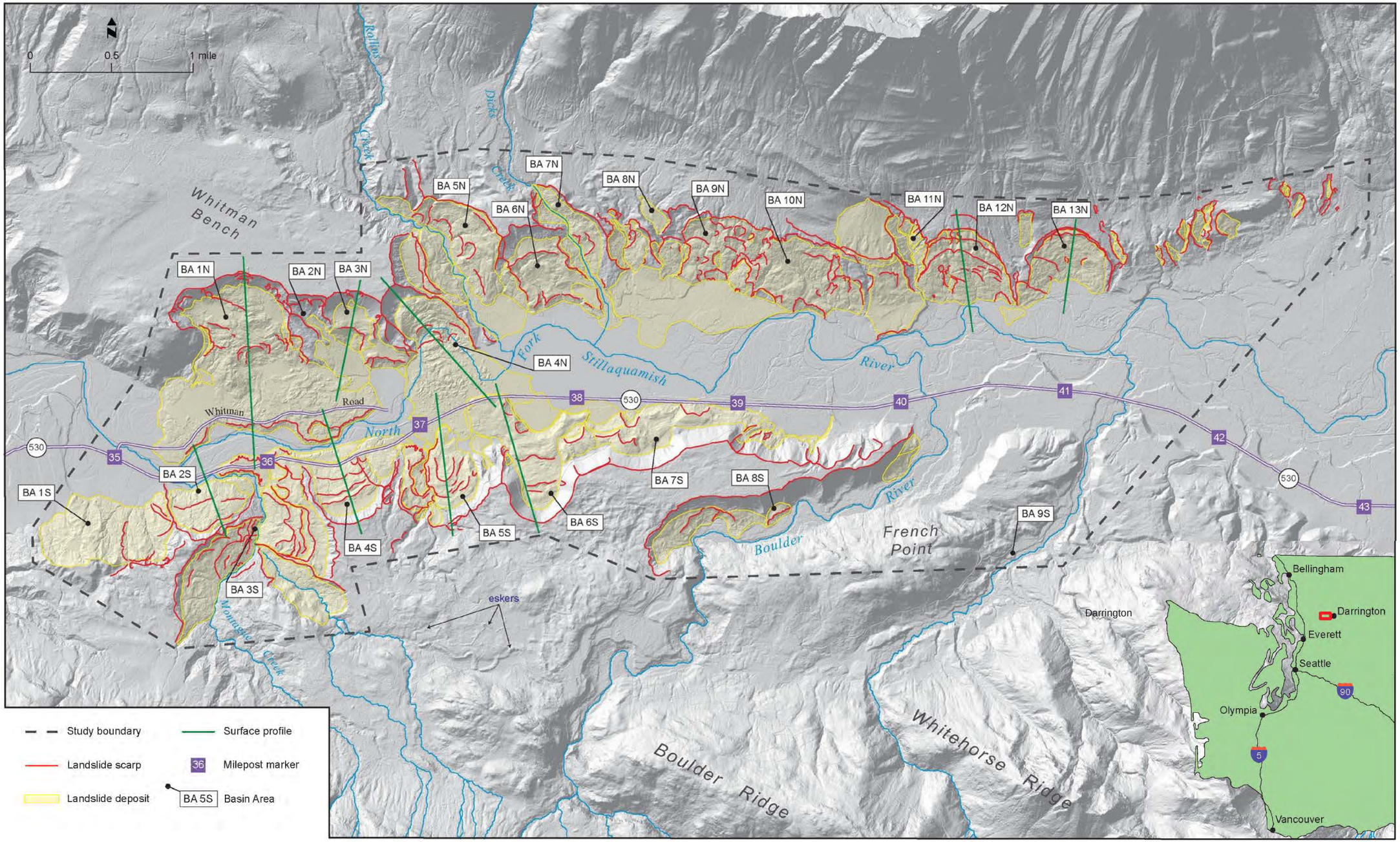

Figure 1A. Map of the study area showing interpreted LiDAR hillshade and basin areas. Hillshade mosaic compiled from 2010, 2013, and 2014 bare-earth LiDAR data obtained from Snohomish County, the Tulalip Tribes of Washington, and WSDOT, respectively.

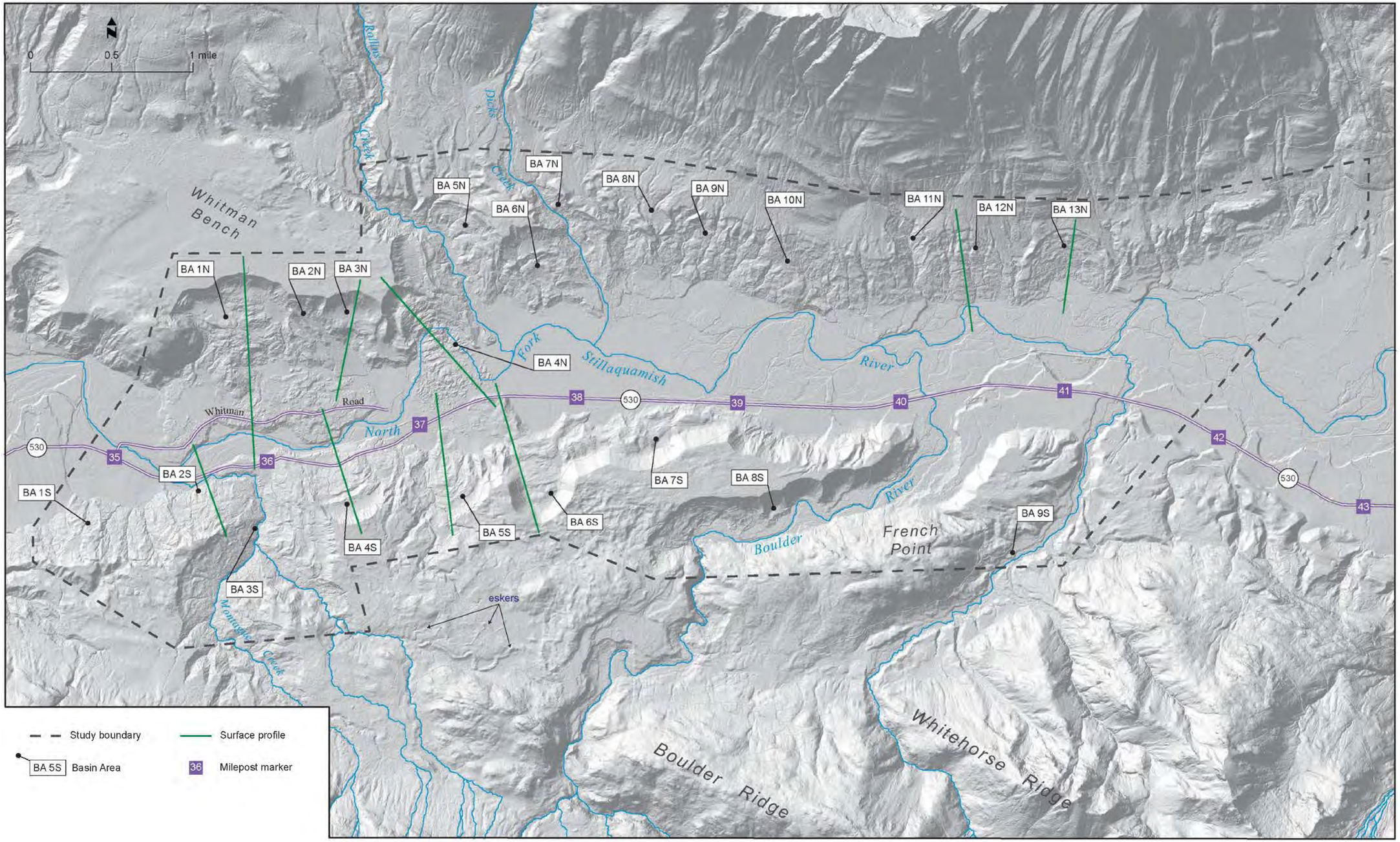

Figure 1B. Map of the study area showing uninterpreted LiDAR hillshade and basin areas .

Figure 2. Oblique aerial photo viewed to the northeast of BA 4N and the north wall of the North Fork valley taken shortly after the March 22, 2014, SR 530 landslide. Note areas of deciduous vegetation, not yet leafed out, delineating adjacent landslides features to the east. Photo credit: Governor Jay Inslee.

the debris field dispersing up- and down-valley at least 1.5 mi at its widest at a distance of about 1 mi from the headscarp. The body of this landslide deposit hosts numerous closed depressions and sag ponds, as well as localized areas of more recent instability occurring as small earthflows and earth slumps. Indications of recent movement of the larger deposit are equivocal, with areas of raveling and possible incipient tension cracks at the base of the current head scarp.

The landslide deposits from BA 1N appear to have traveled across the North Fork valley to the south valley wall. The North Fork has since incised into these deposits, bisecting them and leaving terraces of similar elevation on both sides of the active channel. The location of the current North Fork river channel impinges in several places on the north (right) bank within these deposits, causing active instability and impacting Whitman Road, which is repeatedly in need of repair in several locations (Jeff Jones, Snohomish County, oral commun., 2014).

BA 3N (Fig. A2) is a smaller deep-seated landslide and geomorphically appears to be older than BA 1N. An initial failure forming BA 2N may be similar in age to BA 1N; however, a large debris flow originating from the basin appears to have occurred as a secondary slope failure, the deposits of which incise into and overlie those of BA 1N and BA 3N.

The basin area from which the SR 530 landslide initiated is identified as BA 4N (Fig. A3). The freshness of the morphology associated with this landslide can be used to demonstrate the relative degradation of the other basin areas.

BA 1N through 4N (Figs. A1–A3) flank the terrace locally known as Whitman Bench west of MP 37.5 (Fig. 1) and exhibit extensively evacuated depletion zones. In comparison, east of MP 38.5, where the North Fork valley widens slightly, landslide morphology and deciduous vegetation of BA 7N through 13N (Figs. 1, 2, A4, and A5) suggest chronic deep-seated movement of existing deposits, but without the large-scale evacuation of the depletion zones. The morphology of these eastern landslides appears more indicative of translational failure. BA 5N and 6N (Fig. 1) appear to be transitional in their pattern of deformation between those basin areas to the west and east.

The morphologic contrast from west to east likely corresponds to the difference in the depth to bedrock and nature of the glacial sediments as mapped by Dragovich and others (2003). Although still part of the same terrace sequence, basin areas east of MP 38.5 (particularly BA 8N–13N) lie closer to the presumed terminal position of the last glacial maximum and associated outwash train, and therefore lie within a thinner and less laterally extensive sedimentary sequence than those to the west. The terrace ultimately grades to the valley floor to the north of MP 42, corresponding to the much diminished evidence for slope instability.

Although the North Fork is currently impinging on the toe of the deposits from BA 10N and BA 12N, this may be a relatively recent phenomenon. The erosion at the toe is causing small-scale slumping, but as yet, there is no apparent large-scale slope movement. Conditions of stability could easily change in the future.

Rollins (BA 5N) and Dicks (BA 7N) Creeks, both tributary drainages from the north into the North Fork valley, reveal extensive large-scale slope movement and can (and have) contributed large amounts of sediment to the valley via debris flows. The opposing landslides along the tributary valley walls may periodically dam the tributary channels, resulting in outburst floods that supply large amounts of sediment to the creek bed and into the North Fork valley.

South Valley Wall

The morphology of the south side of the North Fork valley also reveals large-scale, active, deep-seated rotational and debris avalanche/flow-type slope movement within the constricted valley reach (MP 35–37.5). The large landslide deposit from BA 1N is likely what currently holds the North Fork channel along the south side and may be a factor contributing to landsliding in BA 2S through 4S (Figs. 1, A6, and A7). Landsliding in BA 5S through 7S (Figs. 1, A8, and A9) suggests that the channel may have occupied the south side of the valley east of MP 37 in the past.

Notable along the south side basin areas are a number of large, extensively evacuated landslide depletion zones (particularly BA 4S–7S [Figs. 1 and A7–A9]), similar in size to each other but different in morphology. The south-side basin areas seem to defy the general rules of relative degree of dissection/incision commonly used to indicate relative age. Some contain tributary streams, others do not—a possible explanation for the geomorphic variability. Those basin areas displaying a greater degree of stream incision (BA 3S–5S; Fig. 1) appear to be more recently active, with secondary slope movement superimposed on the larger features. Conversely, BA 6S (Fig. A9) shows little stream incision, but has subdued landslide topography, with subsequent erosion of the landslide deposit by what appears to be an old river meander. There are several possible explanations for this apparent set of conflicting attributes. Aside from the internal drainage effects, one possibility is that the North Fork river channel may have occupied the evacuated depletion zone subsequent to slope failure and reworked the headscarp and deposits. Another possibility is that the landslide failed subaqueously into a lake dammed by downstream landslide deposits. Clearly the valley and the river have both altered their position and shape many times due to landsliding. The conflicting morphologic attributes may just reflect a difference in stratigraphy and surface and subsurface drainage characteristics and processes.

BA 3S (Montague Creek; Fig. 1), the tributary entering the North Fork valley just west of MP 36, is one of the larger tributaries flowing north into the valley. It is characterized by a number of large, active, deep-seated landslide features on both sides along most of its channel length. As with the Boulder River (BA 8S) to the east, and Rollins (BA 5N) and Dicks (BA 7N) Creeks to the north, this drainage has clearly been a chronic source of sediment into the North Fork valley, likely as periodic large dam-break debris flows. Damming of the mouth of Montague Creek by the landslide from BA 1N may also have caused dam-break floods and debris flows into the North Fork valley. BA 9S (Fig. 1) appears also to carry a large sediment load, although with no large landslides obvious along its valley walls.

The orientation of the Boulder River drainage (BA 8S) sub-parallel to the North Fork valley suggests that it might be controlled by a moraine representing a recessional position of the east-flowing Cordilleran ice sheet (Dragovich and others, 2003), and that it was fed by glacial meltwater. Several eskers visible on the LiDAR to the south of BA 5S (Fig. 1) support this area being a terminal position of the ice. From here, outwash is mapped as grading east towards Darrington. BA 9S may similarly reflect a terminal ice position and have been similarly fed by sediment-laden glacial meltwater.

DISCUSSION

Quaternary-age glacial deposits, underlying complex bedrock geology, and mapped faults within the North Fork valley and its tributary basins that influence aquifer recharge and groundwater flow. Because surface- and groundwater typically play a key role in landsliding, we propose that the variability in basin-area morphology and suspected landslide processes reflect the differences in sediment characteristics and thickness, and perhaps the relative position of faults.

Dragovich and others (2003) mapped advance glaciolacustrine deposits (unit Qgl_v) and deposits of the "Olympia non-glacial interval" (unit Qc_o) along the eastern base of Whitman Bench in the vicinity of the SR 530 landslide. Landslide deposits obscure their exposure to the west. The deposits are described as being clay-silt-silty fine sand and having silt-clay components, respectively. We infer that one or both of these basal units are controlling failure of the large landslides that flank Whitman Bench. The extensive evacuation of the landslide depletion zones of BA 1N through 4N, coupled with the curvilinear shape of the headscarp and back-tilting of the uppermost slide blocks, are characteristic features of deep-seated, rotational-type slope failure. The combination of observed morphology with the mapped stratigraphy supports an interpretation of deep-seated rotational failures (that possibly transition to translational failures) toeing out near river level. Similar morphology is exhibited by landslides comprising BA 4S through 7S on the south valley wall, where mapping similarly shows advance glaciolacustrine deposits near the base of the slope.

Basin areas along the north valley wall to the east of BA 6N have a different morphology from those to the west, with less evacuation of the depletion zone and more slope-coincident slope movement, suggestive of translational-type failures. Although still part of the same terrace sequence, these eastern basin areas (particularly BA 9–13N) east of MP 38.5 lie closer to the presumed terminal position of the last glacial maximum, and therefore within a thinner and less laterally extensive glacial sequence than those to the west. The terrace ultimately grades to the valley floor north of MP 42. Sediment characteristics and position relative to the valley wall suggest that the underlying bedrock of the eastern basins is closer to the surface. In contrast to the basins along the margins of Whitman Bench, these landslides may be failing along a bedrock–sediment contact. Recharge to these eastern basins could be contributing to landsliding, either as surface runoff infiltrating upslope of the glacial sediments or as infiltration through the sediments to the bedrock–sediment contact.

The mapping identifies areas of greatest concern to transportation infrastructure as those where there is widespread recent activity, where landslide-damming of tributary channels occurs, and where the North Fork is currently impinging on valley walls with mapped landslides or other indications of slope instability; for instance, at BA 10N and 12N. The uncertainty around potential landslide runout distances is confounded by historic and active river meandering. The resulting erosion and sediment transport has modified most of the evidence for other possible long-runout landslides.

SUGGESTIONS FOR FURTHER WORK

To address remaining uncertainties and improve risk assessment, include the following tasks in future investigations:

- Determine the subsurface geology (stratigraphy and structure) of the different basin areas and upland terraces to characterize groundwater movement, including deep groundwater studies and well monitoring. Collectively, these data are necessary to better characterize landslide hazards and assess risks in these areas.
- Field verify landslide features and basin areas identified as currently or recently active, particularly where the active channel of the North Fork is impinging on valley walls.
- Date wood and organic matter recovered from landslide and debris flow deposits in the main valley and from beneath sag ponds on the upper slopes of large landslide deposits to help determine landslide chronology and the effects from and controls on channel migration of the North Fork, particularly where the river currently impinges on valley walls. Efforts must include careful mapping and correlation of terrace deposits to particular landslide basin areas. The landslide chronology as it relates to historic river channel position has bearing on the understanding and assessment of potential future landslide triggers and risks.
- Examine river terraces gradients along and across valley to shed light on river and landslide history (including landslide runout characteristics) in the study reach. River terraces within the study reach may reflect glacial outwash grading eastward, fluvial incision grading westward, and incised surfaces of landslide deposits.

- Correlate headscarp steepness, radius of curvature, and topographic smoothness to determine relationships to landslide age, activity levels, and groundwater movement. Correlating these attributes to age determinations will provide useful information in evaluating landslide risks in other similar and contrasting geologic and geomorphic settings in the state.
- Evaluate the valley reach west of MP 35 where the North Fork channel is currently impinging on the north-side valley wall. Nearby are additional features suggesting slope instability, although bedrock is mapped at this location.

Table 1. Key geomorphic attributes of the major landslide basin areas and their condition as interpreted from LiDAR imagery.

	Headscarp morphology			Minor scarps			Grabens / depressions			Cross-cutting features[1]		Drainages within landslide body			Headscarp formation		Internal instability[2]		River/stream location relative to landslide toe		Degree of depletion zone evacuation			Dispersal of landslide debris		
Basin area	Smooth	Intermediate	Dissected	Fresh	Subdued	Indeterminate	Prominent	Aggraded	Indeterminate	Absent	Present	Absent	Poorly developed	Well developed	Composite	Single	Present	Absent	Currently impinging	Not impinging	Extensive	Moderate	Minor	Considerable	Limited	Indeterminate
North																										
1		•			•			•		•			•		•		•		•		•			•		
2			•			•			•		•		•			•		•		•	•					•
3	•					•			•		•	•				•		•		•	•					•
4	•			•			•				•	•			•		•		•		•			•		
5			•		•			•			•			•	•		•		•			•			•	
6			•		•			•			•			•		•	•			•	•					•
7		•			•				•		•			•	•		•		•			•			•	
8			•		•				•		•			•	•		•		•			•			•	
9			•		•				•		•			•	•		•			•			•		•	
10			•			•			•		•			•	•		•		•				•		•	
11			•		•				•		•			•	•		•		•			•			•	
12			•		•				•	•				•		•	•		•				•		•	
13			•		•				•	•				•		•		•		•			•			•
South																										
1			•		•				•	•				•		•		•		•		•			•	
2			•		•			•		•			•			•		•	•			•			•	
3			•		•			•			•			•	•		•		•			•			•	
4			•		•			•			•		•			•	•		•		•			•		
5			•		•			•			•			•	•		•		•		•			•		
6	•				•			•		•			•			•	•			•	•			•		
7		•				•			•	•			•		•		•			•		•				•
8		•			•				•		•			•	•		•		•			•			•	
9		•				•			•		•			•	•		•		•			•			•	

[1] Cross-cutting features refer to younger landslides that intercept older features and are useful for establishing relative ages.

[2] Internal instability refers to the evidence of secondary movements superimposed on the larger landslide feature as inferred by minor scarps.

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Appendix A. Basin Area Maps and Topographic Profiles

The following illustrations provide a comparative view of slope profiles through some of the major landslides on the north and south sides of the valley, respectively. Note that scales provided are variable between figures. See Index Map (Fig. I) for location of figures and explanation of symbology.

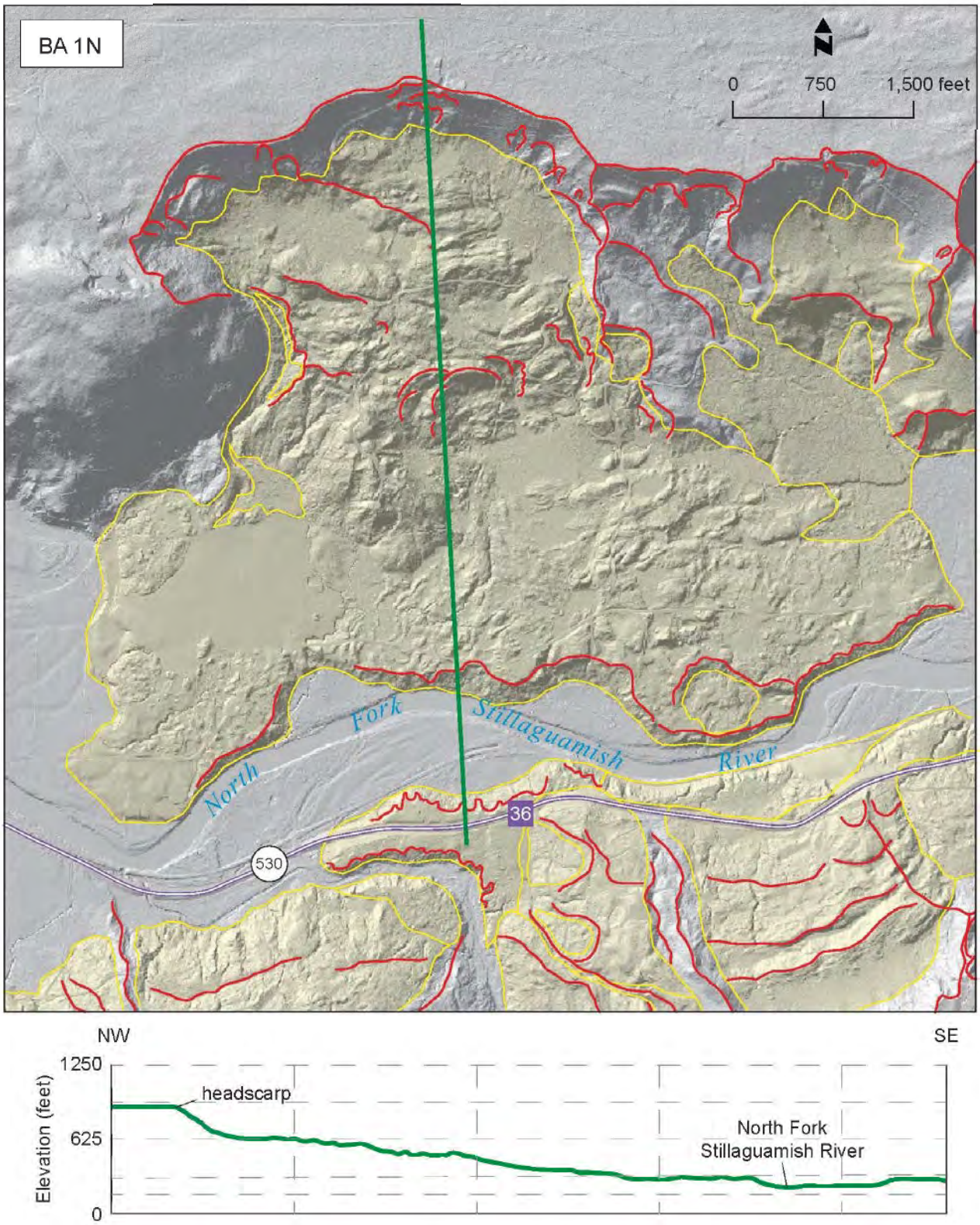

Figure A1. Basin area map and topographic profile of BA 1N. No vertical exaggeration.

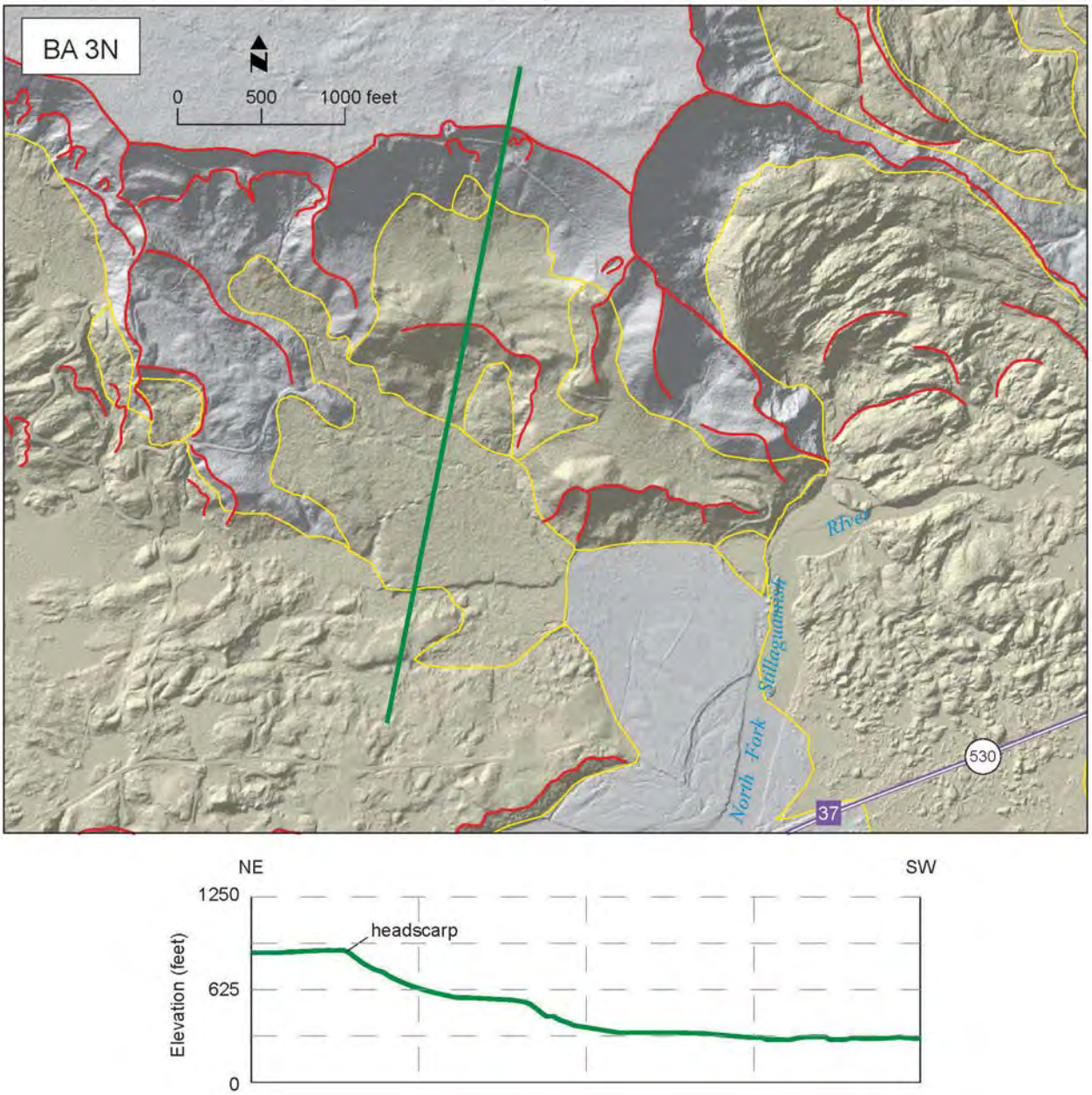

Figure A2. Basin area map and topographic profile of BA 3N. No vertical exaggeration.

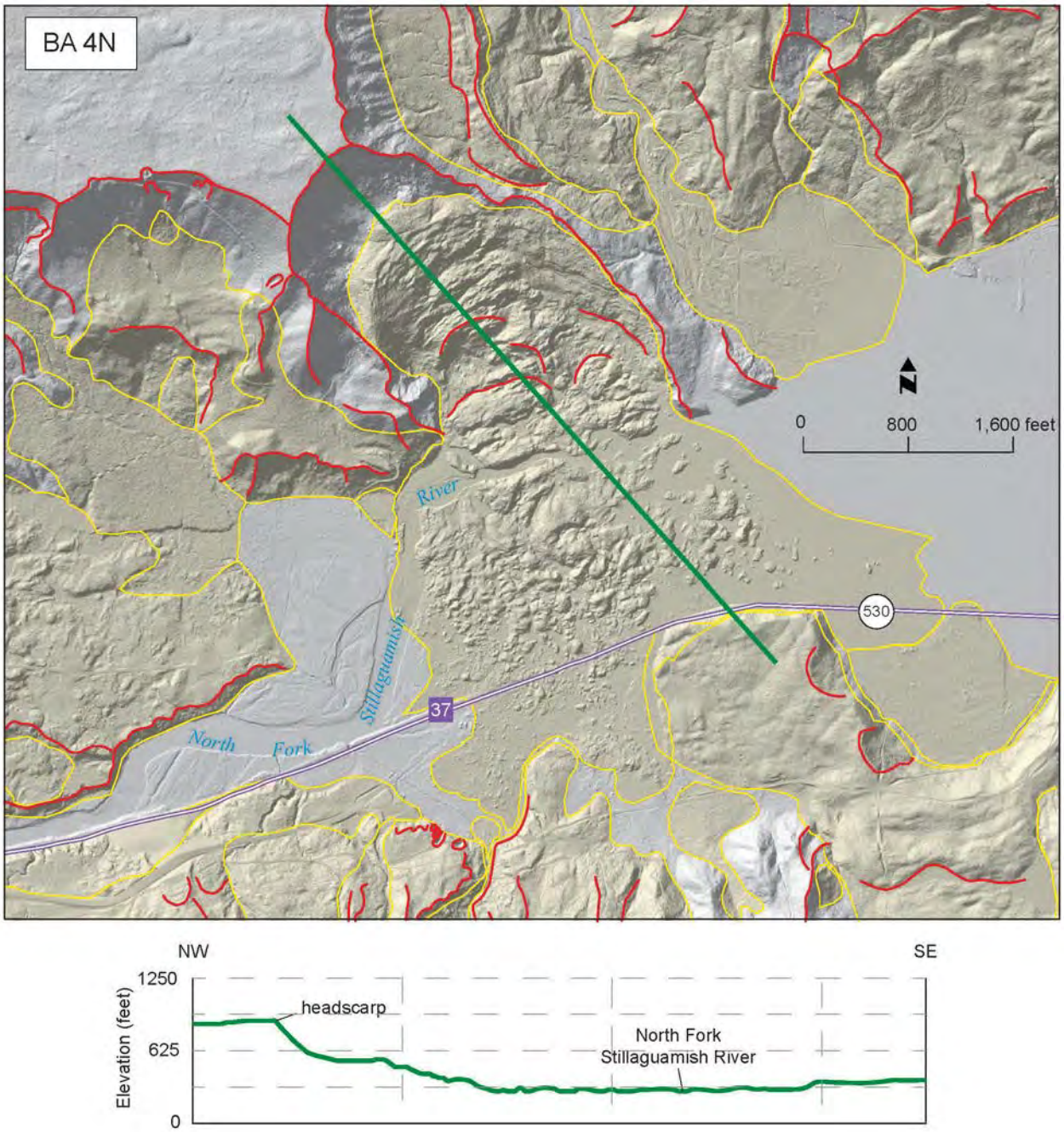

Figure A3. Basin area map and topographic profile of BA 4N. No vertical exaggeration.

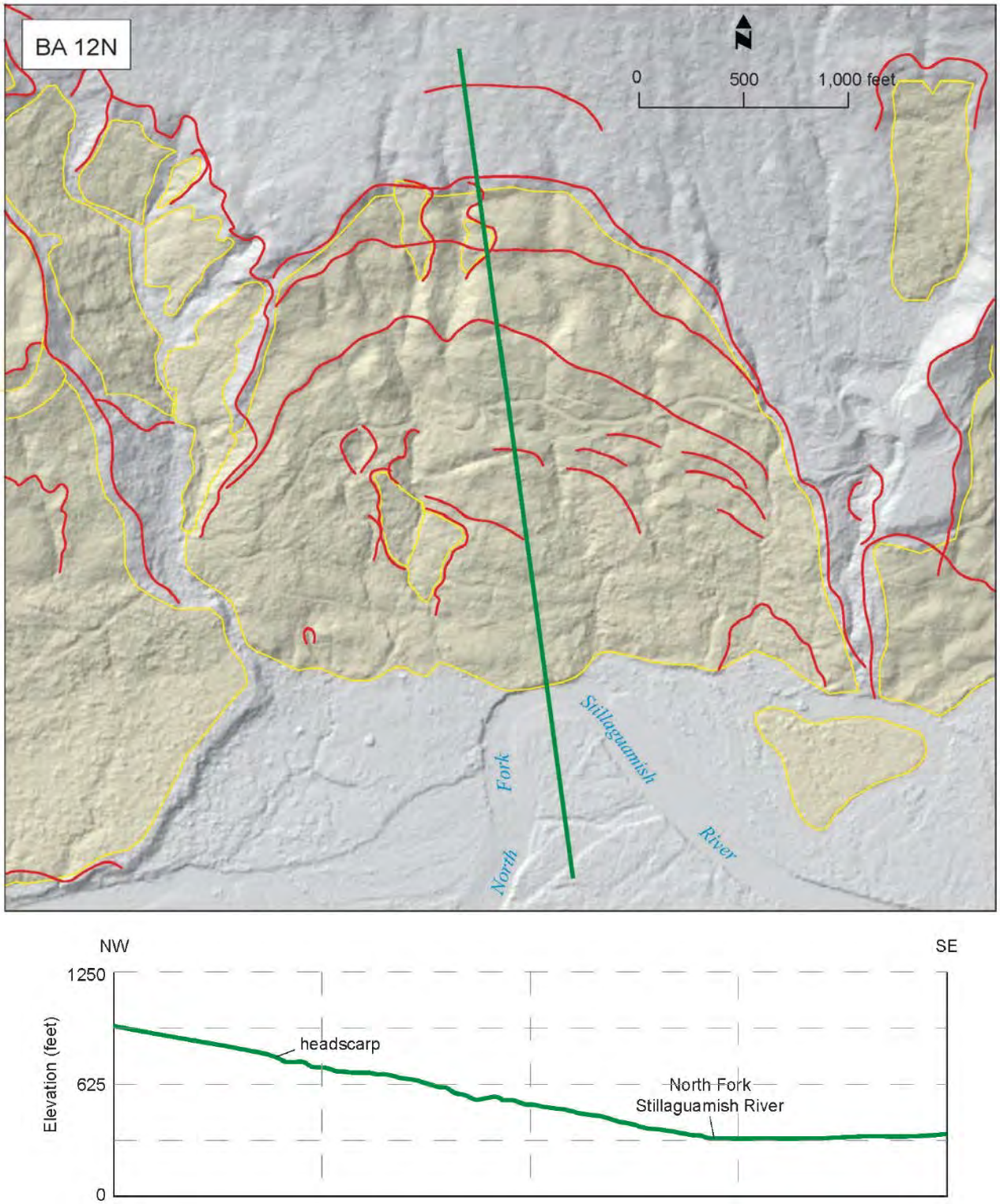

Figure A4. Basin area map and topographic profile of BA 12N. No vertical exaggeration.

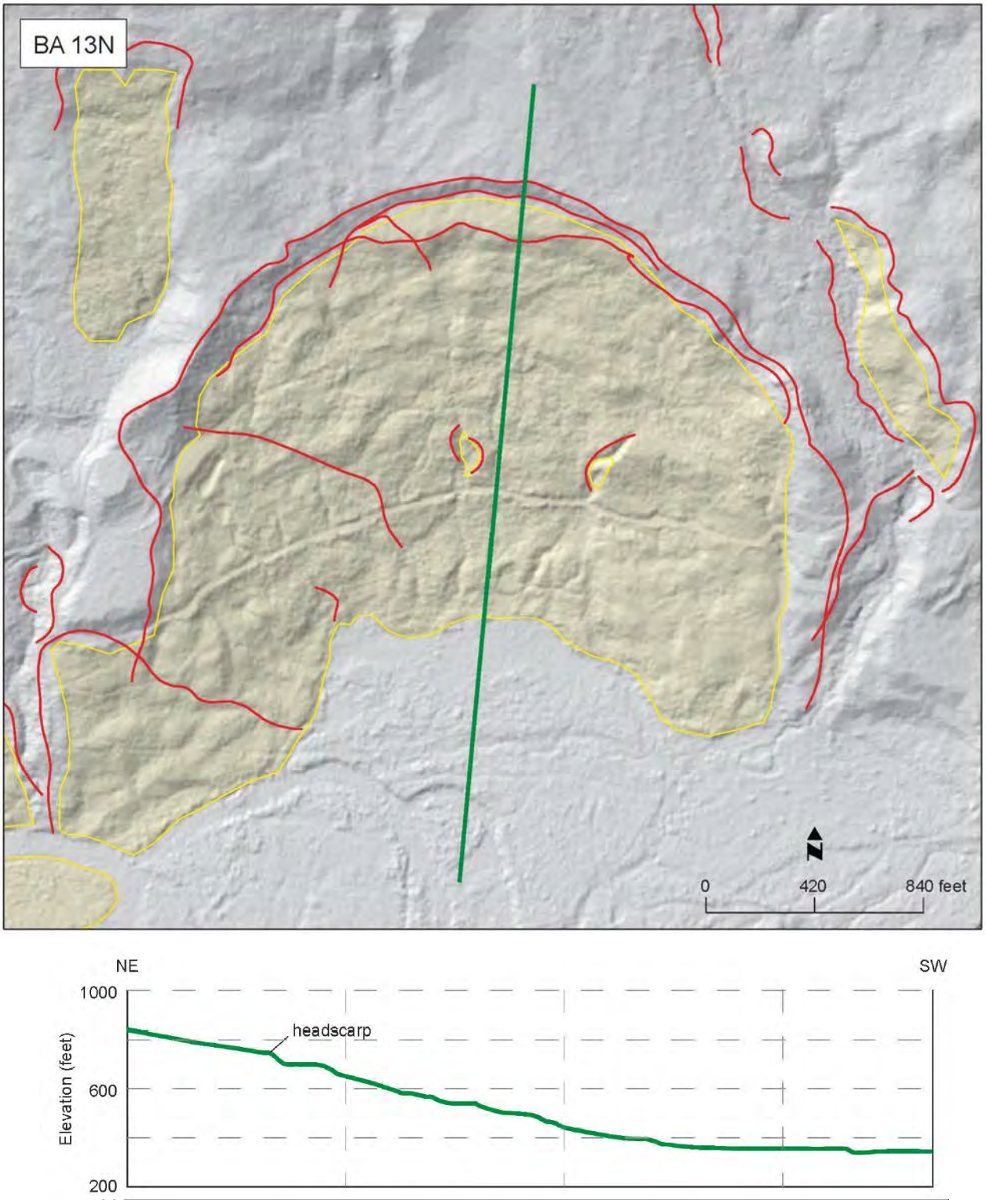

Figure A5. Basin area map and topographic profile of BA13N. No vertical exaggeration.

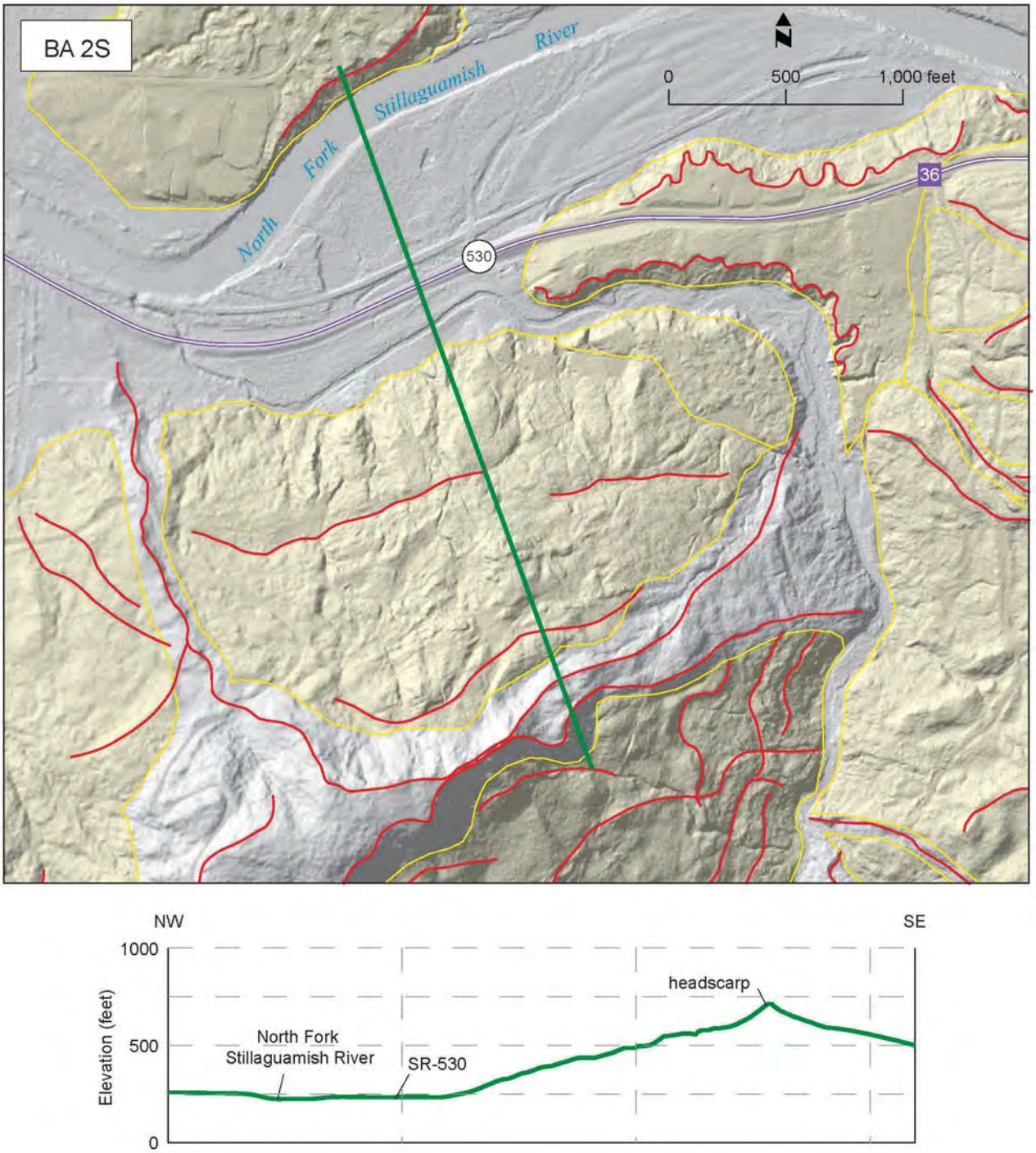

Figure A6. Basin area map and topographic profile of BA 2S. No vertical exaggeration.

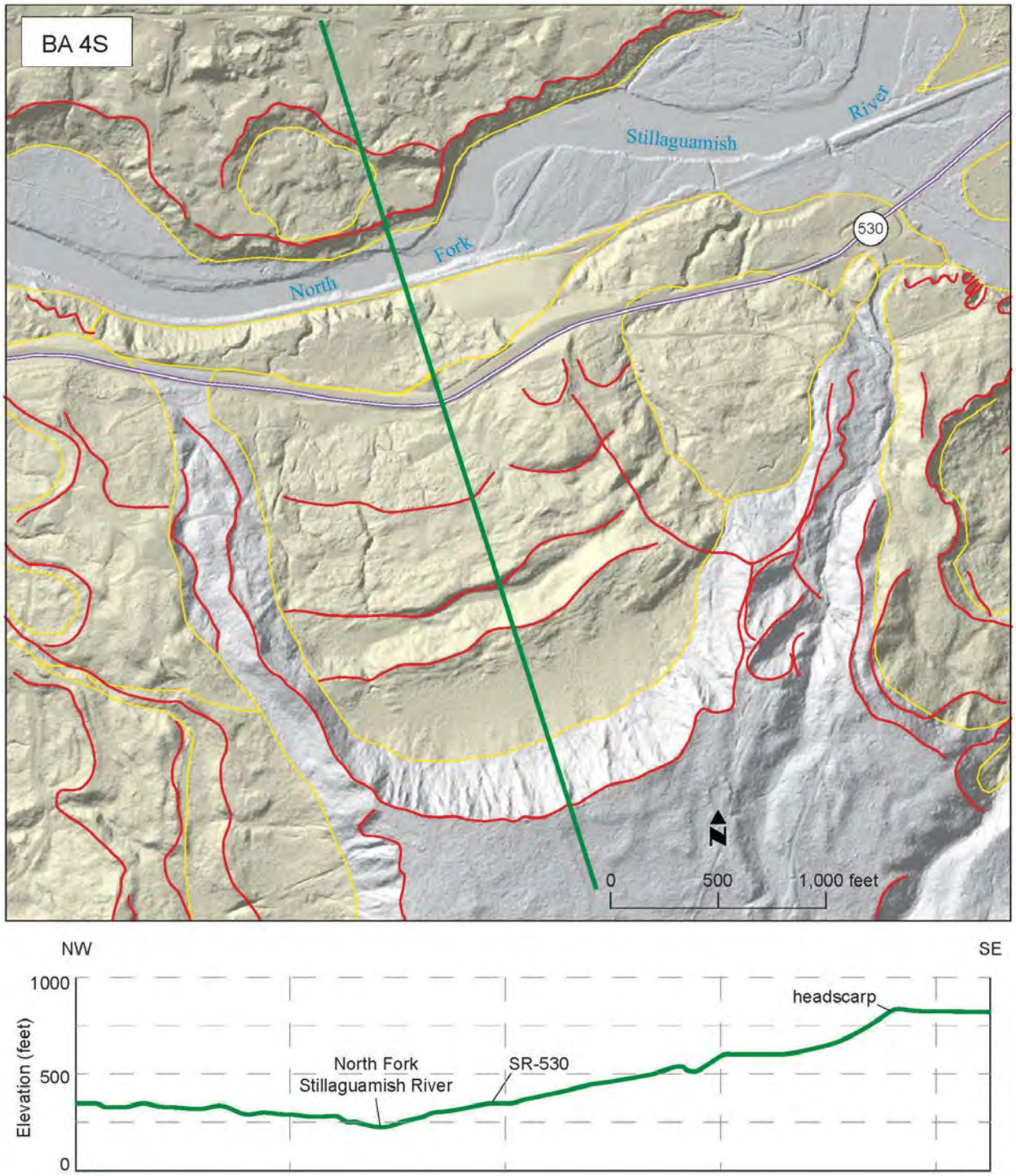

Figure A7. Basin area map and topographic profile of BA 4S. No vertical exaggeration.

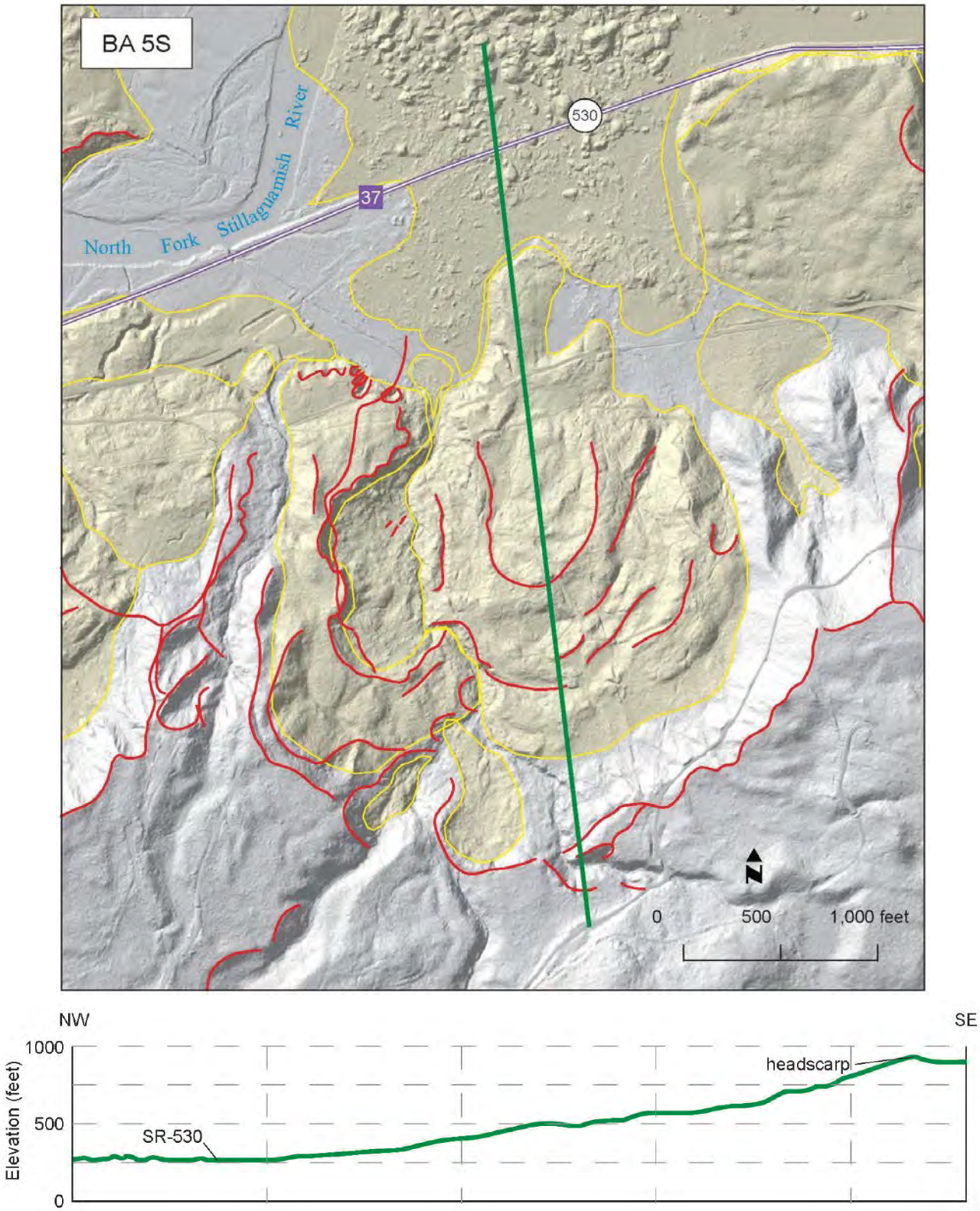

Figure A8. Basin area map and topographic profile of BA 58. No vertical exaggeration.

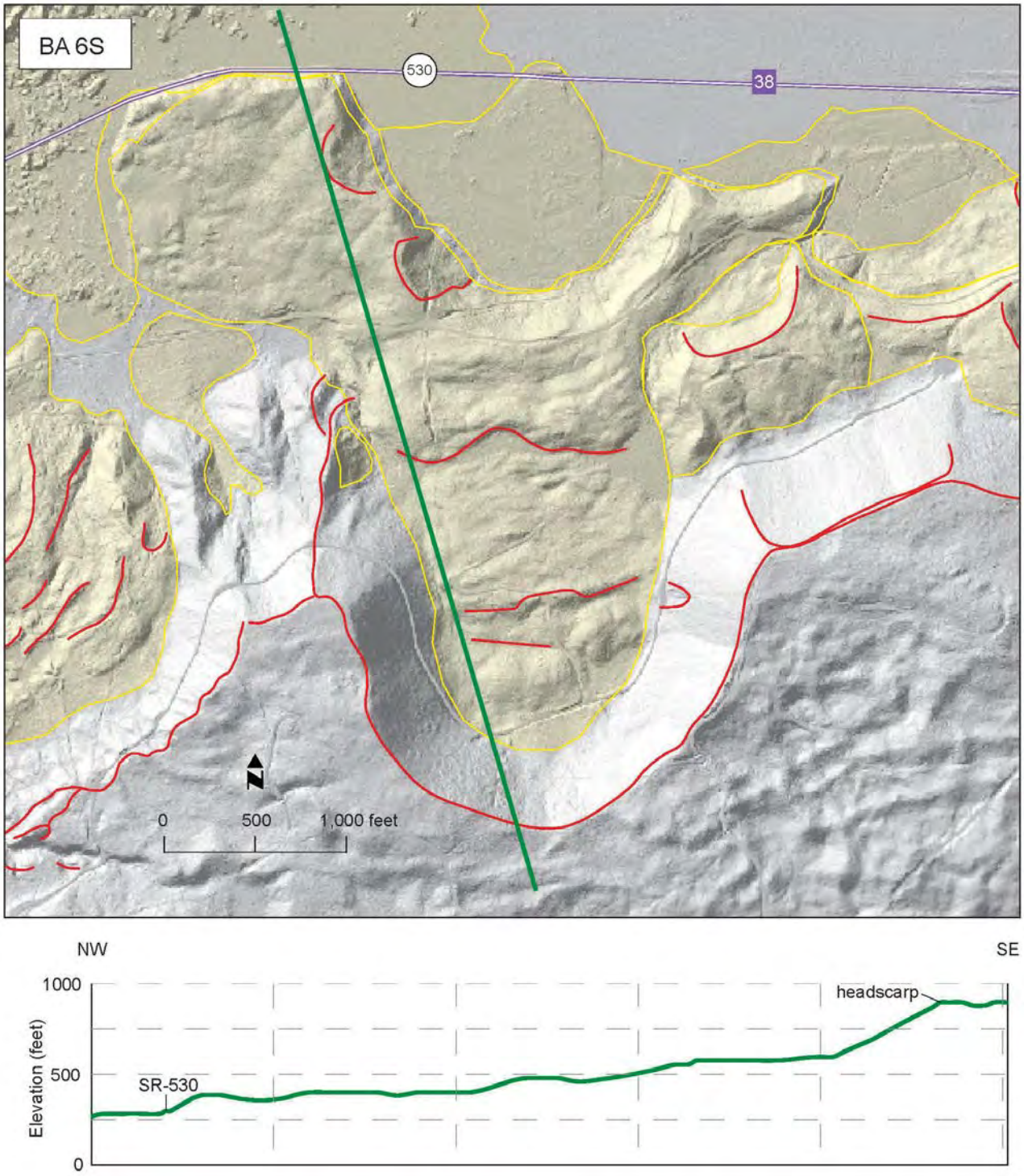

Figure A9. Basin area map and topographic profile of BA 6S. No vertical exaggeration.

Appendix B
Boring Logs

Washington State
Department of Transportation

LOG OF TEST BORING

Start Card RE-10599

HOLE No. H-1vwp-14

Sheet 1 of 27

Job No. JM-1112-M gp01 SR 530 Elevation 891.9 ft

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny Lic# 2742

Component

Inspector Cooper, Kerry #2552

Start October 14, 2014 Completion October 30, 2014 Well ID# BHV-683

Equipment CME 850 (9C2-4)

Station Offset Hole Dia (inches) 4

Historical SPT Efficiency Past Rig Efficiency 87.1%

Northing 471012.001 Easting 1391966.796 Collected by Snohomish County

Method Mud Rotary

Lat 48.2867308 Long -121.8538555 Datum NAD 83/91 HARN, NAVD88, SPN (ft)

Drill Fluid Bentonite-Polymer

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	890.0								Groundwater readings were taken from 10-15-2014 to 10-27-2014	
5	885.0									
10	880.0									
15	875.0									
20			◆	5 8		D-1		Well graded SAND, medium dense, grayish brown, moist, homogeneous. HCl not tested.		

Washington State
Department of Transportation

LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 891.9 ft

HOLE No. H-1vwp-14

Sheet 2 of 27

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
				9 (17)				Recovered: 1.1 ft Retained: 1.1 ft		
	870									
25										
	865									
30										
	860									
35										
	855								10-16-2014	
40				16 13 16 (29)		D-2		At 39 ft, MC= 4.5%, SW-SM. Well graded SAND with gravel, sub-rounded, dense, grayish brown, moist, homogeneous. HCl not tested. Recovered: 1.2 ft Retained: 1.2 ft		
	850									
45										

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

Washington State
Department of Transportation

LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 891.9 ft

HOLE No. H-1vwp-14

Sheet 3 of 27

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

SPT Efficiency
Field SPT (N)
Moisture Content
RQD

Depth (ft)	Elevation (ft)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material
	845					
50						
	840					
55						
	835					
60		12 10 10 (20)		D-3		At 59 ft, SW-SM. Well graded SAND with trace gravel, medium dense, grayish brown, moist, homogeneous. HCl not tested. Recovered: 1.2 ft Retained: 1.2 ft
	830					
65						
	825					
70						

Groundwater

Instrument

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

Washington State
Department of Transportation

LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 891.9 ft

HOLE No. H-1vwp-14

Sheet 4 of 27

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

SPT Efficiency
Field SPT (N)
Moisture Content
RQD
20 40 60 80

Depth (ft)	Elevation (ft)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material
75	820					
	815					
80		13 19 24 (43)		D-4		Well graded SAND with gravel, dense, grayish brown, moist, homogeneous. HCl not tested. Recovered: 1.3 ft Retained: 1.3 ft
85	810					
90	805	21 22 22 (44)		D-5		Poorly graded SAND, dense, grayish brown, moist, homogeneous. HCl not tested. Recovered: 0.8 ft Retained: 0.8 ft
95	800					

Groundwater

Instrument

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

Washington State
Department of Transportation

LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 891.9 ft

HOLE No. H-1vwp-14

Sheet 5 of 27

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

SPT Efficiency
Field SPT (N)
Moisture Content
RQD

Depth (ft)	Elevation (ft)	Profile	20 40 60 80	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	795									
100			>>	26 50/6" (REF)		D-6		Silty GRAVEL with sand, sub-rounded, very dense, grayish brown, moist, homogeneous. HCl not tested. Recovered: 0.5 ft Retained: 0.5 ft		
	790									
105										
	785									
110										
	780									
115										
	775									
120				19 16		D-7		At 119 ft, SM. Poorly graded SAND, dense, grayish brown, moist,		

Washington State
Department of Transportation

LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 891.9 ft

HOLE No. H-1vwp-14

Sheet 6 of 27

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

SPT Efficiency
Field SPT (N)
Moisture Content
RQD
20 40 60 80

Depth (ft)	Elevation (ft)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material
		20 (36)				stratified, laminated. HCl not tested. Recovered: 0.9 ft Retained: 0.9 ft
	770					
125						
	765					
		15 17 20 (37)		D-8		Silty fine SAND, dense, olive brown, wet, homogeneous. HCl not tested. Recovered: 1.4 ft Retained: 1.4 ft
130						
	760					
		>> 50/1" (REF)		D-9		Sandy SILT with gravel, very dense, dark gray, wet, homogeneous. HCl not tested. Recovered: 0.1 ft Retained: 0.1 ft
135						
				C-11		Silty SAND with gravel, sub-rounded, gray, moist, homogeneous. HCl not tested. Recovered: 1.7 ft Retained: 1.7 ft
	755					
				C-12		Silty SAND with gravel, sub-rounded, gray, moist, stratified, laminated. HCl not tested. Recovered: 2.9 ft Retained: 2.9 ft
140						
	750					
145						

Groundwater

Instrument

Washington State
Department of Transportation

LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 891.9 ft

HOLE No. H-1vwp-14

Sheet 7 of 27

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

SPT Efficiency
Field SPT (N)
Moisture Content
RQD
20 40 60 80

Depth (ft)	Elevation (ft)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material
				C-13		Silty SAND with gravel, sub-rounded, gray, moist, homogeneous. HCl not tested. Recovered: 5.0 ft Retained: 5.0 ft
	745					
150				C-14		Silty SAND with gravel, sub-rounded, gray, moist, homogeneous. HCl not tested. Recovered: 5.0 ft Retained: 5.0 ft
	740					
155				C-15		Silty SAND with gravel, sub-rounded, gray, moist, stratified. HCl not tested. From 159 to 160.5 ft, poorly graded sand. Recovered: 5.0 ft Retained: 5.0 ft
	735					
160		>> 50/5" (REF)		D-16		Silty SAND with gravel, sub-rounded, very dense, grayish brown, moist, stratified. HCl not tested. Recovered: 0.5 ft Retained: 0.5 ft
				C-17		Silty SAND with gravel 1-ft-thick horizontal bed of fine sand., sub-rounded, grayish brown, moist, stratified. HCl not tested. Recovered: 4.3 ft Retained: 4.3 ft
	730					
165				C-18		Silty SAND with gravel, sub-rounded, grayish brown, moist, homogeneous. HCl not tested. Recovered: 4.0 ft Retained: 4.0 ft
	725					
170						

Groundwater

Instrument

Washington State
Department of Transportation

LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 891.9 ft

HOLE No. H-1vwp-14

Sheet 8 of 27

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

SPT Efficiency
Field SPT (N)
Moisture Content
RQD
20 40 60 80

Depth (ft)	Elevation (ft)	Profile	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	720				C-19		Well graded GRAVEL with sand, sub-rounded, grayish brown, moist, stratified. HCl not tested. Fines washed out. Recovered: 1.0 ft Retained: 1.0 ft		
175	715				C-20		Silty SAND with gravel, sub-rounded, gray, moist, homogeneous. HCl not tested. Recovered: 5.0 ft Retained: 5.0 ft From 176 to 178 ft, PI= 22, CL.		
180	710				C-21		Silty SAND with gravel, sub-rounded, gray, moist, stratified, interbedded with silt. HCl not tested. Recovered: 1.9 ft Retained: 1.9 ft		
185	705				C-22		Silty SAND with gravel, sub-rounded, grayish brown, moist, homogeneous. HCl not tested. Recovered: 1.4 ft Retained: 1.4 ft		
190	700				C-23		Silty SAND with gravel, sub-rounded, grayish brown, moist, homogeneous. HCl not tested. Recovered: 4.9 ft Retained: 4.9 ft		
195									

Washington State
Department of Transportation

LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 891.9 ft

HOLE No. H-1vwp-14

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Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	695					C-24		Silty SAND with gravel, sub-rounded, grayish brown, moist, homogeneous. HCl not tested. Recovered: 5.0 ft Retained: 5.0 ft		
200	690					C-25		Silty SAND with gravel, sub-rounded, gray, moist, homogeneous. HCl not tested. Recovered: 5.0 ft Retained: 5.0 ft		
205	685					C-26		Silty SAND with gravel, sub-rounded, gray, moist, stratified, interbedded with horizontal silt beds. HCl not tested. Recovered: 5.0 ft Retained: 5.0 ft		
210	680					C-27		Silty SAND with gravel and cobbles, sub-rounded, gray, moist, stratified, with 1.5-ft-thick horizontal layer of clayey silt with slickensides. HCl not tested. Recovered: 5.0 ft Retained: 5.0 ft		
215	675					C-28		Well graded GRAVEL with sand, sub-rounded, gray, moist, stratified, with 6 thick horizontal layer of clayey silt with slickensides. HCl not tested. Recovered: 2.5 ft Retained: 2.5 ft		
220								At approximately 218ft, gradational contact with well graded SAND with gravel, sub-rounded to rounded, gray to brownish gray.		

Washington State
Department of Transportation

LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 891.9 ft

HOLE No. H-1vwp-14

Sheet 10 of 27

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

SPT Efficiency
Field SPT (N)
Moisture Content
RQD

Depth (ft)	Elevation (ft)	Blows/6" (N) and/or RQD FF	Sample No. (Tube No.)	Lab Tests	Description of Material
			C-29		Silty SAND with gravel and cobbles, sub-rounded to rounded, gray, moist, homogeneous. HCl not tested. Recovered: 1.1 ft Retained: 1.1 ft
	670				
225			C-30		Poorly graded SAND with trace gravel and cobbles, grading at 226 ft to Silty SAND, gray, moist, stratified, laminated. HCl not tested. Very wet at 228.7 ft. Recovered: 4.2 ft Retained: 4.2 ft
	665				
230			C-31		Silty fine SAND with 2 horizontal Silt beds, gray, moist, stratified. HCl not tested. Recovered: 4.6 ft Retained: 4.6 ft
	660				
235		17 14 18 (32)	D-32		SILT trace gravel, dense, dark gray, moist, homogeneous. HCl not tested. Recovered: 1.5 ft Retained: 1.5 ft
	655		C-33		Lean CLAY, dark gray, moist, slickensides throughout, with fine sand coatings and/or distorted fine sand laminae. HCl not tested. Recovered: 4.8 ft Retained: 4.8 ft
240			C-34		Poorly graded SAND, gray, moist. HCl not tested. Used Lexan tube. Recovered: 4.6 ft Retained: 4.6 ft
	650				At 242.5 ft, MC= 24.7%, SM.
245					

Groundwater: 10-20-2014

Instrument

Washington State
Department of Transportation

LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 891.9 ft

HOLE No. H-1vwp-14

Sheet 11 of 27

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

SPT Efficiency
Field SPT (N)
Moisture Content
RQD
20 40 60 80

Depth (ft)	Elevation (ft)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
				C-35		Fine Sandy SILT, gray, wet, stratified to laminated, variable orientation. HCl not tested. Sulfur smell.At 245.5 ft, MC= 26.4%, ML. Recovered: 4.5 ft Retained: 4.5 ft		
	645							
250				C-36		Silty fine SAND, gray, wet, stratified to laminated, variable orientation. HCl not tested. Sulfur smell. Recovered: 4.9 ft Retained: 4.9 ft		
	640							
255		>>◆ 18 50/6" (REF)		D-37		Silty fine SAND, very dense, gray, wet, homogeneous. HCl not tested. Sulfur smell. Recovered: 0.9 ft Retained: 0.9 ft		
	635			C-38		Poorly graded SAND, gray, wet, stratified to laminated, variable orientation. HCl not tested. Recovered: 4.1 ft Retained: 4.1 ft		
260				C-39		Silty fine SAND, gray, wet, stratified to laminated, variable orientation. HCl not tested. Sulfur smell. Recovered: 4.9 ft Retained: 4.9 ft		
	630							
265				C-40		Silty fine SAND, gray, wet, stratified to laminated, variable orientation. HCl not tested. Perched water at 260. Recovered: 4.8 ft Retained: 4.8 ft		
	625							
270								

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

Washington State
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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 891.9 ft

HOLE No. H-1vwp-14

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Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

SPT Efficiency
Field SPT (N)
Moisture Content
RQD
20 40 60 80

Depth (ft)	Elevation (ft)	Profile	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	620				C-41		Silty fine SAND, gray, wet, laminated to stratified, horizontal to variable orientation. HCl not tested. Poorly graded sand with 6 thick layer of silt. Recovered: 4.5 ft Retained: 4.5 ft At 271 ft, SM.		
275	615				C-42		Silty fine SAND, gray, wet, laminated to stratified, horizontal to variable orientation. HCl not tested. Poorly graded sand with 4 thick horizontal layer of silt, perched water at 278.5. Recovered: 4.9 ft Retained: 4.9 ft		
280	610				C-43		Silty fine SAND, gray, wet, laminated to stratified, horizontal to variable orientation. HCl not tested. Poorly graded sand with 3 thick horizontal layer of silt,perched water. Recovered: 4.5 ft Retained: 4.5 ft		
285	605				C-44		Silty fine SAND, gray, wet, homogeneous, laminated to stratified, horizontal to variable orientation. HCl not tested. Recovered: 4.7 ft Retained: 4.7 ft		
290	600				C-45		Silty fine SAND, gray, wet, slickensided, laminated to stratified, horizontal to variable orientation. At 293 ft, gradational contact with Elastic SILT, dark gray, moist, slickensides throughout with fine sand coatings and/or distorded fine sand laminae.Slickenside 60 degrees. HCl not tested. Recovered: 4.5 ft Retained: 4.5 ft		
295									

Washington State
Department of Transportation

LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 891.9 ft

HOLE No. H-1vwp-14

Sheet 13 of 27

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
						C-46		Lean CLAY, dark gray, moist, slickensides throughout with fine sand coating and/or distorted fine sand laminae. HCl not tested. Recovered: 5.0 ft Retained: 5.0 ft		
	595									
300			◆	8 13 15 (28)		D-47		Lean CLAY, dense, dark gray, moist, homogeneous, laminated. HCl not tested. Recovered: 1.5 ft Retained: 1.5 ft		
	590					C-48		Lean CLAY, dark gray, moist, distorted fine sand laminae to homogenous. HCl not tested. Recovered: 4.3 ft Retained: 4.3 ft		
305						C-49		Lean CLAY, dark gray, moist, distorted fine sand laminae to homogenous. HCl not tested. Recovered: 5.0 ft Retained: 5.0 ft		
	585									
310						C-50		SILT to Lean CLAY, dark gray, moist, distorted fine sand laminae to homogenous. HCl not tested. Recovered: 3.4 ft Retained: 3.4 ft		
	580									
315						C-51		Fat CLAY, dark gray, moist, distorted fine sand laminae to homogenous. HCl not tested. Silt with ash and vertical fracture. Recovered: 5.0 ft Retained: 5.0 ft		
	575									
320								From 319.5 to 320.5 ft, PI= 32, CH.		

Washington State
Department of Transportation

LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 891.9 ft

HOLE No. H-1vwp-14

Sheet 14 of 27

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
						C-52		SILT, dark gray, moist. HCl not tested. Used Lexan tube. Recovered: 5.0 ft Retained: 5.0 ft		
	570									
325						C-53		SILT, dark gray, moist. HCl not tested. Used Lexan tube. Recovered: 4.9 ft Retained: 4.9 ft		
	565									
330						C-54		SILT, dark gray, moist. HCl not tested. Used Lexan tube. Recovered: 4.9 ft Retained: 4.9 ft		
	560									
335						C-55		SILT, dark gray, moist. HCl not tested. Used Lexan tube. Recovered: 5.0 ft Retained: 5.0 ft		
	555									
340						C-56		SILT, dark gray, moist, homogeneous. HCl not tested. Used Lexan tube. Recovered: 4.6 ft Retained: 4.6 ft		
	550									
345										

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

Washington State
Department of Transportation

LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 891.9 ft

HOLE No. H-1vwp-14

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Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
						C-57		SILT to Elastic SILT, dark gray, moist, homogeneous. HCl not tested. Used Lexan tube. Recovered: 4.9 ft Retained: 4.9 ft		
	545									
350						C-58		SILT to Lean CLAY, dark gray, moist, distorted fine sand laminae to homogenous. Sandy silt with 1-3 thick horizontal layers of silt. Wet zone 350.9 to 351.5 ft. HCl not tested. Recovered: 1.9 ft Retained: 1.9 ft		
	540							From 353 to 355 ft, PI= 20, CL.		
355						C-59		SILT to Elastic SILT, dark gray, moist, distorted fine sand laminae to homogenous with occasional slickensides. HCl not tested. Recovered: 3.7 ft Retained: 3.7 ft		
	535									
360						C-60		SILT, greenish gray, moist, distorted fine sand laminae to homogenous. HCl not tested. Recovered: 2.2 ft Retained: 2.2 ft		
	530									
365						C-61		Elastic SILT, greenish gray, moist, distorted fine sand laminae to homogenous. HCl not tested. Recovered: 1.8 ft Retained: 1.8 ft		
	525									
370										

Washington State
Department of Transportation

LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 891.9 ft

HOLE No. H-1vwp-14

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Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

SPT Efficiency
Field SPT (N)
Moisture Content
RQD

Depth (ft)	Elevation (ft)	Profile	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
			11 27 42 (69)		D-62		SILT, very dense, dark gray, moist, homogeneous. HCl not tested. Recovered: 1.5 ft Retained: 1.5 ft		
	520				C-63		SILT, gray, moist, distorted fine sand laminae to homogenous. HCl not tested. Recovered: 3.5 ft Retained: 3.5 ft		
375					C-64		SILT to Fat CLAY, greenish gray, moist, distorted fine sand laminae. HCl not tested. Recovered: 4.7 ft Retained: 4.7 ft		
	515								
							From 379.5 to 380.5, MC= 26.0%, PI= 34, CH.		
380					C-65		SILT to Lean CLAY, dark gray, moist, possibly graphitic laminae. HCl not tested. Used Lexan tube. Recovered: 5.0 ft Retained: 5.0 ft		
	510								
385					C-66		SILT, dark gray, moist. HCl not tested. Used Lexan tube. Recovered: 3.8 ft Retained: 3.8 ft		
	505								
390					C-67		SILT, dark gray, moist. HCl not tested. Used Lexan tube. Recovered: 4.1 ft Retained: 4.1 ft		
	500								
395									

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 891.9 ft

HOLE No. H-1vwp-14

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Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

SPT Efficiency
Field SPT (N)
Moisture Content
RQD

Depth (ft)	Elevation (ft)	Profile	Blows/6" (N) and/or RQD FF (20 40 60 80)	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
					C-68		SILT, dark gray, moist, possibly graphitic laminae. HCl not tested. Used Lexan tube. Recovered: 4.3 ft Retained: 4.3 ft		
	495								
400					C-69		SILT to Elastic SILT, dark gray, moist, slickensided joint at 50 degrees. HCl not tested. Used Lexan tube. Recovered: 4.9 ft Retained: 4.9 ft		
	490								
405					C-70		SILT to Elastic SILT, dark gray, moist, distorted fine sand laminae to homogenous. HCl not tested. Recovered: 4.4 ft Retained: 4.4 ft		
	485								
410					C-71		SILT to Lean CLAY, greenish gray, moist. HCl not tested. Used Lexan tube. Recovered: 5.0 ft Retained: 5.0 ft		
	480								
415					C-72		Elastic SILT to Lean CLAY, greenish gray, moist, possibly graphitic laminae. HCl not tested. Used Lexan tube. Recovered: 5.0 ft Retained: 5.0 ft		
	475								
420									

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Department of Transportation

LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 891.9 ft

HOLE No. H-1vwp-14

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Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
						C-73		SILT to Lean CLAY, greenish gray, moist, ash apparent. HCl not tested. Used Lexan tube. Recovered: 5.0 ft Retained: 5.0 ft		
	470									
425						C-74		SILT to Elastic SILT, gray, moist, stratified, distorted fine sand laminae to homogenous, 8-inch-thick bed of silt inclined 20 degrees. HCl not tested. Recovered: 5.0 ft Retained: 5.0 ft		
	465									
430						C-75		Lean CLAY, dark gray, moist. HCl not tested. Used Lexan tube. Recovered: 5.0 ft Retained: 5.0 ft		
	460									
435						C-76		Lean CLAY, dark gray, moist. HCl not tested. Used Lexan tube. Recovered: 5.0 ft Retained: 5.0 ft		
	455									
440						C-77		Lean CLAY, dark gray, moist. HCl not tested. Used Lexan tube. Recovered: 3.6 ft Retained: 3.6 ft		
	450									
445										

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

Washington State
Department of Transportation

LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 891.9 ft

HOLE No. H-1vwp-14

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Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
						C-78		SILT to Fat CLAY, dark gray, moist. HCl not tested. Used Lexan tube. Recovered: 4.9 ft Retained: 4.9 ft		
	445									
450								From 449.5 to 450.5 ft, MC= 28.6%, PI= 33, CH.		
						C-79		Lean CLAY, gray, moist, ash apparent. HCl not tested. Used Lexan tube. Recovered: 4.9 ft Retained: 4.9 ft		
	440									
455						C-80		SILT to Lean CLAY, gray, moist, ash apparent. HCl not tested. Used Lexan tube. Recovered: 5.0 ft Retained: 5.0 ft		
	435									
460						C-81		SILT to Lean CLAY, gray, moist, ash laminae apparent, distorted fine sand laminae to homogenous.. HCl not tested. Silt with ash. Recovered: 4.0 ft Retained: 4.0 ft		
	430									
465						C-82		Lean CLAY, greenish gray, moist. HCl not tested. Used Lexan tube. Recovered: 5.0 ft Retained: 5.0 ft		
	425									
470										

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 891.9 ft

HOLE No. H-1vwp-14

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Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
						C-83		Lean CLAY, gray, moist. HCl not tested. Used Lexan tube. Recovered: 5.0 ft Retained: 5.0 ft		
	420									
475						C-84		Elastic SILT to Lean CLAY, gray, moist. HCl not tested. Used Lexan tube. Recovered: 4.4 ft Retained: 4.4 ft		
	415									
480						C-85		SILT to Elastic SILT, gray, moist, horizontal ash laminae apparent. HCl not tested. Used Lexan tube. Recovered: 5.0 ft Retained: 5.0 ft		
	410									
485						C-86		Elastic SILT to Fat CLAY, gray, moist, ash apparent. HCl not tested. Used Lexan tube. Recovered: 5.0 ft Retained: 5.0 ft		
	405							From 487.5 to 490.5 ft, MC= 35.8%, PI= 43, CH.		
490						C-87		SILT to Elastic SILT, dark gray, moist, ash and possible graphite apparent. HCl not tested. Used Lexan tube. Recovered: 4.2 ft Retained: 4.2 ft		
	400									
495										

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 891.9 ft

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Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

SPT Efficiency
Field SPT (N)
Moisture Content
RQD
20 40 60 80

Depth (ft)	Elevation (ft)	Profile	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
					C-88		Elastic SILT to Lean CLAY, gray, moist, rhythmically laminated/stratified, subhorizontal. HCl not tested. Used Lexan tube. Recovered: 4.9 ft Retained: 4.9 ft		
	395								
500					C-89		SILT to Lean CLAY, gray, moist, distorted fine sand laminae grading to horizontally laminated. HCl not tested. Recovered: 5.0 ft Retained: 5.0 ft		
	390								
505					C-90		SILT to Elastic SILT, gray, moist, ash apparent, horizontally laminated to distorted fine sand laminae to homogenous. HCl not tested. Recovered: 5.0 ft Retained: 5.0 ft		
	385								
510					C-91		Elastic SILT to Lean CLAY, gray, moist, horizontally laminated/stratified to homogenous. HCl not tested. Recovered: 5.0 ft Retained: 5.0 ft		
	380								
515					C-92		Lean CLAY, greenish gray, moist, ash and possible graphite apparent, horizontally laminated/stratified to homogenous. HCl not tested. Recovered: 4.7 ft Retained: 4.7 ft		
	375								
520									

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 891.9 ft

HOLE No. H-1vwp-14

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Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	370					C-93		Elastic SILT to Lean CLAY with fine sand/silt laminae, olive gray, moist, horizontally laminated/stratified to homogenous. HCl not tested. Recovered: 4.9 ft Retained: 4.9 ft		
525						C-94		Elastic SILT to Fat CLAY, olive gray, moist, horizontally laminated/stratified to homogenous. 1 inch dropstone. HCl not tested. Recovered: 5.0 ft Retained: 5.0 ft		
	365									
530								From 529.5 to 530.5, PI= 45, CH.		
						C-95		Lean CLAY, greenish gray, moist, horizontally laminated/stratified to homogenous. HCl not tested. Recovered: 5.0 ft Retained: 5.0 ft		
	360									
535						C-96		SILT to Elastic SILT, dark gray, moist, stratified/laminated, possibly graphitic laminae. HCl not tested. Recovered: 4.3 ft Retained: 4.3 ft		
	355									
540						C-97		Lean CLAY, dark gray, moist, horizontally laminated/stratified to homogenous. HCl not tested. Recovered: 5.0 ft Retained: 5.0 ft		
	350									
545										

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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 891.9 ft

HOLE No. H-1vwp-14

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Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
						C-98		SILT to Lean CLAY, olive gray, moist, horizontally laminated/stratified to homogenous. HCl not tested. Recovered: 5.0 ft Retained: 5.0 ft		
	345									
550						C-99		SILT to Elastic SILT, olive gray, moist, horizontally laminated/stratified to homogenous. HCl not tested. Mechanical fractures. Recovered: 5.0 ft Retained: 5.0 ft		
	340									
555						C-100		SILT to Fat CLAY, dark gray, moist, horizontally laminated/stratified to homogenous. HCl not tested. Recovered: 5.0 ft Retained: 5.0 ft		
	335									
560						C-101		SILT to lean CLAY, dark gray, moist, laminated/stratified to homogenous, possible graphitic laminae. HCl not tested. Mechanical fractures. Recovered: 5.0 ft Retained: 5.0 ft		
	330									
565						C-102		SILT to Elastic SILT, dark gray, wet, laminated to homogenous, possible graphitic laminae. HCl not tested. Recovered: 2.9 ft Retained: 2.9 ft		
	325									
570										

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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 891.9 ft

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Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

SPT Efficiency
Field SPT (N)
Moisture Content
RQD
20 40 60 80

Depth (ft)	Elevation (ft)	Profile	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	320				C-103		SILT to Fat CLAY, dark gray, moist, horizontally laminated. HCl not tested. Recovered: 3.7 ft Retained: 3.7 ft At 572 ft, PI= 35, CH.		
575					C-104		SILT to Elastic SILT, dark gray, moist, fissured, horizontally laminated. Fine grained sand at 580 ft. HCl not tested. Recovered: 5.0 ft Retained: 5.0 ft		
	315								
580					C-105		Poorly graded SAND, gray, moist, horizontally stratified. Sulfur smell. HCl not tested. Recovered: 5.0 ft Retained: 5.0 ft		
	310								
585					C-106		Poorly graded SAND, gray, moist, horizontally stratified. Possible 1/2-inch-thick horizontal layer of organics. Recovered: 5.0 ft Retained: 5.0 ft		
	305								
590					C-107		Fine sandy SILT to SAND to Elastic SILT, olive gray, moist, horizontally laminated/ stratified. HCl not tested. Recovered: 5.0 ft Retained: 5.0 ft		
	300								
595									

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

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Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

SPT Efficiency
Field SPT (N)
Moisture Content
RQD

Depth (ft)	Elevation (ft)	Profile (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
					C-108		Silty SAND to SILT, olive gray, moist, horizontally laminated/ stratified. HCl not tested. Recovered: 4.4 ft Retained: 4.4 ft		
	295								
600					C-109		SILT to Fine sandy SILT to SAND, olive gray, moist, horizontally laminated/ stratified. HCl not tested. Recovered: 5.0 ft Retained: 5.0 ft		
	290								
605					C-110		SILT and SAND, dark gray, moist. HCl not tested. Used Lexan tube. Recovered: 4.3 ft Retained: 4.3 ft		
	285								
610					C-111		SILT, dark gray, moist, laminated. HCl not tested. Used Lexan tube. Recovered: 5.0 ft Retained: 5.0 ft		
	280								
615					C-112		Poorly graded SAND, dark gray, moist. HCl not tested. Used Lexan tube. Recovered: 5.0 ft Retained: 5.0 ft		
	275								
620									

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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 891.9 ft

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Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

SPT Efficiency
Field SPT (N)
Moisture Content
RQD
20 40 60 80

Depth (ft)	Elevation (ft)	Profile	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
					C-113		Poorly graded SAND, gray, wet. HCl not tested. Recovered: 4.3 ft Retained: 4.3 ft		
	270								
625					C-114		Poorly graded SAND, gray, wet. HCl not tested. Recovered: 4.9 ft Retained: 4.9 ft		
	265						At 627.5 ft, SM.		
630					C-115		Artesian flow up to 8 ft above ground surface, noted after pulling inner barrel from C-114 run. Flow persisted for at least 5 minutes, then dissipated. No Recovery.		
	260								
635					C-116		Poorly graded SAND, gray, wet. HCl not tested. Recovered: 3.2 ft Retained: 3.2 ft		
	255								
640					C-117		Poorly graded SAND, gray, wet. HCl not tested. Used Lexan tube. Recovered: 4.9 ft Retained: 4.9 ft		
	250								
645									

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 891.9 ft

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Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

SPT Efficiency
Field SPT (N)
Moisture Content
RQD
20 40 60 80

Depth (ft)	Elevation (ft)	Profile	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
					C-118		Poorly graded SAND, gray, wet. HCl not tested. Used Lexan tube. Recovered: 4.9 ft Retained: 4.9 ft		
650	245		50/5" (REF)		D-19		No Recovery.		
655	240						A flush mount monument was installed on this boring. Drill rods twisted off below 534 ft. Abandoned rods and grouted hole with vibrating wire piezometers. Vibrating wire piezometer installed at 128', SN: 12-9732, 100psi Vibrating wire piezometer installed at 230', SN: 09-2993, 500psi Vibrating wire piezometer installed at 290',SN: 10-1001, 250psi		
660	235						End of test hole boring at 650.5 ft below ground elevation. This is a summary Log of Test Boring. Soil/Rock descriptions are derived from visual field identifications and laboratory test data. Note: REF = SPT Refusal		
665	230								
670	225								

Washington State
Department of Transportation

LOG OF TEST BORING

Start Card RE-10599

HOLE No. H-2vwp-14

Sheet 1 of 26

Job No. JM-1112-M gp01 SR 530 Elevation 890.6 ft

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Shepherd, Robert Lic# 2710

Component

Inspector Cooper, Kerry #2552

Start November 3, 2014 Completion November 11, 2014 Well ID# BHV-685

Equipment CME 850 (9C2-4)

Station Offset Hole Dia (inches) 4

Historical SPT Efficiency Past Rig Efficiency 87.1%

Northing 471029.366 Easting 1391919.95 Collected by Snohomish County

Method Mud Rotary

Lat 48.2867767 Long -121.8540488 Datum NAD 83/91 HARN, NAVD88, SPN (ft)

Drill Fluid Bentonite-Polymer

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	890.0								Groundwater readings were taken from 11-05-2014 to 11-09-2014	
5	885.0									
10	880.0									
15	875.0									
20										

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 890.6 ft

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Project SR-530 MP 35 to 41 Geotechnical Study

Driller Shepherd, Robert

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	870									
25	865									
30	860									
35	855									
40	850									
45										

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 890.6 ft

HOLE No. H-2vwp-14

Sheet 3 of 26

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Shepherd, Robert

SPT Efficiency
Field SPT (N)
Moisture Content
RQD

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	845									
50	840		◆	9 12 14 20 (26)		D-1		MC= 4.5% Poorly graded SAND, dense, gray, moist, homogeneous. HCl not tested. Recovered: 1.2 ft Retained: 1.0 ft		
55	835									
60	830									
65	825									
70										

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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 890.6 ft

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Project SR-530 MP 35 to 41 Geotechnical Study

Driller Shepherd, Robert

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	820									
75	815									
80	810									
85	805									
90	800									
95										

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 890.6 ft

HOLE No. H-2vwp-14

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Project SR-530 MP 35 to 41 Geotechnical Study

Driller Shepherd, Robert

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	795									
			>>◆	30 34 50/0" 50/0" (REF)		D-2		MC= 23.2% Poorly graded SAND, very dense, gray, moist, homogeneous. HCl not tested. Recovered: 1.2 ft Retained: 1.0 ft		
100	790									
105	785								11-05-2014	
110	780									
115	775									
120										

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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 890.6 ft

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Project SR-530 MP 35 to 41 Geotechnical Study

Driller Shepherd, Robert

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	770									
125	765									
130	760									
135	755									
140	750									
145										

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 890.6 ft

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Project SR-530 MP 35 to 41 Geotechnical Study

Driller Shepherd, Robert

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	745					C-3L		Silty SAND, gray, moist, stratified. HCl not tested. Used Lexan tube. Recovered: 9.7 ft Retained: 9.7 ft		
150	740									
155	735									
160	730									
165	725									
170										

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 890.6 ft

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Project SR-530 MP 35 to 41 Geotechnical Study

Driller Shepherd, Robert

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	720									
175	715									
180	710								11-09-2014	
185	705									
190	700									
195										

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

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Job No. JM-1112-M gp01 SR 530 Elevation 890.6 ft

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Project SR-530 MP 35 to 41 Geotechnical Study

Driller Shepherd, Robert

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	695									
200	690									
205	685							Lost water at 206 ft.		
210	680									
215	675									
220										

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 890.6 ft

HOLE No. H-2vwp-14

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Project SR-530 MP 35 to 41 Geotechnical Study

Driller Shepherd, Robert

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	670									
225	665									
230	660									
235	655									
240	650									
245										

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 890.6 ft

HOLE No. H-2vwp-14

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Project SR-530 MP 35 to 41 Geotechnical Study

Driller Shepherd, Robert

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	645									
250	640									
255	635									
260	630					C-4L		Poorly graded SAND, dark gray, moist. HCl not tested. Recovered: 9.0 ft Retained: 9.0 ft		
265	625									
270						C-5L		Poorly graded SAND, dark gray, moist. HCl not tested. Used Lexan tube.		

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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 890.6 ft

HOLE No. H-2vwp-14

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Project SR-530 MP 35 to 41 Geotechnical Study

Driller Shepherd, Robert

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	620							Recovered: 5.0 ft Retained: 5.0 ft At 271 ft, SM.		
275	615									
280	610									
285	605									
290	600									
295										

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

Washington State
Department of Transportation

LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 890.6 ft

HOLE No. H-2vwp-14

Sheet 13 of 26

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Shepherd, Robert

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	595									
300	590									
305	585									
310	580									
315	575									
320										

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

Washington State
Department of Transportation

LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 890.6 ft

HOLE No. H-2vwp-14

Sheet 14 of 26

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Shepherd, Robert

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	570					C-6		Silty SAND, dark gray, wet, stratified, possible slickenside. HCl not tested. Recovered: 3.8 ft Retained: 3.8 ft Possible confined or perched water.		
325	565									
330	560									
335	555									
340	550					C-7		Silty SAND, gray, wet, stratified, possible fracture at 342 ft. HCl not tested. Recovered: 5.0 ft Retained: 5.0 ft		
345										

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

Washington State
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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 890.6 ft

HOLE No. H-2vwp-14

Sheet 15 of 26

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Shepherd, Robert

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	545									
350	540									
355	535									
360	530									
365	525									
370										

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

Washington State
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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 890.6 ft

HOLE No. H-2vwp-14

Sheet 16 of 26

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Shepherd, Robert

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	520									
375	515									
380	510									
385	505									
390	500									
395										

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

Washington State
Department of Transportation

LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 890.6 ft

HOLE No. H-2vwp-14

Sheet 17 of 26

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Shepherd, Robert

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	495									
400	490									
405	485									
410	480					C-8		SILT, dark gray, wet, stratified. HCl not tested. Recovered: 5.0 ft Retained: 5.0 ft Wet at 413 ft.		
415	475									
420										

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 890.6 ft

HOLE No. H-2vwp-14

Sheet 18 of 26

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Shepherd, Robert

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	470									
425										
	465									
430										
	460									
435										
	455									
440										
	450									
445										

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 890.6 ft

HOLE No. H-2vwp-14

Sheet 19 of 26

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Shepherd, Robert

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	445									
450										
	440									
455										
	435									
460										
	430									
465										
	425									
470										

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Department of Transportation

LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 890.6 ft

HOLE No. H-2vwp-14

Sheet 20 of 26

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Shepherd, Robert

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	420									
475	415									
480	410									
485	405									
490	400									
495										

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 890.6 ft

HOLE No. H-2vwp-14

Sheet 21 of 26

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Shepherd, Robert

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	395									
500	390									
505	385									
510	380									
515	375									
520										

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 890.6 ft

HOLE No. H-2vwp-14

Sheet 22 of 26

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Shepherd, Robert

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	370									
525	365									
530	360									
535	355									
540	350									
545										

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 890.6 ft

HOLE No. H-2vwp-14

Sheet 23 of 26

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Shepherd, Robert

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	345									
550	340									
555	335									
560	330					C-9L		SILT, dark gray, moist, stratified. HCl not tested. Used Lexan tube. Recovered: 2.4 ft Retained: 2.4 ft At 562 ft, MC= 26.4%, PI= 29, CH.		
565	325									
570										

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 890.6 ft

HOLE No. H-2vwp-14

Sheet 24 of 26

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Shepherd, Robert

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	320					C-10L		SILT, dark gray, moist, stratified. HCl not tested. Used Lexan tube. Recovered: 4.8 ft Retained: 4.8 ft		
575	315							Contact with poorly graded sand at 578 ft.		
580	310					C-11L		Poorly graded SAND, gray, moist, stratified. HCl not tested. Used Lexan tube. Recovered: 4.1 ft Retained: 4.1 ft At 582.5 ft, MC= 26.4%, PI=29, CH.		
585	305									
590	300					C-12L		No Recovery.		
595										

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 890.6 ft

HOLE No. H-2vwp-14

Sheet 25 of 26

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Shepherd, Robert

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	295					C-13		Poorly graded SAND, gray, moist, stratified. HCl not tested. Recovered: 9.1 ft Retained: 9.1 ft		
600	290									
605	285					C-14		Well graded SAND, gray, moist, stratified. HCl not tested. Recovered: 9.0 ft Retained: 9.0 ft		
610	280									
615	275					C-15		Well graded SAND, gray, moist, stratified. HCl not tested. Recovered: 9.6 ft Retained: 9.6 ft		
620										

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

Washington State
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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 890.6 ft

HOLE No. H-2vwp-14

Sheet 26 of 26

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Shepherd, Robert

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
	270									
625	265					C-16		Well graded SAND, gray, moist, stratified. HCl not tested. course to medium sand Recovered: 9.9 ft Retained: 9.9 ft		
630	260									
635	255							A flush mount monument was installed on this boring. Vibrating wire piezometer installed at 450.0 ft S/N 1403392, 250psi Vibrating wire piezometer installed at 570.0 ft S/N 1403391, 250psi Vibrating wire piezometer installed at 585.0 ft S/N 1403677, 500psi Vibrating wire piezometer installed at 625.0 ft S/N 1403678, 500psi TDR installed at 627.0 ft		
640	250									
645								End of test hole boring at 635 ft below ground elevation. This is a summary Log of Test Boring. Soil/Rock descriptions are derived from visual field identifications and laboratory test data. Note: REF = SPT Refusal		

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

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LOG OF TEST BORING

Start Card RE-10806

HOLE No. H-3vwp-14

Job No. JM-1112-M gp01 SR 530 Elevation 580.0 ft

Sheet 1 of 13

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny Lic# 2742

Component

Inspector Cooper, Kerry #2552

Start November 18, 2014 Completion November 21, 2014 Well ID# BHV-688

Equipment CME 850 (9C2-4)

Station Offset Hole Dia (inches) 4

Historical SPT Efficiency Past Rig Efficiency 87.1%

Northing 464675.32 Easting 1397225.84 Collected by HQ Geotech Office-GPS

Method Mud Rotary

Lat 48.2695509 Long -121.8319182 Datum NAD 83/91 HARN, NAVD88, SPN (ft)

Drill Fluid Bentonite-Polymer

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
						C-1		Well graded GRAVEL and cobbles, sub-angular, dark gray, moist, homogeneous. HCl not tested. Recovered: 0.4 ft Retained: 0.4 ft	Groundwater readings were taken from 11-19-2014 to 11-21-2014	
5	575.0					C-2		Well graded GRAVEL and cobbles, sub-rounded, dark gray, moist, homogeneous. HCl not tested. Recovered: 0.3 ft Retained: 0.3 ft		
10	570.0									
			◆	3 5 6 (11)		D-3		SILT with FeO stains, medium dense, olive brown, moist, stratified. HCl not tested. Recovered: 1.5 ft Retained: 1.5 ft		
15	565.0					C-4		SILT with FeO stains, gray, moist, slickensided, blocky, disrupted. HCl not tested. Recovered: 2.4 ft Retained: 2.4 ft		
20	560.0									

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 580.0 ft

HOLE No. H-3vwp-14

Sheet 2 of 13

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
						C-5		SILT, gray, moist, slickensided, blocky, disrupted. HCl not tested. Recovered: 3.0 ft Retained: 3.0 ft		
25	555					C-6		SILT, gray, moist, blocky, disrupted. HCl not tested. Recovered: 3.0 ft Retained: 3.0 ft		
30	550					C-7		SILT, gray, moist, laminated, blocky. Block of advanced glaciolacustrine sediments. At 34.9 ft, SILT with gravels, olive brown, disrupted. HCl not tested. Recovered: 4.0 ft Retained: 4.0 ft		
35	545					C-8		Well graded GRAVEL and cobbles, sub-rounded to rounded, gray, moist, stratified. Fines washed away. HcL not tested. Possible voide between 36 and 38.5 ft. Recovered: 0.9 ft Retained: 0.9 ft		
40	540					C-9		Well graded GRAVEL and cobbles, sub-rounded to rounded, gray, moist, stratified. Fines washed away. HCl not tested. Recovered: 0.6 ft Retained: 0.6 ft		
45	535									

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

Washington State
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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 580.0 ft

HOLE No. H-3vwp-14

Sheet 3 of 13

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

SPT Efficiency
Field SPT (N)
Moisture Content
RQD

Depth (ft)	Elevation (ft)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
		5 7 8 (15)		D-10		Poorly graded SAND, medium dense, gray, moist, homogeneous. HCl not tested. Recovered: 1.0 ft Retained: 1.0 ft		
				C-11		No Recovery. Possible vid at 47-49.5.		
50	530	7 7 10 (17)		D-12		Poorly graded SAND with FeO stains, medium dense, gray, moist, homogeneous. HCl not tested. Recovered: 1.2 ft Retained: 1.2 ft		
				C-13		No Recovery.		
55	525			C-14		No Recovery.		
60	520	7 17 17 (34)		D-15		Poorly graded SAND, dense, gray, moist, homogeneous. HCl not tested. Recovered: 0.8 ft Retained: 0.8 ft		
				C-16		No Recovery.		
65	515			C-17		Well graded GRAVEL with cobbles, sub-rounded, gray, moist. Fines washed away. HCl not tested. Recovered: 0.9 ft Retained: 0.9 ft		
70	510							

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

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LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 580.0 ft

HOLE No. H-3vwp-14

Sheet 4 of 13

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

SPT Efficiency
Field SPT (N)
Moisture Content
RQD
20 40 60 80

Depth (ft)	Elevation (ft)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
		10 14 16 (30)		D-18		Well graded GRAVEL with sand, sub-rounded, dense, gray, moist. HCl not tested. Recovered: 0.8 ft Retained: 0.8 ft	11-20-2014	
				C-19		Well graded GRAVEL and cobbles, sub-rounded to rounded, gray, moist. Fines washed away. HCl not tested. Recovered: 1.0 ft Retained: 1.0 ft		
75	505			C-20		Well graded GRAVEL and cobbles, sub-rounded to rounded, gray, moist. Fines washed away. HCl not tested. Recovered: 1.3 ft Retained: 1.3 ft		
80	500	13 15 16 (31)		D-21		Well graded GRAVEL with sand, sub-rounded, dense, gray, moist. HCl not tested. Recovered: 1.1 ft Retained: 1.1 ft		
				C-22		Well graded GRAVEL and cobbles, sub-rounded to rounded, gray, moist. Fines washed away. HCl not tested. Recovered: 1.1 ft Retained: 1.1 ft		
85	495			C-23		Well graded GRAVEL and cobbles, sub-rounded to rounded, gray, moist. Fines washed away. HCl not tested. Recovered: 1.0 ft Retained: 1.0 ft		
90	490			C-24		No Recovery.		
95	485							

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Department of Transportation

LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 580.0 ft

HOLE No. H-3vwp-14

Sheet 5 of 13

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

SPT Efficiency
Field SPT (N)
Moisture Content
RQD
20 40 60 80

Depth (ft)	Elevation (ft)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material
				C-25		No Recovery.
100	480	>>◆ 16 37 50/4" (REF)		D-26		Well graded GRAVEL with sand, sub-rounded, very dense, gray, moist. HCl not tested. Recovered: 0.7 ft Retained: 0.7 ft
105	475					
110	470	>>◆ 27 50/5" (REF)		D-27		Silty GRAVEL, sub-rounded, very dense, olive brown, moist. HCl not tested. Recovered: 0.6 ft Retained: 0.6 ft
115	465					
120	460	>>◆ 40 50/5"		D-28		Silty GRAVEL, sub-rounded, very dense, gray, moist. HCl not tested.

Groundwater

Instrument

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

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Job No. JM-1112-M gp01 SR 530 Elevation 580.0 ft

HOLE No. H-3vwp-14

Sheet 6 of 13

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
				(REF)		C-29		Recovered: 0.6 ft Retained: 0.6 ft Well graded GRAVEL and cobbles, sub-rounded to rounded, gray, moist. HCl not tested. Fines washed away. HCl not tested. Recovered: 1.0 ft Retained: 1.0 ft	11-21-2014	
125	455					C-30		Well graded GRAVEL sub-rounded to rounded, gray, moist. Fines washed away. HCl not tested. Lost water at 126'. Recovered: 1.1 ft Retained: 1.1 ft		
130	450					C-31		Well graded GRAVEL sub-rounded to rounded, gray, moist. Fines washed away. HCl not tested. Recovered: 0.6 ft Retained: 0.6 ft		
135	445					C-32		Well graded GRAVEL sub-rounded to rounded, gray, moist. Fines washed away. HCl not tested. Recovered: 1.5 ft Retained: 1.5 ft		
140	440					C-33		Well graded GRAVEL and cobbles, sub-rounded to rounded, gray, moist. Fines washed away. HCl not tested. Recovered: 0.6 ft Retained: 0.6 ft		
145	435									

Washington State
Department of Transportation

LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 580.0 ft

HOLE No. H-3vwp-14

Sheet 7 of 13

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

SPT Efficiency
Field SPT (N)
Moisture Content
RQD
20 40 60 80

Depth (ft)	Elevation (ft)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
				C-34		Recovered: 0.0 ft Retained: 0.0 ft		
150	430	24 30 34 (64)		D-35		Silty SAND with gravel with FeO stains, sub-rounded, very dense, gray, moist. HCl not tested. Recovered: 0.8 ft Retained: 0.8 ft		
				C-36		Well graded GRAVEL and cobbles, sub-rounded, gray, moist. Fines washed away. HCl not tested. Recovered: 1.0 ft Retained: 1.0 ft		
155	425			C-37		Well graded GRAVEL sub-rounded to rounded, gray, moist. Fines washed away. HCl not tested. Recovered: 1.5 ft Retained: 1.5 ft		
160	420			C-38		Well graded GRAVEL and cobbles, with FeO stains, sub-rounded to rounded, gray, moist. Fines washed away. HCl not tested. Recovered: 1.2 ft Retained: 1.2 ft		
165	415			C-39		Well graded GRAVEL and cobbles, with FeO stains, sub-rounded to rounded, gray, moist. Fines washed away. HCl not tested. Recovered: 1.0 ft Retained: 1.0 ft		
170	410							

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

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Job No. JM-1112-M gp01 SR 530 Elevation 580.0 ft

HOLE No. H-3vwp-14

Sheet 8 of 13

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

SPT Efficiency
Field SPT (N)
Moisture Content
RQD
20 40 60 80

Depth (ft)	Elevation (ft)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
				C-40		Well graded GRAVEL and cobbles, with FeO stains, sub-rounded to rounded, gray, moist. Fines washed away. HCl not tested. Recovered: 1.1 ft Retained: 1.1 ft		
175	405	>> 31 50/3" (REF)		D-41		Well graded GRAVEL washed out fines, sub-rounded, very dense, gray, moist. HCl not tested. Recovered: 0.2 ft Retained: 0.2 ft		
				C-42		Well graded GRAVEL and cobbles, sub-rounded to rounded, gray, moist. Fines washed away. HCl not tested. Recovered: 0.9 ft Retained: 0.9 ft		
180	400			C-43		Elastic SILT with trace gravel, dark gray, moist, disrupted with slickensides, ash laminae apparent. Bottom 6 inches, horizontally laminated. HCl not tested. Recovered: 3.5 ft Retained: 3.5 ft		
					MC GS AL HT SG RS	CH, MC=32%, PI=35 Fat CLAY.At 183 ft, MC= 32% (sample moisture not well preserved), CH.		
185	395			C-44		SILT to Elastic SILT, dark gray, moist, horizontally laminated to stratified. HCl not tested. Recovered: 5.0 ft Retained: 5.0 ft		
190	390			C-45L		Elastic SILT, dark gray, moist. HCl not tested. Used Lexan tube. Recovered: 4.5 ft Retained: 4.5 ft		
195	385							

Washington State
Department of Transportation

LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 580.0 ft

HOLE No. H-3vwp-14

Sheet 9 of 13

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

SPT Efficiency
Field SPT (N)
Moisture Content
RQD
20 40 60 80

Depth (ft)	Elevation (ft)	Profile	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
					C-46L		SILT, dark gray, moist. HCl not tested. Used Lexan tube. Recovered: 4.6 ft Retained: 4.6 ft		
200	380				C-47L		Elastic SILT, dark gray, moist. HCl not tested. Used Lexan tube. Recovered: 4.9 ft Retained: 4.9 ft		
205	375				C-48		SILT, dark gray, moist, laminated to stratified. Becoming nonplastic with depth. HCl not tested. Recovered: 4.9 ft Retained: 4.9 ft		
210	370				C-49		SILT to Elastic SILT, dark gray, moist, laminated to stratified. HCl not tested. Recovered: 4.6 ft Retained: 4.6 ft		
215	365				C-50		SILT to Elastic SILT, dark gray, moist, laminated to stratified. Bedding locally distorted. HCl not tested. Recovered: 4.4 ft Retained: 4.4 ft		
220	360								

Washington State
Department of Transportation

LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 580.0 ft

HOLE No. H-3vwp-14

Sheet 10 of 13

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
						C-51		Elastic SILT, dark gray, moist, laminated to stratified. HCl not tested. Recovered: 4.7 ft Retained: 4.7 ft		
225	355					C-52		Elastic SILT, dark gray, moist, laminated to stratified. HCl not tested. Sandy SILT laminae with sulfur smell at 229 ft. Recovered: 3.8 ft Retained: 3.8 ft		
230	350					C-53		Lean CLAY to Fat CLAY, dark gray, moist, laminated to stratified. HCl not tested. Sandy SILT between 230 and 231 ft. Recovered: 5.0 ft Retained: 5.0 ft		
235	345					C-54		Elastic SILT, dark gray, moist, laminated to stratified. HCl not tested. Sandy SILT between 236 and 236.6 ft. Recovered: 4.4 ft Retained: 4.4 ft		
240	340					C-55		SILT to Fat CLAY, dark gray, moist, laminated to stratified. HCl not tested. Sandy SILT between 243 to 243.3 ft and 244 to 244.4 ft; very wet. Recovered: 5.0 ft Retained: 5.0 ft		
245	335									

Washington State
Department of Transportation

LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 580.0 ft

HOLE No. H-3vwp-14

Sheet 11 of 13

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

SPT Efficiency
Field SPT (N)
Moisture Content
RQD
20 40 60 80

Depth (ft)	Elevation (ft)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
				C-56		SILT to Lean CLAY, dark gray, moist, laminated to stratified. HCl not tested. Recovered: 4.6 ft Retained: 4.6 ft		
250	330			C-57		Lean CLAY, gray, moist, laminated to stratified. HCl not tested. At 251.9 ft, poorly graded SAND, gray, homogeneous. Recovered: 4.0 ft Retained: 4.0 ft		
255	325			C-58		Poorly graded SAND, gray, moist, homogeneous. HCl not tested. Recovered: 4.8 ft Retained: 4.8 ft		
260	320			C-59		Poorly graded SAND, gray, moist, homogeneous. HCl not tested. At 264 ft, SILT, gray, horizontally laminated to fissured. Recovered: 4.8 ft Retained: 4.8 ft		
265	315			C-60L		SILT, gray, moist, stratified. HCl not tested. Used Lexan tube. Recovered: 4.9 ft Retained: 4.9 ft		
270	310							

Washington State
Department of Transportation

LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 580.0 ft

HOLE No. H-3vwp-14

Sheet 12 of 13

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

SPT Efficiency
Field SPT (N)
Moisture Content
RQD
20 40 60 80

Depth (ft)	Elevation (ft)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
				C-61L		Poorly graded SAND, gray, moist, stratified. HCl not tested. Used Lexan tube. Recovered: 4.6 ft Retained: 4.6 ft		
275	305			C-62		Poorly graded SAND, gray, moist, homogeneous. Sulphur smell. HCl not tested. Recovered: 3.6 ft Retained: 3.6 ft		
280	300			C-63		Poorly graded SAND, gray, moist, homogeneous, horizontally stratified. HCl not tested. Recovered: 4.6 ft Retained: 4.6 ft		
285	295			C-64		Poorly graded SAND, gray, moist, homogeneous. HCl not tested. Recovered: 4.8 ft Retained: 4.8 ft		
290	290			C-65		Poorly graded SAND, gray, moist, homogeneous. HCl not tested. Recovered: 3.9 ft Retained: 3.9 ft		
295	285							

Washington State
Department of Transportation

LOG OF TEST BORING

Job No. JM-1112-M gp01 SR 530 Elevation 580.0 ft

HOLE No. H-3vwp-14

Sheet 13 of 13

Project SR-530 MP 35 to 41 Geotechnical Study

Driller Henderson, Danny

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
						C-66		Poorly graded SAND trace gravel, gray, moist, stratified. HCl not tested. Recovered: 4.2 ft Retained: 4.2 ft		
300	280							A standpipe monument was installed on this boring.		
305	275							The implied accuracy of the borehole location information displayed on this boring log is typically sub-meter in (X,Y) when collected by the HQ Geotech Office and sub-centimeter in (X,Y,Z) when collected by the Region Survey Crew. Elevation is an estimation from 2014 Lidar.		
310	270							End of test hole boring at 300 ft below ground elevation. This is a summary Log of Test Boring. Soil/Rock descriptions are derived from visual field identifications and laboratory test data. Note: REF = SPT Refusal		
315	265							Vibrating wire piezometer installed at 178' SN: 10-1000, 250 psi Vibrating wire piezometer installed at 250' SN: 1403627, 250 psi Vibrating wire piezometer installed at 270' SN: 1403628, 250 psi		
320	260									

ENTERPRISE BORING LOG JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ ENTERPRISE DATA TEMPLATE.GDT 6/10/15

Soil Classification System

MAJOR DIVISIONS			GRAPHIC SYMBOL	USCS LETTER SYMBOL[1]	TYPICAL DESCRIPTIONS[2][3]
COARSE-GRAINED SOIL (More than 50% of material is larger than No. 200 sieve size)	GRAVEL AND GRAVELLY SOIL (More than 50% of coarse fraction retained on No. 4 sieve)	CLEAN GRAVEL (Little or no fines)		GW	Well-graded gravel; gravel/sand mixture(s); little or no fines
				GP	Poorly graded gravel; gravel/sand mixture(s); little or no fines
		GRAVEL WITH FINES (Appreciable amount of fines)		GM	Silty gravel; gravel/sand/silt mixture(s)
				GC	Clayey gravel; gravel/sand/clay mixture(s)
	SAND AND SANDY SOIL (More than 50% of coarse fraction passed through No. 4 sieve)	CLEAN SAND (Little or no fines)		SW	Well-graded sand; gravelly sand; little or no fines
				SP	Poorly graded sand; gravelly sand; little or no fines
		SAND WITH FINES (Appreciable amount of fines)		SM	Silty sand; sand/silt mixture(s)
				SC	Clayey sand; sand/clay mixture(s)
FINE-GRAINED SOIL (More than 50% of material is smaller than No. 200 sieve size)	SILT AND CLAY (Liquid limit less than 50)			ML	Inorganic silt and very fine sand; rock flour; silty or clayey fine sand or clayey silt with slight plasticity
				CL	Inorganic clay of low to medium plasticity; gravelly clay; sandy clay; silty clay; lean clay
				OL	Organic silt; organic, silty clay of low plasticity
	SILT AND CLAY (Liquid limit greater than 50)			MH	Inorganic silt; micaceous or diatomaceous fine sand
				CH	Inorganic clay of high plasticity; fat clay
				OH	Organic clay of medium to high plasticity; organic silt
	HIGHLY ORGANIC SOIL			PT	Peat; humus; swamp soil with high organic content

OTHER MATERIALS	GRAPHIC SYMBOL	LETTER SYMBOL	TYPICAL DESCRIPTIONS
PAVEMENT		AC or PC	Asphalt concrete pavement or Portland cement pavement
ROCK		RK	Rock (See Rock Classification)
WOOD		WD	Wood, lumber, wood chips
DEBRIS		DB	Construction debris, garbage

Notes:
1. USCS letter symbols correspond to symbols used by the Unified Soil Classification System and ASTM classification methods. Dual letter symbols (e.g., SP-SM for sand or gravel) indicate soil with an estimated 5-15% fines. Multiple letter symbols (e.g., ML/CL) indicate borderline or multiple soil classifications.
2. Soil descriptions are based on the general approach presented in the *Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)*, outlined in ASTM D 2488. Where laboratory index testing has been conducted, soil classifications are based on the *Standard Test Method for Classification of Soils for Engineering Purposes*, as outlined in ASTM D 2487.
3. Soil description terminology is based on visual estimates (in the absence of laboratory test data) of the percentages of each soil type and is defined as follows:

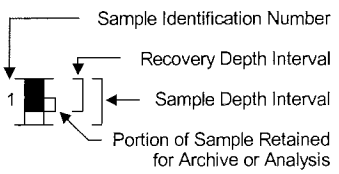
Primary Constituent:	> 50% - "GRAVEL," "SAND," "SILT," "CLAY," etc.
Secondary Constituents:	> 30% and ≤ 50% - "very gravelly," "very sandy," "very silty," etc.
	> 15% and ≤ 30% - "gravelly," "sandy," "silty," etc.
Additional Constituents:	> 5% and ≤ 15% - "with gravel," "with sand," "with silt," etc.
	≤ 5% - "trace gravel," "trace sand," "trace silt," etc., or not noted.

Drilling and Sampling Key

SAMPLER TYPE

Code	Description
a	3.25-inch O.D., 2.42-inch I.D. Split Spoon
b	2.00-inch O.D., 1.50-inch I.D. Split Spoon
c	Shelby Tube
d	Grab Sample
e	Single-Tube Core Barrel
f	Double-Tube Core Barrel
g	Other - See text if applicable
1	300-lb Hammer, 30-inch Drop
2	140-lb Hammer, 30-inch Drop
3	Pushed
4	Rotosonic
5	Air Rotary (Rock)
6	Wash Rotary (Rock)
7	Other - See text if applicable

SAMPLE NUMBER & INTERVAL



Field and Lab Test Data

Code	Description
PP = 1.0	Pocket Penetrometer, tsf
TV = 0.5	Torvane, tsf
PID = 100	Photoionization Detector VOC screening, ppm
W = 10	Moisture Content, %
D = 120	Dry Density, pcf
-200 = 60	Material smaller than No. 200 sieve, %
GS	Grain Size - See separate figure for data
AL	Atterberg Limits - See separate figure for data
GT	Other Geotechnical Testing
CA	Chemical Analysis

Groundwater

▽ ATD — Approximate water elevation at time of drilling (ATD) or on date noted. Groundwater levels can fluctuate due to precipitation, seasonal conditions, and other factors.

7/6/06 \\EDMDATA\GINT\GINT7\PROJECTS\244041.010.GPJ SOIL CLASS SHEET

LANDAU ASSOCIATES

SR 530 (MP 36.5) - Skaglund Hill Landslide
Snohomish County, Washington

Soil Classification System and Key

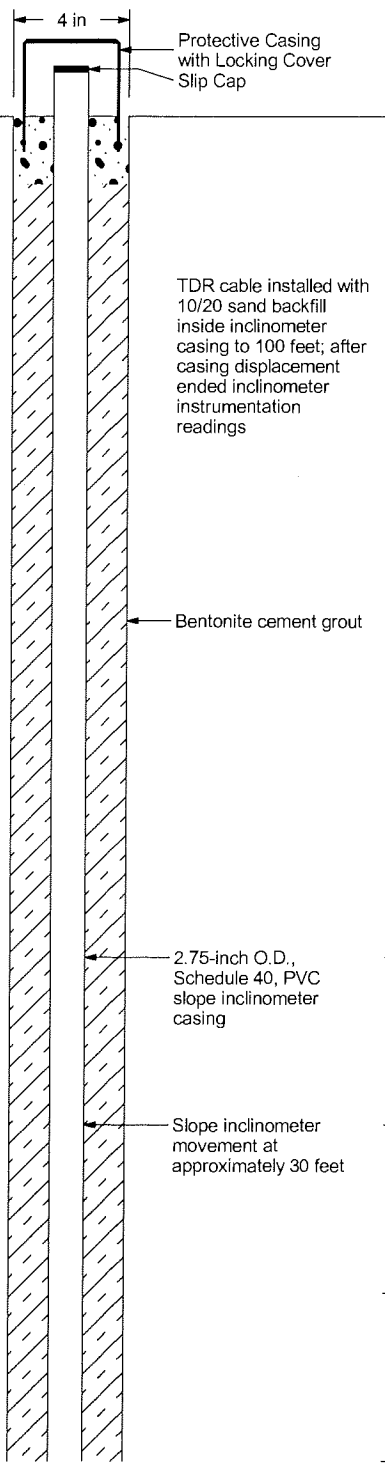
Figure A-1

H-1-06

Drilling Method: Mud Rotary Casing Advancer
Casing: HWx101.0'
Driller (Lic.#): WSDOT - Kerry Cooper (2552)
Ground Elevation (ft): 395.7 (MSL)

Depth (ft)	Sample Number & Interval	Sampler Type	Blows/Foot	Test Data	USCS Symbol	Soil Description
0					CL	Gray, silty CLAY; disturbed bedding, laminated (moist, medium stiff to stiff) **(Slide Debris)**
5	S1	b2	5	W = 33		
	S2	b2	9	W = 33		
10	S3	b2	5	W = 30		
	S4	b2	5	W = 37	CH	Gray, silty CLAY; disturbed bedding, laminated, slickensides (moist, medium stiff)
15	S5	b2	8	W = 32 AL	CH	Gray, silty CLAY (moist to wet, medium stiff) - disturbed bedding, with 1/2" water bearing zones
	S6	b2	5	W = 31		
20	S7	b2	4	W = 33 AL	CL	Gray, silty CLAY (moist to wet, medium stiff) - disturbed bedding, with 1/2" water bearing zones
	S8	b2	8	W = 30		- bedding tilted at ~30 degrees from horizontal
25	S9	c3				
	S10	b2	10	W = 38 AL	CH	Gray, silty CLAY; disturbed bedding, laminated (moist, stiff) **(Glaciolacustrine)**
30	S11	b2	12	W = 34		- bedding tilted at ~15 degrees from horizontal
	S12	b2	12	W = 45		- slickensides
35	S13	b2	15	W = 22		- very stiff
	S14	b2	15	W = 31 AL	CH	Gray, silty CLAY; laminated, horizontal bedding (wet, very stiff)
40						

Inclinometer Detail



Notes:–
1. Stratigraphic contacts are based on field interpretations and are approximate.
2. Reference to the text of this report is necessary for a proper understanding of subsurface conditions.
3. Refer to "Soil Classification System and Key" figure for explanation of graphics and symbols.

244041.01 8/3/06 \\EDMDATA\GINT\GINT7\PROJECTS\244041.010.GPJ WSDOT WELL LOG

LANDAU ASSOCIATES

SR 530 (MP 36.5) - Skaglund Hill Landslide
Snohomish County, Washington

Log of Soil Boring H-1-06

Figure A-2 (1 of 3)

H-1-06

Drilling Method: Mud Rotary Casing Advancer
Casing: HWx101.0'
Driller (Lic.#): WSDOT - Kerry Cooper (2552)
Ground Elevation (ft): 395.7 (MSL)

Depth (ft)	Sample Number & Interval	Sampler Type	Blows/Foot	Test Data	USCS Symbol	Soil Profile
40	S15	b2	16	W = 34	CH	Gray, silty CLAY; laminated, horizontal bedding (wet, very stiff)
	S16	b2	19	W = 36		
45	S17	c3				
	S18	b2	30	W = 29		
50	S19A S19B	b2	36	W = 25 W = 43	CL	Dark gray and gray, interbedded silty CLAY and clayey SILT; some laminations, homogeneous (moist, very stiff to hard) - Slickensides and disturbed bedding
	S20	b2	25	W = 33		
55	S21	b2	25	W = 36		
	S22	b2	23	W = 24		
60	S23	b2	30	W = 32		
	S24	b2	26	W = 33		
65	S25	b2	31	W = 32		
	S26A S26B	b2	50/ 6"	W = 34		
70	S27	b2	50/ 5"	W = 20		
75	S28	b2	81	W = 21 GS	SM	Dark gray to gray, silty to clayey, fine SAND; horizontal bedding (moist to wet, very dense)
					ML	Dark gray, clayey SILT; horizontal bedding (moist, hard)
80						

Water Level: ATD

Inclinometer Detail

Notes:–
1. Stratigraphic contacts are based on field interpretations and are approximate.
2. Reference to the text of this report is necessary for a proper understanding of subsurface conditions.
3. Refer to "Soil Classification System and Key" figure for explanation of graphics and symbols.

244041.01 8/3/06 \\EDMDATA\GINT\GINT7\PROJECTS\244041.010.GPJ WSDOT WELL LOG

LANDAU ASSOCIATES

SR 530 (MP 36.5) - Skaglund Hill Landslide Snohomish County, Washington

Log of Soil Boring H-1-06

Figure A-2 (2 of 3)

H-1-06

SAMPLE DATA					SOIL PROFILE			GROUNDWATER
Depth (ft)	Sample Number & Interval	Sampler Type	Blows/Foot	Test Data	Graphic Symbol	USCS Symbol	Drilling Method: Mud Rotary Casing Advancer Casing: HWx101.0' Driller (Lic.#): WSDOT - Kerry Cooper (2552) Ground Elevation (ft): 395.7 (MSL)	Water Level / Inclinometer Detail
80	S29	b2	88/ 12"	W = 31		ML	Dark gray, clayey SILT; horizontal bedding (moist, hard)	
85	S30A S30B	b2	72/ 11"	W = 20 W = 29		SM	Brown and light brown, silty, fine to medium SAND; homogeneous (moist to wet, very dense) **(Advance Outwash)**	
90	S31	b2	50/ 4"	W = 14				
95	S32	b2	50/ 6"	W = 20				
100	S33	b2	50/ 6"	W = 16				
105								
110								
115								
120								

Boring Completed 02/21/06
Total Depth of Boring = 101.0 ft.
WSDOT Job #: C-7129
Start Card #: R 68295
Ecology Well#: ALP-506

Point located at State Plane Coordinates:
North: 465475.27
East: 1391183.99
Township: 32
Range: 7
Section: 12
Inspector: Ryan Reich/Jonathan Brown

Inclinometer Completed 02/23/06
Elevation at Top of Protective Casing = 397.60 ft.
Elevation at Top of Inclinometer Casing = 397.10 ft.

Notes:
1. Stratigraphic contacts are based on field interpretations and are approximate.
2. Reference to the text of this report is necessary for a proper understanding of subsurface conditions.
3. Refer to "Soil Classification System and Key" figure for explanation of graphics and symbols.

244041.01 8/3/06 \\EDMDATA\GINT\GINT7\PROJECTS\244041.010.GPJ WSDOT WELL LOG

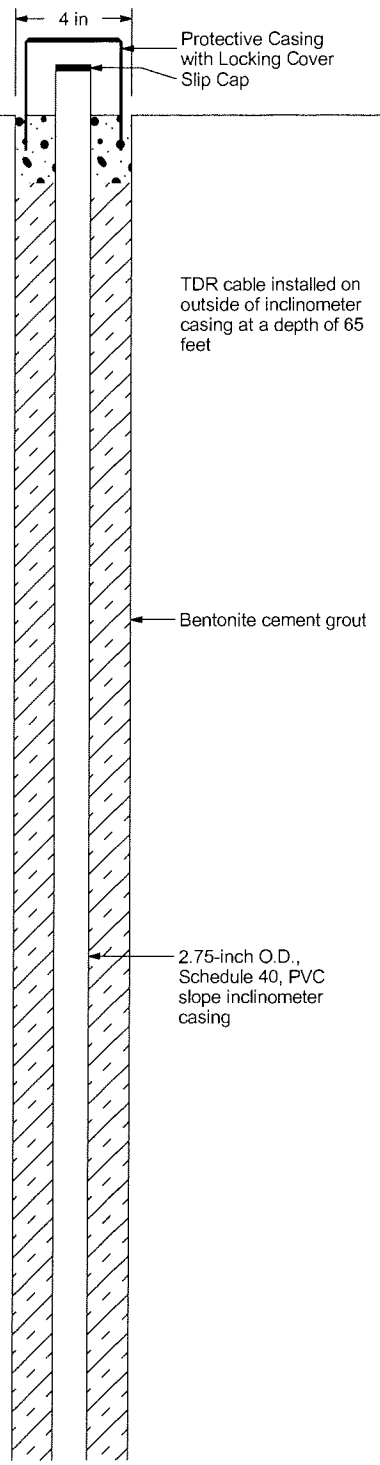
H-3-06

Drilling Method: Mud Rotary Casing Advancer
Casing: HWx70.0'-HQx131.0'
Driller (Lic.#): WSDOT - Kerry Cooper (2552)
Ground Elevation (ft): 363 (MSL)

Depth (ft)	Sample Number & Interval	Sampler Type	Blows/Foot	Test Data	USCS Symbol	Soil Description
0					CL	Gray, silty CLAY (wet, medium stiff) **(Slide Debris)**
5	S1	b2	5	W = 32		
	S2	b2	9	W = 34	CL	Mottled light brown/reddish brown, silty CLAY with trace fine organic debris (wet, stiff)
10	S3	b2	9	W = 25	SM/ ML	Gray and light brown, silty to very silty, fine SAND with medium and coarse sand and interbedded SILT (wet, loose/stiff)
	S4	b2	9	W = 23		- wood twigs with scattered sand and fine gravel
15	S5	b2	9	W = 14		- trace small wood twig and trace fine gravel
	S6	b2	7	W = 22 GS		
20	S7	b2	7	W = 23		
	S8	b2	9	W = 25 GS		- silt clast
25	S9A S9B	b2	9	W = 23	CL	- diagonal contact between S-9A and S-9B contact Gray, silty CLAY; blocky texture (moist, stiff) **(Glaciolacustrine)**
	S10	b2	11	W = 26 AL		- diagonal fine sand filled fracture
30	S11	b2	13	W = 26		- slickensides, blocky texture
	S12	b2	10	W = 31 AL	ML/ CL	Gray, interbedded clayey SILT and silty CLAY; with some slickensides, block texture (wet, stiff)
35	S13	c3				
	S14	b2	14	W = 35 AL		- abundant slickensides, diagonal fractures
40					CL/ CH	Gray, silty CLAY; some slickensides, blocky texture (wet, stiff to very stiff)

Water Level: ATD

Inclinometer Detail



Notes:
1. Stratigraphic contacts are based on field interpretations and are approximate.
2. Reference to the text of this report is necessary for a proper understanding of subsurface conditions.
3. Refer to "Soil Classification System and Key" figure for explanation of graphics and symbols.

244041.01 8/3/06 \\EDMDATA\GINT\GINT7\PROJECTS\244041.010.GPJ WSDOT WELL LOG

LANDAU ASSOCIATES

SR 530 (MP 36.5) - Skaglund Hill Landslide
Snohomish County, Washington

Log of Soil Boring H-3-06

Figure A-4 (1 of 4)

H-3-06

Drilling Method: Mud Rotary Casing Advancer
Casing: HWx70.0'-HQx131.0'
Driller (Lic.#): WSDOT - Kerry Cooper (2552)
Ground Elevation (ft): 363 (MSL)

Depth (ft)	Sample Number & Interval	Sampler Type	Blows/Foot	Test Data	Graphic Symbol	USCS Symbol	Soil Profile	Water Level	Inclinometer Detail
40	S15	b2	9	W = 35 AL		CL/ CH	Gray, silty CLAY; some slickensides, blocky texture (wet, stiff to very stiff)		Slope inclinometer movement at approximately 40 feet
	S16	b2	27	W = 32					
45	S17	b2	30	W = 25 GS		SM	Dark gray, silty, fine SAND; homogeneous, some bedding (wet, medium dense to very dense) - iron staining at 44 ft		
	S18	b2	68	W = 21					
50	S19	b2	27	W = 35		CL	Dark gray, silty CLAY with silt partings; mostly homogeneous, trace laminations (moist, very stiff)		
						SM	Gray to brown,silty, fine SAND; homogeneous, trace laminations (moist, very dense) **(Advance Outwash)**		
55	S20	b2	80/ 12"	W = 18 GS					
60	S21	b2	82/ 12"	W = 15			- trace gravel		
						CL	Gray, silty CLAY with interbedded brown, SILT; homogeneous (moist, hard)		
65	S22	b2	61						
						SM	Gray to light brown, silty, fine SAND; homogeneous (moist, very dense)		
70	S23	b2	88/ 10"						
						SP	Light brown, fine to fine to medium SAND; homogeneous (moist, very dense)		
75	S24	b2	78						
						SM	Gray to light brown, silty, fine SAND; homogeneous (moist to wet, very dense)		
80									

Notes:
1. Stratigraphic contacts are based on field interpretations and are approximate.
2. Reference to the text of this report is necessary for a proper understanding of subsurface conditions.
3. Refer to "Soil Classification System and Key" figure for explanation of graphics and symbols.

244041.01 8/3/06 \\EDMDATA\GINT\GINT7\PROJECTS\244041.010.GPJ WSDOT WELL LOG

LANDAU ASSOCIATES

SR 530 (MP 36.5) - Skaglund Hill Landslide
Snohomish County, Washington

Log of Soil Boring H-3-06

Figure A-4 (2 of 4)

H-3-06

Drilling Method: Mud Rotary Casing Advancer
Casing: HWx70.0'-HQx131.0'
Driller (Lic.#): WSDOT - Kerry Cooper (2552)
Ground Elevation (ft): 363 (MSL)

Depth (ft)	Sample Number & Interval	Sampler Type	Blows/Foot	Test Data	Graphic Symbol	USCS Symbol	Soil Profile	Water Level	Inclinometer Detail
80	S25	b2	84/ 12"			SM	Gray to light brown, silty, fine SAND; homogeneous (moist to wet, very dense)		
85	S26	b2	50/ 6"			SP-SM	Gray to light brown, fine to medium SAND with silt; homogeneous (moist to wet, very dense)		
90	S27	b2	88/ 10"			SM	Gray to light brown, silty, fine SAND; homogeneous (wet, very dense)		
95	S28	b2	98/ 9"			SP-SM	Gray to light brown, fine SAND with silt; homogeneous (wet, very dense)		
100	S29	b2	50/ 6"			SM	Gray to light brown, silty, fine SAND; homogeneous (wet, very dense)		
105	S30	b2	82/ 12"			SP-SM	Gray to light brown, fine SAND with silt; homogeneous (moist to wet, very dense)		
110	S31	b2	50/ 5"						
115	S32	b2	94/ 11"						
120									

Notes:
1. Stratigraphic contacts are based on field interpretations and are approximate.
2. Reference to the text of this report is necessary for a proper understanding of subsurface conditions.
3. Refer to "Soil Classification System and Key" figure for explanation of graphics and symbols.

244041.01 8/3/06 \\EDMDATA\GINT\GINT7\PROJECTS\244041.010.GPJ WSDOT WELL LOG

LANDAU ASSOCIATES

SR 530 (MP 36.5) - Skaglund Hill Landslide
Snohomish County, Washington

Log of Soil Boring H-3-06

Figure A-4 (3 of 4)

H-3-06

SAMPLE DATA				SOIL PROFILE			GROUNDWATER
Depth (ft)	Sample Number & Interval	Sampler Type	Blows/Foot	Test Data	Graphic Symbol	USCS Symbol	Drilling Method: Mud Rotary Casing Advancer Casing: HWx70.0'-HQx131.0' Driller (Lic.#): WSDOT - Kerry Cooper (2552) Ground Elevation (ft): 363 (MSL)	Water Level / Inclinometer Detail
120	S33	b2	83			SP-SM	Gray to light brown, fine SAND with silt; homogeneous (moist to wet, very dense)	
125	S34	b2	90/ 11"					
130	S35	b2	85/ 11"					
135								
140								
145								
150								
155								
160								

Boring Completed 02/17/06
Total Depth of Boring = 130.9 ft.
WSDOT Job #: C-7129
Start Card #: R 68295
Ecology Well#: ALP-508

Point located at State Plane Coordinates:
North: 465568.23
East: 1391139.66
Township: 32
Range: 7
Section: 12
Inspector: Brian Christianson/Ryan Reich

Inclinometer Completed 02/18/06
Elevation at Top of Protective Casing = 365.50 ft.
Elevation at Top of Inclinometer Casing = 365.00 ft.

Notes:
1. Stratigraphic contacts are based on field interpretations and are approximate.
2. Reference to the text of this report is necessary for a proper understanding of subsurface conditions.
3. Refer to "Soil Classification System and Key" figure for explanation of graphics and symbols.

244041.01 8/3/06 \\EDMDATA\GINT\GINT7\PROJECTS\244041.010.GPJ WSDOT WELL LOG

LANDAU ASSOCIATES

SR 530 (MP 36.5) - Skaglund Hill Landslide
Snohomish County, Washington

Log of Soil Boring H-3-06

Figure A-4 (4 of 4)

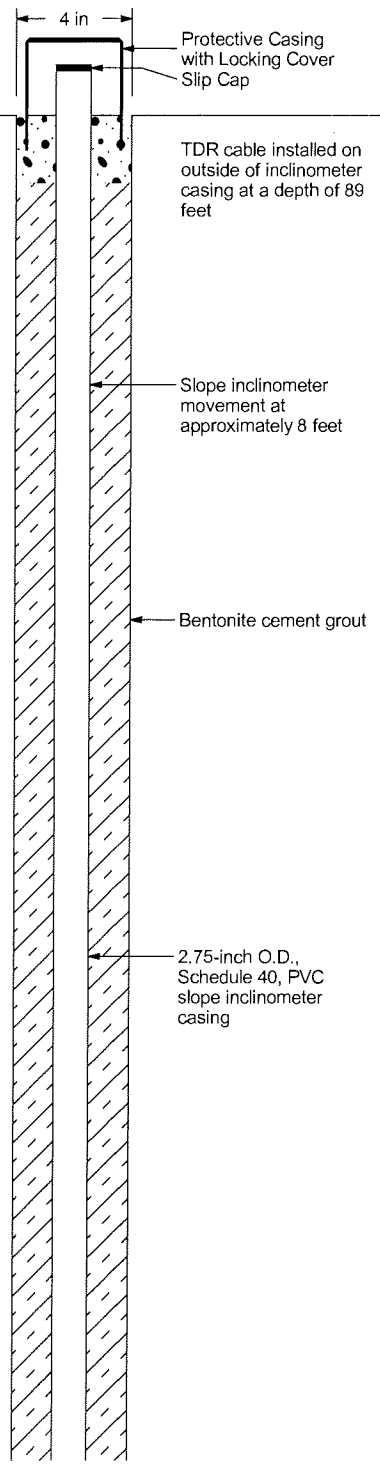
H-5-06

Drilling Method: Mud Rotary Casing Advancer
Casing: HWx89.0'
Driller (Lic.#): WSDOT - Kerry Cooper (2552)
Ground Elevation (ft): 297.9 (MSL)

Depth (ft)	Sample Number & Interval	Sampler Type	Blows/Foot	Test Data	Graphic Symbol	USCS Symbol	Description
0						CL	Gray, silty CLAY with trace roots and wood fragments; blocky texture (wet, soft to medium stiff) **(Slide Debris)**
5	S1	b2	4				- trace slickensides
	S2	b2	4	W = 37 AL			- iron staining, wood fragment, slickensides, sheared
10	S3	b2	11	W = 22		ML	Dark gray, clayey SILT with fine sand; homogeneous, fractures (wet, stiff)
	S4	b2	16	W = 35 AL		CL	Dark gray/gray, silty CLAY with silt partings; faint varving, diagonal fractures with slickensides (wet, very stiff)
15	S5	b2	20	W = 34			- some slickensides
	S6	b2	30	W = 27			- silt and fine sand interbeds, some high angle slickensides, crossing close spaced faint fractures
20							- diagonal contact CLAY/fine SAND
	S7	b2	76	W = 13 W = 32		SM	Light brown, fine SAND with silt; homogeneous (moist, very dense)
						CL	**(Advance Outwash)** Gray, silty CLAY; iron stained, sand filled fractures, slickensides (moist, hard)
	S8	b2	60	W = 16 W = 33		SP-SM	Light brown and gray, fine SAND with trace silt to with silt grading to fine to medium with trace coarse sand and fine gravel (moist, very dense)
25	S9A S9B	b2	56			ML	Alternating light brown and gray, clayey SILT with fine sand; iron staining, faint fractures, contact with SAND high angle (moist, hard)
						SP/SM	Light brown, interbedded silty, fine SAND and fine SAND with silt; iron staining, homogeneous (wet, dense to very dense)
	S10	b2	39	W = 18			
30	S11	b2	40	W = 24			- at 30 feet silty CLAY interbeds with silt partings
	S12	b2	54	W = 23 W = 26		ML	Gray and dark gray, clayey SILT and silty CLAY with silt partings, trace slickensides (wet, hard)
35	S13	b2	81/12"	W = 13		SP/SM	Light brown to gray, fine SAND with silt to trace silt; homogeneous (moist to wet, very dense)
	S14	b2	77				
40							

Water Level: ATD

Inclinometer Detail



Notes:
1. Stratigraphic contacts are based on field interpretations and are approximate.
2. Reference to the text of this report is necessary for a proper understanding of subsurface conditions.
3. Refer to "Soil Classification System and Key" figure for explanation of graphics and symbols.

244041.01 8/3/06 \\EDMDATA\GINT\GINT7\PROJECTS\244041.010.GPJ WSDOT WELL LOG

LANDAU ASSOCIATES

SR 530 (MP 36.5) - Skaglund Hill Landslide
Snohomish County, Washington

Log of Soil Boring H-5-06

Figure A-6 (1 of 3)

H-5-06

Drilling Method: Mud Rotary Casing Advancer
Casing: HWx89.0'
Driller (Lic.#): WSDOT - Kerry Cooper (2552)
Ground Elevation (ft): 297.9 (MSL)

Depth (ft)	Sample Number & Interval	Sampler Type	Blows/Foot	Test Data	Graphic Symbol	USCS Symbol	Soil Profile	Water Level	Inclinometer Detail
40	S15	b2	93			SP/ SM	Light brown to gray, fine SAND with silt to trace silt; homogeneous (moist to wet, very dense)		
	S16	b2	76				- moist		
45						SP-SM	Light brown to gray, fine SAND with trace silt to with silt; homogeneous (moist, very dense)		
	S17	b2	91/ 11"						
50									
	S18	b2	62				- grading to fine to medium SAND		
55									
	S19	b2	88/ 11"			ML	Gray, fine sandy SILT; faint laminations (wet, hard)		
60									
	S20	b2	81/ 11"			ML	Gray, clayey SILT grading to fine sandy SILT; faint laminations, faint fine fractures (wet, hard)		
65									
	S21	b2	64			SP	Gray, fine SAND; homogeneous, faint high angle fractures (wet, very dense)		
70						SM	Gray, silty, fine SAND; homogeneous (wet, very dense)		
	S22	b2	73			CL	Gray, silty CLAY; faint laminations (moist, hard)		
75							- faint fractures		
	S23	b2	67				- interbedded of gray, silty, fine SAND		
80									

Notes:
1. Stratigraphic contacts are based on field interpretations and are approximate.
2. Reference to the text of this report is necessary for a proper understanding of subsurface conditions.
3. Refer to "Soil Classification System and Key" figure for explanation of graphics and symbols.

244041.01 8/3/06 \\EDMDATA\GINT\GINT7\PROJECTS\244041.010.GPJ WSDOT WELL LOG

LANDAU ASSOCIATES

SR 530 (MP 36.5) - Skaglund Hill Landslide
Snohomish County, Washington

Log of Soil Boring H-5-06

Figure A-6 (2 of 3)

H-5-06

SAMPLE DATA				SOIL PROFILE			GROUNDWATER
Depth (ft)	Sample Number & Interval	Sampler Type	Blows/Foot	Test Data	Graphic Symbol	USCS Symbol	Drilling Method: Mud Rotary Casing Advancer Casing: HWx89.0' Driller (Lic.#): WSDOT - Kerry Cooper (2552) Ground Elevation (ft): 297.9 (MSL)	Water Level / Inclinometer Detail
80						CL	Gray, silty CLAY; faint laminations (moist, hard)	
	S24	b2	62					
85								
	S25	b2	57				- thin laminations and silt partings.	
90								
95								
100								
105								
110								
115								
120								

Boring Completed 02/19/06
Total Depth of Boring = 89.0 ft.
WSDOT Job #: C-7129
Start Card #: R 68295
Ecology Well#: ALP-510

Point located at State Plane Coordinates:
North: 465781.34
East: 1391054.84
Township: 32
Range: 7
Section: 12
Inspector: Brian Christianson

Inclinometer Completed 02/20/06
Elevation at Top of Protective Casing = NA
Elevation at Top of Inclinometer Casing = NA

Notes:
1. Stratigraphic contacts are based on field interpretations and are approximate.
2. Reference to the text of this report is necessary for a proper understanding of subsurface conditions.
3. Refer to "Soil Classification System and Key" figure for explanation of graphics and symbols.

244041.01 8/3/06 \\EDMDATA\GINT\GINT7\PROJECTS\244041.010.GPJ WSDOT WELL LOG

SCL-3

LAI Project No: 110026.010

Drilling Method: Mud Rotary
Ground Elevation (ft): 497 (MSL)
Drilled By: Holocene Drilling
Logged By: JJB Date: 09/24/07

Depth (ft)	Elevation (ft)	Sample Number & Interval	Sampler Type	Blows/Foot	Test Data	USCS Symbol	Soil Profile
0						SM	Light brown, silty, fine SAND (medium dense, moist) **(SLIDE DEBRIS)**
	495	S-1	b2	11			
5		S-2	b2	7		SP	Light brown, coarse SAND and gravelly, coarse SAND (loose, wet)
	490	S-3	b2	11	W = 18		
10		S-4	b2	9	W = 13 GS	SP-SM	Light brown, fine to medium SAND with silt and gravel (loose, wet)
	485	S-5	b2	15			
15		S-6	b2	9	W = 12 GS	GP	Light brown, very sandy, fine to coarse GRAVEL with trace silt (loose, wet)
	480	S-7	b2	14			
20		S-8	b2	18	W = 14 GS	SM	Light brown, silty, gravelly, fine to medium SAND to silty, fine SAND (medium dense, moist to wet)
	475	S-9	b2	17			
25		S-10	b2	15	W = 16 -200 = 7		
	470	S-11	b2	13			
30		S-12	b2	22			- diagonal silt interbed
	465	S-13	b2	21	W = 25 -200 = 86	ML	Light brown, SILT with sand (very stiff, moist)
35							

VWP Installation: See Appendix D for Groundwater Data

Moisture Content (%): Plastic Limit 20 — 40 — 60 — 80 Liquid Limit

▲ SPT N-Value ▲ 20 40 60 80

△ Non-Standard N-Value △

× Fines Content (%) × 20 40 60 80

Notes:
1. Stratigraphic contacts are based on field interpretations and are approximate.
2. Reference to the text of this report is necessary for a proper understanding of subsurface conditions.
3. Refer to "Soil Classification System and Key" figure for explanation of graphics and symbols.

110026.01 6/10/09 \\EDMDATA\GINT\GINT7\PROJECTS\110026.010 011 MERGED.GPJ SOIL BORING LOG WITH GRAPH

LANDAU ASSOCIATES

Seattle City Light
Skaglund Hill Landslide
Snohomish County, Washington

Log of Boring SCL-3

Figure A-4 (1 of 3)

SCL-3

LAI Project No: 110026.010

Drilling Method: Mud Rotary
Ground Elevation (ft): 497 (MSL)
Drilled By: Holocene Drilling
Logged By: JJB Date: 09/24/07

Depth (ft)	Elevation (ft)	Sample Number & Interval	Sampler Type	Blows/Foot	Test Data	USCS Symbol	Soil Profile	VWP Installation
35						ML	Light brown, SILT with sand (very stiff, moist)	See Appendix D for Groundwater Data
	460	S-14	b2	14		ML	Gray, fine sandy SILT (stiff to hard, moist) **(GLACIOLACUSTRINE)**	
40								
	455	S-15	b2	38				
45						ML	Gray, gravelly, sandy SILT with trace slickensides (very stiff to hard, moist)	
	450	S-16	b2	25				
50								
	445	S-17	b2	34				
55						CL	Gray, silty CLAY with slickensides (very stiff to hard, moist)	
	440	S-18	b2	38	W = 26		- bedding at 20 degrees	
60								
	435	S-19	b2	42			- thin interbeds of fine SAND	
65								
	430	S-20	b2	31				
70								

Moisture Content (%) — Plastic Limit 20 40 60 80 Liquid Limit

▲ SPT N-Value ▲ — △ Non-Standard N-Value △ — 20 40 60 80

× Fines Content (%) × — 20 40 60 80

Notes:
1. Stratigraphic contacts are based on field interpretations and are approximate.
2. Reference to the text of this report is necessary for a proper understanding of subsurface conditions.
3. Refer to "Soil Classification System and Key" figure for explanation of graphics and symbols.

110026 01 6/10/09 \\EDMDATA\GINT\GINT7\PROJECTS\110026 010 011 MERGED.GPJ SOIL BORING LOG WITH GRAPH

LANDAU ASSOCIATES

Seattle City Light
Skaglund Hill Landslide
Snohomish County, Washington

Log of Boring SCL-3

Figure A-4 (2 of 3)

SCL-3

LAI Project No: 110026.010

Drilling Method: Mud Rotary
Ground Elevation (ft): 497 (MSL)
Drilled By: Holocene Drilling
Logged By: JJB Date: 09/24/07

Depth (ft)	Elevation (ft)	Sample Number & Interval	Sampler Type	Blows/Foot	Test Data	USCS Symbol	Soil Profile	VWP Installation
70						CL	Gray, silty CLAY with slickensides (very stiff to hard, moist)	See Appendix D for Groundwater Data
	425	S-21	b2	24				
75								
	420	S-22	b2	25			- bedding at 70 degrees	
80						CL	Gray, silty CLAY without slickensides (hard, moist)	
	415	S-23	b2	33				
85						CL	Gray, silty CLAY with interbedded fine SAND (very stiff to hard, moist)	
	410	S-24	b2	33				
90								
	405	S-25	b2	30				
95								
	400	S-26	b2	27	W = 29			
100								
105								

Moisture Content (%): Plastic Limit 20 40 60 80 Liquid Limit

▲ SPT N-Value ▲ 20 40 60 80

△ Non-Standard N-Value △

× Fines Content (%) × 20 40 60 80

Boring Completed 09/24/07
Total Depth of Boring = 99.0 ft.

VWP
Installation Completed 09/25/07

Notes:
1. Stratigraphic contacts are based on field interpretations and are approximate.
2. Reference to the text of this report is necessary for a proper understanding of subsurface conditions.
3. Refer to "Soil Classification System and Key" figure for explanation of graphics and symbols.

110026 01 6/10/09 \\EDMDATA\GINT\GINT7\PROJECTS\110026 010 011 MERGED.GPJ SOIL BORING LOG WITH GRAPH

LANDAU ASSOCIATES

Seattle City Light
Skaglund Hill Landslide
Snohomish County, Washington

Log of Boring SCL-3

Figure
A-4
(3 of 3)

SCL-4

LAI Project No: 110026.010

Drilling Method: Mud Rotary
Ground Elevation (ft): 470 (MSL)
Drilled By: Holocene Drilling
Logged By: JJB Date: 09/26/07

Depth (ft)	Elevation (ft)	Sample Number & Interval	Sampler Type	Blows/Foot	Test Data	USCS Symbol	Soil Profile
0	470	S-1	d7			GM	Light brown, sandy, silty GRAVEL (loose to medium dense, moist) **(SLIDE DEBRIS)**
5	465	S-2	b2	10	W = 18 GS	SM	Light brown, very silty, fine to medium SAND with gravel (loose to medium dense, moist)
		S-3	b2	16		CL	Light brown, silty CLAY with fine SAND and iron staining (stiff to very stiff, moist)
10	460	S-4	b2	13			
		S-5	b2	11	W = 31		- trace slickensides
15	455	S-6	b2	12			
		S-7	b2	15			
20	450	S-8	b2	9		CL	Gray, silty CLAY with trace fine sand and iron stained fractures (stiff, moist)
		S-9	b2	12		CL	Gray, silty CLAY with slickensides (medium stiff to stiff, moist)
25	445	S-10	b2	7			
		S-11	b2	8			
30	440	S-12	b2	7			- trace slickensides
		S-13	b2	15		CL	Gray, silty CLAY with blocky to massive texture (medium stiff to very stiff, moist) **(GLACIOLACUSTRINE)**
35	435						

VWP & Inclinometer Installation

See Appendix D for Groundwater Data

Moisture Content (%): Plastic Limit 20 — 40 — 60 — 80 Liquid Limit

▲ SPT N-Value ▲ 20 40 60 80

△ Non-Standard N-Value △

× Fines Content (%) × 20 40 60 80

Protective Casing with Locking Cover

Notes:
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2. Reference to the text of this report is necessary for a proper understanding of subsurface conditions.
3. Refer to "Soil Classification System and Key" figure for explanation of graphics and symbols.

110026 01 6/10/09 \\EDMDATA\GINT\GINT7\PROJECTS\110026 010.011 MERGED.GPJ SOIL BORING LOG WITH GRAPH

LANDAU ASSOCIATES

Seattle City Light
Skaglund Hill Landslide
Snohomish County, Washington

Log of Boring SCL-4

Figure A-5 (1 of 3)

SCL-4

LAI Project No: 110026.010

SAMPLE DATA | **SOIL PROFILE**

Drilling Method: Mud Rotary
Ground Elevation (ft): 470 (MSL)
Drilled By: Holocene Drilling
Logged By: JJB Date: 09/26/07

Depth (ft)	Elevation (ft)	Sample Number & Interval	Sampler Type	Blows/Foot	Test Data	Graphic Symbol	USCS Symbol	Description
35	435	S-14	b2	17			CL	
							CL	Gray, silty CLAY with slickensides (stiff to very stiff, moist)
40	430	S-15	b2	24				- sand filled fracture
45	425	S-16	b2	14				
50	420	S-17	b2	15				
55	415	S-18	b2	20				
60	410	S-19	b2	29				
65	405	S-20	b2	22				
							CL	Gray, silty CLAY without slickensides (hard, moist)
70	400							

VWP & Inclinometer Installation: See Appendix D for Groundwater Data

Moisture Content (%): Plastic Limit 20 — 40 — 60 — 80 Liquid Limit

▲ SPT N-Value ▲ (△ Non-Standard N-Value △): 20 40 60 80

× Fines Content (%) ×: 20 40 60 80

Notes:
1. Stratigraphic contacts are based on field interpretations and are approximate.
2. Reference to the text of this report is necessary for a proper understanding of subsurface conditions.
3. Refer to "Soil Classification System and Key" figure for explanation of graphics and symbols.

110026.01 6/10/09 \\EDMDATA\GINT\GINT7\PROJECTS\110026 010 011 MERGED.GPJ SOIL BORING LOG WITH GRAPH

LANDAU ASSOCIATES

Seattle City Light
Skaglund Hill Landslide
Snohomish County, Washington

Log of Boring SCL-4

Figure A-5 (2 of 3)

SCL-4

LAI Project No: 110026.010

Drilling Method: Mud Rotary
Ground Elevation (ft): 470 (MSL)
Drilled By: Holocene Drilling
Logged By: JJB Date: 09/26/07

Depth (ft)	Elevation (ft)	Sample Number & Interval	Sampler Type	Blows/Foot	Test Data	Graphic Symbol	USCS Symbol	Soil Profile	Moisture Content (%) (Plastic Limit 20, 40, 60, 80, Liquid Limit) / SPT N-Value / Fines Content (%)
70	400	S-21	b2	30			CL	Gray, silty CLAY without slickensides (hard, moist)	
75	395	S-22	b2	32					
80	390	S-23	b2	34			CL	Dark gray and gray, CLAY with thin horizonal laminations (very stiff to hard, moist)	
85	385	S-24	b2	27				- fine sand interbed and trace slickensides	
90	380	S-25	b2	30					
95	375	S-26	b2	36			CL	Gray, silty CLAY with interbedded fine sand and trace medium sand (hard, moist)	
100	370	S-27	b2	61					
105									

VWP & Inclinometer Installation: See Appendix D for Groundwater Data

Boring Completed 09/26/07
Total Depth of Boring = 101.5 ft.

VWP & Inclinometer Installation Completed 09/27/07

Notes:
1. Stratigraphic contacts are based on field interpretations and are approximate.
2. Reference to the text of this report is necessary for a proper understanding of subsurface conditions.
3. Refer to "Soil Classification System and Key" figure for explanation of graphics and symbols.

110026.01 6/10/09 \\EDMDATA\GINT\GINT7\PROJECTS\110026 010 011 MERGED.GPJ SOIL BORING LOG WITH GRAPH

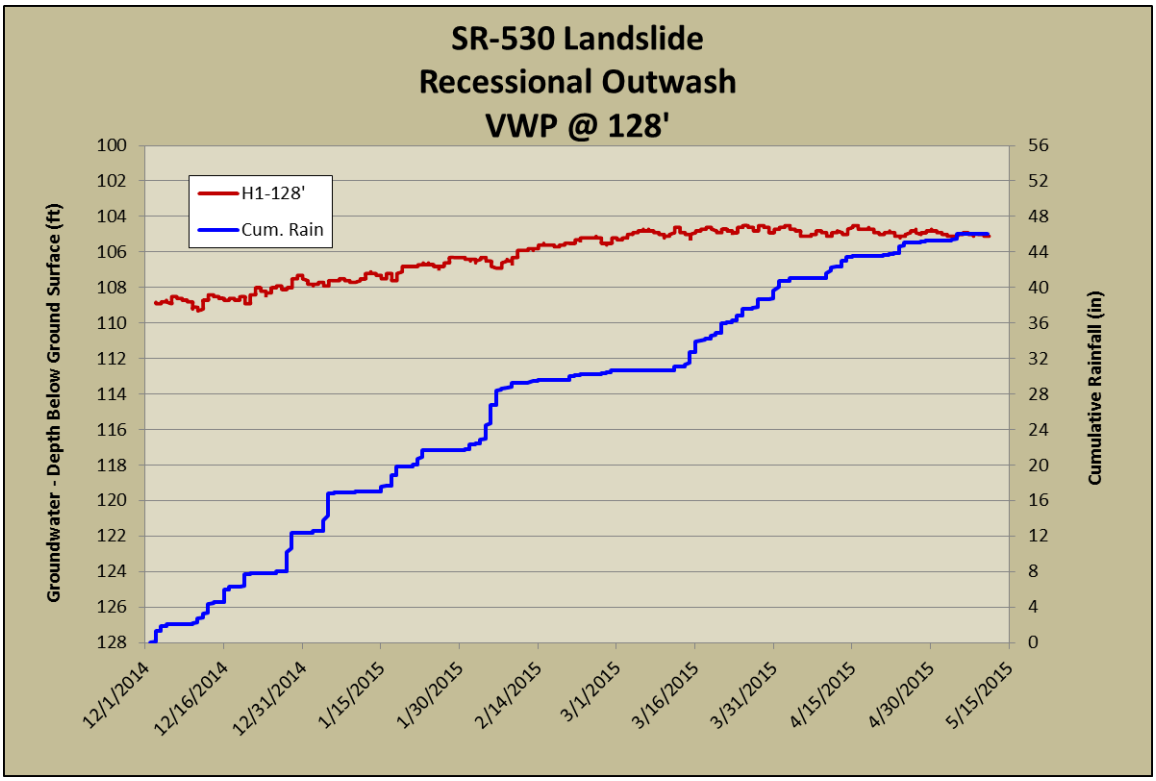
LANDAU ASSOCIATES

Seattle City Light
Skaglund Hill Landslide
Snohomish County, Washington

Log of Boring SCL-4

Figure A-5 (3 of 3)

Appendix C
Instrumentation Data


SR-530 Landslide
Recessional Outwash
VWP @ 128'
Groundwater - Depth Below Ground Surface (ft)
Cumulative Rainfall (in)
H1-128'
Cum. Rain
100
102
104
106
108
110
112
114
116
118
120
122
124
126
128
56
52
48
44
40
36
32
28
24
20
16
12
8
4
0
12/1/2014
12/16/2014
12/31/2014
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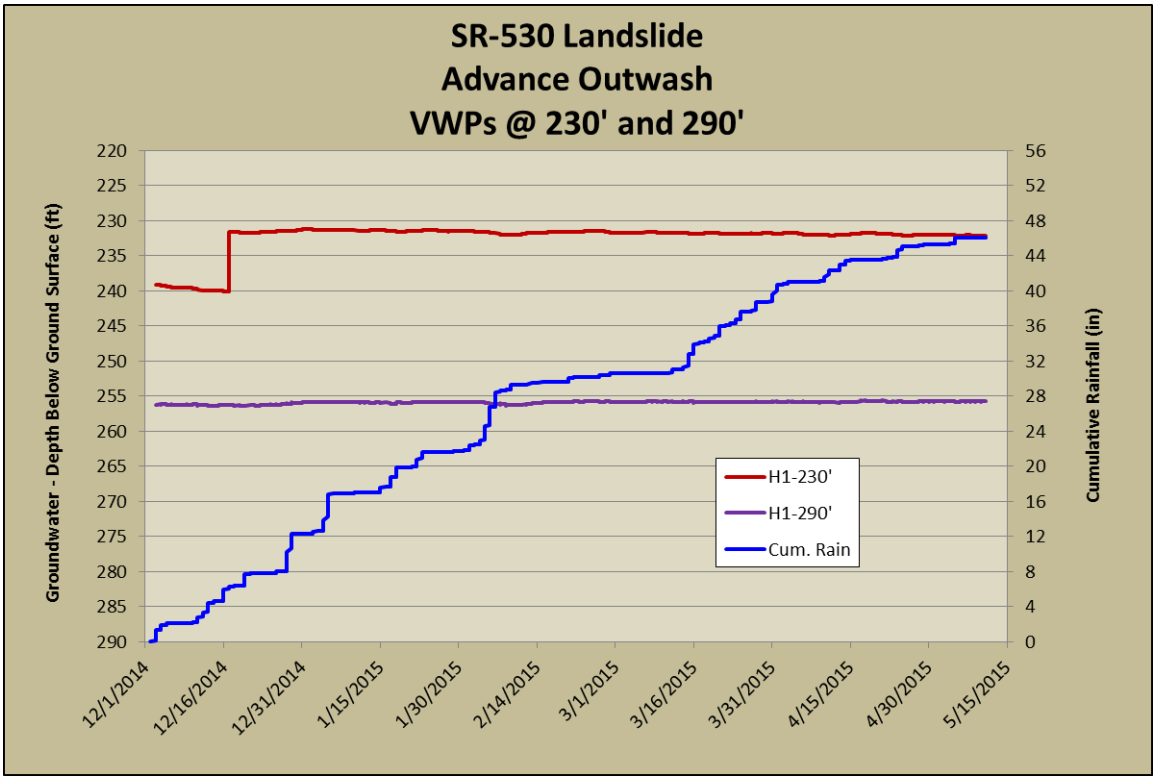
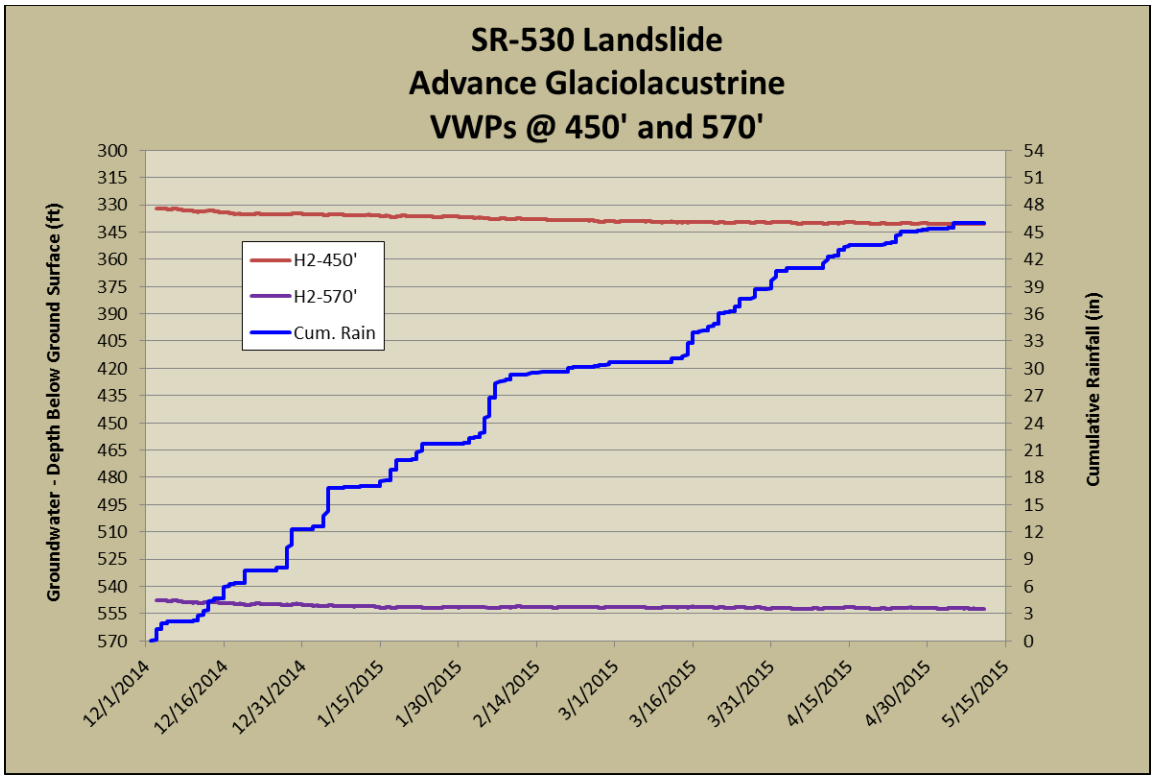
4/30/2015
5/15/2015


SR-530 Landslide
Advance Outwash
VWPs @ 230' and 290'
Groundwater - Depth Below Ground Surface (ft)
Cumulative Rainfall (in)
H1-230'
H1-290'
Cum. Rain
220
225
230
235
240
245
250
255
260
265
270
275
280
285
290
56
52
48
44
40
36
32
28
24
20
16
12
8
4
0
12/1/2014
12/16/2014
12/31/2014
1/15/2015
1/30/2015
2/14/2015
3/1/2015
3/16/2015
3/31/2015
4/15/2015
4/30/2015
5/15/2015


SR-530 Landslide
Advance Glaciolacustrine
VWPs @ 450' and 570'
Groundwater - Depth Below Ground Surface (ft)
Cumulative Rainfall (in)
H2-450'
H2-570'
Cum. Rain
300
315
330
345
360
375
390
405
420
435
450
465
480
495
510
525
540
555
570
54
51
48
45
42
39
36
33
30
27
24
21
18
15
12
9
6
3
0
12/1/2014
12/16/2014
12/31/2014
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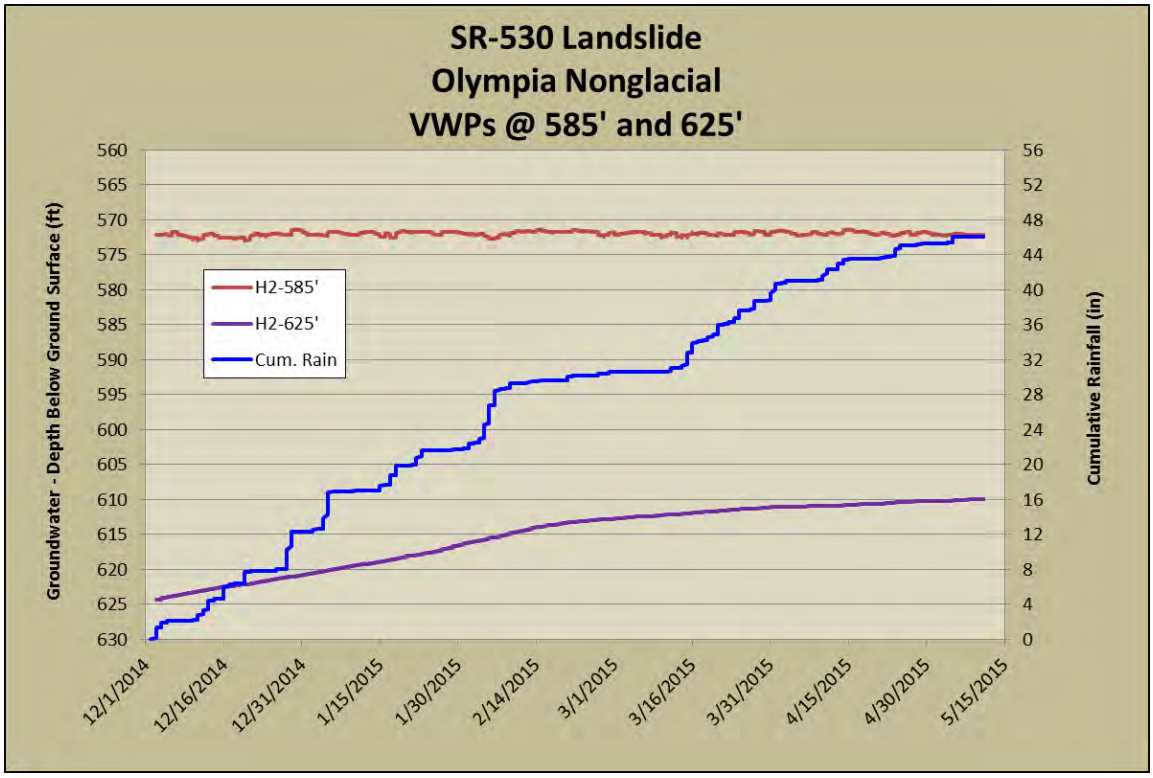
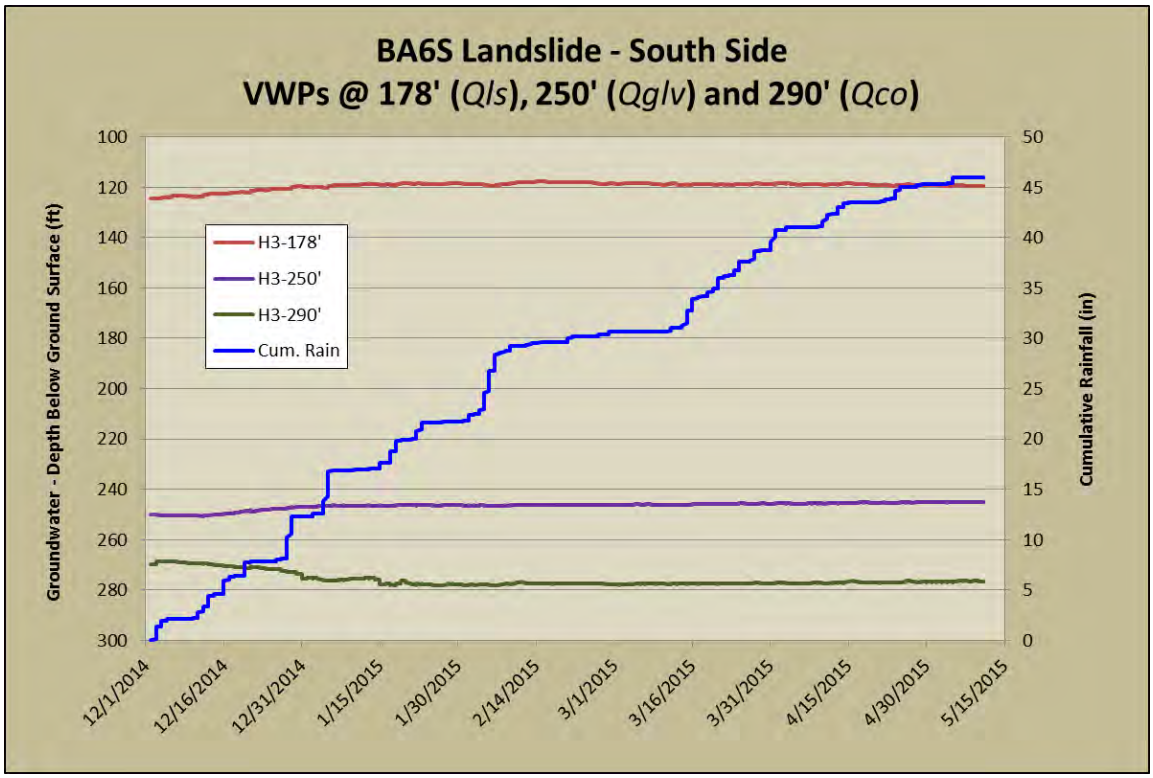
4/30/2015
5/15/2015


SR-530 Landslide
Olympia Nonglacial
VWPs @ 585' and 625'
Groundwater - Depth Below Ground Surface (ft)
Cumulative Rainfall (in)
H2-585'
H2-625'
Cum. Rain
560
565
570
575
580
585
590
595
600
605
610
615
620
625
630
56
52
48
44
40
36
32
28
24
20
16
12
8
4
0
12/1/2014
12/16/2014
12/31/2014
1/15/2015
1/30/2015
2/14/2015
3/1/2015
3/16/2015
3/31/2015
4/15/2015
4/30/2015
5/15/2015


BA6S Landslide - South Side
VWPs @ 178' (Qls), 250' (Qglv) and 290' (Qco)
Groundwater - Depth Below Ground Surface (ft)
Cumulative Rainfall (in)
H3-178'
H3-250'
H3-290'
Cum. Rain
100
120
140
160
180
200
220
240
260
280
300
50
45
40
35
30
25
20
15
10
5
0
12/1/2014
12/16/2014
12/31/2014
1/15/2015
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3/1/2015
3/16/2015
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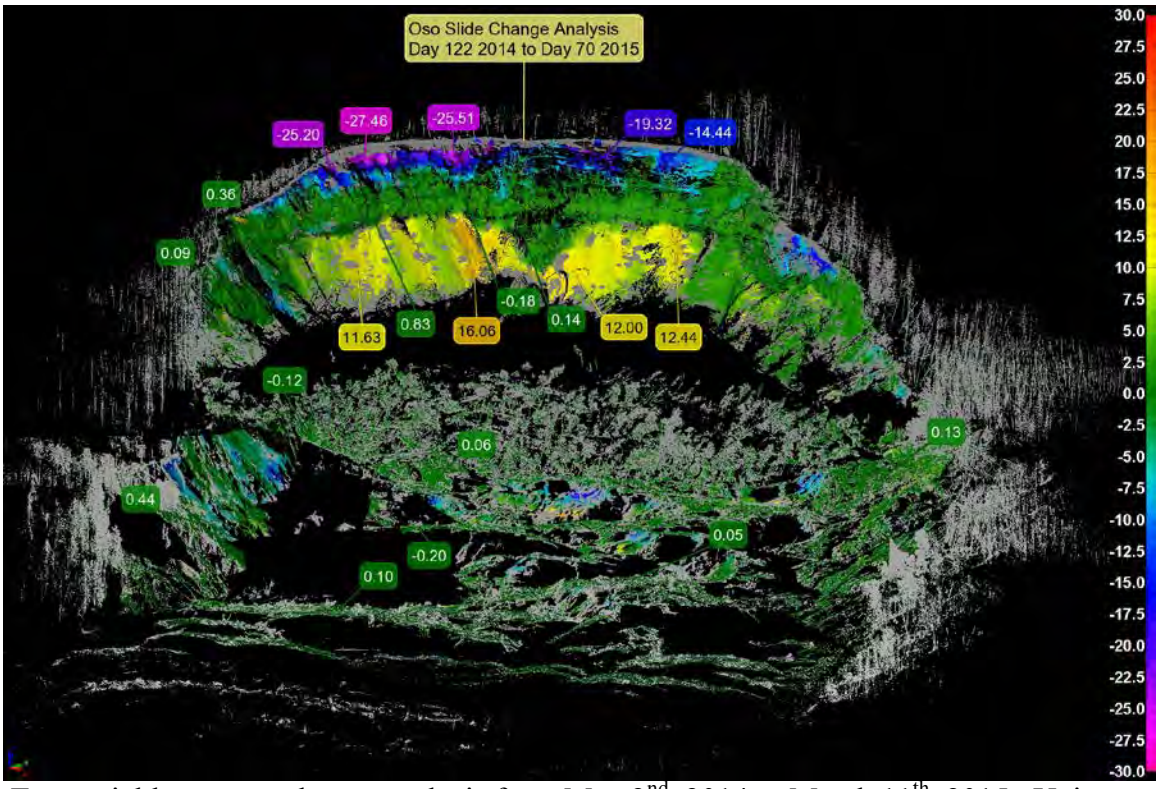
4/15/2015
4/30/2015
5/15/2015



Terrestrial laser scan change analysis from May 2nd, 2014 to March 11th, 2015. Units are in feet with cold colors indicating evacuation and warm colors indicating accumulation.

Appendix D
Laboratory Test Data

Prepared in cooperation with the University of California, Berkeley and the Washington State Department of Transportation

Geotechnical Soil Characterization of Intact Quaternary Deposits Forming the March 22, 2014 SR-530 (Oso) Landslide, Snohomish County, Washington

Open-File Report 2015-1089

U.S. Department of the Interior
U.S. Geological Survey

FRONT COVER: Image of the March 22, 2014, landslide near Oso, Washington showing the distribution of geologic units exposed in both the headscarp (background) and hummock deposits (foreground).

Geotechnical Soil Characterization of Intact Quaternary Deposits Forming the March 22, 2014 SR-530 (Oso) Landslide, Snohomish County, Washington

By Michael F. Riemer, Brian D. Collins, Thomas C. Badger, Csilla Toth, and Yat Chun Yu

Open-File Report 2015-1089

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2015

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The Washington State Department of Transportation managed the geotechnical drilling investigation with geologic field oversight and geotechnical input from Snohomish County Department of Public Works. In addition, the Washington State Department of Natural Resources aided in the stratigraphic interpretation of the samples recovered from the borings. The geotechnical testing was performed by the University of California, Berkeley through cooperation and coordination with the U.S. Geological Survey. Funding for the geotechnical drilling and sampling was collectively provided by the Snohomish County Public Works Department, the Washington State Department of Transportation, the Washington State Department of Natural Resources, the Tulalip Tribes, and the Stillaguamish Tribe of Washington. Funding for the geotechnical testing was provided by the U.S. Geological Survey, Landslide Hazards Program through a cooperative agreement with the University of California, Berkeley, Department of Civil and Environmental Engineering Geotechnical Laboratory. We thank Rex Baum (USGS) and Robert Holtz (University of Washington) for providing reviews that improved the quality of this report.

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Datum Information

Horizontal coordinate information is referenced to the North American Datum of 1983-11 – High Accuracy Reference Network of 1991 (NAD 83-11/91 HARN) and projected to Washington State Plane North coordinates, expressed in feet.

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 expressed in feet. Elevation, as used in this report, refers to distance above the vertical datum.

Conversion Factors

US to Metric

Multiply	By	To obtain
inch (in.)	2.54×10^{1}	millimeter (mm)
foot (ft)	3.048×10^{-1}	meter (m)
cubic foot (ft^3)	2.832×10^{-2}	cubic meter (m^3)
pound per cubic foot (lb/ft^3)	1.571×10^{-1}	kilonewton per cubic meter (kN/m^3)
ounce (oz)	2.835×10^{1}	gram (g)
fluid ounce (fl. oz)	2.957×10^{1}	milliliter (ml)
quart (qt)	9.464×10^{-1}	liter (L)

Geotechnical Soil Characterization of Intact Quaternary Deposits Forming the March 22, 2014 SR-530 (Oso) Landslide, Snohomish County, Washington

By Michael F. Riemer[1], Brian D. Collins[2], Thomas C. Badger[3], Csilla Toth[1], and Yat Chun Yu[1]

Introduction

During the late morning of March 22, 2014, a devastating landslide occurred near the town of Oso, Washington. The landslide (fig. 1), with an estimated volume of 10.9 million cubic yards (8.3 $\times 10^6$ m^3) of both intact glacially deposited and previously disturbed landslide sediments, reached speeds averaging 40 miles per hour (64 kilometers per hour) and crossed the entire 2/3-mile (~1100 m) width of the adjacent North Fork Stillaguamish River floodplain in approximately 60 seconds, resulting in the complete destruction of an entire neighborhood (Iverson and others, 2015). More than 40 homes were destroyed as the debris overran the neighborhood, resulting in the deaths of 43 people.

Landslides in glacial deposits are common in the Pacific Northwest (for example, Baum and others, 2008), and in fact, the site of the March 22, 2014 SR-530 landslide had experienced significant reactivation several times in past decades, with the most recent event occurring in 2006 (for example, Miller and Sias, 1998). However, these previous landslides were of considerably less volume and mobility (Iverson and others, 2015), and debris had never reached the Steelhead Haven neighborhood. Further, no landslides with the type of mobility that the March 22, 2014 landslide underwent have been recorded in historic times within the North Fork Stillaguamish River valley. However, mapping performed immediately following the landslide indicates that several other slopes in the North Fork Stillaguamish River valley have experienced large-volume landslides exhibiting high mobility in prehistoric times (Haugerud, 2014). The presence of previous high-mobility landslides in the valley, and the now well-documented occurrence of one involving many fatalities, underscores both the hazard and risk for those that live and travel in this and other river valleys in the Pacific Northwest with similar steep exposures of glacial deposits.

To understand the hazards posed by highly mobile landslides in the Pacific Northwest, the U.S. Geological Survey (USGS), together with its project partners, the University of California, Berkeley Department of Civil and Environmental Engineering (UCB), and the Washington State Department of Transportation (WSDOT), is undertaking a critically needed study to identify the geologic, hydrogeologic, and geotechnical conditions in which these large landslides initiate, as well as the processes responsible for the exceptional mobility of this, and potentially other, landslides in the region. One of the first study activities involves characterizing the stratigraphy and materials from which the landslide deposits are derived, so that the fundamental geotechnical nature of the soils can be understood. This understanding is required to begin identifying possible conditions leading to slope

[1]University of California, Berkeley
[2]U.S. Geological Survey
[3]Washington State Department of Transportation

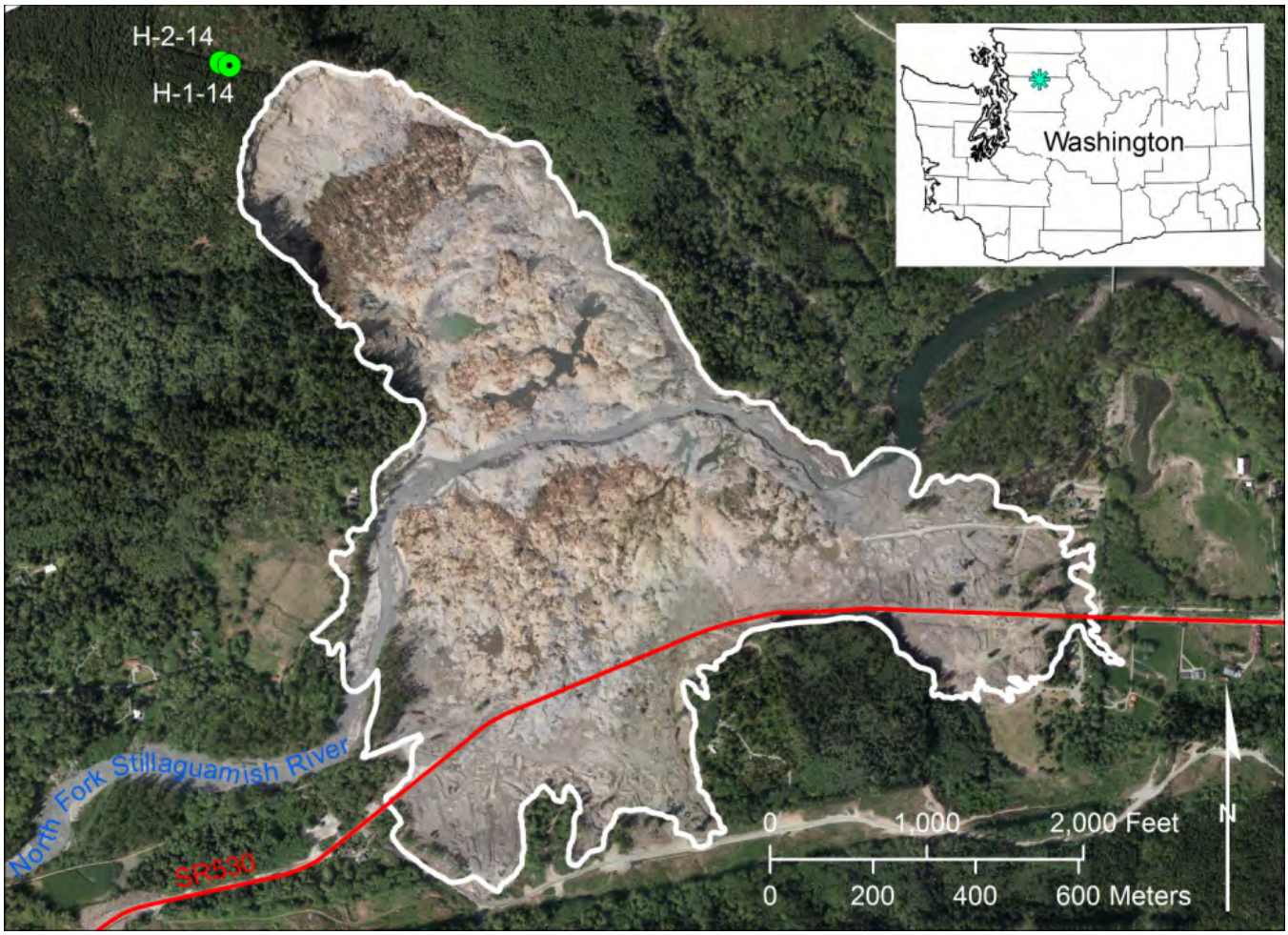

Figure 1. Site map of the March 22, 2014 SR-530 landslide near Oso, Washington. The locations of two boreholes where samples were obtained for geotechnical testing presented in this report are shown (H-1-14 and H-2-14), along with major geographic features of the area. Base photo source and date: Washington State Dept. of Transportation, May 1, 2014

failure and their relation to the landslide's high mobility. In addition, detailed characterization of each stratigraphic unit encountered in initial geotechnical borings is needed to relate stratigraphy between borings for this study and as a part of ongoing investigations by WSDOT and other project partners.

This report provides a description of the methods used to obtain and test the intact soil stratigraphy behind the headscarp of the March 22 landslide. Detailed geotechnical index testing results are presented for 25 soil samples representing the stratigraphy at 20 different depths along a 650 ft (198 m) soil profile. The results include (1) the soil's in situ water content and unit weight (where applicable); (2) specific gravity of soil solids; (3) each sample's grain-size distribution; (4) critical limits for fine-grain water content states (that is, the Atterberg limits); and (5) official Unified Soil Classification System (USCS) designation. In addition, preliminary stratigraphy and geotechnical relations within and between soil units are presented.

Methods

Geotechnical Drilling and Sampling

WSDOT performed geotechnical drilling in the fall of 2014 at three locations near the landslide. Two borings (H-1-14 and H-2-14) located approximately 300 ft and 360 ft (91 and 110 m) behind the 2014 headscarp (fig. 1), were drilled to depths of 650 ft and 635 ft (198 m and 194 m), respectively, in order to sample the major stratigraphic units present in the landslide deposit (fig. 2). A third, 300-ft-deep (91 m) boring (H-3-14) was drilled through a prehistoric landslide deposit on the opposite side of the valley from the 2014 landslide to investigate stratigraphic relations across the valley, to ascertain the existing shear plane depth of the prehistoric landslide, and to characterize the groundwater conditions within and beneath the landslide mass. In this report, only samples from the two boreholes nearest the landslide (H-1-14 and H-2-14) are presented.

WSDOT used a Central Mine Equipment Company CME-850X track-mounted drill rig (http://cmeco.com/drills/track-carrier-mounted-drills/cme-850x-track-carrier-auger-drill/) to advance both HWT-type casing (4.6-in. [116.8 mm] outside diameter) with a tricone casing advancer, and HQ3-type coring equipment (3.782-in. [96.1 mm] outside diameter, 2.375-in. [60.3 mm] core diameter) using reverse circulation, mud rotary drilling. A high-yield bentonite (CETCO Super Gel X; http://www.cetco.com) and a liquid polymer (CETCO Insta-Vis Plus) were used in the drilling mud for advancing casing and coring. Brass liner tubes (with 2.5-in. [63.5 mm] outside diameter and 2.4-in. [61.0 mm] inside diameter) were used for sample collection in the uppermost approximately 120 feet of the borings. Below this depth, HQ3 core samples were typically retained in steel split sleeves (with inside diameter of 2.50 in. [63.5 mm]). However, during some of the coring, transparent polycarbonate (Lexan) core tubes, also with inside diameter of 2.50 in. (63.5 mm), were substituted for the steel sleeves to obtain intact samples at their in situ moisture content for geotechnical laboratory testing. The annular space between the core and the inside surface of the polycarbonate tubes allowed for some swelling and moisture intrusion into the soil samples, but in general, the tubes were successful in retaining the soil core in a more intact and protected state. Where cores were not contained in sleeves, they were placed in a core box and wrapped in plastic to slow drying.

All samples were transported by truck to WSDOT's State Materials Laboratory in Tumwater, Washington. Samples contained in polycarbonate tubes were maintained in an upright position during transport and storage in laboratory wet rooms. Samples selected for geotechnical index testing were transported to the University of California, Berkeley Department of Civil and Environmental Engineering Geotechnical Laboratory by commercial aircraft, shipping company, or truck. All geotechnical testing reported herein was performed at the University of California, Berkeley Geotechnical Laboratory.

Geotechnical Index Testing

We performed a variety of geotechnical index testing on selected samples depending on their sampling method (for example, unit weight was only measured for those samples taken and stored in protective tubes) and soil type (for example, Atterberg limits were only performed for samples exhibiting plasticity). It was observed in the laboratory that many of the core samples were coated with a thin layer of soft, gray material with high moisture content that was suspected to be the drilling mud mixed with the soil cuttings. The cores were trimmed of this outer layer prior to index testing to ensure that tests were not contaminated by this material. Testing protocols outlined by ASTM International (http://www.astm.org/) were followed in nearly all cases. We detail any exceptions that were necessary to the ASTM testing methods in the subsequent test-specific sections.

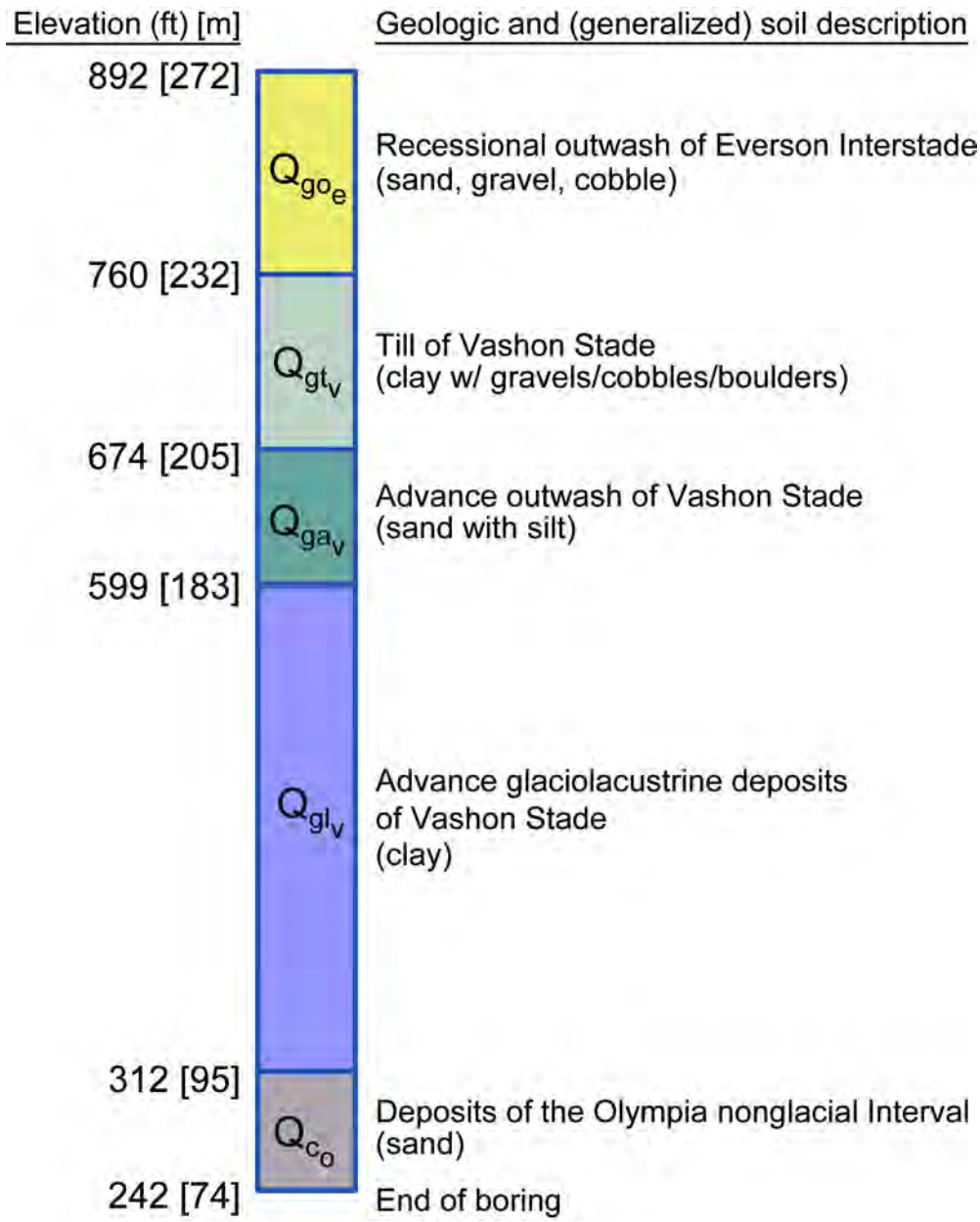

Figure 2. Generalized stratigraphic column of glacial and nonglacial deposits forming the area of the March 22, 2014 SR-530 (Oso) landslide, following the naming convention of Dragovich and others (2003). Unit contacts are assumed horizontal for purposes of presentation.

Water Content

Determination of the water content (w), defined as the ratio of the mass of water relative to the mass of solids in a given volume of soil, is guided by ASTM D2216-10 - Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass (http://www.astm.org/). Water content was measured and recorded for those materials that were transported and stored in a sealed condition, providing confidence that the materials had not dried out between the time of sampling and testing in the laboratory. In general, these were samples either in polycarbonate (Lexan) or brass tubes, as shown by Sample Type in table 1.

It is important to recognize, however, that soils with significant plasticity swell when exposed to water if the confining stress is reduced, and that this will result in a higher water content than was present prior to sampling in the field. Because the polycarbonate tubes had a slightly larger inside diameter than the diameter of the core itself, it is very likely that the samples of the glaciolacustrine formation, for example, experienced significant swelling prior to measurement of the water content, and therefore the measured values reported in table 1 are upper bounds on the likely values in situ.

Unit Weight

Determination of the soil mass density, or unit weight, is guided by ASTM D7263-09 - Standard Test Methods for Laboratory Determination of Density (Unit Weight) of Soil Specimens (http://www.astm.org/). Densities were only measured and recorded for samples which had not been substantially remolded prior to testing. In general, these are samples either in the polycarbonate (Lexan) or brass tubes, as shown by Sample Type in table 1.

Moist densities (γ) were determined by carefully cutting a section of the desired sample tube of approximately 4 in. (102 mm) in length and extruding the soil. The inner diameter of the polycarbonate tube, the length of the extruded core, and the specimen's moist mass were recorded and used to calculate the density. The soil sample was then typically cut along its cylindrical axis and divided into subsamples for subsequent determination of moisture content and other index properties.

As noted earlier, all samples retained in polycarbonate tubes likely underwent swelling due to the available moisture in the tubes and annular space between the tubes and the original core diameter. This suggests that the measured moist unit weights shown in table 1 are probably lower bounds on the values of these soils prior to sampling, particularly in materials that were saturated in the field.

The samples of till available for index testing had not been maintained at original moisture levels, and because of the wide range of particle sizes within this material, it was not possible to trim a uniform, right-circular cylindrical sample from the available core. Instead, the dry density (γ_d) of the till from one depth was estimated by a simple exercise in water displacement when submerged. A relatively large (5-in.-long [127 mm]), roughly cylindrical sample was oven dried to obtain its dry mass, and then was submerged in a 2.1 qt (2 L) graduated cylinder that was partly full of distilled water. Measurements of the water level in the graduated cylinder before and immediately after submersion of the till sample provided an approximate bulk volume of the sample, before water could significantly penetrate the sample voids. Over the following hours, as the till sample slaked and became a pile of sediment on the bottom of the cylinder, the overall volume was observed to decline as air within the original sample voids was released, thereby verifying that the water-volume-displacement measurement was reasonable since the water had not immediately filled the air-filled voids upon submersion.

Specific Gravity

The specific gravity of soil solids (G_s) was measured following the procedures of ASTM D854-14 - Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer (http://www.astm.org/). A 4.23 fluid ounce (125-ml) pycnometer and approximately 1.06 oz (30 g) of oven-dried soil were used, and a combination of both vacuum and heating was applied to ensure removal of air bubbles. Measured values are shown in table 1.

Grain-size Distribution

Gradation curves for the samples were determined using both hydrometer and sieve methods, as described in ASTM D422-63 (2007): Standard Test Method for Particle-Size Analysis of Soils (http://www.astm.org/). In most cases, the soil samples were oven-dried to determine the mass of solids, soaked in the prescribed dispersing solution, and then tested with the hydrometer. Following completion of hydrometer testing, the entire samples were wet-sieved over a No. 200 sieve, and the coarse fraction was retained, oven-dried, and used for sieve analysis. In a few cases, two different samples from approximately the same depth were used for the sieving and hydrometer portions of the test. In several other cases, the material clearly had very few fines, and so no hydrometer test was performed. For the samples of the till, it should be noted that the geometry of the core samples necessarily limited the maximum particle sizes that could be observed, whereas the deposit contains much larger coarse particles (that is, up to and including boulders). As a check for consistency, two samples from the same depth within the borehole and stratigraphic column (fig. 2, table 1) were run on both the till (sample H-1-14-@176) and the glaciolacustrine unit (sample H-1-14-C72). In these cases, both grain-size curves are presented, but only mean values are reported. Gradation curves are shown in figures 3-7, and the values for percent fines (percentage by mass less than the No. 200 sieve which has openings of 0.0030 in., or 0.075 mm), and the clay-size fraction (percentage by mass less than 0.000079 in., or 0.002 mm) are shown in table 1.

Atterberg Limits

The plasticity characteristics of samples with appreciable fines were determined following ASTM D4318-10e1 - Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils (http://www.astm.org/). Using a Casagrande cup, multiple points using the Casagrande cup were run to identify the liquid limit (*LL*). The plastic limit (*PL*) values were determined by manual rolling of threads on glass plates, rather than using a tray. All samples were initially tested by the "wet method" of preparation, without oven drying and pulverizing, although some of the bulk samples of material had apparently lost considerable moisture from their field state prior to testing. Several additional tests were performed on samples that had already been tested for plasticity, following oven drying, to investigate the effect on the liquid limit and thereby identify whether the soils had appreciable organic content. Values of liquid limit, plastic limit, and plasticity index (*PI*) are shown in table 1.

Unified Soil Classification System (USCS) Designation

The results of the index testing of the samples were used to assign Unified Soil Classification System (USCS) soil classifications following ASTM D2487-11 - Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System) (http://www.astm.org/). These designations are listed in the far right column of table 1. It should be noted that the although the

samples of till, as tested, resulted in a low plasticity clay (CL) classification, larger samples that better captured the gradation of the coarsest particles might classify as a coarse-grained soil instead.

Results

Correlation With Previously Mapped Geologic Units

We characterized 25 samples from the two borings that penetrated the intact stratigraphy immediately upslope of the March 22 landslide headscarp (fig. 1). These samples represent 20 generalized depths (table 1) along a 650-ft-deep (198 m) profile of the original (pre-failure) stratigraphic configuration of the northernmost section of the landslide. The number of samples reported in table 1 (20) is less than the number of samples actually tested (25) because, in some cases, additional samples from the same depth were tested but are reported as single mean values. By comparing soil texture observations and index test results with previously mapped Quaternary geologic unit descriptions (Dragovich and others, 2003), we assigned each sample to one of five mapped units (fig. 2). Further, by inspecting the entire core box, along with field notes taken during drilling, we assigned approximate stratigraphic boundaries to each unit. In general, we were able to distinguish boundaries of adjacent units to within a depth of 10 ft (3 m). Due to the inherent variability of nonhorizontally deposited sediments (especially the till), these boundaries should be viewed as approximate with potentially considerable variability throughout the area forming, and adjacent to, the landslide deposit.

The generalized section consists of 132 ft (40 m) of recessional outwash (primarily sand and gravels) of the Everson Interstade (Qgo_e) overlying 86 ft (~26 m) of glacial till (well graded mix of clay to boulder sizes) of the Vashon Stade (Qgt_v). These units overlie a downward fining sequence (that is, the mean grain size becomes smaller with depth) composed of 75 ft (~23 m) of advance outwash deposits (sand and silt) of Vashon Stade (Qga_v) followed by 287 ft (~87 m) of advance glaciolacustrine deposits, also of Vashon Stade (Qgl_v). Underlying the entire Vashon Stade glacial deposits are sand and silt deposits of the Olympia nonglacial interval (Qc_o). Both borings were terminated in this unit, and the Qc_o deposit thickness was not determined.

Index Testing and Soil Classification

The recessional outwash forms the shallowest unit in the stratigraphic sequence (fig. 2). The material is predominantly a broadly graded sand with significant gravel and nonplastic fines content, as shown by the gradation curves in figure 3. Based on the samples selected and tested from these borings, the fines content increases with depth, and the USCS classification ranges from well-graded sand and silty sand (SW-SM) to just silty sand (SM). Because the material is free-draining, measured water contents and moist densities were dependent on a specimen's position within the core, and are likely to vary in the field depending on hydrologic conditions.

The Vashon till forms a sharp contact with the recessional outwash, and is very dense and extremely broadly graded (fig. 4). Due to the condition of the tested core sample, the estimated unit weight of 140 lb/ft^3 (22 kN/m^3) is a dry unit weight. The fines content, as determined from the core sample, is over 50 percent, leading to a USCS classification of this material as a low-plasticity clay (CL) with large sand and gravel fractions. The plasticity values are plotted on the Casagrande chart for classification in figure 8. It is quite possible that larger bulk samples that better captured the coarser gravels and cobbles observed in the field would classify as a coarse-grained soil. Nevertheless, test results characterize the matrix portion of the till, which is probably more relevant to landslide behavior than a bulk classification conducted with larger samples.

Samples of the advance outwash unit have fines content close to 50 percent (fig. 5, table 1) and therefore classify as either a relatively uniform silty fine sand (SM) or a fine sandy low plasticity silt (ML). Clay-size fractions are low, less than 5 percent, as are the *PI* values, when measurable at all.

The advance glaciolacustrine unit is the thickest of the sequence and was the most thoroughly investigated. An apparent gradational contact exists with the advance outwash unit above it. All samples from this unit classify as clays with the clay-size fraction ranging from 26 percent to 66 percent, and only a few contain any measurable sand content (fig. 6). Specific gravity values are typically between 2.78 and 2.83, consistently higher than those in other units. The plasticity of these samples varies considerably, with *PI* values ranging from 20 to 45, and roughly in correspondence with the clay-size fraction as one might expect in a single geologic unit. The plasticity values are plotted on the Casagrande chart for classification in figure 9, in which distribution of low plasticity (CL) and high plasticity (CH) can be seen. Although there are some exceptions, the general trend is that the lower half of the unit has higher plasticity and is finer grained than the upper half. However, this unit shows some variation even with small changes in depth (that is, within 1 ft [30.5 cm], as shown by the somewhat different grain-size curves obtained for sample H-1-14-C72 (fig. 6). These clays showed only a moderate reduction in plasticity when oven dried and rehydrated, as measured by the change in liquid limit. For the two samples tested in this manner, the post-drying liquid limit was approximately 90 percent of its original value, indicating the material does not classify as an organic fine-grained soil.

The measured moist unit weights of the glaciolacustrine samples of between 116 to 124 lb/ft^3 (18.2 and 19.5 kN/m^3) are probably somewhat lower than field values due to swelling following unloading. For the same reason, the measured moisture contents of between 26 percent and 36 percent are probably upper bounds on the field values at the relevant depths.

The deepest unit investigated was the Olympia-age nonglacial deposits, which underlie the advance glaciolacustrine. Based on the limited testing of samples and examination of the core retrieved, this unit ranges from a relatively clean uniform sand (SP) to a silty sand (SM). Gradation curves for two samples from this unit are shown in figure 7.

Conclusions

The deep coring and sampling of the intact materials behind the headscarp of the March 22, 2014 SR-530 landslide have provided valuable insight into the intact sequence of geologic materials involved in the failure. The subsequent geotechnical index testing and resulting characterization of selected samples during this phase of laboratory testing generally confirms the stratigraphic sequence shown in figure 2. In addition, the data provide index-test property values of sufficient precision and spatial distribution through the stratigraphic section to begin to assist in development of geotechnical models of the landslide, and may be useful in estimating behavioral properties based on comparison with similar glacial sediments from other landslide-prone nearby areas of northwestern Washington (Savage and others, 2000).

Table 1. Geotechnical index testing data for deposits forming the March 22, 2014 SR-530 landslide near Oso, Washington

[USCS desig. = United Soil Classification System designation. No data indicates that tests either were not, or could not be, run on these samples.]

Sample no.	Depth below ground surface[1] (ft)	Mean elev.[2] (ft)	Sample type	Water content, w_c (%)	Moist unit weight, γ (lb/ft^3)	Specific gravity, G_s	Liquid limit, LL (%)	Plastic limit, PL (%)	Plasticity Index, PI (%)	Fines content (%)	Clay content (%)	USCS desig.
Recessional outwash of Everson Interstade (Qgoe)												
H-1-14-D2	39.0-40.5	850	Bulk							11	3	SW-SM
H-2-14-D1B	50.0-52.0	839	Brass liner	4.5	119.7							
H-1-14-D3	59.0-60.5	830	Bulk			2.73				14	3	SM
H-2-14-D2A	98.5-100.5	790	Brass liner	23.2	117.8							
H-1-14-D7	119.0-120.5	770	Bulk			2.73				44	5	SM
Till of Vashon Stade (Qgt_v)												
H-1-14-@176	176.0-178.0	713	Loose core		140.3[3]	2.76	40	18	22	56	22	CL
Advance outwash of Vashon Stade (Qga_v)												
H-1-14-C34A	242.5	648	Lexan tube	24.7		2.76				49	3	SM
H-1-14-C34B	245.5	645	Lexan tube	26.4		2.79	27	24	3	63	2	ML
H-2-14-C5L	271.0	619	Lexan tube			2.73	26	25	1	47	4	SM
Advance glaciolacustrine deposits of Vashon Stade (Qgl_v)												
H-1-14-C51	319.5-320.5	570	Loose core			2.81	53	21	32	98	40	CH
H-1-14-@354	353.0-355.0	536	Loose core			2.80	39	19	20	96	26	CL
H-1-14-C64	379.5-380.5	510	Loose core	26.0		2.81	58	24	34	100	45	CH
H-1-14-C72	418.0	472	Lexan tube	35.0	123.5	2.77	48	25	23	100	42	CL
H-1-14-C78	449.5-450.5	440	Lexan tube	28.6	122.2	2.78	57	24	33	100	38	CH
H-1-14-C86	487.5-490.5	401	Lexan tube	35.8	116.5	2.77	69	26	43	100	66	CH
H-1-14-C94	529.5-530.5	360	Lexan tube			2.81	70	25	45	100	57	CH
H-2-14-C9L	562.0	328	Lexan tube	26.4		2.79	54	25	29	99	35	CH
H-1-14-C103	572.0	318	Loose core			2.83	62	27	35	100	64	CH
Deposits of the Olympia nonglacial Interval (Qco)												
H-2-14-C11L	582.5	308	Lexan tube		140.0	2.76				18	3	SM
H-1-14-C114	627.5	263	Lexan tube	4.9		2.75				3	0	SP

[1]Single values of depth represent those samples where the exact location of the sample is known within the core (as opposed to a range).

[2]Sample elevation is based upon an estimated ground surface elevation of 890±5 feet relative to NAVD88 and rounded to the nearest foot.

[3]For the till sample, only a dry density (γ_d) was measured (see Methods).

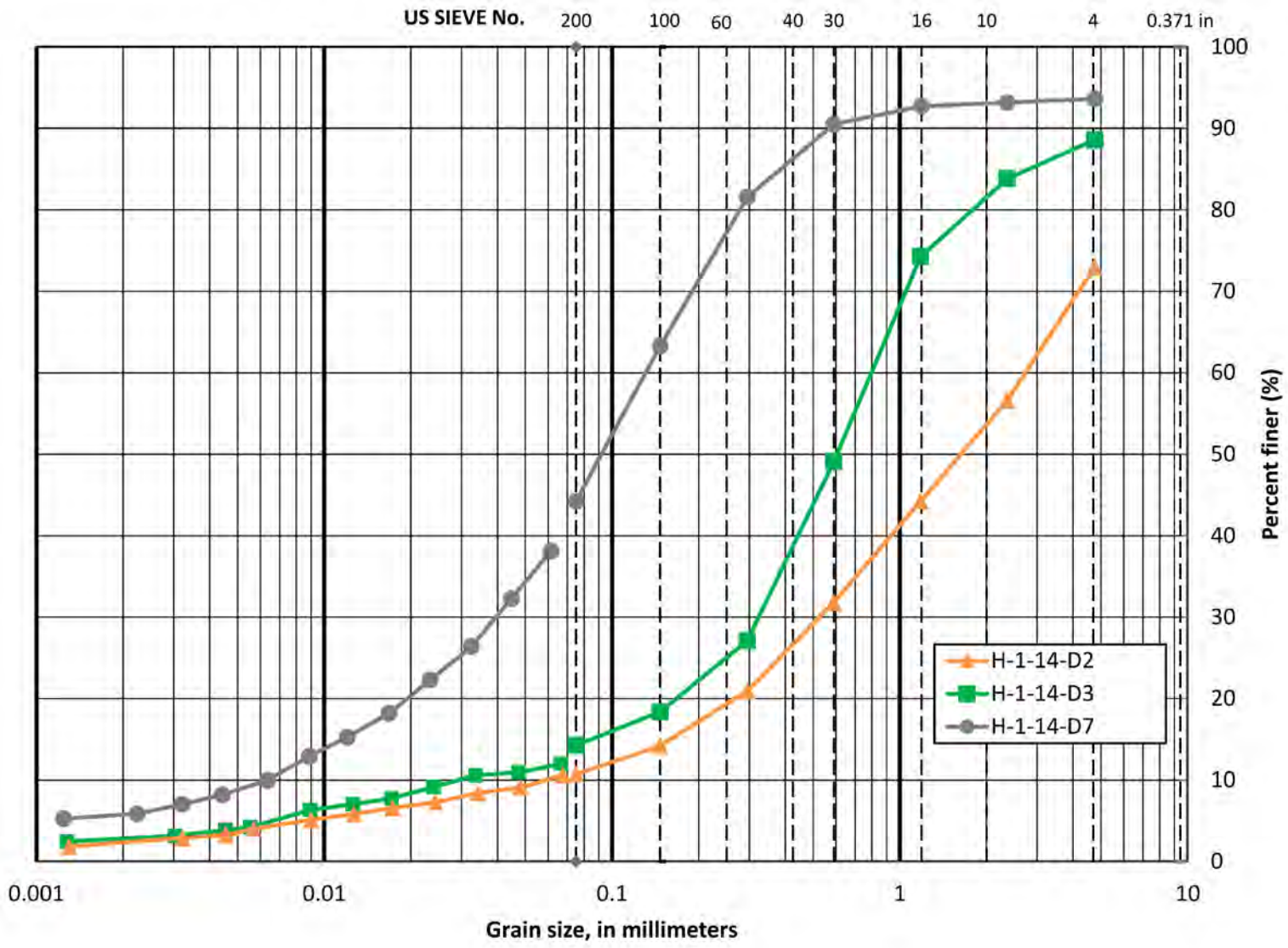

Figure 3. Grain-size curves for recessional outwash samples. Data less than the No. 200 sieve are from hydrometer testing. Data greater than the No. 200 sieve are from sieve testing.

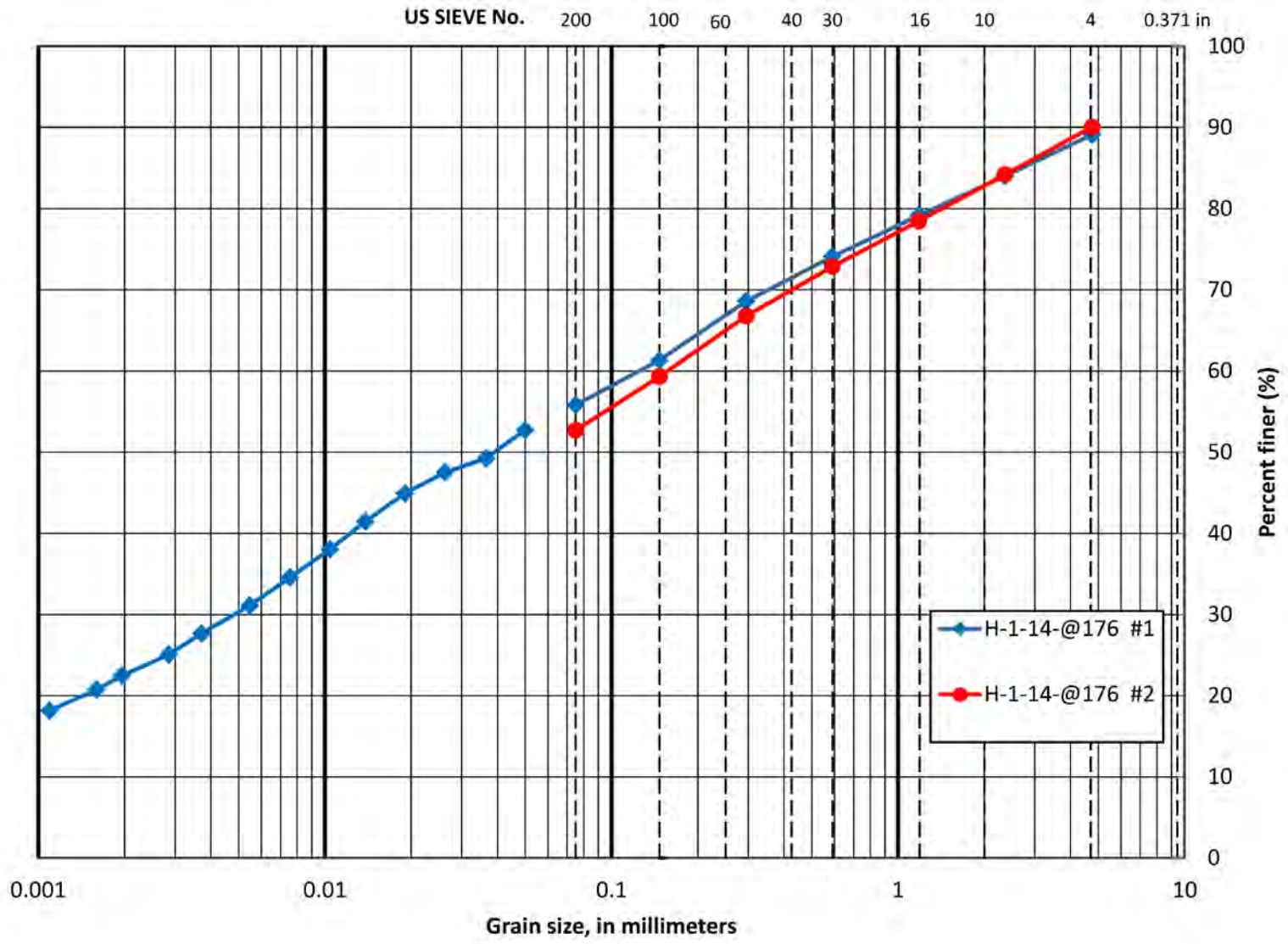

Figure 4. Grain-size curves for till samples. Data less than the No. 200 sieve are from hydrometer testing. Data greater than then No. 200 sieve are from sieve testing. Two samples were tested from the same depth as a check on consistency and mean values are reported in table 1.

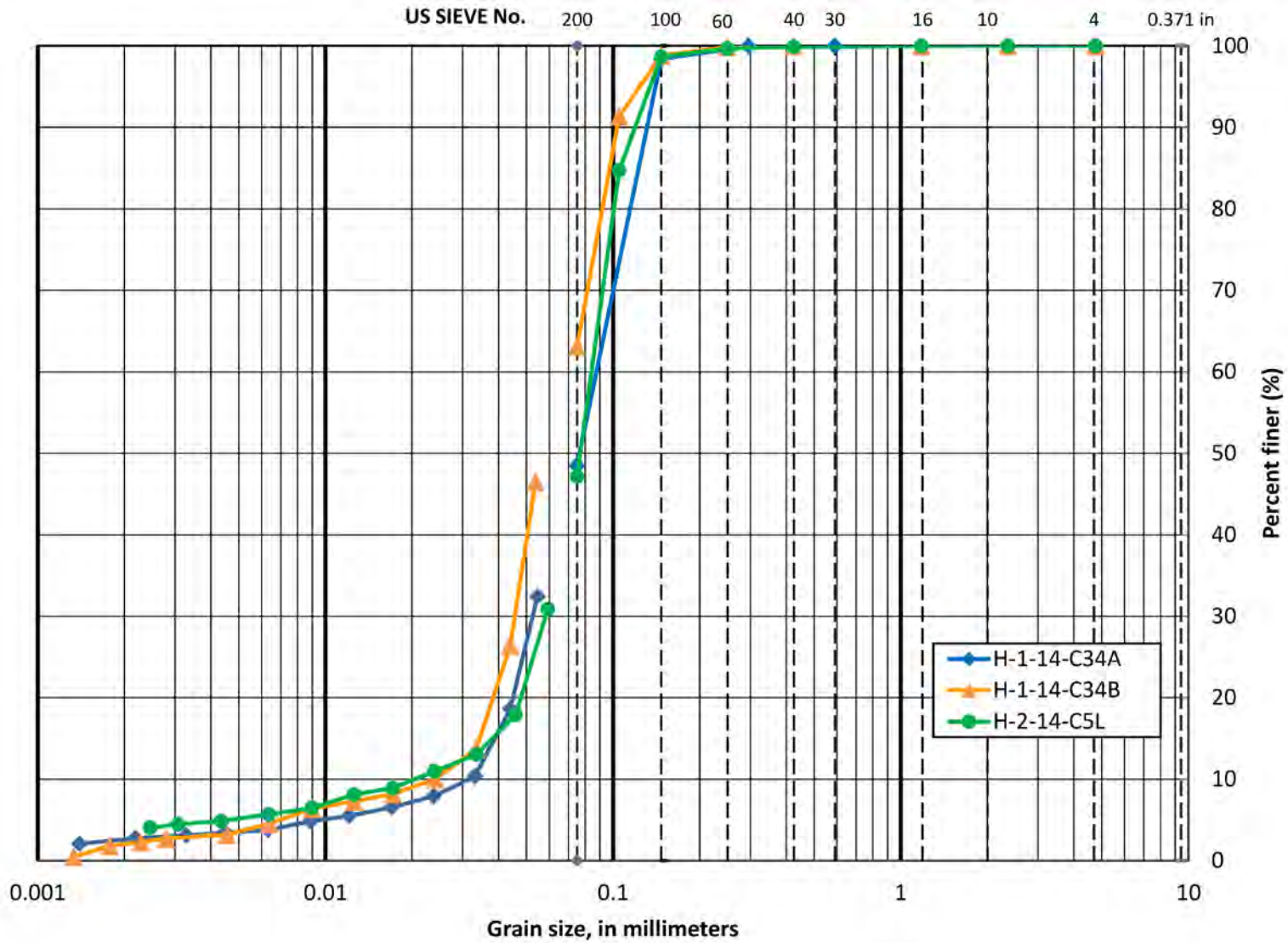

Figure 5. Grain-size curves for advance outwash samples. Data less than the No. 200 sieve are from hydrometer testing. Data greater than the No. 200 sieve are from sieve testing.

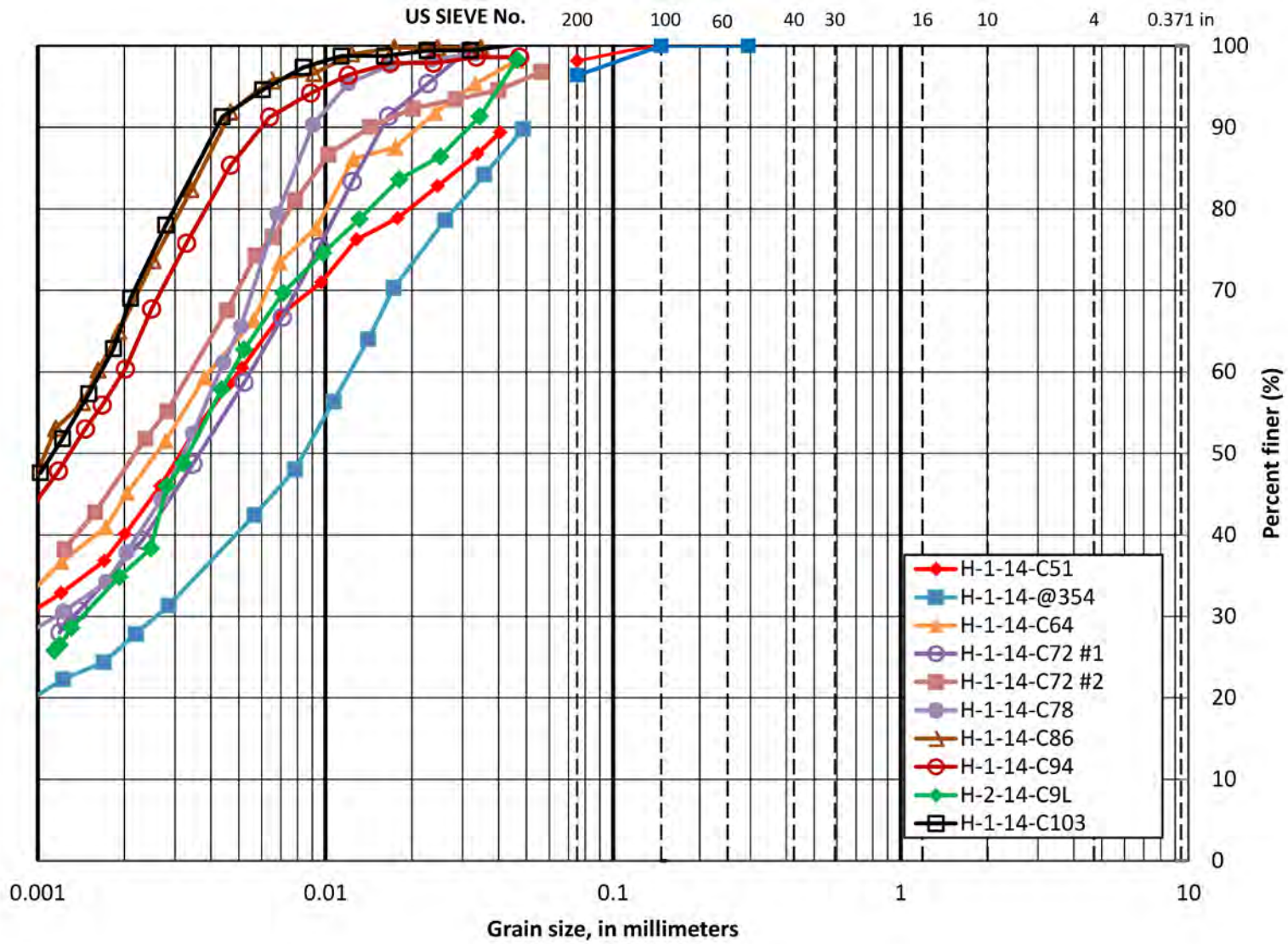

Figure 6. Grain-size curves for advance glaciolacustrine samples. Data less than the No. 200 sieve are from hydrometer testing. Data greater than the No. 200 sieve are from sieve testing. Two samples of H-1-14-C72 were tested from the same depth as a check on consistency and mean values are reported in table 1.

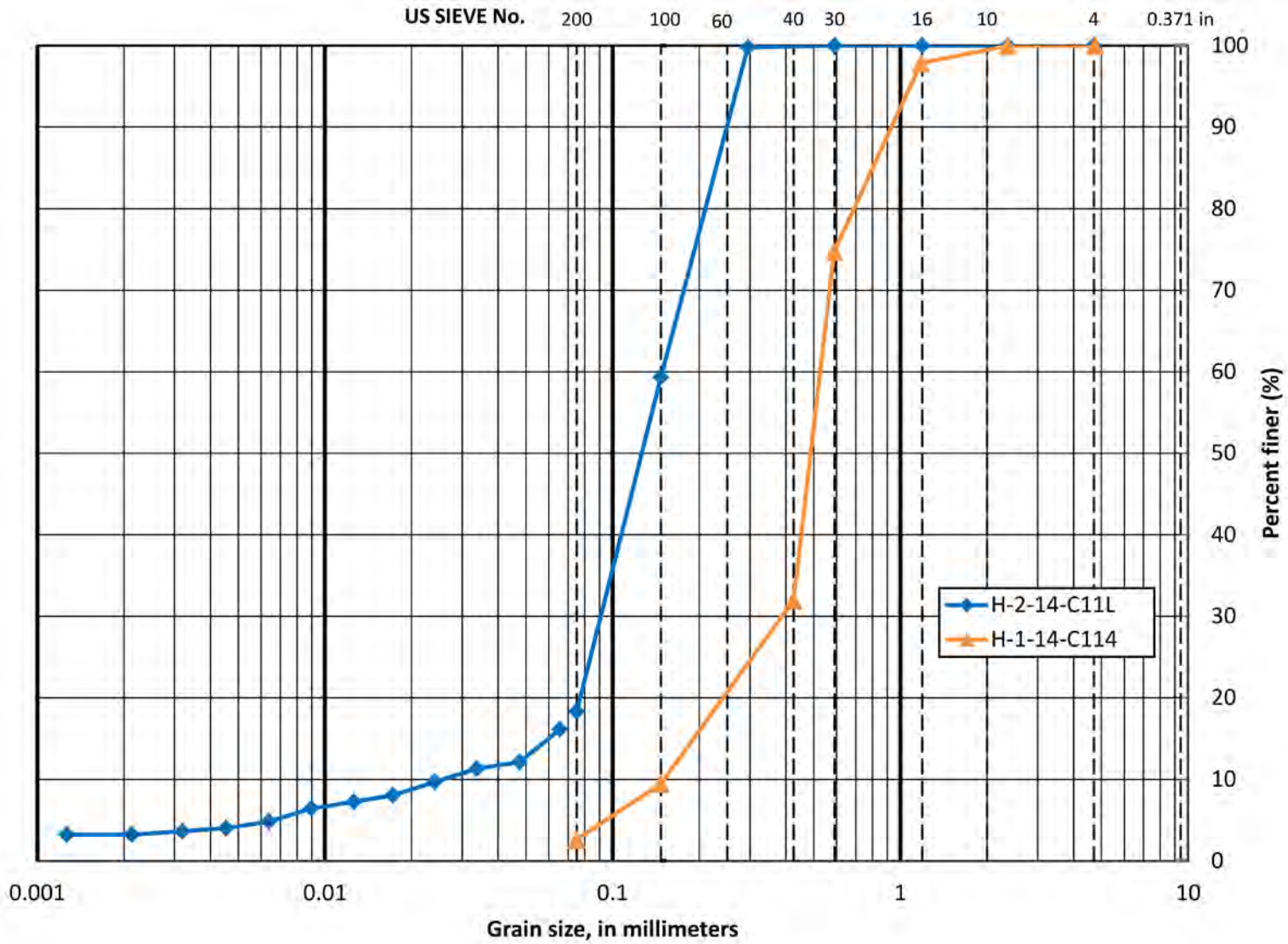

Figure 7. Grain-size curves for Olympia-age nonglacial samples. Data less than the No. 200 sieve are from hydrometer testing. Data greater than the No. 200 sieve are from sieve testing.

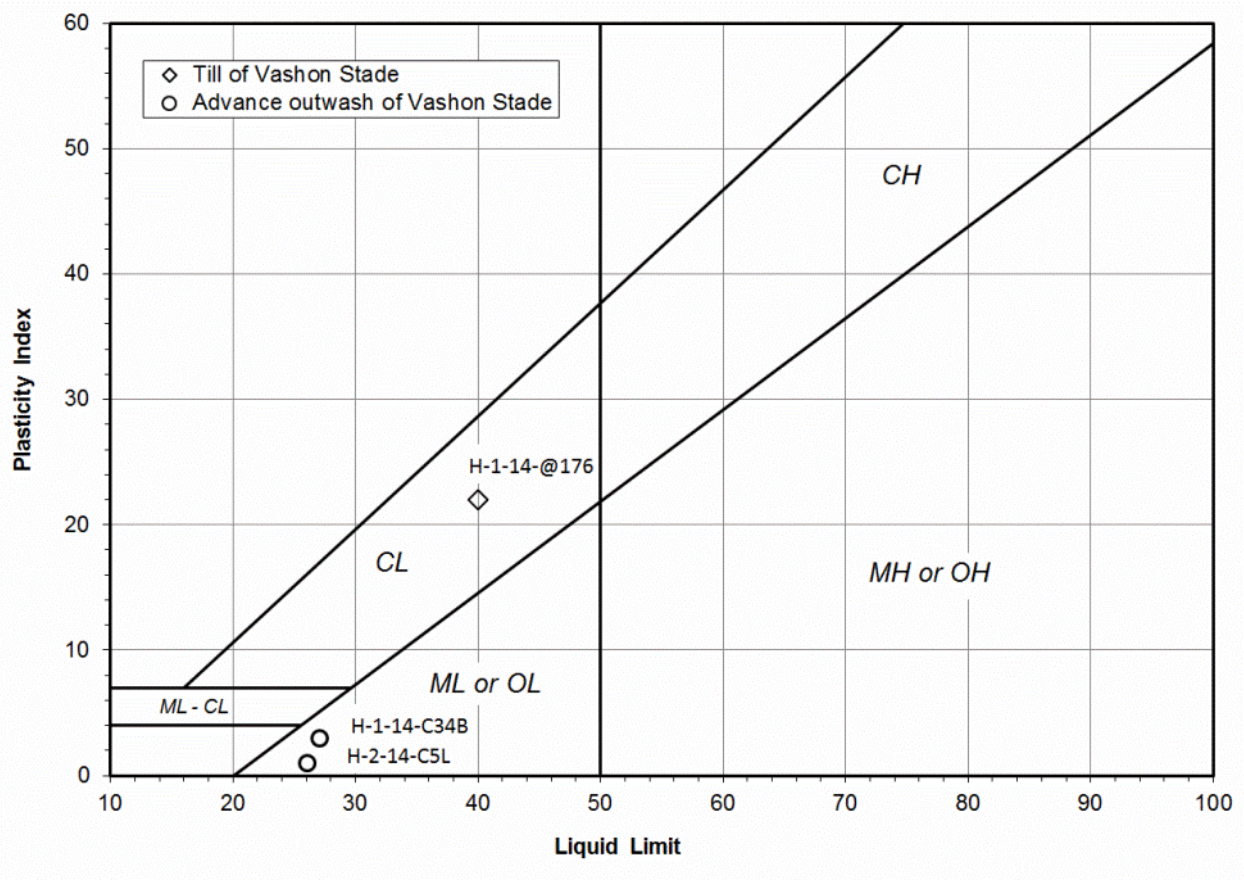

Figure 8. Plasticity chart for till and advance outwash samples. Cx = clay, Mx = silt, Ox = organic, xH = high plasticity, xL = low plasticity.

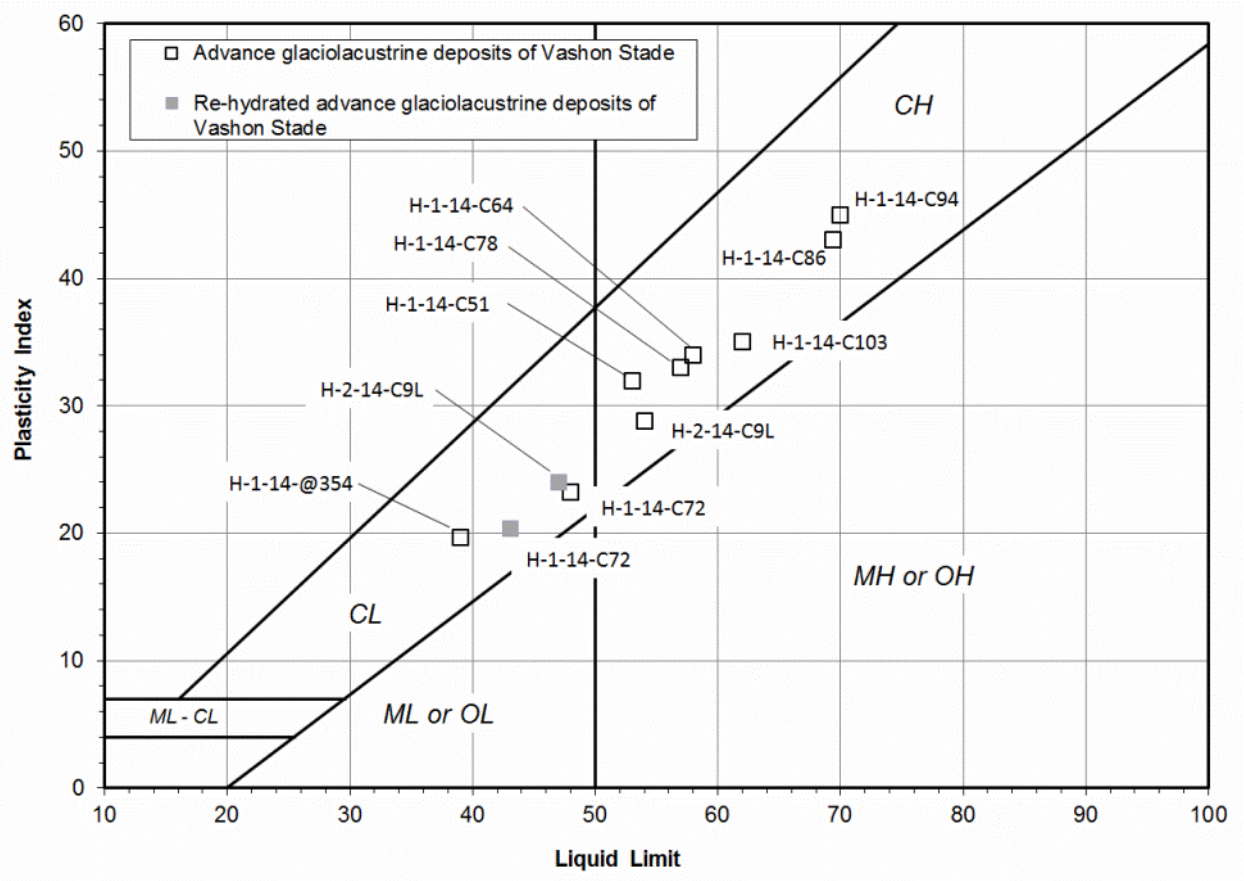

Figure 9. Plasticity chart for advance glaciolacustrine samples. Cx = clay, Mx = silt, Ox = organic, xH = high plasticity, xL = low plasticity.

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Job No. **JM-1112-M gp01** Date **April 15, 2015**

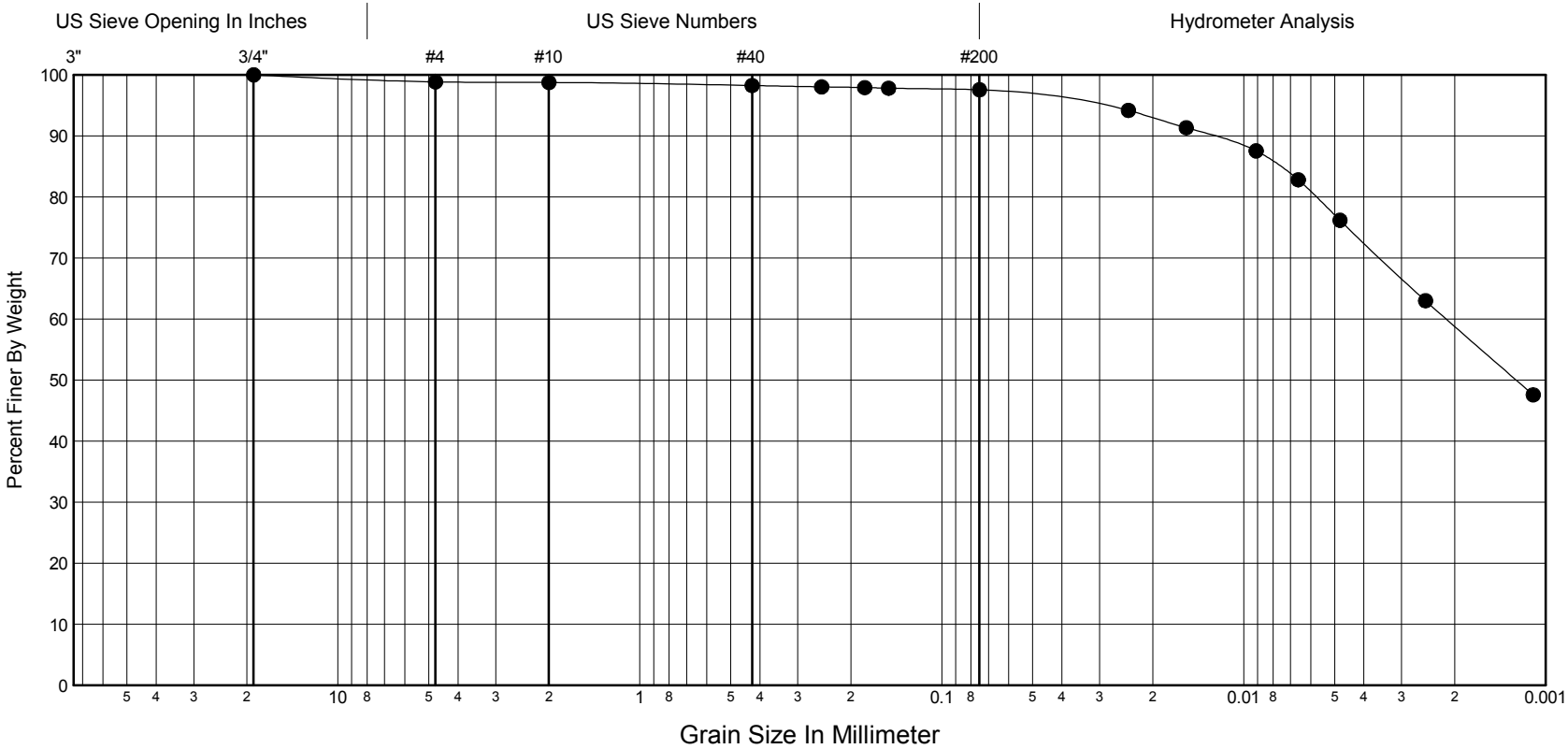
Hole No. **H-3vwp-14** Sheet **1**

Project **SR530 Landslide - Phase 1 Investigation**

Laboratory Summary

Washington State Department of Transportation

	Depth (ft)	Sample No.	USCS	Description	MC%	LL	PL	PI	Moist Density (lbs/ft³)	Specific Gravity	Gravel (%)	Sand (%)	Fines (%)	Cc	Cu	D60	D50	D30	D20	D10
●	**183.0**	**C-43**	**CH**	**FAT CLAY**	**32**	**62**	**27**	**35**		**2.84**	**1.1**	**1.3**	**97.6**			**0.002**	**0.00**			



Gravel	Sand			Silt			Clay
	Coarse	Medium	Fine	Coarse	Medium	Fine	

JM-1112-M 530 OSO LANDSLIDE MONITORING (SNOHOMISH CO).GPJ PUBLIC-COMMON LIBRARY.GLB 4/15/15

Ring Shear Test Report (ASTM D6467-06a)

Washington State Department of Transportation Geotechnical Division

PROJECT INFORMATION			
Project	SR530 Landslide Phase 1 Investigation		
Location	SR530		
Project Manager	Tom Badger	Sample Number	C-43
Project Number	JM-1112-M	Depth	183'
Boring Number	H-3vwp-14	Sample Type	Remolded
Description	CH - FAT CLAY		

	Specimen				
INITIAL	**A**	**B**	**C**	**D**	**E**
Specimen Thickness (in)	0.200	0.200	0.200	0.200	0.200
Internal Ring Radius(in)	1.375	1.375	1.375	1.375	1.375
External Ring Radius(in)	1.970	1.970	1.970	1.970	1.970
Moisture Content (%)	55.8	55.8	55.8	55.8	55.8
SHEAR	**A**	**B**	**C**	**D**	**E**
Rate of Linear Displacement (in/min)	0.0007	0.0007	0.0007	0.0007	0.0007
Rate of Angular Displacement (Deg/min)	0.0240	0.0240	0.0240	0.0240	0.0240
Normal Stress (psi)	3.6	7.3	14.5	58.0	101.0
Residual Shear Stress (psi)	0.644	1.417	3.459	13.750	23.879
Linear Displacement (in)	0.084	0.042	0.168	0.084	0.631
Angular Displacement (Deg)	2.9	1.4	5.8	2.9	21.6
FINAL	**A**	**B**	**C**	**D**	**E**
Final Moisture Content (%)	30.8	30.8	30.8	30.8	30.8
Assumed Cohesion (psi)	0.0	0.0	0.0	0.0	0.0
Liquid limit	62.0	62.0	62.0	62.0	62.0
Plastic Limit	27.0	27.0	27.0	27.0	27.0
Plasticity Index	35.0	35.0	35.0	35.0	35.0
Specific Gravity	2.84	2.84	2.84	2.84	2.84
Angle of Residual Shear Resistance (Deg) **13.3**	10.1	11.0	13.2	13.3	13.3
Clay Fraction (%)	**58**				
COMMENT/REMARKS					

Tested By	Samuel Wade	Date	4/22/2015
Checked By	Mike Polodna	Date	4/22/2015

Ring Shear Test Report (ASTM D6467-06a)

Washington State Department of Transportation Geotechnical Division

PROJECT INFORMATION			
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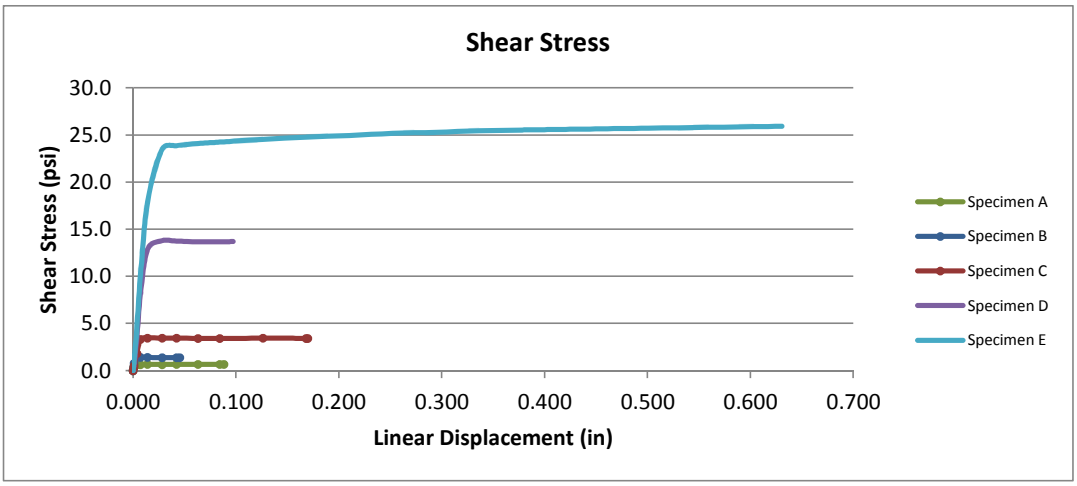
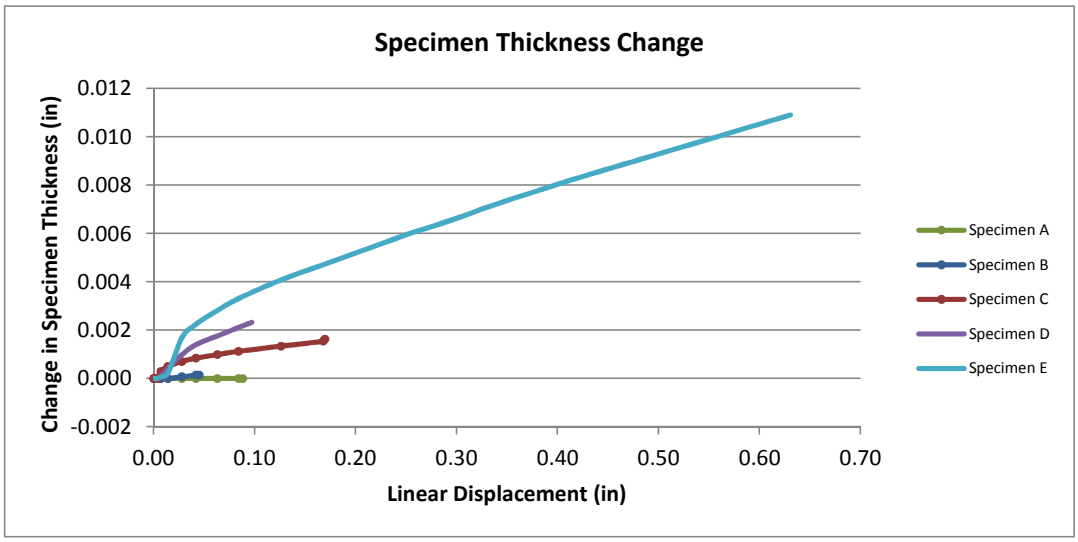
Project Number	JM-1112-M	Depth	183'
Boring Number	H-3vwp-14	Sample Type	Remolded
Description	CH - FAT CLAY		

FINAL GRAPHS (1 of 3)





Ring Shear Test Report (ASTM D6467-06a)

Washington State Department of Transportation Geotechnical Division

PROJECT INFORMATION			
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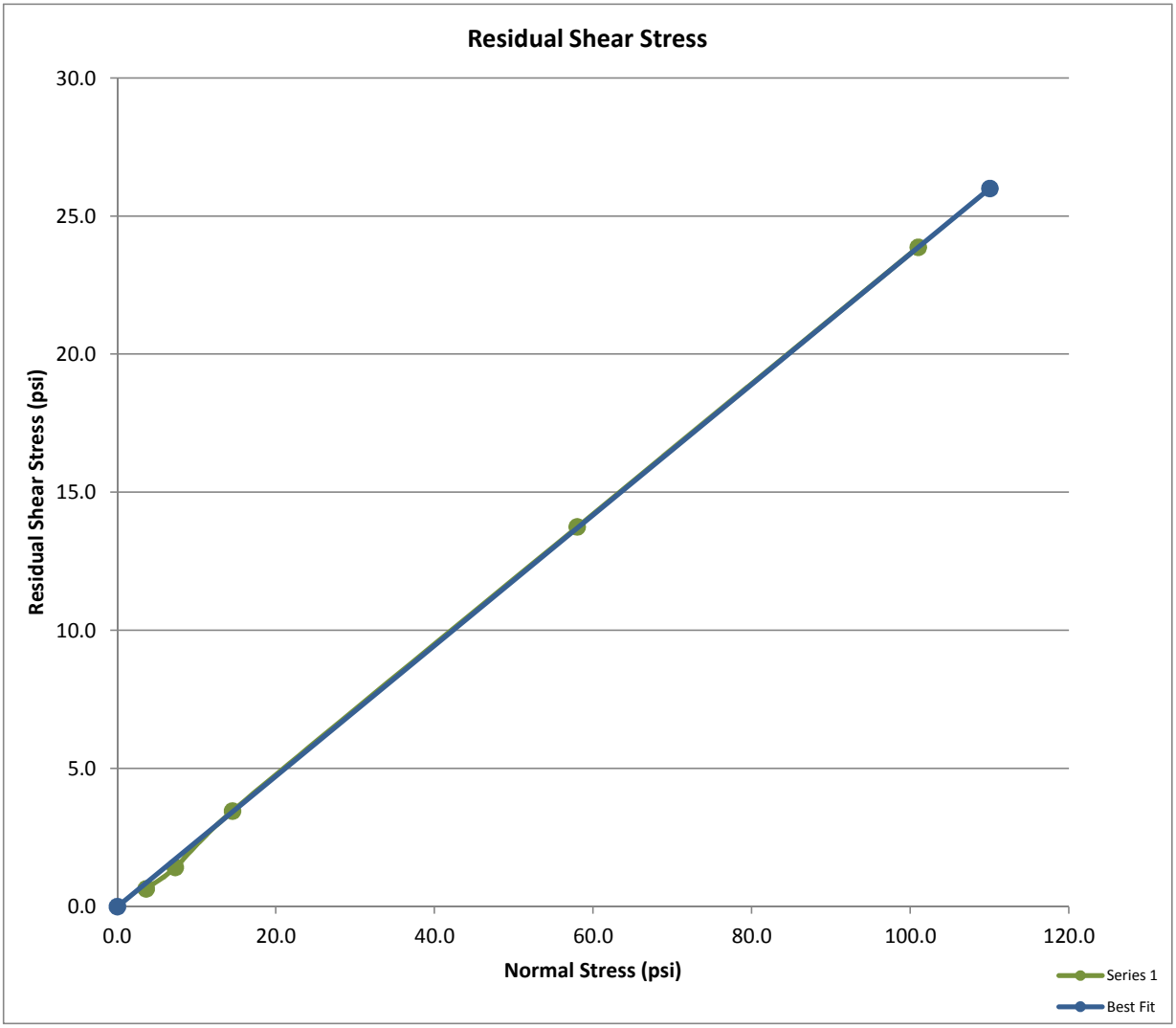
Project Number	JM-1112-M	Depth	183'
Boring Number	H-3vwp-14	Sample Type	Remolded
Description	CH - FAT CLAY		

FINAL GRAPHS (2 of 3)



Ring Shear Test Report (ASTM D6467-06a)

Washington State Department of Transportation Geotechnical Division

PROJECT INFORMATION			
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Project Number	JM-1112-M	Depth	183'
Boring Number	H-3vwp-14	Sample Type	Remolded
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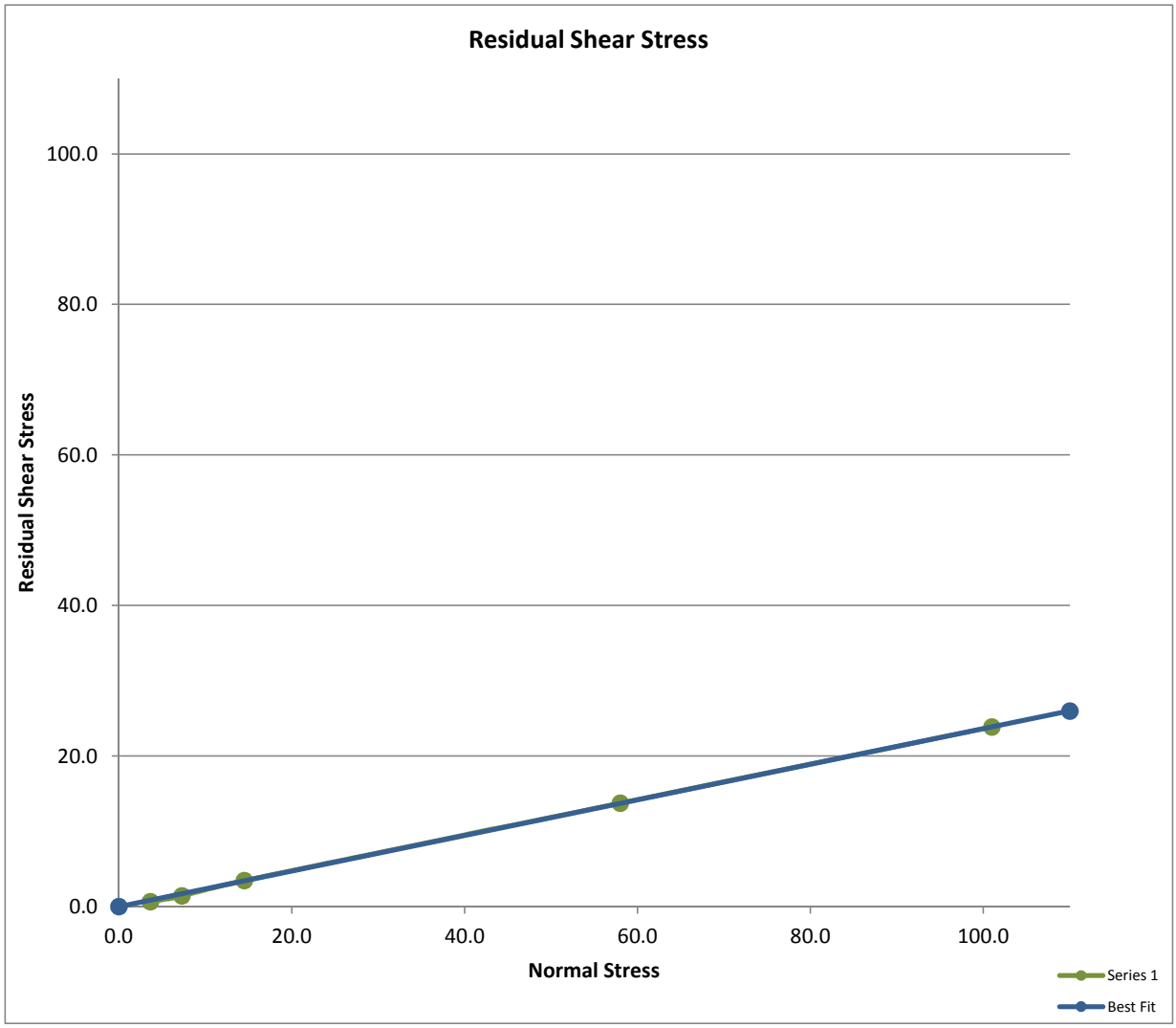
FINAL GRAPHS (3 of 3)