APPENDIX C
Geophysical Surveys

APPENDIX C.1
Report of Geophysical Survey - Slide Curve Bridge and Walls

URS

May 20, 2008

Mr. Brian Hamilton, P.G.
Manager, Transportation and Tunneling
URS Corporation
1501 4th Avenue, Suite 1400
Seattle, Washington 98101

Subject: Geophysical Investigation Report
I-90 Snoqualmie Pass East Project
Snoqualmie Pass, Washington

Dear Mr. Hamilton:

URS Corporation (URS) is pleased to present the findings of a geophysical investigation conducted as part of the Washington State Department of Transportation I-90 improvement project near Snoqualmie Pass, Washington. The objective of the geophysical investigation was to evaluate the depth to bedrock along the alignment of a structural retaining wall. The investigation consisted of a seismic refraction survey.

Background

The I-90 Snoqualmie Pass East project is located along the existing Interstate I-90 between the Hyak interchange and the West Easton interchange in Kittitas County. This investigation was conducted to evaluate conditions in the area of proposed Structural Wall 1 (SW1) shown on Figure 1.

Seismic Refraction Methodology

The seismic refraction method consists of transmitting seismic energy into the ground and recording the arrival of the direct and refracted compressional-waves (P-waves) at preset distances along the ground surface. Seismic energy travels through each subsurface layer with a characteristic P-wave velocity that is dependent on the density, compressibility, pore space, and fluid content of the geologic material. By evaluating seismic velocities, as inferred from the recorded first arrival travel times, and the seismic velocity contrasts, the investigator can interpret the configuration and depths of the subsurface geologic units.

A limitation of the seismic refraction method is that the refracting layer must be sufficiently thick to be detected. The thickness required for detection depends on layer depth, velocity contrast with the overlying and underlying layer, and field parameters utilized during data acquisition and recording. A second limitation is related to the required assumption that seismic velocities increase with depth. That is, the method can detect a relatively hard layer (with a corresponding relatively high seismic velocity) under a relatively soft layer (with a corresponding relatively low seismic velocity). However, the method does not provide a means of determining the depth to, and seismic velocity of, a lower velocity layer underlying a higher velocity layer.

A seismic refraction data collection system includes a seismograph, geophones, cables, and a seismic energy source. The seismic source can be generated using a sledgehammer, a dropped or propelled weight, explosives, or other specialized device. Selection of an appropriate seismic source for a particular study area involves consideration of the required depth of investigation, background noise levels, and the attenuation properties of the near-surface materials.

Seismic refraction surveying is conducted in straight lines or profiles. The geophones are coupled to the ground surface at predetermined distances along the line and connected via data cable to a seismograph. The seismic waves produced by the by the seismic source are sensed by the geophones and translated into an electrical signal. These data are recorded by the seismograph and saved as digital files.

The seismic data can be processed and analyzed using seismic refraction interpretation software programs. The software programs facilitate application of topographic corrections, construction of time-distance plots, determination of apparent layer velocities, and calculation of layer depths and thicknesses. Interpreted results are presented as cross-sections, i.e., velocity sections, depicting depth, thickness, and velocity of the various subsurface layers encountered.

Site Geology

The information regarding site geology was taken from URS reports relevant to the I-90 project from 2006 and 2007. The Project area geology consists of volcanic and sedimentary rocks of the Ohanapecosh and Naches Formations, which are Oligocene to Eocene in age (Tabor et al., 2000). The southern area is underlain by the tuff member of Keechelus Lake of the Ohanapecosh Formation and, to a lesser extent, andesite and basalt of the Ohanapecosh Formation. The tuff member of Keechelus Lake is a dacite crystal-vitric tuff and tuff breccia. The northern area is underlain by sedimentary and volcanic rocks (andesite and/or basalt) of the Naches Formation. Late Pleistocene alpine glacial deposits, and post-glacial Holocene alluvium, colluvium, landslide, and lacustrine deposits of Keechelus Lake are locally present.

Seismic Refraction Field Investigation

The field investigation was completed between April 8 and April 10, 2008, by representatives of the URS Geophysics Group, based in Gaithersburg, Maryland. The seismic refraction survey was conducted using a Geometrics 24 Channel Geode seismograph, with 24 8-Hz P-wave geophones. The geophones were placed along the seismic lines at uniform increments of 10 feet. The seismic pulse was generated by firing a percussion Betsy® Seisgun source at designated shot point locations (shot points). Each seismic spread contained seven shot points.

The Betsy Seisgun is a modified 21-millimeter (8-gauge) industrial shotgun mounted vertically on a base muffle chamber. The seismic pulse was created by manually firing 8-gauge shotgun blanks into 1 foot-deep holes. The number of firings at each shot point ranged from 1 to 3, depending on observed signal quality. The process of collecting multiple firings at each location is referred to as signal stacking and is intended to enhance the overall signal-to-noise ratio, thereby allowing more precise detection of first arrivals. At several shot points, impact of a 10-

pound sledgehammer against a metal plate was used instead of or in combination with the Seisgun to provide the seismic source.

Data were collected along a single line consisting of six seismic spreads. The location of the line was determined by on-site URS project representatives. The original location of the seismic line was positioned to follow the alignment of the structural wall SW1. However, based on safety concerns associated with the unstable surface materials along the steep slope, partial submersion of the wall alignment under Lake Keechelus at the time of the survey, and poor coupling of the geophones to the blocky fill surface materials, the location of the seismic line was adjusted to the right shoulder of the existing eastbound I-90. The line extended along a narrow strip between the jersey barriers and the edge of the embankment above Lake Keechelus as shown on Figure 1. The survey consisted of six adjoining 230 feet long spreads for a total of 1,380 linear feet of surveying. It should be noted that the locations of the off-end shot points are not depicted on Figure 1.

Data Processing and Analysis

The seismic refraction data were analyzed using the software package SeisImager from Geometrics. Initial data processing steps involved setting the survey geometries, filtering noisy data, and selecting the P-wave first arrivals. Additional data processing steps involved making subsurface layer assignments, importing elevation data, and inputting the seismic data into the modeling routine in SeisImager. The elevations of the geophones and shot points were established based on analysis of topographic data on the site plans provided. Contouring and final presentation of the modeled subsurface seismic profile was completed using the program Surfer by Golden Software.

Seismic Refraction Results

The results of the seismic refraction investigation are provided as Figure 2. The seismic profile extends 1,380 feet from test boring SW1-001-07 at Station 1371+50 to approximately Station 1385+17 feet. Highway traffic and concurrent drilling activity near the seismic line during data acquisition resulted in elevated background noise levels and an associated degradation of the signal quality. However, data analysis resulted in adequate signal quality to allow modeling of the refraction cross-section depicted in Figure 2.

The results generally correlate well with the depth to bedrock indicated on three borings (SW1-001-07, SW1-002-07, and SW1-005-07) located along the seismic line as shown on Figure 2. These results indicate that the contact between the gravel and the underlying andesite bedrock correlates with compressional wave velocities in the range of 6,000 to 8,000 feet/second. This velocity range is represented by the transition from the yellow to red contour interval on Figure 2. The depth to the interpreted bedrock surface ranges from about 20 feet to 72 feet but averages approximately 30 feet across the profile. The results appear to indicate a generally U-shaped area of deeper bedrock indicative of a buried valley from about profile distance 650 feet to 950 feet. This area corresponds to about STA 1378+00 to 1382+00 feet. It appears reasonable to assume that the axis of this suspected buried valley is oriented generally perpendicular to the existing slope and that it extends to the alignment of the proposed Structural Wall 1. In general one would expect for such a valley to widen in the down slope direction.

Limitations

This geophysical investigation was conducted in accordance with reasonable and accepted engineering geophysics practices, and the interpretations and conclusions are rendered in a manner consistent with other consultants in our profession. However, all geophysical techniques have some level of uncertainty and limitations. No other representations to the client is expressed or implied, and no warrant or guarantee is included or intended.

We greatly appreciate the opportunity to work with you on this project. Please feel free to contact me at (301) 258-9780 if you have any questions.

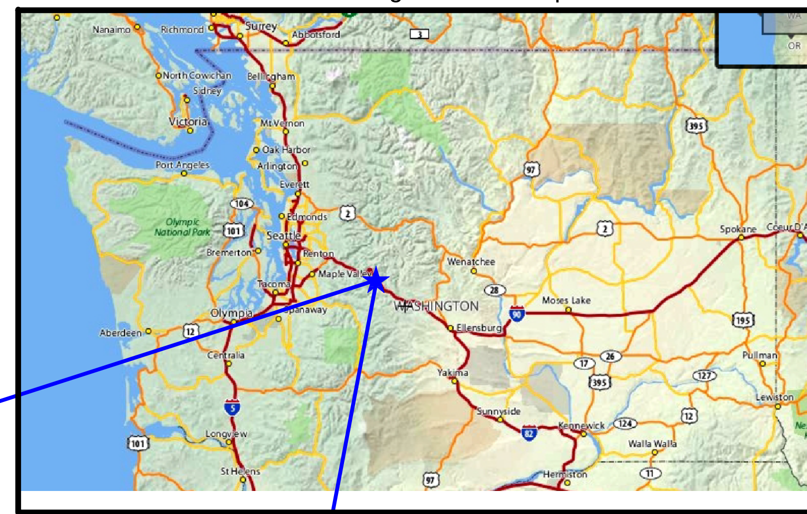
Very truly yours,
URS Corporation

Michael R. Greer, P.G.
Senior Geophysicist

Timothy J. King, P.G.
Principal Geophysicist

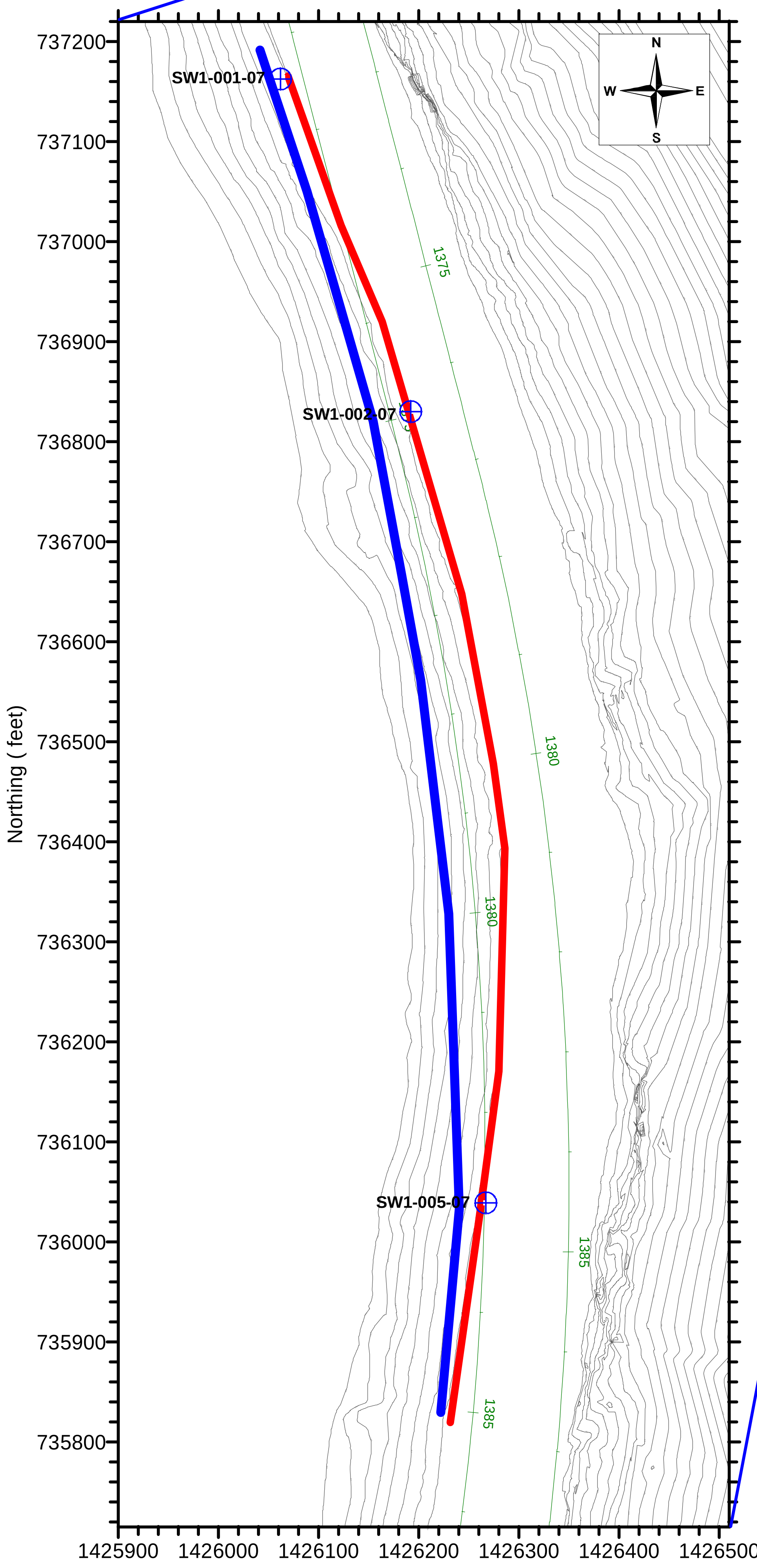
Enclosures: Figure 1 – Site Location Map
Figure 2 – Seismic Refraction Survey Results

Washington State Map



Yahoo! Local Maps

Seismic Line Map



Legend

- Boring Location
- Seismic Line 1
- Center Line Stations
- Sound Wall
- Contours

Scale
1 in. = 150 ft.

0 50 100 150 200 250 300

State Plane NAD-83
Washington South

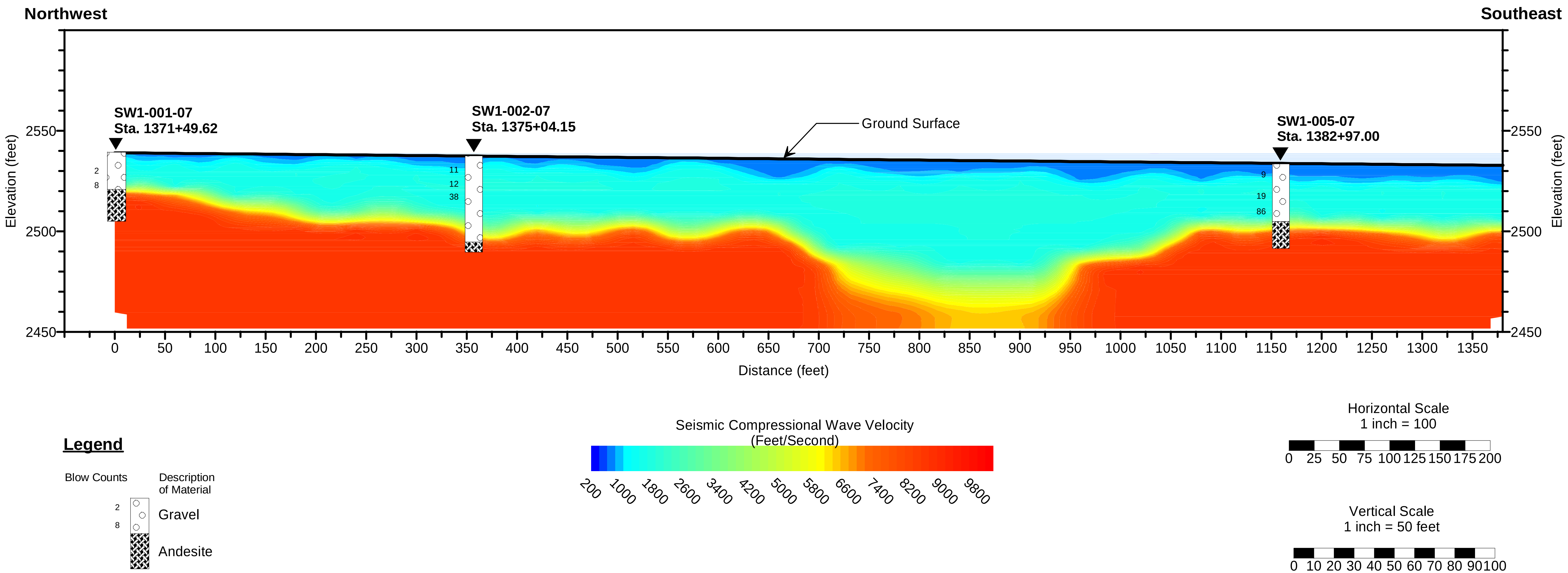
URS
Geophysical Services
200 Orchard Ridge Dr., Ste. 101
Gaithersburg, MD 20878
(301) 258-9780

Geophysical Investigation
Site Location Map

I-90 Snoqualmie Pass Structural Wall 1

Snoqualmie, Washington

DESIGNED BY		DRAWN BY		CHECKED BY		JOB NUMBER	FIGURE
MRG	5/15/08	MRG	5/16/08	TJK	5/20/08	33758632	1



URS Geophysical Services
200 Orchard Ridge Dr., Ste. 101
Gaithersburg, MD 20878
(301) 258-9780

Geophysical Investigation Results
Seismic Refraction Survey

I-90 Snoqualmie Pass Structural Wall 1

Snoqualmie, Washington

DESIGNED BY		DRAWN BY		CHECKED BY		JOB NUMBER	FIGURE
MRG	5/15/08	MRG	5/16/08	TJK	5/20/08	33758632	2

APPENDIX C.2
Report of Geophysical Survey - Slide Curve Median Wall

Northwest Geophysical Associates, Inc.

1600 SW Western Boulevard, Suite 200
PO Box 1063, Corvallis, OR 97339-1063
Phone: (541) 757-7231   FAX: (541) 757-7331
www.nga.com

December 3, 2009
NGA Ref: 717

Mr. Thomas Badger
Washington State Department of Transportation
State Materials Laboratory - Geotechnical Division
PO Box 47365
Olympia, WA 98504-7365

Re: **DRAFT**
Seismic Refraction and MASW Surveys
I-90 Snoqualmie Pass Phase 1C

Dear Mr. Badger:

This letter report conveys the results of a pair of seismic refraction surveys and a multi-channel analysis of surface waves (MASW) survey which Northwest Geophysical Associates, Inc. (NGA) conducted for the Washington State Department of Transportation (WSDOT) as part of a geotechnical investigation for the Hyak to Keechelus Lake portion of the I-90 Snoqualmie Pass East Project (Figure 1, Site Location Map). The work was carried out under NGA's contract with WDOT for On-call Geophysical Services.

This report covers two seismic survey areas:

Snow Shed Site:

The Snow Shed Site is immediately south of the avalanche snow shed covering the westbound lanes of I-90. The objective of the survey was to determine depth-to-bedrock for design of the road cut along the alignment south of the snow shed. NGA employed the seismic refraction technique to acquire depth-to-bedrock. One seismic refraction profile was run along a 630 foot alignment (Figure 2, Seismic Survey Plan). The seismic line ran between WSDOT stations 1363+50 and 1369+00 for the new alignment. A description of the seismic refraction method used to conduct the investigation is attached (Attachment B).

Slide Curve Site:

The Slide Curve Site is at mile post 59 on I-90, approximately 3,300 feet south of the Snow Shed Site. The objective of the survey was to determine thickness of fill/slide debris in a channel feature noted in that area during the original construction of I-90.

Initially a roadside multi-channel analysis of surface waves (MASW) survey was run in an attempt to use traffic noise as a surface wave source. A 600 foot MASW line was run between WSDOT stations 1403+00 and 1409+00 for the new alignment. However, insufficient coherent seismic energy was observed to allow a reliable interpretation of depth-to-bedrock. A description of the MASW technique is attached (Attachment C).

Following preliminary evaluation of the MASW data, NGA and WSDOT elected to proceed with a seismic refraction survey at that site. One seismic refraction profile was run along the same alignment.

SNOW SHED SITE

Field Survey

Northwest Geophysical Associates, Inc., together with Mr. Thomas Williams of Northland Geophysical, PLLC, performed the seismic refraction survey at the Snow Shed Site on October 12-14, 2009.

Along the Snow Shed alignment, seismic refraction data were acquired on one seismic profile, composed of three seismic spreads (SL12-SL14). Those profiles and spread locations are shown on Figure 2. WSDOT boring locations are also shown on that site plan. Interpreted profile is shown in Figure 3. The profile was 630 feet in length.

The locations of the seismic lines were established by Tom Badger of WDDOT and Tom Williams during a site visit on September 2, 2009. NGA established the locations of geophones and shot points along the seismic lines in the field using 300-foot tape measures and survey flagging. The geophone locations were marked with pin flags and their positions were surveyed by a WSDOT survey crew after the completion of the seismic survey. The surveyed elevations and locations were used to develop the interpretation results for this report.

The field investigation was performed using a 24-channel Geometrics GEODE seismograph to record the data. Two sources of seismic energy were employed: Electric shotgun blanks and a 30kg slide hammer. Electric shotgun blanks used for this survey were 300 grains of black powder with an electric primer. Typically 7-10 shots were used on each line including off end shots at both ends of the spread. All seismic refraction lines used a geophone spacing of 10 feet.

Data Processing & Interpretation

Data were processed using SeisImager software from Geometrics, Inc. and the OYO Corporation. Initial three layer models were constructed and then refined using the tomographic modeling capabilities of that software. The resulting tomographic model is shown as the color grid in Figure 3. The interpreted horizons, 4,000 feet/second and 9,000 feet/second, represent smoothed contours of 4,000 feet/second and

9,000feet/second. Smoothing was done manually by the interpreter using his best professional judgment as to which small scale features were artifacts of the software inversion and which features were well supported by the data.

Seismic Interpretation Results

The interpreted results of the seismic refraction survey are shown on the interpreted profile (Figure 3). The 4,000 feet/second and 9,000 feet/second horizons represent significant changes in velocity. Elevations and location coordinates for those horizons are included as Attachment A.

We note that modeled depths from refraction are actually minimum travel path distance from the geophones to the nearest bedrock, which will not be a vertical distance in areas of steep topography, or steeply dipping bedrock. With dipping planer horizons, the distance will be perpendicular to the plane of the horizon.

General Stratigraphy

Layer 1

Materials above the 4,000 feet/second velocity horizon on the seismic profiles (with velocities less than 4,000 feet/second) are interpreted to be overburden. Boring logs indicate this material is mostly composed of some organic material as well as silt, sand, and gravel sediments (colluvium).

Layer 2

Below the 4,000 feet/second velocity horizon seismic velocities are greater than 4,000 feet/second. This horizon corresponds with silt, sand, and gravel materials identified on the boring logs as well as some weathered bedrock. Velocities in this transitional zone increase gradationally to the 9,000 feet/second velocity horizon.

Layer 3

Layer 3 exhibits velocities in excess of 9,000 feet/second. This is interpreted as more competent bedrock. Boring logs indicate bedrock is meta-welded lapilli dacite tuff.

Seismic Lines 12-14

The interpretations of SL12-SL14 are shown in Figure 3. This profile showed a thin overburden, generally less than 10 feet over a transitional layer, generally less than 30 feet thick, over competent bedrock with velocities in excess of 9,000 feet/second.

Boring Log Data

Boring locations are shown on the site plan (Figure 2), and projected onto the interpreted profiles. These borings are offset 0 to 10 feet from the seismic lines. With the extreme topography the boring horizon depths or elevations are not expected to tie with the seismic horizons. However, the geology is expected to be similar.

Three borings fell within 10 feet of SL12-SL14. Boring RKS-09-07 was at seismic station 4. The boring log for RKS-09-07 showed 3 feet of overburden above meta-welded lapilli dacite tuff bedrock. Boring RKS-10-07 was at seismic station 160, offset 4 feet downslope from the seismic line. The boring log for RKS-10-07 showed 4 feet of organic and silty sand materials over meta-welded lapilli dacite tuff bedrock. Boring RKS-38-08 was at seismic station 355, offset 10 feet downslope from the seismic line. The boring log for RKS-38-08 showed 6 feet of silty sand, gravel, and cobbles over meta-welded lapilli dacite tuff bedrock. A 1 to 5 foot thick zone of loose to very-dense silty sand with gravel and cobbles at some locations was logged immediately above the bedrock interface.

SLIDE CURVE MASW

Field Survey

Northwest Geophysical Associates, Inc., performed the MASW survey at the Slide Curve Site on October 15-16, 2009. Along the Slide Curve alignment, MASW data were acquired on one profile, extending 600 linear feet between WSDOT stations 1403+00 and 1409+00. This profiles and spread locations are shown on Figure 2. WSDOT boring locations are also shown on that site plan.

The location of the MASW line was established by referencing WSDOT stationing at the site. NGA established the locations of geophones and shot points along the seismic line in the field using 300-foot tape measures and survey flagging. The geophone locations were marked with paint and their positions were surveyed by a WSDOT survey crew after the completion of the seismic survey. Surveyed locations are shown in Figure 2.

MASW Data Collection

The MASW field investigation was performed using two 24-channel Geometrics GEODE seismographs to record the data. A series of 117.5 foot linear MASW arrays comprised of fourty-eight 4.5 Hz geophones spaced 2.5 feet apart were used to collect MASW data along the 630 foot alignment. MASW lines/spreads were overlapped to provide a continuous velocity profile of the 630 foot alignment. Two sources of seismic energy were employed: A 30kg slide hammer and seismic surface waves caused by passing traffic.

'Active' source shots (e.g. slide hammer) were collected every 15 feet along the spread starting 30 feet off the end of the first array and ending at 630ft. Two hundred sixty-one 'passive' source data (e.g. traffic noise) records were recorded. In keeping with recently developed roadside MASW data collection procedures established by the Kansas Geological Survey, NGA collected passive roadside data that included collection times encompassing a variety of frequencies resulting from different vehicles (e.g. different gross weights, number of axels, velocities, etc.) traveling at different velocities along the MASW array. An explanation of the passive roadside MASW technique can be found at: http://www.kgs.ku.edu/software/surfseis/roadside.html.

MASW Data Processing & Interpretation

MASW data were processed using SurfSeis software from the Kansas Geologic Survey and SeisImager software from Geometrics, Inc. and the OYO Corporation. Overtones were constructed; dispersion curves were picked from the overtone data, and then processed together to create a 2D linear profile.

Analysis of the overtone files (dispersion curves) could not resolve the depth-to-bedrock, particularly where bedrock was less than 5-8 foot depth. Hence, NGA and WSDOT elected to proceed with the seismic refraction survey at this site.

SLIDE CURVE SEISMIC REFRACTION

Field Survey

Northwest Geophysical Associates, Inc., performed the seismic refraction fieldwork November 3-4, 2009. Seismic refraction data were acquired on one seismic profile, extending 630 linear feet between WSDOT stations 1403+00 and 1409+00. The profile and spread locations are shown on Figure 2. WSDOT boring locations are also shown on that site plan. Interpreted profile is shown in Figure 4.

Surveyed position and elevation data was used from our previous MASW survey in the same location. The surveyed elevations and locations were used to develop the interpretation results for this report.

Seismic Refraction Data Collection

NGA conducted a seismic refraction field investigation along the same alignment as the MASW investigation (Figure 2) using two 24-channel Geometrics GEODE seismographs to record the data. A 40kg propelled energy generator (PEG) was used as the sole seismic source. 11 shots were used on each line including off end shots at both ends of the spread. All seismic lines used a geophone spacing of 5 feet. Seismic lines/spreads were overlapped to provide a continuous velocity profile of the 630-foot alignment.

Seismic Refraction Data Processing & Interpretation

Seismic Refraction data were processed using SeisImager software from Geometrics, Inc. and the OYO Corporation. A two-layer model was constructed. The two-layer model is shown in Figure 4. The interpreted layers, 900 feet/second velocity material and 8,900 feet/second velocity material represent an average velocity in the layers above and below the dominant refractor surface.

The interpreted results of the seismic refraction survey are shown on the interpreted profile (Figure 4). The 900 feet/second and 8,900 feet/second horizons represent significant changes in velocity. Elevations and location coordinates for those horizons are included as Attachment A.

We note that modeled depths from refraction are actually minimum travel path distance from the geophones to the nearest bedrock, which will not be a vertical distance in areas of steep topography, or steeply dipping bedrock. With dipping planer horizons, the distance will be perpendicular to the plane of the horizon.

Interpreted Stratigraphy

Layer 1

Materials in the 900 feet/second layer on the seismic profiles (with velocities near 900 feet/second) are interpreted to be fill and/or slide debris. Boring logs indicate this material is mostly comprised of gravel and some silt.

Layer 2

Layer 2 exhibited a range of high velocities, best represented by 8,900 feet/second. This layer corresponds with andesite and lapilli tuff units identified on the boring logs.

Seismic Lines 15-17

The interpretations of seismic lines 15-17 are shown in Figure 4. This profile showed a varying thickness wedge of material, becoming no deeper than 25 feet, over competent bedrock with velocities near 8,900 feet/second.

Two borings fell on seismic lines 15-17. SW2-001 is located at seismic station 445. The boring log for SW2-001 showed 10.5 feet of overburden above andesite bedrock. Boring SW2-003 is located at seismic station 610. The boring log for SW2-003 showed 1.5 feet of overburden over lapilli tuff bedrock.

Boring Log Data

Boring locations are shown on the Site Plan, Figure 2, and projected onto the interpreted profiles. Contacts indicated at depth in the boring logs correlate well with the interpreted interface for seismic velocity layers 1 and 2.

CLOSURE

Northwest Geophysical Associates, Inc. performed this work in a manner consistent with the level of skill ordinarily exercised by members of the profession currently practicing under similar conditions. No warranty, express or implied, beyond exercise of reasonable care and professional diligence, is made. This report is intended for use only in accordance with the purposes of the study described within.

Please feel free to contact us if you have any questions or comments regarding this information, or if you require further assistance. We appreciated the opportunity to work with you on this project and look forward to providing you with geophysical services in the future.

Sincerely,

Northwest Geophysical Associates, Inc.

Rowland B. French, L.G.
President

Neil T. McKay
Project Geophysicist

Figures 1-4
Attachments A-C

File: NGA Snoqualmie Pass Phase 1C Rpt03.doc
NGA Project: 717

LIST OF FIGURES

LIST OF ATTACHMENTS

NGA Project #: 717 FILE: SNOQUALMIE1C_SITE_2000i.DWG DATE: NOV 2009 REVISION: A-24-NOV-09

0 45 90

SCALE (miles)

FIGURE 1

SITE LOCATION

Phase 1C Seismic Refraction Survey
I-90 Snoqualmie Pass East Project
Hyak, Washington

Prepared by:

Northwest Geophysical Associates, Inc.
P.O. Box 1063, Corvallis, Oregon 97339

REVISION: B-2-DEC-09 DATE: NOV-2009 FILENAME: NGA Survey 1C_V2.map NGA PROJECT #: 717

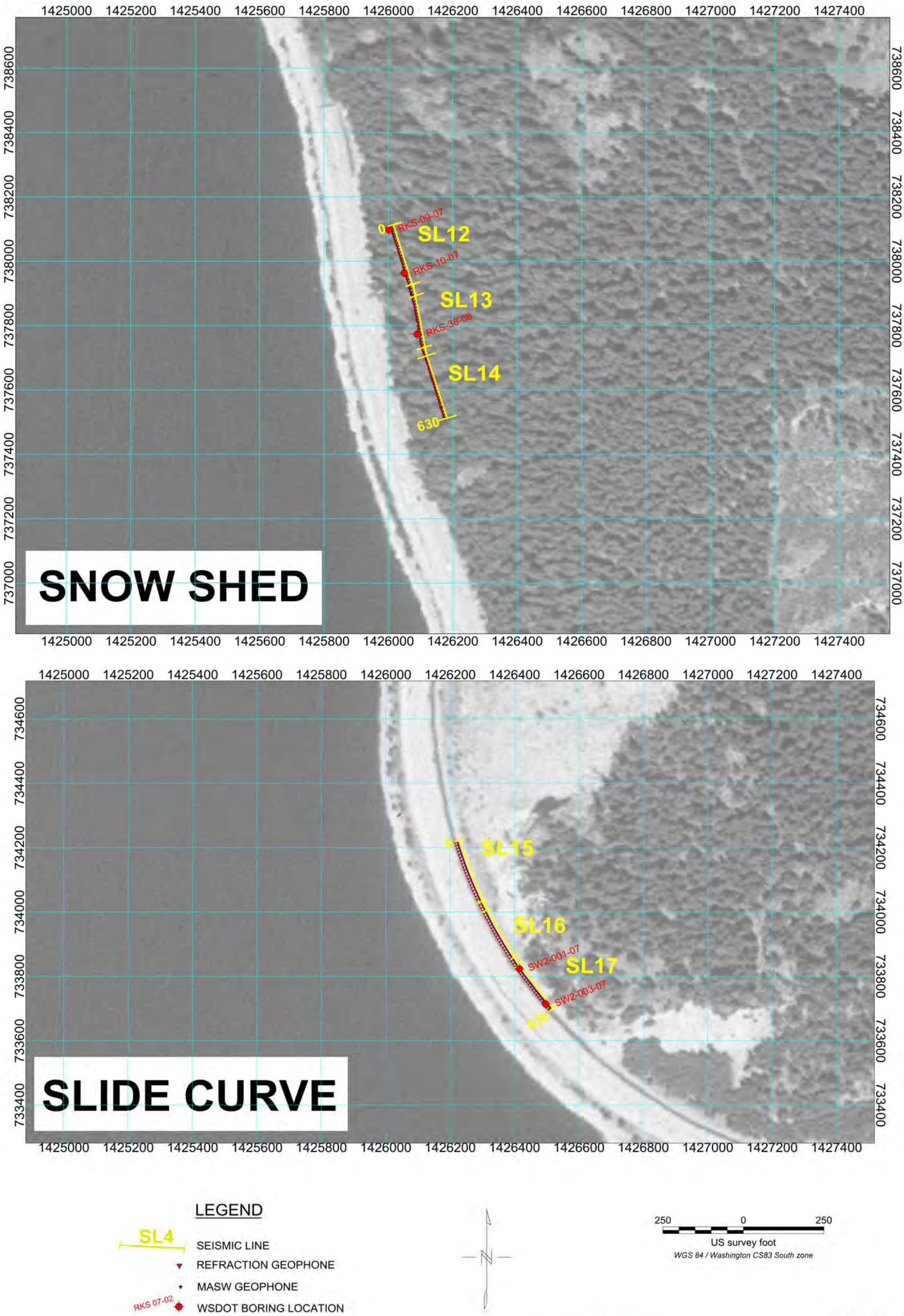


FIGURE 2

PRELIMINARY

Prepared by:

Northwest Geophysical Associates, Inc.

Seismic Survey Plan

Phase 1C Seismic Refraction Survey
I-90 Snoqualmie Pass East Project
Hyak, Washington

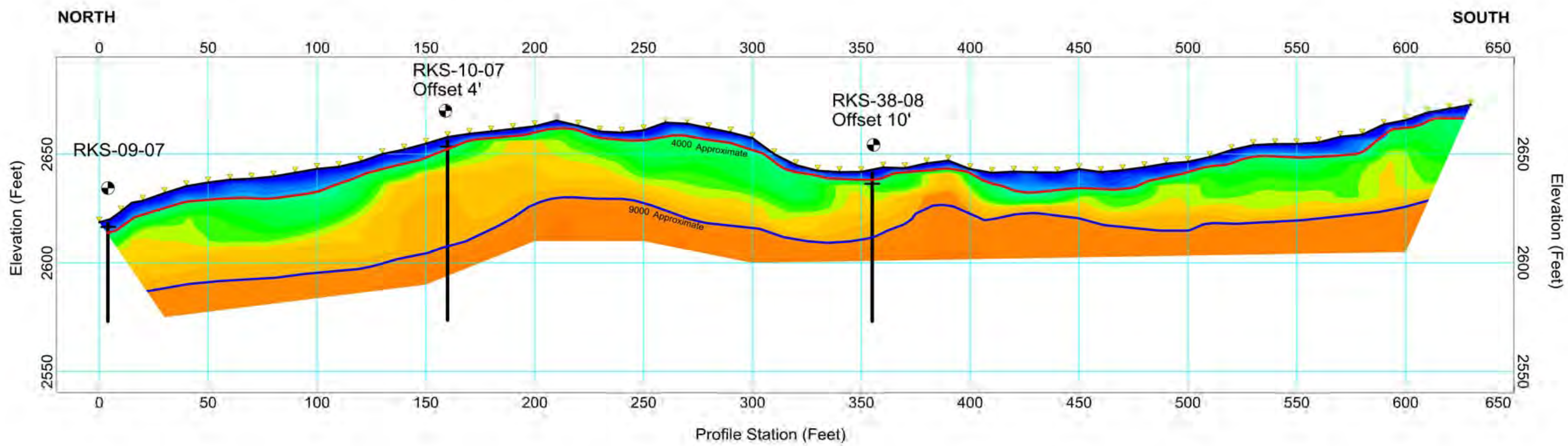
NGA PROJECT #: 717

FILENAME: SL12-14.map

DATE: OCT-2009

REVISION: A-28-OCT-09

Seismic Lines 12-14



LEGEND

GEOPHONE

WSDOT BORINGS
with OFFSET FROM PROFILE

25 0 25 50 75
(feet)

Seismic Velocity
Feet/Second

INTERPRETATION

4000 (Approximate) — WEATHERED BEDROCK - APPROXIMATELY 4000 ft/sec

9000 (Approximate) — COMPETENT BEDROCK - APPROXIMATELY 9000 ft/sec

PRELIMINARY

FIGURE 3

Seismic Lines 12-14

Interpreted Velocity Section
Phase 1C Seismic Refraction Survey
I-90 Snoqualmie Pass East Project
Hyak, Washington

Prepared By:

Northwest Geophysical Associates, Inc.

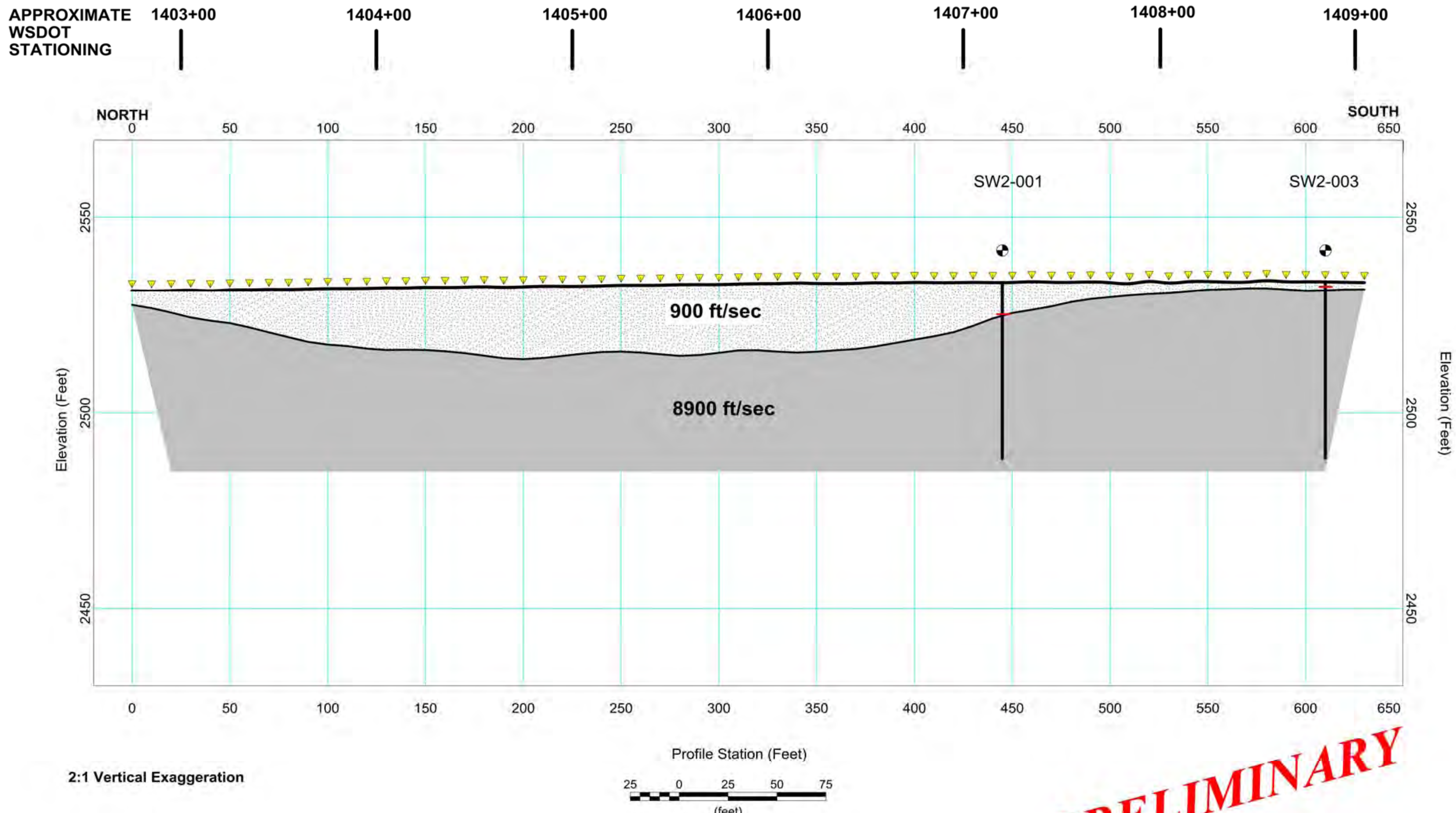
NGA PROJECT #: 717

FILENAME: SL1-3SC.map

DATE: OCT-2009

REVISION: C-1-DEC-09

Seismic Lines 15-17



PRELIMINARY

LEGEND

- GEOPHONE
- WSDOT BORINGS

INTERPRETATION

- FILL/SLIDE DEBRIS (Gravel with some sand and silt - from WSDOT) - APPROXIMATELY 900 ft/sec
- COMPETENT ROCK (Lapilli Tuff / Andesite - from WSDOT) - APPROXIMATELY 8900 ft/sec

Prepared By:

Northwest Geophysical Associates, Inc.

FIGURE 4

Seismic Lines 15-17

Interpreted Velocity Section
Phase 1C Seismic Refraction Survey
I-90 Snoqualmie Pass East Project
Hyak, Washington

Phase 1C Seismic Refraction Survey
I-90 Snoqualmie Pass East Project
Hyak, Washington

Attachment A

Seismic Depth Interpretation Spreadsheet

SL	gp	X-Loc	Surface SURF. ELEV.	Top of L2 elev	ROCK L3 elev	Top of L2 depth	ROCK L3 depth	NORTHING	EASTING
12	1	0	2618.6	2612.7	2582.4	NA	NA	738106.8	1426007.1
12	2	10	2623.6	2616.1	2584.7	NA	NA	738099.6	1426009.5
12	3	20	2628.5	2622.1	2586.8	NA	NA	738091.3	1426012.7
12	4	30	2632.1	2625.3	2588.5	NA	NA	738082.3	1426015.7
12	5	40	2635.2	2628.0	2590.1	NA	NA	738073.5	1426018.5
12	6	50	2637.0	2629.0	2591.2	NA	NA	738063.7	1426021.6
12	7	60	2638.2	2629.6	2591.8	NA	NA	738054.8	1426024.6
12	8	70	2638.7	2629.7	2592.6	NA	NA	738045.2	1426027.8
12	9	80	2639.7	2629.8	2593.4	NA	NA	738036.0	1426030.4
12	10	90	2641.5	2631.0	2594.5	NA	NA	738026.3	1426033.5
12	11	100	2643.2	2632.9	2595.6	NA	NA	738016.8	1426036.7
12	12	110	2644.2	2636.3	2596.4	NA	NA	738007.4	1426039.8
12	13	120	2646.5	2640.5	2597.2	NA	NA	737998.8	1426042.5
12	14	130	2650.0	2643.2	2600.1	NA	NA	737989.3	1426045.3
12	15	140	2652.1	2645.67	2602.68	NA	NA	737979.4	1426047.9
12	16	150	2654.8	2648.63	2604.68	NA	NA	737970.3	1426050.1
12	17	160	2657.9	2652.82	2607.86	NA	NA	737961.6	1426054.8
12	18	170	2659.3	2656.08	2610.36	NA	NA	737951.5	1426056.4
12	19	180	2660.4	2657.38	2615.34	NA	NA	737942.5	1426058.9
12	20	190	2661.6	2658.32	2620.86	NA	NA	737933.2	1426062.4
12	21	200	2662.8	2660.08	2626.68	NA	NA	737923.1	1426064.5
12	22	210	2665.4	2661.64	2629.75	NA	NA	737913.5	1426066.7
12	23	220	2663.1	2661.05	2630.16	NA	NA	737902.5	1426070.4
12	24	230	2660.8	2658.04	2629.83	NA	NA	737894.7	1426072.2
13	1	200	2663.1	2660.08	2626.68	NA	NA	737922.4	1426064.8
13	2	210	2664.2	2661.64	2629.75	NA	NA	737912.7	1426066.9
13	3	220	2663.0	2661.05	2630.16	NA	NA	737903.4	1426070.0
13	4	230	2660.4	2658.04	2629.83	NA	NA	737893.9	1426072.7
13	5	240	2659.9	2656.82	2629.66	NA	NA	737883.7	1426074.9
13	6	250	2660.9	2656.6	2627.71	NA	NA	737874.2	1426078.1
13	7	260	2664.5	2658.21	2624.65	NA	NA	737864.6	1426080.8
13	8	270	2664.0	2658.23	2620.82	NA	NA	737854.7	1426083.0
13	9	280	2662.0	2656.72	2618.47	NA	NA	737845.1	1426084.0
13	10	290	2660.0	2655.3	2616.96	NA	NA	737835.7	1426086.2
13	11	300	2657.3	2651.74	2616.19	NA	NA	737826.2	1426088.3
13	12	310	2650.0	2646.58	2613.6	NA	NA	737817.2	1426088.7
13	13	320	2644.9	2642.26	2611.22	NA	NA	737808.6	1426092.7
13	14	330	2642.3	2640.38	2609.8	NA	NA	737797.7	1426093.2

SL	gp	X-Loc	Surface SURF. ELEV.	Top of L2 elev	ROCK L3 elev	Top of L2 depth	ROCK L3 depth	NORTHING	EASTING
13	15	340	2641.8	2638.51	2609.63	NA	NA	737788.5	1426095.0
13	16	350	2641.8	2638.6	2610.87	NA	NA	737778.3	1426096.7
13	17	360	2643.8	2639	2613.9	NA	NA	737769.0	1426098.3
13	18	370	2643.5	2641.43	2617.87	NA	NA	737757.9	1426099.9
13	19	380	2645.7	2642.48	2625.02	NA	NA	737748.6	1426100.3
13	20	390	2647.0	2643.39	2626.4	NA	NA	737739.0	1426103.8
13	21	400	2643.1	2641.11	2622.69	NA	NA	737729.6	1426106.4
13	22	410	2641.9	2636.5	2620.43	NA	NA	737719.8	1426109.7
13	23	420	2641.9	2633.42	2621.84	NA	NA	737710.7	1426112.2
13	24	430	2641.6	2632.25	2622.77	NA	NA	737701.2	1426115.1
14	1	400	2642.7	2641.11	2622.69	NA	NA	737729.2	1426105.4
14	2	410	2641.4	2636.5	2620.43	NA	NA	737719.9	1426109.0
14	3	420	2642.0	2633.42	2621.84	NA	NA	737710.5	1426112.4
14	4	430	2641.6	2632.25	2622.77	NA	NA	737700.7	1426115.2
14	5	440	2641.6	2633.43	2622.23	NA	NA	737691.4	1426118.6
14	6	450	2643.1	2634.56	2620.62	NA	NA	737682.1	1426121.5
14	7	460	2641.7	2634.26	2618.29	NA	NA	737672.5	1426125.0
14	8	470	2642.6	2633.98	2616.94	NA	NA	737663.1	1426127.7
14	9	480	2644.0	2636.84	2615.71	NA	NA	737653.2	1426130.5
14	10	490	2645.7	2639.33	2614.92	NA	NA	737643.7	1426133.2
14	11	500	2646.5	2642.0	2615.5	NA	NA	737634.2	1426136.4
14	12	510	2648.7	2644.7	2618.3	NA	NA	737625.3	1426139.7
14	13	520	2651.9	2645.9	2618.8	NA	NA	737615.7	1426142.1
14	14	530	2654.1	2648.9	2618.9	NA	NA	737606.4	1426144.7
14	15	540	2654.6	2648.9	2619.1	NA	NA	737597.2	1426147.8
14	16	550	2654.6	2648.6	2619.6	NA	NA	737587.5	1426151.0
14	17	560	2655.4	2648.9	2620.4	NA	NA	737577.8	1426154.7
14	18	570	2658.0	2649.6	2621.6	NA	NA	737568.5	1426157.5
14	19	580	2659.0	2651.1	2622.7	NA	NA	737559.7	1426159.9
14	20	590	2663.6	2658.3	2623.9	NA	NA	737547.8	1426163.2
14	21	600	2665.6	2662.5	2625.7	NA	NA	737542.6	1426164.2
14	22	610	2669.1	2665.21	2628.48	NA	NA	737532.1	1426168.6
14	23	620	2670.9	2666.39	2630.84	NA	NA	737522.4	1426171.1
14	24	630	2672.7	2666	2631.91	NA	NA	737512.9	1426173.9
15	1	0	2531.2	2527.7	NA	3.52	NA	734215.5	1426215.5
15	2	10	2531.1	2526.8	NA	4.32	NA	734205.9	1426218.3
15	3	20	2531.2	2525.7	NA	5.53	NA	734196.5	1426221.4

SL	gp	X-Loc	Surface SURF. ELEV.	Top of L2 elev	ROCK L3 elev	Top of L2 depth	ROCK L3 depth	NORTHING	EASTING
15	4	30	2531.3	2524.4	NA	6.9	NA	734187.0	1426224.7
15	5	40	2531.2	2523.6	NA	7.56	NA	734177.7	1426227.8
15	6	50	2531.4	2523.0	NA	8.4	NA	734168.2	1426231.0
15	7	60	2531.4	2521.9	NA	9.55	NA	734158.6	1426234.4
15	8	70	2531.5	2520.6	NA	10.92	NA	734149.2	1426237.7
15	9	80	2531.5	2519.4	NA	12.13	NA	734139.8	1426241.1
15	10	90	2531.6	2518.2	NA	13.45	NA	734130.6	1426244.6
15	11	100	2531.7	2517.5	NA	14.25	NA	734121.1	1426248.3
15	12	110	2531.8	2517.1	NA	14.66	NA	734111.8	1426251.8
15	13	120	2531.8	2516.5	NA	15.35	NA	734102.4	1426255.6
15	14	130	2531.9	2516.1	NA	15.8	NA	734093.4	1426259.5
15	15	140	2531.9	2516.1	NA	15.78	NA	734084.2	1426263.4
15	16	150	2532.1	2516.1	NA	15.96	NA	734075.0	1426267.3
15	17	160	2532.0	2515.8	NA	16.25	NA	734065.7	1426271.3
15	18	170	2532.1	2515.3	NA	16.82	NA	734056.6	1426275.5
15	19	180	2532.2	2514.7	NA	17.54	NA	734047.5	1426279.5
15	20	190	2532.1	2514.0	NA	18.11	NA	734038.4	1426283.5
16	1	200	2532.2	2513.8	NA	18.43	NA	734029.6	1426287.7
16	2	210	2532.4	2514.1	NA	18.29	NA	734020.5	1426292.0
16	3	220	2532.3	2514.6	NA	17.76	NA	734011.6	1426296.3
16	4	230	2532.3	2515.1	NA	17.22	NA	734002.8	1426301.0
16	5	240	2532.4	2515.6	NA	16.86	NA	733993.5	1426305.6
16	6	250	2532.6	2515.7	NA	16.92	NA	733984.8	1426310.2
16	7	260	2532.6	2515.5	NA	17.15	NA	733976.0	1426314.5
16	8	270	2532.6	2515.0	NA	17.63	NA	733967.1	1426319.1
16	9	280	2532.8	2514.6	NA	18.15	NA	733958.2	1426323.7
16	10	290	2532.8	2514.8	NA	17.98	NA	733949.5	1426328.5
16	11	300	2532.8	2515.4	NA	17.41	NA	733940.8	1426333.3
16	12	310	2532.9	2516.0	NA	16.94	NA	733932.2	1426338.1
16	13	320	2533.0	2516.0	NA	16.99	NA	733923.8	1426343.1
16	14	330	2533.0	2515.7	NA	17.36	NA	733915.1	1426347.9
16	15	340	2533.2	2515.5	NA	17.72	NA	733906.6	1426353.1
16	16	350	2533.1	2515.7	NA	17.42	NA	733898.1	1426358.2
16	17	360	2533.1	2516.0	NA	17.02	NA	733889.1	1426363.8
16	18	370	2533.1	2516.3	NA	16.76	NA	733880.7	1426369.0
16	19	380	2533.2	2517.0	NA	16.24	NA	733872.2	1426374.3
16	20	390	2533.2	2517.9	NA	15.35	NA	733863.8	1426379.6
16	21	400	2533.3	2518.8	NA	14.59	NA	733855.3	1426385.2

Phase 1C Seismic Refraction Survey
I-90 Snoqualmie Pass East Project
Hyak, Washington

Attachment B
NGA Technical Note

Seismic Refraction

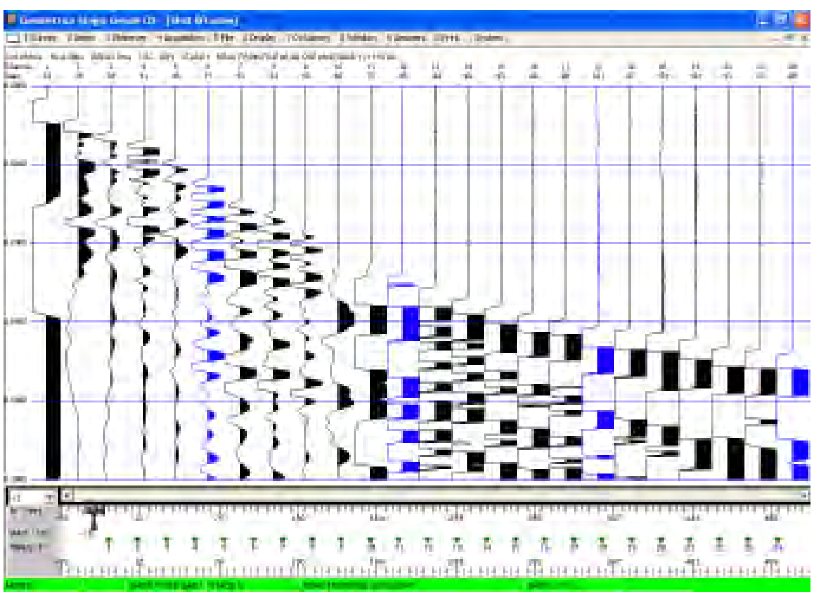
Geophysical Services

Environmental • Groundwater • Geotechnical

TECHNICAL NOTE

Seismic Refraction

Depth-to-Bedrock
Competence of Bedrock
Fault Mapping
Groundwater Investigations



COVER rev.2B, AUG. 2006

Northwest Geophysical Associates, Inc.
P.O. Box 1063, Corvallis, OR 97339-1063
(541) 757-7231 Fax: (541) 757-7331
www.nga.com info@nga.com

SEISMIC REFRACTION

INTRODUCTION

Seismic refraction is a commonly used geophysical technique to determine depth-to-bedrock, competence-of-bedrock, depth-to-water table, or depth to other seismic velocity boundaries. Seismic refraction is widely used in geotechnical and groundwater investigations. It is one of the classic geophysical techniques, presented in most introductory geophysical courses and texts.

PHYSICAL PRINCIPLES

The seismic refraction technique is illustrated in the schematic drawing, Figure 1. An impulsive source creates a seismic wave (sound wave), which travels through the earth. When source to receiver separation is small, the first arrival is generally the direct wave propagating through the surface layer. When the wave-front reaches a layer of higher velocity (e.g. bedrock), a portion of the energy is refracted, or bent, and travels along the refractor as a head wave, at the seismic velocity of the refractor (bedrock). Energy from the propagating head wave leaves the refractor at the critical angle of refraction and returns to the surface, where its arrival is detected by a series of geophones and recorded on a seismograph. The angle of refraction depends on the ratio of velocities in the two materials (Snell's Law). Travel times for the impulsive wave-front to reach each geophone are measured from the seismograph records. From those travel times, seismic velocities in each layer, and depths to each layer can be calculated.

Seismic refraction differs from seismic reflection, which is widely used in petroleum exploration. In reflection seismic the waves reflected off the geologic interface are utilized rather than the refracted arrivals.

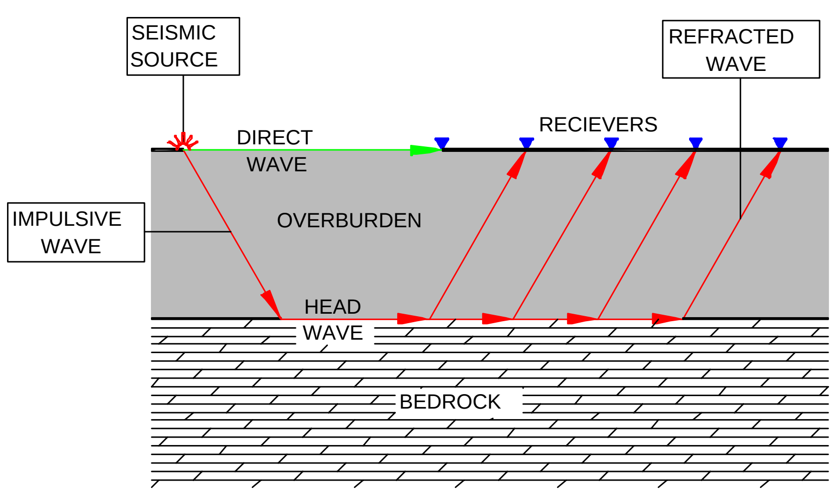


Figure 1
Seismic Refraction Geometry

FIELD PROCEDURES

When acquiring seismic refraction data a series of 12 or 24 geophones (receivers) are placed along the seismic line at set intervals, the *geophone interval*. Each of these set-ups of 12 or more geophones is termed a *spread*. The geophone interval is generally 5 to 50 feet depending on the desired resolution and the desired depth of exploration. Due to the geometry of refraction (governed by Snell's Law), it is necessary for the length of the seismic spread to be approximately 3 to 5 times the depth of the overburden in order to detect the primary refractor (i.e., the bedrock).

A series of 5 to 11 *shots* are initiated for each spread, one at each end, one or more beyond the ends (off end), and one or more along the spread. These additional shotpoints allow dipping interfaces, changes in overburden materials, and intermediate layers to be identified and resolved, increasing the accuracy of the depth-to-bedrock interpretation. Several spreads may be put together to form a longer refraction profile line.

Figure 2
Airless Jack Hammer

Several options are available for the seismic energy source. A sledge hammer striking an metal plate is one of the simplest and most common sources. An airless jackhammer (Figure 2) provides additional energy and may be effective if the bedrock is 30 or 40 feet, particularly if the overburden is sufficiently consolidated. A higher energy source, such as an elastic weight drop (Figure 3) or 8-gauge seismic shells, may be required if the overburden is

Figure 3
Elastic Weight Drop

loose and poorly consolidated, or if the bedrock interface is significantly deeper. Small explosive charges may be used where depth of exploration, near surface attenuation, or high ambient noise demand a stronger source.

DATA PROCESSING & INTERPRETATION

Processing begins with picking the time of the first arrival. While several automated picking programs are available, the first arrival times must be checked for accuracy and consistency and adjusted as needed.

Two basic methods of processing first arrival data are available, each with its strengths and limitations. These can be classified as delay-time techniques and tomographic techniques. Figures 4 and 5 show delay-time and tomographic interpretations of the same data.

Delay-Time Techniques

Delay-time methods treat the earth as discrete layers, with refracted waves coming off each layer. Generally, these methods assume laterally continuous, constant velocity representations of the subsurface. Delay-time methods are sometimes referred to as the plus-minus method or the time-term method. The generalized reciprocal method (GRM) is based on the delay-time approach. Historically, the delay-time is the classic method of interpreting seismic refraction data. Redpath, 1973, is an excellent reference for the basic delay-time technique.

Picked first arrivals are assigned a specific subsurface layer from which that seismic wave was refracted. This is a critical step in the interpretation process. Layer assignment is based on the slope of the travel-time curves and the recognition of parallel curve segments from adjacent shots.

Reduced traveltimes are calculated using refracted arrivals from each direction, effectively removing changing layer thickness on the velocity curve and leading to a better velocity

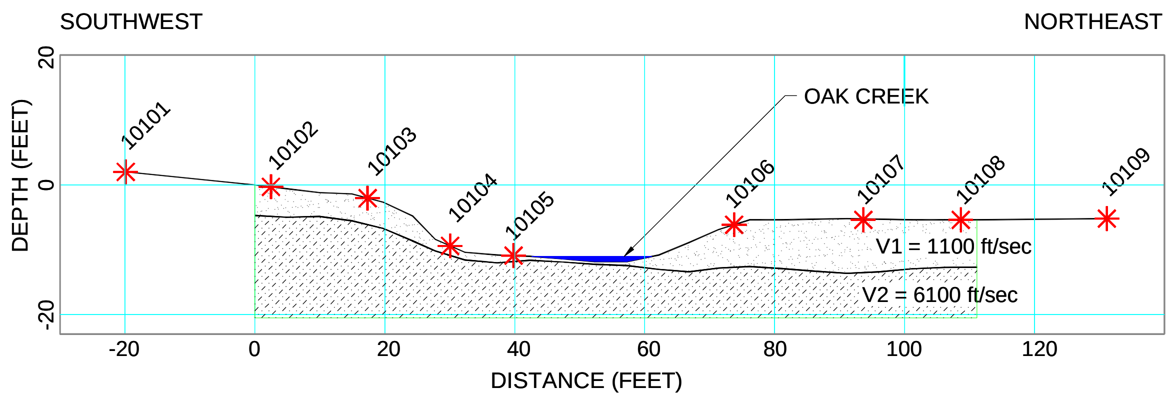


Figure 4
Layered Earth Interpretation

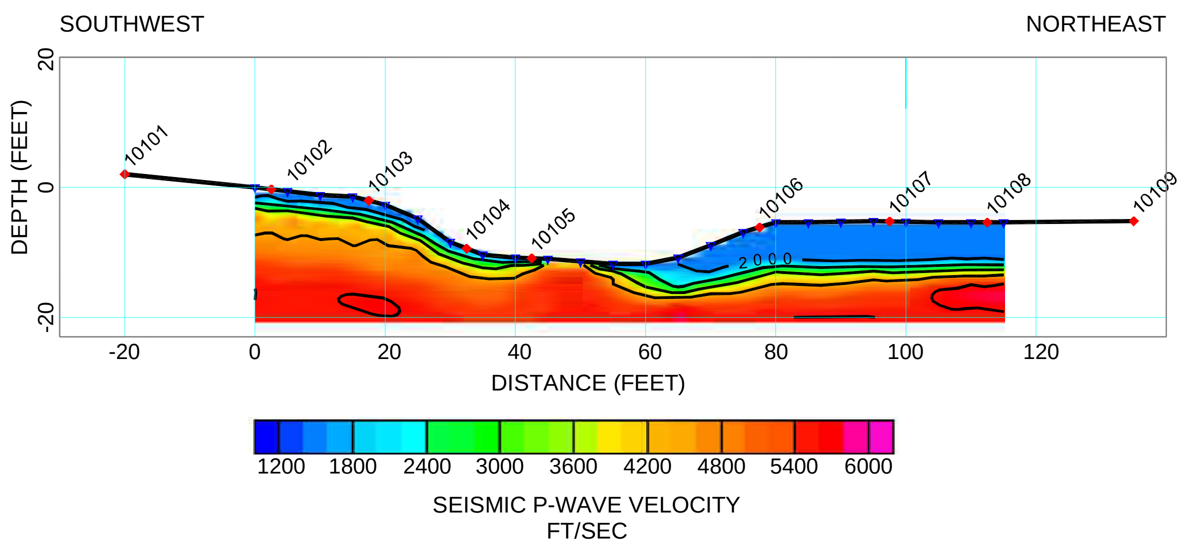


Figure 5
Tomographic Interpretation

determination. Refractor depth is computed from the velocity and delay time, at each geophone.

A common enhancement to the delay time method is to refine the model, using ray tracing. The ray tracing procedure adjusts the depth of the interface at the point the ray enters or emerges from the refractor.

Tomographic Techniques

Tomographic techniques partition the earth model into a mesh of finite-element or finite-difference *elements*, each with an assigned velocity. Element velocities are iteratively adjusted, altering the theoretical ray path(s) through the model. Velocities are adjusted until a best fit between the observed travel-times, and the modeled travel-times is arrived at.

Tomographic methods evolved rapidly in the late 1990s (Zhu et al., 2000). Today there are several commercial software packages available. Each has its own variation of the inversion method, choice of the starting model, and introduction of geologic constraints(see Sheehan et al., 2005).

Tomographic solutions allow for both lateral and vertical changes in velocity. Thus, they can approximate complex geologic situations such as faulting and weathering. However, where sharp geologic/velocity boundaries are present, tomographic interpretations will tend to represent them as gradational boundaries.

Tomographic solutions are inherently non-unique. Several earth models may yield similar travel-time curves. Therefore, it is often useful to look at the layered earth/delay-time solution along with the tomographic solution and geologic constraints to select the most appropriate.

APPLICATIONS

The product or deliverable from a seismic refraction survey is generally a profile, or cross section, along the seismic line showing depth-to-bedrock (or other primary refractor) at each geophone, and seismic velocities in the bedrock and the overburden. Often layers with intermediate velocities (corresponding to layers or units with varying consolidation or lithology) can be identified and resolved.

Seismic velocities relate to the soundness or competence of rock, and to the degree of consolidation, cementation, and/or saturation in soils. The Caterpillar Tractor Co. has developed a series of tables which empirically relate seismic velocities to the *rippability* of bedrock with their equipment (such as a D8 or D9 with one or several ripper teeth). Figure 6 is an example of those rippability tables.

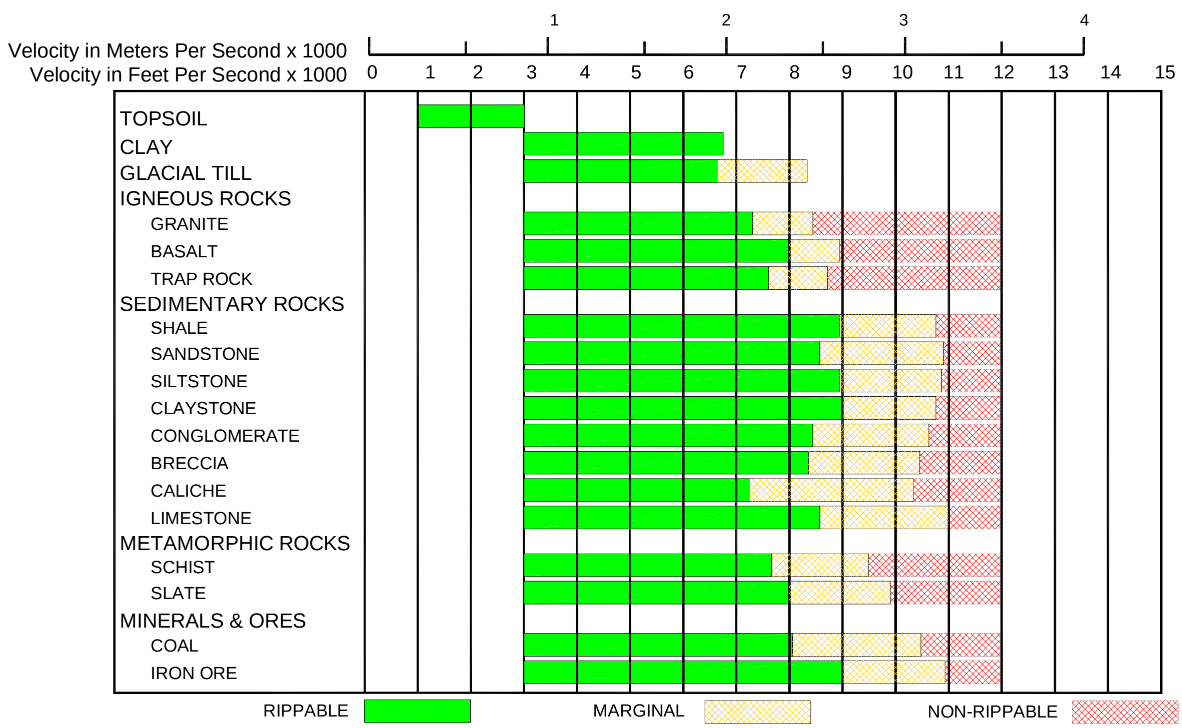
In geotechnical engineering, depth-to-bedrock and rippability surveys are commonly used for design and cost estimates for road cuts, pipelines, and other civil engineering projects. Groundwater applications of seismic refraction include mapping bedrock channels, identifying faults and fracture zones, and delineation of geologic boundaries to constrain hydrogeologic models.

LIMITATIONS

There are several inherent limitations to the seismic refraction technique. Fortunately, for most projects, the required geologic conditions are met, and the seismic refraction program can be successfully. However, these conditions must always be considered when planning a refraction survey, and when examining refraction data.

- **Velocity contrast**
  A velocity contrast between strata is required to refract the seismic wave. Hence, similar stratigraphic units are difficult to differentiate. Weathering zones with gradational changes present problems. Tomographic techniques can now handle some of the weathering zone problems

- **Velocity reversals**
  Standard refraction velocity analysis assumes that the velocity of successive layers increases with depth.
- **Hidden layers**
  Thin layers with small velocity contrast between adjacent layers may be hidden layers, and no first arrival refracted from that layer will be present. These layers are difficult to detect without additional borehole data.
- **Lateral velocity variations**
  Most standard interpretation software does not do a good job at handling geology with gross lateral variations in lithology. Fault zones can be detected from slower velocities in the brecciated fault gouge zones, but often are poorly imaged unless a detailed survey with short geophone spacing is carried out.
- **Shot points coverage**
  Tomographic models require dense shot coverage to properly constrain the models. This is an operational or cost constraint rather than a constraint inherent in the method.
- **Urban Noise**
  Urban noise (traffic, railways, construction, etc.) and natural noise (wind, waves, moving water, etc.) often limit the depth of exploration, or dictate a more energetic source.



D9L Ripper Performance
- Multi or Single Shank Ripper
- Estimated by Seismic Wave Velocities

Taken From:
Caterpillar Performance Handbook, 1983
Caterpillar Tractor Company

Note: Seismic compression wave analysis serves as only one indicator of rippability and the only proven test is a machine trial.

Figure 6
Example of Caterpillar Rippability Tables

Borehole or ground truth data is very useful in constraining the seismic interpretation. Seismic data is often used very effectively to interpolate between borings or to extrapolate away from borings. Downhole seismic velocities surveys are even more effective at constraining refraction interpretations.

FURTHER READING:

Caterpillar Tractor Company, 2004, Caterpillar Performance Handbook, Edition 35, Peoria, Illinois.

Dobrin, M.B. and Savit, C.H., 1988, Introduction to Geophysical Prospecting, 4th Edition, McGraw-Hill, New York, NY, 867 pp

Kassenaar, Dirk, and John Luttinger, 1993, Practical considerations in GRM refraction surveys in glacial terrains: *in* Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems, Environmental and Engineering Geophysical Society, San Diego, California, April 18-22, pp. 355-371.

Langston, Robert W., 1990, High Resolution refraction seismic data acquisition and interpretation: *in* Ward, S., ed., Geotechnical and Environmental Geophysics, Society of Exploration Geophysicists, Tulsa, OK, pp. 45-73.

Palmer, Derecke, 1980, The Generalized Reciprocal Method of Seismic Refraction Interpretation: Society of Exploration Geophysicists, Tulsa, Oklahoma, 104 pp.

Redpath, Bruce B., 1973, Seismic Refraction Exploration for Engineering Site Investigations: U.S. Army Engineer Waterways Experiment Station, Explosive Excavation Research Laboratory, Livermore, California, Technical Report E-73-4, (NTIS AD-768710) 51 pp.

Sheehan, J. R., Doll, W. E. and Mandell, W. A., 2005, An Evaluation of Methods and Available Software of Seismic Refraction Tomography Analysis, Journal of Environmental and Engineering Geophysics, v.10(1):21-34.

Zhu, T., Cheadle, S., Petrella, A., and Gray, S., 2000, First-arrival tomography: method and application: Expanded Abstracts SEG 70th Annual Meeting, 2028-2031p.

DISCUSSION OF GEOPHYSICAL TECHNIQUES

SEISMIC REFRACTION

Northwest Geophysical Associates, Inc.
P.O. Box 1063
Corvallis, Oregon 97339
http://www.nga.com
phone: (541) 757-7231

Rowland B. French, PhD, R.G.
Senior Geophysicist
Mark J. Villa
Project Geophysicist

Revision: August 2006
Printed :August 4, 2006
refraction_teq_2006-08A.doc

SL	gp	X-Loc	Surface SURF. ELEV.	Top of L2 elev	ROCK L3 elev	Top of L2 depth	ROCK L3 depth	NORTHING	EASTING
17	1	410	2533.3	2519.6	NA	13.67	NA	733846.8	1426390.6
17	2	420	2533.3	2520.7	NA	12.63	NA	733838.7	1426395.9
17	3	430	2533.4	2522.3	NA	11.07	NA	733830.6	1426401.6
17	4	440	2533.3	2524.2	NA	9.13	NA	733822.5	1426407.3
17	5	450	2533.3	2525.6	NA	7.77	NA	733814.5	1426413.1
17	6	460	2533.5	2526.4	NA	7.1	NA	733806.4	1426418.9
17	7	470	2533.4	2527.3	NA	6.11	NA	733798.5	1426425.0
17	8	480	2533.4	2528.4	NA	4.96	NA	733790.3	1426431.4
17	9	490	2533.5	2529.2	NA	4.28	NA	733782.5	1426437.5
17	10	500	2533.3	2529.6	NA	3.63	NA	733774.8	1426443.6
17	11	510	2533.0	2530.1	NA	2.91	NA	733766.7	1426449.8
17	12	520	2533.6	2530.4	NA	3.15	NA	733758.8	1426456.0
17	13	530	2533.2	2530.7	NA	2.52	NA	733750.8	1426462.1
17	14	540	2533.5	2531.1	NA	2.44	NA	733742.9	1426468.2
17	15	550	2533.6	2531.4	NA	2.12	NA	733735.2	1426474.3
17	16	560	2533.4	2531.6	NA	1.84	NA	733727.5	1426480.6
17	17	570	2533.4	2531.8	NA	1.64	NA	733719.9	1426487.0
17	18	580	2533.8	2531.8	NA	1.98	NA	733712.0	1426493.4
17	19	590	2533.5	2531.5	NA	2.01	NA	733704.5	1426500.0
17	20	600	2533.5	2531.2	NA	2.29	NA	733697.0	1426506.4
#N/A	RKS-09-07	#N/A	2621.1	#N/A	2618.1	#N/A	3.0	738098.0	1426001.9
#N/A	RKS-10-07	#N/A	2527.0	#N/A	2523.8	#N/A	3.2	737963.5	1426049.6
#N/A	RKS-38-08	#N/A	2523.1	#N/A	2517.1	#N/A	6.0	737773.3	1426089.4

Rock depths for borings are based on WSDOT boring logs.

Phase 1C Seismic Refraction Survey
I-90 Snoqualmie Pass East Project
Hyak, Washington

Attachment C
NGA Technical Note

MASW

Seismic Surface Wave Analysis

PHYSICAL PRINCIPLES

Surface wave methods examine the dispersion curve (velocity as a function of frequency) of Rayleigh surface waves to examine the near-surface, shear-wave velocity structure. Surface wave motion extends approximately ½ wavelength into the earth, the amplitude decaying exponentially with depth. Hence, higher frequencies (shorter wavelengths) are affected by the shallow materials, and the longer wavelengths are affected by deeper soils and/or rock. Thus, by measuring the changes in phase velocity with frequency we can determine the velocity structure with depth. The inversion process involves creating a hypothetical layered earth velocity model, calculating the theoretical surface wave response, and iteratively adjusting the velocities of the layers to minimize error between the calculated and observed response.

For Surface Wave analysis, NGA employs a combination of Multi-channel Analysis Surface Wave (MASW) and Micro-tremor Array Measurements (MAM). For the higher frequency, and shallow depth of investigation, the MASW uses an active impulsive source (e.g., a hammer) and a linear array of geophones. With the impulsive source, the surface wave train can be selected from the seismic records, omitting the earlier body waves (P-waves) from the analysis.

For the lower frequencies, and greater depth of investigation, MAM uses passive noise (e.g., traffic noise) and a 2 dimensional, L-shaped array. The L-shaped array allows determination of the direction of incidence of the signal onto the array. The MASW and MAM dispersion curves are then combined and inverted to arrive at the velocity model.

FIELD PROCEDURES

NGA records seismic data on a Geometrics Geode 24 channel signal enhancement seismograph. Digital computer files of the waveforms are recorded during the field surveys. The digital computer records are subsequently utilized for detailed velocity analysis using SeisImager Wave Equation by Geometrics.

MASW data are recorded using a linear array of 24 4.5-Hz geophones. Generally the initial geophone interval is set at 5 feet. Seismic signals are initiated at 15 to 30 feet off both ends of the seismic line. NGA often uses an airless jackhammer to generate the seismic signal and repeated signals are stacked to enhance the signal. Data are recorded at 0.500 millisecond intervals for 2 seconds. The geophone interval is then increased to 10 feet and a seismic signal are initiated at 20 to 50 feet off both ends of the seismic line. Data are again recorded at 0.500 millisecond intervals for 2 seconds.

Following acquisition of MASW data, MAM data are collected. A two dimensional L-shaped array is laid out utilizing 11 4.5-Hz geophones spaced 30 feet apart. The corner of the L-array is centered on the point of interest. The two dimensional aspect of the method utilized by the MAM method is important in that it allows an azimuth to be determined on the passive surface wave. Twenty records of passive, ambient signal are recorded for 30 seconds at a 2 millisecond sample intervals.

DATA PROCESSING AND INTERPRETATION

NGA uses SeisImager Wave Equation software by Geometrics of San Jose, California, to process

1600 SW Western Boulevard, Suite 200, PO Box 1063, Corvallis, OR 97339-1063
Phone: (541) 757-7231 FAX: (541) 757-7331 www.nga.com info@nga.com

surface wave data. In this processing suite, a dispersion curve of the velocity of the surface waves as a function of frequency is generated for each MASW shot point and for the combined records of the MAM data. Nominally, twenty (20) MAM records are used in development of the passive dispersion curve. The dispersion curves for the MASW and MAM data are then merged and smoothed. A least squares inversion using forward modeling is then used to approximate earth structure.

2D MASW PROFILES

The MASW technique can be extended to obtain a series of dispersion curves by moving the array laterally and repeating the data acquisition process. The resulting one-dimensional models can then be put together in a profile to produce a 2D shear-wave velocity profile.

In practice this is done, laying out a linear array of geophones and “shooting” into the array, i.e. hammering along the array between every 1 or 2 geophones. Traces which have a common midpoint (CMP) between the source and receiver are then collected (gathered) into one record. Each trace in the gather will have a different distance between source and receiver. The dispersion curve is then evaluated for each gather and the resulting velocity model plotted at the midpoint.

LIMITATIONS OF SURFACE WAVE ANALYSIS

Limitations of the seismic surface wave method include:

- The assumption of plane layers from source to receiver.
- Lateral inhomogeneities can produce errors not detectable in the data.
- Higher modes of dispersion which can give erroneous results.

REFERENCES

Martin, A.J. and Diehl, J.G. (2004), Practical experience using a simplified procedure to measure average shear-wave velocity to a depth of 30 m (Vs30), 13th World Conference on Earthquake Engineering, Vancouver, B.C., Canada.

Park, C.B., Miller, R.D. and Xia, J. (1999), Multichannel analysis of surface waves, *Geophysics*, 64(3): 800-803.

Xia, J., Miller, R.D. and Park, C.B. (1999), Estimation of near-surface shear-wave velocity by inversion of Rayleigh waves, *Geophysics*, 64(3): 691-700.

FILE: MASW_2007-07-21.doc
REVISION: 21-Jul-07

APPENDIX C.3
Snowshed COBL® Logs

COBL
CRUX Oriented Borehole Logging

Company	Washington State Dept. of Transportation
Location:	Interstate 90 - Snoqualmie Pass
Project:	I-90 Snoqualmie Pass East

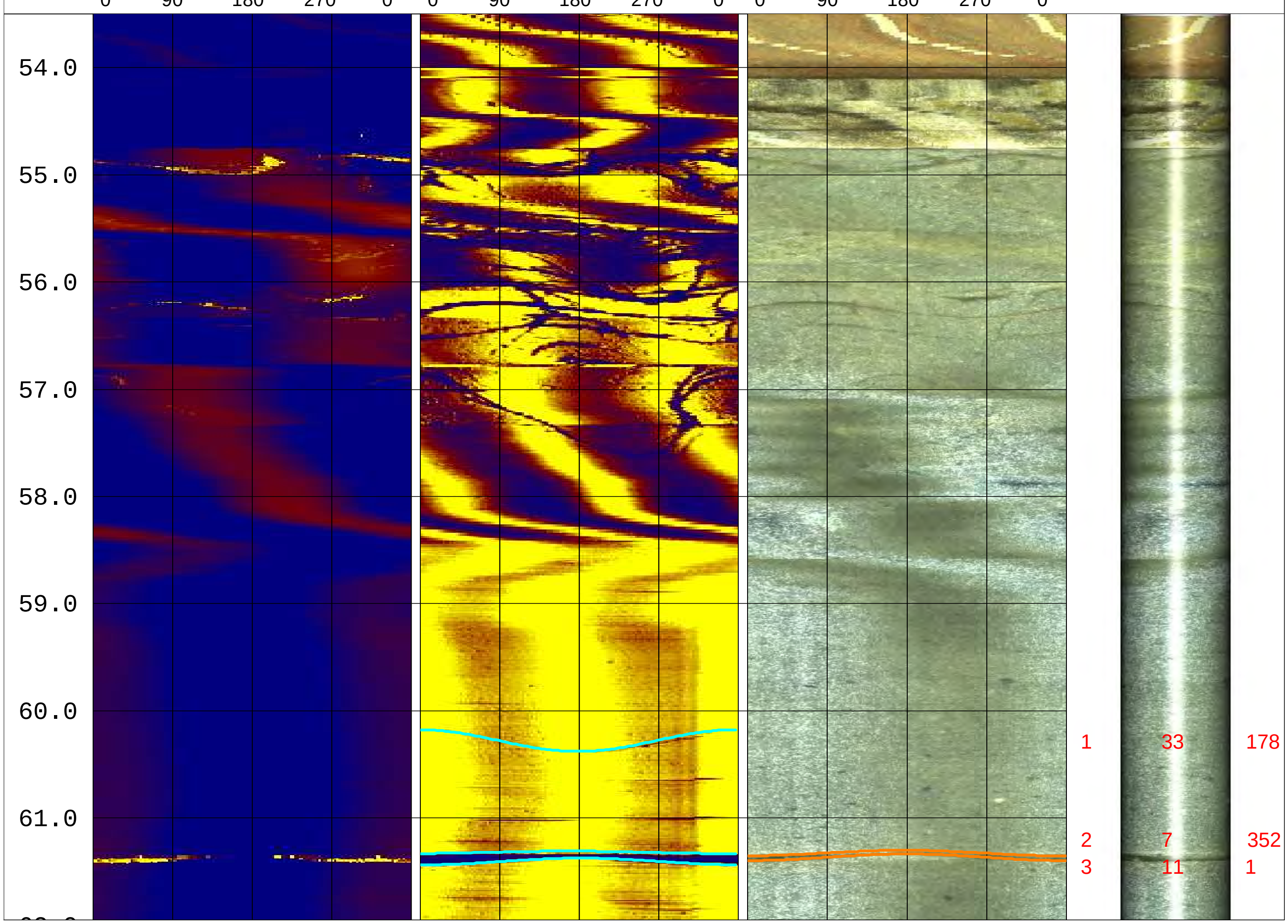
Date Logged:	June 4, 2009	Borehole ID:	SSD-006-09
File Name:	SSD00609-2M.wcl	Logged By:	F G Kruger

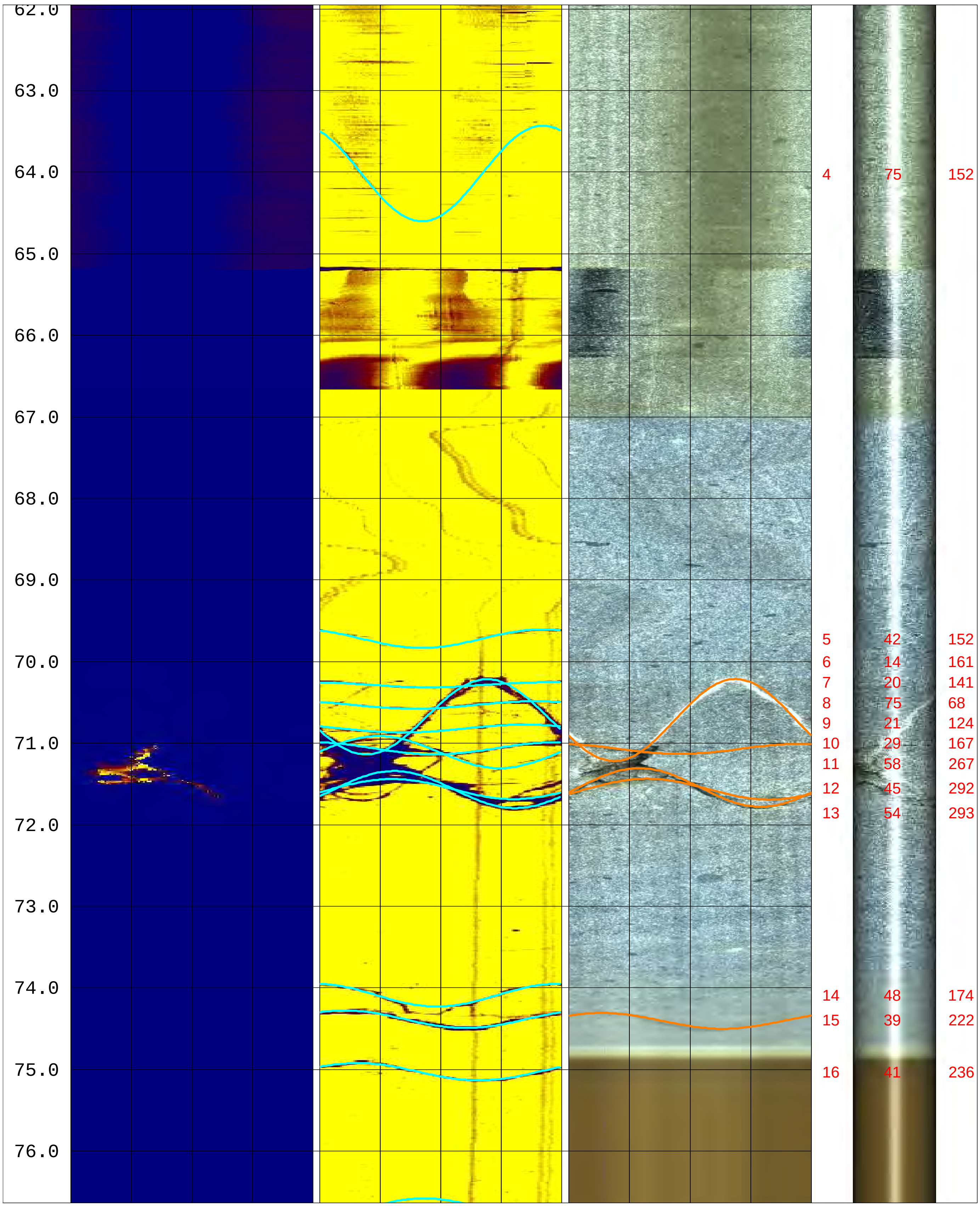
Notes:

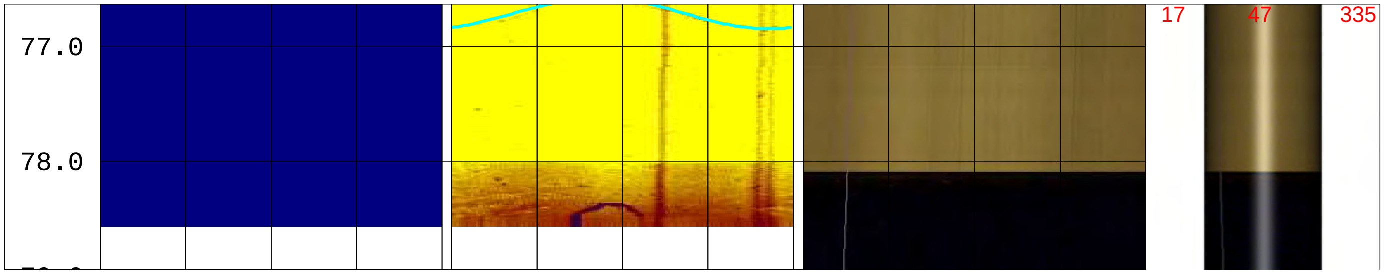
1) Azimuths reference True North. Magnetic declination of +17 degrees applied.
2) 3x Horizontal Exaggeration on HQ Televiewer Images.
3) Dip values presented in degrees from horizontal.
4) Dip direction presented in degrees of azimuth.
5) Simulated Core Image is viewed from north, east on left, west on right.
6) HQ hole 54.0-65.2, NQ hole 65.2-78.9.

Depth | Tool.TravelTime1-NM | Tool.Amplitude1-NM Acoustic Trace | Tool.Image-NM Optical Trace | Simulated Core Image

0° 90° 180° 270° 0°




62.0
63.0
64.0
65.0
66.0
67.0
68.0
69.0
70.0
71.0
72.0
73.0
74.0
75.0
76.0
4 75 152
5 42 152
6 14 161
7 20 141
8 75 68
9 21 124
10 29 167
11 58 267
12 45 292
13 54 293
14 48 174
15 39 222
16 41 236


77.0
78.0
17
47
335

COBL
CRUX Oriented Borehole Logging

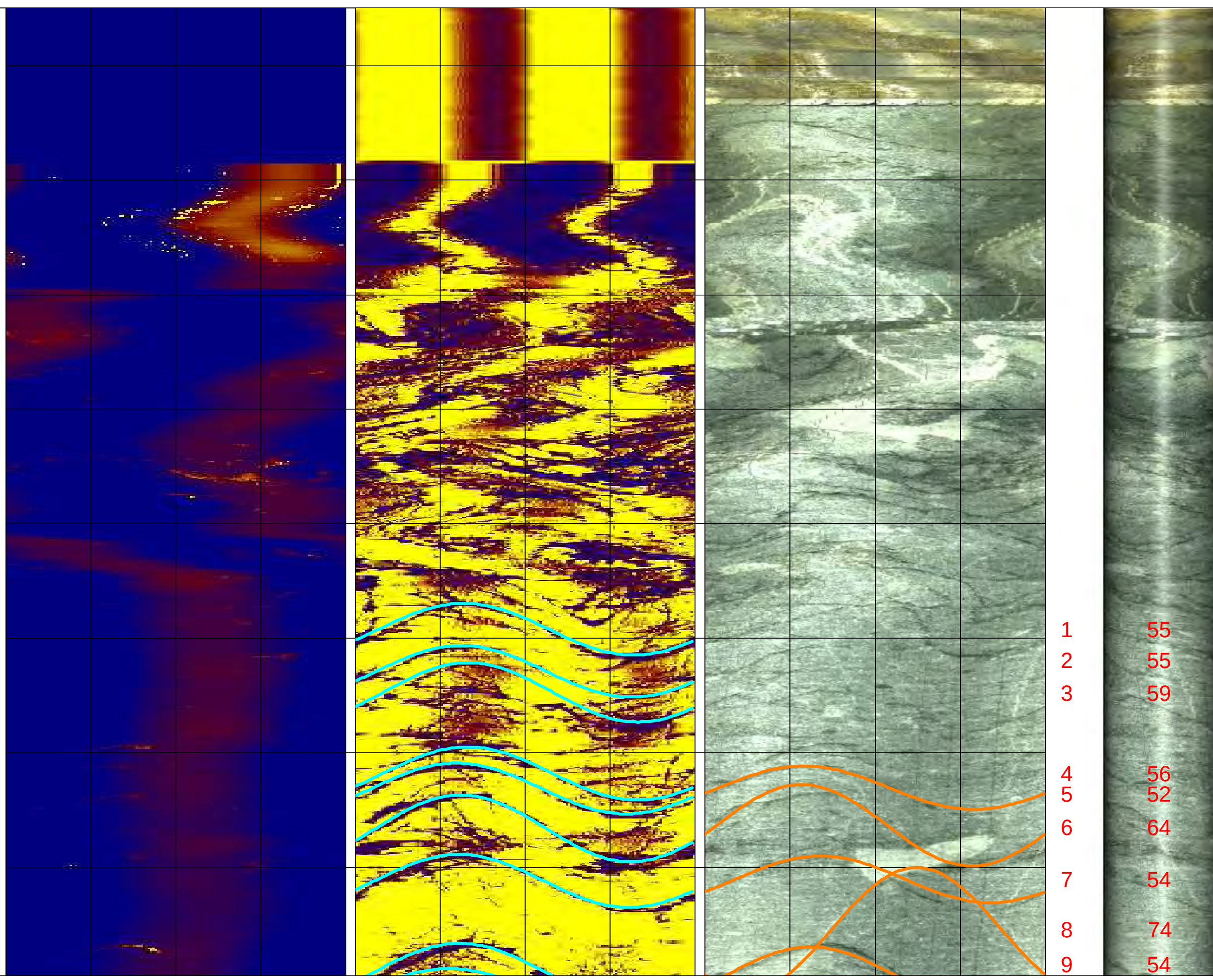
Company	Washington State Dept. of Transportation
Location:	Interstate 90 - Snoqualmie Pass
Project:	I-90 Snoqualmie Pass East

Date Logged:	June 1, 2009	Borehole ID:	SSD-007-09
File Name:	SSD00709-2M.wcl	Logged By:	F G Kruger

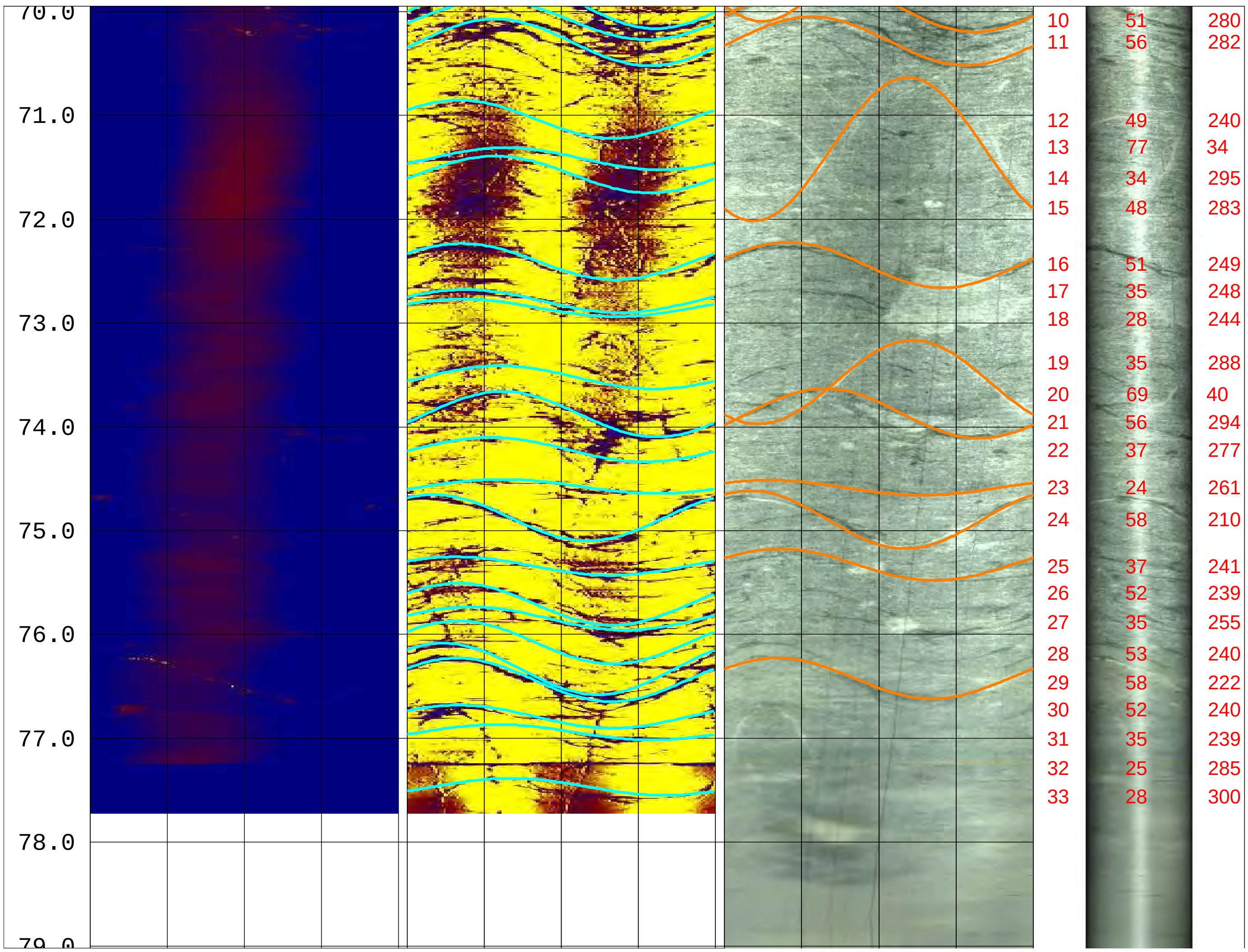
Notes:
1) Azimuths reference True North. Magnetic declination of +17 degrees applied.
2) 3x Horizontal Exaggeration on Televiewer Images.
3) Dip values presented in degrees from horizontal.
4) Dip direction presented in degrees of azimuth.
5) Simulated Core Image is viewed from north, east on left, west on right.

Depth	Tool.TravelTime1-NM	Tool.Amplitude1-NM Acoustic Trace 0° 90° 180° 270° 0°	Tool.Image-NM Optical Trace 0° 90° 180° 270° 0°	Simulated Core Image

62.0
63.0
64.0
65.0
66.0
67.0
68.0
69.0



#	Dip	Dip AZ
1	55	295
2	55	292
3	59	299
4	56	299
5	52	286
6	64	287
7	54	296
8	74	44
9	54	286

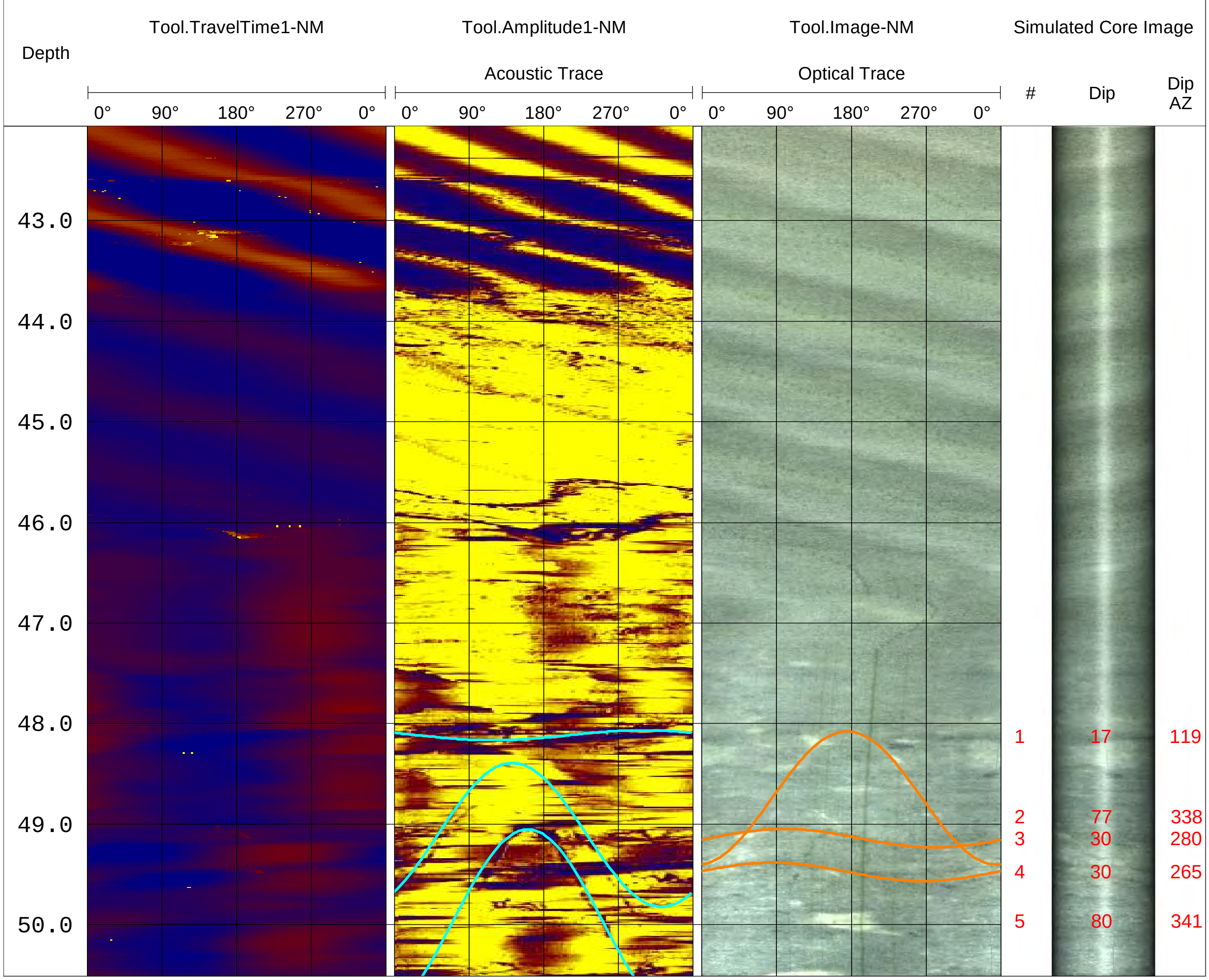

70.0
71.0
72.0
73.0
74.0
75.0
76.0
77.0
78.0
79.0
10 51 280
11 56 282
12 49 240
13 77 34
14 34 295
15 48 283
16 51 249
17 35 248
18 28 244
19 35 288
20 69 40
21 56 294
22 37 277
23 24 261
24 58 210
25 37 241
26 52 239
27 35 255
28 53 240
29 58 222
30 52 240
31 35 239
32 25 285
33 28 300

COBL CRUX Oriented Borehole Logging	Company	Washington State Dept. of Transportation
	Location:	Interstate 90 - Snoqualmie Pass
	Project:	I-90 Snoqualmie Pass East

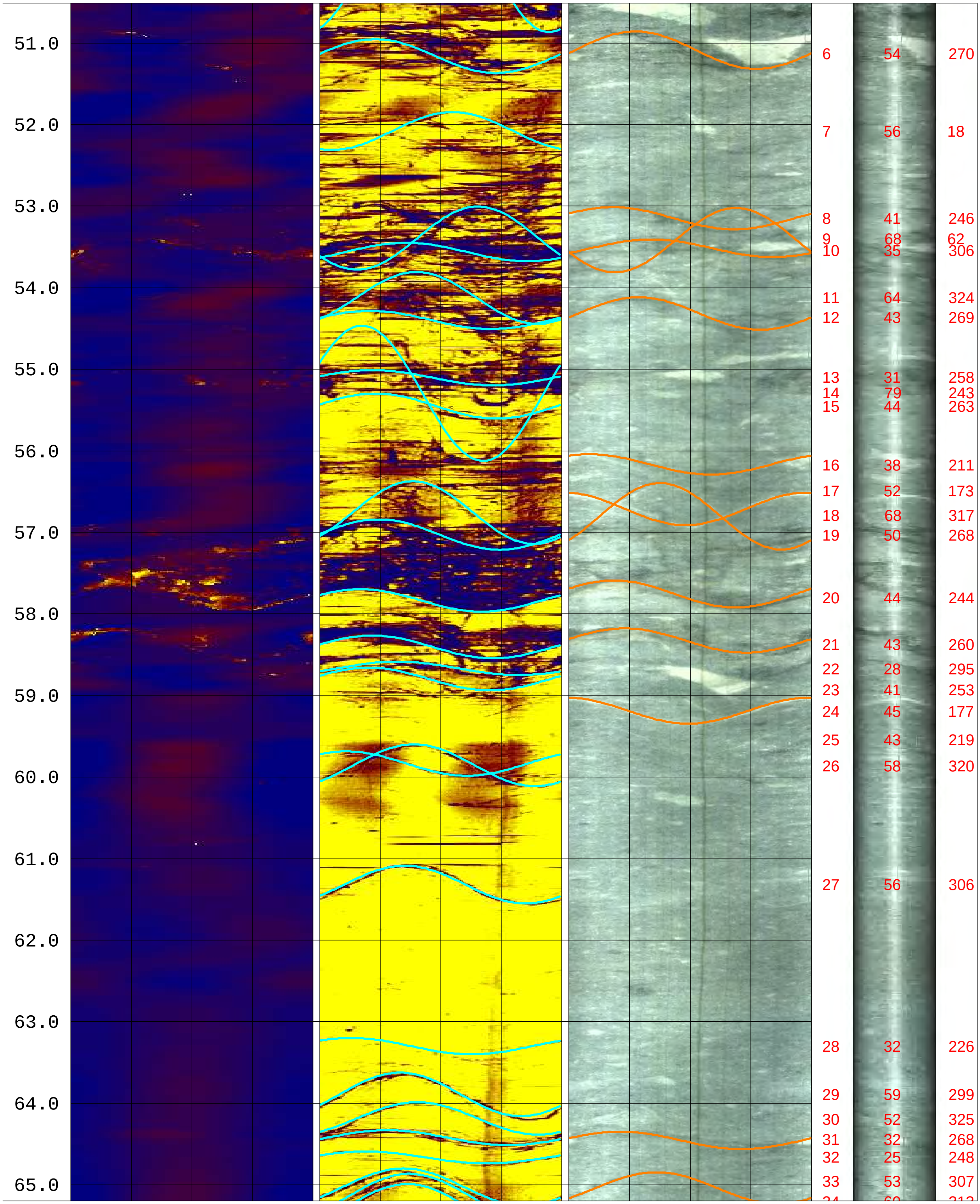
Date Logged:	June 11, 2009	Borehole ID: SSD-008-09
File Name:	SSD00809-2M.wcl	Logged By: F G Kruger

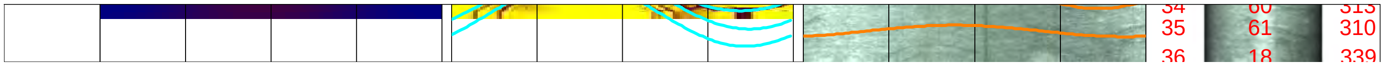
Notes:

1) Azimuths reference True North. Magnetic declination of +17 degrees applied.
2) 3x Horizontal Exaggeration on Televiewer Images.
3) Dip values presented in degrees from horizontal.
4) Dip direction presented in degrees of azimuth.
5) Simulated Core Image is viewed from north, east on left, west on right.



#	Dip	Dip AZ
1	17	119
2	77	338
3	30	280
4	30	265
5	80	341


51.0
52.0
53.0
54.0
55.0
56.0
57.0
58.0
59.0
60.0
61.0
62.0
63.0
64.0
65.0
6 54 270
7 56 18
8 41 246
9 68 62
10 35 306
11 64 324
12 43 269
13 31 258
14 79 243
15 44 263
16 38 211
17 52 173
18 68 317
19 50 268
20 44 244
21 43 260
22 28 295
23 41 253
24 45 177
25 43 219
26 58 320
27 56 306
28 32 226
29 59 299
30 52 325
31 32 268
32 25 248
33 53 307

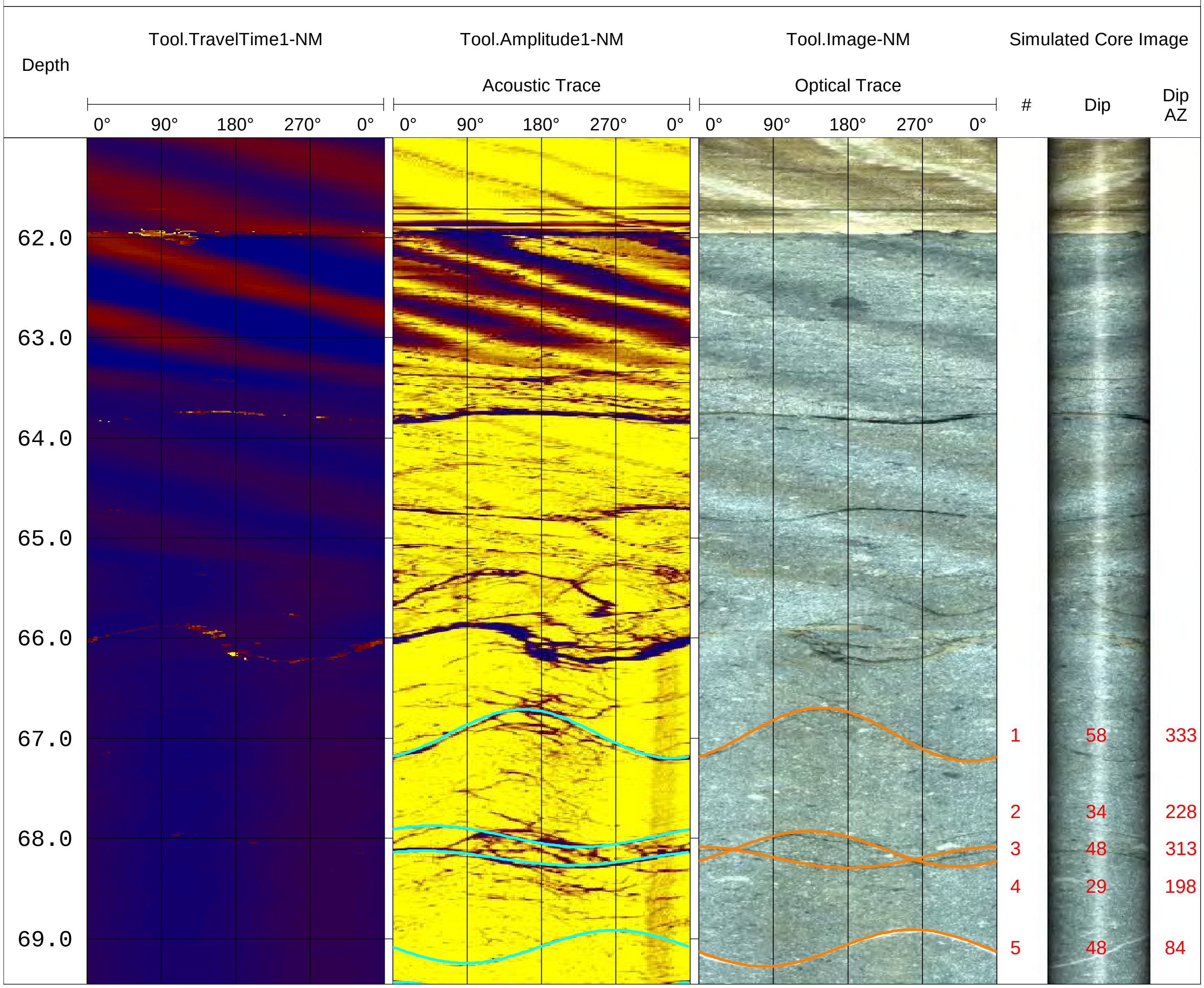

35
61
310

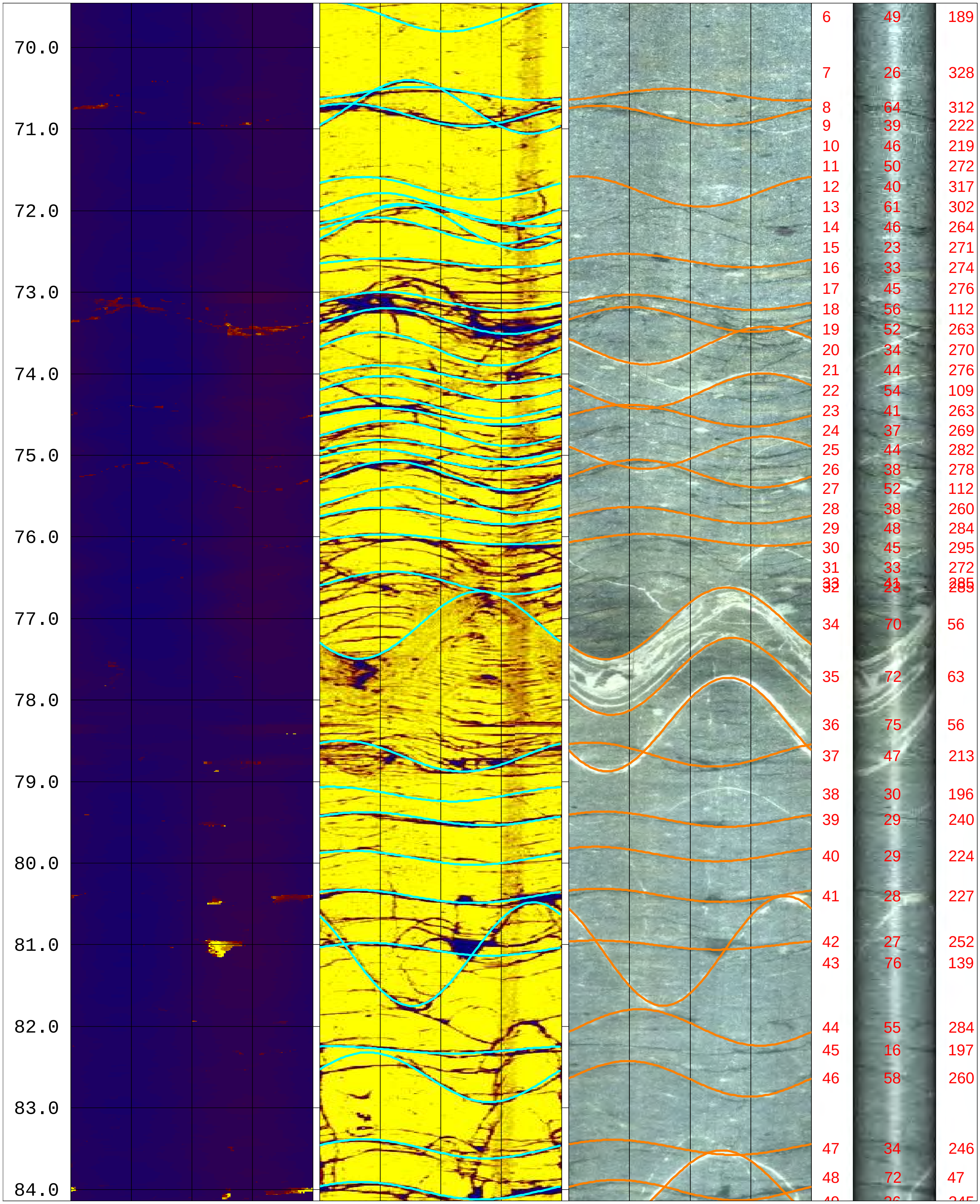
COBL
CRUX Oriented Borehole Logging

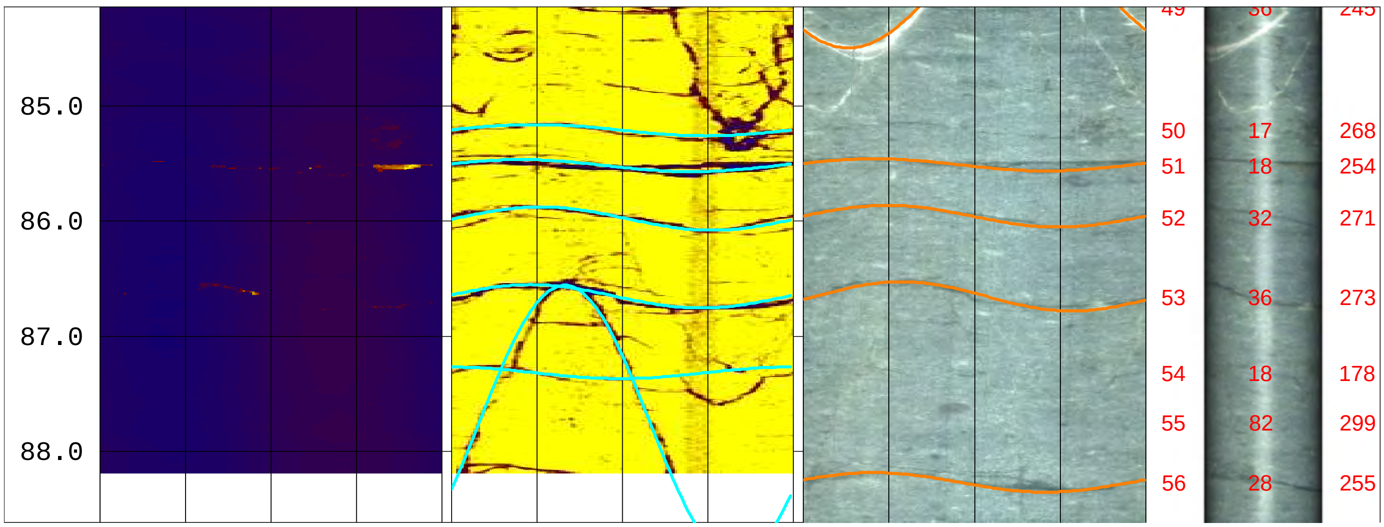
Company	Washington State Dept. of Transportation
Location:	Interstate 90 - Snoqualmie Pass
Project:	I-90 Snoqualmie Pass East

Date Logged:	June 13, 2009	Borehole ID:	SSD-009-09
File Name:	SSD00909-2M.wcl	Logged By:	F G Kruger

Notes:
1) Azimuths reference True North. Magnetic declination of +17 degrees applied.
2) 3x Horizontal Exaggeration on Televiewer Images.
3) Dip values presented in degrees from horizontal.
4) Dip direction presented in degrees of azimuth.
5) Simulated Core Image is viewed from north, east on left, west on right.




70.0
71.0
72.0
73.0
74.0
75.0
76.0
77.0
78.0
79.0
80.0
81.0
82.0
83.0
84.0
6 49 189
7 26 328
8 64 312
9 39 222
10 46 219
11 50 272
12 40 317
13 61 302
14 46 264
15 23 271
16 33 274
17 45 276
18 56 112
19 52 263
20 34 270
21 44 276
22 54 109
23 41 263
24 37 269
25 44 282
26 38 278
27 52 112
28 38 260
29 48 284
30 45 295
31 33 272
34 70 56
35 72 63
36 75 56
37 47 213
38 30 196
39 29 240
40 29 224
41 28 227
42 27 252
43 76 139
44 55 284
45 16 197
46 58 260
47 34 246
48 72 47



85.0
86.0
87.0
88.0
50 17 268
51 18 254
52 32 271
53 36 273
54 18 178
55 82 299
56 28 255

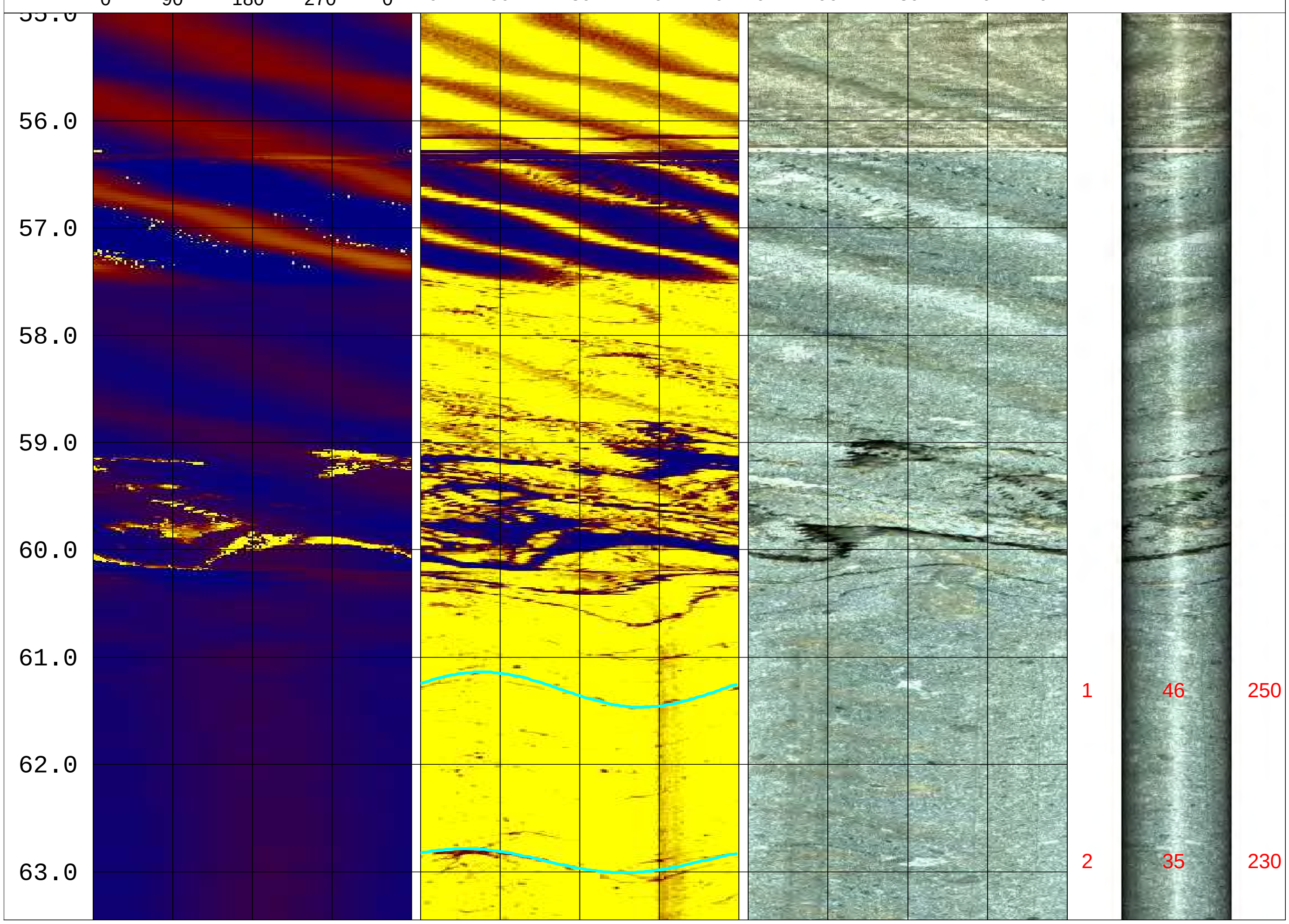
COBL
CRUX Oriented Borehole Logging

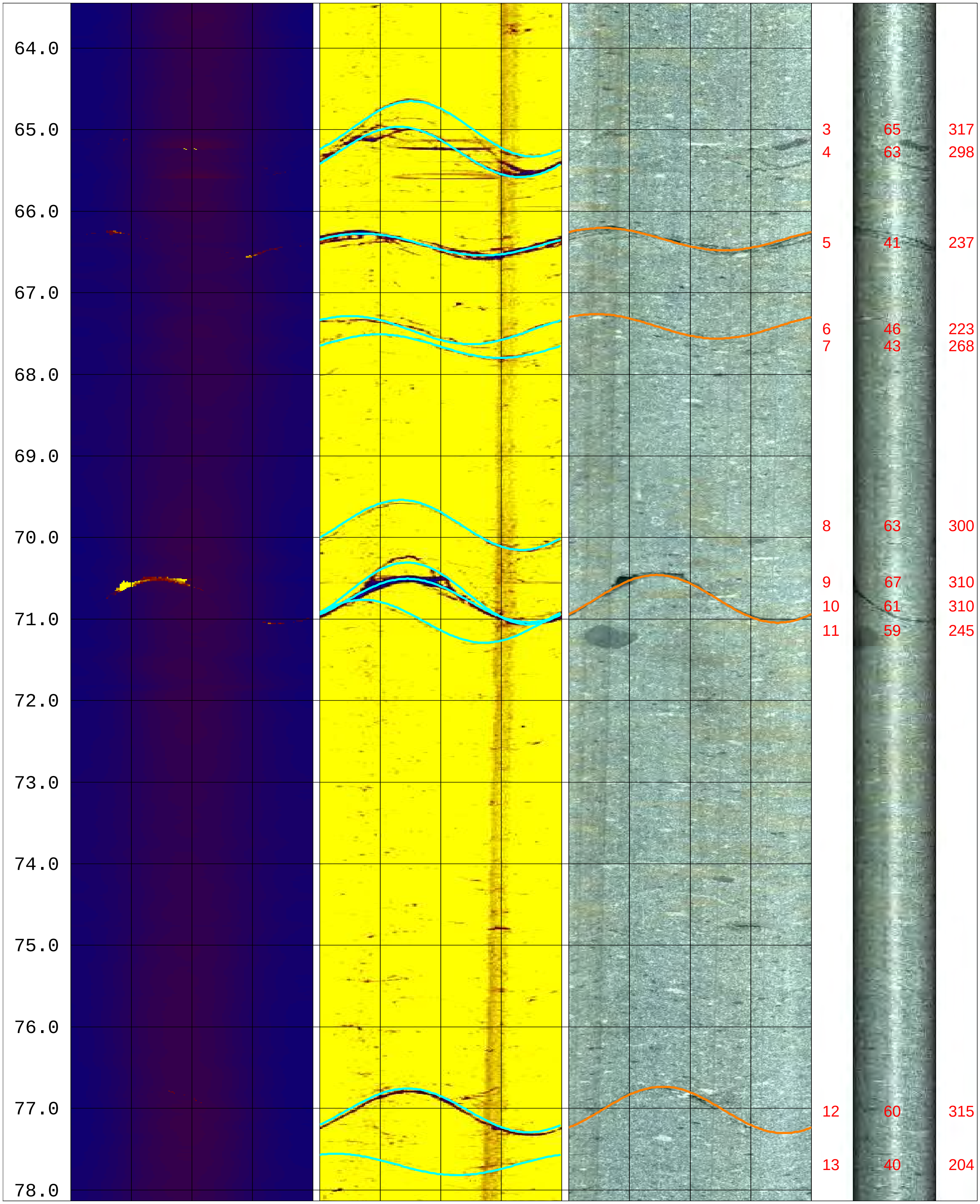
Company	Washington State Dept. of Transportation
Location:	Interstate 90 - Snoqualmie Pass
Project:	

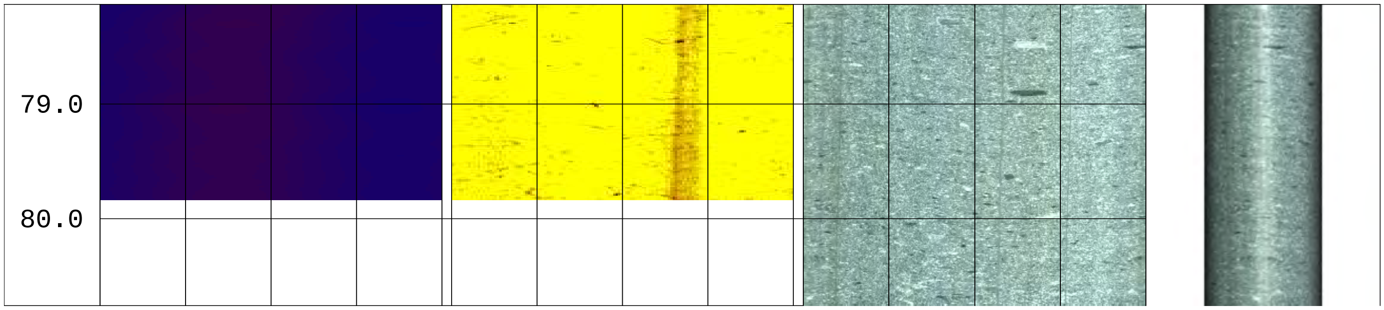
Date Logged:	June 16, 2009	Borehole ID:	SSD-010-09
File Name:	SSD01009-1M.wcl	Logged By:	F G Kruger

Notes:
1) Azimuths reference True North. Magnetic declination of +17 degrees applied.
2) 3x Horizontal Exaggeration on Televiewer Images.
3) Dip values presented in degrees from horizontal.
4) Dip direction presented in degrees of azimuth.
5) Simulated Core Image is viewed from north, east on left, west on right.

Depth	Tool.TravelTime1-NM	Tool.Amplitude1-NM Acoustic Trace	Tool.Image-NM Optical Trace	Simulated Core Image		
	0° 90° 180° 270° 0°	0° 90° 180° 270° 0°	0° 90° 180° 270° 0°	#	Dip	Dip AZ




64.0
65.0
66.0
67.0
68.0
69.0
70.0
71.0
72.0
73.0
74.0
75.0
76.0
77.0
78.0
3 65 317
4 63 298
5 41 237
6 46 223
7 43 268
8 63 300
9 67 310
10 61 310
11 59 245
12 60 315
13 40 204


79.0
80.0

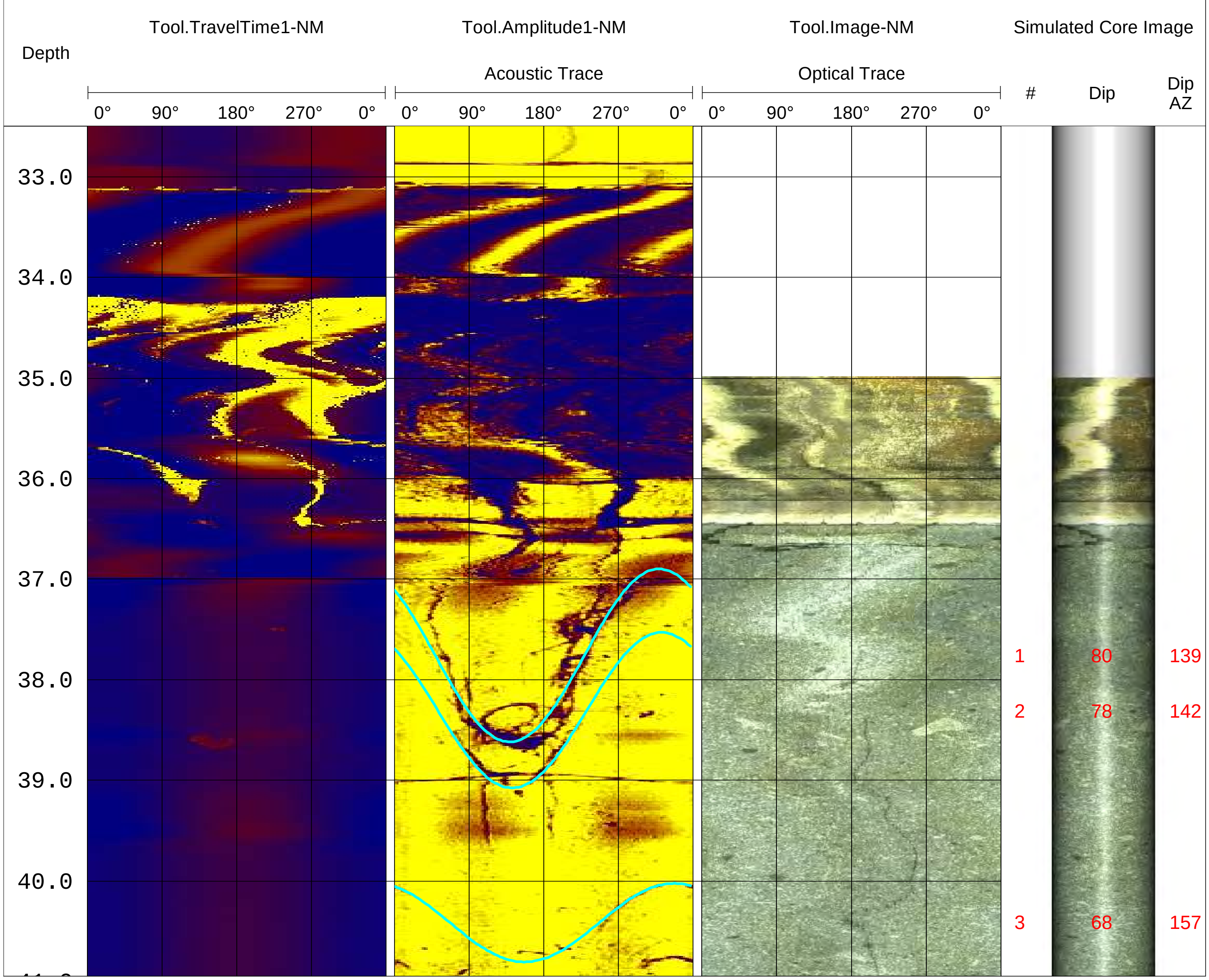
COBL
CRUX Oriented Borehole Logging

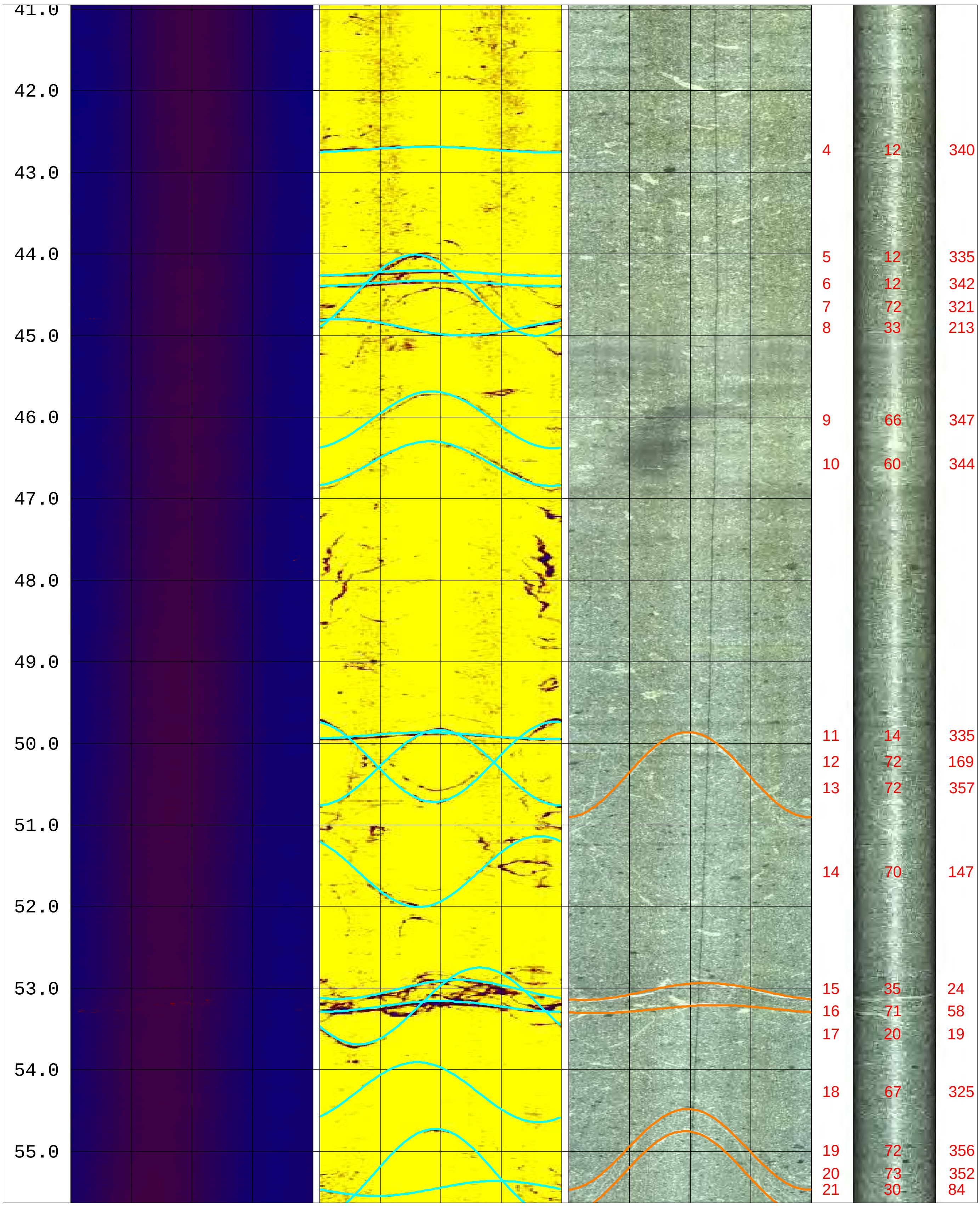
Company	Washington State Dept. of Transportation
Location:	Interstate 90 - Snoqualmie Pass
Project:	I-90 Snoqualmie Pass East

Date Logged:	June 30, 2009	Borehole ID:	SSD-011-09
File Name:	SSD01109-1M.wcl	Logged By:	F G Kruger

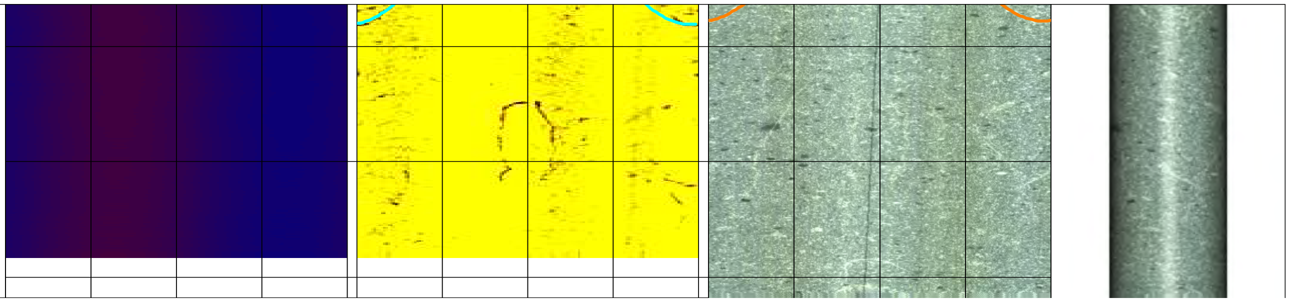
Notes:

1) Azimuths reference True North. Magnetic declination of +17 degrees applied.
2) 3x Horizontal Exaggeration on Televiewer Images.
3) Dip values presented in degrees from horizontal.
4) Dip direction presented in degrees of azimuth.
5) Simulated Core Image is viewed from north, east on left, west on right.




41.0
42.0
43.0
44.0
45.0
46.0
47.0
48.0
49.0
50.0
51.0
52.0
53.0
54.0
55.0
4 12 340
5 12 335
6 12 342
7 72 321
8 33 213
9 66 347
10 60 344
11 14 335
12 72 169
13 72 357
14 70 147
15 35 24
16 71 58
17 20 19
18 67 325
19 72 356
20 73 352
21 30 84

56.0
57.0
58.0



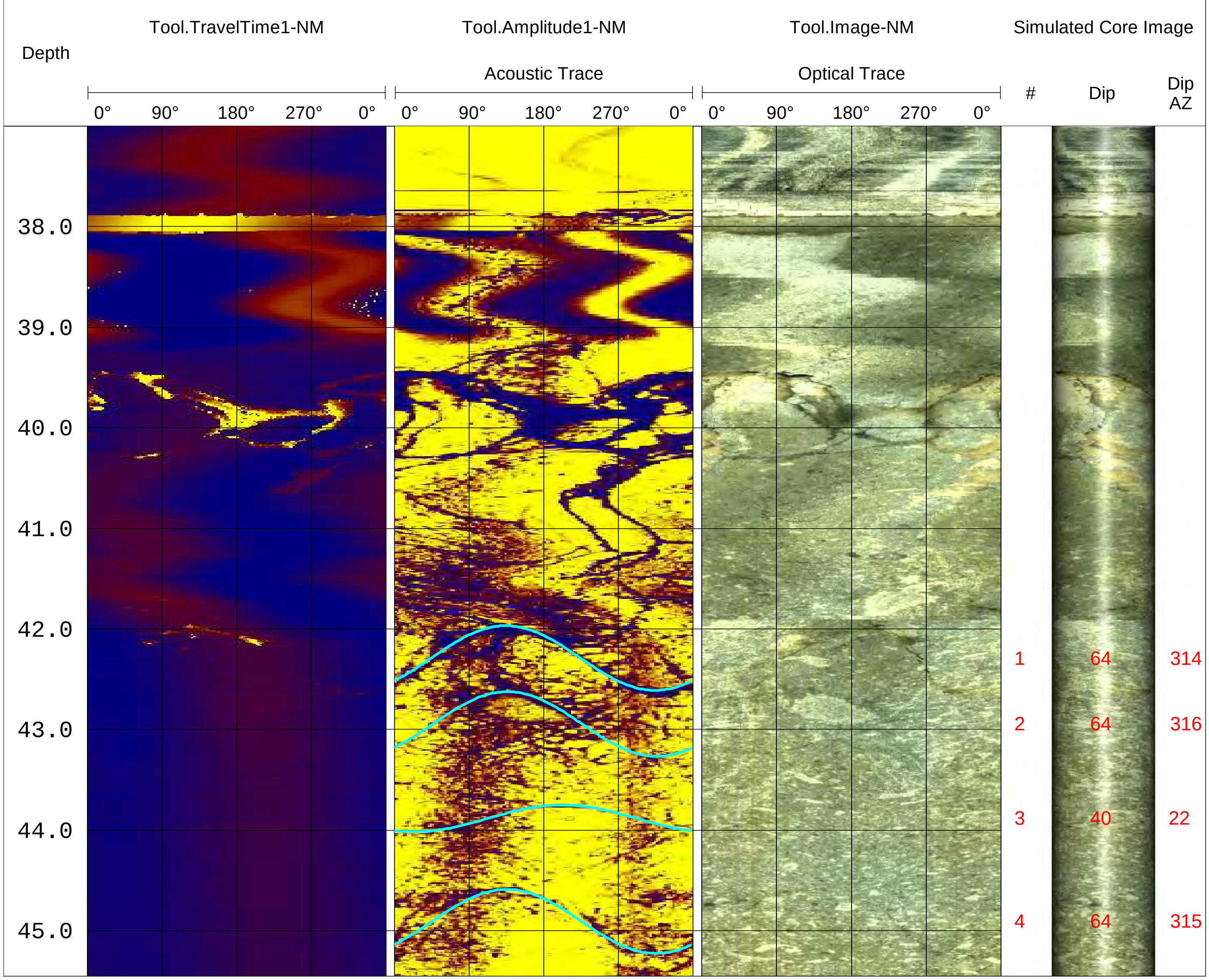
COBL
CRUX Oriented Borehole Logging

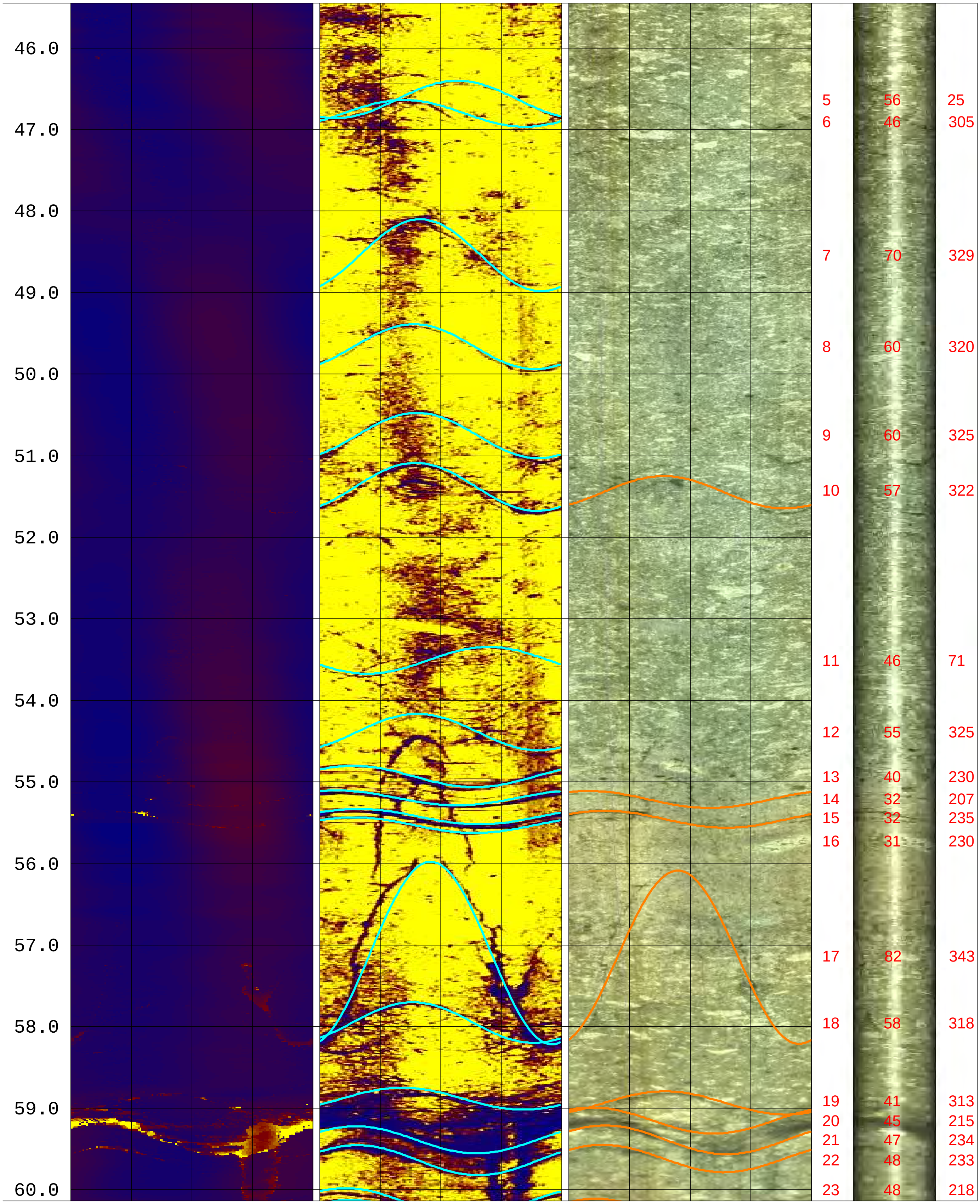
Company	Washington State Dept. of Transportation
Location:	Interstate 90 - Snoqualmie Pass
Project:	I-90 Snoqualmie Pass East

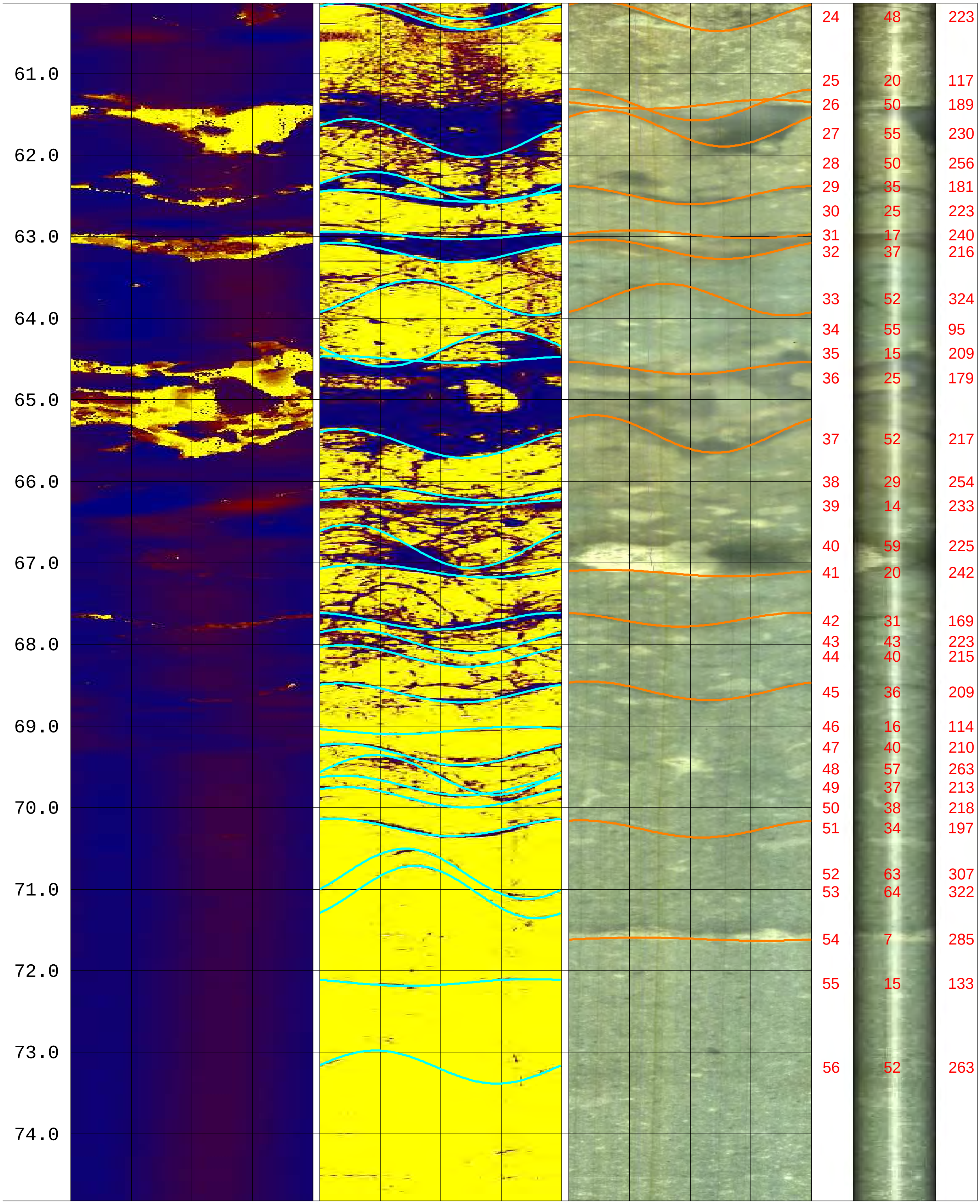
Date Logged:	June 24, 2009	Borehole ID: SSD-012-09
File Name:	SSD01209-2M.wcl	Logged By: F G Kruger

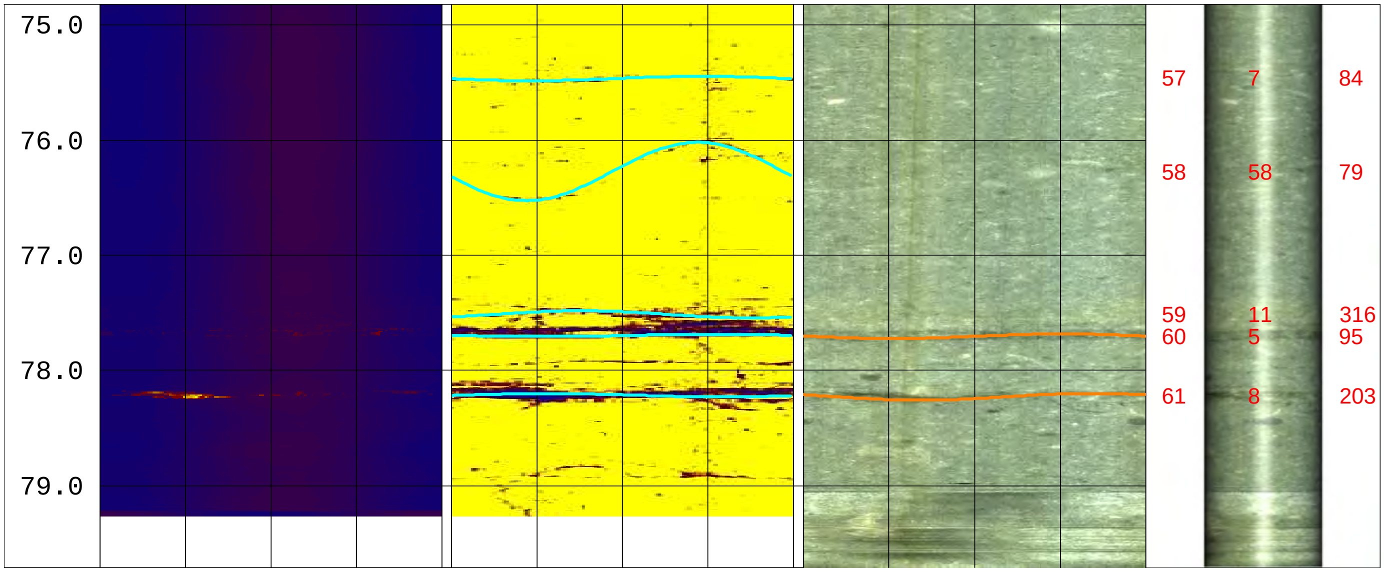
Notes:

1) Azimuths reference True North. Magnetic declination of +17 degrees applied.
2) 3x Horizontal Exaggeration on Televiewer Images.
3) Dip values presented in degrees from horizontal.
4) Dip direction presented in degrees of azimuth.
5) Simulated Core Image is viewed from north, east on left, west on right.




46.0
47.0
48.0
49.0
50.0
51.0
52.0
53.0
54.0
55.0
56.0
57.0
58.0
59.0
60.0
5 56 25
6 46 305
7 70 329
8 60 320
9 60 325
10 57 322
11 46 71
12 55 325
13 40 230
14 32 207
15 32 235
16 31 230
17 82 343
18 58 318
19 41 313
20 45 215
21 47 234
22 48 233
23 48 218


61.0
62.0
63.0
64.0
65.0
66.0
67.0
68.0
69.0
70.0
71.0
72.0
73.0
74.0
24 48 223
25 20 117
26 50 189
27 55 230
28 50 256
29 35 181
30 25 223
31 17 240
32 37 216
33 52 324
34 55 95
35 15 209
36 25 179
37 52 217
38 29 254
39 14 233
40 59 225
41 20 242
42 31 169
43 43 223
44 40 215
45 36 209
46 16 114
47 40 210
48 57 263
49 37 213
50 38 218
51 34 197
52 63 307
53 64 322
54 7 285
55 15 133
56 52 263


75.0
76.0
77.0
78.0
79.0
57
7
84
58
58
79
59
11
316
60
5
95
61
8
203

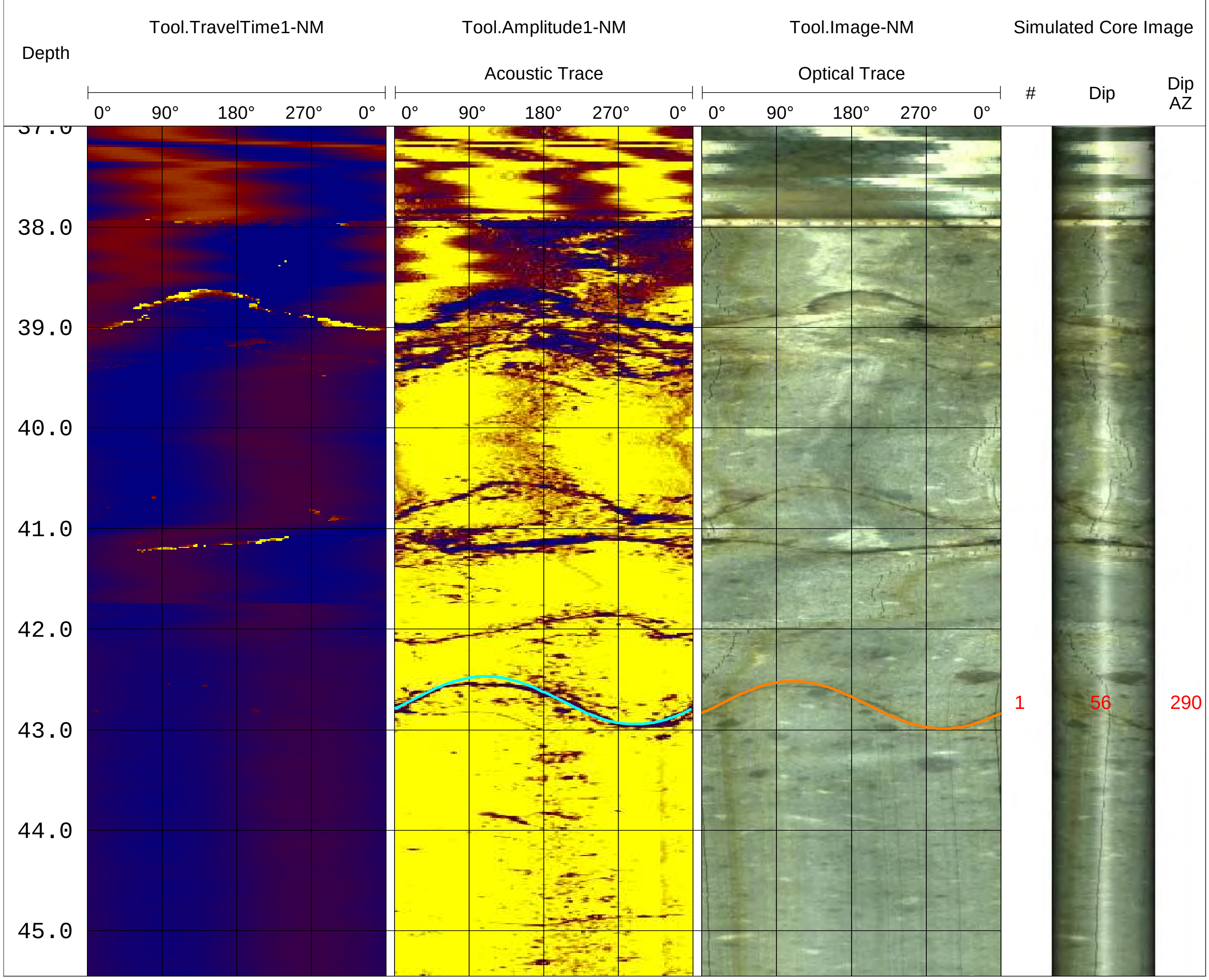
APPENDIX C.4
Slide Curve Bridge COBL® Logs

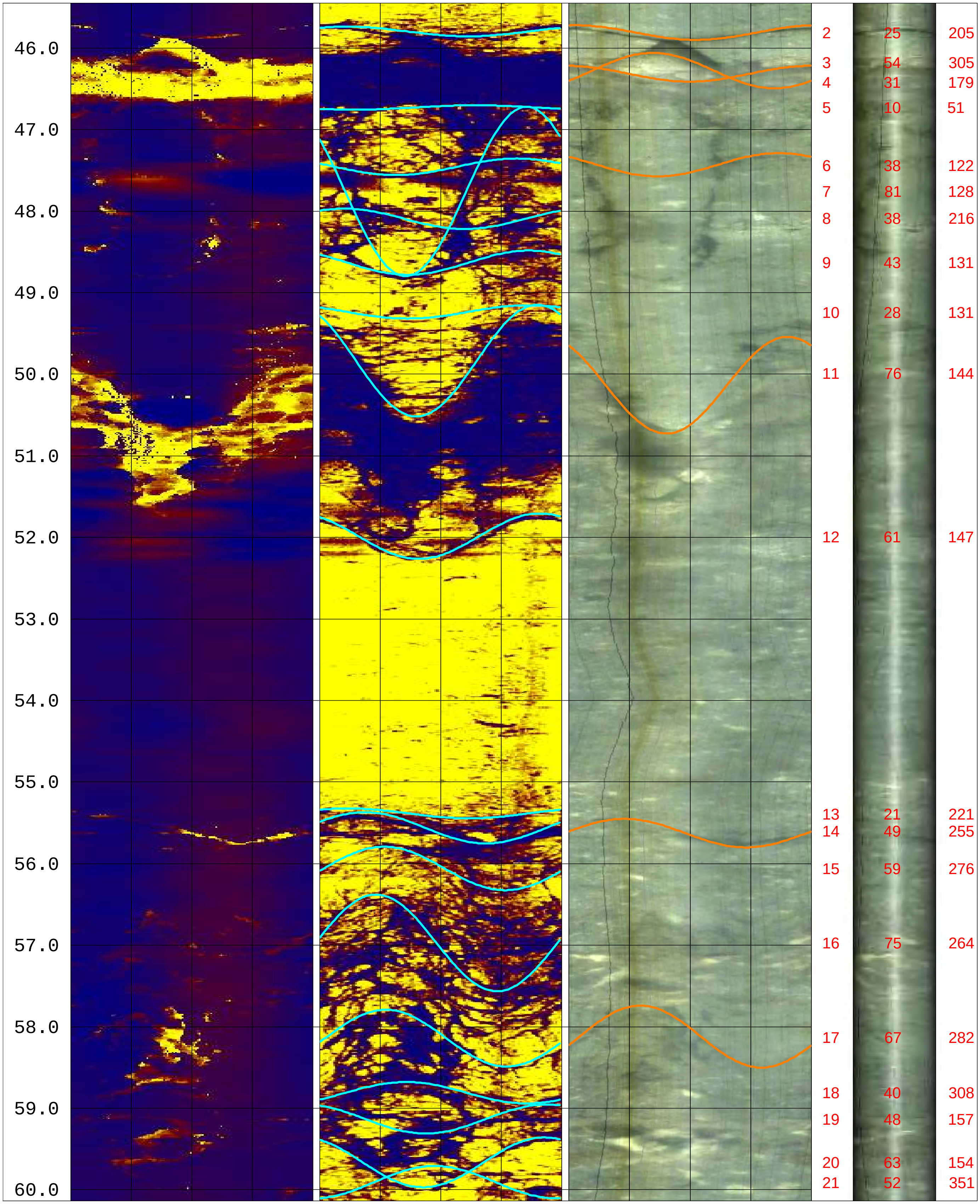
COBL CRUX Oriented Borehole Logging	Company	Washington State Dept. of Transportation
	Location:	Interstate 90 - Snoqualmie Pass
	Project:	I-90 Snoqualmie Pass East

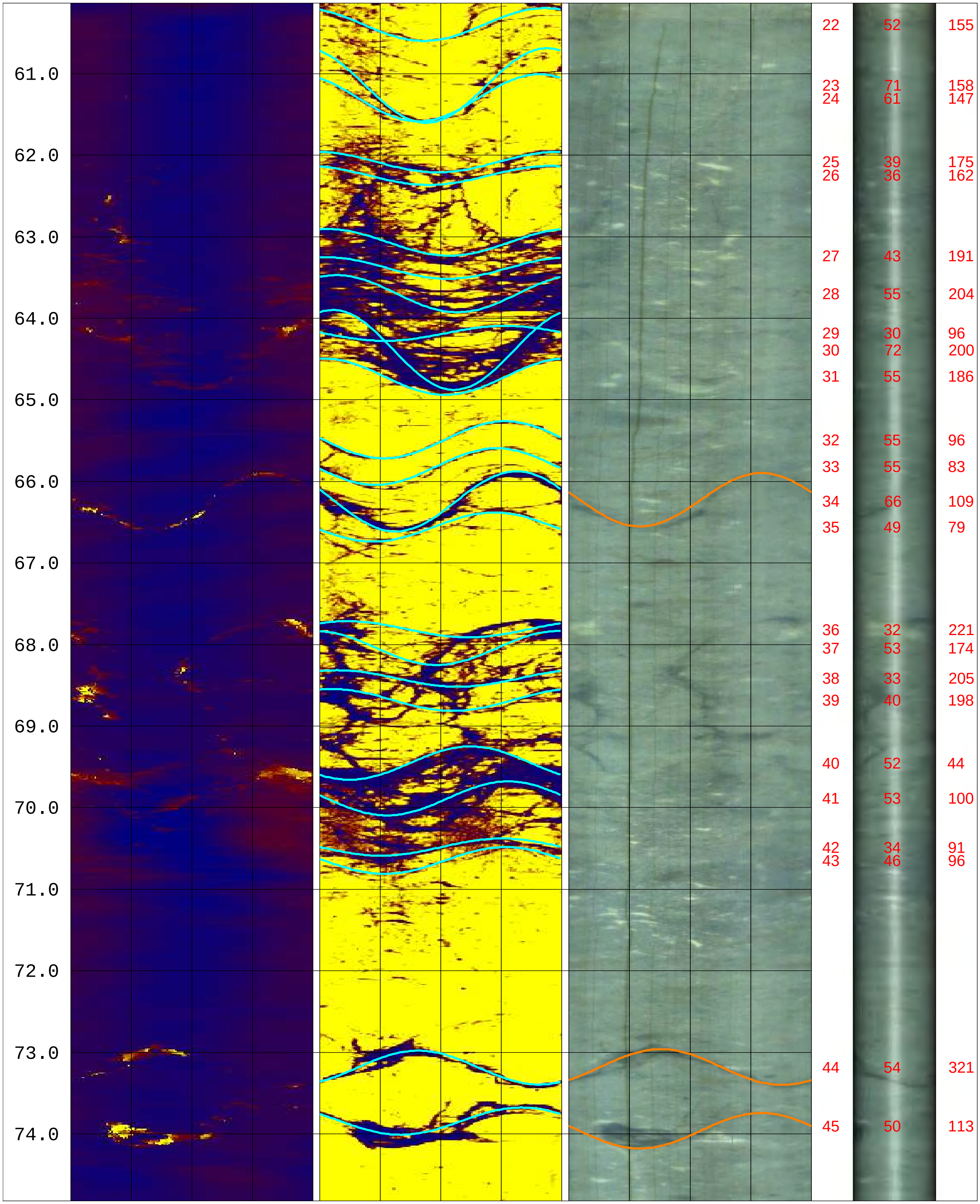
Date Logged:	June 11, 2009	Borehole ID: SCB-024-09
File Name:	SCB02409-1M.wcl	Logged By: F G Kruger

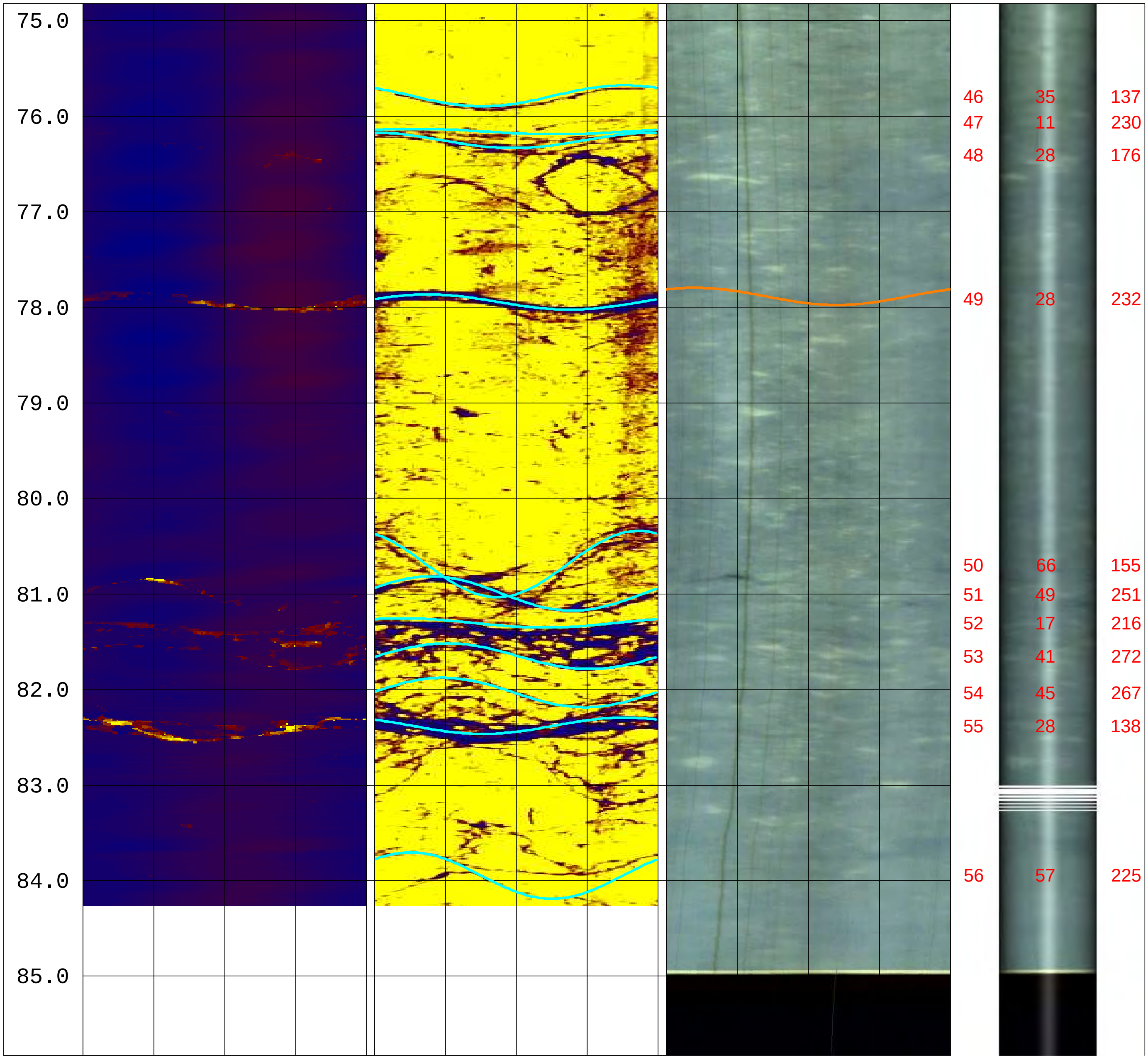
Notes:

1) Azimuths reference True North. Magnetic declination of +17 degrees applied.
2) 3x Horizontal Exaggeration on Televiewer Images.
3) Dip values presented in degrees from horizontal.
4) Dip direction presented in degrees of azimuth.
5) Simulated Core Image is viewed from north, east on left, west on right.




46.0
47.0
48.0
49.0
50.0
51.0
52.0
53.0
54.0
55.0
56.0
57.0
58.0
59.0
60.0
2 25 205
3 54 305
4 31 179
5 10 51
6 38 122
7 81 128
8 38 216
9 43 131
10 28 131
11 76 144
12 61 147
13 21 221
14 49 255
15 59 276
16 75 264
17 67 282
18 40 308
19 48 157
20 63 154
21 52 351


61.0
62.0
63.0
64.0
65.0
66.0
67.0
68.0
69.0
70.0
71.0
72.0
73.0
74.0
22 52 155
23 71 158
24 61 147
25 39 175
26 36 162
27 43 191
28 55 204
29 30 96
30 72 200
31 55 186
32 55 96
33 55 83
34 66 109
35 49 79
36 32 221
37 53 174
38 33 205
39 40 198
40 52 44
41 53 100
42 34 91
43 46 96
44 54 321
45 50 113

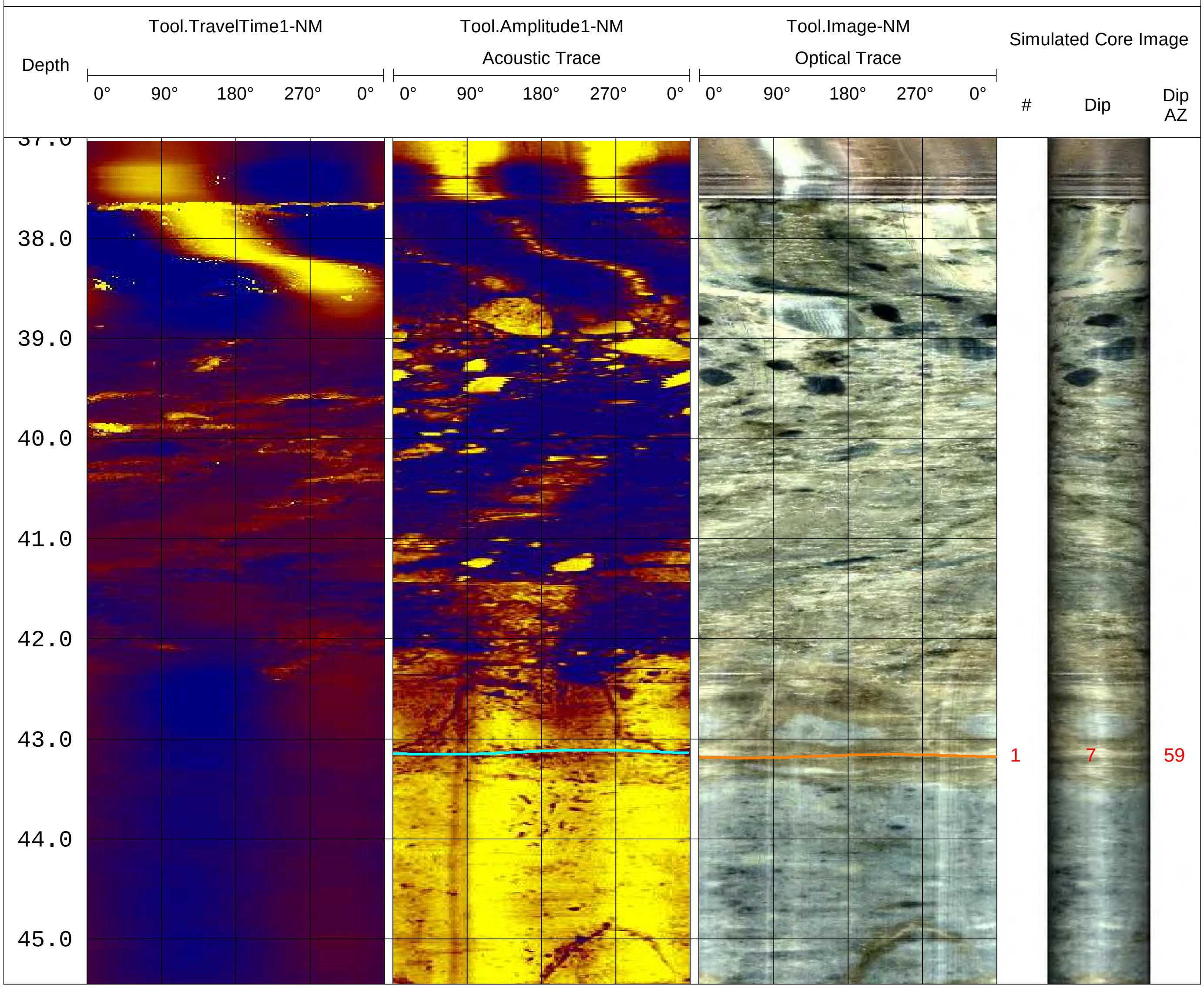

75.0
76.0
77.0
78.0
79.0
80.0
81.0
82.0
83.0
84.0
85.0
46 35 137
47 11 230
48 28 176
49 28 232
50 66 155
51 49 251
52 17 216
53 41 272
54 45 267
55 28 138
56 57 225

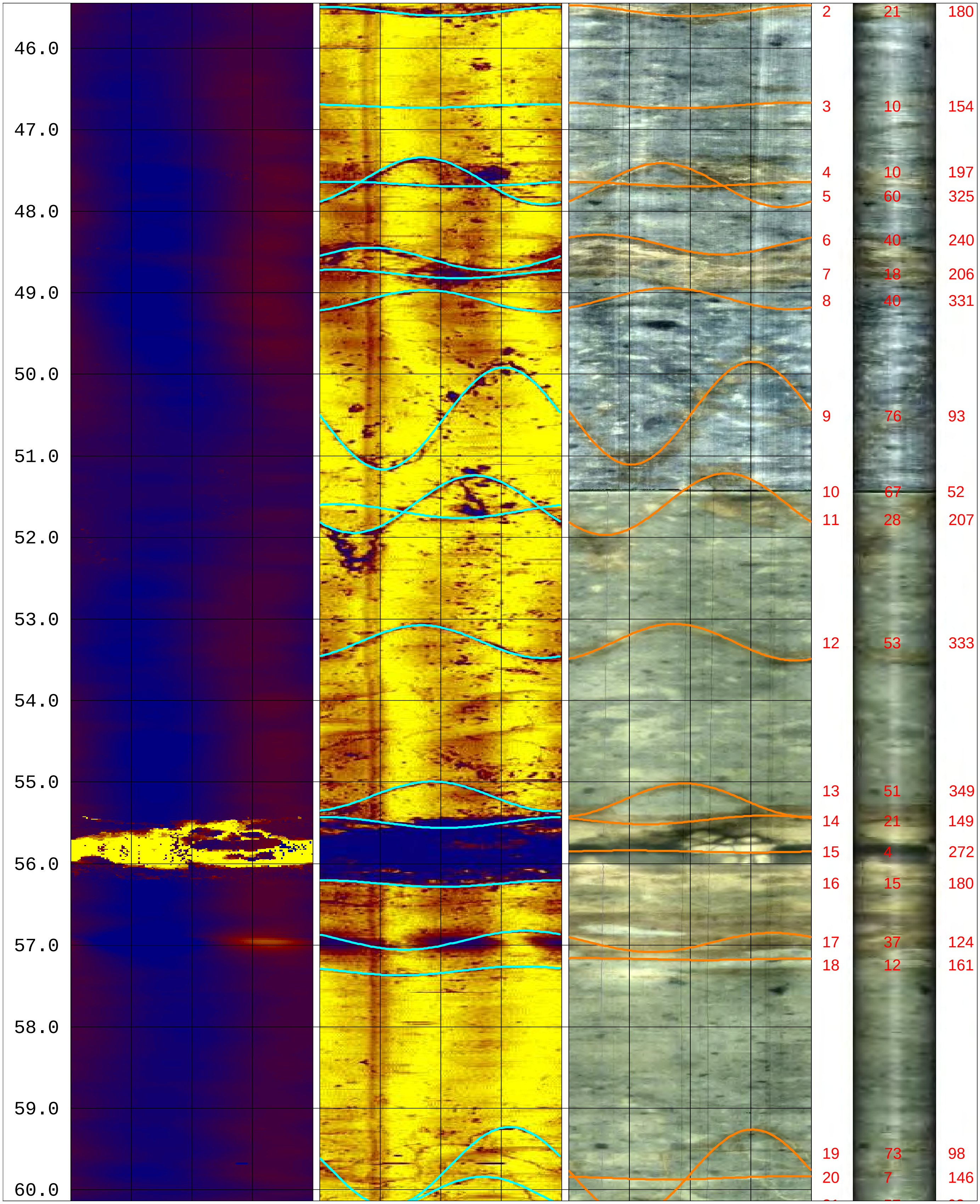
COBL
CRUX Oriented Borehole Logging

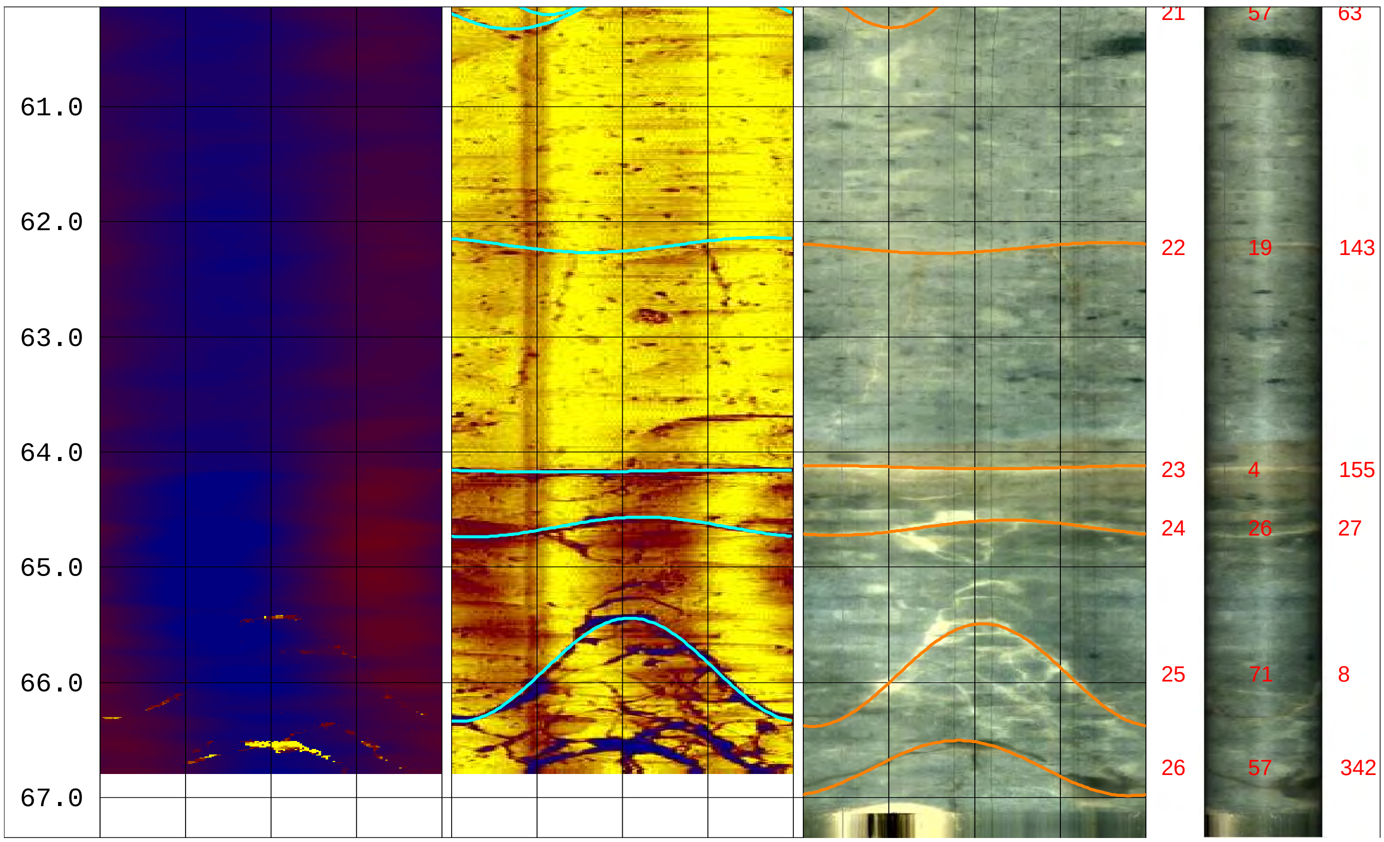
Company	Washington State Dept. of Transportation
Location:	Interstate 90 - Snoqualmie Pass
Project:	

Date Logged:	October 11, 2009	Borehole ID:	SCB-26-09
File Name:	SCB2609-1M.wcl	Logged By:	Steve Wilson

Notes:
1) Azimuths reference True North. Magnetic declination of +17 degrees applied.
2) 3x Horizontal Exaggeration on Televiewer Images.
3) Dip values presented in degrees from horizontal.
4) Dip direction presented in degrees of azimuth.
5) Simulated Core Image is viewed from north, east on left, west on right.




46.0
47.0
48.0
49.0
50.0
51.0
52.0
53.0
54.0
55.0
56.0
57.0
58.0
59.0
60.0
2 21 180
3 10 154
4 10 197
5 60 325
6 40 240
7 18 206
8 40 331
9 76 93
10 67 52
11 28 207
12 53 333
13 51 349
14 21 149
15 4 272
16 15 180
17 37 124
18 12 161
19 73 98
20 7 146

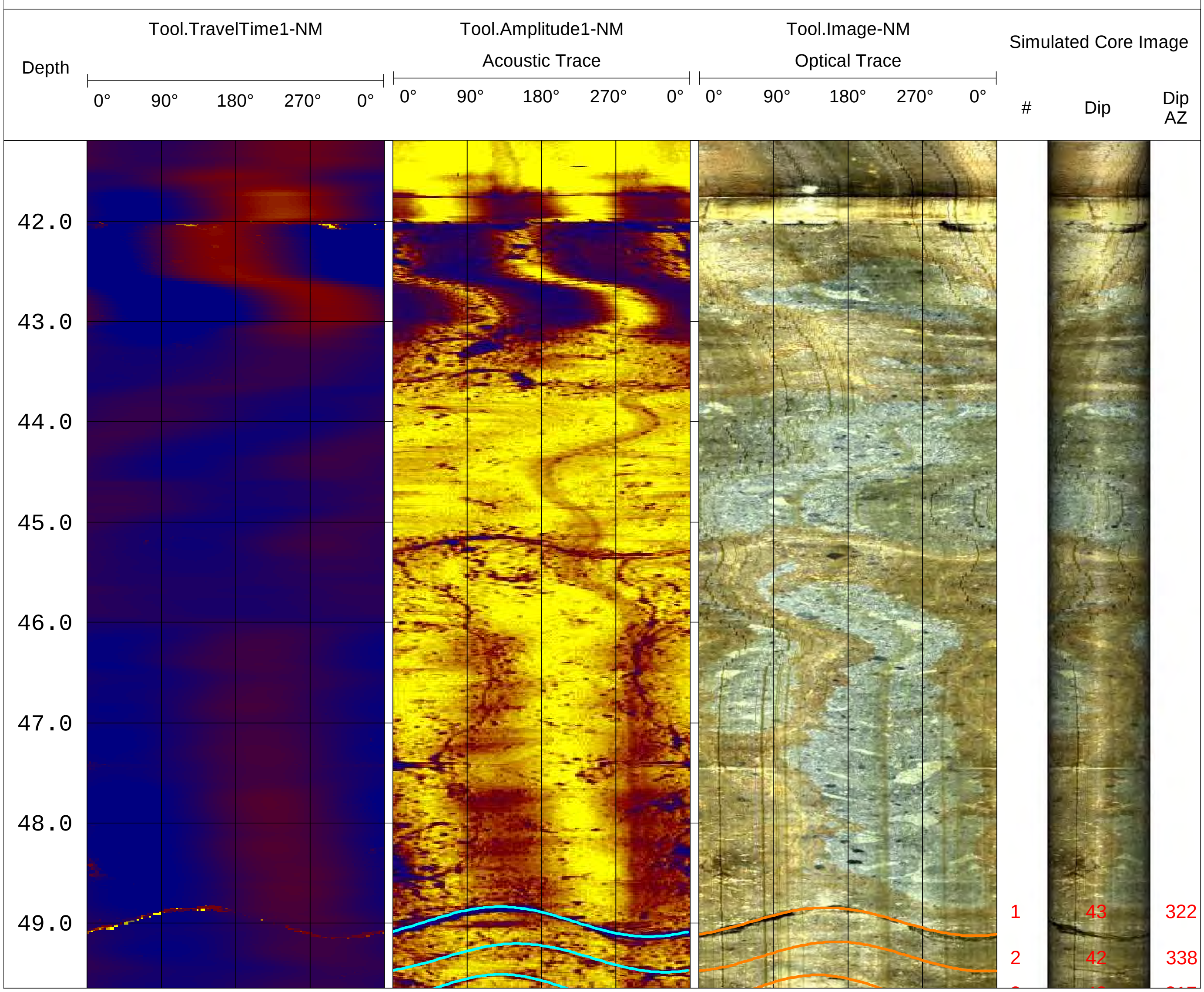

61.0
62.0
63.0
64.0
65.0
66.0
67.0
21 57 63
22 19 143
23 4 155
24 26 27
25 71 8
26 57 342

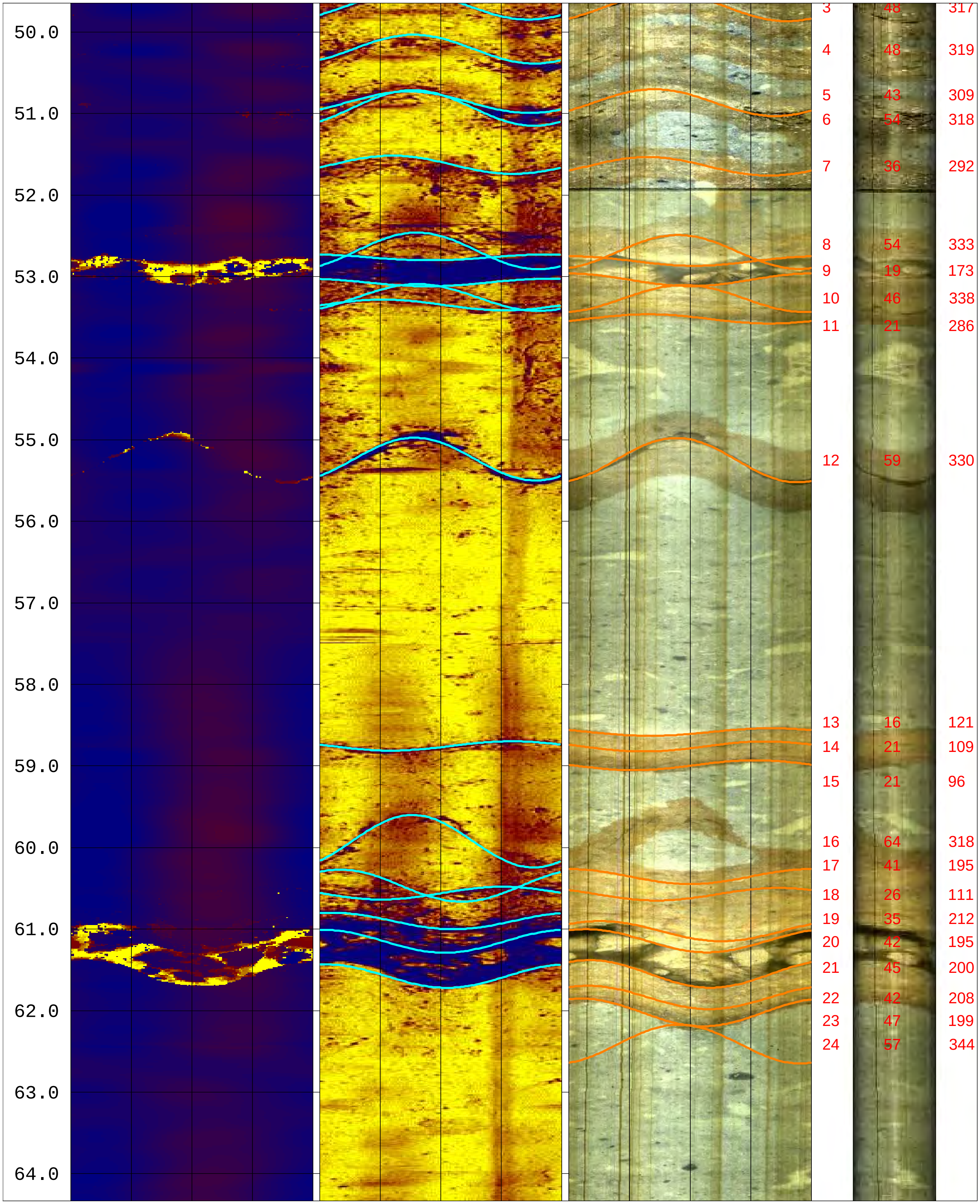
COBL
CRUX Oriented Borehole Logging

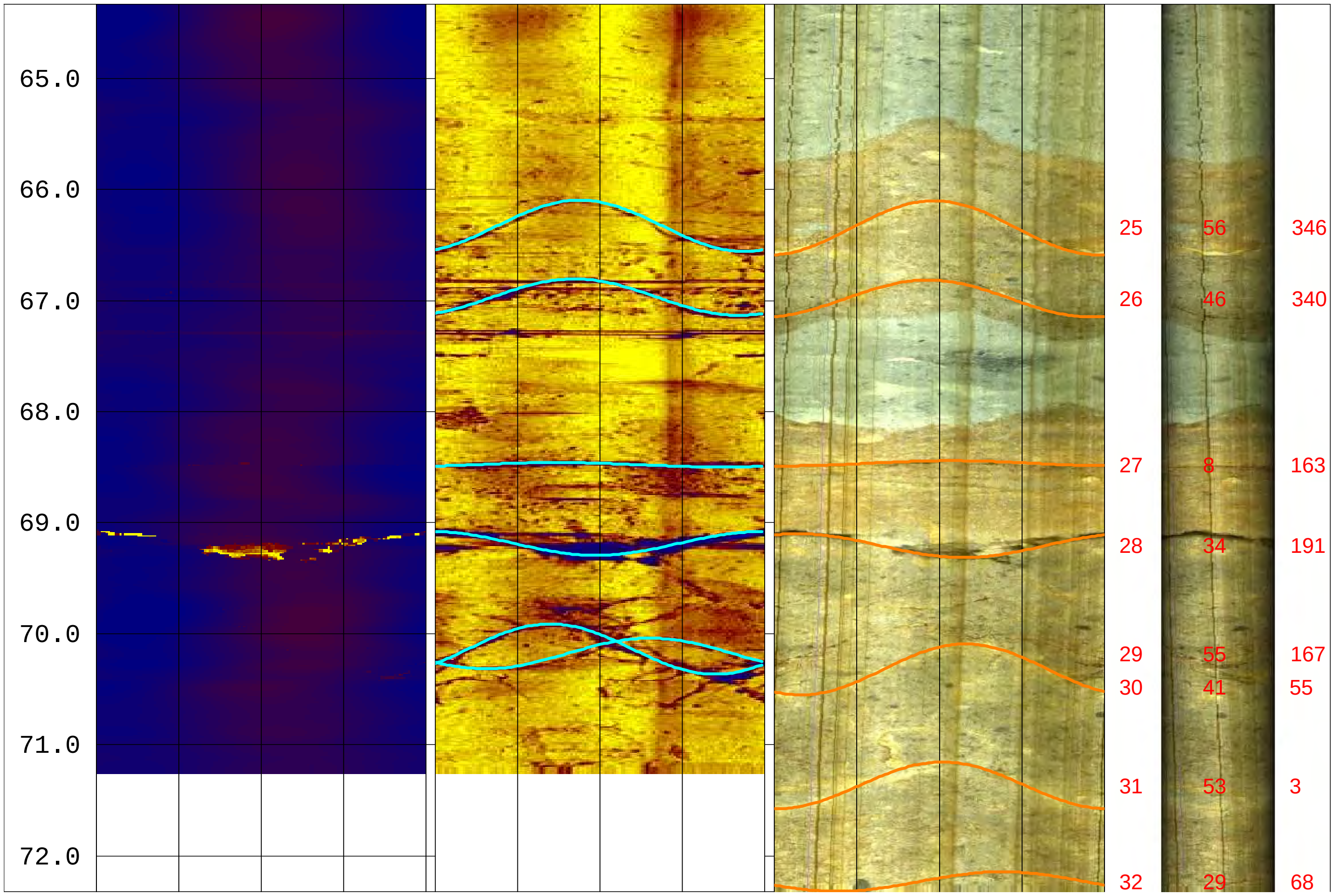
Company	Washington State Dept. of Transportation
Location:	Interstate 90 - Snoqualmie Pass
Project:	

Date Logged:	October 14, 2009	Borehole ID:	SCB-27-09
File Name:	SCB2709-1M.wcl	Logged By:	F G Kruger

Notes:
1) Azimuths reference True North. Magnetic declination of +17 degrees applied.
2) 3x Horizontal Exaggeration on Televiewer Images.
3) Dip values presented in degrees from horizontal.
4) Dip direction presented in degrees of azimuth.
5) Simulated Core Image is viewed from north, east on left, west on right.



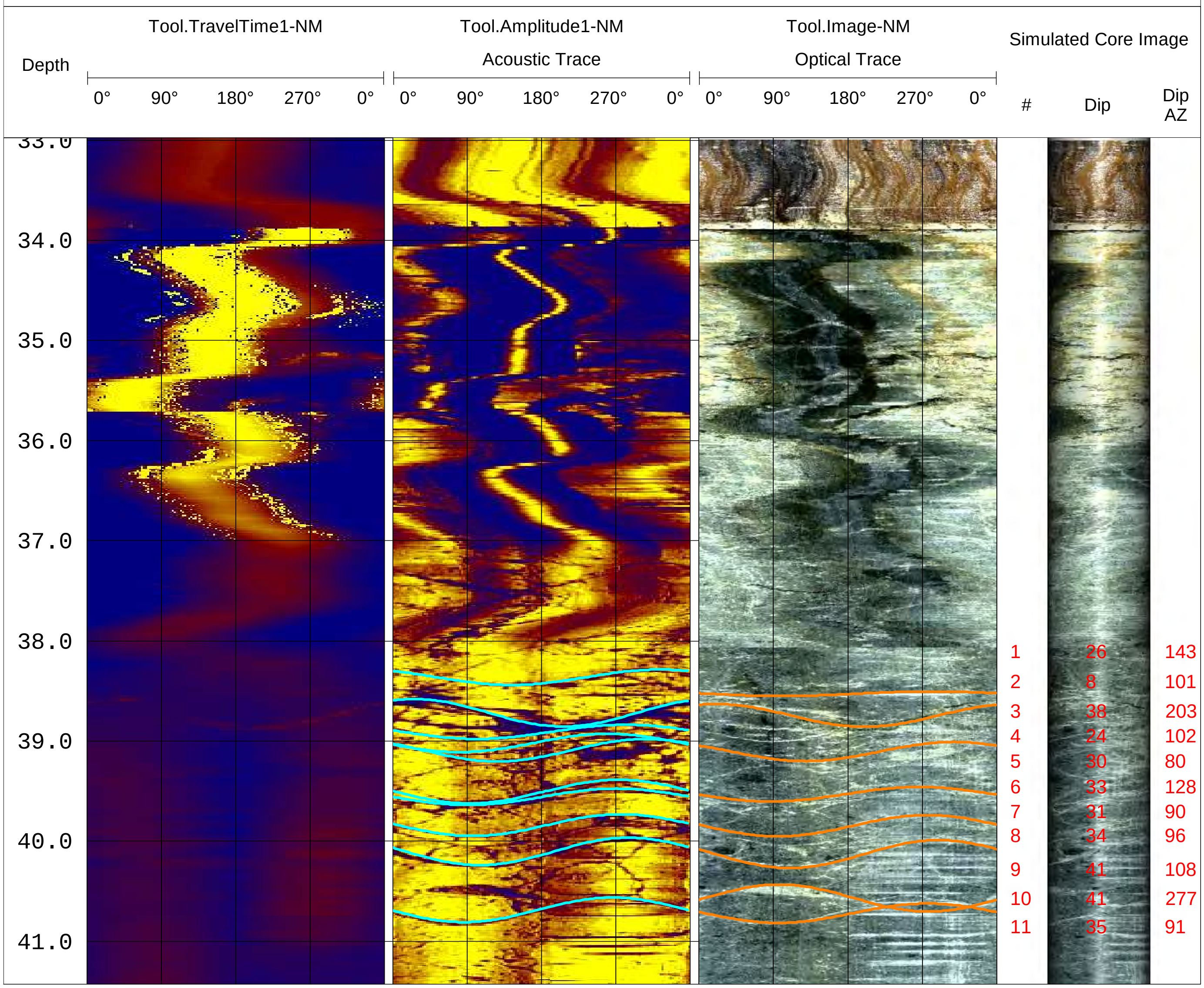

50.0
51.0
52.0
53.0
54.0
55.0
56.0
57.0
58.0
59.0
60.0
61.0
62.0
63.0
64.0
3 48 317
4 48 319
5 43 309
6 54 318
7 36 292
8 54 333
9 19 173
10 46 338
11 21 286
12 59 330
13 16 121
14 21 109
15 21 96
16 64 318
17 41 195
18 26 111
19 35 212
20 42 195
21 45 200
22 42 208
23 47 199
24 57 344


65.0
66.0
67.0
68.0
69.0
70.0
71.0
72.0
25 56 346
26 46 340
27 8 163
28 34 191
29 55 167
30 41 55
31 53 3
32 29 68

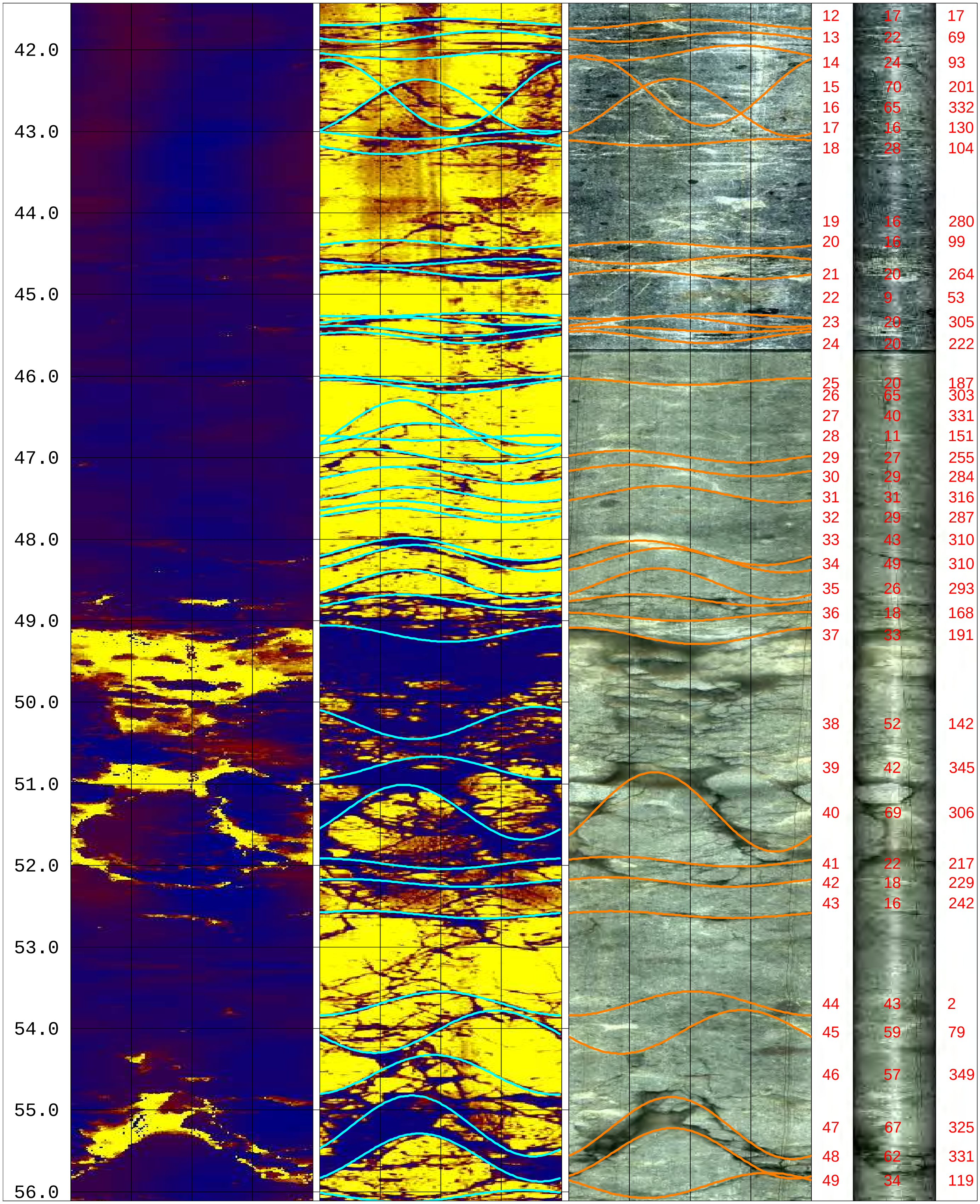
COBL CRUX Oriented Borehole Logging	Company: Washington State Dept. of Transportation
	Location: Interstate 90 - Snoqualmie Pass
	Project:

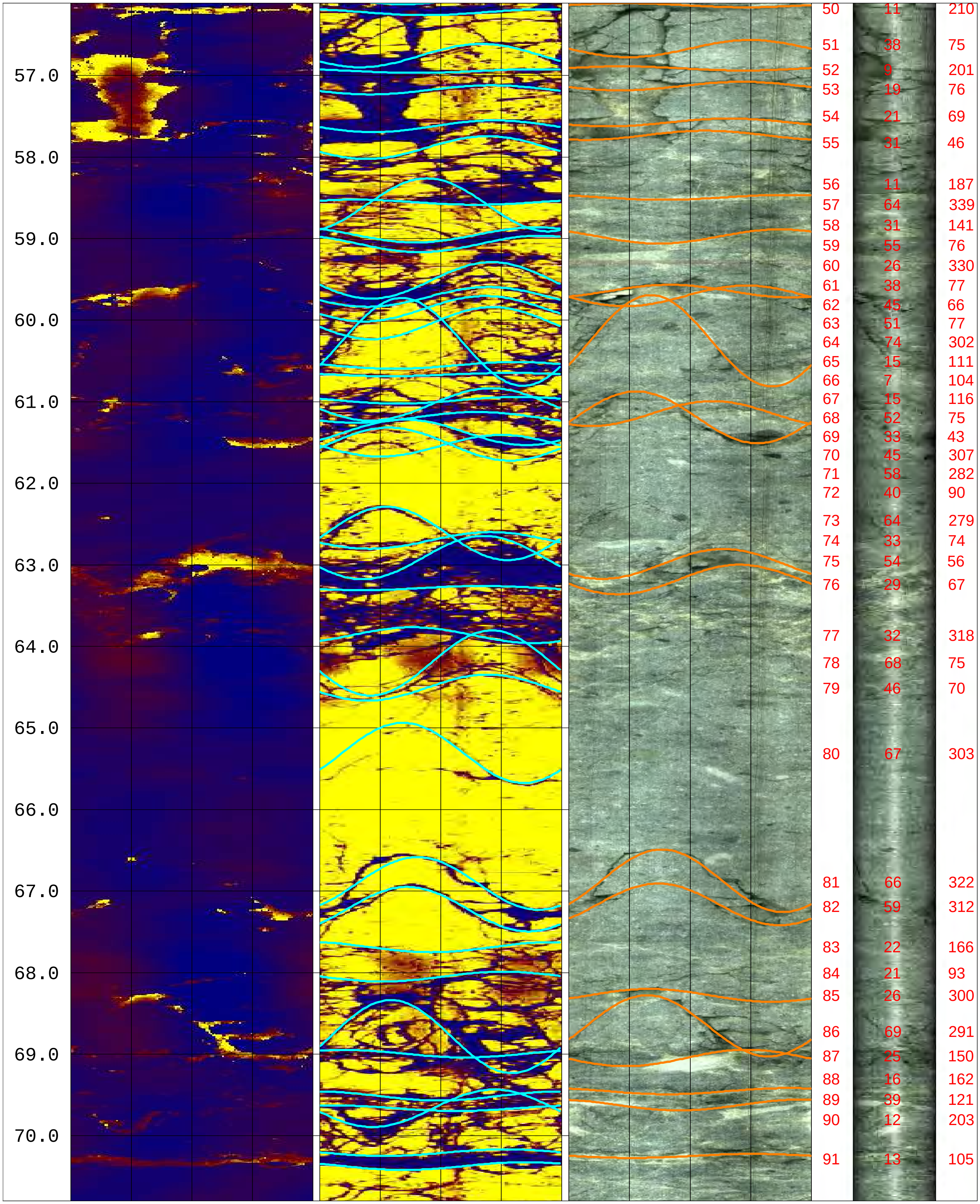
Date Logged:	October 22, 2009	Borehole ID:	SCB-28-09
File Name:	SCB2809-1M.wcl	Logged By:	Chris Mills

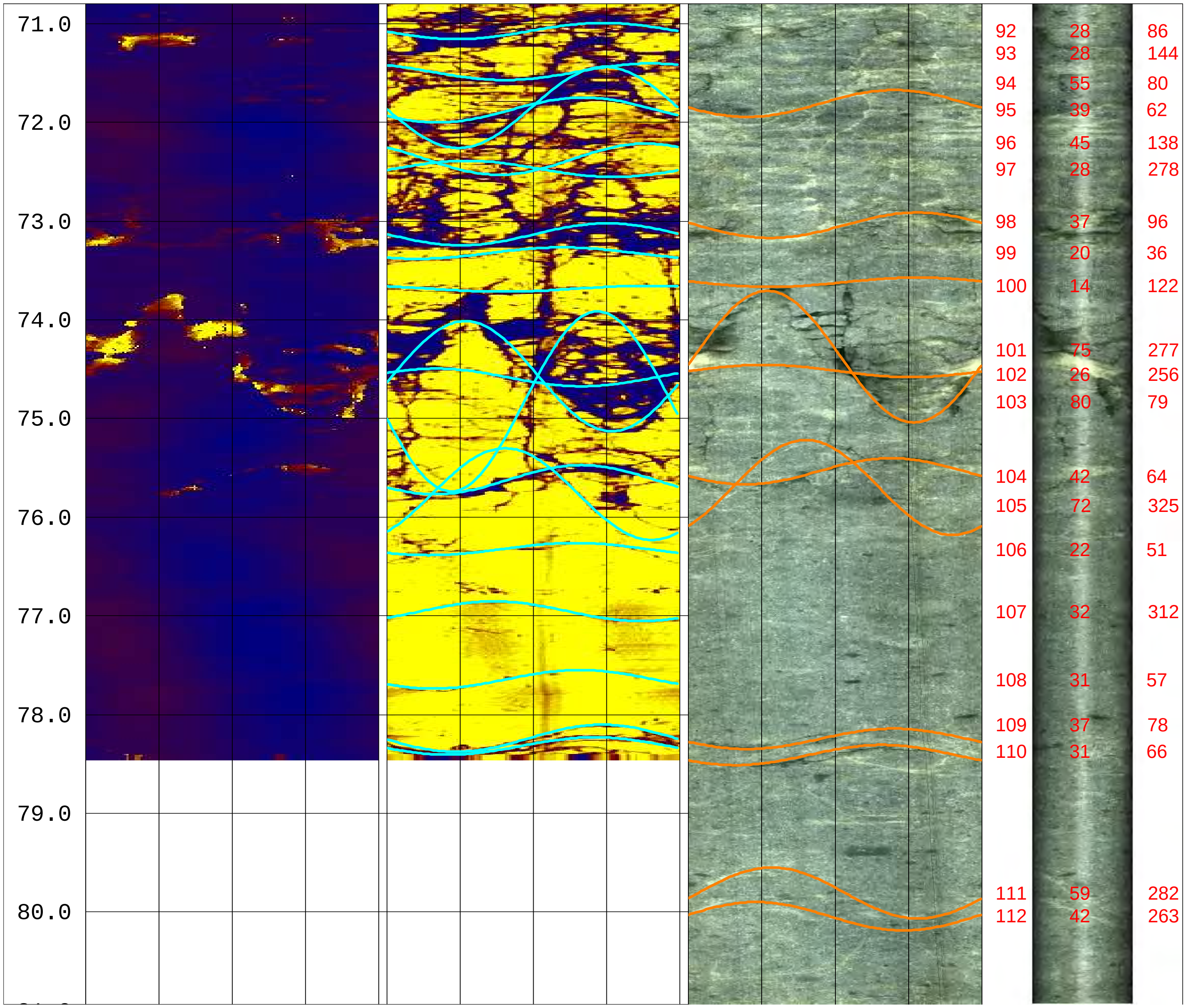
Notes:
1) Azimuths reference True North. Magnetic declination of +17 degrees applied.
2) 3x Horizontal Exaggeration on Televiewer Images.
3) Dip values presented in degrees from horizontal.
4) Dip direction presented in degrees of azimuth.
5) Simulated Core Image is viewed from north, east on left, west on right.



#	Dip	Dip AZ
1	26	143
2	8	101
3	38	203
4	24	102
5	30	80
6	33	128
7	31	90
8	34	96
9	41	108
10	41	277
11	35	91


42.0
43.0
44.0
45.0
46.0
47.0
48.0
49.0
50.0
51.0
52.0
53.0
54.0
55.0
56.0
12 17 17
13 22 69
14 24 93
15 70 201
16 65 332
17 16 130
18 28 104
19 16 280
20 16 99
21 20 264
22 9 53
23 20 305
24 20 222
25 20 187
26 65 303
27 40 331
28 11 151
29 27 255
30 29 284
31 31 316
32 29 287
33 43 310
34 49 310
35 26 293
36 18 168
37 33 191
38 52 142
39 42 345
40 69 306
41 22 217
42 18 229
43 16 242
44 43 2
45 59 79
46 57 349
47 67 325
48 62 331
49 34 119


57.0
58.0
59.0
60.0
61.0
62.0
63.0
64.0
65.0
66.0
67.0
68.0
69.0
70.0
50 11 210
51 38 75
52 9 201
53 19 76
54 21 69
55 31 46
56 11 187
57 64 339
58 31 141
59 55 76
60 26 330
61 38 77
62 45 66
63 51 77
64 74 302
65 15 111
66 7 104
67 15 116
68 52 75
69 33 43
70 45 307
71 58 282
72 40 90
73 64 279
74 33 74
75 54 56
76 29 67
77 32 318
78 68 75
79 46 70
80 67 303
81 66 322
82 59 312
83 22 166
84 21 93
85 26 300
86 69 291
87 25 150
88 16 162
89 39 121
90 12 203
91 13 105



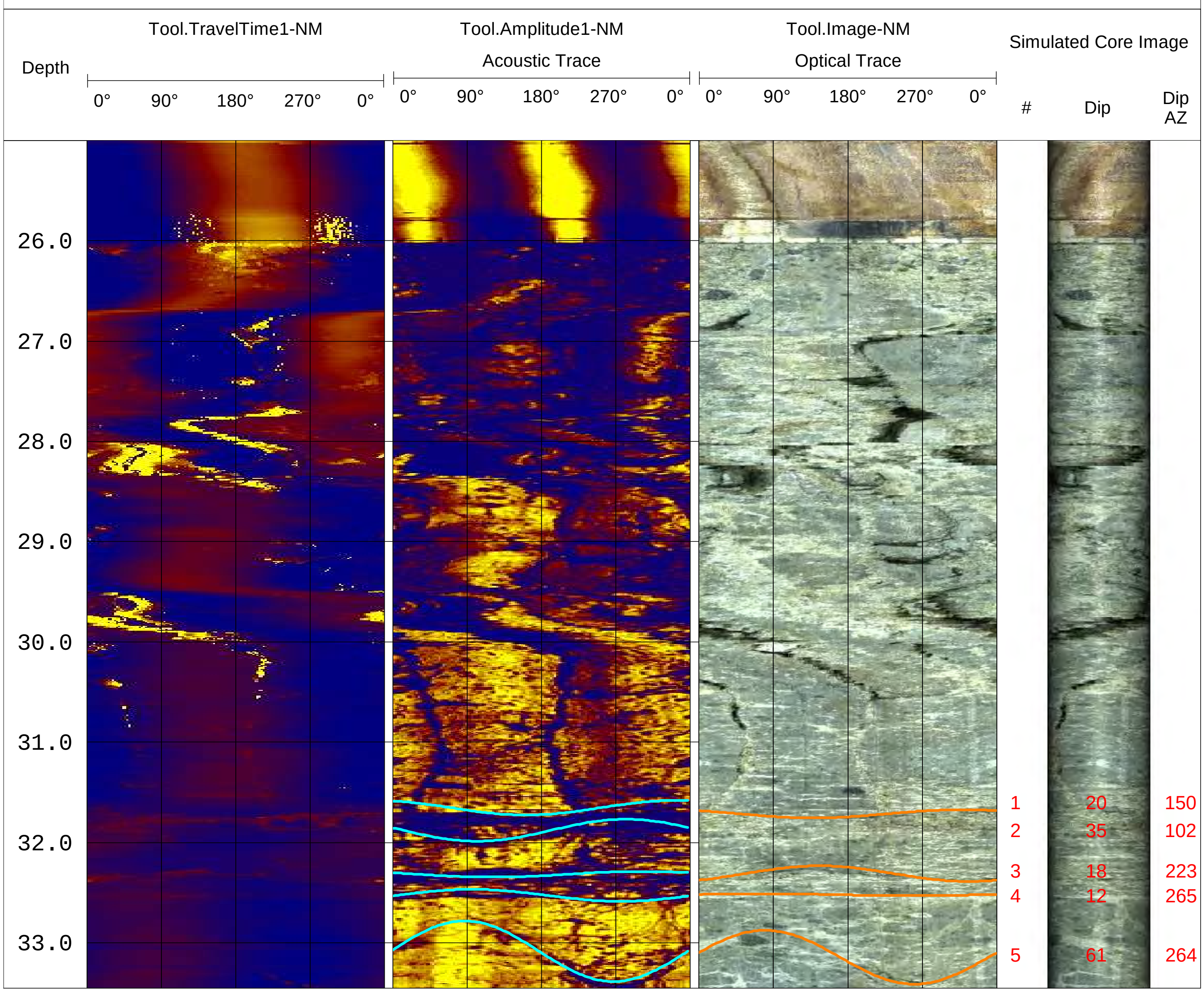
71.0
72.0
73.0
74.0
75.0
76.0
77.0
78.0
79.0
80.0
92 28 86
93 28 144
94 55 80
95 39 62
96 45 138
97 28 278
98 37 96
99 20 36
100 14 122
101 75 277
102 26 256
103 80 79
104 42 64
105 72 325
106 22 51
107 32 312
108 31 57
109 37 78
110 31 66
111 59 282
112 42 263

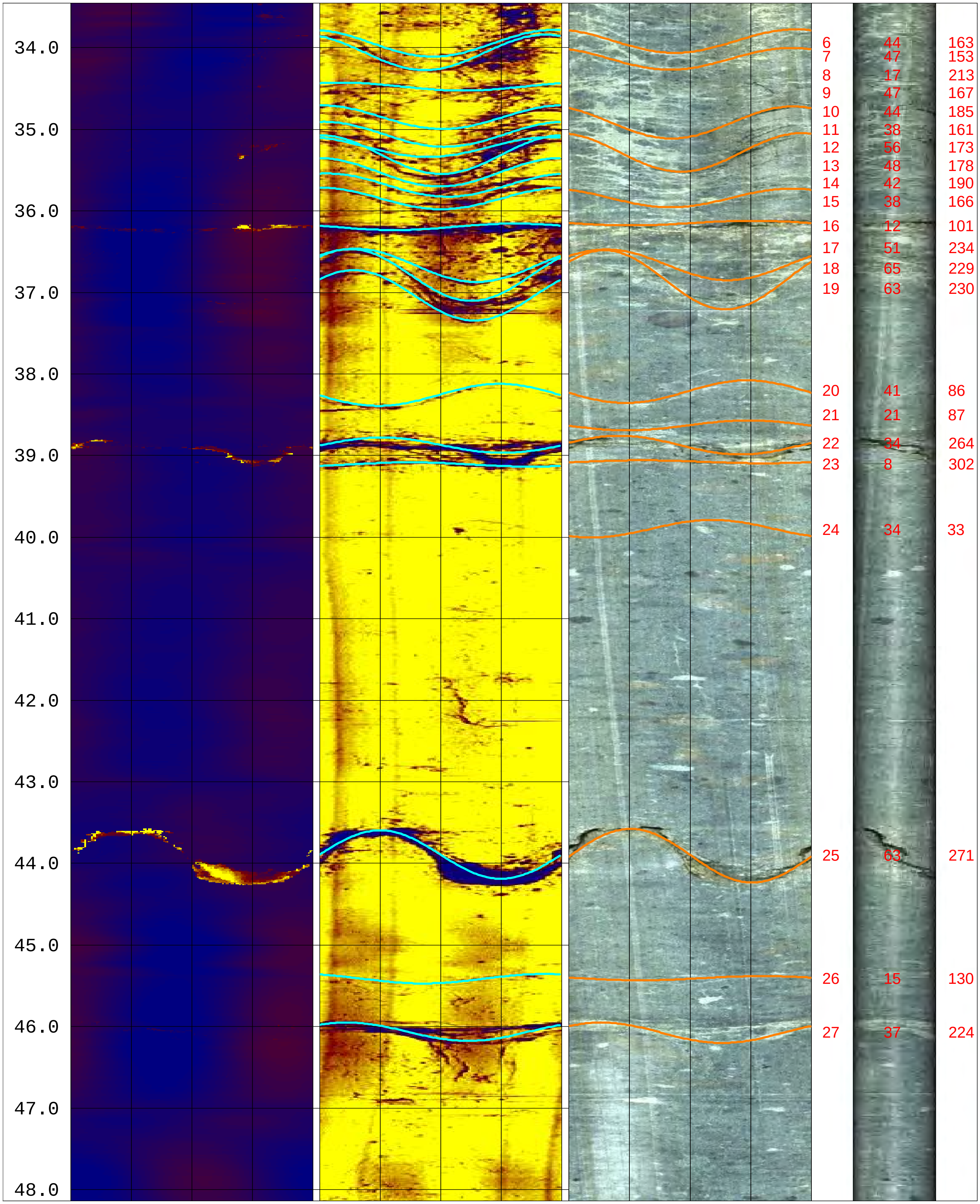
COBL CRUX Oriented Borehole Logging	Company: Washington State Dept. of Transportation
	Location: Interstate 90 - Snoqualmie Pass
	Project:

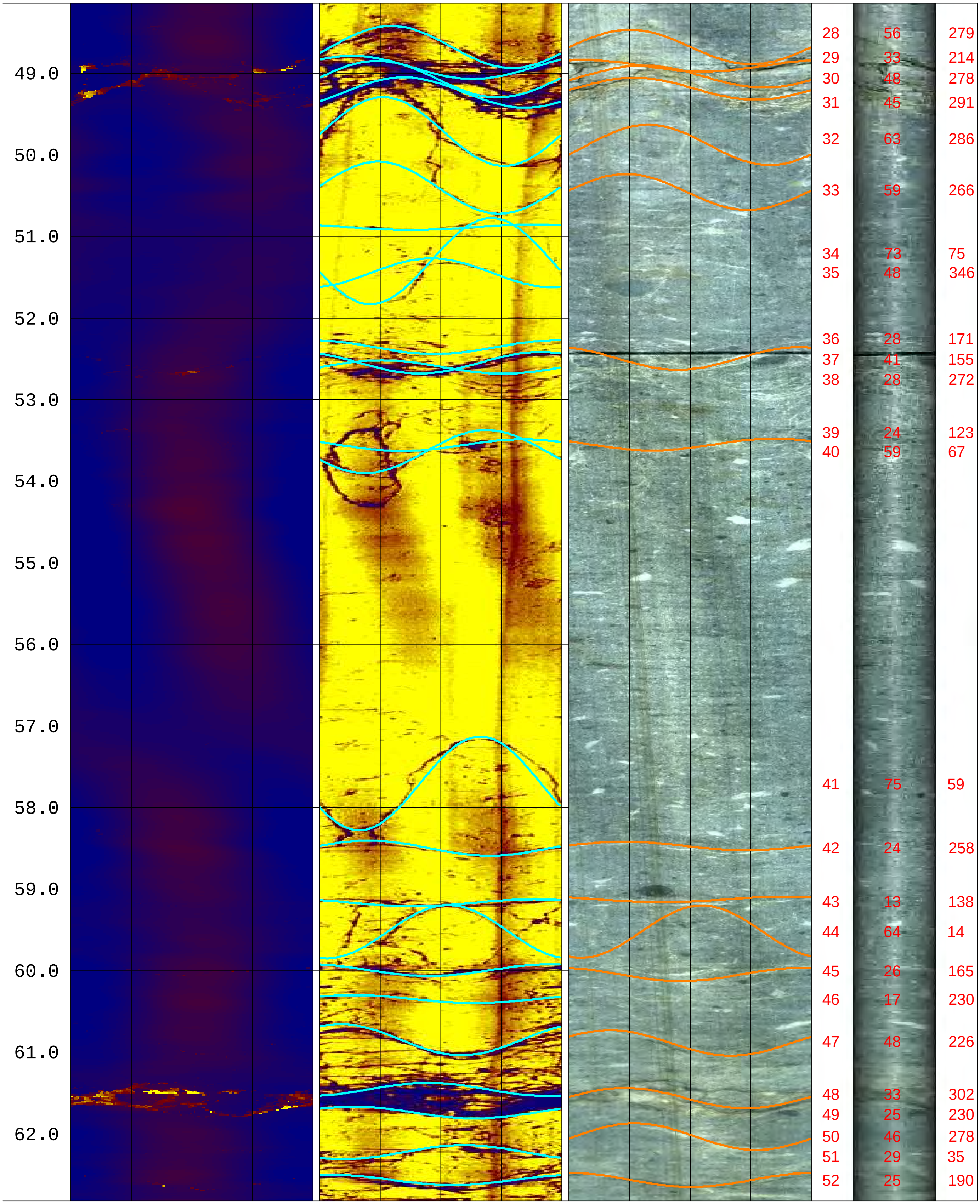
Date Logged:	October 24, 2009	Borehole ID:	SCB-29-09
File Name:	SCB2909-1M.wcl	Logged By:	Chris Mills

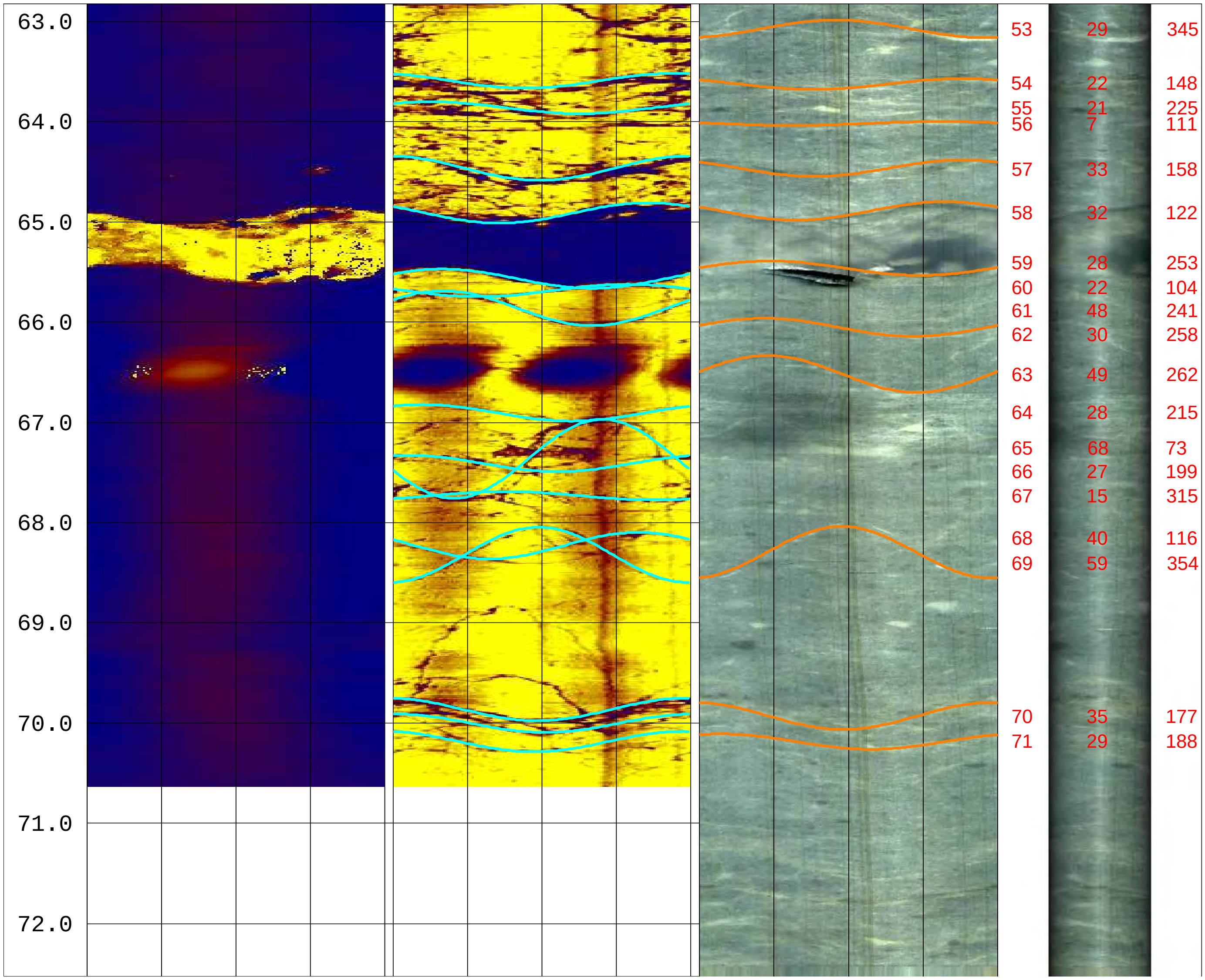
Notes:

1) Azimuths reference True North. Magnetic declination of +17 degrees applied.
2) 3x Horizontal Exaggeration on Televiewer Images.
3) Dip values presented in degrees from horizontal.
4) Dip direction presented in degrees of azimuth.
5) Simulated Core Image is viewed from north, east on left, west on right.




34.0
35.0
36.0
37.0
38.0
39.0
40.0
41.0
42.0
43.0
44.0
45.0
46.0
47.0
48.0
6 44 163
7 47 153
8 17 213
9 47 167
10 44 185
11 38 161
12 56 173
13 48 178
14 42 190
15 38 166
16 12 101
17 51 234
18 65 229
19 63 230
20 41 86
21 21 87
22 34 264
23 8 302
24 34 33
25 63 271
26 15 130
27 37 224


49.0
50.0
51.0
52.0
53.0
54.0
55.0
56.0
57.0
58.0
59.0
60.0
61.0
62.0
28 56 279
29 33 214
30 48 278
31 45 291
32 63 286
33 59 266
34 73 75
35 48 346
36 28 171
37 41 155
38 28 272
39 24 123
40 59 67
41 75 59
42 24 258
43 13 138
44 64 14
45 26 165
46 17 230
47 48 226
48 33 302
49 25 230
50 46 278
51 29 35
52 25 190

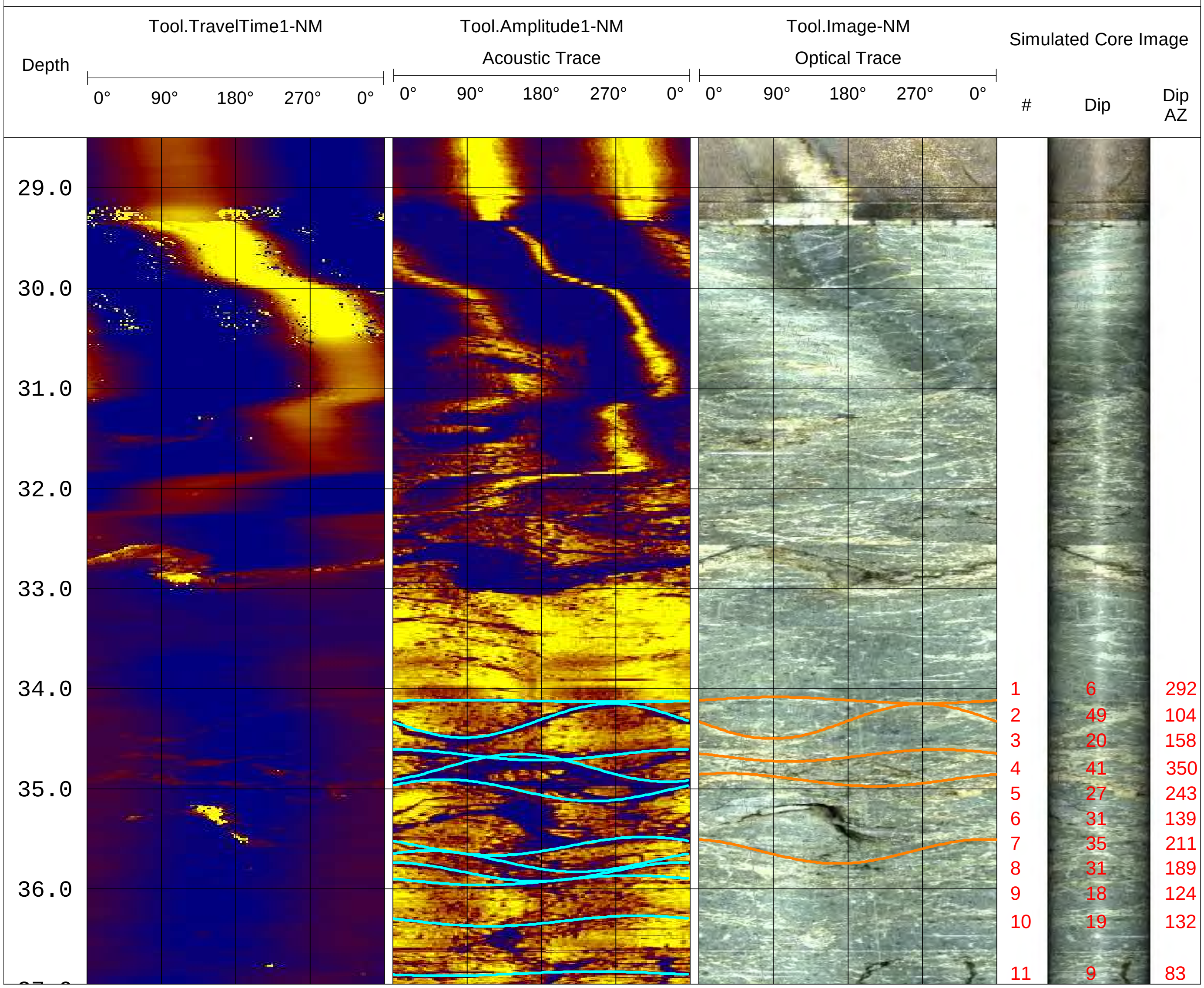

63.0
64.0
65.0
66.0
67.0
68.0
69.0
70.0
71.0
72.0
53 29 345
54 22 148
55 21 225
56 7 111
57 33 158
58 32 122
59 28 253
60 22 104
61 48 241
62 30 258
63 49 262
64 28 215
65 68 73
66 27 199
67 15 315
68 40 116
69 59 354
70 35 177
71 29 188

COBL
CRUX Oriented Borehole Logging

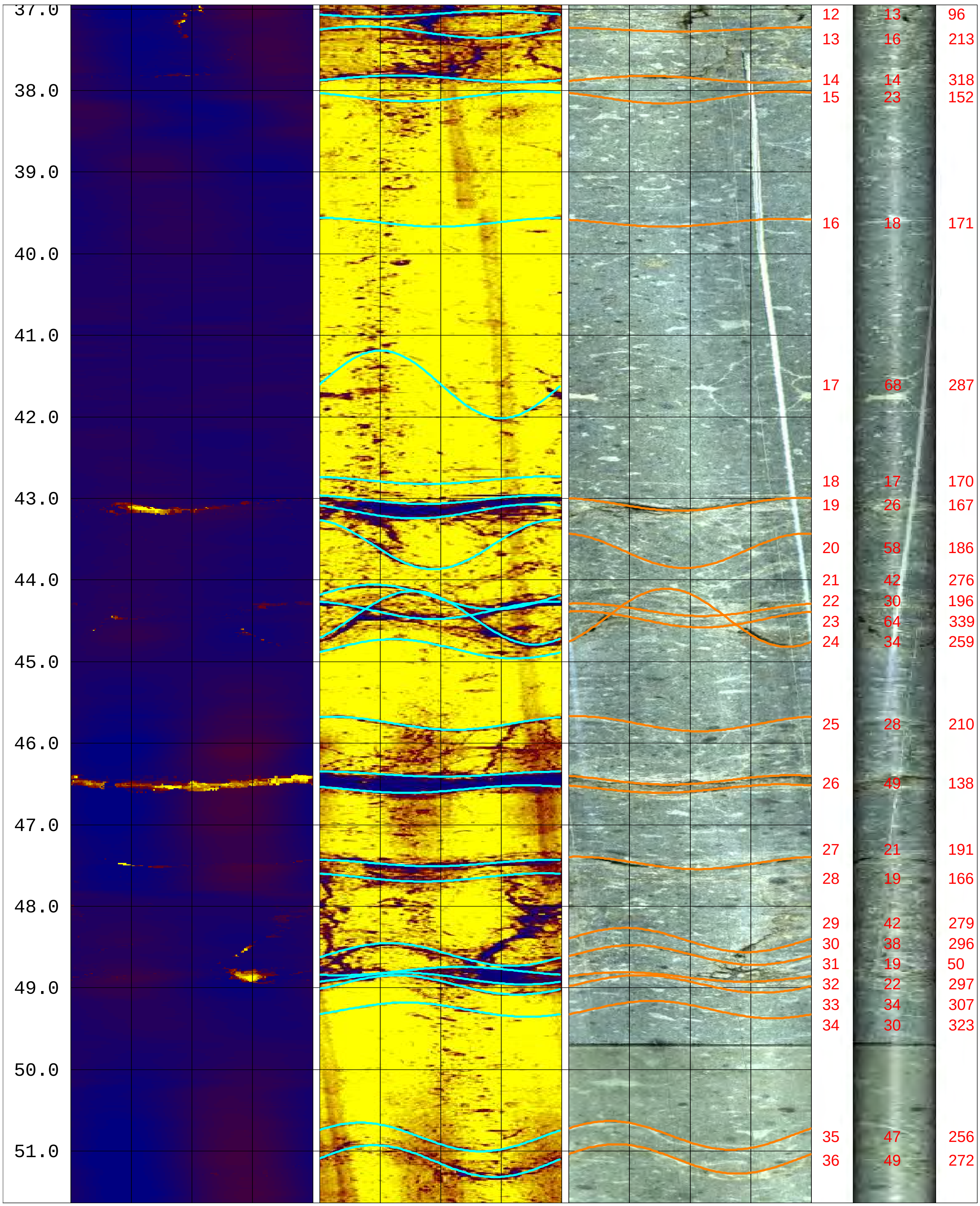
Company	Washington State Dept. of Transportation
Location:	Interstate 90 - Snoqualmie Pass
Project:	

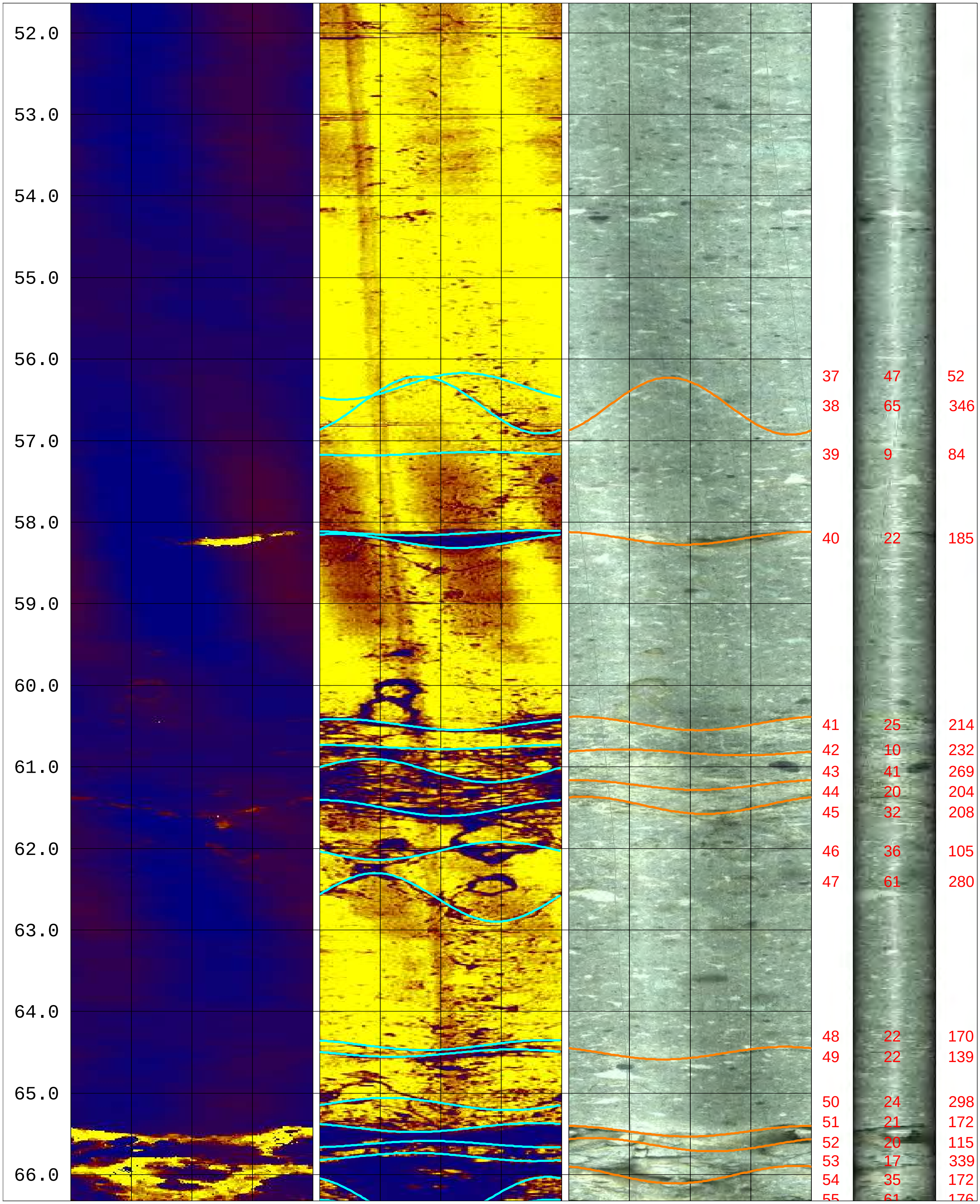
Date Logged:	October 25, 2009	Borehole ID: SCB-30-09
File Name:	SCB3009-1M.wcl	Logged By: Chris Mills

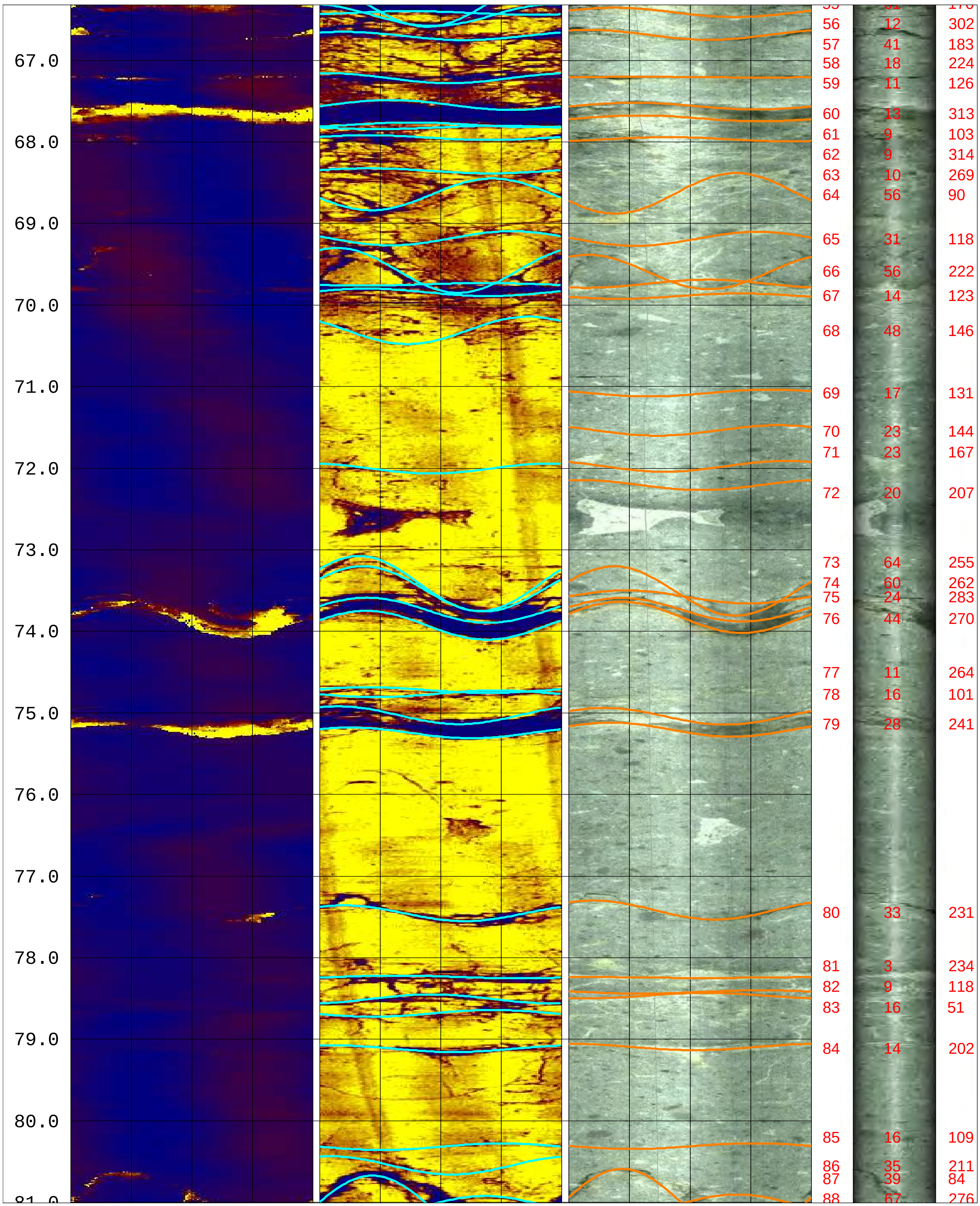
Notes:
1) Azimuths reference True North. Magnetic declination of +17 degrees applied.
2) 3x Horizontal Exaggeration on Televiewer Images.
3) Dip values presented in degrees from horizontal.
4) Dip direction presented in degrees of azimuth.
5) Simulated Core Image is viewed from north, east on left, west on right.



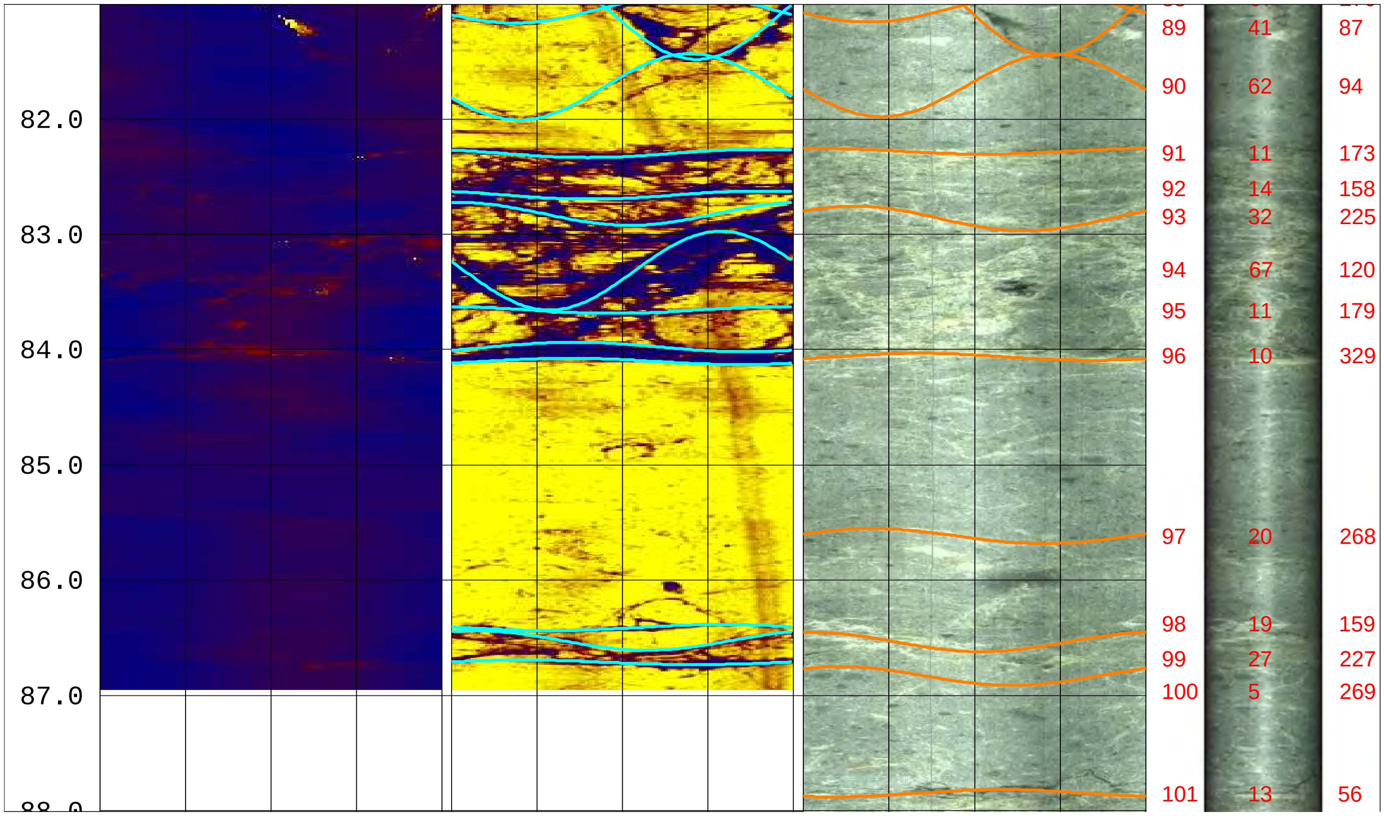
#	Dip	Dip AZ
1	6	292
2	49	104
3	20	158
4	41	350
5	27	243
6	31	139
7	35	211
8	31	189
9	18	124
10	19	132
11	9	83


37.0
38.0
39.0
40.0
41.0
42.0
43.0
44.0
45.0
46.0
47.0
48.0
49.0
50.0
51.0
12 13 96
13 16 213
14 14 318
15 23 152
16 18 171
17 68 287
18 17 170
19 26 167
20 58 186
21 42 276
22 30 196
23 64 339
24 34 259
25 28 210
26 49 138
27 21 191
28 19 166
29 42 279
30 38 296
31 19 50
32 22 297
33 34 307
34 30 323
35 47 256
36 49 272


52.0
53.0
54.0
55.0
56.0
57.0
58.0
59.0
60.0
61.0
62.0
63.0
64.0
65.0
66.0
37 47 52
38 65 346
39 9 84
40 22 185
41 25 214
42 10 232
43 41 269
44 20 204
45 32 208
46 36 105
47 61 280
48 22 170
49 22 139
50 24 298
51 21 172
52 20 115
53 17 339
54 35 172



67.0
68.0
69.0
70.0
71.0
72.0
73.0
74.0
75.0
76.0
77.0
78.0
79.0
80.0
56 12 302
57 41 183
58 18 224
59 11 126
60 13 313
61 9 103
62 9 314
63 10 269
64 56 90
65 31 118
66 56 222
67 14 123
68 48 146
69 17 131
70 23 144
71 23 167
72 20 207
73 64 255
74 60 262
75 24 283
76 44 270
77 11 264
78 16 101
79 28 241
80 33 231
81 3 234
82 9 118
83 16 51
84 14 202
85 16 109
86 35 211
87 39 84
88 67 276


82.0
83.0
84.0
85.0
86.0
87.0
89 41 87
90 62 94
91 11 173
92 14 158
93 32 225
94 67 120
95 11 179
96 10 329
97 20 268
98 19 159
99 27 227
100 5 269
101 13 56