ERCB/AGS Open File Report 2009-18

Results of Sediment Coring at the Town of Peace River, Northwestern Alberta (NTS 84C)

Energy Resources Conservation Board

Alberta Geological Survey

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Abstract

The Peace River Lowlands of Alberta and British Columbia is one of the most historically active mass-movement areas in western Canada. Alberta Geological Survey (AGS), in collaboration with other stakeholders, has initiated a multiyear study, centred on the town of Peace River, to develop a better understanding of the type and extent of landsliding within the municipality. To help establish the geological setting for these landslides, AGS conducted a drilling program using rotosonic coring, wet-rotary drilling and downhole geophysics.

This report details the drill program and contains borehole logs with descriptions of the encountered lithology. The lithological descriptions are accompanied by geophysical logs and selected core photographs from two of the borehole locations. In addition, the report defines the methodology developed to classify discontinuities in the core samples.

1 Introduction

The Peace River Lowlands of Alberta and British Columbia are one of the most historically active mass-movement areas of Western Canada. Mass-movement events have affected, and continue to affect urban centres, such as the town of Peace River in northwestern Alberta, and their associated infrastructure. To better our understanding of these events, Alberta Geological Survey (AGS), in collaboration with various stakeholders, has initiated a multidisciplinary study of urban geology and landslide hazards (Froese, 2007; Morgan et al., 2008) of an area centred on the town of Peace River (Figure 1). This study aims to provide a better understanding of the type and extent of landslides within the Peace River valley. Data obtained from this investigation will be used to aid in municipal planning strategies that will reduce the risk of landslide hazards to population and infrastructure within the study area.

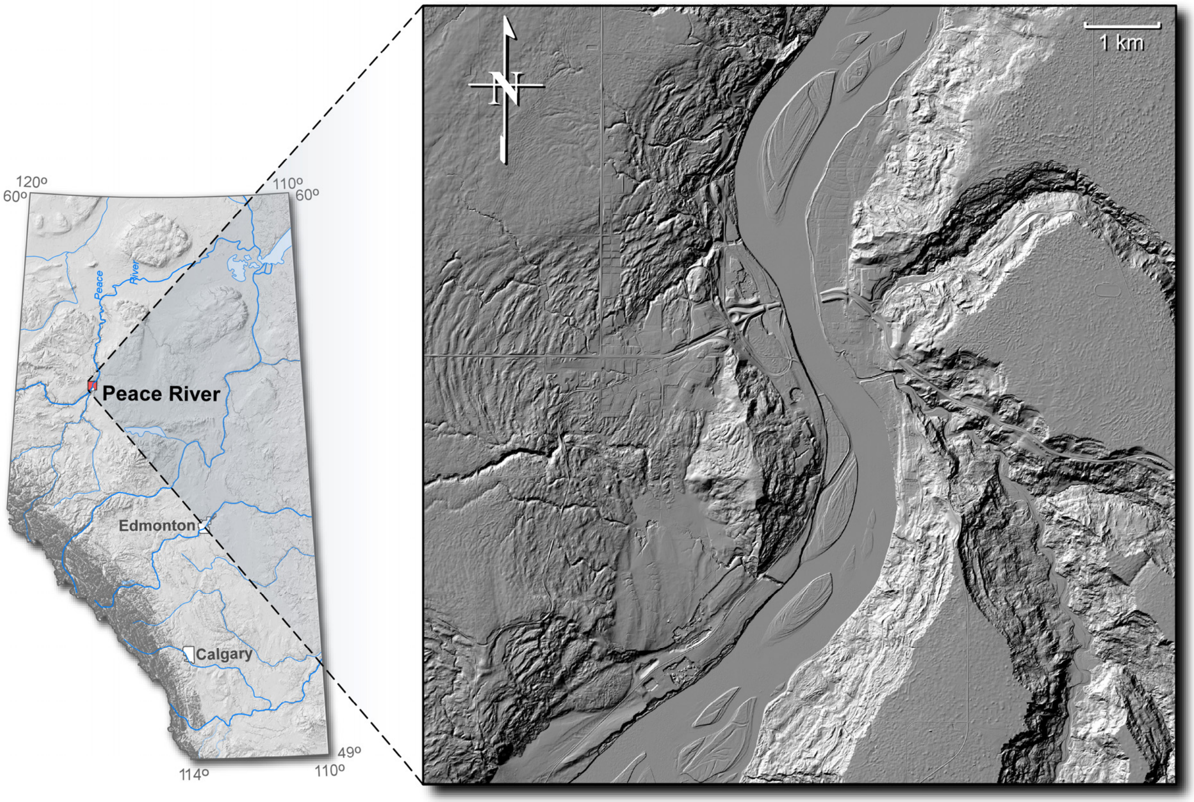

Figure 1. Location of study area.

This report provides a description of an AGS drilling program carried out as part of the landslide study in the town of Peace River in December 2008. The report briefly outlines the investigative methods used and provides the results of the drill program. We will incorporate the data from this program into the larger Peace River Urban Geology and Landslide Hazard Study.

2 Location and Physiography of the Study Area

The study area lies within the Peace River Lowlands physiographic zone of the Interior Plains (Bostock, 1981; Pettapiece, 1986; NTS 84C; Figure 1). Much of the surface morphology in the study area is the result of processes associated with the last glacial event (Late Wisconsinan) and Holocene erosion. The Peace River valley, the predominant morphological feature of the region, developed from incision of the Peace River through the Quaternary sediments and into the Cretaceous bedrock.

The river valley is an important transportation corridor and includes highways and a railway line. The Peace River Lowlands separates the Buffalo Head Hills to the east and the Whitemud and Clear Hills to the west. The Peace River District is composed mainly of fertile farmland, characterized by flat topography and stone-free fields developed on sediments deposited within Glacial Lake Peace, which inundated most of the region below 610 m above mean sea level (m asl; Mathews, 1980; Leslie and Fenton, 2001; Paulen, 2004; Paulen et al., 2004). Elevation within the study area varies from 320 m asl at the floodplain in the town of Peace River to a maximum of 625 m asl in the northwestern part of the study area.

3 Purpose

To better our understanding of the type and extent of landslides within the Peace River Lowlands, we constructed a three-dimensional model using approximately 1400 available drillholes in the study area. The data consisted of logs from shallow geotechnical test holes and water wells, and downhole geophysical profiles obtained from oil and gas wells. As outlined in Morgan et al. (2008), these data, along with field mapping, were used to generate a schematic stratigraphy of the subsurface Quaternary sediments and the topography of the bedrock surface. To provide a greater level of detail on the lithology and sedimentology of the thick Quaternary sediments, a series of sediment cores, complemented by downhole geophysical surveys, was completed in and around the town of Peace River. Data obtained from this investigation will

- improve upon existing stratigraphic modelling of Quaternary and Holocene sediments of the Peace River valley;
- aid in determining the potential mechanism(s) for landslide activity in the Peace River valley;
- aid in determining the type of landslide events that occurred in the Peace River valley;
- aid in determining the deglacial history of the Peace River valley;
- provide high-quality subsurface data that will be used as calibration points during the construction of a geological model of the Peace River valley;
- provide representative sections of the subsurface stratigraphy to aid the geotechnical consulting community in identifying both intact and displaced units within the subsurface;
- provide a spatial distribution of subsurface lithologies in the Peace River area; and
- supply all levels of government, the public and the scientific community with an improved understanding of landslide activity in the Peace River valley that will aid in land-use and infrastructure planning strategies.

4 Methodology

This section provides a brief description of drilling and geophysical methods used in this study. For a more detailed assessment of overburden-drilling methodology and downhole geophysical techniques, see Allen (1993) and Schlumberger (1991), respectively.

4.1 Drilling Methods

The Peace River drill program used two drill rigs, each of which employed a different drilling technique. A truck-mounted Ingersoll Rand T2W rig drilled mud-rotary boreholes through both soil and bedrock, and a truck-mounted Ingersoll Rand TH-60 sonic rig collected continuous core samples through the upper 114 m of the soil column. Brief descriptions of the two drill methods follow.

4.1.1 Mud-Rotary

This drilling method uses a tricone drill bit on the bottom of a string of drill rods that rotate within the borehole. Drilling fluid is pumped into the borehole through the string of drill rods, thereby flushing the drill cuttings (sediment and bedrock samples) to the surface via the space between the drill rods and the borehole wall (annulus). Examination of the returned cuttings is the primary source of lithology determination, although changes in the rate of drilling progress (more commonly called rate of penetration or ROP) or pump pressure can indicate a change in material consistency or lithology, and are commonly helpful as indicators of material boundaries when interpreted by an experienced driller.

4.1.2 Sonic

The sonic method (also termed rotosonic) uses vibration as a means for tool advancement. A hydraulically actuated drilling head is employed to manipulate an inner casing (core barrel) and an outer casing, provide a vibratory source and allow for rotation of the casing. The drilling head applies a sinusoidal vibration to the inner casing, which has a cutting head attached at its end, while at the same time pushing the casing into the ground, typically in 3.05 or 6.10 m (10 or 20 foot) intervals. The outer casing then advances until it reaches the depth of the inner casing, to maintain the borehole. Drilling proceeds in this way, with additional casing segments added as hole depth increases. Once the desired depth is reached, the inner casing is extracted from the hole and the continuous core sample is removed, or vibrated, from the core barrel. A geologist or technician typically examines the core sample on site before it is packed and shipped to a laboratory or discarded, depending on the application.

4.2 Drilling Locations

The AGS Peace River drill program was completed between November 25 and December 16, 2008. Six boreholes were drilled at four sites using both conventional mud-rotary and sonic drilling methods. Figure 2 shows the locations of the boreholes.

At both of the sonic borehole sites, a mud-rotary borehole was drilled approximately 10 m away from the sonic hole. The sonic rig was used to sample the Quaternary sediments overlying the Cretaceous bedrock to the maximum feasible depth based on drilling conditions, whereas the corresponding mud-rotary hole was drilled through the entire sequence of Quaternary sediments and into the Cretaceous bedrock below. These mud-rotary holes were used to ascertain the lithology of the bedrock beneath the adjacent sonic borehole and to facilitate the collection of a suite of downhole geophysical logs, which requires a fluid-filled hole.

Table 1 lists the type, depth, location and order in the sequence of each hole, and indicates the number of the relevant borehole log in Appendix 1.

4.3 Sample Description and Logging

During drilling operations, a geological technologist, sedimentologist or geological engineer was present to provide direction to the rig crew and to receive, examine and describe the drill samples. During mud-rotary operations, soil samples (drill cuttings) were collected at 1.5 m (5 ft) intervals. For sonic operations, the sample interval was effectively continuous, with 5.4 and 2.5 m of lost core reported over 108.2 and 114.3 m of coring in holes PR08-3 and PR08-5, respectively. For both sonic holes, 3.05 m (10 feet) core runs were made to a depth of 15.24 m (50 feet) below ground surface, after which core runs of 6.10 m (20 feet) were made. Due to the expansive nature of the overconsolidated silts, clays and tills that were being sampled, the driller used a drilling mud to lubricate the core barrel and casing during drilling to minimize the chance of getting them stuck in the hole.

The mud-rotary cuttings and the sonic core samples were described on site based on all or some of the following properties: texture, colour, clast lithology, percentage of pebbles and granules, relative

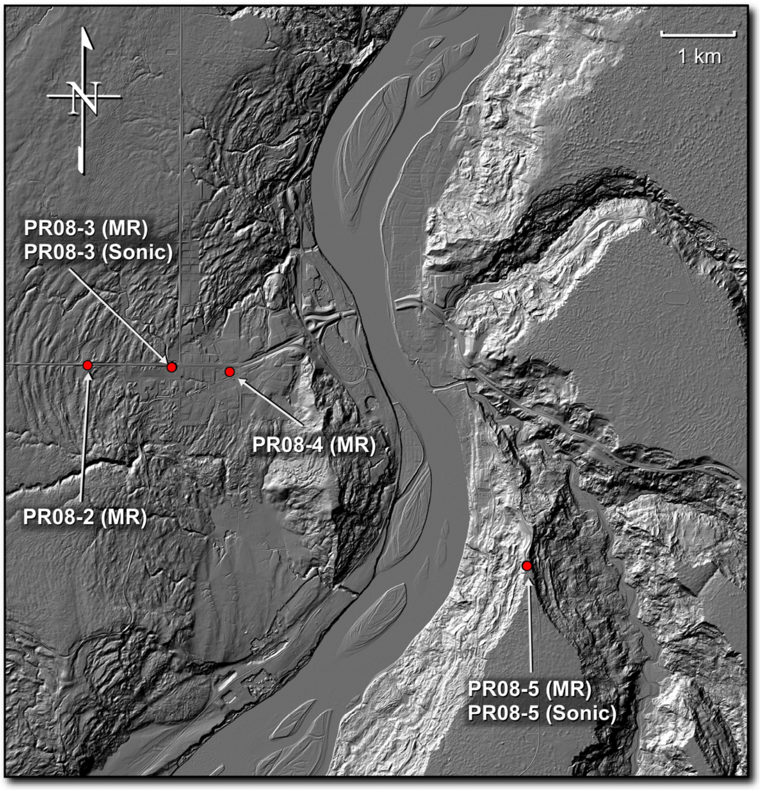

Figure 2. LiDAR image showing locations of mud-rotary (MR) and sonic boreholes.

moisture, and structure. Colour was based on a standardized soil colour chart (Munsell, 1990) and physical soil properties were based on standard methods outlined by Folk (1980). Other descriptive comments included sediment structure (e.g., debris flow, load structures, layering, etc.) and the presence of other relevant features, such as fractures or slickensides. Appendix 2 provides photos of selected intervals and features within the sonic core. After examination and description of the samples in the field, the sonic core was placed in PVC split casing and the mud-rotary cuttings were sealed in plastic bags. All the samples were shipped to the AGS Mineral Core Research Facility (MCRF) in Edmonton for further detailed analysis.

Table 1. Borehole types and locations.

Borehole Name & Type	Total Depth (m)	UTM Location (Zone 11N, NAD83)	Order Drilled	Borehole Log ID (Appendix 1)
PR08-2 Mud-Rotary	172.2	477235E, 6232069N	3rd	PR08-2
PR08-3 Mud-Rotary*	125	478380E, 6232042N	5th	PR08-3 COMP
PR08-3 Sonic	108.2	478388E, 6232046N	2nd	
PR08-4 Mud-Rotary	30.5	479169E, 6231983N	6th	PR08-4
PR08-5 Mud-Rotary*	177	483207E, 6229415N	1st	PR08-5 COMP
PR08-5 Sonic	114.3	483199E, 6229419N	4th	

* Denotes holes where downhole geophysical logs were run.

We finalized the logs (Appendix 1) for the mud-rotary holes after 'truthing' the field logs by examining and confirming the lithology of the preserved samples at the MCRF. For those holes on which we conducted downhole geophysics, we used the resulting geophysical logs to help pick lithological boundaries and provide information between samples.

Two of the logs in Appendix 1 are in a composite log format, which displays the entire depth of the sonic corehole with associated lithological description and then continues using the lithology determined from the mud-rotary borehole. The geophysical logs are also displayed against the lithology information from the sonic and mud-rotary holes.

We re-examined the sonic core in detail at the MCRF to confirm the field logging and create expanded descriptions of sedimentological and geotechnical features. Discontinuities or shearing within the core samples received special attention during logging, particularly as zones of weakness such as these within Quaternary sediments can be indicative of movement zones associated with landsliding in the region. We described the discontinuities in the core using a classification system described in Appendix 3, which was designed for logging of geotechnical discontinuities in mudstones and shales. This classification allows for a systematic description of each discontinuity based on parameters such as spacing, continuity, core breakage, geometry, roughness, sheen and orientation.

4.4 Geophysics

Wireline geophysical measurements were collected in two mud-rotary holes, PR08-3 and PR08-5, which were drilled adjacent to the two sonic coreholes. The suite of wireline services run included standard gamma-ray, spontaneous-potential (SP), single-axis caliper, focused-electric (resistivity) and density measurements. The plots of these measurements are included in the composite logs in Appendix 1. This section provides a brief description of each measurement (Schlumberger, 1991).

The standard gamma-ray reading is a recording of the natural radioactivity of the formation. The gamma-ray tool uses a detector to measure the gamma rays that are spontaneously emitted from radioactive elements, nearly all of them coming from the potassium, uranium and thorium series. In sedimentary formations, the log reflects the clay or shale content because radioactive elements tend to concentrate in clays and shales. Clean formations (e.g., sand, sandstone, carbonates) typically have low levels of radioactivity unless they contain naturally occurring radioactive mineral grains.

The spontaneous-potential (SP) log is a measurement system that records the electric potential (voltage) produced by the interaction of formation connate water, conductive drill fluid and certain ion-selective materials. The SP plot is a recording versus depth of the difference between the electrical potential of a moving electrode and that of a surface electrode. Opposite shales or clays, the plot usually defines a generally straight line. Opposite permeable formations, it shows deviations from this straight line. The SP plot is useful for differentiating the porous and permeable formations (sands, sandstones, limestones) from the nonpermeable clays and shales. The SP measurement also has other uses more applicable to oil field applications, such as the determination of relative salinity and resistivity of formation water.

Focused-electric measurement provides a value for the resistivity, or specific resistance, of the formation. Simply put, the resistivity device emits a current of constant intensity between two current electrodes and measures the resultant potential difference between two measurement electrodes on the tool. Resistivity is determined based on these measured voltages. The wireline tool configuration used in the Peace River project provided a relatively shallow reading of resistivity (i.e., close to the borehole wall).

Density tools provide a measurement of the bulk density of the formation. A radioactive source emits medium-energy gamma rays into the formation. As the gamma rays collide with the electrons in the formation, they lose energy. These scattered gamma rays reach detectors located at fixed distances from the source and are counted as an indication of formation density. Density tools typically have a caliper arm integrated into the tool. In addition to providing a measurement of borehole diameter, the caliper forces the density skid against the borehole wall for optimal measurement when opened.

The composite logs for boreholes PR08-3 and PR08-5 (Appendix 1) include the geophysical plots beside the lithology descriptions.

4.5 Drilling Conditions

Because the Peace River drill program was during the winter, it had to contend with operational delays typical of cold-weather operations. The drilling program achieved the desired results with a few exceptions that were the result of normally encountered drilling issues.

Two of the mud-rotary boreholes encountered borehole stability problems. Borehole PR08-2 advanced successfully to a depth of 172 m below surface, 6 m into the Cretaceous shale bedrock underlying the Quaternary sediments. As the crew was tripping the drillstem out of the hole, the borehole began to collapse about 28 m below ground surface in the sand overlying the diamicton (till). Attempts were made to condition the borehole in preparation for the geophysical wireline runs, but hole integrity worsened and the borehole had to be abandoned and the geophysical logging cancelled.

Borehole PR08-4 was drilled at the end of the program, with limited operational budget remaining. Poor drilling conditions were encountered at 30 m below ground surface in sand and gravel deposits within the diamicton (till, based on drilling response). Attempts to stabilize the borehole were unsuccessful and the decision was made to abandon the hole, as spending had reached the program’s budgetary limit.

Sonic hole PR08-3 reached a maximum core depth of 108 m. The drill rig lost power due to engine problems and required 1.5 days for repairs. During this downtime, the outer casing became stuck in the hole and the borehole had to be abandoned after retrieval of all but some of the lower outer casing.

5 Summary and Conclusions

The program drilled and cored a series of five test holes at the town of Peace River. We chose the locations to provide detailed stratigraphic and geotechnical information in both intact ground and landslide terrain throughout the study area, and to determine depth to bedrock as verification for the previously prepared 3-D geological model. The two sonic boreholes, PR08-3 and PR08-5, provided continuous core for the upper 108 and 114 m, respectively, of the stratigraphy These complemented mud-rotary drilling and downhole geophysical testing into the top of bedrock (more than 170 m below the surface). We expect these test holes will not only aid in interpretation of the Quaternary stratigraphy and bedrock surface orientation, but will also be a significant reference for professionals planning geotechnical investigations and designing mitigatory measures for landslides in the Peace River region.

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Appendix 1 — Borehole Logs

PR08-2 (page 9)

PR08-3 (page 17)

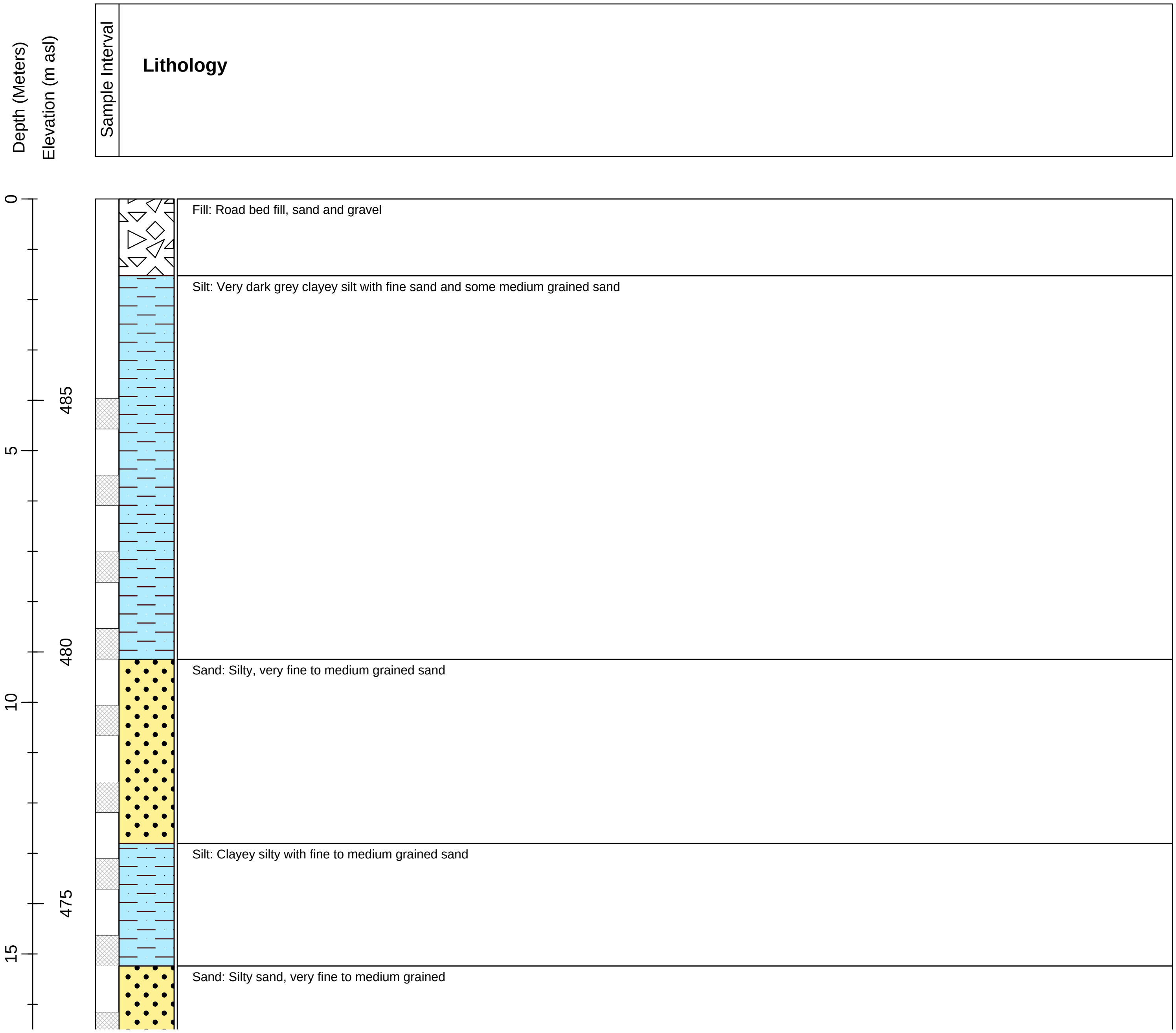
PR08-4 (page 22)

PR08-5 (page 24)

402 Twin Atria Building, 4999 98 Avenue
Edmonton, AB T6B 2X3 Canada
Phone: 780-422-1927
FAX: 780-422-1459

Log ID: **PR08-2**

Total Depth: **172.2 m**
Location: **113-26-083-22W5M**
Northing (UTM Nad83): **6232069**
Easting (UTM Nad83): **477235**
Hole Diameter: **155 mm**
Elevation (Ground Surface): **489 m asl**
Drilling Date: **12/10/08**
Drilled By: **Garrity and Baker (Wet Rotary)**
Lithology Logged By: **J. Warren/ S. Slattery**
Geophysical Log Operator: **N/A**



Fill: Road bed fill, sand and gravel

Silt: Very dark grey clayey silt with fine sand and some medium grained sand

Sand: Silty, very fine to medium grained sand

Silt: Clayey silty with fine to medium grained sand

Sand: Silty sand, very fine to medium grained

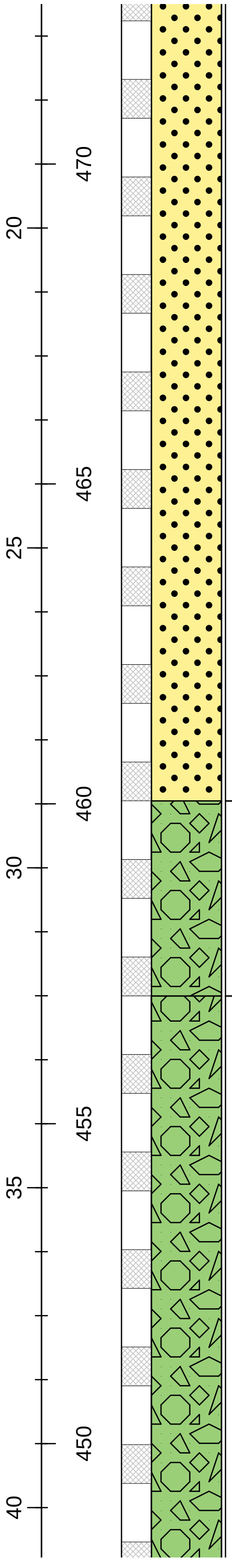
Log ID: **PR08-2**

Depth (Meters)

Elevation (m asl)

Sample Interval

Lithology

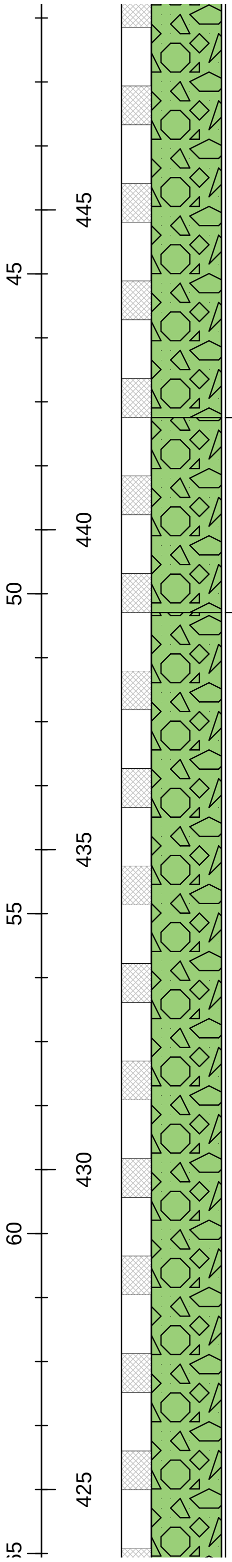


Diamicton: Clayey silt till with very fine to medium grained sand, some fine gravel sizes

Diamicton: ...rocks in hole causing drilling/stability problems, driller cleaned hole.

Log ID: **PR08-2**

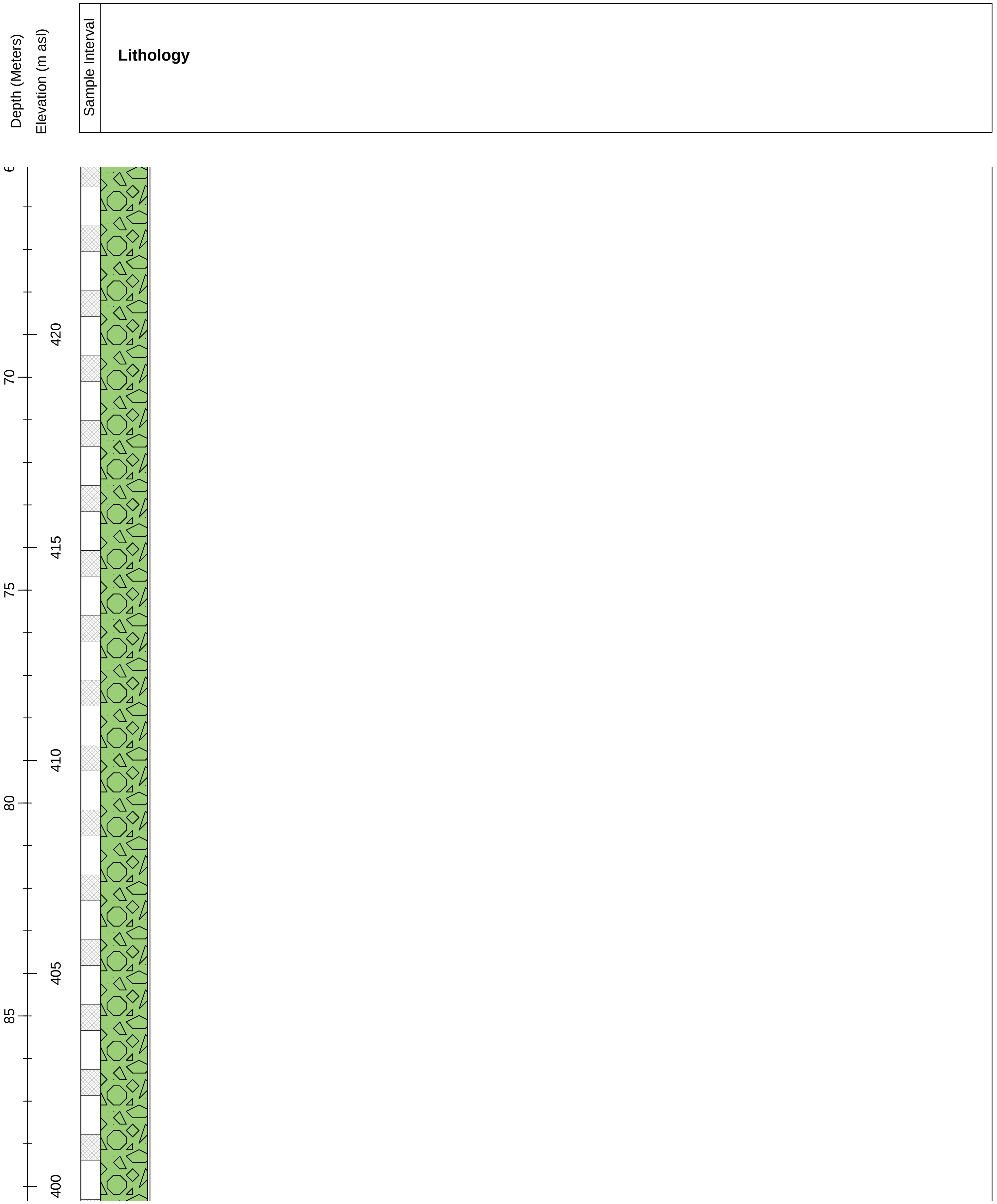
Depth (Meters)
Elevation (m asl)
Sample Interval
Lithology



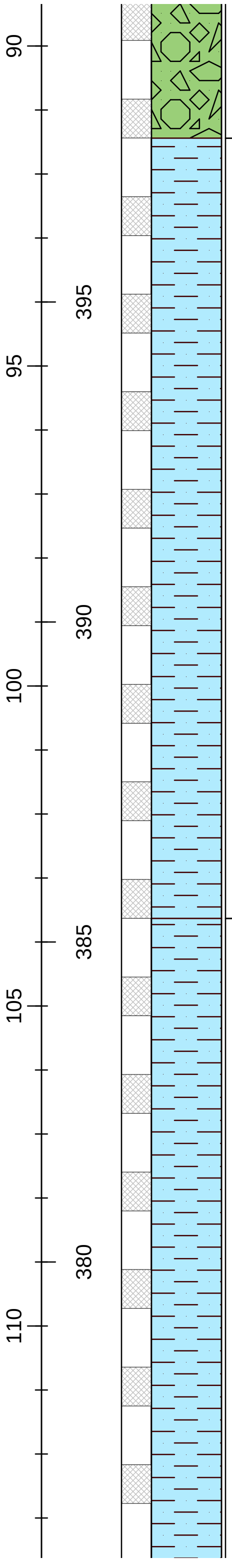
Diamicton: ...drillstem bouncing at 47.5 m depth (441.5 m asl), likely on cobble or boulder.

Diamicton: ...drillstem bouncing at 51.2 m depth (437.8 m asl), drilled through obstruction for 0.4 m, likely cobble or boulder based on drill response.

Log ID: **PR08-2**


Depth (Meters)
Elevation (m asl)
Sample Interval
Lithology
70
75
80
85
420
415
410
405
400

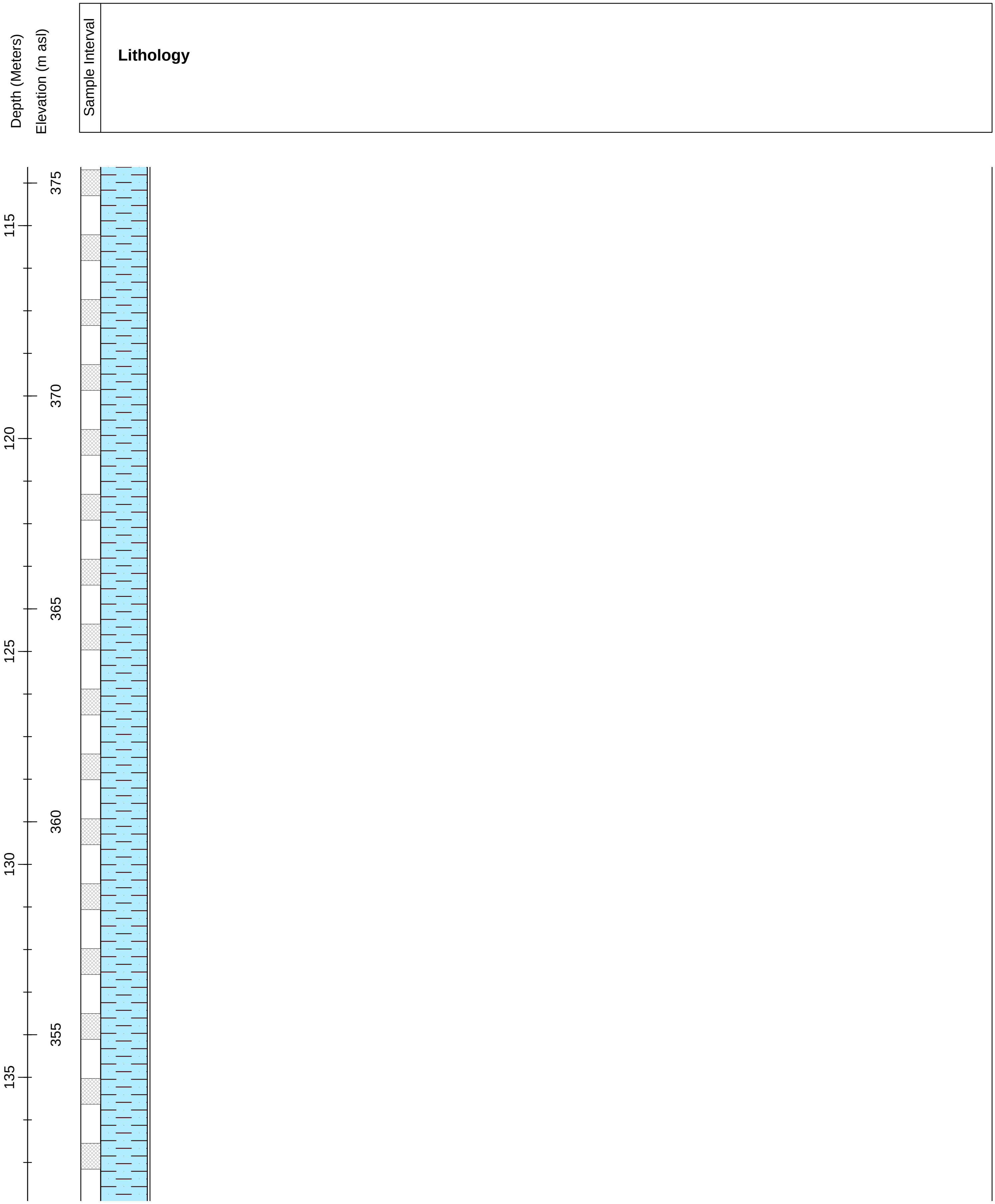
Depth (Meters)
Elevation (m asl)
Sample Interval
Lithology



Silt: Drilling response indicative of a lithology change to silts and clays. Very dark grey clayey silty with minor fine grained sand.

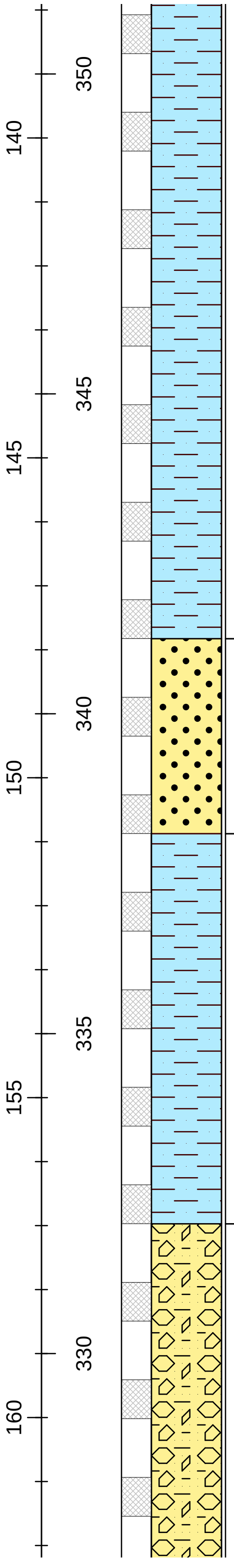
Silt: Drilling slower at 103.6 m (385.4 m asl). Very dark grey clayey silt with fine grained sand, some fine gravel in cuttings.

Log ID: **PR08-2**


Depth (Meters)
Elevation (m asl)
Sample Interval
Lithology
115
120
125
130
135
375
370
365
360
355

Log ID: **PR08-2**

Depth (Meters)
Elevation (m asl)
Sample Interval
Lithology



Sand: Drop in drill pump pressure and drill rate increase, suspect sand.

Silt: Vary dark grey, clayey silt with fine grained sand, some fine gravel in cuttings

Sand and Gravel: Drill rate slows at 157 m depth (332 m asl). Drill response indicative of preglacial sand and gravels as encountered in PR08-3 and PR08-5. Cuttings show medium to coarse sand, clay and silt.

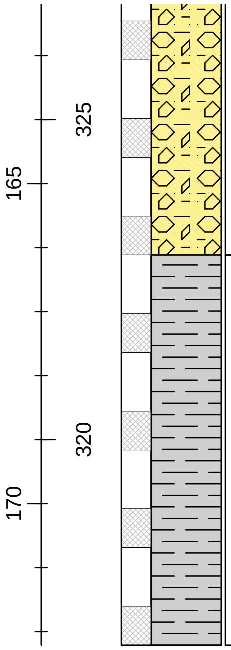
Log ID: **PR08-2**

Depth (Meters)

Elevation (m asl)

Sample Interval

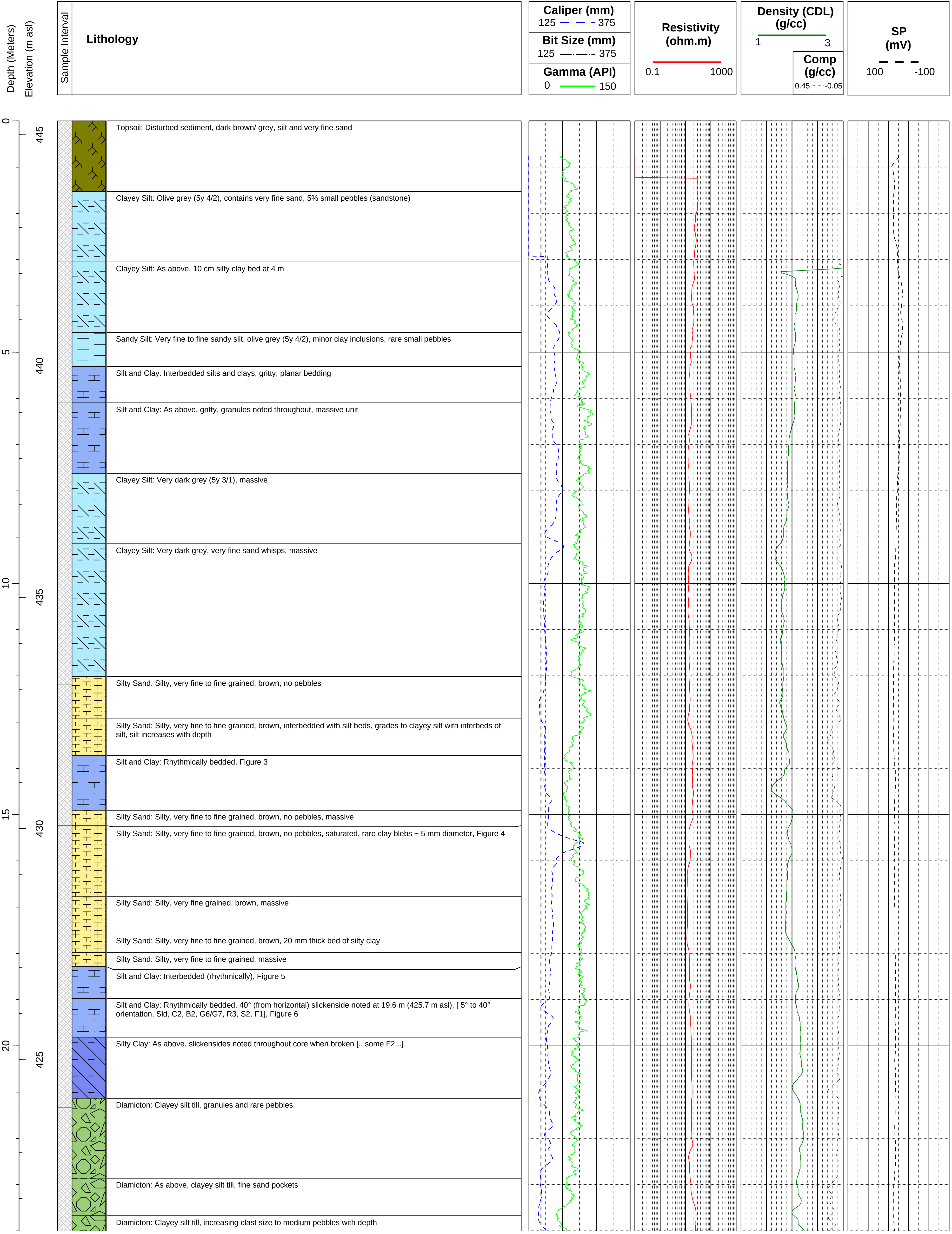
Lithology



Shale: Drill response indicative of lithology change, cuttings contain fragments of shale. End of hole at 172.2 m depth (316.8 m asl).

Log ID: **PR08-3 Composite Log**

Total Depth: **124.97 m**
Location: **16-26-083-22W5M**
Northing UTM Nad83: **6232046**
Easting UTM Nad83: **478388**
Hole Diameter: **155 mm**
Elevation (Ground Surface): **445.3 m asl**
Drilling Date: **12/12/08**
Drilled By: **Boart Longyear (Sonic)/ Garrity Baker (Wet Rotary)**
Lithology Logged By: **S. Slattery/ J. Morgan/ J. Warren**
Geophysical Log Operator: **Century Wireline Services/ D. Sinkwich**



Topsoil: Disturbed sediment, dark brown/ grey, silt and very fine sand

Clayey Silt: Olive grey (5y 4/2), contains very fine sand, 5% small pebbles (sandstone)

Clayey Silt: As above, 10 cm silty clay bed at 4 m

Sandy Silt: Very fine to fine sandy silt, olive grey (5y 4/2), minor clay inclusions, rare small pebbles

Silt and Clay: Interbedded silts and clays, gritty, planar bedding

Silt and Clay: As above, gritty, granules noted throughout, massive unit

Clayey Silt: Very dark grey (5y 3/1), massive

Clayey Silt: Very dark grey, very fine sand whisps, massive

Silty Sand: Silty, very fine to fine grained, brown, no pebbles

Silty Sand: Silty, very fine to fine grained, brown, interbedded with silt beds, grades to clayey silt with interbeds of silt, silt increases with depth

Silt and Clay: Rhythmically bedded, Figure 3

Silty Sand: Silty, very fine to fine grained, brown, no pebbles, massive

Silty Sand: Silty, very fine to fine grained, brown, no pebbles, saturated, rare clay blebs ~ 5 mm diameter, Figure 4

Silty Sand: Silty, very fine grained, brown, massive

Silty Sand: Silty, very fine to fine grained, brown, 20 mm thick bed of silty clay

Silty Sand: Silty, very fine to fine grained, massive

Silt and Clay: Interbedded (rhythmically), Figure 5

Silt and Clay: Rhythmically bedded, 40° (from horizontal) slickenside noted at 19.6 m (425.7 m asl), [5° to 40° orientation, Sld, C2, B2, G6/G7, R3, S2, F1], Figure 6

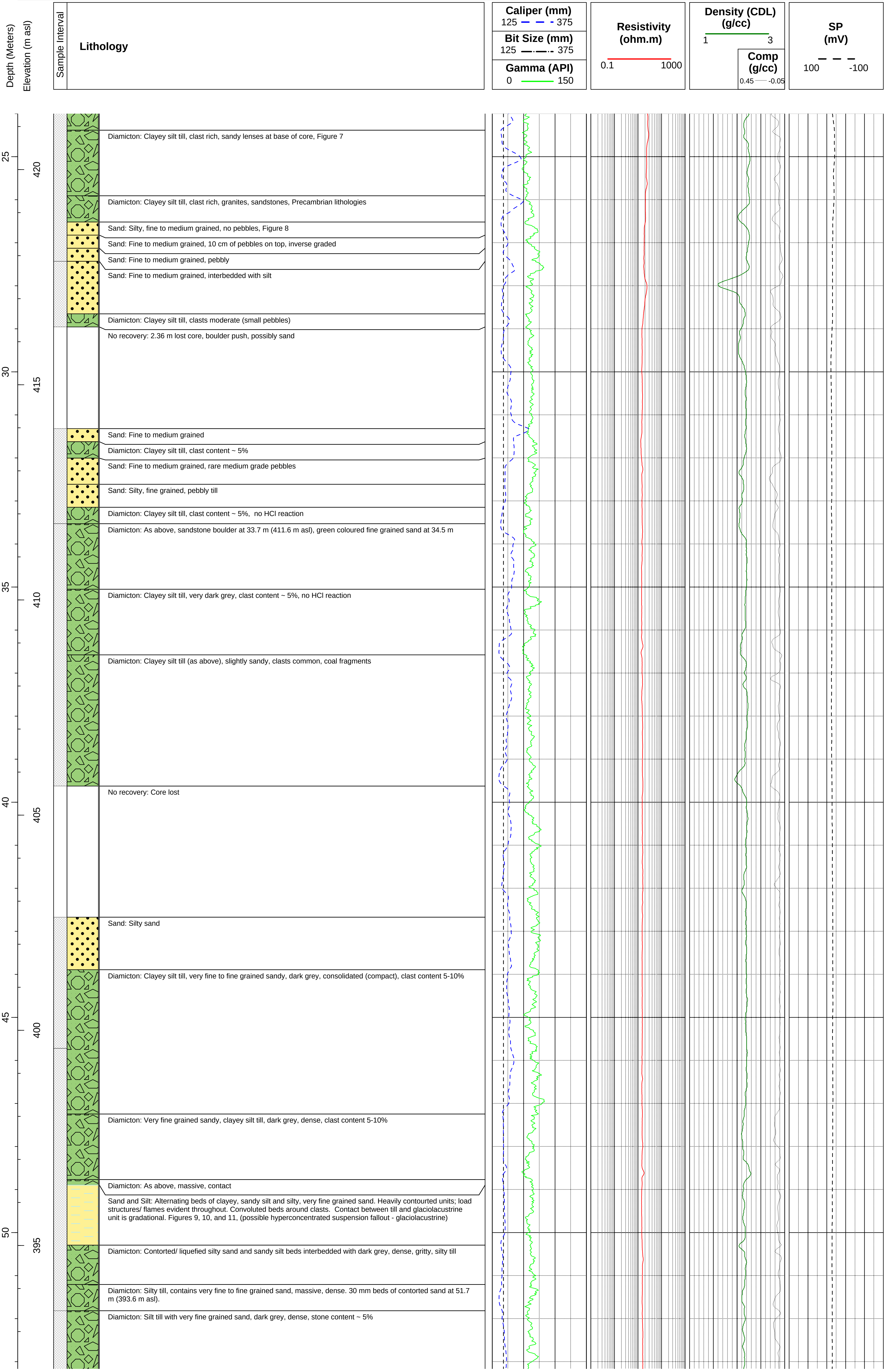
Silty Clay: As above, slickensides noted throughout core when broken [...some F2...]

Diamicton: Clayey silt till, granules and rare pebbles

Diamicton: As above, clayey silt till, fine sand pockets

Diamicton: Clayey silt till, increasing clast size to medium pebbles with depth

Log ID: **PR08-3 Composite Log**



Diamicton: Clayey silt till, clast rich, sandy lenses at base of core, Figure 7

Diamicton: Clayey silt till, clast rich, granites, sandstones, Precambrian lithologies

Sand: Silty, fine to medium grained, no pebbles, Figure 8

Sand: Fine to medium grained, 10 cm of pebbles on top, inverse graded

Sand: Fine to medium grained, pebbly

Sand: Fine to medium grained, interbedded with silt

Diamicton: Clayey silt till, clasts moderate (small pebbles)

No recovery: 2.36 m lost core, boulder push, possibly sand

Sand: Fine to medium grained

Diamicton: Clayey silt till, clast content ~ 5%

Sand: Fine to medium grained, rare medium grade pebbles

Sand: Silty, fine grained, pebbly till

Diamicton: Clayey silt till, clast content ~ 5%, no HCl reaction

Diamicton: As above, sandstone boulder at 33.7 m (411.6 m asl), green coloured fine grained sand at 34.5 m

Diamicton: Clayey silt till, very dark grey, clast content ~ 5%, no HCl reaction

Diamicton: Clayey silt till (as above), slightly sandy, clasts common, coal fragments

No recovery: Core lost

Sand: Silty sand

Diamicton: Clayey silt till, very fine to fine grained sandy, dark grey, consolidated (compact), clast content 5-10%

Diamicton: Very fine grained sandy, clayey silt till, dark grey, dense, clast content 5-10%

Diamicton: As above, massive, contact

Sand and Silt: Alternating beds of clayey, sandy silt and silty, very fine grained sand. Heavily contourted units; load structures/ flames evident throughout. Convoluted beds around clasts. Contact between till and glaciolacustrine unit is gradational. Figures 9, 10, and 11, (possible hyperconcentrated suspension fallout - glaciolacustrine)

Diamicton: Contorted/ liquefied silty sand and sandy silt beds interbedded with dark grey, dense, gritty, silty till

Diamicton: Silty till, contains very fine to fine grained sand, massive, dense. 30 mm beds of contorted sand at 51.7 m (393.6 m asl).

Diamicton: Silt till with very fine grained sand, dark grey, dense, stone content ~ 5%

Log ID:**PR08-3 Composite Log**

Diamicton: Silt till with very fine to fine grained sand, minor clay, dark grey, very dense, stone content ~ 5%

Diamicton: As above, sand stringers ~ 10 mm thick, Figure 12 and 13

Diamicton: As above, 50 mm thick sandy shear plane

Diamicton: As above, slickensided clay at top of core at 64 m (381.3 m asl), [55° - 60° from horizontal, Sld, C3, B2, G2, R3, S2/S3, F2], Figure 14 and 15

Diamicton: Clayey silt till, very fine grained sandy, dark grey, dense, no shear planes

Diamicton: Very fine grained sandy, silty till, dark grey, dense, interbedded with convoluted beds of silty, very fine to fine grained sand. Interbeds are defined by detached/ rotated beds, (possible ripple drift sequence in one bed), Figure 16

Diamicton: Clayey silt till, very fine grained sand, dark grey, massive, clast content ~ 5%

Diamicton: Silty till, dark grey, interbedded with very fine grained silty sand (appears brecciated), Figure 17

Diamicton: As above, slickenside's at 80.5 m (364.8 m asl), occurring in silts [Sld,C3, B3, G5-G3, R2/R3, S2, F2, 50° - 55° from horizontal], Figure 18

Diamicton: As above, slickenside at 80.8 m (364.5 m asl)

Log ID: PR08-3 Composite Log

Diamicton: As above, apparent contact with silt at 83.7 m (361.6 m asl), massive very fine to fine grained silt

Silt: Very fine to fine grained sandy silt, dark to olive grey, slickensided fracture in strata at 84.7 m (360.6 m asl), surface mostly obsured by drilling mud, [53° - 55° from horizontal, Sld, C3, B2, G1, R3/R4, S3/S4, F2], Figure 19

Silt: As above, two slickensided fractures obscured by mud at 85.8 m and 86 m (359.5 & 359.3 m asl),[45° - 50° from horizontal, Sld, C3, B3, G1, R2/R3, S3 and S4, F2], Figure 20 and 21

Diamicton: Very fine to fine grained sandy silt till, dark grey, dense, clast content ~ 5%

Diamicton: Very fine to fine grained sandy silt till, minor clay, dark grey, dense, massive, clast content ~5%, 1 - 30 mm thick silt beds throughout.

Silt and Clay: Rythmites noted at base of core at 89.9 m (355.4 m asl), Figure 22 and 23

Silt and Clay and Sand: Rhythmically bedded fine grained sand, silt, and clay, discontinuous slickensides noted throughout core, [horizontal, Slc, C1, B2, G5, R2/R3, S2/S3, F1], Figures 24, 25, 26, and 27

Silt and Clay and Sand: As above, rare, discontinuous slickensides noted, Figure 28 and 29

Silt and Clay and Sand: Silt, clay, very fine to fine grained sand couplets 17 to 23 cm thick, rhythmically bedded, Figure 30

Silt and Clay and Sand: Silt, clay, very fine to fine grained sand, rhythmically bedded

Silt and Clay and Sand: Silt, clay, very fine grained sand, rhythmically bedded

Silt and Clay and Sand: As above, slickensides noted in clay [horizontal to 50° orientation, Slc/Sld, C1 & C3, B1, G2-G5, R2/R3, S2, F2], Figures 31, 32, 33, and 34

Silt and Clay and Sand: As above, varves of silt, clay, very fine grained sand dark grey/ black

Sand: Very fine to fine grained, grey, structureless. Interbeds of very fine to fine grained sand and silt from 101.6 - 101.7 m, (343.7 to 343.6 m asl), grey/light brown, Figure 35

Sand: Fine to medium grained, grey/ black, some small pebbles/ granules (~2%), black beds may be laminae accented by heavy minerals. From 100.6 - 102.1 m (344.7 - 343.2 m asl), all contacts conformable (non-erosive) with an overall fining upwards sequence

Silt and Clay: Rhythmically bedded, slickensides noted parallel to bedding [Slb/Slc, C2/C3, B2, G2, R2, S2, F1], (NOTE: Slickensides appear to be drill-induced), Figure 36 and 37. 15 cm bed of silty, very fine to fine grained sand at 103.4 m (341.9 m asl).

Silt and Clay: Rhythmically bedded, white coloured granules throughout (possibly dropstones)

Silt and Clay: As above, very fine to fine grained sand stringers present, slickensides parallel to bedding [Slb/Slc, C2/C3, B2, G2/G3, R2, S1/S2, F1], (NOTE: Slickensides appear to be drill-induced), Figures 38, 39, and 40

Sand: Silty, very fine to fine grained

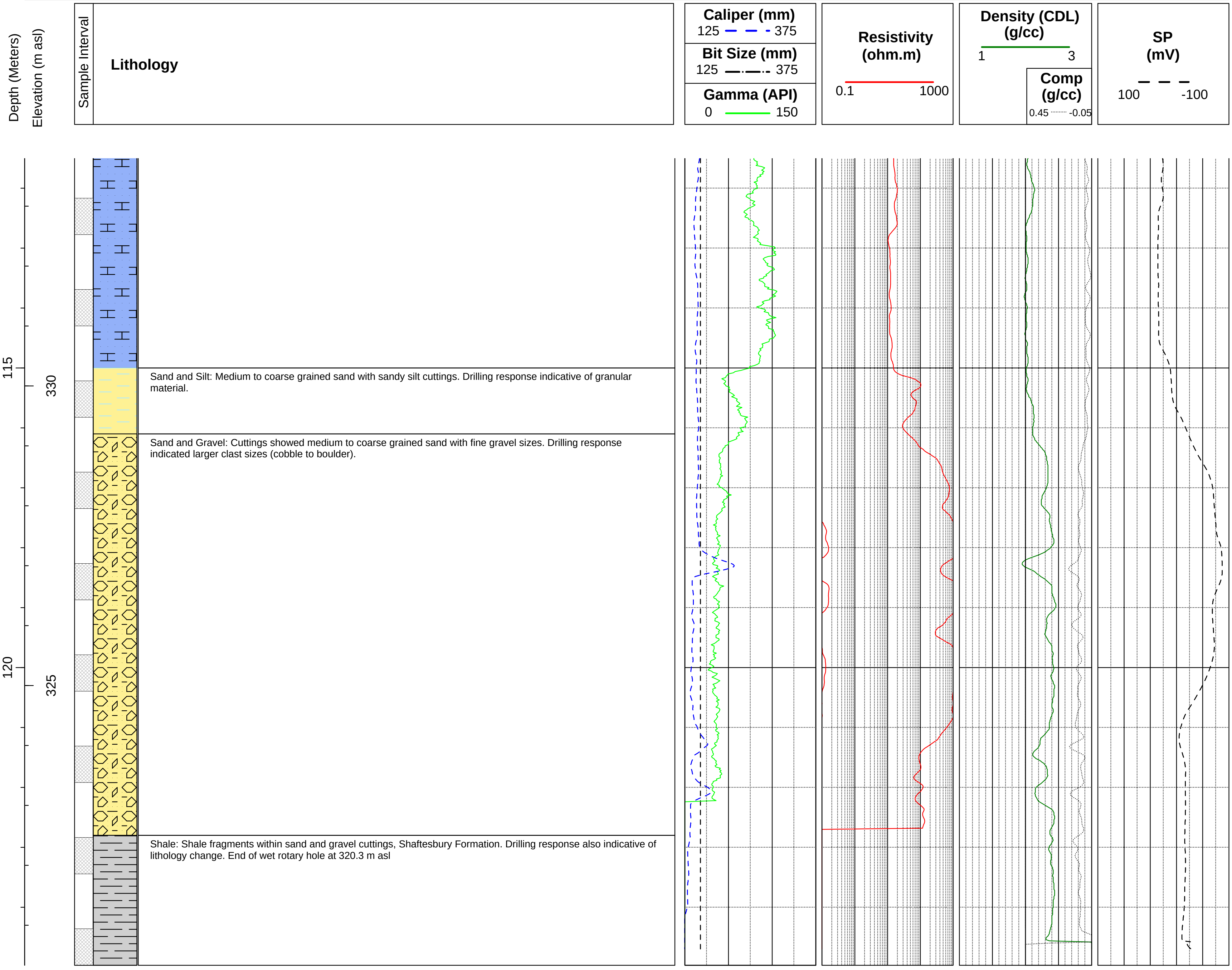
Silt and Clay: Very fine grained sand, silt, and clay, rhythmically bedded, dark grey, 70 mm thick bed of silty, very fine to fine grained sand at 106.2 m (339.1 m asl), slickensides noted [horizontal orientation, Slb/Slc, C1, C2, & C3, B2, G2/G3, R2 & R4, S1 to S4, F1], (NOTE: Slickensides appear to be drill-induced), Figures 41 and 42

Silt and Clay: As above, beds of fine to medium grained sand throughout, horizontal slickensides throughout (as above)

Silt and Clay and Sand: Silt, clay, very fine grained sand, rhythmically bedded, dark grey with 10 cm beds of structuress and planar bedded, dark brown fine grained sand. End of Sonic hole at 337.1 m asl.

Silt and Clay: <*Lithology below 337.1 m asl interpreted from borehole adjacent to sonic corehole, drilled using a wet rotary method. Lithology determined from cutting returns, drill response and geophysical logs run in this fluid filled hole*>

Log ID: **PR08-3 Composite Log**



Sand and Silt: Medium to coarse grained sand with sandy silt cuttings. Drilling response indicative of granular material.

Sand and Gravel: Cuttings showed medium to coarse grained sand with fine gravel sizes. Drilling response indicated larger clast sizes (cobble to boulder).

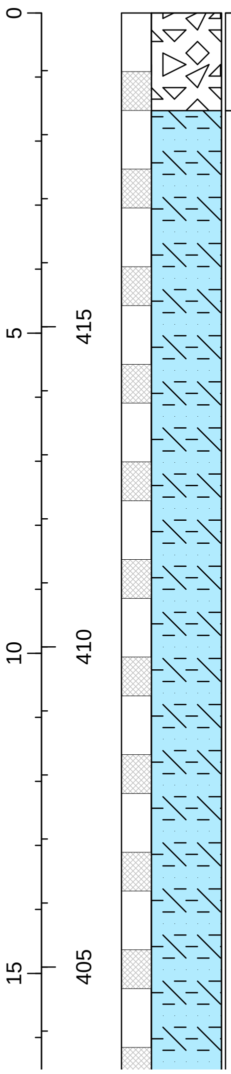
Shale: Shale fragments within sand and gravel cuttings, Shaftesbury Formation. Drilling response also indicative of lithology change. End of wet rotary hole at 320.3 m asl

402 Twin Atria Building, 4999 98 Avenue
Edmonton, AB T6B 2X3 Canada
Phone: 780-422-1927
FAX: 780-422-1459

Log ID: **PR08-4**

Total Depth: **30.5 m**
Location: **14-25-083-22W5M**
Northing (UTM Nad83): **6231983**
Easting (UTM Nad83): **479169**
Hole Diameter: **155 mm**
Elevation (Ground Surface): **419.9 m asl**
Drilling Date: **12/15/08**
Drilled By: **Garrity and Baker (Wet Rotary)**
Lithology Logged By: **J. Morgan**
Geophysical Log Operator: **N/A**

Depth (Meters)
Elevation (m asl)
Sample Interval
Lithology

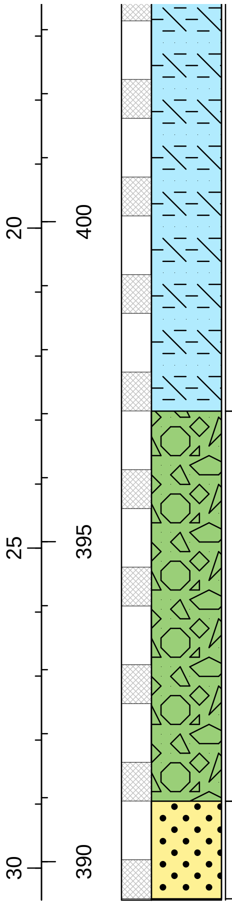


Fill: Fill and brown clay, with some fine sand

Clayey Silt: Silty clay, brown (7.5Yr 5/4), with very fine to fine grained sand, pebble gravel sizes in cuttings

Log ID: **PR08-4**

Depth (Meters)
Elevation (m asl)
Sample Interval
Lithology

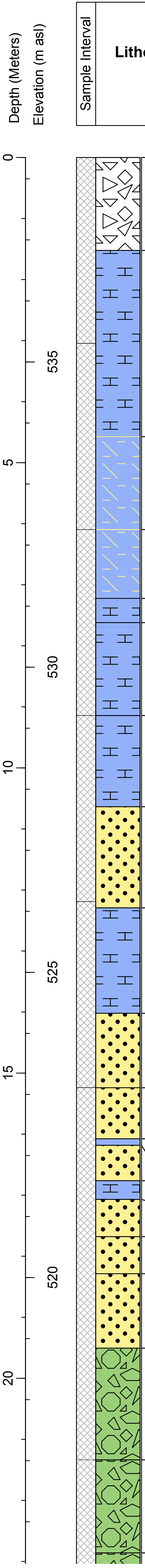


Diamicton: Clayey silt till, very dark grey, with very fine to fine grained sand, trace amount pebble sized gravel

Sand: End of hole at 30.5 m (398.4 masl), borehole collapsing in what appeared to be sands and gravels based on drill response. Hole abandoned.

Log ID:**PR08-5 Composite Log**

Total Depth: **177 m**
Location: **8-20-083-21W5M**
Northing UTM Nad83: **6229419**
Easting UTM Nad83: **483199**
Hole Diameter: **155 mm**
Elevation (Ground Surface): **538.35 m asl**
Drilling Date: **12/04/08**
Drilled By: **Boart Longyear (Sonic)/ Garrity & Baker (Wet Rotary)**
Lithology Logged By: **S. Slattery/ J. Morgan/ J. Warren**
Geophysical Log Operator: **Century Wireline Services/ D. Sinkwich**



Lithology

Fill: Mix of asphalt and construction sand/ gravel

Silt and clay: Rhythmically bedded silts and clays with very fine to fine grained sand stringers, dark to light brown, Figure 43

Silt and Clay and Sand: Silt, clay and very fine grained sand rhythmites from 4.6 - 5.2 m (533.8 - 533.2 m asl); sand content increases with depth from 5.2 to 6.1 m (533.2 - 532.3 m asl)

Silt and Clay and Sand: Silt, clay and very fine grained sand rhythmites, dark brown, sand stringers throughout

Silt and clay: Silt and clay rhythmites, dark brown, minor very fine grained sand, clay content increases with depth

Silt and clay: Silt and clay rhythmites, dark brown, slickensides noted, [Horizontal orientation, Slc/Sld, C1/C2/C3, B2, G2/G6/G7, R2/R3, S2/S3, F2], NOTE: Slickensides appear to be drill-induced, Figure 44 and 45

Silt and clay: As above, same type of slickenside noted as above [horizontal orientation, Slc, C1/C2, B2, G2, R4 to R2, S2/S3, F1], NOTE: Slickensides appear to be drill-induced, Figure 46

Sand: Silty, very fine to medium grained, light to dark brown, rare clay bed 10 mm thick, saturated unit

Silt and clay: Clay, silt and very fine grained sand rhythmically bedded, dark brown (clay) and light brown (silt and clay), silt, clay and very fine sand contorted, Figure 47. Slickensides noted in clays [horizontal orientation, Sld, C2/C3, B2, G5, R3/R4, S3, F1], Figure 48 and 49

Sand: Silty, very fine to medium grained, interbedded with silty clay, fining upward sequence of rhythmites, slickensides in silty clay [horizontal orientation, Sld, C1, B2, G3, R2/R3, S2, F1], NOTE: Slickensides appear to be drill-induced, Figure 50 and 51

Sand: Silty, very fine to medium grained, dark brown (silt) and light brown (sand), no structure, few clasts evident

Silt and clay: Clayey, very fine to fine grained sandy silt, dark grey, bedding destroyed

Sand: Silty, very fine to medium grained, dark to light brown, structureless, no clasts

Silt and clay: Silt, clay and very fine grained, rhythmically bedded

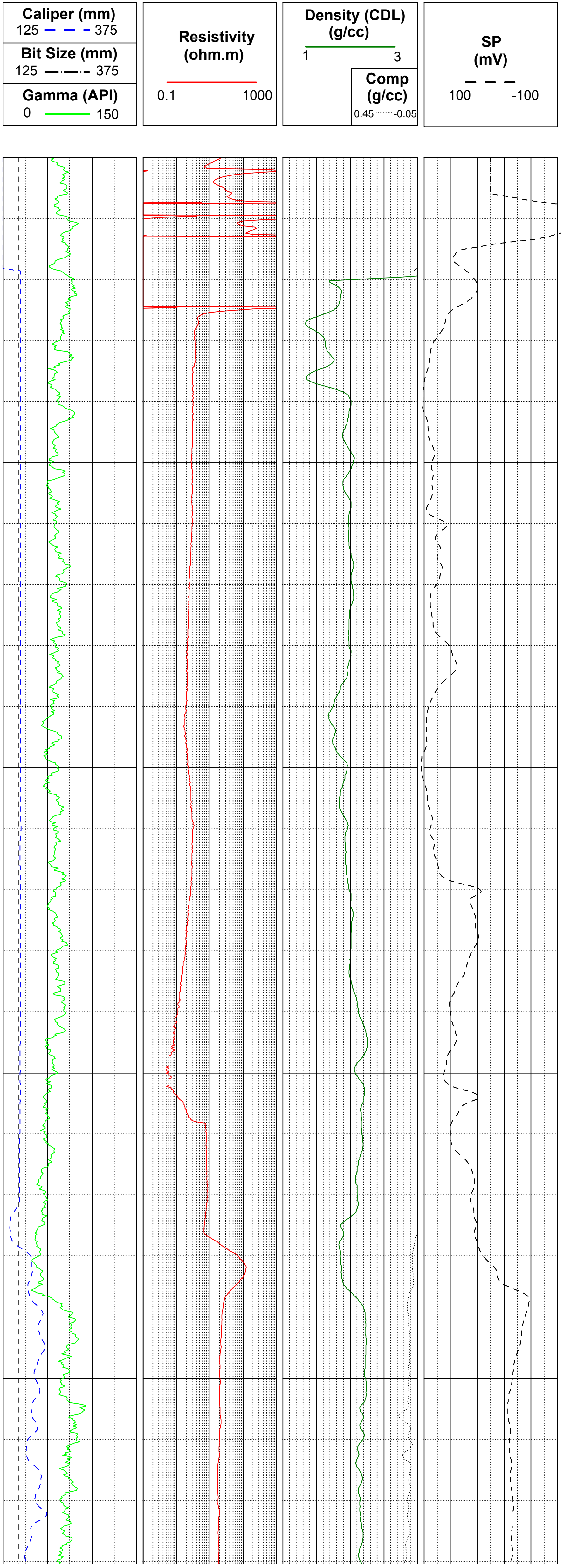
Sand: Clayey, silty, very fine grained, clay drapes common

Sand: Fine to medium grained, light brown/ yellow, no clasts, planar laminae/ beds, Figure 52

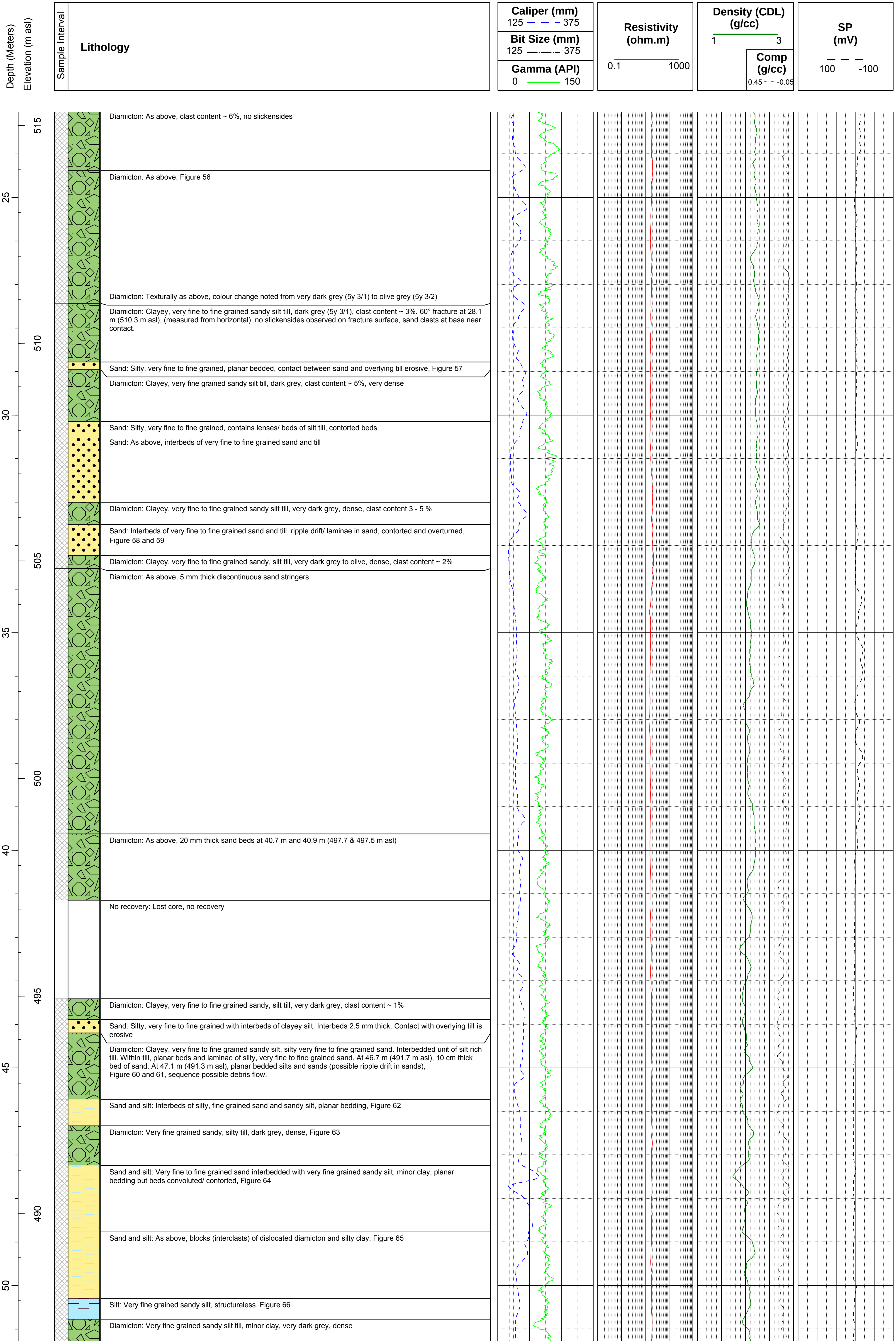
Sand: Fine to medium grained, light brown/ yellow, fine grained sand content increases with depth, Figure 53

Diamicton: Clayey, very fine to fine grained sandy, silt till, very dark grey (5y 3/1), clast content ~ 6%

Diamicton: As above, fracture planes/ shear planes in till, slickenside surface mostly obscured by drilling mud [approximately 60° from horizontal, Sld, C3, B2, G2, R3, S2/S3, F2], Figure 54 and 55



Log ID: **PR08-5 Composite Log**



Diamicton: As above, clast content ~ 6%, no slickensides

Diamicton: As above, Figure 56

Diamicton: Texturally as above, colour change noted from very dark grey (5y 3/1) to olive grey (5y 3/2)

Diamicton: Clayey, very fine to fine grained sandy silt till, dark grey (5y 3/1), clast content ~ 3%. 60° fracture at 28.1 m (510.3 m asl), (measured from horizontal), no slickensides observed on fracture surface, sand clasts at base near contact.

Sand: Silty, very fine to fine grained, planar bedded, contact between sand and overlying till erosive, Figure 57

Diamicton: Clayey, very fine grained sandy silt till, dark grey, clast content ~ 5%, very dense

Sand: Silty, very fine to fine grained, contains lenses/ beds of silt till, contorted beds

Sand: As above, interbeds of very fine to fine grained sand and till

Diamicton: Clayey, very fine to fine grained sandy silt till, very dark grey, dense, clast content 3 - 5 %

Sand: Interbeds of very fine to fine grained sand and till, ripple drift/ laminae in sand, contorted and overturned, Figure 58 and 59

Diamicton: Clayey, very fine to fine grained sandy, silt till, very dark grey to olive, dense, clast content ~ 2%

Diamicton: As above, 5 mm thick discontinuous sand stringers

Diamicton: As above, 20 mm thick sand beds at 40.7 m and 40.9 m (497.7 & 497.5 m asl)

No recovery: Lost core, no recovery

Diamicton: Clayey, very fine to fine grained sandy, silt till, very dark grey, clast content ~ 1%

Sand: Silty, very fine to fine grained with interbeds of clayey silt. Interbeds 2.5 mm thick. Contact with overlying till is erosive

Diamicton: Clayey, very fine to fine grained sandy silt, silty very fine to fine grained sand. Interbedded unit of silt rich till. Within till, planar beds and laminae of silty, very fine to fine grained sand. At 46.7 m (491.7 m asl), 10 cm thick bed of sand. At 47.1 m (491.3 m asl), planar bedded silts and sands (possible ripple drift in sands), Figure 60 and 61, sequence possible debris flow.

Sand and silt: Interbeds of silty, fine grained sand and sandy silt, planar bedding, Figure 62

Diamicton: Very fine grained sandy, silty till, dark grey, dense, Figure 63

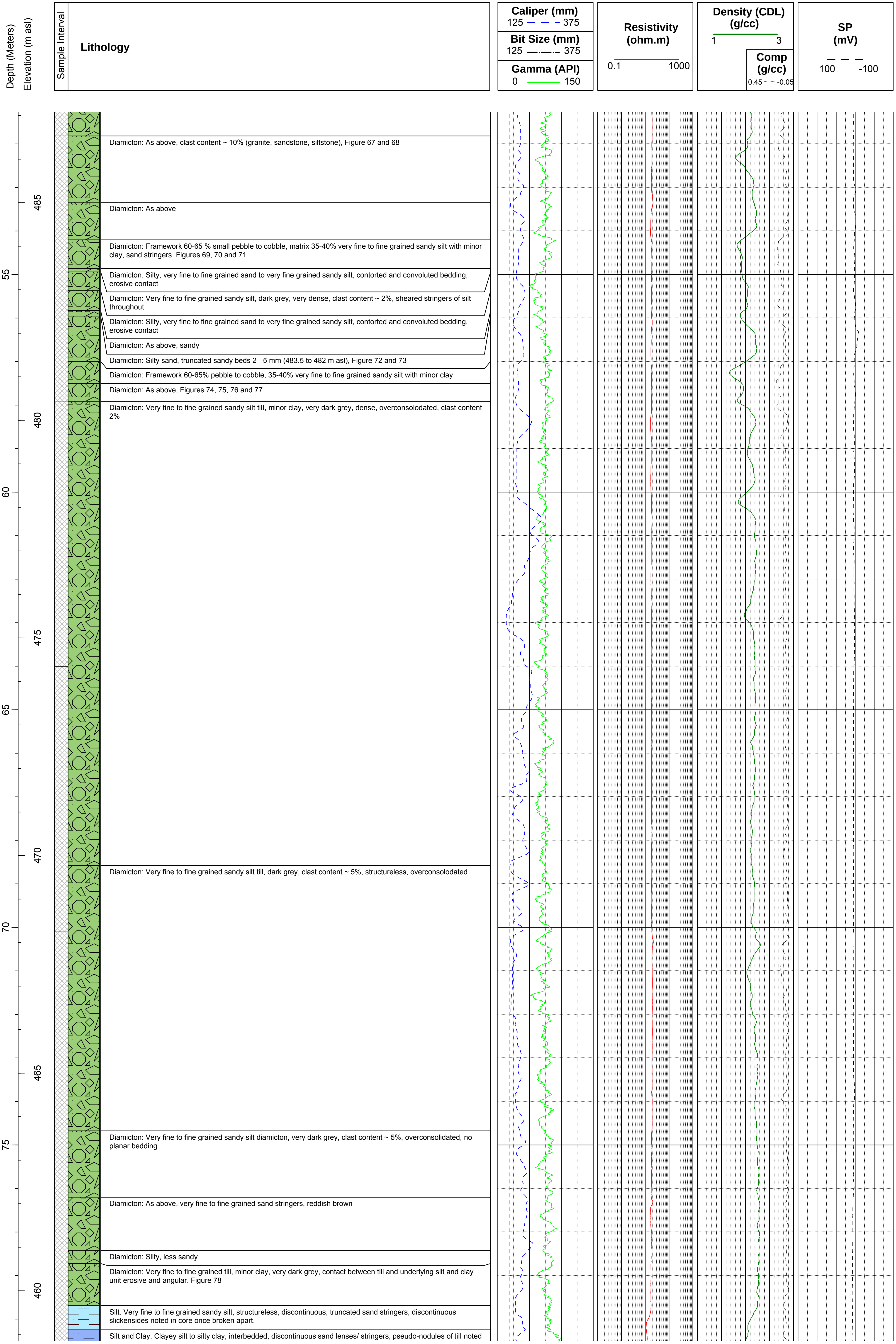
Sand and silt: Very fine to fine grained sand interbedded with very fine grained sandy silt, minor clay, planar bedding but beds convoluted/ contorted, Figure 64

Sand and silt: As above, blocks (interclasts) of dislocated diamicton and silty clay. Figure 65

Silt: Very fine grained sandy silt, structureless, Figure 66

Diamicton: Very fine grained sandy silt till, minor clay, very dark grey, dense

Log ID: **PR08-5 Composite Log**



Diamicton: As above, clast content ~ 10% (granite, sandstone, siltstone), Figure 67 and 68

Diamicton: As above

Diamicton: Framework 60-65 % small pebble to cobble, matrix 35-40% very fine to fine grained sandy silt with minor clay, sand stringers. Figures 69, 70 and 71

Diamicton: Silty, very fine to fine grained sand to very fine grained sandy silt, contorted and convoluted bedding, erosive contact

Diamicton: Very fine to fine grained sandy silt, dark grey, very dense, clast content ~ 2%, sheared stringers of silt throughout

Diamicton: Silty, very fine to fine grained sand to very fine grained sandy silt, contorted and convoluted bedding, erosive contact

Diamicton: As above, sandy

Diamicton: Silty sand, truncated sandy beds 2 - 5 mm (483.5 to 482 m asl), Figure 72 and 73

Diamicton: Framework 60-65% pebble to cobble, 35-40% very fine to fine grained sandy silt with minor clay

Diamicton: As above, Figures 74, 75, 76 and 77

Diamicton: Very fine to fine grained sandy silt till, minor clay, very dark grey, dense, overconsolodated, clast content 2%

Diamicton: Very fine to fine grained sandy silt till, dark grey, clast content ~ 5%, structureless, overconsolodated

Diamicton: Very fine to fine grained sandy silt diamicton, very dark grey, clast content ~ 5%, overconsolidated, no planar bedding

Diamicton: As above, very fine to fine grained sand stringers, reddish brown

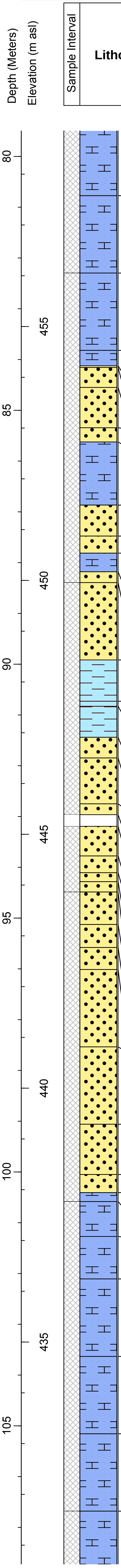
Diamicton: Silty, less sandy

Diamicton: Very fine to fine grained till, minor clay, very dark grey, contact between till and underlying silt and clay unit erosive and angular. Figure 78

Silt: Very fine to fine grained sandy silt, structureless, discontinuous, truncated sand stringers, discontinuous slickensides noted in core once broken apart.

Silt and Clay: Clayey silt to silty clay, interbedded, discontinuous sand lenses/ stringers, pseudo-nodules of till noted

Log ID: **PR08-5 Composite Log**



Lithology

at 80.6 m (457.8 m asl). 45 degree, slickensided shear plane at base of core (457.6 m asl) through silty clay/ clayey silt. Slickensides noted throughout core [40° orientation to horizontal, Slc/Sld, C1/C2/C3, G2-G5, B2, S2/S3, R2/R3, F2], Figure 79 and 80. NOTE: Some slickensides appear to be drill-induced. Figure 81 and 82

Silt and Clay: Clayey silt to silty clay, interbedded, rhythmically bedded, sand stringers and nodules, no diamicton nodules, slickensides noted [0° to 20° from horizontal, Slc/Sld, C2/C3, B2, G2 to G5, R2/R3, S2/S3, F2], NOTE: Slickensides appear to be drill-induced, Figure 83 and 84

Silt and Clay: Clayey silt to silty clay, interbedded, rhythmites, sand and silt lenses and stringers, fractures occurring on clay laminae (mud drapes), horizontal fractures, slickensides continue (i.e. as above)

Silt and clay: Clayey silt to silty clay, interbedded silt lenses, coal inclusions, contact with sand at 84.1 m (454.3 m asl), fracture with slickensides at 84 m, slickensides continue in clays (as above), Figure 85 and 86

Sand: Medium grained, silty sand, grey

Sand: Silty sand with coarse to medium grained sand, brown, possible mixing from drilling, Figure 87 and 88

Sand: Medium to coarse grained, brown, with clayey silt and fine grained sand pockets

Sand: Fine to medium grained silty, grey, erosive 45 degree contact with silt and clay, Figure 89

Silt and Clay: Clayey silt to silty clay, interbedded with grey fine to medium grained sand, Figure 90. From 85.8 to 86.3 m (452.6 to 452.1 m asl) - Mixed sand and clayey silt/silty clay. From 86.3 to 86.9 m (452.1 to 451.5 m asl) - clayey silt with sand deformed by drilling. Silt and clay rhythmites at base of core (451.5 m asl) with horizontal slickensided fractures

Sand: Silty, fine to medium grained, dark grey, contains coarse brown sand and clayey silt nodules/ pockets

Sand: Coarse grained, brown, with pockets or dark grey fine to medium grained sand

Silt and Clay: Clayey silt to silty clay, dark grey, laminated, very fine to fine grained sand stringers, slickensided fracture surfaces in clayey silt [horizontal (0°) to low angle (~10°) orientation, Sld, C2, B2, G5-G7, R2/R3, S1/S2, F2], Figure 91

Sand: Medium to coarse grained, brown, with grey fine grained silty sand, contorted beds at clayey silt/ sand interface, drill induced (?)

Sand: Medium to coarse grained, brown, pockets of dark grey silt and clayey silt from 88.4 to 88.8 m (450 to 450.6 m asl), Figure 92

Silt: *<samples initially lost downhole, sample retreived but disturbed from 89.9 - 92.7 m (448.5 - 445.7 m asl), drill mud with high medium grained sand content in fractures and breaks, sand also intruded into clayey silt in places>* Clayey silt, dark grey with black interbeds of clay, fine sand stringers, laminated

Silt: Lost material, clayey silt, horizontal fractures, void filled with mixture of medium grained sand and drilling mud

Silt: Clayey silt, grey, with reddish brown, fine grained, laminated sand beds, and black to very dark grey clay laminae. Silt is fractured, possibly on sand beds. Discontinuous slickensides in clay when core broken [Horizontal orientation to low angle ~ 10°, Slb/Slc, C1/C2, B2, G2/G3, R3, S1/S2, F1], Figures 93, 94 and 95

Sand: Silty, fine to medium grained, dark brown, pockets of reddish brown medium grained sand, coal pockets, re-recovered core, Figure 96

Sand: Silty, fine to medium grained, grey to dark brown, pockets of well sorted medium grained sand, reddish brown from 92.6 - 92.7 m (445.8 - 445.7 m asl)

Sand: Silty, medium grained, brown, with silt interbeds, lots of horizontal fracturing, possible silt beds, core is dry, back into intact core material

No recovery: Lost core, no recovery (mud saturated sand fell out)

Sand: Silty, medium grained, grey to dark brown, silt stringers, pockets of medium to coarse grained sand, reddish brown

Sand: Medium grained, brown, with very fine to fine grained sand and silt interbeds, caotic bedding at upper contact

Sand: Medium grained, brown, caotic nodules and discontinuous beds of laminated silt/ sand (from unit above), Figure 97

Sand: Fine to medium grained, rhythmically interbedded sand, brown, silt interbeds, reddish brown medium grained sand pockets, very compact, overconsolidated

Sand: As above, very fractured, (likely along sand and silt beds), rhythmically bedded, coal laminae, Figure 98

Sand: Silty, very fine to fine grained, grey, 50 mm bed of medium grained reddish brown sand at contact at 95.13 m (443.2 m asl), structureless, Figure 99

Sand: Medium to coarse grained, brown to reddish brown, with fine to medium grained silty sandy horizontal interbeds up to 3 mm thick, Figure 100

Sand: Silty, medium grained, brown to reddish brown, dark grey from 97.94 to 98.35 m (440.4 to 440 m asl), Figure101

Sand: Medium grained, brown to reddish brown, blebs/ stringers of fine to medium silty sand throughout, weakly cemented sand lenses at 98.8 m (439.6 m asl), Figure 102

Sand: Medium grained, reddish brown, blebs/ stringers of very fine to fine grained sand and silt, pocket of CaCO3, grey, reactive to HCl, Figure 103

Sand: Sand becomes coarse grained and darker brown, some silt

Silt and Clay: Clayey silt or silty clay, very dark grey, stringers of very fine sand and silt, Figure 104

Silt and Clay: Clayey silt/ silty clay, very dark grey, rhythmically bedded with very fine to fine grained grey silty sand. 25 mm bed of light grey silty sand at 101.25 m (437.1 m asl), clayey silt blebs within sand, Figure 105

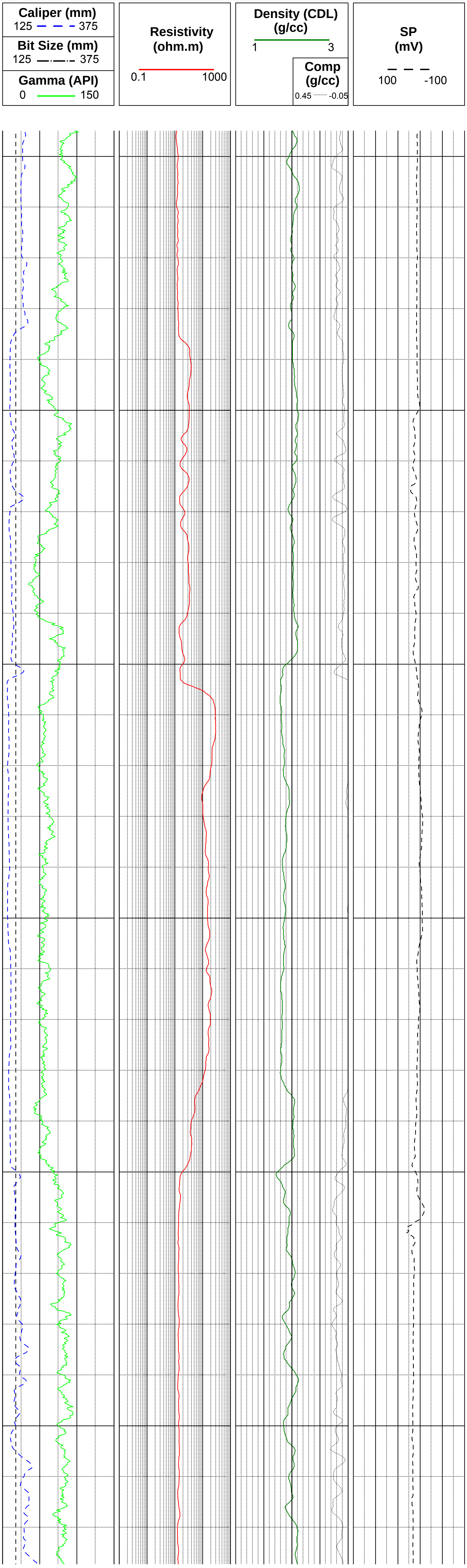
Silt and Clay: Clayey silt or silty clay, very dark grey, stringers of very fine sand and silt, change from darker silty clay to clayey silt at 101.4 m (437 m asl), pockets/ stringers of very fine to fine grained sand, grey, slickensides in clays [horizontal orientation, Slc, C1/C2, B1, G2, R2/R3, S2/S3, F1], Figure106 and 107. NOTE: Some slickensides appear to be drill induced, Figure 108

Silt and Clay: *<from 102.1 to 106.7 m (436.3 to 431.7 m asl), very muddy with drill fluid, fractures difficult to investigate for slickensides, but core contains angled fractures approximately 65° from horizontal>*. Clayey silt to silty clay, very dark grey, with very fine grained grey sand stringers and pockets, no apparent trend to bedding, some discontinuous slickensides noted when core broken; Fine sand pockets at 103.25 m (435.1 m asl), Figure 109

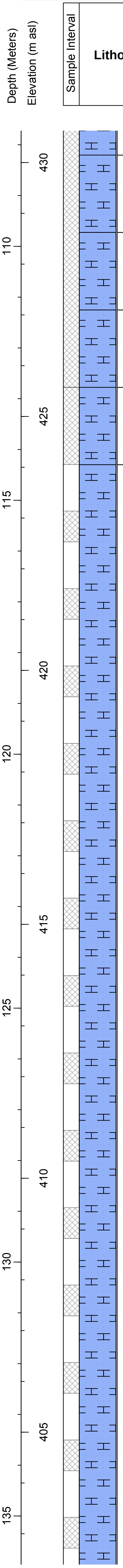
Silt and Clay: As above, at 104.3 m (434.1 m asl), silt lense through core, 30° & 55° fractures (from horizontal) at 104.9 m & 105.2 m (433.5 to 433.2 m asl), slickensides noted when core was broken [Slc, C1, B1/B2, G5, R2 to R4, S2 to S4, F1], Figures 110, 111 and 112

Silt and Clay: As above, with stringers of fine grained silty sand, brown, contorted beds, slickensides noted when core broken as above

Silt and Clay: Clayey silt to silty clay, very dark grey, very fine grained grey silty sand stringers and pockets, slickensided fracture at 107 m (431.4 m asl), (70° from horizontal)



Log ID:PR08-5 Composite Log



Lithology

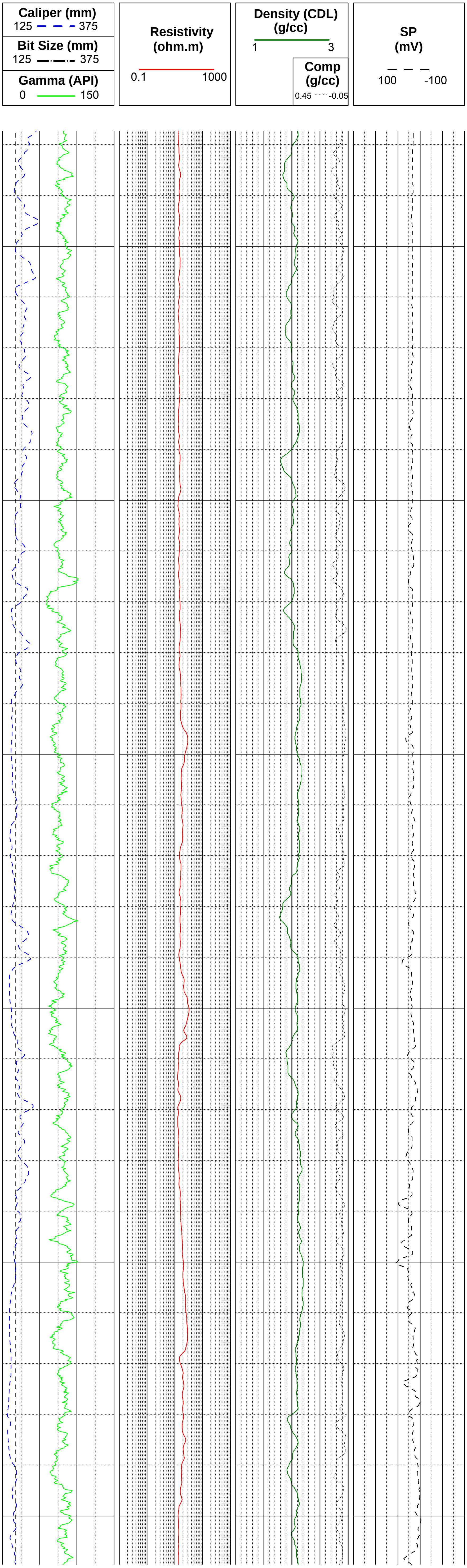
Silt and Clay: As above, 45 degree fracture at 109.4 m (428.9 m asl), slickensided surface, slickensides in broken core continue as above

Silt and Clay: As above, 35° and 55° slickensided fractures at 110 and 110.9 m (428.4 & 427.5 m asl), measured from horizontal, slickensides noted in core when broken as above, Figures 113, 114, and 115

Silt and Clay: As above with an increase in fine grained sand lenses from 112.4 to 112.7 m (426 to 425.7 m asl), no slickensides observed in fractures

Silt and Clay: As above, fracture at 113.1 m (425.3 m asl), 50° slickensided surface, other fractures at 113.31 & 113.87 m (425 & 424.5 m asl), mud obscuring fracture surface. Sonic Hole ends at 424.1 m asl.

Silt and Clay: <*Lithology below 424.1 m asl interpreted from borehole adjacent to sonic corehole, drilled using a wet rotary method. Lithology determined from cutting returns, drill response and geophysical logs run in this fluid filled hole*> Clayey silt to silty clay, very dark grey, some fine to medium grained sand in cuttings. Drill response indicated possible sand beds up to approximately 0.5 m in thickness.



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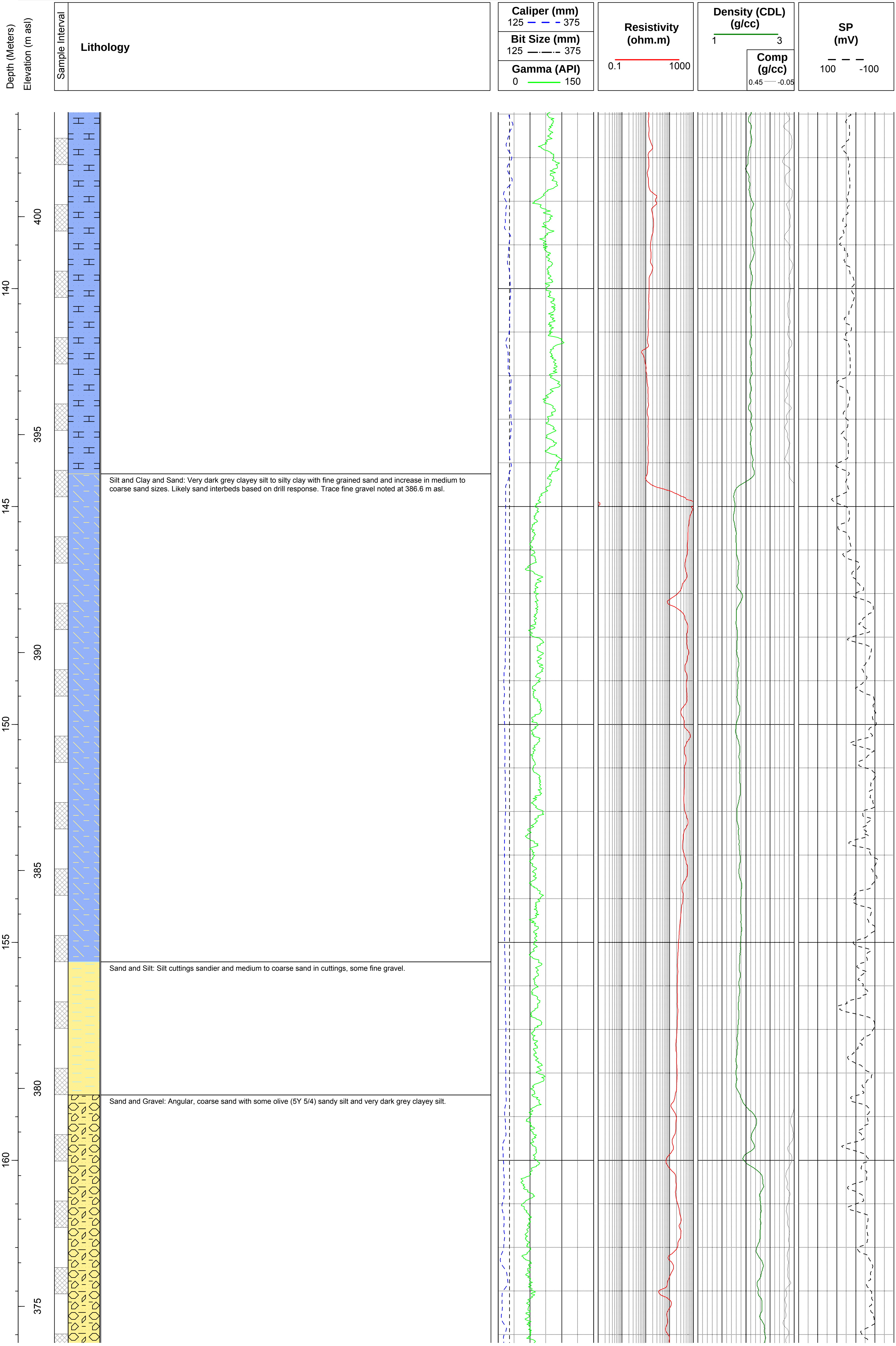
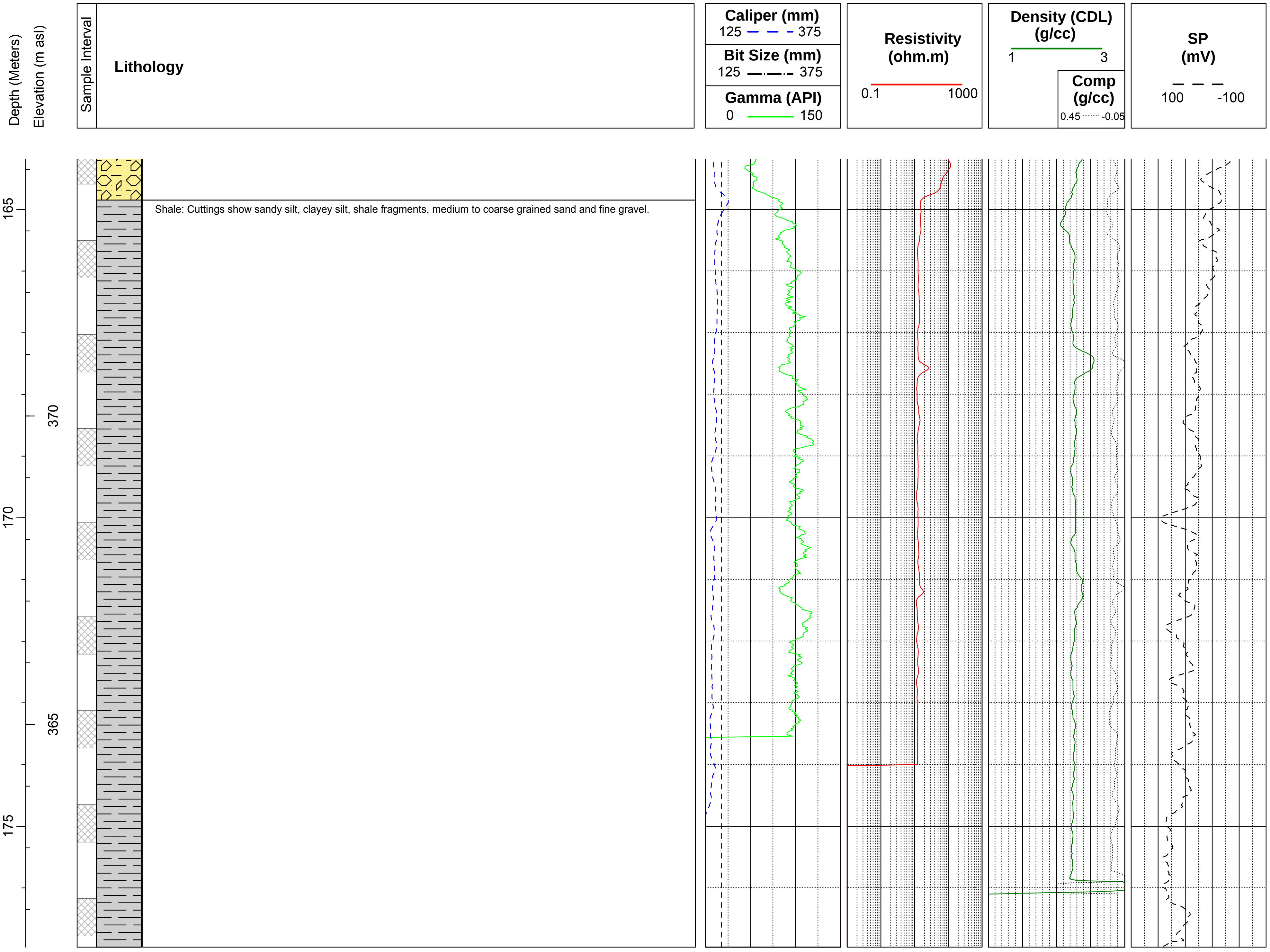


Silt and Clay and Sand: Very dark grey clayey silt to silty clay with fine grained sand and increase in medium to coarse sand sizes. Likely sand interbeds based on drill response. Trace fine gravel noted at 386.6 m asl.

Sand and Silt: Silt cuttings sandier and medium to coarse sand in cuttings, some fine gravel.

Sand and Gravel: Angular, coarse sand with some olive (5Y 5/4) sandy silt and very dark grey clayey silt.

Log ID: **PR08-5 Composite Log**



Shale: Cuttings show sandy silt, clayey silt, shale fragments, medium to coarse grained sand and fine gravel.

Appendix 2 — Core Photographs

Photos from borehole PR08-3 (Figures 3–42; pages 32–51)

Photos from borehole PR08-5 (Figures 43–115; pages 52–87)

Figure 3. Rhythmically bedded silt and clay (PR08-3; 13.7–14.9 m; 431.6–430.4 m asl).

Figure 4. Silty, fine- to medium-grained sand with silty, clay interclasts; (PR08-3; 15.2–16.8 m; 430.1–428.5 m asl).

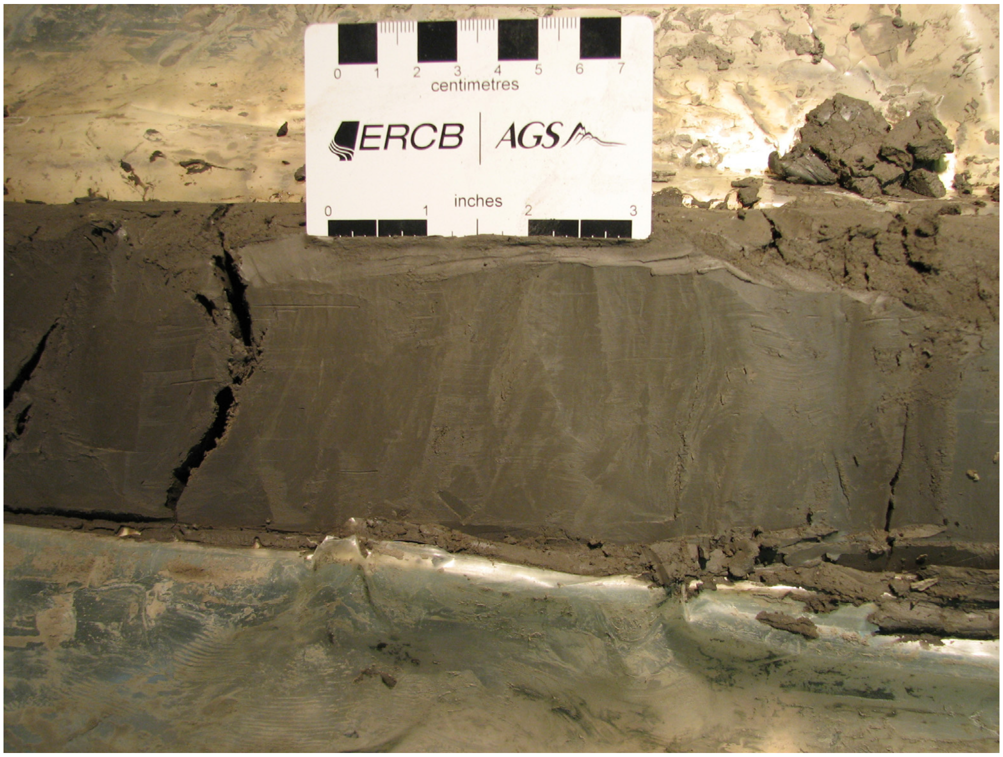


Figure 5. Rhythmically bedded silt and clay (PR08-3; 18.3–19 m; 427–426.3 m asl).

Figure 6. Slickenside in silt and clay (PR08-3; 19.6 m; 425.7 m asl).

Figure 7. Clayey sandy silt to silty sand, stoney diamicton (PR08-3; 24.4–25.9 m; 420.9–419.4 m asl).

Figure 8. Slightly silty, fine- to medium-grained sand (PR08-3; 26.5–26.8 m; 418.8–418.5 m asl).

Figure 9. Interbedded sand and silt (PR08-3; 48.9–50.3 m; 396.4–395 m asl).

Figure 10. Gradational contact between (left of coin) clayey sandy silt to silty sand, stoney diamicton and (right of coin) interbedded sand and silt (PR08-3; 48.9–50.3 m; 396.4–395 m asl).

Figure 11. Deformed beds of sand and silt (PR08-3; 48.9–50.3 m; 396.4–395 m asl).

Figure 12. Clayey sandy silt to silty sand, stoney diamicton with sand lenses and blebs (PR08-3; 61–62.5 m; 384.3–382.8 m asl).

Figure 13. Clayey sandy silt to silty sand, stoney diamicton with sand lenses and blebs (PR08-3; 61–62.5 m; 384.3–382.8 masl).

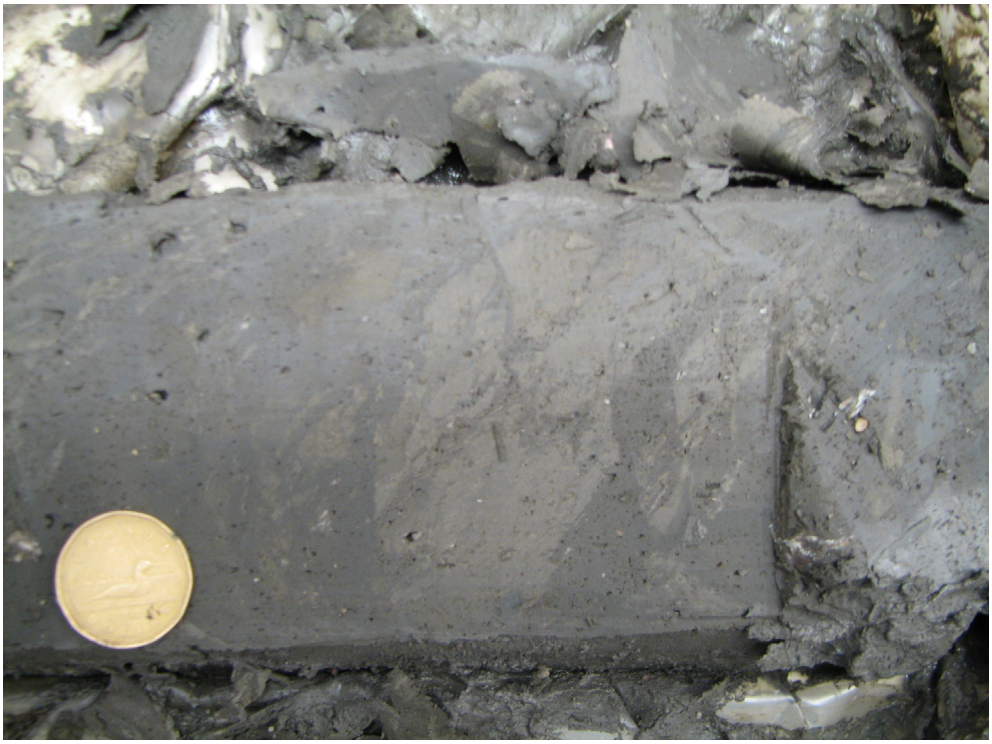


Figure 14. Clayey sandy silt to silty sand, stoney diamicton with sand lenses; note shear planes through sand lenses (PR08-3; 64–65.5 m; 381.3–379.8 m asl).

Figure 15. Slickenside in clay-rich sediments within silty diamicton (PR08-3; 64 m; 381.3 m asl).

Figure 16. Clayey sandy silt to silty sand, stoney diamicton with deformed interbeds of silty sand; note ripple-drift cross stratification in sand (PR08-3; 70.1–71.7 m; 375.2–373.7 m asl).

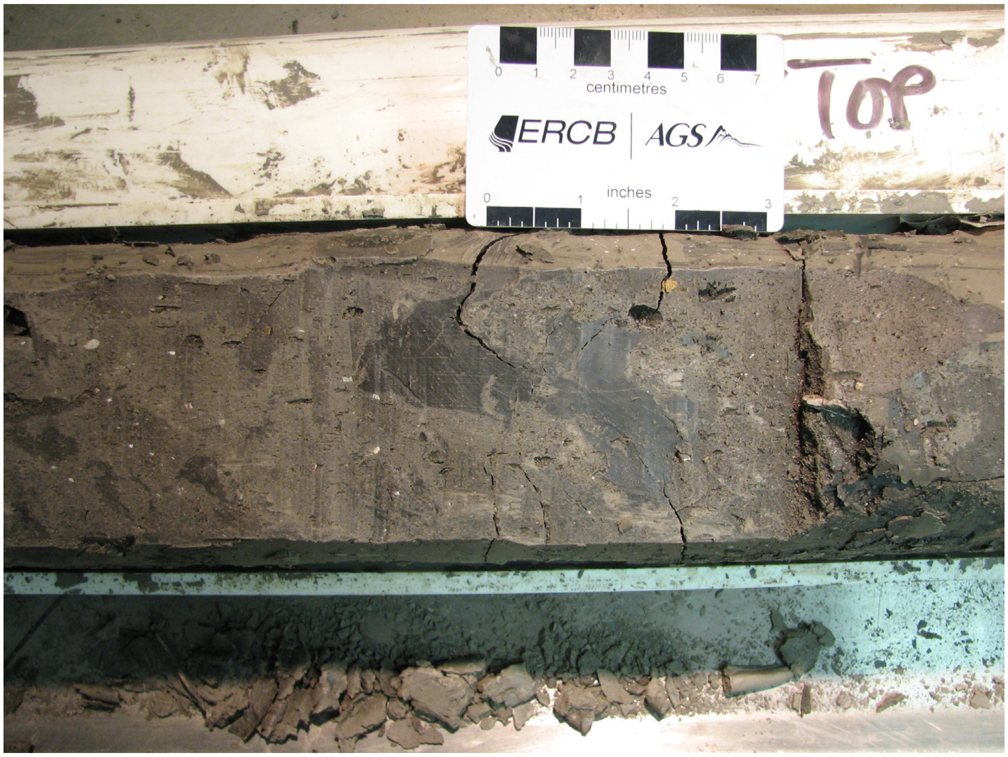


Figure 17. Brecciated, clayey sandy silt to silty sand, stoney diamicton (PR08-3; 73.2–79.2 m; 372.2–366.1 m asl).

Figure 18. Clayey sandy silt to silty sand, stoney diamicton; slickenside in silt-rich sediments (PR08-3; 80.5 m; 364.8 m asl).

Figure 19. Clayey sandy silt to silty sand, stoney diamicton; slickensided fracture in silt-rich sediments is obscured by drilling mud (PR08-3; 84.7 m; 360.6 m asl).

Figure 20. Clayey sandy silt to silty sand, stoney diamicton; slickensided fracture in silt-rich sediments is obscured by drilling mud (PR08-3; 85.8 m; 359.5 m asl).

Figure 21. Clayey sandy silt to silty sand, stoney diamicton; slickensided fracture in silt-rich sediments is obscured by drilling mud (PR08-3; 86 m; 359.3 m asl).

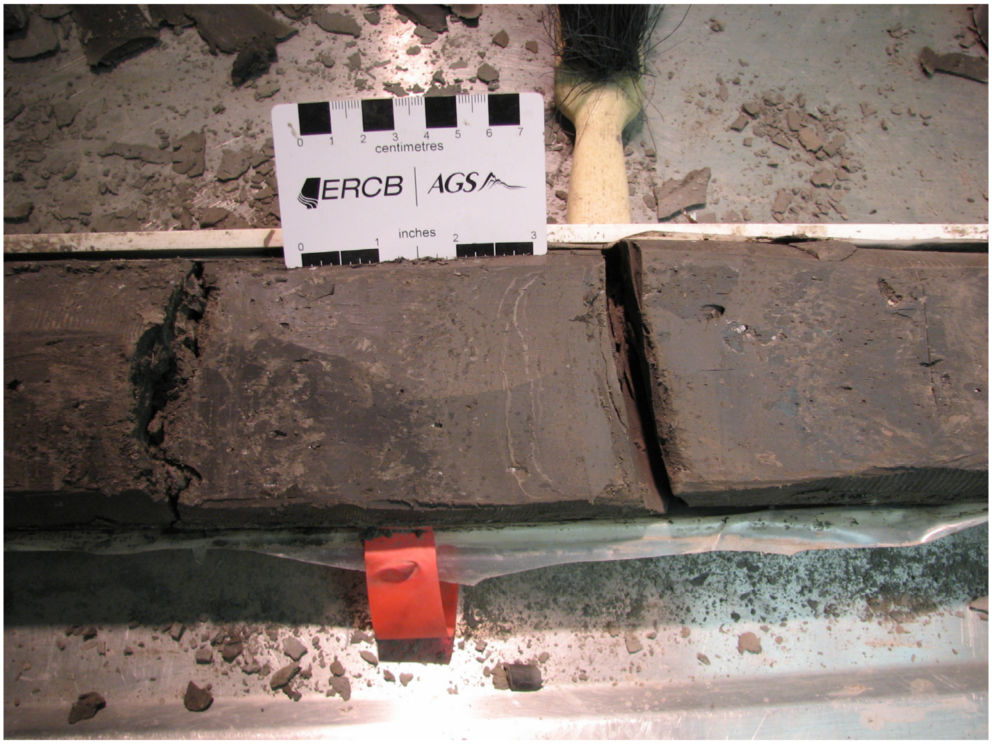


Figure 22. Rhythmically bedded deposits of very fine sandy silt and silty clay pass into brecciated deposits of silt and clay (PR08-3; 89.9 m; 355.4 m asl).

Figure 23. Rhythmically bedded deposits of very fine sandy silt and silty clay (PR08-3; 89.9 m; 355.4 m asl).

Figure 24. Deformed, rhythmically bedded deposits of very fine sandy silt and silty clay (PR08-3; 89.9–93 m; 355.4–352.3 m asl).

Figure 25. Deformed, rhythmically bedded deposits of very fine sandy silt and silty clay; discontinuous slickensides noted throughout (PR08-3; 89.9–93 m; 355.4–352.3 m asl).

Figure 26. Rhythmically bedded deposits of very fine sandy silt and silty clay; discontinuous slickensides noted throughout (PR08-3; 89.9–93 m; 355.4–352.3 m asl).

Figure 27. Rhythmically bedded deposits of very fine sandy silt and silty clay; discontinuous slickensides noted throughout (PR08-3; 89.9–93 m; 355.4–352.3 m asl).

Figure 28. Deformed, rhythmically bedded deposits of very fine sandy silt and silty clay; discontinuous slickensides noted throughout (PR08-3; 93–94.5 m; 352.3–350.8 m asl).

Figure 29. Rhythmically bedded deposits of very fine sandy silt and silty clay; discontinuous slickensides noted throughout (PR08-3; 93–94.5 m; 352.3–350.8 m asl).

Figure 30. Rhythmically bedded deposits of very fine sandy silt and silty clay (PR08-3; 94.5–96 m; 350.8–349.3 m asl).

Figure 31. Rhythmically bedded deposits of very fine sandy silt and silty clay; slickensides noted in silty clay (PR08-3; 99.1–100.6 m; 346.2–344.7 m asl).

Figure 32. Rhythmically bedded deposits of very fine sandy silt and silty clay; slickensides noted in silty clay (PR08-3; 99.1–100.6 m; 346.2–344.7 m asl).

Figure 33. Rhythmically bedded deposits of very fine sandy silt and silty clay; slickensides noted in silty clay (PR08-3; 99.1–100.6 m; 346.2–344.7 m asl).

Figure 34. Rhythmically bedded deposits of very fine sandy silt and silty clay; slickensides noted in silty clay (PR08-3; 99.1–100.6 m; 346.2–344.7 m asl).

Figure 35. Planar–bedded, silty, fine- to medium-grained sand (PR08-3; 101.6–101.7 m; 343.7–343.6 m asl).

Figure 36. Rhythmically bedded silty sand, silt and clay (PR08-3; 103.4 m; 341.9 m asl).

Figure 37. Slickensides parallel to bedding in silty clay to clayey silt (Note: slickensides appear to be drill induced), (PR08-3; 102.7–103.4 m; 342.6–341.9 m asl).

Figure 38. Slickensides parallel to bedding in silty clay to clayey silt (Note: slickensides appear to be drill-induced), (PR08-3; 103.6–105.2 m; 341.7–340.1 m asl).

Figure 39. Slickensides parallel to bedding in rhythmically bedded deposits of silty clay to clayey silt (Note: slickensides appear to be drill-induced), (PR08-3; 103.6–105.2 m; 341.7–340.1 m asl).

Figure 40. Slickensides parallel to bedding in rhythmically bedded deposits of silty clay to clayey silt (Note: slickensides appear to be drill-induced), (PR08-3; 103.6–105.2 m; 341.7–340.1 m asl).

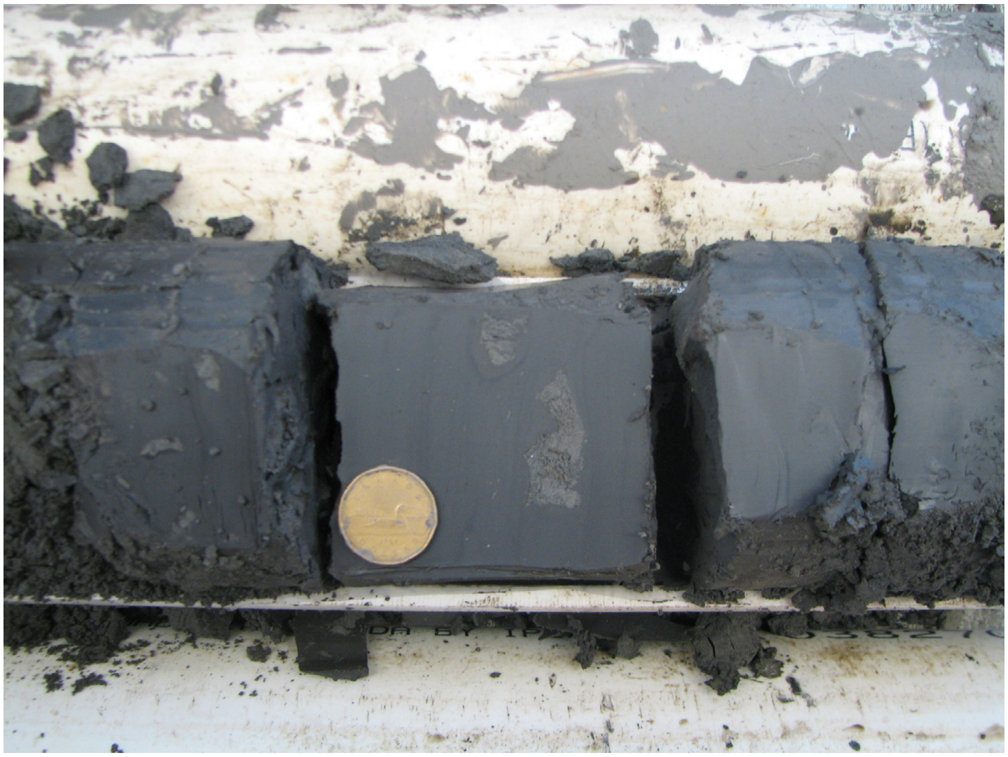


Figure 41. Rhythmically bedded deposits of silty clay to clayey silt; note silt-rich interclasts adjacent to coin (PR08-3; 105.3–106.7 m; 340–338.6 m asl).

Figure 42. Slickensides parallel to bedding in rhythmically bedded deposits of silty clay to clayey silt (Note: slickensides appear to be drill-induced), (PR08-3; 105.3–106.7 m; 340–338.6 m asl).

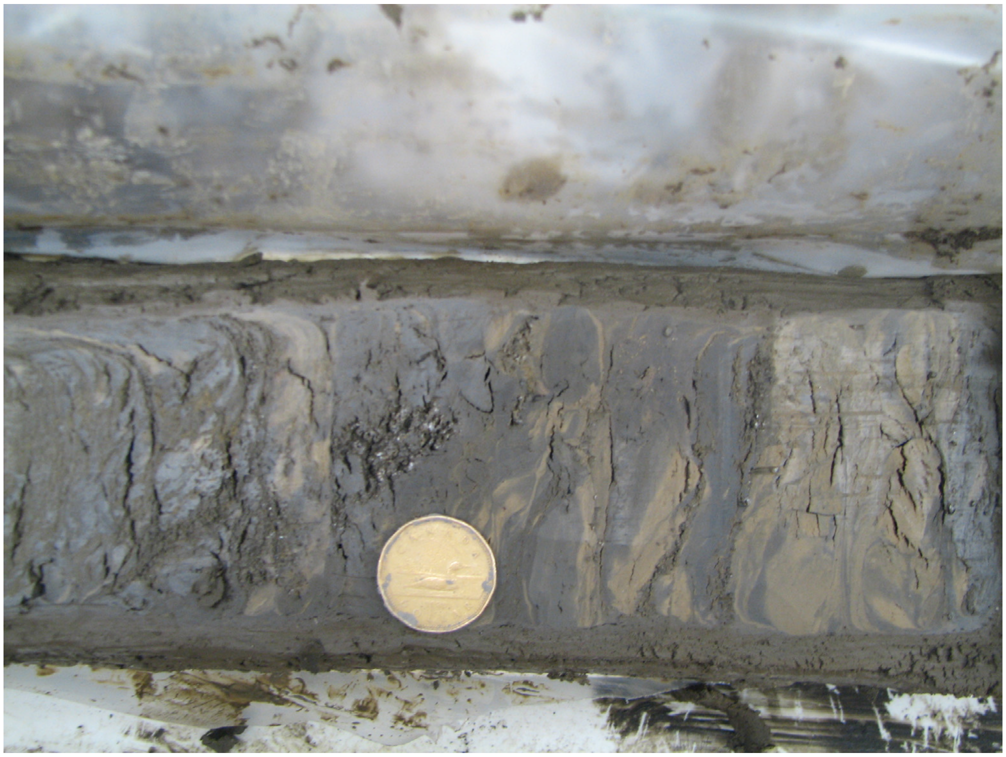


Figure 43. Rhythmically bedded deposits of silt and clay (PR08-5; 1.5–4.6 m; 536.8–535.3 m asl).

Figure 44. Slickensides within silt and clay rhythmites (Note: Slickensides appear to be drill-induced), (PR08-5; 7.6–9.1 m; 530.7–529.2 m asl).

Figure 45. Slickensides within silt and clay rhythmites (Note: Slickensides appear to be drill-induced), (PR08-5; 7.6–9.1 m; 530.7–529.2 m asl).

Figure 46. Slickensides within silt and clay rhythmite (Note: Slickensides appear to be drill-induced), (PR08-5; 9.1–10.6 m; 529.2–527.7 m asl).

Figure 47. Deformed, rhythmically bedded deposits of silty clay to clayey silt (PR08-5; 12.3–14 m; 526.1–524.3 m asl).

Figure 48. Deformed, rhythmically bedded deposits of silty clay to clayey silt (PR08-5; 12.3–14 m; 526.1–524.3 m asl).

Figure 49. Slickenside in slit and clay rhythmite (PR08-5; 12.3–14 m; 526.1–524.3 m asl).

Figure 50. Silty sand with interbeds of silty clay (PR08-5; 14–15.2 m; 524.3–523.1 m asl).

Figure 51. Slickenside in silty clay (Note: Slickensides appear to be drill-induced), (PR08-5; 14–15.2 m; 524.3–523.1 m asl).

Figure 52. Fine- to medium-grained sand (PR08-5; 17.7–18.3 m; 520.7–520.1 m asl).

Figure 53. Fine- to medium-grained sand (PR08-5; 18.3–19.5 m; 520.1–518.8 m asl).

Figure 54. Fractures (jointing?) in silt-rich diamicton (PR08-5; 21.3–22.9 m; 517–515.5 m asl).

Figure 55. Fractures (jointing?) in silt-rich diamicton; surface mostly obscured by drilling mud (PR08-5; 21.3–22.9 m; 517–515.5 m asl).

Figure 56. Clayey sandy silt to silty sand, stony diamicton (PR08-5; 24.4–27.1 m; 514–511.2 m asl).

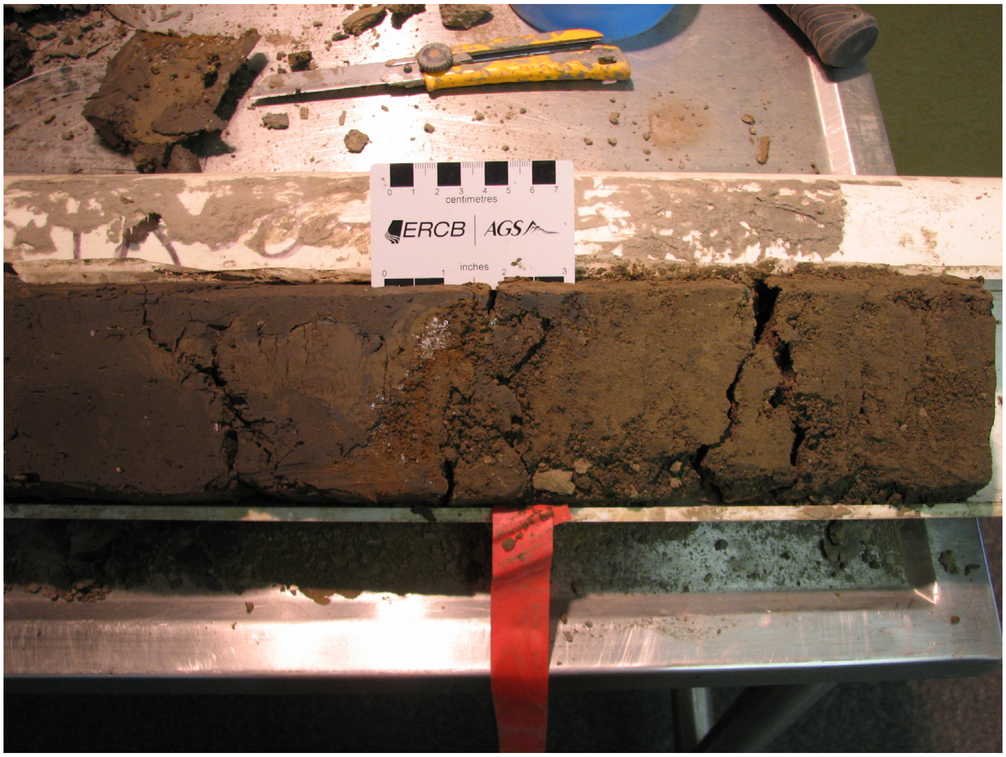


Figure 57. Erosional contact between silty sand (right of flagging tape) and overlying clayey sandy silt to silty sand, stony diamicton (left of flagging tape; 28.8–29 m; 509.6–509.4 m asl).

Figure 58. Fine- to medium-grained sand with interbeds of diamicton; ripple drift in sand, contorted and overturned (PR08-5; 32.5–33.2 m; 505.8–505.1 m asl).

Figure 59. Fine- to medium-grained sand with interbeds of till; ripple drift in sand, contorted and overturned; contact with diamicton shown (PR08-5; 32.5–33.2 m; 505.8–505.1 m asl).

Figure 60. Interclasts of very fine grained sand (PR08-5; right of scale card) in clayey sandy silt to silty sand, stony diamicton (PR08-5; 44.2–45.7 m; 494.2–492.6 m asl).

Figure 61. Beds of silty, very fine to fine-grained sand in clayey sandy silt to silty sand, stony diamicton (PR08-5; 44.2–45.7 m; 494.2–492.6 m asl).

Figure 62. Planar bedded deposits of silty fine sand and silt (PR08-5; 45.7–46.3 m; 492.6–492 m asl).

Figure 63. Clayey sandy silt to silty sand, stony diamicton (PR08-5; 46.3–47.2 m; 492–491 m asl).

Figure 64. Contorted beds of sandy silt and silty sand (PR08-5; 47.2–48.8 m; 491.1–489.6 m asl).

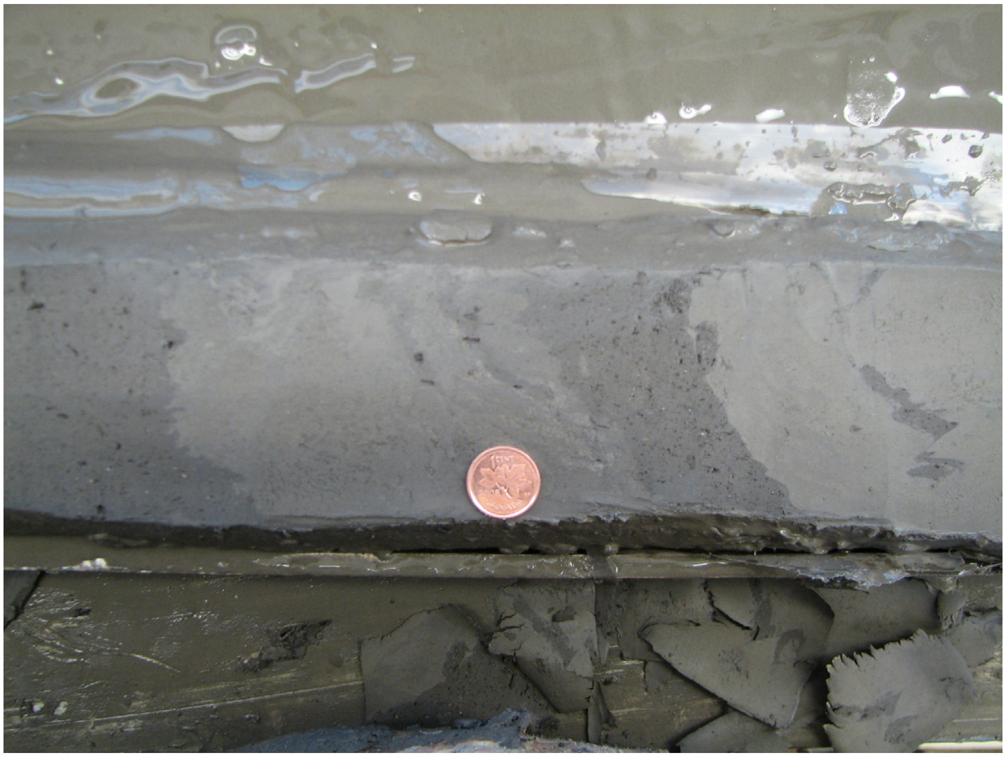


Figure 65. Beds of sandy silt and silty sand, blocks of dislocated clayey sandy silt to silty sand, stony diamicton (PR08-5; 48.8–50.3; 489.6–488.1 m asl).

Figure 66. Contact between sandy silt and clayey sandy silt to silty sand, stony diamicton; note load structure immediately below coin (PR08-5; 50.3–50.8 m; 488.1–487.6 m asl).

Figure 67. Clayey sandy silt to silty sand, stony diamicton (PR08-5; 51.8–53.3 m; 486.5–485 m asl).

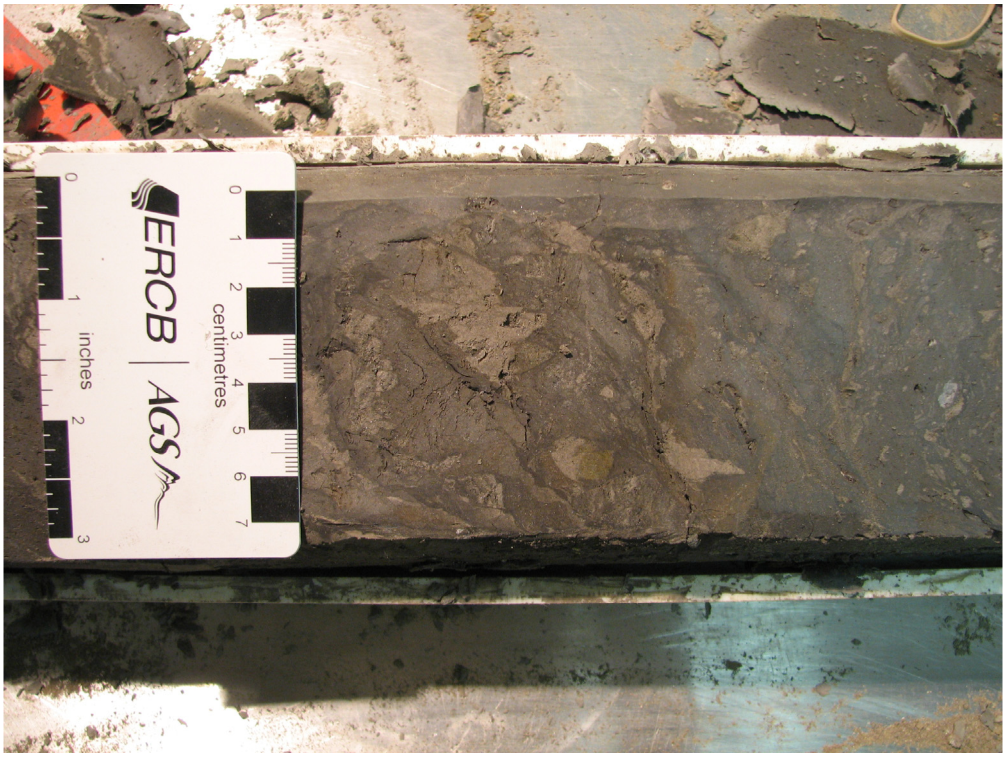


Figure 68. Clayey sandy silt to silty sand, stony diamicton (PR08-5; 51.8–53.3 m; 486.5–485 m asl).

Figure 69. Clayey sandy silt to silty sand, stony diamicton; clast size ranges between small pebble and cobble grade (PR08-5; 54.2–54.9 m; 484.2–483.5 m asl).

Figure 70. Clayey sandy silt to silty sand, stony diamicton; clast size ranges between small pebble and cobble grade (PR08-5; 54.2–54.9 m; 484.2–483.5 m asl).

Figure 71. Clayey sandy silt to silty sand, stony diamicton; clast size ranges between small pebble and cobble grade (PR08-5; 54.2–54.9 m; 484.2–483.5 m asl).

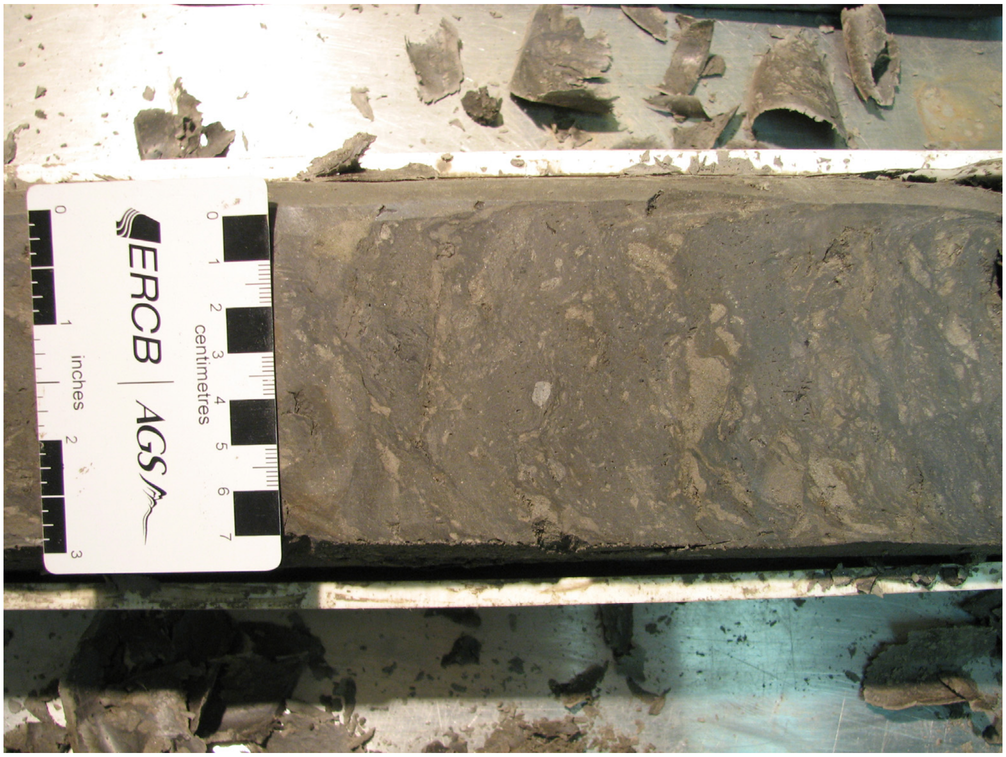


Figure 72. Clayey sandy silt to silty sand, stone-poor diamicton (PR08-5; 56–56.4 m; 482.4–481.9 m asl).

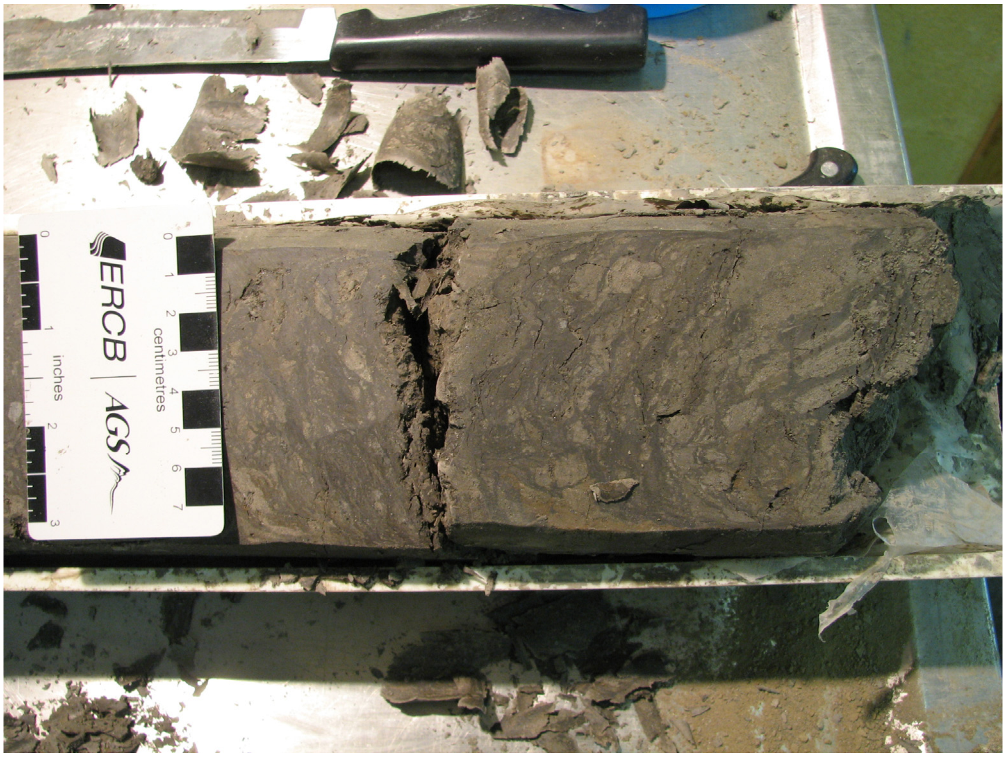


Figure 73. Clayey sandy silt to silty sand, stony diamicton (PR08-5; 56–56.4 m; 482.4–481.9 m asl).

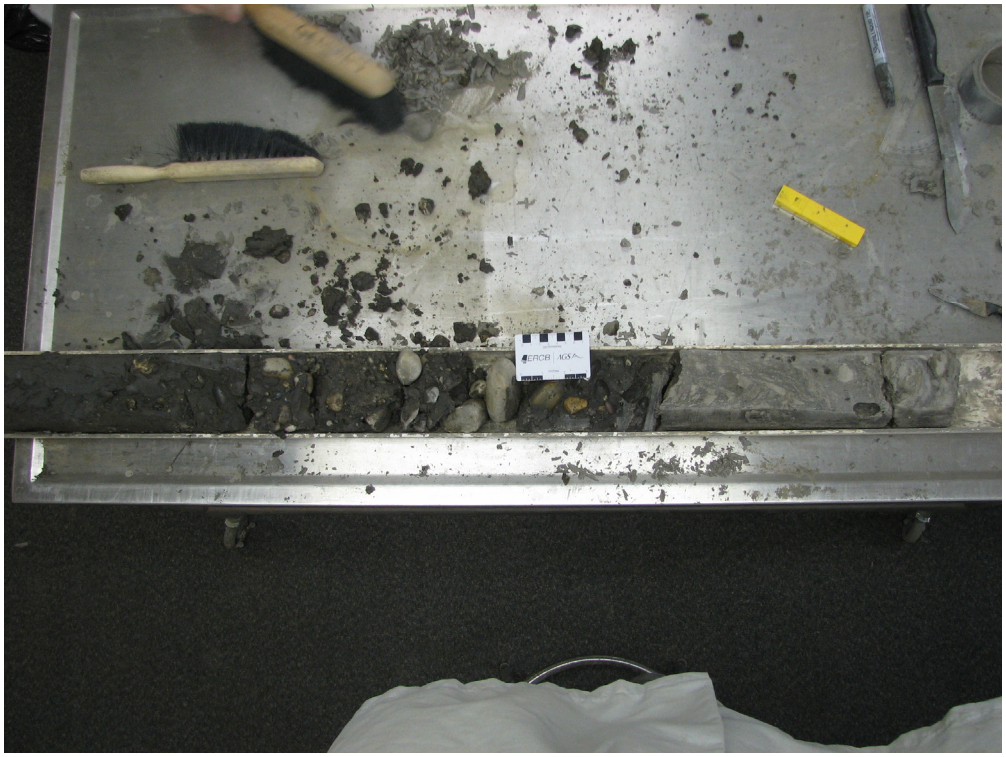


Figure 74. Clayey sandy silt to silty sand, stony diamicton; clast size ranges between small pebble and cobble grade; note cobble lag below scale card (PR08-5; 56.4–57.9 m; 482.4–481.9 m asl).

Figure 75. Clayey sandy silt to silty sand, stony diamicton; clast size ranges between small pebble and cobble grade; note cobble lag below scale card (PR08-5; 56.4–57.9 m; 482.4–481.9 m asl).

Figure 76. Clayey sandy silt to silty sand, stony diamicton; clast size ranges between small pebble and cobble grade (PR08-5; 56.4–57.9 m; 482.4–481.9 m asl).

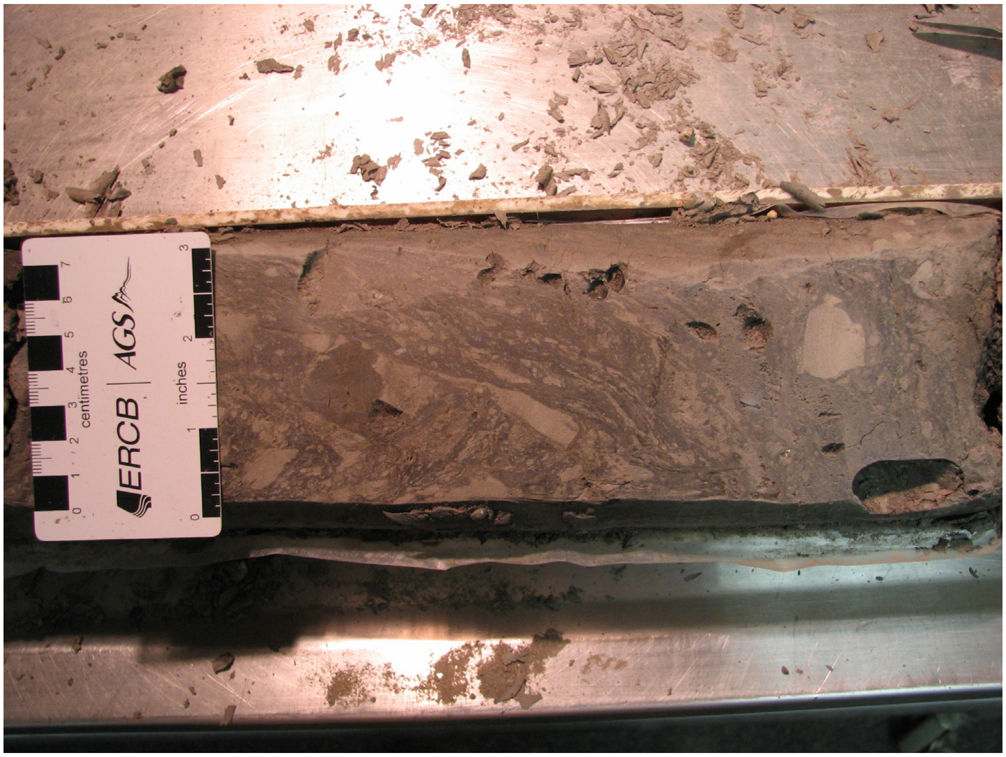


Figure 77. Clayey sandy silt to silty sand, stony diamicton; note interclasts of silty sand to sandy silt (PR08-5; 56.4–57.9 m; 482.4–481.9 m asl).

Figure 78. Erosive contact between clayey sandy silt to silty sand, stony diamicton and underlying silt and clay (PR08-5; 77.7–78.7 m; 460.6–459.7 m asl).

Figure 79. 45° slickenside in silty clay to clayey silt (PR08-5; 80.8 m; 457.6 m asl).

Figure 80. 45° slickenside in silty clay to clayey silt (PR08-5; 80.8 m; 457.6 m asl).

Figure 81. Slickensides in silty clay to clayey silt (Note: Slickensides appear to be drill-induced), (PR08-5; 79.2–80.8 m; 459.1–457.6 m asl).

Figure 82. Slickensides in silty clay to clayey silt (Note: Slickensides appear to be drill-induced), (PR08-5; 79.2–80.8 m; 459.1–457.6 m asl).

Figure 83. Slickensides within clayey silt to silty clay (Note: Slickensides appear to be drill-induced), (PR08-5; 80.8–82.3 m; 457.6–456.1 m asl).

Figure 84. Slickensides within clayey silt to silty clay (Note: Slickensides appear to be drill-induced), (PR08-5; 80.8–82.3 m; 457.6–456.1 m asl).

Figure 85. Gradational contact between silty clay to clayey silt and fine- to medium-grained sand (PR08-5; 84.1 m; 454.3 m asl).

Figure 86. Slickenside within silty clay to clayey silt (PR08-5; 83.8–84.1 m; 454.5–454.2 m asl).

Figure 87. Medium- to coarse-grained silty sand with interclasts of clayey silt (PR08-5; 84.2–84.6 m; 454.2–453.8 m asl).

Figure 88. Medium- to coarse-grained silty sand with interclasts of clayey silt (PR08-5; 84.2–84.6 m; 454.2–453.8 m asl).

Figure 89. Erosive contact between fine- to medium-grained silty sand and silty clay to clayey silt (PR08-5; 85.3–85.6 m; 453–452.7 m asl).

Figure 90. Clayey silt to silty clay interbedded with silty, fine- to medium-grained sand (PR08-5; 85.6–86.9 m; 452.7–451.5 m asl).

Figure 91. Clayey silt to silty clay, laminated, with horizontal slickenside surfaces (PR08-5; 87.8–88.2 m; 450.5–450.1 m asl).

Figure 92. Medium- to coarse-grained sand (PR08-5; 88.4–89.9 m; 450–448.4 m asl).

Figure 93. Rhythmically bedded deposits of clayey silt, silty clay and very fine to fine-grained sand; sample lost downhole and re-recovered (PR08-5; 90.8–91.4 m; 447.5–446.9 m asl).

Figure 94. Rhythmically bedded deposits of clayey silt, silty clay and very fine to fine-grained sand; slickensides in clay-rich sediments; sample lost downhole and re-recovered (PR08-5; 90.8–91.4 m; 447.5–446.9 m asl).

Figure 95. Rhythmically bedded deposits of clayey silt, silty clay and very fine to fine-grained sand; slickensides in clay-rich sediments; sample lost downhole and re-recovered (PR08-5; 90.8–91.4 m; 447.5–446.9 m asl).

Figure 96. Silty, fine- to medium-grained sand; sample lost downhole and re-recovered (PR08-5; 91.4–91.8 m; 446.9–446.5 m asl).

Figure 97. Fine- to medium-grained sand, discontinuous beds (laminae) of silty sand to sandy silt (PR08-5; 94.1–94.3 m; 444.2–444.1 m asl).

Figure 98. Fine- to medium-grained sand with silty interbeds, weakly cemented and fractured (PR08-5; 94.5–95.1 m; 443.9–443.2 m asl).

Figure 99. Very fine to fine-grained silty sand (PR08-5; 95.1–95.6 m; 443.2–442.8 m asl).

Figure 100. Medium- to coarse-grained sand with interbeds of silt (PR08-5; 95.6–96 m; 442.8–442.3 m asl).

Figure 101. Medium-grained silty sand (PR08-5; 96–97.5 m; 442.3–440.8 m asl).

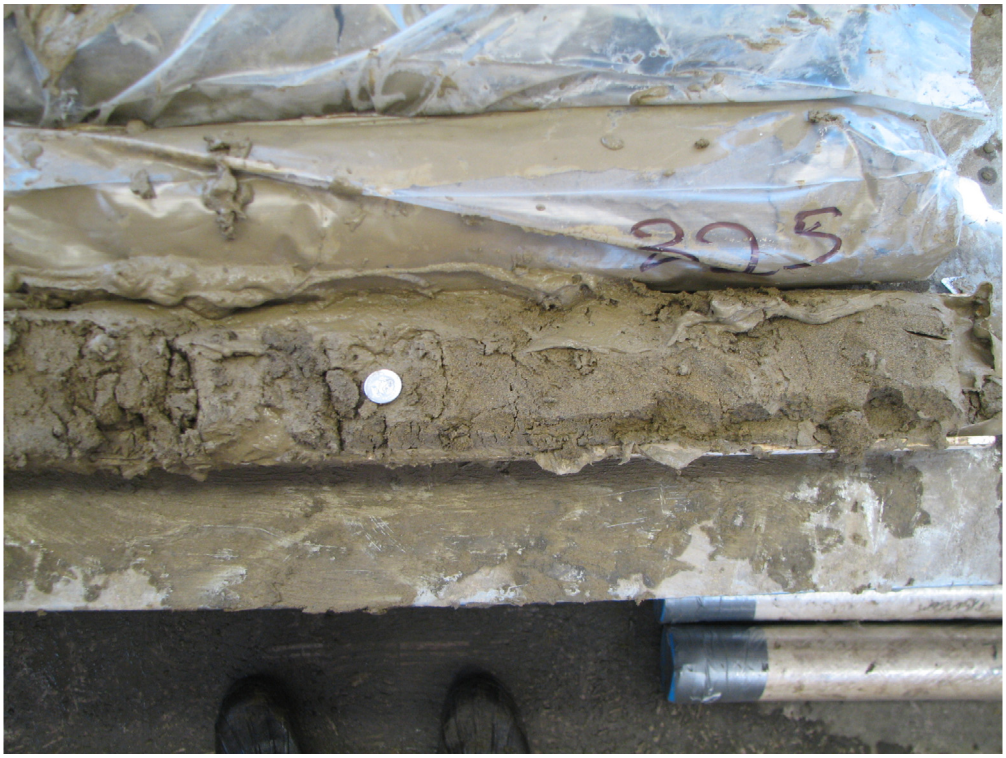


Figure 102. Medium-grained sand with blebs of silty sand (PR08-5; 97.5–99.1 m; 440.8–439.3 m asl).

Figure 103. Carbonate interclast (right of coin) in medium-grained sands (PR08-5; 99.1–100.1 m; 439.3–438.3 m asl).

Figure 104. Erosive contact between silty fine sand and silty clay (PR08-5; 100.4–100.6 m; 438–437.8 m asl).

Figure 105. Clayey silt to silty clay interbedded with silty sand; note 2.5 cm thick bed of silty sand (PR08-5; 100.6–101.3 m; 437.8–437.1 m asl).

Figure 106. Clayey silt to silty clay, wisps of silty, very fine sands throughout (PR08-5; 101.3–102.1 m; 437.1–436.2 m asl).

Figure 107. Clayey silt to silty clay, wisps of silty, very fine sand throughout (PR08-5; 101.3–102.1 m; 437.1–436.2 m asl).

Figure 108. Clayey silt to silty clay, wisps of silty, very fine sand throughout; slickensides in clay (Note: Slickensides appear to be drill-induced), (PR08-5; 101.3–102.1 m; 437.1–436.2 m asl).

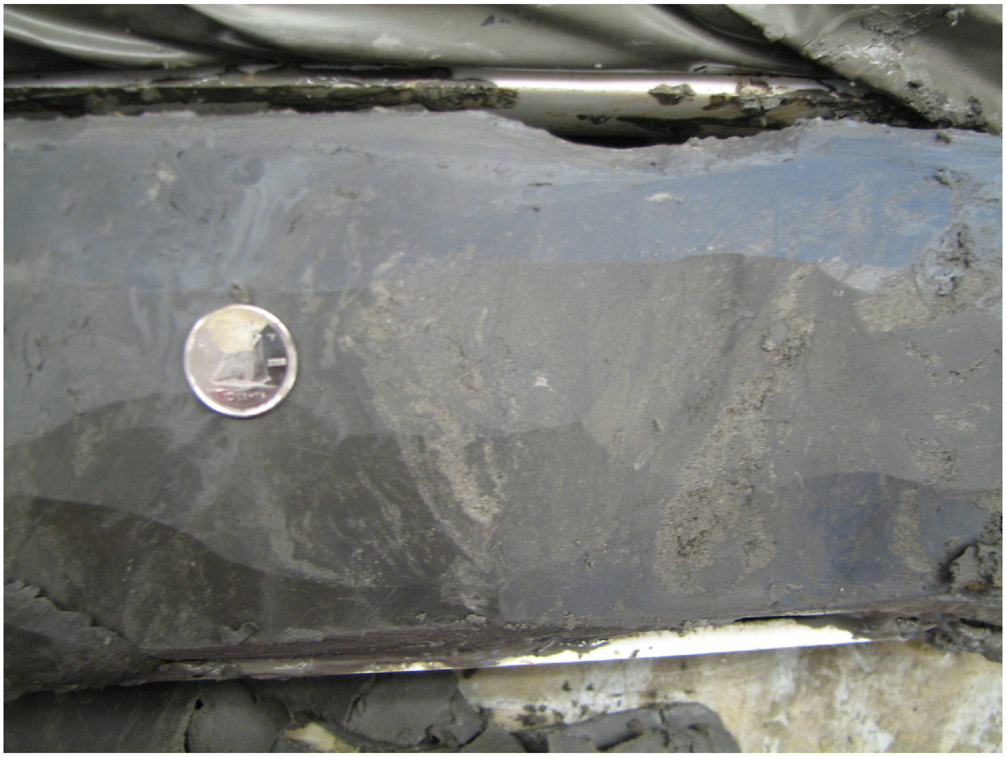


Figure 109. Clayey silt to silty clay, note wisps of silty, very fine sands (PR08-5; 102.1–103.6 m; 436.2–434.7 m asl).

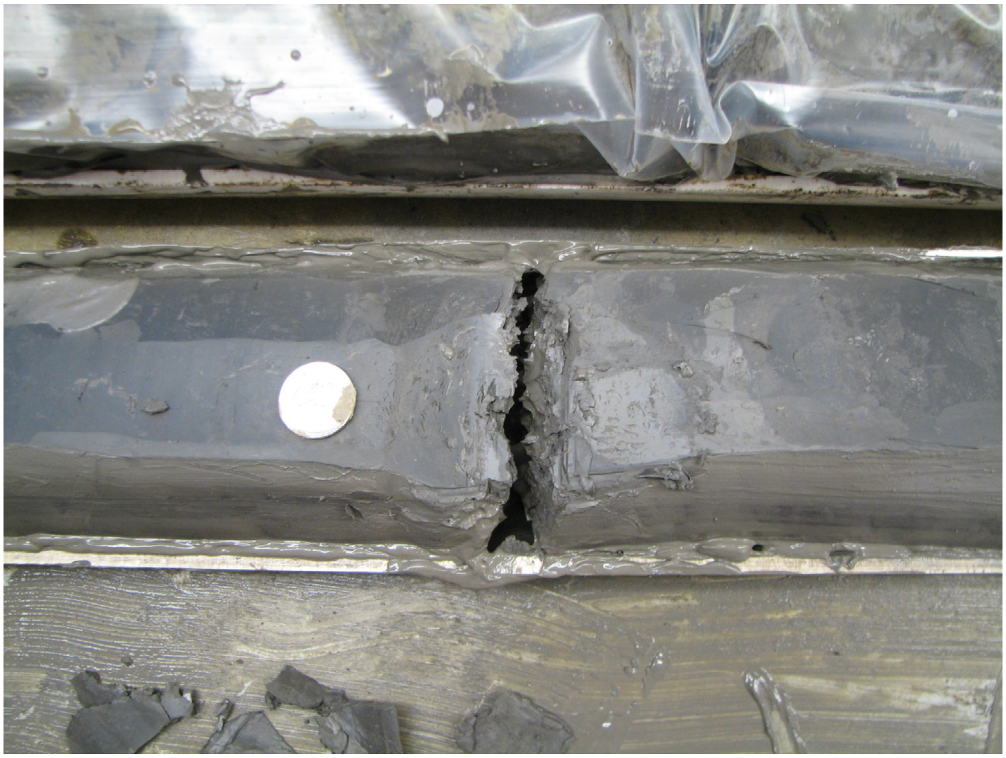


Figure 110. Silt-rich lens in clayey silt to silty clay (PR08-5; 104.3 m; 434.1 m asl).

Figure 111. Slickensides in silty clay to clayey silt (PR08-5; 104.9–105.2 m; 433.5–433.2 m asl).

Figure 112. Slickensides in silty clay to clayey silt (PR08-5; 104.9–105.2 m; 433.5–433.2 m asl).

Figure 113. Silt and clay with very fine grained sand stringers and blebs (PR08-5; interclasts; 110–110.9 m; 428.4–427.5 m asl).

Figure 114. Slickensides in silt and clay (PR08-5; 110–110.9 m; 428.4–427.5 m asl).

Figure 115. Slickensides in silt and clay (PR08-5; 110–110.9 m; 428.4–427.5 m asl).

Appendix 3 — Geotechnical Logging of Discontinuities in Stiff Clays and Argillaceous Bedrock

Introduction

To provide a realistic range of strength parameters for materials, thorough geotechnical logging of core is required to identify the frequency, orientation and condition of all potential structural defects or discontinuities. This document outlines a classification system developed to aid in describing discontinuities in a repeatable manner, such that end users have a clear concept of their potential effects on the strength or behaviour of the material.

For more than 30 years, ‘hard-rock’ geology has used repeatable systems to classify discontinuities. When such systems were applied to Quaternary sediments and weakly cemented rocks, such as Cretaceous shales, their limitations became apparent because sediments and soft rocks deform in a more ductile manner than ‘hard’ rocks. This ductile deformation leads to markedly different shapes and conditions of discontinuities and shear surfaces in these materials.

The main causes of shear surfaces in Quaternary deposits and the immediately underlying bedrock in northern Alberta include

- glacial shear/thrust,
- stress rebound,
- differential compaction, and
- large-displacement shears.

Based on the differences in the deformation properties of soft rocks, we undertook a literature review for classification of discontinuities in overconsolidated sediments and soft rocks. This encountered work undertaken at Imperial College in the late 1960s by Fookes (Fookes and Denness, 1969).

Based on this information and experience with coreholes logged for geotechnical design purposes, we developed a classification system derived from work by Fookes (United States Department of the Interior, 1998), as well as classifications encountered during experience logging Cretaceous shales in the consulting industry.

The purpose of this system is to provide a means by which geologists, technologists and engineers can log core in a repeatable manner that will give end users an increased level of confidence in the choice of soil or rock parameters and/or behavioural characteristics.

Nomenclature

Spacing

The quantification of the spacing of discontinuities in the core gives an indication of whether or not there is a discrete plane of weakness or deformed zone. This also helps in characterizing the potential origin of the discontinuities. The classification in Table 2 quantifies discontinuity spacing.

Table 2. Classification of spacing.

ID	Frequency	Spacing
Slx	Extensive	Completely slickensided (no bedding structure)
Sla	Abundant	<1 cm
Slb	Numerous	1–3 cm
Slc	Occasional	3–6 cm
Sld	Isolated	>6 cm
Slo	Slo	None

Continuity

A continuous joint or fracture is weaker and more deformable than a short, discontinuous fracture bridged by intact bedrock. Identification of the more continuous fractures is an important aspect of formulating rock stability input data. Table 3 provides descriptors for continuity.

Table 3. Classification of continuity.

ID	Continuity	Description
C1	Discontinuous	<50% through sample
C2	Moderately continuous	50%–95% through sample
C3	Very continuous	Completely through sample

Core Breakage

Description of the physical force required to break the discontinuities (Table 4) is a crude but effective method of describing the degree to which a discontinuity has healed. If it takes physical force to break, the discontinuity is likely well healed, which may allow for a more optimistic estimate of the shear strength.

Table 4. Classification of cohesiveness.

ID	Force Applied	Result
B1	Mechanical force	Requires force to break
B2	Hand force	Breaks apart in hand
B3	No force	Falls apart

Geometry

The geometry of the discontinuity can provide important information regarding the origin of the discontinuity. It is most common that planar features are associated with bedding or large displacement shears and that many of the irregular surfaces are the product of consolidation or weathering. Table 5 provides a list of descriptors and schematics for geometry. See Fookes and Denness (1969) for a more detailed explanation.

Table 5. Classification of geometry.

ID	Geometry
G1	Planar
G2	Semi-curved
G3	Curved
G4	Hinged
G5	Semi-undulose
G6	Undulose
G7	Conchoidal

Roughness

The roughness (small-scale asperities) of discontinuity surfaces is critical for evaluating shear strength. Roughness descriptors should be used whenever they are observed. Table 6 provides descriptions of degrees of roughness. See Fookes and Denness (1969) for a more detailed explanation, as well as visual examples of degrees of roughness.

Table 6. Classification of roughness.

ID	Roughness
R1	Striated
R2	Very smooth (polished)
R3	Smooth
R4	Slightly rough
R5	Very rough
R6	Pock Marked
R7	Pitted

Sheen

The sheen describes the degree to which the surface of the discontinuity has been sheared and reworked. A glossy surface likely has the majority of surface defects polished off and is likely closer to a full residual strength. Table 7 provides descriptors for describing sheen.

Table 7. Classification of sheen.

ID	Sheen
S1	Very high gloss (mirror like)
S2	Shiny, glossy
S3	Moderately shiny
S4	Dull

Orientation

The orientation of all fracture with respect to applied loads can be critical to deformation or stability. It is important to distinguish between discontinuities and shear surfaces that form along bedding and those that extend through the rock mass. Table 8 provides descriptors and Figure 116 provides schematic representations of discontinuity orientation.

Table 8. Classification of orientation.

ID	Orientation	Description
F1	Unidirectional (parallel)	Parallel to bedding
F2	Unidirectional (non parallel)	Not parallel to bedding
F2	Multidirectional	In multiple directions
F3	Intersecting	Planes intersect one another

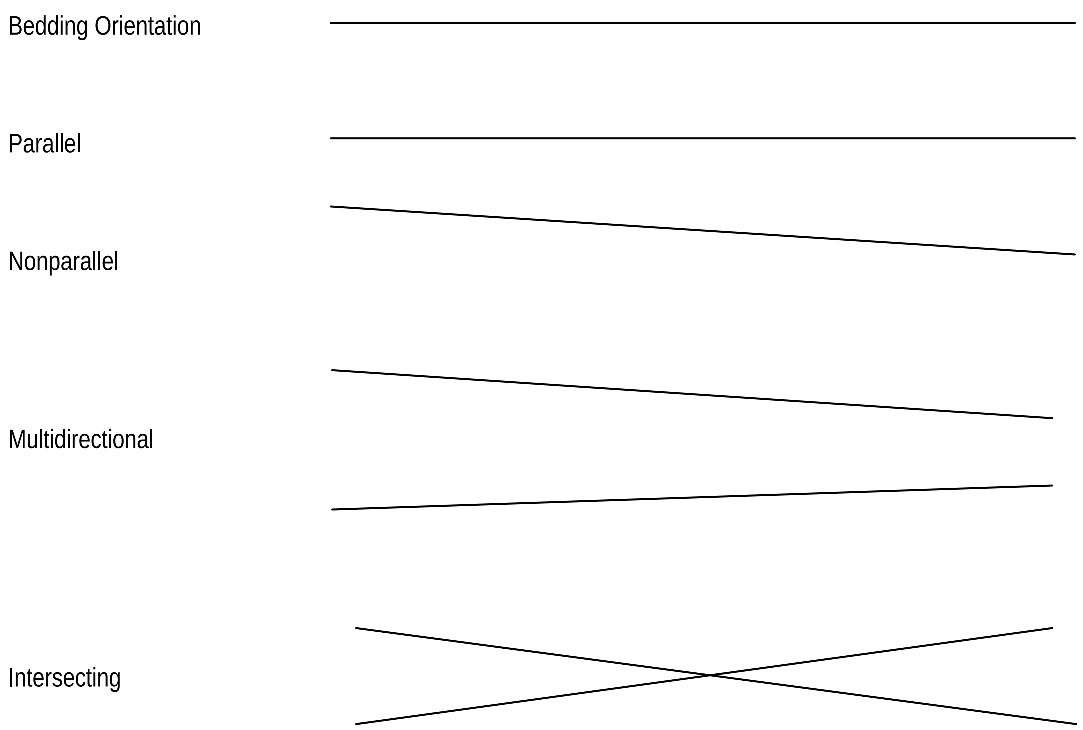


Figure 116. Schematic representations of discontinuity orientation.

Examples of Logged Samples

Figure 117. Discontinuity example: continuous, planar, moderately shiny, striated. Scale indicated by gloved hand holding the 7.6 cm (3 inch) diameter core sample.

Figure 118. Discontinuity example: continuous, planar, slightly rough, dull. Scale indicated by gloved hand holding the 7.6 cm (3 inch) diameter core sample.

Figure 119. Discontinuity Example: Smooth, undulating, polished, continuous, intersecting. Scale indicated by gloved hand holding the 7.6 cm (3 inch) diameter core sample.

Figure 120. Discontinuity example: continuous, curved, striated, polished.

Figure 121. Discontinuity example: continuous, striated, slightly rough, intersecting (7.6 cm [3 inch] diameter core sample).

Figure 122. Discontinuity example: continuous, semi-undulose, striated, moderately shiny (7.6 cm [3 inch] diameter core sample).

Figure 123. Discontinuity example: continuous, semi-undulose, very shiny, striated, intersecting (7.6 cm [3 inch] diameter core sample).

Figure 124. Discontinuity example: continuous, semi-undulose, striated, polished, intersecting (7.6 cm [3 inch] diameter core sample).