Independent Expert Engineering Investigation and Review Panel

Report on Mount Polley Tailings Storage Facility Breach

Appendix C: Surface Investigations

January 30, 2015

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APPENDIX C: SURFACE INVESTIGATIONS

1.0 INTRODUCTION

Appendix C documents observations and interpretations from field mapping in the breach area of the Mount Polley Mine tailings storage facility (TSF). The purpose of these surficial investigations was to document geological and geotechnical features exposed in the area of the breach prior to disturbance by investigation activities or other operations.

The features and conditions observed were interpreted with respect to their interrelationships, morphology, and relevance to related aspects of the Panel's investigation. These interpretations are based on the surficial investigations alone, and there is no attempt to incorporate information gathered from other sources. Interpretations are reserved for the final sections of this Appendix.

2.0 DATA COLLECTION AND SOURCES

2.1 REVIEW OF PRE-FAILURE SATELITE IMAGERY

LANDSAT imagery was obtained from GeoBC. This and other imagery was reviewed to determine the history of tailings deposition and surface water impoundment immediately adjacent to the dam at the breach location.

2.2 REVIEW OF THE CARIBOO VIDEO

A video taken from a helicopter date stamped 8:46am on August 4, 2014 was obtained from Cariboo Regional District. At this time, 7 ½ hours after breach initiation, outflow was still occurring. The video was reviewed to provide overall site content and basic geological information prior to field mapping. Section 3.3 of this Appendix provides a series of screenshots annotated with descriptions of key features. Section 4.5 uses video content to examine the processes of tailings release in progress.

2.3 REVIEW POST-FAILURE OF AIR PHOTOS

A helicopter reconnaissance was conducted by the Panel one month after the breach on September 4, 2014. Aerial photographs taken during the reconnaissance were reviewed to provide geological information. At this time, construction of a containment dike was underway inside the breach that is visible on many of the photos. Section 3.5 of this Appendix provides a series of photographs taken from the helicopter with annotated descriptions of key features.

In addition, post-breach stereopairs were obtained from Mount Polley Mining Corporation (MPMC) and reviewed.

2.4 GROUND PHOTOS, LOCATIONS AND PREPROCESSING

Numerous photographs were also taken from the ground during the site reconnaissance on September 4, 2014.

Selected ground and air photographs were input into Photoscan® software by Agisoft to create a stitched, composite image of the breach area. The digital image can be used to conduct a virtual 3-D flyover of the site in the electronic version of this Appendix.

2.5 TOPOGRAPHICAL BASE MAPS AND CROSS-SECTIONS

A topographical site plan was developed from the post breach LiDAR based topographical data collected on August 5, 2014 by MPMC. The plan was constructed on a series of layers that can be superimposed on each other in the electronic version of this Appendix. The layers include the post-breach LiDAR information, the post-breach orthophoto imagery, the annotated mapping observations, and the sample locations and laboratory testing results.

A cross-section of the dam at the area of the breach was constructed based on a composite of as-built sections at the locations of adjacent Sections D and G. The composite section is provided in section 3.1 of this Appendix.

2.6 FIELD MAPPING

The initial field mapping in the area of the breach was conducted on foot on September 11 and 12, 2014. At that time, access in the breach area was limited to zones deemed safe to conduct mapping. Areas at the base of oversteepened slopes and the entire area upslope of the dam core could not be accessed. It was not possible to access the areas adjacent to the remnant till core on the downstream side. Much of the base of the breach area was covered in unconsolidated fine tailings and was not readily accessible.

Additional mapping was conducted on September 25 and 26, 2014. At this time, some areas upstream of the remnant till core were accessible.

The mapping attempted to identify marker beds within the soil exposures indicative of deformation and shearing offset. Some potential marker beds were visually identified within the rockfill but could not be accessed for detailed inspection due to the steep, unstable slopes.

A total of 13 soils samples (Sa #1 to Sa #13) were collected by hand using a rock hammer and small shovel from various exposures during the mapping program on September 11 and 12, 2014. Index testing was performed on these samples.

Section 3.6 describes the results of the field mapping. The mapping is presented on a series of annotated composite photographs and contained on the Drawings that accompany this Appendix.

2.7 CORE EXCAVATION

Excavation of the remnant core on the right abutment was conducted on November 5 to 14, 2014. The excavation was carried out in slices to allow detailed stratigraphy to be determined. Each was logged and photographed. Section 3.7 provides selected photographs and geological descriptions of the conditions encountered during the excavation. Samples of the core and filter were recovered during the excavation. Laboratory testing on these and other surface samples is reported in Attachment C1. Block sampling of the shear zone encountered in the excavation is described in Attachment C2.

3.0 DATA COMPILATION, PRESENTATION, AND EXPLANATION OF FEATURES

3.1 DEFINITIONS AND CONVENTIONS

This section provides definitions and conventions adopted in this Appendix. Location and direction conventions use the dam as the point of reference. Spatially, the side of the dam that retains the tailings is referred to as the upstream side (south side). Directionally, "upstream" refers to the direction toward the interior of the impoundment.

The opposite side of the dam (away from the tailings) is referred to as the downstream side (north side), and the "downstream" direction is away from the impoundment interior.

The complementary directions are always expressed relative to downstream. Looking downstream through the breach (in the direction of the water outflow and tailings release), the right abutment refers to the right (east) side of the breach while the left (west) abutment is located to the left of the breach.

Figure C3.1.1 shows the pre-breach orthophoto taken on August 21, 2013 and the superimposed post-breach contour lines that identify the area of the breach. The S.O.L. line shown on the figure is the "Setting Out Line," the reference line established for surveying and dimensioning of the dam. The chainage along the S.O.L. increases from east to west in the area of the breach. The till core of the dam is located near the S.O.L. A drainage ditch can be observed at the toe of the downstream shell of the dam.

The "shell" of the dam in **Figure C3.1.1** refers to the mine waste rockfill that provides downstream support for the core. On the upstream side, the dam had no corresponding shell as such, with core support provided by the tailings for the dam's "centreline" configuration.

FIGURE C3.1.1: PRE-BREACH ORTHOPHOTO WITH POST-BREACH CONTOURS

Figure C3.1.2 is a post-breach orthophoto showing the general configuration and conventions used in the breach area. This figure can be compared to **Figure C3.1.1** to identify the areas impacted by the breach. The remaining sections of the dam on the left and right side are referred to as the respective "abutments" of the breach.

FIGURE C3.1.2: POST-BREACH ORTHOPHOTO SHOWING NAMING CONVENTIONS

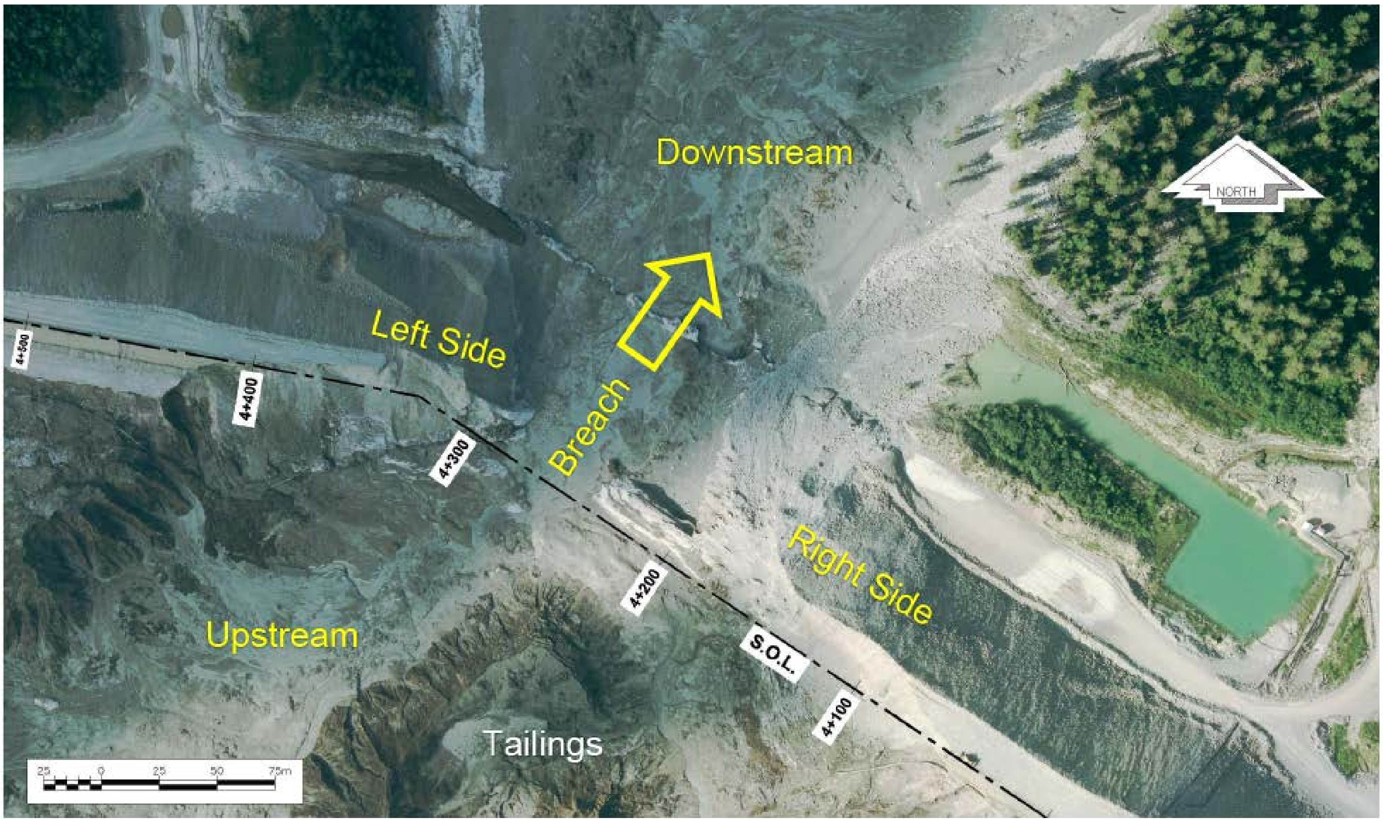


Figure C3.1.3 is a post-breach contour plan showing the topographical features of the breach area. The dam is about 40 m high on the downstream side adjacent to the breach. The Zone C rockfill downstream shell of the dam is indicated on the figure. The existing slope angle of the downstream shell is about 37°, or 1.3 horizontal to 1.0 vertical. Note that the dam alignment changes at the left abutment of the breach at the point known as "Corner 1".

The locations of design cross-sections D and G are shown in the figure for reference purposes. These sections were used in developing the composite breach section as explained below.

FIGURE C3.1.3: POST-BREACH CONTOUR PLAN SHOWING ABUTMENTS AND REFERENCE CROSS-SECTIONS

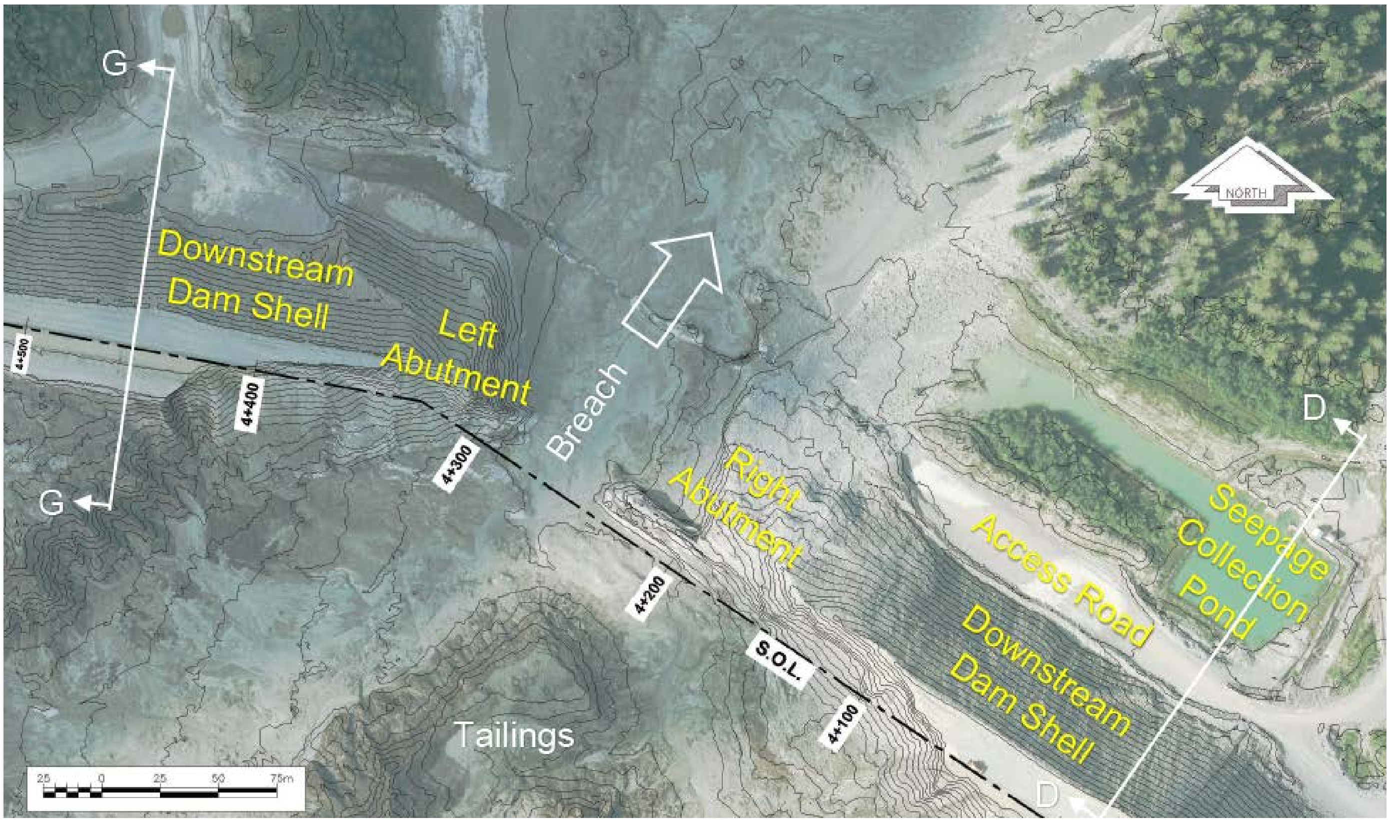
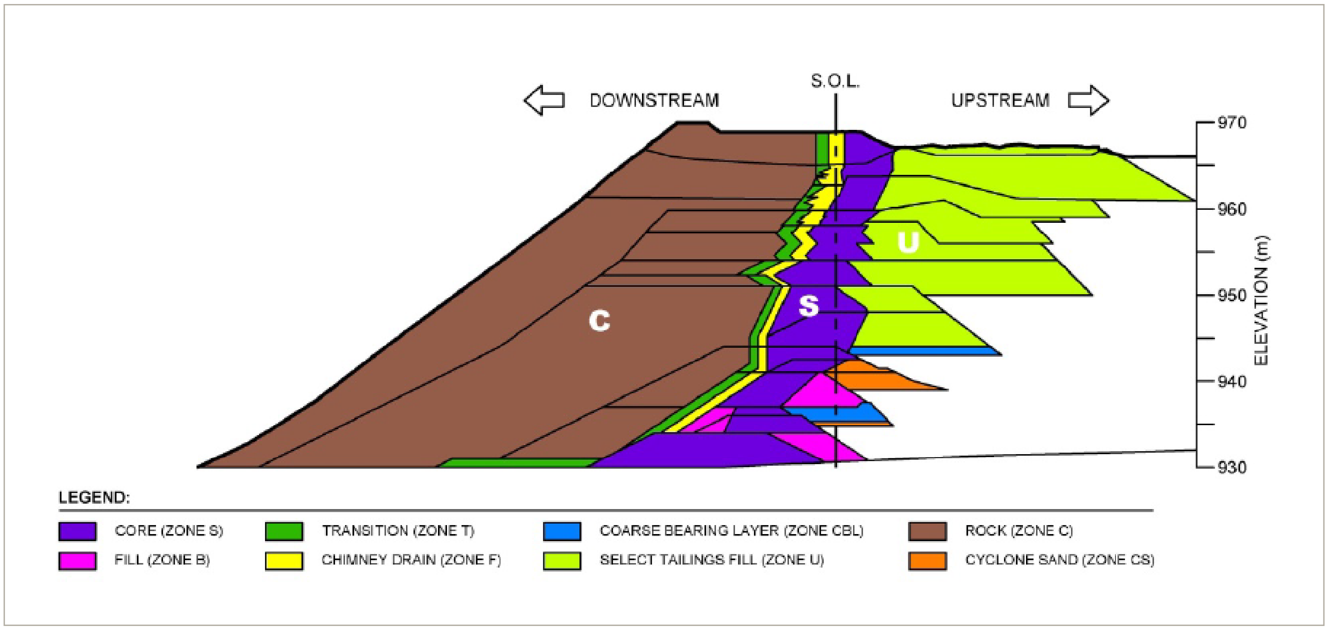


Figure C3.1.4 is an interpreted composite cross-section through the dam in the area of the breach. The black lines in the figure delineate the various stages of dam construction.

The figure combines the internal dam configurations at design Sections D and G to better represent conditions at the breach. At Section D, a downstream trial zone of cyclone sand was placed in the lower portion of the embankment during Stage 2C. This zone did not extend to the breach area. Accordingly, the composite section used as-built information from Section G for raises up to Stage 6B (approximate elevation 958 m), with as-built details above this elevation from Section D.

As shown in **Figure C3.1.4**, the relatively impervious compacted till core is designated Zone S. Zones F and T are the filter located immediately downstream of the core and the transition zone located immediately downstream of the filter, respectively. The downstream mine waste rockfill shell of the dam is designated Zone C. Select tailings fill placed on the upstream side of the dam is designated Zone U.

FIGURE C3.1.4: INTERPRETED COMPOSITE DAM CROSS-SECTION NEAR BREACH



Bedding orientations measured in the field are reported as dip and dip direction (05°/253°). The dip direction is 90° to the strike and is based on compass north (declination at 22°). Marker beds shown on the cross-sections indicate beds that can be traced some distance across the exposure. Shear features are defined as zones of relative ground displacement indicated by displacement of marker beds, slickensides, softened zones, or cracks.

For consistency, the same letter symbols have been used to indicate key geological features. The key to letter symbols is shown in **Table C3.1.1**.

TABLE C3.1.1: KEY TO GEOLOGICAL SYMBOLS

SYMBOL	GEOLOGICAL UNIT OR FEATURE
B	Dam Till fill (Zone B)
C	Dam Rockfill Shell (Zone C)
S	Dam Till Core (Zone S)
F	Dam Filter (Zone F)
T	Dam Transition (Zone T)
U	Dam Select Upstream Fill (Zone U)
CS	Dam Cyclone Sand (Zone CS)
CBL	Dam Coarse Bearing Layer (Zone CBL)
W	Linear native till ridge “Whaleback” Feature (interpreted as thrusted)
D	Displaced Rockfill Material
R	Remnant Haul Road Ramp
J	Till blocks (interpreted to be eroded from till core)
P	Perimeter Embankment Seepage Collection Pond
Q	Pipeline used to return water from collection pond into tailings pond
G	Area of ponded water at downstream toe of dam
L	Area of toe bulge with native till blocks (interpreted as thrusted)
E	Excavated Pit
H	Head scarps
O	Open cracks
M	Seepage points
A	Shear surface
K	Temporary upstream rockfill dike
V	Void in till core
N	Cracks and pockets filled with tailings sand in remnant core excavation
X	Berm of organic till (Fill)
Y	Horizontal layering in remnant core excavation
Z	Marker bed located in remnant core excavation

3.2 PRE-FAILURE IMAGERY

Pre-failure satellite (LANDSAT) imagery over the life of the TSF was obtained from GeoBC. These and other images were reviewed to determine either the presence of surface water or deposited beach tailings immediately adjacent to the Perimeter Embankment at the breach location. This location could be readily identified by the change in alignment at Corner 1. Topographic mapping of surface water location was also referenced where available.

Table C3.2.1 provides the results of this assessment

TABLE C3.2.1: CHRONOLOGICAL CATALOGUE OF IMPOUNDMENT CONDITIONS AT VICINITY OF CORNER 1

IMAGE DATE	WATER	BEACH	SOURCE
pond first reached Corner 1 in March 1998			KP 1998 Annual Inspection Report [1]
5/5/98		X	LANDSAT (GEOBC FILE)
8/22/98		X	ORTHOPHOTO (GEOBC)
7/24/98		X	LANDSAT (GEOBC FILE)
9/03/98		X	LANDSAT (GEOBC FILE)
10/21/98		X	LANDSAT (GEOBC FILE)
7/12/99	X	X	LANDSAT (GEOBC FILE)
7/20/99	X		LANDSAT (GEOBC FILE)
8/20/99	X		LANDSAT (GEOBC FILE)
9/14/99	X		LANDSAT (GEOBC FILE)
10/24/99	X		LANDSAT (GEOBC FILE)
12/26/99	X		LANDSAT (GEOBC FILE)
6/28/2000	X	X	LANDSAT (GEOBC FILE)
9/23/2000		X	ORTHOPHOTO (GEOBC)
12/13/2000		X	LANDSAT (GEOBC FILE)
4/03/2001		X	LANDSAT (GEOBC FILE)
4/12/2001		X	LANDSAT (GEOBC FILE)
5/6/2001		X	LANDSAT (GEOBC FILE)
7/9/2001		X	LANDSAT (GEOBC FILE)
10/4/2001 (begin mill shutdown)		X	LANDSAT (GEOBC FILE)
10/29/2001		X	LANDSAT (GEOBC FILE)
11/14/2001		X	LANDSAT (GEOBC FILE)
2/2/2002		X	LANDSAT (GEOBC FILE)
5/1/2002		X	LANDSAT (GEOBC FILE)
6/9/2002		X	LANDSAT (GEOBC FILE)
7/11/2002		X	LANDSAT (GEOBC FILE)
7/27/2002		X	LANDSAT (GEOBC FILE)

[1] MP00011

TABLE C3.2.1: CHRONOLOGICAL CATALOGUE OF IMPOUNDMENT CONDITIONS AT VICINITY OF CORNER 1

IMAGE DATE	WATER	BEACH	SOURCE
8/21/2002		X	LANDSAT (GEOBC FILE)
12/19/2002		X	LANDSAT (GEOBC FILE)
2/12/2003		X	LANDSAT (GEOBC FILE)
5/12/2003		X	LANDSAT (GEOBC FILE)
6/29/2003		X	LANDSAT (GEOBC FILE)
7/31/2003		X	LANDSAT (GEOBC FILE)
9/1/2003		X	LANDSAT (GEOBC FILE)
9/02/2003		X	ORTHOPHOTO (GEOBC)
10/3/2003		X	LANDSAT (GEOBC FILE)
12/3/2003		X	LANDSAT (GEOBC FILE)
7/17/2004		X	LANDSAT (GEOBC FILE)
8/2/2004		X	LANDSAT (GEOBC FILE)
8/18/2004		X	LANDSAT (GEOBC FILE)
12/31/2004		X	GOOGLE EARTH
2/17/2005 (restart)	date mislabeled: shows 2014 post-failure image		LANDSAT (GEOBC FILE)
7/28/2008	X		LANDSAT (GEOBC FILE)
8/13/2008	X	X	LANDSAT (GEOBC FILE)
11/14/2008	X	X	LANDSAT (GEOBC FILE)
11/30/2008	X		LANDSAT (GEOBC FILE)
2/21/2009	X		LANDSAT (GEOBC FILE)
6/4/2009		X	LANDSAT (GEOBC FILE)
6/13/2009		X	LANDSAT (GEOBC FILE)
7/15/2009		X	LANDSAT (GEOBC FILE)
7/22/2009		X	LANDSAT (GEOBC FILE)
7/22/2009		X	ORTHOPHOTO (GEOBC)
7/31/2009		X	LANDSAT (GEOBC FILE)
8/7/2009		X	LANDSAT (GEOBC FILE)
9/17/2009		X	LANDSAT (GEOBC FILE)
9/24/2009		X	LANDSAT (GEOBC FILE)
10/10/2009		X	LANDSAT (GEOBC FILE)
4/13/2010		X	LANDSAT (GEOBC FILE)
5/15/2010		X	LANDSAT (GEOBC FILE)
8/25/2010		X	LANDSAT (GEOBC FILE)
9/3/2010		X	LANDSAT (GEOBC FILE)
9/10/2010		X	LANDSAT (GEOBC FILE)

TABLE C3.2.1: CHRONOLOGICAL CATALOGUE OF IMPOUNDMENT CONDITIONS AT VICINITY OF CORNER 1

IMAGE DATE	WATER	BEACH	SOURCE
11/23/2010		X	LANDSAT (GEOBC FILE)
4/23/2011	X	X	LANDSAT (GEOBC FILE)
7/5/2011	X	X	LANDSAT (GEOBC FILE)
8/6/2011	X	X	LANDSAT (GEOBC FILE)
9/7/2011		X	LANDSAT (GEOBC FILE)
10/9/2011		X	LANDSAT (GEOBC FILE)
10/16/2011		X	LANDSAT (GEOBC FILE)
-/-/2012		X	AMEC 2012 AS-BUILT REPORT[2]
9/6/2012		X	BGC 2012 ANNUAL REVIEW[3]
4/21/2013	X		LANDSAT (GEOBC FILE)
7/21/2013	X		LANDSAT (GEOBC FILE)
7/26/2013		X	LANDSAT (GEOBC FILE)
8/2/2013		X	LANDSAT (GEOBC FILE)
9/3/2013		X	LANDSAT (GEOBC FILE)
9/12/2013		X	LANDSAT (GEOBC FILE)
10/-/2013		X	BGC STAGE 10 RAISE DESIGN REPORT[4]
10/21/2013		X	LANDSAT (GEOBC FILE)
2/3/2014	X		LANDSAT (GEOBC FILE)
2/26/2014	X		LANDSAT (GEOBC FILE)
5/10/2014	X		LANDSAT (GEOBC FILE)
7/13/2014	X		LANDSAT (GEOBC FILE)
7/29/2014	X		LANDSAT (GEOBC FILE)

[2] MP00217
[3] MP00043
[4] MP00208

3.3 CARIBOO VIDEO AND STILLS

The breach initiated at 1:15am on August 4, 2014. A thirty-seven minute video was taken by the Cariboo Regional District from a helicopter beginning at date stamp 8:46am. The following section reviews screenshots from the video to illustrate various geological features. The figure captions indicate the time within the video at which the still photo was captured (e.g., 11:32 = 11 minutes and 32 seconds into the video).

Features shown on each of the figures are labelled using the key provided in **Table C3.1.1** in section 3.1. The feature labels discussed within the figure text are shaded yellow. White labelled features are provided for background and are discussed elsewhere.

Figure C3.3.1 is a view looking upstream through the breach. It can be seen that the water flowing though the breach originates from both the left and right upstream side of the dam. The right abutment consists of a linear section of remnant till core (S) and a section of displaced downstream shell (D). The left abutment contains of a smaller piece of remnant till core (S) behind the downstream rockfill shell (C). The photograph also shows the linear whaleback feature (W) that runs parallel to the dam near the downstream toe. Comprised of highly erosion-resistant native till, the whaleback uplift was subject to continuous overflow and acted as a broad-crested weir during breach discharge.

FIGURE C3.3.1: VIEW LOOKING UPSTREAM INTO TSF THROUGH THE BREACH (CARIBOO VIDEO AT 11:11)

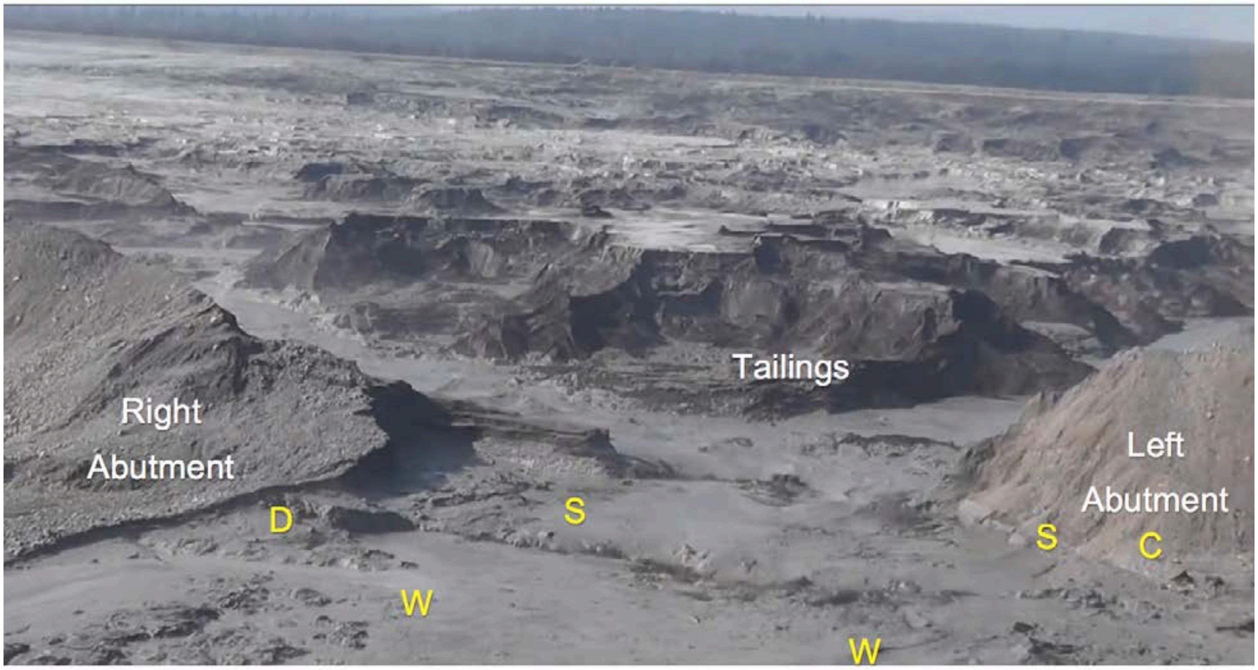


Figure C3.3.2 is a view looking across the breach at the right abutment. The photo shows a different perspective of the section of remnant core (S) that survived the breach, the displaced right embankment shell (D) and the linear whaleback (W). The photo also shows the Perimeter Embankment seepage collection pond (P) at center-left and its return-water pipeline (Q). Ponded water (G) in a low area on the access road at the toe of the dam was not present during later inspections and is believed to be from rainfall that preceded the breach. Also shown is the confluence of the two well-developed flow channels at the upstream entry to the breach.

FIGURE C3.3.2: VIEW LOOKING SOUTHEAST ACROSS THE BREACH (CARIBOO VIDEO AT 11:32)

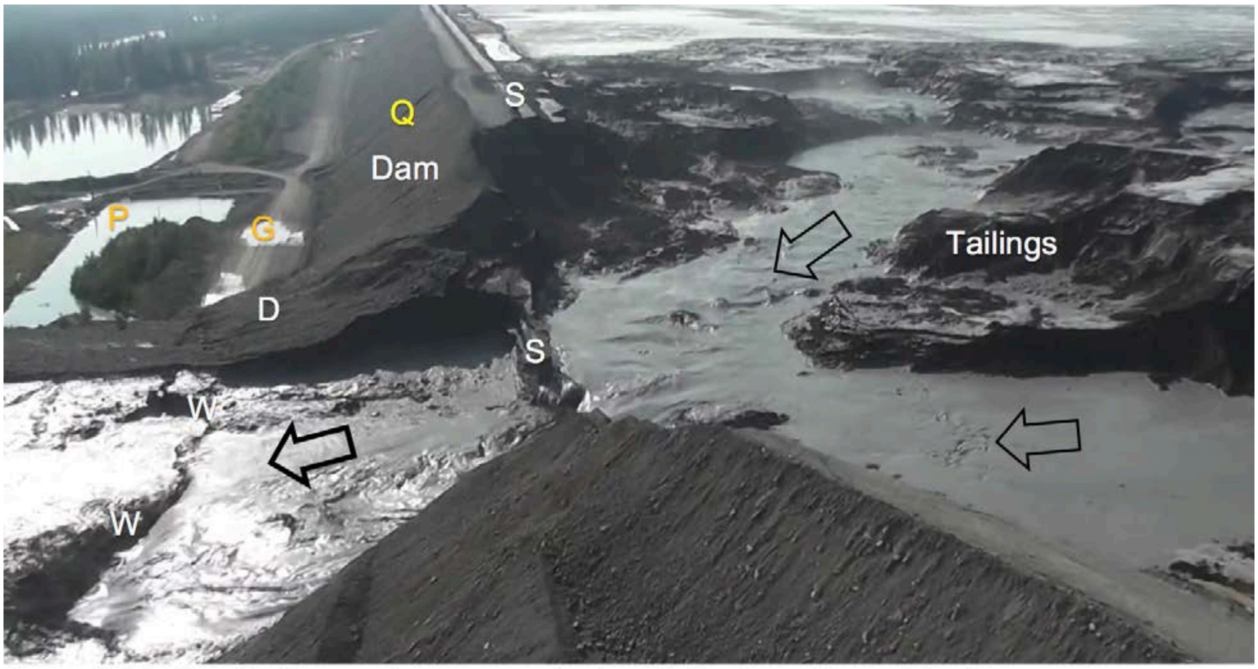


Figure C3.3.3 is an oblique view across the breach showing the flow of water and tailings. The whaleback (W) acts as the control section for downstream flow, with a visible hydraulic jump as water passes over it. A haul road ramp (R) was formerly used to gain access to the dam crest. Fill from this ramp had been salvaged for use elsewhere in dam construction, leaving the steep escarpment on the downstream slope and a circular excavated pit (E). Below this pit is a flat area where Zone F filter material had formerly been stockpiled. A series of large till blocks (J) believed to be pieces of eroded core material have been deposited on the access road during a period of higher breach flow.

FIGURE C3.3.3: OBLIQUE VIEW SHOWING BREACH DISCHARGE (CARIBOO VIDEO AT 11:28)

Figure C3.3.4 shows the right abutment looking south and illustrates the sub-horizontal layering of the remnant till core (S). The crest of the remnant core is at about El. 940 m with a sub-horizontal bench on the downstream side at El. 938.5 m, corresponding approximately to the crest elevations of Stages 2C and 2B respectively. Another prominent sub-horizontal bench on the upstream side (not visible in the photo) is at approximate elevation El. 934 m corresponding to the crest of Stage 1B. A dip angle of 9° upstream was measured near the base of the remnant core. This section of remnant core was subsequently excavated and mapped and is described in section 3.7 of this Appendix.

The dashed line in **Figure C3.3.4** delineates an erosional surface produced by overflow on the displaced slope (D) during breach development. A layer of water-deposited tailings covers the relatively level bench at the base of the escarpment (C). A series of headscarps (H) were observed in the area of slide movement on the right abutment. Numerous open cracks can be observed at the crest of the slope in this area (O).

FIGURE C3.3.4: VIEW OF RIGHT ABUTMENT OF BREACH WITH SCARPS AND CRACKING (CARIBOO VIDEO AT 35:51)

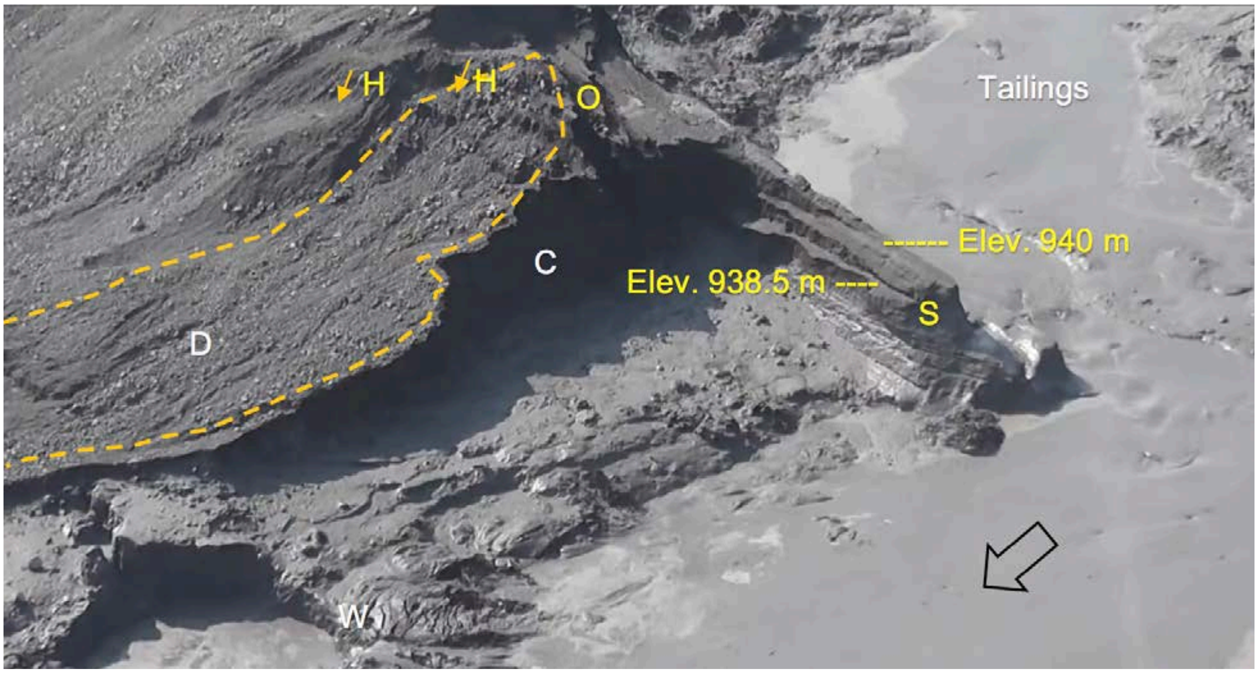


Figure C3.3.5 is a view looking upstream through the breach into the tailings facility. It shows toe bulging and translation displacement on the right abutment where rockfill material covers the access road. Large blocks of dense to compact, intact foundation till (up to 2.5 m high) containing organics and topsoil were observed at Location L. These blocks show evidence of having been upthrust into the displaced rockfill during the ground movement at the right abutment. The depositional area for eroded rockfill is indicated by the dashed line.

FIGURE C3.3.5: VIEW LOOKING UPSTREAM INTO TSF THROUGH THE BREACH (CARIBOO VIDEO AT 33:59)

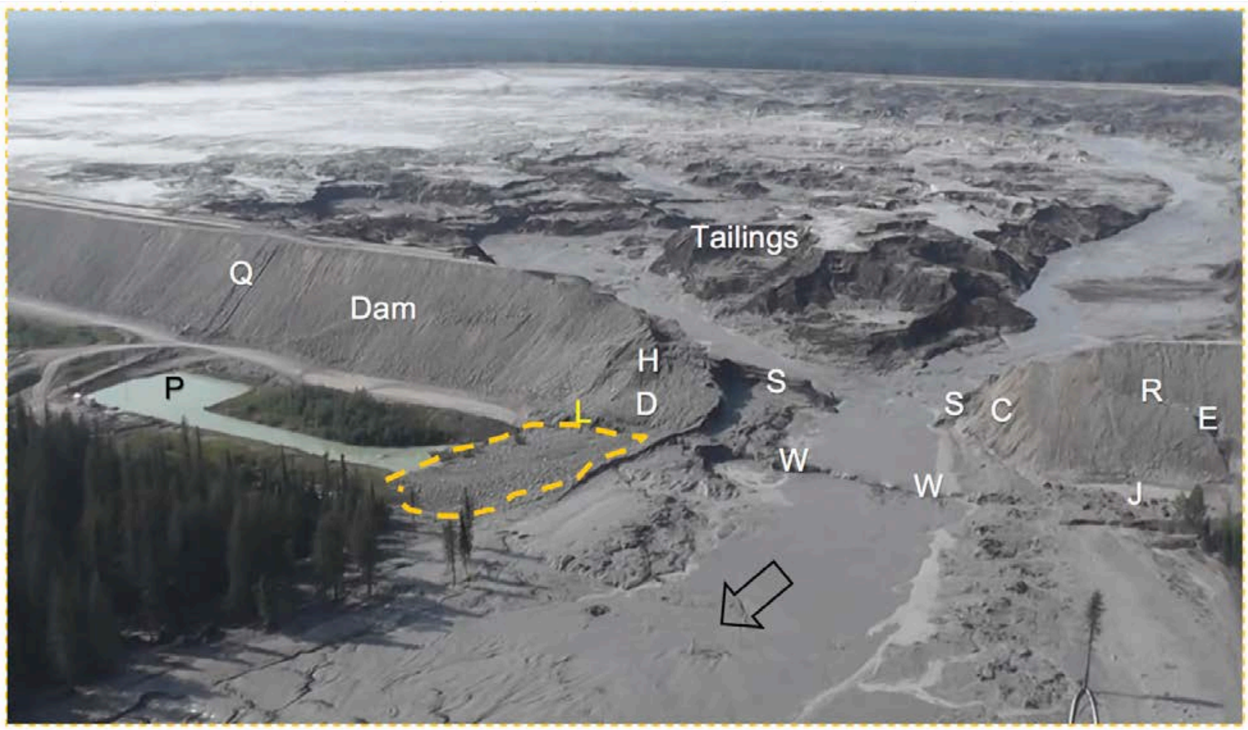


Figure C3.3.6 is a view of the left abutment looking upstream. The photo shows the sub-horizontal layering of the the left abutment rockfill shell at C, with beds dipping about 7° to 10° upstream. Also indicated are the circular excavated pit (E), the former haul road ramp (R), and the flat area below used for storing granular filter material.

The photo also shows three distinct sub-parallel (en echelon) scarps (H) located high on the left abutment. These downdrop scarps are about 3 to 4 m high and are associated with subsidiary movement into the breach subsequent to breach development.

FIGURE C3.3.6: VIEW LOOKING UPSTREAM OF LEFT ABUTMENT OF BREACH (CARIBOO VIDEO AT 35:44)

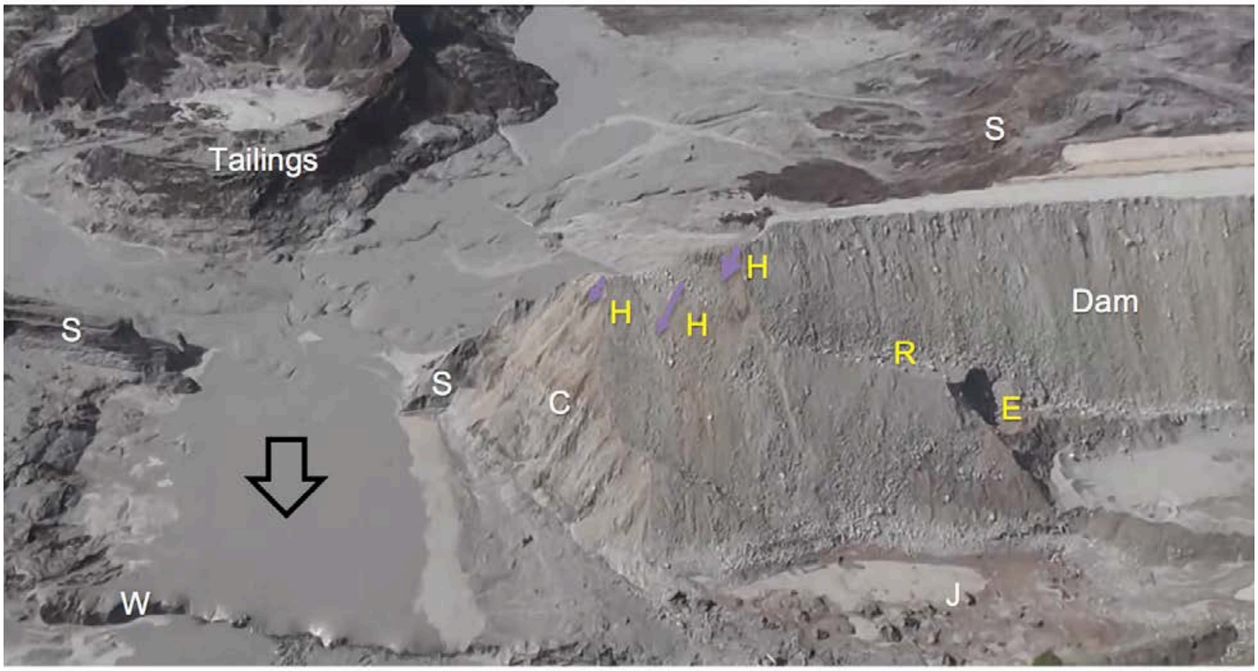


Figure C3.3.7 is a more detailed view of the left abutment en echelon scarps (H) and the dipping beds of the rock fill shell (C). The consistent measured bedding angles between 7° and 10° upstream indicate fairly uniform rotation of the left abutment prior to formation of the downdrop scarps.

FIGURE C3.3.7: VIEW OF LEFT ABUTMENT OF BREACH SHOWING SCARPS (CARIBOO VIDEO AT 35:46)

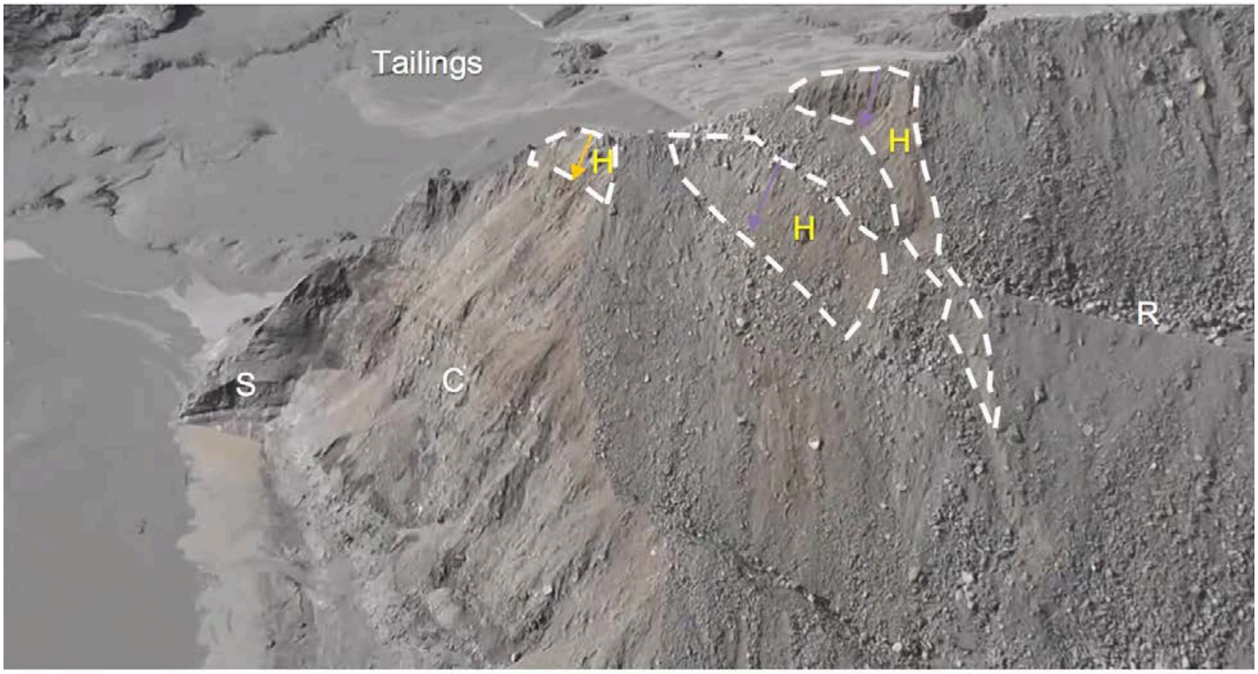


Figure C3.3.8, looking downstream through the breach area, shows the exposed upstream portion of the dam. It illustrates the large lateral extent of upstream collapse due to removal of tailings supporting the dam core. In some areas, the dashed line indicating the crest of the head scarps (H) extends downstream of the till core (S) and into the downstream slope.

The photo also shows the upstream sub-horizontal bench of till core located on the right abutment at approximate elevation El. 934 m. The en echelon scarps (H) located high on the left abutment indicating subsidiary movement into the eroded breach area can also be observed.

FIGURE C3.3.8: VIEW OF THE BREACH AREA LOOKING DOWNSTREAM (CARIBOO VIDEO AT 34:36)

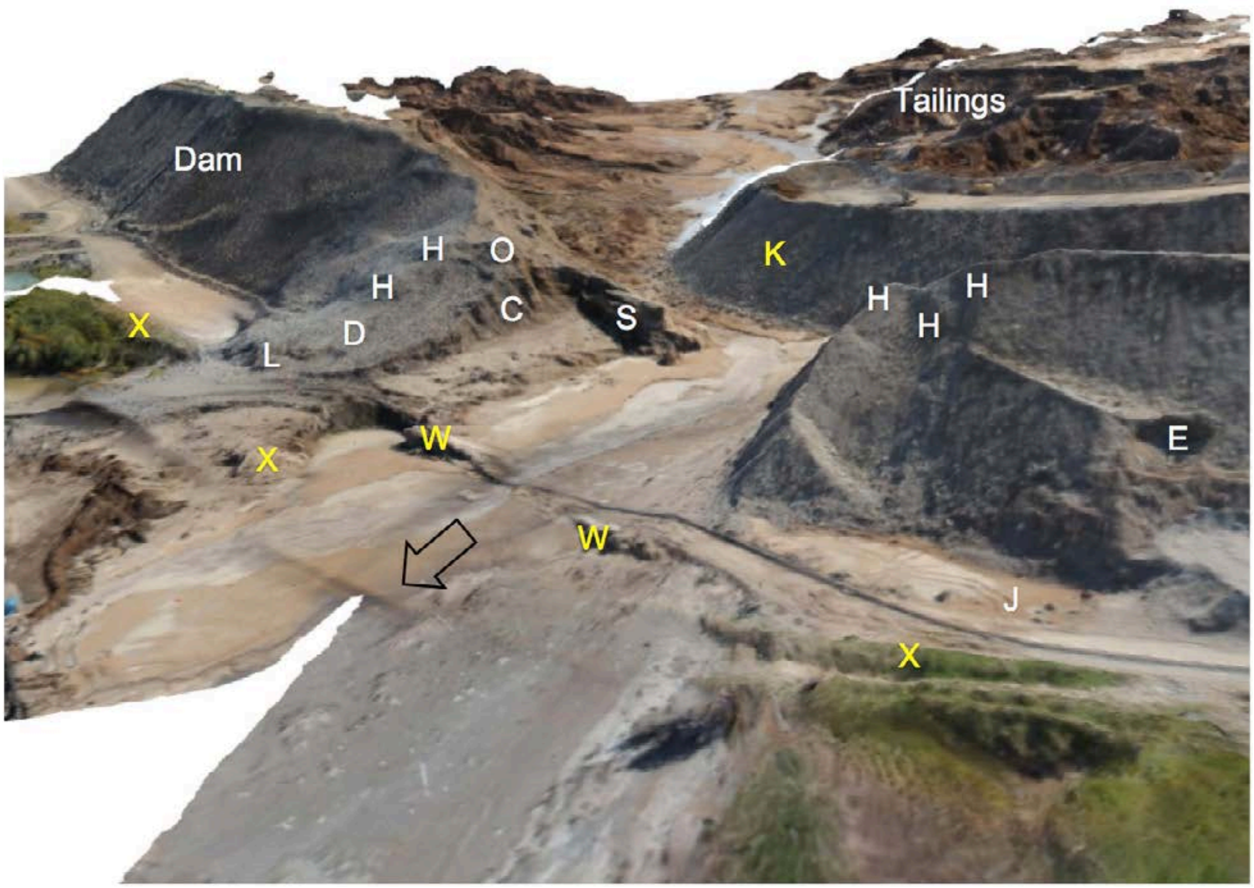
3.4 3-D FLYOVER

A series of photographs taken from the air and from the ground on September 4, 2014 were input into the software program Photoscan® by Agisoft to create a stitched-together composite virtual image of the breach area. The digital PDF image that is provided at the end of this Appendix, can be used to conduct a virtual 3-D flyover of the site.

The flyover can be operated with a computer mouse to zoom in or out of the image. To fly laterally and change perspective simply press and hold the keyboard shift button while navigating with the mouse. The flyover adds insight into the geometrical configurations and interrelationships of breach features that can be difficult to gain from the still photos alone.

Figure C3.4.1 is a 3-D rendering looking upstream toward the right abutment. It shows the upstream rockfill dike (K) being constructed to retain the remaining tailings, which appears prominently in many of the following September 4, 2014 photos. The figure also shows the linear whaleback (W) and a linear roadside berm consisting of organic till (fill) material (X) that can be traced across the breach area.

FIGURE C3.4.1: VIRTUAL IMAGE LOOKING UPSTREAM THROUGH THE BREACH AREA



3.5 SELECTED PANEL HELICOPTER STILLS

This section presents a selection of the photographs taken during the Panel's September 4th, 2014 helicopter tour.

Figure C3.5.1 shows the left abutment. The dipping lift lines on the downstream rockfill shell (C) are clearly visible and highlighted by yellow dashed lines. The uniformity of the bedding inclination (7° to 10°) in the downstream shell suggests similar uniformity in its apparent rotation. The bedding immediately above the remnant core (S), to the left of the photo, appears to be somewhat flatter, indicating a potential shear surface (A) shown in orange. Further geological details of the left abutment are provided in section 3.6.

The three en echelon scarps (H) can be seen above the eroded slope face (C). Transported till blocks and pieces of driftwood (J) indicate that the water level during the breach attained this level. The rockfill retaining dike (K) was under construction in the background.

FIGURE C3.5.1:VIEW FROM HELICOPTER LOOKING WEST AT LEFT ABUTMENT (SEPT. 4, 2014 PHOTO)

Figure C3.5.2 is a view looking upstream (south) across the left abutment of the breach. The photo shows the en echelon headscarps (H), the new rockfill dike (K), the former haul road access ramp (R,) and the excavated circular pit (E). This photo provides good definition of the large fill block bounded by the headscarps that dropped down into the breach subsequent to its rotation.

FIGURE C3.5.2: VIEW LOOKING UPSTREAM AT THE LEFT ABUTMENT (SEPT. 4, 2014 PHOTO)

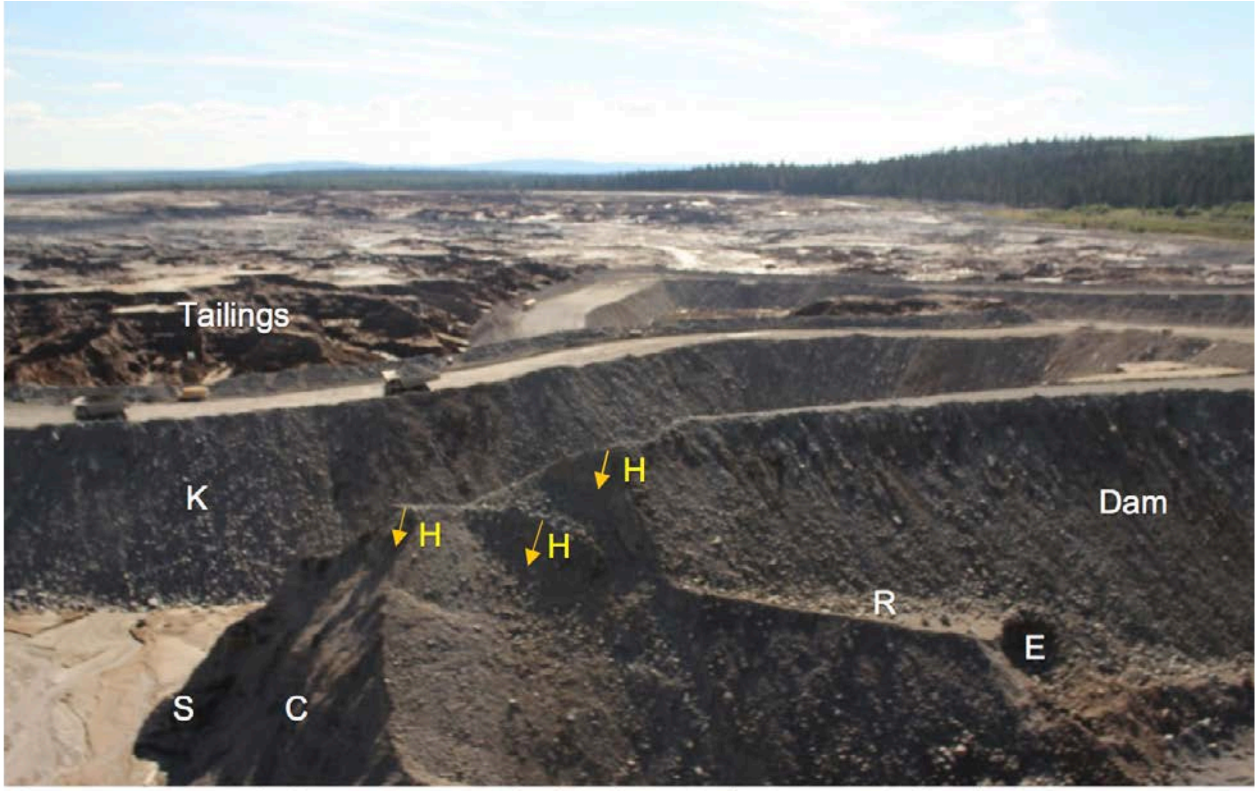


Figure C3.5.3 also shows the left abutment. The three en echelon scarps (H) which are about 3 m to 4 m high are clearly visible. The eroded till blocks (J) and pieces of organic drift wood can be seen at the downstream toe of the dam. The haul road ramp (R) is also visible along with the trace of its downdropped alignment. The estimated vertical displacement is about 5 m.

A lower dipping linear feature is located to the left of the yellow "J". The pre-breach orthophoto was examined to determine if this was also an old haul road. No such evidence could be identified, and therefore this feature may be an erosional surface that developed during breach outflow.

FIGURE C3.5.3: VIEW OF DOWNSTREAM SIDE OF LEFT BREACH ABUTMENT (SEPT. 4, 2014 PHOTO)

Figure C3.5.4 shows the upper portion of the left abutment with the three en echelon scarps (H) outlined. The maximum height of the upper two scarps is about 3 m to 4 m. The upper scarp cuts through the former haul road ramp (R). Below the scarps to the lower left is the upper surface of the downdropped fill block.

FIGURE C3.5.4: VIEW OF THE UPPER PORTION OF THE LEFT ABUTMENT FROM THE DOWNSTREAM SIDE (SEPT. 4, 2014 PHOTO)

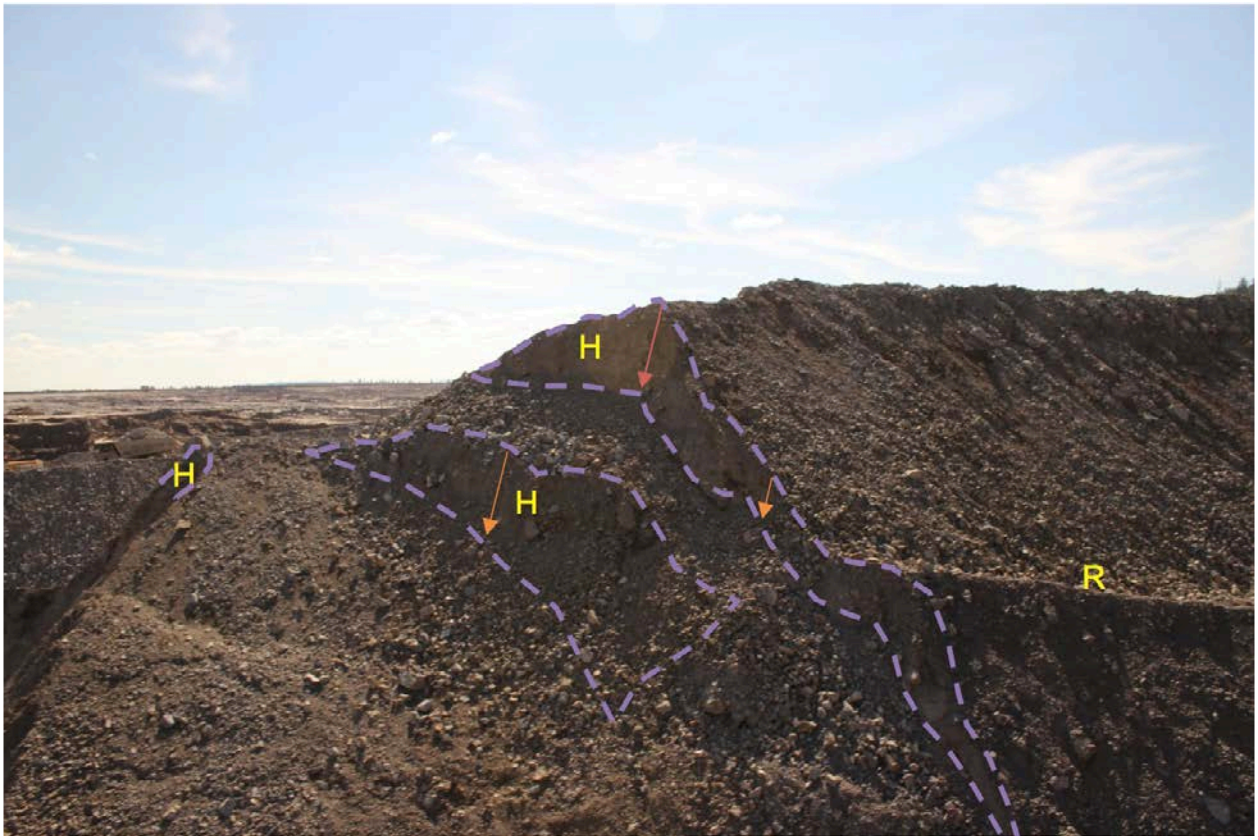


Figure C3.5.5 is a close-up of the upper scarp just above the remnant haul road. At this location, the scarp was measured as 1.7 m high.

FIGURE C3.5.5: CLOSE-UP OF THE UPPER SCARP JUST ABOVE THE REMNANT HAUL ROAD (SEPT. 4, 2014 PHOTO)

Figure C3.5.6 is an overall view looking west across the breach showing the linear whaleback (W), the head scarps on both abutments (H), and surface erosion rills on the displaced right abutment fill (D).

FIGURE C3.5.6: VIEW LOOKING WEST ACROSS THE BREACH

Figure C3.5.7 is a view looking west at the area to the right of the breach. The photo shows another former haul road (R) used to gain access to the crest. The low area on the access road below it that contained ponded water in the Cariboo video a month earlier is nearly dry. Toe bulging and lateral displacement of the right side of the breach can be seen in the area of L.

FIGURE C3.5.7: VIEW LOOKING WEST OF THE AREA TO THE RIGHT SIDE OF THE BREACH (SEPT. 4, 2014 PHOTO)

Figure C3.5.8 is a closer view looking west at the details of the right abutment. The toe bulging and lateral diplacement of the right side of the breach can be seen at the toe of the slope near L. The orange arrows indicate the location and direction of upward thrusting. The estimated maximum vertical displacement at this location is about 3.5 m.

FIGURE C3.5.8: VIEW LOOKING WEST SHOWING DETAILS OF THE RIGHT SIDE OF THE BREACH (SEPT. 4, 2014 PHOTO)

Figure C3.5.9 is a close-up of the upthrusted foundation till blocks and related scarps on the right side of the breach. The large till block (L) can be seen to contain layers of organic material, indicating its original orientation. Its current orientation is consistent with the outer limb of an anticlinal structure. The reverse dip of layering and lamination in the companion block (long arrow) shows it to be consistent with the inner anticlinal limb.

The orange arrows align with the linear whaleback feature (W) in the distance. Hence, the whaleback appears to be a partially eroded product of similar upthrusting to that shown in Figure C3.5.9.

FIGURE C3.5.9: CLOSE-UP OF UPTHRUSTED TILL BLOCKS (SEPT. 4, 2014 PHOTO)

Figure C3.5.10 is a plan view of the right abutment that provides an estimate of the amount of lateral translation on the right side of the breach. Using the rockfill berm along the access road as a reference, an estimated translation of about 11 m has been measured from the figure.

FIGURE C3.5.10: PLAN VIEW OF THE RIGHT ABUTMENT SHOWING INTERPRETED LATERAL TRANSLATION

The photo of the upstream side of the right abutment in **Figure C3.5.11** shows the remnant till core (S) exposed at three locations and the sub-horizontal layering of the downstream rockfill shell (C). Two areas of observed seepage (M) near the base of the upstream side of the dam are also shown. These are thought to be from the upstream toe drain. The fill berm consisting of mixed till and organics (X) along the access road consists of materials stripped from the access road foundation.

The dashed line indicates the approximate area on the right abutment that was subject to overflow erosion during breach development. This erosion occurred very early in the breach development, prior to, or concurrent with sliding displacement, as indicated by the intact cross-cutting scarps at the head and thrust features at the toe of the affected area.

FIGURE C3.5.11: VIEW LOOKING AT RIGHT ABUTMENT OF BREACH (SEPT. 4, 2014 PHOTO)

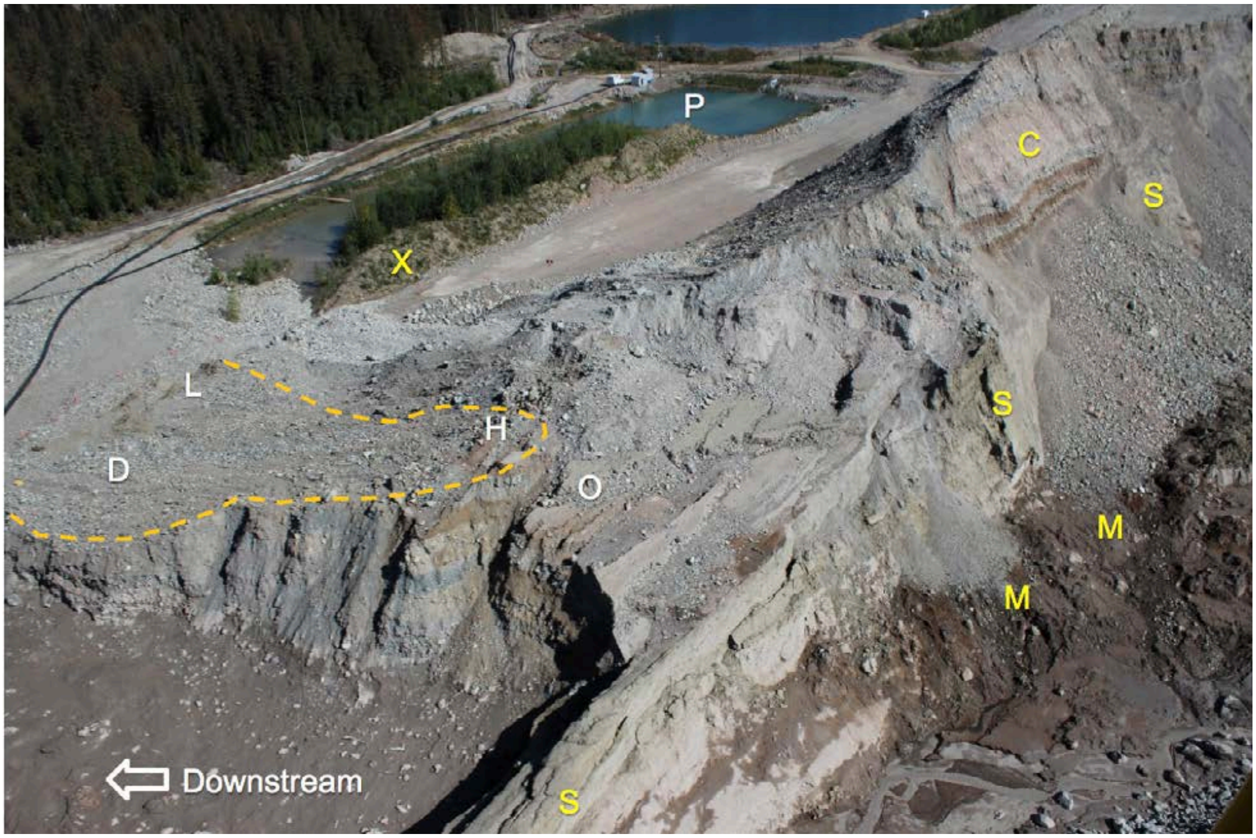


Figure C3.5.12 is a view of the upstream side of the dam to the right of the breach that shows the remnant till core (S), the sub-horizontal layering of the downstream rock fill shell (C) and the select upstream tailings fill (U). The location of the Perimeter Embankment seepage collection pond (P) is indicated, with its return-water pipeline crossing the crest in the distance. The tailings distribution pipeline (Q) originally extended along the upstream side of the crest and was not in service at the time of the breach. The area of upstream toe drain seepage is shown at M. The continuous scarps along the upstream crest of the dam are the result of slope failures caused by removal of supporting tailings during the breach.

FIGURE C3.5.12: VIEW OF THE UPSTREAM SIDE TO THE RIGHT OF THE BREACH (SEPT. 4, 2014 PHOTO)

Figure C3.5.13 is a view of the upstream side of the left abutment that shows exposed native till at the base of the dam, the remaining remnant core (S), and the sub-horizontal bedding in the downstream rockfill shell (C). Zones of seepage were observed at M. A sub-horizontal void was observed within the remnant till core at Location V on the upstream side of the left abutment at El. 936.7 m corresponding to the crest of Stage 2B.

FIGURE C3.5.13: VIEW OF THE UPSTREAM SIDE OF THE LEFT ABUTMENT OF THE BREACH (SEPT. 26, 2014 PHOTO)

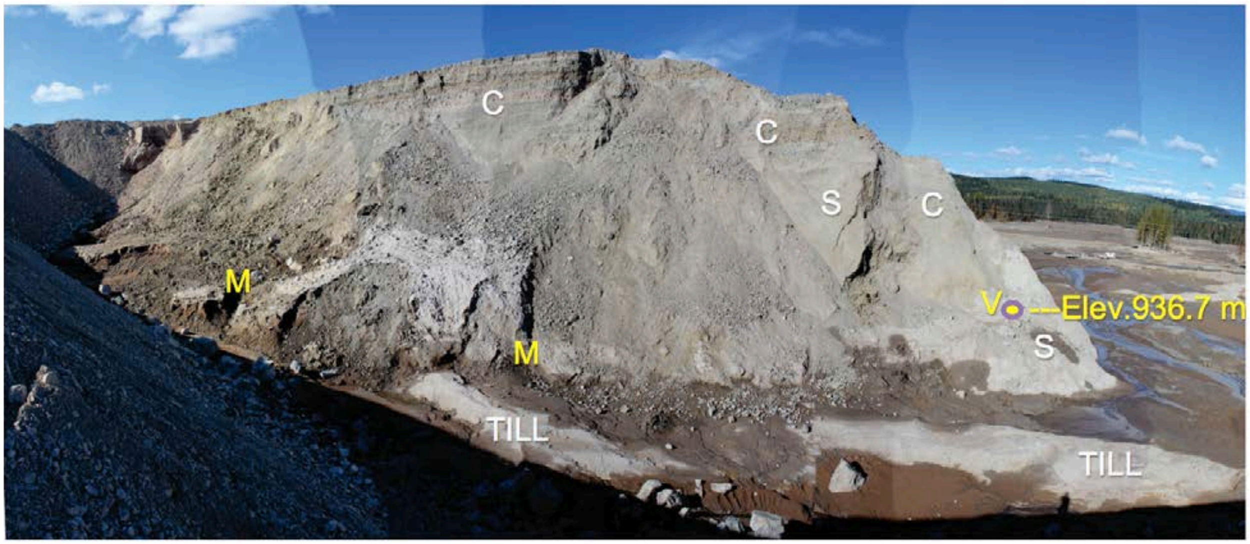


Figure C3.5.14 shows a closer view of the void. Its dimensions were measured at 0.7 m high, 0.3 m wide and 1.1 m deep. The inside surface was covered with a cake of fine sand tailings. The origin and implications of the void are further treated in section 4.3.

FIGURE C3.5.14: VOID ON THE UPSTREAM SIDE OF THE LEFT ABUTMENT (SEPT. 26, 2014 PHOTO)

Figure C3.5.15 shows the linear, ridge-like whaleback feature (W) located near the downstream toe of the dam. It is comprised of dense native till and has a steep downstream face up to 2.8 m high with a shallowly-dipping upstream side. It is attributed to upthrusting (vertical arrows) of foundation till. The smooth and rounded surface of the whaleback is characteristic of both native and compacted till subjected to erosional breach flows throughout the area. Its signature appearance in this figure gives rise to the nomenclature used to describe it.

FIGURE C3.5.15: VIEW OF THE TILL WHALEBACK RIDGE LOOKING SOUTHEAST (SEPT. 4, 2014 PHOTO)

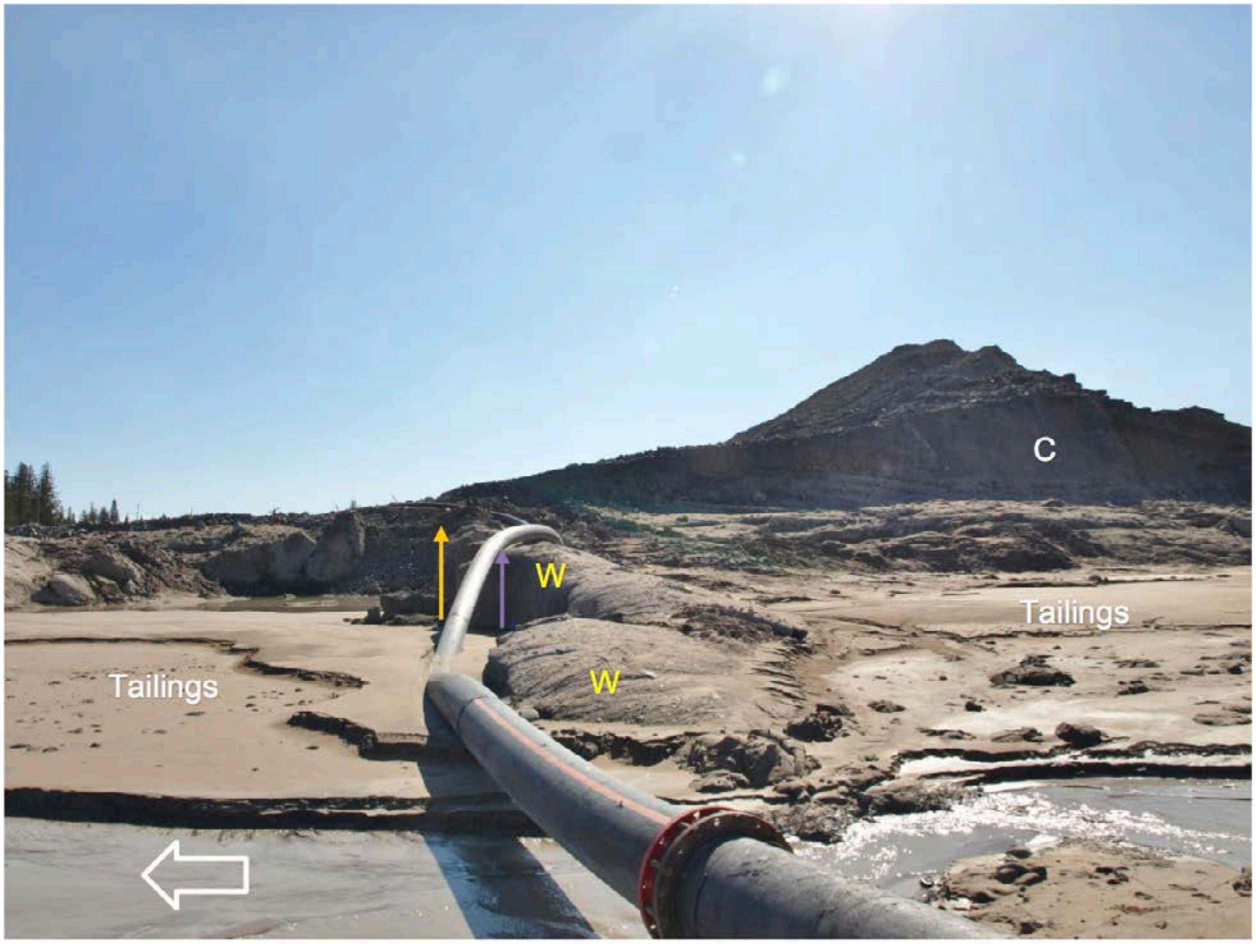


Figure C3.5.16 shows the whaleback (W) near the downstream toe of the right abutment. Here the arrows indicate upthrust of up to 2.8 m.

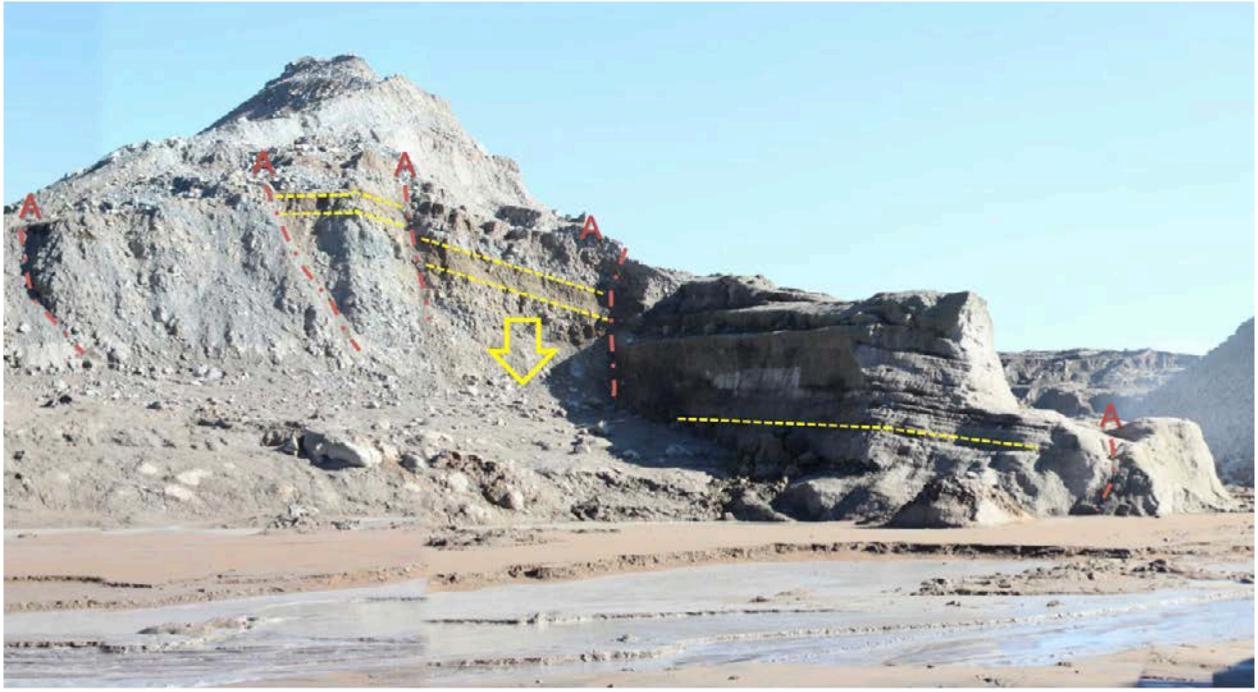
FIGURE C3.5.16: VIEW OF THE LINEAR TILL RIDGE (WHALEBACK) LOOKING SOUTH (SEPT. 4, 2014 PHOTO)

Figure C3.5.17 shows a close-up of one of the till blocks eroded from the dam core and deposited during the breach. The locations of these blocks can be seen on **Figure C3.5.1** (location J). Note the driftwood located on the toe of the dam slope that provides an indication of the water level during the breach. Transport of till blocks in motion can also be seen in the Cariboo video. Their mobility can be attributed in part to the bouyancy provided by the high-density mixture of fluid tailings and water that carried them.

FIGURE C3.5.17: TILL BLOCK INTERPRETED TO BE ERODED FROM THE DAM CORE (SEPT. 4, 2014 PHOTO).

Figure C3.5.18 shows a more detailed view of the right abutment. The yellow dashed lines indicate selected traces of observed bedding from construction lift lines. The orange dashed lines (A) indicate shear features where bedding was offset. The yellow arrow indicates a downdropped graben associated with horizontal movements. Features in this area are described in more detail in section 3.6.

FIGURE C3.5.18: DETAILED VIEW OF RIGHT ABUTMENT SHOWING "GRABEN" FEATURE (SEPT. 4, 2014 PHOTO)



3.6 DETAILED FIELD MAPPING

Initial field mapping in the area of the breach was conducted on September 11 and 12, 2014. At that time, access was limited to zones deemed safe. Additional mapping was conducted on September 25 and 26, 2014 when some additional areas upstream of the core were accessible.

The mapping attempted to identify marker beds that could indicate areas of deformation and shearing. Some potential marker beds were visually identified within the rockfill shell. However, the beds could not be accessed for detailed inspection due to the presence of steep, unstable slopes.

3.6.1 Site Plan

A site plan map was developed from the post breach LiDAR conducted the day after the breach on August 5, 2014. The plan was constructed on a series of digitally superimposed data layers. The attached Drawing C1 shows the plan with all of the data layers turned on, including the Setting Out Line (S.O.L.) and the stationing along it. The various drawing layers are shown on the left hand side of the PDF figure and can be toggled on or off as required.

Features mapped and indicated on the plan (Drawing C1) include:

- Till core remnant (S)
- Rockfill shell (C)
- Area of disturbed rockfill (D)
- Upstream select fill (U)
- Dense native till exposures
- Till core blocks
- Organic till (fill) exposures
- Rounded gravel layer
- Shear features, scarps and cracks
- Near vertical till faces
- Areas of slope bulging, seepage areas
- Possible spring discharge area
- Void in remnant core
- Excavated pit and stockpile area
- Seepage collection pond
- Woody debris depositional area

Areas covered by tailings or recent colluvium are not labelled.

Areas of significant note on the plan include:

- the ridge-like whaleback exposures of native till parallel to the dam axis;
- the native till exposure with organics noted near the toe of disturbed rockfill on the right abutment;
- numerous till core blocks located at the base of the left abutment; and
- several scarps, shears and cracks.

A total of 13 soils samples (Sa #1 to Sa #13) were collected by hand using a rock hammer and small shovel from various exposures during the mapping program on September 11 and 12, 2014. The locations of the soil samples and the results of laboratory index testing are shown in the upper right corner of Drawing C1. These results are also tabulated in Attachment C1 to this Appendix.

3.6.2 Right Abutment Cross-Section

Drawing C2 shows a cross-section through the right abutment of the breach near S.O.L. Station (Sta.) 4+200. For diagrammatic purposes, field mapping notations are shown on oblique panoramic photos that have been stitched together. The composite photograph is not to scale and should not be used for measuring purposes. Pre- and post-breach ground profiles at Sta. 4+175 are shown for reference on the cross-section.

Locations of dense till were mapped below the rockfill shell on the right abutment near the base of the slope. Dense till was also observed to form the ridge-like whaleback feature running approximately parallel to the dam axis just beyond the original toe of the dam (lower left corner of Drawing C2).

The drawing indicates dip measurements (5° to 14°) on marker beds (M1 and M2) that were measured in the field using a handheld CLAR compass. Some of these beds were displaced by steeply dipping shear features near the remnant core of the dam. A graben-type feature was interpreted immediately downstream of the till core.

The lower portion of the rockfill slope was mapped as disturbed (D) since it appeared that the material is now located downstream of the toe of the original dam.

The remnant core of the dam (S) shows signs of layering, with a measured dip angle of 9°. Some sub-vertical cracks were also observed.

Drawing C3 is the same as Drawing C2 except that the composite as-built dam construction zoning has been superimposed onto the cross-section. As explained in section 3.1, embankment zones up to Stage 6B (approximate El. 958 m) are based on as-built details at Section G. Embankment zones above Stage 6B are based on as-built details at Section D.

3.6.3 Left Abutment Cross-Section

Drawing C4 shows a cross-section through the left abutment of the breach near Sta. 4+320. As with Drawing C2, field mapping observations are shown over panoramic photographs that have been stitched together. Neither is this photograph to scale, nor should it be used for measuring purposes. Pre- and post-breach ground profiles at Sta. 4+320 are shown on the cross-section. A layer of rounded gravel was observed at the base of the right abutment (see Sa #8).

The drawing indicates dip measurements on rockfill layers taken using a handheld CLAR compass. A series of parallel (en echelon) scarps oriented perpendicular to the dam axis were mapped on the upper slope of the left abutment.

A near-circular pit that is reported to have been excavated by the Mine is located on the downstream side of the left embankment near El. 948 m (not visible). This is an area where an old haul road ramp up the downstream shell of the dam was previously constructed (see Drawing C1). Other features include a moist sand layer in the downstream shell and the sub-horizontal void located on the upstream side of the remnant core. Drawing C5 is the same as Drawing C4 except that the interpreted as-built dam construction zoning has been superimposed onto the cross-section.

3.6.4 Upstream Profiles

The oversteepened upstream scarps on both abutments could not be accessed due to safety concerns. These areas exhibit extensive displacement due to tailings erosion and loss of support during the breach. **Figures C3.5.11** and **C3.5.12** show the stratigraphy of the right side, and **Figure C3.5.13** shows the left side. The void on the upstream side of the left abutment is shown on **Figures C3.5.13** and **C3.5.14**.

As described in section 4.4, collapse of the upstream slopes occurred during the later stages of breach development as eroded areas of tailings expanded. Section 4.5.2 describes this process and illustrates its progression from the Cariboo video. **Figures C4.5.3** and **C4.5.4** provide panoramic views of the upstream side of the dam.

3.7 REMNANT CORE EXCAVATION AND MAPPING

The remnant core on the right abutment was previously shown in **Figure C3.3.4**. Excavation of the remnant core was conducted on November 5 to 12, 2014 to investigate the nature and extent of a shear surface identified by surface mapping. The excavation was carried out with a large excavator operated by Mount Polley Mine personnel and carried out in slices (about 1 m to 2 m thick) to better detect any anomalous features and allow detailed stratigraphy to be determined.

Figure C3.7.1 shows the remnant core on the right abutment prior to excavation. Indicated are the remnant till core (S), rockfill shell (C), filter (F), open cracks (O), and the surface expression of the shear surface (A). Zone B fill, described in the specifications as "glacial till, glaciolacustrine, or granular material," may also be present on the downstream side of the core (left in photo), but could not be readily distinguished from Zone S in the field.

FIGURE C3.7.1: REMNANT TILL CORE PRIOR TO ACCESS ROAD CONSTRUCTION AND EXCAVATION ACTIVITIES

Excavation work was carried out in two phases, upper and lower. The upper phase involved excavating the portion of the remnant core from approximate El. 934.5 m to 940.5 m. For safety purposes, the slices were completed at a 45° angle (1H:1V). The upper phase consisted of 22 slices (numbered 1-22) and the lower phase consisted of 19 slices (23-41) for a total of 41 slices.

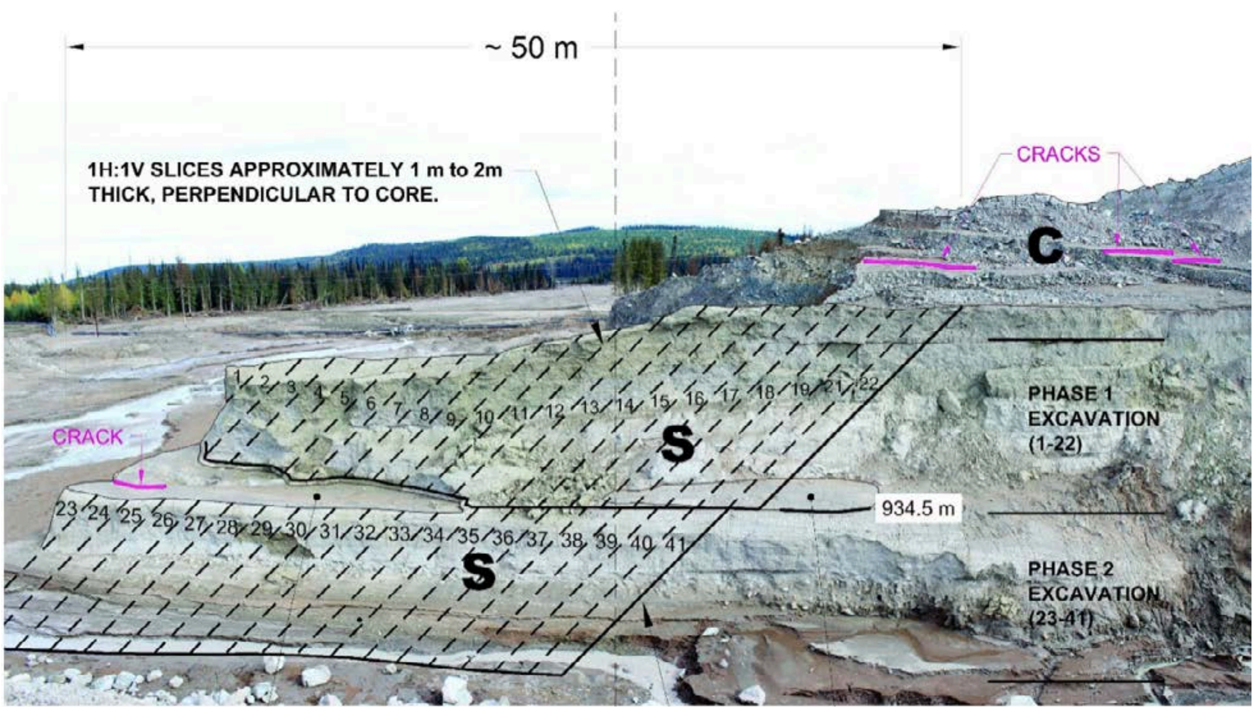
The elevations of the upper phase excavation correspond to the pre-failure Stages 2A, 2B, and 2C of the dam. The lower phase corresponds to the original Stage 1B.

As-built drawings show that Zone B fill was originally present on the downstream side of the Zone S core in Stages 2A and 2B from El. 934 to 937.[5] Zone F was added to the downstream slope of Stage 2 during construction of Stage 3.

As-built drawings also show that Zone B fill was placed on the upstream side of the core for Stage 2C. After its completion, a zone of cycloned sand tailings (Zone CS) was placed on the upstream side of Stage 2C above El. 938.[6]

Figure C3.7.2 shows the excavation sequence diagramatically. The base of the lower phase of the excavation was nominally set at El. 930 m, but some test pits within the excavation extended as deep as El. 925.5 m.

FIGURE C3.7.2: DIAGRAMATIC CROSS-SECTION OF EXCAVATION SLICES THROUGH THE REMNANT TILL CORE



[5] MP10032
[6] MP00072

Figure C3.7.3 presents a section of typical excavation of the upper phase (Slice 16). This photo shows the remnant till core (S), the filter (F), rockfill shell (C) and a pocket of medium-grained, uniformly-graded sand (N). The Zone F material is located at the upper downstream (left in the photo) side of the slice and overlies the till core at the crest of the cut. The Zone C rockfill is visible in the background, but is not contained or exposed in the slice.

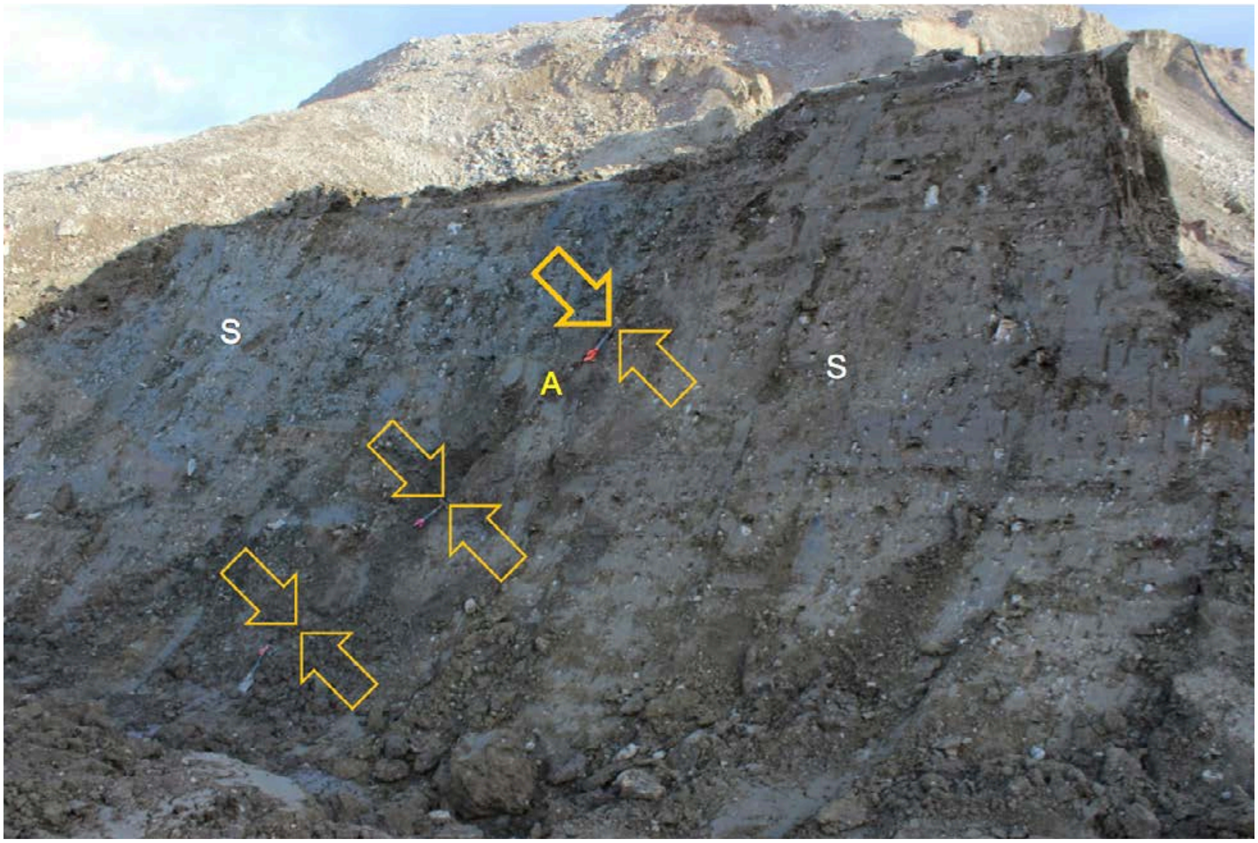
Samples of till core were collected near the Zone S label shown in Figure C3.7.3 in Slices 4, 6, 9, 14 and 20. Samples were collected near the Zone F label in Slices 14, 18 and 20.

FIGURE C3.7.3 TYPICAL FACE IN UPPER PHASE OF SLICE EXCAVATIONS (SLICE 16)

The sand identified as N in the figure has a reddish colour and was observed in slices 5 through 22, except for Slices 10 and 11, in the upper phase of the excavation. In the lower phase, sand-filled cracks were occasionally observed near the top of cut on the downstream side of the shear. Larger sand pockets were observed in Slices 35, 38 and 41 corresponding to the sand zone in the upper slices. In all cases, the sand was present only downstream of the shear surface. Properties of the sand and its possible origin are discussed in Attachment C1.

The second phase involved excavating the lower portion of the remnant core from approximate El. 929.5 m to 934 m. **Figure C3.7.4** shows a typical section of the lower phase (Slice 28). A diagonal shear surface was encountered during excavation of the lower phase (A). The surface was delineated by mapping and surveying of each slice during the excavation. Samples of till core were collected near the downstream (left) and also the upstream (right) side of the shear, corresponding approximately to the Zone S labels shown in **Figure C3.7.4** in Slices 27 and 31.

FIGURE C3.7.4: TYPICAL FACE IN UPPER PHASE OF SLICE EXCAVATIONS (SLICE 28)



Although its geometry was quite consistent, the nature of the shear varied considerably between the slices. Materials ranged from thin (<10 mm wide) zones of softened till with a colour contact from grey to brown, to wet zones up to 1 m wide containing very soft till, red sand, and light brown angular gravel.

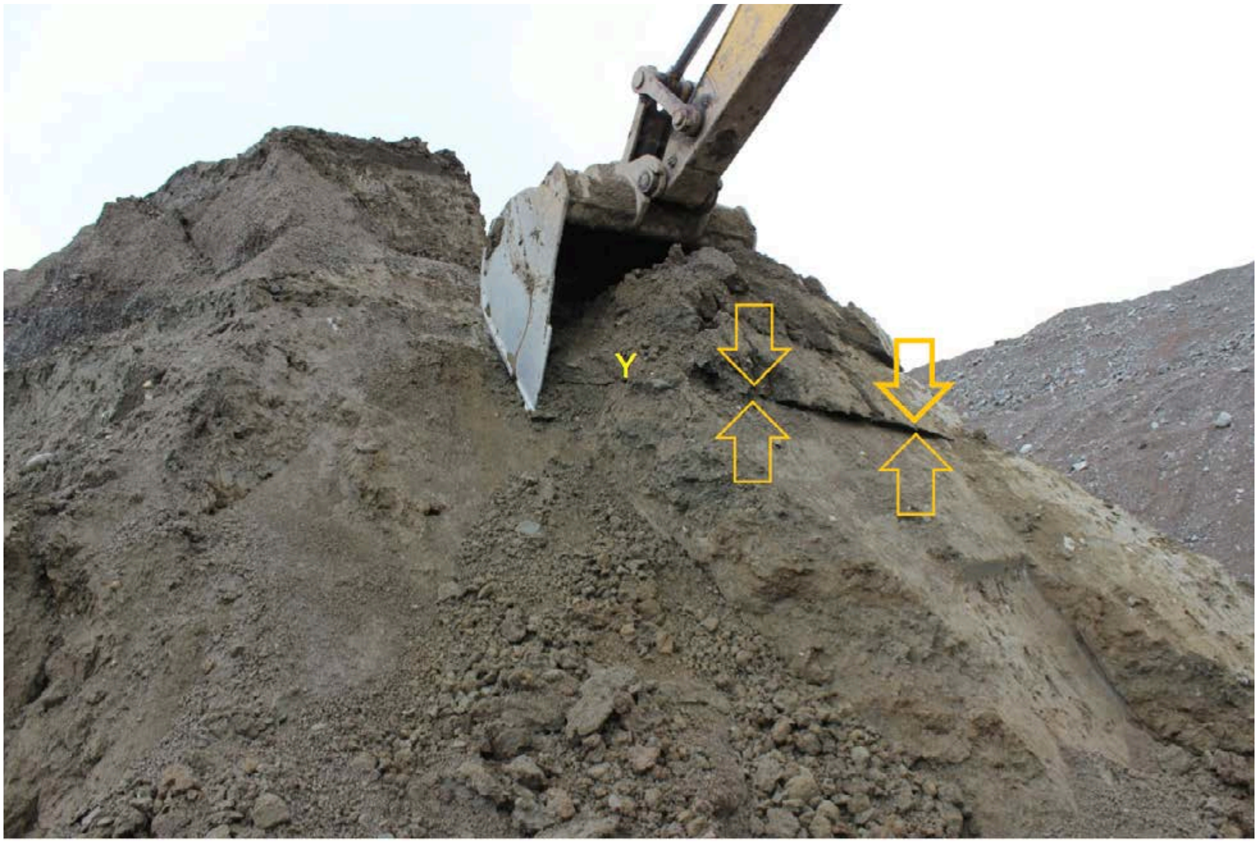
Due to this variability, the appearance, strength, and nature of the shear are difficult to generalize. **Figure C3.7.5** shows a close-up of the shear in Slice 23 with a 330 mm long rock hammer shown for scale. The upper right of the photo shows red sand deposits in the shear and the lower left side shows light brown angular gravel. The shear varies in the photo from about 50 mm to about 150 mm wide (orange arrows).

FIGURE C3.7.5: SHEAR SURFACE IN SLICE 23

In some locations, the base of the shear contained free water. Slices 23 and 24 exhibited approximately 2 litres per minute water flow out of the base of shear. The flowing water also washed fine, red-coloured sand out of the shear and deposited it at the base of the excavation.

Figure C3.7.6 shows smooth planes (Y) associated with interfaces of fill lifts placed during construction. The surfaces were observed to dip upstream with an apparent dip of between about 5° to 20°. Where possible, the dip/dip direction was measured using a Brunton Geological Compass. The range of true dips is 6° to 25° and the range of dip directions is 197° to 300°. A total of 24 apparent dip measurements and 16 dip/dip direction measurements were collected. The average apparent dip is 15° and the average dip/dip direction is 16°/253°.

FIGURE C3.7.6: SLICE 16 DURING EXCAVATION SHOWING THE TILL CORE SEPARATING ALONG CONSTRUCTION LIFT JOINTS



Figures C3.7.7 and C3.7.8 show Slice 25 where a block of material slid out along the shear surface (A) during removal.

FIGURE 3.7.7: VIEW OF SLICE 25 WHEN A BLOCK OF TILL CORE SLID OUT ALONG THE SHEAR PLANE TO REVEAL A LARGE PORTION OF THE SHEAR

The surface of the shear (A) in this location (Slice 25) was coated with reddish coloured uniformly-graded sand.

FIGURE C3.7.8: SHEAR SURFACE IN SLICE 25 AFTER REMOVAL OF THE TILL CORE BLOCK

During the excavation of Slice 26 (lower phase) an open crack (O) that measured 700 mm long, 40 mm wide and 300 mm deep was encountered. **Figure C3.7.9** shows the crack during excavation. Upon the completion of the excavation, the crack was fully removed and not observed to continue in the remaining slices (27 to 41). The surfaces of this discontinuous crack were not softened or otherwise suggestive of hydraulic fracturing. It is believed to be a localized stress-relief feature induced by removal of supporting material during or after breach development.

FIGURE C3.7.9: OPEN CRACK ENCOUNTERED DURING EXCAVATION OF SLICE 26

Observations of the construction surface planes (Y) were less prevalent during the lower phase excavation, especially on the upstream side of the shear. One example of a plane on the upstream side of the shear is shown in **Figure C3.7.10**. The plane is horizontal, in contrast to the dipping planes (average 15°) observed on the downstream side of the shear.

FIGURE C3.7.10: HORIZONTAL CONSTRUCTION PLANE EXPOSED DURING EXCAVATION OF SLICE 28

Figure C3.7.11 shows a marker bed (Z), the shear surface (A) and the till core (S). The marker bed was observed to be a dipping plane in Slices 23 to 30 and curved in Slices 31 to 41. Although the marker bed was clearly visible on the downstream side of the shear, no matching marker bed was observed on the upstream side. Accordingly, relative displacement across the shear is greater than 3.3 m from field measurements.

FIGURE C3.7.11: SLICE 31 SHOWING THE SHEAR (A), TILL CORE (S) AND A MARKER BED (Z) MAPPED IN THE LOWER PHASE OF SLICES

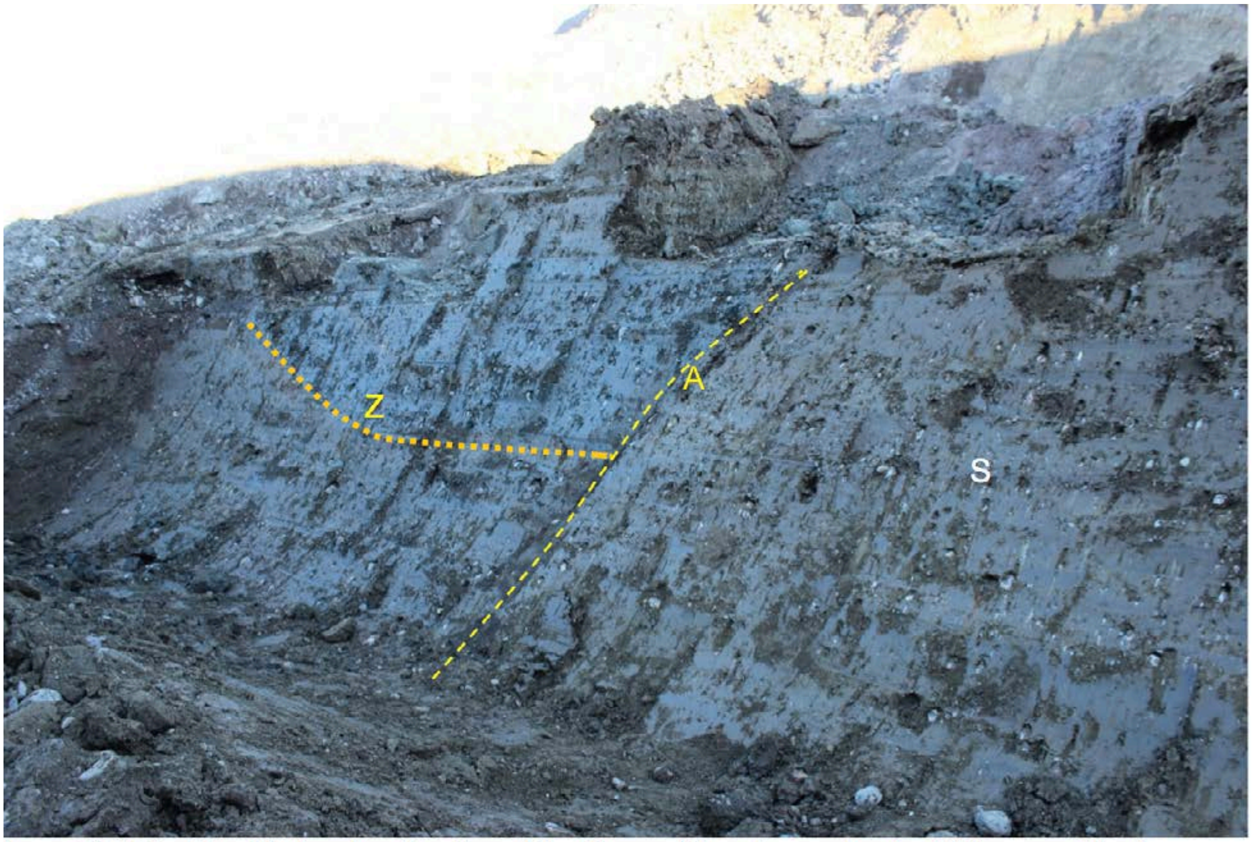


Figure C3.7.12 is a test pit excavated at the base of Slice 39. Shear (A) is expressed in the cut faces as a soft disturbed zone across the base of the excavation at approximately El. 925.5 m. The contact between the till core fill and the lower native till is difficult to definitively identify. The mottled colouring of the downstream (left) side of the shear suggests an origin as compacted core, with the more uniform upstream side better resembling native till. Observations on the upstream side of the shear indicate that the native till contact is likely in the range of El. 929.5 m to 930.5 m.

FIGURE C3.7.12: TEST PIT EXCAVATED IN SLICE 39 SHOWING SHEAR PLANE (A)

During the excavation process, grab samples were collected periodically for grain size analysis and Atterberg limits where applicable. Sample locations and general material types are presented in **Table C3.7.1**.

TABLE C3.7.1: CORE EXCAVATION GRAB SAMPLES

SAMPLE	TYPE	ZONE	NORTHING* (m)	EASTING* (m)	ELEVATION* (m)
SLICE 4	Till Core	S	595,100.99	5,819,894.69	935.16
SLICE 6	Till Core	S	595,099.25	5,819,891.73	933.84
SLICE 9	Till Core	S	595,106.75	5,819,889.91	935.29
SLICE 14	Crushed Sand and Gravel	F	595,115.89	5,819,884.01	940.14
SLICE 14	Till Core	S	595,114.19	5,819,884.65	936.73
SLICE 18	Crushed Sand and Gravel	F	595,120.90	5,819,881.05	940.35
SLICE 18	Sand	N/A	595,111.80	5,819,881.27	933.93
SLICE 20	Till Core	S	595,122.27	5,819,879.32	937.33
SLICE 20	Crushed Sand and Gravel	F	595,124.86	5,819,877.85	941.20
SLICE 24	Gravel	N/A	595,091.65	5,819,897.78	930.13
SLICE 27	Till Core	S (U/S of Shear)	595,097.55	5,819,896.02	930.99
SLICE 27	Till Core	S (D/S of Shear)	595,093.75	5,819,892.48	930.93
SLICE 31	Till Core	S (U/S of Shear)	595,096.73	5,819,886.56	931.65
SLICE 31	Till Core	S (D/S of Shear)	595,103.58	5,819,894.22	931.26

*MPMC Dam Grid

Results of laboratory testing on these samples are reported in Attachment C1. Two block samples of material containing the shear surface were also obtained. Details of the block sampling procedures are provided in Attachment C2.

Figure C3.7.13 shows the surveyed trace of the shear surface (A) at the post-breach ground surface in red (dashed where projected). The black contours (1.0 m interval) represent the shear surface itself as measured during excavation. The surveyed points along the plane indicated a relatively constant dip angle of about 47°. The dip direction varied from about 030° to 064° (Mine North) with an average of about 038°. The average orientation of the shear surface (A) is shown in yellow in the figure.

FIGURE C3.7.13: TRACE AND CONTOURS OF SHEAR SURFACE ENCOUNTERED DURING THE EXCAVATION

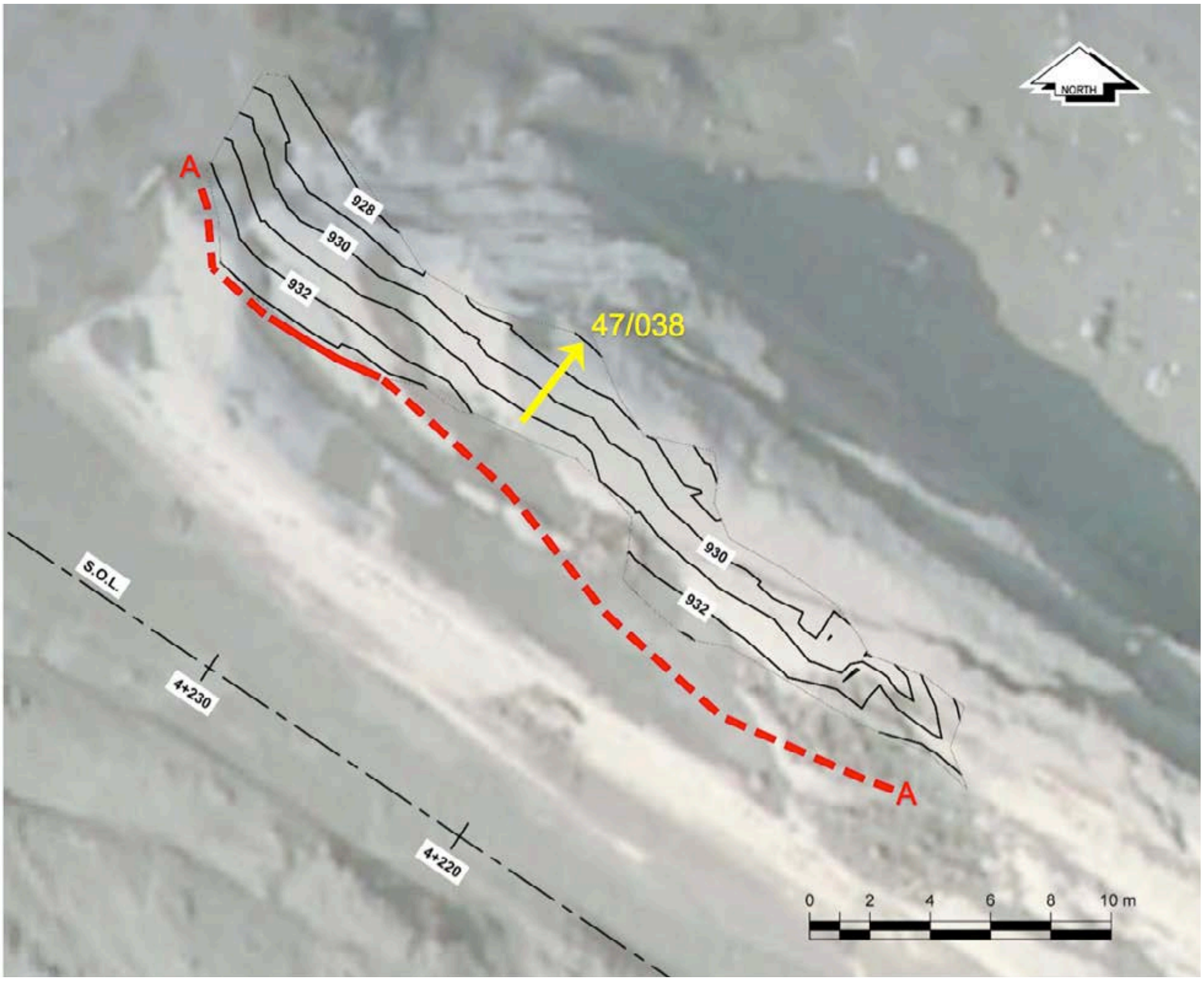
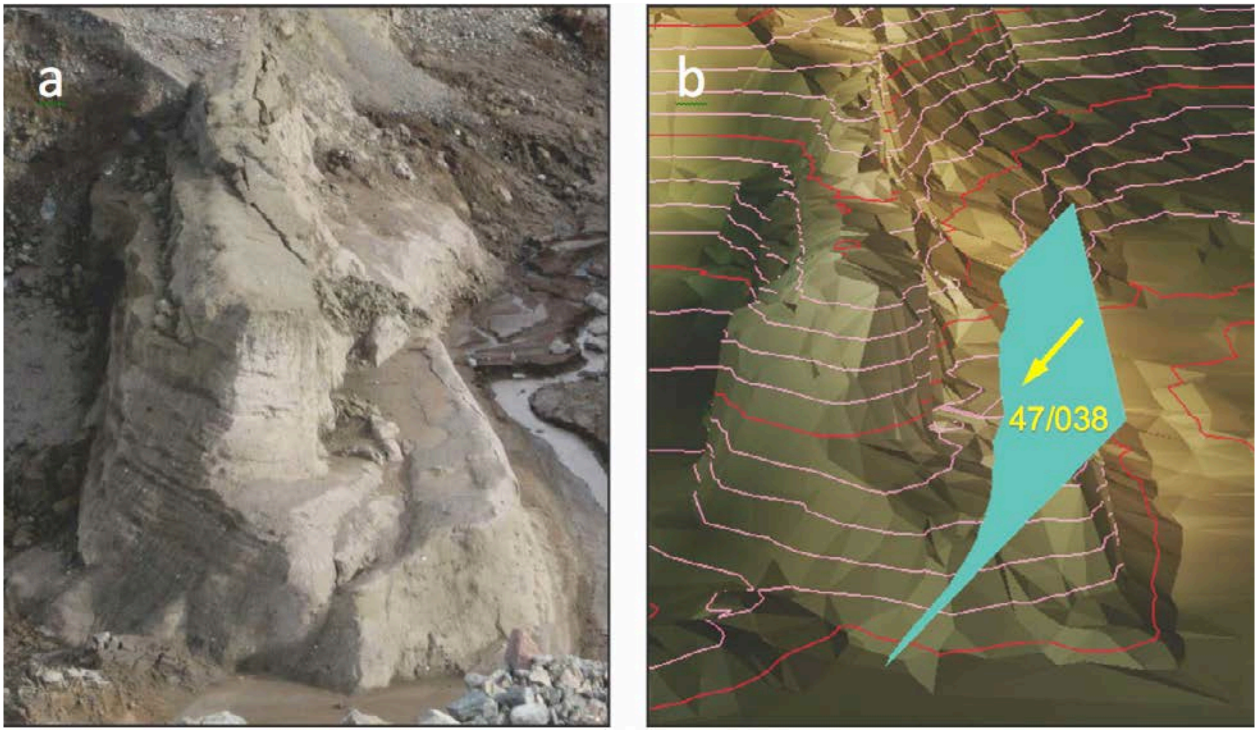


Figure C3.7.14a shows a photograph of the remnant till core of the right abutment. **C3.7.14b** is an isometric surface model with LiDAR-generated contours showing the three-dimensional orientation of the shear surface (47/038).

FIGURE C3.7.14: PHOTO (a) AND SURFACE MODEL (b) SHOWING SHEAR SURFACE ORIENTATION



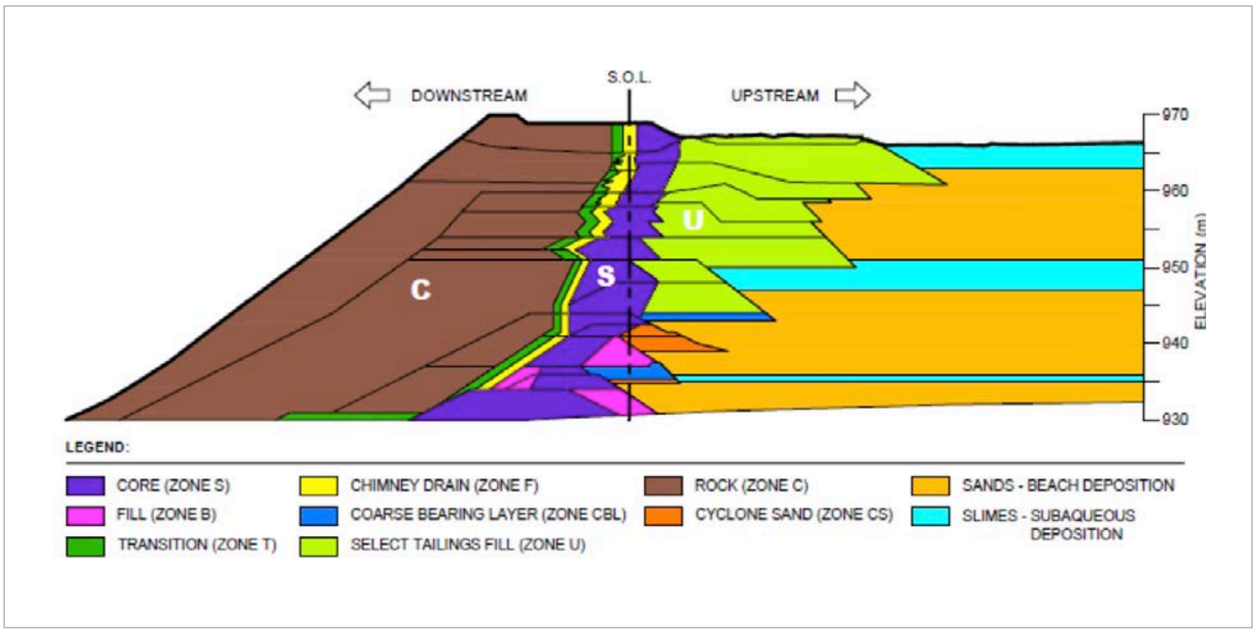
4.0 INTERPRETATION OF GEOLOGIC AND MORPHOLOGIC FEATURES

4.1 RECONSTRUCTED PRE-FAILURE TAILINGS PROFILE

The nature of the deposited tailings that formerly existed at the breach location cannot be determined directly, since they were removed by the failure. Nevertheless, it is possible to make some broad inferences from their mode of deposition. Section 3.2 described review of satellite and other imagery to determine depositional conditions immediately adjacent to the breach section. The results have been reported in **Table C3.2.1** according to image date.

During settling tests, the tailings showed pronounced segregation of their fine and coarse fractions.[7] From this, it would be expected that tailings deposited on above-water beaches would consist predominantly of the sand-size fraction, with the finer fraction (or "slimes") deposited subaqueously in the impounded water. The observed presence in imagery of either water or beach immediately adjacent to the dam can therefore be used to infer whether the tailings were primarily sands or slimes. By relating imagery dates to the dam raising schedule,[8] the corresponding elevations can be estimated. This procedure has been used to reconstruct the idealized tailings profile in **Figure C4.1.1**.

FIGURE C4.1.1: RECONSTRUCTED PRE-FAILURE TAILINGS PROFILE AT BREACH LOCATION



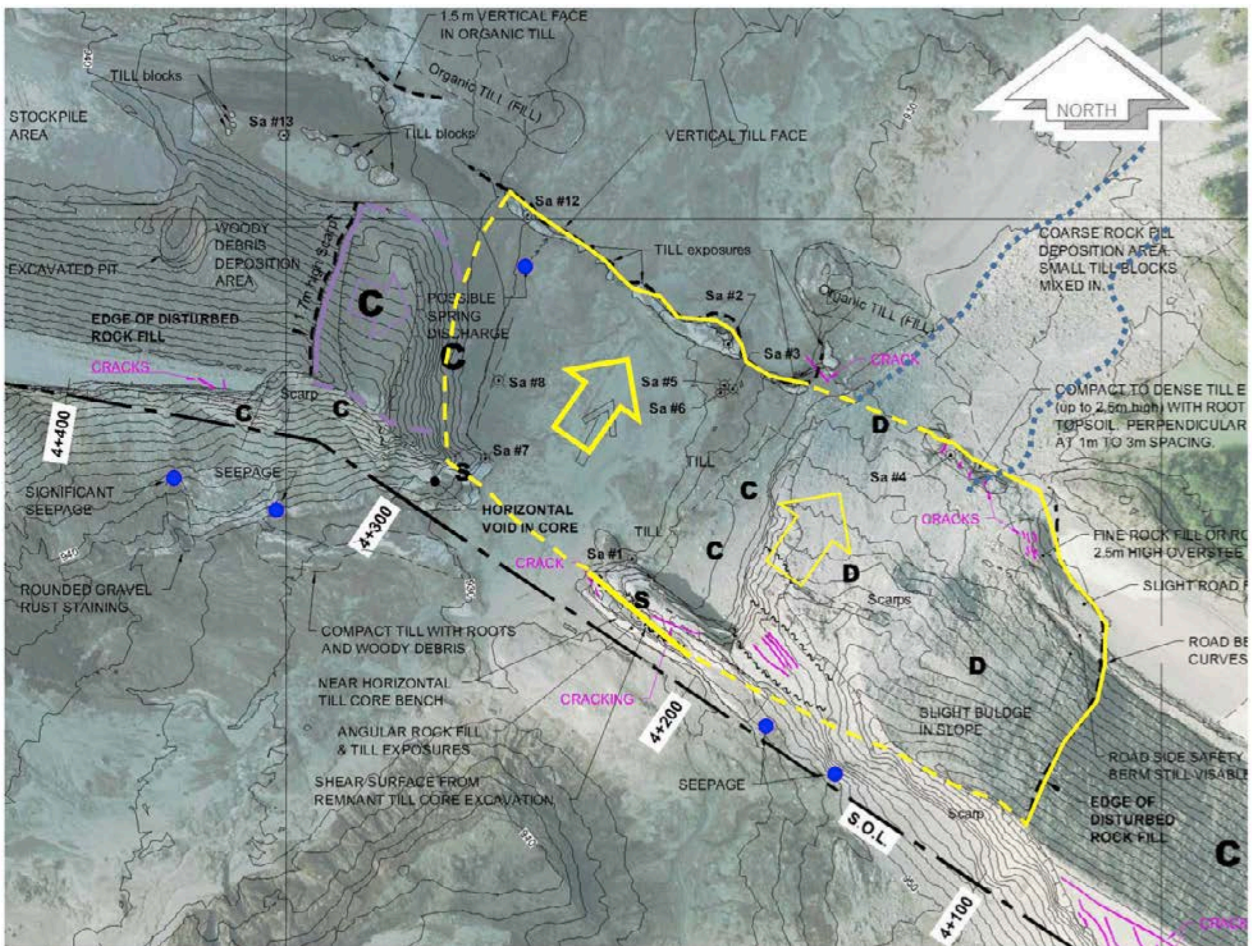
As shown in the figure, sand tailings likely predominated overall, with isolated layers of slimes in the lower, middle, and upper portions of the deposit. This is consistent with the prevailing location of tailings discharge, which was historically concentrated in the vicinity of Corner 1. Pre-failure strength and permeability characteristics typical of sand tailings are therefore likely to have predominated, except for the layers of slimes.

[7] MP00001
[8] MP00208

4.2 SLIDE FEATURES

Geological features observed at the breach site provide direct evidence for shear failure through the dam foundation. These include the well-defined shear surface through the remnant core (entry scarp); the rotated beds of the downstream rockfill shell; the graben feature observed on the right abutment immediately downstream of the till core; and the up-thrusted till blocks and whaleback feature along the toe of the dam. **Figure C4.2.1** shows the interpreted extent of mass movement in yellow. The solid line indicates areas of surface expression, and the dashed line indicates an inferred boundary. The yellow line indicates the boundary of subsidiary displacement into the breach area as a result of erosion and loss of toe support at the left abutment.

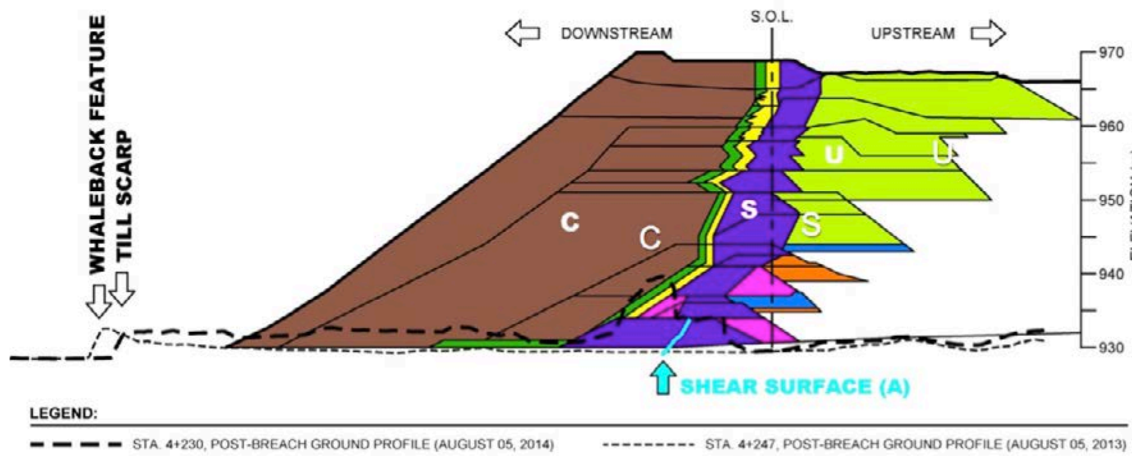
FIGURE C4.2.1: PLAN SHOWING INTERPRETED EXTENTS OF MASS MOVEMENT



The area downstream of the right abutment in Figure C4.2.1 has been modified due to erosion during the breach, and the depositional surface contains coarse rockfill and small till blocks mixed in with tailings. This area is shown as a blue dotted line.

Figure C4.2.2 is a cross-section that shows the location of the mapped shear surface (A) and the whaleback feature in relation to the same composite dam section at the breach location shown previously in **Figure C3.1.4**. The post-breach ground profiles along Sta. 4+230 and Sta. 4+247 are shown with dashed lines.

FIGURE C4.2.2: CROSS-SECTION SHOWING SHEAR SURFACE LOCATION AND WHALEBACK FEATURE



Quantitatively, the magnitude of upthrust observed at the downstream toe whaleback and till scarp is 2.8 m to 3.5 m as shown in **Figures C3.5.8** and **C3.5.16**. Upstream, the amount of downthrow along the shear surface is estimated to be greater than 3.3 m as indicated in **FigureC3.7.11**. Horizontal translation of the right abutment is estimated to be at least 11 m, based on the deflection of the roadside rockfill berm in **Figure C3.5.10**. The parallel orientation of the whaleback to the dam alignment suggests that similar magnitudes of horizontal translation occurred across the entire width of the breach.

Accompanying these displacements is the apparent angular rotation from bedding dip measurements on fill layers and marker beds. These range from 5° to 14° on the right abutment (Drawing C2) and 7° to 10° on the left (Drawing C4).

Displacements are summarized in **Table C4.2.1**.

TABLE C4.2.1 MEASURED OR INFERRED SLIDE DISPLACEMENTS

LOCATION	DISPLACEMENTS AND ORIENTATIONS	
DOWNSTREAM TOE	Vertical: Horizontal:	2.8 to 3.5m upward 11m downstream
UPSTREAM SHEAR SURFACE	Vertical: Entry dip:	>3.3m downward 47 degrees
RIGHT ABUTMENT	Rotation:	5 to 14 degrees
LEFT ABUTMENT	Rotation:	7 to 10 degrees

4.3 INTERNAL EROSION

Several observed features and conditions relate to internal erosion processes. Firstly, a small void was observed at the left abutment (**Figures C3.5.13** and **C3.5.14**) measuring 0.7 m by 0.3 m and extending back 1.1 m into the Zone S core from the exposed face. The angularity and abrupt transitions of the void opening differ from the rounded surfaces and corners formed by surface erosion of the till as displayed, for example, on **Figures C3.5.17** and **C3.7.1**.

Additionally, gradation curves for the three samples of the Zone F filter material on the right abutment are provided in Attachment C1. The gradation data show that none of these samples met filter criteria (i.e., $D_{15} \leq 0.7$mm) that would have enabled them to prevent transport of fines from the till. Together, these factors suggest internal erosion as the likely cause of the left abutment void.

The Zone F samples all exhibit internally unstable gradations.[9, 10] This condition results from a non-uniform distribution of particle sizes in materials containing finer and coarser fractions but deficient in intermediate sizes. If subject to sufficient flow velocity, the fine particles wash through the voids between the coarse particles without being able to serve their filtration function.

However, the Zone F samples still contain their fine fraction, indicating that the filter did not experience large flows during the life of the dam. This, in turn, means that internal erosion of the core at or above the sampled elevation, if it occurred, was not sufficiently severe to have compromised core integrity.

The absence of related features is also significant. Painstaking excavation and thorough logging found no evidence of similar voids in the excavated core. Nor were continuous cracks or softened zones indicative of hydraulic fracturing discovered.

Taken collectively, the evidence is consistent with isolated occurrence or occurrences of internal erosion on the left abutment, but it appears unlikely that internal erosion was pervasive throughout the breach area more generally.

[9] Kenney, T.C., and Lau, D., 1985, Internal stability of granular filters. *Canadian Geotechnical Journal*, v.22, pp. 215-225.

[10] Kenney, T.C., and Lau, D., 1986, Internal stability of granular filters: reply. *Canadian Geotechnical Journa*l, v.23, pp. 420-423

4.4 BREACH DEVELOPMENT

The sequence of breach development provides context for interpreting features observed in the field. The following reconstruction describes in conceptual fashion several key stages in the evolution of post-breach features, starting with the original dam crest in **Figure C4.4.1**.

FIGURE C4.4.1: PRE-BREACH DAM CREST. VIEW LOOKING UPSTREAM (CARIBOO VIDEO AT 11:18)

Section 6 of the main report provides the results of deformation analyses using the PLAXIS computer code. They graphically illustrate how the dam crest subsided and the upthrust whaleback formed during the process of foundation sliding. Taking up where this analysis leaves off, crest subsidence initiated breach development by allowing overflow to begin. In **Figure C4.4.2**, the relic erosional surface on the right abutment is indicative of conditions that prevailed over much of the slide area in the early stage of breach development.

FIGURE C4.4.2: BREACH DEVELOPMENT, FIRST STAGE

Erosional downcutting deepened in the second stage, shown in **Figure C4.4.3**. The dam core, with its highly erosion-resistant compacted till, acted as the control section. Downcutting progressed preferentially on the left side, terminating sheet flow on the right side as the control section became lower.

FIGURE C4.4.3: BREACH DEVELOPMENT, SECOND STAGE

In the third stage, shown in **Figure C4.4.4**, erosion continued to progress on the left side, eventually leaving the projecting core remnant on the right side. This projection acted as a jetty, directing flows still further leftward. On the left abutment, erosional undercutting caused downdrop of the large grabens of dam fill inward toward the breach.

Downstream of the core projection, eddies reduced erosive velocities, preserving much of the remaining rockfill slide mass on the right side. In **Figure C4.4.4**, the linear channel bank extending downstream on the right marks the lateral extent of erosional downcutting in slide debris deposited during initial outflow.

FIGURE C4.4.4 BREACH DEVELOPMENT, THIRD STAGE

In the fourth and final stage, downcutting flows reached a stable base level at the erosion-resistant foundation till. The downstream whaleback in **Figure C4.4.5** became the new control section, acting as a broad-crested weir by the time the Cariboo video was shot. Meanwhile, erosion and mass movement of tailings had removed support for the back (upstream) side of the dam, causing it to collapse far to either side of the breach itself. The resulting headscarp progressed through the crest and into the downstream slope of the remaining dam sections, producing the ridgeline in the final post-breach profile shown in **Figure C4.4.5**.

FIGURE 4.4.5: BREACH DEVELOPMENT, FINAL STAGE

4.5 TAILINGS RELEASE

Throughout breach development, both tailings and water were being released from the impoundment. The operative tailings transport mechanisms can be determined by direct observation in the Cariboo video and by inference from the morphology of the remaining deposits.

4.5.1 Volumetrics

Data obtained from MPMC on impoundment and release volumes are provided in **Table C4.5.1**.

TABLE C4.5.1: REPORTED TAILINGS AND WATER VOLUMES

MATERIAL	PRE-BREACH CONTENTS (million cubic meters)	CONTENTS RELEASED (million cubic meters)
FREE WATER	10.2	10.6
TAILINGS SOLIDS	36.1	7.3
TAILINGS INTERSTITIAL (VOID) WATER	27.2	6.5
TOTAL	**73.5**	**24.41** [a]

[a] Does not include 600,000 m^3 of reported construction debris

The reported data for tailings separate the volume of solids and the volume of interstitial water contained in the voids between the solid particles. These two volumes are combined in **Table C4.5.2** to obtain the bulk volume of the tailings and related properties.

TABLE C4.5.2: BULK TAILINGS AND WATER VOLUMES

MATERIAL/PROPERTY	PRE-BREACH CONTENTS (million cubic meters)	CONTENTS RELEASED (million cubic meters)
FREE WATER	10.6 [b]	10.6
BULK TAILINGS	63.3	13.8
TOTAL	**73.9**	**24.4**
FREE WATER, PERCENT OF TOTAL	14%	43%
FREE WATER/TAILINGS RATIO	0.17	0.77
PERCENT OF CONTENTS RELEASED	-	33%
AVERAGE TAILINGS WATER CONTENT	0.27 [c]	-
AVERAGE TAILINGS VOID RATIO	0.75	-

[b] Adjusted to equal volume of free water released [c] For specific gravity of solids = 2.78

Pertinent observations are as follow:

- Based on total volume released, Mount Polley was among the largest reported tailings dam failures. [11] But due to the large impoundment size, the percentage of contents released was close to average. [12, 13]
- The average void ratio of the tailings prior to release was within the reported range of 0.6 – 0.8 for sand tailings from copper operations. [14]
- At the time of the breach, free water constituted 14% of the total impoundment contents. It was a much larger fraction (43%) of the contents released, with a water-to-tailings ratio of 0.77.

[11] WISE Uranium Project, http://www.wise-uranium.org/mdaf.html

[12] Vick, S.G., 1991, Inundation risk from tailings flow failures, IX Panamerican Conf. on Soil Mechanics and Foundation Engineering, pp. 1137-1158, Sociedad Chilena de Geotecnia, Santiago.

[13] Rico, M., Benito, G. and Diez-Herrero, A., 2007, Floods from tailings dam failures, *Journal Hazardous Materials*, v. 154, no. 1-3, pp. 79-87.

[14] Vick, S.G., 1991, Planning, Design, and Analysis of Tailings Dams, Bi Tech Publishers, Vancouver, 369 p.

4.5.2 Impoundment Landform Morphology

The interior of the post-failure tailings impoundment exhibits features characteristic of natural landforms known as badlands. This is seen in **Figure C4.5.1**, particularly the prominent flat-topped mesa bounded by steep erosion scarps immediately behind the breach. The two major flow channels that converge in front of it attest to the role of fluvial erosion in the formation of this and other features within the impounded tailings.

Badland slope formation is dominated by gully erosion that retreats against the direction of flow. A gully knickpoint, or headcut, is an abrupt break in longitudinal profile of a stream caused by the lowering of its base level by erosion. The headward migration of the knickpoint is always toward the maximum water supply, in this case the surface water in the impoundment. [15] In nature, headward migration will continue until reaching a drainage divide, where the reduced catchment area can no longer supply sufficient water. At Mount Polley, the process continued until available surface water stored in the impoundment was exhausted.

FIGURE C4.5.1: BADLANDS TAILINGS TOPOGRAPHY (CARIBOO VIDEO AT 11:23)

[15] Falk, J.A., Abt, S.R., and Nelson, J.D., 1985, Prediction of gully incision on reclaimed tailings slopes. U.S. Nuclear regulatory Commission, Report no. CER85-86JAF-JDN6, Washington, DC, 76 p.

Figure C4.5.2(a), taken one month after the breach, displays other characteristic morphological features in the Mount Polley tailings, such as dendritic drainages that coalesce at the top of narrow divides.[16, 17] Also notable are the cirque-like arcuate headscarps.

FIGURE C4.5.2: COMPARISON OF POST-BREACH TAILINGS MORPHOLOGIES (a) MT. POLLEY, (b) KOLONTAR, HUNGARY

[16] Schumm, S.A., 1956, Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey, Bull. Geological Soc. of America, v. 67, no. 5, pp. 597-646.

[17] Howard, A.D., 1997, Badland morphology and evolution: interpretation using a simulation model, Earth Surface Processes and Landforms, v. 22, pp. 211-227.

In marked contrast to Mount Polley is the post-breach photo of the Kolontar, Hungary, tailings dam failure in 2010 in Figure C4.5.2(b). It displays features typical of tailings release by flowsliding, with a comparatively uniform, undissected surface in the remaining materials.

The Cariboo video provides a unique opportunity to examine the relative contributions of fluvial erosion and flowsliding in release of the Mount Polley tailings. Seldom have these processes been captured in motion. They are the same geomorphic operations that take place in nature over hundreds or thousands of years, but here took only hours to complete. The Cariboo video began at 8:46am on the morning of August 4, 2014, 7½ hours after the initiation of foundation sliding. By then, the landform was mature but the final stages of its development remained in progress.

Figure C4.5.3, from the Cariboo video, shows two distinct terrace-like erosional surfaces (A). These are confined by arcuate, vertical headscarps like those previously displayed in **Figure C4.5.2(a)**. These headscarps constitute headward-migrating knickpoints for the well-developed surface flows. Also shown is a developing flowslide in motion and its semicircular headscarp in the process of forming (B).

FIGURE C4.5.3: HEADWARD EROSION AND PROGRESSIVE FLOWSLIDING DURING TAILINGS RELEASE (CARIBOO VIDEO AT 13:55)

Figure C4.5.4 is a closer view of the same area that highlights the accompanying fluvial processes. A shallow surface depression on the right (C) is forming by sheet erosion of unconsolidated tailings, enhanced by downward displacement along the developing scarp (D). This depression has captured overland flows emanating from stored impoundment water farther to the right off the image. By the time they reach the semicircular knickpoints, these flows are concentrated into highly erosive cascades (E) that undercut the headscarp and further enhance knickpoint migration.

This is the classic geomorphic process of gully erosion, aided in this case by flowsliding. It continued at Mount Polley, as it does in nature, until the supply of surface water was exhausted.

FIGURE C4.5.4: SURFACE FLOW FEATURES DURING TAILINGS RELEASE (CARIBOO VIDEO AT 12:24)

It is clear from these depictions that the Mount Polley tailings were not released in a single, high-mobility flowslide, as has often been the case elsewhere. Rather, flowsliding acted in concert with fluvial erosion as a subsidiary mechanism in a number of discrete events and locations. It assisted fluvial processes by providing a ready supply of flowslide debris for erosional transport and by producing knickpoints for headward gully migration.

To the extent that fluvial erosion was the dominant tailings transport mechanism, then stored water in the impoundment was central to the volumes released. Beyond its direct contribution to these volumes, this assessment shows how the quantity of water in the impoundment enhanced the extent and duration of gully formation, hence tailings release.

- **Mount Polley 3-D Flyover**

Appendix C: Drawings

- **Drawing C1**: Post-breach Field Mapping – Site Plan
- **Drawing C2**: Right Abutment Field Mapping Notes
- **Drawing C3**: Right Abutment Field Mapping Notes & Zoning at KP Section G (4+300)
- **Drawing C4**: Left Abutment Field Mapping Notes
- **Drawing C5**: Left Abutment Field Mapping Notes & Zoning at KP Section G (4+300)

Appendix C: Attachments

- **Attachment C1**: Laboratory Test Results
- **Attachment C2**: Block Sampling