Abstract The Cheam rock avalanche, which occurred about 5,000 years ago in the lower Fraser Valley, British Columbia, is the largest known catastrophic landslide in western Canada ($175 \times 10^6 \text{ m}^3$). A photo-draped digital elevation model of the rock avalanche reveals two morphologically distinct areas, an eastern area of arcuate hummocky ridges separated by flat-floored depressions and a lower western area with a subdued, gently rolling surface. Debris is up to 30 m thick and consists of rubbly, clast- and matrix-supported diamicton derived from local argillaceous metasedimentary rocks. Failure was probably caused by high pore water pressures on a thrust fault that daylighted in the source area. Plastic deformation of sediment beneath the rock avalanche debris suggests that liquefaction occurred due to undrained loading when the debris struck the Cheam terrace. Liquefaction also explains the morphology and travel distance of the western debris lobe. The coincidence of well-sorted sands (the Popkum Series soil) with the rock avalanche debris indicates that significant amounts of water flowed over the surface of the landslide just after it came to rest. Stó:lō Nation oral history suggests that the debris may have buried a village, causing the first known landslide fatalities in Canada.

Keywords Rock avalanche · Landslide · British Columbia

Introduction

Large ($>10^6 \text{ m}^3$) rock avalanches are infrequent but, because of their size, pose a significant hazard to infrastructure and people in mountain valleys. A case in point is the lower Fraser River valley and contiguous Fraser Canyon of British Columbia, an important transportation and energy corridor that connects Vancouver to the rest of Canada (Fig. 1). The corridor contains the Trans-Canada Highway, two transcontinental rail lines, fibre-optic communication cables, a gas pipeline, and an electrical power transmission line. Identification of slopes that could fail catastrophically in this area is required for accurate hazard assessment and mitigation. Hazard assessment also requires knowledge of the number, age, and size of historic and prehistoric rock avalanches. From these data, the frequency, magnitude, and causes of rock avalanches can be determined.

About 37 prehistoric rock avalanches larger than one million cubic metres were identified during a geomorphic investigation along a 120-km-long section of the corridor extending from Chilliwack to Boston Bar (Fig. 1; Savigny and Clague 1992), but only a few of these have been studied. The early Holocene Lake of the Woods rock avalanche, just north of Hope, extends across the Trans-Canada Highway and has an estimated volume of $20 \times 10^6 \text{ m}^3$ (Naumann 1990). The Katz Slide, west of Hope, is considered to be a product of two separate failures (Naumann 1990), the younger of which produced a debris lobe that covers an area of $1.1 \times 10^6 \text{ m}^2$ and has an estimated volume of $15 \times 10^6 \text{ m}^3$. It is more than 3,500 years old. The historic Hope rock avalanche ($48 \times 10^6 \text{ m}^3$), southeast of Hope, closed Highway 3 for 21 days in January and February 1965 and killed four people (Mathews and McTaggart 1969; 1978). A large landslide in the Fraser Valley or Fraser Canyon, similar to those described above, would have a major impact on the regional economy and would likely claim lives.

The largest prehistoric rock avalanche in the lower Fraser Valley is the Cheam rock avalanche, first identified by Smith (1971) (Figs. 1 and 2). Smith (1971) estimated the deposit to have an area of $7.8 \times 10^6 \text{ m}^2$ and a volume of between $39 \times 10^6 \text{ m}^3$ and $56 \times 10^6 \text{ m}^3$. Naumann (1990), however, estimated the source-area volume to be approximately $150 \times 10^6 \text{ m}^3$, based on pre- and post-slide topography in the source area. He attributed the discrepancy in source-area and deposit volumes to erosion of the toe of the rock avalanche deposit by the Fraser River or to multiple events over a long period. He also noted that a reliable volume estimate depends on correct identification of the areal extent of the debris and the pre-event topography of the source area. Neither of these has yet been accurately determined. Although Naumann (1990) provided the first comprehensive study of the source and depositional areas, the sequence of events during the rock avalanche is not clear from either his or other previous work.

The purpose of this paper is to provide a more detailed interpretation of the Cheam rock avalanche deposit, which may give some insight into the behaviour of large rock avalanches in this part of the lower Fraser Valley. This objective was achieved by combining geomorphologic and new stratigraphic data in a Geographic Information System (GIS). A Digital Elevation Model (DEM) was generated from the GIS to provide a three-dimensional representation of the rock avalanche. We were then able to assess the spatial relationship between the geomorphology and stratigraphy of the rock avalanche deposit.

Study site

The Cheam rock avalanche is located at the southern edge of the Fraser Valley adjacent to the steep slopes of the Cascade Mountains, approximately 125 km east of Vancouver (Figs. 1 and 2). Elevations range from 20 m asl on the Fraser River floodplain bordering the landslide to 2,107 m at Mt. Cheam. The Fraser River has eroded the distal edge of the deposit. Debris flows and snow avalanches are common along steep streams flowing into the river from adjacent mountain slopes (Naumann 1990).

A north- to northwest-trending belt of gneissic and granitic rocks cores the northern Cascade Mountains. The gneiss and granite core is flanked by sedimentary and volcanic rocks that have been metamorphosed to greenschist facies grade (Monger 1966). Bedrock in the vicinity of the Cheam rock avalanche has been assigned by Monger (1966) to the Chilliwack Group and Cultus Formation. The Chilliwack Group is Devonian to Permian.
in age and consists of volcanic arenite, argillite, cherty and argillaceous limestone, conglomerate, and tuff. The Jurassic Cultus Formation unconformably overlies the Chilliwack Group and comprises volcanic arenite, argillite, and slate. Both units are complexly folded, faulted, and jointed. The rocks near Mt. Cheam dip to the northeast.

Episodic ice-sheet and alpine glaciation during the Pleistocene Epoch produced over-steepened slopes, aretes, hanging valleys, and cirques throughout southwestern British Columbia, including the Cascade Mountains. The most recent phase of Pleistocene glaciation, the Fraser Glaciation, began about 30,000 years ago and ended 10,000 years ago (Clague 1981). Southwestern British Columbia was covered by the Cordilleran ice sheet at the peak of the Fraser Glaciation, about 16,000 years ago (Booth et al. 2004), and a remnant lobe of the ice sheet persisted in the eastern Fraser Valley until almost 11,000 years ago. Glaciofluvial gravel and sand were deposited at the margin of this ice lobe at several places in the Fraser Valley, including the site of the Cheam rock avalanche (Armstrong 1981; Naumann 1990).

An evaluation of source area contours indicates the rock avalanche likely originated as an asymmetric wedge failure of about $150 \times 10^6$ m$^3$ volume (Naumann 1990). The head scarp is mantled by rubble and obscured by trees, as are the flanking failure surfaces. Naumann (1990) identified a planar thrust fault surface at the west flank of the source area. Other primary wedge features are joint-controlled. Surface features indicative of deep-seated sagging (sackung) occur on a plateau above the steep east flank of the failure zone. The projected surfaces of the wedge failure intersect along a line that dips 29° on an azimuth of 327°. This azimuth coincides with the centre of the debris lobe on the floor of the Fraser Valley.

Methods
The geomorphology and limits of the Cheam rock avalanche were determined through aerial photograph interpretation, field visits, and the generation of a DEM. The DEM was produced by digitising a 1:5,000-scale topographic map (2-m contour interval) of the landslide area into the ArcMap module of ArcGIS 8.3. Contour lines were converted to 29,000 points, each with known $x$, $y$, and $z$
values, and a surface was generated. Unfortunately, the topographic map excluded the northeastern edge of the rock avalanche deposit, therefore area and volume values derived from the DEM are minima. Two aerial photographs (BC83008–254 and C159255) were geo-referenced and draped over the DEM surface in ArcScene to provide realistic, three-dimensional images of the rock avalanche surface. Topographic detail was maximized by changing vertical exaggeration. The margins of the rock avalanche deposit were delineated and its area calculated directly from the DEM. To calculate the deposit volume, we assumed that the debris in the eastern sector of the deposit rests on a planar surface at 20 m asl and that the debris in the western sector lies on a planar surface at 13 m asl. We further assumed that everything above these planes is rock avalanche debris. The elevations of these surfaces are based on borehole data and limited field observations of the contact of the rock avalanche debris with underlying gravel and sand.

The Cheam rock avalanche deposit and underlying and overlying sediments were examined in gravel pits, road cuts, and backhoe trenches. Supplementary stratigraphic data were obtained from well logs and geotechnical and gravel exploration drill holes. Thirty-seven sections were compiled and entered into a Microsoft Access database. Information in the database includes generalized lithology (e.g., diamicton, sand, silt), unit thickness,
and UTM (Universal Transverse Mercator) co-ordinates. Each geo-referenced section was entered into the DEM as a coded bar to assess the spatial relationship between stratigraphy and surface morphology.

The age of the rock avalanche was estimated from six radiocarbon ages obtained on samples of wood and peat underlying and within the rock avalanche debris. Dating was done at the Geological Survey of Canada Radiocarbon Laboratory, Geochron Laboratories, and the former Simon Fraser University Radiocarbon Laboratory. Approximate calendric ages were calculated from the radiocarbon ages using the program CALIB 4.2.2 (Stuiver et al. 1998).

Results

Geomorphology

The air photograph-draped DEM shows two distinct surfaces associated with the Cheam rock avalanche deposit. The eastern half of the deposit comprises steep-sided (up to 40°), arcuate, hummocky ridges with intervening flat-bottomed depressions (Fig. 2; Smith 1971; Naumann 1990). Some of the ridges rise 60 m above the Fraser River floodplain. The mean elevation of the surface is 44 m asl. The western half of the deposit has a subdued, gently rolling surface with a mean elevation of 23 m asl and a mean slope angle of 1.5° (maximum of 19° at the boundary with the eastern region) (Fig. 2). This surface extends from the higher elevation, eastern region across a low terrace and onto the Fraser River floodplain. By manipulating the DEM, we were able to see that the distal edge of the lower, gently rolling surface terminates abruptly in an arcuate front above the surrounding floodplain.

A drainage anomaly provides further detail on the lower, western part of the Cheam rock avalanche (Fig. 3). A small channel of the Fraser River follows the northwestern margin of the landslide deposit to a point where it abruptly loops to the northwest, south, and then east. The extremely low gradient of the stream (ca. 0.1°) and the absence of other meanders in the area argue that a section of the straight channel was buried by Cheam rock avalanche debris, forcing the stream around the obstruction.
A drill hole inside the meander shows 4 m of rock avalanche debris overlain by 2 m of sandy alluvium.

A small area of subdued, hummocky terrain lies just east of the Cheam rock avalanche deposit. D. Cavers attributed this terrain to a large debris flow named the Popkum Slide (as reported in Savigny and Clague 1992). Its morphology and lithology, however, are similar to those of the western part of the Cheam rock avalanche. Limited excavation into this deposit by Cavers revealed a massive mixture of silt, sand, and gravel. Given the proximity and morphologic similarity of the Popkum Slide to the Cheam rock avalanche, we provisionally consider the two deposits to be products of the same event, rather than two separate events as thought by Cavers.

Size of the landslide

Rock avalanche debris covers an area of about 10×10⁶ m², and we estimate its volume to be roughly 175×10⁶ m³, a ca. 300% increase over Smith’s (1971) volume estimate of 56×10⁶ m³. Assuming 25% bulking, the source volume is about 130×10⁶ m³, slightly less than the source volume of 150×10⁶ m³ suggested by Naumann (1990). If the Popkum Slide is included, the estimates of the deposit and source volumes increase to approximately 200×10⁶ m³ and 150×10⁶ m³, respectively. We recognize that these values are estimates, but our re-evaluation makes the Cheam rock avalanche the largest known catastrophic landslide in the Canadian Cordillera (cf. Evans et al. 1989; Savigny and Clague 1992).

Stratigraphy

Rock avalanche lithofacies

The Cheam rock avalanche deposit has a maximum observed thickness of 30 m (Figs. 4 and 5). The deposit comprises massive to weakly stratified diamicton. Two lithofacies are recognized, although much of the sediment lies within a lithologic continuum between the two end members.

The first lithofacies, which is generally poorly exposed and is inferred largely from drill holes, is rubbly to blocky, clast-supported grey diamicton, commonly termed “broken shale” or “shale rock” by drillers. Angular rock fragments of the local argillitic bedrock constitute more than half of the sediment and range from pebble-size to blocks several meters across. The matrix of the diamicton is a mixture of clay, silt, sand, and angular granules. In some drillholes, this rubbly, blocky diamicton underlies diamicton with a lower proportion of clasts.

The second lithofacies is matrix-supported, olive-grey to olive-brown diamicton. Clasts are dominantly angular to subangular, but some are rounded and subrounded. Fragment size ranges from clay to large blocks more than 3 m across. Clasts larger than 0.3 m across constitute approximately 5–10% of the debris (Smith 1971). Smaller, gravel-size clasts represent approximately 15 to 40% of the deposit, and the remaining 50–80% is silt and sand (Smith 1971). The rounded and subrounded clasts are derived from pre-existing sediments, whereas the angular clasts come...
directly from local bedrock. The matrix of the diamicton consists largely of silt and clay. Fragments of wood, including some tree stems, are common in this lithofacies at some sites.

Stratigraphic context

The eastern half of the Cheam rock avalanche rests on a terrace underlain by more than 25 m of planar- to cross-bedded, late Pleistocene gravel with beds and lenses of fine to coarse sand (Fig. 5). Gravel and sand also form part of the lower surface, on which the western half of the rock avalanche deposit rests.

Gravel and sand exposed in the pit at site A (Fig. 4) are dominantly subhorizontally bedded, but locally dip up to 25°. Regional considerations (Armstrong 1981) indicate that the sediments were deposited at the end of the Fraser Glaciation in a glaciofluvial or glacio-deltaic environment at the margin of a stagnating or stagnant glacier. The gravel unit is capped at site A (Fig. 4) by up to 1 m of fine to medium sand, which, in turn, is overlain successively by up to a few tens of centimetres of silt and a thin peat containing roots in growth position and abundant twigs and branches. Two branches from a silt bed just below the peat yielded radiocarbon ages of 4,720 ± 80 and 4,830 ± 90 14C yr BP (Fig. 2, Table 1). A root extending down from the peat gave an age of 4,690 ± 80 14C yr BP. At several places in the gravel pit, silt below the peat contains a discontinuous layer of Mazama tephra (Naumann 1990).

Cheam rock avalanche debris, in places, lies directly on the peat. More commonly, it rests on the late-glacial outwash or on deformed organic-rich silt and sand. The latter sediments are associated with the peat, but are contorted, disrupted, and contain irregular lenses of peat, silt, and diamicton with clasts up to boulder size. A branch from a peat lens within this disrupted unit at site B yielded a radiocarbon age of 5,510 ± 95 14C yr BP (Fig. 4). These sediments were deposited on a poorly drained surface, probably in part a marsh and a shallow lake, which were destroyed when overridden by the Cheam rock avalanche. The rock avalanche also tilted and sheared beds near the top of the late-glacial outwash unit (Naumann 1990). An apron of clast-supported, rubbly diamicton derived from the adjacent valley wall covers the southern margin of the rock avalanche (e.g., site C, Fig. 4). This sediment was deposited by debris flows derived from the basin of Bridal Veil Creek after the rock avalanche event.

No conclusive stratigraphic evidence has been found for more than one large landslide on the Cheam plateau, but observations in the gravel pit at site A hint at slope instability prior to the Cheam rock avalanche. Specifically, a discontinuous bed of olive-brown, stony silty sand up to 2 m thick, containing silt rip-ups and wood fragments, abruptly overlies the peat dated at 4,700–4,800 14C yr BP. It is separated from overlying Cheam rock avalanche debris by up to 30 cm of stratified, well-sorted sand. We are reluctant to make too much of precursor instability based on stratigraphy seen in one wall of a single gravel pit on the Cheam plateau, but an alternative explanation for the stratigraphic separation of the two diamictons is not obvious. Further, drillers’ logs show two diamicton units separated by sand at sites D and E (Fig. 4), although detail is lacking.

The surface of the rock avalanche deposit, including the Popkum Slide, has a discontinuous cover of soils of the Cheam and Popkum Series (Comar et al. 1962; Luttmerding and Sprout 1967) (Fig. 6). The Cheam Series soil comprises massive, gravelly sandy loam up to 3 m thick (Luttmerding and Sprout 1967) and has formed on the debris of the Cheam rock avalanche. Fine massive sand of the Popkum Series is found mainly in depressions and other low ground on the rock avalanche deposit. The sand associated with the soil is up to 3 m thick and rests sharply on rock avalanche debris (Comar et al. 1962). The Popkum soil is restricted to the Cheam rock avalanche and is not found elsewhere in the study area (Fig. 6). We infer from this coincidence in distribution that the parent material for the Popkum soil was deposited either during, or shortly after, the rock avalanche event.

Fine, organic-rich swamp, lake, and alluvial deposits overlie slide debris in depressions between hummocky ridges (Fig. 6;
Armstrong 1981). Commercial extraction of marl from Cheam Lake, which commenced in 1945, showed that these fine sediments are up to 4 m thick.

Age of the landslide
Radiocarbon ages on woody roots in growth position directly below the landslide debris and on detrital wood from the debris itself indicate that the Cheam rock avalanche occurred about 5,000–5,300 calendar years ago (Table 1). The presence of Mazama tephra (ca. 6,800 14C yr BP; Hallett et al. 1997) in silt underlying the rock avalanche deposit is consistent with this interpretation. The radiocarbon ages clearly show that failure did not occur during or immediately following deglaciation and preclude glacial debuttressing as the trigger.

Discussion

Cause and trigger of failure
Previous research suggests that some large rock avalanches in southwestern British Columbia are preceded by a long period of slow, progressive deformation of slopes (Thompson et al. 1997). Glacial debuttressing of oversteepened slopes at the end of the Pleistocene may have initiated local instability, leading to slow downslope movement of rocks along joints and faults. In some

---

**Table 1 Radiocarbon ages**

<table>
<thead>
<tr>
<th>Laboratory sample no.</th>
<th>Radiocarbon age (14C yr BP)</th>
<th>Calendric age (yr BP)</th>
<th>Location</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFU#667 W-04</td>
<td>4360±90</td>
<td>4660–5300</td>
<td>Wood in rock avalanche debris</td>
<td>Naumann (1990)</td>
</tr>
<tr>
<td>SFU#666 W-03</td>
<td>4690±80</td>
<td>5070–5600</td>
<td>In situ root just below rock avalanche debris</td>
<td>Naumann (1990)</td>
</tr>
<tr>
<td>GSC-6222</td>
<td>4720±80</td>
<td>5320–5580</td>
<td>Branch in peat just below rock avalanche debris</td>
<td>This paper</td>
</tr>
<tr>
<td>GSC-5781</td>
<td>4830±90</td>
<td>5470–5560</td>
<td>Branch in peat just below rock avalanche debris</td>
<td>This paper</td>
</tr>
<tr>
<td>GX-19690</td>
<td>5510±95</td>
<td>6000–6500</td>
<td>Root extending down from peat below rock avalanche debris</td>
<td>This paper</td>
</tr>
<tr>
<td>GSC-4004</td>
<td>5010±70</td>
<td>5650–5890</td>
<td>Wood in rock avalanche debris</td>
<td>This paper</td>
</tr>
</tbody>
</table>

* GSC – Geological Survey of Canada Radiocarbon Laboratory; SFU – Simon Fraser University Radiocarbon Laboratory; GX – Geochron Laboratories; b laboratory-reported error terms are 1σ for SFU and GX ages, and 2σ for GSC ages. Ages are normalized to δ13C = −25‰ PDB; c determined from dendrocalibrated data of Stuiver et al. (1998) using the program CALIB 4.2.2. The range represents the 95% confidence interval (± 2σ) calculated with an error multiplier of 1.0
instances, this slow deformation culminates in catastrophic failure. An example is the 1965 Hope slide, which occurred on a slope displaying geomorphic evidence, in the form of antislope scarps and grabens, of slow, deep-seated sagging (Mathews and McTaggart 1969, 1978). Naumann (1990) inferred similar deformation at Cheam from grabens on a spur just northeast of the rock avalanche headscarp.

The event that triggered the Cheam rock avalanche is unknown, although there are only two likely possibilities. The landslide may have been triggered by an earthquake, as this part of British Columbia is seismically active (Rogers 1998). However, there is not a strong correlation between historic earthquakes and large landslides in the region (Clague and Shilts 1993; Weichert et al. 1994). Further, no other landslides in the Fraser Valley date to around 5,000 $^{14}$C yr BP. A more likely trigger is the development of high porewater pressures on a fault or fractures crossing the slope (Naumann 1990). A thrust fault daylights approximately 400 m above the floor of the Fraser Valley in the wedge-shaped depression that Naumann (1990) inferred to be the source area. The fault surface is a 1-m-thick shear zone containing slickenslided clay gouge dominated by chlorite and illite. This surface may have acted to increase porewater pressures and lower strength in the source area of the landslide. Possible sources of water include rainfall, snow melt, or a pond or lake in the source zone.

**Mechanism**

We postulate that the initial movement occurred in the basin of Bridal Veil Creek on the thrust fault identified by Naumann (1990). This movement compressed the rock mass lower on the slope and triggered catastrophic failure. The rock mass rapidly disintegrated as it moved downslope and may have been saturated before it reached the valley floor. More likely, however, relatively dry, blocky debris entered a shallow lake on the valley floor and entrained water and liquefied fine sediment. Deformed peaty and silty sediments beneath the rock avalanche debris at the margins of the higher area of hummocky debris (e.g., site B, Fig. 4) are evidence for the existence of a lake, much like present-day Cheam Lake, in the rock avalanche area. Diapirs and plastic deformation of the fine sediments and underlying late-glacial gravel and sand
further argue for liquefaction caused by undrained loading, as has
been described elsewhere (e.g. Mathews and McTaggart 1969,
Liquefaction also explains the abrupt change in morphology of
the landslide at the margin of the higher elevation eastern region,
as well as the considerable distance the debris travelled on a
nearly flat surface (Hung and Evans 2004). The Popkum Slide
may be the product of a similar high-velocity, fluidised lobe at the
east side of the landslide. These marginal deposits are similar to
the “sprays” described by Eisbacher (1979, p. 330) in the Mack-
enzie Mountains, Northwest Territories. Eisbacher attributed the
spray deposits to ejection of finer material from the front and
base of the flowing mass.

Liquefaction by undrained loading may also account for the
limited distribution of the Popkum Series soil. The Fraser River
could not have deposited the sand because it has not flowed at
that high level for more than 5,000 years. Furthermore, there are
no continuous erosional channels on the surface of the landslide
that would be expected if the river had flowed across it at some
time in the past. The main source of the sand is, therefore,
probably the glaciofluvial sediments on which the rock avalanche
debris lies. Liquefaction of the glaciofluvial sediments would ex-
plain the coincidence of the soil series with the rock avalanche
deposit. Subsequent reworking of the liquefied sediment by slope
wash may account for focusing of sand into low-lying areas on the
rock avalanche surface. The sand lacks current structures, sug-
gesting that water flowed across the debris and ponded in de-
pressions after the rock avalanche had come to rest. Furthermore,
poorly integrated drainage channels near the western edge of the
deposit may indicate the route of water flowing from the rock
avalanche shortly after failure (Fig. 7). These observations raise
the possibility that significant amounts of water were involved in
the initial failure.

The Fahrböschung (F) of a landslide, which is the tangent of
the angle from the source area to the furthest extent of debris,
provides a rough measure of landslide mobility. The F value for
Cheam is 0.26, slightly larger than the value of 0.2 determined by
Naumann (1990). It is similar to Fahrböschungs of other rock
avalanches in the Canadian Cordillera (Evans et al. 1989; Ryder et
al. 1990), indicating similar mobility.

Historic analogue
The deposit of the 1965 Hope landslide is morphologically similar
to that of the Cheam rock avalanche. The main Hope deposit
consists of a series of irregular arcuate ridges aligned perpen-
dicular to the direction of flow (Fig. 8). The debris in this area is
up to 80 m thick, and its surface is formed of blocks up to 20 m in
diameter, with little material finer than 0.3 m (Mathews and
McTaggart 1969, 1978). Northwest and southeast of the main
blocky deposit are areas of lower elevation and relief underlain by
muddy rock debris. The deposits in these two areas were em-
placed by high-velocity debris flows. Mathews and McTaggart
(1969, 1978) attributed the debris flows to mobilization of water
and mud on the valley floor by the impact of the rock avalanche.
The morphology of the muddy deposits is compellingly similar to
that of the western half of the Cheam deposit and the Popkum

![Image of Hope landslide taken soon after it occurred in January 1965 (Government of British Columbia photo BC (0)447). Dashed lines delineate the landslide boundary; solid lines are crests of hummocky ridges. Note the change in surface morphology from hummocky in the centre of the slide area to gently undulating at its northwestern and southeastern margins.](https://example.com/image)
The Cheam rock avalanche may have resulted in fatalities. Terraces bordering the Fraser River were preferred sites for human occupation in the Fraser Valley as far back as the early Holocene and stones from the area around Mt. Cheam were valued as canoe ballast and in longhouse construction (Carlson 2001; K.T. Carlson, personal communication, 2004). Stó:lō Nation oral history indicates that the Cheam rock avalanche site is xaxa (taboo), because a village was buried there (K.T. Carlson, personal communication, 2004). A further story fragment involves the transformation of Mt. Cheam from human to mountain (K.T. Carlson, personal communication, 2004). The story relates that the wife of Mt. Baker, was transformed into Mt. Cheam by Xeked (the transformers) during a trip back to the Fraser Valley from Washington State. Cheam’s half-sister (an unnamed mountain immediately upstream of Mt. Cheam), who had also been transformed, was jealous of her and threw stones at her. Some of these stones missed Mt. Cheam and rolled down onto the valley floor below. These stories suggest that peoples of the Stó:lō Nation probably occupied the Cheam terrace 5,000 years ago.

Summary

The Cheam rock avalanche is the largest known catastrophic landslide in western Canada. The deposit has an area of 10 x 10^6 m^2, a maximum thickness of 30 m, and an estimated volume of 175 x 10^6 m^3. A photo-draped digital elevation model of the landslide reveals two morphologically distinct surfaces. Steep-sided, arcuate, hummocky ridges and intervening flat depressions define an eastern, higher elevation surface. A western, lower elevation area has a subdued, gently rolling surface that terminates abruptly in an arcuate front on the Fraser River floodplain.

The rock avalanche debris is a diamicton dominated by fragments of local argillaceous metasedimentary rocks up to several meters across. A coarse facies contains little material finer than gravel size, but much of the diamicton has 50–80% sand, silt, and clay.

Plastic deformation of middle Holocene peat and silt, and late Pleistocene sand and gravel underlying the rock avalanche debris provides evidence for undrained loading induced by the rock avalanche. A marsh or lake was present on the impacted terrace, facilitating fluidisation of the debris. Liquefaction and fluidisation explain the marked difference in morphology between the eastern and western parts of the landslide and the distance travelled by the debris in the western region. Liquefaction may also account for well-sorted sand overlying the rock avalanche debris (the Popkum Series soil). The presence of Popkum sand in depressions on the rock avalanche surface indicates reworking of liquefied sand and the involvement of significant amounts of water in the failure.

Stó:lō Nation oral history indicates that the Cheam terrace was likely occupied at the time of the rock avalanche. If so, the rock avalanche is the first known fatal landslide in Canada.

References

Comar VK, Sprout PN, Kelly CC (1962) Soil survey of the Chilliwack map area, lower Fraser Valley. British Columbia Department of Agriculture, Preliminary Report No. 4

J. F. Orwin (✉) · J. J. Clague
Department of Earth Sciences, Simon Fraser University, 8888 University Drive, Burnaby, British Columbia, V5A 1S6, Canada
Tel.: +1-604-2915444, Fax: +1-604-2914198
R. F. Gerath
Thurber Engineering Ltd, 1445 West Georgia Street, Suite 200, Vancouver, British Columbia, V6G 2T3, Canada