

CHAPTER 4

The South Yale Blockfield: An Enigmatic Landform in the Lower Fraser River Canyon, B.C.

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Introduction and Background

As the upstream extent of navigable water on lower Fraser River, Yale (Figure 1) is a natural location for human settlement. First Nations have occupied the area around Yale for at least 9000 years (Borden 1961; Irvine 1973; Haley 1986; Mitchell and Pokotylo 1996; Antiquus 2008). Yale was a boom town during the 19th century gold rush, as it was a transfer point from paddle wheeler to overland travel for prospectors heading to the interior gold fields. The large rock outcrop projecting into the canyon, and marking its southern limit, was named Lady Franklin Rock in honour of the great explorer's dogged wife.

At the mouth of the Fraser Canyon at Yale, terraces on both sides of the Fraser River are studded with oversized blocks and boulders, or megagravel. On the east side of the river, this oversized debris is referred to as the South Yale blockfield (Figure 2). This megagravel was important in the precontact period because it provided overhangs that were used as rockshelters and surfaces that were apparently used for milling food resources, and as a result they are associated with cultural features, such as hearths, and abundant artifacts.

British Columbia historian BA McKelvie (1889-1960) suggested the South Yale blockfield was a large landslide deposit (Paterson 1979:146). In 1995, Greg Brooks of the Geological Survey of Canada examined the South Yale and Milliken archaeological sites to elucidate the geologic history of the area. In McNeely and Clague (1996), he wrote:

“... a large blockfield located on the east side of the valley bottom opposite the town of Yale, is interpreted as a rock avalanche deposit and it may have impounded the Fraser River. [However], there is no evidence of landslide damming in the stratigraphy of the Milliken Site, which is situated at a level that probably would have been inundated by such an impoundment.”

Swondell (1973), while working for Irvine (1973), argued that the South Yale blockfield formed during deglaciation and was part of the outwash of the terrace on the east side of the river. However, details of his argument are not known as the original report is no longer available. This chapter reviews available geomorphic evidence in order to elucidate

the geochronology of the South Yale blockfield, contextualizing the rich archaeological heritage of the South Yale site (Chapter 5).

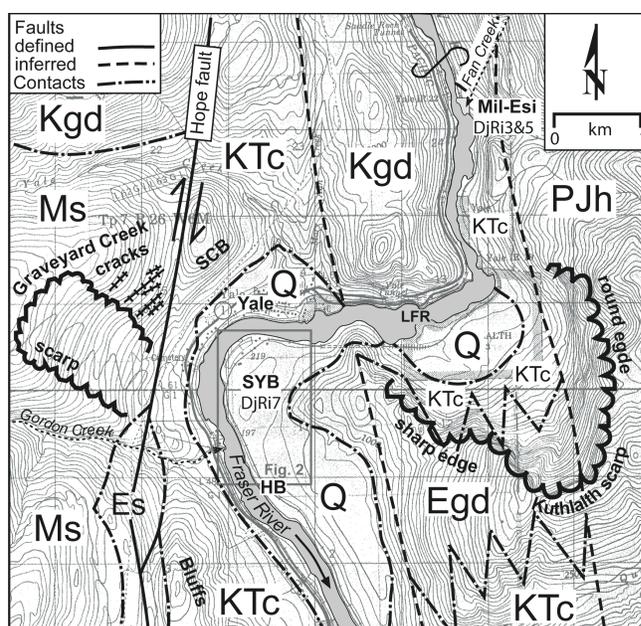


Figure 1. Topography and bedrock geology of the lower Fraser River at Yale. SYB=South Yale blockfield; LFR=Lady Franklin Rock; SCB=Spirit Cave bluffs; HB=Hill's Bar; Mil-Esi=Milliken-Esilao sites; DjRi#=Borden site numbers. Geology: ES, MS=Settlers Schist; KTc=Custer Gneiss; Egd, Kgd=granodiorite; PjH=Hozameen shale.

Methods

In 2003, interest in the aggregate potential at South Yale led to sedimentological and archaeological mapping programs. As part of this effort, terrain mapping was undertaken to explain the South Yale blockfield. Field observation sites were located with a handheld GPS accurate to ± 10 m and were tied to surveyed baselines. Elevation control between Yale, South Yale and Milliken was established by altimeter traverse with ± 1 m accuracy. Rock samples from megagravel in the South Yale blockfield, cobble/boulder gravel in the Kuthlalth colluvial cone and talus in Trans Canada Highway road cuts were collected for lithological

analyses. In 2009, terrain hazard mapping was conducted in the Yale Township planning area, on the west side of the river between Lady Franklin Rock and Gordon Creek (Friele 2009). Available archaeological reports, geotechnical consultant reports and other geological literature were reviewed.

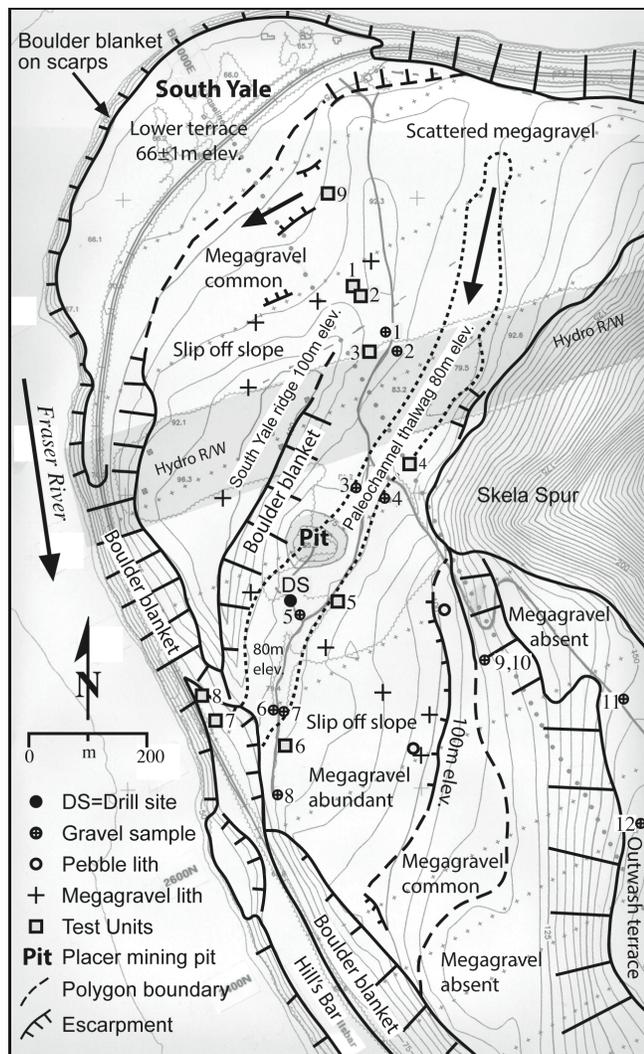


Figure 2. Landform map of the South Yale locality showing terraces, paleochannels and sample locations.

Environmental Setting

Yale (Figure 1) is situated at the downstream end of the Fraser Canyon, a 2000-m deep, 75-km-long gorge cut through the southern Coast Mountains by the Fraser River. The steep bedrock walls of the canyon confine a 100-400 m wide channel characterized by rapids. Below Yale the valley widens to about 1 km and the river is flanked by terraces, alluvial fans and isolated areas of floodplain.

The Fraser River at Yale forms the boundary between two major geologic provinces, the Coast Belt to the west and Intermontane Belt to the east. The parent rocks in both belts are derived from accreted island-arc terranes (Monger and Price 2000); the Coast Belt underwent high-grade, regional

metamorphism during Cretaceous Period, whereas the Intermontane Belt experienced lower grade meta-morphism. These differences may be used diagnostically for gravel provenance analysis.

The Hope Fault (Figure 1), part of the Fraser River fault zone, a major strike-slip fault active during the late Cretaceous and Eocene trends northerly, cutting mid-slope across the western valley side above Yale. Rocks occurring within the range of influence of the Fraser River fault zone have been crushed, shattered, or intensely faulted and jointed (Piteau 1977). Rockfall and deep-seated bedrock instability may be related to structural weakness.

The Coast Mountains and Fraser Canyon were covered by glacier ice numerous times during the Pleistocene Epoch (2.6 million years ago to 10,000 ¹⁴C yr BP). At the end of the last (Fraser) glaciation, the Fraser Canyon and lower Fraser Valley was occupied by a valley glacier as late as 10,600 ¹⁴C yr BP (Clague et al. 1997; Easterbook 2014) (all ages presented as conventional radiocarbon). In the Fraser Lowland, sea level fell from above 180 m asl to about 80 m asl between 12,500 and 12,000 ¹⁴C yr BP, to 20–30 m a.s.l. by 11,000 ¹⁴C yr BP, and to about 10 m asl by 10,000 ¹⁴C yr BP (James et al. 2002). The precise chronology of deglacial outwash terraces and marine limits between Hope and Yale is not known. This review suggests a maximum age for early human occupation of the Yale area at about 10,000 ¹⁴C yr BP.

Quaternary Landforms at Yale

Outwash Terraces

River level near Yale is about 55 m asl. Directly to the west of Yale an outwash terrace stands at 150-160 m asl; the terrace surface is 100-200 m wide with a 2% slope downstream. The terrace has been described as formed in glacial outwash (Thurber 1987). BGC (1994) suggested it may have formed as an ice-contact terrace (kame terrace), but the existence of a paired terrace on the east side of the Fraser River between Hill's Bar and Qualark Creek suggests that it might represent a remnant of a broad outwash surface, or sandur, developed at the mouth of the Fraser Canyon. The outwash surface is most certainly deglacial in age, probably formed at or before 10,500 - 10,000 ¹⁴C yr BP.

Road cuts and quarries in the outwash were examined on the west side of the river. A conspicuous feature is the inclusion of a significant proportion, perhaps 1-5% by volume, of matrix-supported, angular boulders and megagravel of gneissic lithology (Figures 3a, b). Large angular fragments range up to 15 m in medial length. The matrix sediment is composed of granular pebble/cobble gravel with rounded clasts of mixed lithology. Two sediment samples collected from quarries in the terrace west of Yale yielded a matrix texture of 85.5% gravel (<4mm), 10% sand, 4% silt and 0.5% clay. The inclusion of lithologies from a wide geographic area consisting of both high and low grade metamorphics and a sandy gravel texture indicates a fluvial origin for the matrix sediments.



Figure 3. Megagravels at the Yale locality. All clasts are derived from Custer gneiss. A: Trans Canada road cut exposure showing matrix-supported clasts in outwash gravel. B: View south from highway intersection at Yale to large clast projecting from slope eroded in the 160-m asl terrace Yale. C: Large clasts extending above the surface underneath BC Hydro right-of-way on South Yale Ridge. D: Subrounded boulder near the south end of the paleochannel. E: Cluster of blocks and boulders on the southeast end of the paleochannel. F: Large rockshelter block at the northwest end of the paleochannel.

Remnant Fraser River Terrace at the Milliken Locality (DjRi 3)

The Milliken site is about 2 km upstream from Yale. It is located on a terrace at 90 m asl. Railcuts and deep archaeological excavations (Borden 1961) revealed cultural materials extending some 15 m below the terrace surface.

Oldest cultural materials (McNeely and Clague 1996) (Table 1, Zones H, I) rest on and are interbedded with silt, sand and gravel interpreted to be Fraser River sediments, indicating that the earliest occupation about 9000 to 8000 ¹⁴C yr BP was on the floodplain at or just above the high water mark when the river level was about 77-79 m asl.

Table 1. Radiocarbon Age Determinations from the Yale area.

Lab number	Radiocarbon Age (¹⁴ C yr BP) ^a	Calendric Age Range (yr before AD 2000) ^b	Location		Comments
			Lat. (N)	Long. (W)	
SFU-248	3130±500	4790-2120	49° 33.3'	121° 25.9'	South Yale. Minimum surface age for T1, 66 m asl
SFU-225	4200±360	5650-3720	49° 33.3'	121° 25.9'	South Yale. Minimum surface age for T3
M-1546	4880±180	5990-5090	49° 35.1'	121° 24.0'	Esilao. Minimum surface age.
I-8208	5240±100	6280-5750	49° 33.3'	121° 25.9'	South Yale. Minimum surface age for T3
M-1547	5490±500	7430-5050	49° 35.1'	121° 24.0'	Esilao. Minimum surface age.
SFU-238	5900±130	7150-6410	49° 33.3'	121° 25.9'	South Yale. Minimum surface age for T2, 92 m asl
GSC-459	7190±150	8340-7680	49° 35.1'	121° 24.0'	Milliken. Zone D
S-61	7350±150	8410-7870	49° 35.1'	121° 24.0'	Milliken. Zone E
GSC-2163	7490±70	8410-8170	49° 32.7'	121° 26.2'	Gordon Ck. Maximum age for raised fan delta, 92 m asl.
TO-4950	8110±130	9470-8600	49° 35.1'	121° 24.0'	Milliken. Zone I, 77 m asl
S-47	8150±300	9710-8370	49° 35.1'	121° 24.0'	Milliken. Zone G, 79 m asl
S-113	9000±150	10,500-9610	49° 35.1'	121° 24.0'	Milliken. Zone I, 77 m asl

^aLaboratory-reported uncertainties are 1σ for TO ages and 2σ for GSC ages. Ages are normalized to δ¹³C = -25.0‰ PDB.

^bDetermined from atmospheric decadal dataset of Stuiver et al. (1998) using the program CALIB 4.1. The range represents the 95% confidence limit.

The earliest cultural horizons are overlain by 3.5 m of sediment (Table 1, Zones D, E, F), consisting of angular, boulder to pebble gravel beds (Zones D, F) separated by 1-2 thin stringers (Zone E) of black silty granule gravel bearing cultural material. These sediments were attributed by Borden (1961) and Mitchell and Pokotylo (1996) to deposition from a small seasonal creek on an alluvial fan southeast of the site (Fan Creek) (Figure 1).

The South Yale Blockfield (DjRi 7)

The South Yale blockfield and Fraser River paleochannel extend 1.5 km along the east side of the river at Yale south to Hill's Bar, and is about 500 m wide (Figure 2). The surface lies between 80 and 110 m asl and is covered by 5-15-m-sized angular blocks (Figure 3c) and 2-5-m subround boulders (Figure 3d, e). At the upstream end the megagravel consists mostly of scattered blocks about 5-15 m apart. Some of the largest of the blocks overhang and were used as rockshelters during the precontact period (Figure 3f). At the downstream end of the blockfield, especially on the flanks of the paleochannel, round and subround boulders are common to abundant (Figure 3e). Boulders form a continuous blanket where exposed on steep escarpment slopes.

The blockfield was channeled by the paleo-Fraser River. The prominent paleochannel (Figure 2) is about 200-300 m wide, 20 m deep, and has a smooth floor at 80 m asl at its

upstream end, with a downstream gradient of about 0.5%. A few megagravel blocks project from the paleochannel floor, but they are less abundant than on the channel sidewalls and adjacent terrace surface. A drill record provided by Coast Mountain Geological Ltd. (6" Barber drill) from a site at the south end of the paleochannel floor reveals up to 5 m of gravel overlying successively a 3-m-thick layer of boulders, and gravel at 70 m asl. Interstratified gravel and sand extend down to 13 m asl where the hole terminated in "pyritic shale gravel".

The east sidewall of the main paleochannel has a moderate (10-20%) slope rising to a blocky bouldery terrace at about 105-110 m asl. Farther east there is a slight rise to a higher smooth terrace remnant at 115-120 m asl.

The west sidewall of the main paleochannel is a steep scarp blanketed with rounded boulders. It rises to a flat-topped ridge at 100 m asl, termed the South Yale Ridge. The west flank of the ridge slopes gently down to a second smaller paleochannel, and then down farther to the lowest terrace level at 66 m asl.

Approximately 65 subround to round boulders and angular megagravel blocks were sampled for lithology at 10 different stations distributed across the blockfield surface (Figure 2). All are gneissic and derived from the Custer Gneiss.

Twelve backhoe test pits (3-5 m deep) were excavated across the paleochannel and east up onto the 160 m asl outwash surface (Figure 2), and samples were collected for grain size analysis. Truncated at 2 mm grain size, all samples were classified as sandy gravel (Folk 1980), with 55-79% gravel, 20-44% sand, and <1% silt and clay. This indicates a washed gravel consistent with fluvial origin. Stones are rounded with a maximum size between 60 and 150 mm diameter. Gravel lithology is mixed, including igneous, and high- and low-grade metamorphic rocks.

Along the margins of the main paleochannel and at the north end of the South Yale blockfield, Rousseau (2008) performed numerous exploratory shovel tests and nine excavations that terminated at depths of 0.5-1 m depth (test units 1-9; Figure 2).

The stratigraphy consists of a 10-40-cm-thick surface layer of aeolian silty sand overlying stratified sandy gravel. The capping silty sand contains cultural artifacts, whereas the underlying sandy gravel is culturally sterile.

Several radiocarbon samples provide ages for the South Yale blockfield. Borden (1961) excavated a hearth at 90 m asl at the north end of the South Yale blockfield. Charcoal from the hearth yielded an age of 5900 ¹⁴C yr BP (Table 1). He rejected the age on the basis that it is much younger than the early occupation ages from Milliken, and it did not fit into his idea that simple cobble tool technologies were indicative of older, simpler cultures. Haley (1996) re-examined the cobble-tool assemblage, the Pasika Complex, and dated archived carbon from a South Yale hearth at 5240 ¹⁴C yr BP (Table 1); this age confirmed early-mid Holocene occupation at South Yale. On the west bank of the Fraser River opposite the blockfield, wood found at 90 m asl in raised fan deposits of Gordon Creek (McNeely and Clague 1996) yielded an age of 7490 ¹⁴C yr BP (Table 1). Archaeological material from the 66 m asl terrace at South Yale returned an age of 3130 ¹⁴C yr BP (Table 1).

Yale Creek Alluvial Fan

An alluvial fan is located at the mouth of Yale Creek inset into the previously described outwash terrace. This feature was described as a “paraglacial fan” by Bell (1980), Pacific Hydrology Consultants (1981) and BGC (1993/1994). The fan apex, located at the Albert Street bridge over Yale Creek, stands at 110 m asl, and the fan surface descends at an average 7% slope to about 60 m asl at Front Street along the Fraser River. Front Street itself stands about 8–10 m above the normal annual high water mark of Fraser River.

The apical area of the Yale fan has a bouldery surface once channeled by flows from Yale Creek but now entrenched 10-15 m along the northern fan margin. Closer to the Fraser River there are three north-south-trending terraces cut by the Fraser River 10 m, 20 m and 27 m above high water level at 52 m asl. Boulders on the main fan surface are primarily gneiss, but include some granodiorite. Matrix sediments contain schist derived from Yale Creek. Drill core (Pacific Hydrology 1981) reveals 25 m of bouldery and

gravelly fan deposits overlying 43 m of glacial drift (interbedded till, gravel, and silt/sand), with till at the base of the hole.

Landslide and Rockfall Source Areas

Graveyard Creek Landslide

The hillside south of Yale and east of the Fraser River fault (Figure 1) was identified as an immediate post-glacial landslide by Savigny and Clague (1992), and is referred to hereafter as the ‘Graveyard Creek landslide’. The hillside is underlain by Settler’s schist and granodiorite (Monger 1989). Savigny and Clague (1992) suggested the southern portion may have failed catastrophically and blocked the Fraser River, while the northern half shows sign of slope distress but did not fail. No schist-bearing landslide deposits have been identified below 110 m asl, thus the landslide toe may have been eroded by the Fraser River (Friele 2009).

Kuthlath Amphitheatre

The Kuthlath amphitheatre (Figure 1) is located on the east side of the Fraser River about 2 km upstream of Yale. It is a northwest-facing bedrock bowl, 2000 m wide with 1000 m of relief. Bedrock in the amphitheatre area consists of granodiorite, Custer Gneiss, and other low grade metamorphic rocks (Figure 1). The shape of the bowl suggests that it is an enormous landslide headscarp (Piteau 1977; Bell 1980).

The missing volume or amount of rock removed from the entire Kuthlath amphitheatre is 1.5 km³. However, the northern headscarp rim is rounded suggesting that it has been glacially eroded; if a landslide scar, it must predate the last, or Fraser, glaciation (Bell 1980). Only the southern half of the amphitheatre supports an angular scarp edge, indicating post-glacial rockfall and rock avalanche activity. The “missing volume” encompassed by the angular headscarp is about 0.3-0.5 km³, and has been mapped as Custer gneiss (Figure 1).

The amphitheatre is partly filled with a debris cone extending from 400 m asl to river level. The debris consists of a mix of locally derived granodiorite, gneiss and pelitic rocks. Small rockfall and debris flow events are common, and the CNR mainline, which crosses the base of the cone, has been blocked by debris flows several times (Septer 2006). The toe of the debris cone is truncated by a paleochannel located about 10 m above river level.

Directly opposite the Kuthlath amphitheatre on the west side of the Fraser River is a vertical granodiorite rockwall (Figure 1) flanked by a colluvial apron. The colluvial apron might be interpreted as a runup deposit from a large landslide sourced in the Kuthlath amphitheatre. However, the rubble is entirely granodiorite, indicating it is derived from rockfall from the adjacent steep bluff and is not a runup deposit.

Bluffs in Custer Gneiss

Custer gneiss forms outcrops on both sides of the Fraser River in the vicinity of Yale and south past Hills Bar. Due to its proximity to the Fraser River fault, the rock is highly fractured and susceptible to rockfall.

Spirit Cave bluff (Figure 1) is a knoll rising to 590 m asl directly west of Yale. The southeast face is 300 m wide and 150 m high, lying between 350-500 m asl. In plan view there is an irregularity in the line of the bluff that could be the scar of an ancient rockfall with a volume of $0.5-1.0 \times 10^6 \text{ m}^3$. The steep slopes below the bluff are mantled with rockfall debris. At the foot of the slope is the above-mentioned outwash terrace. There is no evidence of rockfall material blanketing the surface of the outwash. Thus, it appears that in the time since the formation of the outwash terrace 10,500-10,000 C^{14} years ago, there has not been a large rockfall or rock avalanche from Spirit Cave bluff, only minor rockfall.

Travel Angles and Landslide Reach

An estimate of the area potentially affected by a landslide is provided by the travel angle, or the slope angle from the failure crown to the toe of a deposit. The travel angle is a function of landslide type and volume, with lower travel angles (i.e., longer travel) for larger volume events (Corominas 1996).

The angle from the southern rim of the Kuthlalth amphitheatre to the south end of the South Yale blockfield at Hills Bar is 0.1 m/m. (Table 2) To reach that far a landslide would have had to have a volume on the order of 1 km^3 (Table 2). Based on the possible volume exhumed from the angular scarp, this degree of landslide reach is not credible for the Kuthlalth escarpment.

Travel angles from the top of Spirit Caves bluff and the bluff to the south of Gordon Creek to different locations along the length of the blockfield range from 0.2 to 0.25 m/m. Landslides with volumes of $500,000 \text{ m}^3$ or more could reach the blockfield (Table 2). It is very unlikely that small rockfall events would spread debris over the full extent of the blockfield, but areas closer to the base of slope would certainly be affected.

Table 2. Travel angles (m/m) for landslides of various volumes estimated using the equations provided by Corominas (1996).

Event	Volume (m^3)				
	500,000	1,000,000	10,000,000	100,000,000	1,000,000,000
All	0.29	0.28	0.23	0.19	0.15
Rockfall	0.39	0.36	0.28	0.22	0.17
Debris Flow	0.25	0.23	0.18	0.14	0.11

Given the widespread extent of Custer Gneiss, with several potential source areas within reach of the South Yale blockfield, it is not possible to identify an unequivocal source area. Gneissic megagravel in the blockfield is certainly colluvial in origin; but the source could be one large event from a single source, or perhaps multiple events from several sources.

Discussion

Deposit Morphology and Sedimentology

At first glance, the megagravel at South Yale appears to be the product of a single large Holocene-age landslide. Uniform Custer Gneiss lithology indicates a colluvial origin from a local source; the mix of large angular blocks and clusters of rounded boulders suggests a complex rock avalanche-debris flow event. The base of the boulders is at 70 m asl, but boulders extend up to 110 m asl. On that basis it might appear that a landslide blanketed the floodplain when the river flowed at a level of about 70 m asl, filling the valley to 110 m asl or more.

However, apart from the presence of blocks and boulders, the surface expression on both sides of the river is not typical of an unmodified landslide deposit, and remnant landslide deposits have not been identified at locations sheltered from erosion or at the base of potential landslide scarps, such as the Kuthlalth amphitheatre or Spirit Cave bluff.

From the highest paired outwash terraces, down through the channelised intermediate surfaces, to the lowest surface above the Fraser River, the surface expression of the Quaternary deposits at Yale is entirely fluvial in character, with abandoned paleochannels and descending flights of terraces. The South Yale Ridge has a flat top, planed off by fluvial erosion.

Moreover, the matrix sediment surrounding the blocks and boulders, investigated up to a depth of several metres, is a well-sorted, sandy pebble/cobble gravel, with mixed lithology representative of watershed-scale provenance. This material is fluvial in origin. Material of a landslide origin would be expected to have a fine matrix and a uniform lithology.

Geochronology and River Level

The first constraint on the age-elevation curve is a deglacial age for the high outwash surface at Yale. At the Milliken archaeological site an ages of about 9000-8000 ^{14}C yr BP appear to be closely associated with a river level of 77-79 m asl (Table 1). An altimeter traverse indicates that high water at Milliken is 4 m higher than at Yale, so assuming similar hydraulics, river level 9000-8000 BP at Yale was 73-75 m asl. The 7490 ^{14}C yr BP date at Gordon Creek provides a maximum limiting age on the 90 m elevation, but river level is poorly constrained by the sample, and the river may have been much lower at that time.

The dates of 5900 ^{14}C yr BP and 3130 ^{14}C yr BP from cultural features at South Yale provide maximum limiting ages on 92 m and 66 m river levels, but their association with the river is not clear. If the data from Milliken are

correct, and considering monotonic downcutting, the dated cultural features on the South Yale ridge were not likely associated with a wetted paleochannel, but some lower river level to the west. If the 5900 C¹⁴ yr BP occupation was associated with a wetted paleochannel, river downcutting was delayed by about 2300 years, perhaps due to landslide-river interruption. The terrace level at Front Street and the paleochannel truncating the Kuthlalth fan are lower than the 66 m asl terrace and must be younger than 3130 ¹⁴C yr BP. Starting from the highest outwash terraces, both monotonic incision and landslide river interruption between 8100-5900 BP affecting the 70-110 m elevation range are plausible with the scanty data (Figure 4).

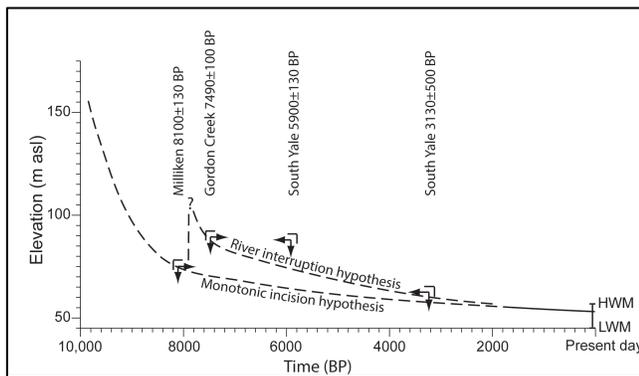


Figure 4. Age-elevation diagram for the Fraser River at Yale. Time scale is radiocarbon years before present (BP). Alternate hypotheses are presented for the pattern of river incision during the Holocene. The direction that the age is constrained is shown with corner-arrow symbols. HWM: high water mark. LWM: low water mark.

Landscape Evolution

The blockfield at South Yale is undoubtedly of colluvial origin. The enigma is the source and timing of its emplacement. The hypothesis that appears to best fit the channeled morphology of the South Yale blockfield and the inference that the matrix supporting the megagravel has a fluvial texture is that one or more landslides and/or rockfall from a Custer gneiss source affected the Fraser River floodplain in the deglacial period when outwash was aggrading at the mouth of the Fraser Canyon. The absence of landslide deposits on the upper outwash surface suggests that adjacent slopes have been stable since the early Holocene. In exposures of the outwash, large gneissic blocks and boulders exist as matrix-supported stones in low abundance. Assuming they form 1-5% of the deposit, winnowing of 80 m of outwash could yield a lag deposit of boulders and blocks 1-4 m thick. This indicates that the South Yale blockfield, boulder accumulations on terraces on the west side of the river and those in the vicinity of Lady Franklin Rock might have become concentrated by the process of winnowing of gravel during river incision, leaving outsized clasts as lag.

An alternative hypothesis is that sometime in the early Holocene before 5900 ¹⁴C yr BP, a large landslide filled the valley from 70 to 110 m asl. Hewitt (1998) outlined five main sets of landforms associated with landslide river interruption: a rock avalanche barrier, river flats formed upstream of a persistent barrier, a complex of river terraces upstream of an eroded barrier, downstream barrier-defended deposits and terraces, and deposits from catastrophic floods. An example of a large Holocene landslide complex in the Fraser Canyon is the Texas Creek landslide, where there is an extensive landslide deposit overlying terrace surfaces (Ryder et al. 1990), and there is some evidence that upstream deposition affected First Nations peoples (Hayden and Ryder 1991).

Greg Brooks (in McNeely and Clague 1996) inferred that if the blockfield was deposited by a Holocene landslide, it should have left a visible signature in the landscape, for which he could see no evidence. The Milliken site is at an elevation that would have been inundated. But there fan gravels overlie river gravels, with no evidence of backwater sedimentation after 8000 ¹⁴C yr BP.

If the Fraser River was blocked by a persistent landslide barrier at Yale, a lake would have extended as far as Hell's Gate, some 30 km upstream. Given the annual clastic yield of the Fraser River at Hope (0.21 Mg km⁻² day⁻¹; Church et al. 1989), such an impoundment would have filled in after about a decade, creating the upstream river flats, which upon subsequent incision would have left valley-side terraces graded to the former barrier elevation (110 m asl). None of this suite of features associated with landslide-river interruption has been identified at Yale or upstream along the Fraser Canyon. Thus if a landslide did occur, it likely occurred prior to 9000 ¹⁴C yr BP.

Geoarchaeological Conclusions

Based on inference from surface morphology and sedimentology, the origin of the South Yale blockfield and adjacent landforms is best explained by a monotonic fluvial incision hypothesis over a landslide-river interruption hypothesis. A very large rock avalanche/debris flow or number of rock avalanches likely occurred during the Late Pleistocene, early deglacial phase when outwash materials were aggrading. With monotonic incision through the Holocene, the South Yale ridge and surfaces above about 80 m asl would have first become available for human occupation somewhat before 9000 ¹⁴C yr BP.

There may have been a slowing of incision due to the formation of a boulder lag, but the lack of sufficient chronological control on the main paleochannel and adjacent terraces preclude determination of the age of river abandonment of these surfaces. The likely scenario would have human occupation of South Yale ridge and the abandoned paleochannel by about 8000 ¹⁴C yr BP or slightly before, with the Fraser River and fishing activities located west of the ridge. Younger ages from cultural features on the ridge, such as 5900 ¹⁴C yr BP and 5240 ¹⁴C yr BP (Table

1), simply indicate that the site was used for salmon and plant processing for many thousands of years. It is possible that future archaeological excavation and radiometric dating will prove human occupation to at least 8000 ^{14}C yr BP, as is the case at Milliken. As the river continued to cut down, finally abandoning the 66 m asl terrace by at least 3130 ^{14}C yr BP, salmon processing and other activities may have shifted west onto the lower surface closer to the river. The right bank terrace at Yale's Front Street is the closest to river level and likely was the most utilized surface at European contact.

A mid-Holocene landslide interrupting the river at Yale would have been an exceptionally large event. The Yale locality was clearly important to First Nations people for resource extraction, trade and settlement. In the Pacific Northwest there are several known instances where large destructive geologic events affecting villages have been recorded in First Nations oral tradition, with memory extending back several thousand years in some cases (Pasqua 1990; Gottesfeld et al. 1991; Budhwa 2002; Orwin et al. 2004; Ludwin et al. 2005; Bornhold et al. 2007). Although perhaps too deep in the past, to date there is no recorded oral tradition that describes such a disaster at Yale.

Better radiometric control on the age of the surfaces at Yale would help more accurately define the timing of river incision. Drilling and geophysical investigations of the blockfield, and mapping of exposures along the railway and along the east bank of the Fraser River would provide a better understanding of the deposit itself. Until then, the geologic history of the South Yale blockfield will remain enigmatic.

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