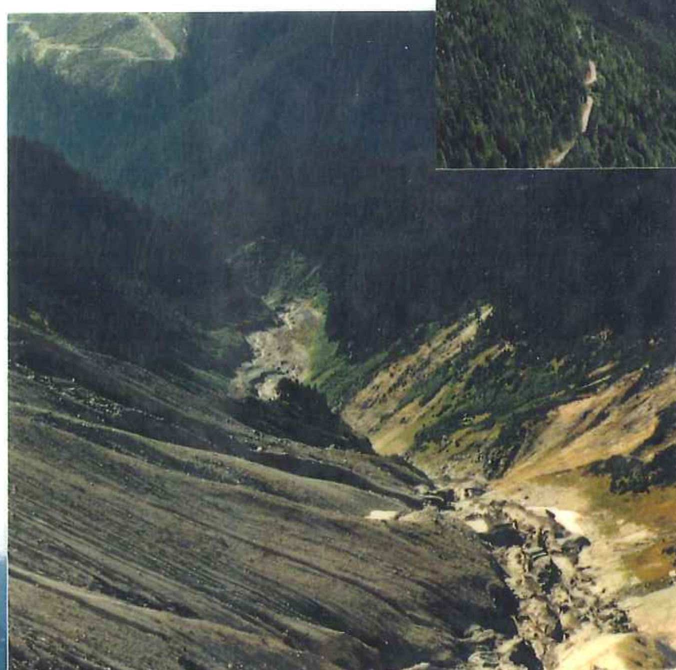
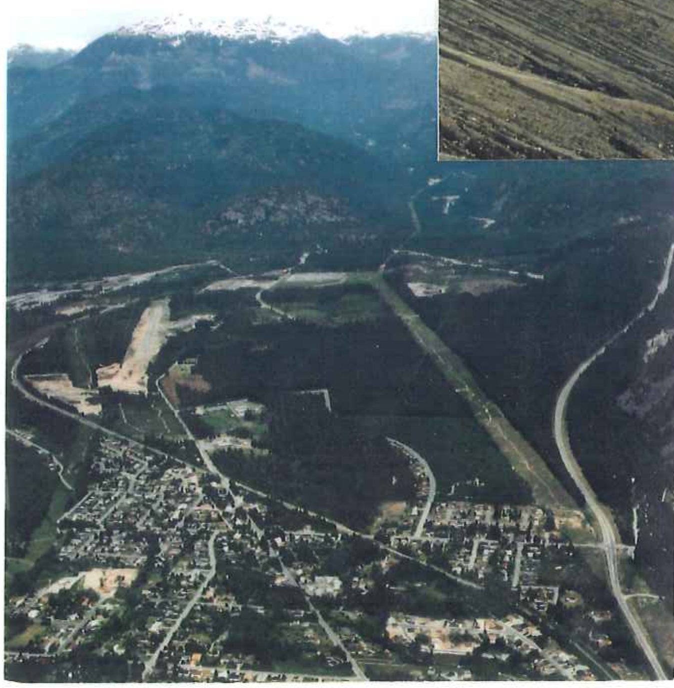
CHEEKYE RIVER

TERRAIN HAZARD
and
LAND USE STUDY





Final Report – Volume 2

March, 1993

THURBER

Golder Associates

Prepared for B.C. Ministry of Environment Lands and Parks

APPENDIX XII

HYDROLOGY

APPENDIX XII-A

CREAGER FLOOD ENVELOPE CALCULATION

APPENDIX XII-B

CHEEKYE RIVER GRAVEL REMOVAL 100 M D/S TO 500 M U/S OF FERNWOOD ROAD BY C.R. BLAND, P. ENG.

WATER MANAGEMENT DIVISION
OIC 1298, AUGUST 1991 SQUAMISH AREA FLOOD

REVIEW SITE: 1.040.020

DESCRIPTION: Cheakamus River at Paradise Valley Bridge, Review of gravel deposition.

BY: C. Robert Bland, P. Eng. DATE: 12 March 1992

1 INTRODUCTION

Gravel build up in the Cheakamus River downstream of the Cheekeye River was reported by local residents following the August 1991 flood. CBA Engineering Ltd. carried out topographical surveying in October 1991 from about 600 m downstream to 300 m upstream of the road bridge (see drawing sheet 1 for locations of cross sections).

Previous Cheakamus River surveys in August 1978 and September 1989 were provided by Water Management. The river bed is also shown on drawings provided by MoTH of old road bridges dated 1926 and 1958 and the current 1980 bridge.

2 REVIEW ACTIVITIES

Comparisons or river bed level were made between the various surveys. Flood flow calculations were made of the flow under and around the bridge using the HEC 2 computer program. Discussions were held with MoTH and District of Squamish personnel, and representatives of the Squamish Nation.

3 COMMENTS

3.1 Flood Flows

The 1991 flood was reported to include a large flow from the Cheekeye River during the evening of August 29, 1991. The peak flow from the upper Cheakamus River catchment was delayed for about 6 hours until early morning on 30 August by the Daisy Lake dam, so that these two peaks did not coincide. The WSC gauge on the Cheakamus River just upstream of the Cheekeye River was not operational during the flood. B.C. Hydro estimated a peak inflow to Daisy Lake dam of 820 m^3/s, and a peak outflow of 675 m^3/s.

The Cheekeye River component of the flood was accompanied by a large quantity of gravel, which was deposited in the lower reaches of the Cheekeye River as well as in the Cheakamus River. The flood caused damage to the roads and houses on the right bank, and to the left bank riprap downstream of the bridge.

A preliminary analysis of flood flow in the Cheakamus River downstream of the Cheekeye River confluence (see figure 1) estimated the following 2 and 20 year flows. The 200 year flow was estimated using a regional analysis.

Return Period y	Peak Instantaneous flow m^3/s
2	400
20	1,000
200	1,600

A regional analysis of Cheekeye River flood flows estimated peak flows for 2, 20, and 200 year return periods as about 130, 220, and 350 m^3/s.

3.2 Gravel Deposition

In comparison with 1989 conditions, material had accumulated in the river bed after the August 1991 flood to a depth of about:

2.6 m at 50 m upstream of the bridge
3.0 m at the bridge
1.8 m at 50 m downstream of the bridge.

At 600 m downstream of the bridge the bed eroded about 2.8 m.

The volume of deposited material was estimated as 17,000 m^3 in the 400 m reach from the Cheekeye River confluence to 250 m downstream of the road bridge.

It should be noted that the river bed level at the bridge after the August 1991 flood was similar to the level shown on the bridge drawings of 1926 and 1958. The reason for the lower bed level during 1978 - 1989 has not been determined. It is known that the 1958 wooden bridge collapsed in 1980 due to undermining of the timber crib piers. Possibly flood flows caused natural erosion and bed degradation, or gravel removal was carried out.

Subsequent to the August 1991 flood, further gravel was deposited at the bridge. The additional deposit was about 0.6 m in thickness in February 1992.

3.3 Flood Control

3.3.1 Gravel Removal

The HEC 2 analysis showed that excavation of the 17,000 m^3 buildup of gravel would lower the water level of a large flood (1,500 m^3/s) by about 0.2 m at the upstream face of the bridge.

If the gravel was removed, it is expected that the river would deposit material back up to the original level. It is likely that a continuing gravel removal program would be necessary in order for it to be effective as a means of flood control. There is the possibility that a lowering of flood water levels would not be achieved if the gravel was redeposited early in a flood.

It is understood that B.C. Environment would not accept responsibility for a continuing program of gravel removal, and some local agency, such as the District of Squamish would have to accept this responsibility.

The left bank riprap downstream of the bridge was reconstructed after the 1991 flood, and according to the owner, does not have an embedded toe. Gravel excavation would likely induce undermining of the toe, and cause damage to this riprap.

Gravel removal cannot be accepted as a satisfactory method of flood control at this location.

3.3.2 Floodway

The left bank downstream of the bridge has been dyked and riprapped. The left bank upstream of the bridge is higher than the right bank. Recent flood flows passed overland on the right bank around the bridge.

The importance of the overland flow around the bridge was checked using the HEC 2 program, and a large flood of 1,500 m^3/s. The results indicate that such a flow will not pass through the present bridge opening without overflow if overbank flow were prevented on both banks.

Since the gravel removal project on the Cheekeye River downstream of the railway bridge has already been approved, an opportunity exists to use the excavated gravel for flood control. The houses on the right bank could be given added protection with a dyke as shown on drawing sheet 4, which would allow for right bank overland flow. This proposal has been submitted to the Squamish Nation, and is currently under its consideration. Raising of the roads at the dyke, and providing erosion protection would also be necessary to complete the work, for which a source of funds has not been identified.

4 CONCLUSIONS

1 The 1991 flood deposited approximately 17,000 m^3 of bed material in the Cheakamus River for about 400 m downstream of the Cheekeye River confluence.

2 This material filled the bed back up to the previous bed level which existed in 1926 and 1958.

3 If the gravel was excavated, the water level of a large flood would be lowered by about 0.2 m upstream of the bridge.

4 Gravel excavation would likely cause damage to the left bank riprap downstream of the bridge.

5 The bridge has insufficient capacity for a large flood of about 200 years return period.

5 RECOMMENDATIONS

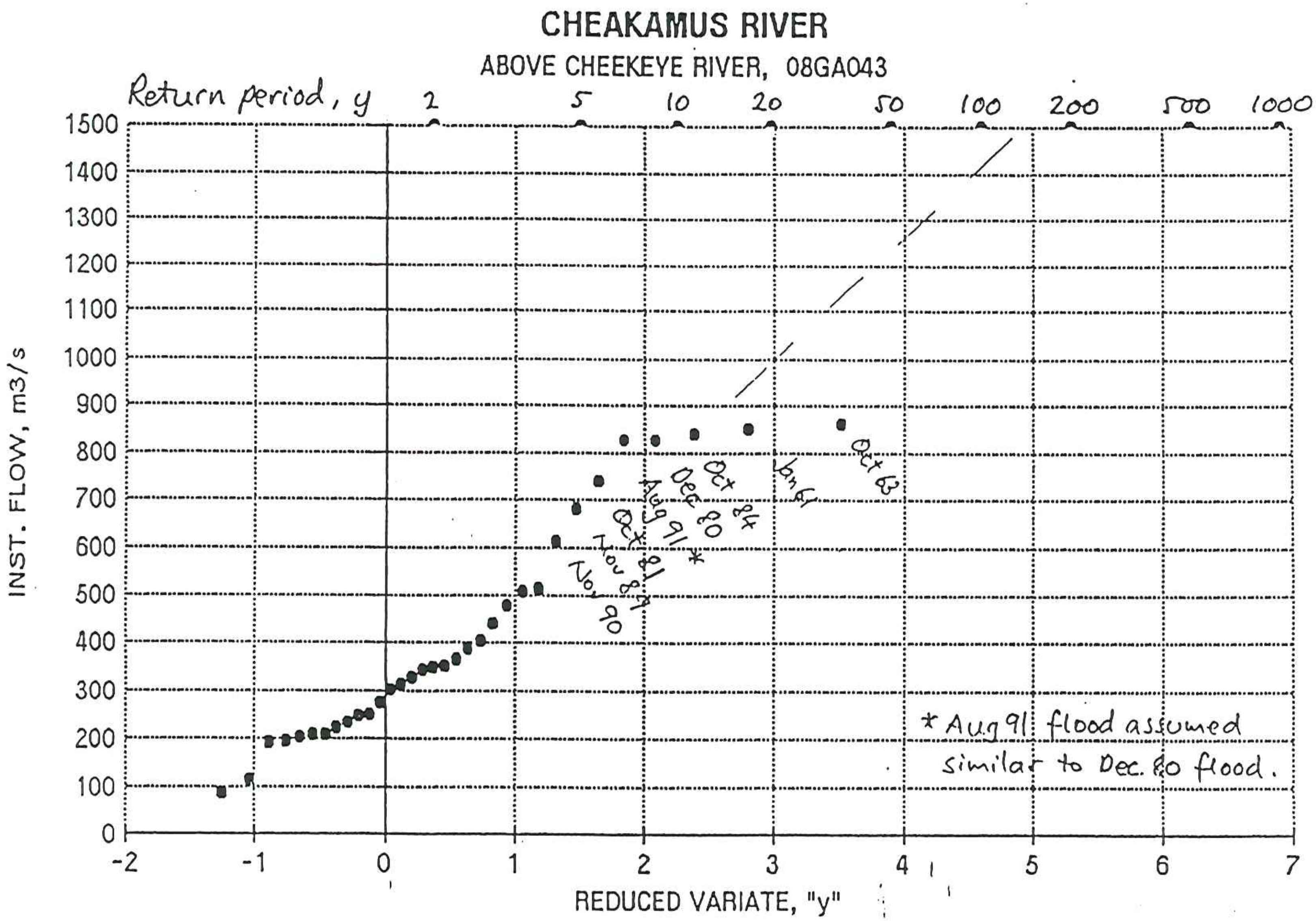
1 It is recommended that gravel removal not be carried out if its principal purpose is to lower flood water levels, due to the relatively small impact, probable damage to the left bank riprap, and the requirement for continuing maintenance.

2 A floodway should be reserved on the right bank around the bridge. The floodway could be dyked, and the road shoulders armoured to reduce future damage in large floods.

6 REFERENCE DRAWINGS

Figure 1.
Site 1.040.020 REVIEW sheets 1-4.

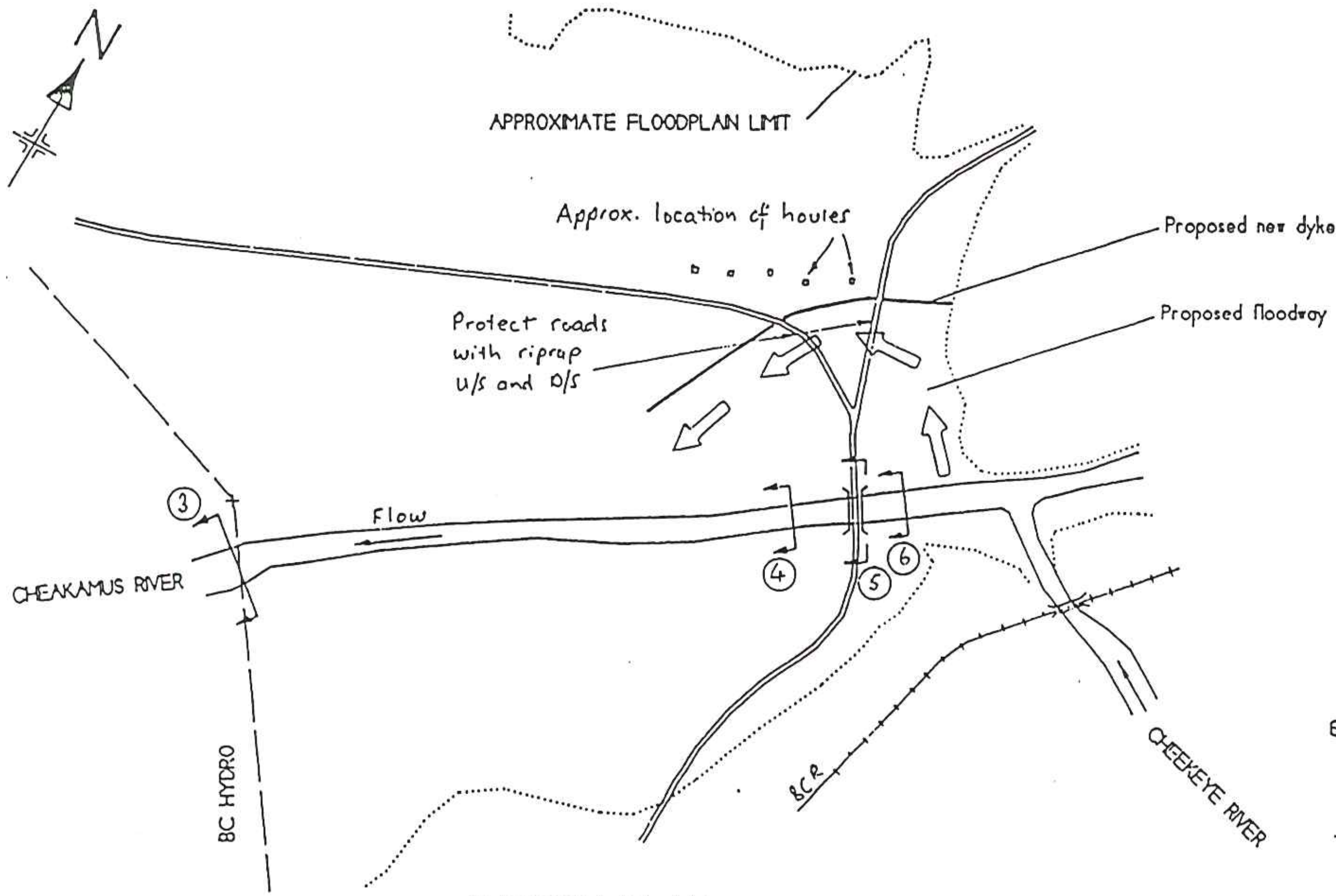
(172R1)



C. Robert Bland, P. Eng., consulting engineer

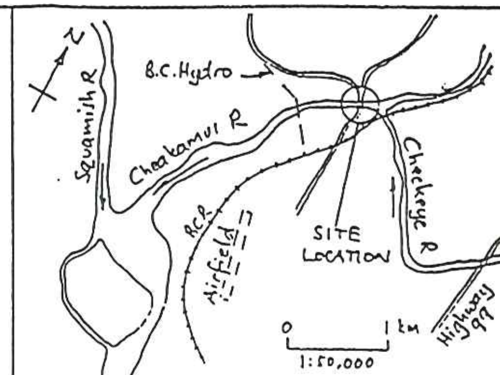
CHEAKAMUS RIVER
FLOOD FLOWS

FIG. 1

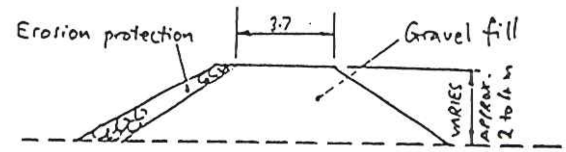


SKETCH PLAN
not to scale

1:5,000 100 0 200 m
Approximate scale



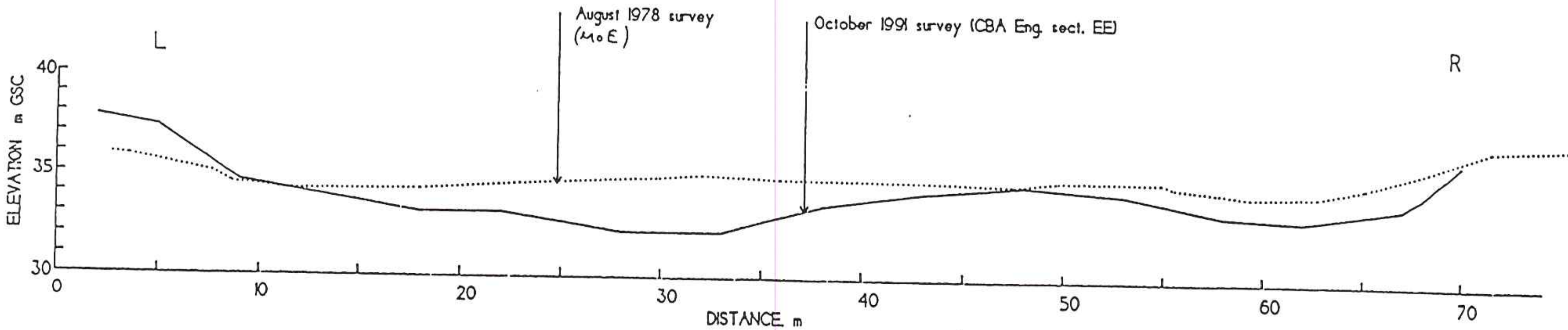
LOCATION PLAN



DYKE CROSS SECTION
not to scale

REVIEW

DATE: 12 March 1992 C. Robert Bland P. Eng. consulting engineer	WATER MANAGEMENT DIVISION OIC 1298. AUGUST 1991 FLOOD	CHEAKAMUS RIVER AT PARADISE VALLEY BRIDGE	SITE: 1.140.020 SHEET 1 OF 4

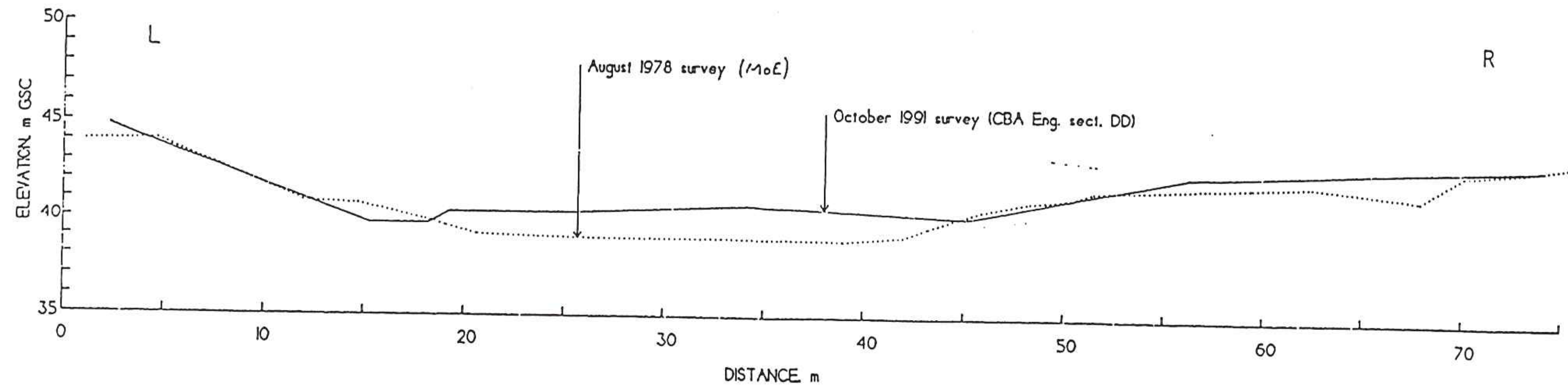


SECTION 3 (600 m D/S of bridge)

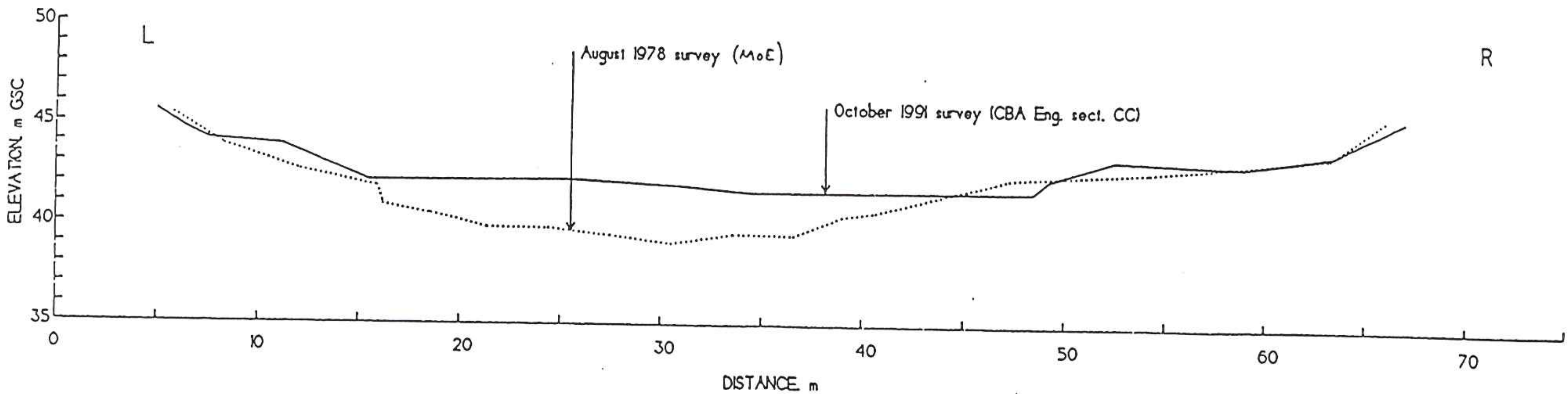
1:200 1 0 10 m

REVIEW

DATE: 12 March 1992 C. Robert Bland P. Eng. consulting engineer	WATER MANAGEMENT DIVISION OIC 1298. AUGUST 1991 FLOOD	CHEAKAMUS RIVER AT PARADISE VALLEY BRIDGE COMPARISON OF BED LEVELS	SITE: 1.040.020 SHEET 4 OF 4



SECTION 4 (50 m D/S of bridge)



SECTION 6 (50 m U/S of bridge)

REVIEW

DATE: 12 March 1992 C. Robert Bland P. Eng. consulting engineer	WATER MANAGEMENT DIVISION OIC 1298. AUGUST 1991 FLOOD	CHEAKAMUS RIVER AT PARADISE VALLEY BRIDGE COMPARISON OF BED LEVELS	SITE: 1 . 040 . 020 SHEET 3 OF 4

APPENDIX XII-C

REVIEW OF GRAVEL DEPOSITION BY C.R. BLAND, P. ENG.

SENT FROM FAX NO. 852-5419 1724

B.C. ENVIRONMENT, LANDS AND PARKS
WATER MANAGEMENT DIVISION
34345 VYE ROAD, ABBOTSFORD, B.C. V2S 4N2

PHONE: 852-5404

DATE: MAY 20/92

TO: KEN ROOD

N.W. HYDRAULICS

FAX: 980-9264

TOTAL PAGES SENT: 2
(including this page)

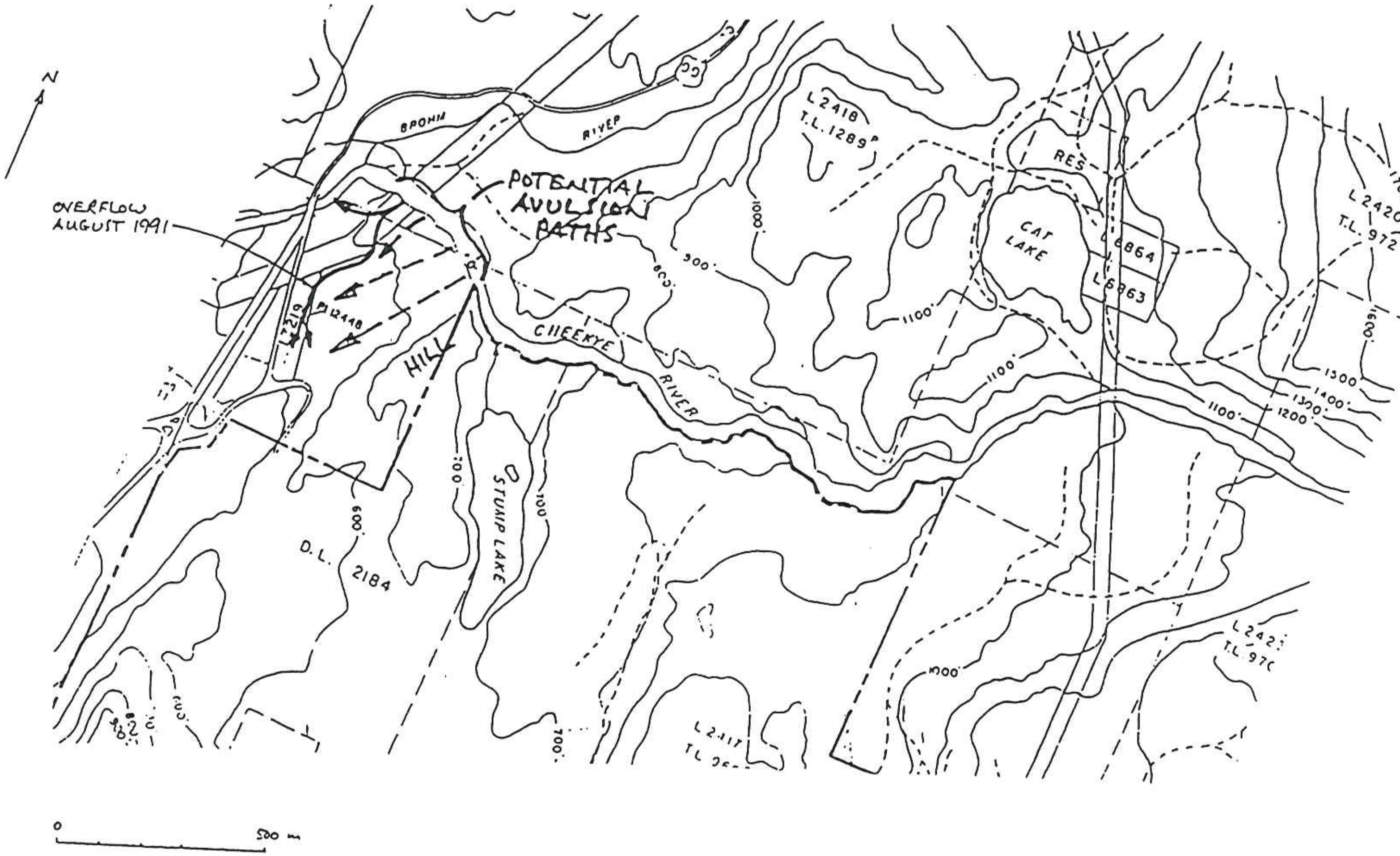
FROM: D.B. PATERSON

Inspector of Dykes' Office, Water Management Division

SUBJECT: CHEEKEYE RIVER

INSTRUCTIONS: IN FEB/85 THERE WAS APPROX. 35,000 m^3 OF GRAVEL REMOVED FROM THE CHEEKEYE RIVER CHANNEL. THE GRAVEL WAS DOZED INTO A LINEAR STOCKPILE ALONG THE LEFT BANK AS SHOWN

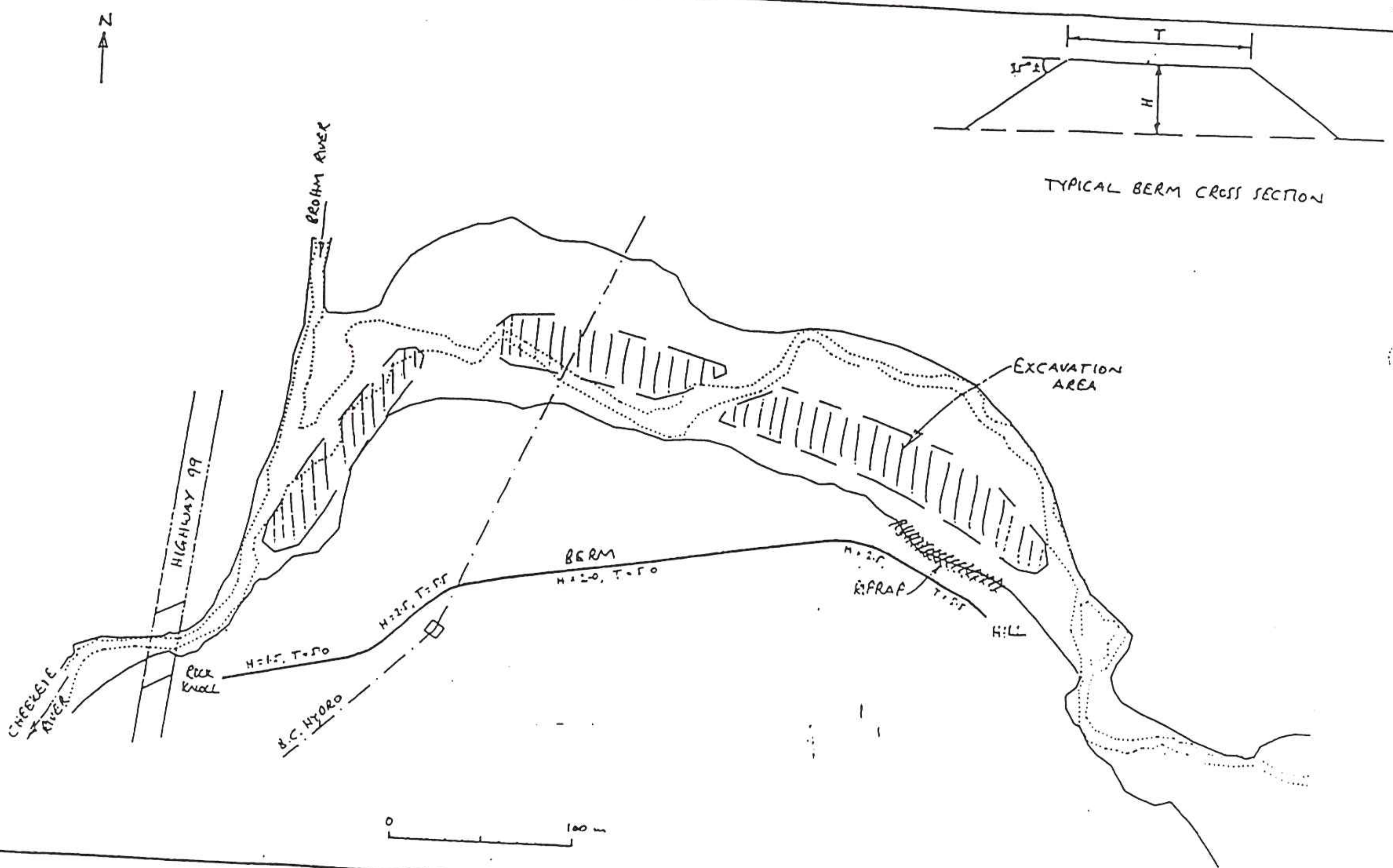
Original to follow? ( ) Yes (✓) No Urgent? ( ) Yes ( ) No



C. Robert Bland P. Eng. consulting engineer

CHEEKEYE RIVER
AVULSION HAZARD

FIG. 4



C. Robert Blond P. Eng. consulting engineer

CHEEKEYE RIVER
BERM

FIG.
5

WATER MANAGEMENT DIVISION
OIC 1298, AUGUST 1991 SQUAMISH AREA FLOOD

REVIEW SITE: 1.050.020

DESCRIPTION: Cheekye River, gravel removal 100m D/S to 500m U/S of Fernwood Road

BY: C. Robert Bland, P. Eng. **DATE:** 16 June 1992

— DRAFT —

INTRODUCTION

The project was identified as "Cheekye River near Fernwood Road. Remove gravel from 100m D/S to 500m U/S Fernwood Road. Same area as Task 2.070.010 under OIC 1819".

This review was required to determine whether further gravel should be removed, since some had already been removed in September 1991.

PREVIOUS GRAVEL REMOVAL

Approximately 35,000 m^3 of gravel was removed from the Cheekye River from opposite Fernwood Road to about 650 m upstream during January to March 1985 (see figure 1). The material was bulldozed mostly to a linear stockpile along the left bank, and a small portion to the right bank. Photographs of the work are included on figure 4. (Information from Mr. B. Patterson, Water Management.)

Following the November 1990 flood, gravel removal commenced in late August 1991. About 4,000 m^3 had been removed before the August 29/30 flood deposited up to about 2.5 m depth of more gravel. Gravel removal continued in September 1991, and a further quantity of approximately 18,000 m^3 of gravel was removed (22,000 m^3 in total). Gravel was removed by truck and used to fill local properties, build up the Cheekye River left bank downstream of Fernwood Road, and for fill by the District of Squamish on the Cheakamus Valley road in IR 11. (Information from CBA Engineering Ltd.)

An analysis of the as-constructed drawings by CBA Engineering Ltd. was made to compare the river bed after excavation in September 1991, to the pre-August 1991 flood condition. This showed that in the reach 0 to 415 m upstream of Fernwood Road, the river bed was lowered below the pre-

1991 flood ~~1991~~ bed by 3,800 m^3, corresponding to an average depth of 0.3 m,. In the reach from 415 m to 550 m upstream of Fernwood Road a further 4,200 m^3 of excavation (0.6 m average depth) would be required to return the river to the pre-August 1991 condition.

HYDROLOGY

Records of flood discharge on the Cheekye River are not available. Flood flow estimates were obtained by means of a regional analysis.

Five rivers were selected from the Water Survey of Canada data for the regional analysis. Criteria used in the selection were a similar mountainous setting, and the availability of instantaneous flow records. A statistical analysis was carried out on each river's records to obtain flood flow estimates for various return periods. Flood flows were related to catchment area using Creager's equation:

$$Q = 46CA^{x} \ ft^3/s, \quad \text{where } A = \text{area, } mi^2, \quad x = 0.894A^{(-0.048)}$$

The results were as follows:

RIVER	CATCHMENT AREA, km^2	CREAGERS "C" 2-yr	20-yr	200-yr
N. Alouette R	37.3	7.3	14.1	19.8
Stawamus R	40.4	5.5	10.9	15.8
Kanaka Cr	47.7	6.0	15.5	24.7
Norrish Cr	117	9.0	18.0	25.2
Mamquam R	334	5.3	8.9	12.1
Range of "C"		5.3-9.0	8.9-15.5	12.1-25.2

(Hydrological note: Gumbel Type 1 extreme distribution, annual maximum series)

In view of the steep slopes of the Cheekye River catchment, flood flows are likely to be near the upper limit of the range of the regional analysis, corresponding to the following flows:

LOCATION	CATCHMENT AREA, km^2	FLOOD FLOW, m^3/s 2-yr	20-yr	200-yr
Cheekye R at BCR bridge	58	130	220	360

HYDRAULIC CALCULATIONS

The as-built drawings after the September 1991 gravel removal show that the The Cheekye River has a bed width varying between about 45 and 80 metres in the study reach. The banks vary in height between 3.0 and 4.5 metres for the left bank, and between 2.0 and 4.0 metres for the right bank.

Figure 2 shows the average surface width of natural gravel bed rivers in relation to their 2-year flood. The Cheekye River in the study reach has sufficient width that instability due to being too narrow is not expected to be a problem.

Flow conditions were calculated for a channel with a bed width of 50 m, a slope of 0.043, and Manning's "n" determined from the estimated D-85 bed material size of 0.4 m as follows:

	2-year	20-year	200-year
Discharge, m^3/s	130	220	360
Velocity, m/s	2.9	3.7	4.7
Depth, m	0.9	1.1	1.5
Froude Number	1.0	1.2	1.3

It is evident that an adequate Cheekye River channel exists for a water flood of at least 200 years return period. At least 1.0 m of further gravel deposition would be required the cause a large flood to overflow the channel banks, and overflow would occur on the right bank before the left bank (unless the left bank berm was eroded away).

Figure 3 shows the calculated bed material transport capability of the Cheekye River in relation to its bed width for water floods. The existing channel width is satisfactory for optimal transport. The Cheekye River is also subject to mud flows. One such event was reported to move at about 5 miles per hour, and have a depth of about 10 ft (Ref. W.C. Jones, B.C. Dept. of Mines, 1959).

It would be advantageous for the channel to be wide so as to accommodate more deposition from floods or mud flows before overflow occurs.

CONCLUSIONS

1. Sufficient gravel has already been removed in the reach 0 to 550 m upstream of Fernwood Road that a large flood as well as gravel deposition similar to the August 1991 flood could be accommodated without overflow of the left bank, although overflow of the right bank cannot be ruled out.

2. Gravel removal in the reach from 550 m to 1,400 m upstream of Fernwood Road would be beneficial. Right bank overflow in this reach occurred in January 1992. This reach was not identified as proposed site of work under OIC 1298.

RECOMMENDATIONS

1. The Cheekye River for 1,400 m upstream of Fernwood Road should be designated an area for commercial gravel removal under B.C. Lands. The site 1.050.020 can then be deleted from OIC 1298.

2. Gravel removal should be encouraged first in the reach from 550m to 1,400m upstream of Fernwood Road (approximate depth of cut 2.0 m over at least 50 m wide bed width), and the reach from 415 m to 550 m upstream of Fernwood Road (approximate depth of cut 0.6 m).

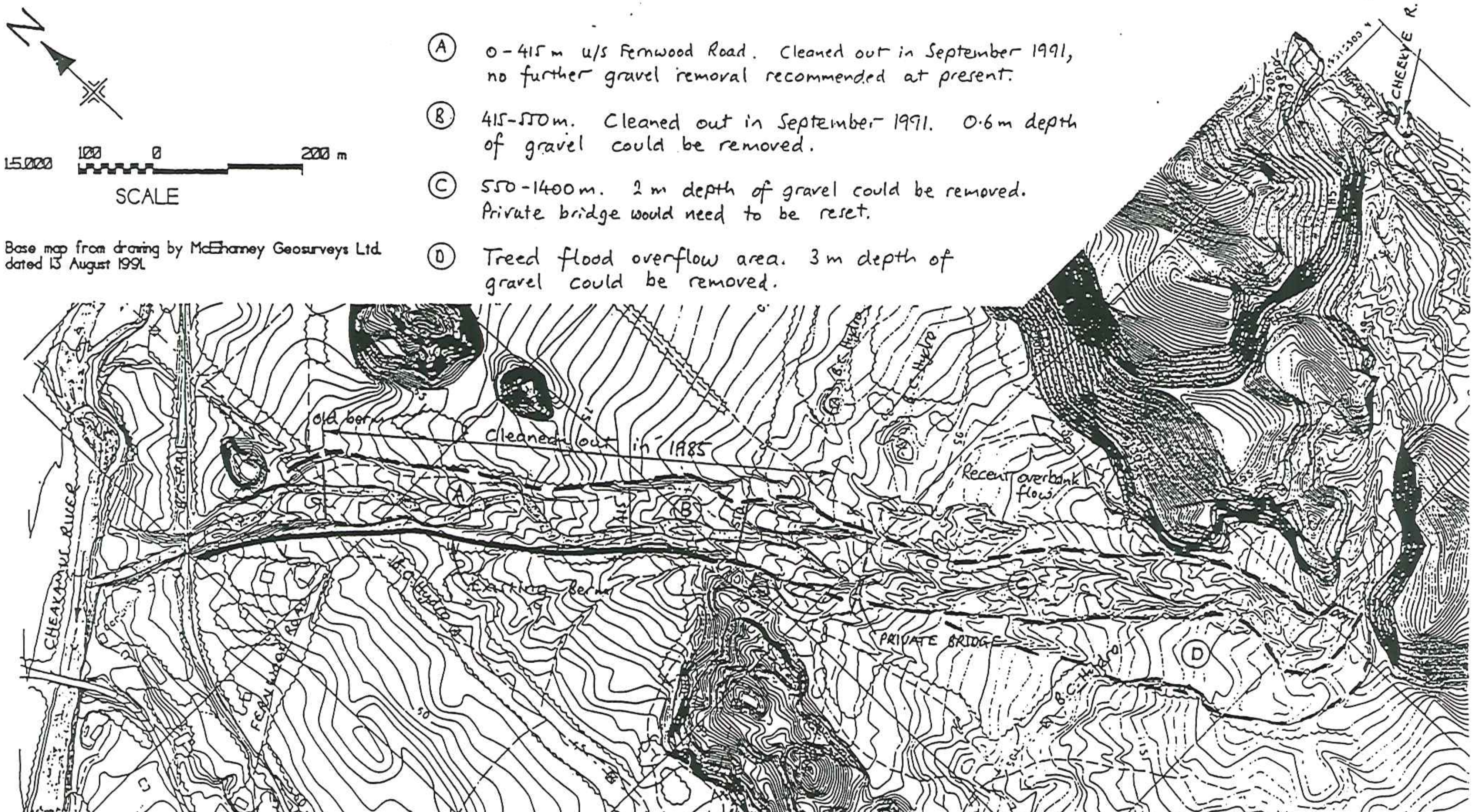
3. The private bridge at 700 m upstream of Fernwood Road will require modification if gravel removal is carried out in the vicinity.

4. After the first years gravel removal the effects should be monitored before further removal is permitted. Particular attention should be given to whether changes to bed material transport occur, which affect the private bridge at 700 m upstream of Fernwood Road, or the riprap and concrete sills of the BCR bridge, or the Cheakamus River downstream of the confluence.

FIGURES

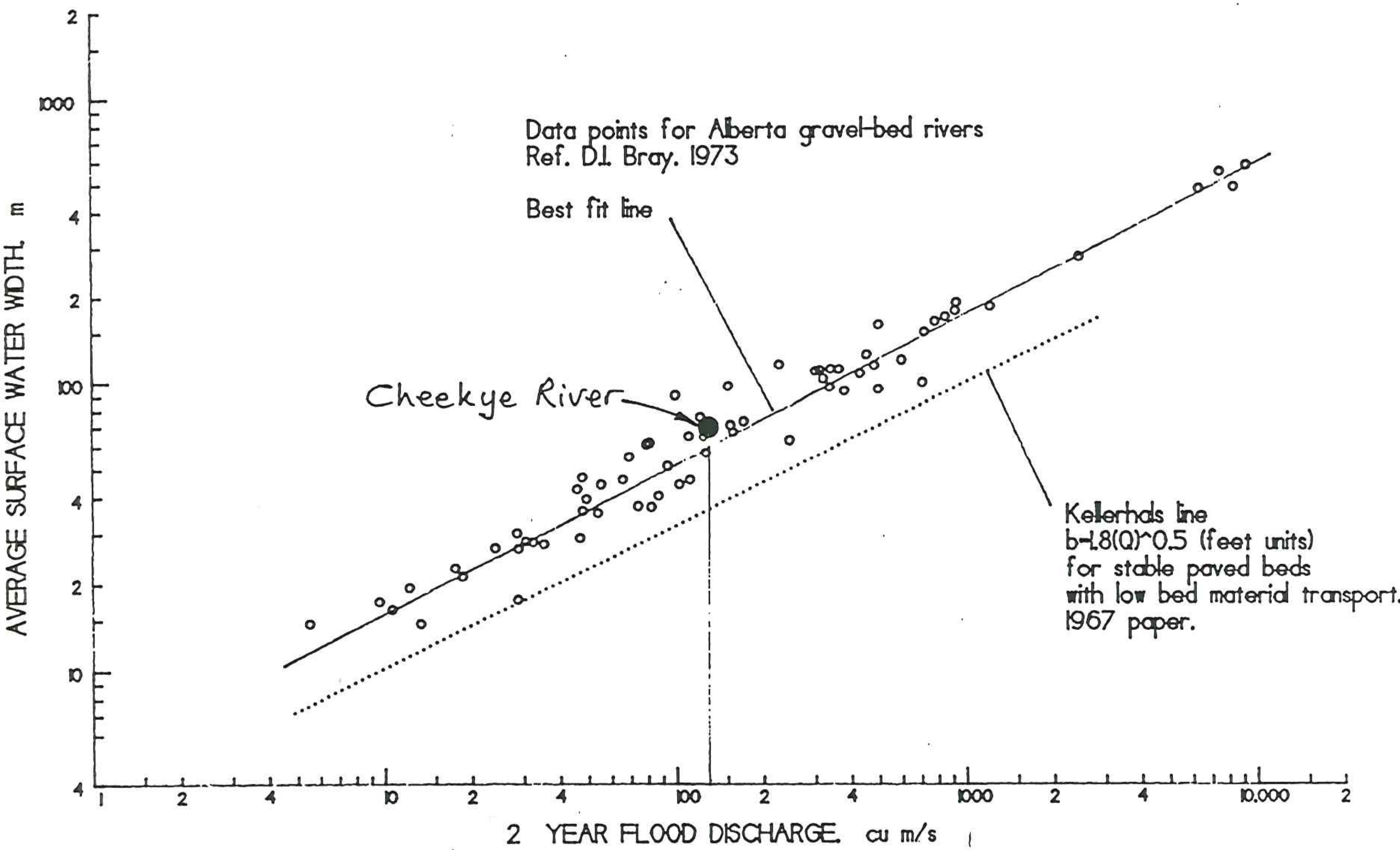
Figure 1, Location plan.
Figure 2, Surface width of natural rivers.
Figure 3, Bed material transport.
Figure 4, Photographs.

(172R14)



REVIEW

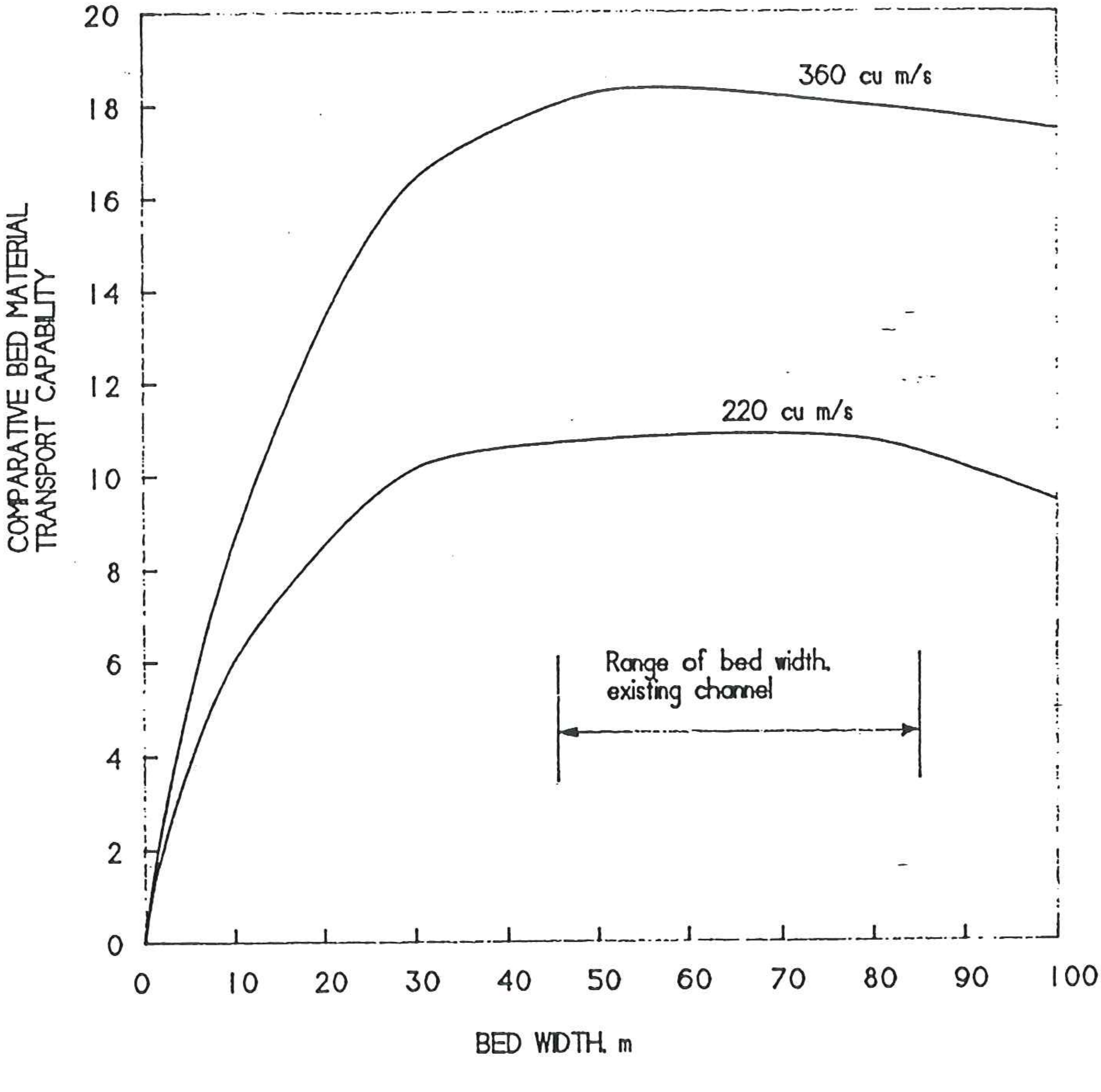
DATE: 15 June 1992 C. Robert Bland P. Eng. consulting engineer	WATER MANAGEMENT DIVISION OIC 1298. AUGUST 1991 FLOOD	CHEEKYE RIVER U/S OF FERNWOOD ROAD LOCATION PLAN	SITE: 1.050.020 SHEET 1 OF 4



C. Robert Bland. P. Eng. consulting engineer

SURFACE WIDTH
OF NATURAL RIVERS

FIG. 2



(Bed material dm-0.25 m, slope-0.043, D-85-0.4m, side slope z-2)

C. Robert Bland, P. Eng., consulting engineer

CHEEKYE RIVER GRAVEL TRANSPORT

FIG. 3

APPENDIX XII-D

AUGUST 1991 SQUAMISH AREA FLOOD BY C.R. BLAND, P. ENG.

A REPORT PREPARED FOR
B. C. ENVIRONMENT
WATER MANAGEMENT DIVISION

FILE NO. 55.4804
OIC 1298 - AUGUST 1991 SQUAMISH AREA FLOOD

CHEEKYE RIVER

INVESTIGATIONS AND BERM DESIGN

(SITE 1.050.040)

24 August 1992

C. Robert Bland, P.Eng.
Consulting Hydrotechnical Engineer
4013 Bayridge Crescent
West Vancouver, B.C.
V7V 3K5

1. SUMMARY

The August 29/30 1991 flood caused a short duration overflow of the left bank of the Cheekye River, just upstream of the highway 99 road bridge. The overflow was probably due to infilling of the river bed with gravel.

The site was inspected, and a left bank avulsion hazard was identified extending from the highway bridge for about 0.5 km upstream. A set-back berm varying in height from 1.5 m to 4.0 m was designed as a control measure. The berm was constructed using bed material from the river during the period 15 October to 9 November 1991. The construction cost was $ 124,583.24 excluding engineering costs.

Erosion of the right bank of the Cheekye River near Cat Lake was investigated in case a flood could be caused by the release of Cat Lake water. It was concluded that there is little danger of a flood at present. Probably at least 50 m of further bank erosion would be necessary to cause a release of water, but a large flood would not necessarily occur. A riprapped berm could be considered to control the ongoing erosion.

2. GENERAL

2.1 Authorization and Terms of Reference.

Following the flooding in the Britannia - Squamish - Pemberton area on 29/30 August 1991, restoration works were assessed under O.I.C. No. 1298 by a Water Management Division task force under Mr. Aubrey Brown, project manager. The Cheekye River was identified as an area to be reviewed.

The review and berm design was assigned to C. Robert Bland, P.Eng., engineering consultant to the task force. The Ministry of Transportation and Highways provided surveying and construction management for the Cheekye River berm project.

2.2 Location of the study area.

This report covers the upper part of the Cheekye river fan, extending from the highway 99 road bridge about 0.5 km upstream, and a right bank erosion site adjacent to Cat Lake, located about 2.0 km upstream from the highway bridge (figure 1).

3. HYDROLOGY

Records of flood discharge on the Cheekye River are not available. Flood flow estimates were obtained by means of a regional analysis.

Five rivers were selected from the Water Survey of Canada data for the regional analysis. Criteria used in the selection were a similar mountainous setting, and the availability of instantaneous flow records. A statistical analysis was carried out on each river's records to obtain flood flow estimates for various return periods. Flood flows were related to catchment area using Creager's equation:

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$$x = 0.894A^{(-0.048)}$$

The results were as follows:

RIVER	CATCHMENT AREA, km²	2-yr	CREAGERS "C" 20-yr	200-yr
N. Alouette R	37.3	7.3	14.1	19.8
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Mamquam R	334	5.3	8.9	12.1
Range of "C"		5.3-9.0	8.9-18.0	12.1-25.2

(Hydrological note: Gumbel Type 1 extreme distribution, annual maximum series)

In view of the steep slopes of the Cheekye River catchment, flood flows were considered to be near the upper limit of the range of the regional analysis. This resulted in the following estimated flows:

LOCATION	CATCHMENT AREA, km²	2-yr	FLOOD FLOW, m³/s 20-yr	200-yr
Cheekye R at highway 99	55.8	130	220	350
Cheekye R upstream of Brohm River	30.0	80	150	230

4 THE CHEEKYE RIVER FAN

4.1 General Description

Just downstream of Stump Lake, the Cheekye River course is bedrock controlled. It emerges onto the fan about 0.5 km upstream of the highway 99 road bridge. The upper part of the fan slopes steeply at about 7 percent slope, and is covered by second growth forest. The fan has numerous old channel depressions which flow to the south, some of which contain exposed cobbles and boulders. The fan surface is thinly covered by vegetation debris. The underlying material appears to be similar to the river bed material.

The Cheekye River is shallowly incised in the fan, about 2 to 3 m below bank level. After the August 1991 flood the channel width was 60 to 90 m, narrowing to about 40 m downstream of the Brohm river. The low flow channel snaked around the flood-worked bed material, and was about 5 to 10 m in width.

The bed material ranged from boulder to sand sizes. The surface layer of boulders was generally free of finer material. Below the surface layer, the boulders were surrounded by a sand-gravel-cobble matrix. The boulder size decreased in a downstream direction.

The size of the surface layer of the bed material was visually estimated as about 1.1 m D-85, and about 2.0 m D-100 equivalent spherical diameter. (D-85 being the size for which 85 percent of the material is smaller).

The Cheekye River is contained in a narrow bedrock canyon at the highway bridge. Bedrock is not exposed in the creek bed, and the depth to bedrock in unknown. The 1973 bridge survey drawing shows that the bed elevation was about 2.0 m lower in 1973 than in October 1991.

Comparison of the 1957 and 1990 aerial photographs (figures 2 and 3) showed that the river location has moved laterally less than about 30 to 40 m in the 0.5 km reach upstream of the highway bridge during this 32 year period.

4.2 The August 29/30 1991 Flood Event

The Cheekye River flood was observed by CBA Engineering at the lower Cheekye River as a wave of water and debris commencing at 5.30 pm on 29 August, and continuing into the evening. After the flood, 28,000 m^3 extra gravel was deposited over 600 m of channel upstream of the BCR railway bridge, and gravel was swept into the Cheakamus River.

There is evidence that a substantial quantity of bed material was deposited, and subsequently eroded in the reach above the highway 99 bridge. A remnant of gravel could be seen after the flood at about 4.0 m above the bed near the road bridge. Remnants of other gravel deposits were observed further up the river, about 2-3 metres above the post-flood bed level.

Water overflowed the left bank upstream of the road bridge adjacent to the BC Hydro tower, and carried cobbles and log debris onto the bank. The silty water marks were followed for about 300 m to the south where they petered out (figure 4). The flow at the overflow point was about 25 m in width, and had a maximum depth of 0.3 m. It was estimated from the flood marks to be in the range 6 to 10 m^3/s, and probably lasted for only a few minutes.

Water surface profiles were computed using the HEC 2 computer program for several discharges, with and without partial channel blockage. It is postulated that water overflowed the left bank because of bed material accumulation in the channel. The flow at the time of maximum bed accumulation was probably less than 200 m^3/s. The bed material accumulations likely were eroded, and transferred downstream during the flood.

Comparison of the post August 1991 flood conditions with the 1990 aerial photograph (figure 3) showed that the river continued to erode the right bank between 100 and 300 m upstream of the highway bridge. In addition, the left bank adjacent to the BC Hydro transmission line was eroded leaving an island of old material. The channel width increased from about 40 m in 1990 to about 100 m after the 1991 flood at this location.

4.3 Avulsion Hazard

The August 1991 left bank overflow at the BC Hydro transmission line is shown on figure 4.

At point "a" on figure 4, the August 1991 high water mark was about 0.3 m below the left bank, at an old south flowing channel location.

It is considered that there is a high risk of a left bank avulsion between the highway 99 road bridge and the range of hills about 0.5 km upstream.

5. BERM DESIGN

The berm design is shown on figure 5. The alignment was selected in the field to reduce the hazard of left bank overflow and potential channel avulsion. The alignment was set back from the present channel where the topography allowed.

The berm varies in height between approximately 1.5 and 4.0 m. It was constructed from well graded fill consisting of boulders, cobbles, gravel, sand and silt, which was excavated from the river channel as indicated on figure 5. Riprap protection on the left river bank was provided near the upstream end of the berm. The riprap material is large boulders from the river bed, supplemented with talus slide material.

6. CONSTRUCTION

Construction of the Cheekye River berm was managed by Ministry of Transportation and Highways (MoTH) during the period 15 October to 9 November 1991. Before and after construction photographs are included as figure 7.

MoTH prepared as-constructed drawings. A summary of the quantities, prepared by MoTH is as follows:

Excavation	21,360 m^3 (includes channelling river bed)
Fill on berm	13,477 m^3
Fill in river	10,311 m^3 (channelling river)
Riprap	1,000 m^3.

The construction cost was as follows:

ITEM	DESCRIPTION	QUANTITY	UNIT	RATE	COST
1	Clearing	1	LS	2880.00	2880.00
2	JD 992 DLC excavator	176.75	hr	160.13	28302.98
3	Cat 245 BH excavator	32.5	hr	230.25	7483.13
4	Cat 245 ME excavator	21.5	hr	236.25	5079.38
5	Cat D9H bulldozer	127	hr	160.50	20383.50
6	Komatsu D355A b.dozer	98	hr	168.50	16513.00
7	Volvo 860/861 off-highway trucks:				
	16cy	16	hr	87.50	1400.00
	18cy	295	hr	87.50	25812.50
8	Truck, 15.3 m^3	40	hr	76.00	3040.00
9	Cat 769 off-highway trucks	81.5	hr	152.50	12428.75
10	Flag persons	97	hr	12.00 basic	1260.00
11	Riprap supply	1000	m^3	0.00	0.00
	TOTAL				124583.24

The above costs do not include MoTH crew costs and supplies.

Riprap material was provided free of charge by MoTH. It was excavated from a talus slide on the east side of Highway 99, about 5.5 km north of the Cheekye River bridge.

7. INVESTIGATION AT CAT LAKE

Cat Lake is located on the right bank of the Cheekye River about 2.0 km upstream of the Highway 99 road bridge.

Concern was expressed that the eroding bank of the Cheekye River might reach the lake, inducing a flood.

The lake and river bank were inspected in October 1991. The lake edge is presently about 100 m from the eroding bank which is about 35 m in height. Soundings in the lake were taken at 5 locations. The maximum depth was 31.6 m.

A comparison was made between the 1957 and 1990 aerial photographs (figures 2 and 3). The toe of the river bank appears to have eroded laterally by about 40 m since 1957, as illustrated on figure 6. The material exposed on the eroding face is a stratified granular material, and stands near vertically to heights of about 20-25 m (see figures 6 and 8). Older slopes are about 1V:1H or flatter.

It was concluded that regression of the existing near-vertical bank to a 1V:1H slope would not induce a flood from Cat Lake. At least 50 m of further erosion would likely be necessary to release lake water.

A flood of a similar magnitude to the 200 year Cheekye River flood would require the release of the top 5 m of water in Cat Lake within about 20 minutes. It is considered unlikely that the bank material could erode at a sufficient rate for this scenario to occur. Even if water were released, it is by no means certain that a large flood would result.

Further erosion of the bank toe could be controlled by construction of a riprapped berm.

C.R. Bland

PROFESSIONAL ENGINEER
PROVINCE OF BRITISH COLUMBIA
C. R. BLAND

Enc: Figures 1-8.

(172REP1)

APPENDIX XII-E

LANDSLIDE BREACH AND MUDFLOW ANALYSIS

LANDSLIDE BREACH AND MUDFLOW ANALYSIS

1.0 INTRODUCTION

In order to obtain a better understanding of one of the possible debris flow initiation mechanisms, studies have been carried out of a breach of a landslide in the upper Cheekye basin and the resulting mudflow down the channel. The analysis was performed using two dambreak computer models available from the U.S. National Weather Service (NWS). The initial breach characteristics and outflow hydrograph were computed using the NWS program BREACH. The resulting outflow was routed along Cheekye River using the NWS dambreak model DAMBRK. A brief description of each model is included as Appendix XII-F.

2.0 ASSUMPTIONS AND INPUT ANALYSIS

To determine the breach characteristics and the outflow hydrograph, BREACH required the following input variables:

- the inflow to the reservoir,
- the reservoir surface area as a function of depth (or landslide height),
- the crest and bottom elevations of the landslide at the start of the breach,
- the first cross-section downstream of the landslide,
- the slope of the upstream and downstream faces of the landslide, and
- the parameters describing the landslide material.

A landslide was assumed to initiate at the Cheekye Ridge linears, blocking the east tributary of Cheekye River from Atwell Peak by a dam at Site A (Figure XII E-1). The reservoir formed behind the landslide was assumed to be completely full at the initiation of the breach and the inflow, with respect to the breach outflow, was assumed to be negligible. Table XII E-1 shows the reservoir area as a function of depth and Table XII E-2 gives the likely landslide dam and material characteristics.

Once the dam breach characteristics and the outflow hydrograph had been computed, they were input into the DAMBRK model. The mudflow subroutine of DAMBRK was utilized which required assigned material properties as shown on Table XII E-3.

Twelve cross-sections were used for the mudflow routing and these extended from the landslide to the top of the lower fan (Figure XII E-2), a distance of about 7.0 km. Preliminary model runs indicated that the solution did not converge at the cross-section beneath the Highway 99 bridge as the channel was too narrow and high, so the mudflow was routed to the left of the bridge.

3.0 RESULTS

3.1 Landslide Dam Breach

Preliminary model tests were carried out to determine the sensitivity of BREACH to small changes to the input variables and it was determined that the maximum breach outflow and time to peak were insensitive to small changes to the material properties listed in Table XII E-2.

Initially, the height of the landslide at Site A was set at 135 m, creating a reservoir with a volume of approximately 4.27 Mm^3. However, based on field observation of debris flow deposits on Cheekye Fan, it was estimated that a larger reservoir was required. Two methods were used to increase the reservoir volume: first the height of the landslide dam was kept at 135 m and the reservoir volume artificially increased by changing the slope of the area in the reservoir area-depth curve; and, second the height of the landslide was increased to 155 m.

The final breach dimensions were used to calculate the volume of sediment removed from the landslide dam and the total outflow volumes were calculated from the area under the outflow hydrographs (Figure XII E-3). Total outflow and sediment volumes for the various landslide dams are shown in Table XII E-5.

The filling times for the three reservoirs at Site A are presented in Table XII E-5. The total depth of rainfall was calculated as the reservoir volume divided by the drainage area (~11.0 km^2), assuming a runoff coefficient of 1.0. The minimum filling times were recalculated using the PMP's reported by B.C. Hydro for Cheakamus River watershed upstream of Daisy Lake Dam. The maximum filling times were calculated using the maximum mean monthly precipitation at Squamish. For a reservoir with a volume of 8.00 Mm^3, the minimum filling time is estimated to be about 3 days. Adjusting the filling time from a PMP event to a 100-year event, the filling time would increase by about 30% to 4 days.

3.2. Dam Break

Results from the breach analysis were input into the DAMBRK program and the maximum depth of flow at each of the twelve cross-sections were computed, the depth being measured from the lowest elevation in the cross-section. Initial sensitivity tests for a 135 m landslide with a reservoir volume of 4.27 Mm^3 indicated that the mudflow depth was sensitive to the initial yield stress (Tables XII-6 and XIIE-7).

Subsequent model runs for the two 8.00 Mm^3 reservoirs attempted to use an initial yield stress of 2 kPa; however, the solutions did not converge. Instead, depths were calculated using initial yield stresses of 10 kPa and 5 kPa for the 135 m (Tables XII E-8 and XII E-9) and 155 m (Tables XII E-10 and XII E-11) landslides, respectively. Since the initial yield stresses were greater than 2 kPa, water was routed down the channel to give a lower limit for the depths. Depths for a mudflow with an initial yield stress of 2 kPa would fall between the depth for water and the depth for a mudflow with an initial yield stress of either 5 kPa or 10 kPa.

Generally, the mudflow depths calculated for the larger reservoirs were similar to depths for the smaller reservoir, for similar initial yield stresses. For this reason, the depths calculated for the smaller reservoir using an initial yield stress of 2 kPa could be assumed to be representative of the depths for the larger reservoirs if an initial yield stress of 2 kPa were used.

4.0 CONCLUSIONS

The analyses yielded the following summary results:

- The breach of a landslide impounding a reservoir of 8.00 Mm^3 would release approximately 5.45 Mm^3 of water and 1.95 Mm^3 of sediment;

- Peak outflows would be upwards of 1,700 m^3/s and would occur within one hour of the initial breach;

- A reservoir with a volume of 8.00 Mm^3 would be filled by a 3-day PMP event, assuming a runoff coefficient of 1.0;

- The non-convergence problem encountered in the mudflow routing was associated with the selection of appropriate values for the timesteps, intermediate cross-sections, and weighting factors. Because the mudflow depths compared favourably between the smaller and larger reservoirs for similar yield stresses, it was considered that additional effort to fine-tune the model would not produce additional benefits

TABLE XII E-3

"DAMBRK" INPUT VARIABLES - MUDFLOW CHARACTERISTICS

Material Property	Value
Unit weight	20 kN/m^3
Dynamic viscosity	1 kPa-s
Yield stress	2 to 14 kPa
Exponent in power function which represents the stress-rate of strain relation (if Bingham plastic is assumed for fluid, then exponent set to 1.0)	1.0

TABLE XII E-4

"BREACH" OUTFLOW CHARACTERISTICS AND VOLUMES

Landslide Height (m)	Reservoir Volume (m^3)	Peak Outflow (m^3/S)	Time to Peak (hrs)	Total Outflow (Mm^3)	Total Sediment (Mm^3)
135	4.27 (10^6)	925	0.60	2.61	1.16
135	8.00 (10^6)	1,758	0.73	5.60	1.80
155	8.00 (10^6)	1,824	0.70	5.30	2.10

TABLE XII E-5

SITE A - RESERVOIR FILLING TIMES

Top Elevation of Landslide (m)	Hieght of Landslide (m)	Reservoir Volume (m^3)	Total Required Precipitation[1] (mm)	Filling Time	
				PMP[2]	Mean Rainfall at Squamish[3]
775	135	4.27E + 06	0.388 m	1.0 day	1.1 months
775	135	0E + 06	0.727 m	3.0 days	2.2 months
795	155	8.00E + 0.6	0.727 m	3.0 days	2.2 months

Note:

1) Calculated as the reservoir volume divided by the drainage area (~ 11.0 km^2), assuming a runoff coefficient of 1.0.

2) Based upon reported probable maximum precipitation (PMP) estimated for Cheakamus River watershed.

3) Based upon the maximum mean monthly precipitation at Squamish for the months of October to January.

TABLE XII E-6

MAXIMUM ELEVATION REACHED BY MUDFLOW

Sensitivity to Initial Yield Stress
Landslide Height = 135 m
Reservoir Volume = 4.27 Mm^3

X-Section	Distance from Landslide (km)	Thalweg Elevation (m)	Mudflow Elevation (m) Initial Yield Stress (kPa)			
			2	5	10	14
XS-1	1.75	480	485	486	490	495
XS-2	2.25	420	428	431	444	455
XS-3	2.70	400	405	406	416	425
XS-4	3.15	360	366	368	383	394
XS-5	3.60	330	336	340	357	363
XS-6	4.10	295	302	306	316	326
XS-7	4.60	260	266	270	280	292
XS-8	5.10	230	237	241	253	263
XS-9	5.46	210	217	221	231	241
XS-10	5.70	195	202	206	216	226
XS-11	6.41	165	169	172	178	188
XS-12	6.89	130	136	139	146	160

TABLE XII E-7

MAXIMUM DEPTH OF MUDFLOW

Sensitivity to Initial Yield Stress
Landslide Height = 135 m
Reservoir Volume = 4.27 Mm^3

X-Section	Distance from Landslide (km)	Thalweg Elevation (m)	Mudflow Elevation (m) Initial Yield Stress (kPa)			
			2	5	10	14
XS-1	1.75	480	5	6	10	15
XS-2	2.25	420	8	11	24	35
XS-3	2.70	400	5	6	16	25
XS-4	3.15	360	6	8	23	34
XS-5	3.60	330	6	10	27	33
XS-6	4.10	295	7	11	21	31
XS-7	4.60	260	6	10	20	32
XS-8	5.10	230	7	11	23	33
XS-9	5.46	210	7	11	21	31
XS-10	5.70	195	7	11	21	31
XS-11	6.41	165	4	7	13	23
XS-12	6.89	130	6	10	16	30

TABLE XII E-8
MAXIMUM ELEVATION REACHED BY MUDFLOW AND WATER

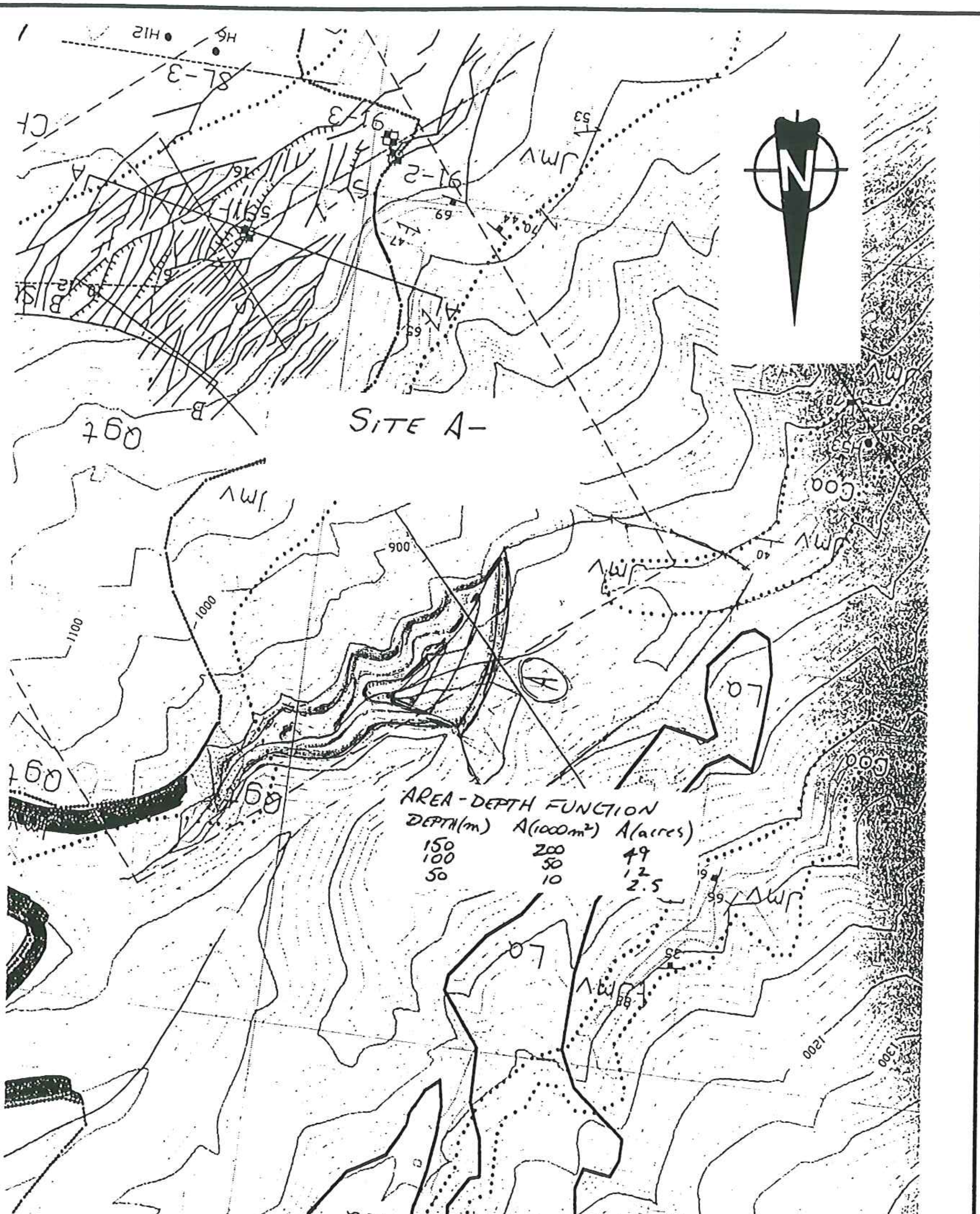
Initial Yield Stress = 10 kPa (mudflow only)
Landslide Height = 135 m
Reservoir Volume = 8.00 Mm^3

X-Section	Distance from Landslide (km)	Thalweg Elevation (m)	Mudflow Elevation (m)	
			Mudflow	Water
XS-1	1.75	480	490	483
XS-2	2.25	420	445	424
XS-3	2.70	400	416	403
XS-4	3.15	360	383	363
XS-5	3.60	330	357	334
XS-6	4.10	295	316	297
XS-7	4.60	260	280	263
XS-8	5.10	230	253	233
XS-9	5.46	210	231	213
XS-10	5.70	195	216	199
XS-11	6.41	165	179	166
XS-12	6.89	130	147	134

TABLE XII E-9
MAXIMUM DEPTH OF MUDFLOW AND WATER

Initial Yield Stress = 10 kPa (mudflow only)
Landslide Height = 135 m
Reservoir Volume = 8.00 Mm^3

X-Section	Distance from Landslide (km)	Thalweg Elevation (m)	Mudflow Elevation (m)	
			Mudflow	Water
XS-1	1.75	480	10	3
XS-2	2.25	420	25	4
XS-3	2.70	400	16	3
XS-4	3.15	360	23	3
XS-5	3.60	330	27	4
XS-6	4.10	295	21	2
XS-7	4.60	260	20	3
XS-8	5.10	230	23	3
XS-9	5.46	210	21	3
XS-10	5.70	195	21	4
XS-11	6.41	165	14	1
XS-12	6.89	130	17	4



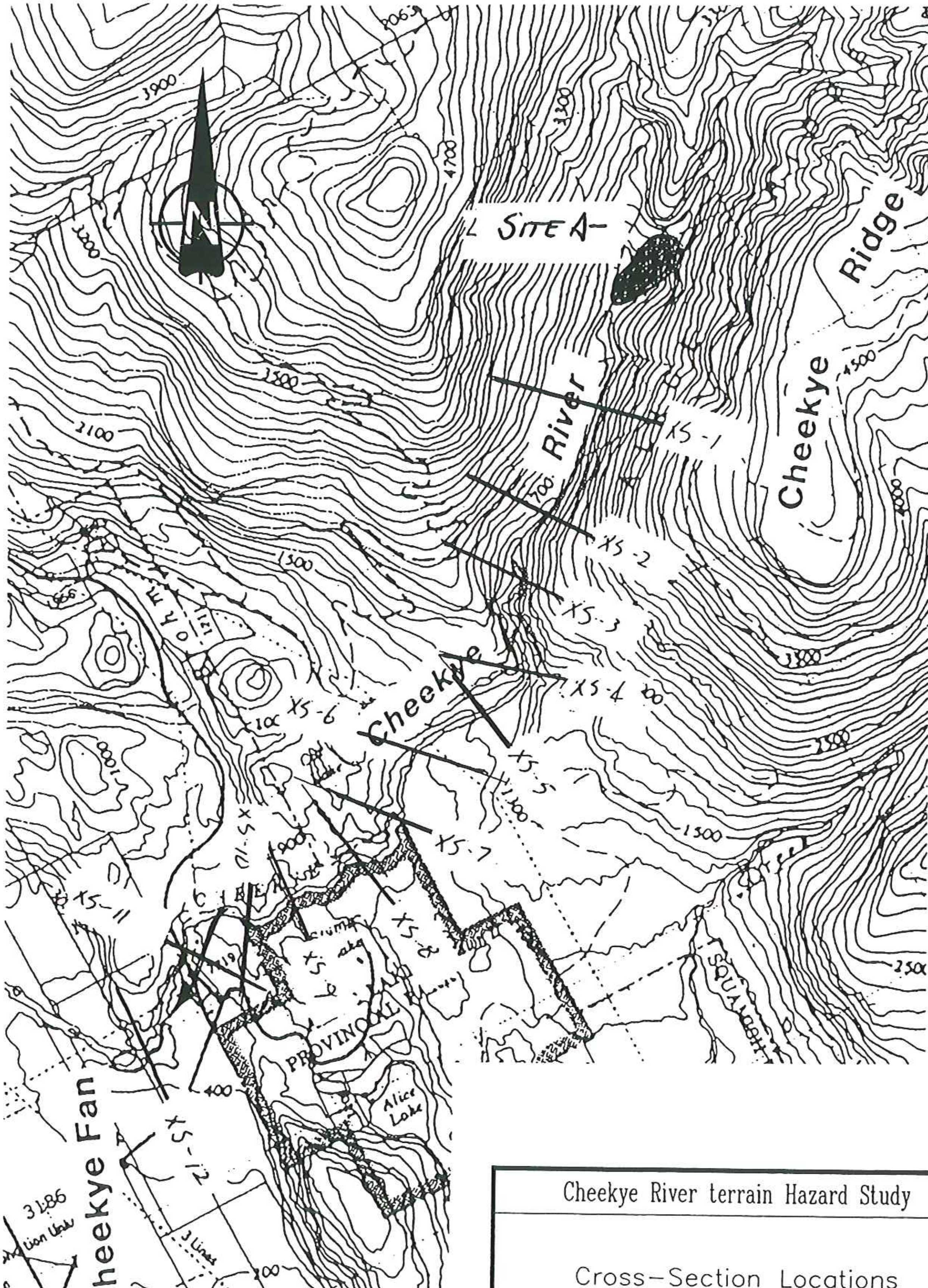
Cheekye River Terrain Hazard Study

Landslide Location
Site A-

northwest hydraulic consultants

NHCV 1724-014

Figure XIIE-1



Cheekye River terrain Hazard Study

Cross-Section Locations

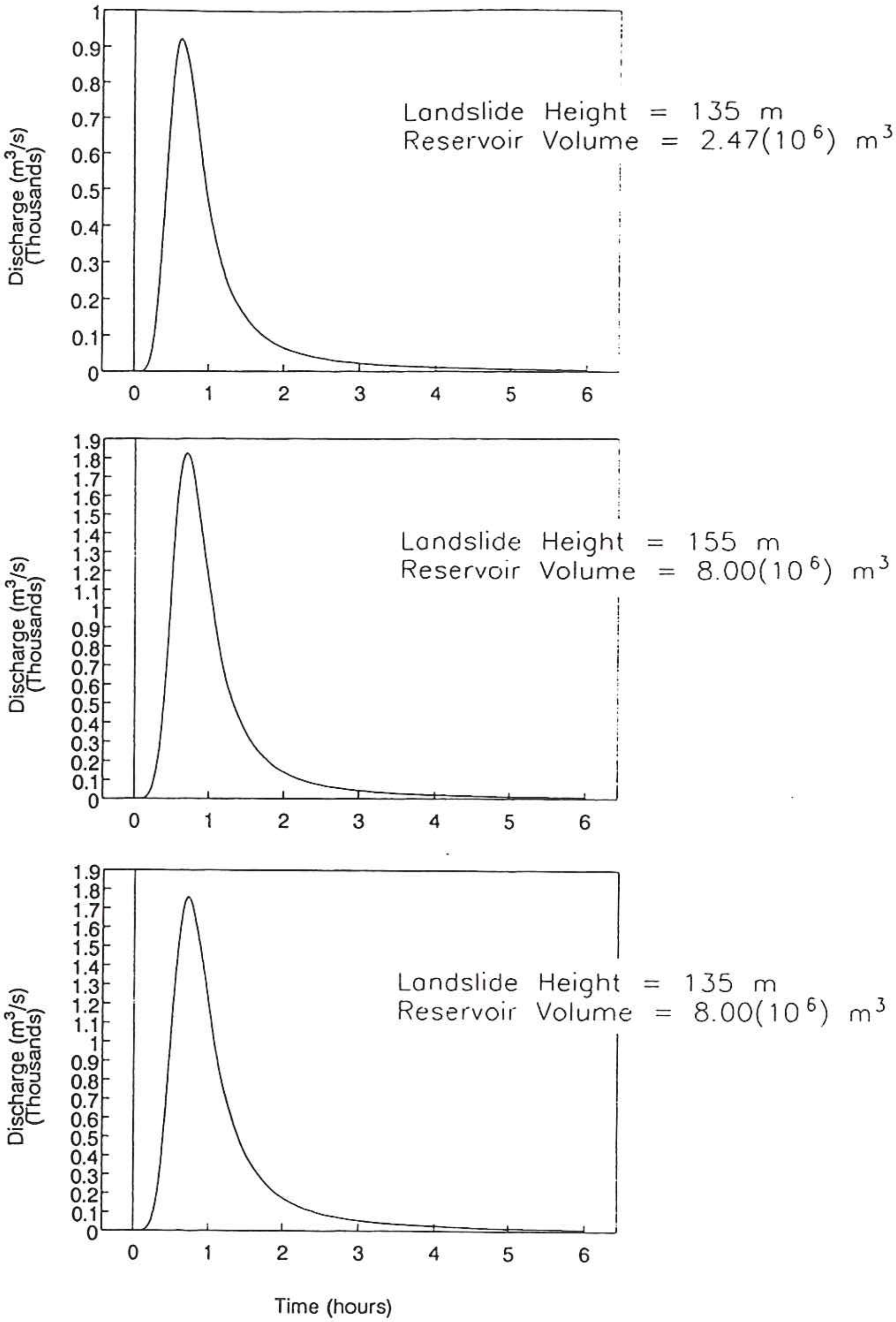
northwest hydraulic consultants

NHCV 1724-015

Figure XIIE-2

BREACH OUTFLOW HYDROGRAPHS - SITE A

Figure XIIE-3



REFERENCE: Drawing from report by Northwest Hydraulic Consultants

APPENDIX XII-F

DESCRIPTIONS OF NWS COMPUTER PROGRAM "BREACH" AND MODEL "DAMBRK"

APPENDIX XII-F

DESCRIPTION OF NWS COMPUTER PROGRAM "BREACH" AND MODEL "DAMBRK"

BREACH -- The BREACH program is a physically based mathematical model that predicts the breach characteristics (size, time of formation) and the discharge hydrograph emanating from an earthen dam. The earthen dam may be man-made or naturally formed by a landslide. The model is developed by coupling the conservation of mass of the reservoir inflow, spillway outflow, and breach outflow with the sediment transport capacity of the unsteady uniform flow along an erosion-formed breach channel. The bottom slope of the breach channel is assumed to be essentially that of the downstream face of the dam. The growth of the breach channel is dependent on the dam's material properties (D_{50} size, unit weight, friction angle, cohesive strength). The outflow hydrograph is obtained by a time-stepping iterative solution.

The model is not subject to numerical stability or convergence difficulties; however, it is sensitive to estimates of the internal friction angle of the dam's material and the cohesive strength of the material composing landslide-formed dams.

DAMBRK -- The DAMBRK model is based on a system of equations solved by a non-linear weighted 4-point implicit finite-difference solution of the one-dimensional equations of unsteady flow (Saint-Venant equations). The flow may be either subcritical or supercritical of a combination of each varying in space and time. Fluid properties may obey either the principles of Newtonian (water) flow or non-Newtonian (mud/debris flow or the contents of mine-tailings dam) flow. The hydrograph to be routed may be specified as an input time series or it can be developed by the model using specified breach parameters (size, shape, time of development).

The effect of any downstream dams which may be breached by the flood, bridge/embankment flow constrictions, tributary inflows, river sinuosity, levees located along the downstream river, and tidal effects can each be considered during the downstream propagation of the flood.

DAMBRK can also be used to route mud and debris flows or rainfall/snowmelt floods using specified upstream hydrographs. High water profiles along the valley, flood arrival times, and hydrographs at selected locations are standard output.

THURBER ENGINEERING LTD. (in association with **GOLDER ASSOCIATES LTD.**)

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Vancouver, B.C. V6G 2T3
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CHEEKYE RIVER TERRAIN HAZARD AND LAND USE STUDY

FINAL REPORT

VOLUME 2
APPENDICES

Submitted to:

B.C. Ministry of Environment, Lands and Parks
Lower Mainland Region
Suite 401 - 4603 Kingsway
Burnaby, B.C.
V5H 4M4

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March 1993

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PHASE I

Phase I will gather baseline data and assess the potential and extent for a catastrophic event.

Requirements

1. Assess all available information shown in **Addendum A** and undertake additional literature reviews as required.

2. Prepare topographic mapping of the fan using available aerial photography and ground surveys as required. A suggested scale is 1:5000 at one metre intervals.

3. Undertake geological investigation and mapping of deposits on the fan and in the headwaters to identify landslide-prone materials and associated deposits.

4. Undertake field investigation of an apparent large slump deposit on Cheekye ridge to identify potential for rapid catastrophic failure that might directly affect the fan or localized deposition that might indirectly affect the fan. Establish permanent reference survey monuments for monitoring during the course of the study.

5. Undertake a review of available mapping and aerial photography to assess historical slide activity.

6. Undertake additional subsurface investigations, samplings and datings of fan deposits as required to assess the size and frequency of past events.

7. If potential for a significant rapid rockslide exists from any source in the headwaters, evaluate runout and delineate affected area(s) using state of the art mathematical and/or physical models. Assess the probability of occurrence and risk relative to such event(s).

8. Evaluate the probability and size of possible debris flow events.

9. Present a brief report summarizing the progress and results of Phase I. Include recommendations regarding completion of studies itemized in Phase II. This shall include a presentation to the Steering Committee.

PHASE II

Based on the results of Phase I, some or all of the following items will be required. Phase II will only be begun once the Steering Committee has reviewed the results of Phase I and instructed the consultant to continue.

10. Evaluate and delineate potential debris flow inundation area(s) using state of the art mathematical and/or physical models as required. This should include flooding and channel avulsion effects as applicable.

11. Determine a probability of occurrence of a rockslide and/or debris flow landslide(s) which would cause property damage to areas on the fan under present conditions; that is not protected by mitigation works. Assess the sensitivity of results to assumptions and provide confidence limits. The determined probabilities are relevant to application of Section 82 of the Land Title Act regarding subdivision.

12. Assess risk to individuals on the fan. Assess the sensitivity of results to assumptions and provide confidence limits. The determined risks are relevant to application of Section 734 of the Municipal Act.

13. Provide advice regarding acceptable types of land use based on hazard probability thresholds and risk to individuals. The advice should be based on approaches documented by Cave, Morgan, and others if applicable.

14. If mitigative works are considered feasible, provide a conceptual design layout and describe the nature of the possible works to protect existing and future types of development as per the "Coriolis" proposal. Provide advice concerning design standards and requirements to implement such work. Layout of works should consider the potential for transfer of risk towards existing development on the fan.

15. Prepare a final summary report incorporating the findings of Phase I and II of the study. Details of the technical aspects of the study shall be provided as appendices. The summary report and appendices shall first be submitted in draft form for review and commentary by the Working Group and the Advisory Panel.

16. Prepare a brief public information brochure outlining the study and its results.

17. Present the results of the study in a formal presentation to the Steering Committee. Provision should be made for a presentation to the District of Squamish municipal council.

18. Documents shall be provided as follows:

    150 bound copies of the summary report;
    25 bound copies of the technical appendices.
    500 copies of the public information brochure.

    In addition, one unbound "original" suitable for duplication shall be submitted for all documents.

Reports

Baumann, F	*Geologic and Hydrologic Hazard Evaluation, Lot 5276, Plan 19878*	Apr 1988
Baumann, F	*Report on the Garbage Dump Debris Flow Deposit and Its Relationship to the Geologic History of the Cheekye Fan*	Mar 1991
B.C. Dept. Mines	*Cheekye River Mudflows*	Jul 1959
Coriolis Consulting	*Analysis of Potential Golf Course and Residential Development Opportunities on Crown Land in Squamish, B.C.*	Aug 1990
Crippen Engineering	*Investigation of Cheekye Fan*	1974
Crippen Engineering	*Cheekye Fan Development Design Report on Proposed Protection Works*	1975
Crippen Consultants	*Cheekye Fan Development Report on Hazard Areas and Protective Works*	May 1981
Hardy Associates	*Proposal for Cheekye Fan Dyking - District of Squamish*	Dec 1981
Klohn Leonoff Cons.	*Cheekye Fan Dyking Proposal for Engineering Services*	Dec 1981
Morgan, G. C.	*Cheekye River Fan - Terrain Hazard Assessment*	Nov 1990
Thurber Consultants	*Cheekye Fan Dyking Proposal*	Dec 1981

Articles/Abstracts/Letters

Cave, Peter W.	*Hazard Acceptability Thresholds for Development Approvals by Local Government*, for B.C. Geological Hazards Workshop Feb. 20/21, 1991.	Feb 1991
Crippen Consultants	Review of Cheekye Fan Development Zoning and Mud Slide Hazard	Oct 1985
Crippen Consultants	*Plan to Build on Cheekye Fan (Dittus Property)*	Dec 1987
Environment Canada	*Impacts of Mass Movement Events on Rivers in the Southern Coast Mountains - Summary Report*	1987
Jordan, P, and Assoc	*Terrain Hazards and River Channel Impacts in the Squamish and Lillooet Watersheds*	Aug 1987
Keeney, Ralph L.	*BC Hydro Seminar on Risk Management and Risk Analysis*	Nov 1990
Morgan, G. C.	*Quantification of Risks from Slope Hazards* preprint GAC proceedings *Landslide Hazard in the Canadian Cordillera*	1990
University of Victoria	*Field Trip Guidebook - Slope Stability and Mtn. Torrents, Fraser Lowlands and Southern Coast Mtns., B.C.*	May 1983

Maps

NTS 1:50,000 92G/14 East

Floodplain Mapping Cheakamus River 85-15-1 and 85-15-2.

Air Photos

BC 7556	225 to 227
BC 7521	222 to 227
BC 7521	254 to 258

Controlled 1:10,000 Aerial Photography of the Cheekye Fan. March 4, 1991.

Literature Searches

Evans, Dr. S. G.	Known and dated occurrences of rock avalanches and debris flows within the Garibaldi Complex.
Jordan, Dr. P.	Physical characteristics of debris flows that have occurred on Mt. Meagher and Mt. Cayley as they relate to the Cheekye Basin.
Hungr, Dr. O.	Analytical procedures for assessing the stability and runout performance of rock avalanches and fine grained debris flows.

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CHEEKYE RIVER TERRAIN HAZARD STUDY

E/91/M0690

September 9, 1991

Mr. Al Columbo
Development Officer
Ministry of Lands & Parks
Lower Mainland Region
Suite 401, 4603 Kingsway
Burnaby, B.C.
V5H 4M4

Dear Mr. Columbo:

Re: Amendment to Proposal dated May 7, 1991

Further to our meeting on September 4, 1991, I am sending herewith the agreed amendments to the Phase I and Phase II tasks.

In summary, these cover the incorporation of the planning aspects and the attendance of TEL/GA/Coriolis personnel at three public meetings. Savings have been made by deletion of the presentation to the District of Squamish at the time of the Final Report Presentation. An allowance of $2,000 has been made for the digitization of the cadastral data.

These changes require a budget adjustment from $274,075 to $296,753.

We realize the constraints on the budgets for this project and have tried to effect savings wherever possible. I hope that this provides you with what you need. Please contact me further if you have any queries.

Yours very truly,

G.E. Rawlings, P. Eng.
Project Manager

GER/jah/kc
912-1462
2/GR-1462
Enclosure

A. Modifications to Task Descriptions

TASK A5 - AIRPHOTO TERRAIN ANALYSIS

A detailed terrain map will be prepared by means of airphoto interpretation and plotted at the largest mapping scale available in each part of the study area, in order to be used in field work. We expect the terrain map to identify topographic features such as scarps, depressions, linears and cracks, bedrock lithology and structure as far as possible, surficial units such as talus, floodplain deposits, fans, moraines and colluvium, meltwater channels, ice margins, stream and debris flow channels and landslide fractures.

Concurrently detailed maps of existing land use and development, existing land ownership, mineral claims, existing zoning and known development proposals in the study areas will be prepared from information provided by the District of Squamish and B.C. Lands. The cadastral data will be digitized to be compatible with the 1:5000 topographic maps. A budget allowance has been made for this.

TASK A17 - PROBABILITY OF OCCURRENCE OF CATASTROPHIC LANDSLIDES

Combining objective data from Task A16 and more subjective estimates from Task A12, we will formulate a range of failure scenarios similar to that proposed by Dr. Evans (see Section 1.2). Each of the scenarios will be assigned one or several magnitudes and probabilities of occurrence, using probabilistic updating methods outlined in Einstein (1988) and others.

Scenarios connected with a volcanic eruption will be assigned probability only (based on Task A3), but not magnitude. We expect that our understanding of volcanic hazards at Mount Garibaldi will remain qualitative at the end of the study.

TASK A18 - RUNOUT ANALYSIS

The area effected by each non-volcanic landslide scenario will be estimated by means of runout analysis. We will use three methods of runout analysis in parallel for both rockslides and debris flows:

a) Empirical method, correlating the dimensions of the deposit with the position and volume of the detachment.

b) A lumped-mass dynamic model.
c) A fluid mechanics numerical model formulated especially for flow slides.

The present state-of-the-art of dynamic analysis of flow slides is such that it is not realistic to obtain solutions with any model based on assumed or laboratory measured material behaviour. The models must therefore be calibrated against carefully selected case histories which are similar to the event under consideration in a variety of aspects, including material composition of the source and path deposits and overall geometrical configuration. The model thus serves merely to account for changes in scale and geometry from the prototype event to the predicted one. Without such careful calibration, no available analytical method can be regarded as reliable.

We propose to select prototype case histories for each of the landslide and debris flow scenarios. The case histories will, as much as possible, be chosen from the B.C. volcanic centres region. Some will be from the Garibaldi Region. All identified debris flow events from Cheekye Fan (Task A16) will also be used as prototypes, after estimating their most probable source areas.

Some of the failure scenarios will require coupling of two solutions in a staged analysis, such as debris flows mobilized by rock avalanche emplacement or by the catastrophic breaching of a landslide dam. Again, such coupling analysis will be guided by observed precedents.

The three alternative analytical methods will be applied to the prototype events and their parameters will be adjusted by trial and error. The resulting calibrated models will then be applied to the predicted failure scenarios in their various magnitude categories. A range of inundation maps will be produced with confidence margins derived from the scatter of the different solutions. These results will be used for an initial determination of risk zones based on assigned probabilities for more detailed consideration in Phase II.

The evaluation of the consequences of the findings regarding the potential catastrophic scenarios will be carried out. Implications for existing land uses and implications for future use and development in the study area, will be assessed.

There will be interaction between the engineering and planning members of the team with regard to the severity and impact of the catastrophic events on land-use.

TASK A19 - PHASE I REPORTING

A comprehensive report will be issued at the end of Phase I. The report will include:

- a summary of work completed;
- a list of interim conclusions; and
- recommendations for Phase II work.

Budget items shown for reporting cover all secretarial/drafting requirements in Phase I.

TASK A20 - PHASE I PRESENTATIONS

Presentations will be made periodically during the course of Phase I. A team member will participate in the Open House in early September. The Phase I study results will be presented to the Steering Committee by four team members. Three team members will participate in the Public Meeting prior to release of the Phase I Report.

TASK B4 - FLOODING ANALYSIS

The hydraulic capacity of the existing channel of Cheekye River will be reassessed, using discharge data from Task B1. Debris flow-flooding interaction will then be considered, including discharge bulking due to surging behaviour associated with debris flow events. Flow avulsion paths due to channel modification by debris deposits will be described.

Flooding resulting from events on the Cheakamus River (such as further potential instability at the Barrier) will be reviewed. The current MOE flood plain maps will also be used in the analysis of potential flooding on the fan.

TASK B6 - RISK AND LAND USE CONSIDERATIONS

The hazard parameters in each of the risk maps produced for the Cheekye, Cheakamus and Squamish Catchments will be combined with land use characteristics, to obtain estimated cumulative probabilities of death, injury and property damage for different risk-land use combinations. These will then be compared to established criteria of risk acceptability; recommendations for land use will be given. We expect to define several land use zones, including:

- Hazard corridors with full development restrictions (deposition areas, buffers).
- Zones of limited development (recreation transportation, other residential uses).
- Zones suitable for low density residential development only.
- Unrestricted development zones.

An evaluation of the implications of the risk zoning for existing uses and development will be made. Particular emphasis will be placed on those developments shown to be exposed to an unacceptable level of risk.

The tools that can be used to implement the land use recommendations will be reviewed.

TASK B7 - MITIGATIVE MEASURES

Engineered mitigative measures such as dyking or channelization may be used to reduce the areal extent of restricted zones in those areas where low magnitude-high frequency hazards control the land use restriction. Depending on the results of Task B5, such areas may or may not exist on the Cheekye Fan. For example, should all zoning be restricted due to an excessive risk of a high magnitude event, mitigative measures may not be practicable.

Other mitigative measures including relocation, land acquisition, land use regulation will be identified and evaluated.

A legal review of issues pertaining to the implementation of the study's land use and mitigation recommendations will be made. These issues could potentially include approving officer liability, municipal authority to limit development, authority to construct works, relocations of facilities, placing notice on title of crown lands sold, and others.

TASK B8 - PREPARATION OF FINAL REPORT AND BROCHURE

The final study report will contain a full documentation of all tasks performed and their results. Important output products will be the risk map, land-use zoning map and recommendations for mitigative works and further studies, if required. The content of

Figure I-1

STUDY FLOW CHART, Phase 1

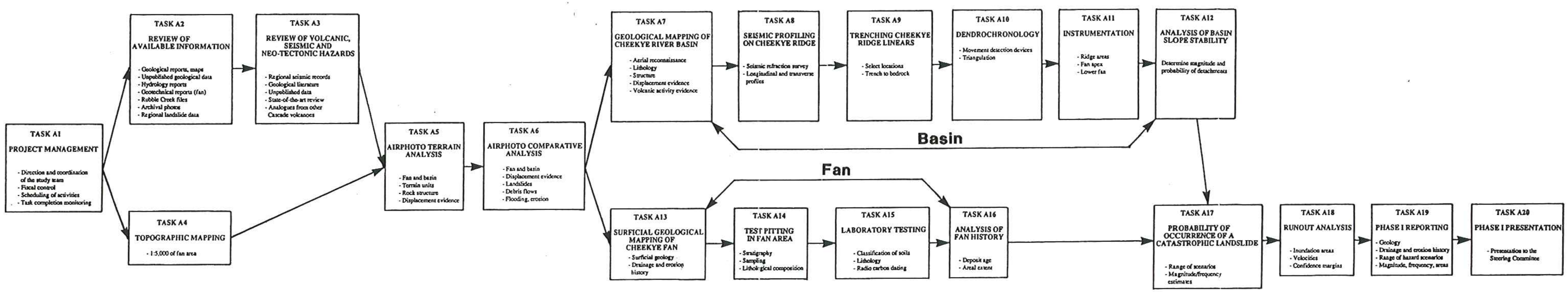
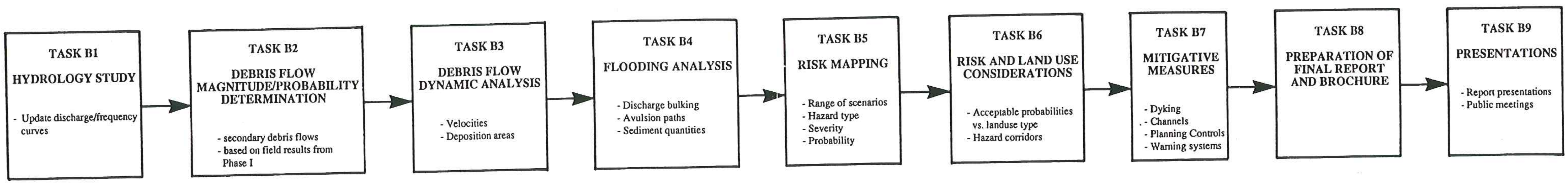


Figure I–2

STUDY FLOW CHART, Phase II



the public information brochure will be determined in consultation with the Steering Committee. The final report and brochure will be issued first as confidential drafts and finalized following approval by the Committee and the Advisory Board.

The budget items for report preparation include all the secretarial/drafting requirements for Phase II.

TASK B9 - PRESENTATIONS

The study findings will be presented to the Steering Committee by four team members. In addition, the public presentation will be attended by three members of the Project team.

It is understood that a separate presentation to the Squamish Municipal Council is no longer required.

GR/jah/kc
912-1462
2/GR-1462

APPENDIX I

TERMS OF REFERENCE

APPENDIX II

ASSESSMENT OF SEISMICITY

ENERGY, MINES AND RESOURCES CANADA
GEOLOGICAL SURVEY OF CANADA

ENERGIE, MINES ET RESSOURCES CANADA
COMMISSION GEOLOGIQUE DU CANADA

SEISMIC HAZARD CALCULATION * / CALCUL DE PERIL SEISMIQUE *

REQUESTED BY/ DEMANDE PAR Graham Rawlings / Golder Associates Ltd.

SITE Cheekye Fan, Squamish Area.

LOCATED AT/ SITUE AU 49.78 NORTH/NORD 123.15 WEST/OUEST

PROBABILITY OF EXCEEDENCE PER ANNUM/ PROBABILITE DE DEPASSEMENT PAR ANNEE	0.010	0.005	0.0021	0.001
PROBABILITY OF EXCEEDENCE IN 50 YEARS/ PROBABILITE DE DEPASSEMENT EN 50 ANS	40 %	22 %	10 %	5 %
PEAK HORIZONTAL GROUND ACCELERATION (G) / ACCELERATION HORIZONTALE MAXIMALE DU SOL (G)	0.062	0.089	0.136	0.196
PEAK HORIZONTAL GROUND VELOCITY (M/SEC) / VITESSE HORIZONTALE MAXIMALE DU SOL (M/SEC)	0.066	0.097	0.153	0.222

* REFERENCES

1. NEW PROBABILISTIC STRONG SEISMIC GROUND MOTION MAPS OF CANADA: A COMPILATION OF EARTHQUAKE SOURCE ZONES, METHODS AND RESULTS. P.W. BASHAM, D.H. WEICHERT, F.M. ANGLIN, AND M.J. BERRY EARTH PHYSICS BRANCH OPEN FILE NUMBER 82-33, OTTAWA, CANADA 1982.

2. ENGINEERING APPLICATIONS OF NEW PROBABILISTIC SEISMIC GROUND-MOTION MAPS OF CANADA. A.C. HEIDEBRECHT, P.W. BASHAM, J.H. RAINER, AND M.J. BERRY CANADIAN JOURNAL OF CIVIL ENGINEERING, VOL. 10, NO. 4, P. 670-680, 1983.

3. NEW PROBABILISTIC STRONG GROUND MOTION MAPS OF CANADA. P.W. BASHAM, D.H. WEICHERT, F.M. ANGLIN, AND M.J. BERRY, BULLETIN OF THE SEISMOLOGICAL SOCIETY OF AMERICA, VOL. 75, NO. 2, P. 563-595, 1985.

4A. SUPPLEMENT TO THE NATIONAL BUILDING CODE OF CANADA 1985, NRCC NO. 23178. CHAPTER 1: CLIMATIC INFORMATION FOR BUILDING DESIGN IN CANADA. CHAPTER 4: COMMENTARY J: EFFECTS OF EARTHQUAKES.

4B. SUPPLEMENT DU CODE NATIONAL DU BATIMENT DU CANADA 1985, CNRC NO 23178F. CHAPITRE 1: DONNEES CLIMATIQUES POUR LE CALCUL DES BATIMENTS AU CANADA. CHAPITRE 4: COMMENTAIRE J: EFFETS DES SEISMES.

20-NOV-91 14:34:50

(2)

SITE Cheekye Fan, Squamish Area.

ZONING FOR ABOVE SITE/ ZONAGE DU SITE CI-DESSUS

** 1985 NBCC/CNBC: Za = 3; Zv = 3

ACCELERATION ZONE/ ZONE D'ACCELERATION Za = 3
ZONAL ACCELERATION/ ACCELERATION ZONALE a = 0.15 G

** VELOCITY ZONE/ ZONE DE VITESSE Zv = 3
** ZONAL VELOCITY/ VITESSE ZONALE v = 0.15 M/S

1985 NBCC/CNBC
SEISMIC ZONING MAPS/ CARTES DU ZONAGE SEISMIQUE

PROBABILITY LEVEL: 10% IN 50 YEARS
NIVEAU DE PROBABILITE: 10% EN 50 ANNEES

G OR M/S	ZONE	ZONAL VALUE/ VALEUR ZONALE
0.00		
	0	0.00
0.04		
	1	0.05
0.08		
	2	0.10
0.11		
	3	0.15
0.16		
	4	0.20
0.23		
	5	0.30
0.32		
	6*	0.40

* ZONE 6: NOMINAL VALUE/ VALEUR NOMINALE 0.40;
SITE-SPECIFIC STUDIES SUGGESTED FOR IMPORTANT PROJECTS/
ETUDES COMPLEMENTAIRES SUGGEREES POUR DES PROJETS D'IMPORTANCE.

** For NBCC applications, when Zv=0 and Za>0, the values of Zv and v should be taken as 1 and 0.05, respectively. See NBCC 1985, Sentence 4.1.9.1 (4).

Pour applications selon le CNBC, lorsque Zv=0 et Za>0, les valeurs Zv et v deviendraient 1 et 0.05, respectivement. Voir CNBC 1985, paragraphe 4.1.9.1 4).

20-NOV-91 14:34:50

LEGEND FOR SEISMICITY MAPS

X = mag <2

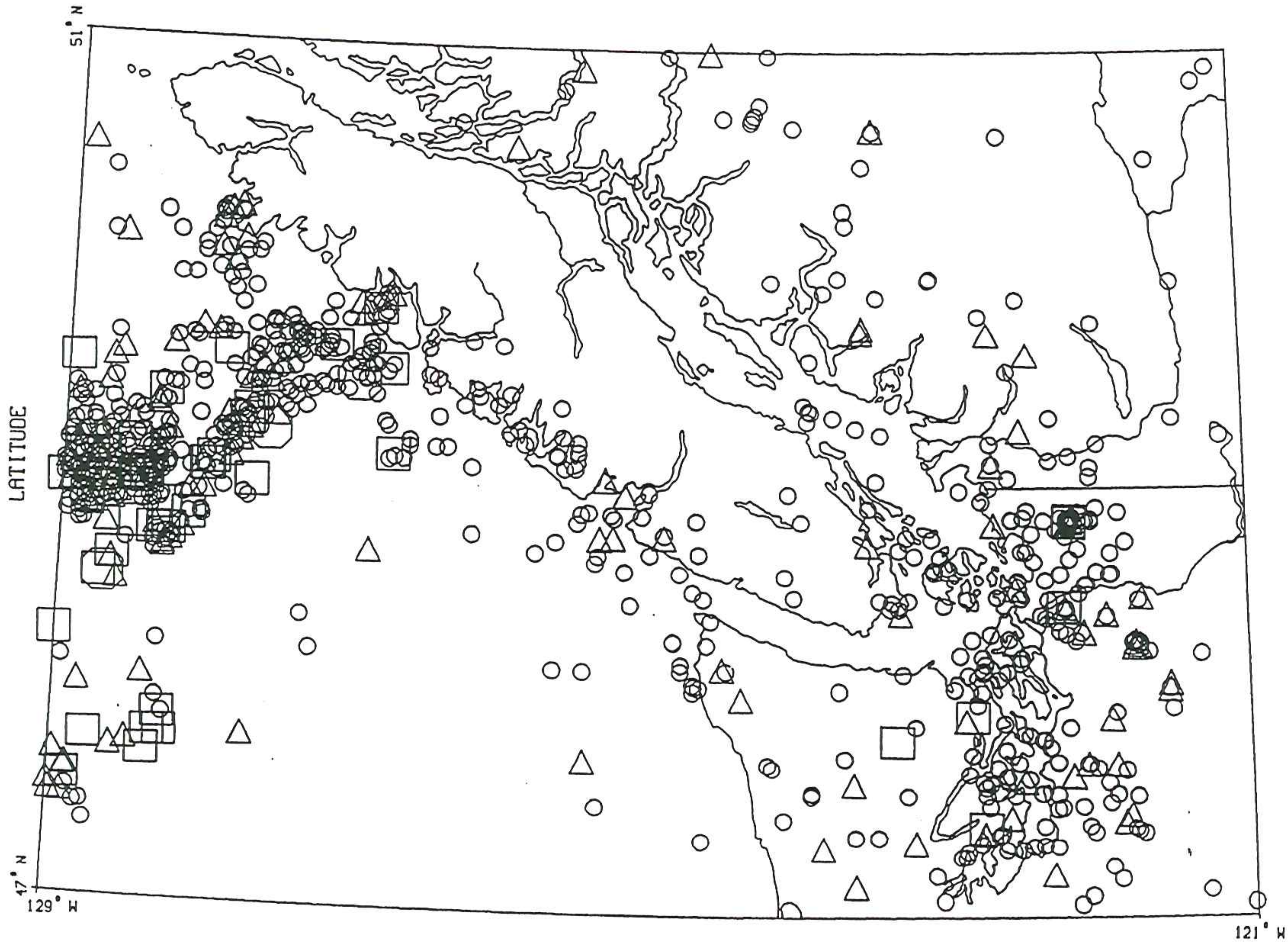
○ = mag 2.0 – 2.9

△ = mag 3.0 – 3.9

□ = mag 4.0 – 4.9

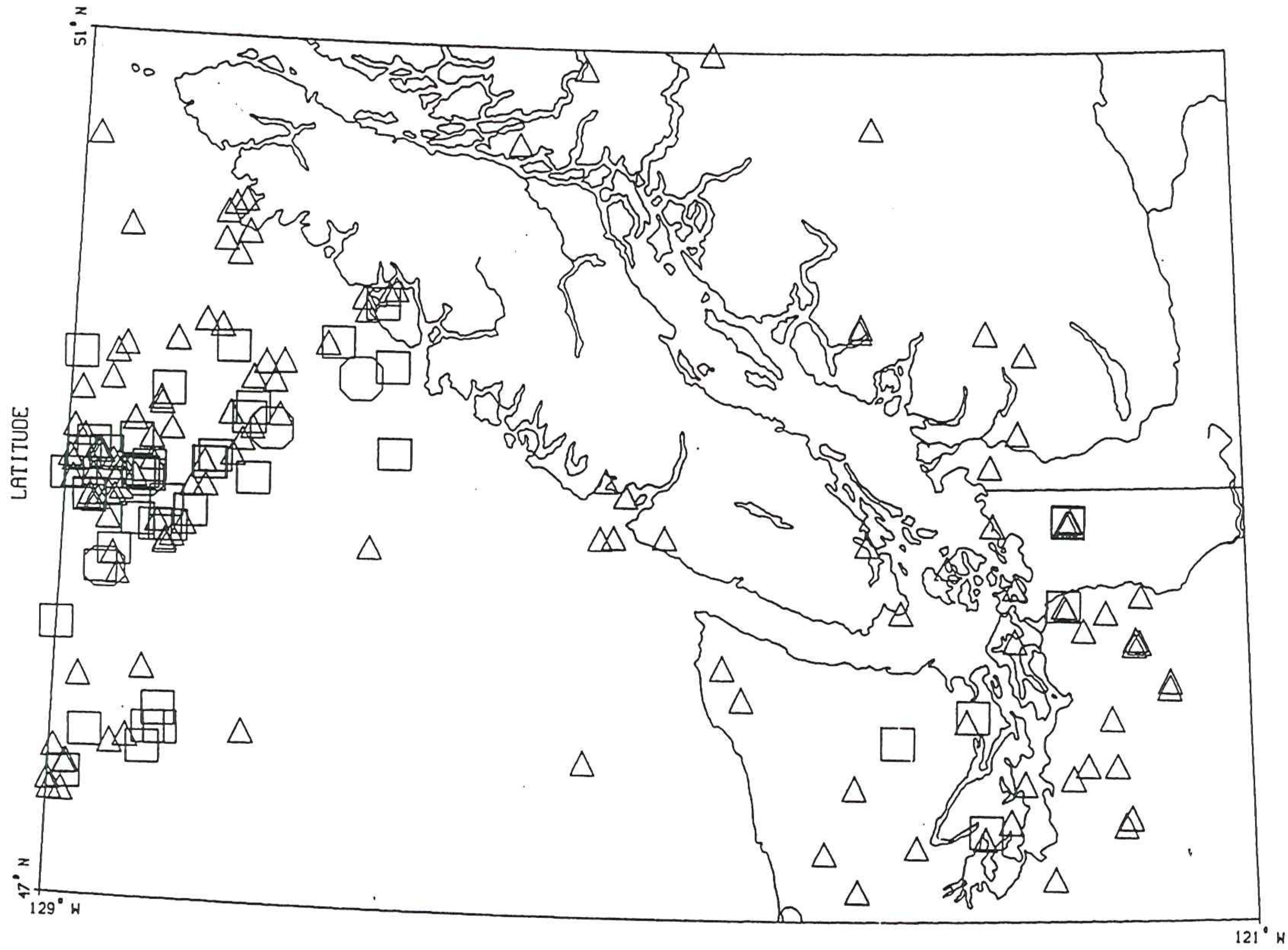
⯃ = mag ≥5.0

Jan 1982 - Nov 1991
Magnitude .ge. 2.0



Date: 91/12/03 Time: 13:16:11 Produced at the Pacific Geoscience Centre Sidney BC

Jan 1982 - Nov 1991
Magnitude .ge. 3.0



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APPENDIX III

SEISMIC AND VOLCANIC HAZARDS

MEMORANDUM

TO: G. Rawlings December 17, 1991

FR: D. West DDW 913-7063

RE: REPORT - REVIEW OF CHEEKYE PROJECT VOLCANIC AND SEISMIC HAZARDS

This memorandum is a revision and update of the draft memorandum to you and O. Hungr dated August 22, 1991. It incorporates the thoughts from review comments made by W.H. Mathews, O. Hungr, W. Savigny and P. Cave. The following discussions include my observations made during the field trip to the Cheekye fan area on August 12-15, 1991, descriptions and evaluations of the potential volcanic and seismic hazards that may affect the Cheekye fan, and a discussion as to the completeness of the data and information regarding volcanic and earthquake hazards, with respect to the assessment of risk.

OBSERVATIONS FROM THE FIELD TRIP OF AUGUST 12-15 1991

During the period from August 12 through 15, 1991, I reviewed the available data and information (in Golder's Vancouver office) regarding volcanic and seismic hazards as they relate to the Cheekye River Terrain Hazard Study, and conducted a one-day field reconnaissance of the Mt. Garibaldi/Cheekye River drainage. The review of data included: the examination of technical literature and geotechnical reports specific to the Cheekye River area and specific to the subject matter, a brief examination of stereo aerial photographs of the Cheekye and Brohm river basins, and discussions with project team and local experts on the general geology, Quaternary geology, debris flow hazards, seismic hazards and volcanic history of the Mt. Garibaldi area.

The review of available data included the examination of articles pertinent to the geology, volcanology and seismicity of the Cheekye region (Mathews, 1951, 1952a, 1952b, 1958a, 1958b; Nasmith et al, 1967; Souther, 1977, 1980; Green, 1981, 1990; Green et al, 1988; B.C. Hydro, 1985) as well as reports of previous investigations specific to the study of the Cheekye fan and vicinity (Crippen Engineering, 1975; Baumann, 1980, 1990, 1991; Morgan 1990; Jordan, 1991; Evans, 1991). In addition, general articles and papers dealing with volcanic and seismic hazards, landslides and debris flows (including earthquake-induced landsliding), and regional tectonics were reviewed in preparation for the field reconnaissance (Bolt et al, 1977; Decker and Decker, 1981; Washington Public Power Supply System, 1982, 1988; Eisbacher and Clague, 1984; Whitehouse and Griffiths, 1983; Nicoletti and Sorriso-Valvo, 1991; Thurber

General observations regarding potential terrain hazards that result from the field reconnaissance follow below.

It appears from the field reconnaissance that landslides, whether they are rock avalanches, debris flows or lahars, and whether they are initially generated by volcanic eruptions, earthquakes or meteorological events, may be the primary terrain hazards to the Cheekye fan. The widespread presence of such deposits underlying the Upper, Middle and Lower Cheekye fans indicates that the processes responsible for the deposits have been occurring commonly during the Holocene. Although there is geologic evidence to show that the largest volumes of debris flows apparently occurred in the late Pleistocene to early Holocene with the retreat of the Fraser ice lobe (Mathews, 1952a), the 1,100 year-old "Garbage Dump" debris flow, as well as radiocarbon dates of from about 300 to 6,000 years from other parts of the Lower Cheekye fan, suggest that several relatively small (a few million cubic meters) events have happened through the latest Holocene, and have reached the lower parts of the fan.
The character of the Atwell Peak pyroclastic deposits suggest that small volume ravelling of the slopes is the primary mechanism of current slope failure. Likewise, the dacite flows and plug of Dalton Dome appear to have failed in the past in relatively small volume rock falls, and such failures are likely to be type to be expected in the future.

The linear topographic features of Cheekye Ridge, and the newly-discovered features of Brohm Ridge, exhibit broadly distributed extension and apparent slight downslope translational(?) movement. The linear features are expressed as topographic scarps that generally face downslope, although there are a few antislope scarps on both ridges. Both the Cheekye and Brohm ridge areas have what appear to be a "main" downslope-facing scarps that occur near the uphill extent of the features. This scarp exhibits the largest vertical offset of the topography at both areas. On Cheekye Ridge, the main scarp is about 800 meters long and about 20 meters high (Baumann, 1980).

Although most of the features are downslope-facing, graben with small uphill-facing scarps occur at both locations. No lateral scarps could be observed to define the lateral extent of the features. Geomorphically, the linear features at Brohm Ridge appear fresher and younger that those at Cheekye Ridge. A test pit excavated across one of the scarps (near the main scarp) at Cheekye Ridge revealed a peat bed about one third of the way down in the test pit. A sample of the peat collected for radiocarbon age analysis resulted in a value of 3,220 +/- 70 radiocarbon years.

At both locations, the metamorphic bedrock of the Gambier Group exposed in the slopes below the scarp features appears to be strongly altered, presumeably by upwelling hydrothermal fluids. In addition, the scarps appear to be spatially associated with the altered metamorphic bedrock.

The areas of the linear features at Cheekye and Brohm ridges have the appearance of incipient landslides. The geomorphic expression of the scarps, plus the available radiocarbon age date suggest that the formation of the scarps at both ridges could have been at least 3,200 years ago or younger. Although the volumes of potential debris flows in the failure areas may not be sufficient in themselves to reach the lower Cheekye fan, the landslides may dam the drainages such that subsequent dam failure may mobilize sufficient material to reach the fan.

POTENTIAL VOLCANIC HAZARDS

Mt. Garibaldi, and the volcanoes of the Mt. Garibaldi complex, are part of Cascade Range arc volcanism that is associated with subduction, and partial melting of magma, along the Cascadia subduction zone (Gill, 1981; Washington Public Power Supply System, 1982, 1988; Decker and Decker, 1981). The Cascade Range extends for more than 1,200 km from British Columbia to northern California, and includes many Holocene-age composite volcanoes (Figure 1).

The common volcanic products from these composite volcanic centers are generally silicic (e.g., dacites and andesites), compared to spreading centers, hot spots or back arc areas (which are primarily basaltic). The extrusion of silic volcanics typically results in violent eruptive processes (Bolt et al, 1977; Williams and McBirney, 1979). The 1980 Mt. St. Helens eruption is an example of a violent silicic volcanic arc eruption with well-developed pyroclastic airfall (tephra), pyroclastic flow (including lahars) and explosion activity, and moderately-developed lava flow (dome growth) activity (Christiansen and Peterson, 1981).

As summarized by Bolt et al (1977), Williams and McBirney (1979) and Crandell and Mullineaux (1978), typical, primary volcanic processes (thus potential hazards) that may be associated with renewed eruptions of composite volcanoes in general and of the Cascade Range in particular include:

- o tephra fall
- o pyroclastic flow (nuee ardente, base surge, debris flow/lahar)
- o explosion phenomena (overpressure, directed blast)

- o ground deformation (uplift, subsidence, faulting)
- o lava flow/dome building
- o volcanic earthquakes
- o flooding, erosion and sedimentation (secondary effects)

Except for tephra fall, the majority of these processes, and their extreme effects, in terms of potential hazards, occur within close proximity of the composite volcano; that is, within about 10-15 km of the edifice (Crandell and Mullineaux, 1978; West and Alt, 1981). However, the flow (pyroclastic and lava) and flooding processes are controlled in most part by drainages and may affect areas several tens of kilometers downstream of the volcano (Crandell and Mullineaux, 1978). Tephra fall may affect areas several hundereds of kilometers downwind (Bolt et al, 1977).

A review of the volcanic history of the Mt. Garibaldi volcanic complex indicates that volcanic eruptions, that have affected the Cheekye River drainage, have occurred in about four distinct stages or phases during the past 700 ka (Green, 1990; Green et al, 1988). Each of these stages may have involved numerous individual as well as repeated eruptions at the various volcanic centers in the Mt. Garibaldi volcanic complex. The Mt. Garibaldi volcanic complex, as used here, includes the Mt. Garibaldi edifice, the ancestral Mt. Garibaldi and Round Mountain. A summary of the four eruptive stages, in terms of volcanic products and/or processes is given below, from oldest to youngest:

- o 460-670 ka; Round Mountain eruptive stage (new terminology, this study) that consisted of the eruption of hypersthene-augite andesite, hornblende andesite and hornblende-hypersthene dacite lava flows that are as much as 150 m thick; these flows filled the Brohm and Cheekye paleovalleys to distances of at least 10 km (as scaled from Green et al, 1988), as well as to about 6 km in the Mashiter paleovalley,

- o 220-260 ka; Cheekye eruptive stage that consisted of the eruption of dacite domes and lavas, and tuff breccias; these flows extended at least 9 km in the Cheekye and Brohm paleovalleys (as scaled from Green et al, 1988),

- o 11-26 ka; Atwell Peak eruptive stage that consisted of the eruption of voluminous pyroclastic flows, composed primarily of hornblende-hypersthene dacite, from Atwell Peak on Mt. Garibaldi; the flows were deposited against ice margins of continental and alpine glaciers of the Fraser glaciation and extended at least 5 km from Atwell Peak (as scaled from Green et al, 1988), o 7-11 ka; Dalton Dome eruptive stage that included dacite dome building and dacite lava flows that extended about 3-4 km down the upper Cheekye drainage from Dalton Dome (as scaled from Green et al, 1988); the eruption is interpreted to be post-glacial based on stratigraphic relationships; it is possible that there may have been minor pyroclastic flows associated with this eruption as well, since possible nuee ardente deposits are exposed in the upper Cheekye River basin, topographically in a post-glacial position; the Ring Creek lava flow, that extends 15 km downstream from Opal Cone, was erupted during this time period.

The volcanic processes associated with these past eruptive stages in the Mt. Garibaldi volcanic complex have been primarily pyroclastic flows (including hot debris flows and lahars) and lava flows. This is evident from the volcanic deposits that have remained behind as a result of the eruptions. There appear to be no known tephra falls associated with past eruptions at Mt. Garibaldi because no such deposits have yet been recognized.

Based on the eruptive history of Mt. Garibaldi listed above, it appears that major eruptive stages could occur on the order of a few hundred thousand years, based on the early history, or on the order of a few thousand to a few tens of thousands of years, based on the more recent history. Alternatively, it may be that both the Atwell Peak stage and the Dalton Dome stage are in the same overall eruptive stage that is still in progress. It should be noted that there is great uncertainty in the volcanic history data that derive both from potential errors in the available age dates and also from the lack of completeness in the geologic record of past eruptions. This uncertainty would suggest that caution be used in attempting to interpret return periods for volcanic activity in the Mt. Garibaldi volcanic complex.

By inference, because of the type of the events associated with andesitic and dacitic eruptions, it is interpreted that future volcanic activity in the Mt. Garibaldi complex, with the possible exception of tephra fall, will likely include to some level, all the volcanic processes listed above. A brief description of the magnitude and possible extent of these processes, based on the volcanic record at Mt. Garibaldi and in the Cascade Range, as well as world-wide, is given below. This will provide a preliminary view of what may be expected in terms of impact from possible volcanic hazards from future eruptions.

o <u>Tephra Fall</u>: Because tephra falls have not been documented in past eruptions within the Mt. Garibaldi complex, it is interpreted that future eruptions will also be essentially devoid of this volcanic process; thus, at this point it is not considered as a potential volcanic hazard.

o Pyroclastic Flow: Past eruptions within the Mt. Garibaldi complex (particularly the Atwell Peak stage) have included extensive pyroclastic activity. This has been in the form of "hot" flows, such as nuee ardente and lahars, and cold flows such as debris flows and mudflows. These flows were also likely accompanied by downstream flooding, erosion and sedimentation. As indicated above, the downstream extent of pyroclastic flows in past eruptive stages from the Mt. Garibaldi complex has varied from about 3 to 10 km. This is somewhat misleading because many flows were placed against, and backed up behind ice margins such that their true potential for downstream extent is unknown. However, by examining the geologic and historic record of pyroclastic flows at other Cascade volcanoes, an idea of the potential future extent and timing of pyroclastic flows at Mt. Garibaldi can be estimated.

An idea of the magnitude, extent and timing of pyroclastic flows (hot flows, lahars, mudflows, debris avalanches) at other Cascade Range volcanoes is indicated in the attached tables that characterize aspects of landslides (as expressed by lahars and debris avalanches) and hot pyroclastic flows. The volcanoes that are represented in these tables include: Glacier Peak, Mt. Rainier, Mt. St. Helens, Mt. Hood and Mt. Shasta (see Figure 1 for location). In examining the tables it should be noted that lahars, as described in the literature for the Cascade volcanoes, include "hot" mudflows associated with a volcanic eruption and cold mudflows that may either be associated with an eruption, or occur in the absence of volcanic activity. In addition, these lahars also may include more distal flood-type or hyperconcentrated flow deposits.

With respect to lahars and debris avalanches, it is evident that they can occur because of eruptive activity or in the absence of it. For example, at Mt. St. Helens all (100%) of the lahars and debris avalanches that have been recorded have occurred with eruptive activity. At Mt. Rainier on the other hand, 85% have occurred during non-eruptive periods and 10% are interpreted to have been seismically-induced, while only 5% are related to eruptions.

Regarding the extent of lahars and debris avalanches, the attached table indicates that for all the Cascade volcanoes examined, past landslides have traveled from 2 to 120 km downstream. The range of average downstream extent, derived from each volcano, is from 7 to 55 km.

With respect to the timing of past lahar and debris avalanche events at other Cascade volcanoes, it appears that two sets of repose periods may be derived from the data: one from the pre-historic, geologic record and one from the historic record. The historic record tends to result in shorter repose periods, and this is probably because it is more complete than the geologic record. When examining the pre-historic record from all the volcanoes, repose periods range from 70 to 11,850 years, while the range in average repose periods from individual volcanoes is from about 200 to 4,440 years. The historic record indicates repose periods that range from 2 to 270 years, with average repose periods that range from 18 to 200 years.

Hot pyroclastic flows at Cascade volcanoes have traveled from 3 to 30 km downstream (see attached table). The range in average extent of the flows in from about 6 to 25 km as derived from the individual volcano.

o <u>Lava Flow</u>: Dacitic lava flows have been a primary volcanic process in past eruptions within the Mt. Garibaldi complex. These eruptions have resulted in a number of lava flows that have extended from about 1 to 18 km from the volcanic source with an average extent of about 7 km. Data from work at Mt. St. Helens and Mt. Shasta (Crandell and Mullineaux, 1978; Miller, 1980) indicate that lava flows from such eruptions have extended from 3 to 12 km from the source and average about 6 to 7 km.

o <u>Volcanic Earthquakes</u>: Volcanic earthquakes within the Mt. Garibaldi complex have not been documented because no historic eruptions have occurred. However, world-wide data suggest that earthquakes of up to magnitude 5.5-6.0 could occur accompanying a volcanic eruption. Such earthquakes would likely be centered at shallow depth (e.g., 1-5 km) beneath the volcanic edifice. The potential impact of volcanic earthquakes, in terms of strong ground motion, is discussed later under seismic hazards.

o <u>Ground Deformation</u>: Ground deformation has also not been documented within the Mt. Garibaldi complex because no historic eruptions have occurred. However, data from Hawaii and Japan (Walsh and Decker, 1971; Yokoyama, 1974; Stuart and Johnston, 1975) suggest that ground deformation in the form of uplift, subsidence and faulting, that is associated with magma intrusion, generally occurs within about 20 km of the volcanic center. The magnitude of maximum uplift or subsidence is generally less than 1 to 2 m and decreases to less than 20% of maximum within about 10 km of the volcano.

o <u>Explosion Phenomena</u>: Explosion phenomena, because they are associated with an eruption, have also not been documented for the Mt. Garibaldi complex since such eruptions have not occurred during historic time. Data from the study of the attenuation of airshock overpressure with distance (USAEC, 1964) would suggest that these processes would generally occur within about 10 km of the volcanic center.

o Flooding: Flooding, and the erosion and sedimentation that are associated it, is likely to have occurred at some level in all the past eruptive stages at the Mt.Garibaldi complex. Because there are no historic examples of such events in the Mt. Garibaldi complex, Cascade Range data from Mt. St. Helens and Mt. Rainier (Crandell, 1971; Janda et al, 1981) data would suggest that downstream flooding could extend to 120 km from the volcanic center.

POTENTIAL SEISMIC HAZARDS

The potential primary seismic hazards that could affect the Cheekye fan include surface fault rupture and strong earthquake shaking. Prominent secondary effects of earthquakes could be soil liquefaction and earthquake-induced landsliding. Because no documented moderate or strong historic earthquakes appear to have affected the Cheekye River and fan area (B.C. Hydro, 1985), the following descriptions of magnitude and extent of potential earthquake hazards are based primarily on regional seismotectonic investigations in western North America (Washington Public Power Supply System, 1982, 1988; Coppersmith and Youngs, 1990).

Based on the available data, and discussions with the local experts, there are apparently no known active faults in the immediate region of the Cheekye fan. An active fault for this study would be defined as one with evidence of surface fault rupture during the Holocene (past 10,000 years). A preliminary review of the available stereo aerial photos also reveals no obvious linear topographic disturbance of the Cheekye fan surface. This information, taken together would suggest that the potential for active surface faulting in the Cheekye fan may be non-existent or may be a low probability seismic hazard.

However, a linear topographic scarp, parallel to the lower reaches of Brohm River, may be fault-controlled. Its nature and age may need to be evaluated to confirm the lack of fault rupture in the vicinity of the Cheekye fan.

The primary seismic sources that should be considered for strong earthquake shaking are those within the crust of the North American plate and those associated with the subduction of the Juan de Fuca and Explorer oceanic plates, beneath the North American plate, along the Cascadia subduction zone (see Figure 2). With respect to the Cascadia subduction zone, two potential sources are considered: the Juan de Fuca/Explorer-North American plate interface, and earthquakes from within the subducted oceanic plate (Washington Public Power Supply System, 1982, 1988; B.C. Hydro, 1985; Coppersmith and Youngs, 1990).

Work by B.C. Hydro (1985) to identify seismic hazards in the Cheekye area for the Cheakamus Dam has resulted in the identification of several potential earthquake sources, in the crust and the Cascadia subdcution zone, that could affect development of the Cheekye fan. The work by BC Hydro has included the assignment of source parameters (e.g., maximum earthquake magnitudes) and the development of site ground motions at the Cheakamus Dam.

Because the source distances are different for the Cheekye fan, then the site accelerations developed by B.C. Hydro are not applicable. Thus, estimates of site ground motions specific to the Cheekye fan are made below. The potential earthquake sources, as identified by B.C. Hydro (1985) are listed below with maximum magnitudes and estimated distances to the Cheekye fan. Some modifications in terms of maximum magnitudes for the sources have been made to incorporate recent data developed for investigations of neotectonics in western North America (Washington Public Power Supply System, 1988; Coppersmith and Youngs, 1990).

- Subduction Zone:
  - Interplate thrust event: M 8.5 @ about 145 km
  - Intraplate normal event: M 7.5 @ about 40 km
- Crustal:
  - Beaufort Range fault: M 7.5 @ about 100 km
  - Volcanic event: M 6.0 @ about 10 km
  - Random event: M 6.5 @ about 15 km

The magnitudes of possible horizontal accelerations that may be expected on the Cheekye fan from these sources are given below. These are deterministically developed ground motions that do not consider the probability of occurrence or location. These accelerations are for soil sites and are derived from current ground motion attenuation relationships for crustal and subduction zone sources (Joyner ands Boore, 1988; Washington Public Power Supply System, 1988).

- o Subduction Zone:
  - Interplate: 0.10-0.15 g
  - Intraplate: 0.30-0.40 g
- o Crustal:
  - Beaufort Range fault: 0.02-0.06 g
  - Volcanic event: 0.15-0.25 g
  - Random event: 0.15-0.25 g

Recurrence data for the earthquake sources are incomplete or uncertain, such that it is difficult to assess the probability of experiencing the ground motions that could emanate from these sources. Studies conducted for a nuclear power plant in Washington (Coppersmith and Youngs, 1990) suggest that subduction zone maximum earthquakes could reccur on the order of every 500 years. Little is known of the recurrence intervals for the crustal sources, but because the rates of strain are significantly less than those across the Cascadia subduction zone, the recurrence for these structures is likely to be much longer than for the subduction zone. Because the historic seismic record is so short, it is likely to underestimate the frequency of recurrence for the maximum earthquakes.

A probabilistic assessment of site ground motions, done by the Geological Survey of Canada (1991) for this project, and based on the historic earthquake record, results in the following 50-year probabilities of exceedence of horizontal acceleration:

- o 0.062 g, 40%
- o 0.089 g, 22%
- o 0.136 g, 10%
- o 0.196 g, 5%

Besides the strong earthquake ground shaking that can damage or destroy structures, secondary effects of the shaking, such as soil liquefaction and earthquake-induced landsliding can also be hazards. Soil liquefaction under seismic loading depends on the presence of saturated (below the water table), loose to medium-dense, cohesionless soil such as medium- to fine-grained sand. Such soil/groundwater conditions may be present in the Cheekye fan. If the magnitude of strong motion and/or its duration are sufficiently large with respect to the soil properties, then liquefaction may occur. Because the potential for liquefaction is very site specific, and because site specific data regarding soil type, nature, and properties, as well as depth to groundwater are unknown, then specific estimates of the liquefaction potential cannot be made at this time.

Earthquake-induced landsliding can occur to several hundreds of kilometers from large magnitude (e.g., M 7.0+) earthquakes, and the area affected can be from 10,000 to more than 100,000 square kilometers (Keefer, 1984a, 1984b). Such landslides are, in general, small volume rockfalls, rockslides, soil slides and disrupted slides. Occasionally, large volume rock avalanches (e.g., the 50 million cubic meter Mt. Huascaran rock avalanche) or soil avalanches can be generated by large magnitude earthquakes. The effects of magnitude 6.0, 7.0 and 8.0 earthquakes would be the following (Keefer, 1984a):

o magnitude 6.0:

- area affected by earthquake-induced landslides is about 1,200 square kilometers,

- the maximum distance to which rock falls or disrupted landslides may occur is about 70 km, while for coherent landslides it is about 30 km.

o magnitude 7.0:

- area affected by earthquake-induced landslides is about 15,000 square kilometers,

- the maximum distance to which rock falls or disrupted landslides may occur is about 200 km, while for coherent landslides it is about 140 km.

o magnitude 8.0:

- the area affected by earthquake-induced landslides is about 110,000 square kilometers,

- the maximum distance to which rock falls, disrupted landslides or coherent landslides may occur is about 350 km.

Keefer (1984a) also notes the minimum magnitude needed to cause landsliding:

o M 4.0 for rock falls, rock slides, soil falls, disrupted soil slides,

o M 4.5 for soil slumps and soil block glides,

o M 5.0 for rock slumps, rock block glides, slow earthflows, soil lateral spreads, rapid soil flows and subaqueous landslides,

o M 6.0 for rock avalanches, and

o M 6.5 for soil avalanches.

Because of the number of potential earthquake sources that could affect the Cheekye fan, and because of the above information on earthquake-induced landslides, earthquake-induced landslides in the Cheekye River drainage could likely be primarily of small volume but of large number. The debris from such failures themselves may not reach the Cheekye fan, but could dam the drainages and provide a source of debris and sediment, that with dam failure could reach the fan. A very large volume rock avalanche, generated by a large-magnitude earthquake, that could potentially reach the fan, may be a low probability event and would be related in part to the probability of a large earthquake occurring along the potential seismic sources.

DISCUSSION

Because the available data for quantifying the nature and ages of seismic and volcanic hazards specific to the Cheekye fan are generally incomplete and uncertain, and because the situation is not likely to improve soon, it is suggested that analogs, for volcanic and seismic hazards, from elsewhere in western North America and the Cascade Range be used to develop the necessary data to examine the hazards in a probabilistic sense. Where analog data may not be available, then expert and professional judgement may be employed to develop the needed data. In addition, conceptual models to support the evaluation of seismic and volcanic hazards should be based on the known geologic record from the Cheekye fan/ Mt. Garibaldi area and region, and augmented as necessary with data from analogs.

The potential for volcanic processes from the Mt. Garibaldi complex to affect devlopment on the Cheekye fan depends in large part on the expected life of the developments. If the recurrence interval for volcanic activity is very long in relation to the life of the development, then the probability of the fan to be affected will be relatively low. For example, if the recurrence for volcanic activity at the Mt. Garibaldi complex is a few thousand to a few

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TABLE III-1
PYROCLASTIC FLOWS FROM CASCADE VOLCANOES

Volcano	Age yr BP	Volume M. cu. m	Distance Traveled km	Remarks	Source
Glacier Peak	11,250—12,750	<3	20	—	1
	5,100—5,500	———	—		
	1,700—1,800	500—1,000	—	100m thick in adjacent valleys	
	1,000–1,1000	100—250	30–	80–100m thick	
Mt. Rainier	2,500	—	5+		2
Mt. St. Helens	3,500—4,500	—	4—7		3,6
	2,700—3,300	—	13+	8+ pyroclastic flows	
	2,100—2,300	—	4+		
	630	—	4—9	4+ pyroclastic flows	
	230	—	5+		
	Historic (1980)	—	3—8+		
Mt. Hood	12,000—15,000	—	10–		4
	1,500—1,800	—	9–		
	200—300	—	7–		
Mt. Shasta	9,800+	—	10+		5
	9,800	—	6.5–21+		
	8,600	—	10.5+		
	6,000	—	9.5		
	3,400	—	8+		
	1,800–3,400	—	5.5+		
	2,000—3,000	—	9–18+		
	1,800	—	13+		
	700	---	8+		

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TABLE III-2

LANDSLIDES FROM QUATERNARY VOLCANOES IN THE CASCADE AND GARIBALDI VOLCANIC BELTS

Volcano	Landslide(1) Type	Age yr BP	Volume M. cu. m.	Distance Travelled km	Cause(2)	Remarks	Sources(3)
Glacier Peak	L	14,000	—	—	Eruption	—	1,2,9
	L	11,250—12,750	<3000	120	Eruption		
	L	5,100—5,600	<9000	100	Eruption	Skagit R. valley	
	L	2,800	—	20	Non-eruption(?)	Valley west of mountain	
	L	1,700—1,800	<500	100	Eruption	Skagit R. valley	
	L	<1,800	—	30	Non-eruption	Valley west of mountain	
	L	1,000—1,100	<100	30	Eruption		
	L	300—1,000	—	30—50	Non-eruption	Several valleys from mountain	
	L	Historic	—	12	Non-eruption	Several lahars	
Mt. Rainier	DA	9,000	—	—	Eruption(?)	Nisqually R. valley	3,4,5,9
	L	7,000	—	—	Non-eruption(?)	Ohanapecosh R. valley	
	DA-L	5,700—6,600	—	45	Earthquake(?)	Greenwater lahar	
	DA-L	5,800—6,600	50—100	29	Earthquake(?)	Paradise lahar	
	DA-L	5,700	1,500	113	Non-eruption	Osceola lahar	
	L	3,600—6,600	—	6—29	Non-eruption(?)	At least 10 lahars	
	L	2,300—3,600	—	5—29	Non-eruption(?)		
	L	<3,600	—	41	Non-eruption(?)		
	L	450—3,600	—	6—23	Non-eruption	At least 20 lahars	
	L	600	150	49	Non-eruption		
	L	275—450	—	2-29	Non-eruption	At least 11 lahars	
	L	Historic (1860)	—	7	Non-eruption	Nisqually R. Valley	
	L	Historic (1932)	—	5	Non-eruption	Nisqually R. Valley	
	L	Historic (1934)	—	2(?)	Non-eruption	Nisqually R. Valley	
	L	Historic (1947)	—	—	Non-eruption	Nisqually R. Valley	
	L	Historic (1955)	—	—	Non-eruption	Nisqually R. Valley	
	DA	Historic (1963)	—	7	Non-eruption	White R. Valley	
	L	Historic (1947)	—	10	Non-eruption	Kautz Cr. Valley	
	L?	Historic (1961)	—	9	Non-eruption	Kautz Cr. Valley	
	L	Historic (1967)	—	6	Non-eruption	Tahoma Cr. Valley	
Mt. St. Helens	L	3,500—4,500	—	4—30+	Eruption	Preceeded by 4000-yr dormancy	6,9
	L	2,700—3,300	—	18—70+	Eruption		
	L	2,100—2,300	—	10—30+	Eruption	7+ lahars	
	L	400	—	3—9+	Eruption		
	L	Historic (pre-1980)	—	3+	Eruption(?)	Confined to flanks	
	DA	Historic (1980)	2.8	22	Eruption	Velocity up to 50 m/s	
	L	Historic (1980)	—	120	Eruption	Velocity 1.5 - 40 m/s	
Mt. Hood	L	12,000—15,000	—	10—15+	Eruption		7,9
	L	1,500—1,800	—	9-80	Eruption		
	L	200—300	—	7-20+	Eruption	Numerous hot and cold lahars	
	L	Historic (1800)	—	40+	Non-eruption	Pollallie Cr. Valley	
Mt. Shasta	DA-L	300,000 - 360,000	26.0	43	Non-eruption(?)	Ancestral Mt. Shasta	
	L	9,800	—	6.5+	Eruption	Up to 12 lahars	8,9,12
	L	8,200	—	7—11+	Eruption(?)		
	L	8,000	—	16+	Eruption		
	L	5,900—6,000	—	9.5—18+	Eruption	3+ hot and cold lahars	
	L	4,500	—	19+	Eruption		
	L	4,000	—	30+	Eruption(?)	2+ lahars	

TABLE III-2

LANDSLIDES FROM QUATERNARY VOLCANOES IN THE CASCADE AND GARIBALDI VOLCANIC BELTS

Volcano	Landslide(1) Type	Age yr BP	Volume M. cu. m.	Distance Travelled km	Cause(2)	Remarks	Sources(3)
	L	3,100	—	13+	Eruption		
	L	2,800	—	12+	Eruption		
	L	2,600	—	15+	Eruption	1 hot lahar	
	L	1,700—1,800	—	13—15+	Eruption(?)	10+ lahars	
	L	1,000—1,500	—	11+	Eruption(?)	1+ lahars	
	L	700—750	—	11—14+	Eruption(?)		
	L	100—200	—	10-19+	Eruption	20+ lahars	
	L	Historic	—	20+	Eruption		
Mt. Meager*	L	0—11,000	>1	—	Eruptions(?)	Ten events	10
	L	0—90	>1	—	Non-eruption	Three events	10
	L	0—10	<0.1	—	Rainfall	Ten events	10
	L	900	10	—	Non-eruption		10
	L	60	5	20	Rainfall	(1931)	10
	DA	16	15	5	Ice Melting	15% ice	11
	DA	5	1	1.3	Non-eruption	—	12
Mt. Cayley*	DA	4800	200—300	—	Non-eruption		13
	DA	1100	<20	—	Non-eruption		13
	DA	500	—	—	Non-eruption		13
	DA	28	5	3	Non-eruption		14
	DA	7	<1	8	Rainfall		15
Mt. Garibaldi	DA/L	0—11,000	<50	9	—	5 to 10 events	16
	L	0—6,000	<10	15	—	3 events	this study
	DA	136	36	7	Non-eruption	—	16
	DF	0—100	<1	15	Rainfall	2 events	17

Notes: (1) L = lahar generic term for hot or cold debris flows; DA = debris avalanche or rock avalanche

(2) Where eruption or non-eruption is queried, it means that the opposite cause could have triggered the landslide.

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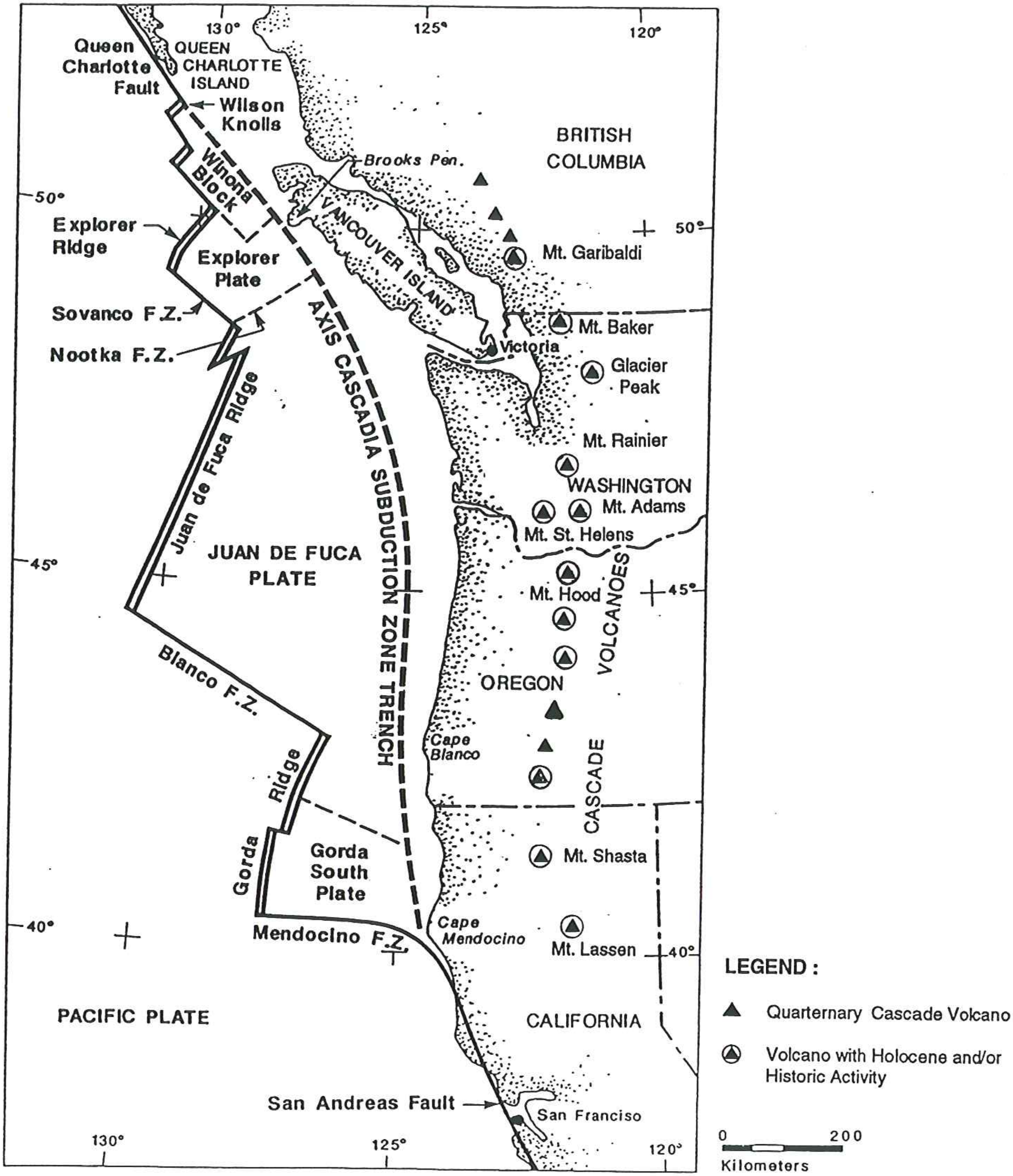
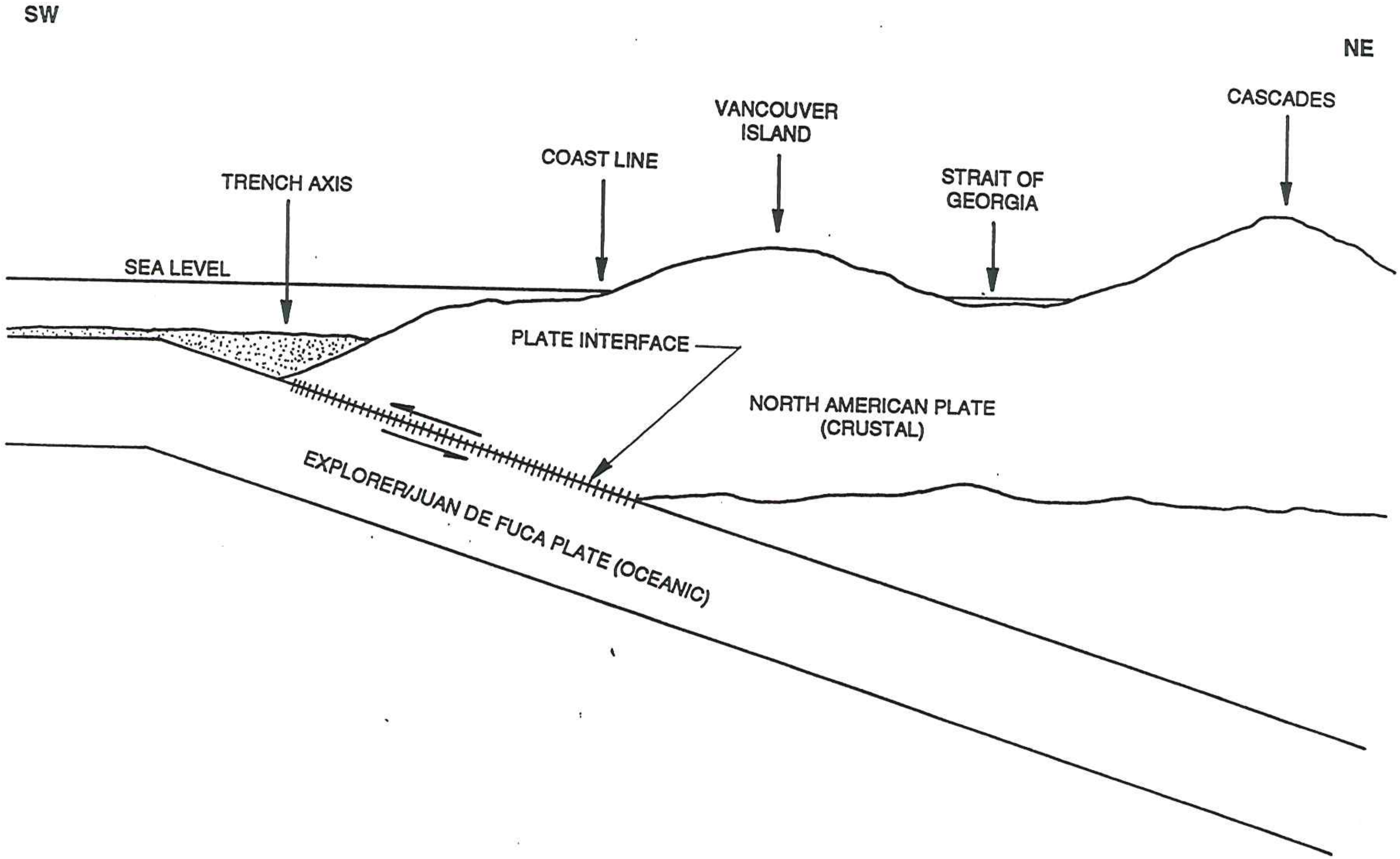


Modified from : Riddihough, 1984.
Simkin et al, 1081.

Job No. 913-7063	Scale As Shown	**TECTONIC SETTING OF THE CASCADIA SUBDUCTION ZONE**	
Drawn DVR	Date Dec 1991		
Checked DOW	Dwg. No. OAK0001403		
Golder Associates		BC LANDS/912-1462 VANCOUVER/BC	FIGURE **III–1**



Job No. 913-7063	Scale N/A	SCHEMATIC TECTONIC CROSS-SECTION
Drawn DVR	Date Dec 1991	
Checked DOW	Dwg. No. OAK0001404	
Golder Associates	BC LANDS/912-1462 VANCOUVER/BC	Figure III-2

APPENDIX IV

GEOLOGICAL REPORT ON CHEEKYE BASIN

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FIGURE IV-1 Geological Section X-X

APPENDIX A List of Rock and Water Samples
APPENDIX B Field Notes - Cheekye River Terrain Hazard Study

1.0 AUTHORIZATION

Mr. J. F. Psutka was retained by Thurber Consultants for geological services, by letter of June 24, 1991 from Mr. G. Rawlings to Mr. D. P. Moore of B. C. Hydro.

2.0 TERMS OF REFERENCE

Mr. Psutka's services were requested by Thurber Consultants to undertake regional geological mapping within the Cheekye River basin. Mr. Psutka's task was to geologically map areas of particular concern to the overall study, and produce a report which would summarize his findings and address these concerns. It is understood that Mr. Psutka's work will be incorporated, as appropriate, into the final report by the project team.

3.0 INTRODUCTION

As part of the Cheekye River Terrain Hazard Study, a program to geologically map parts of the upper Cheekye River basin was carried out. The purpose of this part of the study was not to remap the area, which was mapped in detail by Mathews in the 1950's, but rather to focus attention on unresolved questions in the areas of potential stability problems, particularly in the areas of the Cheekye Ridge and Brohm Ridge linears.

The results of this report are based on 13 days of field mapping on the crest and north slope of Cheekye Ridge, and the crest and south slope of Brohm Ridge. The areas covered in this study are shown on Figure 3.2 (in main text).

Air photos at various scales were used during the course of the work. Geological mapping was carried out in the field on a 1:10,000 scale orthophoto with 20 m contours, provided by Thurber Consultants.

Lists of rock and water samples collected during the field work and all field notes recorded are contained in Appendices A and B. The photographic records are submitted under separate cover.

4.0 OBJECTIVES

The prime objective of this study is to assess the geology of Cheekye and Brohm ridges focusing on unresolved geological questions.

The main areas of concern in the Cheekye River basin covered in this study are:

1) investigation of the Cheekye Ridge linears to assist in defining the depth of movement, depth to basement rock, areal extent of the linears, and the hydrology;

2) assessment of the basement rock characteristics, in particular altered vs unaltered;

3) to map the basement/pyroclastic rock contact in the region of the linears on Cheekye and Brohm ridges;

4) inspection of the "bulge area" below Cheekye Ridge,

5) an investigation of the linears on Brohm Ridge and a comparison with those on Cheekye Ridge. Investigate possible linears due east of the Brohm Ridge linears.

6) to define other areas of potential stability problems in the course of the work.

5.0 STRATIGRAPHY

The stratigraphic sequence in the study area is divided into two main groups: basement rocks, and overlying young volcanic and unconsolidated deposits. The basement rocks are composed of lower Cretaceous or Jurassic Gambier Group, and Cretaceous Cloudburst Quartz Diorite; the overlying young volcanic and unconsolidated deposits are composed of Quaternary Garibaldi Group volcanics and Recent glacial deposits. The stratigraphic column for the study area, modified from Green (1977) is shown on Figure 3.2.

5.1 Gambier Group (Jmv)

The basement rocks of the study area (upper Cheekye River basin) are composed primarily of Gambier Group metavolcanics. The Gambier here is composed of dark green plagioclase porphyry flows and volcanic breccias with minor rhyolite flows or dikes, tuffaceous sediments, and diabase dikes. The metavolcanics are mainly massive but locally develop a weak to moderate foliation. Chloritization and epidotization are common in these rocks.

At localities where the siliceous (rhyolite) dikes are intensely sheared they resemble siliceous phyllite. However on occasion there is a gradational boundary between the sheared and unsheared material and the protolith is identifiable.

5.2 Cloudburst Quartz Diorites (Coa)

The second subdivision of the basement rocks identified in the study area is diorite, rather than the typical quartz diorite reported elsewhere. The diorite is massive to weakly foliated, dark green, fresh, fine to medium grained, and locally occurs as dikes in the Gambier Group rocks. The diorite is composed of hornblende and plagioclase, locally containing a small percentage of biotite.

Both subdivisions of the basement rocks are weakly to intensely altered in the area covered by Garibaldi pyroclastic rocks. Discussion of this alteration is presented in Section 7.0.

5.3 Garibaldi Group

The rocks of the Garibaldi Group as mapped in this study, belong to three episodes of volcanism as described below. The subdivisions are based on work by Green (1977 and 1990).

(i) Rocks of the 0.4 - 0.7 Ma volcanic episode (**Qva, Qvb**)

These volcanic rocks were encountered in this study on Brohm Ridge (Figure 3.2). They are composed of hard, grey, plagioclase porphyry dacite flows (Qva) with a trace of hornblende and display a distinct flow banding. The flows overlie a sequence of andesitic pyroclastics (Qvb) that are quite different from the younger pyroclastics mapped in the area of Cheekye Ridge. They are massive, well indurated and contain a variety of volcanic clasts. The clastic framework is composed of a wide variety of volcanic lithologies about 5 to 60 cm in size, and are angular to subangular. The base of the unit contains some fragments of the underlying metavolcanic basement rocks. The top of the unit is occupied by a 10 - 15 m thick bedded, brick red to maroon tuffaceous layer. The sequence dips from 15° to about 45° to the west.

(ii) Rocks of the 0.2 - 0.3 Ma volcanic episode (**Qvi**)

These rocks were observed at only one locality in the area mapped for this report, at the very western extremity of Cheekye Ridge at 1,350 m elevation (Figure 3.2, Stn C3).

These rocks consist of essentially flat lying, dark grey plagioclase porphyry flows. Plagioclase phenocrysts are 1-2 mm and the matrix is aphanitic. Columnar jointing is developed locally. A possible feeder dike for these flows was mapped downslope at station C16 (Figure 3.2).

(iii) Rocks of the < 0.1 Ma volcanic episode (**Qgt**)

One of the youngest volcanic events to have taken place in the Cheekye River area was the deposition of grey and maroon dacitic pyroclastics. There appear to have been two stages of eruption, separated by an unconformity (Mathews, 1952). The only obvious difference in the material across the unconformity is a change from a fine texture below to a coarser texture above.

The material consists of grey and maroon plagioclase hornblende dacitic clasts ranging from sand size to boulders several metres across. The deposit appears bedded when viewed from a distance but becomes diffuse when observed on an outcrop scale. The deposit is unconsolidated and fresh.

The pyroclastics on Cheekye Ridge were found locally to extend to a lower elevation, downslope and northeast of the slump area, than previously mapped (Figure 3.2, Stn C35). This may represent in situ material deposited on the original ground surface, but the possibility that it has been transported to this area cannot be ruled out. If the deposit was bedded the answer would be clear, but as previously mentioned, the bedding is difficult to see on an outcrop scale. Exposures of pyroclastics are limited and small in size in this area.

On Brohm Ridge there were no definite in situ young pyroclastics identified. Rather, the few exposures of grey and maroon pyroclastics appear to be loose reworked or slumped material. There are some bedded lacustrine sediments similar to exposures on the Brohm Ridge logging road.

5.4 Late Glacial Surficial Deposit (La)

The late glacial surficial deposit was observed toward the southwest end of Cheekye Ridge (Figure 3.2). The deposit is thin, with a maximum thickness of 5 m exposed. It is composed of subangular to angular volcanic clasts 1 mm to 4 - 5 cm and about 10% 15 to 60 cm boulders scattered throughout the exposures. Clast compositions range from grey, green, maroon, light grey, and yellow volcanic rocks and some (5%) rounded basement rocks composed of massive, coarse, hornblende diorite to granodiorite. The occurrence of rounded foreign material in the deposit suggests a glacial origin. The unit appears to be unbedded. The basement surface upon which it was deposited is fresh and the contact sharp.

6.0 STRUCTURE

6.1 Cheekye Ridge Structures

The Cheekye Ridge slump is a localized area of closely spaced linear depressions and scarps developed in Atwell Peak pyroclastics (**Qgt**) near the west end of the ridge. The main cluster of linears is exposed over a length of 100 m along the ridge crest and from 1400 m elevation down to 1200 m (Figures 3.2 and IV-1). There is no clear evidence that basement rock is involved in the deformation.

The linears show no signs of being active at the present time. Straight, old trees growing on the scarp faces indicate no movement over their growth period. No tree roots are obviously displaced by offset on the linears; tree roots exposed on the scarp faces grow parallel to the scarp surface. There is local ravelling of pyroclastic material on the faces of some scarps, but this phenomenon occurs only in the logged off area. No ravelling was observed on the scarp surfaces in the adjacent virgin forest.

Linears similar to the ones involved in the Cheekye slump continue east along the ridge to an elevation of 1540 m. One isolated linear at 1800 m is a northerly trending fault with 2-3 m normal displacement with its west side downdropped (Figure 3.2, Stn C23). This linear has an orientation indicating it is related to instability other than that expected near the crest of the steep pyroclastic cliff face. There are local signs of instability related to proximity to the steep cliff face in the pyroclastics at a few localities along the ridge.

There are other linears that extend westward from the main cluster for a distance of 110 m, but these appear to be developed in the thin late glacial deposits (La).

Linears in the lobe of pyroclastics that extends down the slope (Figure 3.2, Stn C29), are controlled by the local topography. They are developed on the flanks of steep sided ridges, subparallel to the trend of the ridge.

There is a marked steepening in the topography at about 1100 m elevation below the slump area. Numerous vegetated and recent landslide scars occur in the pyroclastics across the slope at this level.

The toe of the slope in the "bulge" area was traversed at river level. All exposures mapped were intact bedrock.

6.2 Brohm Ridge Structures

No linears were observed on the south facing slope of Brohm Ridge in basement rocks or lava flows below about the 1300 m elevation level. Linears were identified near the crest of the ridge on an east facing curve in the ridge.

The Brohm Ridge linears (Figure 3.2) are developed in both pyroclastic rocks and in overlying lava flows. These rocks belong to the 0.4 - 0.7 Ma Quaternary volcanics discussed in Section 5.3 (i). Where developed in the pyroclastics the linears are similar in morphology to the ones on Cheekye Ridge. There are large undisturbed trees growing on the crests and faces of the scarps, with no signs of recent activity. Where developed in the old lava flows they are sharply defined and commonly display recent looking holes in the moss cover in the troughs. This may however be a function of a slow rate of erosion of material from the scarp faces.

As at Cheekye Ridge there is no clear evidence that basement rock is involved in the deformation.

Another area of concern lies east of the main Brohm Ridge linears (Figure 3.2, Stn C90). In this area a series of continuous arcuate linear structures were identified and were investigated to determine if they were similar to the aforementioned linears. Upon ground inspection they appear to have resulted from erosional or "thin skin" instability. The surface material is a 1-1.5 m thick light brown, fine grained sand deposit similar to that observed over much of the study area at comparable elevations. This sand overlies a bouldery glacial deposit. The "linears" appear to be located at the edges of wide zones of bouldery glacial deposits from which the overlying fine sand layer has been removed by erosion. There are commonly scarp like ridges both upslope and downslope of the eroded area. The features may have been initiated by small downslope movements resulting in cracking of the surface sand layer which allowed erosion to widen and enhance the features. The features currently are ephemeral drainage channels.

7.0 DISCUSSION

7.1 Basement Lithology

The basement rocks as mapped during the course of this study, were found to be significantly different from those shown on the more recently published maps of the area. Rather than belonging largely to intrusive rocks of the Cloudburst Quartz Diorites, they were found to be composed mainly of an assortment of metavolcanic rocks of the Gambier Group. On account of the complex stratigraphic relationships within the metavolcanic basement rocks individual rock units could not be mapped. The distribution of the basement rocks is shown on Figure 3.2.

7.2 Basement Structure

The basement rocks in the study area are characterized by both foliated and unfoliated metavolcanic rocks as described above, but locally there are exposures of unfoliated diorite dikes. Mathews' (1958) work on a more regional scale than this study, identified foliated intrusive rocks as well. Foliation trends in the metavolcanic rocks are northwesterly with northeast and southwest dips, with the northeast dips dominant. Minor shears, developed in the metavolcanics trend subparallel to the foliation. No clay gouge was observed in these shears. Rather the deformation appears to be restricted to narrow zones of intense phyllitic foliation. One example of this occurs in the Cheekye River bottom (Figure 3.2, Stn C48) where a weakly foliated rhyolite layer is in gradational contact with grey and white siliceous phyllite. It appears that the rhyolite has been locally intensely sheared to develop what resembles a phyllitic foliation. The massive metavolcanic flows and breccias generally do not develop a foliation. Samples of this rock were collected (Appendix A) and a petrographic examination of some of these specimens could be conducted to verify whether the phyllitic material is a metasediment or sheared rhyolite.

No significant throughgoing? faults were mapped in the area. The rocks underlying the Brohm and Cheekye ridge linears are composed dominantly of Gambier Group metavolcanics. It is not until the western end of Cheekye and Brohm ridges that evidence of the dioritic intrusive rocks is seen and it is in the form of fine to medium grained diorite dikes. The main body of the Cloudburst Quartz Diorite lies west of the mapped area and its general relationship to the Gambier was not investigated.

7.3 Basement Alteration

The metavolcanic and plutonic basement rocks are locally altered in the areas mapped in this study. The alteration consists of rusty to yellow ochre and black staining of jointed and sheared basement rock. The alteration commonly consists of intense pyritization with rust staining occurring on exposed joint surfaces. The unaltered rock is clearly evidence of the alteration in the overlying pyroclastics, but there apparently is none. Alteration similar to that in the headwater area of Cheekye River was observed in roadcuts on the west end of Brohm Ridge (Figure 3.2, Stn C69). Because of the limited area of altered basement mapped in this particular study, no alternative explanation can be proposed at the present time.

7.4 Paleotopography

There appears to be a paleovalley beneath Cheekye Ridge, which was first identified by Mathews (1952, 1958). This feature has been confirmed by seismic surveys conducted this summer.

7.5 Distribution of Pyroclastics

One modification to the distribution of the pyroclastic rocks was made in the area of Cheekye Ridge. The pyroclastics were traced further down the slope in the area north and east of the ridge crest.

7.6 Dalton Dome

This section is included to review the important aspects of this lava flow namely, that it is non-glaciated, and represents volcanic activity that took place not long after withdrawal of the ice sheet (Mathews, 1952, 1958). Mathews (1958) suggests that the progressive melting of ice in the surrounding valleys led to the collapse of the western flank of the supraglacial Atwell Peak pyroclastic cone. After most of the ice sheet beneath the cone had disappeared, a new vent opened in the vicinity of Dalton Dome and dacite lava flowed westward down a landslide scar which truncates more gently dipping tuff breccias (Green, 1990; Mathews, 1952).

7.7 Miscellaneous Items

The only mafic mineral identified in the Cheekye Ridge pyroclastics is hornblende. Yet one exposure of a debris flow on the Cheekye fan, in a borrow pit upslope from Alice

Lake, contains clasts of plagioclase + biotite pyroclastics. The source of this material is unknown.

Seepage was noted issuing from basement rocks below the base of the pyroclastics on Cheekye Ridge.

8.0 CONCLUSIONS

1) The linears on Cheekye Ridge appear to be developed in pyroclastic rocks only. The linears on Brohm Ridge are developed in pyroclastic rocks and overlying volcanic flows.

2) Alteration of the basement rocks immediately downslope of the Cheekye linears is not uniform. It occurs in zones that trend downslope. At the base of Dalton Dome and Atwell Peak, the alteration appears to be uniform and more intense. The basement rocks underlying the pyroclastic rocks at Cheekye and Brohm Ridge are dominantly Gambier Group metavolcanics. The basement alteration observed at Brohm Ridge is uniform over a wide area.

3) No direct evidence that the Cheekye slump involves basement rocks was identified in the course of this study.

4) Cheekye Ridge and Brohm Ridge linears are similar in morphology, and there is no clear evidence of recent movement. The localized active sloughing on some of the linear scarps on Cheekye ridge are likely due to deforestation.

5) Both young and old pyroclastics are apparently unaltered where lying on altered basement.

6) No alteration of the basement rocks was observed on the south or west sides of Cheekye Ridge, nor on the south slope of Brohm Ridge.

7) No other significant areas of instability other than those outlined in the objectives were observed in the course of this study.

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APPENDIX A

LIST OF ROCK AND WATER SAMPLES

APPENDIX A

CHEEKYE RIVER TERRAIN HAZARD STUDY
GEOLOGICAL MAPPING – CHEEKYE BASIN
ROCK SAMPLE LIST

Sample Number	Lithology	Item of Interest
C1	Matrix of reworked pyroclastics	Look for evidence of reworking; rounding, foreign material
C3	Dark grey plag porphyry lava flow (0.3 Ma)	Mineralogy
C18	Siliceous pale green dike rock	Is this rhyolite
C19	Grey phyllite	Mineralogy
C31	Medium green plagioclase porphyry	Mineralogy
C35	Grey plag and Hb porphyry pyroclastics	Mineralogy
C40	Maroon plag and Hb porphyry pyroclastics	Mineralogy
C45A	Maroon plag and Hb porphyry pyroclastics	Mineralogy
C45B	Greenish grey plag+ Hb porphyry pyroclastics	Mineralogy
C45C	Grey plag and Hb porphyry pyroclastics	Mineralogy
C48	Pale green siliceous rock	Lithology
C48A	Grey phyllite	Lithology
C48B	Pale green siliceous rock	Lithology
C48C	White (bleached) massive rock	Lithology
C48D	Grey–green phyllite from adjacent to shear zone	Is this sheared equivalent of Sample C48
C48E	Massive greenstone	Lithology
C53	Weakly foliated plag porphyry metavolcanic	Lithology
C56A	Pale green siliceous dike(?) with plagioclase phenos	Lithology, structure
C56B	Sheared part of siliceous rock	Is this the sheared equivalent of Sample C56A
C60A	Old volcanic flows on Brohm Ridge	Mineralogy
C60B	Old pyroclastics, deep maroon, red	Mineralogy
C66A	Tuffaceous sediments	Lithology
C66B	Thinly banded siliceous rock (rhyolite ?)	Lithology, structure
C70	Slightly rusty phyllitic sheared(?) rock	Lithology, mineralogy, structure
C73	Altered basement rock at contact	Lithology, mineralogy, structure
C73A	Altered basement rock immediately below contact	Lithology, mineralogy, structure
C73B	Altered basement rock 20m below contact	Lithology, mineralogy, structure
C88A	Sheared slightly rusty fine grained Hb diorite	Lithology, structure
C88B	Old pyroclastics with fresh and altered metavolcanic clasts	Lithology, structure
C88C	Old pyroclastics 20m above base of unit	Lithology, structure

APPENDIX A
(cont'd)

CHEEKYE RIVER TERRAIN HAZARD STUDY
GEOLOGICAL MAPPING – CHEEKYE BASIN
WATER SAMPLE LIST

Sample Number	Location
1	Sample from side stream issuing from altered rock, Station C48
2	Cheekye River water sample, Station C48
3	Water sample from northwest flowing stream, Station C51
4	Water sample from northeast flowing stream, Station C51

Note: These water samples may be contaminated with soapy residue from sample bottles

2/L/TAB-91/DEC/GR-1462.wk3

Diorite: Medium to dark green Hb diorite. Massive. Shot through with bleached alteration veinlets and epidote stringers. Slightly open, blocky. Random jointing. Rust stained. Curved to planar, slightly rough. Block size 10 cm - 60 cm. Shape is cubic to tetrahedral, no infillings. No seepage.

Minor seepage from colluvium between outcrops, at edge of road.

C3 (1320 m) Med - dark grey plagioclase porphyry flow. Exposure 5 - 20 m high. Traced good lava flow outcrops to east of peak. Massive, jointed, uniform in composition and locally contains dark green Hb phenocrysts 1 - 1.5 mm. Cannot determine relationship between pyroclastics and lava flows. Class 6 - very strong. Grain size of plagioclase - 1 - 2 mm. Matrix is aphanitic. Sample C3.

Rock Mass:

Upper half - W2 (slightly weathered), block size 5 - 30 cm, platy, tight, no seepage, no clay.

Lower half -W2 (slightly weathered), block size 20 - 400 cm, blocky, tight, no seepage, no clay.

Structure:

J1 (Joints) 094°/74°N, [74°/004°]; 094°/88°S [88°/184°] - smooth, curviplanar, tight, hematite, spaced 20 - 100 cm (30 -50 avg), 1.5 m long.

J2 (Joints) 076°20°SE [20°/166°]; 062°/15°SE [15°/152°]; 074°/19°SE [19°/164°]; slightly rough, curviplanar, tight, hematite, spaced 5 - 100 cm, 1 - 50 cm (in area of measurements - in lower half of outcrops these flat dipping joints are uncommon). Thin <0.5 mm staining of hematite on all joint surfaces of both sets. Occasional random joints - also with hematite staining.

At 1415 m - on main linear at ridge crest. Continue to follow it downslope.

C4 (1415 m) On trace of main linear followed from clear cut area to ridge crest, and continues down a gully. Presently at ridge crest. Old growth trees up to 1 m diam, straight, growing on crests and locally on scarp faces. The ravelling slopes seen on some of the scarp faces in the clear cut area are not present in the old growth forest. The ravelling is likely due to denudation rather than current slope movement.

C5 (1360 m) On SW end of main linear. Only isolated patchy exposures of pyroclastics on ridge behind linear. Linear dies out. Where most prominent, is a broad 2 - 3 m deep, 5 - 6 m wide trough.

Steady rain, high gusty winds all night August 8, continued all day August 9. Since no way to dry out or cook meals - came down to Squamish for the night.

August 9, 1991 Steady rain, fog.
Traverse on Cheekye Ridge.

C6 (1365 m) At 4 m high road cut in what appears to be pyroclastic unit but cannot dig more than about 40 cm depth in brown colluvium. Surface covered by grey and maroon volcanic clasts 2 - 30 cm. Road bed appears to be composed of med green chloritic metavolcanic but have not seen it in place. Linears in this area trend 010°.

Following logging road down to 1300 m only see dominantly 2 clast types in pyroclastics - med grey plag and Hb porphyry and maroon plag and Hb porphyry. Plag and Hb well dispersed throughout rock - not crowded with phenocrysts.

C7 (1205 m) Came downslope in no outcrop in densely vegetated slope. On a linear trending 012°.

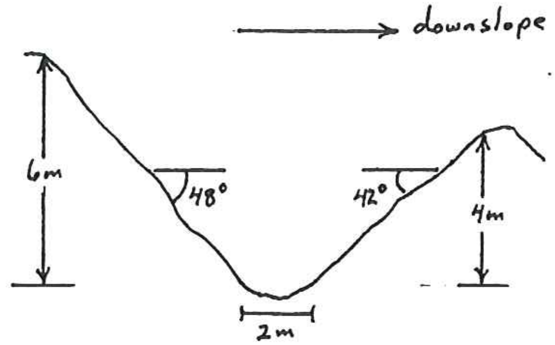
C8 (1185 m) Looks like metavolcanic. Med green weakly foliated plagioclase porphry. Tight, no seepage.
S_1 135°/65°NE [65°/045°]

On ridge crest to east at 1200 m is a minor linear. At 1250 on ridge crest, small exposure of pyroclastics. Grey and maroon as seen on logging road above.

At 1300 m is the first major linear 100 m+ long and 8 m deep, below lower logging road. At 1360 m second major linear 100 m+ long, 10 m deep, above road, further to NE.

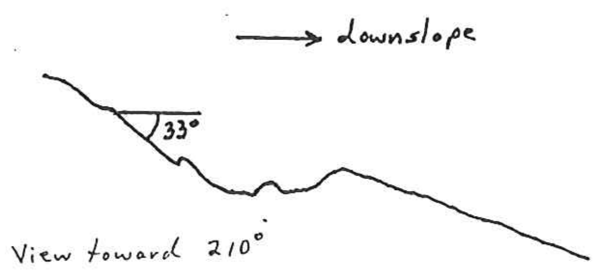
August 10, 1991 Steady rain, heavy fog all day.
Traverse on Cheekye Ridge.

C9 (1460 m) On a prominent linear behind (upslope) from main scarp. Blocks of volcanic rock in trough, some young trees on upslope ridge are slightly bent.



C10 (1550 m) Crossed main Camp Linear and continued upslope along ridge to here. Still crossing smaller linears (Azi 210°) upslope from Camp Linear.

C11 (1510 m) On Camp Linear, Azi 205°. Appears to continue into or east of main Cheekeye Valley slope. Linear is 5 - 10 m wide at base. Several smaller scarps near toe of main camp.



C12 (1345 m) At roadcut in pyroclastics. Contains variety of volcanic clasts including dark green fine grained massive volcanic, grey, maroon and others. Matrix very sandy-1 mm. Fragments range in size from 2 - 3 mm to 4 cm, 10% >20 cm blocks in exposure. Colour is light brownish grey to cream. Friable, but weakly indurated. Sandy matrix breaks around most clasts.

C13 (1360 m) At contact between dark grey lava flows and maroon pyroclastics. Matrix still sandy 0.5 - 1.0 cm, friable but more indurated than last station. According to age relationships pyroclastics (<0.1 Ma) were deposited upon the flows (0.2 - 0.3 Ma).

C14 (1342 m) Dark grey plagioclase porphyry lava flows. Plagioclase 1 - 3 mm). Joints spaced 1 - 10 cm, 2 cm - 2 m in length, hematite stained, slightly rough, planar to curved. Platy.
Joint 158°/11°SW [11°/248°]

C15 (1292 m) In possible grey till composed primarily of green chloritic metavolcanic fragments. Angular. Contains a small % of clays. Occasional pink and grey volcanic clasts. Some boulder size, rounded, striated metavolcanics.

Appears to be a deformed fragmental metavolcanic rock in places, about 100 m from station proper. Some fragments are augen shaped. Highly strained. Locally plagioclase phyric.

S_1 155°/82°SW [82°/245°] weak foliation in medium dark green metavolcanic. Outcrop is about 100 m from station.

Joint set 146°40°NE [40°/056°] curved, rough, tight, no infilling, 1 m long. Glacial striations - 20° 005°. Much chlorite and epidote.

At 1230 m is an outcrop of medium green phyllitic greenstone. May be out of place. S_1 145°/46°NE, [46°/055°], foliation.

C16 (1240 m) Dark green foliated metavolcanic similar to nearest Station C15. Exposure 50 - 60 m wide, 25 m high, highly fractured, random. Metalvolcanics are chloritized and epidotized. Sample of metavolcanic - C16.

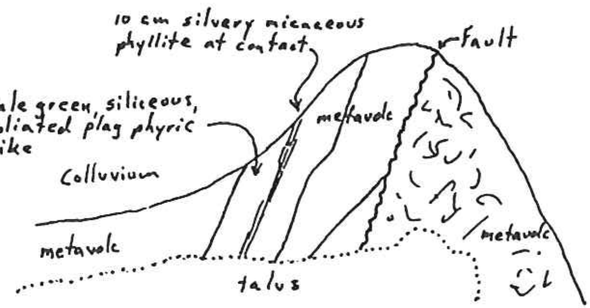
S_1 foliation 080°/53°NW [53°/350°].

075°/85°NW [85°/345°] - Orientation of a 4 m+ dark grey plag and Hb porphyritic dike cutting metavolcanics.

C17 (1250 m) Metavolcanics intruded by a pale green, foliated, siliceous plagioclase phyric dike, with a 10 cm silvery micaceous phyllite at its contact.

S_1 foliation 135°/70°NE [70°/045°]

Fault 178°/70°E [70°/088°] - gouge 5 - 10 cm, highly fractured rock to 1 cm, clay, oxidized. Prominent jointing is parallel to foliation.



C18 (1268 m) Rock is highly siliceous pale green dike or intrusive rock. Plag. phenos 2 - 4 mm, ~10 - 20%. Hard, massive.

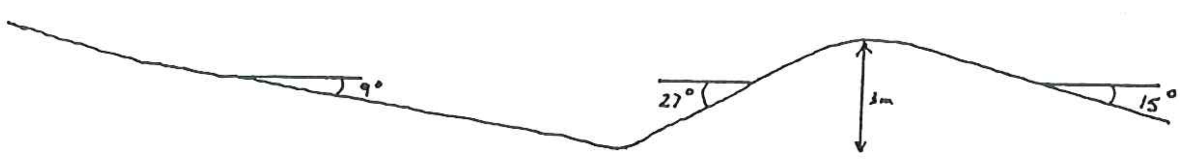
Joint 124°/44°SW [44°/214°] wavy, wave length 15 cm amplitude 2 cm, clean oxidized (brown stain) tight, slightly rough, spaced 30 cm - 50 cm.

Joint 105°/69°NE [69°/015°], slight staining - (yellow-brown), spaced 20 cm, curved, blocky. Random joints also. Slightly weathered. Exposure 4 m high by 4 m long. Small trickle of water on NE side of exposure. Sample of siliceous rock, C18.

C19 (1285 m) Phyllite well foliated. Grey and white. Locally very rusty. Contact with pyroclastics lies nearby to the east. Sample of grey phyllite, C19.
S_1 foliation 115°/47°NE [47°/025°] in white phyllite.

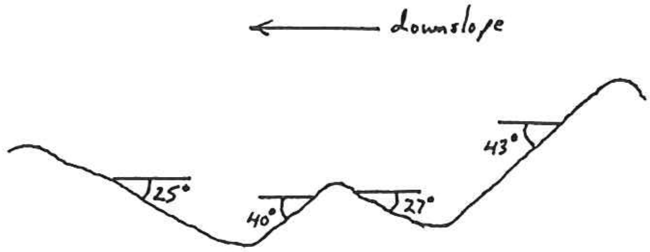
<u>August 11, 1991</u> Heavy fog all day.
Traverse on Cheekye Ridge.

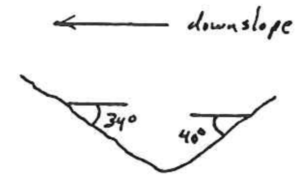
C20 (1360 m) On minor linear on backside of ridge. Came to here in no outcrop. Scarp on linear contains volcanic clasts. West side down.



C21 (1365 m) Outcrops of dark grey plagioclase porphyry flows as seen further to west.

C22 (1410 m) In trough of one of the last major linears south of the slump. Though we are on south slope of ridge the movement direction is still downdropped to the north. Scarp face is composed of reworked (thin grey clay laminations) pyroclastics. Could be a reworked mantle. Thickness unknown. Must be thin because road cuts have pyroclastics exposed. The pyroclastics are more indurated; reworked pyroclastics are looser, and have a finer grained matrix. Matrix of pyroclastics is more sandy. Maroon with grey, green and maroon clasts.

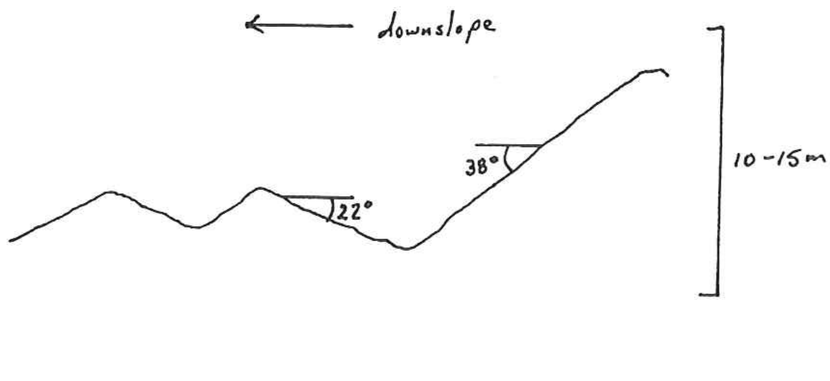




<u>August 14 1991</u> Sunny, hot.
Traverse on Cheekye Ridge.

C23 (1835 m) On Diamond Head Ridge. In maroon and grey pyroclastics. Numerous widely spaced linear gullies - uncertain if linear features related to large scale instability or just drainage. Azimuth of linear 192°. Vegetation below disconformity in pyroclastic sequence may be due to finer sediments comprising the unit. Overlying pyroclastics contain much more blocky material. One linear scarp is 4 - 5 m high on upslope side of linear. Looks like NW side down. Confirmed that this is a structure that offsets the pyroclastics by 2 - 3 m.

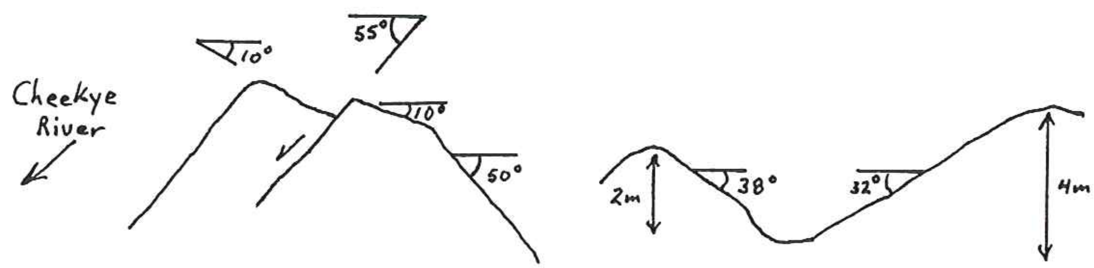
C24 (1670 m) On slump block moving into the Cheekye Basin, related to ridge crest instability, not regional linears. Sketch shows slope angles on prominent linear behind station.



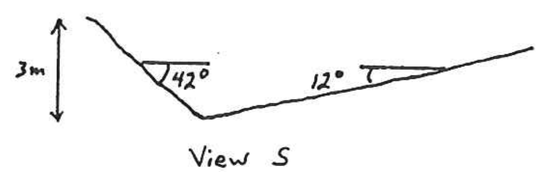
C25 (1630 m) Came along ridge to here, crossing minor slump linears relating to instabilities into Cheekye Basin. No prominent linears yet, relating to slumping. Crossed one major linear further up ridge. Rusty weathering rock below pyroclastics is locally volcanic. Pyroclastics above are not altered at all - could they have been deposited on a pre-existing altered surface? Top of rusty rock is at about 1625 m.

C26 (1580 m) Orientation of linears 188°. Linears start at this location on ridge. Linears show steep, prominent scarps but not clear as to movement direction.

At 1570 m - measured slope angles on small but prominent linear. Trend 200°.



C27 (1480 m) On prominent linear. Trend 190°.



Thoughts for the day:

1. No obvious difference in pyroclastics across discontinuity except noticeably finer grained, no large blocks as those above. May be the reason for seepage. Much altered basement rock in upper basin.

2. Primary linears trend NE, secondary parallel the slope.

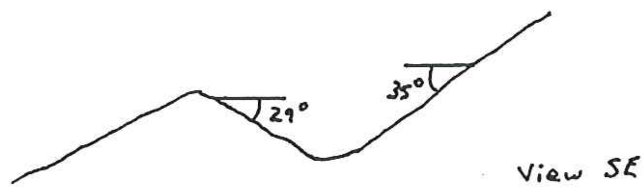
3. Check for hot springs low down on ridge.

4. Seem to be more flows dipping west off of Atwell Peak than realized before.

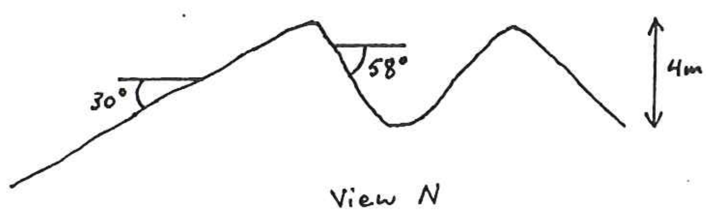
5. Pyroclastics unaltered where resting on intensely altered basement.

August 15, 1991 Sunny, hot.
Traverse on Cheekye Ridge.

C28 (1390 m) On prominent linear contouring slope. Azimuth 132°.



C29 (1365 m) 187° Azimuth of several linears subparallel to north trending ridge.



C30 (1230 m) On flank of stream gully in altered basement consisting probably of diorite. Rock has a sheen on some surfaces (phyllitic) and is bleached white. Very rusty, some green relict chlorite masses 1 - 2 mm. Quite a lot of water in gully at this point. Where does it originate? Water in stream can be seen flowing over altered basement to about 1,400 m. Then cannot see higher from this vantage point.

C31 (1155 m) Medium green plagioclase porphyry metavolcanic. Weakly foliated with phyllitic sheen. Sample C31. Rock moderately rusty but not so intense as at last station. Much pyrite.

137°/59°NE [59°/047°] Foliation in metavolcanics.

C32 (1010 m) In outcrops of rusty but not deeply altered med green porphyritic metavolcanics. Only a few plag phenocrysts seen. Massive. (Lowered altimeter from 1030 to 1000 m at 1120 hrs).

C33 (1000 m) Came across a prominent gully or Linear? 100 m to east of station. Azimuth 000°.

C34 (940 m) Sizeable stream in gully. Slight rusty brown deposit on all submerged rocks and twigs. Metallic after taste to water. Water is cold.

C35 (975 m) On exposure of maroon pyroclastics with blocks of grey plag and Hb porphyry (Sample C35). Is fairly loose, sandy. Probably originally deposited here. Lowest exposure of pyroclastics seen yet. No more exposure 50 m+ downslope. 5 - 6 m grey plag, + Hb porphyry flow exposed behind pyroclastics.

C36 (990 m) On prominent linears trending 175°. At 965 m - grey plag + Hb porphyry. Underlies pyroclastics.

At 1035 are near a recent pyroclastic headscarp.

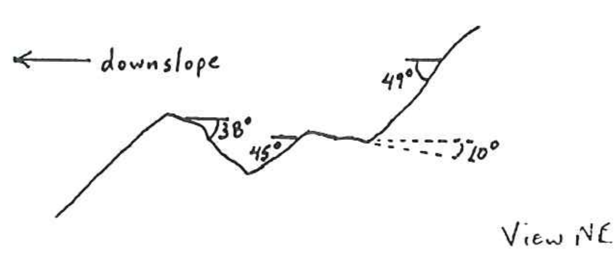
At 1180 m - Coming up narrow ridge in subcrop (under roots) of highly altered, rusty brecciated* and cemented basement rock. Some parts are white, phyllitic (metaseds), others are possibly altered diorite. Subcrop from 1120 m to here at 1,180 m.

C37 (1350 m) On logging road south of camp. Medium green plag porphyry metavolcanics. Volcanic breccia textures locally. Unfoliated. Thin lens of grey, rusty phyllite. Seepage.

C38 (905 m) On sharp ridge of pyroclastics, small to large failures occurred in this material. Some in the last few years. Can see altered basement about 50 m below but inaccessible.

<u>August 16, 1991</u> Sunny hot.
Traverse on Cheekye Ridge.

C39 (1405 m) On prominent linears on ridge crest. Azimuth 234° upslope, 222° downslope.



C40 (1315 m) On prominent linear. Sample C40 of maroon plag + Hb porphyry. Pyroclastics.

C41 (1170 m) At source of cold springs. Pale, rusty phyllite at spring origin. Rock outcrop above is medium green chloritic plag porphyry (+Hb) basement.

Spring issues from basement. At the spring origin the blocky rock debris is only weakly altered. Rock just to SW of the station is medium green weakly foliated metavolcanics. Only slightly rusty. Yet slide scar to NE is highly altered.

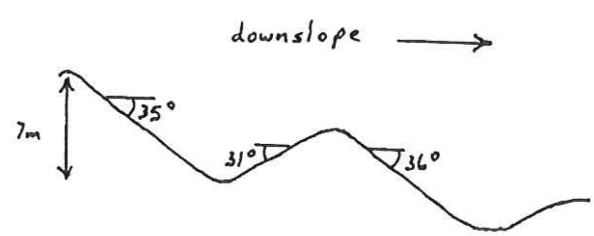
C42 (1100 m) Came across slope in sporadic outcrops of medium to dark green metavolcanic with a faint phyllitic sheen.

C43 (1145 m) Crossed main gully in unaltered green metavolcanics on other side - came across slope after gully in unaltered metavolcanics.

C44 (1140 m) Crossed small gully - now in same medium to dark green metavolcanic. Unaltered. Moderate foliation in green plag porphyry metavolcanic. Encountered 1st linear at 1200 m with steep scarp facing upslope. At 1,285 m - crossed 1st major linear in pyroclastics. S_1 in metavolcanics 110°/85°SW [85/200°].

C45 (1300 m) On lower logging road in pyroclastics. Three samples C45A - maroon plag + Hb porphyry; C45B - greenish grey plag + Hb porphyry; C45C - grey plag + Hb porphyry.

C46 (1335 m) Azimuth of linear 205°. Linears nearly symmetrical. Linear below station looked like downslope facing scarp steeper than upslope facing scarp.



Additional work at end of traverse:

1. Spotted "Fault" trench location.
2. Spotted section line 313°.
3. Spotted Linear Trench No. 1 - steep slope facing upslope.
4. Spotted Linear Trench No. 2 - steep, ravelling slope facing downslope. Large volcanic clasts in this exposure.
5. Spotted Linear Trench No. 3 adjacent to road. Steep scarp facing upslope.
6. Spotted Sag Pond Trench.
7. Spotted Linear Trench No. 4 on Main Scarp.

C47 (1350 m) Photos of small "Sag" pond. 20 cm deep, 2.5 m long, 1 m wide.

<u>August 17, 1991</u> Sunny, hot.
Traverse along Cheekye River. Helicopter set out and moves.

C48 (770 m) Bedding or foliation in medium pale green siliceous rock - 136°/68°NE [68°/046°]. Sample C48.

S_1 170°/74°E [74°/080°] in foliated siliceous rock or grey and white phyllite.

Cheekeye water sample No. 1 from side stream issuing from altered rock. Cheekye No. 2 - Cheekye River water sample.

<u>Samples:</u>

C48A	Grey phyllite.
C48B	Siliceous rock, pale green.
C48C	White massive rock.
C48D	Grey-green phyllite - from adjacent to shear zone
C48E	Massive greenstone.

Outcrop cut by green-siliceous rock - possibly rhyolite. All rocks silicified. Massive rock less altered.

C49 (950 m) Landing spot in river. Traverse upstream keeping to right at tributaries. At 980 m stream junction 2 levees of debris flows on flanks of stream, composed primarily of altered basement.

C50 (1025 m) For the last 20 m in main stream, observed milky white coatings on stream boulders. Took right stream channel. Boulders in this tributary has rust coatings in a narrow band just in present stream channel. Water is clear.

C51 (1045 m) At junction of 2 streams. This rusty one coming from the right (facing upstream). The right steam is depositing the rusty material the left stream has no deposits. After the 2 streams mix, they appear to form the milky deposit noted at the last station. Must be a chemical reaction upon mixing. Cheekye water sample No. 3 - clear stream to NE. May be soapy due to contamination of water bottle. Cheekye Water sample No. 4 - rusty stream to SE.

At 1070 m in unaltered plag porphyry volcanic rock, dark green, pyritic.

C52 (1115 m) At base of cliff in stream, in altered basement. Majority of rock is a med green pyritic metavolcanic, sheared and altered. Other bleached boulders around. Altered, bleached rock may be metavolcanic also and not diorite. Some boulders display gradational bleaching of metavolanic. 1st sign of seepage coming upstream is in NE bank of stream at Stn. C51. Seepage at 1050 m.

Foliation in sheared metavolcanic - 150°/75°NE [75°/060°].

C53 (910 m) 1st outcrop of weakly foliated plag porphyry metavolcanic in stream bottom. Fresh. Sample C53. Pyritic. Just below station are good volcanic breccia textures in basement rocks. Outcrop continues downstream to next tributary.

S_1 - 137°/86°NE [86°/047°],

Joint - 065°/88°SE [88°/155°] (Undulating, slightly rough, 0.5 m long.

Joint - 150°/39°SW [39°/246°] Planar, smooth, clean, 0.5 m long, spacing 20 cm - 3 m.

C54 (900 m) Cliffs above station are rust stained and altered, lower down at stream level outcrops are fresh, green plag porphyry volcanic basement rocks. Altered rock is more highly jointed and sheared. But is fresh, grey, closely jointed in stream bottom. Alteration may be only rust on joint surfaces.

C55 (600 m) Still in medium to dark green metavolanic. Breccia texture, plag porphyry groundmass. Minor local rust staining in some narrow gullies on south bank.

At junction of North and South Cheekye Rivers slight alteration zone in jointed metavolcanics. (580 m). C56 (580 m) Still in metavolcanics, thin grey-green to whitish phyllitic layers may be relict bedding. Sample C56A 100 m downstream from station. Looks like a pale green very siliceous plag porphyry dike cutting metavolcanics.

Contact of dike: 090°/40°N [40°/000°]. Upper dike contact 030°/60°NW [60°/300°]. Dike is banded pale green/paler green, wispy, almost gnessic. Sample C56B - NE margin of siliceous dike is sheared.

We have seen this combination before: on lower logging road west of Cheekye Slump. A siliceous, plag porphyry dike has white siliceous phyllite at its margins. In highly altered zones the siliceous phyllites are probably sheared siliceous dike rock. Probably rhyolite. Could see this at downstream end of that outcrop. Banding in dike - 090°/40°N [40°/000°].

C57 (565 m) On opposite side of stream is a large outcrop of diorite. Massive, jointed. The siliceous dikes seen at the last station do not occur in the diorite. Dikes are commonly foliated therefore are part of the older metavolcanic sequence. Alteration postdates these dikes.

C58 (555 m) Rock is mainly massive diorite with local vestiges of metavolcanics. Pervasive joint set spacing 0.4 - 0.5 m, curved, length 2 - 5 m. Many discontinuous short, subhorizontal joints.

Joints: 175°78°E [78°/085°]; 160°/68°NE [68°/070°]

C59 (550 m) Outcrops are largely metavolcanic with 2 - 3 m wide dikes of massive diorite.

Foliation in metavolcanics - 120°/89°SW [89°/210°].

August 18, 1991 Clear, sunny, hot.
Traverse on Brohm Ridge - south slope logging roads.

C60 (1225 m) On logging road at contact between pyroclastics and overlying flow. These are the older volcanics (0.5 - 0.7 Ma). Flows are finer grained, banded. Sample of flow C60A. Flow has plagioclase phenocrysts only, grey, irregular base. Sample C60B Pyroclastics - deep maroon to red, plag + Hb phenocrysts.

C61 (1190 m) Layered silt and sands. Problematical. Ash, tuff or glacial lacustrine. Some of the bedded material looks like large clasts. Almost looks like layered blocks incorporated in a maroon volcanic with pale green clasts. Silts and sands continue around corner to 1170 m. Dropstones of volcanic clasts in the silts indicate a lacustrine environment. C62 (1120 m) Terrace of moraine material. Some bedded sands near top of moraine. Lacustrine silts above may be related to ponding of water adjacent to ice or moraine.

C63 (1060 m) Highly fractured, slight rust weathering metavolcanic. (Medium green Hb diorite at 1080 m).

170°/71°NE [71°/080°] foliation in dark green metavolcanic.

C64 (1010 m) Still in dark green, fresh metavolcanics with plag phenocrysts and breccia textures.

C65 (1000 m) 177°/82°E [82°/087°] foliation in plag porphyry metavolcanic.

Joint set 084°/35°S [35°/174°] 40 cm long, spacing 20 - 50 cm, planar, slightly rough. Dike oriented along foliation.

C66 (970 m) Probably tuffaceous sediments. Sample C66A. Compositional layering joint continuous for 8 - 9 m, spaced 20 - 50 cm, planar to curviplanar, sl. rough. Occasional subhorizontal jointing. Near stream are 1 - 2 cm siliceous dikes, outcrops also cut by lamprophyre dikes at various orientations but near vertical. Sample C66B - Sample of thinly banded siliceous rock - possibly rhyolite?

085°/51°S [51°/175°] Joint set curviplanar spaced 10 cm - 2 m, continuous 8 - 9 m, slightly rough, clean slabby.

Joint: 020°/66°SE [66°/110°]; 030°64°NE [64°/120°].

028°/66°SE [66°/118°] Compositional layering in metavolcanic.

C67 (960 m) Good section thru layered volcanic tuffs, breccias, rhyolites, intruded by minor diorite (fine grained and Hb bearing) dikes.

C68 (880 m) Still in dark green Hb diorite, wispy, epidotized, some metavolcanic xenoliths.

C69 (850 m) Now in metavolcanics, last 100 m of outcrop was altered leucocratic diorite.

<u>September 5, 1991</u> Sunny, warm.
Traverse on Cheekye Ridge with Oldrich Hungr (Thurber).

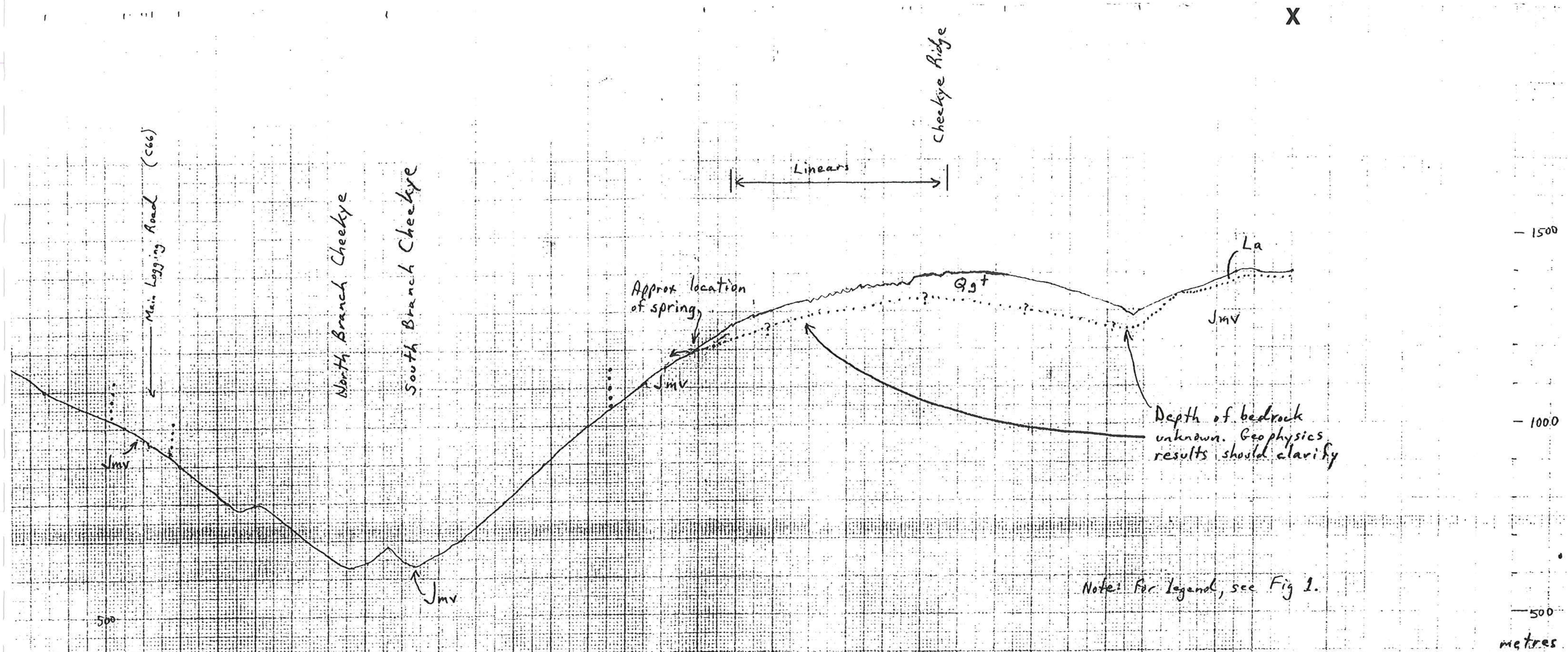
C70 (1340 m) Phyllitic shear zone, white, phyllitic fabric 138°/76°SW [76°/228°]. Sample C70 of slightly rusty sheared material. This was originally mapped as a phyllitic xenolith. Shear zone is within diorite ~30 cm wide.

C71 (1375 m) Single fractured outcrop of dark green metavolcanics. May have been used as a borrow pit. Sag pond is very near the basement exposure and the linear may be developed in basement rocks. Water is ~2 - 3 m deep.

<u>September 6, 1991</u> Sunny to overcast, intermittent showers.
Traverse with Oldrich Hungr on Cheekye Ridge.

C72 (1400 m) Just above contact with altered basement rocks. Basement rocks appear to have compositional layering oriented at ~052°/25°SE [~25°/142°]. Orientation of contact between pyroclastics and basement 110°/15°SW [15°/200°]. Basement appears to be altered metavolcanics.

C73 (1385 m) Oldrich Hungr on basement/pyroclastic contact. Orientation of contact 050°/25°SE [25°/140°]. Collected samples of basement at



SECTION X–X

CHEEKYE RIVER TERRAIN HAZARD STUDY

GEOLOGICAL SECTION X–X

Report GEO.2144

Figure IV – 1

contact. C73 altered basement rock. C73A - basement immediately below contact. C73B basement 20 m below contact.

September 7, 1991 Heavy fog all day. Cold.
Traverse on Brohm Ridge crest in area of linears.

C74 (1460 m) Traced several linears from this viewpoint. Some steep faces face uphill, others downhill.

Traversing due east down slope. Prominent linears 5 - 10 m high-steep scarps face downslope. V-shaped sag pond. No signs of recent movement. Linears at sag pond trend 000°. 15 m high. Coming downslope in boulders of plag and Hb porphyry.

At 1300 m in no outcrop. Came across a few linears but they generally tend to die out.

C75 (1300 m) Poor exposure of pyroclastics. May be primarily colluvial.

C76 (1260 m) On ravelling exposures of rusty, altered metavolcanics. Talus is 2 - 4 cm (small). Rock looks intensely fractured. At 1280 m, foliation 130°/55°NE [55°/040°].

C77 (1295 m) At contact with grey plag and Hb pyroclastics overlying altered metavolcanics. Silicified, pyritized. At ridge crest at linear offsetting other linears.

C78 (1535 m) Pyroclastics overlying plag porphyry and trace of Hb, flows. Pyroclastics contain 60% clasts 5 - 60 cm, 40% <5 cm. Clast composition dark green andesite, plagioclase porphyry; maroon plag porphyry. No good grey plag porphyries as seen in Cheekye Ridge pyroclastics. Clasts are subangular to subrounded. Exposures are well indurated. Linear trends 028°. Steep slope faces upslope. Scarp 10 - 20 m high.

C79 (1545 m) Came short distance up road in pyroclastics, here at contact with overlying plag porphyry flow. Flow is plag porphyry with minor Hb, fresh, hard, maroon at base.

165°/48°W [48°/255°] layering at base of flow. C80 (1580 m) In drainage gully cut thru grey and maroon plag porphyry pyroclastics.

But these are likely to be glacial deposits. Many rounded plutonic (diorite) boulders nearby on surface.

C81 (1570 m) At 75° exposed cliff face of andesite bearing pyroclastics. No grey and maroon plagioclase phyric clasts. Well indurated. Clast size 0.5 - 2.0 m. Andesite and various other volcanic clast types. Subangular, crudely bedded on very large scale. Dominantly unbedded. Traced a linear to edge of slope. Could not see basement rocks below.

C82 (1565 m) On trace of prominent linear. 25 - 30 m scarp facing downslope. Exposes grey plag porphyry flow of old volcanics. Azimuth of linear 000°.

C83 (1535 m) Came down slope, crossing several minor but deep linears in grey plag porphyry flows. Narrow and short linear troughs, some longer linears have rock/soil bridges (mainly at west end of linears). Downslope facing scarp 3 - 15 m high.

C84 (1440 m) On exposure of andesite bearing, indurated old pyroclastics. Exposure contains one 30 cm by 100 cm block of altered, silicified basement rock. Could it have been incorporated in the deposit as a xenolith?

<u>September 8, 1991</u> Sunny, cool.
Traverse on Brohm Ridge.

C85 (1660 m) Small debris flows in glacial deposits. Rounded plutonic pebbles in glacial deposits.

C86 (1600 m) At top of old pyroclastics. Overlain by stratified reworked pyroclastics with silty, sandy beds. 20 m thick section with subhorizontal layering.

C87 (1550 m) S_0 140°/15°SW [15°/230°] Bedding in laminated sandstone lens just above base of old pyroclastics.

C88 (1525 m) Basement rock is a sheared slightly rusty fine grained Hb diorite (Sample C88A). Base of old pyroclastics contains many fresh and altered metavolcanics and white phyllite clasts (Sample C88B). This exposure is slightly rust stained, but mainly along a fracture zone. If some of the basement rock fragments resist alteration within the pyroclastics - can you expect basement to be altered to such a degree. Cannot get onto highly altered basement rock slope but near surface it looks intensely altered. Rock in deep gully in basement rocks is quite fresh with a few rusty sheared zones. Slopes above station consist of large angular toppled blocks of pyroclastics. C88C - Sample of pyroclastics 20 m above station.

S_1 150°/73°NE [73°/060°] at 1530 m in gully. S_1 is a shear fabric.

C89 (1435 m) At contact with altered basement overlain by reworked grey and maroon plag porphyry. What appears to be loose reworked? plagioclase porphyry pyroclastics overlie rusty altered basement.

C90 (1690 m) At linear scallops in thin glacial deposits. No rock exposures. Looks like either erosional gullies or thin skin slides in glacial deposits.

C91 (1390 m) In overgrown, weathered outcrops of old andesitic pyroclastics. Contains 0.5 to 60 cm blocks of grey plag porphyry volcanic and andesites. *Blocks seen in first descent yesterday below the chalet are probably the old volcanics.

JFP/GER/sc/kc
2/R/DEC/APP-1462

APPENDIX V

GEOPHYSICAL SURVEY

SUMMARY GEOPHYSICAL REPORT

ON A

SEISMIC REFRACTION STUDY

FOR THE

CHEEKYE FAN PROJECT

FOR

GOLDER AND ASSOCIATES LTD.
THURBER CONSULTANTS LTD.

VANCOUVER, BRITISH COLUMBIA

BY

DAVID G. MARK, GEOPHYSICIST

OCTOBER, 1991

SUMMARY

Four seismic refraction survey lines, totalling 3,135 metres in length, were completed on Cheekye Ridge which is at the headwaters of Cheekye River near Squamish, B.C.

The primary purpose of the survey was to determine the thickness of pyroclastic material overlying basement bedrock as well as the shape of the bedrock profile. Some of this bedrock was altered by the overlying pyroclastic material and thus a purpose was also to determine the thickness of the altered bedrock.

For the area covered by SL-1, SL-2 and SL-4, the thickness of the pyroclastic material varied from 10 m to 74 m and the thickness of the altered bedrock from 24 m to 93 m. The total depth to competent bedrock varied from 78 m to 132 m.

SL-3 encountered a broad buried valley filled with pyroclastic material up to 136 m thick. There was no altered bedrock encountered. However, the survey did reveal a fault zone/buried canyon within the bedrock.

SUMMARY GEOPHYSICAL REPORT

ON A

SEISMIC REFRACTION STUDY

FOR THE

CHEEKYE FAN PROJECT

SQUAMISH, BRITISH COLUMBIA

INTRODUCTION AND GENERAL REMARKS

This report discusses the results of a seismic refraction survey carried out on Cheekye Ridge located at the headwaters of Cheekye River, just north of Squamish, B.C.

The purpose of the seismic work was to determine the thickness of pyroclastic material overlying basement bedrock as well as the thickness of altered bedrock directly underlying the pyroclastic material. (The alteration was caused by the pyroclastic material when it was laid down during volcanic activity.) An additional purpose was to determine the shape of the surface of the underlying competent basement bedrock. The reason for wanting to know the above information was to help determine the stability of the pyroclastic material since it contained numerous northeasterly-striking cracks or crevices. Therefore, there is the potential danger of a massive landslide which could reach the Cheekye Fan, several kilometers downriver, and which is proposed for development.

The work was carried out from September 19 to 22 by David Mark, geophysicist, with the assistance of one geophysicist and three geophysical technicians.

The work was undertaken at the request of Golder and Associates Ltd. and Thurber Consultants Ltd., the geotechnical consultants for the Cheekye Fan Project. The Geotronics crew visited the project site in the presence of Dr. Oldrich Hungr of Thurber Consultants. The survey lines were placed following the directions of Dr. Hungr.

It was also attempted to take resistivity measurements across what was thought to be the contact between altered bedrock and pyroclastic material on SL-1 at G-1. The readings wre taken with a Terrameter 300 resistivity meter using the dipole-dipole array with a 30-m dipole length and a dipole separation of one to five levels. It was found in places the readings were somewhat erratic or non-existent. This was thought to be due to large voids or crevices within the pyroclastic material. No doubt with greater effort and more powerful equipment, the readings could be obtained. However, since the seismic refraction method appeared to be achieving the desired results, it was decided not to proceed with the resistivity measurements.

LOCATION AND ACCESS

Cheekye Ridge, where the work was done, is located at the headwaters of Cheekye River and is 14 km N30°E of downtown Squamish. Cheekye Fan, which is located at the confluence of Cheekye River with Cheakamus River, is about 10 km due north of downtown Squamish.

Access from Squamish is via Garibaldi Highway, the Alice Lake access road, and thence a narrow, very rough 4-wheel drive gravel road once used for logging. Driving distance from downtown Squamish is about 27 km and driving time is 70 to 90 minutes.

INSTRUMENTATION

Two 12-channel seismographs, model 1210F, manufactured by E.G. & G. Geometrics of Sunnyvale, California were used on the project. They were interfaced together to form a 24-channel system.This instrument features signal enhancement by stacking repeated signals in a digital memory. A CRT (cathode ray tube) continuously displays the signal stored in the memory on all channels simultaneously, or on selected combinations of fewer channels. The stored signal can then be printed on a permanent paper recorded by a built-in electric writing oscillograph. The instrument also contains active signal filters on each amplifier.

Twelve-channel geophone cables of 335-m length and 30.5-m geophone spacing were used as well as 8 cycle/sec marsh geophones. Both items are manufactured by Mark Products of Houston, Texas.

The blasting was done by radio signal with one encoder and two decoders, series 200, manufactured by Input/Output of Houston, Texas. These were interfaced with Motorola portable FM radios.

FIELD PROCEDURE

The 'two-way, in-line, shot' seismic method was used for all seismic lines. The technique consists of laying out 24 geophones in a straight line and recording arrival times from shots fired at either end of the spread. Arrival times from three additional

DISCUSSION OF RESULTS

A three-, four-, or five-layer case was encountered under the area surveyed. The following is a table of the velocity layers classified as to what they probably reflect. Dr. Oldrich Hungr, from his geological knowledge of the area, assisted in the classification.

Layer	Velocity (m/s)	Classification
1	300 - 500	Overburden: surficial, loose, dry pyroclastic material.
1,2	500 - 900	Overburden: partially water-saturated pyroclastic material.
2,3	900 - 1,400	Overburden: pyroclastic breccia.
3,4	2,000 - 2,300	Bedrock: altered basement.
4,5	3,000 - 3,500	Bedrock: possibly fractured basement.
4,5	3,800 - 5,600	Bedrock: competent basement.

As can be seen on the above table, the pyroclastic material includes the three layers with velocities of up to 1,400 m/s. The thickness of this material on SL-1, a 4-layer case, is 67 m along G-18 to G-21 and thins out to 10 m at G-12SW. The atlered bedrock layer varies in thickness from 24 m below G-17 to 93 m below G-8SW. The total depth to competent bedrock varies from 82 m below G-1 and G-1SW to 132 m below G-23.

For SL-2, a 4-layer case, the thickness of the pyroclastic material varies from 47 m below G-4 to 71 m below G-24. The altered bedrock varies in thickness from 26 m below G-24 to 65 m below G-1. The total depth to competent bedrock varies from 97 m below G-6 to 125 m below G-1.

For SL-4, a 5-layer case, the pyroclastic material varies from 37 m below G-1, to 74 m below G-21. The altered bedrock varies in thickness from 34 m below G-21 to 45 m below G-9. The total depth to competent bedrock varies from 78 m below G-3 to 112 m below G-8 and G-9.

SL-2 and SL-4 cross SL-1, as can be seen on the survey plan and on the profiles. The correlation of the velocities and of the layer thicknesses is very good. The exception, however, is that SL-1 encounters a 4-layer case whereas SL-4 encounters a 5-layer case. The difference is that the second layer on SL-1, with a velocity of 1,190 m/s, is divided into two layers on SL-4; a thin layer with a velocity of 720 m/s, and a thick layer with a velocity of 1,300 m/s. Obviously the 720 m/s layer was too thin to be seen on SL-1.

There was no altered bedrock encountered on SL-3. Dr. Hungr suggested this part was covered by glacier during the volcanic activity. The thickness of the pyroclastic material, and therefore the depth to the competent bedrock, varies from 24 m below G-24 to 136 m below G-14.

The shape of the competent bedrock profile indicates a broad buried valley. Of strong interest is a slow zone within the bedrock from G-14 to G-18. Slow zones such as this can be fault zones, buried canyons, or both. The probability here is that it is both since (1) the slow zone velocity is similar to that of the overlying pyroclastic material, indicating it is a buried canyon filled with pyroclastic material, (2) canyons are usually produced by faults, and (3) the bedrock velocity on one side of the slow zone is 4,000 m/s, and on the other, 5,600 m/s, indicating a rock contact that is probably also a fault.

Respectfully submitted,
GEOTRONICS SURVEYS LTD.

David G. Mark
Geophysicist

October, 1991
52/G454

GEOPHYSICIST'S CERTIFICATE

I, DAVID G. MARK, of the City of Vancouver, in the Province of British Columbia, do hereby certify:

That I am a Consulting Geophysicist of Geotronics Surveys Ltd., with offices at #405-535 Howe Street, Vancouver, British Columbia.

I further certify that:

1. I am a graduate of the University of British Columbia (1968) and hold a B.Sc. degree in Geophysics.

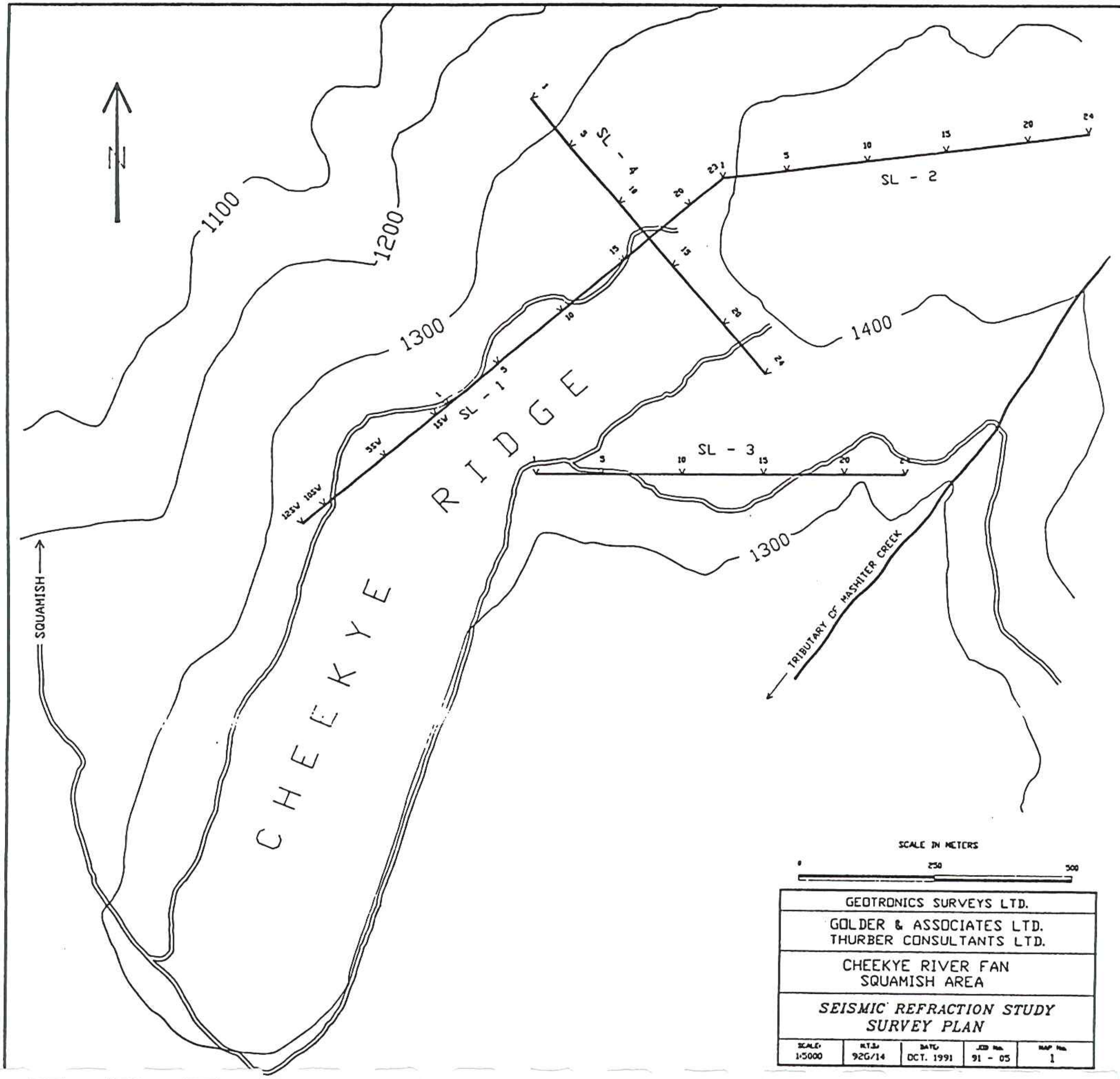
2. I have been practising my profession for the past 23 years.

3. This report is compiled from data obtained from a seismic refraction survey carried out under my supervision, during the period September 19 to 22, 1991.

4. I do not hold any interest in any aspect of the Cheekye Fan project, nor do I expect to receive any interest as a result of writing this report.

David G. Mark
Geophysicist

October, 1991



GEOTRONICS SURVEYS LTD.
GOLDER & ASSOCIATES LTD. THURBER CONSULTANTS LTD.
CHEEKYE RIVER FAN SQUAMISH AREA
SEISMIC REFRACTION STUDY *SURVEY PLAN*

SCALE:	N.T.S.:	DATE:	JOB No.	MAP No.
1:5000	92G/14	OCT. 1991	91 - 05	1

APPENDIX VI

MONITORING - CHEEKYE RIDGE

CHEEKYE RIDGE LINEARS - MOVEMENT SURVEY

1.0 MONITORING PROGRAM

The survey monitoring program, as established, comprises a total of five target stations, and two monitoring stations, the approximate locations of which are shown on the attached Figure VI-1.

After initial review of the available survey methods, with consideration given to the desired accuracy of plus or minus 2 cm, an EDM total station was used for the survey program. Although the use of a satellite positioning system would have provided reasonably true coordinates of the target locations, it was considered too inaccurate for the purpose of determining relatively small changes in plan position.

2.0 TARGET FABRICATION AND INSTALLATION

In designing the target and monitoring stations, consideration was given to the following:

- General terrain of the chosen locations
- Lack of vehicle access
- Potential for vandalism
- Frost heave potential
- Ability to identify any local tilt of the individual target stations, not related to overall terrain movement
- Potential for error due to variance in survey equipment set-up

The target stations were fabricated and installed as follows:

> A concrete base of some 600 mm by 600 mm by 200 mm high was cast at the base of a hand dug excavation, some 1 m below ground surface. A 1 m long black iron pipe was installed within the base, extending to near ground surface, and encased in a concrete column. The top of the iron pipe was provided with a welded horizontal plate, approximately 100 mm square, and a central, machined thread to accept a prism target staff, some 1 m in height.

The top of the target staff was provided with a 75 mm square horizontal plate, with a central, threaded bolt on which the prism attached. A small "v" notch was scribed at the central point of each side of the 75 mm top plate, through which a conventional plumb bob could be hung.

The target foundation was backfilled to within 300 mm of ground surface, and provided with a timber surface hatch for protection and access. The remaining void between the top of backfill and timber cover was filled with conventional insulation material. The survey prism staff was fabricated to thread into the base rod and butt onto the machined portion of the pipe. Each target station was designated a specific rod, which was numbered accordingly.

A typical target installation detail is shown on Figure VI-2.

3.0 MONITORING STATIONS

The two monitoring stations were installed in a similar manner to the target stations. However, due to the weight of the EDM Total Station, the vertical pipe was composed of 75 mm black iron, resulting in a stronger and necessarily more ridged structure. All screwed connections were similarly provided with machined end butts.

The materials fabrication was carried out in Vancouver, and the target and monitoring stations were constructed in the field utilizing a contractor based in Squamish, B.C. The installation program was carried out between September 24 and 27, 1991.

4.0 FIELD SURVEY

The field survey was carried out by a two party crew, on September 30, and October 3, 1991, using a Nicon DMT A5 EDM Total Station. The instrument had provision for manual entry of ambient temperature and barometric pressure, resulting in automatic corrections for both. The instrument was also programmed to take 10 individual distance measurements, and provide an average distance for each required measurement.

After initial target set-up at each location, a plumb bob was used to establish vertical reference points from the above noted scribe marks on the upper, or top plate, relative to the lower, or base plate. These points were recorded by means of a metal punch on the base plate. Future readings by plumb bob will provide a means of identifying any local tilt at the target stations, possibly unrelated to overall terrain movement.

On September 30, 1991, a complete set of data was recorded from both monitoring station A and B, and the data reduced. Distances were calculated between target station 1 to 3, 4, and 5, and from target station 2, to 3, 4, and 5, and the results compared for accuracy. A similar set of data was recorded on October 3, 1991.

Due to the position of monitoring stations A and B, relative to targets 1 and 2, morning shots were, by necessity, taken into the sun, and also were taken during more hazy morning environmental conditions. Accordingly, the order in which the second survey was carried out, was reversed to that carried out on September 30, 1991, providing a complete set of data at each station under most suitable environmental conditions.

A review of the recorded data indicates greater precision during the afternoon surveys.

The survey results, as documented, reflect readings taken during the afternoon periods of surveying.

On completion of the survey, all target and monitoring stations were repacked with insulation and the surface protective timber cover re-installed.

5.0 SURVEY RECORDS

Table VI-1 attached, provides a summary of the recorded data, and includes slope distance, calculated horizontal and vertical distance, and vertical angle, from monitoring stations A and B, to target stations 1 to 5 inclusive. Recorded horizontal angles between target stations 1 to 3, 4, and 5, and target station 2, to 3, 4, and 5 are also presented. Calculated true distances between the above noted target stations are also presented.

The calculated distance comparison between readings from monitoring station A and B range in error from 0.00008 m, or 8/100 mm to a maximum of 0.0168 m, or 1.68 cm, over an average distance of about 1 km.

With the above order of accuracy, and the ability to differentiate between local tilt of the target installations and overall movement, it is expected that any significant overall terrain movement can be identified, and quantified.

GER/kc

Attachment

2/APP-1462

TABLE VI-1
SUMMARY OF SURVEY DATA

Station A

Target	Distance in Meters		Angles in Degrees	
	Slope Dist.	Horiz. Dist.	Vert. Dist.	Vert. Angle
1	815.417	814.923	28.408	1.993333
2	823.017	822.724	21.997	1.533333
3	179.364	177.318	-27.011	-8.661944
4	226.117	221.706	-44.439	-11.336667
5	266.505	262.38	-46.701	-10.093333

Station A

Horizontal Angles	
Target	Angle
1 to 3	167.652500
1 to 4	213.475278
1 to 5	218.921389
2 to 3	169.606389
2 to 4	215.430883
2 to 5	220.876389

Station B

Target	Distance in Meters		Angles in Degrees	
	Slope Dist.	Horiz. Dist.	Vert. Dist.	Vert. Angle
1	1219.3265	1216.7321	79,6063	3.739167
2	1209.8298	1207.6194	73.2023	3.465000
3	713.3401	712.9333	24.1382	1.936389
4	552.4909	552.4503	6.7223	0.695000
5	509.8007	509.7813	4.4664	0.500278

Station B

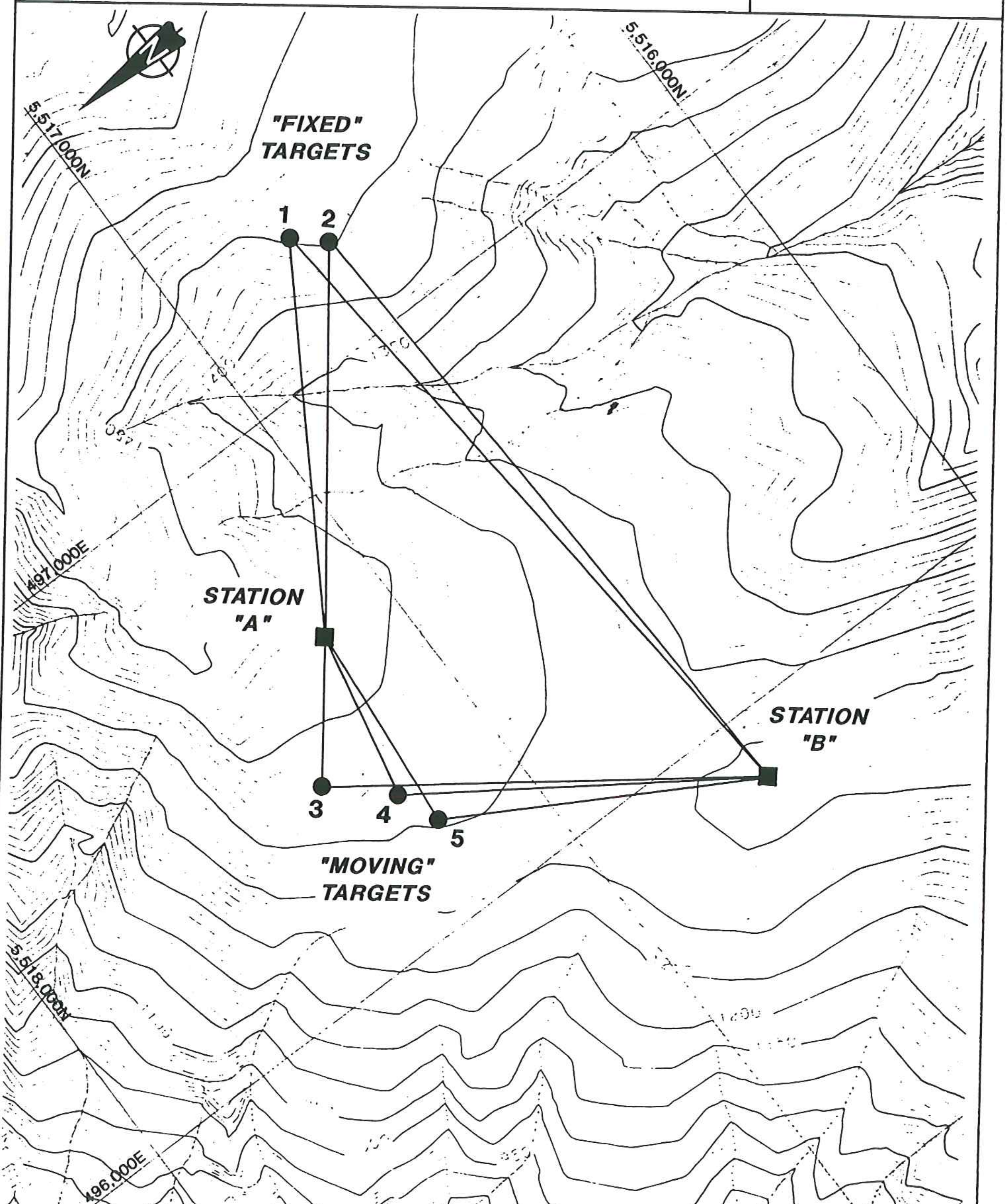
Horizontal Angles	
Target	Angle
1 to 3	54.360833
1 to 4	55.006111
1 to 5	57.054167
2 to 3	55.659444
2 to 4	56.303889
2 to 5	58.350000

CALCULATED DISTANCES

Station A		Distance (m)	Difference A and B
From Target	1 to 3	990.416688	0.016869
	1 to 4	1009.931785	0.002088
	1 to 5	1035.029884	-0.000080
	2 to 3	998.848368	0.011752
	2 to 4	1013.751116	-0.005218
	2 to 5	1037.729269	0.007974

Station B			
From Target	1 to 3	990.399819	
	1 to 4	1009.929697	
	1 to 5	1035.029964	
	2 to 3	998.836616	
	2 to 4	1013.756334	
	2 to 5	1037.721295	

SCHEMATIC LAYOUT | Figure **VI-1**



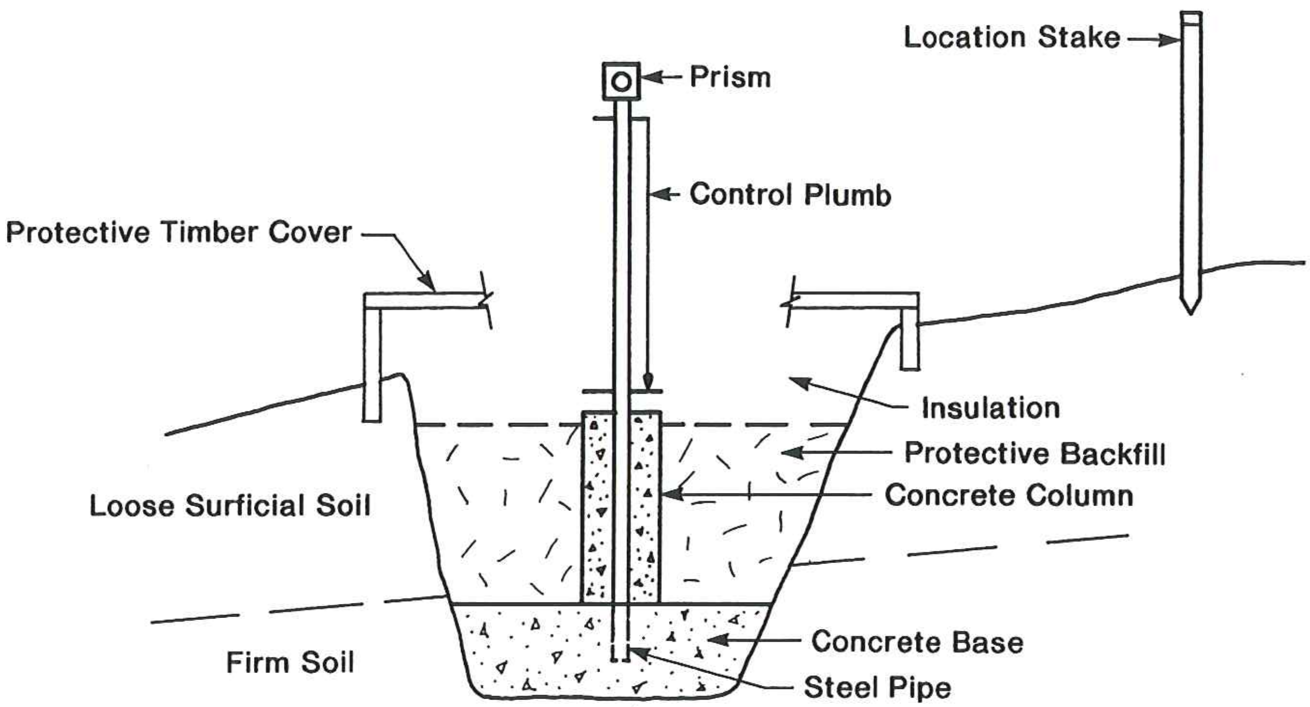
Scale 1:10,000

PROJECT NO. 912-1462K DRAWN R.D. REVIEWED DATE Oct. '91

Golder Associates

TYPICAL TARGET INSTALLATION

Figure **VI-2**



Schematic Only - Not to Scale

PROJECT NO. 912-1462K DRAWN R.D. REVIEWED .... DATE Oct. '91

APPENDIX VII

TEST PIT LOGS AND WATER WELL LOGS

(Test Pit Locations Shown On Figures 3.2 and 3.4 of Main Text)

TEST HOLE LOGS

Notes:

1) Depths shown are in metres, measured from ground surface at the test pit location.
2) The estimated combined percentage of sand, silt and clay by weight in diamicton is indicated by "matrix" in the logs.

TP 91-1

0 - 2.0	FLUVIAL - brown to grey, rounded, silty SAND with a trace of clay.

TP 91-2

0 - 2.1	DIAMICTON - brown, matrix supported, subrounded to angular, silty SAND and GRAVEL with some cobbles and boulders. Matrix = 50%.

TP 91-3

0 - 0.25	TOPSOIL
0.25 - 1.8	DIAMICTON - brown, matrix supported, subrounded to subangular, cobbly SAND and GRAVEL with traces of silt and boulders. Matrix = 40%.

TP 91-4

0 - 0.3	TOPSOIL
0.3 - 0.9	DIAMICTON - orange-brown, matrix supported, subrounded to subangular, silty SAND and GRAVEL with some silt and cobbles. Matrix = 50%.
0.9 - 1.9	FLUVIAL - greyish brown, weakly stratified, clean, subrounded to rounded, mixture of SAND, GRAVEL and COBBLES with trace of boulders.

TP 91-5

0 - 0.3	TOPSOIL
0.3 - 1.0	FLUVIAL - brown, stratified, subrounded to rounded, gravelly SAND with traces of silt and cobbles.
1.0 - 1.3	FLUVIAL - brown, laminated SAND with some silt.
1.3 - 2.4	FLUVIAL - brown, stratified, subrounded to rounded, gravelly SAND with traces of silt and cobbles.

TP 91-6

0 - 0.2	TOPSOIL
0.2 - 1.6	FLUVIAL - brown, stratified, subrounded to rounded, SAND and GRAVEL with some cobbles and trace of silt.
1.6 - 2.0	FLUVIAL - brown, rounded GRAVEL with some sand and cobbles.

TP 91-7

0 - 0.1	SAND with some organics and silt.
0.1 - 1.4	DIAMICTON - brown, matrix supported, subrounded to angular, cobbly, gravelly SAND with some boulders and traces of silt and clay. Matrix = 45%.
1.4 - 1.9	FLUVIAL - brown SAND with some silt.

TP 91-8

0 - 0.3	TOPSOIL
0.3 - 1.6	DIAMICTON - brown, matrix supported, subrounded to subangular, SAND and GRAVEL with some silt, cobbles and boulders. Matrix = 40%.
1.6 - 2.1	FLUVIAL - green-grey, weakly stratified, subrounded to rounded, SAND with trace to some silt.

TP 91-9

0 - 0.2	TOPSOIL
0.2 - 0.6	DIAMICTON - brown, partially matrix supported, subangular to subrounded, sandy GRAVEL with some cobbles and trace of silt and boulders. Matrix = 25%.
0.6 - 1.6	FLUVIAL - orange-brown, stratified, subrounded, sandy, cobbly GRAVEL with traces of silt and boulders and trace of sand as laminations.

TP 91-10

0 - 1.1	Orange-brown, gravelly COBBLES with some sand and boulders and trace of silt. Origin of unit uncertain.
At 1.1	Refusal. Material too coarse to dig any deeper.

TP 91-11

0 - 2.2	DIAMICTON - brown, matrix supported, subangular to subrounded, SAND and GRAVEL with some silt and cobbles and trace of boulders. Cobbly below 1.5 m. Matrix = 50%.

TPH 91-12

0 - 0.3	TOPSOIL
0.3 - 2.1	DIAMICTON - brown, matrix supported, subrounded to angular, silty SAND with some gravel and cobbles and traces of clay and boulders. Matrix = 65%

TP 91-13

0 - 0.3	TOPSOIL
0.3 - 1.8	DIAMICTON - brown, matrix supported, subrounded to subangular, mixture of SILT, SAND and GRAVEL with traces of clay, cobbles and boulders. Matrix = 55%.
1.8 - 3.2	DIAMICTON - grey, subangular, sandy GRAVEL with some silt and cobbles. Matrix = 35%.

TP 91-19

0 - 2.1	DIAMICTON - light brown, subrounded to subangular, gravelly SILT and SAND with traces of clay and cobbles. Matrix = 75%.
2.1 - 2.9	DIAMICTON - mixture of SILT, SAND, GRAVEL and COBBLES with trace of boulders. Matrix = 50%.
2.9 - 4.1	FLUVIAL - debris flood.

TP 91-20

0 - 1.55	DIAMICTON - GRAVEL with some silt and sand and traces of cobbles and boulders. Matrix = 30%.
1.55 - 2.9	DIAMICTON - Coarse; boulders at bottom of pit may indicate bottom of unit.

TP 91-21

0 - 1.15	DIAMICTON - Grey, matrix supported, subangular, silty, sandy GRAVEL with traces of clay, cobbles and boulders. Matrix = 50%.
1.15 - 1.5	FLUVIAL - Brown, rounded GRAVEL.

TP 91-22

0 - 1.7	DIAMICTON - Mix of coarse diamicton and sand.
1.7 - 2.0	FLUVIAL(?) - Rounded boulders.

TP 91-23

0 - 1.2	FLUVIAL
1.2 - 1.9	DIAMICTON - coarse.
1.9 - 2.7	DIAMICTON(?) - sandy.
2.7 - 3.0	DIAMICTON - coarse.

TP 91-50

0 - 0.2	TOPSOIL
0.2 - 1.6	DIAMICTON - Subrounded to subangular, sandy SILT and GRAVEL with traces of clay, cobbles and boulders. Matrix = 65%.
1.6 - 1.9	FLUVIAL - GRAVEL.

TP 91-51

0 - 0.1	TOPSOIL
0.1 - 1.6	DIAMICTON - Subrounded to subangular, sandy SILT and GRAVEL with traces of clay, cobbles and boulders. Matrix = 65%.
1.6 - 2.0	FLUVIAL
2.0 - 3.2	DIAMICTON - Subrounded SILT, SAND and GRAVEL with some cobbles and boulders.

TP 91-52

0 - 0.1	TOPSOIL
0.1 - 1.5	DIAMICTON - coarse.
1.5 - 3.5	FLUVIAL - sandy.

TP 91-53

0 - 1.2	DIAMICTON - coarse.
1.2 - 2.7	FLUVIAL (or DIAMICTON?) - Silty GRAVEL with some sand and traces of clay, cobbles and boulders.

TP 91-54

0 - 0.15	TOPSOIL
0.15 - 1.4	DIAMICTON - coarse.
1.4 - 2.4	FLUVIAL.

TP 91-55

0 - 0.8	DIAMICTON
0.8 - 2.2	FLUVIAL

TP 91-56

0 - 1.8	DIAMICTON
1.8 - 2.8	FLUVIAL

TP 91-57

0 - 3.2	FLUVIAL

TP 91-58

0 - 0.2	TOPSOIL
0.2 - 1.3	DIAMICTON - SILT with some subrounded sand, gravel, cobbles and boulders. Matrix = 70%.

TP 91-61

0 - 0.8	FLUVIAL - Rounded to subrounded GRAVEL.

TP 91-62

0 - 1.6	DIAMICTON - coarse, rounded GRAVEL.
1.6 - 1.8	FLUVIAL - GRAVEL.

TP 91-63

0 - 0.8	DIAMICTON - coarse.

TP 91-64

0 - 0.8	FLUVIAL - silty.
0.8 - 2.0	DIAMICTON - SILT and rounded GRAVEL with some sand and traces of clay and cobbles. Matrix = 45%.
2.0 - 3.5	FLUVIAL - coarse.

TP 91-100 DIAMICTON - SILT and angular GRAVEL with some sand and traces of clay, cobbles and boulders. Matrix = 45%.

TP 91-101

0 - 0.6	FLUVIAL - Rounded GRAVEL.
0.6 - 0.8	DIAMICTON(?)
0.8 - 1.3	FLUVIAL - rounded.

Dittus Property Test Pit

0 - 0.2	TOPSOIL
0.2 - 1.4	FLUVIAL - Flat-lying, graded SAND and SILT.
1.4 - 2.2	FLUVIAL - SILT with some clay.
2.2 - 2.4	FLUVIAL - Graded SAND and SILT.
2.4 - 3.0	FLUVIAL - Rounded BOULDERS in a silty, sandy matrix.
3.0 - 5.6	FLUVIAL(?) - Partially sorted, poorly stratified, rounded SILT, SAND, GRAVEL and COBBLES with some boulders.

91-M-1

0 - 1.6	FILL - brown mixture of LOGS, SAND and GRAVEL. Probably filled to create a landing for vehicles.
1.6 - 3.8	DIAMICTON - brown and grey layered, partially matrix supported, subangular SAND and GRAVEL with some silt and traces of cobbles and boulders. Matrix = 45%.
3.8 - 4.4	FLUVIAL - grey SAND and GRAVEL with some cobbles and traces of silt and boulders.

91-M-2

0 - 1.6	DIAMICTON - brown over maroon-brown, partially matrix supported, subangular to angular SAND and GRAVEL with some silt and cobbles and trace of boulders. Matrix = 45%.
1.6 - 3.7	DIAMICTON - maroon-brown, angular GRAVEL with some sand and cobbles and traces of silt and boulders. Matrix = 30%.

91-M-3

0 - 0.75	FLUVIAL - brown, subrounded mixture of SAND, GRAVEL, COBBLES and BOULDERS with trace of silt.
0.75 - 0.9	FLUVIAL - maroon, weakly stratified, subrounded to rounded, SAND with some silt and gravel.
0.9 - 3.0	DIAMICTON - greyish maroon, subangular, mixture of SAND, GRAVEL and COBBLES with some silt and boulders. Matrix = 35%.

WATER WELL LOGS

Notes:

1) Geological information taken from Water Well Records submitted to Water Resources Service, B.C. Ministry of Environment.
2) All depths in metres from ground surface at the well location.
3) Wells installed between 1957 and 1982.

WW-1

0 - 21.3	Drilled down old hole.
21.3 - 24.4	Loose, water-bearing gravel. Water table at 21.3 m.
24.4 - 27.7	Tight, water-bearing gravel.

WW-2

0 - 9.8	Old hole? Water table at 3.1 m
9.8 - 11.3	Loose, water-bearing gravel.
11.3 - 15.9	Tight, water-bearing gravel.

WW-3

0 - 6.1	Clay, gravel and boulders. Water table at 4 m.
6.1 - 9.5	Water-bearing gravel.

WW-4

0 - 11.0	Gravel and boulders. Water table at 9.8 m.
11.0 - 13.7	Water-bearing sand and gravel.

WW-5

0 - 4.3	Silty gravel and boulders.
4.3 - 5.5	Glacial till with a few boulders.
5.5 - 16.8	Silty sand with some gravel. Water table at 11 m.
16.8 - 17.4	Fine to medium gravel.

THURBER

APPENDIX VIII

LABORATORY TEST RESULTS

- Specific Gravity / Atterberg Limits
- Grain Size Distribution
- Point Load Tests
- Direct Shear Tests

Specific Gravity / Atterberg Limits

LAB TESTING SUMMARY

Specific Gravity and Atterberg Limits

1.0 SPECIFIC GRAVITY

Test 1	Test 2	Test 3	Test 4	Average
2.827	2.879	2.791	2.774	2.818

2.0 ATTERBERG LIMITS

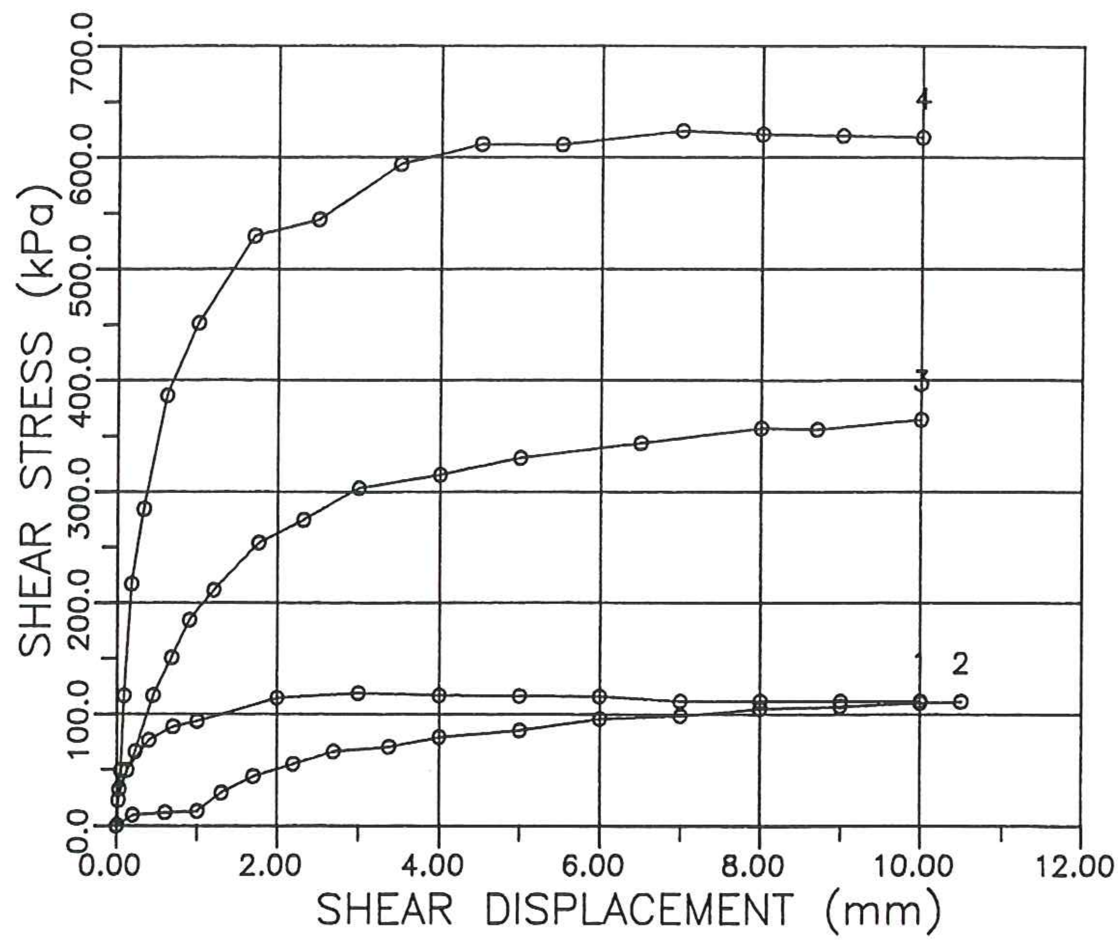
Test	Natural Moisture Content	Liquid Limit	Plastic Limit	Plasticity Index	Liquidity Index
1	13.2	20.2	17.2	3.0	-1.3
2	-	25.6	24.6	1.0	-

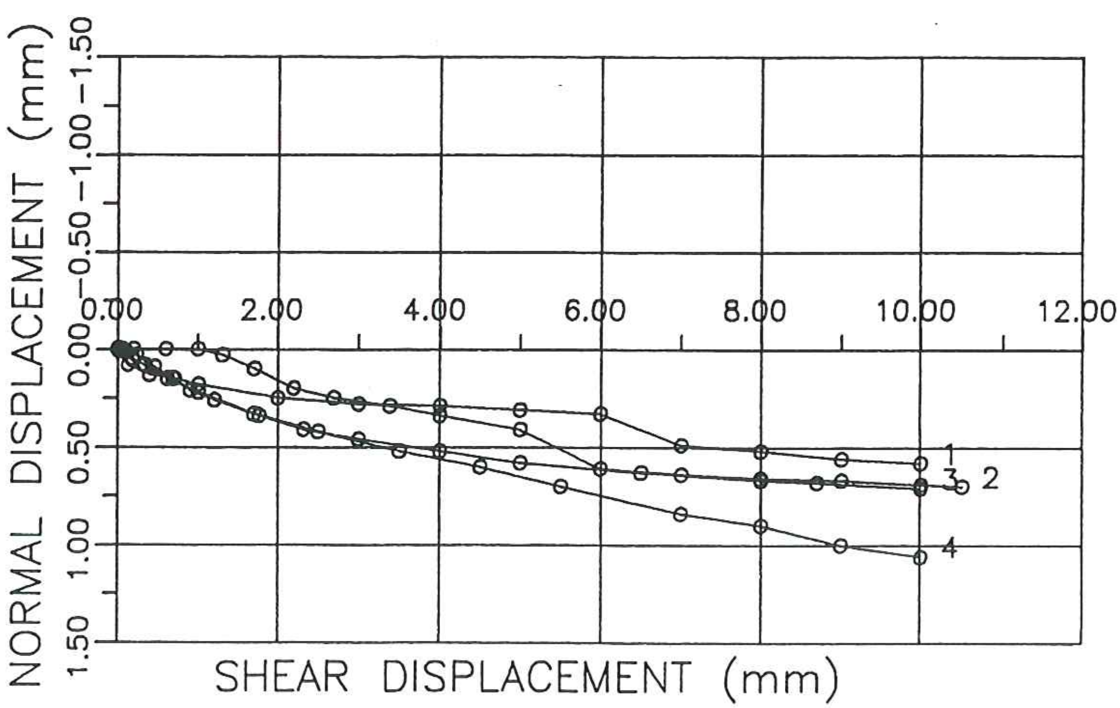
Point Load Tests

Direct Shear Tests

DIRECT SHEAR TEST
SAMPLE 1

Figure **VIII-4**





PROJECT NO. ....9121462..... DRAWN .... REVIEWED .... DATE ..NOV-6-91....

Golder Associates

SUBJECT		
Job No. Ref.	Made by Checked Reviewed	Date Sheet of

APPENDIX IX

AGE DATING

KRUEGER ENTERPRISES, INC.
GEOCHRON LABORATORIES DIVISION
24 BLACKSTONE STREET • CAMBRIDGE, MASSACHUSETTS 02139 • (617) 876-3691

NOV 2 8

RADIOCARBON AGE DETERMINATION — REPORT OF ANALYTICAL WORK

Our Sample No. GX-17397 PRIORITY BASIS — Date Received: 11/18/91

Your Reference: letter of 11/14/91 — Date Reported: 11/21/91

Submitted by: Bob Gerath
Thurber Engineering Ltd.
200-1445 W. Georgia St.
Vancouver, B.C. V6G 2T3
CANADA

Sample Name: Housing site TP 64.
Charcoal.

AGE = 7820 +/- 95 C-14 years BP (C-13 corrected).

Description: Sample of charcoal.

Pretreatment: The charcoal fragments were separated from any sand, silt, rootlets, or other foreign matter. The sample was then treated with hot dilute HCl to remove any carbonates, and with hot dilute NaOH to remove humic acids and other organic contaminants. After washing and drying, the cleaned charcoal was combusted and the carbon dioxide was recovered for the analysis.

Comment:

$\delta^{13}C_{PDB} = -24.5$ ‰

Notes: This date is based upon the Libby half life (5570 years) for ^{14}C. The error stated is $\pm 1\sigma$ as judged by the analytical data alone. Our modern standard is 95% of the activity of N.B.S. Oxalic Acid.
The age is referenced to the year A.D. 1950.

OCT 21 1991

KRUEGER ENTERPRISES, INC.

GEOCHRON LABORATORIES DIVISION

24 BLACKSTONE STREET • CAMBRIDGE, MASSACHUSETTS 02139 • (617) 876-3691

RADIOCARBON AGE DETERMINATION — **REPORT OF ANALYTICAL WORK**

Our Sample No. GX-17269 **Priority** — Date Received: 10/09/91

Your Reference: letter of 10/08/91 — Date Reported: 10/16/91

Submitted by: Robert Gerath
Thurber Engineering Ltd.
1445 West Georgia Street, Suite 200
Vancouver, B.C. V6G 2T3
CANADA

Sample Name: Sample #1 (C14-25 Highway Pit).
Bark.

AGE = 305 +/- 60 C-14 years BP (C-13 corrected).

Description: Sample of bark.

Pretreatment: The bark sample was cleaned of dirt or other foreign material and was split into small pieces. It was then treated with hot dilute HCl to remove any carbonates and with hot dilute NaOH to remove humic acids and other organic contaminants. After washing and drying it was combusted to recover carbon dioxide for the analysis.

Comment:

$\delta^{13}C_{PDB}$ = -25.7 ‰

Notes: This date is based upon the Libby half life (5570 years) for ^{14}C. The error stated is $\pm 1\sigma$ as judged by the analytical data alone. Our modern standard is 95% of the activity of N.B.S. Oxalic Acid. The age is referenced to the year A.D. 1950.

OCT 21 1991

KRUEGER ENTERPRISES, INC.
GEOCHRON LABORATORIES DIVISION

24 BLACKSTONE STREET • CAMBRIDGE, MASSACHUSETTS 02139 • (617) 876-3691

RADIOCARBON AGE DETERMINATION — REPORT OF ANALYTICAL WORK

Our Sample No. GX-17270 **Priority**

Date Received: 10/09/91

Your Reference: letter of 10/08/91

Date Reported: 10/16/91

Submitted by: Robert Gerath
Thurber Engineering Ltd.
1445 West Georgia Street, Suite 200
Vancouver, B.C. V6G 2T3
CANADA

Sample Name: Sample #2 (Garbage Dump Tree - 07/19/91)
Wood.

AGE = 1390 +/- 65 C-14 years BP (C-13 corrected).

Description: Sample of wood.

Pretreatment: The wood sample was cleaned of dirt or other foreign material and was split into small pieces. It was then treated with hot dilute HCl to remove any carbonates and with hot dilute NaOH to remove humic acids and other organic contaminants. After washing and drying it was combusted to recover carbon dioxide for the analysis.

Comment:

$\delta^{13}C_{PDB}$ = -24.0 ‰

Notes: This date is based upon the Libby half life (5570 years) for ^{14}C. The error stated is $\pm 1\sigma$ as judged by the analytical data alone. Our modern standard is 95% of the activity of N.B.S. Oxalic Acid. The age is referenced to the year A.D. 1950.

OCT 21 1991

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GEOCHRON LABORATORIES DIVISION
24 BLACKSTONE STREET • CAMBRIDGE, MASSACHUSETTS 02139 • (617) 876-3691

RADIOCARBON AGE DETERMINATION — **REPORT OF ANALYTICAL WORK**

Our Sample No. GX-17271 **Priority** Date Received: 10/09/91

Your Reference: letter of 10/08/91 Date Reported: 10/16/91

Submitted by: Robert Gerath
Thurber Engineering Ltd.
1445 West Georgia Street, Suite 200
Vancouver, B.C. V6G 2T3
CANADA

Sample Name: Sample #3 (91-C9)
Wood.

AGE = 1340 +/- 65 C-14 years BP (C-13 corrected).

Description: Sample of wood.

Pretreatment: The wood sample was cleaned of dirt or other foreign material and was split into small pieces. It was then treated with hot dilute HCl to remove any carbonates and with hot dilute NaOH to remove humic acids and other organic contaminants. After washing and drying it was combusted to recover carbon dioxide for the analysis.

Comment:

$\delta^{13}C_{PDB}$ = -22.9 ‰

Notes: This date is based upon the Libby half life (5570 years) for ^{14}C. The error stated is $\pm 1\sigma$ as judged by the analytical data alone. Our modern standard is 95% of the activity of N.B.S. Oxalic Acid. The age is referenced to the year A.D. 1950.

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RADIOCARBON AGE DETERMINATION | **REPORT OF ANALYTICAL WORK**

Our Sample No. GX-17892 PRIORITY | Date Received: 04/24/92

Your Reference: letter of 04/23/92 | Date Reported: 04/30/92

Submitted by: Dr. Oldrich Hungr/R.F. Gerath
Thurber Engineering Ltd.
1445 West Georgia Street, Suite 200
Vancouver, B.C. V6G 2T3 CANADA

Sample Name: EXPOSURE G3 Sample 1B.
Organic matter.

AGE = 1,215 +/- 120 C-14 years BP (C-13 corrected).

Description: Sample of charcoal.

Pretreatment: The charcoal fragments were separated from any sand, silt, rootlets, or other foreign matter. The sample was then treated with hot dilute HCl to remove any carbonates, and with hot dilute NaOH to remove humic acids and other organic contaminants. After washing and drying, the cleaned charcoal was combusted and the carbon dioxide was recovered for the analysis.

Comment: Small sample. Counted for two days.

$\delta^{13}C_{PDB} = -25.8$ ‰

Notes: This date is based upon the Libby half life (5570 years) for ^{14}C. The error stated is $\pm 1\sigma$ as judged by the analytical data alone. Our modern standard is 95% of the activity of N.B.S. Oxalic Acid. The age is referenced to the year A.D. 1950.

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RADIOCARBON AGE DETERMINATION | **REPORT OF ANALYTICAL WORK**

Our Sample No. GX-17893 PRIORITY

Date Received: 04/24/92

Your Reference: letter of 04/23/92

Date Reported: 05/04/92

Submitted by: Dr. Oldrich Hungr/R.F. Gerath
Thurber Engineering Ltd.
1445 West Georgia Street, Suite 200
Vancouver, B.C. V6G 2T3 CANADA

Sample Name: EXPOSURE G3 Sample 5B.
Organic matter.

AGE = 5,975 +/- 180 C-14 years BP (C-13 corrected).

Description: Sample of charcoal.

Pretreatment: The charcoal fragments were separated from any sand, silt, rootlets, or other foreign matter. The sample was then treated with hot dilute HCl to remove any carbonates, and with hot dilute NaOH to remove humic acids and other organic contaminants. After washing and drying, the cleaned charcoal was combusted and the carbon dioxide was recovered for the analysis.

Comment: Small sample. Counted for two days.

$\delta^{13}C_{PDB}$ = -25.5 ‰

Notes: This date is based upon the Libby half life (5570 years) for ^{14}C. The error stated is $\pm 1\sigma$ as judged by the analytical data alone. Our modern standard is 95% of the activity of N.B.S. Oxalic Acid. The age is referenced to the year A.D. 1950.

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RADIOCARBON AGE DETERMINATION | **REPORT OF ANALYTICAL WORK**

Our Sample No. GX-17890 PRIORITY | Date Received: 04/24/92

Your Reference: letter of 04/23/92 | Date Reported: 05/04/92

Submitted by: Dr. Oldrich Hungr/R.F. Gerath
Thurber Engineering Ltd.
1445 West Georgia Street, Suite 200
Vancouver, B.C. V6G 2T3 CANADA

Sample Name: TP 92-5 Sample 6A (organics).
Organic matter.

AGE = 8,715 +/- 100 C-14 years BP (C-13 corrected).

Description: Sample of charcoal.

Pretreatment: The charcoal fragments were separated from any sand, silt, rootlets, or other foreign matter. The sample was then treated with hot dilute HCl to remove any carbonates, and with hot dilute NaOH to remove humic acids and other organic contaminants. After washing and drying, the cleaned charcoal was combusted and the carbon dioxide was recovered for the analysis.

Comment:

$\delta^{13}C_{PDB}$ = -24.1 ‰

- -

Notes: This date is based upon the Libby half life (5570 years) for ^{14}C. The error stated is $\pm 1\sigma$ as judged by the analytical data alone. Our modern standard is 95% of the activity of N.B.S. Oxalic Acid. The age is referenced to the year A.D. 1950.

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RADIOCARBON AGE DETERMINATION

REPORT OF ANALYTICAL WORK

Our Sample No. GX-17891 PRIORITY

Date Received: 04/24/92

Your Reference: letter of 04/23/92

Date Reported: 04/29/92

Submitted by: Dr. Oldrich Hungr/R.F. Gerath
Thurber Engineering Ltd.
1445 West Georgia Street, Suite 200
Vancouver, B.C. V6G 2T3 CANADA

Sample Name: TP 92-6 Sample 1D.
Organic matter.

AGE = 1,665 +/- 65 C-14 years BP (C-13 corrected).

Description: Sample of charcoal.

Pretreatment: The charcoal fragments were separated from any sand, silt, rootlets, or other foreign matter. The sample was then treated with hot dilute HCl to remove any carbonates, and with hot dilute NaOH to remove humic acids and other organic contaminants. After washing and drying, the cleaned charcoal was combusted and the carbon dioxide was recovered for the analysis.

Comment:

$\delta^{13}C_{PDB} = -24.6$ ‰

Notes: This date is based upon the Libby half life (5570 years) for ^{14}C. The error stated is $\pm 1\sigma$ as judged by the analytical data alone. Our modern standard is 95% of the activity of N.B.S. Oxalic Acid. The age is referenced to the year A.D. 1950.

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RADIOCARBON AGE DETERMINATION

REPORT OF ANALYTICAL WORK

Our Sample No. GX-17894 PRIORITY

Date Received: 04/24/92

Your Reference: letter of 04/23/92

Date Reported: 04/30/92

Submitted by: Dr. Oldrich Hungr/R.F. Gerath
Thurber Engineering Ltd.
1445 West Georgia Street, Suite 200
Vancouver, B.C. V6G 2T3 CANADA

Sample Name: SQUAMISH RIVER Sample 6B Station 25.
Organic matter.

AGE = 6,595 +/- 90 C-14 years BP (C-13 corrected).

Description: Sample of charcoal.

Pretreatment: The charcoal fragments were separated from any sand, silt, rootlets, or other foreign matter. The sample was then treated with hot dilute HCl to remove any carbonates, and with hot dilute NaOH to remove humic acids and other organic contaminants. After washing and drying, the cleaned charcoal was combusted and the carbon dioxide was recovered for the analysis.

Comment:

$\delta^{13}C_{PDB}$ = -24.3 ‰

Notes: This date is based upon the Libby half life (5570 years) for ^{14}C. The error stated is $\pm 1\sigma$ as judged by the analytical data alone. Our modern standard is 95% of the activity of N.B.S. Oxalic Acid. The age is referenced to the year A.D. 1950.

APPENDIX X

PETROGRAPHY AND MINERALOGY OF SELECTED SAMPLES
(P. READ)

CHEEKYE BASIN STUDY:

PETROGRAPHY AND MINERALOGY OF SELECTED SAMPLES

1. INTRODUCTION

B. Gerath and Dr. O. Hungr of Thurber Associates, Suite 200, 1445 W. Georgia St., Vancouver, B.C. submitted three samples for X-ray diffraction analysis and four samples for petrographic examination. The samples submitted for X-ray diffraction were packaged damp in plastic bags. Only the fine disaggregated material was selected for X-ray diffraction. The thin sections from samples for petrographic examination were oriented perpendicular to the layering if present.

2. PROCEDURE FOR X-RAY DIFFRACTION

The X-ray diffraction analysis was done on a Siemen's Kristalloflex D5000 automated X-ray diffraction unit housed at the Department of Geological Sciences, University of British Columbia. The generator was set at 40kV and 30mA which produced Ni-filtered monochromatic CuK radiation. The X-ray detector moved in steps of $0.02^{\circ}2\theta$ and collected counts for 0.5 seconds at each step which yields a scan speed of 2.4° 2θ/minute. Each sample was powdered in a mortar by means of a pestle, spread on three glass slides as a slurry of rock powder and water, and slowly dried at low temperature under a heat lamp. For each sample, one slide was left untreated, the second slide was glycolated for 24 hours, and the third slide was heated for 1 hour at 575°C. The untreated powder was run through diffraction angles of $2\theta = 4^{\circ}$ to 35° for a qualitative mineral composition. The glycolated (series G) and heated slides (series H) were run through angles of $2\theta = 5^{\circ}$ to 13°. After a slide is run, the stored counts are displayed with background eliminated and compared to the ASTM standard file of minerals for mineral identification. The sample pattern and matches with ASTM standard mineral patterns are given in Appendix A.

3. X-RAY DIFFRACTION ANALYSIS

All samples are dominated by quartz, have common muscovite, contain less chlorite, and carry disseminated pyrite (Table 1 and Appendix A). This mineral assemblage does not reflect the mineralogy of the protolith but is typically of an intense hydrothermal alteration that produces an assemblage of quartz-muscovite-chlorite-pyrite. Kaolinite may have been introduced into the assemblage as the final stage of hydrothermal alteration or could be the product of later weathering of the assemblage (see Discussion). In all samples, kaolinite is the only clay mineral developed. Its presence is indicated by a diffraction line at about 12.4° 2θ in untreated and glycolated samples, but the absence of this line in heated samples which are chlorite-free.

TABLE 1: X-RAY DIFFRACTION ANALYSIS OF SAMPLES

Sample #	Quartz	Muscovite	Chlorite	Kaolinite
B1-A (PBR 1A)	++	+	-	-
(PBR 1AG)		present	absent	present
(PBR 1AH)		present	present	absent
B1-B (PBR 1B)	++	-	tr	tr
(PBR 1BG)		present	present	present
(PBR 1BH)		present	present	absent
H4-B (PBRH4)	++	+	-	-
(PBRH4G)		present	present	present
(PBRH4H)		present	present	absent

++ = dominant (60%±20%) + = major (35%±10%) - = minor (15%±5%)
tr = trace (5-10%) n.d. = not detected

4. PETROGRAPHY

The three samples submitted for X-ray diffraction are quartz-muscovite-chlorite-pyrite schist developed as a result of a hydrothermal alteration that was so intense that the protoliths of the samples are unknown.

Of the rocks studied in thin section, three of the four samples are either volcanic flows or hypabyssal intrusions, and the fourth sample is a phyllite developed from a sedimentary of felsic volcanic protolith. Low grade metamorphism of the biotite zone or less has affected all samples. Foliated and unfoliated quartz diorite of the Cloudburst pluton, mapped in the sampled area by Mathews (1957), Roddick and Woodsworth (1979), and Green (1977), is absent. Because the samples have been described as "Gambier roof pendants" (Hungr and Gerath, pers. comm., Oct. 1991), they would be of Early Cretaceous age and should lie nonconformably on the Late Jurassic Cloudburst pluton which has been zircon-dated at 145±2 Ma by Friedman and Armstrong (1990). However, the sampled area lies within the 50 km wide, northwesterly trending Squamish River Tract which contains common pre-Gambier rocks (Monger, 1990; 1991). In the sectioned rocks, the common albite-muscovite-epidote-chlorite-calcite-quartz matrix assemblage with albite phenocrysts is typical of keratophyres which characterize the Harrison Lake Formation. Rocks of the Lower to Middle Jurassic Harrison Lake Formation would form roof pendants in the Late Jurassic Cloudburst pluton and may be the correlative unit for the sectioned rocks rather than the Gambier Group.

5. DESCRIPTION OF SAMPLES

The following three samples were investigated by X-ray diffraction:

(a) Sample B1-A:

A rusty weathering, but white on fresh surfaces, fine-grained (0.5 mm) quartz-muscovite-chlorite schist. The absence of pyrite may result from its oxidation to produce the rusty colour of the sample.

(b) Sample B1-B:

A light grey, fine-grained (0.5 mm) quartz-muscovite-pyrite schist.

(c) Sample H4-B:

A white fine-grained (0.5 mm) quartz-muscovite-chlorite-pyrite schist.

The following four samples were examined in thin section:

(d) Sample C18:

Medium grey-green porphyritic (plagioclase ½%, 2 mm) felsic flow or hypabyssal intrusion.

Thin Section:

The following minerals are present in amounts given by a visually estimated mode:

A. Phenocrysts (½%):

1. Plagioclase (½%):

Subhedral, albite-twinned laths up to 2.5 mm long which are selectively replaced by calcite-clinozoisite-muscovite.

B. Matrix (80%):

1. Plagioclase (70%):

Subhedral laths up to 0.2 mm long with a marked trachytic texture. The laths are lightly flecked with fine muscovite flakes. The grains are too fine for a flat-stage plagioclase composition determination, but the negative relief of the plagioclase with respect to adjacent quartz grains indicate albite and a single flat-stage composition determination yields An_0.

2. Quartz (10%):

Shapeless grains up to 0.15 mm in diameter which are unstrained and unaltered, and which are spatially associated with clinozoisite.

C. Alteration (19¼%):

1. Clinozoisite-epidote (10%):

Colourless prismatic grains up to 0.2 mm long with up to second order interference tints. They are spatially associated with quartz grains in clinozoisite-epidote-rich clots and as prismatic grains within plagioclase laths.

2. Muscovite (8%):

Very fine (less than 0.01 mm long) colourless flakes sprinkled throughout the matrix.

3. Chlorite (less than ¼%):

A few scattered medium to pale green pleochroic flakes scattered throughout the matrix.

4. Carbonate (less than ¼%):

Colourless, shapeless, fine grains (less than 0.1 mm in diameter) developed within plagioclase.

Remarks: The relict porphyritic texture indicates that the rock was either a volcanic or a hypabyssal intrusion. The relict igneous assemblage has been obliterated by a muscovite-chlorite-calcite-albite-quartz assemblage. The rock shows no strain features and the presence of subhedral plagioclase phenocrysts, rather than plagioclase augen, indicates that the rock has not been sheared.

(e) Sample C52:

Massive, medium grey-green, pyritized (4%), porphyritic (plagioclase 2%, 2 mm) felsic flow or hypabyssal intrusion.

Thin Section:

The following minerals are present in amounts given by a visually estimated mode:

A. Phenocrysts (15%):

1. Plagioclase (15%):

Subhedral laths up to 1.0 mm long which are extensively altered to calcite and muscovite.

B. Matrix (38%):

1. Plagioclase (28%):

Thin subhedral laths up to 0.15 mm long partly altered to muscovite and calcite.

2. Quartz (10%):

Shapeless grains less than 0.05 mm in diameter with a uniaxial positive interference figure.

C. Alteration (47%):

1. Calcite (15%):

Shapeless, untwinned grains 0.1 mm or less in diameter which, along with muscovite, selectively replace the plagioclase phenocrysts.

2. Epidote (3%):

Strongly pleochroic golden yellow to pale yellow prismatic grains up to 0.2 mm long.

3. Muscovite (15%):

Fine colourless flakes less than 0.05 mm long mainly replacing plagioclase phenocrysts.

4. Chlorite (10%):

Pleochroic pale green to colourless flakes with medium grey interference tints which are length-fast and form clots up to 0.8 mm long.

5. Pyrite (4%):

Equant brass yellow cubes 0.1 to 0.3 mm on edge sprinkled throughout but largely within the plagioclase phenocrysts.

Remarks: The relict porphyritic igneous texture indicates that the protolith was either a porphyritic volcanic or a hypabyssal intrusion. The original igneous assemblage has been obliterated by a chlorite-muscovite-calcite-albite-quartz assemblage typical of, but not unique to, the chlorite zone of the greenschist facies. The rock shows no strain features and the presence of subhedral plagioclase phenocrysts, rather than plagioclase augen, indicates that the rock has not been sheared.

(f) Sample C66A:

A light grey-green layered felsite.

Thin Section:

The following minerals are present in amounts given by a visually estimated mode:

1. Epidote (30%):

Granular grains less than 0.2 mm in diameter which are pleochroic from pale yellow to colourless. They form clots up to 6 mm in diameter containing 80% epidote with 20% inclusions of mainly quartz and minor plagioclase.

2. Chlorite (5%):

Fine (0.05 mm long) flakes which are pleochroic from medium green to colourless, have light grey interference tints, and are length-fast.

3. Biotite (10%):

Fine (0.05 mm long) flakes which are pleochroic from pale brown to medium green-brown and have second order interference tints. The chlorite and biotite are randomly oriented and spatially associated.

4. Plagioclase (40%):

Albite-twinned, subhedral laths up to 0.15 mm long. The laths are unzoned and have a marked negative relief with respect to adjacent quartz grains suggesting an albite composition.

5. Quartz (15%):

Shapeless grains 0.05 mm in diameter with a uniaxial positive interference figure.

Remarks: The mineral assemblage of biotite-chlorite-epidote-albite-quartz is typical of the biotite zone of the greenschist facies. Strain features are absent in the rock.

(g) Sample B1-C:

Light grey-green to white, weakly pyritized (2%) phyllite. Note that the white parts of the rock look like a less altered equivalent of samples B1-A, B1-B, and H4-B.

Thin Section:

The following minerals are present in amounts given by a visually estimated mode:

1. Muscovite (73%):

Fine (less than 0.02 mm long) colourless flakes which are partly preferentially oriented to define a foliation.

2. Chlorite (5%):

Medium to pale green pleochroic flakes which have medium grey interference tints and are length-fast. These are spatially oriented with the muscovite flakes and also form clots up to 0.8 mm in diameter consisting of 0.2 mm long flakes. The clots may be pseudomorphs of original mafic minerals.

3. Quartz (20%):

Shapeless, colourless grains 0.1 mm and less in diameter which do not show any strain features.

4. Pyrite (2%):

Brass yellow cubes 0.05 to 0.1 mm on edge sprinkled throughout.

Remarks: The muscovite-chlorite-quartz assemblage may develop from either a pelitic or felsic protolith such as a siltstone or felsic tuff respectively. The assemblage is typical of, but not unique to, the chlorite zone of the greenschist facies.

6. DISCUSSION

In Cheekye Basin, a conspicuous zone of alteration in greenish schistose quartz diorite occurs immediately beneath late glacial tuff-breccia (Mathews, 1952). Although Mathews (p. 87) stated that the alteration was caused by the overlying tuff-breccia, he noted that oddly enough neither the tuff-breccias themselves nor the buried dacite domes exhibit this alteration. In Cheekye Basin, an alternate suggestion for the cause of the alteration is that the conspicuous alteration predates the deposition of the tuff-breccias, perhaps by millions of years, but that these easily eroded, altered rocks have been preserved nearly exclusively beneath the protective cap of Quaternary tuff-breccia. The cause of the alteration might well be intense hydrothermal alteration developed along either a faulted or intensely sheared zone, that could measure hundreds of metres in width and thousands of metres in length. Mathews (1957) noted that Cloudburst pluton and its wallrocks are locally intensely sheared but not faulted. A K/Ar radiometric age of the conspicuous muscovite in the altered rocks should provide a critical test for the mode of genesis of the alteration.

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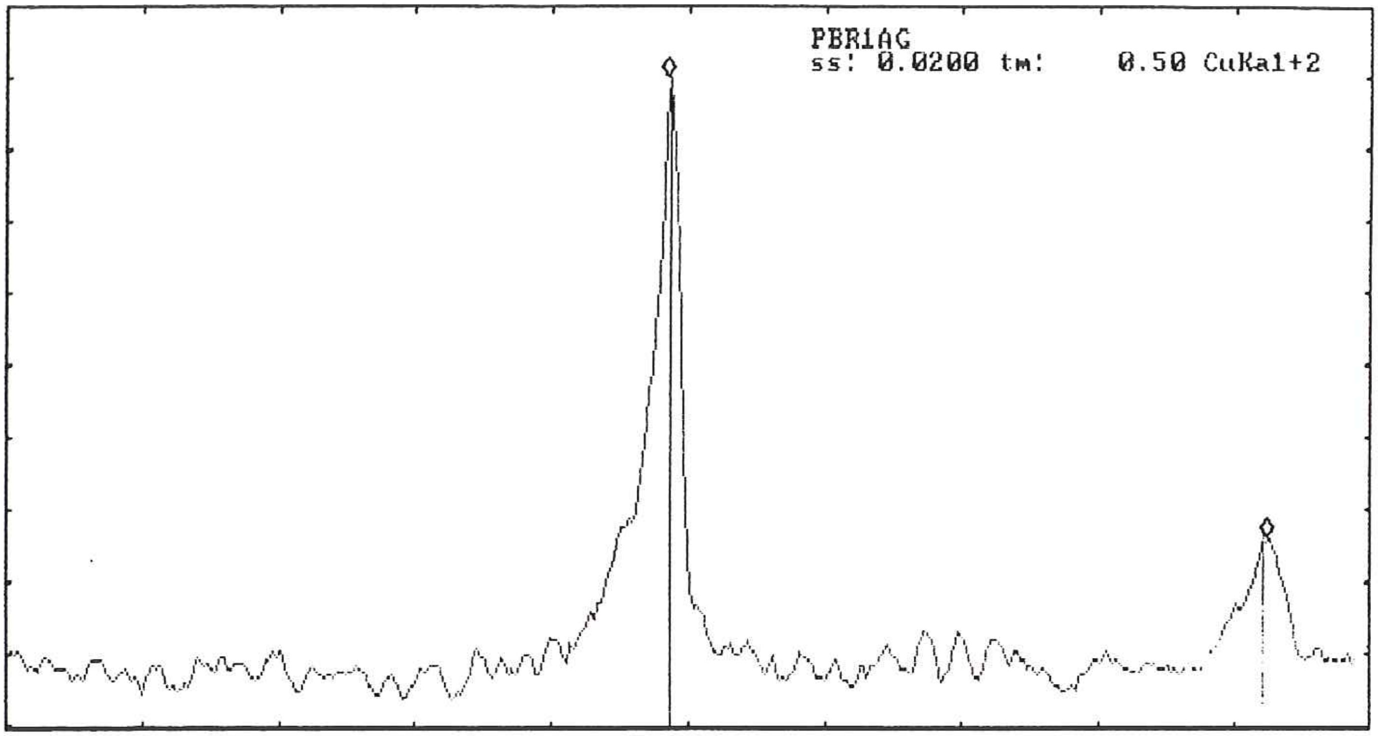
1979: Geology of Vancouver west half and mainland part of Alberni; Geological Survey of Canada, Open File 611.

APPENDIX A: X-RAY DIFFRACTOGRAMS

(coloured inks for mineral matching in original copy only)



< 5.000 x : 2theta y : 87. Linear 12.980>

6-0263 I KAl2(Si3Al)O10(OH,F)2 Muscovite IT M RG
14-0164 I Al2Si2O5(OH)4 Kaolinite IT A RG

?help Zoom **Match** File Clear Back. Null K a2 Peaks Smoo. Comp. Wfile -> M

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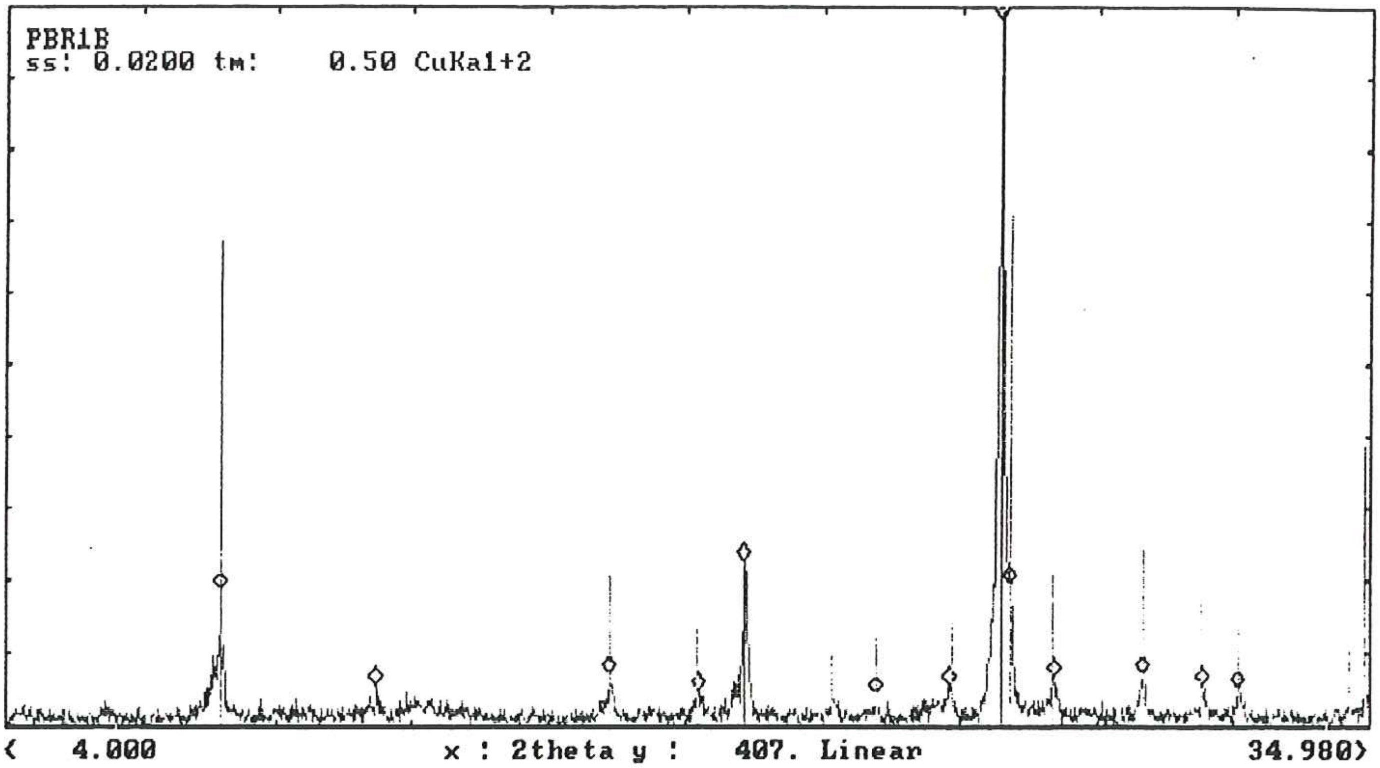
D-ta file: PBR1AH.RAW

Seq	2theta	d	rel. I
1	6.340	13.9315	25.42
2	8.863	9.9714	100.00

Seq	2theta	d	rel. I
2	8.863	9.9714	100.00
1	6.340	13.9315	25.42

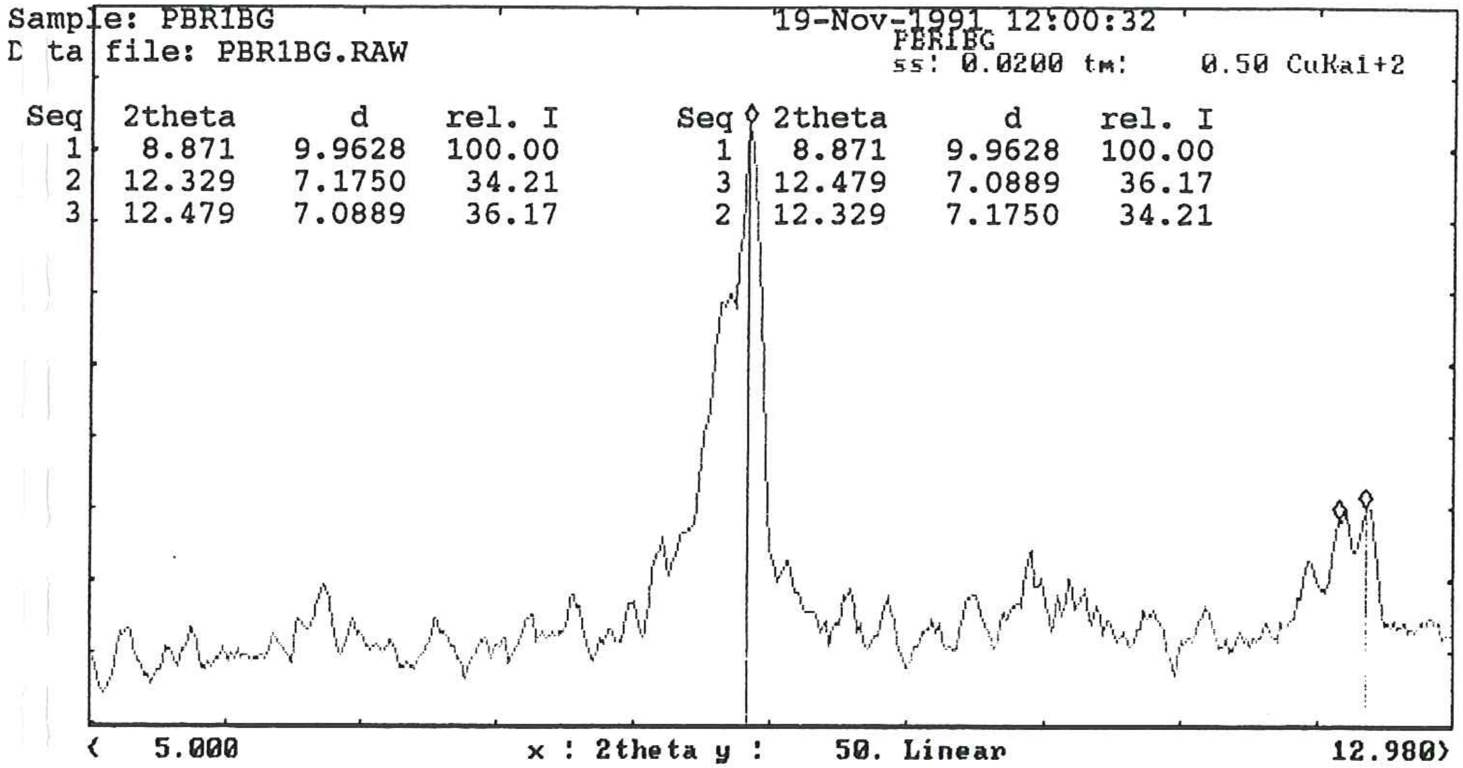


33-1161 * SiO2 Quartz syn
6-0263 I KAl2(Si3Al)O10(OH,F)2 Muscovite 1T M RG

Test rm_Ab tgl_O Quant Imm_Q sUbtr Retrn -> R

Sample: PBR1B 19-Nov-1991 11:16:19
Data file: PBR1B.RAW

Seq	2theta	d	rel. I		Seq	2theta	d	rel. I	
1	8.860	9.9741	18.92		8	26.633	3.3450	100.00	
2	12.474	7.0919	5.41		5	20.842	4.2594	22.85	
3	17.773	4.9876	7.13		9	26.860	3.3172	19.66	?
4	19.800	4.4812	4.67	?	1	8.860	9.9741	18.92	
5	20.842	4.2594	22.85		11	29.873	2.9891	7.37	
6	23.837	3.7306	4.42		3	17.773	4.9876	7.13	
7	25.503	3.4905	5.65		10	27.881	3.1980	6.63	
8	26.633	3.3450	100.00		7	25.503	3.4905	5.65	
9	26.860	3.3172	19.66	?	12	31.236	2.8617	5.41	
10	27.881	3.1980	6.63		2	12.474	7.0919	5.41	
11	29.873	2.9891	7.37		13	32.046	2.7912	5.16	
12	31.236	2.8617	5.41		4	19.800	4.4812	4.67	?
13	32.046	2.7912	5.16		6	23.837	3.7306	4.42	



6-0263 I KAl2(Si3Al)O10(OH,F)2 Muscovite IT M RG
14-0164 I Al2Si2O5(OH)4 Kaolinite IT A RG

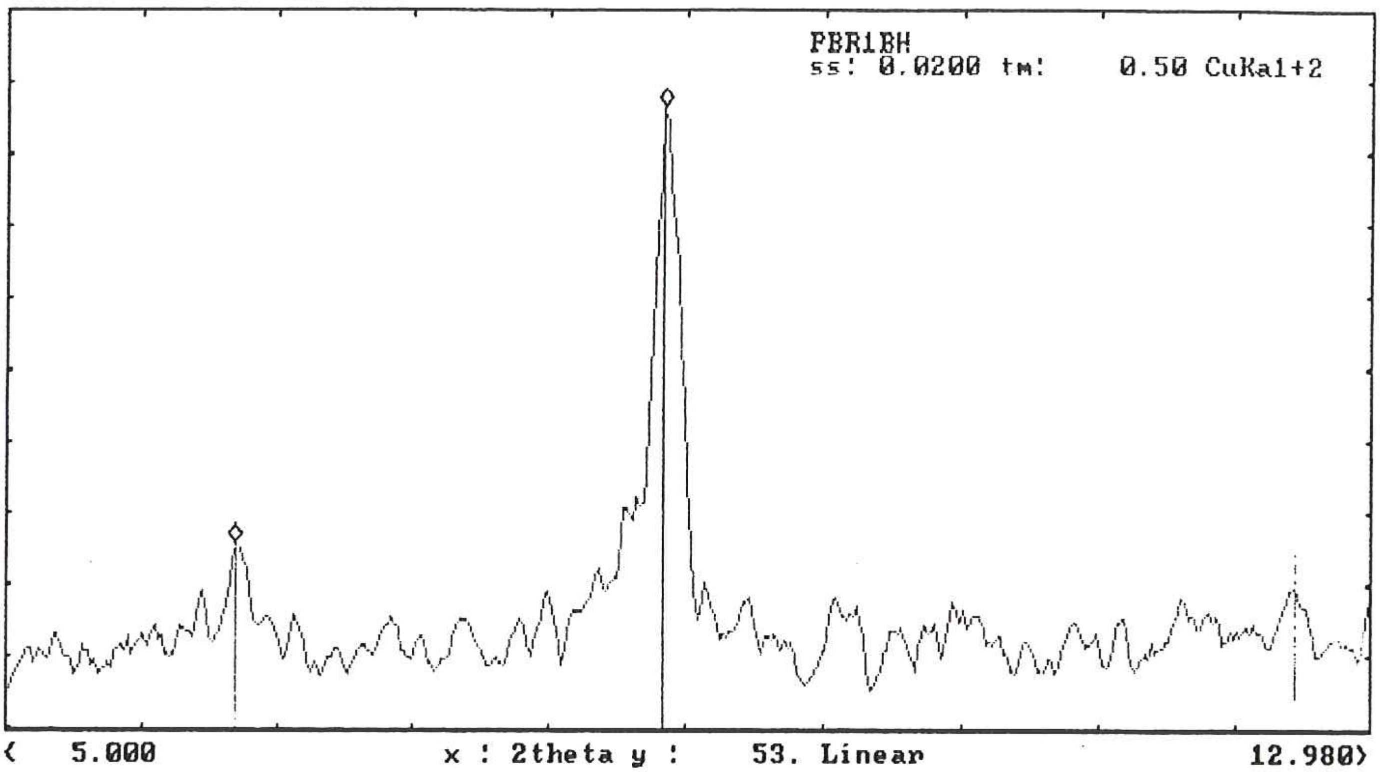
?help Zoom Match File Clear Back. Null K a2 Peaks Smoo. Comp. Wfile -> M

Sample: PBR1BH
Data file: PBR1BH.RAW

19-Nov-1991 12:07:13

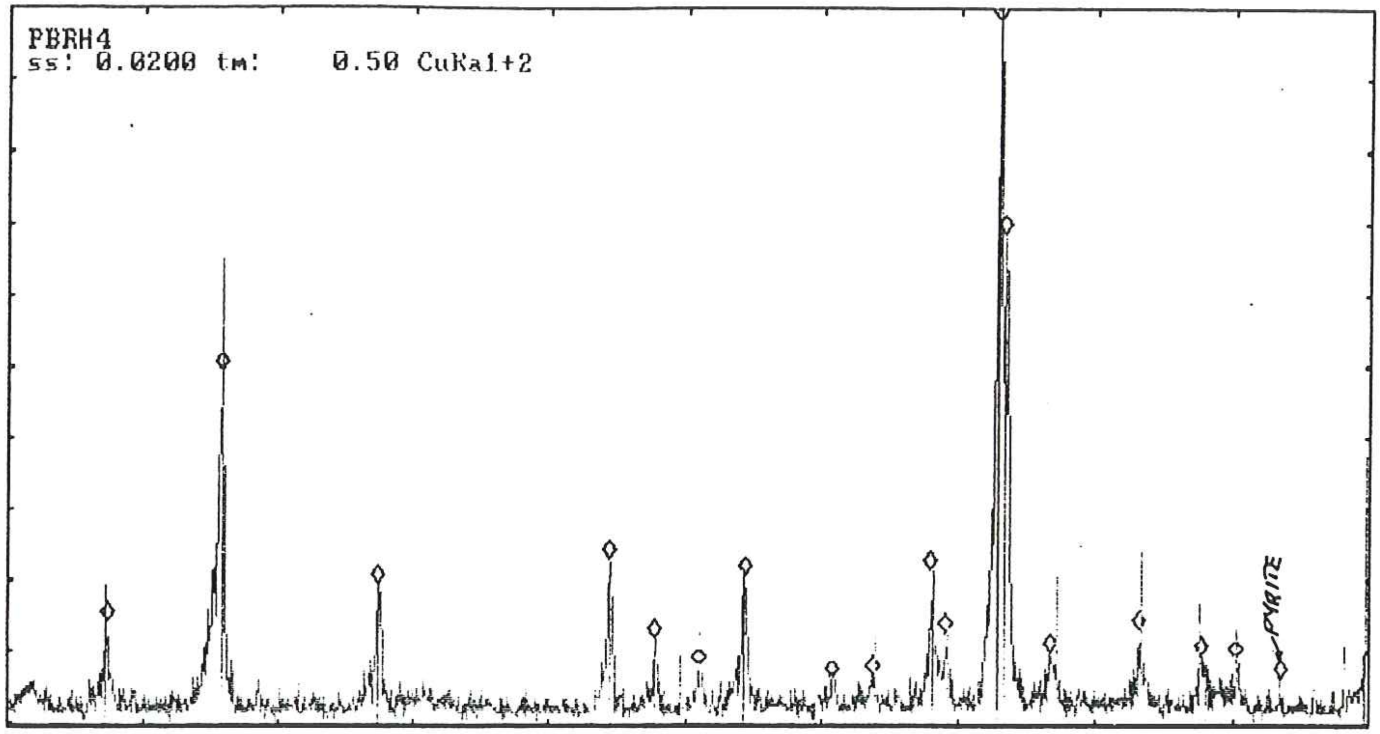
Seq	2theta	d	rel. I
1	6.340	13.9315	30.12
2	8.875	9.9580	100.00

Seq	2theta	d	rel. I
2	8.875	9.9580	100.00
1	6.340	13.9315	30.12



6-0263 I KAl2(Si3Al)O10(OH,F)2 Muscovite IT M RG
7-0165 (Mg,Al,Fe)6(Si,Al)4O10(OH)8 Clinochlore IT M I I b RG

?help Zoom **Match** File Clear Back. Null K a2 Peaks Smoo. Comp. Wfile -> **M**



< 4.000 x : 2theta y : 274. Linear 34.980>

33-1161 * SiO2 Quartz syn
6-0263 I KAl2(Si3Al)O10(OH,F)2 Muscovite IT M RG
7-0165 (Mg,Al,Fe)6(Si,Al)4O10(OH)8 Clinochlore IT M I I b RG

?help Zoom **Match** File Clear Back. Null K a2 Peaks Smoo. Comp. Wfile -> **M**

Sample: PBRH4 19-Nov-1991 11:20:25
Data file: PBRH4.RAW

Seq	2theta	d	rel. I
1	6.215	14.2119	14.60
2	8.841	9.9966	49.64
3	12.480	7.0880	19.71
4	17.757	4.9918	23.36
5	18.782	4.7217	12.04
6	19.806	4.4798	8.03
7	20.857	4.2564	20.80
8	22.865	3.8869	6.57
9	23.787	3.7384	6.93
10	25.125	3.5422	21.53
11	25.468	3.4952	12.77
12	26.624	3.3460	100.00
13	26.778	3.3272	68.98
14	27.831	3.2037	9.85
15	29.842	2.9922	13.14
16	31.246	2.8609	9.49
17	32.029	2.7927	9.12
18	33.016	2.7114	6.20

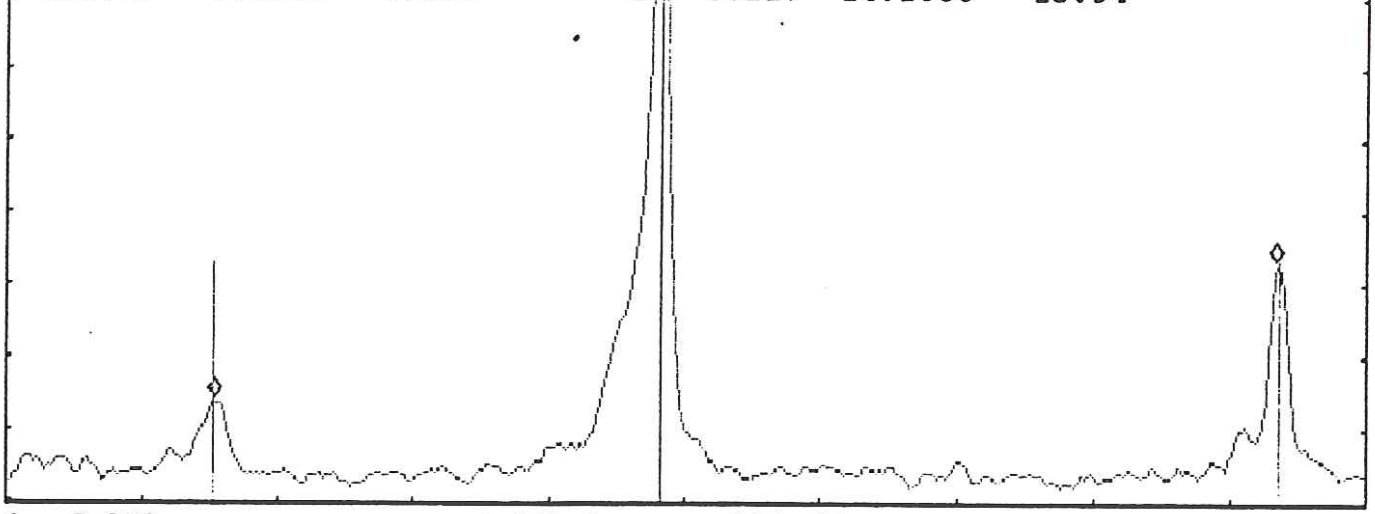
Seq	2theta	d	rel. I
12	26.624	3.3460	100.00
13	26.778	3.3272	68.98
2	8.841	9.9966	49.64
4	17.757	4.9918	23.36
10	25.125	3.5422	21.53
7	20.857	4.2564	20.80
3	12.480	7.0880	19.71
1	6.215	14.2119	14.60
15	29.842	2.9922	13.14
11	25.468	3.4952	12.77
5	18.782	4.7217	12.04
14	27.831	3.2037	9.85
16	31.246	2.8609	9.49
17	32.029	2.7927	9.12
6	19.806	4.4798	8.03
9	23.787	3.7384	6.93
8	22.865	3.8869	6.57
18	33.016	2.7114	6.20

Sample: PBRH4G
Data file: PBRH4G.RAW

19-Nov-1991 12:12:06
PBRH4G
ss: 0.0200 tm: 0.50 CuKa1+2

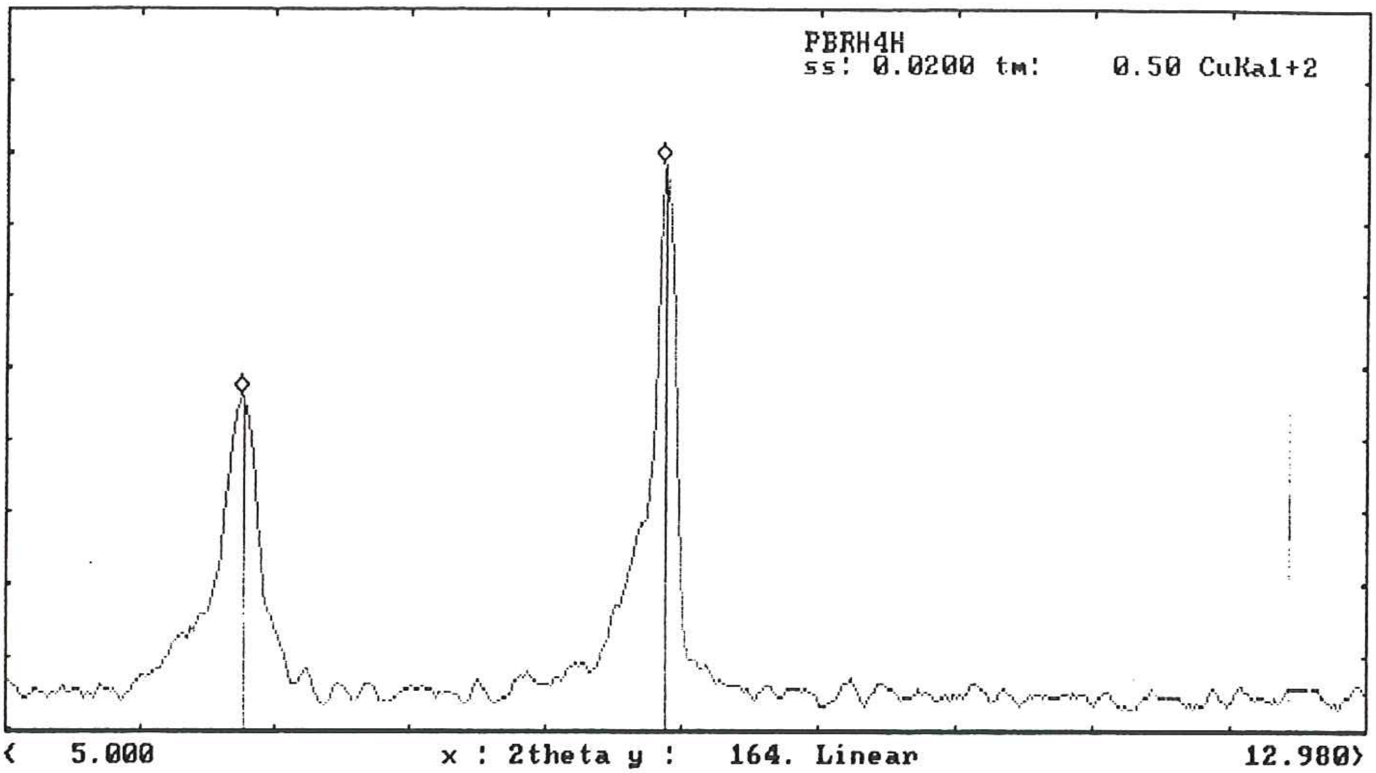
Seq	2theta	d	rel. I
1	6.217	14.2080	15.94
2	8.831	10.0067	100.00
3	12.472	7.0928	37.50

Seq	2theta	d	rel. I
2	8.831	10.0067	100.00
3	12.472	7.0928	37.50
1	6.217	14.2080	15.94



6-0263 I KAl2(Si3Al)O10(OH,F)2 Muscovite IT M RG
7-0165 (Mg,Al,Fe)6(Si,Al)4O10(OH)8 Clinochlore IT M I I b RG

?help Zoom Match File Clear Back. Null K a2 Peaks Smoo. Comp. Wfile -> M



6-0263 I KAl2(Si3Al)O10(OH,F)2 Muscovite IT M RG

7-0165 (Mg,Al,Fe)6(Si,Al)4O10(OH)8 [illegible]chlore IT M I I b RG

?help Zoom **Match** File Clear Back. Null K.a2 Peaks Smoo. Comp. Wfile -> **M**

Sample: PBRH4H 19-Nov-1991 12:22:19
Data file: PBRH4H.RAW

Seq	2theta	d	rel. I
1	6.387	13.8305	58.97
2	8.885	9.9469	100.00

Seq	2theta	d	rel. I
2	8.885	9.9469	100.00
1	6.387	13.8305	58.97

APPENDIX XI

SURVEYED PROFILES THROUGH CHEEKYE AND BROHM RIDGES

APPENDIX XIII

RISK ANALYSIS

APPENDIX XIII

RISK ANALYSIS

MAGNITUDE FREQUENCY RELATIONSHIP

1.1 Introduction

If it is required to assess risk to life (PDI, PND) or risk to property (ARC) due to future debris flows, it is necessary to assess the likelihood that these events will occur. As discussed in Morgan, Rawlings, & Sobkowicz (1992), there is usually a relationship between event magnitude (in this case, the volume of a debris flow, M) and the probability that it will occur [P(H)]. Since event magnitude is usually also directly related to the severity of the consequences, estimating the relationship between M and P(H) is an important first step in evaluating risk.

In the case of the Cheekye fan, there is very little data on actual events, and some of it is of a summary nature, which means that a large amount of judgement needs to be applied in estimating M vs P(H). The statistical approach described in Morgan et al (1992) will be used to help clarify the assumptions inherent in this judgement.

1.2 Data

The following series of events is presumed from the existing deposits:

Table XIII-1 - Description of Events

Years B.P.	No. of events	Maximum Event Magnitude (Mm^3)	Comments
6000	1	4	Volume not well-determined.
2000 to 5000	1	1	Occurred sometime between the two larger events.
1000	1	7	A single event is considered to be of at least 3 M m^3 magnitude.
<100	2	.1	These events were likely quite common.

It is estimated that the total volume of material accumulated from debris flows over this time period (i.e. since the 6000 year B.P. horizon) is 17.4 M m^3, plus possibly some portion of another 17 M m^3 of deposits which have been interpreted as reworked fluvial or debris flow material. It is unlikely that larger debris flows have contributed to this reworked material, as it has a relatively "fine" gradation. It is not clear how much of the reworked deposits have their origin in "finer" debris flow; it is assumed that this volume is fairly small, in the order of a few million m^3, and so the total volume of debris flow related deposits has been increased from 17.4 to 20 Mm^3.

The total volume of material deposited during the assumed events (Table XIII-I) is 10 to 13 Mm^3, thus there is about 8 to 10 Mm^3 of material attributable to debris flows but not identifiable as discrete events, (i.e. 40 to 50% of the total volume). This is probably because these events were not large in size, say less than 1 Mm^3, and possibly more likely in the range 100,000 to 500,000 m^3.

The Probable Maximum Magnitude event (i.e. the debris flow with the maximum volume at this location) is estimated to be 7 Mm^3. This is referred to as the PMM event. In fact it might have been a combination of several more closely spaced smaller events.

The information on the data is somewhat skewed. Normally it could be expected that there would information on events slightly larger than the threshold magnitude. In this case, there is data on the largest events, but very little on the smaller magnitude events except for their total volume. These smaller magnitude events will play an important part in future predictions, however.

1.3 Analysis of Data

The approach suggested in Morgan et al (1992) can be used to rank the events that have occurred over the last 6000 years, and by assigning a recurrence interval R; where

$$R = (N + 1) / m$$

m = Rank
N = number of years of record

Table XIII-2 - Approximate Return Period of Events

Event Magnitude (Mm^3)	Rank m	Return Period R (years)
5 - 7	1	6000
4	2	3000
1	3	2000

This is a very coarse approach, and ignores the possibility of other moderate-size events (about 1 Mm^3) that may not have been recorded by the existing deposits.

The data in Table XIII - 1 can be illustrated in another manner, as shown in Table XIII-3. The possible magnitude of the debris flow events is arbitrarily divided into a number of intervals (column 1), the number of events on record for each magnitude and the total volume of debris is listed (columns 2 and 3), and an estimate is made of the actual number of events and actual total volume of debris (columns 4 and 5). The sum of all values in column 5 should add up to about 20 Mm^3, and the number of events in each row in column 4 should seem reasonable. Then the cumulative number of events exceeding each magnitude is listed (column 6).

Table XIII-3 - Possible Distribution of Events

Event size ($M\ m^3$)	Number of events on record	Total volume ($M\ m^3$)	Possible or likely number of events	Total volume ($M\ m^3$)	Cumulative number of occurrences[1]
0.1	2	.2	50	5	59
0.5	0	0	5	2.5	9
1	1	1	2	2	4
3	1	4	1	4	2
7	1	7	1	7	1
Totals	**5**	**12.2**	**59**	**20.5**	**59**

1 Exceeding given event magnitude.

The next step is to match the magnitude vs likely number of events in Table XIII-3 with a return period.

Figure XIII-1 shows the results of calculations using the binomial distribution (equation 5 of Morgan et al (1992)), which predicts the probability of "X" occurrences of a debris flow with a particular return period. The return periods have been purposely selected to give peak values for X = 1, 2, 4, and 9.

The benefit of using Figure XIII-1 is that the inherent assumptions is assigning a particular return period to a particular magnitude debris flow can be seen. For example, it was previously estimated that there were about 9 debris flows in excess of 500,000 m^3 in the last 6000 years, and from Figure XIII - 1 a return period of about 630 years might be assigned to flows in excess of this magnitude. The probability of 9 events occurring in 6000 years is 0.130, but it is also evident that with almost equal probability there could have been 7 events [P(X)=0.104], 8 events [P(X)=0.123], 10 events {P(X)=0.123]. or 11 events [P(X)=0.106]. Another way of looking at this is that the return period for debris flows in excess of 500,000 m^3 could be between 550 and 750 years, as this would only move the peak in the probability curve in Figure XIII-1 between 8 and 10 events. But it is unlikely that debris flows in excess of 500,000 m^3 have a return period of say 1500 years, because the probability of 9 events occurring over 6000 years would be quite small compared to other values of X (for example, see the curve for a return period of 1340 years in Figure XIII-1, and values of X equal to 3 to 5).

In a similar manner, Figure XIII-2 illustrates the probability curves for events with shorter return periods, (which correspond to debris flows in excess of a smaller magnitude). From this figure, a return period of about 100 years might be assigned to debris flows in excess of 100,000 m^3.

Figures XIII-1 and XIII-2 allow the construction of Table XIII-4, which gives the best estimate of return period for debris flows in excess of certain magnitudes. It has been assumed in this table that an event near the PMM has been experienced over the period of observation. A return period of 4250 years is assigned to this event, which gives the maximum probability of 1 occurrence over 6000 years (compared to 0 or 2 occurrences), but note that a return period of 6000 or even 10,0000 years would not be totally unreasonable.

Table XIII-4 - Better Estimate of Return Period for Debris Flows

Debris flow volume	Likely number of debris flows in excess	Return Period
(Mm^3)	of this volume	(years)
0.1	59	100
0.5	9	630
1	4	1350
3	2	2450
5 - 7	1	4250

The information in Table XIII-4 is replotted in Figure XIII-3. a return period of 4250 years has been assigned to debris flows in excess of 5 Mm^3, and a P(H) of zero to debris flows in excess of 7 Mm^3.

It should be clear that the approach discussed above incorporates a large amount of judgement with respect to the smaller magnitude events, because of the lack of data. It is possible that there may be error in this judgement. There would be most concern about the case where the estimate of the volume to be assigned to the very rare events (i.e. the large magnitude events) erred on the high side (which might occur if the upper end of our estimated volumes for these events was always selected), because there would then be less volume to distribute amongst the less rare (i.e. smaller magnitude) events. If some aspect of the design was sensitive to the smaller magnitude events, (e.g. maintenance of the remedial structures, which rely upon cleanout of debris accumulating from small events), then it might be possible to be less conservative when using the curves developed previously.

What is meant by smaller magnitude debris flows here partly depends upon the size of event that is distinguishable in the historical record as a distinct unit. It was assumed that debris flows less than 1.0 Mm^3 are not really distinguishable as separate events (unless they are located at the surface), because they are mostly confined to the channel, do not cover a lot of ground laterally, and are subject to reworking by later flood waters.

With the above considerations, it was decided to modify Table XIII-3 as follows:

Table XIII-5 - Another Possible Distribution of Events

Event size (Mm^3)	Number of events on record	Total volume (Mm^3)	Possible number of events	Total volume (Mm^3)	Cumulative number of occurrences[2]
0.1	2	.2	100	10	116
0.5	0	0	10	5	16
1	1	1	4	4	6
3	1	4	1	4	2
5	1	5	1	5	1
Totals	**5**	**10.2**	**116**	**28**	**116**

The main changes in Table XIII-5 are the reduction in size of the maximum historical event, increasing the frequency of the "smaller" event s (1 Mm^3 and less), and increasing the amount of reworked deposits that are assigned to the `debris flow' category (mostly as small debris flows). The total volume of debris flow deposits is now about 28 Mm^3, or roughly 80% of the total observed volume of colluvial/fluvial material (of 34 Mm^3).

The binomial distributions used to estimate return periods for these events (previous Figures XIII-1 and XIII-2) are thus modified as shown in Figures XIII-4 and XIII-5.

Figures XIII-3, which plotted debris flow volume vs annual probability of exceedance, may then be modified to show a range of probabilities at the low magnitude end. This graph is replotted as Figure XIII-6 and XIII-7. Note that the x-axis has been changed to a logarithmic scale in Figure XIII-6 and both axes to a logarithmic scale in Figure XIII-7 to facilitate taking numbers off the graph.

In revising the judgement with respect to the frequency of small magnitude events, the resulting band of probability is still fairly narrow, with the range representing a factor of

2 Exceeding given event magnitude.

about 2. While this is significant, it is not overwhelming. It would not be comfortable to increase the estimate of probability above this level, as it would imply volumes of debris which are not justified by the historical record.

What are the implications of Figure XIII-6 or XIII-7 on the design of future structures, either those that may be built in an area that could be impacted by a debris flow, or those that may be built to protect life and/or property? The answer to this question depends upon the life of the structure in question. For the moment, it is assumed that the foreseeable life of a structure is about 200 years. Curves similar to those shown in figures XIII-4 and XIII-5 could be constructed using 200 years as the period of "observation" and using one of the relationships between debris flow volume and return period on figure XIII-7. The resulting information is brought together in Figure XIII-8 which uses the upper curve from Figure XIII-7.

The y-axis on Figure XIII-8 is plotted using a logarithmic scale (compared to the 'normal' scale used in figure 3d of Morgan et al, 1992), again simply to facilitate use of the graph. Because of the long return periods of the moderate and larger sized events (in relation to the life of the structure), these curves on a normal scale plot would be compressed towards the lower and right-hand sides of the graph, and would be difficult to read.

As an example of how to use this plot, consider the case where a protection berm is being designed for a number of existing buildings or for a road. The berm might be required to contain the debris from a large flow. If protection of life is an issue, particularly if it is a community which is being protected (and thus the exposure to life is almost continuous), it might be required to design for a very low P(H), perhaps less than 1:100,000. This is equivalent to a design volume of 5 or 6 Mm^3, (Figure XIII-7). If it is simply a matter of protecting property, or a road within frequent travellers, then a higher P(H) and lower storage volume might be acceptable, (e.g. P(H) < 1:1000, design volume about 1 Mm^3).

2.0 RISK ACCEPTABILITY CRITERIA FOR GROUPS OF PEOPLE

This section discusses:

- Review of risk acceptability criteria for groups of people.
- Proposed risk acceptability criteria for groups of people.

The "sample size" that being referred to in this quotation is the number of dams, landslide sites, etc. in the area used to produce the frequency data. For example, one of the figures in the Morgan paper provides information on the frequency of N or more deaths due to dams in the U.S. (Figure XIII-9). Clearly the number of dams in the U.S. during the period of record is important, as that directly influences the frequency data.

If it is necessary to use the "Dams (U.S.)" curve from the Morgan paper in comparison to the number of deaths due to dams in Canada, it would have to be moved down on the graph (i.e., the frequency values would need to be reduced by the ratio of dams in Canada to dams in the U.S.). If it was necessary to compare the curve to expected number of deaths at a specific site then the frequency data should really be expressed in terms of:

> Annual Frequency of Events with N or more Deaths per Dam (or landslide site, or whatever) in the study area.

Consideration must be given to Society's acceptance of these risks. The "Landslides (Alps)" data shown on Figure XIII-9 is a summary, compiled originally by Schuster and Fleming (1986) from data presented by Eisbacher and Clague (1984). It is based on 750 years of historic records, and, since the exposed populations have not changed either their living patterns or the effort put into mitigating the risks, one could conclude that the risk has been accepted. On the other hand, the "Landslide (Japan)" data on Figure XIII-9 is based on only 50 years of data and shows a frequency of death an order of magnitude higher than in Europe.

An acceptance criterion of a form similar to Oosthuisen's is derived from this data as follows:

1. The frequency data for landslides in the Alps derives from 137 individual sites described in Eisbacher and Clague (1984), all of which are typical communities or sites in the Alps with some history of landslide activity or accidents. To make allowance for sites with similar exposure to landslide hazard which were not counted, the size of the sample is considered to be about four times larger, i.e., 500. The typical relationship between the group size and probability of an accident for a single site is thus obtained by shifting the cumulative probability curve of Figure XIII-9 down by a factor of 500.

2. The frequency curve as reported by Morgan are for N or more deaths. This is a practical way to describe a relatively small number of data points. A curve for N

2.1 Review of Risk Acceptability Criteria

Only two references (Oosthuizen, 1988 and Dutch Environmental Policy Plan, 1989) have been obtained which purport to be risk acceptability criteria for groups of people.

Considering Oosthuizen's paper and the logic by which the criteria were derived the graph plots annual probability of failure of a dam (i.e. **probability of a hazard**) vs number of lives endangered (dashed lines in Figures XIII-8). There is no inclusion of **severity** on this graph. Hence, it is not a PDG relationship at all, but another relationship for the hazard-based assessment.

While it does not help with the PDG discussion, Oosthuizen's chart nonetheless provides some very useful supplementary information to the Fraser-Cheam approach. As critiqued in Volume I, the Fraser-Cheam approach takes no cognizance of the size of the group threatened, while Oosthuizen's chart does.

On the negative side, Oosthuizen's logic in constructing his chart is somewhat questionable and probability not based on any real data.

2.2 Proposed Risk Acceptability Criteria for Groups of People

Given the apparent lack of acceptability criteria, there is no choice but to develop a new set. The derivation can start with this concept: if, over a long period of time, society has comfortably lived with a particular risk, then the frequency of death data for that particular risk constitutes an acceptability criteria. Our task, then, becomes one of compiling data on the frequency of multiple deaths due to various natural and man-made hazards, and then gaining some sense of how acceptable these frequencies are to society generally.

Morgan (1991) has summarized multiple death frequency data for a number of hazards, and has in fact directed the careful reader on how to use the data:

> "Data on catastrophic events permits significant comparisons only when the sample size is known and taken into consideration ...."
>
> "Allowable probability levels for individual sites should be selected so that the cumulative effect of events at those sites would be compatible with the background model ..."

deaths is generated mathematically by applying the following formula to each point on the curve:

F_i = $f_i - f_{i+1}$, where
F = frequency for N deaths
f = frequency for N or more deaths.

Applying this procedure to the cumulative probabilities of landslide accidents from the Alps produces the lower line in Figure XIII-10, which is designated as the lower limit of "moderate" risk.

3. The Japanese landslide frequency data is about an order of magnitude higher than the European Alps data and there may be somewhat fewer large landslide sites in Japan than in the Alps. The corresponding single site frequency curve was placed about 1 $^1/_2$ orders of magnitude above the previously derived line in Figure XIII-10, and it is taken to represent the boundary between moderate risk and high risk at this level, (i.e., extending down from an annualized probability of 0.001 for 1 person, and with the same slope as the lower boundary).

   Important Note: We offer the above acceptability criteria as a logically derived quantitative guideline. However, the final decisions concerning acceptability must be made by those who are subject to the hazards, i.e., the population and their governments, based on a synthesis of the information presented here as well as their own preferences and experience.

   The above discussion is based entirely on the considerations of life-threatening risks. Risks to property or environment can be assessed in detail by cost-benefit analysis in course of specific design of developments or remedial works.

3.0 RISK ZONATION

3.1 Terminology

The fan is divided into 4 zones, representing areas of approximately constant severity (for a discussion of "severity", see below) from debris flow. These are labelled 1 through 4 from the top to the end of the fan, in order of decreasing severity.

When a debris flow occurs, it will cover a certain area of the fan. The larger the debris flow magnitude, the larger the area covered. The area covered by a debris flow in each zone of the fan, divided by the zone length, is referred to as the "corridor width". The corridor width will vary from zone to zone, and for each magnitude of debris flow.

3.2 PDI

Probability of death of a specific individual (annual) is calculated as follows:

PDI = P(H)*P(S:H)*p(T:S)*P(L:T), where

P(H) = Probability of the hazard occuring. For the sake of discussion in this analysis, the possible debris flows have been divided into a number of ranges, as shown in Table XIII-6.

Table XIII-6 - Hazard Probability

Debris Flow (Mm^3)	Magnitude	P(H)
A	3 - 7	1/2450 to 1/10,000
B	1 - 3	1/930 to 1/2450
C	.1 - 1	1/52 to 1/930
D	<.1	>1/52

P(S:H)= Probability of spatial impact, i.e. of a house being in the path of the debris flow, given that the debris flow occurs. Generally speaking, for PDI this equals corridor width/Zone width.

This value also depends upon the depth of flow (i.e., it can be diverted by structures such as small berms or roads in the outer zones of the fan) and the existence of mitigation works. If mitigation factor M were to be introduced, then this value would equal the corridor width/Zone width * M

P(T:S)= Probability of temporal impact, i.e. of a house being occupied, given that the debris flow occurs and that the house is in its path. The value calculated for, or assigned to, this probability depends upon the type of development, work and recreation habits of the community, seasonality of usage, etc. In general, the question might be asked, "What is the average % of time that an individual spends in his home?"

The value assigned to P(T:S) also depends upon what type of warning systems are in place. If without any warning system the value of P(T:S) is P#, then with a warning system, the value would be P#*W, where W, the "Warning Factor", represents the effectiveness of the warning system. An ineffective warning system is assigned a value of 1; as the warning system becomes more effective, W decreases towards (but never reaches) zero.

Also related to the effectiveness of the warning system is the time of day, as W might be higher during the night, when people are normally sleeping, than during the day.

P(L:T)= Probability that there would be a loss, (i.e. that an individual would die), given the occurrence of all previous events on the event path. The value of this probability depends mostly on the nature of the debris flow, (specifically, its depth and velocity), and in some individual cases might also be affected by other unusual and unquantifiable factors.

3.3 PDG

PDG_X is calculated in a similar manner to PDI:

P(H) has the same value for a certain debris flow, (i.e. A, B, or C).

P(S:H), P(T:S), and P(L:T) are calculated for the groups under consideration, and not for an individual.

Severity is defined as P(S:H)*P(T:S)*P(L:T), so that

PDI or PDG_X = P(H)*Severity

3.2 Development Zoning Based Upon Hazard

One of the approaches suggested by Cave (1991) is to zone on the basis of P(H) only, using development approval regulations similar to those proposed in Cave (1991). There are two figures from this reference which might apply to the Cheekye situation, i.e. those labelled "Debris Flow/Debris Torrent" and "Debris Flood" (Table 8.4 of the Main Report). There is a significant difference between these two types of phenomena, with debris floods being the less severe. Mountain stream erosion or avulsion is dealt with separately.

Based on these criteria, it is evident that zoning for a new community would not be allowed unless P(H) for a debris flow was less than 1:10,000. If this table were applied to the Cheekye fan, no new development would be allowed, and existing development in Zone 4 of the fan would be severely restricted.

From Cave's paper, zoning for a new community would be allowed without restrictions if P(H) for a debris flood was less than 1:500, but not allowed at all if it was greater than 1:500.

Thus it is of interest to discuss in what situations these two figures should apply. Cave's distinction is between debris flows/torrents, and debris floods. In a more general sense, it is likely that we are looking for a distinction that markedly changes the value of P(L:T). It is suggested here to draw the line between debris flows with velocities greater than 3 m/sec, and those with velocities less than 3 m/sec. Morgan, Rawlings and Sobkowicz (1992) also use this velocity as the demarcation between slow and rapid debris flows and they assign the same severity to slow moving debris flows as to debris floods. Hence it might not be unreasonable in this preliminary stage to apply Cave's Figure 5 criteria for debris flow to areas of the fan where the predicted debris flow has a velocity > 3 m/sec, and his criteria for debris flood to those areas where the predicted debris flow has a velocity <3 m/sec

Table XIII-7 - Debris Flow Velocities by Group

	Debris Flow Magnitude		
	A	B	C
Zone on Fan	P(H) = 1/2450 to 1/10,000	P(H) = 1/930 to 1/2450	P(H) = 1/52 to 1/930
1	7 m/sec	4	3
2	4	3	2
3	3	2	1
4	2	1	1

The table indicates that Zone 4 is the only location where predicted debris flow velocities are consistently below 3 m/sec, and hence the only area that is a candidate for development without mitigation.

3.5 <u>Development Zoning Based Upon PDI</u>

Morgan, Rawlings and Sobkowicz (1992) discuss the methodology for zoning a debris fan for PDI. The present zoning plan is similar.

PDI was calculated for each of the current fan zones and for debris flows of magnitudes A through C as shown on Table I. This table uses:

- the corridor widths from Table 7.1 of the Main Report;
- an estimate of the total zone width;
- P(H) values calculated for each magnitude range from Figure 7.22 of the Main Report;
- P(S:H) values calculated as "corridor width/zone width" (no mitigation, and no redirection of flow in zone 4, where the flow depth is small);
- P(T:S) values assuming continuous occupation (very conservative) and using warning factors discussed in the report text; and
- Estimated P(L:T) values, based upon flow depth and velocity values.

Using these numbers and an acceptability limit for PDI of <1/10,000, both Zones 3 and 4 should be open to development.

3.6 Development Zoning Based upon PDG_X

This approach to assessment of risk has much potential interest as it has the possibility of defining not only the zones to be developed but also the allowable population density.

The method is based on the following assumptions:

- A uniform population distribution in each zone. If some area of the zone is not developed to this maximum density level, then the estimated risks are of course conservative.
- How the land in each zone might be used (as shown in Table XIII-9).

Table XIII-9 - Assumptions regarding Land Use and Population Density Ratios

Zone	Development and Land Use	Population Density
1	No development; no land use	0
2	No residences or work places; temporary recreational use only	$D_2 = 0.1 * D_3$
3	Light commercial/industrial use; no concentrated populations; no residences	$D_3 = 0.5 * D_4$
4	No restrictions on development, except on concentrated populations, such as schools, hospitals.	D_4

The procedure for calculating the PDG (Probability of Death of a Group of Individuals) value was as follows:

1. Assume a group size X.

2. Divide the range of debris flow magnitudes as shown in Figure 7.22 into ten classes (the original division into three classes was deemed too coarse).

3. Calculate the incremental probability of occurrence in each class.

4. Estimate the average corridor width, temporal factor P(T:S) and loss probability P(L:T) for each zone and each debris flow class.

5. Calculate the size of the average ("optimal") group of persons impacted by the average event from each class, by multiplying the appropriate population densities, corridor widths and lengths and temporal and loss factors (see Table I).

6. Determine the incremental impact probability of the particular group size under consideration (X) being impacted by the debris flow from the given class, assuming a probability distribution of group sizes centered around the optimal group size. The probability distribution was taken approximately as a bell-shaped curve with the 80% confidence limits being 50% wide. Its amplitude was chosen so that the area under the curve equals unity.

7. Calculate the PDG value for the selected group (x) by summing the impact probability from all ten debris flow classes, multiplied by their appropriate incremental impact probabilities.

8. Repeat the procedure for a number of group sizes, to produce successive points on the group size - probability diagram, to be compared with the acceptability criteria.

The above procedure is complex and has been implemented only as an example calculation, using an assumed population density of 1500 per square km in Zone 4. The results are indicated in Figure XIII-10 both for "no mitigation" and for "with mitigation by dyking" designed to reduce the hazard probability of events smaller than $2Mm^3$ by a factor of 100. The "peak" in the probability estimates results from the predicted concentration of the debris flow hazards into a relatively narrow impact zone in the populated Zone 4, irrespective of event size.

The method of calculation is considered to have most application when applied to actual development plans, where it could account for spatial distribution factors.

TABLE XII E-1

RESERVOIR AREA-DEPTH FUNCTION

Depth (Landslide Height) (m)	Reservoir Area	
	Hectares (ha)	Acres (acres)
150	20	49
100	5	12
50	1	2.5

TABLE XII E-2

"BREACH" INPUT VARIABLES - LANDSLIDE DAM CHARACTERISTICS

Parameter	Value
Slope of upstream face	3.3
Slope of downstream face	4.1
D_{50}	0.4 mm
Porosity ratio	0.30
Unit weight	18.5 kN/m^3
Internal friction angle	38°
Cohesive strength of outer material	0
Ratio of D_{90} to D_{30}	50

TABLE XII E-3

"DAMBRK" INPUT VARIABLES - MUDFLOW CHARACTERISTICS

Material Property	Value
Unit weight	20 kN/m^3
Dynamic viscosity	1 kPa-s
Yield stress	2 to 14 kPa
Exponent in power function which represents the stress-rate of strain relation (if Bingham plastic is assumed for fluid, then exponent set to 1.0)	1.0

TABLE XII E-4

"BREACH" OUTFLOW CHARACTERISTICS AND VOLUMES

Landslide Height (m)	Reservoir Volume (m^3)	Peak Outflow (m^3/S)	Time to Peak (hrs)	Total Outflow (Mm^3)	Total Sediment (Mm^3)
135	4.27 (10^6)	925	0.60	2.61	1.16
135	8.00 (10^6)	1,758	0.73	5.60	1.80
155	8.00 (10^6)	1,824	0.70	5.30	2.10

TABLE XII E-5

SITE A - RESERVOIR FILLING TIMES

Top Elevation of Landslide (m)	Hieght of Landslide (m)	Reservoir Volume (m^3)	Total Required Precipitation[1] (mm)	Filling Time PMP[2]	Filling Time Mean Rainfall at Squamish[3]
775 775 795	135 135 155	4.27E + 06 0E + 06 8.00E + 0.6	0.388 m 0.727 m 0.727 m	1.0 day 3.0 days 3.0 days	1.1 months 2.2 months 2.2 months

Note:

1) Calculated as the reservoir volume divided by the drainage area (~ 11.0 km^2), assuming a runoff coefficient of 1.0.

2) Based upon reported probable maximum precipitation (PMP) estimated for Cheakamus River watershed.

3) Based upon the maximum mean monthly precipitation at Squamish for the months of October to January.

TABLE XII E-6

MAXIMUM ELEVATION REACHED BY MUDFLOW

Sensitivity to Initial Yield Stress
Landslide Height = 135 m
Reservoir Volume = 4.27 Mm^3

X-Section	Distance from Landslide (km)	Thalweg Elevation (m)	Mudflow Elevation (m) Initial Yield Stress (kPa)			
			2	5	10	14
XS-1	1.75	480	485	486	490	495
XS-2	2.25	420	428	431	444	455
XS-3	2.70	400	405	406	416	425
XS-4	3.15	360	366	368	383	394
XS-5	3.60	330	336	340	357	363
XS-6	4.10	295	302	306	316	326
XS-7	4.60	260	266	270	280	292
XS-8	5.10	230	237	241	253	263
XS-9	5.46	210	217	221	231	241
XS-10	5.70	195	202	206	216	226
XS-11	6.41	165	169	172	178	188
XS-12	6.89	130	136	139	146	160

TABLE XII E-7

MAXIMUM DEPTH OF MUDFLOW

Sensitivity to Initial Yield Stress
Landslide Height = 135 m
Reservoir Volume = 4.27 Mm^3

X-Section	Distance from Landslide (km)	Thalweg Elevation (m)	Mudflow Elevation (m) Initial Yield Stress (kPa)			
			2	5	10	14
XS-1	1.75	480	5	6	10	15
XS-2	2.25	420	8	11	24	35
XS-3	2.70	400	5	6	16	25
XS-4	3.15	360	6	8	23	34
XS-5	3.60	330	6	10	27	33
XS-6	4.10	295	7	11	21	31
XS-7	4.60	260	6	10	20	32
XS-8	5.10	230	7	11	23	33
XS-9	5.46	210	7	11	21	31
XS-10	5.70	195	7	11	21	31
XS-11	6.41	165	4	7	13	23
XS-12	6.89	130	6	10	16	30

TABLE XII E-8
MAXIMUM ELEVATION REACHED BY MUDFLOW AND WATER

Initial Yield Stress = 10 kPa (mudflow only)
Landslide Height = 135 m
Reservoir Volume = 8.00 Mm^3

X-Section	Distance from Landslide (km)	Thalweg Elevation (m)	Mudflow Elevation (m)	
			Mudflow	Water
XS-1	1.75	480	490	483
XS-2	2.25	420	445	424
XS-3	2.70	400	416	403
XS-4	3.15	360	383	363
XS-5	3.60	330	357	334
XS-6	4.10	295	316	297
XS-7	4.60	260	280	263
XS-8	5.10	230	253	233
XS-9	5.46	210	231	213
XS-10	5.70	195	216	199
XS-11	6.41	165	179	166
XS-12	6.89	130	147	134

TABLE XII E-9
MAXIMUM DEPTH OF MUDFLOW AND WATER

Initial Yield Stress = 10 kPa (mudflow only)
Landslide Height = 135 m
Reservoir Volume = 8.00 Mm^3

X-Section	Distance from Landslide (km)	Thalweg Elevation (m)	Mudflow Elevation (m)	
			Mudflow	Water
XS-1	1.75	480	10	3
XS-2	2.25	420	25	4
XS-3	2.70	400	16	3
XS-4	3.15	360	23	3
XS-5	3.60	330	27	4
XS-6	4.10	295	21	2
XS-7	4.60	260	20	3
XS-8	5.10	230	23	3
XS-9	5.46	210	21	3
XS-10	5.70	195	21	4
XS-11	6.41	165	14	1
XS-12	6.89	130	17	4

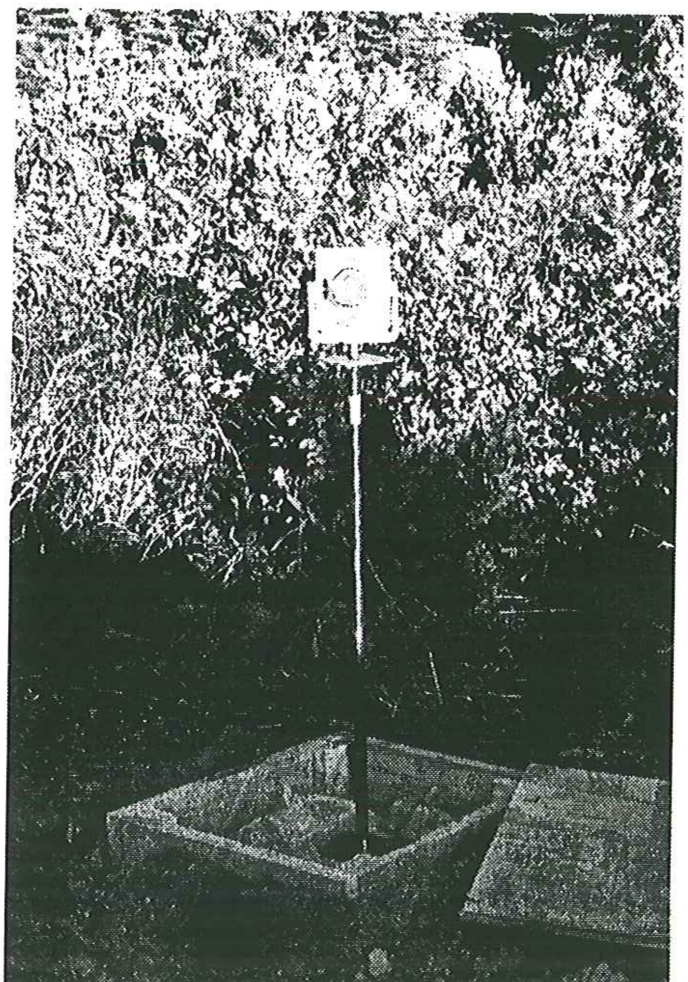
TABLE XII E-10
MAXIMUM ELEVATION REACHED BY MUDFLOW AND WATER
Initial Yield Stress = 5 kPa (mudflow only)
Landslide Height = 155 m
Reservoir Volume = 8.00 Mm^3

X-Section	Distance from Landslide (km)	Thalweg Elevation (m)	Mudflow Elevation (m)	
			Mudflow	Water
XS-1	1.75	480	490	483
XS-2	2.25	420	433	424
XS-3	2.70	400	407	404
XS-4	3.15	360	369	363
XS-5	3.60	330	341	334
XS-6	4.10	295	307	297
XS-7	4.60	260	270	263
XS-8	5.10	230	241	233
XS-9	5.46	210	221	213
XS-10	5.70	195	206	199
XS-11	6.41	165	172	166
XS-12	6.89	130	140	134

TABLE XII E-11
MAXIMUM DEPTH OF MUDFLOW AND WATER
Initial Yield Stress = 5 kPa (mudflow only)
Landslide Height = 135 m
Reservoir Volume = 4.27 Mm^3

X-Section	Distance from Landslide (km)	Thalweg Elevation (m)	Mudflow Elevation (m)	
			Mudflow	Water
XS-1	1.75	480	10	3
XS-2	2.25	420	13	4
XS-3	2.70	400	7	4
XS-4	3.15	360	9	3
XS-5	3.60	330	11	4
XS-6	4.10	295	12	2
XS-7	4.60	260	10	3
XS-8	5.10	230	11	3
XS-9	5.46	210	11	3
XS-10	5.70	195	11	4
XS-11	6.41	165	7	1
XS-12	6.89	130	10	4

Typical Prism
Foundation Setup



Typical Prism Setup

Monitoring Station Setup

Instrument Setup