GeoPacific Consultants Ltd.

#215 – 1200 West 73rd Avenue, Vancouver, BC, V6P 6G5
Phone (604) 439-0922 / Fax (604) 439-9189

District of Squamish
37955 Second Avenue
P.O. Box 310
V8B 0A3

May 5, 2015
File: 12942

Attention: Mr. Rod MacLeod, Director of Engineering

Re: Preliminary Geotechnical Review, Angels Crest Rock Fall, Stawamus Chief, Squamish, BC

1.0 Introduction

A rock fall, referred herein as the Angels Crest Rock Fall, with an estimated volume of 1,200 to 1,600 cubic meters occurred at about 11:50 AM on Sunday April 19, 2015 from the North Walls of the Stawamus Chief (The Chief).

GeoPacific Consultants Ltd. (GeoPacific) was asked to carry out an initial site reconnaissance of the rock fall by the District of Squamish. The purpose of the initial review was to determine whether there were any other immediate rock fall threats and to provide an opinion on whether it was safe for Squamish Search and Rescue (SSAR) to initiate ground based activities near the impact zone.

GeoPacific carried out an initial reconnaissance with SSAR by helicopter. The initial review was carried out about 45 min after the rock fall had occurred. Following our review, it was determined that there may have been potential for additional rocks to fall and we advised against a ground based search effort within the impact deposition zone. As a precaution, it was recommended to close the Mamquam Forest Service Road (FSR) to all but essential vehicles until further evaluation could be carried out.

Prior to making any further decisions with respect to public safety, it was recommended that additional experts be brought in so that collaborative decisions could be made. GeoPacific engaged Duncan Wyllie, Ph.D, P.Eng., of Wyllie & Norrish Rock Engineers Ltd. and Paul Schlotfeldt, Ph.D., P.Eng., of Golder Associates Ltd. to work with us on this assignment. Additional reconnaissance by helicopter was carried out at about 4 pm with Dr. Wyllie and Dr. Schlotfeldt followed by ground reconnaissance to the downslope edge of the impact zone.

This report presents our observations, a general discussion on the findings and the potential for future instability, and makes recommendations for further consideration. This report does not include, and we have not been engaged to carry out, a comprehensive probability based risk assessment for the area for future users.

2.0 Site Description

The Chief is a granodiorite pluton, a coarse intrusive igneous rock, which has been exposed, through environmental erosion and glacial processes over tens of millions of years. In general the rock is very strong and contains moderately to widely spaced joints in the range of 0.4 to 4.0 m in places and with much wider spacing in other places of the rock mass. One of the principal joint sets is near vertical and is orientated approximately parallel to the existing rock face, and this is particularly evident near the recent rockfall source area near the top of the north wall and is likely as a result of stress relief as a result of de-

glaciation and parallel retreat of the rock face over time. A sub-horizontal set and near vertical set that runs perpendicular to the rock face is also present in the vicinity of the rock fall source area.

The Angels Crest rock fall occurred along the north side of The Chief in an area referred to as the North Walls. In this area The Chief rises to about 630 m elevation. We estimate that the rock fall source area is at about elevation 550 m.

At the location of the rock fall The Chief rises almost vertically as can be seen on the Section included in Appendix A. There is an apron about 30 m high, which projects about 10 m outward from the base of the wall, on to which it appears that much of the falling rock impacted prior to breaking up and bouncing and rolling, and destroying the existing forest cover and being distributed over the existing talus.

The talus slope along the North Walls has a relatively uniform grade along the upper portion of the talus and becomes shallower and concave with offset distance from the cliff face. Based on our field observations, and Lidar data made available to us from the District of Squamish, we estimate that the upper talus slope has an angle of about 34 degrees.

The talus is comprised of angular rock fragments generally up to 1 m in diameter with much larger blocks located in places near the Forest Service Road, however, larger random boulders up to about 3 m in diameter were also noted higher up the slope. Except of the impact zone, the area is overgrown with mature coniferous trees estimated to be 60 to 80 years in age, although, some much older trees were observed. The existing talus is covered with moss and tree litter.

3.0 Field Observations

3.1 Source Area

At the source area there was a major near vertical back release plane (natural joint or fracture) that trends approximately parallel with North Wall that now forms the back scarp of the failure. Review of photographs taken before the rock fall shows that the failed block (Block A) contained, and was flanked on either side by side release joints dipping about 75 degrees to the northeast (near perpendicular to the rock face) and that there was a major joint that dips about 10 degrees to the northeast at the base of the block (ref. Figure 1). We estimate that the failed block protruded beyond the rock face below resulting in an overhang of about 1-2 m. The failed block also had a series of stepped overhanging rock with another 2 m overhang at about the midpoint on the failed block. We estimate rough dimensions of the failed block at 20 m wide by 15 – 20 m high and with an average depth of 4 -5 m; the estimated rock volume is between 1,200 and 1,600 cubic metres.

Review of photographs taken prior to the rock fall show that the failed block had a flat top that was vegetated by numerous mature trees estimated to be up to 10 m in height. It is likely that much of the root system of these trees had grown into the back release joint behind the failed block. Organic staining, soil, and root fragments are visible along the back scarp of the failure and within the remaining joints (ref. Figure 2).

The rock which formed the ledge (or pedestal) on which the overhanging failed block was supported (Block B) was more fractured and weathered. The top of the pedestal rock that supported the failed block rock appears to have been crushed along the outer margin and may have failed in in tension towards the

back (ref. Figure 3).

Below the rock ledge a wedge- like sliver of rock (Block C) with a vertical extent of close to 20 m failed in a steep open book or dihedral-like pattern (ref. Figure 4). It is not known if this failed prior to or as a result of the main rock fall.

There was a significant impact to the "tooth" feature directly below the rock fall source area (Block D). The impact appears to have caused a new crack to open and intersect an existing near vertical fracture on the backside of Block D. This potential release fracture appears to have opened up somewhat compared to before the impact (ref. Figures 4 and 5).

3.2 Deposition Zone

It is estimated that the failed block free fell about 310 m before impacting the ramp-like or apron feature at the base of wall and scattering across the talus slope. Prior to the rock fall this area was treed. We expect that upon impact the rock was broken up into smaller blocks and fragments and that these were projected laterally from the apron destroying the nearby forest before being deposited over the talus slope. The apron was completed stripped of trees and loose rock (ref. Figure 6).

The rock fall debris was distributed over an area up to about 100 m wide and 150 m downslope along the talus slope. A site reconnaissance to the downslope margin of the debris field identified very large angular rock fragments up to 3 m in diameter. The mature trees, and rough and irregular talus slope, were helpful in limiting the downslope mobility of the rock fall debris.

4.0 Anecdotal Accounts

We understand from the climbing community that in the week which proceeded the main failure there was an unusually high number of smaller rock falls in this area of the North Walls. Reports indicate that on Saturday April 18, 2015, small rocks could be heard falling throughout the day. Climber reports from the morning of April 19th note that several large falling rocks were observed. We have reports that significant rock falls occurred about 30 to 40 minutes and 15 to 20 minutes before the main rock fall.

We have spoken to, or heard second hand accounts from, several witnesses to the actual falling rock. Eyewitness accounts describe a succinct and very loud "snap" as the failed block broke loose from the cliff face which caused them to direct their attention to the area. Following the loud noise the failed block fell from the cliff face as intact piece with trees attached.

5.0 Discussion

5.1 General

We have limited our review to the portion of The Chief where the rock fall occurred on April 19, 2015 and the immediately surrounding rock.

Based on anecdotal evidence from the climbing community and residents of Valleycliff, we understand that this area is prone to regular small rock falls. A substantial talus slope is located along the base the North Walls and there are some very large boulders strewn along the valley floor within the rock fall run

out zone. It is believed that the magnitude of the April 19, 2015 rock fall was greater than any rock fall which has occurred in this area in at least the last 60 years. This belief is supported by the mature growth forest which extends to the base of The Chief along the North Walls area.

5.2 Failure Mechanism

It appears as that the rock fall occurred as a result of root jacking behind the failed block (Block A) which in turn crushed the supporting weathered and fractured pedestal of rock (Block B) below Block A. Block A was completely detached on the backside and was likely on the brink of failure for some time as the roots jacked it outwards. This coupled with the completely detached geometry of Block A and overhanging nature of the front face would have caused the centre of gravity of the block to shift outward. This, in turn, would have induced additional downward pressure on the supporting rock pedestal. The supporting rock was highly jointed and slightly weathered and noted by climbers as being "loose". The outward rotation would have overstressed the supporting rock mass and it eventually yielded to the imposed stress or pressure from Block A causing it to ultimately fail; resulting in possible small precursor rock falls. As this support was gradually lost, additional force would have been distributed to the limited area where Block A was affixed to the greater rock mass where it ultimately would have failed in compression and sheared off; this can be seen as the clean break in photographs (ref. Figure 3).

5.3 Potential for Future Rock Fall

Much of the rock surrounding the failure zone has not been fully exposed to environmental weathering processes until now. Therefore, this could be one of the most active areas for environmental weathering processes on The Chief including freeze / thaw effects, water pressure development within cracks, and/or thermal expansion, to occur. Some small rock falls due to weathering processes should be expected.

The release of such a large block will change the stress regime within the rock in the immediate area. We expect that most of these stress changes have now occurred. How the surrounding rock will respond under varying environmental conditions is not yet known.

As noted above, there was an impact to the "tooth" feature (Block D) located beneath the rock fall source area and a new crack appears to have opened. The fact that this feature took a direct hit during the rock fall and did not dislodge indicates some level of stability. However, further evaluation of this feature in the field should be considered.

There is a block above and to the west of the source area (Block E) which may have been affected by the loss of Block A (ref. Figure 7). It appears as though Block A did not provide much support to this adjacent block, however, there was likely some contact between these blocks. The exposed back release joint behind Block A extends behind Block E. As well there are established trees on top of Block E. It was not possible to view the joint from the top of Block E from the helicopter because of the trees. Further evaluation of this feature in the field should be considered.

6.0 Conclusions

The April 19, 2015, Angels Crest rock fall is attributed to natural physical weathering processes. Based on our observations and anecdotal accounts, we estimate that events of similar magnitude have a return period in the range of 50 to 150 years along the North Walls area of The Chief.

The existing Mamquam FSR is located within the "rock fall shadow" (where a line drawn from the apex of the talus slope at an angle of 27 degrees below the horizontal intersects the ground surface beyond the toe of the talus) below the North Walls of The Chief. We have not been asked to carry out a detailed risk assessment, but it is our considered opinion that the source area is largely cleared itself out and the risk of future large rock falls from the same area is likely less than it was before this event.

Based on our observations of the source area, there are no indications that a rock fall of greater magnitude is imminent. On this basis, we conclude that the hazard posed to persons using the Mamquam FSR is no greater now than before the Angels Crest rock fall.

Residual fragments and blocks of broken rock are still present below and adjacent to the area of the failed block and these pose a hazard at the base of the cliff. This would likely manifest itself as small scale rock falls. Therefore, the hazard posed to persons at the base of the Angels Crest climb, on the Alaska Highway climb, or who are traversing the new debris is still present, albeit with smaller fragments of rock.

The hazard posed by small scale rock falls could be mitigated by carrying out rock scaling (removal of loose rock by hand and by using basic tools such as pry-bars and picks). We expect that scaling could be carried out by rappelling down to the source area from the top of the North Walls.

While initial observations did not confirm any significant hazards concerns, further review of the so called "tooth" feature, Block D, and of Block E above and to the west of the source area is recommended to determine if the rock fall hazard posed by these features has increased.

7.0 Recommendations

1. We recommend that the Mamquam FSR remains open to normal vehicle use. Consideration should be given to signage noting that vehicles are passing through a rock fall hazard area and that no stopping or parking be allowed.

2. The Angels Crest access trail should be closed until the hazard from the source area above the base of the Angels Crest climb and along the Alaska Highway climb is determined to be acceptable, or measures acceptable to stakeholders have been implemented.

3. Scaling of the source area should be considered to dislodge any remnant smaller loose fragments, blocks, debris and poor quality rock under controlled conditions.

4. A geotechnical assessment of the source area by a rock mechanics expert to determine the extent of the damage to the impacted rock on the "tooth" feature (Block D) and to determine the overall stability of the larger block up and west of the failure area (Block E) should be considered. We expect that this could be carried out by rappelling down to the source area by rope from the top of the North Wall.

We trust the foregoing is sufficient at this time. We are pleased to be of assistance to you on this project. If you have any questions or require further information please contact the undersigned.

For:
GeoPacific Consultants Ltd.

ORIGINAL SIGNED

Steven Fofonoff, M.Eng., P.Eng.
Senior Geotechnical Engineer

Reviewed by:

ORIGINAL SIGNED

Paul Schlotfeldt, Ph.D, P.Eng.
Principal, Golder Associates Ltd.

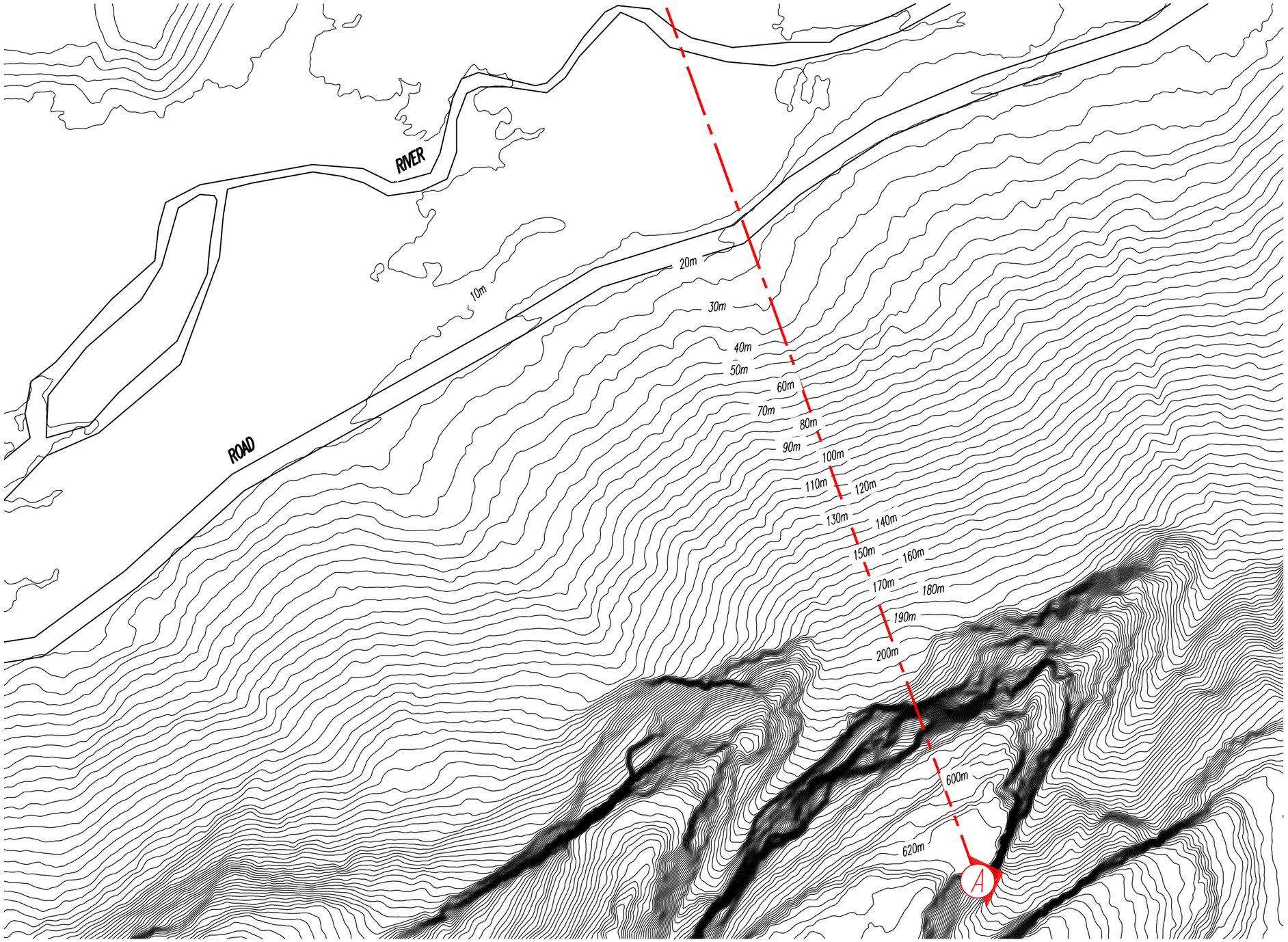
Reviewed by:

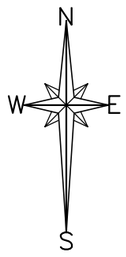
ORIGINAL SIGNED

Duncan Wyllie, Ph.D, P.Eng.
Principal, Wyllie & Norrish Rock Engineers Ltd.

APPENDIX A

SITE PLAN AND SECTION





LEGEND:

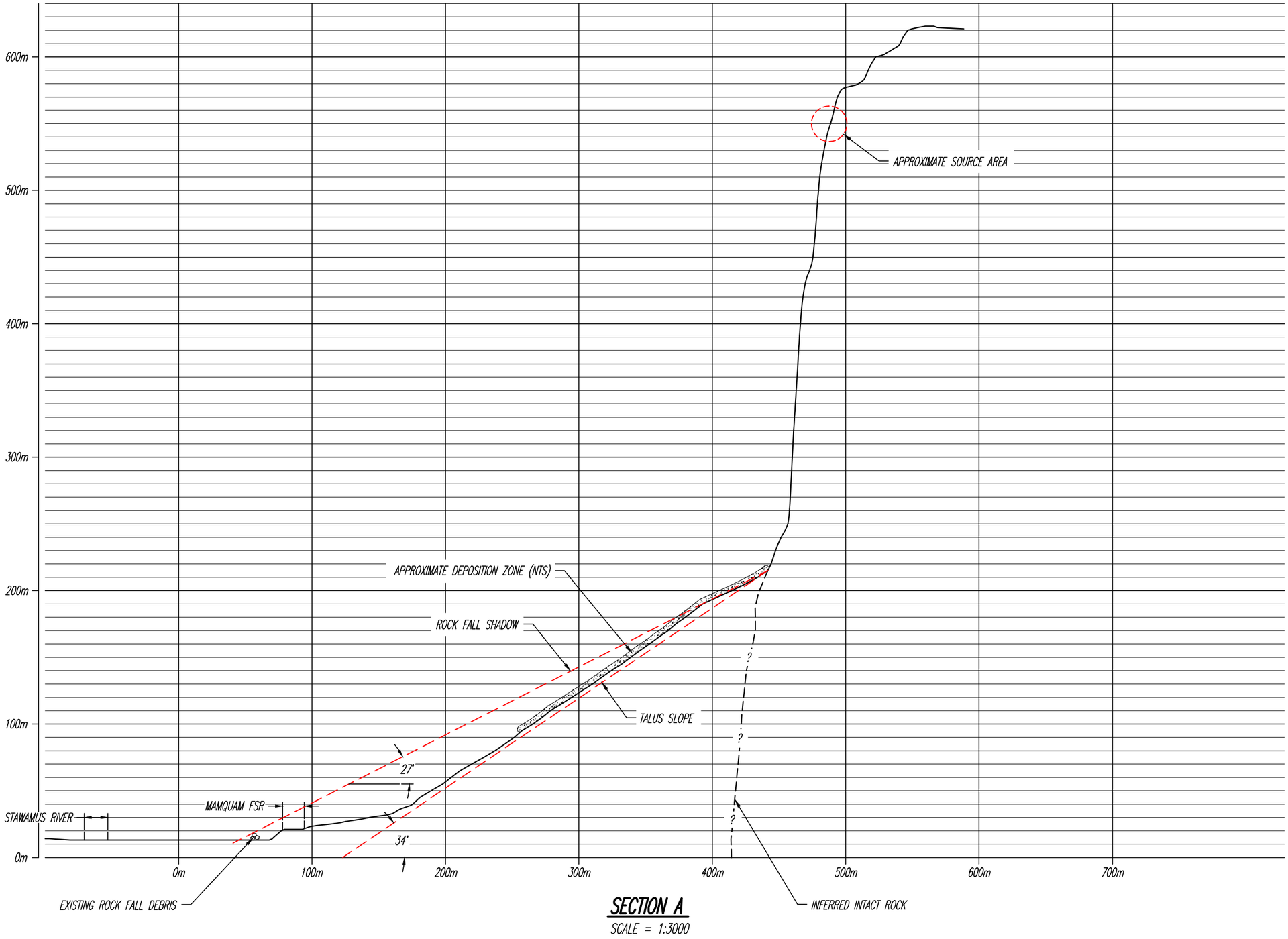
—— 160m —— - EXISTING CONTOUR LINE

SITE PLAN

SCALE = 1:3000

ORIGINAL PAPER SIZE 11"x17"

REFERENCE:	#215–1200 West 73–rd Ave. Vancouver, B.C. Canada V6P 6G5 Ph. (604) 439–0922 Fax (604) 439–9189 GeoPacific Consultants Ltd.	DATE: APRIL 22, 2015 DRAWN BY: H.S. / APPROVED BY: S.M.F. / REVIEWED BY: S.M.F. SCALE: AS SHOWN	ROCK FALL REVIEW ANGELS CREST ROCK FALL, STAWAMUS CHIEF, SQUAMISH, BC SITE PLAN	FILE NO.: 12942 DWG. NO.: G–P1	REVISIONS: A. B. C.



SECTION A

SCALE = 1:3000

ORIGINAL PAPER SIZE 11"x17"

REFERENCE:

#215–1200 West 73–rd Ave.
Vancouver, B.C.
Canada V6P 6G5
Ph. (604) 439–0922
Fax (604) 439–9189
GeoPacific Consultants Ltd.

DATE:	APRIL 22, 2015	
DRAWN BY: H.S.	APPROVED BY: S.M.F.	REVIEWED BY: S.M.F.
SCALE:	AS SHOWN	

ROCK FALL REVIEW

ANGELS CREST ROCK FALL, STAWAMUS CHIEF, SQUAMISH, BC
SECTION A

FILE NO.: 12942
DWG. NO.: G–SEC1

REVISIONS:
A.
B.
C.

APPENDIX B

FIGURES

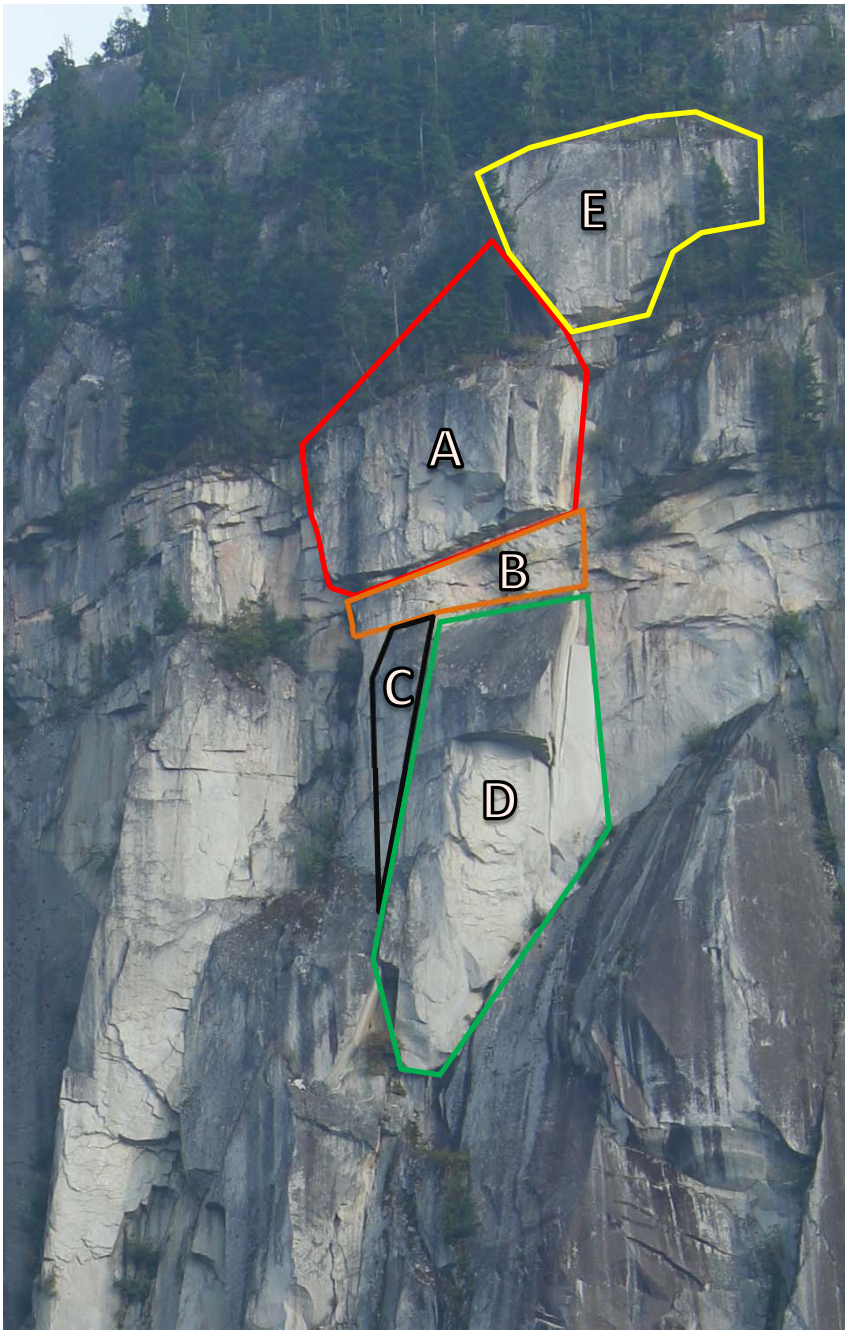


Figure 1 – Source area before the rock fall (photo Jim Hegen).

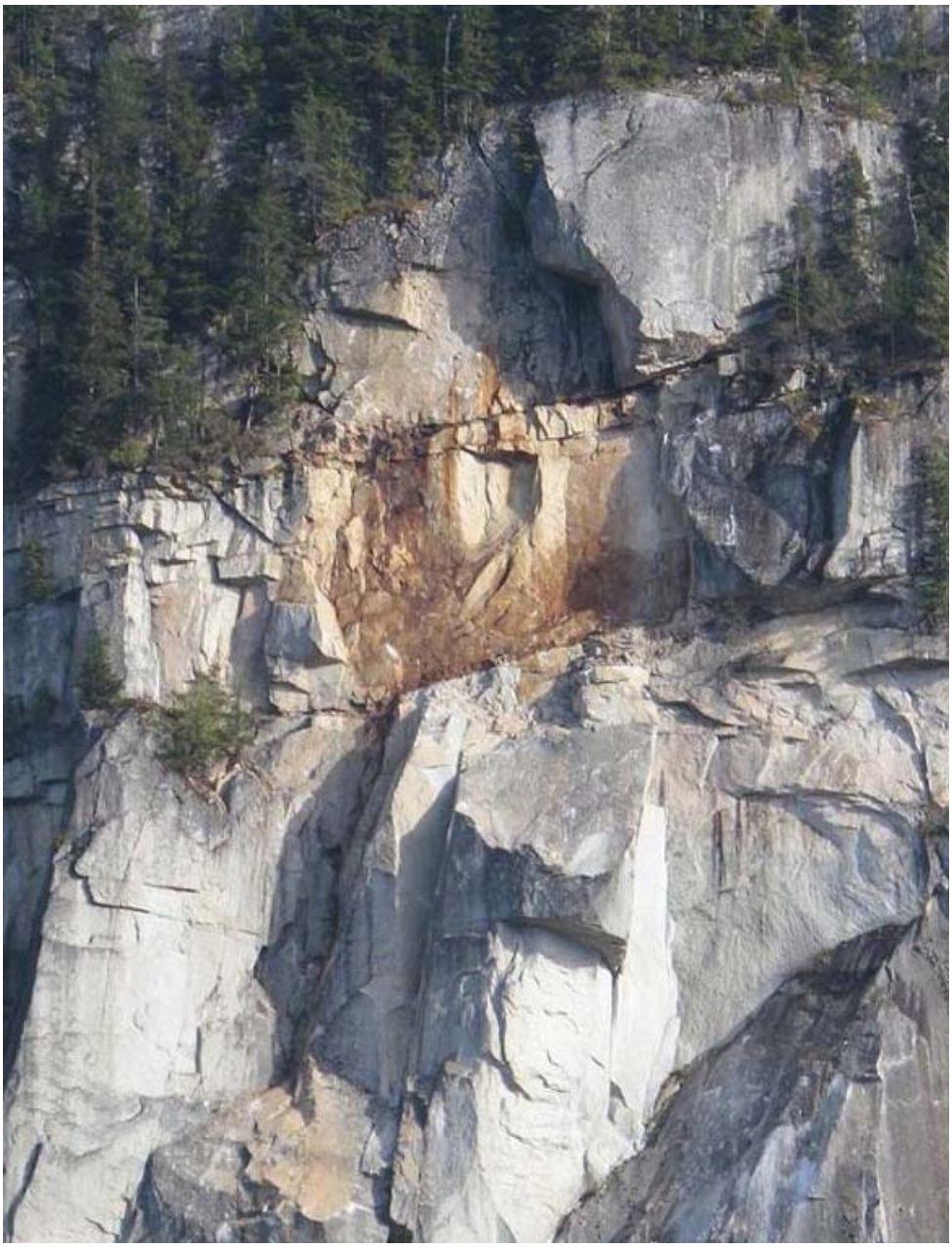


Figure 2 – After the rock fall, note staining along back release joint (photo Jim Hegan)

Figure 3 – Tightly spaced joints in area of Block B and where break occurred (at left)

Figure 4 – Steep wedge-like failure (Block C) below source area

Figure 5 – Impact location on Block D and open joints

Figure 6 – Impact zone on apron at base of slope and deposition on talus

Figure 7 – Existing overhanging block (Block E) above and west of the source area