Landslides at Rock Glacier Site,
Highwood Pass, Alberta

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Abstract:

Twenty topples are described from Rock Glacier Site, 2 km north of the summit of the Highwood Pass in the Front Ranges of the Rocky Mountains in Alberta. Insitu field testing and laboratory tests indicated that the external force driving the toppling process is frost action within a weathered shale zone. Surfaces of rupture develop when the amount of angular rotation of the toppling rock mass was over 16°. Slides along continuous surfaces of rupture are possible in rock masses with no cohesion and reduced friction angles.

Keywords: Topple, rupture surface, rock fall, rock slide, rock, Rockies

Introduction:

This paper furthers the study of topples on underdip cataclinal slopes. Rock Glacier Site, 2 km north of the Highwood Pass in Kananaskis Country, Alberta, (Figure 1) has suffered at least 20 block topples, numerous rock falls and one large complex rock topple - rock slide. Detailed mapping of the rock topples has widened the limits on suggested block ratios for block toppling and the amount of rotation necessary to create surfaces of rupture in displaced rock masses. For the first time frost action within a weathered shale is shown to drive toppling and progressively damage the displaced rock mass which can then slide.

The physical environment is first documented, then the modes of toppling identified; the driving processes of toppling, rupture surfaces, stability of the slope, and finally the sequence of movements are discussed. Symbols and descriptions used for the airphoto interpretation are from Cruden and Thomson (1987) and landslide nomenclature follows WP/WLI (1993).

Previous Research:

Early research on toppling was on anaclinal slopes (De Freitas and Watters 1973, Goodman and Bray 1976), where penetrative discontinuities dip into the slope (Cruden 1987). Topples in Highwood Pass are situated on slopes where bedding dips more steeply but in the same direction as the slope, slopes referred to as underdip cataclinal slopes (Cruden 1987). Cruden and Hu (1994) reported the characteristics of

16 topples in the Highwood Pass, and found that the mode of toppling was controlled by discontinuity spacing, bed thickness, and slope. To normalize the mean spacing, h, of discontinuities, the spacing was divided by the bedding thickness, b, of the toppling mass, giving the block ratio of De Freitas and Watters (1973). This ratio, h/b, was then used as a guide to predict the style of toppling to be expected on other underdip cataclinal slopes. Cruden and Hu (1994) examined three topples (T10, T11, and T12) on Rock Glacier Site.

Physical Environment:

Rock Glacier Site was estimated by McAffee (1995) to have a mean annual temperature of -0.8°C and precipitation at 662.1 mm from data extrapolated from other sites in Kananaskis Country (Environment Canada 1993). Most of the precipitation falls as snow. Access to the area is restricted between December 1 and June 15.

A detailed airphoto interpretation (Figure 2) of the site provided information on areas of toppling, zones of accumulation, and an overview of the entire slope. Loose and incoherent deposits, colluvium or talus, were abundant over most of the slope. Alluvial fans could be seen at the base of the gullies on either side of the slope. These alluvial fans are possibly a result of snow avalanches, slush avalanches, or debris flows as well as the spring runoff being channelled through the narrow gullies. At the toe of the slope there is a large mass of colluvium. The volume of this colluvium was estimated at approximately two million cubic metres. In places, the colluvium was estimated to be as thick as 55 m and inclined at angles up to 40°. With no evidence of permanent interstitial ice within the colluvial mass, the slope cannot be accurately called a "rock glacier", as this site has been named. There is also no evidence of longitudinal and concentric transverse ridges or collapse pits which are typically associated with rock glaciers (Jackson 1987). It is likely that the downward motion of the rock mass can be explained as simply a result of gravity. However, ice and snow assist the downward movement of the colluvium during the winter months.

Transverse faults, normal faults, thrust faults, and anticlinal and synclinal folds create the complex geological environment (McMechan 1989). In the area of Highwood Pass, several north-west south-east trending thrust faults exist, including the Lewis Thrust Fault (McMechan 1989). The topples located on Rock Glacier Site are in the Rundle Thrust Sheet (Bielenstein et al. 1971). Transverse faults, perpendicular to the thrust faults also complicate the structural geology in Highwood Pass. In fact, there are transverse faults located in gullies in the proximity of Rock Glacier Site (McMechan 1989).

Three different rocks, a fine grained sandstone, shale, and a quartzite comprise the lithologies at the site. In the slope, shales from the Fernie Formation overlie massive sandstones, sandstones with interbedded shales, shales with interbedded sandstones, an intact shale, and finally a weathered shale, all from the Spray River Group. At the top of the slope are quartzites from the Rocky Mountain Group. The toppling movements at the site are all within the Triassic sandstones and shales of the Spray River Group. A stratigraphic profile of the area is given by Cruden and Hu (1994: Figure 5).

The weathered shale, approximately 40 m thick, is located between the thick-bedded quartzites and the toppling rock masses. Figure 3 illustrates the weathered shale zone as seen in profile. Using the system proposed by Price (1993), a rock mass weathering rating of -10 was determined for the weathered shale zone. A rating of -10 corresponds to a Class D2 material, a geotechnical soil with relict discontinuities. Price (1993) correlated his classification with the British Code of Practice for Site Investigation (BS 5930: 1981). The material is completely weathered with original structure and texture largely intact (Price 1993). Because all topples were down slope of the weathered shale, the expansion of the shale may have been the driving force for the toppling at Rock Glacier Site.

The rock mass at Rock Glacier Site was found to be closely jointed (ISRM 1978). Contouring the joint orientations for the site indicates the presence of three joint sets, two sets of kathetal joints and one set of strike joints (Figure 4).

The quartzites represent the untoppled orientation of bedding at Rock Glacier Site. The quartzites had an average orientation of 79°~238° (dip and dip direction). The orientation of all other bedding at the site indicates the amount of rotation about strike and dip of the toppling rock masses. The beds which have toppled have rotated their strikes an average of 13° and rotated their dips an average of 66°. Some topples rotated about strike only one or two degrees while some were measured as having rotated 24°. The rotation of dip varied from only one or two degrees to rotations as large as 88°. Figure 5 illustrates the results of contouring the bedding orientations measured at Rock Glacier Site.

Rock Fall Hazard:

Rock falls occur with great frequency at Rock Glacier Site. Field observations noted the occurrence of two to three rock falls per hour. Gardner's (1980) research indicated an average frequency of 0.83 events per hour of observation in the entire Highwood Pass area. The average size of these rocks varied between a few centimetres in diameter to tens of centimetres in diameter. This suggests that small rock falls might make a substantial contribution to the colluvium amassed at the base of the slope. Larger magnitude and higher frequency rock falls in the past would be expected, justifying the volume of colluvium at the toe of the slope.

The geometry of the colluvium at the toe of the slope also suggests that rock falls have been important. Gardner (1980) found that low magnitude/high frequency type events, such as rock falls, were the largest contributors to the debris slopes in Highwood Pass. Evans and Hungr (1993) described rock fall talus as being steepened to the angle of repose by the continuous deposition of material and as having a marked reduction in the slope angle near the toe, a typical rock fall-dominated talus sloped at

38°, reducing at the toe to 20° to 10°. The large mass of colluvium at the toe of Rock Glacier Site at its angle of repose, 40°, exhibits near its toe a slope which is significantly less steep, 20°.

Evans and Hungr (1993) also determined an empirically based rock fall shadow angle of 27.5° for rock fall slopes in the Cordillera. The rock fall shadow angle is the angle between the tip of the boulders displaced by rock falls and the apex of the talus slope, measured from the horizontal (Evans and Hungr 1993). At Rock Glacier Site, the rock fall shadow angle is 31°. However, the rock fall shadow angle might be closer to the 27.5° found by Evans and Hungr (1993), but for the deep ditch constructed up slope of Highway 40 trapping boulders that would otherwise have travelled further down slope. Boulders likely pre-dating the construction of the highway can be found on the down slope side of Highway 40.

Evans and Hungr (1993) also described typical rock fall talus as graded. The colluvium at the toe of Rock Glacier Site is graded. At the top of the mass, the size of rock debris is significantly smaller than the size of debris at the toe of the slope. The average size of rocks located at the top of the colluvium was 0.1 m^3 while at the toe of the slope the size of the rocks was 0.5 m^3. Therefore, grading of the talus also supports rock falls as the process forming the large mass of colluvium at the toe of Rock Glacier Site.

Rock falls at Rock Glacier Site are not destabilizing, each fall is small and the transfer of material reduces slope angles. The small risk of boulders rolling or bouncing onto the highway is reduced by the steep-sided deep ditch which captures boulders which reach it; there is no evidence of scarring on the highway. Boulders may be entrained in snow avalanches, slush avalanches, or debris flows which can pass over Highway 40, but these events are probably restricted to the winter and spring months when Highway 40 is closed through Highwood Pass.

Modes of Toppling:

Two different modes of toppling are preserved at Rock Glacier Site, block topples, and multiple block topples. Topple A (Table 1) at Rock Glacier Site (Topple 10, Cruden and Hu, 1994) was used as an example of a block flexure topple by Cruden and Hu (1994, Figure 8). However, as block flexure topples are characterized by gradual changes in bedding orientation within the toppling mass and a rotation of 58° between adjacent blocks was discovered at the base of the topple after the snow had melted, it is now classified as a block topple. Block topples are characterized by abrupt changes in orientation between blocks within the toppling rock mass. An angle of 10° or greater between adjacent blocks has been proposed as indicating an abrupt change in orientation (Cruden and Hu 1994). Two other topples at Rock Glacier Site were classified as multiple block topples (Topples 11 and 12, Cruden and Hu, 1994; B, C, Table 1). Multiple block topples are characterized by more than one distinct zone of abrupt change in bedding orientation between adjacent blocks within a toppling mass (Cruden and Hu 1994). Four possible block flexure topples (Topples M, N, O, P, Table 1) have rotated 13° or less, so their mode is difficult to establish. Cruden and Hu (1994) suggested that block flexural topples did not develop surfaces of rupture. They were thus not prone to subsequent sliding as block topples are.

Cruden and Hu (1994) gave a criterion for predicting toppling style from the h/b ratio; block flexure topples occur where the h/b ratios are less than two, while block topples and multiple block topples form where the h/b ratios are larger than two.

Table 1 lists the style of toppling, thickness of bedding, and the h/b ratio for each of the 20 topples. Figure 6 shows the location on the airphoto of all 20 topples listed in Table 1. Table 1 indicates that the possible block flexure topples occur with h/b ratios ranging from 0.1 to 10, block topples occur with h/b ratios below 1.5 and multiple block topples have h/b ratios ranging from 1 to 6.7. Clearly, these results suggest that the limits in Cruden and Hu's (1994) criterion might be expanded. The variations between the two samples can be attributed to the small databases used for forming these empirical relationships.

There are difficulties with using the block ratio for predicting toppling modes. Although the bedding thickness and joint spacing reported by Cruden and Hu (1994), for topples 10 - 12 are close to the values for topples A - C, they give h/b ratios, differing by up to an order of magnitude. This indicates that h/b ratios may be subject to large sampling variations. Another point to consider is that the h/b ratio of a rock mass may change as the mass topples. Specifically, the spacing between joints may decrease as new joints open as the topple rotates. This suggests that the h/b ratio measured for a displaced rock mass may be less than the h/b ratio at earlier stages in the toppling process, a trend visible in Figure 7 where the h/b ratio is plotted against the angular rotation for each topple.

Driving Process for Toppling:

It is believed that the weathered shale zone located near the top of the slope is directly related to the process driving the toppling at Rock Glacier Site. The weathering of the shale near the top of the slope resulted in the shale having undergone significant expansion, either by mechanical means or chemical processes. To determine the extent of the expansion, the insitu density of the shale and the density of unweathered fragments from within the mass were determined. Insitu density tests were performed using the rubber balloon method (ASTM 1993). The average insitu density of the weathered shale was found to be 1.58 Mg/m^3. Density tests on unweathered shale fragments indicated the expansion of the weathered shale zone to be approximately 54% (McAffee 1995, Table 6.1). Grain size analysis of the weathered shale indicated that 17% of the material was of clay sized particles and that the remaining 83% of the material was of silt sized particles (McAffee 1995, Table 6.1). The liquid and plastic limits of the weathered shale were 26% and 20% respectively. The weathered shale was not found to be susceptible to swelling and the slake durability index of 84% indicated that the mechanical breakdown of the weathered shale, as a result of wetting and drying cycles, would be low to moderate (McAffee 1995, Table 6.1).

Frost susceptibility may be assessed from grain size distributions. According to Casagrande (1931), considerable ice segregation is expected in non-uniform soils containing more than 3% of grains smaller than 0.02 mm and in very uniform soils containing more than 10% grains smaller than 0.02 mm in diameter. The weathered shale was deemed uniform and has 45% of its particles smaller than 0.02 mm, indicating that the material is frost susceptible. The U.S. Army Corps of Engineers used a criterion, related to the Unified Soil Classification System, which required information about grain size distribution and Atterberg Limits (Chamberlain 1981). Using their classification, the weathered shale is medium to extremely frost susceptible. After comparing laboratory frost heave tests with the two classification schemes above, Chamberlain (1981) rated Casagrande's criterion as 75% reliable and the U.S. Army Corps of Engineers criterion as 91% reliable for predicting frost susceptibility.

A more recent approach for predicting frost susceptibility of soils and the degree of frost heave expected, the segregation potential, was based on parameters derived from the specific surface area and mineral content of the fines fraction of the soil (Davila et al. 1992, Davila 1992). Davila, Sego, and Robertson (1993) related these same parameters to the liquid limit of the fines fraction of the soil and the percentage of clay in the fines fraction of the soil. Because the grain size distribution of the weathered shale zone was such that 100% passed the #200 sieve, the liquid limit determined in the laboratory tests was, in fact, the liquid limit of the fines fraction of the soil. Similarly, the percentage of clay measured in the hydrometer tests also gave directly the percentage of clay in the fines fraction of the soil. Using the liquid limit of the fines fraction, 26%, the percentage of clay in the fines fraction, CS = 17%, and Davila, Sego, and Robertson's (1993) correlation criteria, the weathered shale is highly frost susceptible and has nearly the maximum segregation potential possible ($SPo = 22x10^{-4}$ $mm^2/s°C$).

The mechanical breakdown of the shale by freezing increases its porosity and specific surface area eventually producing the weathered shale which is extremely frost susceptible if exposed to adequate moisture and to sufficiently low temperatures (McAffee 1995). Simple ground freezing resulting in only a 9% expansion of pore fluids provides only a small degree of expansion of the soil matrix each freezing cycle. However, because the process is repeated in freeze-thaw cycles, which have been occurring since the last glaciation, the frost sensitive zone can expand to a significant degree over time. Because the quartzite up slope is stiff and supported by material further up slope, the expansionary forces push the intact shale and sandstone beds down slope. The depth of frost penetration in the weathered shale is enhanced by the presence of the deeply incised gullies. The freezing front in the weathered shale advances from the top of the slope and from the sides. Once expansion has been achieved, the opening is supported by infilling material (Cruden et al. 1993) and by the weathered shale layer relaxing into a continually expanding zone. Successive freeze-thaw cycles over a long period of time cause the intact shale and sandstone beds to topple. After some rotation, the toppling of the beds causes them to rupture at depth.

Surfaces of Rupture:

Cruden and Hu (1994) found toppled rock masses had been displaced by sliding along surfaces of rupture. These near planar surfaces develop between toppled and untoppled rock masses as a direct result of the toppling process. As a rock mass topples it forms a surface of rupture by the rotational shearing of the steeply dipping beds. Chigira (1992) described mass rock creep faults which appear to be similar in nature to the surfaces of rupture found at Rock Glacier Site.

Sixteen of the 20 topples identified at Rock Glacier Site (McAffee 1995) have formed surfaces of rupture (Table 1). One large surface of rupture, identified in the north gully, could be traced for approximately 200 m. The remaining 15 surfaces of rupture were between 3 to 20 m in length. The dips of surfaces of rupture varied between 20° and 30°. Surfaces of rupture were not perfectly planar, their dip angles varied up to 5° from their mean dip along their length.

Figure 8 shows a surface of rupture in the north gully at location "D" (Figure 6, Table 1). The surface of rupture crosses sandstones with interbedded shales. Immediately above the surface of rupture, the beds have rotated 33°, the bedding is rotated further within the displaced mass but not by more than 10° between adjacent blocks . According to Cruden and Hu (1994) this topple is classified as a block topple. Detailed observation of the surface of rupture was possible in several areas where it gaped to depths up to 1 m. The surface of rupture was rough and stepped (ISRM 1978) but free of loose debris and moisture along the entire length of the surface.

Figure 9 shows surfaces of rupture in the upper south gully at "E" (Figure 6, Table 1) developed in shales and interbedded sandstones. These surfaces of rupture were not open but filled with local debris. This topple is a multiple block topple (Cruden and Hu 1994). The 46° angular rotation of the beds was divided between two displaced masses, suggesting that two topples have occurred here. Clearly, the characteristics of the surface of rupture and the style of toppling vary with the rock types in the displaced mass.

Tabulating the topples at Rock Glacier Site shows a threshold of angular rotation of the toppling beds necessary to form a surfaces of rupture. Figure 7, a plot of the h/b ratios and angular rotations of the topples, distinguishes between rock masses with rupture surfaces and those without. The angular rotations of the topples with surfaces of rupture ranged between 16° and 74°. The angular rotations of the topples without surfaces of rupture ranged between 6° and 13°. This limited database suggests that rupture surfaces may form within a toppling rock mass once the angular rotation of the topple exceeded 16°.

Rock Slide Hazard:

Sliding can occur along surfaces of rupture created by toppling or a sliding surface may develop as a result of the destruction of cohesion in the rock mass due to weathering. The stability analysis of the large mass of colluvium at the toe of the slope indicated many failure surfaces in the colluvium with factors of safety below unity (McAffee 1995). However, all of these failure surfaces were shallow, between 1 and 5 m in depth. Failure surfaces at this depth, if they are to exist, pose no major concern for the stability of the entire slope. This is because the volumes of displaced material are small. An example of one of the deepest failure surface found in the colluvium is shown in Figure 10.

A second part of the stability analysis evaluated the stability of the upper part of the slope. The results of the analysis are illustrated in Figure 11. A 25 m deep slip surface in the upper part of the slope had a factor of safety less than unity (McAffee 1995). The failure would involve approximately 50 000 m^3 of material with the assumption of a continuous slip surface with no effective cohesion (Terzaghi 1962). Since the slope has not failed, we can conclude that there is adequate cohesion within the rock mass. This raises concern for long term stability in this area, as cohesion cannot be relied upon in perpetuity. Cohesion will eventually be destroyed by weathering or by the formation of a surface of rupture brought about by the toppling processes that are currently active in the upper slope. Once cohesion is destroyed, there will likely be a large movement in this area of the slope if smaller movements do not occur first.

There is evidence of several slides of large blocks having occurred at Rock Glacier Site in the past. Five large masses of rock have been identified on the airphoto interpretation in the colluvium at the bottom of the slope (Figure 2). The lithology of these large masses of rock can be matched to rocks in place near the top of the slope. Since these displaced rock masses originated from much further up the slope, sliding is the most probable mechanism for their displacement. These block slides indicate that either the destruction of cohesion or the formation of surfaces of rupture in the past have led to movements and may continue to do so again.

The topography of the slope itself suggests a single large movement created the colluvium at the toe of the slope. The slip surface used for the analysis was based on the shape of the slope itself and the pre-failure profile, illustrated in Figure 12. A factor of safety for the back analysis of 1.4 was determined. A friction angle of 39° along the slip surface was used for the analysis. This value was determined in the field using a portable tilting table and testing samples of sandstone. If the friction angle along the slip surface was reduced to 30.5°, then the slope would fail at a factor of safety of unity. A reduced friction angle along surfaces of rupture can arise from weaker materials, accumulation of debris, or from water pressures. While the colluvium exhibits features suggestive of rock fall origin, it is also possible that the colluvium may have been derived from slides and rock falls.

Conclusions:

The processes which led to slope movements at Rock Glacier Site are as follows. Frost action within the weathered shale at the upper plateau led to toppling of the intact shale and sandstone beds located down slope. The toppling of the steeply dipping beds led to rock falls; as beds topple, rocks break free and fall from the toppling mass. These rock falls have created the colluvium accumulated at the toe of the slope. Toppling also formed surfaces of rupture after an angular rotation of 16°. The surfaces of rupture in turn allow toppling to continue more easily and creates a surface upon which the toppling mass may slide.

Twenty topples were identified at Rock Glacier Site. The style and h/b ratio of these topples extend to the criterion relating the two developed by Cruden and Hu (1994). Scatter in the h/b ratios suggests they may be sensitive to sampling variations. Small differences in h or b values can significantly affect the h/b ratio. The h/b ratio of a rock mass may change as the mass topples and new joints open. As a rock mass topples the h/b ratio is likely to decrease (Figure 7).

Field observations and laboratory test results suggest that the weathering of the shale is driving the toppling process at Rock Glacier Site. As the shale expands through frost action, it pushes the toppling beds located directly down slope from the weathered shale. Although probably a more intense process in the past, frost action within the weathered shale is likely still an ongoing process today.

Rock falls were shown to have played a major role in the creation of the colluvium at the toe of the slope. Slides within the colluvium at the toe of the slope were shown to be very shallow and of no significant concern. In contrast, slides near the top of the slope might involve much larger masses and may be possible on a deep surface of rupture with no cohesion.

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Table 1: Summary of information for the 20 topples identified at Rock Glacier Site.

Topple Identification	Bedding Thickness (cm)	h/b Ratio	Type of Topple	Rupture Surface	Angular Rotation
A	100	0.2	Block Topple	YES	52
A	150	0.1	Block Topple	YES	58
B	15	1.7	Multiple Block Topple	YES	74
C	1.5	3.3	Multiple Block Topple	YES	27
C	1.5	3.3	Multiple Block Topple	YES	39
D	30	0.7	Block Topple	YES	33
E	1.5	6.7	Multiple Block Topple	YES	46
F	10	1.5	Block Topple	YES	24
G	5	1	Multiple Block Topple	YES	72
H	5	2	Multiple Block Topple	YES	58
I	5	2	Multiple Block Topple	YES	63
J	20	1.5	Multiple Block Topple	YES	16
K	4	2.5	Multiple Block Topple	YES	21
L	65	0.4	Block Topple	YES	67
M	200	0.07	†Block Flexure	NO	11
N	100	0.2	†Block Flexure	NO	10
O	1.5	10	†Block Flexure	NO	13
P	1.5	10	†Block Flexure	NO	6
Q	1.5	*N/A	Block Topple	YES	16
R	11	*N/A	Multiple Block Topple	YES	59

* Note: h/b ratio not available

† Note: These 4 block flexural topples have rotated less than 13 degrees, so their mode is difficult to establish.

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Figure 11:	Possible location for failure surface at upper section of the slope found using SLOPE/W.
Figure 12:	Back analysis of single large movement creating colluvium at toe of slope found using SLOPE/W.

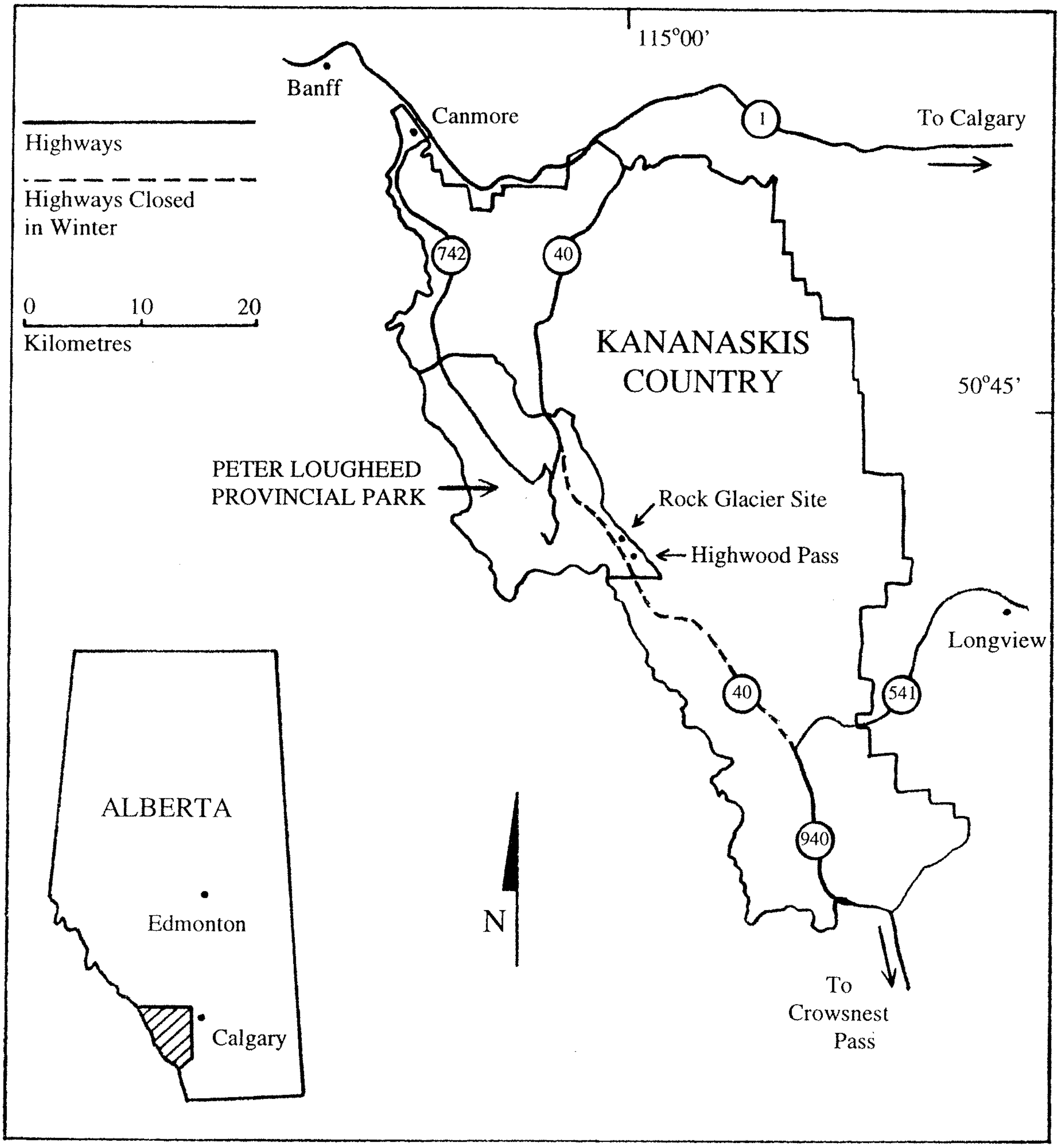

115°00'
Banff
Canmore
1
To Calgary
Highways
Highways Closed in Winter
742
40
0
10
20
Kilometres
KANANASKIS COUNTRY
50°45'
PETER LOUGHEED PROVINCIAL PARK
Rock Glacier Site
Highwood Pass
Longview
40
541
ALBERTA
Edmonton
Calgary
N
940
To Crowsnest Pass

Figure 1

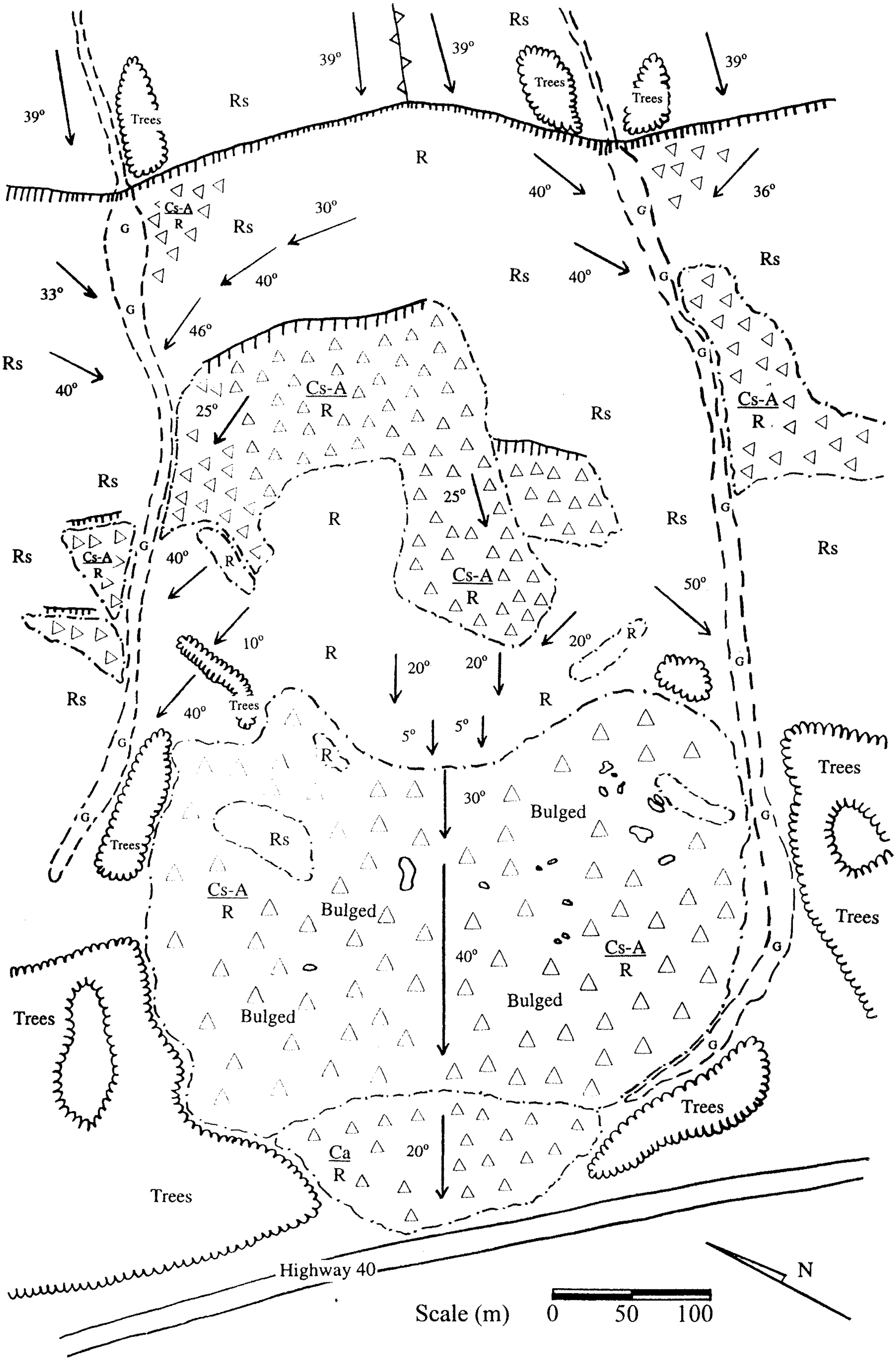

Rs
39°
39°
39°
39°
Trees
Trees
Trees
Rs
R
Cs-A
R
Rs
30°
40°
36°
40°
40°
33°
G
Rs
46°
Rs
40°
Cs-A
R
25°
Rs
Cs-A
R
Rs
R
25°
Rs
Rs
Cs-A
R
40°
R
Cs-A
R
50°
10°
R
20°
20°
20°
R
R
Rs
40°
Trees
5°
5°
R
Trees
30°
Bulged
Trees
Rs
Trees
Cs-A
R
Bulged
40°
Cs-A
R
Trees
Bulged
Bulged
Trees
Ca
R
20°
Trees
Highway 40
Scale (m)
0
50
100
N

Figure 2

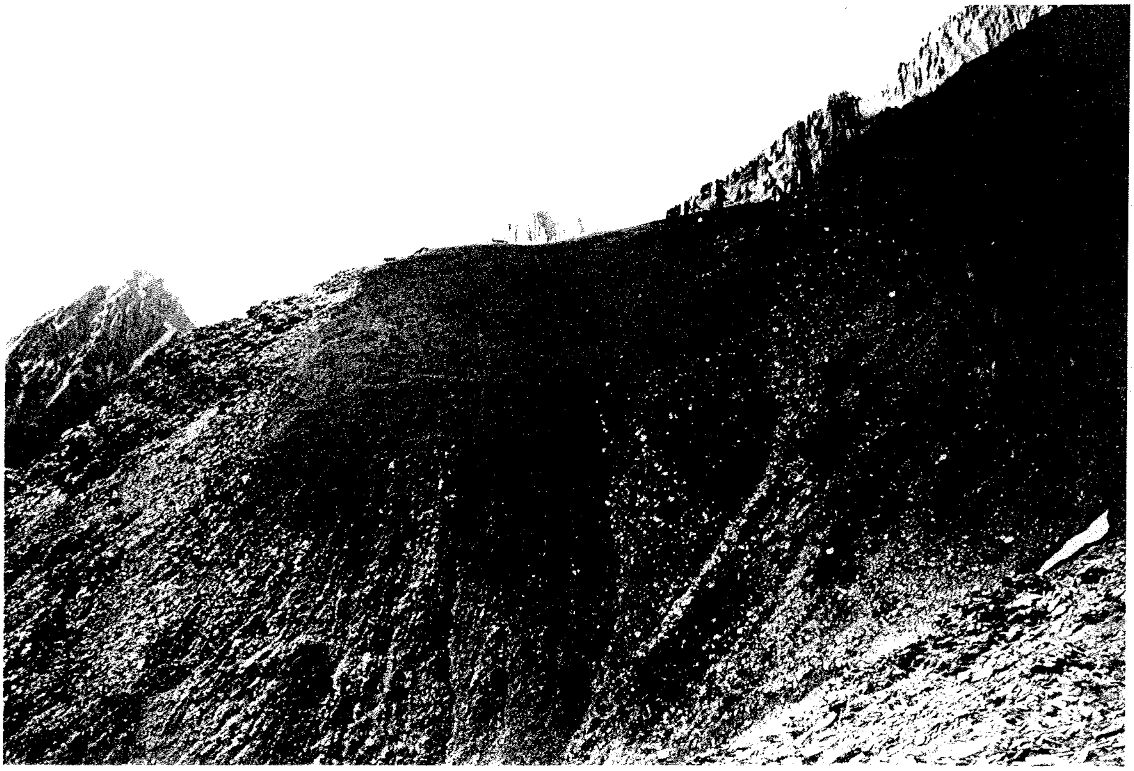
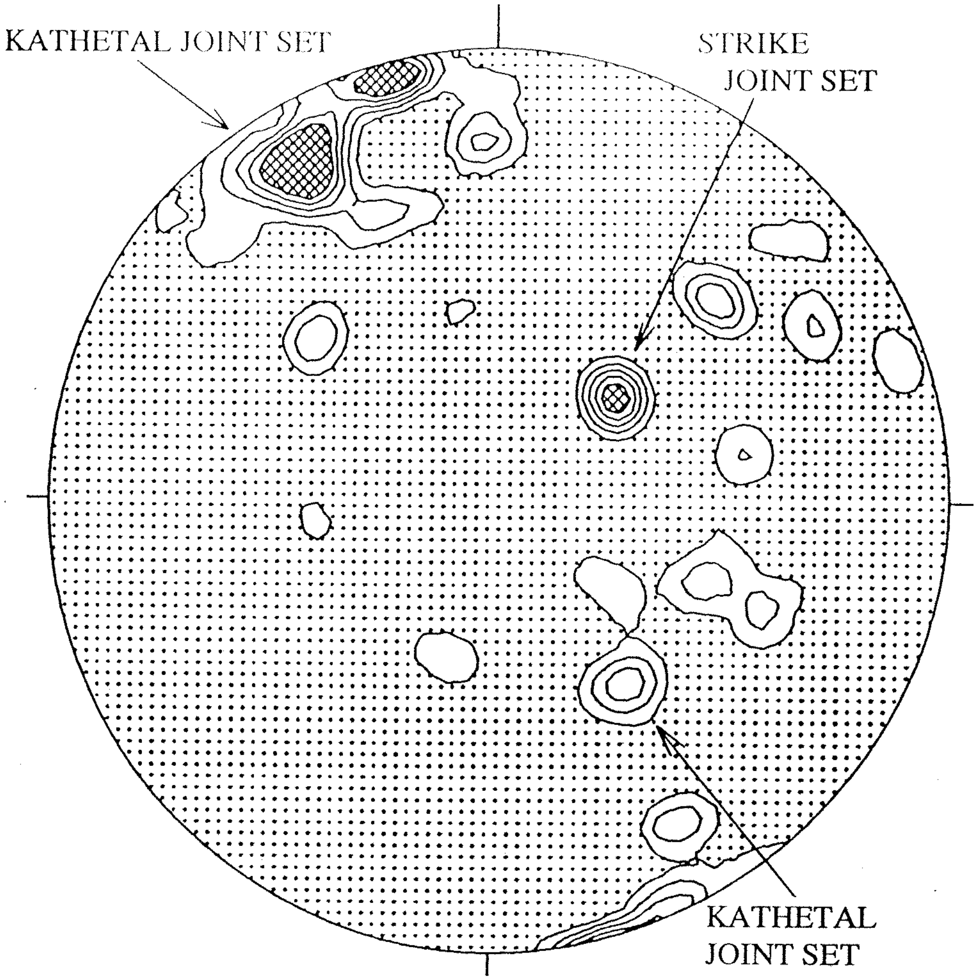


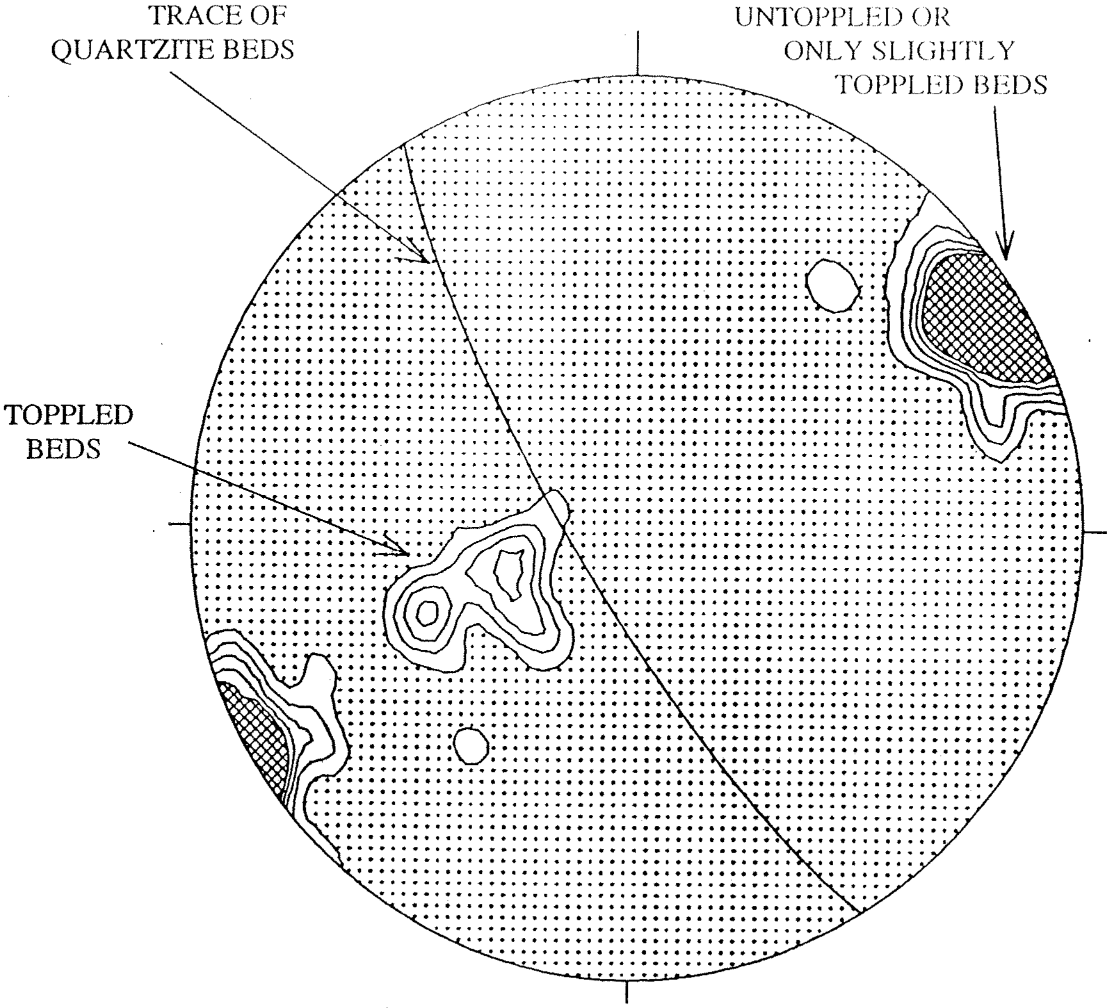
Figure 3



Contours 2 4 6 8 10

Sample Size = 235
Lower Hemisphere Input Data
Lower Hemisphere Plot

Figure 4



Contours 2 4 6 8 10

Sample Size = 248
Lower Hemisphere Input Data
Lower Hemisphere Plot

Figure 5

Figure 6

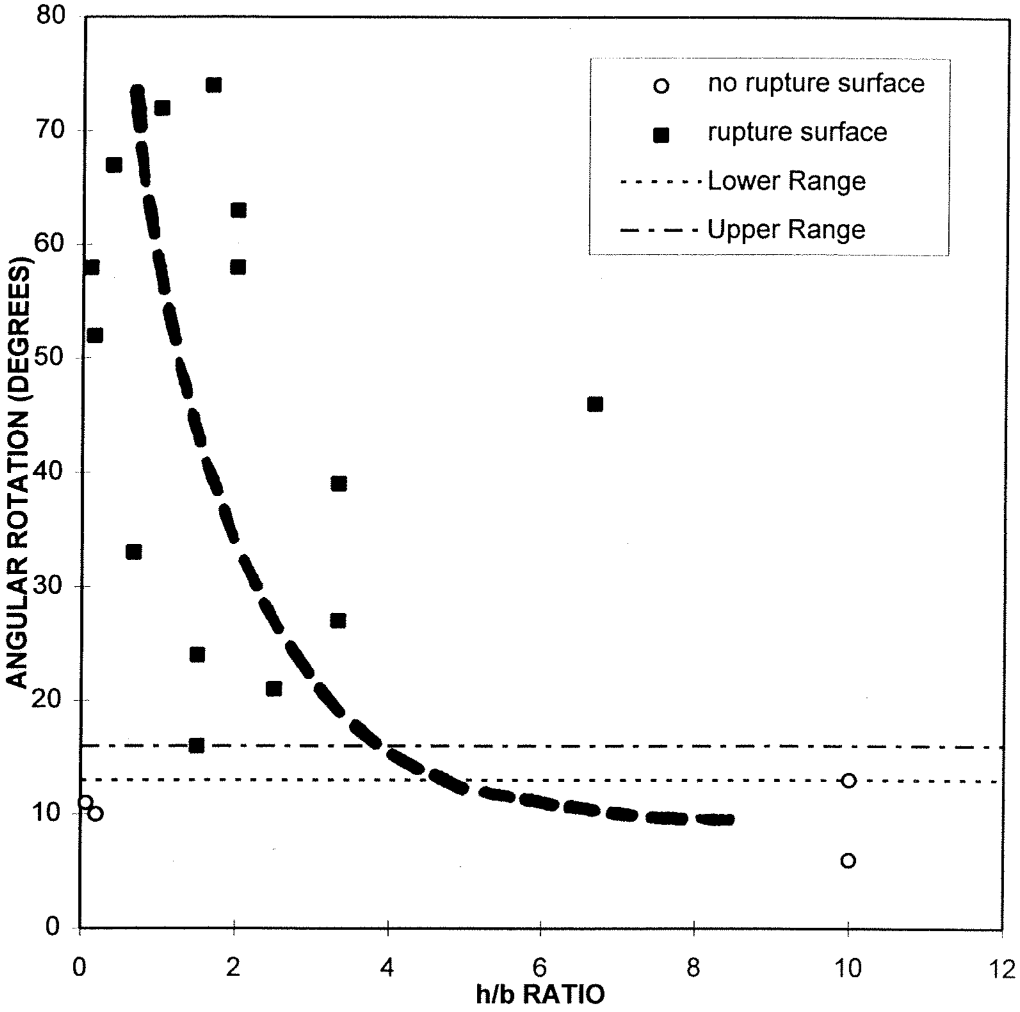

ANGULAR ROTATION (DEGREES)
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
12
h/b RATIO
no rupture surface
rupture surface
Lower Range
Upper Range

Figure 7

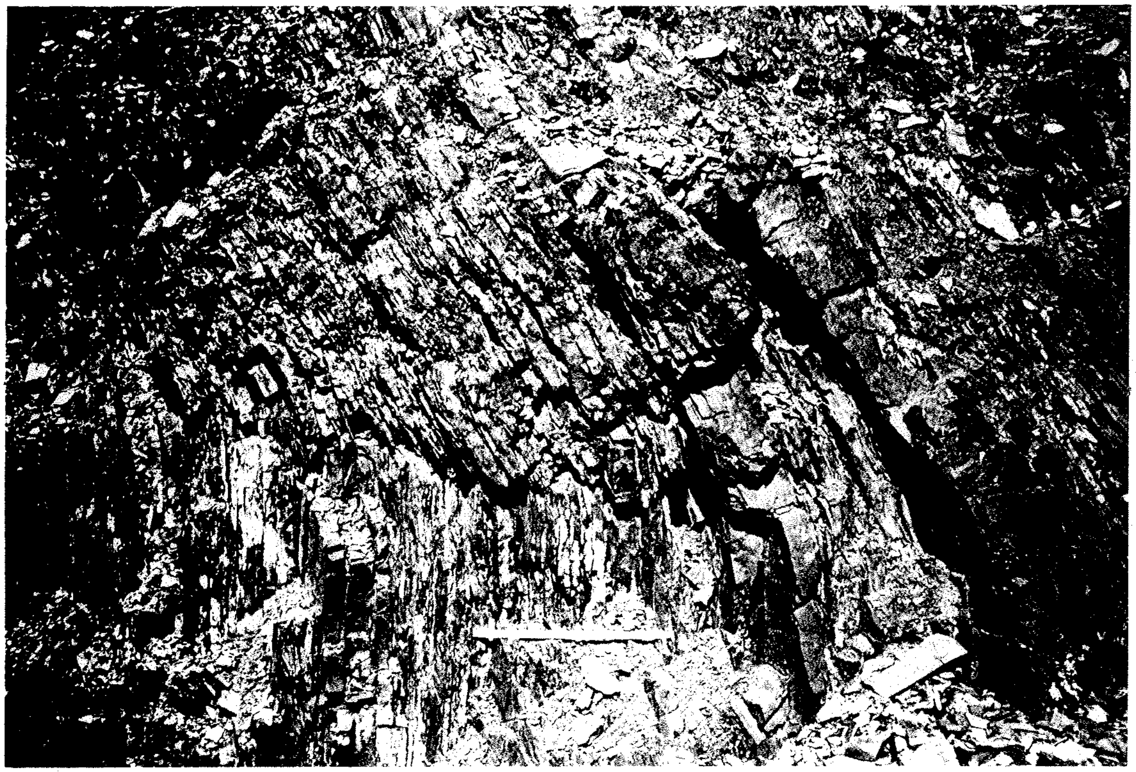


Figure 8

Figure 9

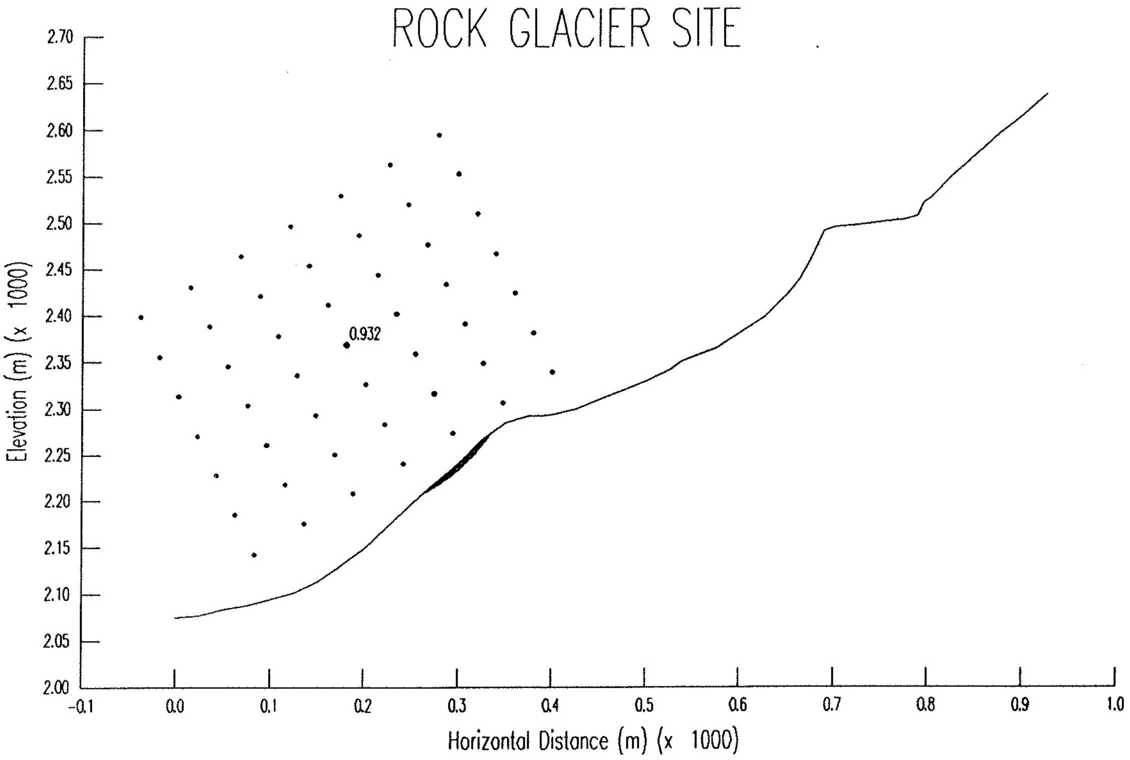

ROCK GLACIER SITE
2.70
2.65
2.60
2.55
2.50
2.45
2.40
2.35
2.30
2.25
2.20
2.15
2.10
2.05
2.00
Elevation (m) (x 1000)
0.932
-0.1
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Horizontal Distance (m) (x 1000)

Figure 10

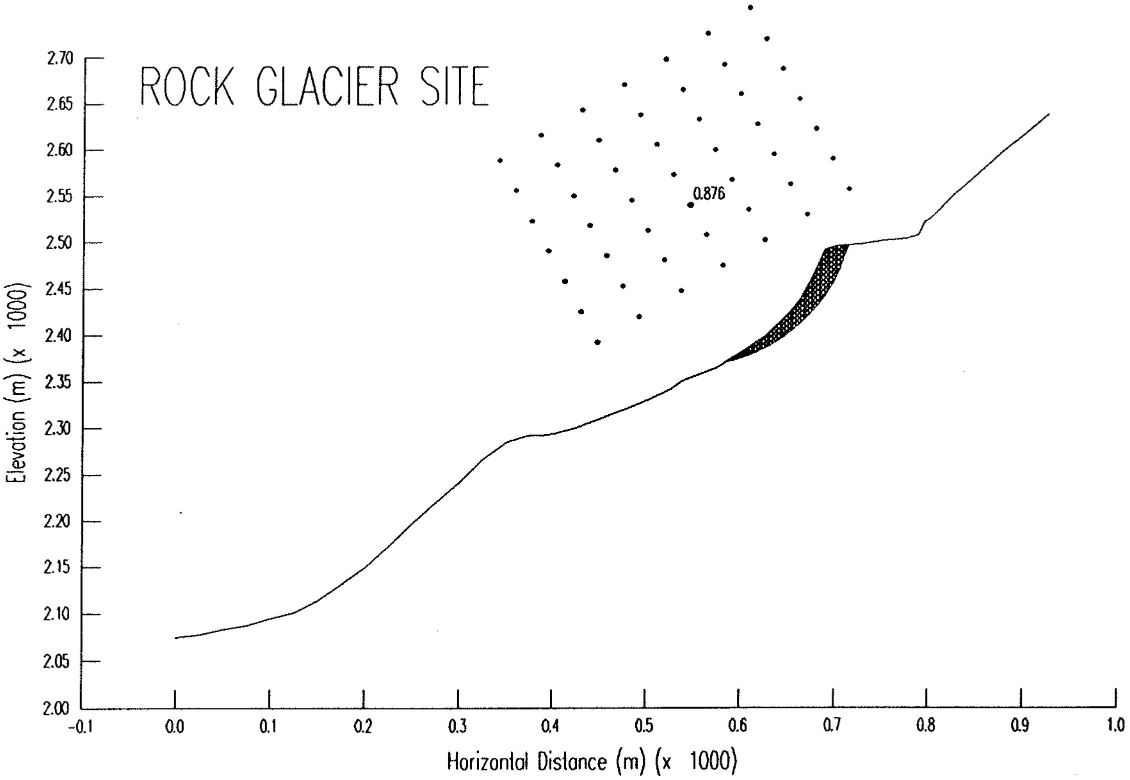
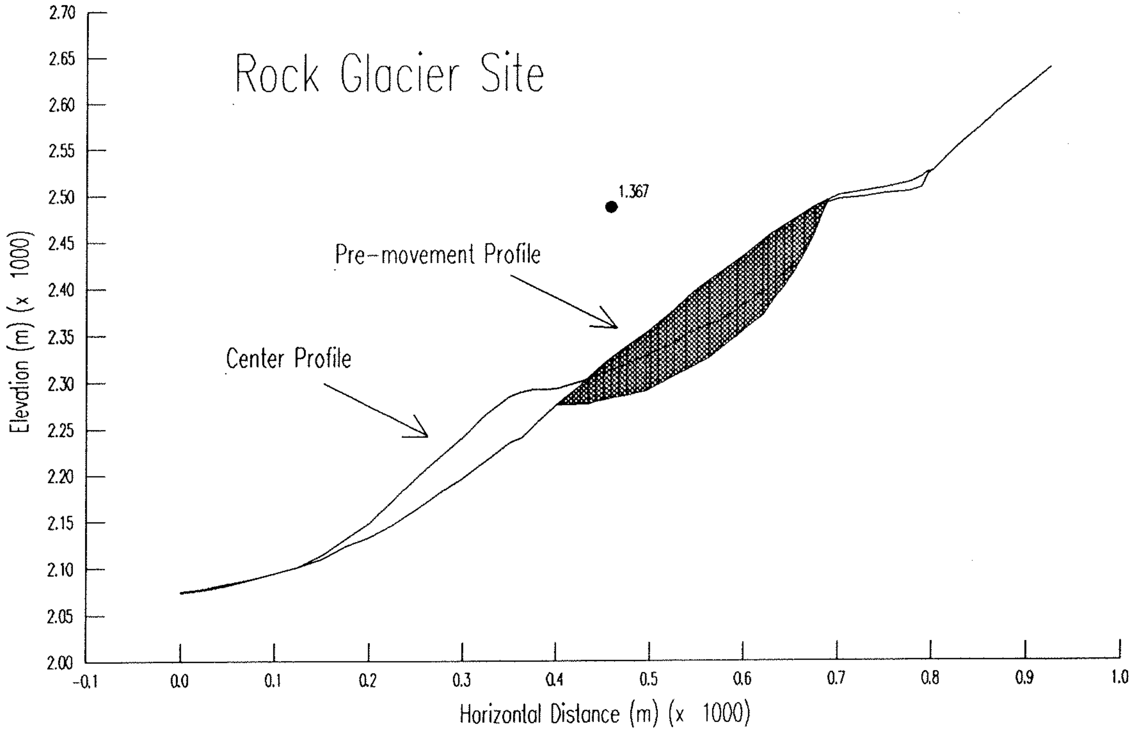

ROCK GLACIER SITE
0.876
Elevation (m) (x 1000)
2.70
2.65
2.60
2.55
2.50
2.45
2.40
2.35
2.30
2.25
2.20
2.15
2.10
2.05
2.00
-0.1
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Horizontal Distance (m) (x 1000)

Figure 11



Rock Glacier Site
1.367
Pre-movement Profile
Center Profile
Elevation (m) (x 1000)
Horizontal Distance (m) (x 1000)
2.70
2.65
2.60
2.55
2.50
2.45
2.40
2.35
2.30
2.25
2.20
2.15
2.10
2.05
2.00
-0.1
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

Figure 12