~Km 5.2 To ~Km 6.1 Cut Slopes

Site Observations

Heading southbound along the highway, bedrock exposures begin to appear in the cut slopes around Km 5.2. Further southbound, the cut slopes are entirely within bedrock from approximately Km 5.5 southbound.

The road surface along this segment of the highway is very narrow and is as little as 6 to 8 m wide in places. There is no guardrail along the downslope edge of the road between ~Km 5.2 and ~Km 5.5. There is a guardrail extending southbound from ~Km 5.5.

The upslope road ditch is typically undersized or altogether absent along this segment of the highway. Cut slope and/or ditch issues were noted in the following areas:

- From ~Km 5.2 to ~Km 5.5:
  - The cut slopes are up to approximately 6 to 8 m high and expose rocky soil and rock talus at up to 45° inclination. Photos 742-21 and 742-22 show typical views of these cut slopes.
  - There is no upslope ditch along this segment.
  - Cobble-sized rocks have rolled across and onto the road, as shown in Photos 742-23 and 742-24.
  - There is no guardrail along this segment of the road. The fill slope below the road is up to 40 to 45° inclination. Photo 742-25 shows a typical view.
- From ~Km 5.5 to ~Km 5.8:
  - The cut slopes along this segment are up to approximately 10 to 12 m high and expose bedrock. The cut slopes are at variable cut angles, ranging from around 45° to vertical, and are typically greater than 60°. The crest of the cut slopes blend into the natural slopes above that are a mix of exposed rock and talus-covered areas. Photos 742-26 to 742-29 show typical views of the cut slopes in this area.
  - Photo 742-28 from approximately Km 5.55 shows a typical view of a vertical to near-vertical cut slope roughly 10 to 12 m high, with no ditch and adjacent road approximately 6 m wide. At the time of the October 2008 inspection, there were only gravel to isolated cobbles along the toe of this slope.

- At the time of the October 2008 site inspection, there were no rocks on the traffic surface. Numerous cobble-sized rocks were noted along the guardrail line along the downslope side of the road. It appeared that these cobbles had been pushed to that side of the road during road grading, and therefore the cobbles may have fallen out from the cut slopes and onto the road surface.

- The exposed bedrock consists of limestone (appears reefal), with a bedding strike of 330 and dip down towards the southwest at approximately 45°. The road is aligned along a bearing of approximately 330 to 350 in this area, therefore the bedding planes dip into the cut slope which is favorable with respect to potential slope instability along the bedding planes.

- There is a set of sheet joints visible in the exposed bedrock. The sheet joints are perpendicular to the bedding planes and dip down towards the road at approximately 40 to 45° down from horizontal. The orientation of the sheet joints is shown on Photos 742-27 and 742-28. The sheet jointing effectively creates an overdip slope[3] in the cut slope along this segment of the road, with the potential for large blocks of rock to break off along the sheet joint planes and fall towards the road.

- The exposed bedrock also shows signs of solution weathering, i.e. the limestone is eroded and dissolved over time by water. This leads to gravel to cobble-sized pieces of rock breaking free from the slope face and falling down to the road.

- At approximately Km 5.6, there is an orange paint marker visible roughly mid-way up the cut slope where a large block of rock appears to be close to breaking off from the slope and sliding down a joint plane and onto the road. Photos 742-29 and 742-30 show this location. Photo 742-31 shows another, similar location a short distance southbound of approximately Km 5.6.

- At approximately Km 5.7:

  - There is a gully eroding below the guardrail, as shown in Photos 742-32 to 742-34. The gully erosion is occurring at a location where soil and gravel that has been graded from the road surface has built up below the guardrail and caused a concentration of surface runoff from the road to

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[3] See Figure D1 in Appendix D for an illustration of an overdip slope.

discharge onto the downslope fill face. There is a negligible upslope road ditch along this segment of the road.

- From ~Km 5.8 to ~Km 6.1:
  - At approximately Km 5.8, the road bends (to the right, when driving southbound) as the mountain slope transitions from east-facing to southeast-facing. The bearing of the road alignment transitions from around 330 to 350 between Km 5.5 and Km 5.8 to a bearing of roughly 060 between Km 5.8 and Km 6.1. See the oblique aerial view on Figure A5 for an illustration of the road curve and slope geometry.
  - From Km 5.8 to 6.1, the bedrock cut slope inclinations are around 50 to 55 degrees, and the cut slope heights are variable to a maximum of approximately 5 m. Heading southbound, the cut slopes taper out around approximately Km 6.1, roughly at the access road turnoff to North Whiteman's Dam.
  - The bedding of the exposed bedrock has a strike of roughly 330 and a dip of roughly 45° down to the southwest. The road bearing is approximately 060 (northeast/southwest), therefore the bedding dip direction is roughly parallel to the road. This is relatively favorable with respect to cut slope instability along the bedding planes. The sheet jointing noted in the cut slopes between approximately Km 5.5 and 5.8 did not appear to be present between approximately Km 5.8 and 6.1.
  - Cobble-sized rockfall debris was noted along the toe of the cut slopes. There appeared to be little to no solution weathering of the rock in the cut slopes in this area, and the rockfall debris appeared to be from mechanical weathering of the cut slopes.

At ~Km 5.9:

- The gabion wall that partially collapsed in the summer of 2007 is along the downslope side of the highway around Km 5.9. The gabion wall was constructed in the 1980's to provide erosion protection for the downslope face of the geogrid reinforced road fill embankment spanning a drainage draw in the natural slope at this location. The collapse of the gabion wall has not directly destabilized the reinforced fill embankment, however some gullying and loss of ground around the guardrail along the downslope edge of the road at this site has been ongoing since 2007. Please refer to AMEC's 2008 annual site inspection report[4] for the gabion wall site for further details and assessment.

Assessment

- In summary, the segment of the highway between Km 5.2 and Km 6.1 is very narrow and the upslope road ditch is undersized or even absent in some places. There is a risk of rockfall debris from the cut slopes landing or bouncing/rolling onto the road along this segment of the highway. This is evidenced by the rockfall debris that was noted on the road at the time of the October 2008 inspection. It is understood that this unpaved segment of the highway is graded frequently to maintain a relatively smooth road grade, so the volume rockfall debris visible on the road at the time of the October 2008 inspection would have accumulated only since the previous grading.

- The upslope road ditch, where there is one, does not meet the ditch sizing guidelines shown on the rockfall catch ditch design chart attached as Figure C1 in Appendix C. For reference, the guidelines shown on Figure C1 call for a ditch in the order of 3.7 m wide and 1.3 m deep along the toe of a 5 m high rock cut slope at 45° inclination. This size of a cut slope is on the lower end of the range of sizes of cut slopes along this segment of the highway. However, no portion of the existing ditch is close to such a width or depth and in many locations there is a negligible ditch to no ditch at all.

- There is also a risk of large blocks of rock breaking free from the cut slope and sliding down along the planes of the sheet joints with the debris spilling onto the road surface. This could occur at the locations shown in Photos 742-29 and 742-31 as the exposed bedrock weathers further and experiences more freeze/thaw periods along with rainfall and snowmelt infiltrating into the open joints and tension cracks around the rock blocks.

- The undersized upslope road ditch does not appear to have led to significant erosion along the road surface due to ditch flow spilling onto the road. However, the lack of visible erosion along the road surface at the time of the October 2008 inspection may also be the result of frequent grading of the road surface as part of ongoing maintenance operations.

- There is one location at approximately Km 5.7 where a concentration of surface runoff from the road is eroding a gully below the guardrail and into the downslope side of the road surface. The surface runoff along the road appeared to be

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[4] AMEC report "Southern Region Geohazard Assessment Program, Site S30 – Gabion Wall, Highway 742:02, 2008 Annual Inspection Report", submitted to AT on September 8, 2008, AMEC project number CG25277.B.

channeled and concentrated into the head of the gully by soil and rock debris accumulating along the guardrail line due to repeated grading of the road surface.

- The lack of guardrail between approximately Km 5.2 and 5.5 is a hazard to motorists, due to the steep and high slope below the road.

- Vehicle recovery from striking a rock on the road may be hazardous. Where ditches and shoulders are absent, vehicles may impact rock cut slope faces or break through the guardrail and continue down the slope below the highway. Injuries are likely to be serious in any departure from the road surface. Vehicles remaining on the road surface present a significant obstruction to traffic flow and remain at risk from possible subsequent rockfall during the time that they are on the road.

- Long vehicles encountering a roadway completely obstructed by snow avalanche debris or fallen rock would have difficulty turning around on this narrow road. Forced reversing into oncoming traffic prolongs exposure to the hazard that blocked the road. It also endangers oncoming traffic.

Risk Level

The primary risk along this segment of the highway is debris from rockfalls landing on the road and/or spilling out from the upslope road ditch (where present). The recommended Risk Level for this segment of the highway, based on AT's rockfall geohazard matrix, is as follows:

- Probability Factor of 12 to reflect the active rockfall conditions, with a qualitative description of somewhere between up to two falls per year (corresponding to a Probability Factor of 11) and "several" falls occurring each year (corresponding to a Probability Factor of 13).

- Consequence Level of 4 because the narrow roadway, shoulder and ditch conditions resemble those brought about by a rock fall sufficiently large to cause partial closure of the road, fill ditches and cover the shoulders of the road. The consequences of these chronic conditions are mitigated by frequent grading of the roadway. This value also accounts for the possibility of vehicles being struck by falling rocks and vehicles striking rocks that have been deposited on the road with loss of vehicle control resulting.

Therefore, the current recommended Risk Level for rockfall along this segment of the highway is 48. This is higher than the Risk Level of 6 recommended after the 2003 inspection of these sites. The increase in Probability Factor from the 2003 inspection is considered accurate because in 2008 cobble-sized rocks were noted on the road surface itself and upon further inspection the amount of rockfall activity is judged to be higher than was estimated at the time of the 2003 inspection. The doubling of the Consequence Factor is prompted by more detailed knowledge of comparable local highway conditions.

For comparison, the risk to the highway at the locations around Km 5.6 where large blocks of rock may break off and slide down a joint plane and onto the road is evaluated as follows:

- Probability Factor of 4 to reflect the current inactivity of this type of rockfall but with a fall occurrence considered to be "improbable" or a "remote" probability.

- Consequence Factor of 6 because if one of the large blocks of rock were to slide onto the road, it could severely damage a vehicle and injure the occupants or require complete closure of the road for at least a period of hours before the debris could be cleared by a loader.

This generates a Risk Level of 24 for this hazard, which is less than the same Risk Level as for the more frequent, but lower consequence, rockfalls along this segment of the highway.

Also for comparison, the recommended Risk Level for the lower probability, but higher consequence, hazard of boulder-sized rockfall from the natural slopes above the highway cut slopes is as follows:

- Probability Factor of 2, which corresponds to rockfalls originating on the natural slopes above the highway reaching the road being "very improbable" to "improbable".

- Consequence Factor of 6 because if boulder-sized rockfall from natural slopes above the highway were to reach the road, this could damage or destroy vehicles and severely injure or even kill the occupants. Such an event would likely also require a complete closure of the road while the rockfall debris is cleared.

This generates a Risk Level of 12 for this hazard, which is lower than the recommended Risk Level for rockfalls originating in the cut slopes along the highway.

The Risk Level specific to the partially collapsed gabion wall site at approximately Km 5.9 is 78, as described in AMEC's 2008 site inspection report to AT.

Recommendations

Maintenance and Short Term Actions

- Install rockfall warning signs between ~Km 5.2 and ~Km 5.5 (if not already in place).

- Extend the existing guardrail for a few hundred metres further northbound, between ~Km 5.2 and ~Km 5.5. This would be consistent with the requirements of Figures H3.4 and H3.5 of AT's November 2007 Roadside Design Guide.

- At the two sites around Km 5.6, remove the large blocks of rock that appear to be close to breaking off and sliding down the joint plane slope onto the road. This could be done by a specialist rock slope contractor experienced with scaling and cleaning of highway rock cut slopes in British Columbia.

- Post a reduced speed limit in order to increase the time available for motorists to see and safely avoid rocks on the road

- Establish a maximum vehicle length permitted on this segment of the highway so that the vehicles on the narrow road will have sufficient maneuverability to avoid rockfall debris on the road or turn around if necessary. Long vehicles and tows should be directed to alternate routes.

Aside from the two locations around Km 5.6 noted above, scaling of the slopes in general is not recommended as it would likely require a lot of effort with likely relatively little long-term reduction in the Risk Level. Furthermore, it is not realistic to expect to remove all of the loose, cobble-sized or larger rocks while scaling and without inadvertently loosening more rocks. A similar amount of effort spent in more frequent checks of the road and kicking cobbles out of the traffic path would likely be more effective, and the draped nets recommended under "Medium To Long Term Actions" would provide more lasting benefit.

In addition to the above, maintenance crews should inspect and maintain the traffic cones marking the gully encroachment below the guardrail at Km 5.7.

Medium to Long Term Actions

There are the following options for reducing the rockfall risk to the highway:

1. Establishing a suitably large catchment ditch along the toe of the cut slope, by:

   a. Widening the road in the downslope direction and excavating a ditch along the toe of the existing cut slope.

      and/or

   b. Cutting back the toe of the existing cut slope by the width of the new ditch, leaving either a vertical along the upslope side of the ditch or steepening the entire cut slope.

   Neither of these options are desirable, for the following reasons:

   - The existing road is as narrow as 6 to 8 m in places and the natural slope below the highway is as steep as 40 to 45° in places. Therefore any downslope widening of the road would require high, reinforced fills and possibly a continuous MSE-wall style fill along the highway similar to that used for the recent expansion of segments of the Sea to Sky Highway between West Vancouver and Squamish. Such an expansion of the existing highway would be possible from a technical perspective, however it is likely not a cost-effective option for this secondary highway amongst other priorities within AT's highway network.

   - If the toe of the existing cut slope were to be "pushed back" by the new ditch width and a vertical cut left at the base of the cut slope, then rockfall debris from the upper portion of the cut slopes would be prone to bouncing and rolling over the ditch and directly onto the road. Furthermore, the existing cut slopes are near-vertical in places, and excavating further into the slope above the highway would require a tremendous volume of excavation and create very high, near-vertical to vertical cuts along the road.

2. Trimming back the existing cut slopes to a lower crest-to-toe inclination, and thus reducing the probability of rockfalls.

- This option is generally not possible for this site because the natural rock slopes above the existing cut slopes are up to approximately 45° inclination or even greater in some places. A tremendous to impractical volume of rock excavation would required to establish gentler cut slope angles.

3. Installing protective measures to minimize the volume of rock fall debris deposited on the road.

- Draped netting would be suitable to direct rock falls into the upslope road ditch or confine the debris along the toe of the cut slope in areas without a ditch. The use of draped netting would require maintenance in the form of cleaning out rockfall debris that accumulates along the toe of the slope in order to prevent an excessive amount of debris buildup behind the net and loss of effectiveness.

- This option is the most practical for this site because it avoids having to widen the existing road or excavate into the existing cut slopes.

AMEC recommends the installation of draped netting (Option 3, above) at selected locations across the slope above the road to reduce the rockfall risk at this site.

With respect to the gully erosion below the guardrail at approximately Km 5.7:

- It is judged impractical to establish an upslope road ditch to contain surface runoff from the road due to the limited road width in this area and impracticality of widening the road to accommodate an upslope ditch as noted above.

- Moving forward, the best option to manage the hazard of the gully erosion into the road surface is judged to be:

    - Attempting to backfill the eroded portion of the road surface with granular material.

    - Taking care to avoid accumulations of graded material along the guardrail line that concentrate surface runoff from along the road into the head of the erosion gully – or - establishing culverts or flumes extending down the slope face below the road, into which surface runoff from the road can be directed into in the absence of an upslope ditch and buried culverts below the road surface.

~Km 5.2 to ~Km 6.1

Photo 742-21 (top) – Typical view facing southbound along the segment of the highway between ~Km 5.2 and ~Km 5.5. Note the lack of upslope road ditch along the toe of the approximately 45° cut slope exposing rocky soil. Note also the lack of guardrail along the downslope edge of the narrow road.

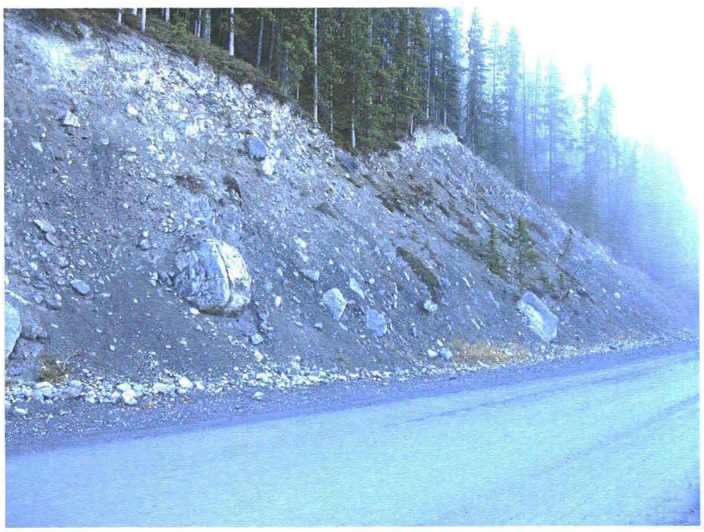

Photo 742-22 (middle) – Typical cut slope between Km 5.2 and Km 5.5, roughly 6 to 8 m high at up to 45° inclination. There is no ditch along the toe of the slope, and rocks that erode out from the cut slope may roll onto the road surface.

Photo 742-23 (bottom) – Facing southbound along the highway between Km 5.2 and Km 5.5. Note the cobble-sized rocks that have rolled out from the toe of the cut slope and onto the road surface. It is likely that other rocks have rolled out onto the road at other times and have been cleared to the edge by the maintenance contractor.

~Km 5.2 to ~Km 6.1

Photo 742-24 (top) – Another view of cobbles eroded out from the cut slope that have rolled onto the road between ~Km 5.2 and ~Km 5.5.

Photo 742-25 (middle) – Facing northbound along the segment of the highway between ~Km 5.2 and ~Km 5.5. Note the narrow road width and lack of guardrail along the downslope side.

Photo 742-26 (bottom) – Facing southbound from around Km 5.5. The cut slopes expose bedrock from around this point southwards. There is also a guardrail along this segment of the highway.

~Km 5.2 to ~Km 6.1

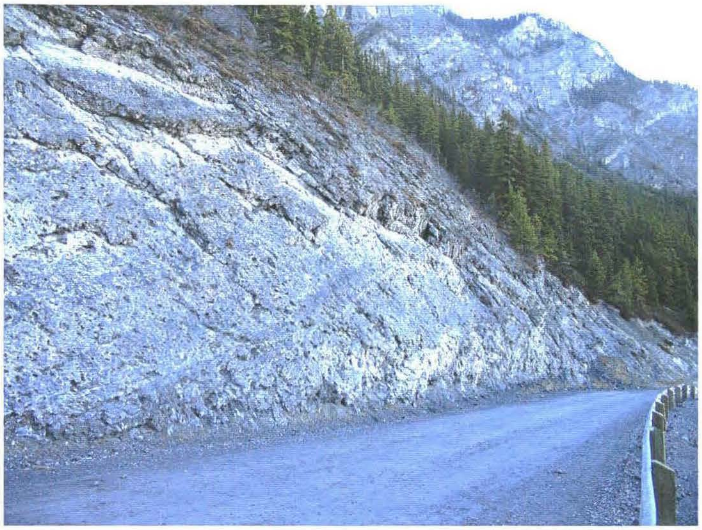

Photo 742-27 (top) – Typical cut slope between Km 5.5 and Km 5.8. The cut slopes are typically steeper than 60° and expose limestone with bedding that dips into the slope, which is favorable with respect to slope stability. However, there is a set of sheet joints perpendicular to the bedding that dips down towards the road at around 40°, effectively creating an overdip slope along this segment of the highway. Also note the narrow road and lack of a ditch along the toe of the cut slope.

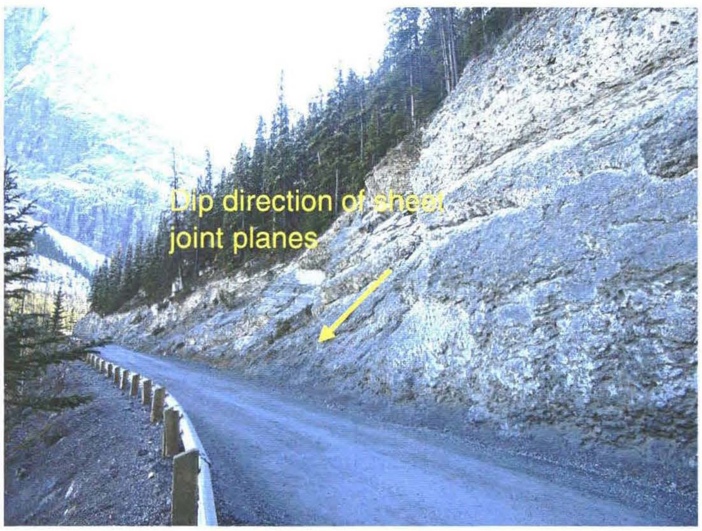

Photo 742-28 (middle) – Another view of a typical cut slope around Km 5.55. This cut slope is around 10 to 12 m high without a ditch along the toe. The adjacent road surface is approximately 6 m wide. There appeared to be relatively little rockfall in this area, with gravel and occasional cobbles along the toe of the cut slope. It appeared that the cut slopes in this area appear to be undergoing solution weathering with the exposed limestone slowly dissolving over time when wet from rain or snowmelt.

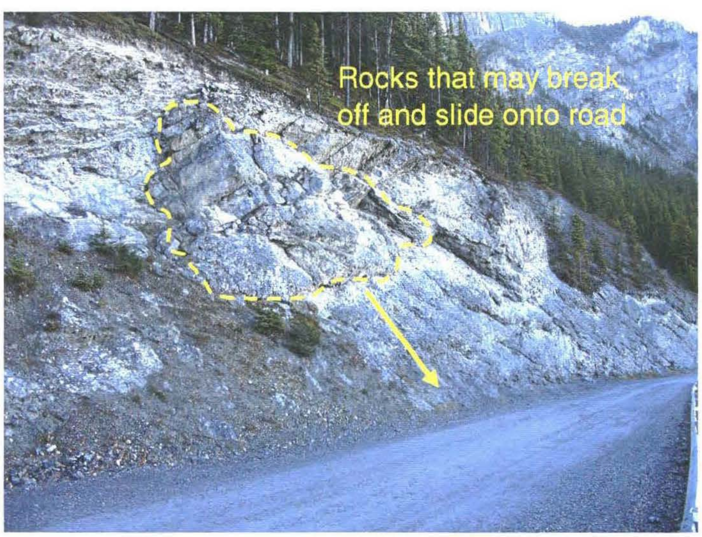

Photo 742-29 (bottom) – Rockfall/rockslide hazard at ~Km 5.6 from a number of boulder-sized rocks that appear to be close to breaking off the cut slope face and sliding down the sheet joint plane and onto the road surface. This location had been previously marked by others with orange paint near the middle of the slope.

~Km 5.2 to ~Km 6.1

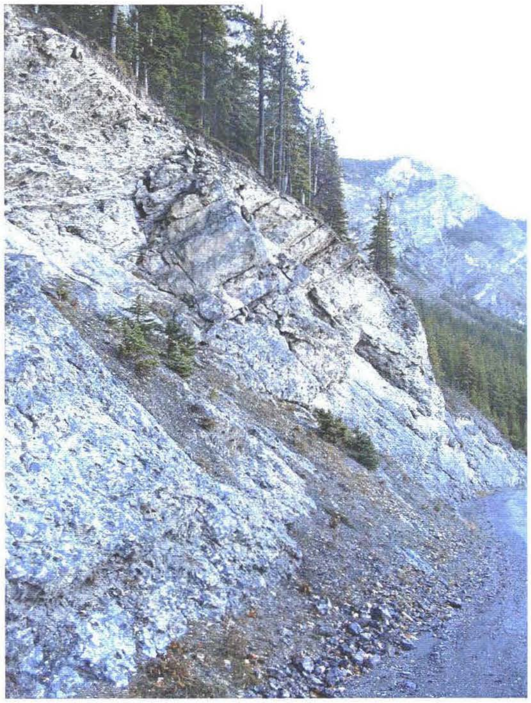

Photo 742-30 (top) – Another view of the location at ~Km 5.6 where a number of boulder-sized rocks appear to be close to breaking loose and sliding down onto the road.

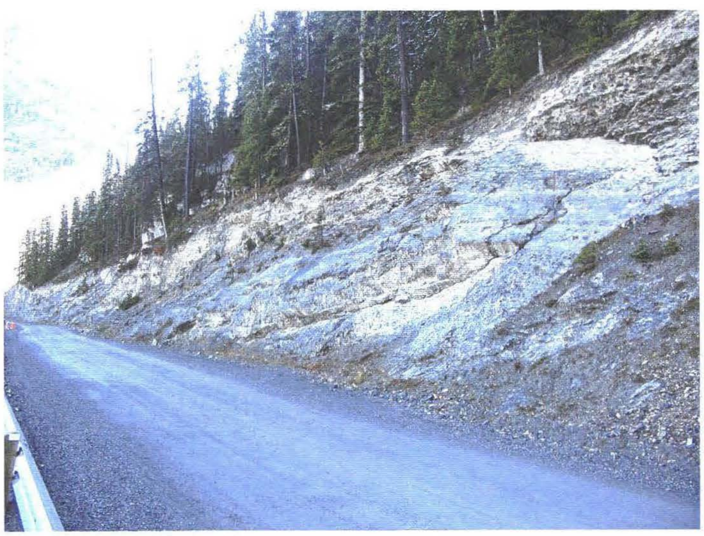

Photo 742-31 (bottom) – An area a short distance southbound from ~Km 5.6 where there appears to be a hazard of some large rocks breaking loose and sliding down the sheet joint plane and onto the road.

~Km 5.2 to ~Km 6.1

Photo 742-32 (top) – At ~Km 5.7, gully erosion in the fill slope below the road that has encroached below the guardrail and reduced the trafficable width of the road. Debris from plowing and grading the road surface has built up below the guardrail in the segment of the highway upslope /southbound from this location and has caused a concentration of surface runoff to discharge onto the fill slope below the road at this location, which has led to the gully erosion.

Photo 742-33 (middle) – Facing southbound towards the gully erosion and illustrating the reduction in road width adjacent to the gully.

Photo 742-34 (bottom) – Another view of the head of the gully erosion, showing how the guardrail posts have been undermined.

~Km 5.2 to ~Km 6.1

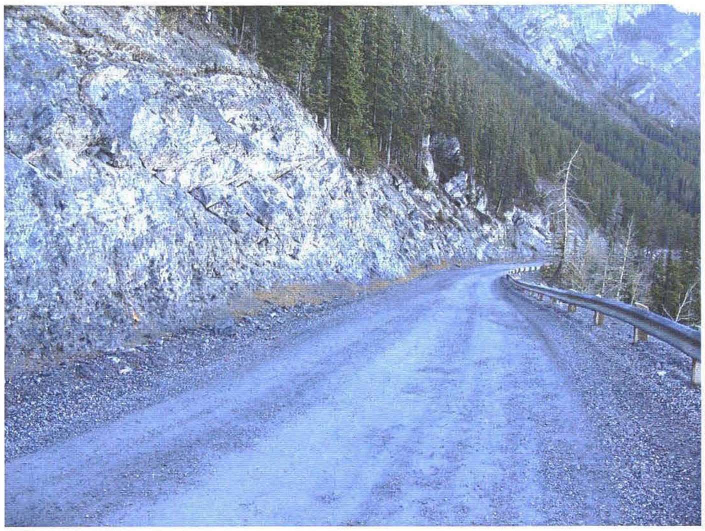

Photo 742-35 (top) – Typical view of the cut slopes around Km 5.8, a short distance northbound from the curve in the road. Note the accumulation of gravel and cobble-sized rocks along the toe of the cut slope. The cut slopes in this area also appeared to be primarily undergoing solution weathering, with relatively minor volumes of resulting rockfall.

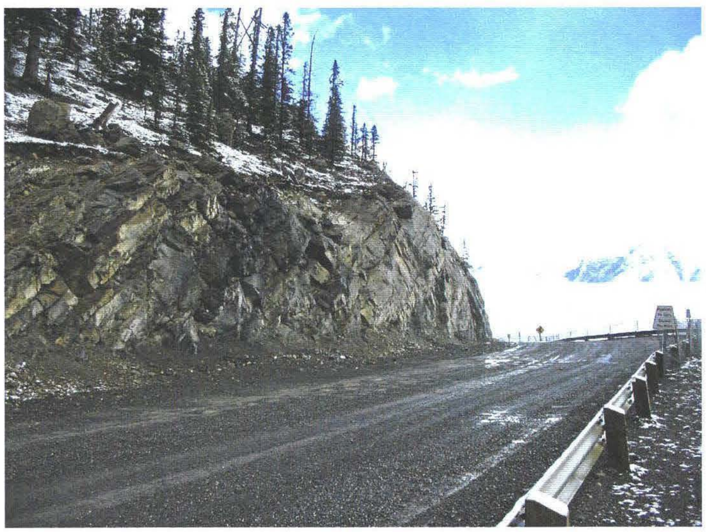

Photo 742-36 (middle) – Typical view of the cut slopes between ~Km 5.8 and ~Km 6.1. The cut slopes along this segment are typically around 50 to 55° inclination and 5 m or less in height. The cut slopes face southeast, therefore the southwest dip direction of the bedrock exposed in the cut slopes is roughly parallel to the bearing of the highway. This is less favorable with respect to slope stability than along the segment between ~Km 5.5 and ~Km 5.8 where bedrock dip direction is downwards into the cut slopes, however not a significant risk to this segment of the highway.

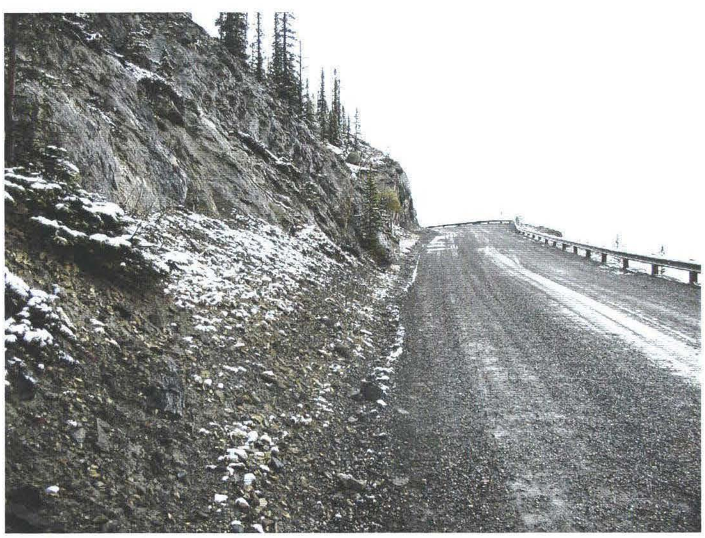

Photo 742-37 (bottom) – Typical view facing northbound towards the sharp bend in the highway around Km 5.8. Note the accumulation of gravel-sized debris along the lower part of the cut slope in some areas. Erosion and minor rockfall appear to be ongoing along this segment of the highway, but not a significant risk.