KLUANE TERRAIN HAZARD MAPPING STUDY

FINAL REPORT

GREATER KLUANE LAND USE PLAN

This project was completed for the Greater Kluane Land Use Plan. It is one of a number of resource inventory projects that were compiled as background information.

KLUANE TERRAIN HAZARD MAPPING STUDY
FINAL REPORT

Report
to
Yukon Land Use Planning Office

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SUMMARY

Terrain hazards are evaluated in the mountainous 35,000 km^2 Kluane Regional Planning Area in the southwest Yukon. Hazardous terrain was interpreted from 650 aerial photos and mapped onto 56 National Topographic Series sheets (separate from this report) at 1:100,000 scale.

Hazard map units are colour coded with a "stoplight" classification system. The colours red, yellow and green mean stop, caution and go respectively. Geotechnical investigations of terrain hazards may be required in stop and caution areas.

Most terrain hazards in the area are natural geomorphic processes influenced by storm and seismic activity, permafrost and other effects. An extraordinary variety of hazards occurs in the Kluane Lake Corridor from Silver Creek (Alaska Highway km 1694) to Burwash landing (km 1760). These hazards are mapped and evaluated in more detail than in the larger study area.

Storm activity in July 1988 brought many of the landslide and flood hazards in the Kluane Lake corridor to attention. The travelling public and highway operations are at risk from storm-generated landslides along the Alaska Highway from the south shore of Kluane Lake north to the area of Congdon Creek.

There is a continuing risk of alluvial fan flooding, erosion and deposition along the Alaska Highway throughout the area. Silver City is at risk of flood erosion and deposition. Destruction Bay and Burwash Landing may be affected by stream flooding.

Hazards and risks are defined; concepts of stated and estimated risk and determinations of acceptable risk are discussed for guidance in planning.

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THURBER

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THURBER

1. INTRODUCTION

This is a map study of terrain hazards covering 35,000 km^2 within the Kluane Regional Planning Area (KRPA) of the southwest Yukon Territory (Figure 1). The terms of reference for the study are given in Appendix D.

The KRPA includes the Kluane Wildlife Sanctuary in three separate areas along the eastern boundary of Kluane National Park. Kluane National Park is not included in the study unless hazards within the park affect the KRPA. The study area includes 56 1:50,000-scale National Topographic Series (NTS) maps (Figure 2).

Two sets of hazard maps have been prepared during the study. In Phase 1, hazardous features were mapped by photo interpretation on to 56 1:100,000-scale sheets. Selected areas of high or significant risk ("hot spots") were mapped on to 8 1:50,000 scale sheets for field checking during Phase 2. All hazards maps are submitted separately.

2. PREVIOUS HAZARD ASSESSMENT

2.1 General

Terrain hazards are defined as naturally occurring geological and geomorphic processes and unstable conditions that present a risk to life and property (Ryder and MacLean, 1980, p. 1). Landslide terminology in this report generally follows the nomenclature of Varnes (1978).

This study is preceded by similar work which focused on the southwest margin of the KRPA near Kluane Lake. Clague (1979b, 1981 and 1982) discussed the variety of natural hazards in the Shakwak Valley; his work is a foundation for this study. He (1982) notes the following potential hazards which are generally defined for later use in this report:

a) A variety of landslides in which bedrock moves slowly or rapidly by falling, toppling, rotation, translation or other complex movements.

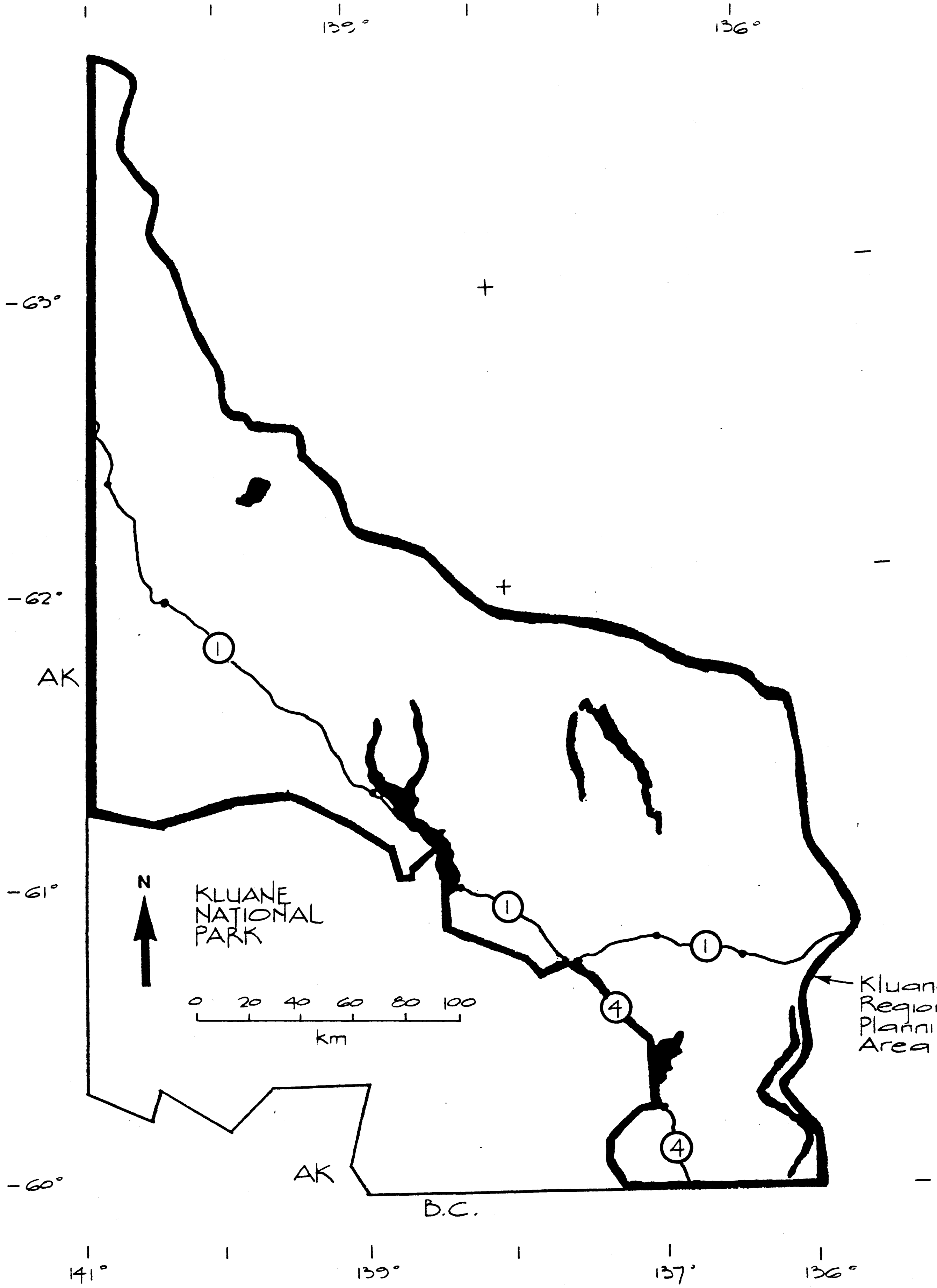

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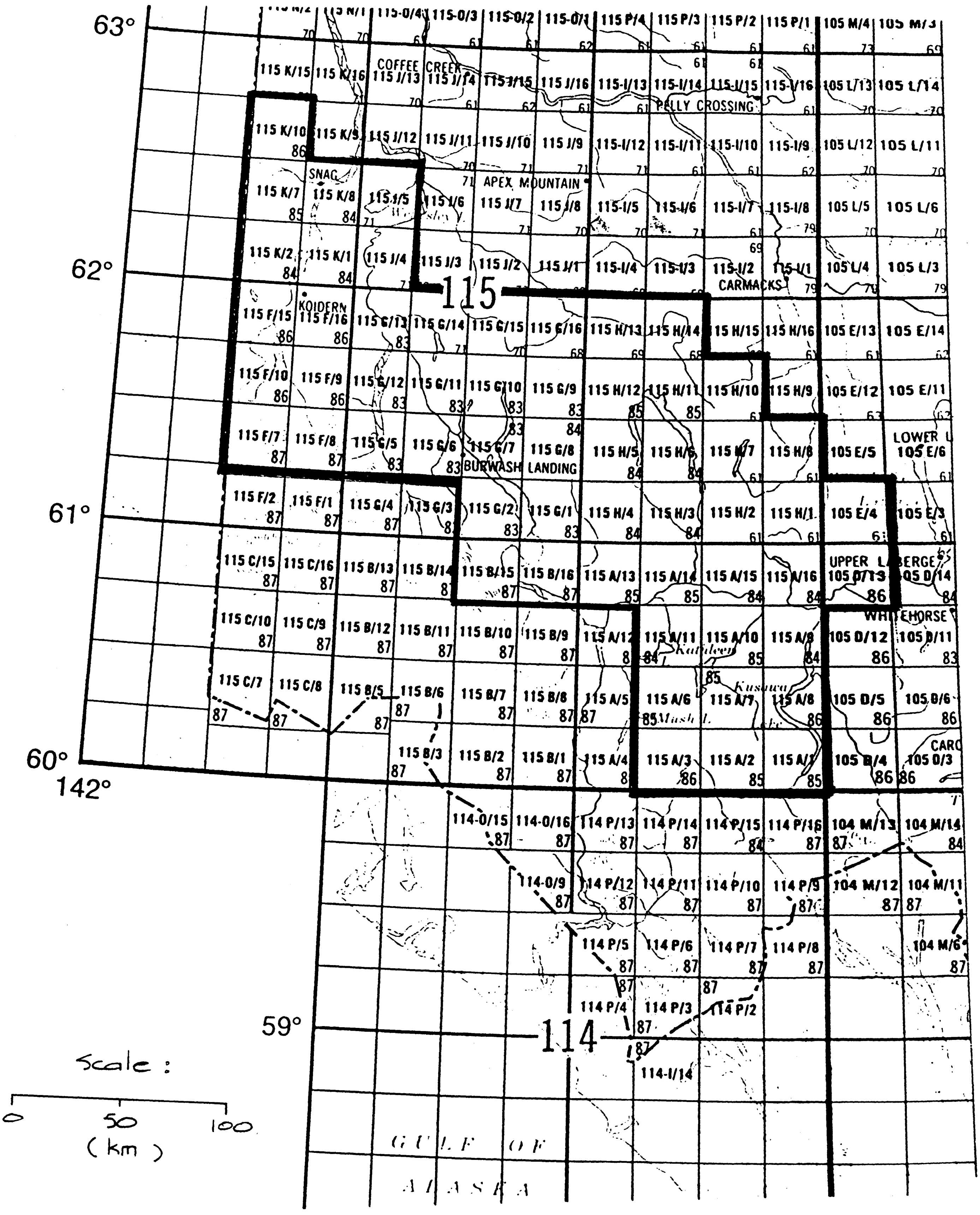
Fig. 1



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115 K/15 115 K/16 115 J/13 115 J/14 115 J/15 115 J/16 115-I/13 115-I/14 115-I/15 115-I/16 105 L/13 105 L/14
COFFEE CREEK
PELLY CROSSING
115 K/10 115 K/9 115 J/12 115 J/11 115 J/10 115 J/9 115-I/12 115-I/11 115-I/10 115-I/9 105 L/12 105 L/11
SNAG
APEX MOUNTAIN
115 K/7 115 K/8 115 J/5 115 J/6 115 J/7 115 J/8 115-I/5 115-I/6 115-I/7 115-I/8 105 L/5 105 L/6
115 K/2 115 K/1 115 J/4 115 J/3 115 J/2 115 J/1 115-I/4 115-I/3 115-I/2 115-I/1 105 L/4 105 L/3
CARMACKS
KOIDERN
115 F/15 115 F/16 115 G/13 115 G/14 115 G/15 115 G/16 115 H/13 115 H/14 115 H/15 115 H/16 105 E/13 105 E/14
115 F/10 115 F/9 115 G/12 115 G/11 115 G/10 115 G/9 115 H/12 115 H/11 115 H/10 115 H/9 105 E/12 105 E/11
115 F/7 115 F/8 115 G/5 115 G/6 115 G/7 115 G/8 115 H/5 115 H/6 115 H/7 115 H/8 105 E/5 105 E/6
BURWASH LANDING
LOWER
115 F/2 115 F/1 115 G/4 115 G/3 115 G/2 115 G/1 115 H/4 115 H/3 115 H/2 115 H/1 105 E/4 105 E/3
115 C/15 115 C/16 115 B/13 115 B/14 115 B/15 115 B/16 115 A/13 115 A/14 115 A/15 115 A/16 105 D/13 105 D/14
UPPER LABERGE
115 C/10 115 C/9 115 B/12 115 B/11 115 B/10 115 B/9 115 A/12 115 A/11 115 A/10 115 A/9 105 D/12 105 D/11
WHITEHORSE
115 C/7 115 C/8 115 B/5 115 B/6 115 B/7 115 B/8 115 A/5 115 A/6 115 A/7 115 A/8 105 D/5 105 D/6
115 B/3 115 B/2 115 B/1 115 A/4 115 A/3 115 A/2 115 A/1 105 D/4 105 D/3
CARC
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114 P/5 114 P/6 114 P/7 114 P/8 104 M/6
114 P/4 114 P/3 114 P/2
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GULF OF
ALASKA
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0 50 100
(km)

16-10-18

Fig. 2

b) Soil landslides which move slowly or rapidly by rotational and translational movements. Soil creep and landslides involving the shallow active layer of permafrost terrain are included.

c) Debris flows, meaning rapid channelized movements of old slide debris and other soil and rock material. Debris torrent is an equivalent term. Debris flows may become debris floods (also sediment-laden water flows, Pierson and Costa, 1987) on flatter slopes.

d) Seismic shaking and ground rupture associated with earthquakes.

e) Permafrost degradation resulting in thaw terrain (thermokarst).

f) Flood inundation, erosion and deposition triggered by heavy rain and snow melt.

g) Jökulhlaups (catastrophic floods generated by englacial meltwater) in the upper Slims, Donjek and White River valleys (Clague, 1982, p. 27-30). Jökulhlaups may have severe effects in some areas but their probability of occurrence may be low and their flow energy may be attenuated along wide, braided river beds (Clague, 1981, p. 31).

h) Inundation of the Haines Junction area by glacier-dammed Lake Alsek. The community of Haines Junction lies just above the probable flood limit (el. 595 m on NTS 115 A/13, see Clague and Rampton, 1982). Such a lake would take several years to form. A detailed mapping study is required to evaluate possible shoreline effects.

i) Explosive volcanism near the Alaska-Yukon border (Clague, p. 34-35) and related ash falls or other accumulations of pyroclastic debris. There is a low probability of such a damaging eruption.

j) Snow avalanches throughout the mountain region (Appendix B5) or ice falls in glacier areas.

These diverse natural phenomena reflect the high activity of geologic and geomorphic processes in the region (Clague, 1981).

Terrain in the communities of Champagne, Haines Junction, Destruction Bay and Burwash Landing has been evaluated by Terrain Analysis and Mapping Services Ltd. (1980). That study should be used for planning in each community.

2.2 Conditioning of Terrain Hazards

2.2.1 Storm Events

Severe rain storms in July 1988 caused widespread landsliding and flooding in the KRPA (Evans and Clague, 1989). Future storms will activate landslides and floods throughout the KRPA.

2.2.2 Seismic Activity

The KRPA is in an area of high seismic risk (National Research Council of Canada, 1985, p. 221-241). The geologic literature has a number of references to strong earthquake activity and surface disturbances along faults within the area (Eisbacher and Hopkins, 1977 and Clague, 1979, 1982). Earthquake hazards can be minimized by proper engineering design and construction.

Large landslides can be triggered by small earthquakes, as was the 1965 Hope Slide in British Columbia (Wetmiller and Evans, 1989). Areas of sensitive soil (e.g. saturated silts and sands) and distressed slopes may have failures triggered by seismic activity. Clague (1982, p. 26) notes the front of the actively prograding Slims River delta at the south end of Kluane Lake is subject to subaqueous landsliding or liquefaction. This activity could also affect the nearby Alaska Highway (Section 5.4).

2.2.3 Permafrost

There is widespread, discontinuous permafrost in the region (Brown, et al., p. 32). The limits of permafrost cannot be reliably determined on aerial photos. Nonetheless, active-layer processes cause a degradation of stability conditions on most north-facing slopes. Several areas of thawing permafrost (thermokarst) were observed in the northern KRPA. The many rock glaciers in the area show evidence of flow caused by buried or interstitial ice.

Ground ice (probable permafrost) was encountered by Foothills Pipe Lines Ltd. in its alignment investigation in the Kluane Lake Corridor (FPL, 1981).

Shallow landslides ("skin flows") may start where active-layer soil loses cohesive strength by thawing. These slides may occur on comparatively shallow slopes. Soil movements, including heave and creep phenomena, occur seasonally in permafrost and non-permafrost terrain. Such processes are very widespread (Appendix B4).

Permafrost must be considered by engineering and construction work throughout the KRPA. Seasonal conditions such as severe icings in ditches and culverts may also cause difficulties which are recognized by local experience.

2.2.4 Kluane Lake Level and Drainage Reversals

The geologic record shows that the surface elevation of Kluane Lake has changed considerably during the last 10,000 years. During most of this time Kluane Lake was smaller and its surface elevation was about 12 m lower than present. It drained southward via the Slims and Kaskawulsh Rivers into the Alsek System (Bostock, 1969).

The Kaskawulsh Glacier advanced across the valley at its terminus about 2640 years ago (Denton and Stuiver, 1966). Outwash gravels aggraded in the valley north of the glacier and reversed the gradient of the Slims River. This reversal blocked the former outlet of Kluane Lake and raised its level. The raised lake overflowed northward and cut the present Kluane River outlet into the Yukon system. Clague (1981, p.963 - 964) notes Kluane Lake was 12 m deeper than present within the last 260 years. The snout of the Kaskawulsh Glacier was the drainage divide between the Alsek and Yukon River systems in historic time.

The snout of the Kaskawulsh Glacier has down wasted and retreated in recent historic time. A study of NTS map contours (NTS 115 B/15 and G/6) shows there is only a 19 m difference in elevation between the head of the Slims River outwash system and the lake level. The Slims River has a very low gradient - less than 1 percent toward Kluane Lake.

The elevation difference between the bedrock-controlled lake outlet and the uppermost Slims River is little more than the 19 m just noted. Seismic activity (Bostock, 1969) and fluvial erosion (Clague, 1981) at the Kluane River outlet may account for the geologically recent 12 m drop in lake level.

In 1989, the Kaskawulsh River captured the glacial drainage of its glacier and intercepted its Slims River discharge. This caused an approximate 2 m drop in the level of Kluane Lake. Similar, but temporary, interceptions occurred in recent decades and resulted in silt-sand storms along the dried bed of the Slims River (pers. com., Dr. Gerald Holdsworth, National Hydrology Research Institute, Saskatoon).

If the Slims River is not resupplied by the capricious englacial plumbing system of the Kaskawulsh Glacier or the glacier does not readvance, Kluane Lake's water supply will stay reduced and the lake may continue to drop. In this case, the present upper Slims flood plain will form the drainage divide between the Kaskawulsh River and Kluane Lake. Much depends on the state of the Kaskawulsh Glacier.

It is conceivable that the Kaskawulsh River will erode headward into the abandoned Slims River deposits and, hundreds or thousands of years from now, will recapture Kluane Lake. This possibility is limited by the geologically recent, and possibly continuing, erosion of the lake's outlet upon which much also depends.

The recent lowerings of the lake surface affect base levels of tributary creeks. Some amount of stream incision may be expected on many alluvial fans along the lake shore (Sections 5.2 and 5.6).

3. METHODOLOGY

3.1 Phase 1

In consultation with the Scientific Advisors early in Phase 1, it was decided that the aerial photo interpretive mapping would use the Terrain Classification System for British Columbia (Howes and Kenk (eds.), 1988). This classification system is ideally suited for reconnaissance work at a variety of map scales.

A literature has developed for incorporating it into planning and hazard studies (Ryder and MacLean, 1980; Ryder and Howes, 1986 and Maynard, 1979) as well as for thematic mapping in a Geographic Information System (Kenk et al., 1987).

Appendix B contains the simplified terrain map legend and important interpretive information. The full (expanded) version of the classification system is given in Appendix C.

In the Phase 1 work, terrain hazards were mapped from 650 small-scale aerial photos taken 10 or more years ago (see photo reference). Photo coverage is missing for some portions of the KRPA and there are obscuring shadows on some images (Figure 3).

The regional bedrock geology was reviewed on maps of 1:1,000,000 scale (Gabrielse et al., 1980) and 1:125,000-scale (Geological Survey of Canada, 1983).

The surficial geology and terrain are mapped over most of the area (Figure 4) by Rampton (1978 a-e and Rampton and Paradis, 1981 a-c). Rampton (1981) also mapped much of Kluane National Park at 1:250,000 scale. These maps show important information that supplements the hazard maps in this study.

3.2 Phase 2

The Phase 2 field work was carried out jointly with Dr. S.G. Evans of the Geological Survey of Canada, assisted by Mr. S. Dennison. This work was completed in excellent weather during July 1989.

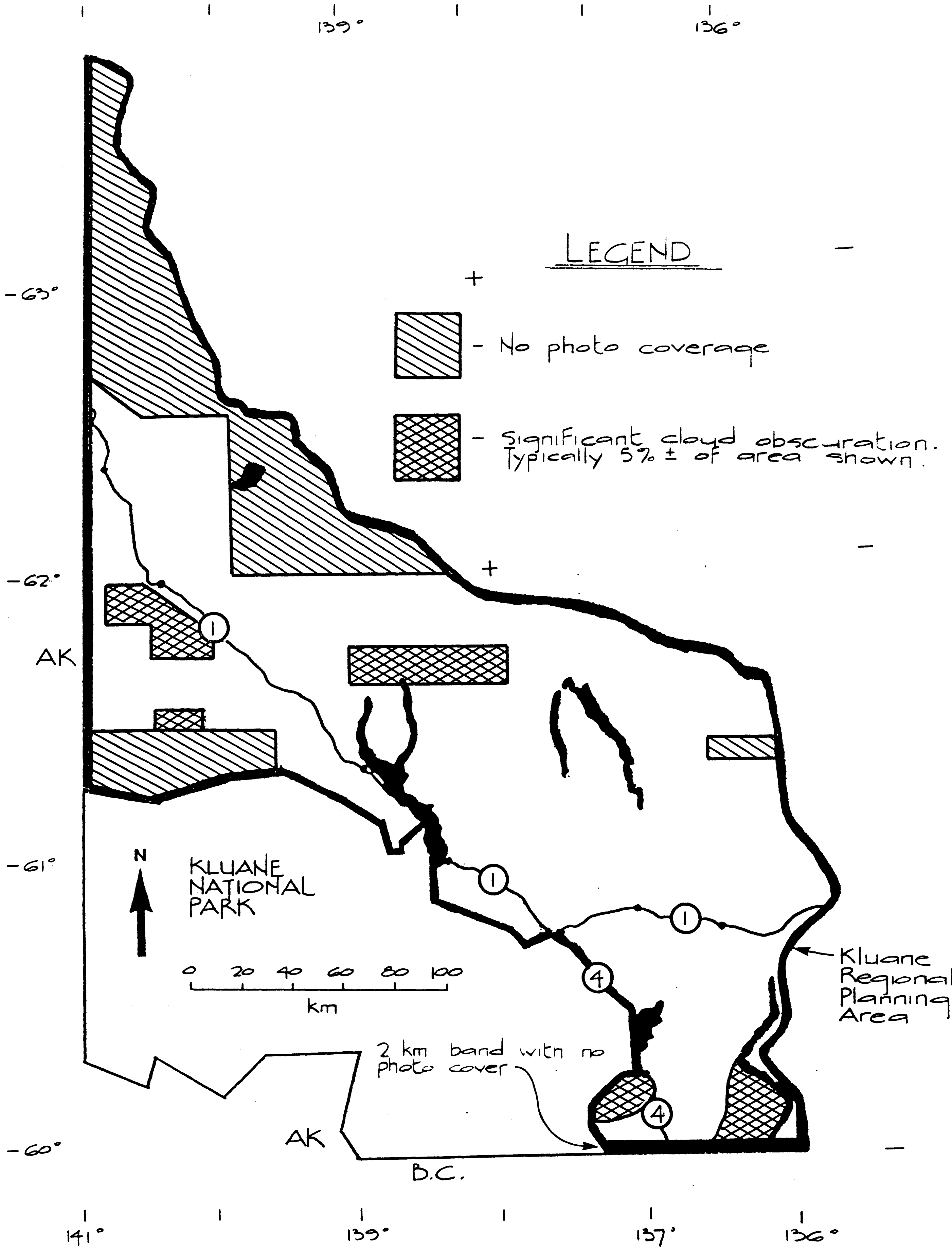

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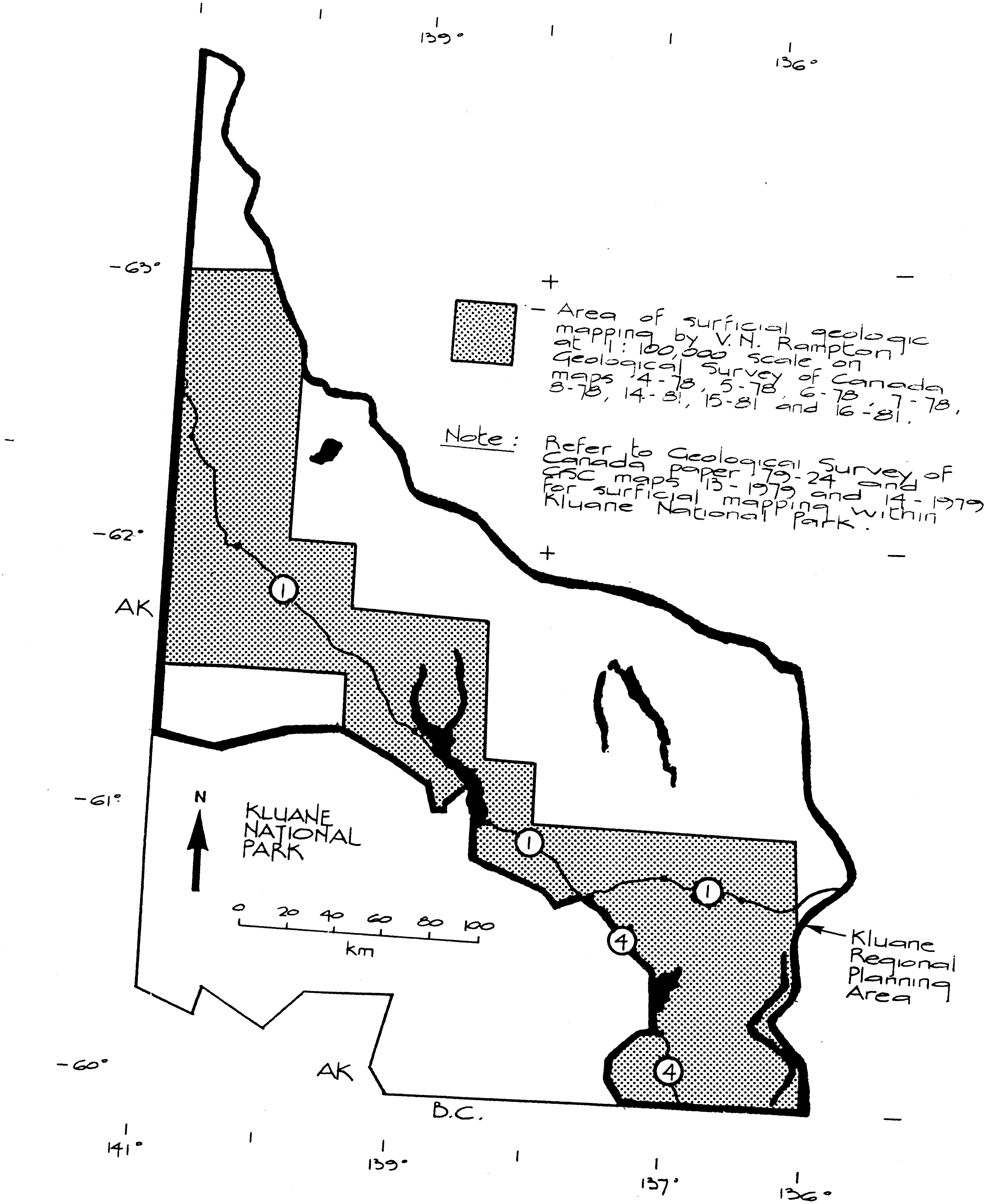
Fig. 3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Area of surficial geologic mapping by V.N. Rampton at 1:100,000 scale on Geological Survey of Canada maps 4-78, 5-78, 6-78, 7-78, 8-78, 14-81, 15-81 and 16-81.
Note: Refer to Geological Survey of Canada paper 79-24 and GSC maps 13-1979 and 14-1979 for surficial mapping within Kluane National Park.
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Fig. 4

Our field work reduced concerns over many of the hot spots tentatively identified in the Phase 1 study and permitted the hot spot designation to be dropped. This Phase 2 report considers only confirmed hot spot locations in the Kluane Lake corridor between Silver Creek and Burwash Landing. These are discussed in Section 5.

We issued a letter (August 24) regarding public safety at a facility on the north side of the Slims River at Kluane Lake (Section 5.5). More aerial photo studies and research followed the field work.

3.3 Use of Terrain Hazard Maps

Reference to the terrain hazard maps may be required throughout this report. The following points are for the guidance of map users.

a) The maps are specialized and edited to emphasize terrain hazards.

b) Map units are subjectively evaluated for risk to property and life. Features such as rockfalls, landslides, snow avalanches and colluvial fans are judged to present high risks. Active-layer soil processes, some colluvial-fluvial fans and other features on slopes less than 50% (27° from horizontal) are often judged to be comparatively moderate hazards. Areas with no apparent hazards are unmapped or mapped only to clarify adjacent units.*

c) A "stoplight" system (see Varnes, 1974, p. 36) was used to colour the mapped terrain units. Red (stop) was applied to high hazard areas. Yellow (caution) was applied to moderate hazard areas. The colour

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* "Hazardous" terrain should be distinguished from "difficult" terrain. Difficult and restrictive terrain includes muskeg, areas of soft silt or clay-rich soil and areas where there is a shortage of granular borrow for construction purposes (Hardy and Associates, 1984). Such areas may not be identified as "hazardous" in this study.

green (go) is shown in some locations and is implied in unmapped areas.

d) Active soil processes are important considerations in yellow-coloured (caution) map areas. In green coloured areas, such processes may not always be mapped because of poor photo resolution. They should be cautiously anticipated throughout the KRPA.

e) Hot spots are shown with red (stop) coloration on the 1:100,000 (regional) and 1:50,000-scale (hot spot) maps which accompany this study. Areas of caution (yellow) are also shown on each map set.

f) Geotechnical hazard investigation should be required in both red and yellow areas on on each map set. Good geotechnical design and construction practice and sensible avoidance of potential problems is expected to be standard regardless of the colour coding.

Many of the red coded areas on the hazard maps have a prevalence of objective hazards. Many of the yellow coded areas have a prevalence of subjective hazards.

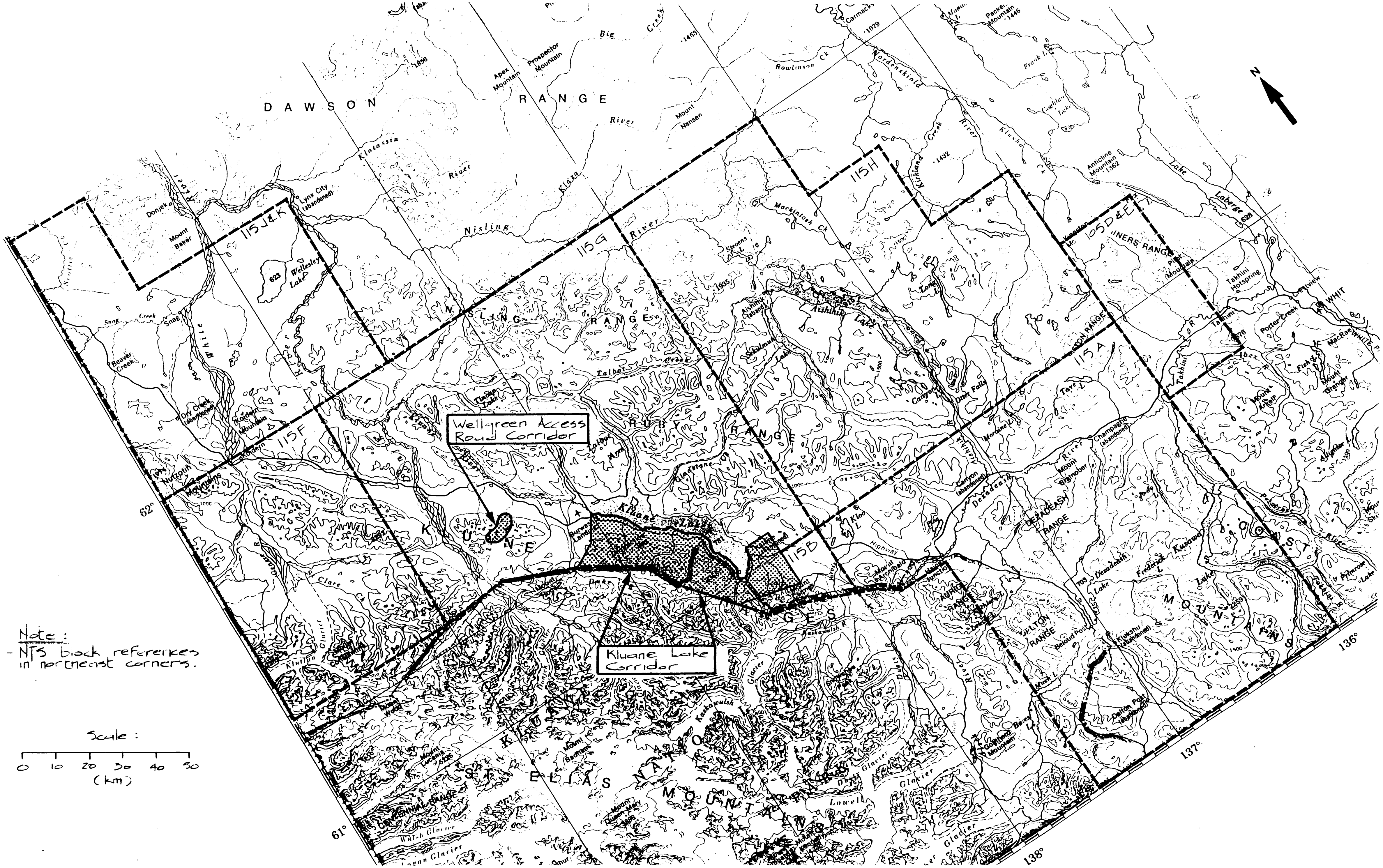
4. AREA DESCRIPTION OF TERRAIN HAZARDS

4.1 General

This section of the report presents a discussion of regional terrain hazards shown on 1:100,000 scale maps. Figure 5 shows the study area's NTS map blocks in relation to major geographic features.

4.2 NTS Blocks 105 D and E

There are two map sheets (105 D/13 and E/4) in this area at the eastern limit of the KRPA. The area covers the broad valleys of the east-flowing Takhini River (Yukon River drainage) and its tributary, Thirty-seven Mile Creek. Except for small areas of possible snow avalanching and eroded slopes along the Takhini River, the greatest hazards result from active soil processes.



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GEOGRAPHIC FEATURES OF THE STUDY AREA

Fig. 5

4.3 NTS Block 115 A

This is the southern portion of the KRPA and includes 13 NTS sheets. The eastern third of this area, including Kusawa Lake, is drained by the Takhini River. A small area at the southwest lies within the Tatshenshini basin. Most of the area is drained by the north and westward flowing Dezadeash River which feeds the Alsek River beyond the KRPA.

There is a variety of terrain hazards in the area with active soil processes predominating. Debris flow fans are identified along the Haines Highway north and south of the Takhanne crossing. There is deep-seated bedrock distress high above the Haines Highway south of the Takhanne. Other areas of interest include distressed bedrock on steep slopes north of the Takhanne River and east of the Tatshenshini.

Very steep and severely fractured bedrock slopes occur above Kusawa Lake. Although several major rock falls have occurred, evidence of landsliding that might generate catastrophic flood waves was not observed.

In 1982, a large debris flow followed heavy rain at the north end of Kusuwa Lake (Bremner, 1986). Our reconnaissance indicates a camp site affected by this activity has since been abandoned and moved to a safer location.

4.4 NTS Block 115 B

This area includes two NTS maps (115 B/15,16) within the Kluane Wildlife Sanctuary (KWS). The entire area lies within the Kluane Lake basin which drains north to the Yukon River system.

The upland area east of Vulcan Creek lies within the Kluane Lake corridor (Section 5). Bedrock landslides occur south of the Slims River between Vulcan Creek and the Alaska Highway bridge. Several debris flow fans along the Slims River and the Alaska Highway are fed from steep upland sources (Clague, 1982 and Gustafson, 1986).

NTS sheet 115 B/16 shows the alpine headwaters of Silver Creek and an un-named creek to its west. Silver

Creek caused flood problems in the storms of July 1988 (Evans and Clague, 1989).

4.5 <u>NTS Block 115 F</u>

This area lies mostly within the Kluane Wildlife Sanctuary and includes 6 NTS sheets. The southern area is heavily glacierized and includes the immense stagnating snout of the Klutlan Glacier. It drains into the wide braided expanse of the Generc River and thence to the White River (Yukon drainage). The Generc and White River systems may be affected by jökulhlaups (Clague, 1982).

There is a large amount of very steep alpine terrain with rockfall, snow avalanches, debris flows and several large landslides. An interesting ancient landslide is located on the south shore of Tepee Lake (NTS 115 F/9).

4.6 <u>NTS Block 115 G</u>

This large area of 15 NTS sheets is the core of the hazard study area. The western portion drains northward into the White River via the heavily braided Donjek River. This river may also be affected by jökulhlaups. Most of the eastern area lies within the Kluane Lake basin which drains into the Donjek. The very northern area is drained by another Donjek tributary, the Nisling River.

This area also has a variety of hazardous terrain. The Alaska Highway was severely affected by the storm events of July 1988 especially at Silver City and in the Slims River, Sheep Mountain and the Congdon Creek areas. These hazards are discussed in Section 5 (also Clague, 1981, 1982 and Evans and Clague, 1989).

A possible landslide fan extends 3 km beyond the foot of the Kluane Ranges in the Kluane Wildlife Sanctuary north of Congden Creek (115 G/2). This feature is discussed in Section 5.8.

The Burwash Uplands and the Amphitheatre Mountain area, between the Duke River and Burwash Creek, displays an interesting variety of landslide features caused by weak rock and soft-soil deformations. Heavily gullied (badland) topography is located near Amphitheatre Mountain (115 G/6, see Eisbacher and Hopkins, 1977).

The mine road access corridor to the Wellgreen Property along Quill Creek (115 G/5,6) was the focus of special interest and is discussed in Section 6.

4.7 NTS Block 115 H

This area of 13 NTS maps has comparatively subdued terrain. The northern area is drained by the Nisling River which flows northwest to the Donjek. The central area, including Sekulmun and Aishihik Lakes, drains south into the Dezeadash system via the Aishihik River. Most of the eastern area is drained northward by the complex upper system of the Nordenskiold River (Yukon drainage).

Rock falls, debris flow and flood hazards occur throughout the area. Active soil processes are very common. There is photo evidence of permafrost and thermokarst in the northern portion.

4.8 NTS Blocks 115 J and K

This area includes 7 NTS maps at the northern limit of available photo coverage within the KRPA (Figure 5). The braided courses of the White and Donjek Rivers flow north through this generally subdued area.

Active soil processes are dominant although avalanches, rockfalls and landslides are noted in mountain areas on maps 115 K/1 and 2. There is photo evidence for permafrost and thermokarst in many muskegs.

5. KLUANE LAKE CORRIDOR

5.1 Introduction

The Kluane Lake corridor contains the most critical terrain hazards in the KRPA. Many important features were mapped by Rampton (1978 c and e) with hazards evaluated by Clague (1981 and 1982). The hazards were activated and brought to public attention by the storms of July 1988.

Figure 5 shows the location of the corridor within the larger study area. Terrain Analysis and Mapping Services Ltd. (TAMSL, 1980) gives detailed information for the communities of Destruction Bay and Burwash Landing.

Descriptions of hazards begin with the Silver Creek alluvial fan and continue northward 65 km along the Alaska Highway to the Halfbreed Creek alluvial fan at Burwash Landing. All kilometre stations are approximated from Public Works Canada logs.

The descriptions may require reference to 1:50,000-scale maps which are submitted separately. Slide areas activated by the 1988 storm activity are shown with arrow symbols on these maps. Appendix A has photographs referred to in this section.

5.2 Silver Creek Alluvial Fan

This fan is a composite feature fed by Silver Creek (crossing at km 1694) and an un-named Alaska Highway crossing several kilometres to the west. The activity of Silver Creek dominates the fan.

The 1972 aerial photos show the Silver Creek channel splits in the area of the present Highway crossing. (These photos were taken before the highway was relocated southward from what is now the Silver City access road.) Then and now, the right channel (facing downstream) flowed directly toward Silver City; the left channel followed a more southerly course toward the airstrip near Kluane Lake (see Photos A-1 and A-2).

The 1972 photos also show stream control works on the lower right channel in the area of Silver City. The 1988 flood more or less followed this channel. Photo A-1 shows the fresh alluvial fan which has formed at the channel's lake outlet during the year 1988 - 1989. It also shows the lower creek has been controlled with earthworks since the 1988 storms.

The active left channel on the Silver Creek fan is the larger of the two (Photos A-1 and A-2). The new Alaska Highway follows this channel for several kilometres below the Silver Creek crossing to the less dominant un-named creek system which enters from the left. Both streams feed a system of distributary channels which radiate toward the air strip near Kluane Lake (Photo A-2).

The Silver Creek feature is a classic large alluvial fan. The Silver Creek fan is sustained by an unlimited supply of easily mobilized sediment generated by weak bedrock in its alpine headwaters (Geological Survey of Canada, 1983). This sediment is readily activated during periods of heavy rain. The volume of mobilized sand and gravel may overwhelm the carrying capacity of flood water when it reaches the fan so widespread deposition occurs.

Gravelly material is first deposited from the sediment charged streams on the upper reaches of the fan. As channel gradients decrease on the middle fan, water velocities decrease. The last of the gravel load may be deposited while sand and finer material remains suspended in the flood water. Sediment may fill minor channels and force flood deposition to spread over the fan surface.

It is likely that much of the July, 1988 deposition on the lower fan was sandy textured. The heavy sediment load carried by the left channel of Silver Creek was apparently distributed along its braided course and into several natural distributaries at the lower end of the fan (A-2). Our 1989 observations showed recent stream flows, much reduced from the flood discharges and unburdened with sediment, have energy enough to incise the 1988 storm deposits below the Highway.

If storms did not generate so much sediment, the fan would be starved of its supply and Silver Creek would incise deeply. Fan deposition has also been promoted by the base-level control of the comparatively high stand of Kluane Lake in the last several thousand years (Section 2.2.4). It is probable that lowering lake level of the last few hundred years is reflected by some amount of stream incision on the fan. If the level of Kluane Lake continues to fall, Silver Creek may become more entrenched.

The entire fan surface should be considered active and is coded red (stop) on the hazard maps. Flood erosion and deposition should be expected during future periods of heavy rain. These hazards will lead to risks of property damage and possible injury. Detailed effects may be unpredictable without further study. Erosional or depositional control works should only be undertaken after comprehensive hydraulic studies.

The essential elements of the above discussion apply to other fans including transitional process (colluvial-alluvial) features just west of the Silver Creek fan (Section 5.3) and north of Sheep Mountain (Sections 5.6 to 5.7). The great fan of Congdon Creek and others to its north are similar in most respects to the Silver Creek fan.

5.3 Colluvial Aprons: South Shore of Kluane Lake

Between the west end of the Silver Creek fan and the Alaska Highway crossing of the Slims River, there is a continuous hazard from debris flows (Photos A-3 and A-4). Flows were activated in 1988 and the area has a history of such activity (Appendix B3). Snow avalanches probably also run out on the upper portions of these aprons.

Debris flows are a type of rapidly moving landslide which may involve a wide range of sediment textures. Such flows are transitional with alluvial processes. Debris flows commonly translate into sediment-laden water flows (Pierson and Costa, 1987) on the lower slopes of colluvial fans. In the Canadian Rocky Mountains, Jackson et al. (1987) note that the slope transition between alluvial and fans is between 2.5 and 4° from the horizontal.

Sediment-laden water flows probably crossed the Alaska Highway near the Silver Creek fan (Photo A-3) while debris flows crossed the highway on steeper fans to the west (Photo A-4).

The 1988 activity resulted from heavy rain in the very steep and debris-loaded alpine basins south of the highway. The flows probably began as debris avalanches (very rapid slides of mixed soil and rock) which torrented down the steep channels and ran out across the coalescing fans (aprons) near the lake. The debris included boulders, cobbles and gravel, tree roots and mud. The coarse nature of the rock debris reflects the comparatively high competence of granitic rocks in the upper basins (Geological Survey of Canada, 1983).

Evans and Clague (1989, p. 196) note the Alaska Highway was blocked for a distance of about 500 m at one location in this area. The debris flow that blocked the highway in 1967 (see Appendix B3) occurred on a prominent fan where there was little apparent activity in 1988.

Debris flows move rapidly and there is not sufficient warning time to evacuate their path. There is strong evidence for past activity in the area, including alpine basins of several creeks which remain loaded with debris. Debris flows are life-threatening hazards and may also cause severe property damage. The colluvial aprons in this area are colour coded red on the hazard maps.

There is extensive bedrock landsliding on the slopes just west of colluvial fan system. Almost all this activity lies within Kluane National Park.

5.4 Slims River Crossing

The flood plain of the Slims River is the alluvial surface of a lacustrine delta. The Alaska Highway crossing of the river is a critical location with approach fills each about 1 km long. The bridge is comparatively short.

Clague (1981, p. 963-964) indicates Kluane Lake was recently 12 m above present level (Section 2.2.4). The Highway crossing would have been submerged. There was probably silt-sand deposition in this marginal portion of the deeper lake. Saturated fine-grained soil may now lie beneath surface gravel along the approach fills and bridge piers. Such soil could liquefy under seismic stress and severely damage the crossing. Geotechnical investigations may be required to evaluate the seismic risk.

5.5 Sheep Mountain Area

This is a section along the Alaska Highway between km 1707 and approximately km 1711 just south of Horseshoe Bay. Photo A-5 shows slope details in the area of km 1707. The larger area is shown on Photo A-6.

The Sheep Mountain area is of geologic interest because of its widespread evidence of landslides including the Sheep Mountain rock avalanche which occurred between 490 and 1950 years ago (Photo A-6 and Clague, 1981). (A rock avalanche is an extremely rapid and highly destructive bedrock landslide.) Clague (p.966-969) notes the steep slopes formed of fractured bedrock are susceptible to a variety of landslide processes which may be triggered by rain storms, periods of rapid thaw or seismic activity. He further notes (p. 969) the threat of bedrock landslides is low relative to debris flow activity on nearby colluvial fans.

Thurber Consultants Ltd. has advised (in a letter dated August 24, 1989 also signed by Dr. S. G. Evans of the Geological Survey of Canada) there is a risk of debris slides at a public facility at the colluvial fan just north of the Slims River (A-5). The fan was described by Clague (1981, p. 964-965).

We noted the probability of debris slides was low at this site. However, the travelling public is burdened by involuntary risk when making routine or refuge stops during adverse weather such as the storm event of 1988 when the Alaska Highway was cut off by slides to the north and south.

Two debris avalanches crossed the Alaska Highway near km 1711 during the July 1988 storm (Photo A-5). These were rapidly moving, comparatively shallow slides which involved saturated soil and included tree roots and logs (Photo A-7). Such slides are often triggered by intense rain storms. They have considerable destructive potential and apparently blocked the Highway in July 1988.

This short sector of the Kluane Lake corridor is coded red on the hazard maps because of its widespread landslide hazards.

5.6 Horseshoe Bay to Congdon Creek Fan

This sector of the Kluane Lake corridor extends from about km 1711 to 1721 of the Alaska Highway. It is an area of mixed terrain hazards consisting mostly of debris flows but with an interval of possible debris avalanching for 1 km north of Williscroft Creek.

From km 1711 to just north of Horseshoe Bay there is comparatively little hazard along the Highway (see maps) although cautious concern is warranted because of potential debris flows or other slide activity west of the Highway.

North of the bay, there are debris flow hazards on steep aprons above the Highway. Although old scars are evident, slides were not activated by the 1988 storms (Photo A-8). These hazards continue northward across the well-defined fan of Williscroft Creek (km 1716) which was activated in July 1988 (Photo A-9).

North of the Williscroft fan, a comparatively steep slope shows gullies and scarred evidence of past debris avalanches (approximate km 1717 to 1718, Photo A-9). North of the fan, two large colluvial-alluvial fans present debris flow and flood hazards as far as the right flank of the Congdon Creek alluvial fan (Photo A-10).

This sector is also coded red on the hazard maps because of debris flow and debris avalanche hazards.

5.7 Alluvial Fan Complexes: Congdon Creek to Halfbreed Creek and Burwash Landing

At km 1722, the Alaska Highway begins its crossing of the Congdon Creek alluvial fan near the north boundary of Kluane National Park. Beyond Congdon Creek, the boundary between the Kluane Game Sanctuary and Crown and other land follows the Alaska Highway.

The Highway's north to west alignment on the lower Congdon fan shows it was laid out to avoid a more direct but difficult route across rock features in the nearby Congdon Creek landslide (Photo A-11 and Section 5.8). Beyond an abandoned erosional channel at the slide margin, the Highway continues directly northwestward for 19 km to Burwash Landing.

The Highway crosses the large gravel fans of Congdon, Nines, Bock's, Lewis and Halfbreed Creeks in the remainder of the corridor. There are also several un-named creek systems (see maps).

There are several low plateaus along the Highway and west shore of Kluane Lake. These rise slightly above the alluvial surfaces and were formerly incised by the lower creeks, a reflection of the low stand of Kluane Lake (Section 2.2.4). The plateaus are formed of various glacial deposits and wind-blown sand (Rampton, 1977 c and e and TAMSL, 1980).

Ground ice was noted in exploratory work for the proposed Alaska Highway Gas Pipe Line (Foothills Pipe Lines Ltd., 1981). We found massive ice beneath organic topsoil near the Congdon Creek. There is widespread permafrost in this portion of the Kluane Lake corridor resulting in extensive yellow coding on the accompanying maps.

The most significant hazards are flooding and related erosion and sedimentation. All of the major creeks in the area were activated during the July 1988 storms. Culverts and highway bridges were blocked or lost and there was extensive gravel deposition. The active channels have since been widened and controlled with earthworks; bridges and culverts have been repaired and replaced.

The active channels of the alluvial fans are colour coded red to reflect hazards of flood deposition and erosion. Most of these channels have major divisions (see maps) and new channels may cut across now inactive surfaces. The inactive portions of the fans are coded yellow to reflect uncertainty over future creek behavior. Some incision should be expected along the lower creeks if the level of Kluane Lake continues to fall.

Where these streams affect developed areas, there could be property damage. There is a possibility of such damage in the communities of Destruction Bay and Burwash Landing (see maps). Detailed information for the communities of Destruction Bay and Burwash Landing is available in TAMSL, 1980.

The alpine basins of these creeks were mapped from aerial photos and explored by helicopter. They are similar to the Silver Creek basin in that they contain much weak bedrock (Geological Survey of Canada, 1983) and unlimited supplies of comparatively fine-grained sediment which is easily mobilized by rain storms. Like the Silver Creek fan, their form is a direct result of such storms. Each fan requires a comprehensive study to evaluate its flood hazards.

5.8 Congdon Creek Rock Avalanche

This area is colour coded red on the hazard maps. It was first mapped as landslide debris by Rampton (1978 e). Its volume may be on the order of 70,000,000 m^3.

An exploratory drill hole log provided by Mr. John Elwood of Foothills Pipe Lines Ltd. indicates 4.5 m of rockslide debris overlies mixed frozen soil and rock material to a depth of 12 m at a location along the old pipe line (Photo A-11). This log, the faint radiating pattern of the slide debris (seen on aerial photos) and other lines of evidence support a landslide interpretation. However, several characteristics of the feature cast doubt on its origin. For instance, the slide would have had to run out a remarkable distance (3.5 km) from an ill-defined source. Our field observations indicated the area is an extensive field of hummocky bedrock.

No evidence of imminent failures of similar nature were noted by our helicopter reconnaissance along the mountain front. Nonetheless, this feature may indicate that a very large landslide occurred in the Congdon Creek area. It may be a relict rock glacier or a slide mass which once rested on local glacier ice. We do not completely rule out a bedrock interpretation. More study is needed to gain assurance about the bedrock stability of the nearby mountain slopes.

6. WELLGREEN ACCESS ROAD CORRIDOR

The Wellgreen property is served by an existing road that extends west of the Alaska Highway near km 1789 (NTS 115 G/6 and 11). The critical terrain hazards begin where the road approaches the mountain front and continue for the remaining 9 km to the property on the north side of Nickel Creek, a tributary of Quill Creek.

Even though there is a potential for debris slides and possibly snow avalanches along the route (see maps including NTS 115 G/6), our helicopter reconnaissance suggests major geotechnical difficulties can be minimized or avoided with an improved road.

The most important hazard is erosion and deposition from Quill Creek itself. As the road approaches the mountain valley, it crosses the active alluvial fan and then ascends the left (north) side of the creek along the valley floor. It continues in similar fashion up the Nickel Creek valley. A relocation may be warranted in the area of the Quill Creek fan. Riprap erosion protection may be required along the side slopes upstream.

A small debris slide crosses the road where it enters the narrow valley of Quill Creek. This slide probably occurred in 1988. We do not know if this was a natural event, but similar slides could occur upstream if the future road cuts heavily into the side hill. No other debris slides were noted. Although snow avalanches are suspected on the upper slopes, there is little avalanche activity reported because of comparatively light snow fall in the area.

An improved road is feasible. Detailed geotechnical advice is warranted when the road is to be upgraded.

7. GUIDELINES FOR DETAILED HAZARD EVALUATION

7.1 Risk Defined

A definition of terrain hazards is given in Section 2.1. It implies that hazards create risks; risk is defined as exposure of life and property to danger.

7.2 Objective and Subjective Hazards

It is useful to note that terrain hazards may be classified as objective or subjective. Objective hazards exist without the presence of human activity. They include all naturally occurring phenomena including landslides, snow avalanches, and flooding. They are well defined, though not always recognized, and pose direct risks to property and life. Such hazards can either be avoided, controlled with expensive works or accepted on the basis of low probability.

Subjective terrain hazards exist only because of the presence of human activity. They include phenomena that arise from human intervention such as the cutting of a slope which causes a landslide. The risks imposed by subjective hazards are less obvious than objective hazards and their effects are highly conditional and conditional. Such risks can generally be reduced to acceptable levels with cautious awareness and proper engineering and construction.

Terrain hazard investigations are an increasingly specialized branch of geotechnical engineering and engineering geology. The determination of landslide probabilities requires consideration of a wide variety of physical evidence and much careful judgement. Investigation of snow avalanches is a separate, but related, field in which procedures are more established (Perla and Martinelli, Jr., 1976) but still require specialist skills.

7.3 Actuarial Statements of Risk

We assume risks in daily life. When we face risk with some degree of awareness (for example, driving a car), we assume a voluntary risk. When we are exposed to a danger beyond our awareness (for example, an unknown landslide), we are burdened with involuntary risk.

Pack and Morgan (1988, Table 5) give actuarial estimates of voluntary risks including a 0.03% annual probability (equivalent to 1:3500 annually) of being killed in a car (based on 1984 B.C. data). Actuarial estimates of involuntary risks include a 0.0003% annual probability (equivalent to 1:350,000 annually) of being killed by a "natural hazard" (Norwegian data).

These data are based on population statistics with allowances for different population bases, the data cited by Morgan and Pack indicate that a population may be 100 times more likely to be killed by voluntary car travel than by an involuntary exposure to natural hazards. They suggest that society (the customs and organization of a population) may be willing to accept voluntary risks which are roughly 1000 times greater than involuntary. Pack and Morgan also note that an individual member of society should not have to assume an involuntary risk of death greater than the pertinent actuarial probability (e.g. 1:350,000 annually for natural hazards in Norway).

7.4 Estimates of Risk from Terrain Hazards

The evaluation of total risk from a hazard requires practiced judgement and, under ideal circumstances, involves a linked series of calculations that begin with the probability of occurrence of that hazard. Pack and Morgan (1988) give a methodology for risk calculations.

In a hypothetical example, let us assume that a geotechnical specialist determines the probability of a landslide occurrence behind a residential dwelling in Norway to be 10% in 100 years (1:1000 annually). Based on the behavior of the expected slide and topographic considerations, the geotechnical specialist estimates the slide has a 40% probability (per landslide occurrence) of reaching the back yard of the house. He further estimates there is a 20% probability of the slide damaging the house but not hurting the occupants and a 10% probability of destroying the house and killing its occupants.

With the landslide probability of occurrence, P(O) = 1:1000 annually (or 0.001); the probability of slide runout to the back yard, P(Y) = 2/5 (or 0.4) per occurrence; the probability of house damage, P(D) = 1/5 (or 0.2) and the probability of house damage and death, P(X) = 1/10 (or 0.1), the probabilities are as follows:

a) Probability of slide reaching the back yard equals:

$$P(O) \times P(Y) = (0.001 \times 0.4) = 0.0004 \text{ (1:2500/yr)}$$

b) Probability of slide damaging the house equals:

$$P(O) \times P(Y) = (0.001 \times 0.2) = 0.0002 \text{ (1:5000/yr)}$$

c) Probability of slide causing occupant's death equals:

P(O) x P(X) = (0.001 x 0.1) = 0.0001 (1:10,000/yr)

Note that the probability of landslide occurrence is the critical first factor in these calculations. The geotechnical specialist may have to use considerable judgement in its determination and require much qualification in its use. Nonetheless, these idealized calculations illustrate the probabilities of risk to life and property may be significantly less than the probability of the hazard itself.

The ruling probability in the above example is that of the slide reaching the back yard where children may be endangered. If the assumed actuarial standard of involuntary risk (Section 7.2) is applied, the neighbour's children are burdened with an involuntary risk of injury or death by playing in the back yard.

An individual's situation may involve high risk. If the risk is realized, the unfortunate result may only contribute marginally to the population statistics. It is therefore important for an individual to distinguish between his actuarial and his situational risks. We minimize our situational risk of automobile death by wearing seat belts and maintaining our car. The Norwegian individual cannot seek assurance in the actuarial statistics if he chooses to accept the landslide risk to his home.

The Norwegian approving officer may condemn the home unless the owner builds landslide protective works as designed and approved by a geotechnical engineer. The abandoned site might be approved for other uses such as log storage yard where workers will have only infrequent exposure to the landslide hazard.

7.5 Acceptable Risk

Geotechnical estimates of risk are usually judgement based. In ideal circumstances, estimates are supported by various calculations including those for percentage probabilities.

Geotechnical specialists do not normally determine levels of acceptable risk for which political judgement is required. With an understanding of the nature of hazards and risks in this section, and the use of the hazard maps (Section 3.3), the Yukon Land Use Planning Office can formulate its planning procedures in the Kluane Regional Planning Area.

8. RECOMMENDATIONS FOR KLUANE LAKE CORRIDOR

There are significant hazards to the residents and travelling public in the Kluane Lake corridor (Section 5). We make the following general recommendations:

a) During periods of heavy rain and sudden thaws, the travelling public should be strongly discouraged from stopping along the Alaska Highway on the south shore of Kluane Lake (approximate km 1698 to 1704, Section 5.3) and the west shore (approximate km 1711 to 1722, Sections 5.5 and 5.6) where there is a possibility of dangerous landslides. Potential slide areas should be posted. Road closures may be required during periods of heavy rain and thaw.

b) Other recommendations concerning the public facility north of the Slims River (km 1707) have been given in our letter of August 24, 1989. Those recommendations relate to item a.

c) Stream erosion and deposition studies should be completed for the Silver Creek fan consistent with the information given in Section 5.2.

d) The possibility of stream flooding should be evaluated in the communities of Destruction Bay and Burwash Landing. Destruction Bay may be affected by an unnamed creek system; Burwash Landing by an abandoned path of Halfbreek Creek (see maps). The evaluations will require the use of information in the study by Terrain Analysis and Mapping Services Ltd. (1980).

e) Future developments on the alluvial fans elsewhere in the corridor will require comprehensive studies of stream behaviour.

f) The seismic risk to the Slims River bridge crossing should be evaluated with a geotechnical investigation (Section 5.4).

g) A multi-disciplinary study of the hydrology, geology and geomorphology of the Kluane Lake system should be undertaken. The study should concentrate on determinations of short and long-term variations in lake levels which could affect land use along the shore.

h) When the physical study of Kluane Lake is complete (or well underway), a geotechnical study of potential shoreline hazards is recommended. A shore zone setback (safeline) may have to be established in critical areas.

i) Residents and the travelling public should be informed of the unusual variety of natural hazards in the area.

REFERENCES

BOSTOCK, H. S., 1969: Kluane Lake, Yukon Territory, its drainage and allied problems (115 G and 115 F, E). Geological Survey of Canada Paper 69-28, 19 p.

BREMNER, T. J., 1986: Kusawa Lake fan - a brief geological assessment. 23 p.

BROWN, R. J. E., G. H. JOHNSTON, J. R. MacKAY, N. R. MORGENSTERN and W. W. SHILTS, 1981: Permafrost distribution and terrain characteristics. In Permafrost Engineering Design and Construction, G. H. Johnston ed., John Wiley and Sons, p. 31 -72.

CLAGUE, J. J., 1979a: The Denali Fault System in the southwest Yukon Territory - a geologic hazard? Geological Survey of Canada Paper 79-1A, p. 169-178.

CLAGUE, J. J., 1979b: An assessment of some possible flood hazards in Shakwak Valley, Yukon Territory. Geological Survey of Canada Paper 79-1B, p. 169-178.

CLAGUE, J. J., 1981: Landslides at the south end of Kluane Lake, Yukon Territory. Canadian Journal of Earth Sciences,, v. 18, p. 959-971.

CLAGUE, J. J., 1982: The role of geomorphology in the identification and evaluation of natural hazards. In Applied Geomorphology edited by R. G. Craig and J. L Craft. George Allen and Unwin, p. 17-43.

CLAGUE, J. J. and V. N. RAMPTON, 1982: Neoglacial Lake Alsek. Canadian Journal of Earth Sciences, v. 19, p. 94-117.

DENTON, G. H. and M. STUIVER, 1966: Neoglacial chronology, northeastern St. Elias Mountains, Canada. American Journal of Science, v. 264, pp. 577 - 599.

EISBACHER, G .H. and HOPKINS, S. L., 1977: Mid-Cenozoic paleogeomorphology and tectonic setting of the St. Elias Mountains, Yukon Territory. Geological Survey of Canada Paper 77-1B, p. 319-335.

EVANS, S. G. and CLAGUE, J. J., 1989: Rain induced landslides in the Canadian Cordillera, July, 1988. Geoscience Canada, v. 16, no. 3, p. 193 -200.

FOOTHILLS PIPE LINES (SOUTH YUKON) LTD., 1981: Geotechnical atlas: The Alaska Highway gas pipe line project. Km 71 to 247 (White River to Christmas Creek), drawings 0011 to 0035.

GABRIELSE, H. D., J. TEMPELMAN-KLUIT, S. L. BLUSSON and R. B. CAMPBELL, 1980: MacMillan River, Yukon-District of Mackenzie-Alaska, Geological Survey of Canada Map 1398A (1:1,000,000-scale).

GEOLOGICAL SURVEY OF CANADA, 1983: Open file maps 829 and 830, Southwest Kluane Lake and St. Elias map areas. Compiled by C. J. Dodds, 1:125,000 scale.

GUSTAFSON, C., 1986: Debris flows along the Slims River Valley, Kluane National Park, Yukon Territory. Unpublished M.Sc. thesis, University of Calgary, 148 p.

HARDY ASSOCIATES (1978) LTD., 1984: Land Use Guidelines; Access Roads and Trails. Prepared for Land Resources, Northern Affairs Program, 49 p.

HOWES, D. E. and E. KENK (contributing editors), 1988: Terrain classification system for British Columbia (revised edition). B.C. Ministry of Environment Manual 10. 90 p.

HUGHES, O. L., V. N. RAMPTON and N. W. RUTTER, 1972: Quaternary geology and geomorphology, southern and central Yukon. 24th International Geological Congress Guidebook A11, 59 p.

JACKSON, L. E., R. A. KOSTASCHUK and G. M. MacDONALD, 1987: Identification of debris flow hazard on alluvial fans in the Canadian Rocky Mountains. in Costa, J. E. and G. F. Wieczorek, eds., Debris flows/avalanches: process, recognition and mitigation. Geological Society of America, Reviews in Engineering Geology, v. 7, pp. 115-124.

KENK, E., M. W. SONDHEIM and H. QUESNEL, 1987: B. C. Ministry of Environment and Parks Thematic Mapping Geographic Information System - Data entry and validation procedures for soil, agriculture capability, surficial geology and the all purpose entity. 156 p.

MAYNARD, D., 1979: Terrain capability for residential settlements. Background and summary working reports published by the B.C. Ministry of Environment. 152 and 61 p. respectively.

NATIONAL RESEARCH COUNCIL OF CANADA, 1985: Supplement to the National Building Code of Canada. 278 p.

PACK, R. and G. MORGAN, 1988: Evaluation and acceptance of risk in geotechnical engineering. In Risk and Liability in Geotechnical Engineering, Vancouver Geotechnical Society.

PERLA, R. I. and M. MARTINELLI, Jr., 1976: Avalanche Handbook. United States Department of Agriculture Handbook 489, 254 p.

PIERSON, T. C. and J. E. COSTA, 1987: A rheologic classification of subaerial sediment-water flows. In Costa, J. E. and G. F. Wieczorek, eds., Debris flows/avalanches: process, recognition and mitigation. Geological Society of America, Reviews in Engineering Geology, v. 7, pp. 1-12.

RAMPTON, V. N., 1978a: Surficial Geology and Geomorphology; Mirror Creek, Yukon Territory. Geological Survey of Canada Map 4-1978, Scale 1:100,000.

RAMPTON, V. N., 1978b: Surficial Geology and Geomorphology; Koidern Mountain, Yukon Territory. Geological Survey of Canada Map 5-1978, Scale 1:100,000.

RAMPTON, V. N., 1978c: Surficial Geology and Geomorphology: Burwash Creek, Yukon Territory. Geological Survey of Canada Map 6-1978, Scale 1:100,000.

RAMPTON, V. N., 1978d: Surficial Geology and Geomorphology; Generc River, Yukon Territory. Geological Survey of Canada Map 7-1978, Scale 1:100,000.

RAMPTON, V. N., 1978e: Surficial Geology and Geomorphology; Congdon Creek, Yukon Territory. Geological Survey of Canada Map 8-1978, Scale 1:100,000.

RAMPTON, V. N., 1981: Surficial materials and landforms of Kluane National Park, Yukon Territory. Geological Survey of Canada Paper 79-24, 36 p.

RAMPTON, V. N, and S. PARADIS, 1981a: Surficial Geology and Geomorphology; Taye Lake, Yukon Territory. Geological Survey of Canada Map 14-1981, Scale 1:100,000.

RAMPTON, V. N. and S. PARADIS, 1981b: Surficial Geology and Geomorphology; Frederick Lake, Yukon Territory. Geological Survey of Canada Map 15-1981, Scale 1:100,000.

RAMPTON, V. N. and S. PARADIS, 1981c: Surficial Geology and Geomorphology; Pine Lake, Yukon Territory. Geological Survey of Canada Map 16-1981, Scale 1:100,000.

RYDER, J. M. and D. E. HOWES, Undated: Terrain information: a user's guide to terrain maps in British Columbia. Surveys and Mapping Branch, Province of British Columbia, 16 p.

RYDER, J. M. and B. MacLEAN, 1980: Guide to the preparation of a geologic hazards map. Working report for the British Columbia Ministry of Environment, Resource Analysis Branch. 17 p.

TERRAIN ANALYSIS AND MAPPING SERVICES LTD., 1980: Geologic and hydrogeologic interpretations of Destruction Bay, Burwash Landing and Champagne, Yukon Territories. Report for the Canada-Yukon General Subsidiary Agreement on Renewable Resource Information and Tourist Industry Development. 130 p and 1:20,000-scale terrain maps.

VARNES, D. J., 1974: The logic of geological maps, with reference to their interpretation and use for engineering purposes. United States Geological Survey Professional Paper 837. 48 p.

VARNES, D. J., 1978: Slope movement types and processes, in Landslides: Analysis and Control. United States National Academy of Sciences, Transportation Research Board Special Report 176. Edited by R. L. Schuster and R. J. Krizek, p. 12-34.

WETMILLER and S. G. EVANS, 1989: Analysis of earthquakes associated with the 1965 Hope Landslide and their effects on slope stability on the site. Canadian Geotechnical Journal, v. 26, 3, pp. 484 -490.

AERIAL PHOTOS

ROLL NUMBER	FRAMES	DATE	APPROXIMATE SCALE (VARIES)	NTS BLOCK
A22997	001-170	8/72	1:70,000	115 A,F,G,H
A22999	131-183	8/72		
A23000	007-223	8/72	1:70,000	115 A,F,G,H
	228-244			
A23001	001-020	8/72	1:70,000	115 A
	023-042			
	171-234			
A24763	008-017	8/77	1:70,000	115 B, C
	065-072			
	082-089			
	139-147			
A25192	119-125	7/79	1:57,000	105 D
	159-156			
	219-266			
A25264	070-078	8/79	1:50,000	105 D
	112-120			
	180-189			
A25265	017-026	8/79	1:50,000	105 D
	178-185			
	205-212			
A25275	021-030	8/79	1:50,000	105 D
	040-049			
	083-090			
	100-108			
A25287	177-209	8/79	1:59,000	115 J and K
A25288	019-029	8/79	1:59,000	115 J and K
	030-065			
A25549	161-166	8/80	1:59,000	115 J and K
	168-172			

N.B. Photo scales are computed from flight information on some aerial photos and data provided by the National Air Photo Library in Ottawa.

THURBER

APPENDIX B

TERRAIN MAP LEGEND AND INTERPRETIVE INFORMATION

B1. COLLUVIAL SURFACE MATERIALS

Colluvium ("C") is the predominant surface material on the hazard maps. It is defined as products of mass wastage including a variety of landslide debris which has reached its present position as a result of direct, gravity-induced movements (British Columbia Terrain Classification System, Howes and Kenk (eds.), 1988, p. 11). Also see Ryder and Howes (1986).

Consistent with the specialized purpose of the hazard maps, colluvium is broadly defined to include any near-surface soil material (mineral or organic) that may be subject to slope movements. Colluvium is often associated with grouped active-layer or alpine soil processes (see Appendix B.4). For information on the geologic origin of surface materials in the study area, refer to surficial geologic maps by Rampton (1978 a-e, 1981 and Rampton and Paradis, 1981).

B2. COLLUVIAL FANS AND APRONS

A colluvial fan can have many textures ranging from rock fall blocks to muddy sediment. This study classifies fans which appear (on aerial photos) to be affected by debris flows as colluvial fans.

Many colluvial fans shown on the 1:100,000 hazard maps may, upon inspection, prove to be alluvial features.

The lower case letter "a" as in "Ca" should be read as apron (colluvial apron) and taken to mean a series of coalescing fans. This usage differs from its meaning as a "unidirectional moderate slope" in the current terrain classification system (Appendix C).

B3. DESCRIPTION OF A DEBRIS FLOW

At the south end of Kluane Lake, a debris flow blocked the Alaska Highway at Mile 1057.1 in 1967. Hughes et al. (1972) give this description of a debris flow on a colluvial fan:

> "A small debris flow blocked the Alaska Highway in the summer of 1967 following a period of intense rainfall. The flow originated near the headwall of a small ravine at an elevation of about 5,200 feet (1,585 m). It then proceeded down the ravine and along the creek bed on the alluvial-fan at the mouth of the ravine. Three to five foot (1 m to 1.5 m) levees were built along the edges of the creek and some vegetation was uprooted and moved down the creek. The debris flow finally spread out as a fan at the break in slope near the highway, which here is at an elevation of 2,570 feet (785 m). The flow material is composed mainly of diorite boulders up to 8 feet (2.4 m) in diameter with a sandy silt matrix."

B4. PERMAFROST and RELATED PROCESSES

The terrain classification system uses "-X" to show permafrost processes. The classification system also uses the symbol "-Z" for general periglacial processes including solifluction, cryoturbation and nivation. Because slope stability processes in the KRPA are so strongly conditioned by alpine activity, the symbol "-Z" is used extensively for all active-layer processes.

B5. SNOW AVALANCHES

Snow avalanche tracks may be poorly defined on open alpine slopes and unforested lowlands Variable snowfall amounts may also complicate the recognition of snow avalanche hazards. Snow avalanches (marked by the symbol "-A") may be over-mapped throughout the KRPA.

B6. GEOLOGICAL PROCESS SYMBOLS

The following geologic process symbols are widely used in this study. There is no significance to their order of appearance on the hazard maps.

Erosional Processes:

-V for gully erosion

Fluvial Processes:

-B for braiding channel;
-J for anastamosing channel;

Mass Movement Processes:

-A for snow avalanching;
-F for slow mass movements (e.g. distressed bedrock slopes)
-R for rapid mass movements (e.g. rock falls or debris flows)

Periglacial Processes:

-S for solifluction;
-Z for group alpine processes including frost heave and solifluction.

B7. UNDIFFERENTIATED SURFACE MATERIAL AND STEEP SLOPES

Undifferentiated geologic materials are identified by "U" which should be interpreted to mean more than one type of surface material (including bedrock) outcropping on a slope. The symbol -U is often associated with surface expression symbol "s" (steep) and geologic process symbols -V (gullying) and -F (slow mass movements).

Some areas of colluvium (C) may also be associated with the symbol "s" as in Cs-AV meaning steep colluvial slope with snow avalanches and gullying.

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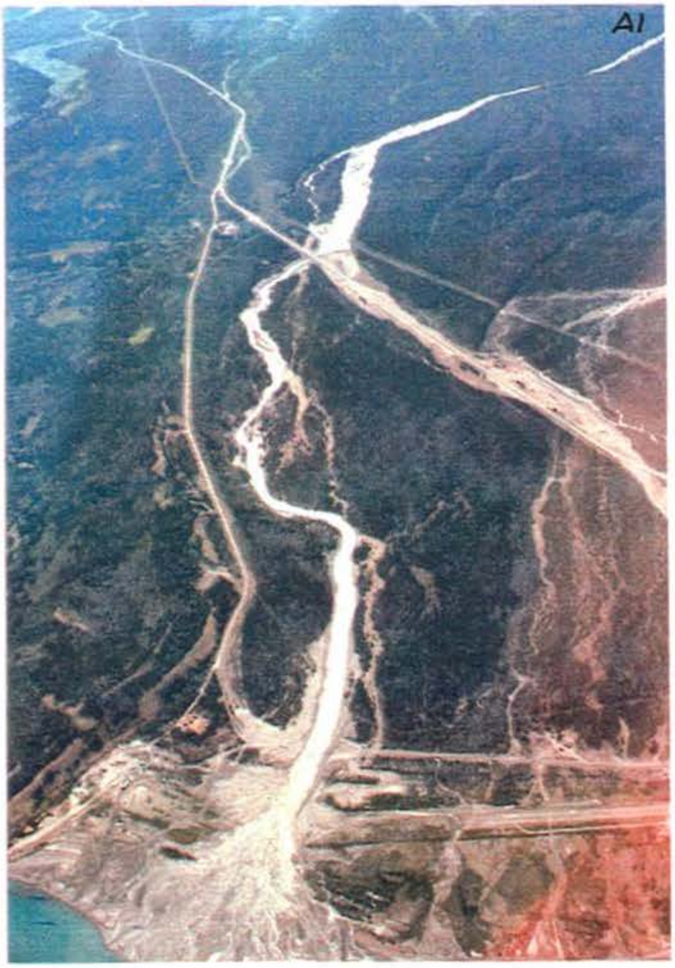
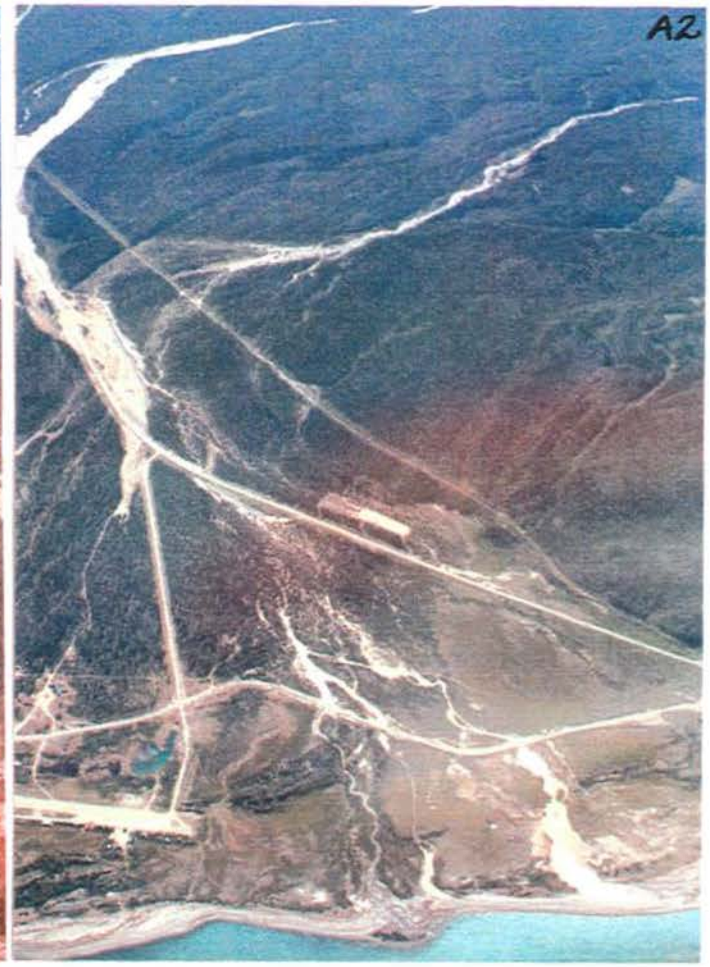
Photo A-1 — Helicopter view east showing right (north) channel of Silver Creek activated in July 1988. Silver City lies just north of the recent alluvial fan on the Kluane Lake shore. Note the recent earthworks to control the lower channel. Highway follows the active left channel in the middle distance. 07/89.

Photo A-2 — Helicopter view east showing the left (south) channel of the Silver Creek fan. This channel was also activated in July 1988. Note the un-named creek system which enters from the south and the radiating distributaries of the fluvial system below the AKH. Old slide scars (possibly permafrost active-layer detachments) are seen as light-green vegetation swaths south of the fan at the center right. 07/89.

Photo A-3 — Helicopter view south showing colluvial-alluvial fans just west of the Silver Creek fan at the lower left. Field of photo view A-3 lies just to the right. Kluane Lake in the foreground. 07/89.


A1


A2


A3

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Photo A-4 Helicopter view south-southwest showing colluvial aprons on the shore of Kluane Lake. Note the very steep alpine basins which fed debris flows in July 1988. Large debris slide blocked the Alaska Highway at the near centre. Alluvial surface of the Slims River delta is in the foreground. 07/89

Photo A-5 Helicopter view north showing debris flow area north of the Slims River near km 1707. Note steep upper basin with well defined fan at its base. A public facility and its parking area lie along the Highway which curves right along the Kluane Lake shore. A relict rock glacier is located at the upper right. 7/89


A4


A5

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Photo A-6	Helicopter view west showing Sheep Mountain area with fan of the Sheep Mountain rock avalanche extending into Kluane Lake at the left centre. Note two debris avalanche tracks at right centre. These are in the area of km 1711 and date from the 1988 storm activity. The Highway follows Kluane Lake shore; Horseshoe Bay lies just off photo to the right. 07/89
Photo A-7	Ground view west showing debris avalanche area near km 1711. This track is also seen in Photo A-6. Note the comparatively shallow depth of sliding and the extensive incorporation of organic debris in the slide material. The Alaska Highway in the foreground. 07/89
Photo A-8	Helicopter view west showing colluvial-alluvial fans above the Alaska Highway between km 1713 and 1716. Horseshoe Bay lies just off left photo; Williscroft Creek just off to the right. Note old debris flow scars but lack of evidence of significant activity in 1988. 07/89.
Photo A-9	Helicopter view west showing fan of Wiliscroft Creek and the Highway at km 1716. Reforested scars on steep, gullied slope right (north) of the fan indicate past debris avalance activity. Km. 1718 lies near right side of photo. 07/89.


A6


A8


A7


A9

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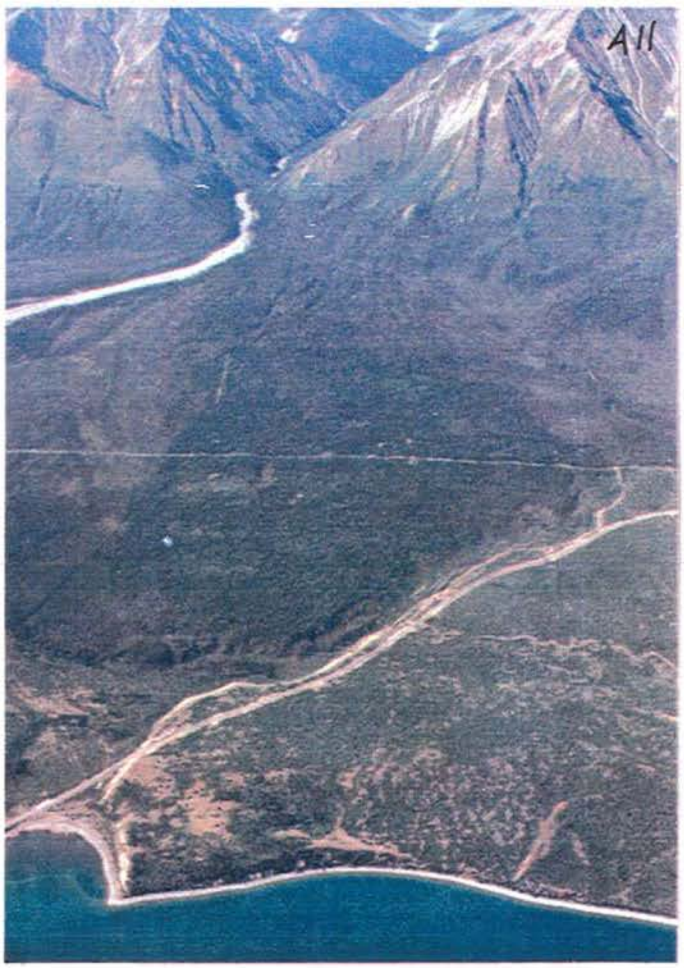
Photo A-10 — Helicopter view west showing large colluvial-alluvial fans just north of Williscroft Creek. Km 1722 and Congdon Creek alluvial fan is at lower center. Flank of this large fan extends upwards to the right. Note the steep, gullied alpine basins above each fan and lack of evidence for significant debris activity in the 1988 storms. 07/.89

Photo A-11 — Helicopter view southwest showing the enigmatic Congdon Creek deposits in the dark area extending toward Congdon Creek and the mountain front. Note the old pipe line strikes directly across the rocky surface of this feature. The Highway avoids it in the foreground. Congdon Creek is at the upper left. 07/89.


A10


A11

APPENDIX C

EXPANDED TERRAIN MAP LEGEND

This appendix provides the complete legend from the Terrain Classification System of British Columbia (Revised by Howes and Kenk (eds.), 1988). It permits a fuller understanding of the simplified fold-out legend given in Appendix B.

Note that the texture categories in the expanded version use Wentworth particle-size classifications. The Unified Soil Classification is used in the Thurber Consultants Ltd. legend in Appendix B.

TERRAIN MAPPING LEGEND

TEXTURE ①

(Particle sizes based upon Unified Soil Classification System and N.R.C. Field Description)

Specific Clastic Terms:

a	blocks	angular 203 mm plus
b	bouldery	203mm plus
k	cobbly	76 – 203mm
p	gravelly	5 – 76mm
s	sandy	.075 – 5mm
$	silty	.002 – .075mm
c	clayey	minus – .002mm

Common (Grouped) Classes:

d	mixture of fragments	
r	rubbly	angular cobbles and boulders
g	mixture of gravel and coarser	
-s-	silt and sand	mixture $ and s
f	fines	mixture $ and c

Organic Soils

e fibric u mesic h humic

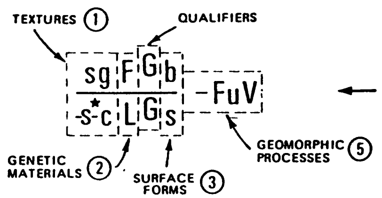
Well-sorted materials are described by the use of a single textural term; less well-sorted and poorly sorted materials are described using two textural terms with the subordinate textural term given first.

SURFICIAL MATERIAL ②

A	Anthropogenic▲	M	Morainal (Till)
C	Colluvial▲	O	Organic▲
D	Weathered Bedrock	R	Bedrock
E	Eolian	U	Undifferentiated
F	Fluvial (Alluvial)	V	Volcanic
FG	Glaciofluvial	W	Marine
I	Glacier Ice▲	WG	Glaciomarine
L	Glaciolacustrine		
LG	Lacustrine		

▲ Materials for which formative processes are assumed to be active; all others are assumed inactive. In areas mapped by photo interpretation with little or no fieldwork, textures of surficial materials may not be shown. Textures are then assumed to lie within a range defined in a supporting document.

EXAMPLE



The horizontal bar indicates the upper material overlies the lower material.

Interpretation: A blanket of sandy gravel and coarser glaciofluvial material (outwash) overlies water-bearing silt-sand and clayey glaciolacustrine (glacial-lake) deposits in steep erosional slopes. The entire unit is subject to soil slumps and active gullying.

SURFACE FORM ③

a	moderate slope unidirectional 15-26° (apron)	l	level
b	blanket	m	rolling
d	depression	p	plain
c	cone	r	ridged
f	fan	s	steep
h	hummocky (15-35°)	t	terraced
j	gentle slope	u	undulating (hills-hollows to 15°)
k	moderately steep uidirectional (26-35°)	v	veneer

The use of two (or rarely three) surface forms together implies there is a mixing of discrete forms and not a combination of intermediate forms. Blanket indicates deposits greater than 1 metre thick; veneer indicates deposits less than 1 metre thick. The use of s is reserved for erosional slopes generally greater than 26° on both consolidated and unconsolidated materials.

QUALIFIER ④

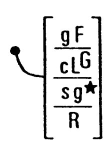
These superscripts are used to qualify genetic materials or geomorphic processes.

G	Glacial	B	Bog	Reserved for organic genetic materials
A	Active (contemporary)	F	Fen	
I	Inactive (has ceased)	S	Swamp	

Superscript modifiers A and I are used only where process states are contrary to the assumptions made for genetic materials and geomorphic processes.

SITE-SPECIFIC STRATIGRAPHY

Brackets tied to point locations shown stratigraphic details at significant exposures. Locations typically consist of isolated sections on steep erosional slopes. Asterisk (★) shows units with seepage. Materials may be texturally and/or genetically identifiable. Unit thickness not given or implied.



Example:

Gravelly alluvium-(texturally and genetically identifiable) overlying clayey glaciolacustrine deposits overlying water-bearing sandy gravel (texturally identifiable); the entire sequence rests on bedrock.

GEOMORPHIC PROCESSES ⑤

▲ Geomorphic processes assumed to be active; others are assumed inactive.

ARCTIC, ALPINE AND PERIGLACIAL PROCESSES

– C	Cryoturbated▲
– N	Nivated▲
– S	Soliflucted▲
– Z	Grouped (–C,–N,–S)▲
– X	Permafrost▲
– H	Kettled
– T	Thermokarst▲

FLUVIAL PROCESSES

– B	Braided▲
– E	Channelled by Meltwater
– J	Anastomosing▲
– M	Meandering▲
– U	Flooded▲
– I	Irregularly sinuous▲

MISCELLANEOUS EROSION PROCESSES

– D	Deflated▲
– K	Karst▲
– P	Piping▲
– V	Gullied▲
– W	Washed▲

MASS MOVEMENT PROCESSES

All of these processes are assumed to be active

– A Snow Avalanched

– F Extremely slow to moderate rates of failure in soil and bedrock:

- c soil creep
- g rock creep
- e earthflow
- u soil slump

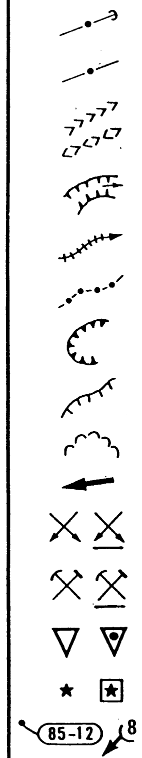
– R Moderate to extremely rapid rates of failure in soil and bedrock (1.5m/d to >3m/s):

- m rock slump
- s debris slide
- r rockslide
- d debris flow
- t debris torrent
- a debris avalanche
- f rockfall
- x rock avalanche

Where possible, lower case letters are given as subscripts to –F or –R. In some cases more than one subscript may be used.

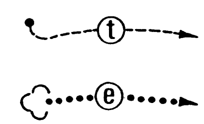
ON-SITE SYMBOLS

These and other symbols are used to show features of special interest and limited extent.



- Drumlin, crag-and-tail or drumlinoid ridge
- Glacial fluting or striae
- Esker. Known and unknown direction of depositional flow
- Large glacial meltwater channel
- Small glacial meltwater channel
- Moraine ridge
- Cirque
- Erosional escarpment
- Landslide escarpment
- Snow avalanche track. Runout limits are not implied.
- Borrow pit: active and inactive
- Mine or quarry: active and inactive
- Observation of frozen ground or ground ice; observation of thaw
- Spring or seep; saline seep
- Numbered sample location; numbered photo orientation

Linear Landslide Symbols and Mass Movement Types



- Rapid mass movement (debris torrent) with known point source
- Slow mass movement (earthflow) with landslide escarpment source

Limits of landslide runout are not implied by these symbols

COMPOSITE UNITS

=	Units are of roughly equal extent (1:1)
/	Unit to the left is more extensive than the unit to the right (approx. 2:1)
//	Unit to the left is much more extensive than the one to the right (>2:1)

Modified by Thurber Consultants Ltd. from "Terrain Classification System British Columbia", B.C. Ministry of Environment Manual 10.

TERRAIN MAPPING LEGEND

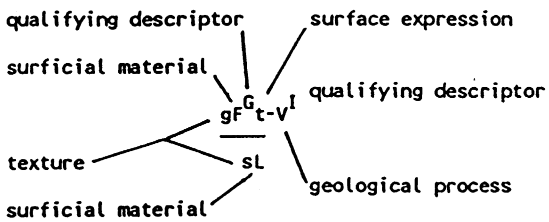
THURBER CONSULTANTS LTD.

CALGARY EDMONTON VANCOUVER VICTORIA

MAP UNIT LETTER NOTATION

A terrain map unit symbol is composed of combination of letters which designate different characteristics of the terrain. The relative position of letters within the symbol indicates the characteristic that they represent.

SIMPLE TERRAIN UNIT SYMBOL



This map unit consists of a gravelly glaciofluvial terrace that overlies sandy lacustrine materials and is modified by gullies that are no longer active.

Explanatory Notes:

1. Units consisting of two or more types of terrain are designated by two or more groups of letters separated by slashes and/or dots (see Composite Units below).
2. Materials underlying the surface unit are shown by a symbol that is written beneath the surface unit symbol and separated from it by a horizontal line.

TEXTURE

Texture refers to the size, roundness and sorting of particles in clastic sediments, and the proportion and degree of decomposition of plant fibre in unconsolidated organic sediments.

Clastic Terms (Wentworth)

Symbol	Name	Size (mm)	Other Characteristics
a	blocks	>256	angular particles
b	boulders	>256	rounded & subrounded particles
k	cobbles	64-256	rounded & subrounded particles
p	pebbles	2-64	rounded & subrounded particles
s	sand	.062-2	
$	silt	.002-.062	
c	clay	<.002	
d	mixed fragments	>2	mix of rounded & angular particles
g	gravel	>2	mix of boulders, cobbles & pebbles
a	angular fragments	>2	mix of rubble and blocks
r	rubble	2-256	angular particles
m	mud	>.062	mix of clay and silt
s	shells	-	shell or fragments

Organic Terms

Symbol	Name	Characteristics
e	fibric	least decomposed organic material; well-preserved fibre (40%) can be identified as to botanical origin after rubbing.
u	mesic	intermediate decomposition between fibric and mesic.
h	humic	advanced decomposed organic material; less than 10% of fibres identified as to botanical origin after rubbing.

Explanatory Notes

1. The absence of a textural term from a unit symbol indicates that texture of the material was not observed in the field and cannot be reliably interpreted from air photos or from a knowledge of the bedrock geology. The reader is referred to surficial material descriptions for general textural information.
2. Where two or three textural terms are used together, they are written in reverse order of importance and indicate that either the various textures are intermixed or interstratified.

QUALIFYING DESCRIPTORS

Qualifying descriptors qualify either surficial material or geological process terms. They are used in order to supply additional information about the mode of formation and/or depositional environment of surficial materials and the status activity of geological processes.

Symbol	Name	Description
G	glacial	Used to qualify non-glacial surficial materials where there is evidence that glacier ice affected the mode of deposition of materials (See surficial materials FG, LG, WG).
A, I	active, inactive	Used to qualify surficial materials and geological processes with regard to their current state of activity. Active: there is evidence that a geological process is either operating continuously or is of a recurrent nature at the present time; there is evidence that the process of formation of a surficial material is operative at the present time. Inactive: there is no evidence to suggest that a geological process is continuing or recurrent; the process of formation of a surficial material has ceased.

Explanatory Notes

An activity qualifying descriptor for surficial materials and geological processes are shown only in unit symbols where the current state of activity is contrary to the designated state.

SURFICIAL MATERIALS

Surficial materials are classified according to their mode of formation or deposition. This influences their physical characteristics such as texture, structure and compaction, which in turn control conditions of drainage and slope stability.

Each surficial material has an assumed status of activity. Status is either active or inactive. It is only indicated when the actual state of formation is contrary to the assumed state defined for each surficial material and is indicated by the Qualifying Descriptor Symbol (see below).

Symbol	Name (Assumed Status of Formative Process)	Description
A	anthropogenic (A)	Man-made or man-modified materials, including those associated with mineral exploitation, waste disposal and landfill.
C	colluvial (A)	Products of mass wastage; generally consists of massive to moderately well-stratified to non-sorted sediments with a variety of particle sizes and shapes; includes talus slopes, avalanche cones, mantles of weathered bedrock, landslide debris, earthflows and debris flows.
D	weathered bedrock(A)	Bedrock decomposed in situ by processes of mechanical and/or chemical weathering; the character of the bedrock debris depends on the process of formation and type of bedrock.
E	eolian (A)	Materials transported and deposited by wind action; generally consist of medium to fine sand and coarse silt that is well-sorted and poorly compacted; includes dunes and loess.
F	fluvial (I)	Materials transported and deposited by streams and rivers, alluvial materials; generally consist of gravel, sand, or silt; gravels are typically well-rounded and contain interstitial sand; sediments tend to be moderately to well-sorted and stratified; includes floodplains, river terraces, deltas, and some alluvial fans.
F^G	glaciofluvial (I)	Fluvial materials deposited in association with glacier ice; generally consist of gravels and sand, and show evidence of ice melting such as kettles and slump structures; sorting, stratification, and particle size and shape are variable; includes kettled outwash, kames, kame terraces and eskers.
I	ice (A)	Permanent snow and ice; glaciers and icefields.
L	lacustrine (I)	Sediments deposited in lakes or reworked by wave action around lake shorelines; generally consist of stratified sand, silt and clay deposited on the lake floor or well-sorted littoral sands or gravels; includes beaches, spits and bars, and lacustrine terraces of silt or clay.
L^G	glaciolacustrine (I)	Lacustrine materials that were deposited in association with glacier ice; generally similar to lacustrine materials but display features such as slump structures, ice-rafted stones and kettles.
M	morainal (I)	Material deposited directly by glaciers, till; generally consists of well-compacted material that is non-stratified and contains a heterogeneous mixture of particle sizes, shapes, and lithologies in a matrix of sand, silt and clay; includes moraines, till plains and drumlins.
O	organic (A)	Material resulting from the accumulation and decay of vegetative matter; generally consists of peat, although minor amounts of marl and inorganic detritus may be included; includes bogs, fens, swamps and thin organic veneers over bedrock (folisols).
R	bedrock (I)	Outcrops and rock covered by less than 10 cm of unconsolidated material.
U	differentiated (I)	A layered sequence of more than three types of material outcropping on a scarp slope.
V	volcanic (I)	Unconsolidated pyroclastic sediments including volcanic ash, lapilli and coarser ejecta.
W	marine (I)	Sediments deposited in marine waters, or reworked by wave action along marine shorelines; generally consist of clay, silt, sand or gravel that is sorted and stratified and may contain shells; includes spits, bars, beaches and deeper water deposits.
W^G	glaciomarine (I)	Sediments of glacial origin, laid down in a marine environment in close proximity to glacier ice; generally relatively poorly sorted and stratified or massive, and may contain shells; includes marine drift and marine stoney clays.

SURFACE EXPRESSION

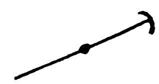
Surface expression is the topography of form of the land surface. In general, the terms listed here are used to describe features that are not adequately shown on the topographic base map.

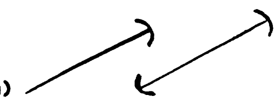
Symbol	Name	Description
a	moderate slope	An unidirectional surface with a slope gradient >15° to >26°; local surface irregularities are less than 1 metre.
b	blanket	A mantle of unconsolidated materials which derives its general surface expression from the topography of the unit which it overlies; it masks minor topographic irregularities in the underlying unit and is more than 1 metre thick; if the underlying unit consists of unconsolidated materials, it is shown in the unit symbol; if no underlying unit is shown, it may be assumed to be bedrock; if the underlying unit consists of unconsolidated materials of unknown origin, then only its surface expression is shown.
c	cone	A cone or segment of a cone with a relatively smooth slope gradient greater than 15°.
d	depression	Circular or irregular area of lower elevation lower than the surrounding terrain; depressions are greater than 2 metres deep.
f	fan	A smooth segment of a cone with a slope gradient up to 15°.
h	hummocky	Steep-sided hillocks and hollows that are rounded or irregular in plan; slopes of 15-35° predominate on unconsolidated materials and slopes of 15-90° predominate on bedrock; local relief is greater than 1 metre.
j	gentle slope	An unidirectional surface with a slope gradient >3° and <15°; local surface irregularities have a relief <1 metre.
k	moderately steep	Unidirectional surface with a slope gradient >26° and <35°; local surface irregularities have a relief <1 metre.
m	rolling	Elongate hillock(s) with slopes dominantly between 3 and 15° with local relief >1 metre; in plan an assemblage of parallel or sub-parallel linear forms with subdued relief.
p	plain	A level or gently sloping unidirectional surface with gradients up to 3°; local surface irregularities have a relief of <1 metre.
r	ridged	Elongate or linear, parallel or subparallel hillock(s) or ridges with slopes predominantly between 15 and 35° on unconsolidated materials and between 15 and 90° on bedrock; local relief is >1 metre.
s	steep	Steeply inclined slopes (scarps) with gradients >35° on both unconsolidated materials and bedrock.
t	terraced	Step-like topography; include both scarp face and the horizontal or gently inclined surface above it.
u	undulating	Gently sloping hillock(s) and hollow(s) with slopes up to 15°; local relief is <1 metre; in plan, an assemblage of non-linear, chaotic forms.
v	veneer	A mantle of unconsolidated materials which has no constructional form of its own, but derives its surface expression from the topography of the underlying unit; it reflects minor irregularities of the underlying surface, is generally between 10 cm and 1 metre in thickness, and outcrops of the underlying unit are common; if the underlying material is unconsolidated, it is included in the unit symbol; if no underlying unit is indicated, it is assumed to be bedrock.

Explanatory Notes

1. The use of two or three surface expressions symbols together implies that there is a mixing of discrete forms, not a set of intermediate forms.
2. Where more than one surface expression symbol is used, the symbols are written in order of decreasing importance based on their areal extent.

ON-SITE SYMBOLS

drumlin, drumlinoid ridge 

striae (ice direction known, unknown) 

glacial meltwater channel (major) 

landslide scar 

GEOLOGICAL PROCESSES

These terms indicate geological processes that are currently modifying or have modified surficial materials and surface expressions.

The status of all geological processes are assumed to be active. The exceptions are the processes, channeled by meltwater and kettled which have an assumed status of inactive.

Symbol Name (Assumed Process Status)	Description
A avalanches (A)	Slopes modified by frequent snow avalanches and by the deposition of rock debris transported by snow avalanches; slopes affected by ice falling from glaciers.
B braiding channel (A)	A channel zone characterized by many diverging and converging channels separated by unvegetated bars and temporary islands of gravel and sand.
C cryoturbation (A)	Unconsolidated sediments modified by frost heaving and churning due to frost action; includes patterned ground.
D deflation (A)	The removal of sand and silt from unconsolidated materials by wind action.
E channelled (I)	Erosion and channel formation by meltwater alongside, beneath and in front of a glacier.
F slow mass (A) movement	Downslope movement of masses of cohesive or non-cohesive surficial material and/or bedrock by creeping, flowing, or sliding.
H kettled (I)	Depressions formed in surficial materials due to the melting of buried, or partially buried glacier ice.
I irregular (A) channel	A single, clearly defined main channel displaying irregular turns and bends without repetition of similar features.
J anastamosing (A) channel	A channel zone where channels diverge and converge around many islands; the islands are vegetated.
K karst processes (A)	Processes associated with the solution of carbonates and other soluble rocks; includes underground and surface weathering and subsidence resulting from solution.
M meandering (A) channel	A clearly defined channel characterized by a regular and repeated pattern of bends with relatively uniform amplitude and wave length.
N nivation (A)	Erosion of bedrock and surficial materials beneath and along the margin of snow patches by freeze-thaw processes, snow meltwater action and snow creep.
P piping (A)	Subterranean erosion of surficial materials by flowing water that results in the formation tubular underground conduits.
R rapid mass (A) movement	Rapid downslope movement of dry, moist or saturated debris derived from surficial material and/or bedrock by falling, sliding or flowing.
S solifluction (A)	Slow downslope movement of saturated overburden across a frozen or otherwise impermeable substrate.
U inundation (A)	Terrain seasonally under standing water which results from high watertable.
V gully erosion (A)	Modification of unconsolidated or consolidated surfaces by various processes such as running water, mass movement and snow avalanching that results in parallel or subparallel ravines.
W washing (A)	Modification by wave action resulting in lag deposits formed by the removal of fines, and wave cut platforms.
X permafrost (A)	Processes controlled by the presence of permafrost, and permafrost aggradation or degradation; permafrost is earth material whose temperature remains below 0°C for more than two continuous years.
Z general periglacial processes (A)	Solifluction, cryoturbation and nivation occurring together within a single unit.

Explanatory Note

Geological process symbols are used where a relatively large portion of a terrain map unit is affected by the process. On-site symbols may be used to indicate modification of a small part of the unit by a single or a few features.

COMPOSITE UNITS

Composite units are employed where two or three types of terrain are intermixed or occupy such small areas that they cannot be designated as separate units at the scale of mapping. Symbols (defined below) are used to indicate the relative amounts of each terrain type, and the components are always written in decreasing order of importance.

=	The components on either side of this symbol are approximately equal.
/	The component in front of the symbol is more extensive than the one that follows.
//	The component in front of the symbol is considerably more extensive than the one that follows.

For example:

Mb//R Mb is considerably more extensive than R.

Mb//R.Cv Mb is considerably more extensive than R; R and Cv are of roughly equal extent.

Mb/R//Cv R is less extensive than Mb; Cv is considerably less than R.

APPENDIX D

TERMS OF REFERENCE

The terms of reference of the work are defined in Section S.W.3 of the Contract as follows:

> "The Contractor shall carry out terrain hazard mapping and assessment of the KRPA , which is approximately 35,000 square kilometers in the southwest part of the Yukon Territory (Figure 1). The project shall be carried out in two phases."

The basic terms of reference for the Phase 1 and 2 studies, as defined in Section S.W.3.1 of the Contract, are as follows:

> "The Contractor shall identify the main hazard types (including landslide types) that are found in the Kluane Regional Planning Area (KRPA). It shall include inventory maps at a scale of 1:100,000 of hazard sites in the study region. This shall include identification of high hazard areas (or hot spots) within the KRPA. The Contractor shall submit a report to the Departmental Representative based on a literature survey and the interpretation of approximately 766 aerial photographs provided by the Department. Progress map and textual evidence of project work shall be provided to the Department Representative. No field work shall be involved."

> "A Meeting will be held in Whitehorse on, or shortly after July 15, 1989 between the Contractor, the Departmental Representatives and Scientific Authorities to review the work completed in Phase 1. A presentation to the Kluane Regional Planning Commission on the initial findings in Phase 1 shall be held during the Contractor's trip to Whitehorse for the review meeting."

"A report in both hard copy and floppy disc form written using WordPerfect 5.0 (on 5 1/4 or 3 1/2 disc) shall be submitted to the Departmental Representative by July 7, 1989, which shall discuss, in general terms, terrain hazards in the KRPA."

"The Contractor shall conduct further aerial photograph interpretation. This will be based on approximately 14 days of field work in the KRPA which may be jointly carried out with the Geological Survey of Canada personnel. The Contractor shall be responsible for the cost of transportation to and from the KRPA and for accommodation associated with the field work."

"A final report shall be submitted to the Departmental Representative by October 27, 1989 (revised per October 2 memo) which shall document in detail on 1:50,000 scale maps high hazard areas (hot spots) identified in Phase I, and within these areas, areas which are exposed to greater hazard."

"The written report shall be in both hard copy and floppy disk form, written using WordPerfect 5.0 and on either 5 1/4 or 3 1/2 discs."

"A meeting will be held in Whitehorse on, or shortly after November 7, 1989 (revised per October 2 memo) to present the study findings to the Kluane Regional Planning Commission."

The following terms are slightly edited from memoranda dated August 28 and Septmeber 1, 1989:

"Thurber Consultants Ltd. (TCL) will number polygons and enter labels onto dBase IV for "hotspots" shown on the 1:50,000-scale hazard mapping prepared for the study. Data entry will use actual wording of attributes rather than coding."

"TCL will extend our 1:50,000-scale hot spot mapping from Congden Creek northward to the area of Burwash Landing along the west side of Kluane Lake and include this area in our dBase entry."

"The Yukon Land Use Planning Office will prepare the required dBase file disk to meet your format requirements. You will send us the disk for data entry and return."

"Hotspots on the 1:100,000 scale mapping prepared for the Phase 1 study are designated by red colored areas. These should be understood to be potential high-hazard areas."