1979 SLOPE STABILITY STUDY

MEAGER MOUNTAIN

GEOTHERMAL AREA

Submitted to

British Columbia

Hydro and Power Authority

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VTN CONSOLIDATED, INC.

Irvine, California

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ACKNOWLEDGEMENTS

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1.0 INTRODUCTION

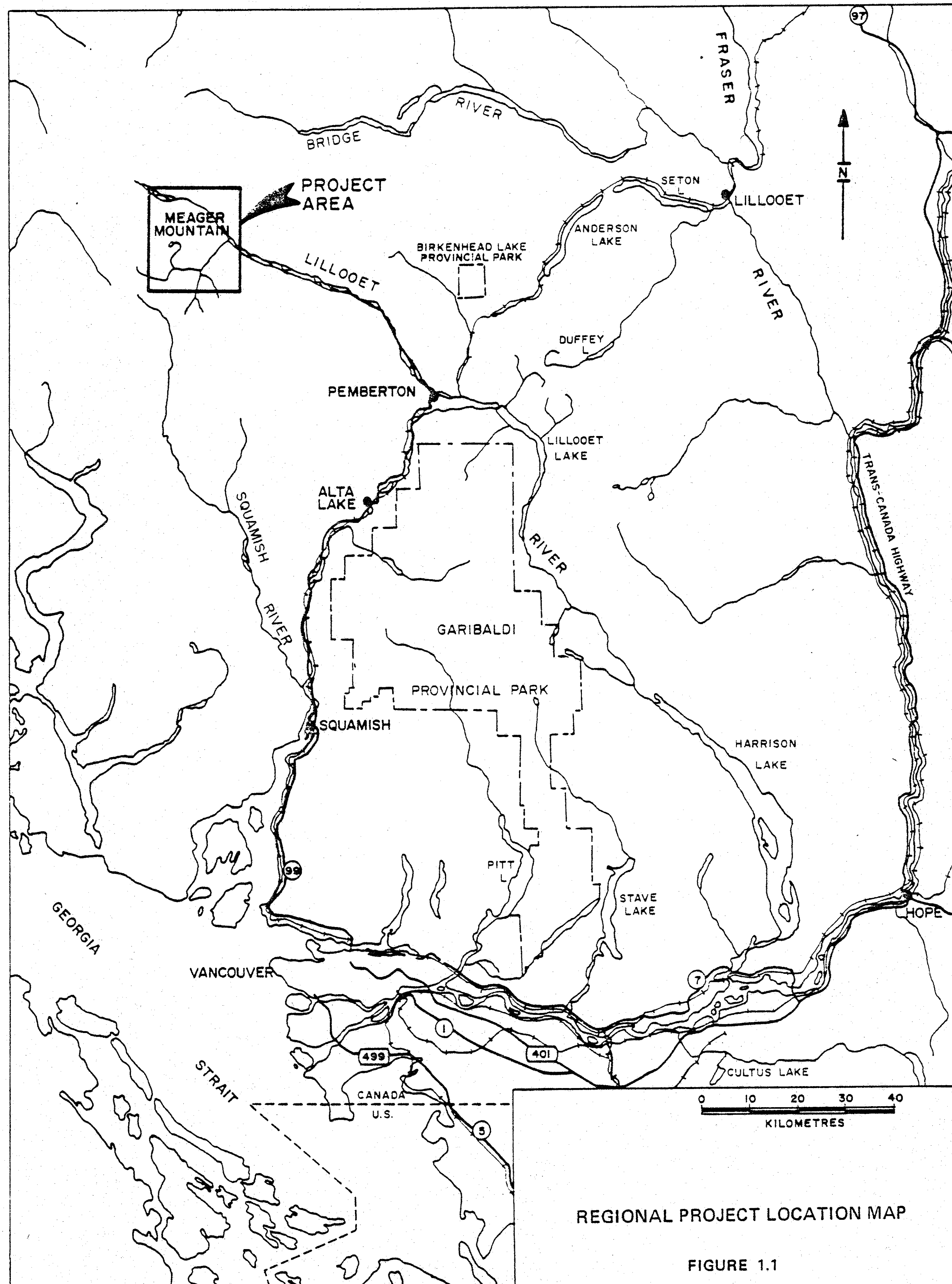
This report has been prepared in response to certain findings discussed in the Environmental Reconnaissance Report prepared for the Meager Mountain Geothermal Area (B.C. Hydro 1979). That report indicated that slope instability would present a major environmental constraint to future geothermal exploration and development activities within the B.C. Hydro Geothermal Project Area. The purpose of this study, therefore, is to document and delineate areas of potential and existing geologic instability within B.C. Hydro's Meager Mountain geothermal exploration area, shown on the Regional Project Location Map (Figure 1.1).

1.1 Study Objectives

The objective of this study is to indicate areas where future geothermal exploration and development activities would be constrained by geologic hazards, namely, failing slopes. To this end, the entire geothermal exploration area has been mapped to show five gradations of slope stability/instability. It should be noted, however, that this is not a siting study, but rather an indicator of where siting studies may be warranted, as well as areas unworthy of future consideration (see Section 4.0).

1.2 Study Area

The area reserved to B.C. Hydro for mineral exploration is 480 km^2 within the Meager Mountain volcanic complex, and is herein referred to as the B.C. Hydro Geothermal Project Area. The entire 480 km^2 were not within the limited scope of this study. Therefore, this investigative effort was concentrated in those areas where geothermal exploratory drilling was ongoing or scheduled in the foreseeable future. This area of investigation covered approximately 240 km^2, about one-half of the entire B.C. Hydro Project Area. This area of investigation,



REGIONAL PROJECT LOCATION MAP

FIGURE 1.1

the Meager Mountain Geothermal Exploration Area, has been divided into three "study areas" for purposes of this report. These are the Meager Creek, Job Creek and Lillooet River study areas, as presented in Figure 1.2. As discussed later in the report, the Meager Creek study area is the location of the tentatively identified geothermal reservoir and ongoing drilling activities; the Job Creek study area is scheduled for exploratory drilling in 1980. The Lillooet River study area serves as the access corridor to the Meager Creek and Job Creek study areas, as well as being the location of the base camp and headquarters for exploration drilling activities.

Within this report, references to Job Creek and Affliction Creek reflect the recent change in their delineation. What was known as Affliction Creek until P.B. Read changed the name to coincide with Job Glacier is now Job Creek, and old Job Creek is now Affliction Creek, coinciding with Affliction Glacier.

1.3 Method of Analysis

To this end, certain geologic parameters were compiled and evaluated according to their potential effect on slope stability. These parameters were then compiled in a matrix in order to evaluate six surficial units and three generalized bedrock units (Figure 1.3). Each of the nine geologic units was then assessed by twelve parameters. The matrix shows separate parameters which may render a particular geologic unit more or less stable. At the lower margin of the matrix, each unit has been assigned a letter from A (best) to F (worst) to indicate relative stability. Some geologic units have a variable rating (such as B to C), depending upon local site conditions, especially slope angle and vegetation cover.

Information presented on both the Engineering Geology Map (Map 1) and the matrix was combined to produce a Terrain Rating Map (Map 2). The terrain rating map shows overall slope stability in a simplified manner to assist in planning decisions regarding future development of the geothermal resource. The terrain rating map shows that two diverse areas, such as talus chutes and unaltered volcanic rocks, may have an equal rating, but for different geologic reasons. The former are known as landslide areas, while the latter have a potential for landsliding. Both are rated "C to D" for overall suitability.

1.4 Data Sources

The material contained herein was obtained through field reconnaissance during June and July 1979, aerial photo interpretation (1964) subject to verification from photos scheduled to be taken during October 1979, review of published and unpublished literature pertinent to slope stability in general and the Meager Mountain Geothermal Exploration Area in particular, plus conversations with knowledgeable persons familiar with the area and with the issues under investigation.

2.0 ENGINEERING GEOLOGY

2.1 Regional Geologic Setting

The B.C. Hydro geothermal project is located in the Meager Mountain volcanic complex, southwest of the Lillooet River (see Figure 1.1). The volcanic complex marks the northern end of the Garibaldi Volcanic Belt, chemically similar to the Cascade Volcanic Range of the northwestern United States, and essentially an extension of the Cascade Range into southwestern British Columbia.

The B.C. Hydro project area is characterized by a basement complex of intrusive igneous and metamorphic rocks overlain by three main volcanic units of late Cenozoic age. The older volcanic rocks occur in the southern portion of the geothermal exploration area, and the younger units occur in the northern portion. These units are finally overlain by an unstable regolith formed by the weathering of the basement complex and the volcanic units.

2.2 The Basement Complex

The Mesozoic basement complex includes intrusive igneous and metamorphic units described by Read (1978) and Nevin Sadlier-Brown Goodbrand Ltd. (NSBG) (1978). They are generally competent, although certain areas have undergone hydrothermal alteration and intense weathering. The basement complex is composed of biotite hornblende quartz diorite, hornblende diorite and roof pendents of greenstone, phyllite and amphibolite. The youngest unit is a biotite quartz monzonite of Miocene age, which forms the Fall Creek stock on the northeast flank of Meager Mountain (NSBG 1978). Some of the unstable areas occur along the Meager North Main logging road which parallels the north bank of Meager Creek.

2.3 Volcanic Units

There are three major phases of volcanic activity in the Meager Mountain volcanic complex. For purposes of slope stability mapping, these three phases have been divided into two units, altered volcanics and unaltered volcanics, with alteration apparently caused by hydrothermal activity.

The altered and unstable volcanic unit includes portions of the first phase of activity (the Devastator assemblage), landslide and/or lahar deposits, portions of the Mosaic assemblage, and a pumice unit of the Bridge River tephra, as described by Read (1978).

The unaltered volcanic unit includes a portion of the first phase, plus most of the second and third phases of volcanic activity. More complete descriptions of the volcanic units are contained in Read (1977, 1978), NSBG (1975, 1978), Souther (1976), and Woodworth (1977).

2.4 Surficial Units

This study emphasizes the stability evaluation of surficial units which consist of debris avalanches, debris flows and rock-block slides, fluvioglacial deposits, talus, colluvium and alluvium. Soil profiles are described in the text but are not designated on the geologic map.

2.4.1 Debris Avalanches

Debris avalanches are large masses of incoherent and heterogeneous mixtures of soil, rock and ice which move very rapidly over distances of greater than one kilometre. An example of a debris avalanche is the Devastation Slide. The slide is about 29 million cubic meters in volume and is composed of weak volcanic rock and ice. During the summer of 1975, it moved seven horizontal kilometres and dropped 1,000 vertical metres down Devastation Creek (Patton 1976). A debris avalanche such as this is believed capable of moving such large distances because air which is trapped and compressed beneath the landslide (rocks) provides a frictionless flow surface. A debris avalanche has high density, high specific gravity, and unusually high velocity (Crandell and Fahnestock 1965, Varnes 1958). The Devastation Slide is composed of hydrothermally-altered rhyodacite tuff, ranging in size from large blocks (5-10 m in diameter) to sands and silts, with the majority of the material consisting of boulders and cobbles.

2.4.2 Debris Flows

Debris flows are similar to debris avalanches except that the velocity of flow and the distance traveled are generally less than one kilometre. Debris flows in the Meager Creek study area are derived from hydrothermally-altered tuff and other friable rocks. They are composed of a heterogeneous mass of boulders and cobbles, with a muddy matrix. Often the muddy matrix is winnowed away by subsequent erosion, with the coarse fraction remaining. Debris flows originate through loss of shear strength caused by saturation of the loose heterogeneous mass, with moisture resulting from either rapid snowmelt or heavy precipitation. Debris flows may occur below over-steepened cliffs, as in the banks above portions of Meager Creek, or from dissected terminal moraines of glaciers, as occurs in Capricorn Creek.

In this classification, debris flows are included with rock-block slides, although the two kinds of slides are different. Rock-block slides are slower moving masses of intact crystalline bedrock that have translational movement along an unsupported planer surface. They have a major block of intact rock, but the block may be pervasively fractured along weak joint planes. Movement occurs along a weak joint or fracture which may be opened by the freeze-thaw cycle. The only major rock-block slide which occurs within the study areas is located west of Peak 5321 in the southwestern headwaters of Meager Creek.

2.4.3 Fluvioglacial Deposits

Fluvioglacial deposits are a heterogeneous assemblage of large granitic boulders, highly-weathered volcanics, reworked tephra, older rhyodacite flows, and glacial silt. These units range in size, with approximately 15% very large boulders, 20% boulders, 15% cobbles, 20% pebbles, 10% sand and 20% silt and clay. Organic debris is occasionally present. The fluvioglacial deposits are variable from massive deposits of unstratified till, with large boulders, to locally stratified but discontinuous lenses of sand and gravel underlayered with clay. Fluvioglacial deposits were formed as terminal moraines, with some lateral moraines, during the retreat of Wisconsin-age glaciers (the youngest stage of North American glaciation, Upper Pleistocene).

These deposits occur throughout the three study areas. The largest deposits are southeast of Meager Creek Hot Spring and south of the Lillooet River between Job Creek and the pumice bluff (see Maps 1 and 3).

2.4.4 Talus

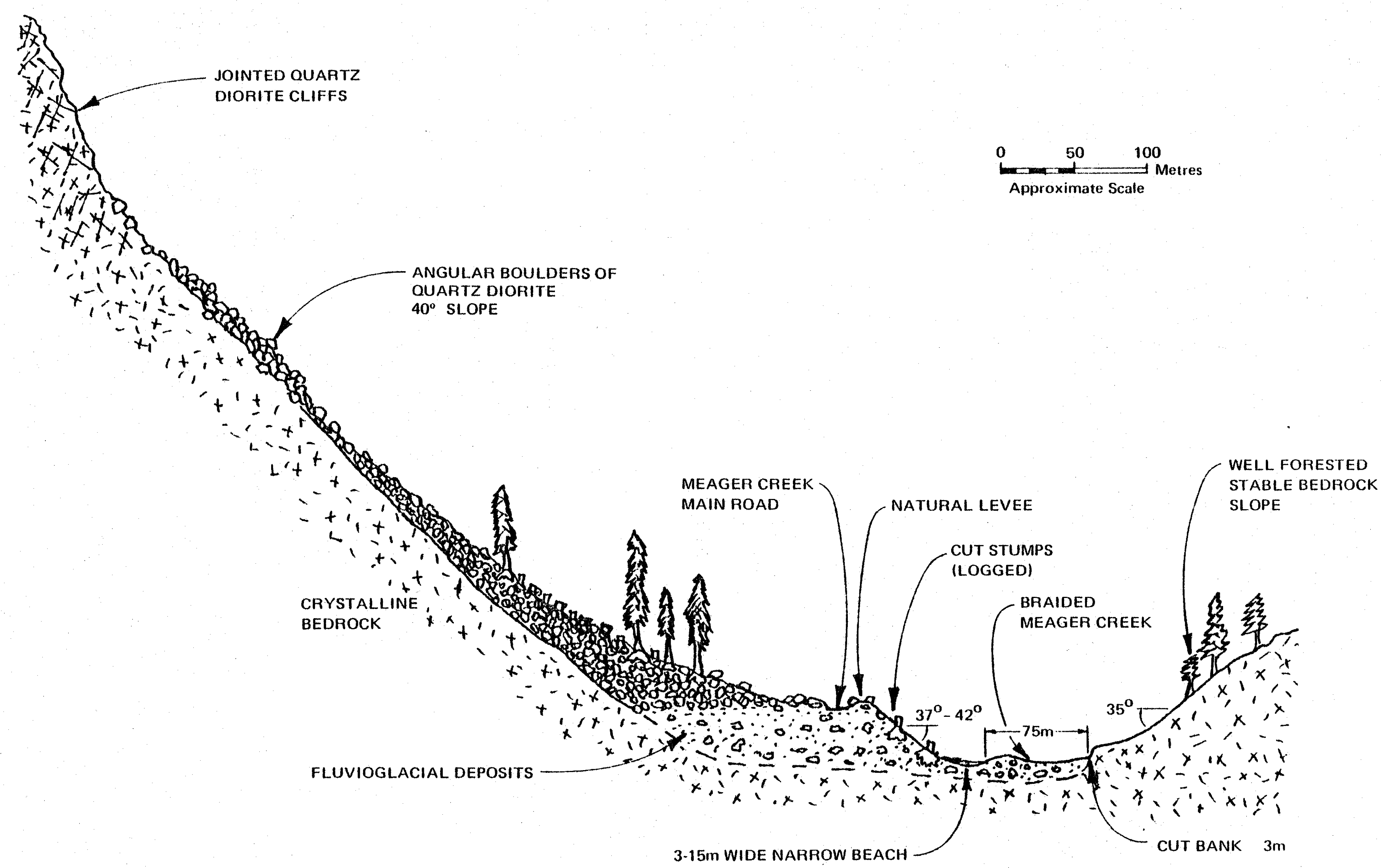
Talus is a rock-fall unit moving under the influence of gravity and local snow avalanches. It originates from mechanical weathering (frost wedging) of bedrock along structural planes of weakness. Talus occurs at intermediate elevations on steep mountain faces and at the bases of cliffs. This unit may form talus cones, talus chutes or elongated fans which are transitional into colluvium at lower slope angles. The talus drapes most of the steep slopes within the three study areas, and is composed of angular cobbles and boulders of plutonic, metamorphic, and hard volcanic rocks. The lithology is variable and directly related to the source rock. The clast sizes are generally about 10% pebbles, 20% cobbles, 60% boulders and 10% large boulders, and are angular to subangular with no cohesive matrix. Little organic debris is present except for localized avalanche debris. The size of talus varies, as some chutes contain mostly cobbles to pebble-size clasts, while others have very large boulders. An example of talus deposits is presented in Figure 2.1.

2.4.5 Colluvium

Colluvium is a heterogeneous unit of variable grain size ranging from boulders to clay size, and may contain as much as 5% organic material. The rock fragments are usually angular, and the cohesive matrix ranges from 30% to 40%. Colluvium may be derived from any bedrock or other surficial unit. It forms by sheet-flow erosion and downslope creep under the influence of gravity. Colluvium is not winnowed by concentrated water, so fluvial stratification is absent, although some soil profiles may overlap due to progressive down-slope creep. Colluvium occurs along the flanks of moderate to gentle hill slopes, interfingers with alluvium at the toes of slopes, and may be dissected by talus chutes. The thickness of colluvium ranges from a minimum of one metre to a maximum of 20 metres. It overlies the fluvioglacial deposits north of Meager Creek and west of No Good, Boundary and Devastation Creeks (see Map 1).

2.4.6 Alluvium

Alluvium in this study is defined as a fluvial unit restricted to major creeks and rivers. It does not include water-transported debris in steep gullies, chutes, and cirques, where landsliding and snow avalanches are major agents of degradation. Alluvium within the geothermal exploration area is primarily composed of quartz diorite, phyllite and rhyodacite clasts. The clasts are of variable size and estimated to be 10% boulders, 40% cobbles, 30% pebbles, and 20% sand, with negligible silts and clays. The fine-grained fraction is carried away by fast-flowing water (50 to 70 m/sec).



SCHEMATIC GEOLOGIC CROSS SECTION THROUGH MEAGER CREEK NEAR 5 KM MARKER

FIGURE 2.1

Alluvium is transported and deposited by large creeks and rivers within the major valleys. Clasts are rounded to sub-angular if volcanic, and rounded to sub-rounded if intrusive igneous. The sediment grain size is coarse, because nearly all of the clays and silts are carried in suspension by Meager Creek and the Lillooet River. Meager Creek is a degrading creek, while the Lillooet River is an aggrading river below Pebble Creek and above Mosaic Creek. Lower Meager Creek and the Lillooet River are the limited areas of alluvial deposition.

2.5 Soils

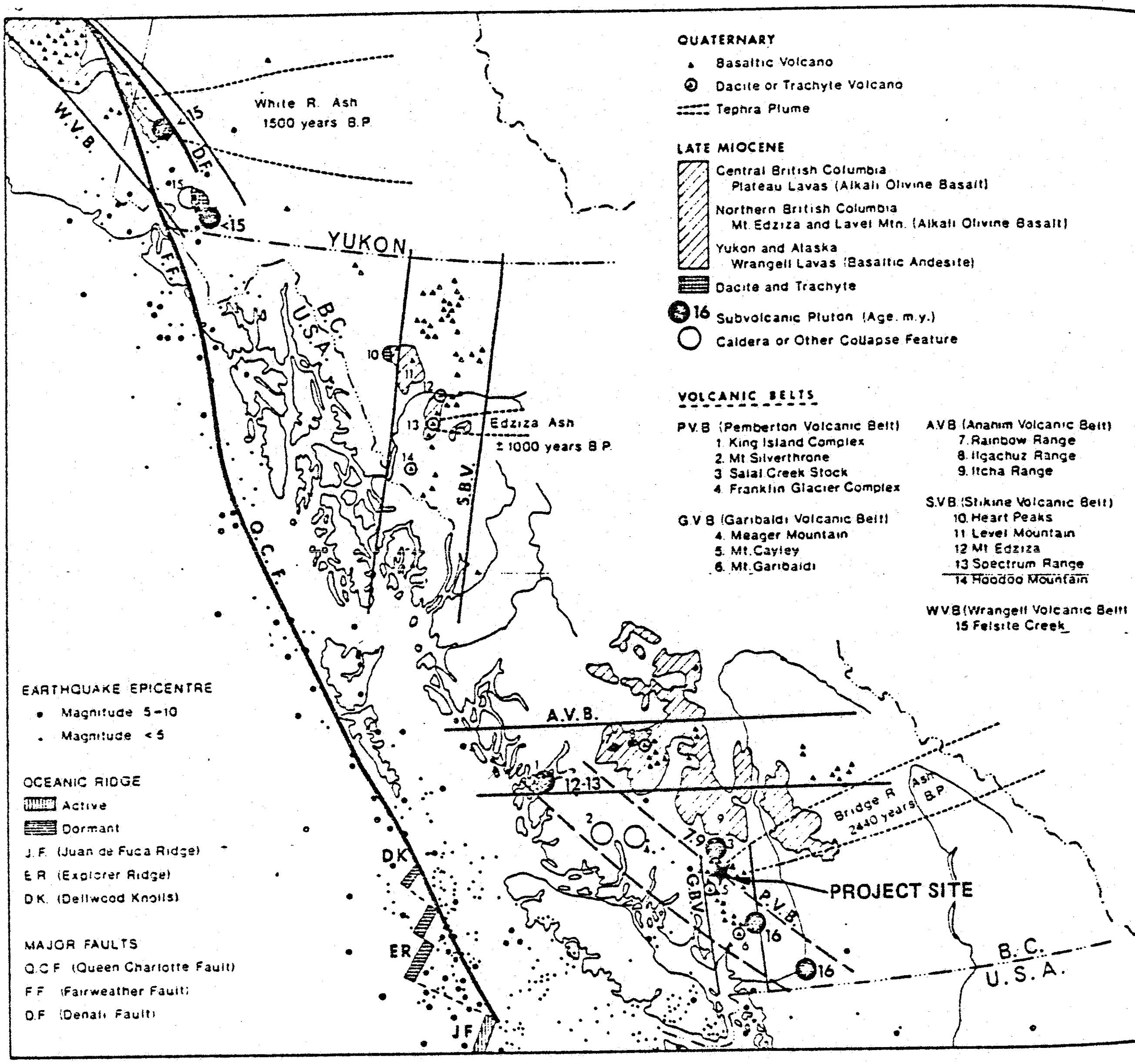
The soils of the geothermal study area are derived from the underlying rocks which are a combination of metamorphic and intrusive igneous, overlain by a series of volcanic flows of various ages. They are predominantly lithic, including bare rock and accumulations of Ferro-Humic Podzols and Folisols, with ice fields (non soil) at higher elevations. Ferro-Humic Podzols are moist to wet over most of the year, but rarely freeze to any significant depth. In general, they are subject to continuous seepage, which is associated with their high organic content. Common parent material is colluvium, described above.

The soils have low trace saturation levels, low pH values, high organic carbon, and high Al and Fe content. The folisols are organic soils consisting of shallow organic material overlying bedrock. These soils are not continuous or extensive, but occur as a minor associate in the Ferro-Humic Podzol landscape. A complete pedologic description is contained in Valentine and others (1978).

2.6 Seismicity

The Canadian Cordillera is an area of low seismicity compared with other parts of the Pacific margin. Most earthquake epicenters are located along four northwest trending zones on or near the continental shelf, while the remainder are scattered at random throughout the western and central cordillera (see Figure 2.2). Souther (1970, 1976) reports that there are no records of earthquakes around the Meager Mountain geothermal area. This is supported in recent studies by Rogers and Riddihough (1979).

The microseismic study (NSBG 1975) during the winter of 1974 to 1975 showed that apparent microearthquakes occurred over 5% of the recording time (35 of 730 hours). The study concluded that a portion of these consisted of actual microearthquakes related to some faulting process. However, limitations on the study included the freeze-thaw cycle, with soil rock shifting, snow sliding and snow falling from trees. Similar studies in the summer of 1975 recorded no distinct microearthquakes (Rogers 1975). From these data, it may be concluded that there are minimal chances of a major seismic event occurring in the vicinity of the Meager Mountain geothermal area. Therefore, seismicity is not likely to affect either the slope stability or any human activities which may occur in the area.



Source: Souther, 1976

EARTHQUAKE EPICENTER MAP

FIGURE 2.2

3.0 LANDSLIDES AND SLOPE STABILITY

3.1 Introduction

Of the three study areas designated within the Meager Mountain Geothermal Exploration Area, the Meager Creek study area is emphasized in this section of the report for several reasons: 1) the south geothermal reservoir (Meager Creek) is the area of current exploration and development activities; 2) initial surface exploration in the area is complete; 3) three of the five drill holes proposed for 1979 are located there, with the first being drilled during this writing, and 4) the area is readily accessible by road.

The Job Creek study area was identified as the secondary area of investigation because: 1) it is the secondary area of geothermal surface exploration activities; 2) preliminary surface exploration is underway; 3) it includes a pumice bluff that was the center of discussion regarding the north access road along the Lillooet River, and 4) access to the area was difficult, precluding detailed investigations within the scope of this study.

In the Lillooet River study area, the analysis was concentrated along the proposed road alignment parallel to the river. The primary interest was slope stability related to potential access road routes leading to the Job Creek area.

3.2 General Characteristics

Within the Meager Mountain geothermal area, landslides are an acute problem, varying in size and importance from small rock falls on road cuts to a huge debris avalanche which occurred in 1975 (see Map 1). Landslides are prevalent because of the very steep terrain, and the occurrence of weak volcanic rocks and relatively high precipitation (see B.C. Hydro 1979).

Snow avalanches also appear to be an acute problem in the Meager Mountain area and for planning purposes should be given as much consideration as orthodox landslides. Avalanches are often coincident with talus chutes, but some descend across otherwise stable granitic slopes. Studies are currently being performed to evaluate the snow avalanche hazard in the Meager Mountain area (see Mellor 1978, for general information concerning snow avalanche problems).

The effect of logging operations on the stability of forest slopes has been extensively studied in the Pacific Northwest (Bishop and Stevens 1964, Swanston 1969, 1970, Barr and Swanston 1970, Fredericksen 1970, Gray 1970, Swanson and Dryness 1975, and Swanston and Swanson 1976). A dissertation concerning stability of forest soils in coastal British Columbia was prepared by O'Loughlin (1972). It is generally concluded that logging operations increase the erosion of a steep forest soil by several orders of magnitude, and that slopes steeper than about 34° are likely to become critically unstable if they are logged by clearcut methods (Swanston 1970). The full impact of logging activities may not become apparent until three to five years after timber harvesting, as decay progresses through the root systems of trees and other forest vegetation. Loss of this subsurface root structure may decrease the effective cohesion of forest soils as much as 30%, with resultant downslope creep of the entire soil mantle.

3.3 Meager Creek Study Area

The limits of the Meager Creek study area extend from the west bank of Devastation Creek, east to Capricorn Creek, and from the northernmost section of Devastation Slide to 2.5 km south of the toe of the slide. The approximate area of the projected geothermal reservoir extends from Meager Creek Hot Springs on the east to No Good Creek on the west, and from the Devastator on the north to the south bank of Meager Creek. These boundaries are shown on Figure 1.2.

Meager Creek trends from northwest to east to northeast and flows toward the Lillooet River. Thus, for purposes of this discussion, areas north or northwest of Meager Creek will be designated as the "north bank," and areas south or southeast of Meager Creek will be designated the "south bank."

3.3.1 Areas of Primary Concern

The areas of primary concern within the Meager Creek study area are the east bank of Devastation Creek about six kilometres north of its confluence with Meager Creek, and Hill 5321 south of Meager and opposite the confluence of Meager Creek and Devastation Creek. The east bank of Devastation Creek consists of rhyodacite (acid) tuff, breccia, and flows that have been hydrothermally altered. Most areas underlain by this unit are susceptible to sliding, with the largest potential slide mass located on the western flanks of the Devastator.

The retreating toe of the Devastation Glacier (Patton 1975, Read 1977) is removing its support from the base of slopes that are composed in part of the weak acid tuff, breccia and flow unit. The retreating glacier and sub glacial activity are blamed for the initial sliding. This process is accelerated during some years when unusually warm summer weather contributes to the melting of glacial ice. The acid tuff, breccia and flow unit underlies most potential slide units described by Read (1977, 1978). Additional information can be found in Patton (1975).

The Devastation Slide is about 29 million cubic metres in volume of weak volcanic rock and ice. During the summer of 1975 it moved seven horizontal kilometres and dropped 1,000 vertical metres down Devastation Creek.

An example of slide activity comparable to the Devastation Slide were the Little Tahoma Rock Slides which occurred in Washington state during

1963. One of these slides moved 6.4 horizontal kilometres, dropped 1,891 metres, and had a total volume of 10.7 million cubic metres.

Little Tahoma Peak is the highest peak (3.4 km) of a wedge pointing toward Mount Rainier. The initiator of the slide is thought to have been a steam explosion caused by water coming in contact with hot rock under pressure. However, the slide dynamics were similar to the Devastation Slide, where the initial rock fill material hit glacial ice. The result was a "rock fragment flow," a mixture of rock debris and air, providing the body of the slide with a medium over which to flow. This material had a high specific gravity and moved with high velocity (Crandell and Fahnestock 1965, Fahnestock 1978).

The Devastation Slide occurred in summer when temperatures were warming. The Little Tahoma Rock Slide occurred in winter, indicating that large slides could occur at any time of year. The difference involves the initiator of the rock slide, in these cases removal of supporting rock (in summer) and steam explosions (in winter).

Within the Meager Creek study area, Hill 5321 is an igneous body with a basaltic cap and extensive north-south jointing (see Map 1). Large pieces of joint-controlled igneous rock are peeling off the hill very slowly (rate unknown), forming cracks at least three metres wide and of unknown depth. The landslide scarp is extensive, spanning the entire hillside that parallels the south bank of Meager Creek, near the confluence of Devastation Creek.

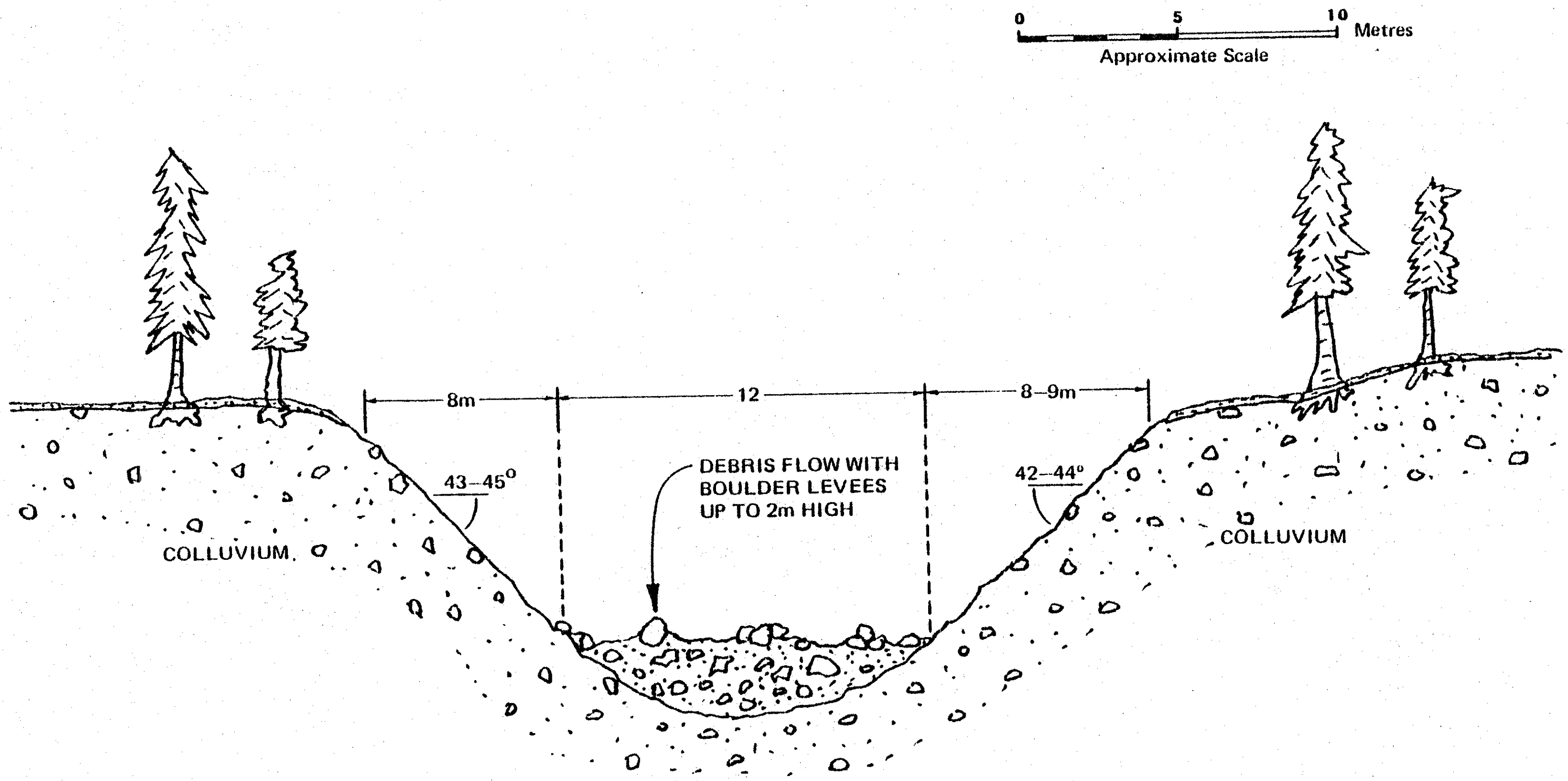
3.3.2 Areas of Secondary Concern

Areas of secondary concern within the Meager Creek study area include Boundary Creek, No Good Creek, Angel Creek, Hot Spring Creek, Capricorn Creek and portions of Meager Main logging road. From field observations, Boundary and No Good Creeks would be susceptible to occasional avalanches and/or rock slides. Evidence for this observation lies in the angles of the walls of the canyons of both creeks (an average of 42° to 45°) and lack of vegetation at the bottoms and sides of the canyons (Figure 3.1). During the week of September 9, 1979, the most recently known series of slides occurred down No Good Creek. The slides, comprised of boulders, cobbles and pebbles, with a sandy/silty matrix, blocked the culvert of the bridge crossing (Figure 3.2) of No Good Creek. The slides then backed up one against the other, some having enough material to flow over the roadway. This series of slides occurred after a week of very heavy rain (Sadlier-Brown 1979).

The benches above the creek beds of No Good and Boundary Creeks are composed of colluvium, which covers thick fluvioglacial deposits. The slope angles range from 8° to 28°, with thick, mature forest covering much of the area. This type of forest cover indicates that the area has been stable for at least the 200 to 250 years the trees have been alive (B.C. Forest Service 1975).

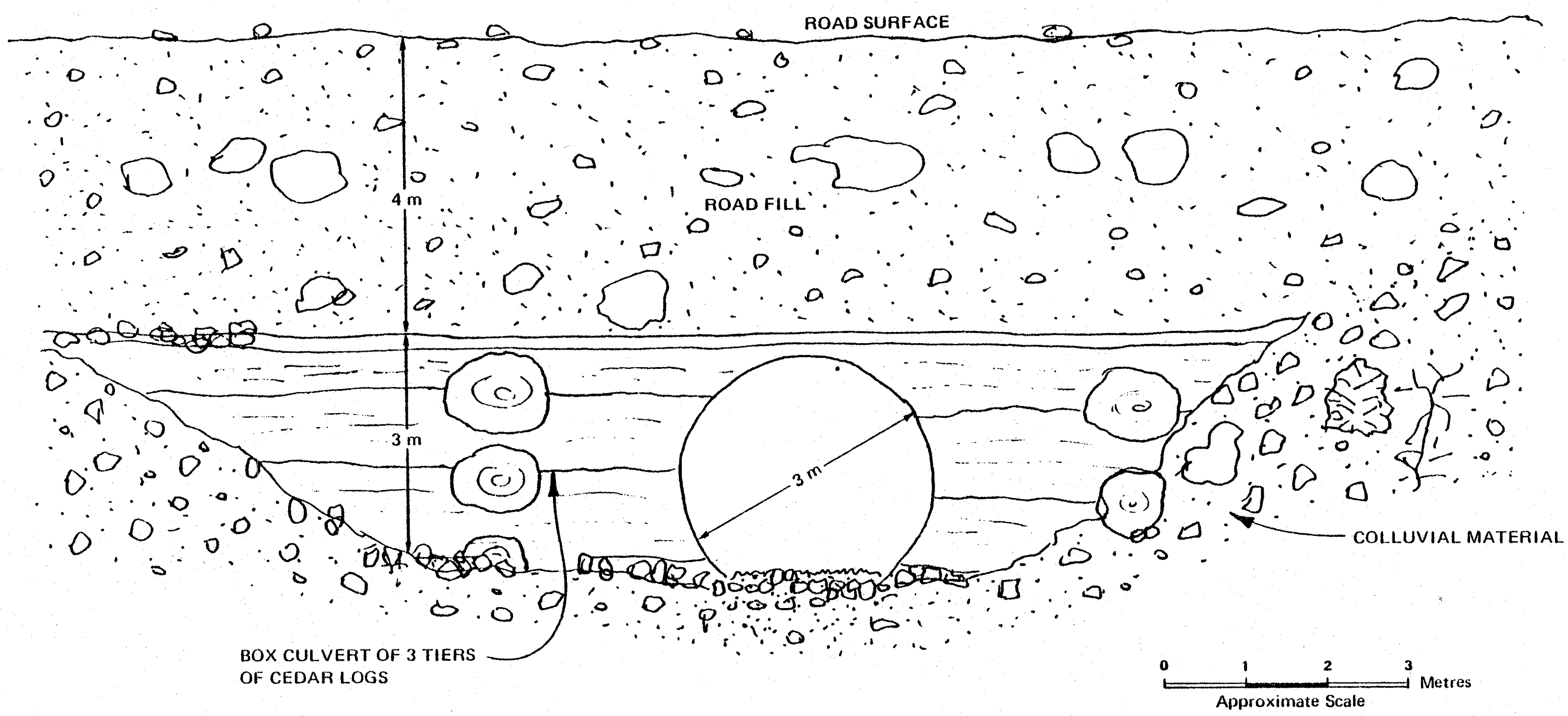
The talus unit is exposed at the break in slope (slope angles of 28° to 40°). There are isolated slide areas that are fairly recent, judging from the absence of trees and the presence of fresh talus. The headwaters area of No Good and Boundary Creeks is a cirque with aerial photographic interpretations showing talus debris below the headwall. Below the talus unit, altered volcanic material is mapped. There is a thin layer of talus covering the unstable volcanic unit.

Aerial photographic interpretation of Angel Creek indicates an old snow avalanche chute following the course of the creek, indicated by differences in vegetation cover. The vegetation cover was confirmed during field investigations, showing alders in suspected snow avalanche areas. The avalanche chute extends from above the Angel Creek falls to the terminal moraine on the south side of Meager North Main logging road. Presently, logging activities have occurred over much of the area around the chute, with more logging planned for the future (see Map 3).



SCHEMATIC CROSS SECTION OF NO GOOD CREEK

FIGURE 3.1



SCHEMATIC CROSS SECTION OF THE BRIDGE AT NO GOOD CREEK
SHOWING UNDERSIZED CULVERT

FIGURE 3.2

Unlike Boundary and No Good Creeks, no large debris flows are associated with the bed of Angel Creek, and stream flow seems to be minimal, as indicated by the small bridge which has been built across the creek. This bridge could be subject to inundation by snow avalanching. Some debris sliding occurs above Angel Creek falls, as evidenced from the bare rock face of the upper elevations.

Canyon Creek cuts a steep walled canyon of igneous and metamorphic rock where a bridge for Meager North Main logging road spans the waterway. The only area of rock failure is above the roadway, approximately one kilometre northwest of the logging road.

South of Meager Creek, along Meager South Main logging road, large boulder fields were encountered. The boulders were semi-rounded and varied in size from one to three metres in diameter. The creek that drains southwest of Meager Creek Hot Springs, Hot Spring Creek, seems be a source from which the boulders fan into Meager Creek.

Northeast of Hot Spring Creek is a series of terminal moraines, some of which are composed of volcanic material which comes in contact with basement complex rocks about 1.5 kilometres from the end of a branch of the logging road just east of Hot Spring Creek. South and west, the boulders grade into volcanic-covered, hummocky land.

Hot Spring Creek originates at a cirque south of Meager Creek, indicating that the boulders may be of glacial origin. The morphology of Hot Spring Creek is similar to No Good and Boundary Creeks in angle of the canyon walls, debris in the canyon, and levees which have formed. Therefore, similar conclusions can be drawn; that is, the three creeks are all subject to frequent debris flows cutting the walls and hindering the growth of vegetation along the creek beds.

Logging activities have been ongoing on both the south and north banks of Meager Creek since 1977, and substantial logging has been implemented in the area south of Meager Creek. Some of this activity occurs on steep talus bluffs just under avalanche chutes, with the remainder on fluvioglacial material. Slope angles on the fluvioglacial material are varied, averaging about 7°, while forest cover that was logged on nearby talus was from slopes of 28° to 30°. South of Meager Creek, logging activities extend to within 300 metres of Meager Creek Hot Springs.

North of Meager Creek, logging has started further east (near km 5 on Meager Main logging road) and is proposed to the edge of the east bank of Boundary Creek. This logging activity has been mainly on colluvium, with some on talus slopes and some on fluvioglacial material and alluvium near the logging maintenance shed east of the fork in Meager Main. The colluvial unit ranges in slope angles from 8° to 15°. The fluvioglacial material is terminal moraine material that gives a hummocky pattern to the bank, with a 43° drop to Meager Creek. The alluvium is at a stream gradient from 7° to 8°.

Capricorn Creek is the major drainage closest to the confluence of Meager Creek and the Lillooet River, and it forms the eastern boundary of the Meager Creek study area. Material in the creek bed is derived from both fluvioglacial and rock avalanche activity.

3.4 Job Creek Study Area

The Job Creek study area extends west to east from Affliction Creek to the Lillooet Falls, and north to south from the Lillooet River to Plinth Peak (Figure 1.2). The actual area traversed on foot during field investigations extended from the pumice bluff on the north and east, to the tip of Job Glacier on the north and west.

3.4.1 Areas of Primary Concern

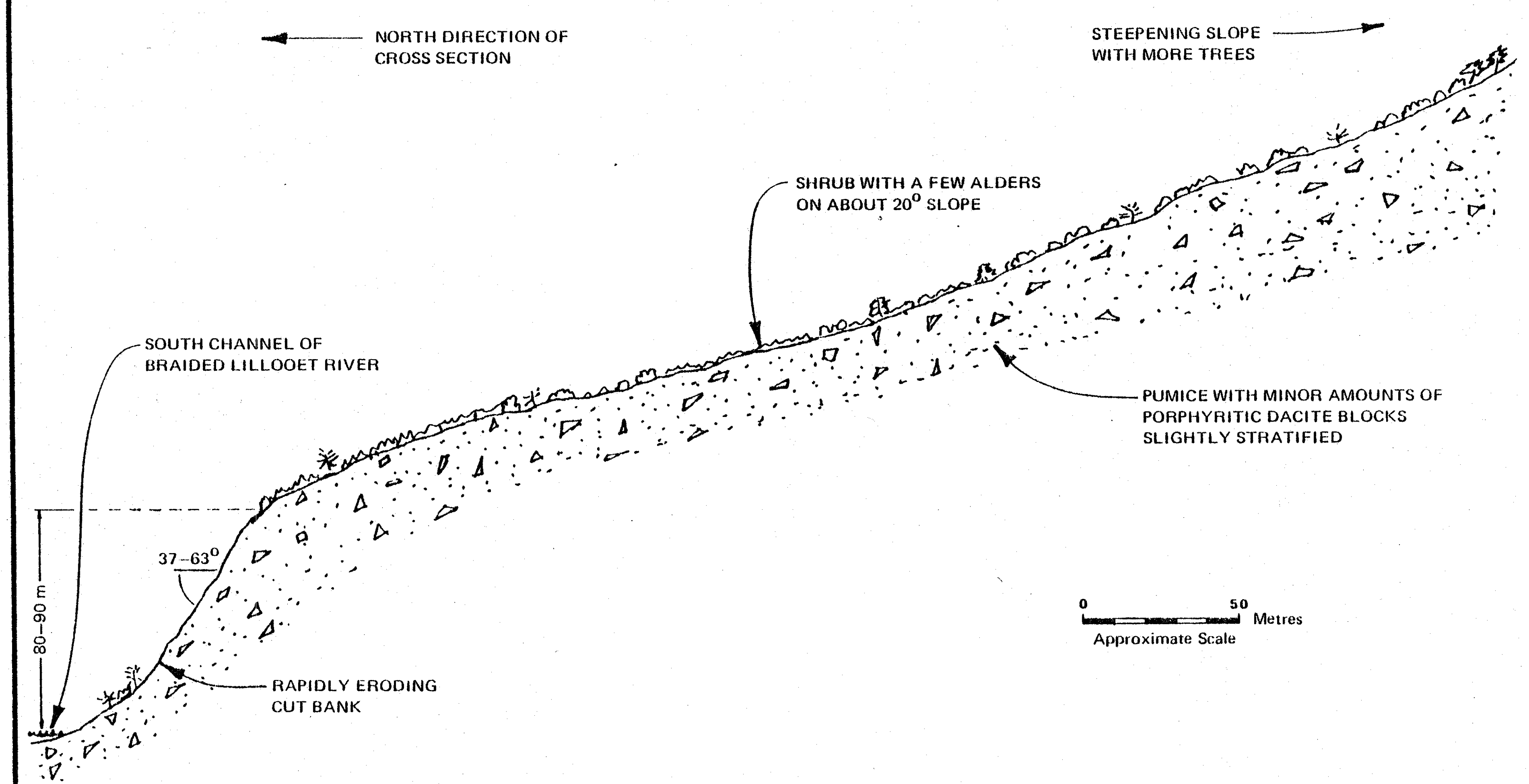
Within this study area, primary concerns include the pumice bluff bordering the Lillooet River, avalanche chutes between drill hole DDH-78-4-1 and Job Creek, and an unstable area of volcanic material along Affliction Creek. The pumice bluff was one of two choices for an access road, but the unstable nature of the unit eliminated it from consideration (see Figure 3.3).

Avalanche chutes are present between Job Creek and the NSBG 1978 drill camp, and the presence of downed pines and fir trees is evidence of large snow avalanches. Aerial photography shows extensive snow avalanche chutes, from the peaks northwest of Plinth Peak to areas east and northeast of Mount Meager. The chute grades from talus material at the higher elevations to colluvial material at the break in slope (see Map 1). The colluvial material is covered with alders, defined as non-productive brush by the B.C. Forest Service.

3.4.2 Areas of Secondary Concern

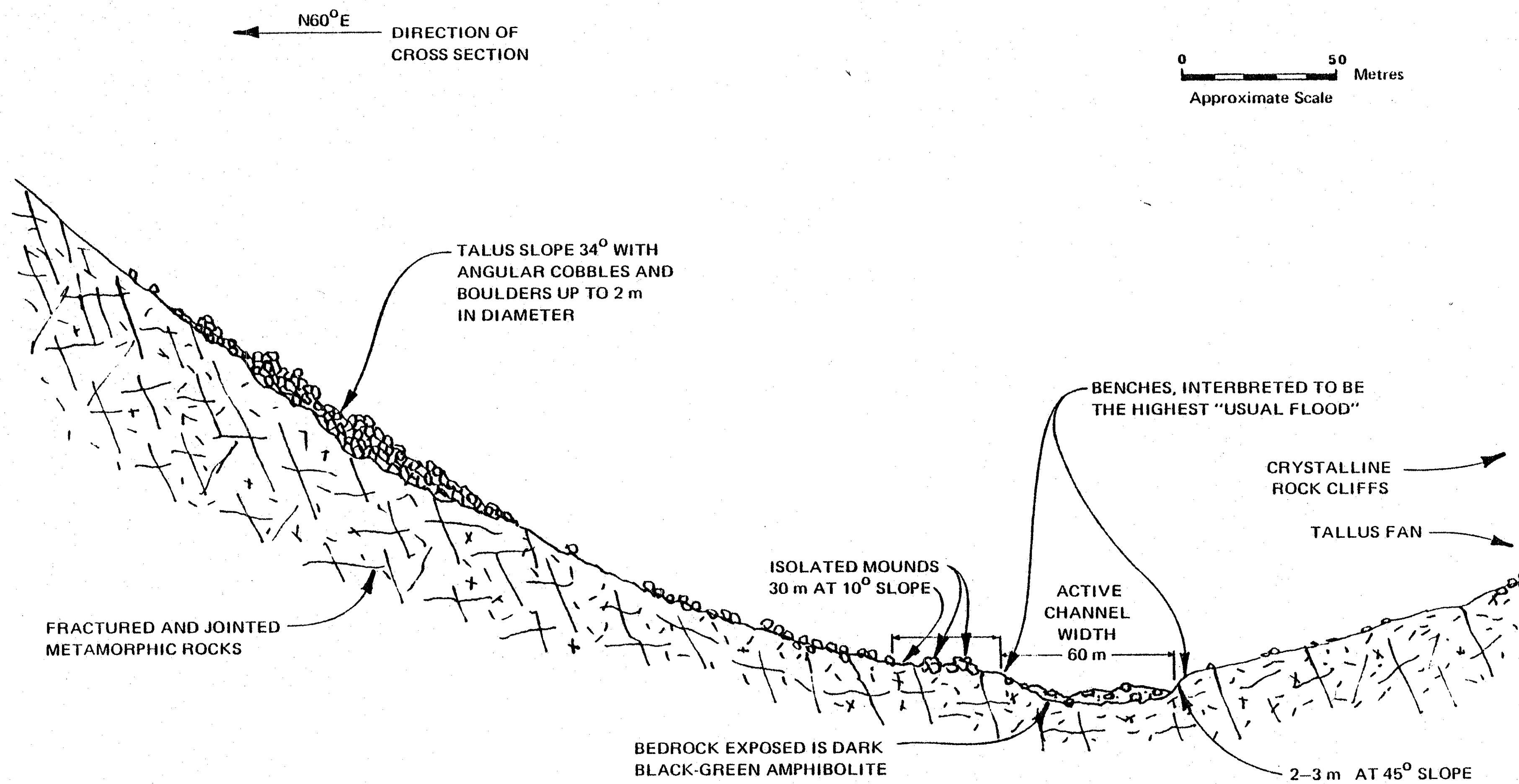
An area of secondary concern, which may require further investigation, is the till area described by Read (1978) on the east bluff of Job Creek. It is overlain by volcanics, and the stability is unknown. Air photo investigations show that the areas are weak, forming peaks of unknown stability (see Map 1). A schematic diagram of Job Creek shows a typical section with talus boulders covering the surface of the hillsides and fluvioglacial material at the bottom of the creek. It indicates a typical section where talus drapes over basement complex rocks (see Figure 3.4).

Another area of concern stems from a volcanic unit above the west bank of Affliction Creek, mapped by Read (1978) as a potential slide unit. This would be an area for further investigation if the NSBG resistivity studies show a substantial resource along Affliction Creek or along its confluence with Job Creek.



SCHEMATIC CROSS SECTION OF CUT BANK COMPOSED OF PUMICE AND TEPHRA, LILLOOET RIVER, 2 KM WEST OF SALAL CREEK

FIGURE 3.3



SCHEMATIC GEOLOGIC CROSS SECTION THROUGH JOB CREEK NEAR NSBG LINE M, STATION 10N, 40 W

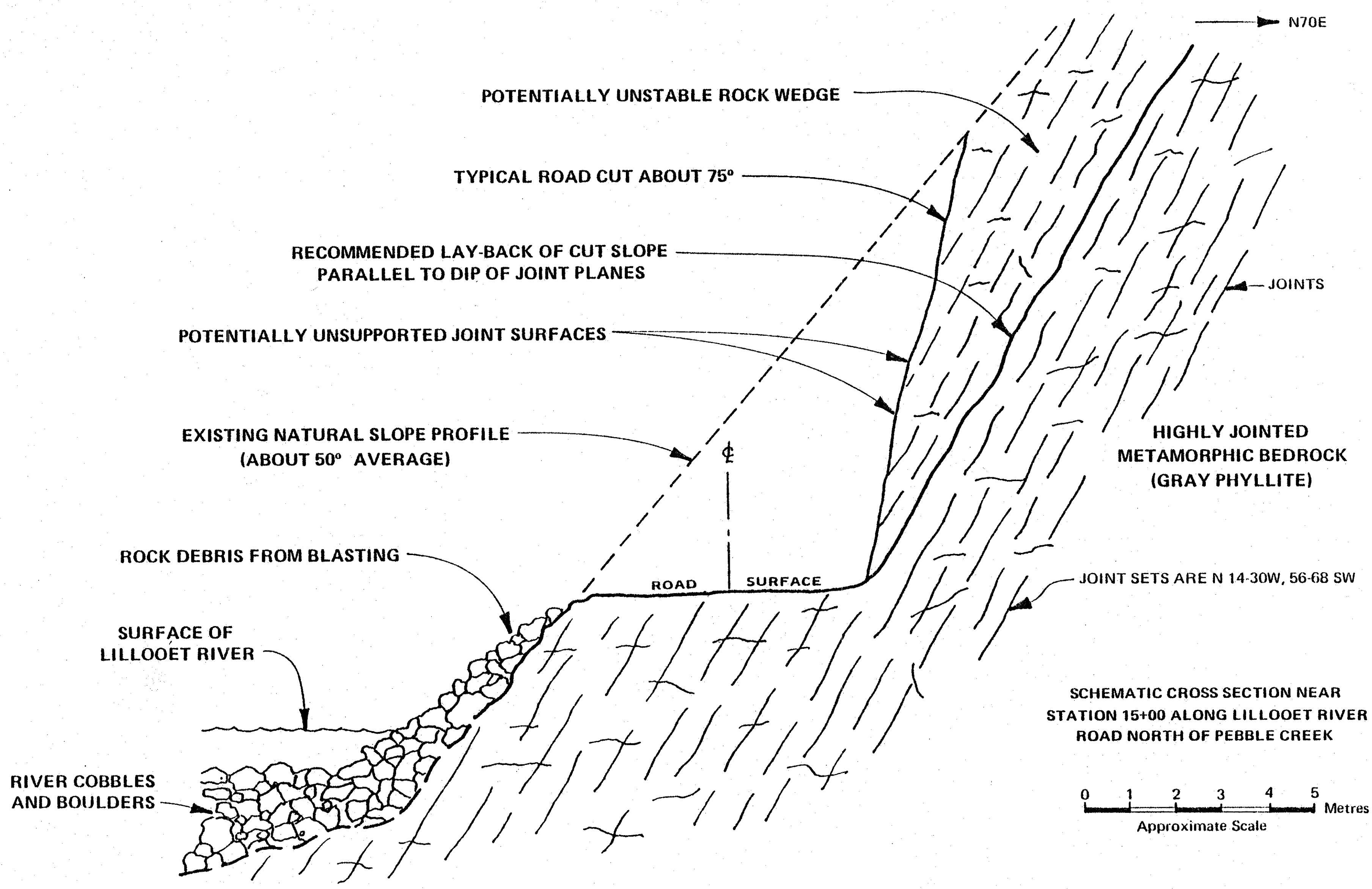
FIGURE 3.4

3.5 Lillooet River Study Area

The Lillooet River study area extends from the Lillooet Falls on the west to the confluence of Meager Creek and Job Creek on the east, and from Capricorn Creek on the south to about two kilometres north of the BC Hydro exploration drilling camp. This area is basically used as an access route to both the Meager Creek and Job Creek areas, the major concern being access to Job Creek. The main obstacle in achieving access to the Job Creek study area was a section of basement complex rocks outcropping at the edge of the Lillooet River. The obstacle was not only the rock face, but also its jointing pattern, which dips an average of 60° to the south. If insufficient material is removed for the access road, blocks of material could slide onto the roadway. Overhangs could be avoided by removal of sufficient material so the new rock face would be at the same angle as the main joint pattern (see Figure 3.5).

There are numerous avalanche chutes on the south side of the Lillooet River which should be avoided if any development or drilling is planned for the area. To date, all of the camp sites and drill holes have been located on the north bank of the Lillooet River (see Map 1).

Logging activities in the area have been quite heavy and have been concentrated on alluvial and colluvial material. No map of the 5-Year Logging Development Plan was available at the time of this report, so these areas were omitted from the land use map (Map 3). The 5-Year Plan should soon be available through either Macmillian-Bloedell or the BC Forest Service office in Pemberton.



POTENTIAL WEDGE-FAILURE IN ROCK SLOPE AVOIDED BY PROPER LAY-BACK OF CUT SLOPE

FIGURE 3.5

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Introduction

The conclusions reached in this report are directed toward areas of potential geothermal exploration activity. These exploration activities will include the preparation of drill pads of approximately 6400 m^2, the drilling of both intermediate depth (600 m) slim holes and production depth (1500-3000 m) holes and construction of access roads. Once a commercial-scale resource is confirmed, sufficient land would be cleared, graded and compacted to support the necessary network of access roads, wells, pipelines and power plant. Approximately 20 acres are characteristically needed to support a 50 MW power plant. For this study, lands proximate to the potential reservoir were given the most attention. Presently, the Meager Creek study area is of primary concern because it is here that a potential geothermal reservoir has been best identified. This area is currently experiencing subsurface exploration, with the drilling of intermediate depth slim holes.

The conclusions contained in this section of the report were made using the engineering geology map (Map 1),. land use map (Map 3) and the matrix (Figure 1.3), which were compiled from information collected during field reconnaissance, current publications investigation, and aerial photographic interpretation. Factors considered in rating the various sections of the geothermal exploration area included rock type, degree of weathering or alteration of plutonic and volcanic rocks, slope angle, and vegetation cover. The rating scale ranges from A (very stable area) to F (former landslide with a high potential for sure sliding).

Areas rated "A" would require little engineering, as slope angles are low (3°-12°) for the Job and Meager Creek areas. These areas are on fluvioglacial deposits or colluvium, and both have mature forests growing on them.

Areas rated "B" would require more engineering than "A" areas because of higher slope angles, and any structures would have to be keyed into the existing natural slope. Mature forests grow on "B" areas except where extensive talus chutes exist, and are also found on fluvioglacial deposits near the confluence of Job Creek and the Lillooet River.

Areas rated "C" are those that would require substantial engineering and include some stream channels, areas where some talus exists, and basement bluffs with high slope angles.

Areas rated "D" are those where access is extremely difficult, even on foot. Engineering is near impossible in places. These areas include stream channels with the potential for major flooding, areas of slide potential, steep peaks, cirques, and some talus areas.

Areas rated "F" are old slide areas which have a high potential for more movement, rendering engineering efforts virtually useless.

Ice is denoted as such on the terrain rating map. Over one-half of it is glacial and connected to one or more sources which overlie the volcanic complex.

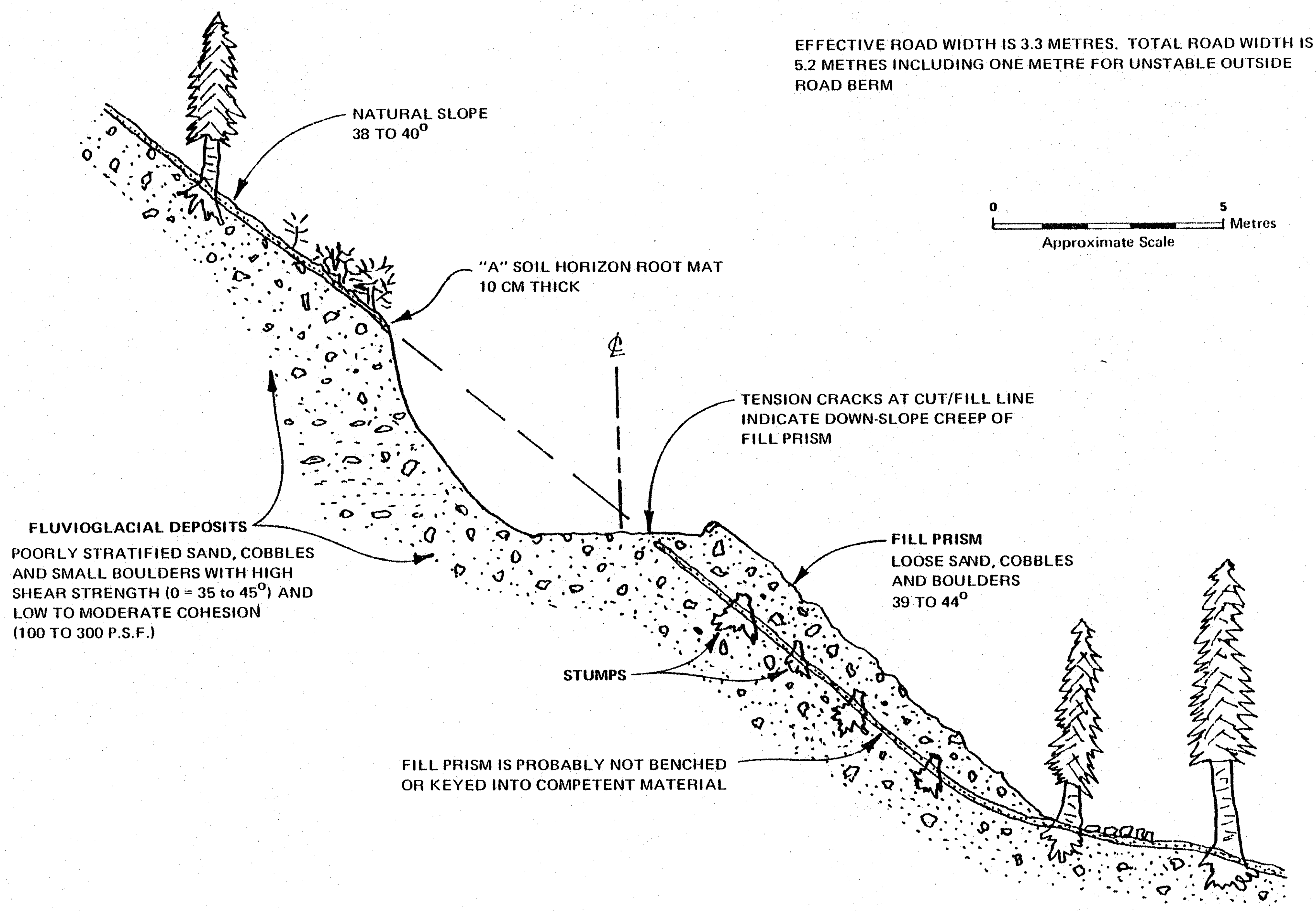
4.2 General Comments

Some of the data can be generalized for all three study areas, such as causes of snow avalanches and the effects of logging activities on the stability of the surficial material. Other data, such as the slide-prone areas of Hill 5321, and Devastation, Boundary and No Good Creeks, are more appropriately addressed within the context of the individual study areas. Snow avalanches occur in areas of talus slides and deposit rocks that add to talus chutes. Therefore, temporary and permanent structures should be placed well away from these chutes, due to their potential hazard. An avalanche expert should be selected to assess the potential dangers of snow avalanching within the geothermal exploration area.

There is abundant logging activity within the B.C. Hydro Geothermal Project Area. Within the Geothermal Exploration Area, most of the activity occurs within the Meager Creek study area, while the Lillooet River study area is experiencing increasing activity. To date, no logging has occurred in the Job Creek study area, as it has been relatively inaccessible due to lack of a road. Currently, however, a road is being constructed, thereby opening the area to both logging and geothermal exploration activities.

Logging activities employed in the geothermal exploration area include the requisite road building, clear cutting, and skidding/yarding the cut logs to a central loading area. The road building activities adversely affect slope stability, due to existing geologic characteristics and the road building methods employed. According to at least one source (Dodge and others 1976), road building is the most damaging of the logging activities, with soil failures resulting largely from slope loading (from road fill and sidecasting), oversteepened bankcuts, and inadequate provision for slope and road drainage. This situation occurs over much of the length of Meager Main logging road, which field investigations revealed to be slumping from one day to the next. A typical cross section is shown in Figure 4.1 (additional discussion of roads occurs in section 4.6).

The practice of clearcut logging exposes large areas of forest ground to the characteristically inclement weather, thereby increasing the opportunity for erosion. In addition, as logging activities progress from the lower to the higher and steeper slopes, stability is further affected, due to: 1) disruption of surface vegetation cover, thereby altering soil water distribution; 2) obstruction of main drainage channels by logging debris, and 3) destruction of tree root systems, which are the natural mechanical support of slope soils (Dodge and others 1976).



SCHEMATIC GEOLOGIC CROSS SECTION THROUGH MEAGER CREEK MAIN ROAD NEAR 3 KM MARKER

FIGURE 4.1

After clear cutting, logs are transported to a central loading area by skidding or yarding. Both methods are employed in the geothermal exploration area, and both adversely affect slope stability. Skidding, which involves pulling the logs with tractors, is considered more harmful and increases soil disturbance more than yarding, which utilizes cableways to move the newly cut logs. Of the total area harvested for timber, yarding further disturbs 12% to 43%, with skidding at 35% to 64% (Dodge and others 1976).

Impacts from logging practices which tend to induce erosion can be mitigated by timely reforestation programs, while those induced by road construction can be minimized by application of proper engineering practices.

4.3 Meager Creek Study Area

4.3.1 Favorable Conditions

The Meager Creek study area is generally favorable for geothermal exploration activities on the colluvium-covered areas, and on some of the talus areas. The excavation of a drilling pad to the recommended limits of about 100 m x 100 m (see Appendix A) would not be difficult on colluvium-covered material. Minimum engineering would be needed to cut and fill this area (see Map 2 for rating).

The construction of a drilling pad on basement complex slopes would require extensive grading and reworking of the ground, due to the higher slope angles and an increased degree of difficulty in the handling of the material. Fluvioglacial deposits would be difficult to handle in places where large boulders one to two metres in diameter are present. Areas where deposits are composed of small boulders, sand, silt, cobbles and pebbles are the most desirable fluvioglacial deposit areas to be utilized for drilling pads and roads.

4.3.2 Unfavorable Conditions

Areas that would be unsafe for intermediate and deep hole drilling operations are discussed below. Considerable engineering work would be needed to successfully conduct exploration activities in these areas.

Areas of Primary Concern

Units described by P.B. Read as being unstable or potential slide units are areas that are the primary slide units. The unit above the Devastation slide is rated the worst, although other areas underlain by the same acid tuff breccia unit are also slide-prone (see Map 2). No matter what the triggering mechanism is, another rock slide in this area could result in a Devastation-type slide due to the highly weathered and altered condition of the volcanic units, plus the presence of glacial ice. Devastation slide was a result of a retreating glacier and the consequent removal of support from the underlying weak volcanic units.

Hill 5321 is an active slide area. Blocks of the basement complex could slide into Meager Creek and possibly dam the creek, creating a possibility of flooding down Meager Creek with the breaching of the dam. Additional study would be necessary to more precisely assess the potential for this occurrence.

Areas of Secondary Concern

Areas of secondary concern include Boundary, No Good, Hot Spring, Angel, and Capricorn Creeks, and portions of Meager Main logging road. Areas susceptible to occasional avalanches and/or rock slides include Boundary, No Good and Hot Spring Creeks (Figure 3.1). The bridge access to No Good Creek is constructed from a tank car body about three metres in diameter, the conduit being smaller than the width of the stream (Figure 3.2). During the week of

September 9, 1979, a series of slides occurred on No Good Creek. The amount of material transported was enough to block the culvert, splash over the constructed roadway, and accumulate on the upstream side of the culvert. In addition to being of inadequate size, the life of the structure is limited, as it was not constructed to hold a large mass of material. A larger culvert or structure would be needed to avert similar situations in the future.

The boulder field located southwest of Meager Creek Hot Springs is not unstable but would be difficult to work, as the boulders are large (one to two metres in diameter). Blasting might be required to break some of the boulders into workable units in order to build any access road(s) and drill pad(s).

The Angel Creek area has a large avalanche chute that crosses the Meager North Main logging road between the 10 and 11 km markers. If work is to continue through the winter, this hazard should be taken into consideration in planning traffic movements.

The Capricorn Creek bridge is subject to breaching due to the possibility that large flows may occur. The source of material is from a large moraine, plus constant rockfalls which occur about 2.5 kilometres upstream.

A typical section of road access across Meager Creek Main logging road has a total road width of 5.2 metres, which includes two metres of unstable outside roadbed, for an effective load width of about 3.2 metres. The road was not engineered to specifications that would allow it to withstand years of use, and in places is only wide enough for a single logging truck. Sections of the road are subject to constant slumping from loose colluvium, fluvioglacial deposits and old alluvium. A schematic is shown in Figure 4.1, which illustrates a road without properly engineered benches or keys in the natural slope.

Major geothermal exploration and development activities could be supported by the colluvium-covered terrace above Meager Creek, but not to the edge of the creek.

Work on the upper slopes is possible through site-specific slope stability work and planned engineering of the access roads and drill pads.

4.4 Job Creek Study Area

4.4.1 Favorable Conditions

Fluvioglacial deposits cover most of this area, between the NSBG camp and Job Creek. In terms of slope stability, the most stable areas would be those just north and west of the pumice slope area. Here, slope angles are minimal (3° to 6°), the forest area is fairly stable, and there has been no logging or disturbance other than the surficial geothermal exploration efforts.

4.4.2 Unfavorable Conditions

Unfavorable conditions will be covered geographically, i.e., from east and north to west and south, from the pumice bluff to Job Glacier. The unstable nature of the pumice slope is due to a variety of geologic factors summarized here and discussed in detail in Appendix B.

The pumice exposed in the cut slope appears to be steeper than its normal angle of repose. This, plus its moderate shear strength but very low cohesion, makes it subject to continual landsliding. There is serious ground water seepage in the lower center of the slope, and the Lillooet River is actively eroding the base. This erosion induces some blocks to actually float away down the river, as the pumice has a very low unit weight. This situation is enhanced by the characteristics of the river gravels, which consist of well-rounded cobbles unsuitable for rip-rap or erosion protection. In addition, snow avalanches occur on the talus cone each winter and carry rock debris and logs over the edge of the cliff.

Talus slopes in the study area are extensive, as identified on aerial photographs and confirmed in the field. The talus chutes are also corridors for snow avalanches in the winter, as evidenced by broken trees and patches of snow in June at elevations of 760 metres. These talus chutes overlap stable fluvioglacial deposits rated "A" because of low slope angle (see Map 2). The stability of the talus is "D" due to rockfall hazards, slope angle, and, during winter, avalanche potential.

Job Creek has fluvioglacial deposits in its creek bed. They rate "C" due to the high angle basement complex material that forms the canyon walls. Perched above creek level is a deposit of fluvioglacial material overlain by volcanic material. The stability of this fluvioglacial material would require further study if exploration efforts were to continue up the canyon.

A unit of weak porphyritic basalt occurs on the west bank above Affliction Creek. If exploration efforts confirm the extent of the reservoir to include Affliction Creek, further investigation of this unit is recommended.

4.5 Lillooet River Study Area

Current exploration data have shown a low reserve in this study area, and there are currently no plans for further exploration here. The major interest in this area is as a location for a base of operations and access corridors to the Meager Creek and Job Creek study areas.

Major concerns focus on the access corridor to the Job Creek study area. The projected road crosses sections of old landslide and lahar deposits from the Plinth Assemblage. The corridor also cuts a highly-jointed section of basement complex rocks. Major jointing dips at a 60° angle and would be hazardous if a sufficient amount of material were not removed (see Figure 3.5).

4.6 Roads

Most of the roads within the geothermal exploration area have been built within the designated Meager Creek study area, in support of the logging activities. Within this area, roads are constructed by cutting away a natural section of the hillside, thereby removing stabilizing material and introducing the likelihood that the exposed material above the road will slump. In addition, the newly exposed surfaces are susceptible to erosion, further degrading the stability of existing slopes. Concurrently, disposal of this material as fill below the level of the road surface places added stress on the natural hillside. Therefore, unless the hillside is benched or keyed, the excess material may collapse, possibly including a portion of the roadway.

It is recommended that logging roads be upgraded as necessary to service traffic associated with geothermal exploration activities. This upgrading would include: 1) widening the roads to a minimum of five metres, plus shoulders, to accommodate the overhang of large drilling rigs; 2) compacting the roads to support the weight of 50- to 70-ton truck-mounted drill rigs; 3) allowing a minimum turning radius no less than the longest wheel base of the largest rig (70 feet in the U.S.), the radius varying inversely with the width of the road, and 4) adjusting the degree of road cuts to minimize the slumping now characteristic of hillside roads in the exploration area.

In instances where drilling locations are remote, the drill rigs could be emplaced by caterpillar tractor or helicopter. This might significantly reduce time and money involved in road construction, especially in areas where no additional geothermal development or logging activities are planned.

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APPENDICES

APPENDIX A

APPENDIX A

GENERAL RECOMMENDATIONS
DRILL PAD AND ACCESS ROAD CONSTRUCTION
DEEP GEOTHERMAL EXPLORATORY/PRODUCTION WELL
from: Roger Bowers, Hunt Energy Corporation
September 11, 1979

Many items must be considered in siting a deep geothermal well. For example, items to be considered include the projected aquifer characteristics, approximate depth and type of hole to be drilled, the drill pad dimensions, and road specifications.

The aquifer characteristics (including temperature, lithology and porosity) will determine what type of equipment to use and roughly what temperatures to expect at great depths. For instance, if a region is noted for highly fractured ground, and circulation loss is a large factor, air drilling might be considered for part of the exploration program. Large compressors would be needed to provide large air volumes and pressures. When high temperatures are encountered, mud or water would be used as the drilling medium and a mud cooling tower might be considered to cool the mud before recirculation. Next, the depth of the hole to be drilled has to be determined (usually between 1500 and 2600 m). That would be determined by the projected aquifer parameters.

If many holes are planned to be drilled and the depth of the aquifer is uncertain, a slim hole might be considered over a production size hole. The differences are in casing size, blowout preventor (BOP) size, the extra amount of fluid needed to drill a larger hole, larger reserve mud pit and possibly larger compressors, and larger cooling towers.

The size of casing for slim holes and production holes is given in Figure A-1. Blowout prevention equipment is relative to the size of the casing.

The larger reserve pit and compressors would be needed to accommodate the larger fluid volumes necessitated by the larger hole.

The drilling pad dimensions are variable with the location of the pad. An average size for a drilling pad for a large rig (capacity 4000-5000 m) is roughly 100 m x 100 m, with a lower limit of about 30 m x 60 m, not including the reserve mud pit (see Figure A-2). The reserve mud pit will vary in size with the accessibility of water for drilling and requirements for discharge for pump tests if a large aquifer is encountered.

Road Specifications

Large drilling rigs are recommended to be pulled up steep grades by Caterpiller tractor or flown in by helicopter. The reasons for this over construction of a new road are cost and time. It is presumed that a new road would cost more in time and money to install, especially in an area where no other activity is planned.

For improvement of existing roads, road width should be a minimum of 5 m wide (excluding shoulders). The turning radius on sharp turns should be no less than the longest wheel base of the largest rig (70 feet as an example in the U.S.A.). The radius would vary with the width of the road (the largest radius for the narrowest road). The truck mounted drill rigs in the U.S.A. weigh between 50 and 70 tons.

Further information is contained in the Geothermal Resources Operating Orders printed by the United States Geological Survey.

The logging roads would have to be upgraded to a minimum width of 5 metres, plus shoulders, to allow for overhang of large drilling rigs. Various sections of the existing logging road (Meager Main) are subject to constant slumping as shown in Figure 2.5. The man-made cut is 47° compared to the natural slope angle of 38° to 40° in many instances. The underlying material is fluvioglacial material; it is not well consolidated and has low cohesion.

Figure A-1

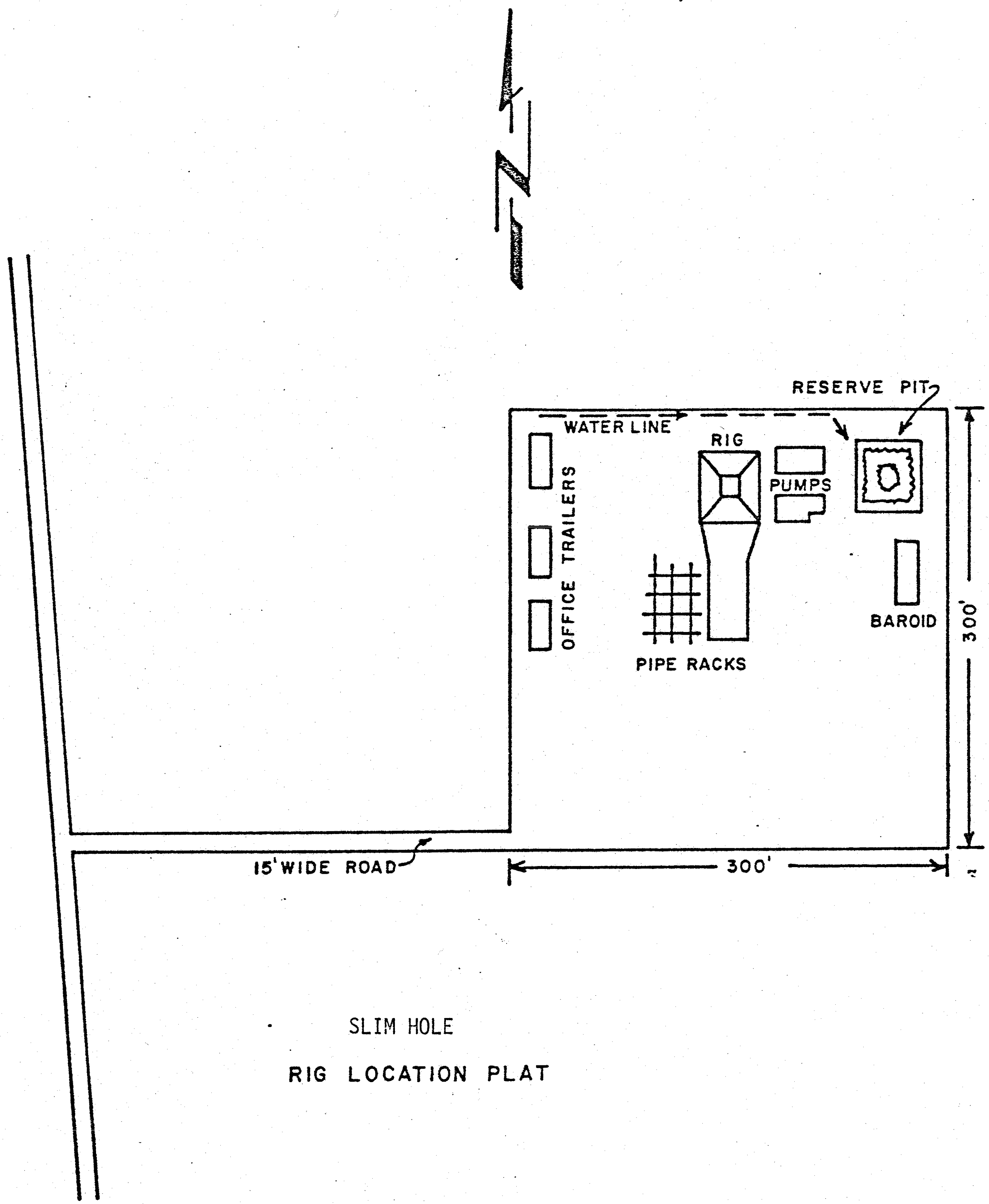
	Slim Hole	Production Hole
Conductor Casing*	13-3/8"	20"
Surface Casing**	9-5/8"	13-3/8"
Intermediate Casing***	7"	9-5/8"
Liner or In-Hole Production Casing	5"	7"

* Minimum depth of 15 metres (50 feet), maximum depth 60 metres (200 feet)

** Minimum depth 600 metres, maximum depth 400 metres (1300 feet)

*** Can be set at any time to control loss of circulation.

For more information see Geothermal Resources Operational Orders (GRO Order 2) (1976)



SLIM HOLE

RIG LOCATION PLAT

FIGURE A-2

APPENDIX B

APPENDIX B

M E M O R A N D U M

LILLOOET RIVER ROAD ALIGNMENT
Mount Meager Geothermal Area
Northwest of Pemberton, British Columbia

GEOLOGICAL REVIEW
10 July 1979

TO: Graham Seagel, M.Sc., Project Manager - Reid, Crowther & Partners

FROM: Robert Sydnor, M.Sc., Engineering Geologist - VTN Consolidated Inc.

INTRODUCTION

The purpose of this report is to summarize the geologic conditions relating to the alignment of the northern extension of the Lillooet River Road. At the present time the road terminates about 2 kilometres north of Pebble Creek on the east bank of the Lillooet River. B.C. Hydro wishes to extend this road up the Lillooet Valley to the vicinity of Job Creek. The purpose of the planned road extension is for geothermal exploration and drilling.

Our principal assignment is the slope stability and landslide potential for the north and south sides of the Meager Geothermal Area. Portions of two days were spent reviewing rock and talus slopes along the Lillooet River, both from the air and on the ground.

Road alignments have been proposed for both the north and south sides of the Lillooet Valley. This report presents some geologic considerations for road planning purposes.

ENGINEERING GEOLOGY

Pumice Cut Bank

A pumice cut bank is located about 1.6 kilometres northwest of Salal Creek and 1.3 kilometres southeast of the NSBG geology camp along the south bank of the Lillooet River. The Universal Transverse Mercator grid coordinates are 644-145. The pumice cut bank varies from 30 to 50 metres in height and about 250 to 300 metres in length. The Lillooet River is actively eroding the toe of the slope because of a sharp bend in the river.

The upper 30 to 40 metres of the cliff has an average slope angle of 63 degrees and the lower 10 metres of the cut is about 37 degrees. Just above the brink of the cliff, the alder-covered talus slope is about 22 degrees.

The cut bank is composed of tan-coloured pumice (95%) and dark grey rhyodacite (5%). The pumice has poorly-developed horizontal stratification. The pumice blocks and clasts are about one to twenty centimetres in diameter and are generally subangular in shape.

Because of its vesicular (air-holes) nature, most of the pumice clasts are very light and some blocks have a specific gravity less than unity; these blocks will float on water. Since the density of the river (water - 1.0) is greater than the pumice, the scour and erosion of the river bank is very great. The river velocity was estimated at about 1.0 metre/second or 60 metres/minute at the time of our reconnaissance on 4 July 1979.

The origin of the pumice appears to be related to the Bridge River Tephra which is believed to be quite young in geologic age, about 2490 years before present, according to Read (1978). The pumice appears to have been reworked by running water and landsliding immediately after volcanic activity ceased. The pumice deposit is draped in an apron-shaped manner on the north shoulder of Plinth Peak. Geomorphic evidence would indicate that the pumice cone thins out rapidly towards the apex of the cone.

Groundwater Seepage

In the lower centre of the pumice slope, a significant zone of water seepage was observed. The seepage zone is one to seven metres above the river and extends laterally for about 60 metres along the centre of the pumice cliff. Water is bleeding down the lower pumice slope at an estimated rate of 80 to 100 litres/minute. Local slumping of the pumice occurs all along the zone of active seepage. The perched or elevated zone of seepage is probably an indication of groundwater travelling along a clay-rich layer of altered volcanic ash. It is also possible that groundwater is travelling along the base of the pumice cone and along the top of a less-pervious volcanic "bedrock" unit.

Cut Bank Stability

The angle of repose of loose pumice talus was measured at 37 degrees. The face of the upper pumice cut slope averages 63 degrees, with some local vertical portions. The angle of internal friction is high for pumice, but the cohesive strength is very low. It can briefly stand-up in slopes steeper than its normal angle of repose, but it soon fails by massive slumping in a wedge-failure mode. The presence of groundwater is very detrimental to the stability of a pumice slope.

Avalanche Potential

There appears to be a significant hazard from snow avalanches descending from the steeply-sloping north ridge of Plinth Peak. Large trees are absent and the talus slope is covered by deformed alder bushes. There are several bare talus chutes within the alders. A residual snowbank from the past winter's avalanches occurs just above the river at the foot of the slope. Some rock debris is evidently rafted down-slope by the annual snow avalanches. Large tree trunks (stripped of bark and branches) were also noted at the foot of the pumice slope; these trees evidently descended the slope with a moderately high velocity.

CONCLUSIONS

Favourable Geologic Conditions

1. All earth materials exposed in the pumice slope can be readily ripped and graded by conventional earthmoving equipment (ie., a D-8 type of caterpillar tractor).
2. A road alignment parallel to the 2800-foot contour and well above the pumice cliff is geologically feasible. This temporary alignment could be built to minimal road specifications and would accommodate NSBG drilling equipment for a one-time exploration effort in the Fall Creek geothermal area. This alignment would be subject to minor damage each winter from up-hill snow conditions, but could be reopened by remedial grading, as necessary.

Unfavourable Geologic Conditions

1. The pumice exposed in the cut slope appears to be steeper than its normal angle of repose and is subject to continual landsliding.
2. The pumice has moderate shear strength but very low cohesion.

3. There is serious groundwater seepage in the lower centre of the slope.

4. The Lillooet River is actively eroding the base of the pumice slope.

5. The pumice has a very low unit-weight and some blocks actually float away down the river.

6. Snow avalanches occur on the talus cone each winter and carry rock debris and logs over the edge of the cliff.

7. River gravels consist of well-rounded cobbles which are not suitable for rip-rap or erosion protection.

8. There is no convenient quarry for suitable rip-rap (hard, angular boulders, 1 to 2 metres diameter) within one kilometre from the pumice cliff.

9. The supposed thickness of the pumice is unproven by subsurface drilling or surface geologic mapping. To our knowledge, the volume of the pumice has not been calculated by any mining geologist. Although there are apparently active mining claims on the pumice deposit, the economic feasibility of the resource remains to be demonstrated.

RECOMMENDATIONS

1. This brief letter-report has considered only one major geologic hazard on the south side of the Lillooet River; however, there are nearly a dozen other serious geologic hazards on the south side of the river.

2. The north side of the Lillooet has only one steep rock face, about two kilometres north of Pebble Creek. The actual length of the steep (50 degree) rock slope is only about 100 metres. Once this problem section is passed, the north side of the Lillooet River can accommodate a fairly good road alignment without any significant geologic hazards. The rock slope consists of very hard phyllite (a metamorphic rock) that can be readily drilled and blasted. Because of planar joints dipping out-of-slope, we recommend that the rock slope be cut to an angle not steeper than 0.5:1 or 63 degrees between Station Numbers 13+00 and 16+00. This will help to lessen the potential for rockfalls along this alignment.

3. In summary, it is recommended that the advantages of the north-side route be given full consideration. There appear to be too many geologic hazards and other engineering constraints for a road alignment on the south side of the Lillooet River.

There are no significant avalanche or landslide problems on the north side of the river.

Robert Sydnor