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Ministry of Transportation and Infrastructure

Geotechnical, Materials and Pavement Engineering Section

MEMORANDUM

December 5, 2012

IAO

Re: DISCLAIMER STATEMENT for the Quesnel Landslide Report entitled "The Landslide Problem in the Quesnel Area: Its Implications for Sub-Division Approval" by S.G. Evans and R.L. Crook dated September 1973

The Quesnel Landslide Report entitled "The Landslide Problem in the Quesnel Area: Its Implications for Sub-Division Approval" by S.G. Evans and R.L. Crook dated September 1973 was prepared for the information and guidance of Regional Highway Engineers in the Prince George area to help in decisions being made in regards to sub-dividing farmland in the Quesnel area in 1973.

This report covers an investigation that was completed over 40 years ago. The information that is presented within this report reflects the state of practice at the time period in which the report was written. However, over the past 40 years updated information has become available due to more recent investigations that have been completed in the Quesnel area. This updated information is available in more recent reports completed by others and should be used alongside the information provided within this report.

Since the time it was written, significant technological change has taken place allowing the collection of accurate surface movement and deep seated movement data. These tools have greatly improved the mapping and interpretation ability within BC. Earthquake requirements specified in the BC Building Code have changed from the 10% in 50 year earthquake, which was the requirement in 1973, to the 2% in 50 year earthquake (APEGBC, 2010). All seismic considerations are therefore no longer valid and all slopes identified within this report need to reconsider the new seismic loading requirements. Also since 1973, climate change effects have become apparent and now the new standard practice requires that climate change effects be included in slope stability considerations (APEGBC 2010). There is, also, a new expectation that slope stability consider the effect of changes to lands beyond the site in question (APEGBC 2010).

The 1973 report remains the property of the Ministry of Transportation & Infrastructure and any effort to use the information contained in this report should be done recognizing that the report is 40 years old and not done to current standards. Slope stability inquiries for any particular site should be addressed by a qualified professional using the APEGBC document (APEGBC 2010) as a guideline.

Reference:

APEGBC (May 2010) "Guidelines for Legislated Landslide Assessments for Proposed Residential Developments in BC"

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GOVERNMENT OF BRITISH COLUMBIA

N. Pocyson

CONFIDENTIAL

MEMORANDUM

CONFIDENTIAL

Mr. J. W. G. Kerr, P. Eng.
c. Geotechnical & Materials Eng.
Department of Highways

FROM

Geotechnical & Materials Branch

October 1st, 1973.

SUBJECT: QUESNEL LANDSLIDE STUDY

OUR FILE: 31-11-00

YOUR FILE:

We have completed our investigations into the above subject and enclose our report entitled "The Landslide Problem in the Quesnel Area: Its Implications for Sub-division Approval". As pointed out in the report, it may serve as a guide for sub-division approvals and as a reference source for investigators who will necessarily become involved in landslide problems in the Quesnel area.

It has been found that a unique set of landsliding conditions exist in the Quesnel area (i.e. the existence of slide prone materials from two geological eras and a regional perched water table) and, because of this, landsliding is the dominant mode of slope transformation. About twenty-five foci of landsliding have been detected.

Because of the close relationship between geology and landsliding we have gone to considerable lengths to reconstruct the geological history and to detail the soil and rock types encountered in the area. The main materials involved are overconsolidated stiff fissured Tertiary silts and clays which are affected by a complex retrogressive mode of failure. The consequences of this geology and mode of failure were examined. An inventory of landslides was made and through both a consideration of slope development and a field slope stability chart, an assessment of slope stability was carried out.

Although it is very difficult to forecast the time of future landsliding it has been possible to indicate the place. Figure 11 is the outcome of such a prognostication and constitutes the main guide for sub-division approval (an extra copy is to be found in an envelope at the back of the report). It is seen that a problem exists not only along the banks of the Fraser and Quesnel Rivers (related to river action) but also on the flanks of the Plateau in which the valleys are cut (related to long-term instability).

..... 2

Areas have been delimited which are either unsuitable or marginally suitable for sub-dividing. It is recommended that no sub-dividing be approved in the former category.

Because of the regional nature of the study (and as pointed out in our conclusions in Section VII) it was not possible to rule on the specific stability of slopes in the marginal zone. It is felt, however, that they possess sufficient landslide potential to warrant geotechnical examination before construction is permitted to take place. Obviously slopes in this zone are maintained in a wide spectrum of stability states (see Section IV) from stable to unstable.

An example of marginal land that through the development of a slide complex has become unsuitable is the land along the rim of Red Bluff. Homes have been built in this zone (and have suffered damage in some cases) in ignorance or defiance of natural processes.

To obtain an indication of the rate of land loss through progressive failure the advance of the head of slide B9 in the Big Slide complex was measured. Air photos between 1949 and 1969 were used and a figure of 5,000 square yards per year was obtained.

The unshaded areas in Figure 11 are deemed suitable for sub-dividing only with reference to the landslide hazard.

Sections on flooding and earthquake hazards have also been included. These hazards do not appear great. However, due to the material structure and the groundwater situation, small seismic shocks will have an indirect effect in that they will reduce slope stability.

Our specific recommendations are made in Section VII.

Related to the findings of the report, it is recommended that a detailed geotechnical investigation be carried out as soon as possible to evaluate;

(a) the probability of homes being destroyed by retrogressive sliding along the rim of the still active Red Bluff complex (see Figure 12 in report).

(b) the hazard to possible sub-divisions in the Sub-division Slide area (see Figure 13 in report).

Following a discussion with the Senior Approving Officer on September 28th, he made it clear that the contents and existence of the Quesnel Landslide Report should be kept strictly confidential.

R. L. Cook

for S. G. Evans
Geotechnical Engineering Assistant

SGE/RLC/jhn

Enclosure

British Columbia Department of Highways

Victoria, British Columbia

THE LANDSLIDE PROBLEM IN THE QUESNEL AREA: ITS IMPLICATIONS FOR SUB-DIVISION APPROVAL

by

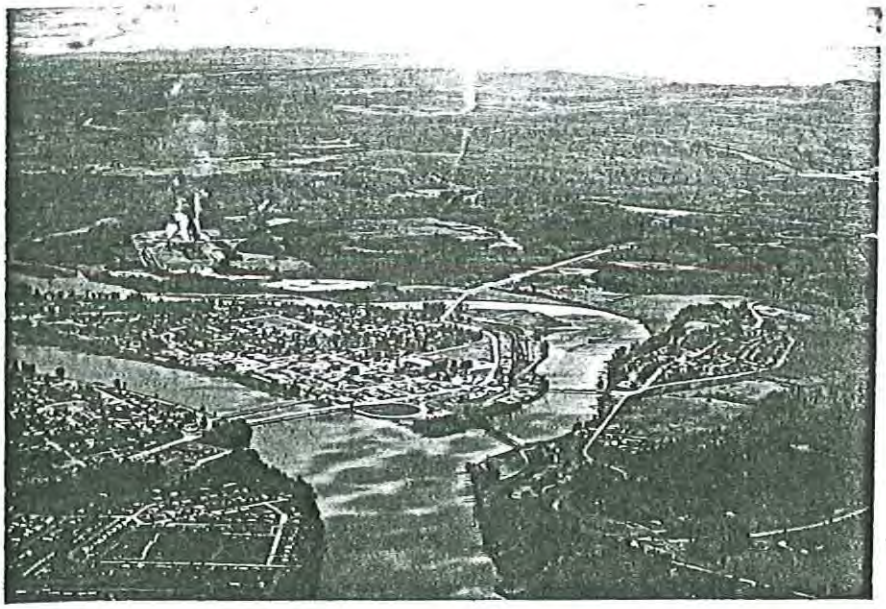
S. G. Evans

and

R. L. Crook

Geotechnical and Materials Branch

September 1973



FRONTISPIECE

View of Quesnel showing Fraser Plateau surfaces with present valleys cut into it. Slides occur on the flanks of these surfaces and in this picture the Quesnel River (behind pulp mill and left), Quesnel Hill (right centre), and Plywood Hill Slides (foreground), are seen.

ABSTRACT

This report evaluates the suitability of lands in the Quesnel area for sub-division with respect to risk which may be anticipated from hazards such as landsliding, flooding and earthquakes. Based on hazard risk, a map is presented which designates areas as suitable, marginal and unsuitable for sub-division.

The landslide potential of the Quesnel areais high and is the major hazard to be considered in approving lands for sub-division. The report describes how a complex geology and an adverse ground-water situation, river-undercutting and human activities (logging, construction, etc.) contribute towards sliding. Failure modes are varied (retrogressive, flow, slump, etc.) and the sizes of affected areas also exhibit considerable variation.

The earthquake hazard is considered low but some lands adjacent to major rivers are subjected to the risk of flooding.

The report makes several general recommendations concerning sub-division approval. Sub-divisions should not be approved in areas of landsliding. Approval should be preceded by extensive geotechnical investigations in marginal areas (adjacent to the head or toe of existing slides, in the vicinity of areas with a high potential for first-time slides etc.). Specific recommendations are made concerning the risk in critical areas such as Red Bluff and the Sub-division Slide. Areas not designated as marginal or unsuitable are considered to be zones of low hazard risk where sub-division approval is concerned.

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I INTRODUCTION

This report is the outcome of an extensive investigation into the problem of landslides in the Quesnel area as it relates to the possible sub-dividing of lands in the vicinity of the town. The study was requested by Mr. L. Broddy, Regional Highway Engineer in Prince George since, as he pointed out in his letter of request, the new policy of farmland preservation will make those lands which have been favoured by sub-dividers more or less unavailable. As a result, sub-dividers will seek more hazardous terrain along river banks, terrace edges or mountain margins where the threat to life and property from landslides, snow avalanches and floods is substantial.

A landslide is a natural hazard and before embarking on the background to the work it would be as well to consider certain concepts related to natural hazards and their occurrence. We have used as a reference in this investigation a report prepared for the City of Juneau, Alaska (City of Juneau, 1972) on geomorphological hazards that affect the city. As the report points out, the accurate prediction of hazards in terms of probability can only be achieved if a long record of hazard which can be used in a mathematical model is available. In this study, as in Juneau, we are not in a position to do this because the length of our event record is so short. We are able, however, to attempt a prediction on the basis of a qualitative, or subjective, probability.

With this objective in mind we have produced a report that

(a) locates and delineates areas of landsliding

(b) locates areas of high landslide potential.

(c) assesses the landslide hazard in terms of a classification which can act as a guide to government officials involved in sub-division approval.

The report gives a first approximation to the landslide problem, and represents the initiation of "appropriate action necessary to minimize losses to life and property .... " (City of Juneau, 1972). As will be seen, the history of the area is rich with hazard events and it is hoped that the data contained here will help to reduce the problem faced by the residents of expanding Quesnel.

To meet the objective of the report we have gone to great lengths to reconstruct the geological history of the area as well as to detail the rock and soil types encountered since the links between history, materials and landsliding are extremely significant. Indeed it is believed that a unique set of landslide conditions exists in the vicinity of Quesnel which has given rise to a very high incidence of instability. We have also considered the related hazards of flooding and earthquakes in the interest of completeness.

We have conducted substantial bibliographical research into Branch files, the files of the Ground-water Division and the Water Investigations Branch of the Department of Lands and Forests, and into material at the Provincial Archives. Field trips were undertaken to inspect slides and map the geology between May 30 and June 1, and between June 18 and 22. An aerial inspection, using the Government Beaver, was made on June 26.

The main text of the report is largely a summary of the detailed Appendices. We have included these Appendices so that they may serve as a reference source for future work on the landslide problem and for the use of personnel responsible for sub-division approvals.

The "Quesnel area" mentioned above is centred roughly on Quesnel Airport, extends north to about the north end of Ten Mile Lake and south to the southern end of Dragon Lake, a corridor twelve miles in length and six miles wide (Fig. 1).

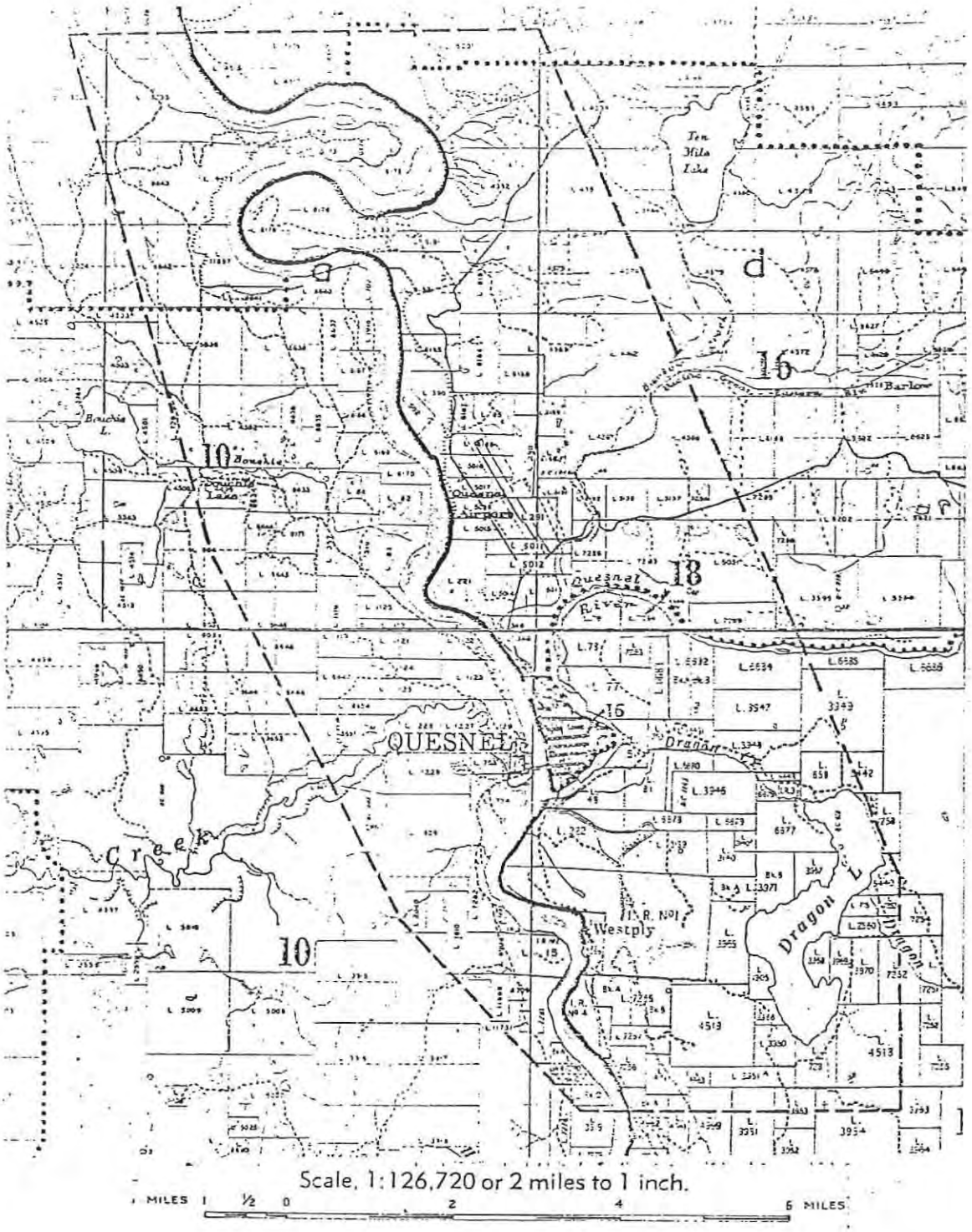


FIGURE #1 QUESNEL LANDSLIDE STUDY: BOUNDARIES OF STUDY AREA.

II GEOLOGY, GROUNDWATER AND CLIMATE

Local variations in the stratigraphy of the Quesnel region exert a considerable influence on the probability of landsliding. Soils vary in grain-size, sorting, compaction, consolidation, permeability and lithification and are arranged in very complex and discontinuous sequences.

In this report, therefore, the local geology is considered in depth. No detailed memoirs have been published for the Quesnel region, but geological reports which pertain to much larger areas of the Interior have been scanned for references to it. From these sources, the geological history has been reconstructed. This history is important to an understanding of individual soil sequences and provides a useful background to the problems which are associated with the local soils.

The available geology reports have also yielded some detailed information on the nature of the soils. Difficulty was encountered, however, in mapping the locations of these soils. Existing geological maps have been prepared at small scales and lack detail. These maps are intended to cover large areas of the Fraser Plateau and neighbouring regions and prove useful only in the preliminary location of formations. There is not always agreement concerning the locations of formations and actual geological situations may be much more complex than the maps indicate.

Rudimentary geotechnical information was gathered from the stratigraphical sections which are available in some reports. Additional sections were recorded by the writers and other information was obtained from both borehole and landslide records of the Department of Highways and

from well logs of the Groundwater Division of the Water Resources Section, Department of Lands and Forests.

(A) GEOLOGICAL HISTORY

The following is a summary of the sequence of events which contributed to the present geology. A detailed reconstruction of events is reported in Appendix A. The figures in brackets indicate the corresponding points in Appendix A.

PERMO - CARB

1. (1) In Carboniferous times, an incursion of the sea deposited extensive sedimentary sequences in the Interior of B.C. These rocks (the Cache Creek series), which are the oldest soils in the Quesnel area, have suffered subsequent metamorphism and bracciation.

2. (2 - 4) The marine phase was followed by a long period during which uplift alternated with erosion. The Fraser Plateau was reduced to an undulating plain of low relief by erosion and by the spread of fluid lava sheets. By the beginning of the Tertiary era, the ancestral Fraser River had carved an enormous trench for itself. The river at this time flowed northwards into the Peace River system.

3. (5) The Cenozoic (Tertiary and Quaternary) history of the Quesnel area has witnessed (i) the burial of this trench by lavas and sediments and (ii) a more recent episode during which streams and glaciers have begun to exhume it.

4. (6 - 7) During middle Eocene times, burial of the trench was initiated by a phase of lava outpourings (the Lower Lavas series). The proto-Fraser River was dammed at several points where lava accumulations were particularly substantial.

5. (8 - 10) At Quesnel, the trench became a large lava-dammed lake basin into which were deposited hundreds of feet of lignite measures, intercalated with clays, sands and gravels - the Lower series of the Fraser

formation. After deposition, these beds were tilted to angles between 15 and 40 degrees.

6. (11) Eventually the lava dams were lowered by erosion and the river resumed a normal flow. It deposited hundreds of feet of alluvial soils, particularly gravels, which constitute the Middle series of the Fraser River formation. The Middle series is probably Miocene in age. The Lower and Middle series virtually completed the burial of the pre-Eocene trench at Quesnel. These series occur beneath all of the present river terraces and outcrop in the valley sides up to the level of the Fraser Plateau.

7. (12 - 15) Towards the end of the Miocene epoch, lacustrine conditions were established once again. The onset of these conditions is related to the fact that Middle series soils become finer-grained towards the tops of sections. During this late stage, diatomite was deposited, forming the Upper series of the Fraser River formation. The lacustrine conditions were probably promoted by the lava outpourings of the Upper Lavas series in late Miocene/early Pliocene times. These lavas blocked the valley at many points.

8. (16 - 17) Uplift which accompanied the lava eruptions spurred the Fraser River to a new phase of erosion which has continued spasmodically ever since. It may have been at this time that the proto-Fraser River at Quesnel began to flow southwards. The disruption of river flow by lava damming could have permitted the Chilcotin system to capture these waters.

9. (18 - 19) Downcutting was interrupted by the advance and retreat of four ice sheets during Pleistocene times. Extensive drift sheets were deposited and are well-preserved on the Fraser Plateau. At the

termination of the last glaciation, a glacially-dammed lake deposited varved silts over the drift sheets in the Quesnel area.

10. (20 - 22) Since the retreat of the ice, the land surface has rebounded hundreds of feet, providing a new impetus to fluvial downcutting. River erosion has resulted in a series of bluffs and terraces. The Fraser valley at Quesnel is now at least 600 feet deep. The new trench is located predominantly within materials of the Fraser River formation. The landslide problem stems from this phase of erosion which has produced bluffs within essentially slide-prone materials.

(B) SOILS

This section summarizes available information concerning the disposition and characteristics of the soils in the Quesnel area. A fuller description is presented in Appendix B, together with geology maps, detailed sections and photographs. Much of the information was derived from personal field observations and from published descriptions of geological sections.

It became clear during the study that the nature of the local geology is more complex than published reports suggest. Generalizations can give no more than a superficial impression. Soil sequences tend to show little correlation from place to place while soil properties, notably grain-size, preconsolidation history and lithification, exhibit remarkable contrasts even within a single section. It is important, therefore, to establish the soil sequence in any area of proposed subdivision which has been designated as unsafe in this report.

There are very few test records available concerning geotechnical properties such as shear strength, residual strength, sensitivity, plasticity and consistency. Where available, these pertain to particular slide histories and lack generality. They are reported during the discussion of case histories in Section IV. Groundwater attributes of the soils are also considered separately.

1. The Cache Creek Series

The series includes marine sediments of Carboniferous age which have been subjected to intense folding, shearing and metamorphism. Exposures are found only in the steep walls of Baker Creek Canyon but they may underly most of the region. The materials weather to a residual clay of little or no plasticity.

2. Lower Lavas Series

Basalts and andesites of this series underly the Fraser River formation in the bottom of the trench but are exposed only in Baker Creek Canyon and along the west bank of the Fraser River to the south of Quesnel. Folding, faulting and brecciation has weakened the lavas and exposures are intensely weathered and altered to clay. These materials may be significant in connection with landsliding. They are found, for example, in the base of the Subdivision Slide.

3. The Fraser River Formation

Soils of this formation are remarkably prone to failure and feature in most of the landslides which are present around Quesnel. Soil sequences characteristically contain thin beds of gravels, sands, silts, clays, lignites and diatomite. The beds tend to be lensed and discontinuous. The entire Fraser River trench has been eroded within these soils which straddle the river along a linear outcrop of several miles width. The degree of lithification (i.e. compaction, consolidation, cementation) of these soils varies considerably and while some soils resemble bedrock, others are as unlithified as Pleistocene or Recent soils. The clays and silts have usually been heavily preconsolidated and are very stiff or hard, and typically fissured. The strata are tilted and faulted in places. The formation consists of three recognizable series.

(a) Lower Series - The trench has evolved largely within the Lower series at, and to the south of, Quesnel. Clays, silts and lignites dominate in this area, and have been excessively preconsolidated. In places, the lignites have

been burnt out, baking adjacent beds and leading to fissuring. Several major slides, including the Red Bluff, Plywood Hill, Subdivision and Westply Slides have developed in these soils.

(b) Middle Series - Soils of this series, which usually consist of thick gravels interstratified with sands, silts, clays and lignites, predominate in the trench north of Quesnel. The younger strata, occurring uppermost in soil sequences, may, however, be composed largely of fine-grained soils, especially east of the Fraser River in the north of the study area. Massive failures are present in both the coarse and fine sequences, notably the Big Slide, Paradise Road, East Bank, West Bank, Gravel Pit and Garbage Dump Slides.

(c) Upper Series - A continuous deposit of diatomite may once have covered the Lower and Middle series of the Fraser River formation but only isolated outcrops remain. Diatomite is a white, highly porous material which contributes to failures by facilitating seepage and by becoming rapidly incoherent as moisture content increases because of its low plasticity. It is present in the Paradise Road and Plywood Hill Slides.

4. The Upper Lavas Series

The series consists of basalts, andesites, tuffs and breccias which spread fluidly over the Fraser Plateau as plateau lavas. Not Tuffs & Breccias Outcrops are usually fresh and unweathered and are confined to the area west of the Fraser River and north of Baker Creek, where black olivine basalts are present. These lavas are not found within the trench and tend to occur as a caprock to the main valley slopes, as at the Paradise Road Slide where they protect the slope from failure to some extent.

5. Pleistocene Glacial Drift

A complex assortment of drift soils mantle the Fraser Plateau and occur in many places in the trench itself. The drift includes tills, boulder clays, outwash, glaciolacustrine and interglacial soils. The fine-grained soils except for the late-glacial lake clays have been glacially loaded and stiff

and fissured. Gravels, where present, tend to be loosely packed and show few signs of lithification. Drift soils often occur in the summits of landslides where they may be found to be zones of seepage (see chapter II, section C).

6. Recent Soils

The Fraser River has deposited sequences of sands, silts and gravels over its terraces during the post-glacial period. The materials form thin sequences usually, not often exceeding 10 feet in thickness. Their role in landsliding is relatively minor.

(C) GROUNDWATER

The presence of seepage moisture is noted in most of the landslide zones and undoubtedly contributes to failure. The moisture is channeled into these zones along porous strata such as sands, gravels and some fissured, fine-grained soils. Bluffs which have not failed may do so in the future where this process is operative while existing slides may be reactivated.

The Quesnel area is said to possess only limited aquifer potential for the supply of farm wells. This may be attributed to the absence of large continuous aquiferous strata. Water is unable to establish major groundwater nets because of the lensed nature of individual strata. Minor aquifers, while transporting inadequate supplies of groundwater for wells, nevertheless are capable of encouraging the build-up of moisture in critical zones.

The aquiferous potentials of the major geological groups of soils are variable. Moisture migration through Cache Creek soils depends on the presence of fractures and is usually low. Flows may be considerable through weathered sections of the Lower Lavas series. Except where fissured, the fine-grained soils of the Fraser River formation do not form aquifers. Both the gravels of the Middle series and the diatomite, however, are highly porous and may be expected to encourage groundwater seepage. Some of the drift soils, including the tills and varved lake sediments, are non-porous. Interglacial and glacio-fluvial outwash sands and gravels, however, appear to act as important

aquifers, particularly on the Fraser Plateau.

The well logs suggest that two major aquiferous zones are present in the region. The first is below the level of the Fraser River and appears to be located at a level of 1510 feet. Most of the wells below the margins of the Fraser Plateau are dependant upon this supply, which is indicative of the absence of substantial aquifers below 1900 feet. The second is a shallow zone, variable in depth but often less than 50 feet deep, which occurs over the Fraser Plateau. It is probable that the groundwater is found within porous glacial drift although the possibility exists that these wells may have penetrated the upper horizons of the Fraser River formation.

The second aquiferous zone may be particularly significant with respect to sliding. Considerable quantities of water exist above 1900 feet within aquiferous strata which may extend laterally to outcrop in the slopes of the Fraser Valley, at least in places. Spring and seepage activity would then result, leading to possible failure situations, as in the case of the Red Bluff Slide and Big Slide (see Appendix C).

(D) CLIMATE AND VEGETATION

Pertinent climatic data are presented in Table 1 for meteorological stations at Quesnel town and at Quesnel Airport. The mean monthly temperature at Quesnel is 40.7° F. and temperatures from November to March (inclusive) are below freezing point, the corresponding period during which most of the 57.2 inches of snow falls. Total annual precipitation is 19.72 inches, of which 14.00 inches falls as rain. The months of June, July and August bring most rain (greater than 2 inches) while rainfall during the months of spring melting is rather low. The figures for Quesnel Airport are similar.

The total annual precipitation figure of 19.72 inches indicates that Quesnel is situated in one of the drier areas of B.C. Furthermore, in summer, much moisture is lost through evaporation while in winter and spring, percolation into the ground is restricted by a surface layer of frozen soil.

TABLE 1 - CLIMATIC DATA

ELEMENT and STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	YEAR
QUESNEL	LATITUDE 52 59 N LONGITUDE 122 29 W ELEVATION 1600 FT ASL												
MEAN DAILY TEMPERATURE (DEG F)	14.8	21.1	31.7	42.7	52.2	57.9	61.9	60.1	52.9	42.4	29.6	21.0	40.7
MEAN DAILY MAXIMUM TEMPERATURE	23.3	32.1	43.7	56.4	66.9	71.1	75.6	73.5	65.7	52.9	37.2	28.2	52.2
MEAN DAILY MINIMUM TEMPERATURE	6.3	10.1	19.6	29.0	37.4	44.7	48.2	46.7	40.1	31.9	21.9	13.7	29.1
MAXIMUM TEMPERATURE	59	66	74	88	96	98	105	101	94	83	76	59	105
MINIMUM TEMPERATURE	-51	-50	-30	- 7	12	18	30	29	12	- 4	-31	-52	-52
MEAN RAINFALL (INCHES)	0.15	0.11	0.49	0.75	1.37	2.36	2.22	2.26	1.57	1.60	0.82	0.30	14.00
MEAN SNOWFALL	16.0	10.4	5.5	1.1	0.2	0.0	0.0	0.0	T	1.8	8.2	14.0	57.2
MEAN TOTAL PRECIPITATION	1.75	1.15	1.04	0.86	1.39	2.36	2.22	2.26	1.57	1.78	1.64	1.70	19.72
NO. OF DAYS WITH MEASURABLE RAIN	2	1	3	5	8	12	10	12	10	10	5	2	80
NO. OF DAYS WITH MEASURABLE SNOW	8	6	4	1	*				*	1	5	7	32
NO. OF DAYS WITH MEAS. PRECIPITATION	10	8	7	6	8	12	10	12	10	10	9	9	111
MAXIMUM PRECIPITATION IN 24 HRS.	1.00	1.00	0.80	0.69	1.46	2.84	1.26	1.54	1.26	1.36	1.05	1.05	2.84
QUESNEL AIRPORT	LATITUDE 53 02 N LONGITUDE 122 31 W ELEVATION 1787 FT ASL												
MEAN DAILY TEMPERATURE (DEG F)	13.7	20.7	30.7	42.6	51.4	57.7	61.7	60.0	52.9	42.0	29.7	20.6	39.7
MEAN DAILY MAXIMUM TEMPERATURE	22.3	31.2	41.5	55.2	65.7	70.2	75.9	72.9	65.6	51.6	37.1	27.7	50.8
MEAN DAILY MINIMUM TEMPERATURE	5.0	10.2	19.9	30.0	37.0	45.2	47.4	47.0	40.2	32.3	22.2	13.4	28.5
MAXIMUM TEMPERATURE	50	59	67	80	90	96	98	96	86	78	63	54	98
MINIMUM TEMPERATURE	-52	-44	-38	- 4	14	26	33	29	16	- 6	-36	-40	-52
MEAN RAINFALL (INCHES)	0.08	0.08	0.35	0.67	1.32	2.60	1.90	3.02	1.32	1.46	0.72	0.22	13.74
MEAN SNOWFALL	21.4	14.5	7.4	1.4	0.1	0.0	0.0	0.0	0.2	2.7	10.6	16.7	75.0
MEAN TOTAL PRECIPITATION	2.22	1.53	1.09	0.81	1.33	2.60	1.90	3.02	1.34	1.73	1.78	1.89	21.24
NO. OF DAYS WITH MEASURABLE RAIN	1	1	4	6	10	13	11	13	10	11	6	2	88
NO. OF DAYS WITH MEASURABLE SNOW	13	10	7	2	*				*	2	8	12	54
NO. OF DAYS WITH MEAS. PRECIPITATION	13	11	10	8	10	13	11	13	10	12	13	14	138

(FROM CANADA DEPARTMENT OF TRANSPORT, 1967)

Despite the limited nature of supplies to groundwater reservoirs, however, the available seepage moisture is sufficient to trigger landslides. It may be expected, therefore, that the incidence of sliding will increase, perhaps dramatically, where supplies of groundwater are suddenly augmented. This could occur locally, for example, in the presence of septic tanks, lawn sprinklers and burst water mains, as in the case of the A & W Slide.

The stripping off of vegetation may lead to greater supplies of groundwater and, in turn, to sliding. The natural vegetation of the Quesnel area is a heavy tree cover which removes considerable soil moisture by evapotranspiration. The characteristic natural trees of the Quesnel region include Douglas Fir, Lodgepole Pine and Black Spruce plus significant stands of birch, cottonwood, aspen, willow and alder (Farstad and Laird, 1954). Where this tree cover has been removed from sloping areas, for example along pipelines and power lines, failures are common (e.g. the Pipeline Slide).

The tree cover has already been removed in several places. The Fraser Plateau remains predominantly forested but much is second growth. Several significant enclaves of farmland are situated on the Plateau, notably east of Big Bend, along the Barkerville road, and adjacent to Dragon Lake. Clearing for farming purposes is more widespread on the terrace surfaces of the Fraser and Quesnel Rivers, especially around the Airport and on the opposite side of the river. The bluffs adjacent to terrace farmland, however, typically retain their tree cover since the land is useless for agriculture and stripping would interfere with bluff stability. If terraces are zoned for subdivision in the future, developers may wish to strip the bluffs for the benefit of view lots and special attention should be afforded to the drainage problem.

III TOPOGRAPHY

(A) GENERAL CONFIGURATION

The Fraser valley at Quesnel is a deep trench which is incised into the Fraser Plateau to depths of greater than 600 feet. The Fraser River drops from 1580 to 1520 feet through the study area and the upper rims of the valley are normally located between 2000 and 2300 feet.

The detailed form of the trench is complex. Above the eastern rim of the Fraser valley, the Plateau is notched by a distinct bench which is especially obvious to the south of the Quesnel River where it is four or five miles wide (see Fig. D1). According to Lay (1940), the bench may be traced over a distance of 50 miles between Ten Mile Lake and Soda Creek. The bench is characterized by very low gradients and is often almost flat. Meadowlands and a string of lakes (including Ten Mile Lake and Dragon Lake) occupy the bench. The bench gradually dips northwards and is believed to be a remnant of one channel which was followed by the Fraser River when it flowed northwards. The valley-side slopes downwards from the bench across a semi-continuous zone of river cuts and landslide scars. Some slopes are actively undercut while others are separated from the river by very narrow terraces. North of the Quesnel River, the bench is not found to the east of the Fraser River and may have been removed by river erosion and landsliding.

A narrow, high-level bench occurs on the western rim of the trench at elevations between 2000 and 2200 feet. It occurs both north and south of Quesnel. Like its eastern counterpart, it is veneered with late-Pleistocene lake silts and probably constitutes another remnant of an ancient channel system, dating back at least as far as the Pleistocene epoch. The bench is overlooked by cliffs which are capped in places by conspicuous basalt ramparts, particularly adjacent to Baker Creek. South of Quesnel, the valley-side descends steeply from this bench and, close to the river, is notched by several narrow, bench-like terraces. North of Quesnel, the valley slopes

on both sides of the river grade downwards more gently to river level across a series of extensive terrace surfaces. Whereas the valley rims to the south of Quesnel are usually less than two miles apart, to the north, they may be as much as four miles apart. In the extreme north of the study area, at Big Bend, the benches are absent and the valley sides rise sheer from river level to the Fraser Plateau, although slope gradients have been reduced in many places by very large-scale sliding. At Big Bend, the western slope is the steeper (in the Paradise Road Slide area) possibly because of the presence of a caprock of basalt which is absent above the Big Slide. Cementation in the Tertiary gravels also helps to maintain the steeper slopes which are being undercut by a very active double-hairpin meander system. The presence of terrace remnants within the meander loops indicates that the present meandering course has only recently been assumed.

Four important tributaries in the study area are worthy of note. The largest is the Quesnel River but significant valleys have also been incised into the Fraser Plateau by Baker Creek, Bouchie Creek and Barlow Creek. The Quesnel River formerly flowed north-westwards into the Ten Mile Lake area but now swings westward, where it occupies a gorge which is 500 feet deep, and finally southwards before flowing into the Fraser River. The change in course has been caused by the reversal in the direction of flow of the Fraser River. A massive slide (the Quesnel River Slide) occurs north of this bend in the river. Baker Creek, which flows eastwards, also swings southward before debouching into the main river. It has incised a 600-foot canyon into the Fraser Plateau. The canyon possesses active, precipitous slopes in a critical condition, often exceeding 50 degrees in gradient. The canyon terminates at the western rim of the trench and the creek thereafter meanders through the drift which floors the trench. Bouchie Creek drains Bouchie Lake which is situated at an elevation of 2,260 feet. The creek then follows a shallow,

V-shaped valley to the level of the 1800 - foot surface where its course becomes indistinct. Barlow Creek is a right-bank tributary of the Quesnel River which descends rapidly from the Plateau surface. The creek occupies a deep, steep-sided gorge which at its mouth is 300 feet deep. The winding valley is followed by the B.C.R. (P.G.E.).

The Fraser Plateau flanks the Fraser River trench, rising very gradually to east and west from 2,300 feet, attaining 3,000 feet only after six to eight miles, except in the south east where the Dragon Mountain Range (2,900 feet) is located immediately to the east of Dragon Lake. Although the general relief of the Plateau is subdued, the small-scale topography of the drift cover is very irregular. Drift ridges are profuse and are characteristically separated by swampy depressions. The pre-glacial drainage was disrupted during glaciation and has been largely replaced by a sluggish drainage system which is not integrated and possesses only a very limited capacity for erosion. The rate of evolution of landforms is very gradual. Landsliding is exceptional because slopes lack sufficient height and declivity to induce the necessary stresses while basal stream undercutting is absent or ineffectual. The continuity of the Plateau surface is interrupted by the trench and its tributary valleys and communications are hindered except along the main trench.

(B) THE TERRACE AND BLUFF SEQUENCE

A morphometric examination of the relief of the study area was conducted, using maps at a scale of 1:6000 which were provided by the B.C. Department of Lands and Forests. Special attention was directed towards the Fraser River terraces and bluffs. The quasi-flat terraces are suitable for several types of development, particularly in the immediate Quesnel area, while the intervening bluffs may be susceptible to sliding. Terrace locations were plotted and seventy-two slope profiles were measured in order to compare the

bluffs. The details of this examination are presented in Appendix D. From this discussion the following main points emerge.

1. The terraces may be classified into five major groups, based on elevation. These are the 1800 - foot, 1700 - foot, 1650 - foot, 1600-foot and 1550 - foot, surfaces (see Fig. D1). These groups are ordered from oldest to youngest.

2. Such a classification is useful because the intervening bluffs may be placed within a relative time scale. The terrace at the base of each bluff is a measure of the minimum period which has elapsed since the bluff was modified by basal stream action. Bluffs may be examined in this light in order to reconstruct slope evolution after stream action ceases.

3. Remnants of the 1800 - foot surface are much more extensive than those of younger surfaces and are found dominantly north of Quesnel.

4. Slope heights range from less than 30 feet to greater than 500 feet. Loading stresses, therefore, vary considerably. The taller slopes have been active at several stages of terrace formation and their patterns of slope development are complex.

5. Stream undercutting produces unstable slopes with distinctive forms. Before failure takes place, they tend to be convex - upwards. On active slopes where sliding has occured, the profiles are concave - upward, and may be potentially less unstable than the convex slopes which have yet to fail. In some transitional situations, the upper slope may be convex while the lower slope has become concave.

6. The rate of change of actively-undercut slopes depends on the disposition of the stream channel at the slope base. Most erosion is accomplished by a meandering stream on the outer bends of its meanders. It is at these points, therefore, that slopes will be most active. By contrast, the stream expends very little energy in undercutting on the insides of meander bends. The most active slopes in the Quesnel area occur on the outer bends of the rivers, for

example, in the cases of the Quesnel River, Paradise Road and Big Slides.

7. The convex, concave and convexo-concave slope forms which result from basal stream action have survived on abandoned slopes of all ages. It appears, therefore, that the convex and convexo-concave slopes have not relaxed to more stable concave forms over time, perhaps because of exceptional soil strength or lack of subsurface seepage.

8. The mean angles of the slope profiles tend to be inversely related with bluff age. The average mean angle declines from 29.8 degrees for active slopes to 19.0 degrees for slopes above the 1800 - foot surface. The correlation is not simple and dispersion in the data is high because of the influence of factors not directly related to time, including soil properties, groundwater behaviour and slope height.

9. The relationship between mean angle and slope height is plotted in Fig. D7, and tends to be negative. Line AB appears to represent a stability envelope for these slopes since slopes do not plot above it as a rule. It seems likely that line AB indicates the maximum height/angle tolerance of the soils. Above the line, stresses exceed soil strength. Undercut slopes, as expected, are closest to this threshold while abandoned slopes tend to be somewhat below it. In fact, few abandoned bluffs occur above the line CD which may, therefore, represent a longer-term stability envelope than line AB.

10. The lowest observed gradients of slopes range from ten to fifteen degrees. It seems that bluffs do not decline below these grades, perhaps because their residual strengths will support such angles, whatever slope height.

IV LANDSLIDES

A. EARLY HISTORY AND OBSERVATIONS

Instability, manifested by landslides of varying types and sizes, is very widespread in the Quesnel area. It is not a new phenomenon and is part of the natural degradation of slopes in the area. Although human activity has contributed to the initiation of some relatively minor slides, the majority of them are a result of a long-term operation of geomorphological processes. Indeed, the magnitude and frequency of slope changes through landsliding should be viewed with reference to this geological time scale.

The earliest landslides may have occurred in the Tertiary deposits during their deposition; Reinecke (1920) postulates that some of the Tertiary sediments were affected by sub-aqueous mass movements during their deposition. This process could explain the localized erratic dips in the deposits. Slides were in existence long before the area was settled in the mid-eighteenth century and both early explorers and geologists were quick to point out their existence. One of the first such workers, Selwyn (1871-72), noted their presence, and Dawson (1875-76) has reference to a "great slide" (probably Big Slide, which is described below). Reports by early P.G.E. surveyors also noted the presence of slides. One of the first suggestions of landslides affecting property is the note by Brawner (1956) that several places of business had to be moved from the vicinity of the Front Street slide area in 1864, possibly in response to a landslide problem. The recent history of slides in the area is treated in Appendix F.

B. CONTRIBUTING FACTORS

The high incidence of landsliding in the Quesnel area is attributable to the existence of a unique combination of landslide conditions which have resulted from its complex geological history. The geotechnical consequences of this history are profound in that an assessment of stability of the slopes developed on the Tertiary and Quaternary deposits is substantially complicated by two factors; the gross structure of the materials and their stress history.

As detailed in Section II (and in Appendices A and B) the succession of environment that existed in late Tertiary times resulted in a semi-rhythmic pattern of deposition in which sands, gravels, silts and clays are seen to recur (For example, see Geological Section B10). Various organic sediments such as diatomite and lignite occur at certain horizons in this sequence in addition to various volcanic tuffs. Thus heterogeneity existed, therefore, prior to the Pleistocene glaciation and associated events which in turn also deposited a complex sequence.

With reference to slope stability and the wider question of slope developement, this heterogeneity in the gross structure is of primary importance. Due to the inherent differences in strength and failure characteristics between the weaker fine-grained materials and the stronger coarse-grained material, analysis of slopes in the area is almost confounded due to the difficulty of selecting a meaningful shear strength parameter that can be applied over the whole slope. Henkel (1967) for example, has drawn attention to the crucial importance of local geology in a consideration of failure modes and stability, noting that there are not only strength differences between layers but also other factors such as permeability.

The history of loading and unloading of sediments in the area has also created a number of problems associated with overconsolidation. The silts, clays and organic deposits were subjected to very high overburden pressures by the thickness of successive sedimentation. The additional loads of various glaciers and their deposits have led to further overconsolidation. Some of the clays and silts have become lithified to the point where they are similar to clay shales or siltstones and the organic material has formed lignite. It is well known that the compression which resulted from this loading is recoverable and during unloading cycles and the long-term decrease in overburden pressure through erosion, there has probably been substantial rebound in the overconsolidated materials. The rate of erosion has been high and so one would expect the related rebound to remain a factor in slope stability.

Rebound has been cited as an important contributory factor in landslides in the Cretaceous shales and sandstones of the Peace River area. It is mainly a function of the magnitude of the consolidation pressure and the properties of the clay (i.e. the more plastic the clay, the greater its propensity for rebound) (Bjerrum, 1967). Fissures develop during the rebound process (and also as a response to tectonic movements), the clay expands and the net result is an increase in voids and water content, two factors that weaken the material and increase its slide potential. In addition to these factors, horizontal stresses have been found to develop in similar geological situations and are thought to be an important factor in landsliding in the Quesnel area.

In a consideration of the detailed factors that lead to instability in the area it is convenient to draw a distinction between external factors that lead to a change in stress conditions in a slope, and internal factors (Terzaghi, 1951).

1. External Factors

(a) When the location of presently-active landslides is examined it becomes obvious that an intimate association exists between slides and the outside of river meanders. In the process of meander migration and valley formation, stresses are concentrated at these locations and, either by local oversteepening or by increasing the height of the slope by downcutting, instability results. It is suggested, therefore, that the erosional activity of the Fraser and Quesnel Rivers together with smaller streams such as Dragon, Baker and Barlow Creeks is by far the most important factor in changing the stability of slopes in the area.

(b) Construction activity associated with highways, railroads and pipelines has also been an important factor in initiating instability although the scale of these failures is much smaller than those attributable to natural processes. Slopes are oversteepened in road cuts and railcuts and this has led to the majority of failures in this group. Foundation failures have also taken place due to the placing of heavy fill loads.

2. Internal Factors

(a) The existence and disposition of both Tertiary and Quaternary unstable soils has been examined in detail in Section II and in Appendices A and B.

The geotechnical properties of the materials have been collated from various Branch reports and although data are scanty the following observations seem in order;

(i) The cohesive materials have fairly low liquid limits (i.e. in the range between 30 and 60) in general, although there are the occasional strata with fairly high liquid limits in excess of 70. According to Skempton and Hutchinson (1969) this puts the material in general in the low to medium plasticity range. Plastic limits range from about 20 to 40.

(ii) Beneath the recent fluvial sands and gravels, soils are extremely dense generally with values for N in excess of 75.

(iii) All the Tertiary clays are very stiff and fissured.

(iv) In general, the cohesive material has a low index of plasticity which means that strength loss is very high once the moisture content increases past the plastic limit.

(v) Data on shear strength does exist and various values for shear strength parameters are available. However, since the clays and silts are fissured, peak strengths are unlikely to be of any use in assessing the shear strength of a mass of material. Residual strength is perhaps the more appropriate parameter, a point which will be pursued in the following sections.

(b) Seepage and pore pressures are very important in the initiation and continued movement of landslides in general. In the Quesnel area, most slides

are a result of these forces which represent the chief internal factor that contributes to landsliding. As pointed out above, the alternating sequence of a gravel or sand seam being sandwiched between relatively impermeable material creates a deleterious ground-water situation, pore water pressures develop and failure is begun. Wetting also results in a strength loss because of the low plasticity index. Because of the existence of a high-level aquifer (perched water table) in the Fraser Plateau (see Section II), a constant supply of water is assured into those materials between the Plateau elevation and the river bed which is reflected in the fact that seepage sources abound in many of the slides. Factors such as leakage of water pipes and the discharge of effluent from septic tanks have caused local failures (see Section II) e.g. the A & W Slide. Vegetation removal also results in high local piezometric levels in slopes and has contributed to instability.

(c) Vegetation removal exerts its influence on slope stability in general in other ways, specifically, in the development of a slope. The effect of root systems in bonding the top soil prevents erosion and the formation of gullies on slopes. As we shall see in the following section, gully development is one of the first steps in the development of landslide terrain and if vegetation can prevent this progression then it would seem desirable to keep it on the steeper slopes.

(d) Changes in the structure of the clay may affect its shear strength and these may be a response to the following:

(i) Overconsolidation and fissuring

(ii) Burning and baking related to the ignition of lignite seams*

(iii) Weathering of clays near the surface

* Selwyn (1871-1872) notes that near the mouth of Quesnel River 'smoke and hot vapours have for several years issued from the ground.'

C. LANDSLIDE TYPES AND CHARACTERISTICS

1. Location

Landslides in the Quesnel area have been located using aerial photographs and by field observation. There are approximately 25 foci of landsliding in the area which have been detected on air photographs and which show a wide range in size, failure mode and activity (Fig. 2). As has been mentioned above, there is an obvious concentration of slides on the river bank, particularly on the outside of meanders. A secondary location of slides occurs on the margins of the 2000' surface away from the existing river channel. A tertiary location are those slides associated with human activity in the vicinity of highways, railroads and pipelines.

2. Initial Grouping

The basis for the initial grouping of slides will be whether the slide is affected by the river (Group A), whether the slides occur on slopes away from the river (Group B) or whether the failure is attributable to human activity (Group C) and the initial grouping appears in Table 2. It is worthy to note the following observations in relation to location and Table 2.

(a) Downstream from the Big Bend there seems to be a relation between landslides and the terrace levels they affect, e.g. Big Slide and Paradise Road Slide affect the Fraser Plateau Level (2200'), the next slides downstream, East Bank, West Bank and Gravel Pit affect the next terrace down (1800-foot surface) whilst the Garbage Dump Slide occurs in the 1700' surface. Down at the A & W and Front Street Slides, a lower slip-off surface is affected whilst at West Quesnel and Westply other masses of landslide materials have been involved.

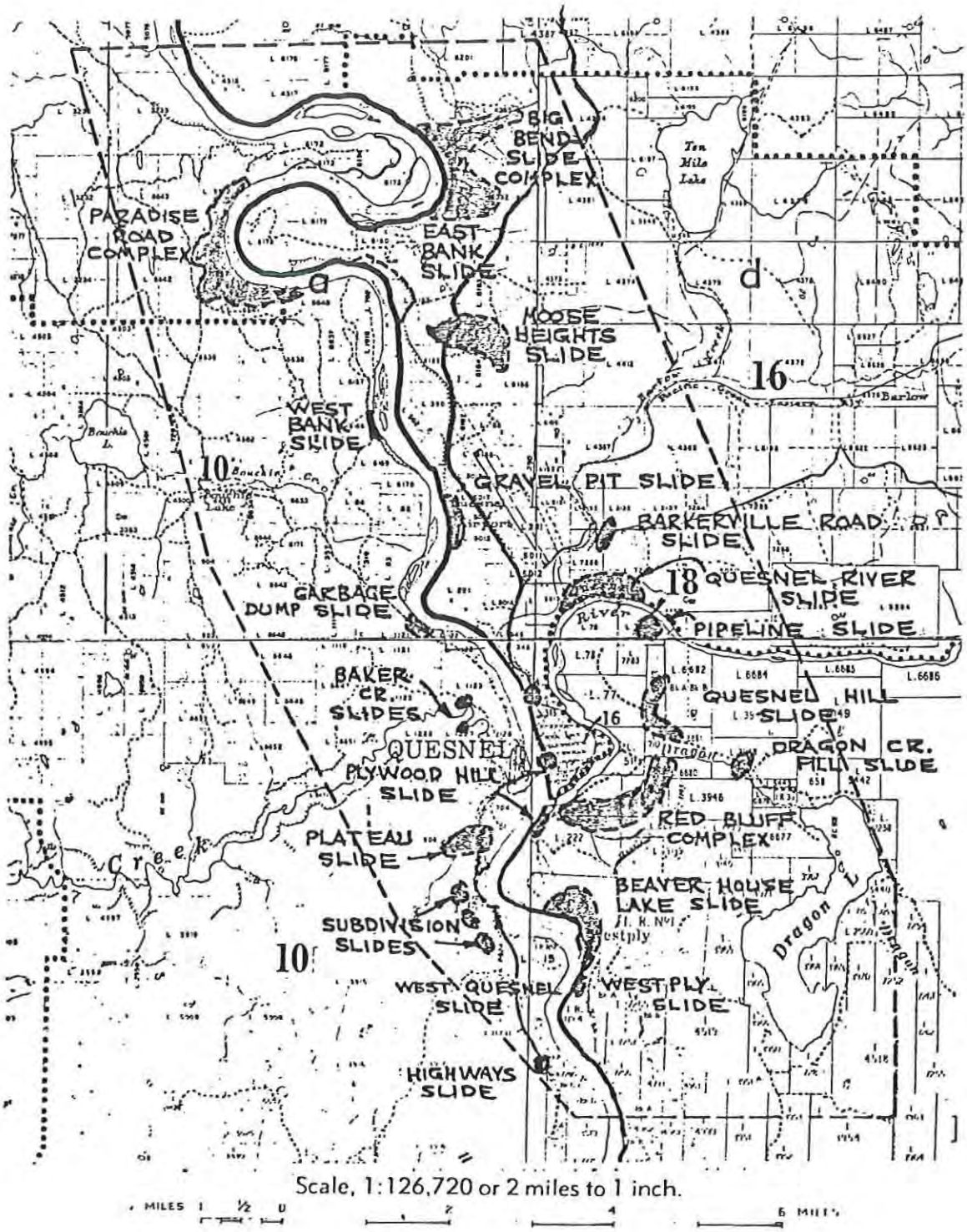


FIGURE #2: LOCATION OF LANDSLIDES IN THE QUESNEL AREA.

TABLE 2

Group A		Group B		Group C	
A1	Big Slide	B1	Red Bluff (G)	C1	Barkerville Road Slide
A2	Paradise Road Slide	B2	Beaver House Lake Slide	C2	Pipeline Slide
A3	East Bank Slide	B3	Sub-division Slides	C3	Dragon Creek Fill Slide
A4	West Bank Slide	B4	Plywood Hill Slide (G)	C4	Highways Slide
A5	Gravel Pit Slide	B5	Quesnel Hill Slides	C5	Logging Road Slide
A6	Garbage Dump Slide	B6	Plateau Slide		
A7	A & W Slide (G)	B7	Moose Heights Slide		
A8	Front Street Slide (G)				
A9	Baker Creek Slides				
A10	Quesnel River Slide				
A11	Westply Slide				
A12	West Quesnel Slide				

(G) = Geotechnical Investigation and data available.

N.B. Names of slides are not necessarily local names; official names have been used where applicable.

(b) All the slides on natural slopes within Group B occur on the margins of the 2000-foot surface.

3. Landslide Types

It will be important to classify the landslides found in the Quesnel area. Classification will be especially difficult, however, due to the great variation in the geology of each slide site and the many combinations of causes for each movement. Most of the slides show a complex form of failure and to facilitate their grouping a classification proposed by Skempton and Hutchinson (1969), illustrated in Fig. 3, will be used. The grouping according to landslide type is found in Table 3.

The incidence of complex landslide types reflects the heterogeneity of the material involved in the movement. In such complex slides the failure surface is formed of a combination of curved and planar elements and slide movements are part rotational, part translational and part flow. The degree of break-up of the slide mass varies from, for example, the total break-up of the debris involved in the West Bank Slide to the more or less intact slide mass at the Garbage Dump Slide and is in part a reflection of the magnitude of movement, the non-circularity of the failure plane and the nature of the strata involved in the slide (Skempton and Hutchinson, 1969).

With reference to the slides nearest the river, it is seen that the most complex slides (Paradise Road, Big Slide, Quesnel River and Westply) are all developed in either the 2200-foot (Fraser Plateau) or the 2000-foot surface, whilst the simpler slides affect on lower levels (i.e. younger terraces). This would tend to suggest that the older the surface, the older and more complex the slide. The multiple retrogressive slide develops from

TABLE 3

Group A

A1 Multiple earthflow toward river and complex multiple retrogressive toward head

A2 Multiple retrogressive

A3 Compound slide - (with an element of fall)

A4 Compound slide - (with an element of fall)

A5 Compound slide

A6 Compound slide

A7 Compound slide

A8 Compound slide

A9 Slump

A10 Multiple retrogressive

A11 Multiple retrogressive

A12 Multiple retrogressive

Group B

B1 Multiple earthflow and complex multiple retrogressive

B2 Multiple retrogressive

B3 Slump

B4 Slump earthflow

B5 Multiple retrogressive

B6 Multiple earthflow and complex multiple retrogressive

B7 Multiple retrogressive

Group C

C1 Slump

C2 Slump

C3 Slump

C4 Non-rotational compound slide (or flow)

C5 Non-rotational compound slide

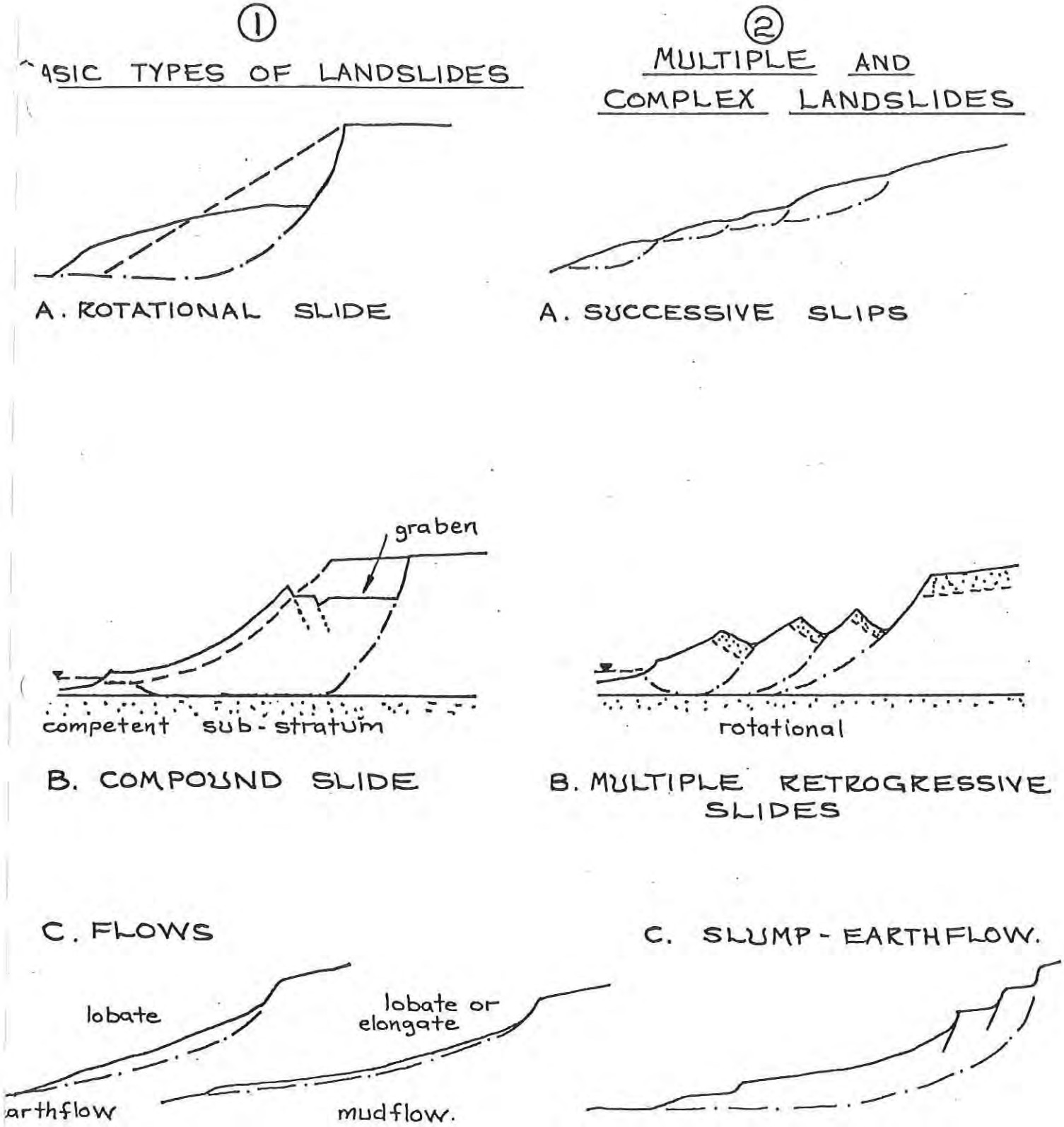


FIGURE #3: CLASSIFICATION OF LANDSLIDE TYPES FOUND IN THE QUESNEL AREA
(after SKEMPTON AND HUTCHINSON 1969)

a single failure by the occurrence of further retrogressive failures upslope through time which interact to form a common basal slip surface. Of course, similar reasoning applies to multiple retrogressive slides in Group B that are not presently related to river action, but which have been in the past, perhaps at different river levels, i.e. the slides at Red Bluff, Beaver House Lake, Plywood Hill, Quesnel Hill and Moose Heights. In the absence of a cap rock of more competent strata (e.g. basalt) the scarp formed at the rear of the initial (or top) rotational slip degrades rapidly by shallow slides and mudflows and the retrogressive development of further deep-seated movements is usually inhibited.

Flows are also common, and Skempton and Hutchinson (1969) have noted the tendency of fissured clays, particularly when they are intercalated with sands, to provide a constant source of seepage for the flow movement. Softening of the clay as well as undermining by seepage erosion in the sand layers are thought to be important.

Group C are seen to be simpler, mainly non-rotational slumps (see Appendix F for detailed inventory of landslides). Details of the slides are found in Table 4.

3. Landslide Occurrence in Time

Many of the slides in the Quesnel area may have been active for thousands of years. Others have only recently failed (e.g. West Bank Slide). It seems that the occurrence of a slide in time is less important than the periodicity of its movements following failure. Terzaghi (1951) produced a diagram to illustrate the variations in the Factor of Safety against sliding

LANDSLIDE CHARACTERISTICS

Number [1]	Name	Type[2]	Materials[3]	Height of Slope[4]	Width of Zone	Mean Angle of Slide Mass	Causes[5]	Terrace or Surfaces Affected[6]	Probability of Expansion & Further Movement[7]	Present Housing Threatened[8]
A1	BIG SLIDE	ME - MR	MFRF	500'	13,000'	10°	SP-ER	FP	H	N
A2	PARADISE ROAD SLIDE	MR	MFRF	500'	12,000'	10-15°	SP-ER	FP	H	N
A3	EAST BANK SLIDE	CS	MFRF	150'	4,000'	23°	ER	1800'	H	N
A4	WEST BANK SLIDE	CS	MFRF	250'	1,000'	20°	ER	1800'	I	N
A5	GRAVEL PIT SLIDE	CS	MFRF	230'	4,200'	30°	ER	1800'	H	N
A6	GARBAGE DUMP SLIDE	CS	MFRF	140'	660'	23°	SP-ER	1700'	H	Y
A7	A & W SLIDE	CS	LFRF	-	200'	-	SP	1570-1640 SOS	I	Y
A8	FRONT ST. SLIDE	CS	LFRF	25'	220'	14°	SP	1570-1640 SOS	L	Y
A9	BAKER CRK. SLIDES	S	PD	-	-	-	ER	O.S.M.	H	Y
A10	QUESNEL RIVER SLIDE	MR	MFRF	430'	7,920'	12°	SP-ER	FP	H	Y
A11	WESTPLY SLIDE	MR	LFRF	190'	1,320'	21°	SP-ER	O.S.M.	H	Y
A12	WEST QUESNEL SLIDE	MR	LFRF	80'	1,200'	10°	SP-ER	O.S.M.	H	Y
B1	RED BLUFF COMPLEX	ME-MR	LFRF	390'	10,000'	10°	SP	2000'	H	Y
B2	BEAVER HOUSE LAKE SLIDE	MR	LFRF	380'	6,600'	11°	SP	2000'	I-L	N
B3	SUBDIVISION SLIDE	S	LFRF	-	1,100'	-	SP	2000'	H	Y
B4	PLYWOOD SLIDE	S-E	LFRF	220'	150'	-	SP	1800'	H	N
B5	QUESNEL HILL SLIDE	MR	LFRF	240'	7,000'	10°	SP	2000'	I-H	Y
B6	PLATEAU SLIDE	ME-MR	LFRF	-	1,900'	-	SP	2000'	L	N
B7	MOOSE HEIGHTS SLIDE	MR	MFRF	500'	4,000'	10°	SP	FP	L	N
C1	BARKERVILLE ROAD SLIDE	S	PD	-	50'	-	O	FP	H	N
C2	PIPELINE SLIDE	S	PD-FRI	-	150'	-	SP	-	H	N
C3	DRAGON CREEK FILL SLIDE	S	PD	-		-	SP-F	-	L	N
C4	HIGHWAYS SLIDE	NCR	LFRF	-	100'	-	SP	-	L	N
C5	LOGGING ROAD SLIDE	NCR	LFRF	-	200'	-	O	-	I	Y

1 A represents slide affected by river activity; B represents slide unaffected by present river activity; C represents slide caused by human interference.

2 Classification of Slides; ME-multiple earthflow; MR-multiple retrogressive; CS-compound slide; S-slump; E-earthflow; NCR-non-circular rotational slide.

3 FRF-Fraser River Formation; L-Lower Series; M-Middle Series; PD-Pleistocene Drift.

4 Data availably only where large-scale topographic maps exist.

5 ER-erosion; SP-seepage; O-oversteepening; F-fill loading.

6 Surfaces Affected (in feet); - FP-Fraser Plateau, SOS-Slip-Off Slope. O.S.M. - Other slide material

7 H-High, L-Low, I-Intermediate.

8 " " " "

for natural slopes which is reproduced in Fig. 4 with modification. It is seen that failure (with concomitant pre-failure strain) is related to the vicissitudes of pore water pressure which in turn are related to the elevation of the ground-water table and its seasonal variations. Usually landslides take place during or immediately after the wet season but in Quesnel there is hardly a wet season (see Section II). The incidence of slides may be independent of seasonal weather e.g. it was noted in a report on one of the slides at Red Bluff (which failed under excess water conditions) that the event occurred following a rainless two months. The only conclusion is that the slides take place (and movement is continued on old slides) during times of high ground water pressures and high flow in the perched aquifers. (At Folkestone, England, Hutchinson (1969) correlated movements at the Folkestone Warren Landslide with the period of maximum seasonal ground-water pressure). What factors control the flow of the ground-water and the variation in pressure is not known.

Further consideration will be given to the temporal aspects of landslide incidence in the section on slope development below.

D. SLOPE DEVELOPMENT AND LANDSLIDING

1. Slope Form, Materials and Age

The development of slopes through time (i.e. the changes in slope geometry in response to the processes of slope wash, creep and landsliding) is of great importance in an appraisal of slope stability and in locating of future landslides. This approach has been used by several authors in their assessment of landslide problems, among them being Skempton (1953) in his study of unstable slopes in the vicinity of Peterlee, County Durham, U.K. Jones et. al. (1961) in his study of the slopes around Roosevelt Lake, Washington, and Nasmith (1964) in the Meikle Valley of Alberta.

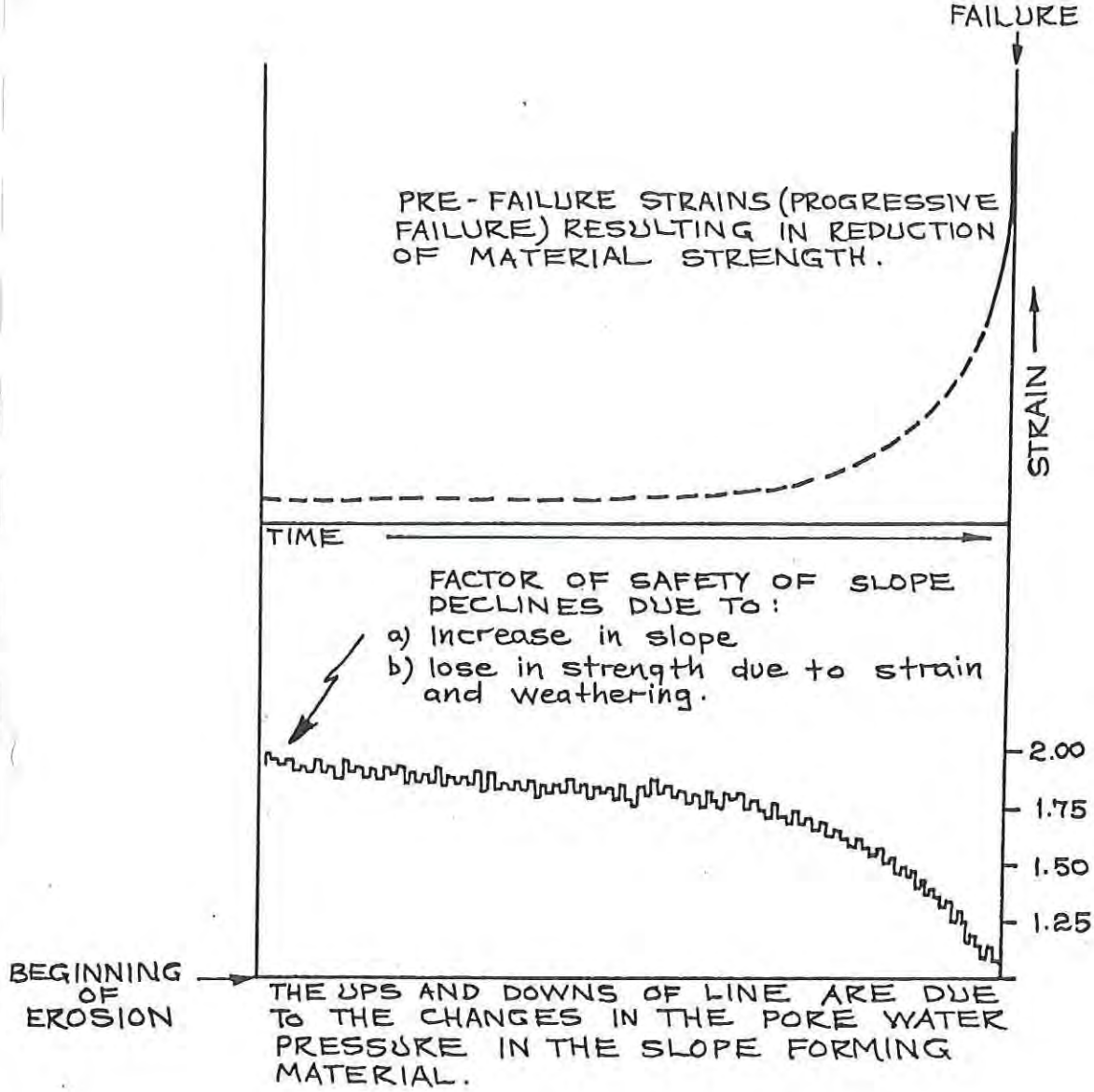


FIGURE 4. DIAGRAM ILLUSTRATING THE VARIATIONS OF THE FACTOR OF SAFETY OF SLOPE AFTER BEING UNDERCUT BY FRASER RIVER AND PRIOR TO A LANDSLIDE. (modified after Terzaghi - 1951)

Before looking into the problem in detail it is worth noting certain concepts related to boundary problems in slope studies. It is well known that a slope of a given height has a maximum angle at which the slope can be maintained without failure taking place. This slope angle is variously called the threshold or limiting slope (γ). At the other end of the spectrum, the lower angle at which the slope finally becomes stable against landsliding is referred to as the angle of ultimate stability (θ) (Skempton and Hutchinson, 1969). Obviously most slopes in nature stand at or near angles that are somewhere between these two values and are either being steepened towards γ or declining towards θ.

In geotechnique, these two angles have commonly been related to the properties of the materials concerned (e.g. Skempton 1964, Hutchinson 1967, Peterson et. al., 1960). The threshold slope is related to the peak strength of the material whilst the angle of ultimate stability has been related to its residual strength. It has been fairly well established that landslides (and therefore slope stability) in materials similar to those at Quesnel can be accounted for by stresses exceeding residual rather than peak strength. What leads to this reduction in strength from peak is not clear but it is probably a combination of the following:

(i) The pervasion of fissures through the cohesive materials.

(ii) The existence of ancient shear surfaces attributable to processes such as solifluction or stress release (cf. Palladine and Peck, 1972)

(iii) The results of the development of a series of discontinuous failure surfaces into a continuous one by progressive failure which is manifested by pre-failure strains.

Since all these factors are widespread in the Quesnel area it is logical to suppose that peak strengths are no longer operative and on most slopes residual strengths determine slope stability. Where strengths are in excess of residual, they will decrease with time.

In addition to this, the relation between failure and the magnitude and frequency problem is of importance. For example, as the slope angle decreases under landsliding, a time-related decrease in shear strength takes place whilst at the same time shear stresses also decrease (decline of slope, less intense processes). As change takes place, the propensity for change decreases.

As is detailed in Section III, 72 slope profiles were selected for analysis. The mean slope angle for the 72 profiles was 26.2° with a range between 9° and 45°. Since the successive terrace levels represent time planes, slopes on the upper terraces are older than the ones on the lower terraces and by comparing the sequence and form of slope transformation from young (lower) to old (higher), a picture of slope development can be obtained.

As mentioned in Section III and in Appendix D, there does not appear to be a consistent variation in slope angle with increase in age. It does appear, however, that the youngest slopes (i.e. the slopes immediately adjacent to the river) are far steeper on the average than slopes above the 1800' surface, i.e. the oldest slopes in the region.

This lack of direct correlation is to be expected, since other controls apart from the simple operation of processes over time affect slope form. Slopes of varying heights, varying geology, are subjected to varying magnitudes and frequencies of landslide processes. Height is an important variable as seen in the height of slopes below the 2000-foot surface (most are between 150 and 200 feet) and the slopes bordering the 1550-foot surface (most are under 50 feet in height).

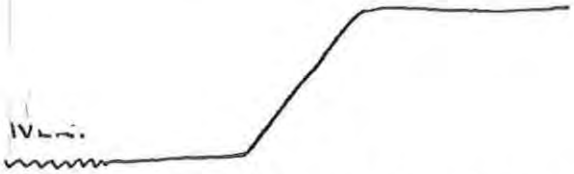
If a series of slopes profiles is examined that have a constant height, the decline in slope angles can be seen to be correlated with age (e.g. the slopes between 50 and 75 feet). Thus, there is some evidence that natural degradation of slopes is taking place through geomorphic processes and further, that in geological terms this transformation is quite rapid.

2. Mode of Slope Failure and Slope Evolution Related to Erosive Activity of River

On examining the shape of the slope profiles it becomes clear that four basic slope types exist. Type A (Fig. 5) represents a rectilinear slope that is not affected by basal erosion and has been left abandoned by the swing of the meander belt and bordered at the base by a flood plain and at the top by a terrace.

Type B is Type A that has undergone basal steepening due to the activity of the river. The removal of this lateral support probably results in sufficient movement to reduce the strength of the material. Type C results from slumping and falls and here, due to the fact that the rate of slope retreat is greater than the swing of the meander, an accumulation zone is formed. Type D follows, and represents a slope under mass failure (probably of the multiple retrogressive or compound type) and exhibits an upwardly concave form. Type E is a stabilized convexo-concave slope which is a degraded form of Type D.

TYPE A.



RECTILINEAR SLOPE, ABANDONED BY MEANDER DURING FLOOD PLAIN DEVELOPMENT.

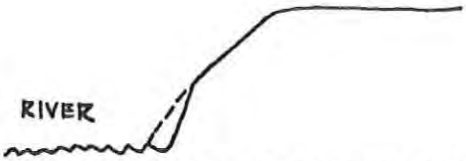
TYPE D.

LARGE SCALE MASS FAILURE USUALLY OF RETROGRESSIVE TYPE: eg. WEST BANK, GIVING A CONCAVE SLOPE.

TYPE E.

CONCAVE - CONVEX SLOPE, FLATTENED OUT BY POST FAILURE MOVEMENTS. NOW ABANDONED BY RIVER.

TYPE B.



MOVEMENT OF MEANDER INTO SLOPE BASE RESULTING IN BASAL EROSION, MINOR SLUMPS. RETROGRESSIVE FAILURE INITIATED. DEBRIS CARRIED AWAY.

TYPE C.

MINOR SLUMPING AND FALLS. RATE OF SLOPE RETREAT GREATER THAN MOVEMENT OF MEANDER ∴ ACCUMULATION ZONE BUILDS UP. RETROGRESSIVE FAILURE CONTINUES.

FIGURE 5: GENERAL MODE OF SLOPE EVOLUTION IN THE QUESNEL AREA. (Type A to E)

This model of evolution is of course very general, since there is likely to be a variation in development due to the following factors;

(i) the amount of gravels and/or sands in the slope

(ii) the existence of a cap rock

(iii) the behavior of the meander belt

(iv) the role of pore-water pressure

Certain cases will be examined, the first being a cliff made up of a cohesionless material. The mode of evolution is described in Fig. 6. A situation similar to this exists at the Plywood-P.G.E. cut where mass movements are merely falls of material from the slightly more indurated gravel face which collect as a debris slope beneath.

A second case will be examined where a sand or gravel layer is sandwiched between two cohesive layers. Whilst the broad form of evolution is the same as in Fig. 5 there are the differences noted (Fig. 7). In this mode of development (Henkel, op.cit) suggests that the stable angle of the sand, α, (and, one would assume, of the slope made out of the unit), is approximated by:

$$\alpha = \tfrac{1}{2}\phi_s'$$

where ϕ_s' is the effective angle of shearing resistance of the sand and/or gravel. In this case an effective angle of shear resistence is probably in the order of $30^\circ - 35^\circ$ which would give a value of α between 15° and 17°.

In the third case we have a situation similar to the West Bank Slide where sand and gravel is found on top of a clay or clay-shale layer (see Fig. 8). A seepage flow through the sand, parallel to the clay-sand boundary is

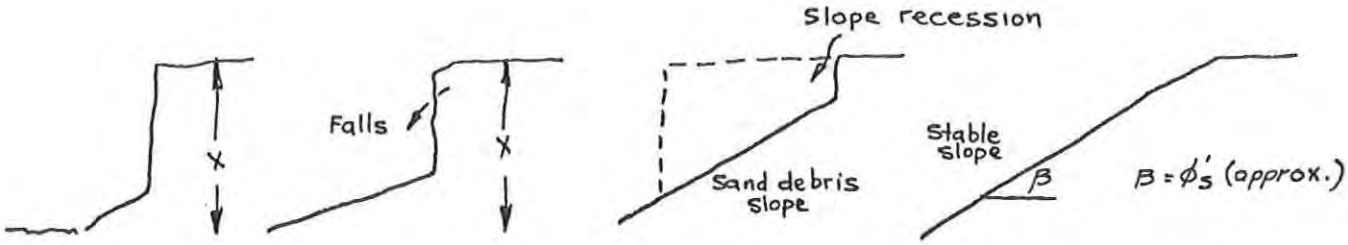


FIGURE 6: EVOLUTION OF SLOPE COMPOSED OF SAND AND/OR GRAVEL (WITH NO BASAL REMOVAL) eg. PLYWOOD P.G.E. CUT

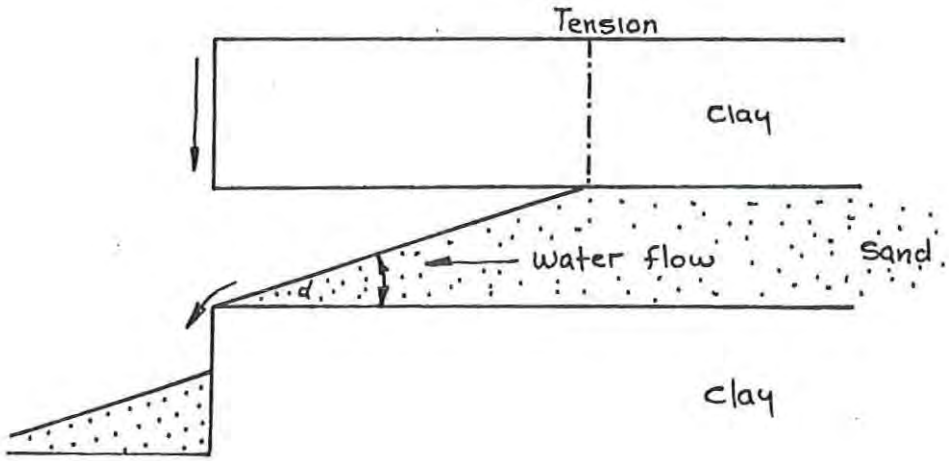


FIGURE 7: INSTABILITY IN A SYSTEM OF A HORIZONTAL SAND LAYER SANDWICHED BETWEEN TWO CLAY LAYERS. (after HENKEL 1967.)

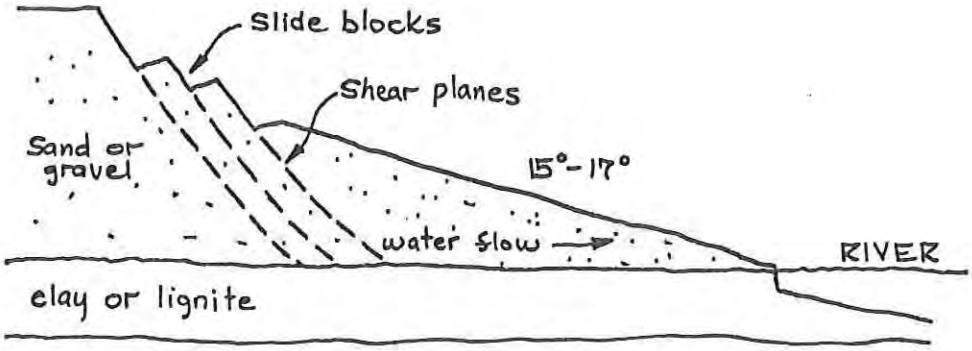


FIGURE 8: FAILURE OF SAND OR GRAVEL OVER CLAY OR LIGNITE LAYER. eg. WEST BANK.
(modified after HENKEL 1967)

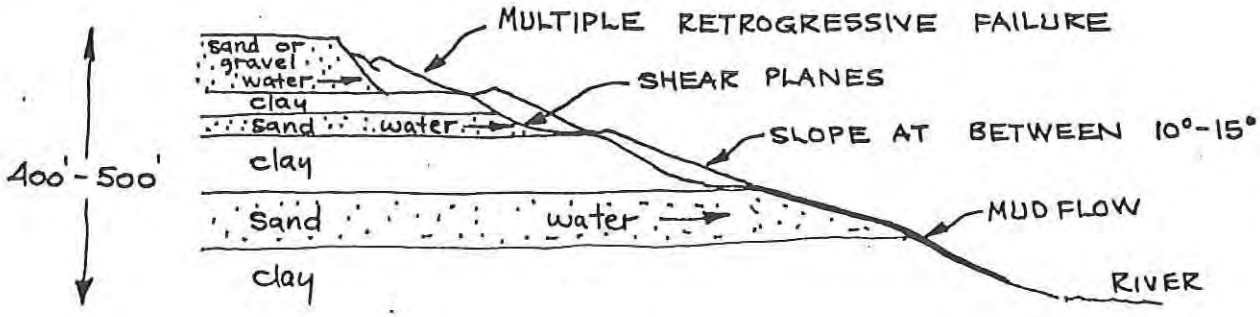


FIGURE 9: MODES OF FAILURE ON SLOPE CONSISTING. OF A SAND (GRAVEL)-CLAY (SILT) INTERCALATIONS.
eg. BIG SLIDE (modified after HENKEL 1967)

assumed. Henkel, (op. cit.) notes that a stable angle for most sands and gravels on such a clay surface will usually lie between 16° and 18° depending on the operating shear resistance on the clay surface (which would be close to the residual).

A fourth case involves a multiple complex situation where we have a succession of cohesive and cohesionless materials (Fig. 9). The field situation in this case becomes extremely complex due to the following factors; clay material becoming mixed up with sand released by seepage erosion (cf. Plywood Slide), the mudflow/slide-debris mantle covering the slope, blocking off drainage from the gravel-sand layers and giving rise to excess pore-water pressures. Interaction of such factors would account for the complex form of failure at the Quesnel River, Red Bluff, Beaver House Lake, Paradise Road and Big Slides. At Red Bluff, the average gradient of the failing surface is coincidentally (see above) between 10° and 15°. A similar figure is obtained from Big Slide (15° - 17°).

The above discussion of special cases does not account for the effect of basal erosion which will serve to maintain the sliding, the failing slope and the working back of the landslide into the river bank (i.e. providing that there are adequate supplies of water). Instead of seepage erosion, lateral erosion could be the cause of undermining.

This discussion of failure modes, therefore, points to the fact that sliding can take place away from the river bank and needs only sufficient seepage water to maintain the sliding.

3. Field Slope Stability Chart

The construction of field slope stability charts has been used as a tool by workers such as Skempton (1953), Lane (1961) and Shuk (1965) in

situations where the geology is so complex as not to allow a conventional stability analysis. By relating slope angle and height to stability and failure mode, information is obtained that can be of use in defining stable slopes and identifying potentially unstable ones.

A field slope stability chart has been constructed for slopes in the Quesnel area (Fig. 10) from the slope profiles mentioned above. As noted in Section III, there is not a distinct correlation between the variables but certain envelopes can be distinguished which define the following zones.

Zone I: A group which exhibits high slopes and steep to fairly steep slope angles which give rise to large multiple complex slides at Paradise Road and Big Slide. Sliding is taking place on angles as low as 10°.

Zone II: Moderately high slopes ($<500'$) and fairly steep slope angles giving rise to the compound slides such as East Bank, West Bank, etc.

Zone III: An intermediate zone which contains compound slides as well as slopes that are apparently stable. The latter group can be slopes which are steepening towards failure or those slopes that have failed, and are stable (or at least quiescent)

Zone IV: A zone with stable slopes; some slopes in this group may be steep cut-bank slopes but there are no slides present.

From a consideration of this delineation the following comments are put forward:

(a) Any slopes in Zones I and II must be unstable.

(b) Any slopes in Zone IV must be stable.

(c) Any slopes in the marginal zone, Zone III, will be either stable or unstable and will require investigation.

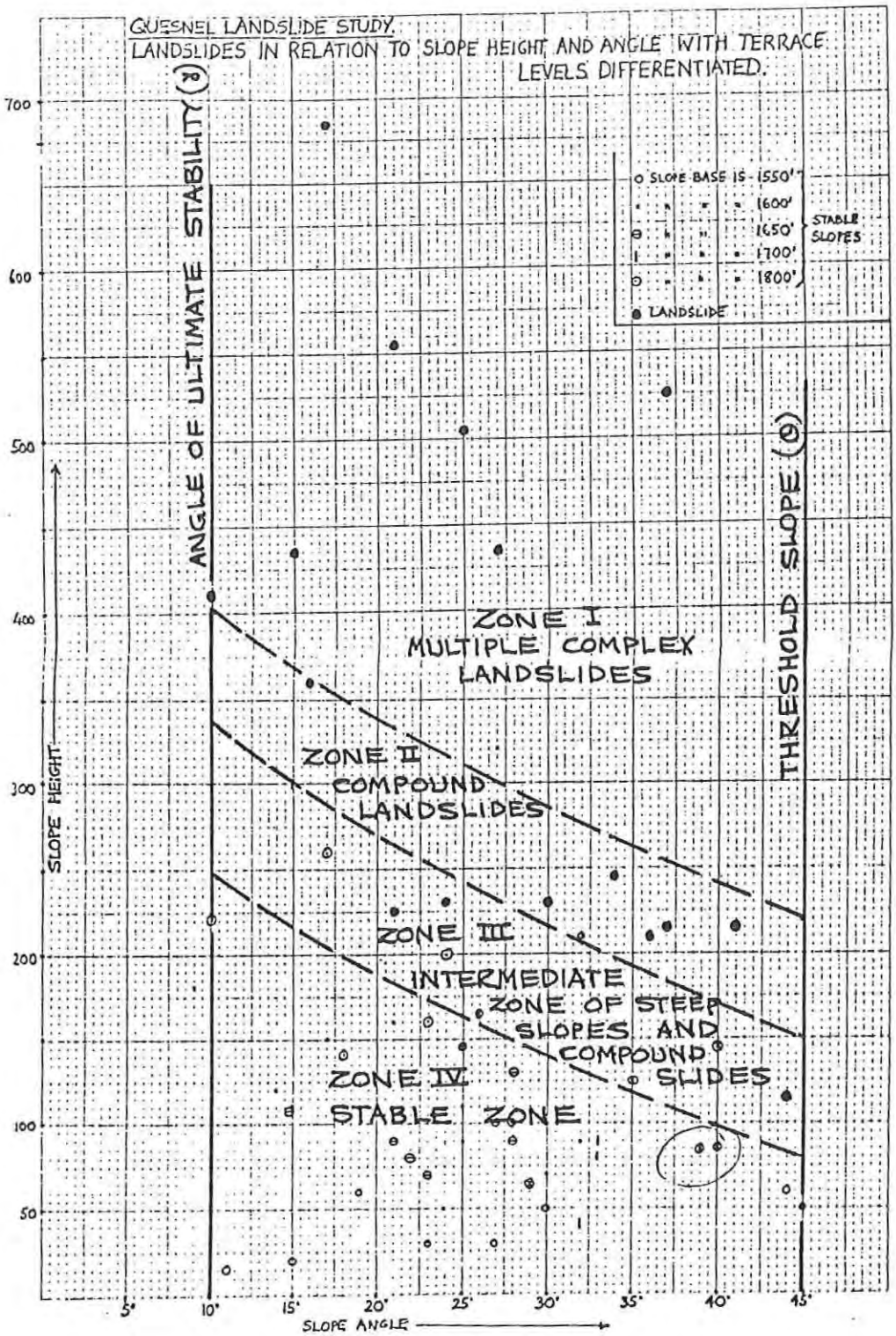


FIGURE 10: FIELD SLOPE STABILITY CHART FOR QUESNEL AREA.

(d) The threshold (or limiting) slope, γ , appears to be in the order of 45° since no slope is standing higher than this.

(e) The angle of ultimate stability appears to be between 10° and 15° because these are the lowest angles on which landsliding is taking place.

The angle of ultimate stability is remarkably similar to the angle of residual shear resistance obtain from some Tertiary shales at Cinema, north of Quesnel, and also appears to be comparable with the figure obtained in the calculation above for the sand slopes.

V FLOODING

At present, the Department of Lands and Forests is involved in the mapping of areas subject to flooding along the Fraser River but this work has not yet covered the Quesnel area. Accurate flood-zone mapping must be based upon detailed surveying. It is, however, possible to produce a preliminary map with the aid of data from gauging stations at certain points along the river. These data indicate variations in water levels throughout the year.

The flood zoning map is presented in Appendix E which also includes a full description of the methods employed in zoning. It must be emphasized that the map is tentative because of the severely restricted available information. For this reason, the zoning is very conservative and the higher areas may be affected by floods of periodicities in excess of 100 years.

Although zoning is cautious, the area of zoned land is not considerable. Interviews in the district suggested that flooding is not a notable hazard. The river appears to have cut a channel well below its previous terrace level (the 1550 - foot surface) in most places.

If more definite information on flooding is required for a specific site, local landowners may act as a useful source of information. If records for 1972 are confirmed, it appears that the flood-peak for that year represents a 45-year flood. Flooding in that year is likely to be fresh in their recollections.

It should be noted that very little information is available concerning floods in small tributary valleys. The only documented flooding occurs periodically around Dragon Lake and along the lower reaches of Dragon Creek at the base of Red Bluff (Wester, 1963 - see Fig. E1).

VI EARTHQUAKES

Data furnished by Dr. W.G. Milne of the Dominion Observatory (Dept. of Mines, Energy and Resources) shows that in terms of earthquakes Quesnel is in a very stable zone of the province. Although the probability of severe earthquakes (and related damage) is very low, the existence of critically unstable slopes in the area makes it possible that old landslides could re-activate and that first-time slides could occur under small seismic accelerations.

With regard to the National Building Code of Canada (1970) the Quesnel area is in Seismic Zone 1 and marginal zone 0. This is based on the acceleration with a return period of 100 years which for Quesnel is only 1.6% g. (Mercalli Intensity IV-V). About ten earthquakes have probably been felt in the 65-year period between 1899-1963. Intensities of IV accompanied the 1899, 1946 and 1949 earthquakes (i.e. accelerations were probably in the order of 1%. The details of the earthquake record are included in Appendix G.

VII IMPLICATIONS FOR SUB-DIVISION DEVELOPMENT

A. IMPLICATIONS

Out of the study the following implications are clear for sub-division development.

1. The landslide problem in the Quesnel area has been shown to be of such severity that it will be the critical factor in determining the suitability of available lands for sub-dividing.

2. It is recommended that no construction of any kind take place on landslides (as designated on Fig. 11). The old or inactive landslides cannot be said to be stable. There is no evidence of old slides being stabilized by natural processes. Because of the erosive activity of the river and/or the presence of water (which has the effect of weakening much of the materials in the area as well as leading to excess pore water pressures) old slides can very quickly become active. Even slides away from the effect of the river remain active, e.g. Red Bluff. Movement is sporadic but when failure does take place, displacement is substantial. Furthermore, the slide mass has a tendency to break up. These two facts together would mean certain destruction for any houses which might be involved in landslides.

3. It is recommended that no construction of any kind take place on lands in the vicinity of slide scarps or the heads of slides (as designated on Fig. 11). Because of the mode of failure and slope

development through multiple retrogressive sliding and progressive failure, there is a tendency for slides to enlarge upslope until the whole slope has achieved a stable angle. These recessions will take place in the presence of seepage waters (which are supplied by high-level aquifers on the 2200' and 2000' surfaces) and in the presence of toe erosion. The recession of the slope at Big Slide was measured as an example and between 1949 and 1969 the annual loss of farmland was 5000 sq. yrds. Although this loss is excessive it is illustrative of the magnitude of loss at the head of a slide. A similar mode of head advancement is anticipated at Red Bluff, Paradise Road, Quesnel River, Sub-division Slide, and at other slides that become activated. On the 1800' surface above the Plywood-P.G.E. cut, recession will take place until that slope has reached the angle of repose of the granular materials which is about 30°. Thus in all areas where recession of slopes is anticipated, a set-back from the slide scarps and heads, which would be consistent with a stable slope, should be insisted upon.

4. It is recommended that no construction of any kind be carried out in areas that are thought to have a high potential for first-time slides (as designated by Fig. 11). It is thought that slides may take place in the following zones;

(a) Downstream of meanders, i.e. downstream of the point of maximum inflection, since this zone will become the

zone of maximum bank erosion as the meander belt migrates downstream (see note on river erosion in Appendix D). The localization of slides at this point on meanders has been repeatedly noted.

(b) On slopes that are within Zone III in Fig. 10 that show no signs of instability. It is believed that their form is not consistent with stability and any disturbance of ground-water equilibrium would result in instability.

It is noted that the slides which occur on slopes between the existing river bank and the base of the slopes that skirt the 2000' and 2200' plateau levels (i.e. on the intermediate terrace levels) are all induced by human activity and are associated with construction and related developments. Attention must be paid to implication No. 7 below.

5. It is recommended that no construction or excavation be carried out in the vicinity of, or on, slide toes (as designated in Fig. 11). Although this may seem self-evident it is noted that, in West Quesnel, land appears to be cleared for sub-dividing dangerously near the base of Sub-division slide (see Plate F21). Of course, excavation of old slide toes will probably re-activate them.

6. It is believed that the danger to sub-division development from flooding is moderate. Areas prone to floods (using the levels of a 100 yr. flood) are approximated in Fig. E1. The Earthquake hazard is not considered great (see Appendix G).

7. It is recommended that any party constructing in what are designated as marginal areas in Fig. 11 should be cognisant of the following effects;

(a) Vegetation Stripping; affects ground-water patterns, leads to gully erosion which in turn could lead to landsliding.

(b) Septic Tanks, Lawn Sprinklers, etc.; any infusion of water from these or any other sources will reduce the stability of a slope through the effects of wetting and pore pressures. Landslides have occurred in the area because of this.

(c) Asphalt; will increase runoff which may lead to gullying or to increases in ground-water levels.

(d) Excavation; any excavation in cohesive materials will be unstable because of swelling. Road cuts should be carefully designed and under no circumstances should homes be built under a cut at the toe of a slope.

(e) Blockage of free-draining sand layer; any materials or structure which are laid down or built will have the effect of blocking free draining sand layers which, in turn, will build up pore water pressures and possibly lead to a failure situation.

8. It is recommended that the following procedures be carried out when development is planned in marginal areas (as delineated in Fig. 11) to minimize landslide risk;

(a) Geology and Ground-water: Because of the complexity of the geology in the area one cannot hope to map the

disposition of soils in sufficient detail for the purpose of ruling on marginal cases. It is strongly recommended that any development should be preceded by a subsurface investigation to map elementary geology and ground-water levels.

(b) Vegetation stripping should be minimized.

(c) Good storm drains should be inserted to pipe runoff away.

(d) Septic tanks are in some cases the source of harmful seepage. Where density of development is high, a sewage system might be installed to pipe away effluence.

(e) Water table: Where high water tables are encountered some form of slope drainage system should be installed to lower it.

B. DISCUSSION OF IMPLICATIONS WITH REFERENCE TO CRITICAL AREAS.

1. Red Bluff Area

As noted in Appendix F, sliding has, and is, taking place at regular intervals on the slopes that skirt the 2000' plateau in the area known as Red Bluff between Dragon Creek and Plywood Hill. Sliding is taking place on slopes as low as 10°. Excess water and slide-prone materials are the cause. Since the late 1950's the old highway (marked in Fig. 12) has been obliterated by slides and the old P.G.E. grade is no longer visible (Plate F9).

Sliding will obviously continue since there is no way to prevent it. The source of water may be Dragon Lake but in any event the seepage is coming from the top portion of the slope, probably through the high-level aquifer in the area.

Since there is no basal erosion, landsliding will continue but will probably cease when the angle of ultimate stability is reached. In Fig. 12, this angle is presumably about 10° so it can be anticipated that homes along the rim of the slide zone and within the "10° set back" will be damaged or destroyed by sliding. It may be noted that as early as 1958 the Senior Materials Engineer warned of the future continued instability of the slope.

This area should not be considered as future sub-division land.

2. Plywood-P.G.E. Cut

It seems that the slope of the material at what we have called Plywood-P.G.E. cut has reached its angle of repose of 30°. Very little further slope recession is expected since the base of the slope is well buttressed and protected from erosion by the P.G.E. fill. At the north end of the cut the gravels grade into silts and the possibility of failure here is higher. This northern end, therefore, should only be settled outside the zone marked in Fig. 12. (see Plate F13A-B)

3. Westply-Beaver House Lake Area

A prognostication is more difficult here. The slope that skirts the 2000' plateau and goes down to the Fraser River definitely exhibits slump topography with an average inclination of between 13° and 14°. There is a distinct scarp at the head of the slide noticeable from the road and on the air photographs although it is difficult to tell whether sliding as active as at Red Bluff is taking place. The protection of the base of the slope afforded by the booming grounds at Westply is probably a major stabilizing factor and all in all the slope seems dry. What will happen if the vegetation

is removed from the head area and excess water is introduced in the slope is not clear but it is probable that some sliding will result.

It is suggested that the slope is at present in a delicate state of equilibrium and sub-dividing, with its associated effects of vegetation removal etc., should not be permitted within the zone marked in Fig. 12.

4. Sub-division Slide (West Quesnel)

Apart from the problem along the rim of Red Bluff, the situation at the Sub-division Slide may be considered the most critical. Our interpretation of it is severely limited by the lack of large-scale topographic maps but the elements of the problem that give rise to the anxiety are;

(a) The existence of slides, slide-prone materials and evidence of seepage in the slope that flanks the 2000' plateau.

(b) The sub-division of land immediately at the top of this slope.

(c) The sub-division of land immediately at the bottom of the slope.

(d) Movement in the West Quesnel slide that could lead to instability in the main slope of Sub-division Slide (as expected through the slope evolution models proposed in Section IV)

(e) The stripping of vegetation right up to the crest of the slope (here and in the Logging Road Slide area)

(f) The existence of old gullies that have been uncovered by vegetation stripping (the development of gullies is thought to be an important precursor to the development of landslides).

For an appreciation of the problem see Plate F21. The area is a critical one in that the development of the slope through landsliding will obviously affect both the residents at the top of the slope and beneath it. A detailed discussion of Sub-division Slide is given in Appendix F; zones of hazard are given in Fig. 13.

It is recommended that construction be halted at the base of Sub-division Slide and that a geotechnical investigation be carried out to ascertain the specific hazard arising from the clearing of land at the top of the slope and other activities associated with construction.

5. Quesnel River Slide Area

Although the rim of the slide is apparently stable (i.e. there is no obvious movement along it) the extreme western and eastern portions of the slide are very active. Recent failures in the eastern part were inspected in the field and the impression was gained that the whole slide area is in a state of very delicate equilibrium or quasi-failure. If the secondary landsliding noted above continues it is believed inevitable that an expansion of the slide area will take place. The lowest angles measured on the Quesnel Slide are in the order of 10°- 11° (cf. Red Bluff) and although these may be near the angle of ultimate stability, unlike Red Bluff, toe erosion is taking place. The areas of presently-active slides are inclined at angles of between 15° and 18°.

It is recommended that no sub-division development be permitted in the head region of the Quesnel River Slide as designated in Figure 14.

6. Quesnel Hill Slide

This is yet another slide that flanks the 2000' surface. Here the slides are related to erosive activity associated with the Quesnel River when it was flowing at the 1760'-1800' level. They appear to be some of the more stable slides in the area, standing at about 11°-12°. Sliding has apparently taken place on the south east of the bend on Highway 97 which traverses one of the slides in the complex. Although the pipeline traverses the plateau near the head of one of the slides, construction is not recommended in the areas marked in Fig. 14.

7. West Bank of Fraser Between Baker Creek and Paradise Road Slide

In this stretch of the Fraser there is a serious landslide hazard attributable to the downstream migration of the meander belt. When a comparison is made between 1963 and 1973 air photos, it is fairly clear that a downstream movement is taking place which will effectively move the point of maximum scour (cf. Fig. D8). The areas that are thus threatened are downstream of West Bank and Garbage Dump Slides and are delineated in Fig. 15.

8. East Bank of Fraser Between Quesnel and Big Slide

Under the influence of very similar processes to those occuring on the west bank of the Fraser, landsliding will take place downstream of present landslide foci, i.e. East Bank, Gravel Pit and a small developing site of instability near Quesnel. (Of course, in Quesnel itself, the Front Street and A&W Slides occurred in erosive positions on the river bank). The areas that are threatened are marked on Fig. 15.

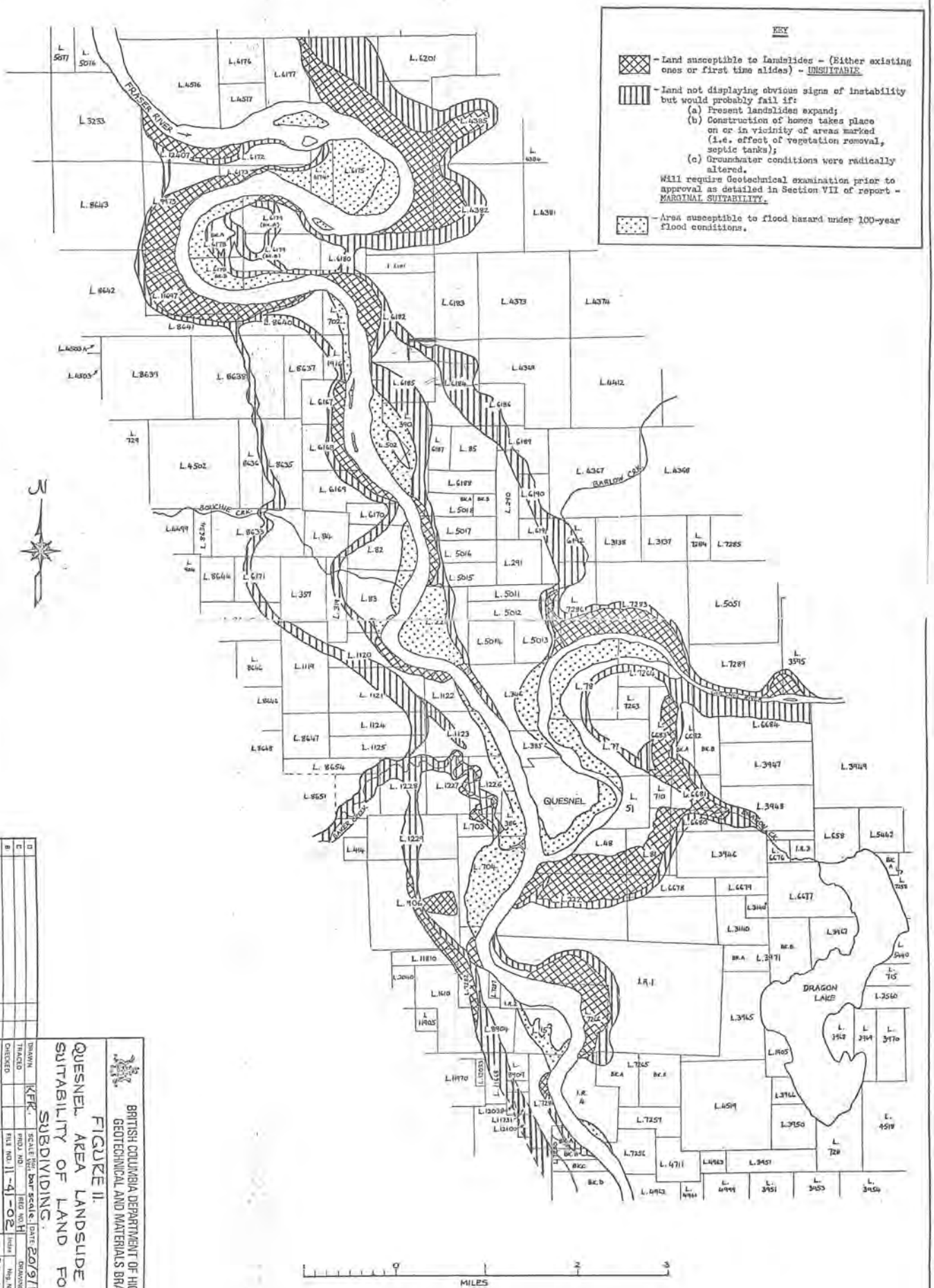


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FIGURE II.
QUESNEL AREA LANDSLIDE STUDY
SUITABILITY OF LAND FOR SUBDIVIDING.

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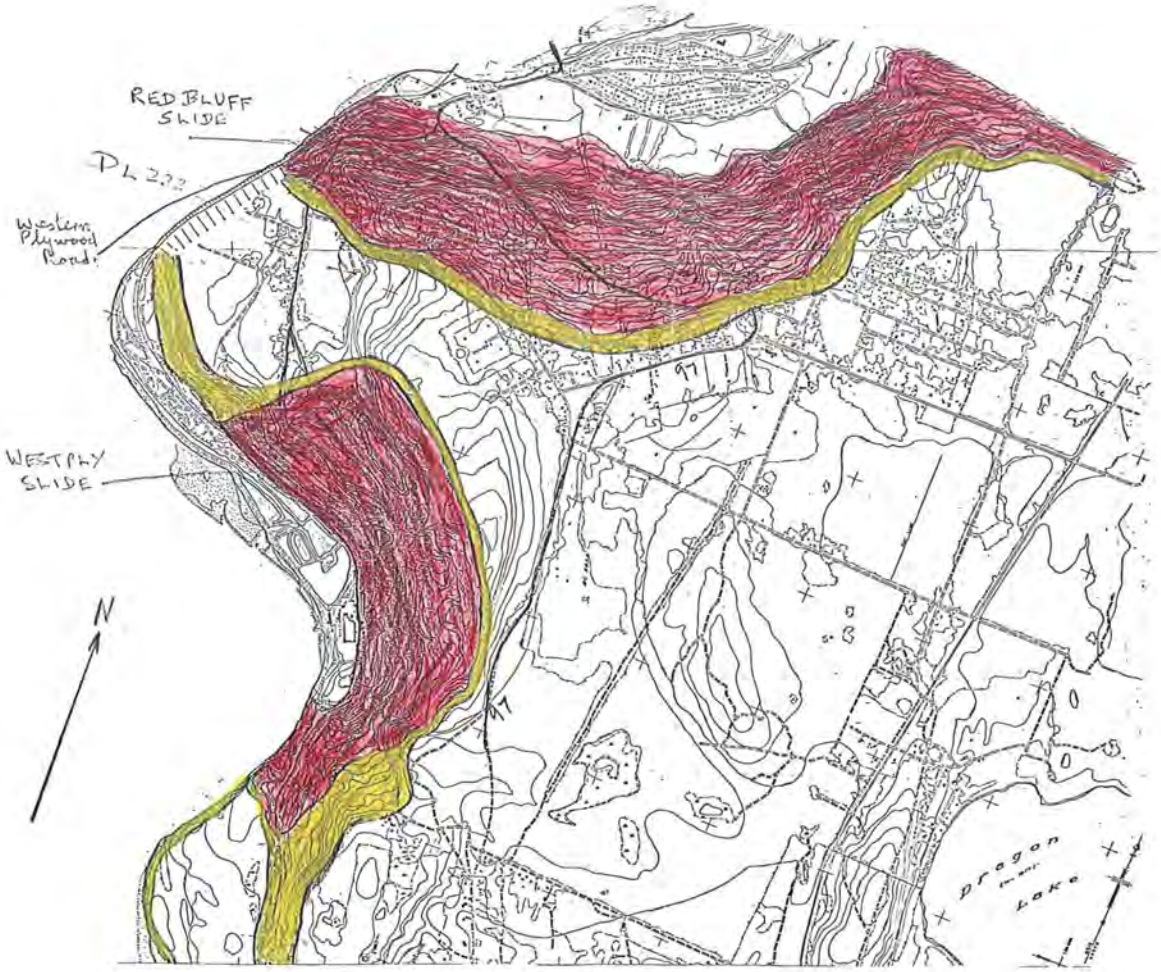

KEY.

- MARGINAL
- UNSUITABLE.

0' 1000' 2000' 3000'

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FIG. 12 - SUITABILITY OF LANDS IN THE RED BLUFF / WESTPLY AREA FOR SUBDIVIDING.

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A				APPROVED		APPROVED		of
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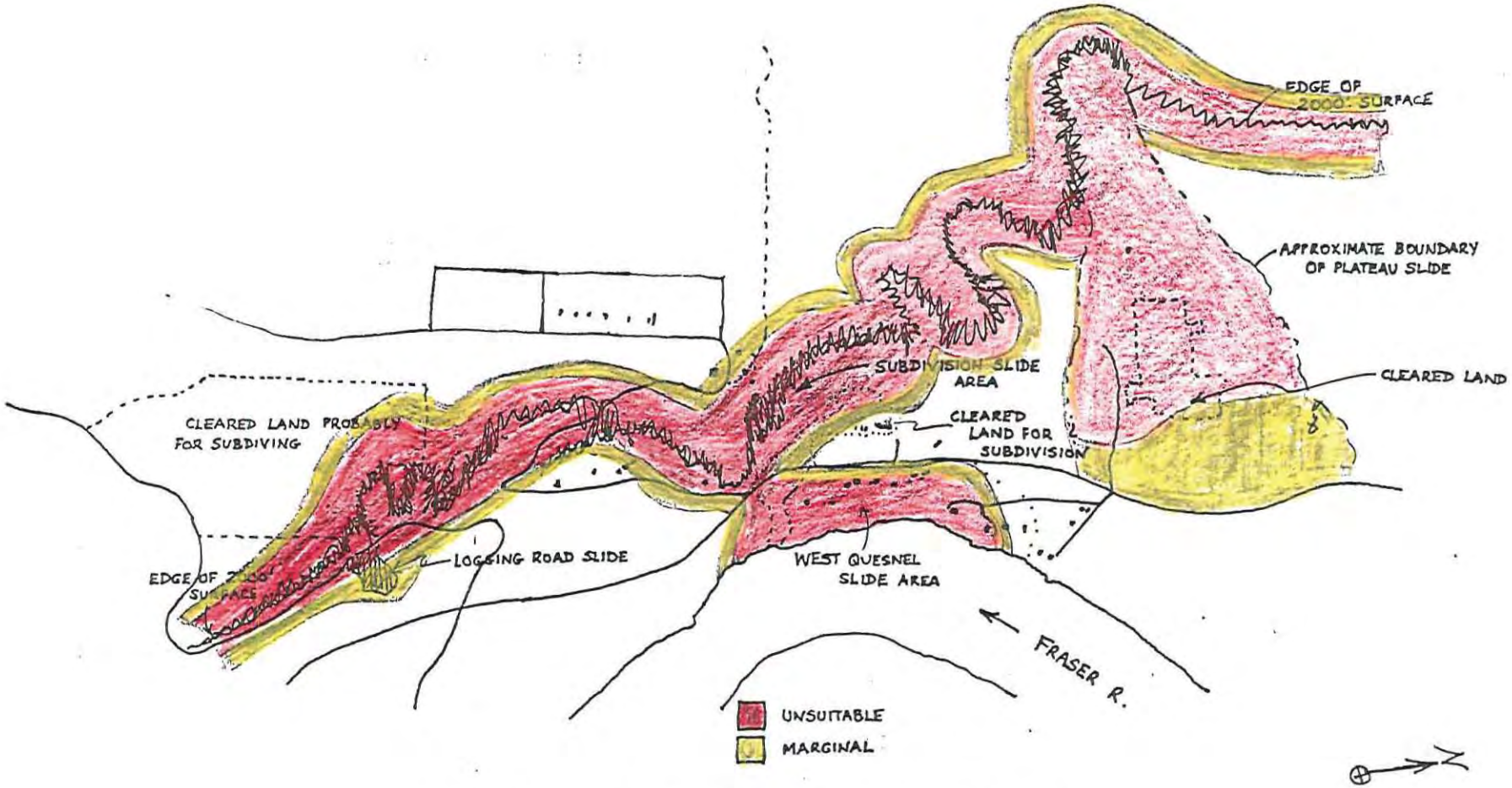
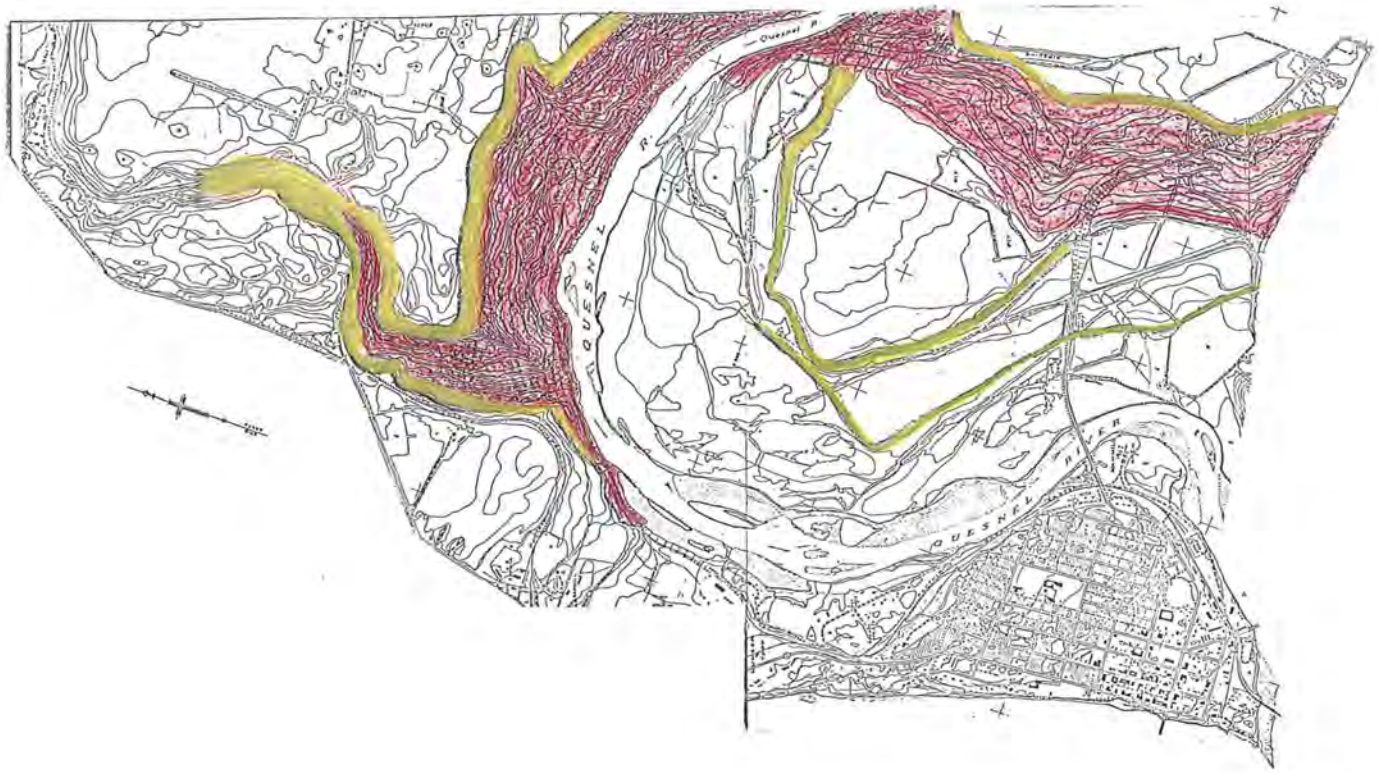


FIG. 13. SUITABILITY OF AREAS IN VICINITY OF SUBDIVISION SLIDE FOR SUBDIVIDING. (Scale 1" = 440 yds.)

(DRAWN FROM B.C. AIR PHOTOS B.C. 7510: 39-40)

NEG. # 90061 11 of 1



KEY

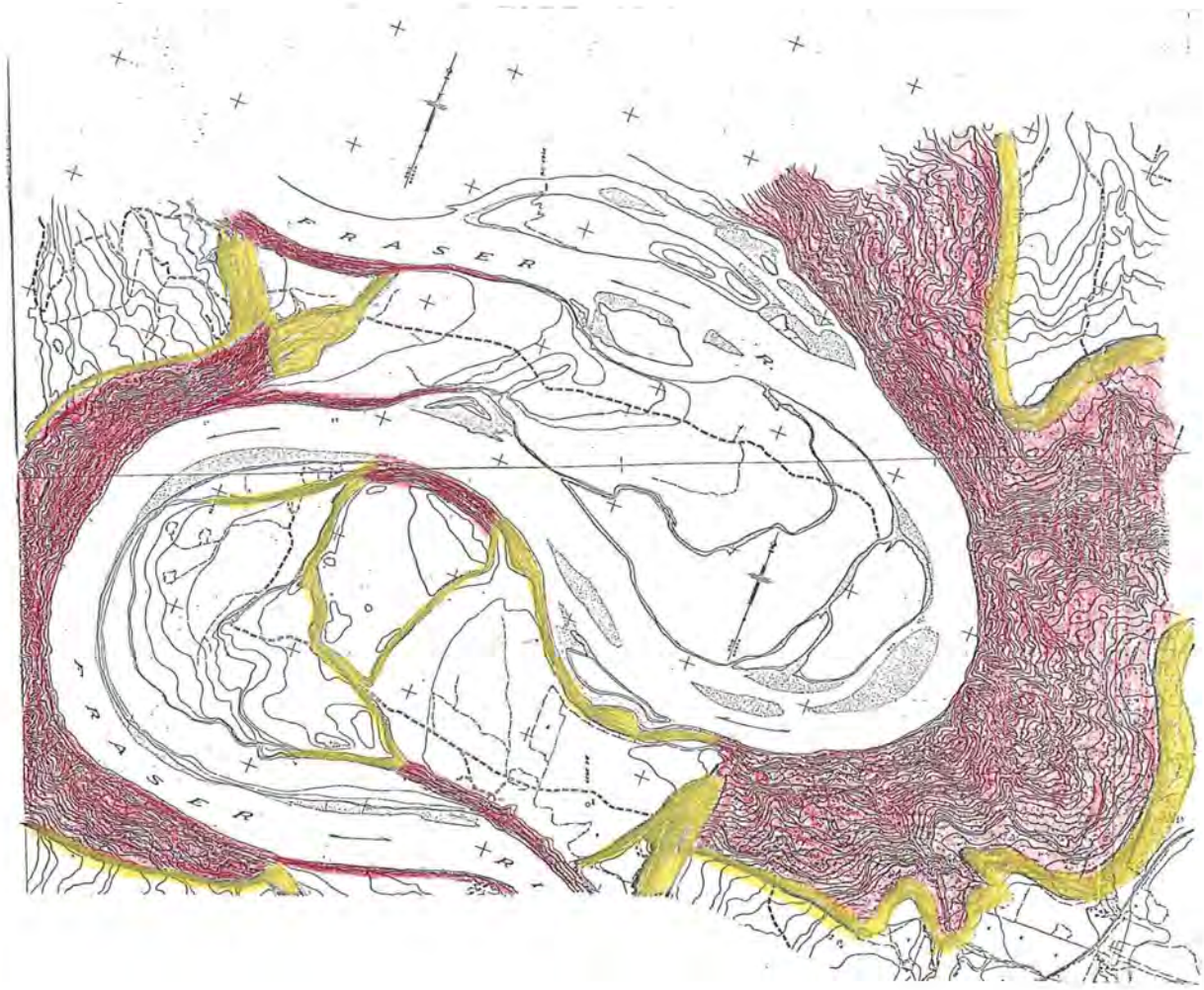
- MARGINAL
- UNSUITABLE

0' 1000' 2000' 3000'

BRITISH COLUMBIA DEPARTMENT OF HIGHWAYS
GEOTECHNICAL AND MATERIALS BRANCH

FIG. 14 - SUITABILITY OF LANDS IN THE QUESNEL RIVER AREA FOR SUBDIVIDING.

D				DRAWN	KFR.	SCALE Hor. - Vert. -	DATE 24/9/1973.	
C				TRACED		PROJ NO. REG NO H	DRAWING NO.	
B				CHECKED		FILE NO 11-41-02	Index / Reg. No.	Sheet No.
A				APPROVED			Q 90062	12, 16
	REVISIONS							



KEY

- MARGINAL
- UNSUITABLE

0' 1000' 2000' 3000'

BRITISH COLUMBIA DEPARTMENT OF HIGHWAYS
GEOTECHNICAL AND MATERIALS BRANCH

FIG. 16 - SUITABILITY OF LANDS IN THE BIG SLIDE AREA FOR SUBDIVIDING.

D				DRAWN	K.F.R.	SCALE Hor. Vert.	-	DATE	24/9/1973.
C				TRACED		PROJ. NO	REG. NO 14	DRAWING NO	
B				CHECKED		FILE NO 11-41-02		Index	Reg. No.	Sheet No
A				APPROVED		APPROVED		Q	90064	14 of 14
	REVISIONS								

9. Moose Heights Slide

The slide is one of the more inactive slides in the Quesnel area. Although no construction is recommended on the body of the slide, reservations about the head that were in order about other slides are not held concerning the head of Moose Heights Slide. After a consideration of the outline of the slide it is very likely that it was related to the erosive activity of the Fraser when it was at the 1760-1800' level (see Fig. 15).

10. Paradise Road Slide

Slide development is expected to proceed, as discussed in Appendix F, by multiple retrogressive failure. Continued erosion at the toe as well as continued seepage from the high-level aquifer will result in more instability. See Fig. 16 for details of suitability.

11. Big Slide

As discussed in Appendix F, sliding and recession of slopes has continued and probably will continue. It would be interesting to know what effect the clearing of the land has had on the rate of recession. Zones of suitability are given in Fig. 17.

12. Baker Creek Slides

There are one or two residences on the north side of Baker Creek that are in danger of falling into the river. Slides and backfalls have taken place on the margins of Baker Creek as a result of the meander swing effect. It is probable, however, given the small scale of slides in the Baker Creek area, that adequate rip-rapping of the banks of Baker Creek should solve the problem. For a detailed zonal map see Fig. 18.

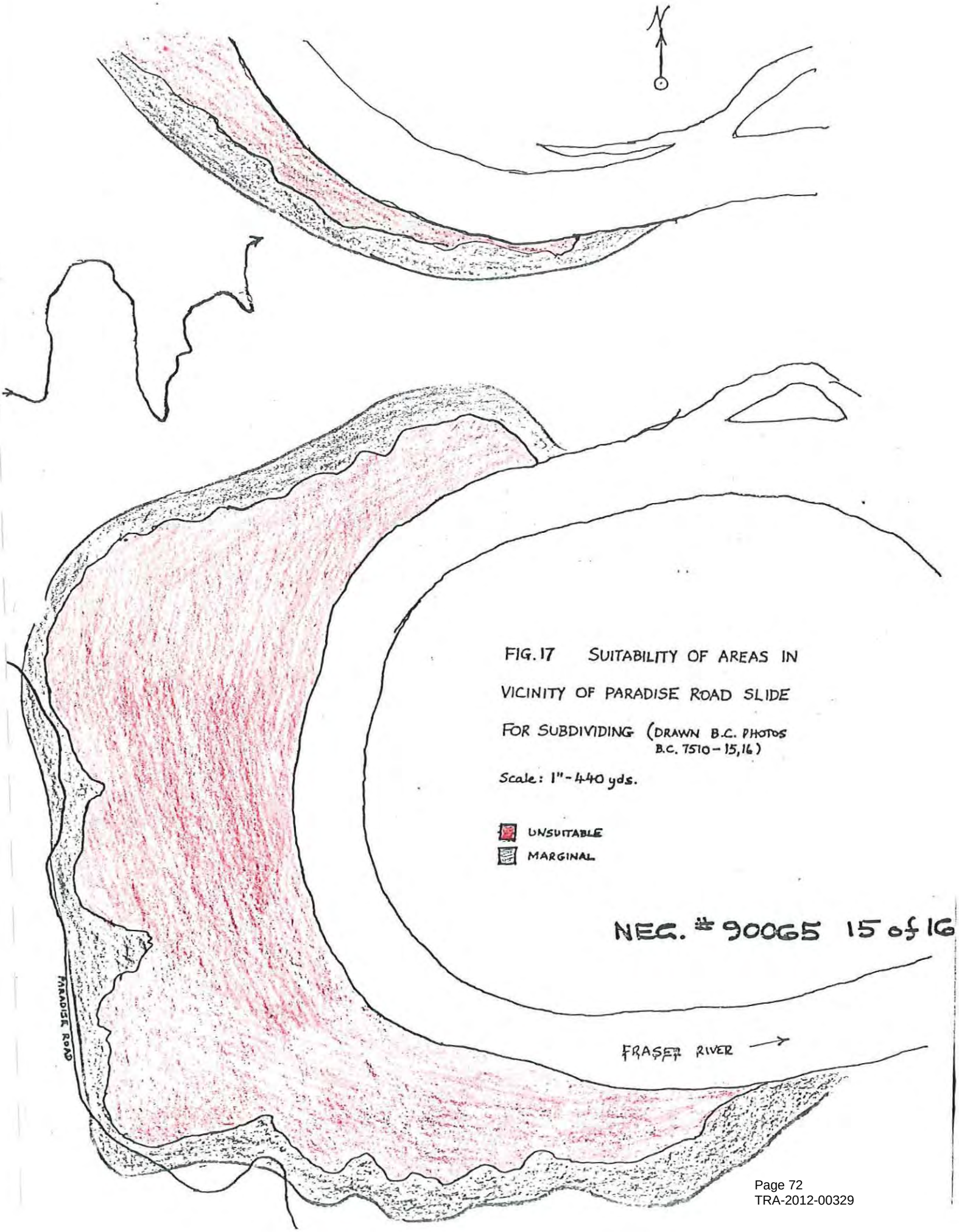


FIG. 17 SUITABILITY OF AREAS IN VICINITY OF PARADISE ROAD SLIDE FOR SUBDIVIDING (DRAWN B.C. PHOTOS B.C. 7510 – 15, 16)

Scale: 1" - 440 yds.

NEG. # 90065 15 of 16

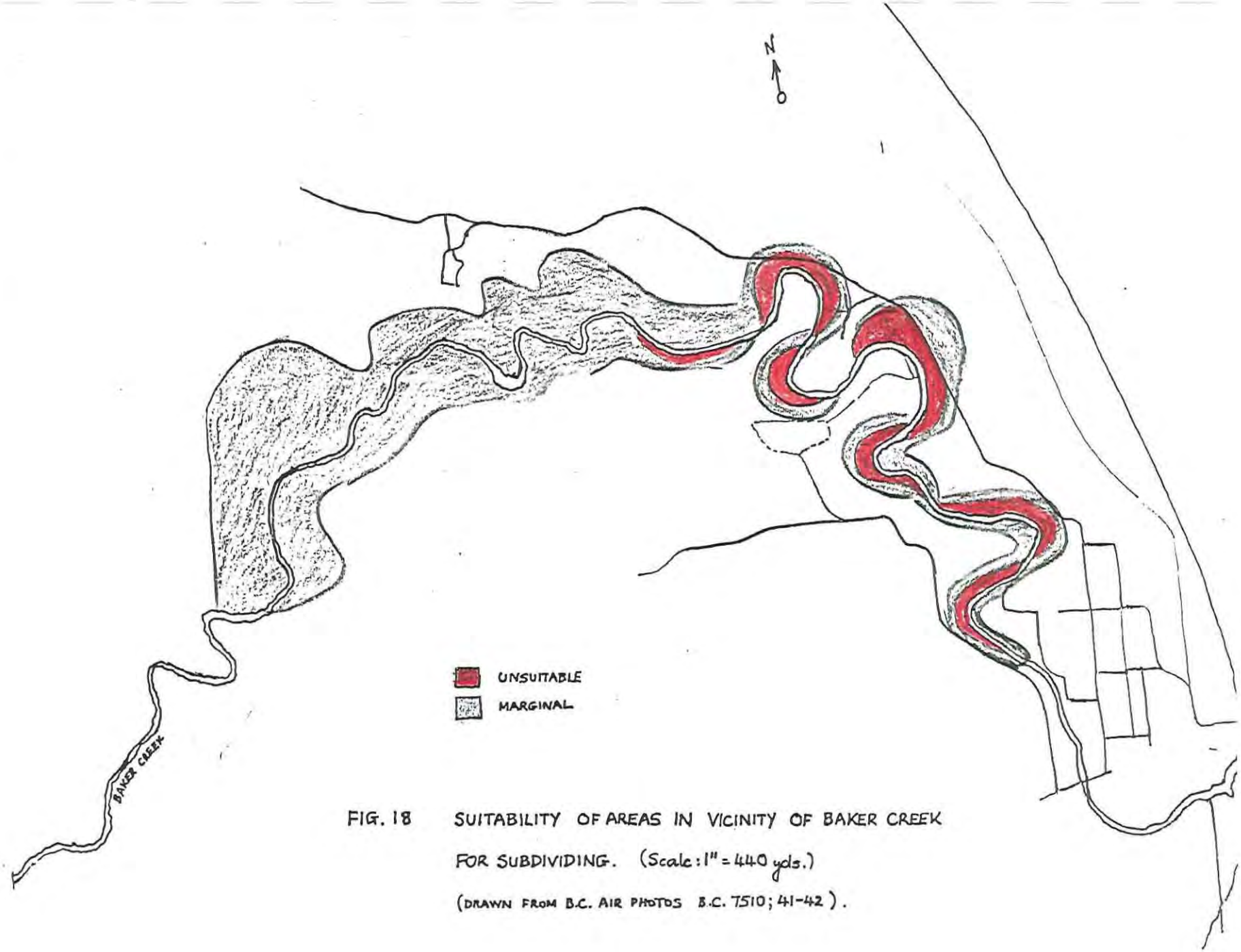


FIG. 18 SUITABILITY OF AREAS IN VICINITY OF BAKER CREEK FOR SUBDIVIDING. (Scale: 1" = 440 yds.)

(DRAWN FROM B.C. AIR PHOTOS B.C. 7510; 41-42).

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C. CONCLUSIONS

1. The unique geological and ground-water conditions existing in the Quesnel area have resulted in widespread instability. Although it was realized that landslides were a problem, it was not anticipated that so many existed. This report has uncovered the great incidence of landsliding not only along the Fraser River but on the flanks of the Fraser Plateau, a location where sub-divisions are likely to be proposed in the future.

2. The report has pointed out the landslide problem, mapped its occurrence, probed its causes, and suggested avoidance procedures. It must be remembered, however, that the study is of a regional nature and it is recommended that any slope falling within the "marginal suitability" range will have to be investigated in the manner prescribed since detailed geotechnical investigation was not one of the objectives at this scale of enquiry.

3. There is a long history of slide trouble in the Quesnel area and there now exists no reason why people should build on, or in the vicinity of, unstable land as they have on the rim of the Red Bluff complex. In this respect, a remark made in the City of Juneau Study (1972,p. 23) is worth noting;

> "In those instances where a hazard is known to exist prudence demands an assumption that a (hazard) event will take place . . . . ."

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APPENDIX A

GEOLOGICAL HISTORY

(1) The oldest, known circumstance in the Quesnel area is the presence of a shallow sea in Devonian, Carboniferous or Permian times. The sea deposited a series of marine sediements which underly the region today and are found to be highly metamorphosed (Reinecke, 1920). The deposits are part of the Cache Creek series.

(2) Little is known concerning events during the long period between the end of the marine phase and the beginning of the Tertiary period. East of Quesnel, in the Beaver valley, marine sediments of the Jurassic and Cretaceous periods have been identified but Mesozoic sediments appear to be absent from the Fraser valley in the vicinity of Quesnel (Cockfield, 1931). It is probable that the period was predominantly one of erosion. It is believed that, at the end of the Jurassic period, a phase of uplift gave added impetus to erosion processes which proceeded to reduce the Fraser Plateau to an undulating plain of low relief by the end of the Cretaceous period (P.G.E., 1929). The elimination of relief variations may have been furthered by the spread of fluid, non-viscous, basic lava flows of various ages (Tipper, 1971).

(3) Remnants of ancient fluvial sediments in the Cariboo District, although not around Quesnel itself, demonstrate that great rivers had occupied what is now the Fraser River valley by Paleocene times. Until perhaps Pliocene times, the valley north of Williams Lake drained northwards into the Peace River system while the lower valley belonged to the Chilcotin system (Lay, 1940; Armstrong and Leaming, 1967). Tributaries of the Fraser River, including the Quesnel River, continue to approach it from either the southeast or the southwest as a consequence of the former northerly flow.

(4) At the beginning of the Paleocene period, the dimensions of the trench were immense. Depths are unknown but its width in the Quesnel area may have exceeded 10 miles. Today, the distance across the valley from rim to rim is less than 2 miles in places, especially to the south of Quesnel.

(5) The Cenozoic (Tertiary and Quaternary) history of the Quesnel area has witnessed (i) the burial of this trench by both basic lava flows and freshwater sediments and (ii) the beginnings of a subsequent re-excavation by fluvial and glacial processes.

(6) The Tertiary period began with a phase of extensive vulcanicity which inundated many parts of the Fraser valley. The basalts and andesites of this phase constitute the Lower Lavas series and may exceed 1200 feet in thickness. They have been dated as middle Eocene, according to Piel (1969). Earth movements which accompanied the vulcanicity caused serious folding and faulting of the lava flows.

(7) The proto-Fraser River was dammed at many points by the Lower Lavas, for example, at the mouth of Narcosli Creek which is approximately 12 miles south of Quesnel. At Quesnel, however, the trench was not totally inundated with lava flows and became a large lava-dammed lake basin. The proto-Fraser River at first struggled to maintain an uninterrupted flow and fluvial deposits are intercalcated with the late stages of the lava sequence. (The late-stage sequences of sediments and lavas are less disturbed than the main Lower Lava series and must post-date the most destructive phases of earth movements which accompanied vulcanicity.)

(8) Eventually, the proto-Fraser River degenerated into an interconnected series of lava-dammed lake basins. Within the basin at Quesnel, extensive brown coal (lignite) measures accumulated. Characteristically, the series consists of alternating lignite and clay strata which are indicative of lacustrine conditions and the presence of abundant vegetation. These deposits were originally termed the "Lignite Series" by Dawson (1875 - 76) but have more recently been labelled (i) the <u>Australian series</u> (<u>members (a)</u> of the Fraser River formation) by Lay (1940) and (ii) <u>the Tertiary A sedimentary unit</u> by McCullum (1969). The most recent literature suggests an early Oligocene age for the series (Piel, 1969). For convenience, these soils are termed the <u>Lower</u> series in this report.

(9) Eventually, the proto-Fraser was able to "normalize" its course. It re-established regular streamflow both by downcutting through the lava dams and by raising the level of its bed through the accumulation of the lignite deposits. The upper beds of the Australian series are often coarse gravels which reflect this trend.

(10) A phase of moderate tilting occurred at some time during the Oligocene period which inclined the series to dips of between 15 and 40 degrees in the Quesnel region.

(11) Following tilting, the proto-Fraser River laid a thick sequence of interstratified fluvial gravels, sands, silts and clays which are horizontal and overlie the Australian series at an angular unconformity (Lay, 1940). These sediments virtually completed the burial of the large Paleocene valley in the Quesnel area. Lay (1940) refers to these deposits as an "imbricated" gravel sequence (members (b) of the Fraser River formation) and they are termed the Tertiary B sediments by McCullum (1969). They are believed to be Miocene in age (Piel, 1969). In this report, these are the Middle series.

(12) It is evident from the Middle series accumulations that the activity of the proto-Fraser River during the Miocene was predominantly depositional. Power to remove materials appears to have lessened progressively and both Dawson (1875-6) and Reinecke (1920) recorded the tendancy for the grainsize of these deposits to become finer upwards through the sequence. Lay (1940, 1941) concluded that this trend signalled the onset of a further lacustrine phase.

(13) During the late Miocene/early Pliocene period, according to McCullum (1969) and Piel (1969), volcanic activity was renewed and extensive basalts of the Upper Lavas series were deposited. The flows are usually horizontal and unfolded. Topographically, they cap the rims of the Fraser valley, particularly the western rim, at Quesnel, and extend under the glacial drift

sheets of the Fraser Plateau.

(14) This phase of vulcanicity disrupted once more the flow of the proto-Fraser River. Some sediments are intercalated with lava flows but others were deposited in lava-dammed lakes. One material which may have been deposited in the lava-dammed lakes is diatomite, a familiar deposit of the Quesnel area. Thicknesses in excess of 40 feet have been reported (Reinecke, 1920). The P.G.E. report of 1929 noted that the deposition of diatomite is favoured by the presence of hot springs such as would accompany volcanic activity. Both McCullum (1969) and Piel (1969) suggest that the diatomite and the Upper Lavas are contemporaneous and McCullum termed the joint series the Tertiary C volcanic and sedimentary unit.

(15) Lay (1940) noted, however, that the diatomite overlies the "imbricated" gravel sequence conformably. He argued that the river had progressed to a lacustrine stage prior to the eruption of the Upper Lavas as a result of purely riverine processes. He considered the diatomite layers to be members (c) of the Fraser River formation. He claimed, furthermore, that he had visited sections in which the diatomite is overlain by lavas. Other workers have been unable to locate such sequences. The P.G.E. study (1929), however, reports the presence of a bed of volcanic ash which underlies diatomite at Big Bend. The study speculates that the vulcanicity which was associated with the Upper Lavas was of longer duration than had been previously suggested. It is possible, therefore, that the progression to lacustrine conditions in the Tertiary B sequence (see point 12) was aided by lava-damming and that the diatomite was deposited in lava-dammed lakes at a time when the flow of the proto-Fraser was again fully disrupted. In this report, the diatomite is referred to as the Upper series.

(16) In the Quesnel area, the extrusion of the Upper Lavas appears to have been accompanied by a phase of upwarping. The latter probably increased the

erosive capacity of the proto-Fraser River so that it was able to re-open its channel and to embark upon the present major phase of excavation which is rapidly exposing the buried Paleocene valley. The phase of excavation almost certainly post-dates the Upper Lavas since the latter are symmetrically developed on both rims of the trench to the south of Quesnel. Excavation processes would have been inhibited in Pleistocene times by the presence of ice in the valley but they have subsequently resumed. Today, the Fraser River at Quesnel lies at least 600 feet below the highest deposits of the Fraser River formation.

(17) While the phases of lava outpourings, uplift and entrenchment, were in progress during Pliocene times, it is possible that the major reversal of the proto-Fraser drainage was accomplished so that large segments of the Peace River system began to drain southwards into the Chilcotin system. It is believed that the capture of the present headwaters of the Fraser system was accomplished by a headward-eroding tributary of the Chilcotin River. Perhaps this process was assisted by the drainage disruption which was caused by the Upper Lavas. Both Armstrong and Leaming (1967) and McCullum (1969) have suggested that sediment structures in the Fraser River formation to the north of Williams Lake indicate that river flow was still northerly when they were deposited. Lay (1940, 1941), by contrast, argues that imbrication in this formation indicates a southerly flow and he places reversal in pre-Eocene times.

(18) During the Pleistocene epoch, four major glaciations covered the Quesnel area. At least three, possibly four, till sheets have been identified. These are separated by interglacial fluvial sediments. The most recent major ice advance was the Fraser glaciation. It coincides approximately with the Wisconsin advance, the last major glaciation over most of Canada and the northern U.S.A. (Tipper, 1971). At Quesnel, the Fraser valley was inundated by simultaneous advances from the Cariboo Mountains and Coast Ranges. Fraser tills occupy extensive areas of the Fraser Plateau but, adjacent to the Fraser

valley, they are overlain by more recent deposits while, in the valley itself, erosion has removed most traces of them.

(19) After the main Fraser deglaciation, a minor ice readvance from the Cariboo Ranges caused ice to block the Fraser valley as far north as Dragon Mountain, 10 miles south east of Quesnel. An extensive pro-glacial lake backed up from this ice dam at least as far north as the confluence of the Fraser River with Cottonwood Creek. The main trench and adjacent plateau surfaces were drowned to an estimated elevation of 2,300 - 2,600 feet (Tipper, 1971). Extensive varved silts and clays cap the rims of the Fraser Plateau and are found in the trench also, but less frequently because of river erosion.

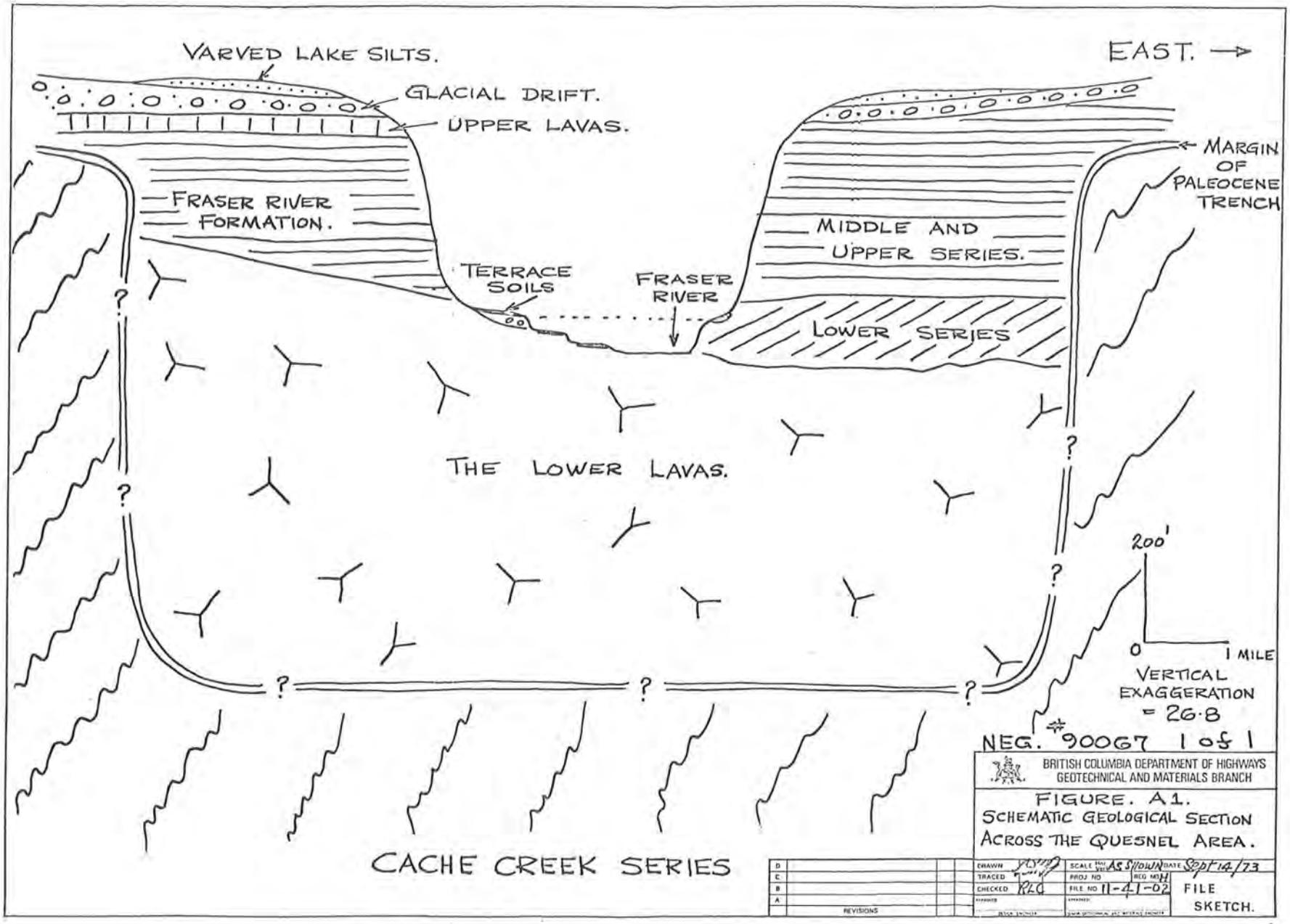
(20) The deglacial and post-glacial phases in the Quesnel area have witnessed rapid erosion. During deglaciation, enormous quantities of meltwater swelled the volume of discharge of the Fraser River. As glacier ice disappeared, this volume declined to its present, relatively meagre, magnitude. These developments were accompanied by considerable isostatic rebound (Holland, 1964). The Fraser River, which was initially rejuvanated during Pliocene times, was further rejuvanated and has cut downwards into the Pleistocene and Tertiary materials beneath it.

(21) The combination of downcutting and discharge decline has produced a series of river terraces. The highest and widest of the terraces, the 1800 - foot surface, may be a product of the period of great discharge which accompanied deglaciation. By contrast, the present lower terrace, the 1550 - foot surface, is areally very restricted. Like many rivers in formerly glaciated areas, the Fraser River is underfit, that is, it occupies a valley which was initially widened by a river of much greater discharge. The terrace surfaces are veneered with fluvial gravels and silts but the bluffs which separate the terrace surfaces are cut into Tertiary lavas and sediments.

Landsliding along these bluffs is very common.

(22) Landscape development on the Fraser Plateau in post-Pleistocene times has been slow. The glacial phase totally disrupted drainage on a surface of relatively low relief variations. There is little energy in the landscape, therefore, for modification by surface processes such as river erosion or sliding. Swamps and brooks interspaced with drift ridges form the characteristic landscape.

(23) In conclusion the geological history of the Quesnel area may be summarized in a simple sketch cross-section (Fig. A1). The diagram is schematic and does not represent the geology along any one particular transect. In the diagram, the large Paleocene valley is buried beneath a succession of Lower Lavas, the Lower, Middle and Upper series of the Fraser River formation and the Upper Lavas. Subsequent re-excavation has exposed outcrops of the valley fill down to the level of the Lower Lavas in places. The rims of the valley are overlain by till and by Pleistocene lake silts but these are largely absent from within the valley. The valley configuration consists of a series of terraces and bluffs of recent origin.


VARVED LAKE SILTS.
GLACIAL DRIFT.
UPPER LAVAS.
EAST. →
MARGIN OF PALEOCENE TRENCH
FRASER RIVER FORMATION.
MIDDLE AND UPPER SERIES.
TERRACE SOILS
FRASER RIVER
LOWER SERIES
THE LOWER LAVAS.
200'
0
1 MILE
VERTICAL EXAGGERATION = 26·8
CACHE CREEK SERIES
NEG. # 90067 1 of 1
BRITISH COLUMBIA DEPARTMENT OF HIGHWAYS
GEOTECHNICAL AND MATERIALS BRANCH
FIGURE. A1.
SCHEMATIC GEOLOGICAL SECTION
ACROSS THE QUESNEL AREA.
REVISIONS
DRAWN
TRACED
CHECKED
SCALE AS SHOWN
DATE Sept 14/73
PROJ NO
REG NO
FILE NO 11-41-02
FILE SKETCH.

APPENDIX B
SOILS

(1) The Cache Creek Series

The Cache Creek materials are predominantly sedimentary in origin and include chert, argillite, limestone, greenstone, serpentine, greywacké and conglomerate (Cockfield, 1931; Tipper, 1959). They are tightly folded, contorted, sheared, metamorphosed and recrystallized. The materials are usually invaded by complex networks of quartz and calcite veins.

The outcrops of Cache Creek sediments in the Quesnel region are confined to Baker Creek. The P.G.E. map of 1929 (Fig. B2) indicates an extensive area of these materials extending westwards from the Fraser valley. This mapping is conjecture, however, as there are virtually no outcrops of bedrock beneath the Pleistocene drift of this part of the Fraser Plateau.

In Baker Creek, the outcrops have been severely weathered, according to Reinecke (1920). Pillars have developed on valley sides in the material as a result of differential weathering (see Plate B1). The materials weather to residual kaolinites and pigmented clays of little or no plasticity.

(2) Lower Lavas Series

These extrusives consist of andesites, basalts and tuffs. They were deposited as valley fill in the Paleocene trench. In the Fraser valley, they are exposed only between Quesnel and Soda Creek and, within the study area itself, they are known only in Baker Creek and along the west bank of the Fraser River to the south of Quesnel (see section locations, Fig. B1, and P.G.E. map, Fig. B2).

Reinecke described the outcrops of Lower Lavas to the south west of Quesnel in some detail. Augite andesites and white, finely-banded, dense, glassy lavas are present. They are severely faulted, folded and brecciated.

They are intruded by later sills and dykes and, while in some places they are relatively well preserved, in others, they are intensely weathered and altered to clay (Plate B2). The writers observed outcrops of Lower Lavas at several points along the west-bank road to the south of Quesnel. In one section, where they were found at the base of the Subdivision Slide, they were intensely weathered and crumbled readily. The residue suggested a peculiar arkosic appearance, resembling a coarse, dirty gritstone.

Lay (1940) reported the presence of well-lithified, interstratified river deposits in some sections but such sediments are not known in the lava outcrops south west of Quesnel. They have been reported in Baker Creek, however, in the Minister of Mines report of 1938. At a point on the southern boundary of Lot 8651, ancient river gravels are intercalated with agglomerates of volcanic origin. At the base of the cliff section are lignites and clays. Above these are subangular gravels which contain lava pebbles with diameters of 3 - 4 inches. Within these gravels are beds of agglomerate. Overlying the coarse gravels are finer well-sorted gravels. One mile further downstream, Lay (1941) described a sequence in which 80 feet of decomposed quartzites are overlain by a 12-foot sequence of tuffaceous grit, gravel, clay and an extensively kaolinized lava flow (see Section B1). The condition, degree of lithification, etc., of these soils is not recorded.

(3) <u>The Fraser River Formation</u>

The soils of this formation are of greatest interest to the present study because they feature prominently in all of the identified landslides within the Quesnel region. The formation consists of sequences of gravels, sand, silts, clays, lignites and diatomites. These materials were deposited by the proto-Fraser River, possibly while it followed a northward-flowing course, and they now outcrop in a linear zone which straddles the present course of the Fraser

(see Figs. B2 and B3). The width of this zone is uncertain because of the blanket of more recent materials which cover its margins. It is possible, however, that the zone exceeds 10 miles in width astride the present river. This width is suggested by the location of outcrops along the deeply incised valleys of the Quesnel River and Baker Creek and also by the mapping of McCullum (1969; see Fig. B4).

Soils of the Fraser River formation exhibit considerable variations in their degree of lithification. At one extreme, they may be totally unlithified and, as a result, are indistinguishable from Pleistocene and Recent Soils (Armstrong and Leaming, 1967). At the other extreme, they may be cemented into hard shales, argillites, sandstones and conglomerates. The gravels are particularly well-known for their brownish or yellowish colours which are caused by a cement of ferric oxide ($Fe_2 O_3$).

Gravels appear to dominate the formation. They are usually well-rounded. Their composition reflects the underlying source materials. Over Cache Creek sediments, the pebbles consist of quartz or argillite while over the Lower Lavas, pebbles of basalt and andesite are most common. The clays are generally greyish but some are almost white. When in close proximity to lignite seams, however, the clays are contaminated by organic matter and may vary in colour through buff to brown or black. The diatomaceous earth is cream-coloured to white, very porous and of low specific gravity. The lignites vary from brown carbonaceous clays to black lignites of good quality. Fine-grained silts, clays and lignites are heavily overconsolidated and fissured as a result of loading by younger soils and by ice.

Locally, folding and faulting has affected the strata but much of the material is undeformed and dips only at very low angles, except in landslide zones. A major characteristic of the formation is that there is no general correspondence of sections at different points. Beds are usually thin

and lensed, reflecting the transitory nature of depositional environments within a river valley.

In reports prior to 1940, geologists did not differentiate distinct parts of the formation into units of differing ages. Probably they did not perceive any pattern in the variation of soils, being baffled by the complexity of the variations in facies, In 1940 and 1941, however, Douglas Lay recognized three units or members in the Fraser River Formation and later work, including that of McCullum (1969) and Piel (1969), accepts these divisions. The basal members, the Lower series, dip at angles up to 40° having been moderately folded following deposition. The Middle series lies unconformably on the basal strata and the Upper series lies conformably on the Middle series.

The Lower Series

The Lower series of the Fraser River formation is also known as the Australian series (Lay, 1940) and as the Tertiary A sedimentary unit (McCullum, 1969). Usually, the strata consist of sands, clays and fine subangular gravels which are interstratified with lignite beds. They are characteristically tilted. The materials outcrop extensively at, and to the south of, Quesnel and are also found at high elevations in the left (west) bank of Baker Creek. North of Quesnel, however, they have been reported only rarely because the Fraser River has not cut down sufficiently through the Upper and Middle series to expose them. At Big Bend, for example, exposures of the Fraser River formation may exceed 700 feet in height but only the lowest 20 feet belong to the Lower series. These are exposed only at very low water levels and consist of carbonaceous grits which dip north westwards at 30 degrees (Lay, 1940).

In 1875 - 76, Dawson described soils of what he termed the "Lignite series" in the left bank of the Fraser River at a point beneath Front Street. The soils "consist of impure lignities and clays, with layers of soft sandstone and ironstone concretions. These are followed in ascending order by clays and arenaceous clays of pale-greyish, greenish and yellowish tints, with a general southward or south-westward dip at low angles. These form the trough of a shallow synclinal over which the town of Quesnel exists." (Dawson, 1875-76, p. 257). On the south bank of the Quesnel River, where the highway bridge crosses, Dawson described exposures of cemented gravels, sands and clays with discontinuous seams of lignite. In places, paper shales are present.

Lower series soils are also exposed along the railway cutting beneath Red Bluff in the left bank of the Fraser River (at the Plywood - P.G.E. cut - see Fig. B1). The beds dip generally northwesterly into the trough of the syncline at angles up to 22°. A section which is reported by Dawson (see Section B2) indicates a preponderance of clays at this point, lignite being confined to relatively few strata.

Sections of these clays have been affected by combustion. In 1871-72, Selwyn described a sequence in an abandoned cliff beneath Red Bluff which is now protected from further erosion by the railway. The sequence (Section B3, Fig. B1) is the earliest known published section for the Quesnel area. The materials are highly lignitiferous and include a series of reddish-orange and cream clays (Plate B3). The clays are baked and owe their colour and induration to the burning of beds of lignite which they formerly held. These materials are essentially compaction shales which revert to silty clays when saturated and slake readily. Many rocks now resemble brick and porcelain. Some layers have become semi-vitrified while others which contain iron have melted to form a vesicular slag (Dawson, 1875-76). Much of the material has also been

subsequently brecciated and may have been involved in an ancient landslide (Internal Groundwater Division Notes, 1963). Baked clays occur elsewhere on Red Bluff, for example, in a disused quarry along an abandoned stretch of Highway 2 (see Fig. B1).

Further south along the Plywood-P.G.E. cut, the soils change abruptly, the north-westerly dipping strata giving way to more recent sands, silts and gravels. It appears that the Lower soils have been truncated by erosion and that more recent materials have been deposited against their exposed edges so that the continuity of Red Bluff, as it overlooks the Fraser River, is not broken. The contact zone was examined in detail by the writers since the Plywood Hill Slide occurs here. This zone is very confused because of sliding but an approximation of the sequence of Lower soils in the slide is given in Section B4. Near the base of the section are dipping beds of lignite which are essentially overconsolidated carbonaceous shales (Plate B4). These are overlain by extensive fissured bedded silts (Plate B5), diatomite (Plate B6), sandy silts, fissured clays, recent lake silts (Plate B7) and gravels. All of the finer-grained materials tend to be hard, fissured and heavily overconsolidated. The whole succession at this point dips south-westwards into the zone of contact.

Across the contact zone, Section B5 was recorded. Middle soils appear to be present at the base but these are overlain by silty sand with lignite inclusions and by buff, fissured, layered silts adjacent to the contact. Further south, away from the contact, recent gravels occur high in the cliffs but the sequence beneath them is obscured by scree soils. The newer materials afford evidence of slight tilting.

Several exposures of Lower soils have been identified along the Fraser River to the south of Red Bluff. These materials are prominently

exposed at the Westply Slide where the writers observed a rapidly alternating sequence of lignites (in strata up to three feet thick), silts (heavily overconsolidated and fissured) and fine gravels which dipped northwards (Plate B8). Approximately 1000 feet to the south of the slide, Reinecke (1920) recorded a sequence (Section B6, Fig. B1) which is probably from Lower soils. The section is dominated by clays, some of which are lignitiferous. Lay (1941) reported outcrops of these soils less than one mile further south at Rich Bar. The accumulations here exceed 500 feet in thickness.

In the extreme south of the study area, north of Dog Prairie Creek, the upper Lower series soils usually consist of gravels which may exceed 100 feet in thickness. The pebbles vary from 4 to 10 inches in diameter. These coarse soils, however, are exceptional and most Lower materials are fine-grained.

The Middle Series

Middle soils are equivalent to the Tertiary B sedimentary unit of McCullum (1969). Lay (1940, p. 15) stated that these soils consist of "imbricated well-sorted gravel, with overlying interstratified beds of fine gravel, sand, silt, clay, lignite, and occasional tuff beds". Lay (1941) noted several characteristics: (i) the strata are horizontal or nearly so, (ii) the gravels are imbricated and their lithification is often well advanced, (iii) the size of pebbles decreases upwards from the base of most sequences and the uppermost beds in some exposures consist of sand or clay or lignite.

McCullum (1969) observed the contrast between the lower gravels and the finer upper soils and recognized two distinct facies of deposition. The "Channel Facies" consists of sands and gravels which were deposited in the major river channels. The "Off-Channel Facies" consists of lacustrine and paludal clays, silts and lignites which were deposited in lakes and swamps

adjacent to the river.

Dawson (1875 - 76, p p. 263-4) also recognized a gradation in the soil types and commented: "The material of the gravels is generally small and subangular, and is chiefly derived from Lower Cache Creek rocks, the pyritous character of which causes them to assume rusty colours, like the decomposed parts of the Cache Creek series itself. Sections of the Fraser River show over 200 feet of these beds. They are sometimes seen to be overlaid by pale brownish and yellowish-brown sand and clay beds of earthy appearance, though with some layers of gravel. These occasionally rest with an appearance of conformity on the yellowish gravels below, but often fill eroded hollows in them, or lap round elevated masses."

Outcrops of Middle soils are most common to the north of Quesnel and are particularly well known at the Big Bend. Reinecke (1920) reported a section in the Paradise Road Slide (Section B7) which contained about 460 feet of cemented gravels and clays and a few seams of lignite. The clays dominate the upper soils. Lay (1940) considered Reinecke's section in detail and noted that the sands and gravels within the lower 335 feet are well-lithified and are pinnacled as a result of differential weathering. On the east bank at Big Bend, the sequences are rather different. Reinecke (1920) recorded a section immediately south of Big Bend (Section B8) in the East Bank Slide, which appears to be dominated by fine-grained materials and represents off-channel deposition for the most part. A section reported by Lay (1940) from the base of the Big Slide (Section B9) is composed entirely of clays, silts and lignites. He states that up to 165 feet of these soils occur at the base of the river cliffs. Higher in the sequence, soils are obscured by sliding. Sections from inexact locations in the vicinity of the Big Bend (Sections B10 and B11) are reported by the P.G.E. study (1929) and demonstrate very clearly the gradation from one facies to another which occurs upwards through the sequence.

South of Big Bend, the only recorded section is located in Baker Creek canyon where a small syncline in Cache Creek rocks is filled with conglomerate (of angular fragments of Cache Creek rocks), sands and clays in which were two thin seams of lignite (Section B12). Middle soils were observed by the writers in several other locations, however, notably at the Garbage Dump Slide and at the West Bank Slide (Plate B9).

The Upper Series

Although Lay (1940) considered the diatomite to be pre-Upper Lavas, McCullum (1969) regards it as the sedimentary component of the Tertiary C volcanic and sedimentary unit.

Its properties have been especially well documented in the Quesnel region by such reports as Camsell (1917), Reinecke (1920) and the P.G.E. study (1929). The following comments are reproduced from the P.G.E. study, Part A, vol 2, p p. 695-696.

"The diatomite occurrences at Quesnel and vicinity form the most important non-metallic deposits of the West Cariboo and the largest of their kind in Canada. This mineral has been variously called diatomaceous earth, infusorial earth, tripolite and diatomite.....

"The diatomite occurs as a solid, white, porous substance, much like chalk though it is softer and of less density. It has a very low specific gravity and floats until it becomes saturated with water which it quickly absorbs. This fact, together with an absence of grit enable it to be distinguished from clays and silts. The color of dry diatomite is white but when in place it is commonly grey owing to moisture, and in some cases it is brownish from iron oxide impurities.

"Diatomite is formed by the accumulation of countless hosts of the tests (shells) of diatoms, which belong to a group of flowerless, aquatic plants called algae. They are found living in salt and fresh waters in all parts of the earth and may be recognized as the yellowish slime seen clinging

to stones and debris at the bottom of ponds. The mineral is formed by the accumulation of the skeletons of dead diatoms on the bed of a body of water. If the process is long enough continued, thick strata are built up. As the diatomite accumulates, impurites such as clay, iron oxide, lime and carbonaceous matter mix in with it to some extent. Thus it seldom occurs as pure silica.

"The skeletons of diatoms are porous and because of their shapes do not form a compact mass when accumulated. For these reasons diatomite is a very porous substance . . . ."

"Its porosity makes it of great value as a filtrant, for it builds up within the filter cake an open sponge-like structure which allows free passage for the filtrate and at the same time holds back the minute particles which would ordinarily clog filter leaves, by so doing not only does it considerably increase the clarity of the filtrate but also the rate of filtration."

Reinecke (1920) has also pointed out that the material possesses a very low plastic range. On the addition of water, powdered diatomite at first behaves quasi-coherantly although it tends to be crumbly. As water content increases, however, the mass becomes rapidly incoherant.

Some of the diatomite locations in the study area are shown in Fig. B1. The isolated occurrences suggest that the area of deposition may formerly have been very extensive. The exact stratigraphical relationships of these sediments to other soils is one of the more controversial aspects of the local geology. McCullum (1969) discovered diatomite overlying olivine basalts in the Nechako valley which is 60 miles north of the study area. He concluded that the diatomite and lava outpourings were contemporaneous. Lay (1940), however, claims that diatomite overlies Middle soils conformably but is unconformably overlain by the Upper Lavas.

This assessment is difficult to substantiate and may be overly simplistic. Only on lot 906, 2 miles south-west of Quesnel, are the Upper Lavas actually seen to overly diatomite. Here, 45 feet of diatomite are exposed at 750 feet above river level and, although heavily faulted, appears to be in place. It is seamed with clays. Elsewhere diatomite may be found at topographically lower elevations but, usually in such instances, it has been involved in sliding. Some thin seams also occur exceptionally as definite strata in the Middle sequences (see Section B8).

Lay (1940) noted that six detached masses of diatomite in the Paradise Road Slide lie stratigraphically above the soils of Section B7. Reinecke, who located the masses, estimated that they were 650 feet above river level despite having been affected by sliding. There are no reports, however, that they are overlain by lava.

On lot 6182, near the East Bank Slide, two miles east of the Paradise Road Slide, two masses of diatomite occur at only 335 feet above river level. A quarry in the material was inspected by the writers and diatomite was found to overly a partly weathered lava outcrop along a very steeply inclined contact (Plate B10). There was no metamorphic aureole in the diatomite which therefore post-dates the lava. It is possible, however, that the soils are not in place. On lot 1122 adjacent to the west bank of the Fraser River, diatomite deposits of 20 feet thickness are found only 40 feet above river level. They possess high dips and have undoubtedly been involved in sliding. Low level deposits also occur in the Quesnel brickyard area and in the Plywood Hill Slide (Plate B6 - deposits in the slide were positively identified by the B.C. Department of Mines).

(4) The Upper Lavas

The Upper Lavas consist of basalts, andesites, tuffs and breccias. The flows are flat-lying, and the magma, being basic in composition, appears

to have been very fluid, spreading readily from fissure eruptions. In the Quesnel area, black, olivine-rich basalts dominate. These are usually unweathered and may be vesicular or amygdaloidal. Columnal jointing is common. Average thicknesses are about 40 feet.

In the study area, the Upper Lavas have not been definitely identified to the east of Quesnel where they are possibly buried beneath the Pleistocene drift cover. They occur north of Baker Creek (Plate B1), immediately to the west of Quesnel. South of Baker Creek, isolated outcrops of the lavas have been located as, for example, above the diatomite on lot 906. The lavas, however, form distinct upper rims on both sides of the Fraser valley to the south of the study area (Tipper, 1959). Along the west (left) bank of Baker Creek, on lot 8651, the lavas form the valley rim and overly gravels, silts and sands which were deposited by a river which was dammed by the lava flows (Section B13). The sediments are compacted but not cemented (Lay, 1940).

(5) Pleistocene Glacial Drift

Glacial drift is widespread over the Fraser Plateau both east and west of the Fraser River and consists of a complex assortment of ground moraines, boulder clays, interglacial fluvial soils, outwash materials and late-Pleistocene lake sediments. These soils overly the Upper Lavas. For convenience, the following discussion is divided into (a) glacial drift and (b) late-Pleistocene lake sediments.

(a) Glacial Drift - Horcoff (1960) examined in detail the drift between Quesnel and Barkerville. He noted that drift soils often occur as valley fills and may be present on valley slopes 1000 feet above the valley bottom. The average thickness of drift east of Quesnel probably does not exceed 100 feet (in fact, Lay, 1940, suggested that in the immediate Quesnel area, it rarely exceeds 25 feet). Horcoff (p p. 2-5) summarized the range of the materials as follows:

"The glacial drift consists in part of boulder clay and moraine

material; in part of stratified, fine sand and silt - known as "slum" - and in part of stratified gravels and bouldery deposits. The boulder clay contains comparatively few boulders and in other places is very stony. The upper weathered part is a yellowish, unstratified clay; the part below water level is in most places bluish grey. The part above the permanent ground water-level is in many cases hardened or slightly cemented as a result of alternate wetting and drying.

"The moraines are composed of materials deposited at the ends of the valley glaciers. Their surface is usually characterized by irregular hillocks and undrained basins; and the materials consist in part of stratified sands and gravels, in part of boulder clay, and, in places, ... mostly of angular blocks of country rock.

"Glacial outwash gravels deposited by streams coming from the melting ice in the upper parts of the valleys occur in considerable quantities as valley filling. The glacial gravels in the beds of streams frequently show imbricated structure; that is, the pebbles dip upstream and overlap downstream and have their long axes in the direction of the current. Glacial gravels also occur in places... in the form of irregular hills or kames and as long, winding ridges or eskers. The gravels are in many places coarse and in places overlain and underlain by boulder clay.

"The stratified combination of silt and clay is recognized by its uniform character and almost complete freedom from stones... The silt and clay combination varies somewhat in character in different parts of the area. In places it is fairly stiff and nearly impervious clay, but for the most part it is composed of fine sand and silt glacier flour - which is readily permeable by water, hence the name "slum". The glacial gravels, especially the coarse gravels and occasionally the fine gravels, contain considerable quantities of it. It is overlain and underlain in places by boulder clay. The silt, judging by its stratification and wide extent, was deposited in a series of lakes, formed during Pleistocene time through the blocking of the valley

drainage by uneven deposition of drift or by the advance of glaciers from Cariboo Mountains. The stratified deposits form a large part of the glacial drift of the area and indicate the great volumes of flood-water which must have existed during parts of Pleistocene time - a remarkable feature, especially considering the fairly high altitude of the area and the small amounts of flood water at the present time.

"Cemented glacials occur at many places in the area both at the surface and at depths of over 200 feet below the level of the creeks. The cement consists partly of iron oxide and partly of lime or calcium carbonate..... Cementation is known to take place fairly rapidly in gravels near the surface in places where there is a marked oscillation of ground-water level or alternate wetting and drying of material, but at great depths where circulation must be slow or stagnant it is more likely that cementation of the lower gravels took place during an interglacial period, when streams flowed at considerably lower levels."

Horcoff (1961) and others (Nasmith, 1953; McCullum, 1969) have also noted that interglacial sediments may be widespread although they rarely form extensive outcrops. The soils are usually dominated by sands and gravels but may contain a few thin clay interbeds. These materials are often densely compacted.

West of the Fraser valley at Quesnel, Horcoff (1961) investigated the Fraser Plateau drift cover as far west as Nazko. He commented that:

"The glacial drift largely in form of till is derived from two glacial advances... The first advance eroded much rock debris from the weathered outcrop and deposited it in the low-lying areas. In comparison to the earlier ice advance, the later advance carried a relatively much lighter load of till and essentially re-arranged the earlier till into drumlins.

During stagnation and decay of the last ice sheet, glacial lakes formed in the low-lying areas whilst recessional moraine was being deposited in the valleys. The large deposits accruing from the two glacial advances, up to 400 feet in thickness, severely disturbed the plateau's drainage pattern. The hundreds of swamp meadows and shallow lakes that now are scattered over the upland surface reflect the disrupted drainage and widespread deposition of glacial material associated with the retreat of massive ice-sheets of glacial times." Bog soils are widely reported on the Fraser Plateau in this area (see Figs B5 and B6).

Few specific drift sequences have been described in the Quesnel region. Pleistocene facies variations are so chaotic that it was not possible to plot in detail the variations in soil types through the study region. Tipper (1959, 1960) mapped the drift cover as a continuous undifferentiated blanket (Fig. B3). The pedological mapping of Farstad and Laird (1954) is more detailed but considers only the immediate surface soils (Fig. B5). These are classified as they overlie undifferentiated Glacial/glacio-fluvial (Pleistocene), lacustrine (late Pleistocene) and alluvial (Recent) materials. The undifferentiated glacial soil (the Chilako stony sandy loam) is located on the Fraser Plateau but outcrops only at some distance from the Fraser valley because of more recent deposits.

The most detailed mapping in the area was published by Leaming and Armstrong (1969) but covers only the northern half of the study area (Fig. B6). The map indicates that, adjacent to the Fraser valley, the Plateau is covered by ground moraine which is overlain by lake-bottom silts, sands and clays. Glacio-fluvial ice-contact and stratified drifts apparently do not occur adjacent to the valley. Outwash plains are, however, identified to the west of Ten Mile Lake and north of Quesnel River. The situation which is

reconstructed by this mapping is exceedingly generalized.

A few instances of detailed observations may be mentioned. Armstrong and Leaming (1967) claim to have observed four tills in the Big Slide area. Three tills are positively identified in Section B8 from the East Bank Slide. The tills consist of boulder clay strata which are separated by interglacial sands and gravels. Only one till, however, occurs in Reinecke's section (Section B7) at the Paradise Road Slide and no other reported sitings of two or more tills are known to the writers.

Contrary to the impression which is conveyed by some mapping and reports, the Pleistocene drift cover is not entirely removed from within the Fraser valley. It has been selectively preserved from erosion in places and underlies more recent soils. A complex geological section from the Cariboo Pulp and Paper Pit (Section B14) attests to this. In the section, over-consolidated, fissured, contorted, Tertiary clays and shales are overlain irregularly by a structureless, tightly packed stony till which is, in turn, overlain by more recent lake silts and river sands and gravels (Plates B11 and B12). Large masses of stratified drift (outwash material) were encountered in several locations, particularly on the margins of the Fraser Valley. Two of the most impressive exposures were viewed at the Barkerville Road P.G.E. over-pass and along the Pinnacles Park road to the north of Baker Creek (Plate B13). The large sections of crudely stratified gravels, which exhibit pronounced original dips, resemble kame terrace deposits.

(b) Late-Pleistocene Lake Sediments

A series of silts, sands and clays were deposited in a pro-glacial lake at the end of the Pleistocene epoch. They have been segregated from the rest of the Pleistocene drift for consideration here because they are relatively homogeneous and form a widespread, readily recognizable and datable

mapping unit which caps all other drift deposits indiscriminately on the Fraser Plateau adjacent to the Fraser valley.

The lake soils occur at elevations up to 2600 feet and were deposited in the valley and along adjacent sections of the Fraser Plateau (mapping of these soils was discussed in the preceding section on drift). Buff and pale grey silty clays and clays are most common. The soils are varved and tend to split into flat chips when dried. The deposition of the lake sediments tended to reduce relief variations, being accumulated in thicker units in depressions than on ridges. In places, small sand and gravel accumulations may constitute ice-rafted deposits while at the margins of the lake zone, some outwash sands and gravels were probably deposited directly into the lake. The tops of some drift ridges were reworked by waves and now possess gravel deposits.

Varved silts and clays have been observed in many parts of the study area. Reinecke (1920) reports a section (Section B15) in the east bank of the Fraser River, one mile south of Quesnel, which contains 135 feet of bedded silts which are probably of lacustrine origin. A lacustrine origin may perhaps be ascribed to the bedded silts in Section B5, south of the Plywood Hill Slide. Lake silts were observed at many points on the top and flanks of Red Bluff (Fig. B1). Here they were often fissured and appeared to be overconsolidated, perhaps in response to dessication (Plate B14). They were also observed in the Cariboo Pulp and Paper pit (Section B14) and at the summit of the Barkerville Road P.G.E. overpass cut where 20 feet of varved silts is present. At a location on Paradise Road, at the top of a bluff above the 1800 - foot surface, a roadside exposure of varved silts (at 2000 feet) was unfissured and appeared to be scarcely overconsolidated (Plate B15).

(6) Recent Soils

The post-glacial Fraser River has deposited extensive sands, silts and gravels on its terraces which, around Quesnel, are located at and below 1800 feet in a narrow zone astride the Fraser River (see Figs. B5 and B6). The materials are thin, often not exceeding 10 feet in thickness. Farstad and Laird (1954) reported that sandy loams and silty loams dominate in the study area (Fig. B5). These indicate an off-channel, flood plain facies. The coarser gravels, where present, however, indicate a channel facies. These materials are found to overly many of the sections which have been reported in the Quesnel area (see, for example, Sections B4, B5, B6, B14, B15). The writers observed river gravels at the summit of the Plywood Slide and in Plywood Pit (Fig. B1), which is on the 1800 - foot surface. Here, sandy gravels (with stones up to 4 inches in diameter) are overlain by a structureless uniform sand (1½ feet) which actually resembles loess (Plate B16). Other Recent soils are found at the Cariboo Pulp and Paper Pit (Plates B11 and B12). A complex sequence of materials was observed at Wiers Sawmill (on the northern outskirts of the town of Quesnel) which could well consist entirely of Recent soils (Section B16, Plate B17).

Plate B1 - North wall of Baker Creek at Pinnacles Park; note earth pillars in Cache Creek sediments and cap-rock of Upper Lavas basalt.

Plate B2 - Rotted basalts (Lower Lavas) along west bank road south of Quesnel; varved lake sediments are present at top of section.

Plate B3 - Burnt lignite bands (red and yellow) at north end of Plywood - P.G.E. cut.

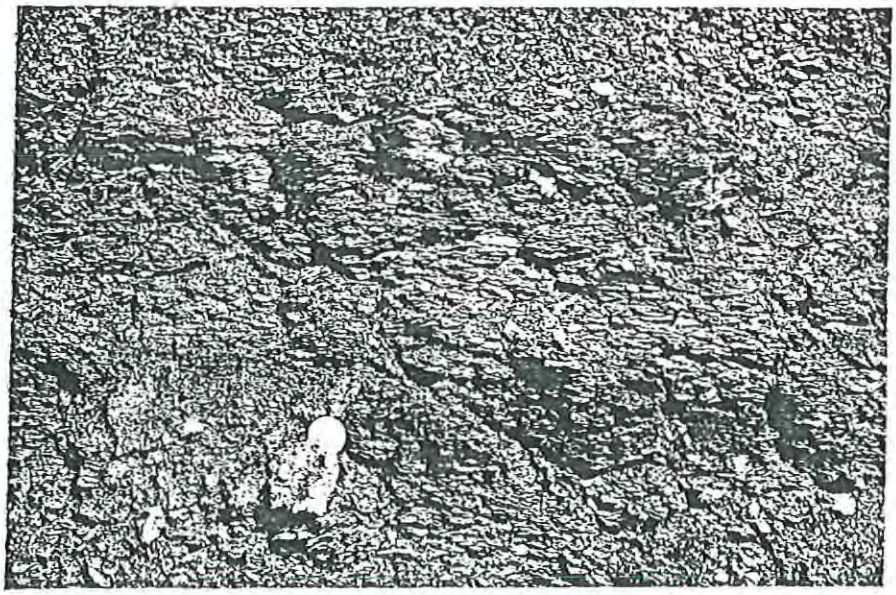


Plate B4 - Lignite (Lower series) in the Plywood Hill Slide.

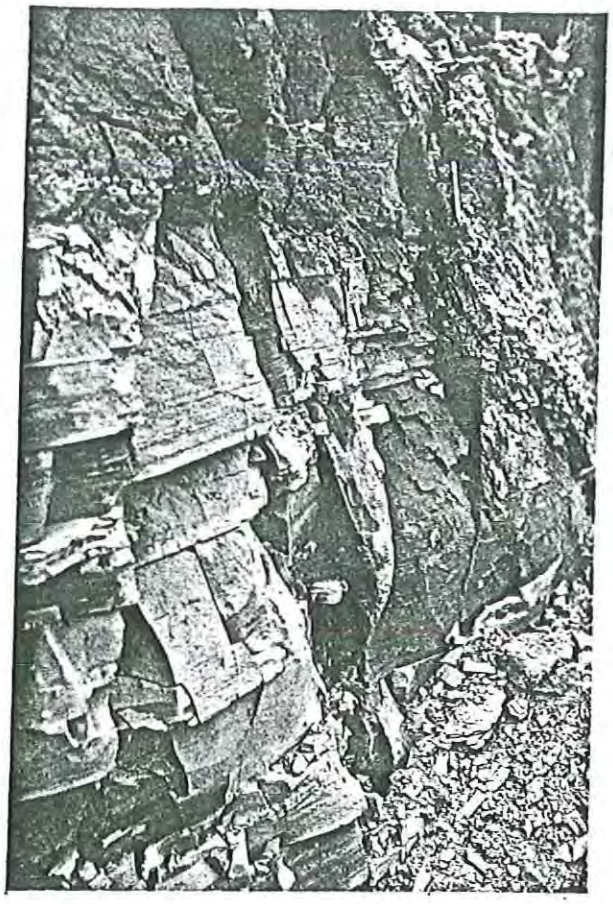


Plate B5 - Fissured bedded silts near the top of the Plywood Hill Slide.

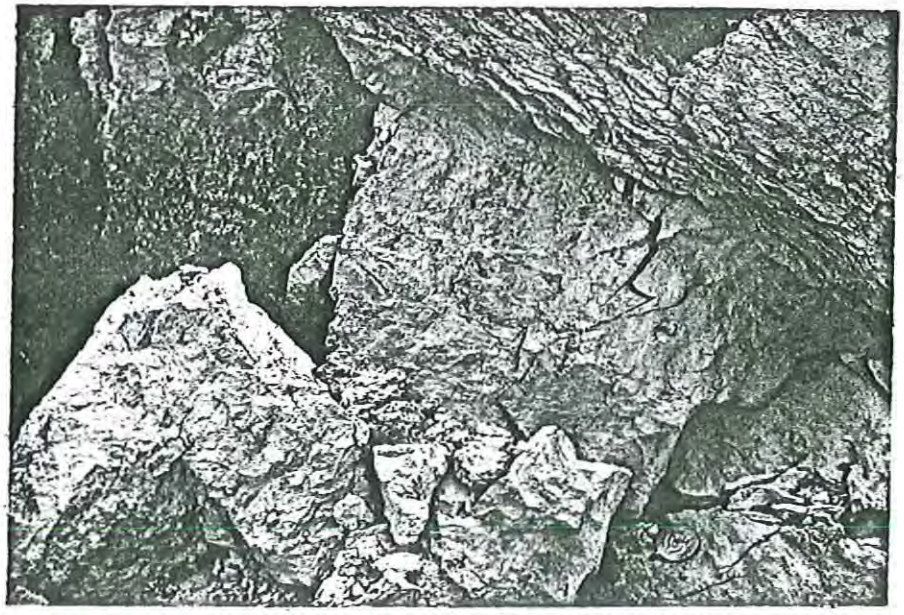


Plate B6 - Diatomite in the Plywood Hill Slide (not in place).

Plate B7 - Varved Pleistocene lake silts at the top of the Plywood Hill Slide.

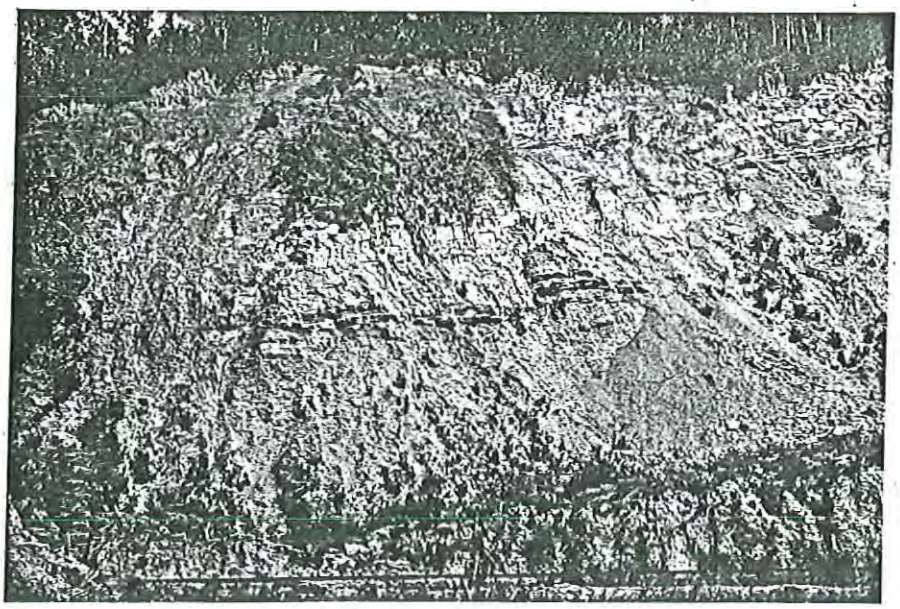


Plate B8 - Lower series soils at Westply Slide; note prominent lignite band and P.G.E. in foreground.

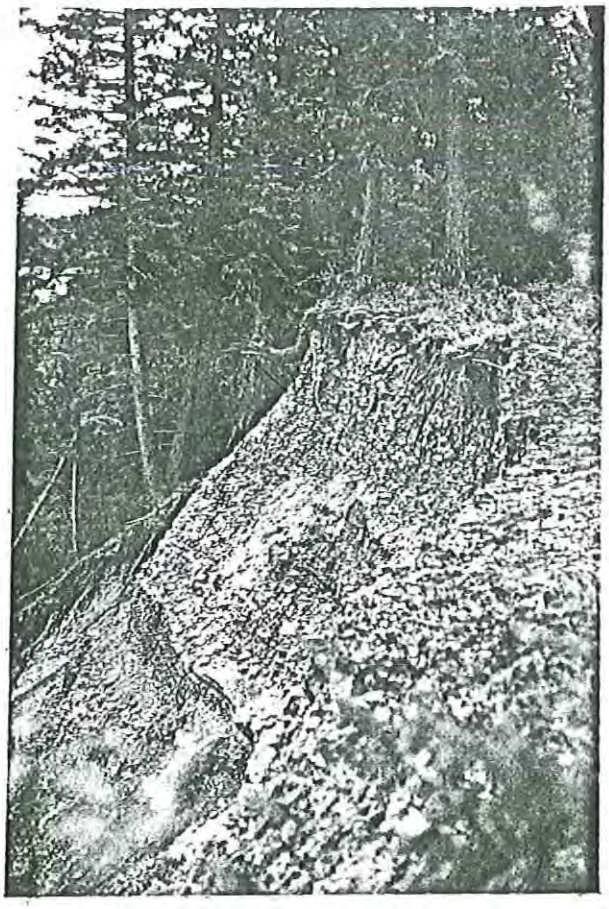


Plate B9 - Middle series gravels and silts in the West Bank Slide.

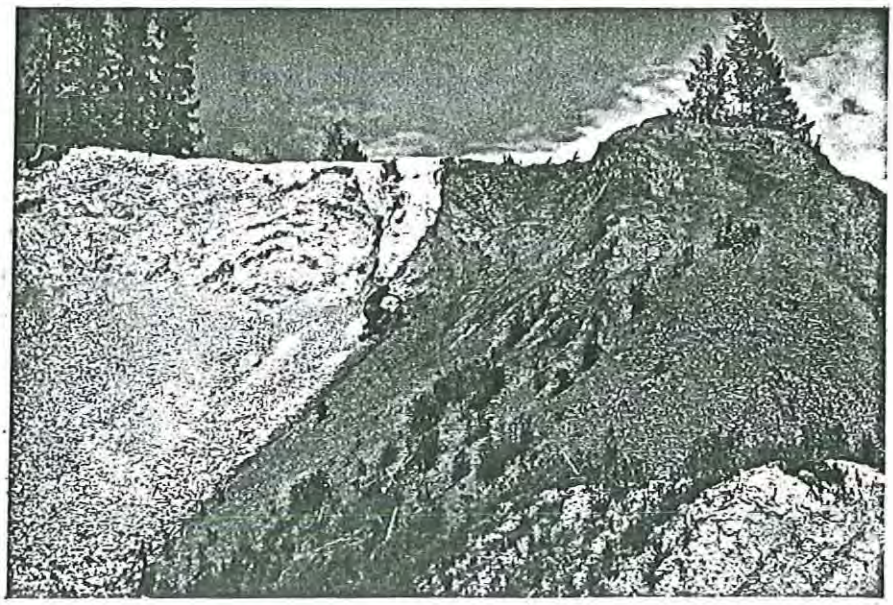


Plate B10 - Diatomite overlies rotted lava at very pronounced contact, near East Bank Slide.

Plate B11 - Hard, banded, fissured Tertiary silts at the Cariboo Pulp and Paper Pit.

Plate B12 - Cariboo Pulp and Paper Pit, showing till overlain by gravels and bedded sands.

Plate B13 - Crudely-stratified outwash sand and gravels at Baker Creek Pit.

Plate B14 - Heavily-preconsolidated banded silts on Red Bluff.

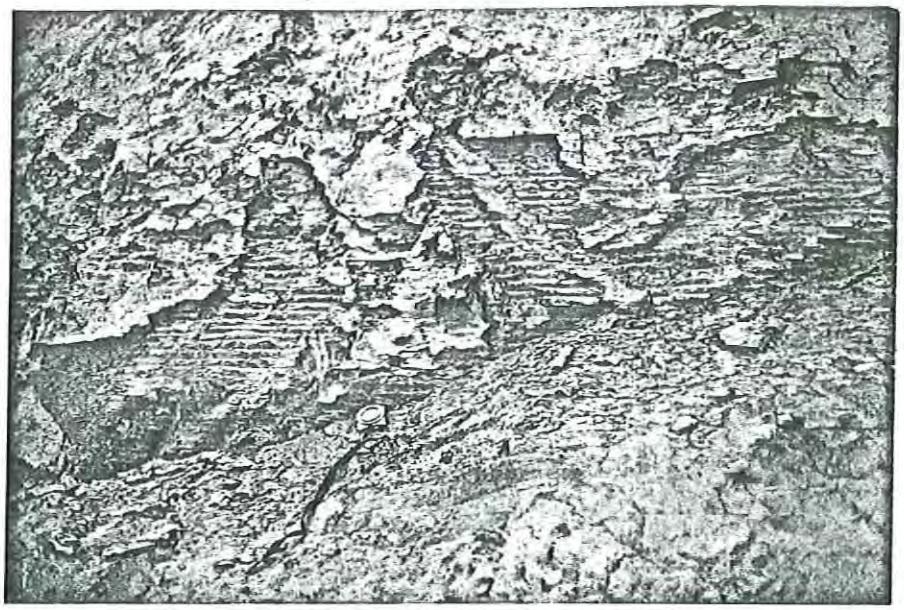


Plate B15 - Normally-consolidated varved silts along Paradise Road.

Plate B16 - Recent gravels overlain by structureless sands at the Plywood Pit.

Plate 317 - Recent soil sequence at Wier's Sawmill, Quesnel.

SECTION B1

Sequence of sediments intercalated with Lower Lavas soils, strike north 52 degrees west, dip 15 to 20 degrees northeast.

Location -- Baker Creek, west slope, 2½ miles upstream from mouth (see Figure B1)

Origin -- exposure indicates lava - damming of a northerly-flowing ancestor of Baker Creek.

Age -- Middle Eocene

Source -- Lay, 1941, page 42

Materials	Depth (Feet)
Surface soil	2
Lava flow, red, kaolinized	3-4
Tuffaceous grit bed (with small seams of lignite and veinlet of fibrous barite, 3/4 inch thick	0.5-0.75
Gravel, containing pebbles 2 inches in diameter composed mainly of schistose, quartzite, and argillite with some quartz	1.25-4.0
Tuffaceous grit bed	0.75
Bluish-coloured clay with seams of lignite	4
Decomposed and kaolinized rock, apparently mainly quartzite but some decomposed lava may also be present.	40
Quartzite	40
Baker Creek Level (ca. 1600 feet) TOTAL	91.5-95.5

SECTION B2

Sequence of sediments of the Lower series of the Fraser River formation, dip 22 degrees N.

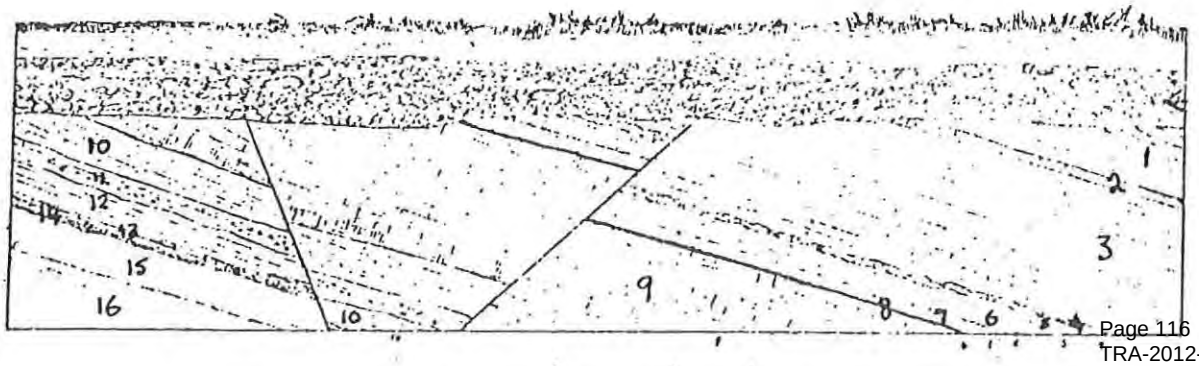
Location -- left (east) bank of Fraser River immediately to the south of the Quesnel River confluence (along the Plywood - P.G.E. cut), see Figure B1.

Origin -- lake deposits in basin dammed by lower lavas

Age -- middle-late Eocene

Source -- Dawson, 1875-1876, pages 258 and 259.

Materials	Depth (Feet)
1. Sands and arenaceous clays, light coloured and whitish, regularly bedded	20.0
2. Grey sand	1.0
3. Grey arenaceous clay, thin-bedded	11.75
4. Ferruginous sandstone, nodular and irregular	1.0
5. Fine grey clay, distinctly bedded	2.0
6. Fine yellowish-grey clay	0.2
7. Very fine greyish and greenish-white fire-clay, in thin layers, with coniferous and angiospermous leaves, seeds and insect remains	0.66
8. Carbonaceous clay, or impure lignite, in many places seen to be composed of matted leaves, mingled with clay	0.16
9. Arenaceous clay, yellowish-grey, and much divided by rusty cracks, pretty distinctly bedded, but in thick layers	13.0
10. Coarse yellowish-grey arenaceous clay	4.0
11. Grey arenaceous clay with small siliceous pebbles, probably derived from rocks of the Lower Cache Creek group	1.5
12. Grey arenaceous clay	2.0
13. Coarse grey sand, with occasional flattened masses of lignite six inches to	1.0
14. Coarse sand and gravel. A rusty irregular layer, about	0.5
15. Yellowish clay	2.5
16. Greyish clay	4.0
Total	65.66



SECTION B3

Sequence of baked clays and lignites of the Lower series of the Fraser River formation.

Location -- left (east) bank of the Fraser River between Section B2 and the Plywood Hill Slide, beneath Red Bluff; now protected from erosion by P.G.E. (see Figure B1).

Origin -- lake deposits and basin dammed by Lower Lavas, subsequently indurated by spontaneous combustion of the lignite seams.

Age -- middle-late Eocene

Source -- Selwyn, 1871-1872, pages 58 and 59.

Materials	Depth (Feet)
Pale grey, yellow, red and black beds, some of a very light compact rock containing thin grass-like stems and in places pieces of coal, others hard	100
Grey mud	20
Grey sandstone with leaves and stems of plants	1
Sand with rounded pebbles	25
Mud with impure coal	26
Drab ferruginous sandstone with leaves and stems of plants from two inches to	2
Impure coal, mixed with earth, stems and leaves of plants. On the top a few trees remain with part of the stems and roots as they grew, both being partly mineralized . . .	10
Grey clay	6
Total	190

SECTION B4

Schematic approximation of materials of the Lower series of the Fraser River formation, dip 20 to 30 degrees SW, MioPliocene (?), Pleistocene (?) and Recent periods.

Location -- the Plywood Hill Slide; the sequence is incomplete, being considerably disturbed by sliding and flowage.

Origin -- the bulk of the section consists of lacustrine deposits; the Pleistocene (?) materials are lacustrine also; the Recent gravels are alluvial.

Age -- middle-late Eocene, MioPliocene (?), Pleistocene (?), Recent

Source -- Crook and Evans, May-June 1973.

Materials	THICKNESS Depth (Feet)
9. Gravels, ill-sorted (probably Recent)	20
8. Clay, olive brown-grey, plastic and fissured, preconsolidated	5
7. Sandy silts	3
6. Sands with very thin diatomite lenses (<1")	1
Obscured	20
5. Silts, banded and fissured, heavily preconsolidated, containing seams of lignite (sometimes exceeding 2 feet) which are dark brown or black, fissile, heavily preconsolidated organic shales	80
4. Green clay	5
3. Gravel, lensed out laterally	0 - 5
2. Lignite, black, fissile, obvious SW dip, forms base of slide zone	5 - 10
1. Clay, blue-grey, very plastic	5 - 10
P.G.E. Railway Level (ca 1550 feet)	
	ca.170

* All depths estimated.

Two materials which were found in the slumped material were not seen in place and are not shown above.

(A) Seams of diatomite (1 foot), possibly MioPliocene
(B) Varved, unfissured silts, possibly Pleistocene lake silts

SECTION B5

Approximate sequence of materials of Middle series of the Fraser River formation, possibly Pleistocene lake silts, and Recent gravels; horizontal or slight dip to north.

Location -- the Plywood - P.G.E. cut immediately south of the Plywood Hill Slide (See Figure B1)

Origin -- off-channel facies of a river flood-plain below the buff silts; silts are lacustrine and are overlain by alluvial gravels.

Age -- Miocene flood-plain soils, late-Pleistocene lake soils and Recent alluvial soils.

Source -- Crook and Evans, June 1973.

Materials	Depth (Feet)*
10. Gravels, very thin layer, Recent	1
9. Silts, buff, layered and fissured, Pleistocene (?)	20
8. Stiff clay bands intercalated with silty sands which contain lignite inclusions (as sequence below 1-7)	130
7. Sand, unlayered	1
6. Lignite, rolled pieces rather than layers	1½ inches
5. Sands	3 inches
4. Lignite	1½ inches
3. Sands	4 inches
2. Clay, moist, brown, plastic	7 inches
1. Sands	4
P.G.E. Railway Level (ca. 1550 feet)	
	ca. 156

* All depths estimated.

SECTION B6

Sequence of soils of the Lower or Middle series of the Fraser River formation.

Location -- along the left (east) bank of the Fraser River, 1000 feet south of the Westply Slide.

Origin -- probably lacustrine soils of the Lower series.

Age -- probably middle-late Eocene.

Source -- Reinecke, 1920, page 16.

Materials	Depth (Feet)
Top of bluff.	
River silt - Recent	6
River gravel - Recent	15
Grey clay with lignitic partings	10
Gravel cemented with clay	3
Grey and reddish clay	17
Gravel	30
Carbonaceous clay	15
Cemented gravel	10
Grey clay with a gravelly bed	25
Cemented sand and gravel	4
Grey clay	7
Sandy clay	3
Grey clay	12
Green clay	6
Green clay with lignitic partings	17
Sandy, green clay	3
Coarse gravel	12
Concealed	10
Fraser River level (1520 feet) Total	205

SECTION B7

Sequence of soils from the Middle series of the Fraser River formation, gradually dipping northwards.

Location -- the southern end of the Paradise Road Slide - see Figure B1.

Origin -- off-channel flood-plain deposits.

Age -- Miocene; the basalt is MioPliocene, the boulder clay, Pleistocene.

Materials	Depth (Feet)
Boulder clay - Pleistocene	48
Basalt - MioPliocene	30
Concealed	91
Alternating thin beds of clay and gravel	4-3/4
Red clay	3
Cemented gravel	12
Yellowish red clay	5
Firmly cemented gravel	11
Mottled clay	5
Cemented gravel	8
Reddish yellow clay with, in middle, a bed of fine-grained, cemented gravel	7
Concealed	36
Alternating bands of clay and gravel	8
Red, consolidated clay	14
Gravel with clay	3
Grey sandy clay	5
Alternating bands of chocolate and grey clay	4-1/3
Well cemented, grey, sandy clay	3-1/3
Fine-grained gravel	2
Grey, yellow brown clay with lignite band	4-1/2
Fine-grained gravel	6
Sand and gravel in irregular beds	128
Sandy clay, red at top	2-2/3
Gravel, reddish and cemented at top with iron oxide	15
Sandy, yellow clay	10
Grey, sandy clay, with a 1-foot band of fine-grained, well cemented gravel	20
Gravel	16
Grey Clay	22
Sandy, lignitic clay	4-1/2
Gravel with one foot at top well cemented	28
Sand	2
Character not recorded	25
Sand, streaks of iron oxide	2
Gravel	27
Fraser River Level (1570 feet) Total	613-1/6

SECTION B8

Sequence of soils from the Middle series of the Fraser River formation.

Location -- the East Bank Slide area - see Figure B1.

Origin -- off-channel flood-plain deposits.

Age -- Miocene; materials above the 150-foot concealed zone are Pleistocene.

Source-Reinecke, 1920, page 15.

Materials	Depth (Feet)
Grey boulder clay: pebbles of dense metamorphic rocks, of granodiorites, and a few of amygdaloidal basalt, in clay matrix	65
Sand and gravel	9
Boulder clay with, amongst many other kinds, a few basalt pebbles	6
Sand and gravel	4
Boulder clay - Pleistocene	20
Concealed by a slide of boulders in large sections up to 100 feet by 30 feet by 20 feet and sliding today	150
Blue grey clay, floor of slide, water running over it	4
Gravel	11
Blue and grey silty clay in thin beds	9
Gravel and sand	10
Grey lignitic clay, fossil leaves, well bedded	6
Sand and gravel with a 2-inch bed of clay	50
Grey clay	2
Gravel and silt	5
Brown silty clay	3
Sand	5
Gravel. The base of the bed dips downstream, south 16 degrees east, with an inclination of about 40 feet in 1000 feet; thickness at north end is 10 feet, at south end, 15 feet	15
Concealed	5
Silt, brown, thin-bedded, carbonaceous	4
Fine sand	5
Coarse gravel	10
Grey clay, weathering cream, lignite at base	5-1/2
Green clay	4
Concealed	5
Buff clay, lignite seam at base	3

Materials	Depth (Feet)
Buff clay	10
Green clay	8
Silt	6
Coarse gravel	35
Silt with 2-inch gravel layer	4
Coarse gravel with 3-inch layer of ironstone containing remains of leaves	12
Buff and grey clay	12
Cream clay with infusorial earth - diatomite	3
Buff clay	3
Dark grey clay	6
Sand and gravel	12
Fraser River Level (1570 feet) Total	527-1/2

SECTION B9

Sequence of soils from the Middle series of the Fraser River formation, horizontal.

Location -- the southern end of the base of Big Slide, just west of Lot 4382; a cliff section below the base of a slide zone.

Origin -- off-channel flood-plain deposits overly channel gravels.

Age -- Miocene

Source -- Lay, 1940, page 21.

Materials	Depth (Feet)
Clay and surface soil	4
Lignite seam	2
White clay	2
Lignite seam	2-1/4
White clay	2
Lignite seam	1/2
White clay	5
Lignite seam	1/2
White clay	3
Green clay	10
Silt, compacted	10
Gravel, well-sorted, well-lithified	20
Fraser River Level (1575 feet) Total	61-1/4

SECTION B10

Sequence of soils from the Middle series of the Fraser River formation.

Location -- the Big Slide

Origin -- off-channel flood-plain deposits overly channel gravels.

Age -- Miocene

Source -- P.G.E. Study, 1929, page 709

Materials	Depth (Feet)
Top of bank	
Boulder clay - Pleistocene	40
Clay	6
Silt	8
Clay	1
Silt	6
Clay	5
Fine sand	4
Clay	3
Sand and silt	14
Sand	12
Clays and silt	25
Sand	35
Clay	10
Sand	8
Sands and silt	75
Clay	5
Silt	15
Clay	8
Silt	4
Clay	12
Sand	20
Clays and sand (interbedded)	90
Gravel	8
Clays and silt	8
Gravel	100
Fraser River — Total	428

SECTION B11

Sequence of soils from the Middle series of the Fraser River formation.

Location -- in the vicinity of Big Bend - cannot be more precise.

Origin -- off-channel floodplain deposits overly channel gravels.

Age -- Moicene; Pleistocene till at top.

Source -- P.G.E. Study, 1929, pages 684 and 685.

Materials	Depth (Feet)
Boulder clay (Pleistocene)	40
Bedded clays	6
Silt	8
Clay	1
Silt	6
Bedded clay	5
Fine sand	4
Clay	3
Sand and silt	14
Sand	12
Clays and silt	25
Sand	35
Clays	10
Sand	8
Clay	6
Sands and silt	75
Clay	5
Silts	15
Clay	8
Silt	4
Clay grading into silt below	12
Silt	20
Clays and silts thinly interbedded	90
Gravel	8
Clays and silts	8
Gravel	100

Fraser River TOTAL 528 Feet

SECTION B12

Sequence of soils from the Middle series of the Fraser River formation.

Location -- Baker Creek Canyon, not more specifically located.

Origin -- channel and flood-plain deposits.

Age -- Miocene.

Source -- P.G.E. Study, 1929, pages 685 and 686.

Materials	Depth (Feet)
Alternating sands, gravels and silts	60
Coarse gravel	7
Silt	1.5
Gravel	3
Silt	1
Fine gravel	2
Silt	3
Angular gravel	15
Silt	2
Fine gravel	3
Silt	1
Gravel	4
Sandy clay	2
Gravel and clay	4
Gravel	6
Clay	8
Black strata of fine mudstone with two veins of satin spar	6
Fine gravel	3
Silt	1
Gravel	1
Clay	0.5
Coarse Cache Creek gravels	5
Clay	1.5
Gravel	1
Clay	1
Sand	0.25
Lignitiferous clay	3
Coarse sand	0.5
Clay	1.5
Conglomerate	2
Clay	1
Conglomerate of angular Cache Creek gravels	5
Cache Creek rocks much weathered	3-12
Baker Creek	
Total	160

SECTION B13

A sequence of sediments and lavas of the Upper Lavas series, strike due north, dip 7 degrees west.

Location -- the left bank of Baker Creek on Lot 8651 near the point of emergence into the Fraser Valley; elevation of creek 922 feet above that of Fraser River.

Origin -- the sediments were deposited in a lake caused by lava-damming of a stream.

Age -- MioPliocene

Source -- Lay, 1940, pages 21 and 22.

Materials	Depth (Feet)
Glacial drift, Pleistocene	15-20
Basalt, the basal 10 feet is pillow lava i.e. deposited under water	40-45
Sands, silts and gravels, sorted	8
Baker Creek	63-73

SECTION B14

Sequence of soils of Pleistocene and Recent age. The sequence is composite and is based on observations along the wall of a gravel pit (see over for sketch).

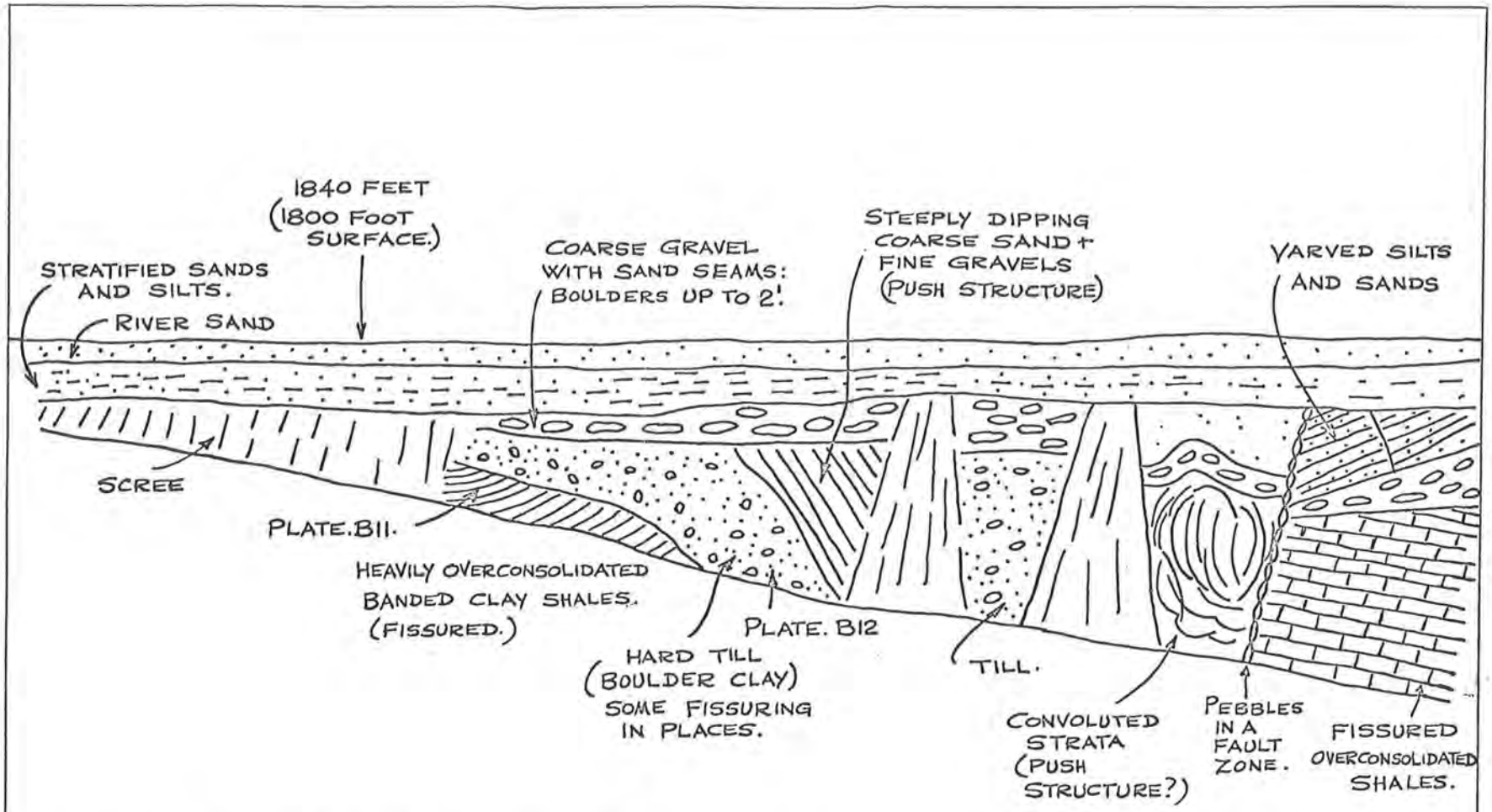
Location -- south wall of Cariboo Pulp and Paper Pit (see Figure B1), cut into 1800-foot surface.

Origin -- a complex drift sequence - see text.

Age -- basal clay is Tertiary, other soils Pleistocene and Recent.

Source -- Crook and Evans, June, 1973.

Materials	Depth (Feet)*
River sands, horizontal, Recent	2
Stratified sandy silts, horizontal, Recent	3-4
Silty sands, varved, tilted, Late Pleistocene	4
Gravels, coarse, poorly sorted, some sand seams included, horizontal or tilted	2
Till, very tightly packed, hardened, mostly silt and clay flour small stones scattered throughout, Pleistocene	4-8
Clay-shales and silty shales, banded, highly fissured, very heavily over-consolidated	4
* Estimated as averages for section	ca. 21



GEOLOGICAL FIELD SKETCH OF THE SOUTH WALL, CARIBOO PULP & PAPER PIT, TO ACCOMPANY SECTION. B14.

10' 25' SCALE VERY APPROXIMATE.

NEG. # 90068 1 of 15

BRITISH COLUMBIA DEPARTMENT OF HIGHWAYS
GEOTECHNICAL AND MATERIALS BRANCH

TO ACCOMPANY SECTION · B14.

D		DRAWN	SCALE AS SHOWN DATE SEPT 14/73.
C		TRACED	PROJ. NO. REG. NO.
B		CHECKED RC	FILE NO. 1-41-02
A		APPROVED	APPROVED
	REVISIONS	REGIONAL ENGINEER	CHIEF GEOTECHNICAL AND MATERIALS ENGINEER

FILE SKETCH.

SECTION B15

Sequence of soils of the Lower series of the Fraser River formation, plus late-Pleistocene and Recent.

Location -- a section along the east bank of the Fraser River in the vicinity of the Plywood-P.G.E. cut.

Origin -- complex, see text.

Age -- 1 to 4 - middle Eocene; 5 - late Pleistocene; 6 to 8 - Recent.

Source -- Reinecke, 1920, page 19.

Materials	Depth (Feet)
8. Soil	1
7. Gravelly sand, rusty at top	9
6. Coarse-grained, unconsolidated gravel, with boulders up to 1 foot in diameter, mostly of dense, metamorphosed rocks, a few of granite	15
5. Grey silt in well-defined beds	135
4. Coarse gravel, partly concealed	15
3. Sand with seams of lignite	7
2. Sand with a 1-foot bed of gravel at the base	13
1. Concealed down to level of Fraser River (1530 feet)	20
	215

SECTION B16

Sequence of soils of either Pleistocene or Recentage.

Location -- cliff along access road into Wier's Sawmill in the northern area of Quesnel.

Origin -- either outwash or alluvial

Age -- Pleistocene or Recent

Source -- Crook and Evans, June, 1973.

Materials	Depth (Feet)
Surface soil	1
Silts and sands, interbedded	2
Gravel, fine and crudely bedded	3
Gravel, coarse and crudely bedded	3
Sand, unstructured	1
Sands, cross-bedded (false-bedded)	2
Sands, brown, unstructured	1
Sands, cross-bedded and/or ripple marked	2
Scree to road level	3
Total	18

FIG. B1 - SITE LOCATION MAP

The Quesnel area is depicted on seven large-scale contour maps. The locations of plates, geological sections, place-names, etc., are indicated. Maps reduced to a scale of 1"=1,000' (1:12,000).

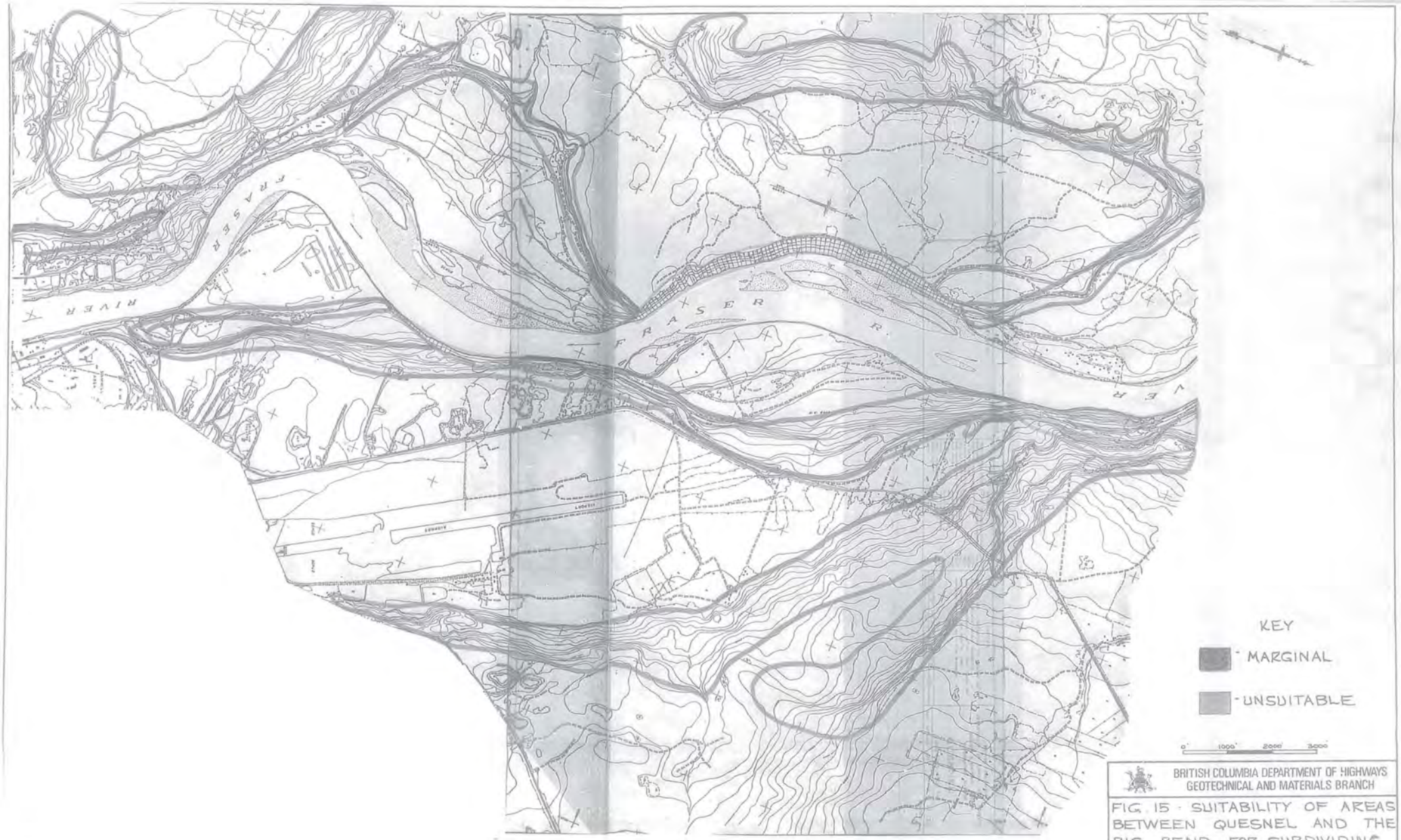


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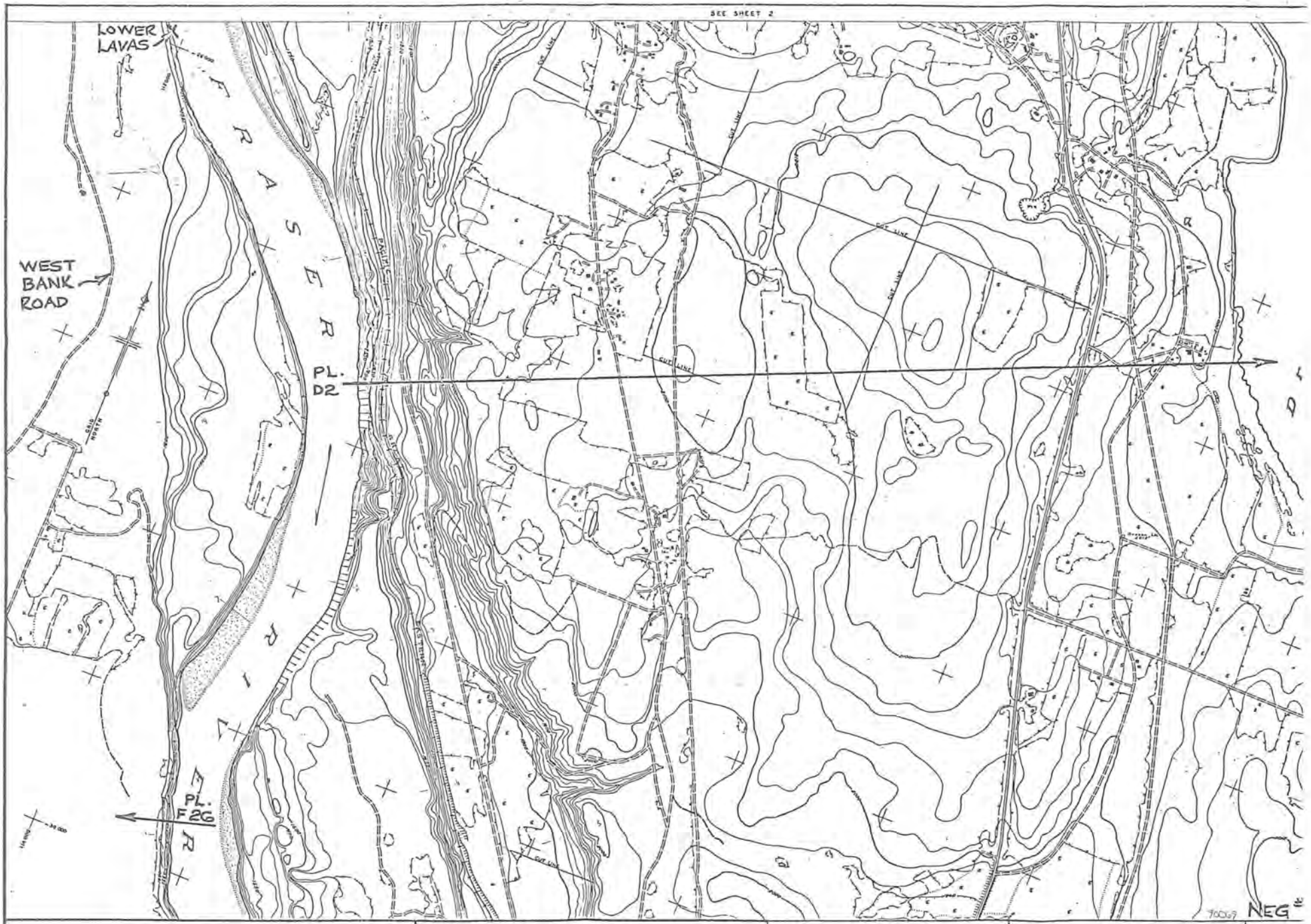
FIG. 15 - SUITABILITY OF AREAS BETWEEN QUESNEL AND THE BIG BEND FOR SUBDIVIDING.

D	DRAWN KFR.	SCALE Hor. – Vert. –	DATE 24/9/1973.		
C	TRACED	PROJ. NO.	REG. NO. 14	DRAWING NO.	
B	CHECKED	FILE NO. 11-41-02		Reg. No.	Sheet No.
A				Q 90063	13 of 16



KEY PLAN

LEGEND

TRIANGULATION STATION △	CONTOURS & ELEVATIONS
BENCH MARK T	CONTOURS INDEFINITE
GROUND CONTROL POINT □	CLIFF
AIR PHOTO POINT ×	CUT
AIR PHOTO CENTRE & FL. NO. ○	FILL
ROAD MAIN – HARD TOP	FENCES
ROAD SECONDARY HARD TOP	GRAVEL PIT
ROAD OTHER	BUILDINGS
TRAIL	CULTIVATED
POWER LINE	ORCHARD
CREEK	WOODED AREA
CREEK INTERMITTENT	SCRUB
CREEK INDEFINITE	
SWAMP	

NOTES

GRID ORIGIN :- REFERRED TO 53°00' 123°00'
DATUM OF ELEVATIONS :- GEODETIC
CONTOUR INTERVAL 10' TO 1700' THEN 20'
AIR PHOTOS :- B.C. GOV'T 1981
GROUND CONTROL BY :- A.M. BARBER, B.C.L.S.

COMPILED BY: KELSH | CHECKED BY: JCC

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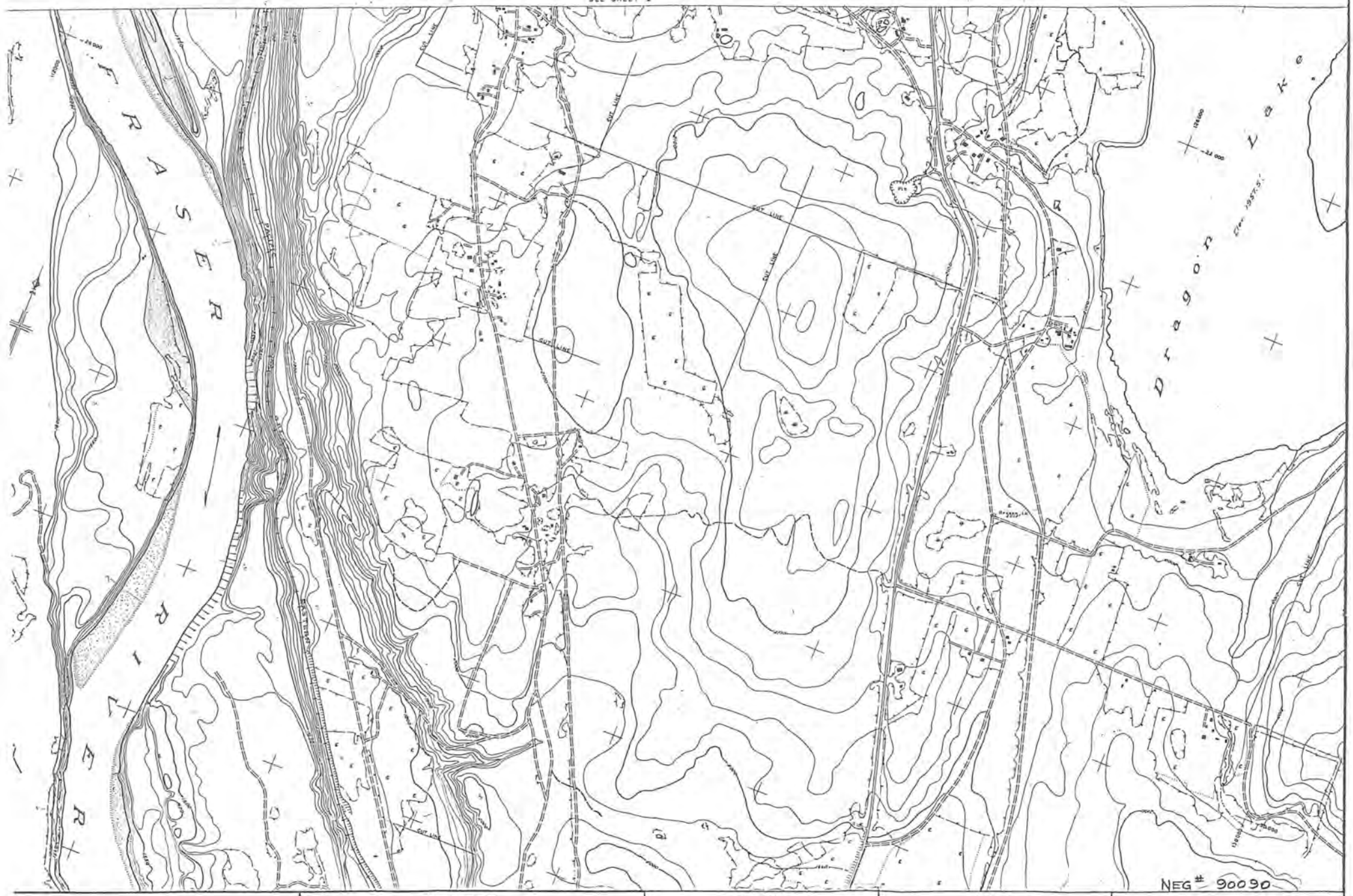
SU

SEE SHEET 2



KEY PLAN

LEGEND

TRIANGULATION STATION △	CONTOURS & ELEVATIONS
BENCH MARK T	CONTOURS INDEFINITE
GROUND CONTROL POINT ⊙	CLIFF
AIR PHOTO POINT •	CUT
AIR PHOTO CENTRE & FL. NO ○	FILL
ROAD MAIN – HARD TOP	FENCES
ROAD SECONDARY HARD TOP	GRAVEL PIT
ROAD OTHER	BUILDINGS
TRAIL	CULTIVATED
POWER LINE	ORCHARD
CREEK	WOODED AREA
CREEK INTERMITTENT	SCRUB
CREEK INDEFINITE	
SWAMP	

NOTES

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CONTOUR INTERVAL 10' TO 1700' THEN 20'
AIR PHOTOS :- B.C. GOV'T 1961
GROUND CONTROL BY :- A.M. BARBER, B.C.L.S.

COMPILED BY KELSH | CHECKED BY
TRACED BY D.C.O. | SPLICED

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SURVEYS & MAPPING BRANCH
TOPOGRAPHIC DIVISION

QUESNEL

Feet

DATE: AUGUST 1964 | DRAWING No. 135

KEY PLAN

LEGEND

TRIANGULATION STATION	△
BENCH MARK	T
GROUND CONTROL POINT	○
AIR PHOTO POINT	+
AIR PHOTO CENTRE & FL. NO	○
ROAD MAIN – HARD TOP	
ROAD SECONDARY HARD TOP	
ROAD OTHER	
TRAIL	
POWER LINE	
CREEK	
CREEK INTERMITTENT	
CREEK INDEFINITE	
SWAMP	
CONTOURS & ELEVATIONS	
CONTOURS INDEFINITE	
CLIFF	
CUT	
FILL	
FENCES	
GRAVEL PIT	
BUILDINGS	
CULTIVATED	
ORCHARD	
WOODED AREA	
SCRUB	

NOTES

GRID ORIGIN :- REFERRED TO 53°00' 123°00'
DATUM OF ELEVATIONS :- GEODETIC
CONTOUR INTERVAL 10' TO 1700' THEN 20'
AIR PHOTOS :- B.C. GOV'T. 1981
GROUND CONTROL BY :- A.M. BARBER, B.C.L.S.

COMPILED BY: R.E.S.M. | CHECKED BY: J.C.C.
TRACED BY: D.P.D. | REVISED:

DEPA.

DATE:

SEE SHEET 3

SEE SHEET 1

NEG. # 90091

KEY PLAN

LEGEND

TRIANGULATION STATION △	CONTOURS & ELEVATIONS
BENCH MARK T	CONTOURS INDEFINITE
GROUND CONTROL POINT □	CLIFF
AIR PHOTO POINT ×	CUT
AIR PHOTO CENTRE & FL. NO ○	FILL
ROAD MAIN – HARD TOP	FENCES
ROAD SECONDARY HARD TOP	GRAVEL PIT
ROAD OTHER	BUILDINGS
TRAIL	CULTIVATED
POWER LINE	ORCHARD
CREEK	WOODED AREA
CREEK INTERMITTENT	SCRUB
CREEK INDEFINITE	
SWAMP	

NOTES

GRID ORIGIN :- REFERRED TO 53°00' 123°00'
DATUM OF ELEVATIONS :- GEODETIC
CONTOUR INTERVAL 10' TO 1700' THEN 20'
AIR PHOTOS :- B.C. GOV'T. 1951
GROUND CONTROL BY :- A. M. BARBER, B.C.L.S.

COMPILED BY KELSH	CHECKED BY J.C.C.
TRACED BY R.S.D.	REVISED

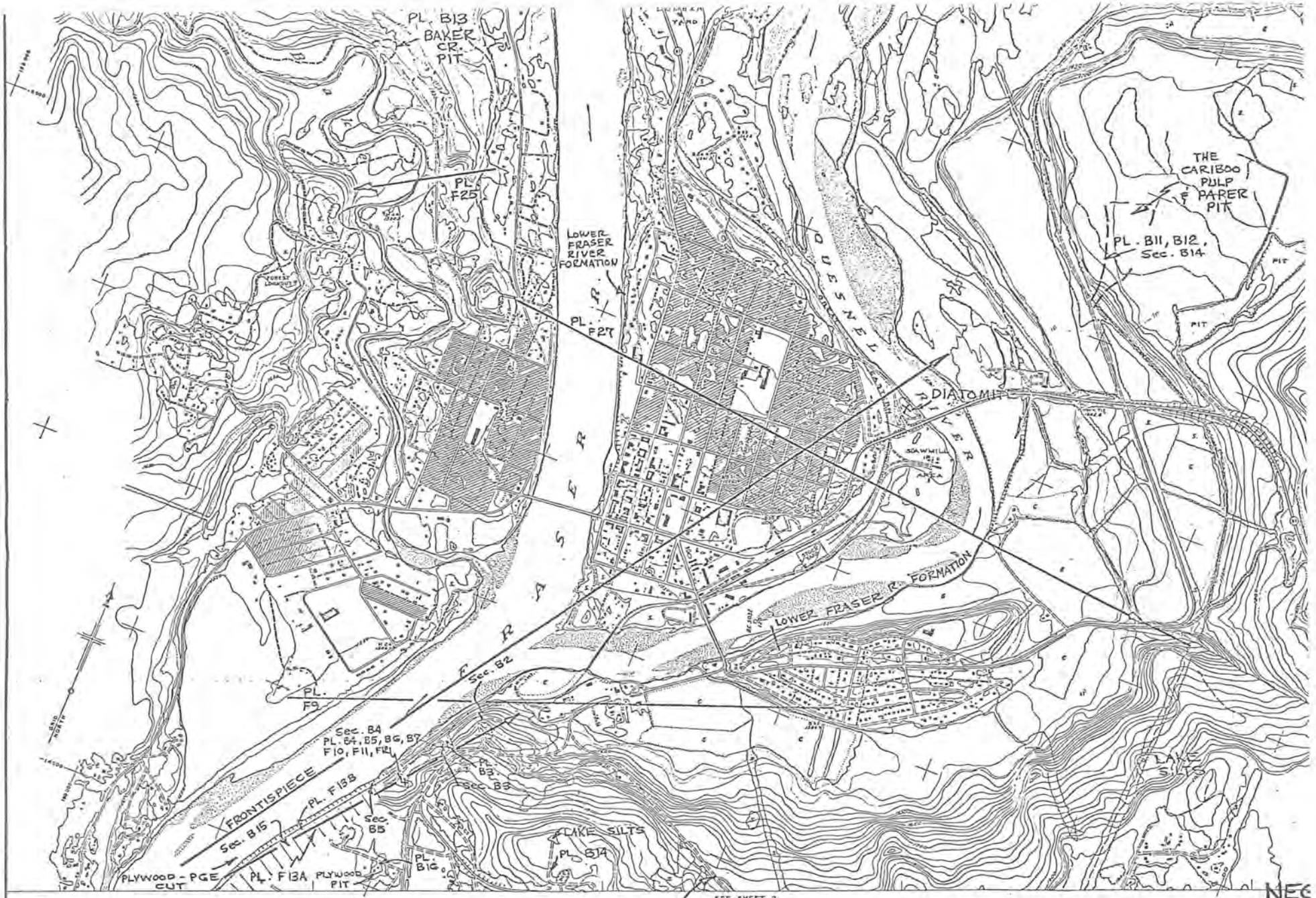
BRITISH COLUMBIA
DEPARTMENT OF LANDS AND FORESTS
SURVEYS & MAPPING BRANCH
TOPOGRAPHIC DIVISION

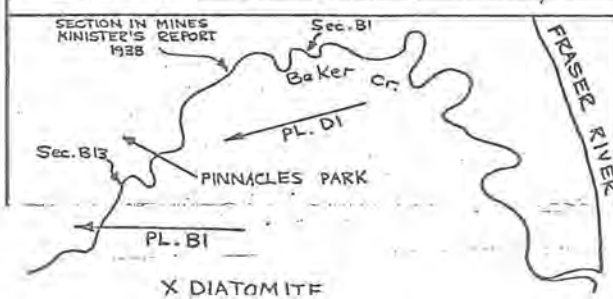
QUESNEL

Scale 1 Inch = 500 Feet

DATE JANUARY 1962 DRAWING NO M-135

SHEET 2





KEY PLAN

BURNT LIGNITE SEAMS, LOWER SERIES

LEGEND

TRIANGULATION STATION	CONTOURS & ELEVATIONS
BENCH MARK	CONTOURS INDEFINITE
GROUND CONTROL POINT	CLIFF
AIR PHOTO POINT	CUT
AIR PHOTO CENTRE & FL NO	FILL
ROAD MAIN - HARD TOP	FENCES
ROAD SECONDARY HARD TOP	GRAVEL PIT
ROAD OTHER	BUILDINGS
TRAIL	CULTIVATED
POWER LINE	ORCHARD
CREEK	WOODED AREA
CREEK INTERMITTENT	SCRUB
CREEK INDEFINITE	OIL STORAGE TANKS
SWAMP	SENSELY POPULATED AREAS

NOTES

GRID ORIGIN - REFERRED TO 53°00' 123°00'
DATUM OF ELEVATIONS - GEODETIC
CONTOUR INTERVAL 10' TO 1700', THEN 20'
AIR PHOTOS :- B.C. GOV'T. 1951.
GROUND CONTROL BY :- A.M. BARBER, B.C.L.S.

COMPILED BY MULTIPLEX	CHECKED BY J.J.C.
TRACED BY C.J.P.	REVISED

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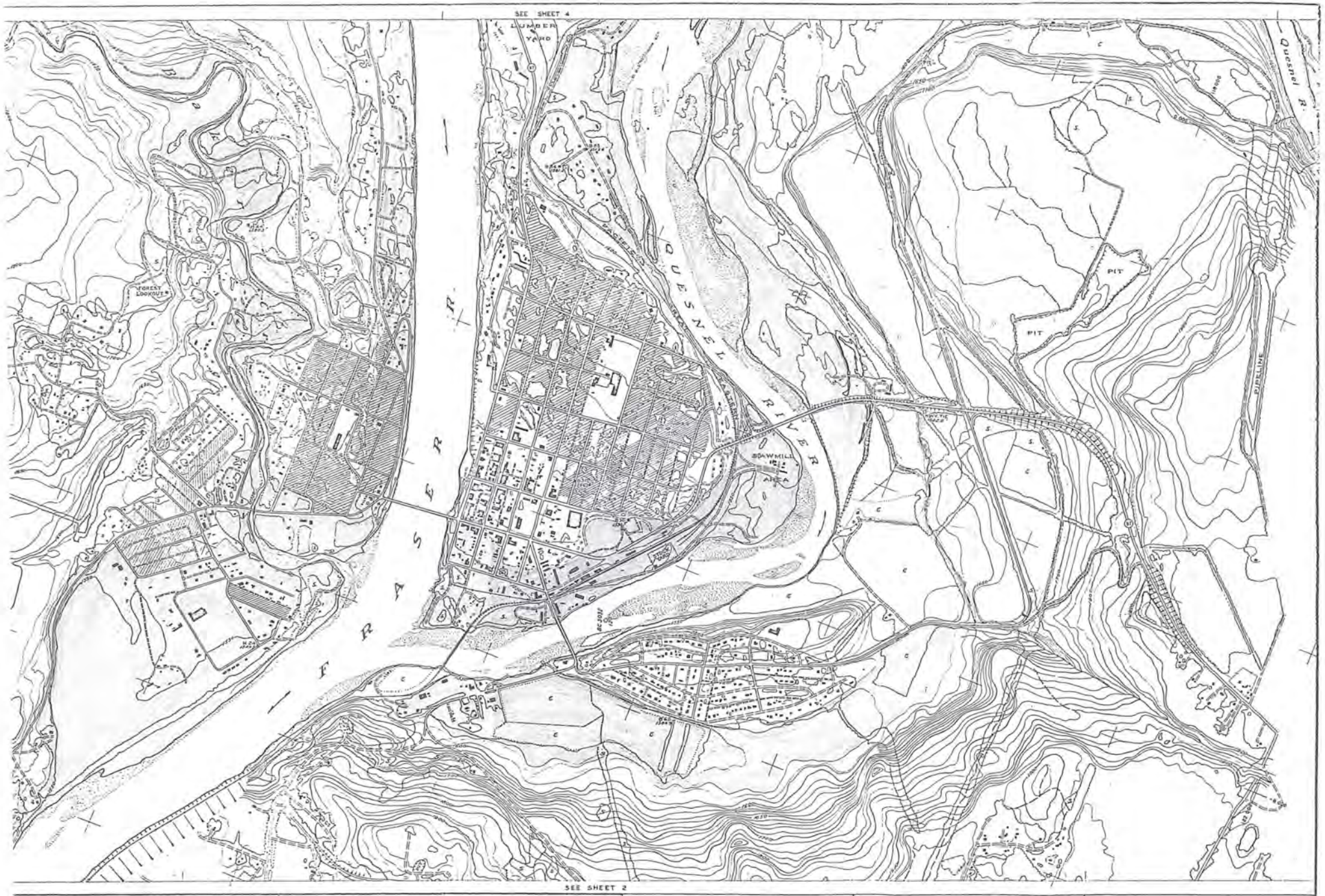
DATE: JANUA

SCALE OF INSET: 1" = ½ mile.



KEY PLAN

LEGEND

TRIANGULATION STATION	CONTOURS & ELEVATIONS
BENCH MARK	CONTOURS INDEFINITE
GROUND CONTROL POINT	CLIFF
AIR PHOTO POINT	CUT
AIR PHOTO CENTRE & FL. NO.	FILL
ROAD MAIN – HARD TOP	FENCES
ROAD SECONDARY HARD TOP	GRAVEL PIT
ROAD OTHER	BUILDINGS
TRAIL	CULTIVATED
POWER LINE	ORCHARD
CREEK	WOODED AREA
CREEK INTERMITTENT	SCRUB
CREEK INDEFINITE	OIL STORAGE TANKS
SWAMP	DENSELY POPULATED AREAS

NOTES

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DATUM OF ELEVATIONS – GEODETIC
CONTOUR INTERVAL 10' TO 1700', THEN 20'
AIR PHOTOS – B.C. GOV'T. 1961.
GROUND CONTROL BY – A.M. BARBER, B.C.L.S.

COMPILED BY MULTIPLEX	CHECKED BY
TRACED BY C.J.P.	REVISED

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SURVEYS & MAPPING BRANCH
TOPOGRAPHIC DIVISION

QUESNEL

Scale 1 inch = 500 Feet

DATE JANUARY 1963 | DRAWING NO M-135

s.22

KEY PLAN

LEGEND

TRIANGULATION STATION	CONTOURS & ELEVATIONS
BENCH MARK	CONTOURS INDEFINITE
GROUND CONTROL POINT	CLIFF
AIR PHOTO POINT	CUT
AIR PHOTO CENTRE & FL. NO	FILL
ROAD MAIN — HARD TOP	FENCES
ROAD SECONDARY HARD TOP	GRAVEL PIT
ROAD OTHER	BUILDINGS
TRAIL	CULTIVATED
POWER LINE	ORCHARD
CREEK	WOODED AREA
CREEK INTERMITTENT	
CREEK INDEFINITE	
SWAMP	

NOTES

GRID ORIGIN :- REFERRED TO 53° 123°
DATUM OF ELEVATIONS :- GEODETIC
CONTOUR INTERVAL 10' TO 1700' THEN 20'
AIR PHOTOS :- B.C. GOV'T. 1981
GROUND CONTROL BY :- A.H. BARBER, B.C.L.S.

COMPILED BY: MULTIPLEX	CHECKED BY: J.J.C
TRACED BY: J.D.H.	REVISED:

BRITISH COLUMBIA
DEPARTMENT OF LANDS AND FORESTS
SURVEYS & MAPPING BRANCH
TOPOGRAPHIC DIVISION

QUESNEL

Scale: 1 inch = 500 Feet

DATE: JANUARY 1983 | DRAWING NO. M 135

SHEET 4

KEY PLAN

LEGEND

TRIANGULATION STATION △	CONTOURS & ELEVATIONS
BENCH MARK T	CONTOURS INDEFINITE
GROUND CONTROL POINT □	CLIFF
AIR PHOTO POINT +	CUT
AIR PHOTO CENTRE & FL. NO. ○	FILL
ROAD MAIN – HARD TOP	FENCES
ROAD SECONDARY HARD TOP	GRAVEL PIT
ROAD OTHER	BUILDINGS
TRAIL	CULTIVATED
POWER LINE	ORCHARD
CREEK	WOODED AREA
CREEK INTERMITTENT	
CREEK INDEFINITE	
SWAMP	

NOTES

GRID ORIGIN – REFERRED TO 53° 123°
DATUM OF ELEVATIONS – GEODETIC
CONTOUR INTERVAL 10' TO 1700' THEN 20'
AIR PHOTOS – B. C. GOV'T. 1961
GROUND CONTROL BY – A.M. BARBER, B.C.L.S.

COMPILED BY: MULTIPLEX	CHECKED BY:
TRACED BY: J.D.H.	REVISED:

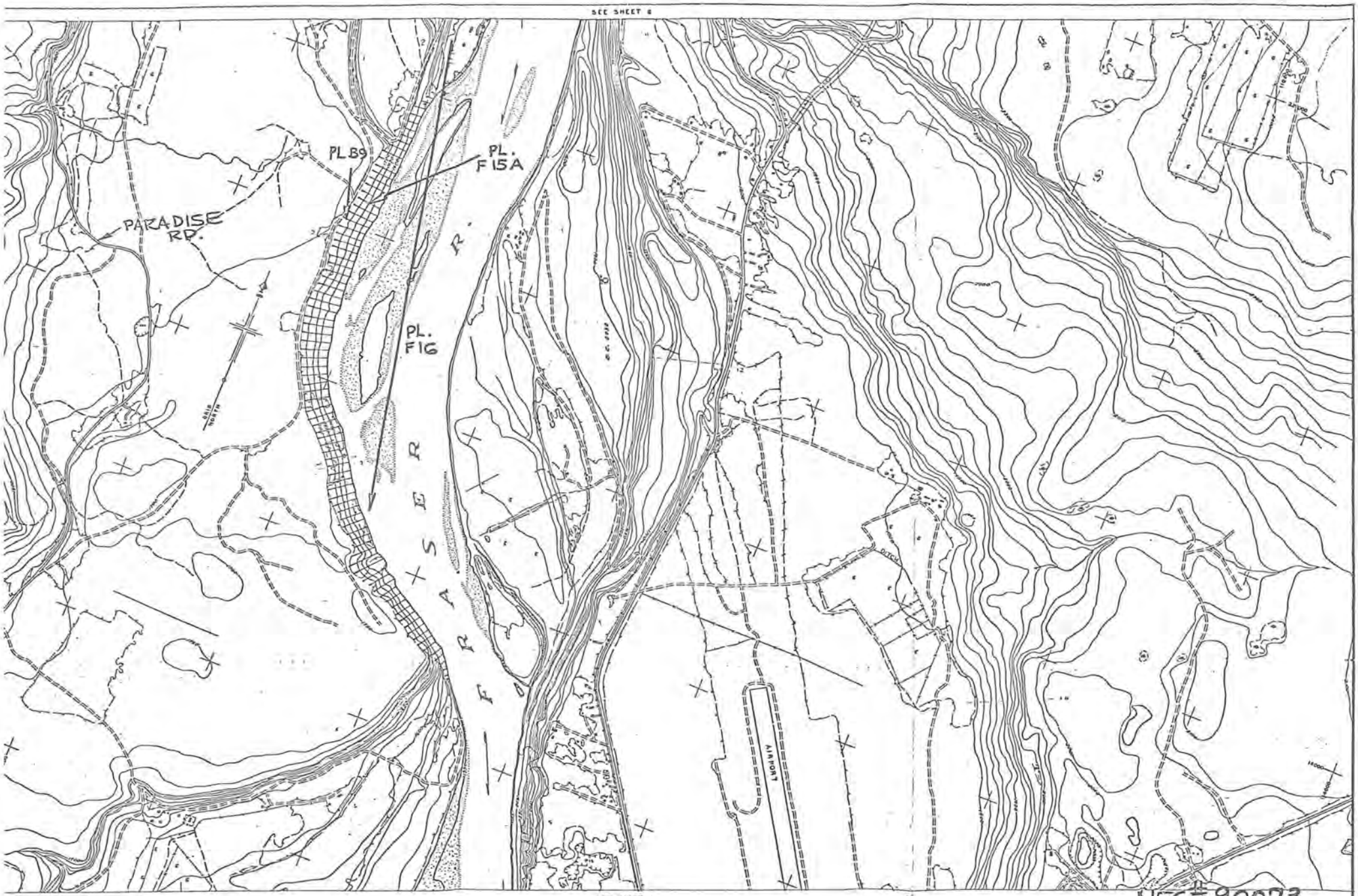
BRITISH COLUMBIA
DEPARTMENT OF LANDS AND FORESTS
SURVEYS & MAPPING BRANCH
TOPOGRAPHIC DIVISION

QUESNEL

Scale: 1 Inch = 500 Feet

DATE: JANUARY 1963 DRAWING NO. M 135

SHEET 4



NEG # 90073

KEY PLAN

LEGEND

TRIANGULATION STATION	CONTOURS & ELEVATIONS
BENCH MARK	CONTOURS INDEFINITE
GROUND CONTROL POINT	CLIFF
AIR PHOTO POINT	CUT
AIR PHOTO CENTRE & FL. NO.	FILL
ROAD MAIN — HARD TOP	FENCES
ROAD SECONDARY HARD TOP	GRAVEL PIT
ROAD OTHER	BUILDINGS
TRAIL	CULTIVATED
POWER LINE	ORCHARD
CREEK	WOODED AREA
CREEK INTERMITTENT	SCRUB
CREEK INDEFINITE	
SWAMP	

NOTES

GRID ORIGIN :- REFERRED TO 53°00' 123°00'
DATUM OF ELEVATIONS :- GEODETIC
CONTOUR INTERVAL 10' TO 1700' THEN 20'
AIR PHOTOS :- B.C. GOV'T 1981
GROUND CONTROL BY :- A.M. BARBER. B.C.L.S.

COMPILED BY: K.E.S.N. CHECKED BY: J.C.C.
TRACED BY: R.S.P. REVISED:

BRITISH COLUMBIA
DEPARTMENT OF LANDS AND FORESTS
SURVEYS & MAPPING BRANCH
TOPOGRAPHIC DIVISION

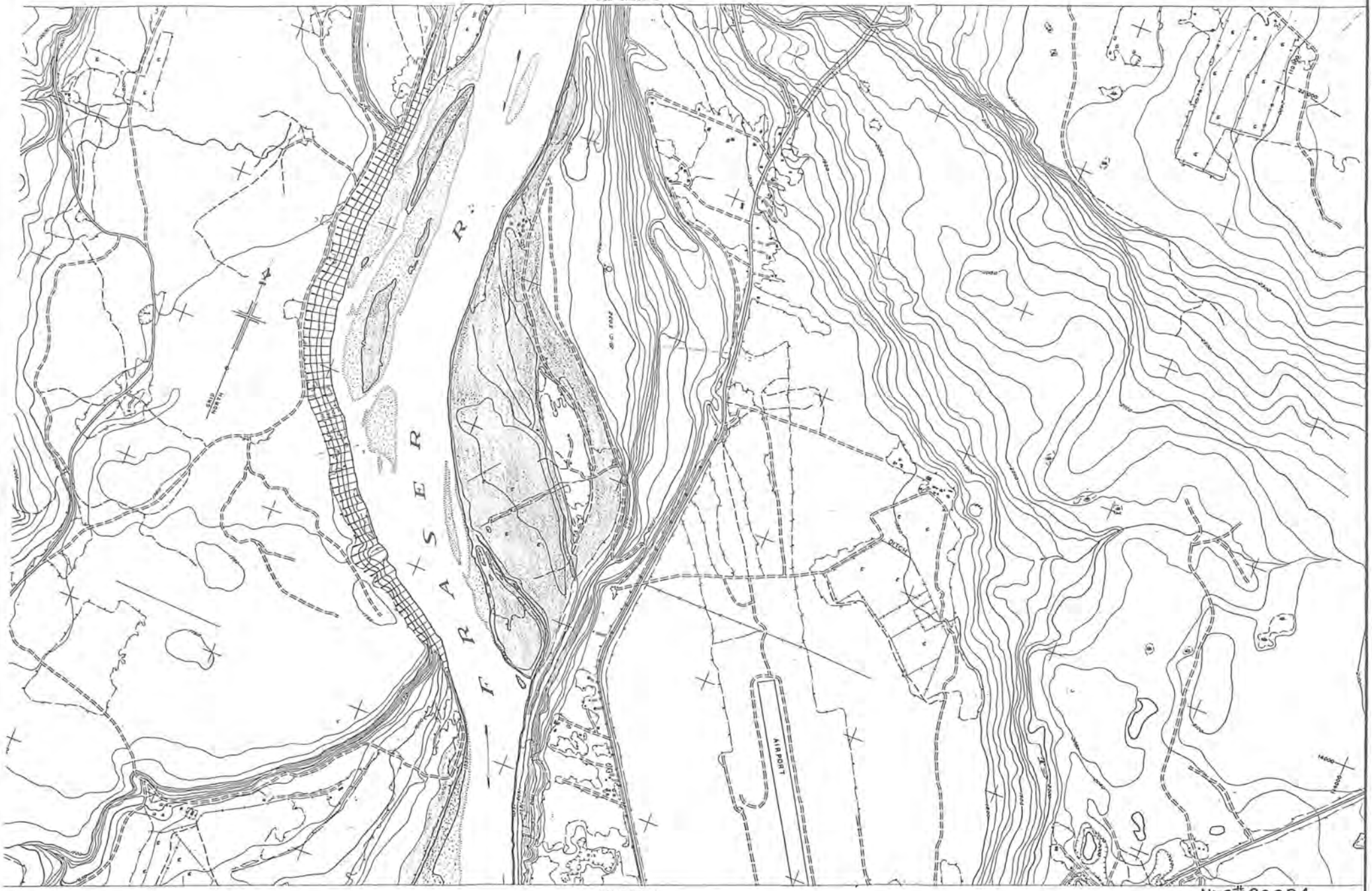
QUESNEL

1 Inch = 500 Feet

DATE [illegible] DRAWING NO. M 135

SHEET 8

SEE SHEET 6



SEE SHEET 4

NEG # 90094

KEY PLAN

LEGEND

TRIANGULATION STATION △	CONTOURS & ELEVATIONS
BENCH MARK T	CONTOURS INDEFINITE
GROUND CONTROL POINT O	CLIFF
AIR PHOTO POINT +	CUT
AIR PHOTO CENTRE & FL. NO.	FILL
ROAD MAIN – HARD TOP	FENCES
ROAD SECONDARY HARD TOP	GRAVEL PIT
ROAD OTHER	BUILDINGS
TRAIL	CULTIVATED
POWER LINE	ORCHARD
CREEK	WOODED AREA
CREEK INTERMITTENT	SCRUB
CREEK INDEFINITE	
SWAMP	

NOTES

GRID ORIGIN – REFERRED TO 53°00' 123°00'
DATUM OF ELEVATIONS – GEODETIC
CONTOUR INTERVAL 10' TO 1700' THEN 20'
AIR PHOTOS – B.C. GOV'T 1961
GROUND CONTROL BY – A.M. BARBER, B.C.L.S.

COMPILED BY: KELSH	CHECKED BY: J.E.C.
TRACED BY: R.S.P.	REVISED

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SURVEYS & MAPPING BRANCH
TOPOGRAPHIC DIVISION

QUESNEL

1 Inch = 200 Feet

DATE: OCTOBER 1965 | DRAWING NO. M 135

SHEET 5

KEY PLAN

LEGEND

TRIANGULATION STATION	CONTOURS & ELEVATIONS
BENCH MARK	CONTOURS INDEFINITE
GROUND CONTROL POINT	CLIFF
AIR PHOTO POINT	CUT
AIR PHOTO CENTRE & FL. NO.	FILL
ROAD MAIN — HARD TOP	FENCES
ROAD SECONDARY HARD TOP	GRAVEL PIT
ROAD OTHER	BUILDINGS
TRAIL	CULTIVATED
POWER LINE	ORCHARD
CREEK	WOODED AREA
CREEK INTERMITTENT	SCRUB
CREEK INDEFINITE	
SWAMP	

NOTES

GRID ORIGIN > REFERRED TO 33°00' 123°00'
DATUM OF ELEVATIONS > GEODETIC
CONTOUR INTERVAL 10' TO 1700' THEN 20'
AIR PHOTOS > BC GOV'T 1961
GROUND CONTROL BY > A.M. BARBER, B.C.L.S.

COMPILED BY: KELSH	CHECKED BY: JCC
TRACED BY: R.S.P.	REVISED

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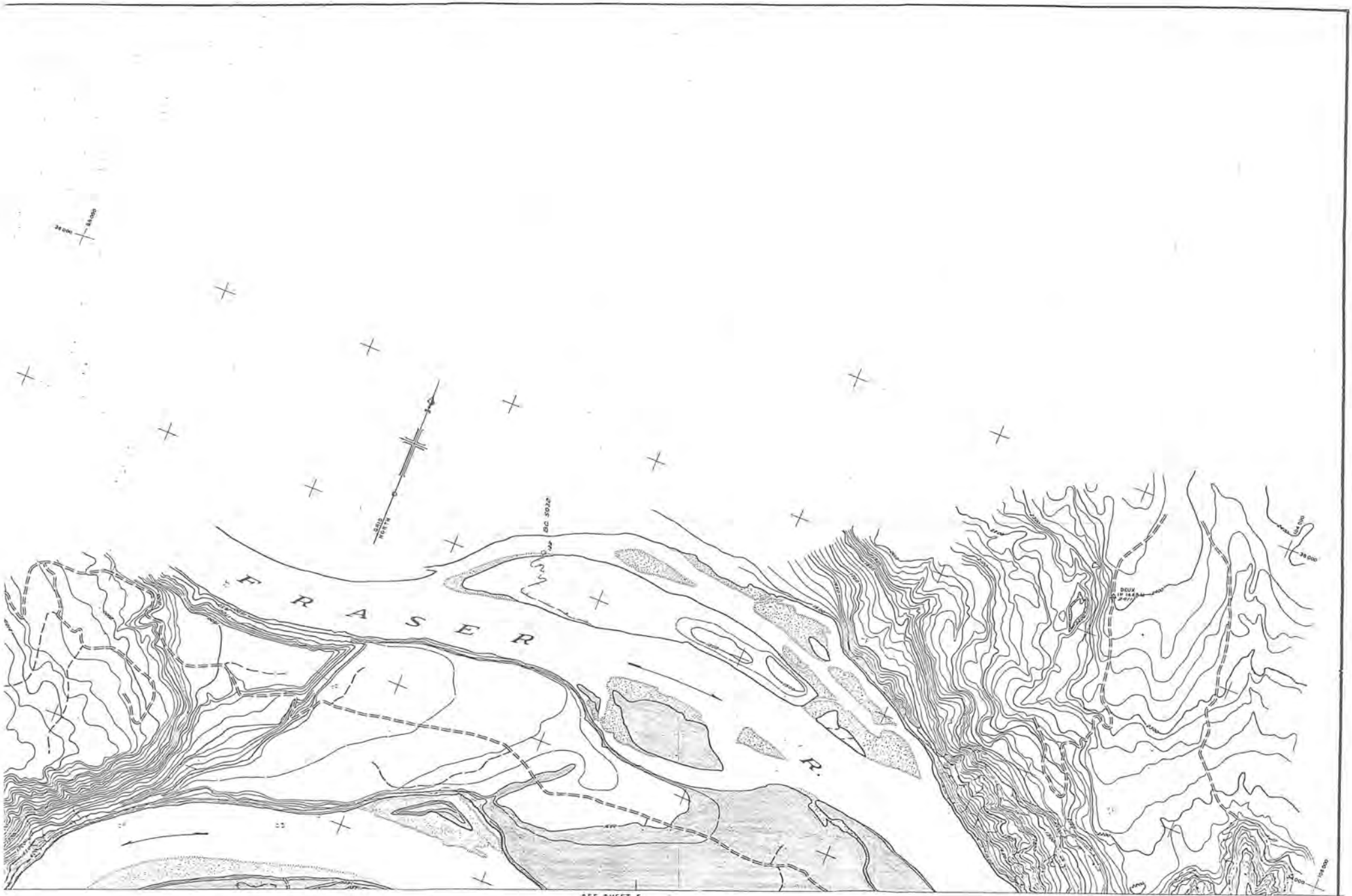
DATE: OCTOBER



SEE SHEET 6

NEG # 90096

KEY PLAN

LEGEND

TRIANGULATION STATION	CONTOURS & ELEVATIONS
BENCH MARK	CONTOURS INDEFINITE
GROUND CONTROL POINT	CLIFF
AIR PHOTO POINT	CUT
AIR PHOTO CENTRE & FL NO	FILL
ROAD MAIN – HARD TOP	FENCES
ROAD SECONDARY HARD TOP	GRAVEL PIT
ROAD OTHER	BUILDINGS
TRAIL	CULTIVATED
POWER LINE	ORCHARD
CREEK	WOODED AREA
CREEK INTERMITTENT	SCRUB
CREEK INDEFINITE	
SWAMP	

NOTES

GRID ORIGIN - REFERRED TO 53°00' 123°00'
DATUM OF ELEVATIONS - GEODETIC
CONTOUR INTERVAL 10' TO 1700' THEN 20'
AIR PHOTOS :- B.C. GOV'T. 1961
GROUND CONTROL BY :- A.M. BARBER, B.C.L.S.

COMPILED BY KELSH	CHECKED BY J.C.C.
TRACED BY R.S.P.	REVISED

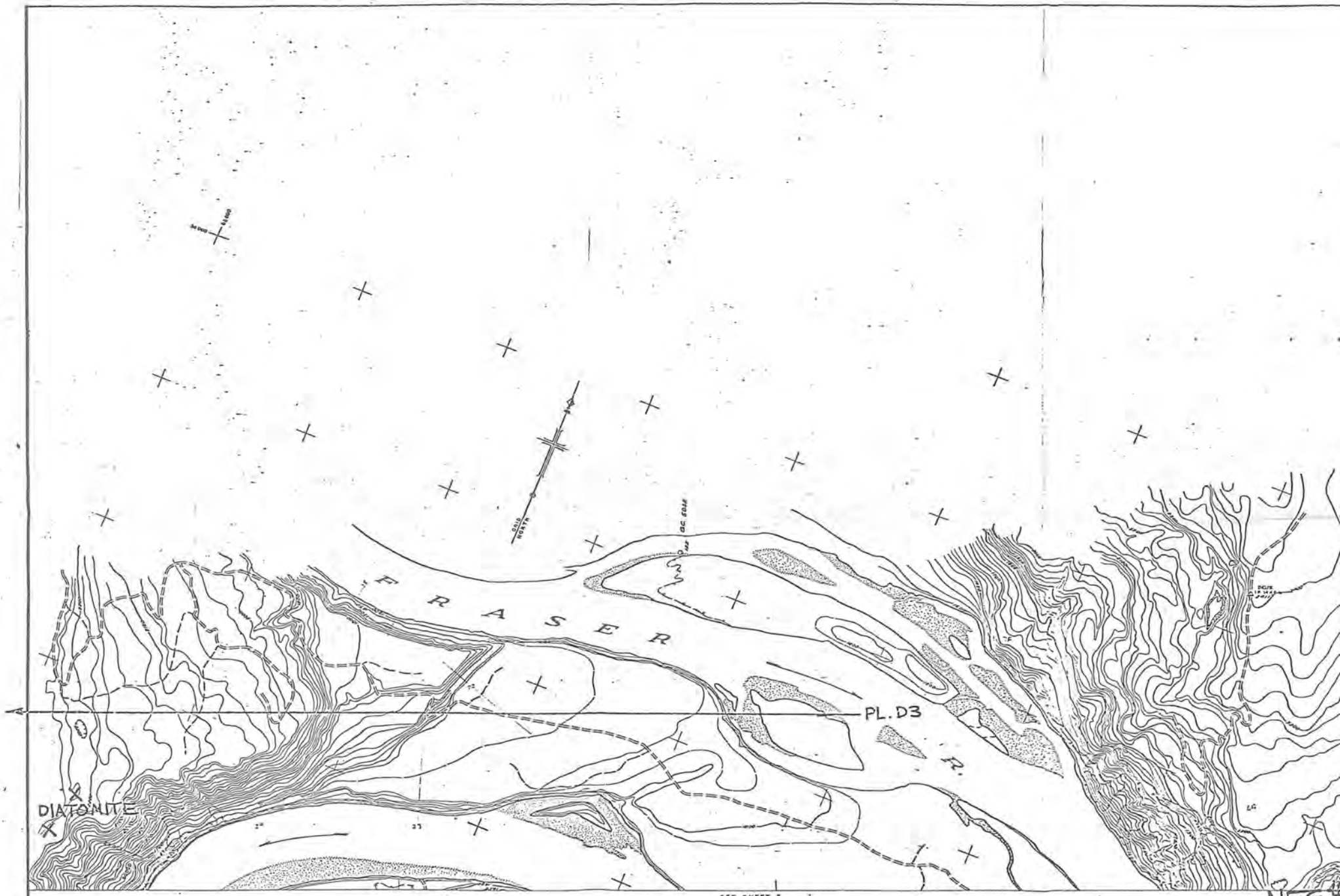
BRITISH COLUMBIA
DEPARTMENT OF LANDS AND FORESTS
SURVEYS & MAPPING BRANCH
TOPOGRAPHIC DIVISION

QUESNEL

Feet

DATE NOVEMBER 1963 | DRAWING NO. M 135

SHEET 7



KEY PLAN

LEGEND

TRIANGULATION STATION △	CONTOURS & ELEVATIONS
BENCH MARK T	CONTOURS INDEFINITE
GROUND CONTROL POINT □	CLIFF
AIR PHOTO POINT +	CUT
AIR PHOTO CENTRE & FL. NO ○	FILL
ROAD MAIN – HARD TOP	FENCES
ROAD SECONDARY HARD TOP	GRAVEL PIT
ROAD OTHER	BUILDINGS
TRAIL	CULTIVATED
POWER LINE	ORCHARD
CREEK	WOODED AREA
CREEK INTERMITTENT	SCRUB
CREEK INDEFINITE	
SWAMP	

NOTES

GRID ORIGIN – REFERRED TO 53°00′ 123°00′
DATUM OF ELEVATIONS :- GEODETIC
CONTOUR INTERVAL 10′ TO 1700′ THEN 20′
AIR PHOTOS :- B.C. GOV'T. 1961
GROUND CONTROL BY :- A.H. BARBER, B.C.L.S.

COMPILED BY: KELSH	CHECKED BY: A.C.C.
TRACED BY: P.S.P.	REVISED:

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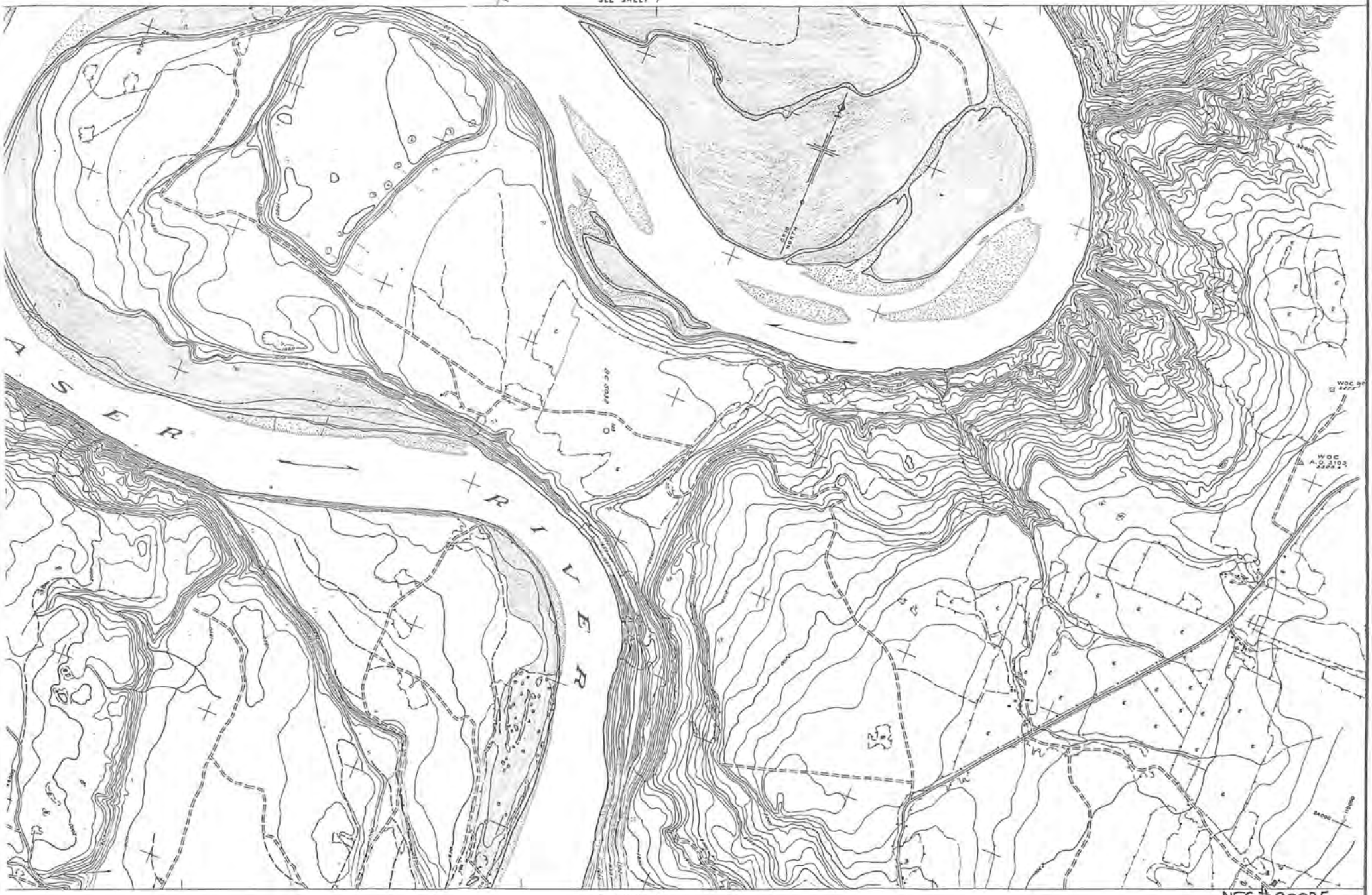
Scale: 1
DATE: NOVEMBER 1962

SEE SHEET 7



SEE SHEET 5

NEG # 90035

KEY PLAN

LEGEND

TRIANGULATION STATION	CONTOURS & ELEVATIONS
BENCH MARK	CONTOURS INDEFINITE
GROUND CONTROL POINT	CLIFF
AIR PHOTO POINT	CUT
AIR PHOTO CENTRE & FL. NO	FILL
ROAD MAIN – HARD TOP	FENCES
ROAD SECONDARY HARD TOP	GRAVEL PIT
ROAD OTHER	BUILDINGS
TRAIL	CULTIVATED
POWER LINE	ORCHARD
CREEK	WOODED AREA
CREEK INTERMITTENT	SCRUB
CREEK INDEFINITE	
SWAMP	

NOTES

GRID ORIGIN – REFERRED TO 53°00′ 123°00′
DATUM OF ELEVATIONS – GEODETIC
CONTOUR INTERVAL 10′ TO 1700′ THEN 20′
AIR PHOTOS – B.C. GOV'T 1981
GROUND CONTROL BY – A.M. BARBER, B.C.L.S.

COMPILED BY: KELSH	CHECKED BY: J.C.C.
TRACED BY: R.S.P.	REVISED:

BRITISH COLUMBIA
DEPARTMENT OF LANDS AND FORESTS
SURVEYS & MAPPING BRANCH
TOPOGRAPHIC DIVISION

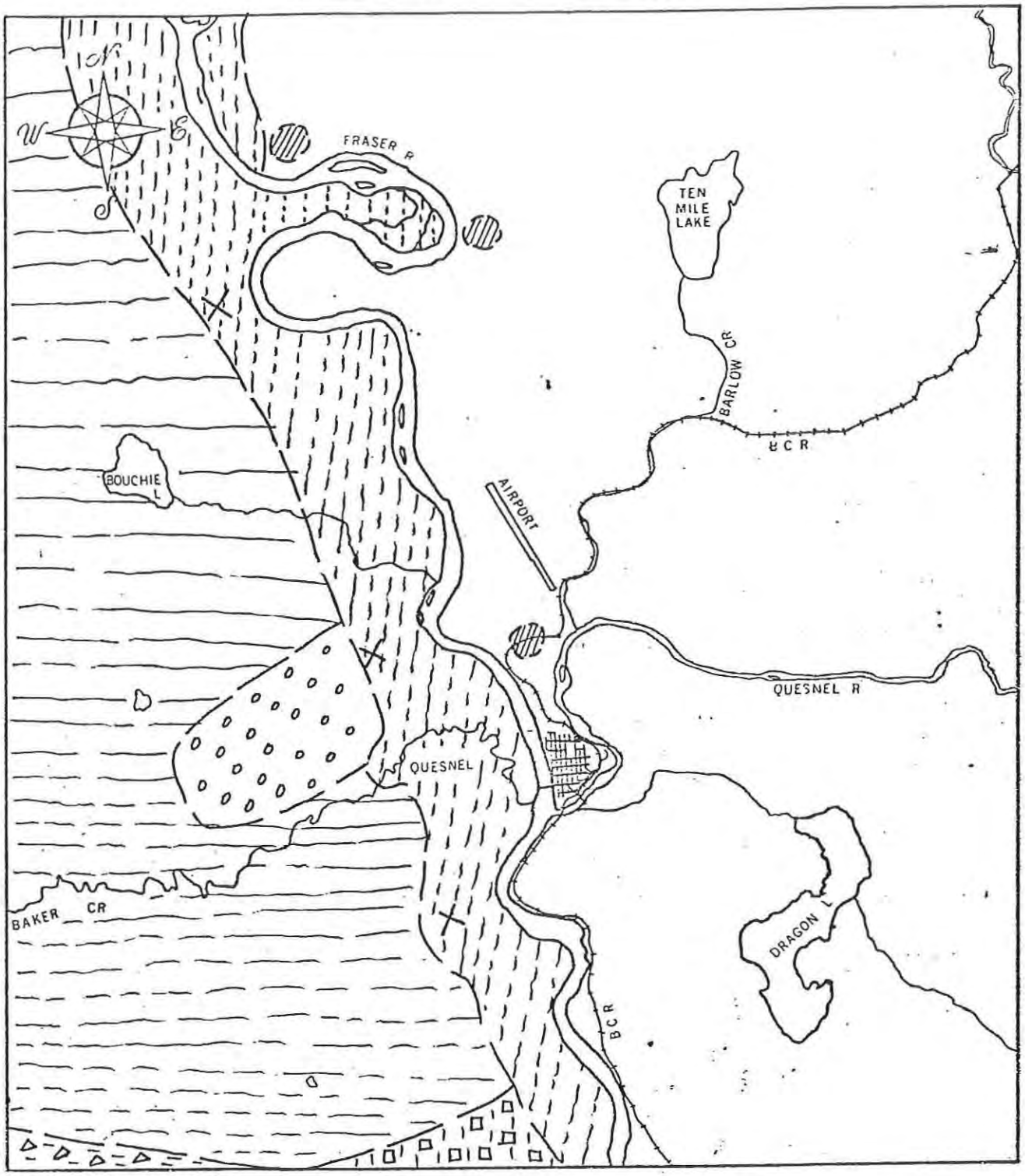
QUESNEL

Scale: 1 Inch = 500 Feet

DATE OF OBSERVATION: [illegible] DRAWING NO. M 135

SHEET 6

BEDROCK GEOLOGY WEST OF THE FRASER RIVER



After P.G.E., 1929

1 0 2 4 6
MILES

PLEISTOCENE OR RECENT - UPPER LAVAS, BLACK, WITH OLIVINE

MIOCENE LAVAS-PORPHYRITES, BRECCIAS, AGGLOMERATES, ASH

EOCENE - FRASER RIVER GRAVELS, SANDS, SILTS, CLAYS, LIGNITES AND DIATOMITES

LATE LOWER OR EARLY UPPER CRETACEOUS - LOWER LAVAS PORPHYRITIC FLOWS AND BRECCIAS

CARBONIFEROUS - CACHE CREEK SERIES - QUARTZITES, ARGILLITES, LIMESTONE

DIATOMITE — X

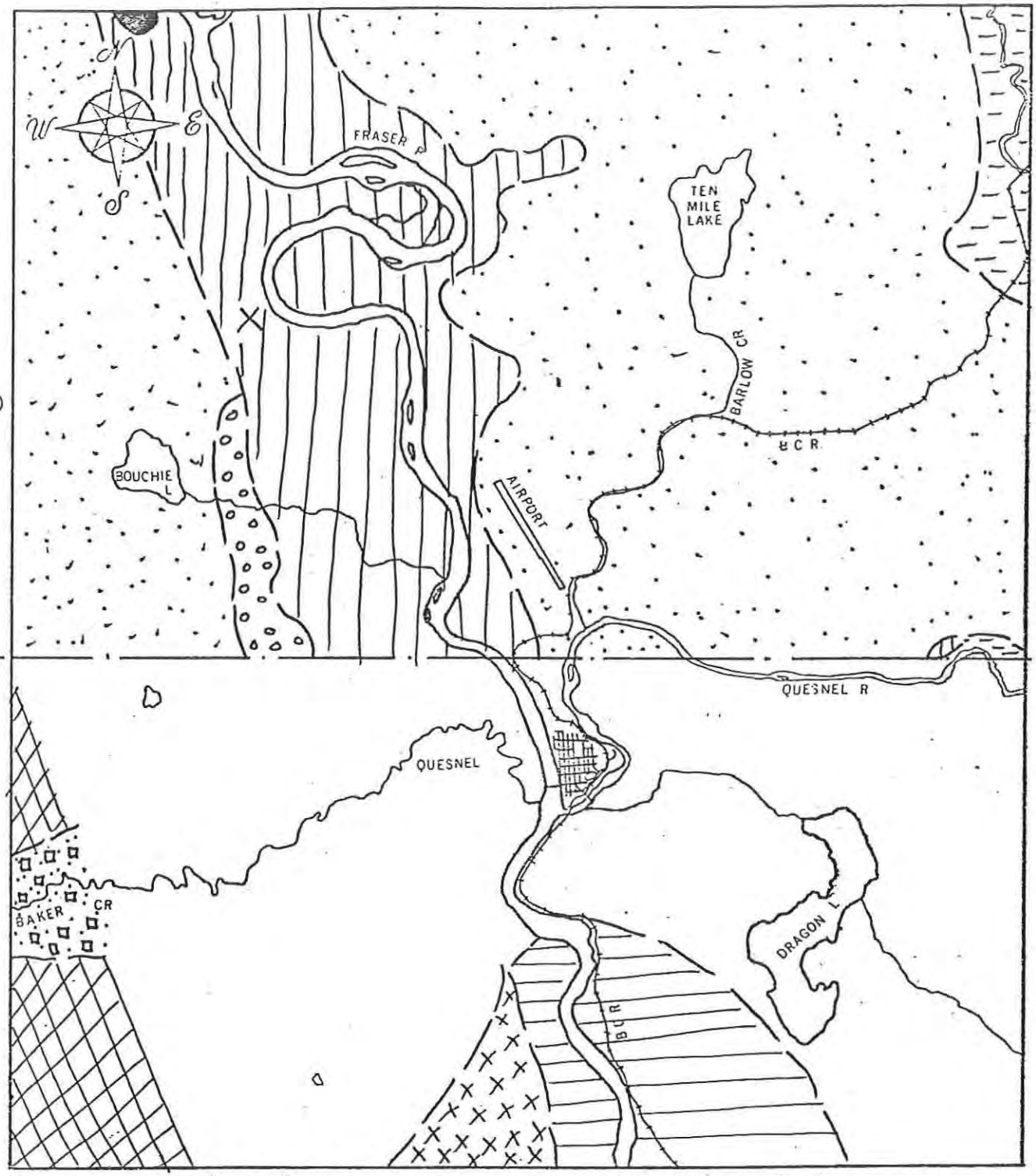
CLAY —

NEG. # 90076 9 of 15

BEDROCK GEOLOGY OF THE QUESNEL REGION

TIPPER
Map 49-1960

TIPPER
Map 12-1959



from TIPPER, 1959, 1960 - unmapped areas extrapolated by R. L. C.

1 0 2 4 6
MILES

Map 49-1960

- -PLEISTOCENE & RECENT
  Till, Gravel, Sand, Silt, Clay
- -MIOCENE AND/OR LATER
  Basalt, Andesite
- -MIOCENE (?)
  Conglomerate, Sandstone, Mudstone, Lignite, Diatomite
- -TRIASSIC-JURASSIC
  Sediments & Intrusions
- -PENN (?) & PERMIAN-Cache Creek Series

Map 12-1959

- -PLEISTOCENE & RECENT
  Till, Gravel, Sand, Silt, Clay
- -EOCENE AND/OR OLIGOCENE
  Basalt, Andesite
- -EOCENE AND/OR OLIGOCENE
  Conglomerate, Sandstone, Greywa
  Shale, Lignite
- -PERMIAN & EARLIER
  Cache Creek series
  Fault (?)
- X DIATOMITE LOCATION

NEG.# 90077
10 of 11

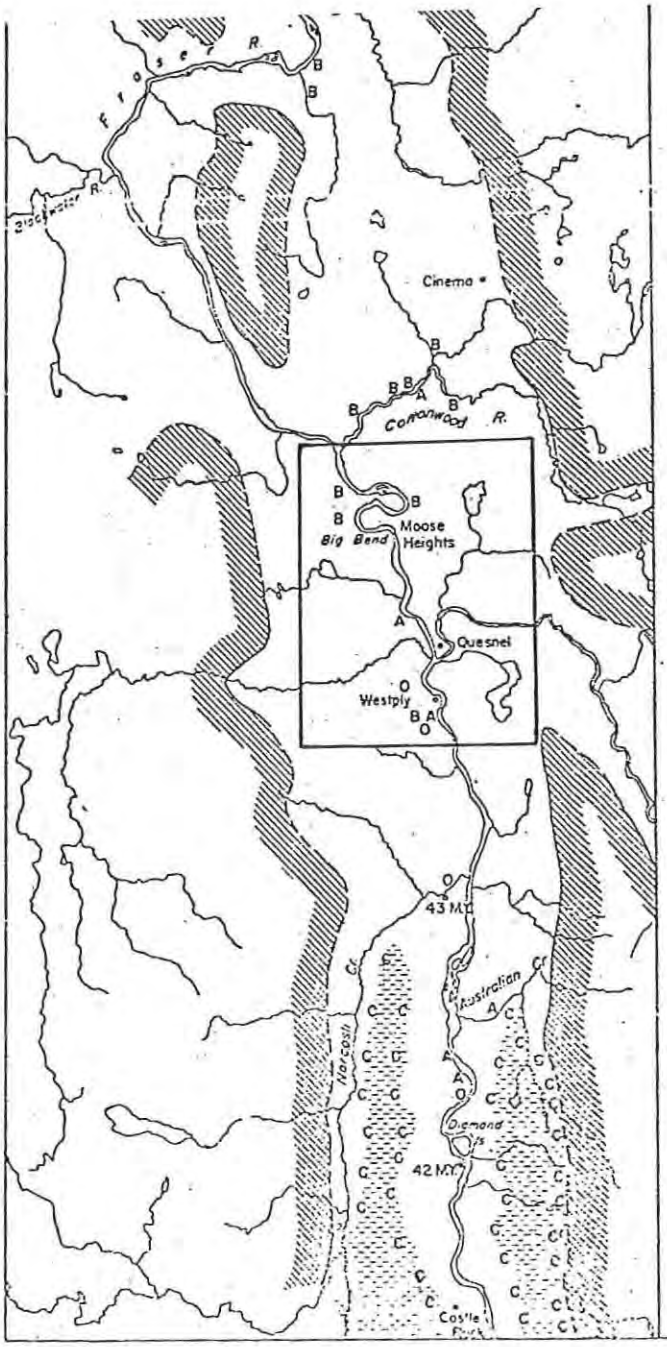


FIGURE B.4

TERTIARY GEOLOGY

UPPER FRASER BASIN

5 0 5 10
MILES

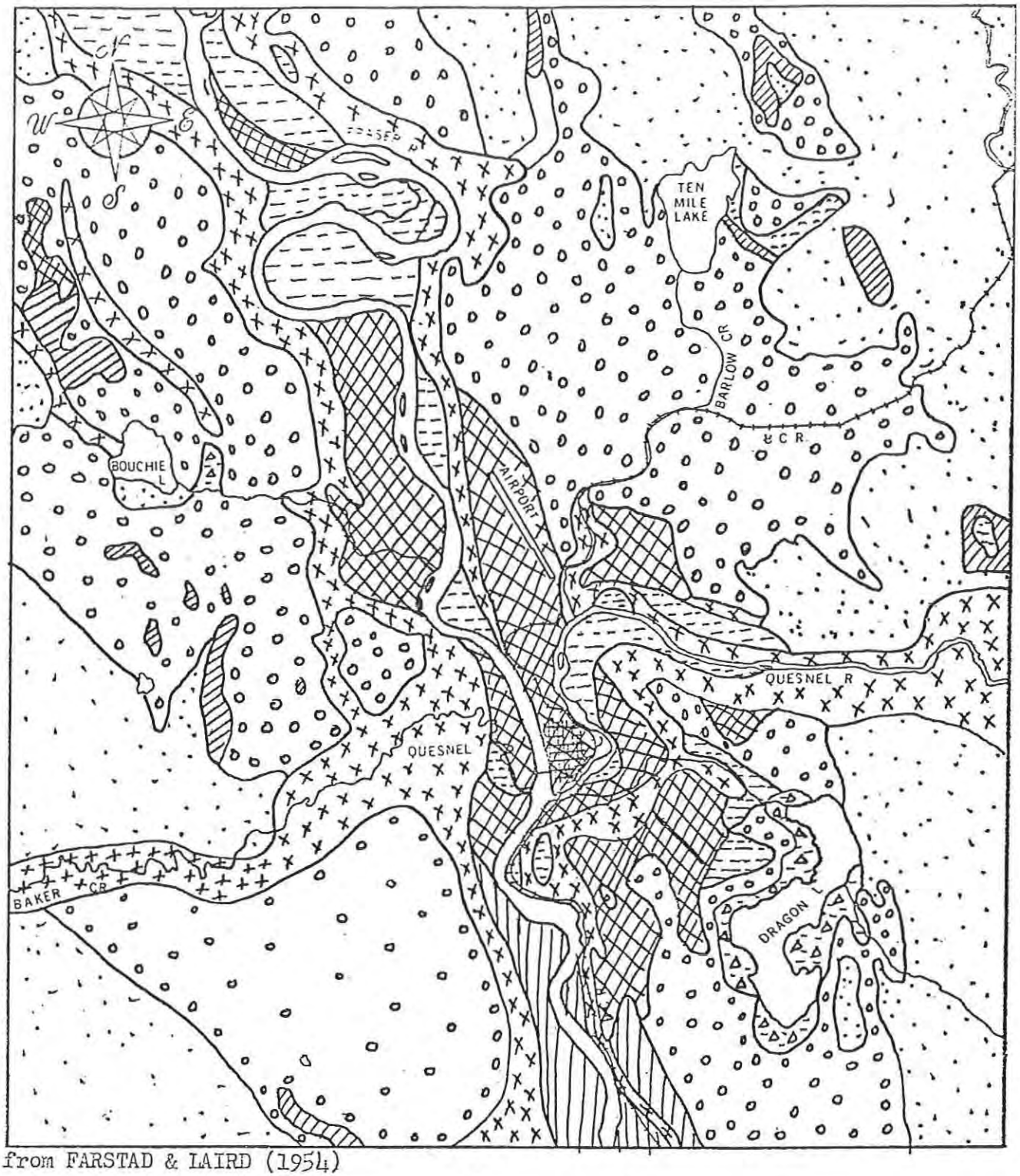
NEG. # 90078
11 of 15

GROUNDWATER & GEOLOGY
of the
SOUTH PRINCE GEORGE AREA

AS SHOWN

J. A. McCALLUM

PEDOLOGY OF THE QUESNEL REGION



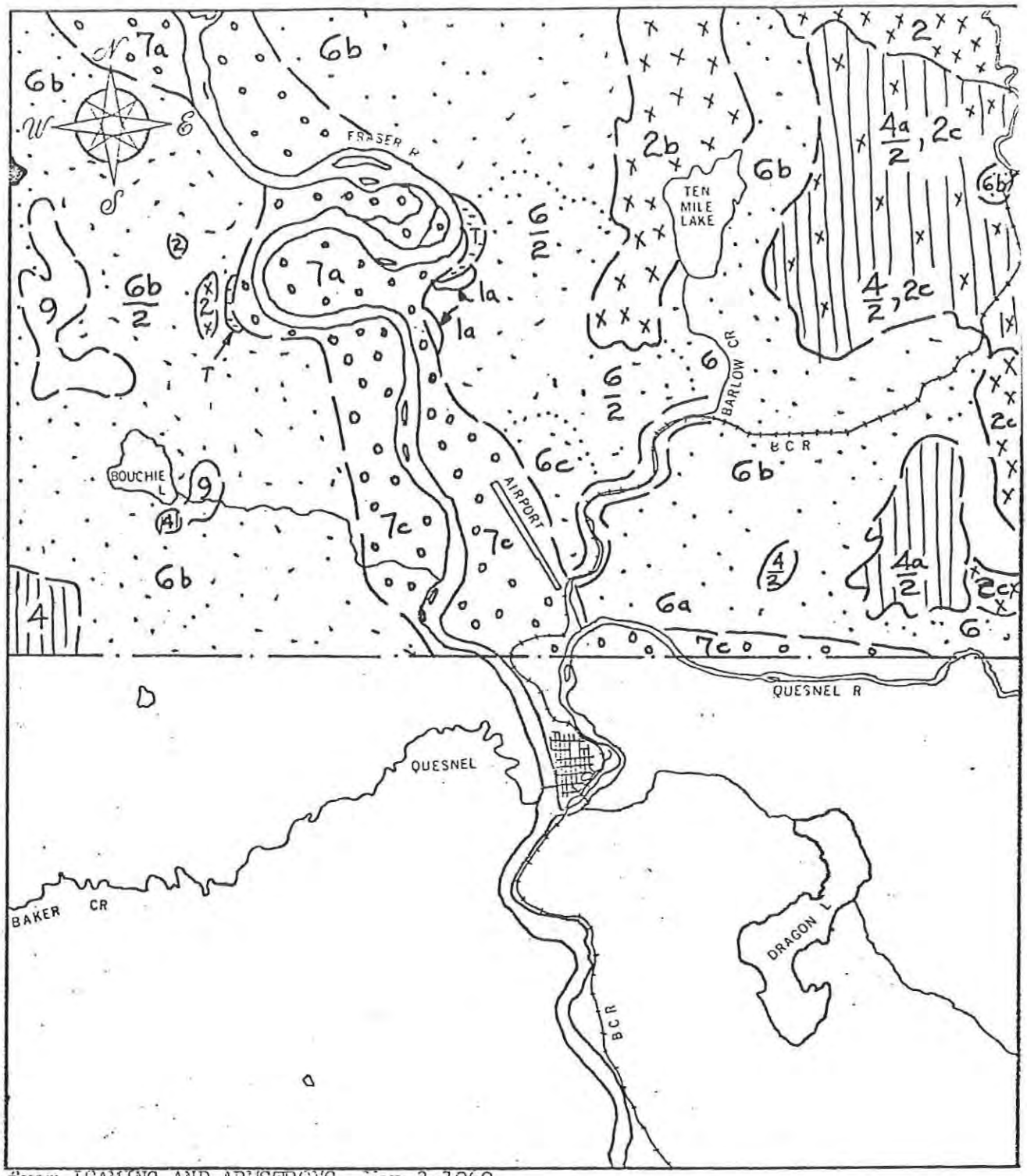
from FARSTAD & LAIRD (1954)

1 0 2 4 6
MILES

- SAXTON LOAMY SANDS & SANDY LOAMS
  POST-PLEISTOCENE TERRACE DEPOSIT
- KERSLEY LOAMY SANDS & SANDY LOAMS
  POST-PLEISTOCENE TERRACE DEPOSIT
- FRASER SILT LOAM
  POST-PLEISTOCENE TERRACE DEPOSIT
- PINEVIEW-NARCOSLI CLAY
  LATE-PLEISTOCENE LAKE DEPOSIT
- ERODED LAND-POOR SOILS, STEEP EXPOSURES OF PRE-PLEISTOCENE MATERIALS
- SHALLOW MUCK
- PEAT
- CHILAKO STONY SANDY LOAM
  PLEISTOCENE TILL

NEG. # 90079 12 of 1

SURFICIAL GEOLOGY OF THE NORTHERN QUESNEL REGION



from LEAMING AND ARMSTRONG, Map 3-1969

1 0 2 4 6
MILES

(9) POST-GLACIAL BOG DEPOSITS

(7) POST GLACIAL ALLUVIAL DEPOSITS
- 7a MAINLY S + G
- 7o MAINLY M
- 7c MAINLY S + G ON TERRACES

(6) GLACIOLACUSTRINE DEPS-LAKE BOTTOM
- 6a SILT
- 6b CLAY
- 6c SAND

(4) GLACIO-FLUVIAL-PROGLACIAL STRATIFIED DRIFT
- 4a OUTWASH PLAIN

(3) GLACIO-FLUVIAL ICE CONTACT STRATIFIED DRIFT

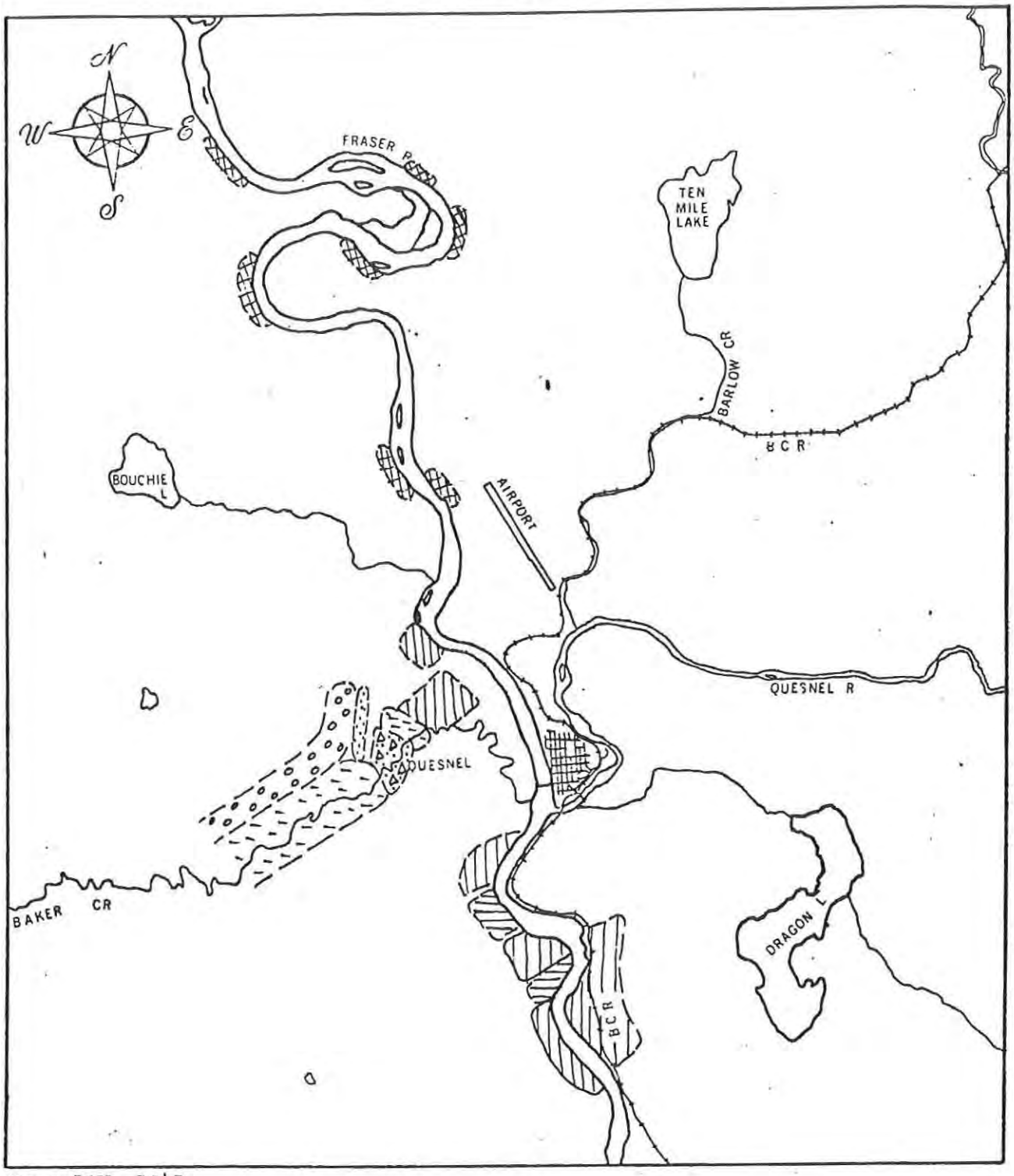
(2) GROUND MORAINE
- 2a COMPACT, DRUMLINOID
- 2b ABLATION TILL
- 2c THIN (<5') + GLACIO-FLUVIAL SOILS

(1) PRE-FRASER TILL
- 1a 2 TILLS

(T) MIO-PLIOCENE POORLY CONSOLIDATED SEDIMENTS

NEG. # 90080 Fig. 15

FIG. B7
BEDROCK EXPOSURES IN THE QUESNEL REGION



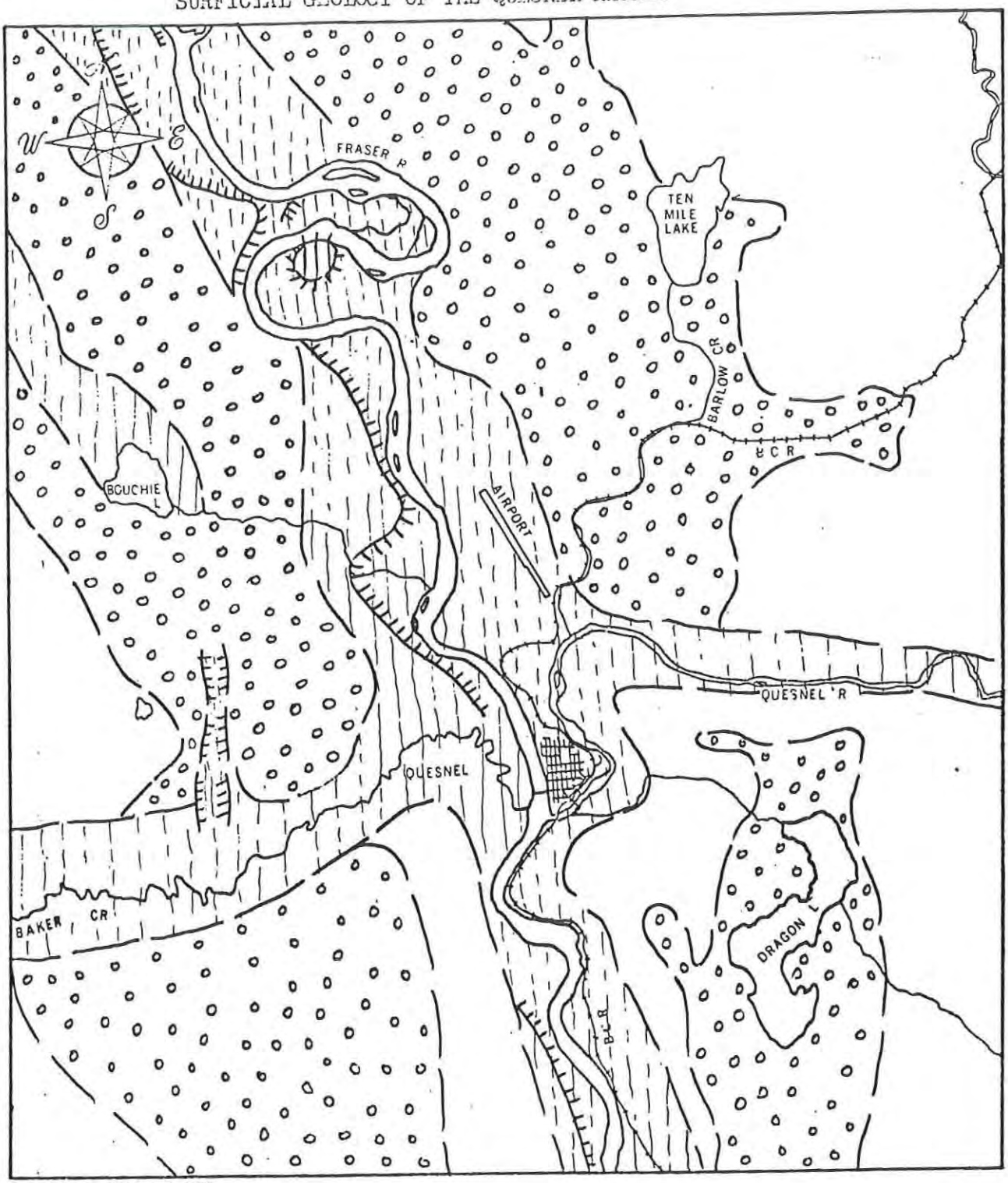
from LAY, 1941

1 0 2 4 6
MILES

Sediments intercalated with Upper Lavas
Upper Lavas
Upper Fraser River formation (members b, c)
Lower Fraser River formation (members a - Australian)
Sediments intercalated with Lower Lavas
Lower Lavas
Cache Creek Series

FIG. 50

SURFICIAL GEOLOGY OF THE QUESNEL REGION



from TIPPER, 1971

1 0 2 4 6
MILES

Large meltwater or outwash channels and river channels bounded by cutbanks and terraces.

Lake Deposits

APPENDIX C
GROUNDWATER

Subsurface seepage flow has been cited as an important factor in virtually all of the landslide histories which have been documented by the Department of Highways in the Quesnel area. It is usually possible to observe the emergence of seepage moisture along the old failure surfaces of past slides. Groundwater seepage through a bluff, cut, or other potential slide area may act as a catalyst to failure by, for example, building up pore pressures, by causing liquid limits of soils to be exceeded and by promoting volumetric changes in swelling clays.

The pattern of groundwater seepage in the Quesnel area is controlled by the complex interstratifications of permeable and impermeable soils. In a simple groundwater situation, all soils contain openings of sufficient size to permit the appreciable movement of water. The water table in such a situation often assumes the form of a subdued replica of the topography, that is, the water table outcrops at river level (in the valley bottoms) and increases in elevation beneath the ridges which separate the rivers. This simple relationship of the water table to topography is disrupted where permeable and impermeable soils are intercalated. Free water, which percolates downwards under gravity, is only present in the permeable materials which lie above the uppermost impermeable stratum. Where the free water is able to gain access to other permeable strata at lower levels, it becomes confined groundwater.

Confined groundwater is overlain by material which is sufficiently impermeable to sever free hydraulic connection with the overlying groundwater except at the point of intake. Movement of confined water is partly independant of gravity. The water is channeled through strata or conduits at a rate which reflects the pressure differences between the intake and exit zones. Unlike free water in entirely pervious soils, confined water does not necessarily

emerge into the atmosphere at river level. Channeling of the flow may result in the presence of springs or seepage zones on slopes or in the faces of bluffs or cuts. Perched water tables may also produce this effect. In the Quesnel area, water-bearing strata are constantly subject to truncation by the natural or artificial processes of bluff development.

The Groundwater Division of the Department of Lands and Forests made available some records and reports on groundwater supplies and their relationship to geology in the Quesnel area. The information is primarily concerned with the availability of water supplies for farming purposes. Apparently such supplies are generally inadequate. This is partly a result of the lensed nature of the Tertiary and Quaternary soils in the area. Lensing inhibits the development of extensive aquifer networks. The Tertiary strata are reported to be particularly unfavourable as aquifers in one study (Internal Groundwater Division Notes, 1963). Aquifers within the Pleistocene sands and gravels, however, are said to offer greater storage potential.

The following is an evaluation of the aquifer potential of the major soil groups in the Quesnel region. It is based upon personal field observations and upon the reports of Nasmith (1953) and McCullum (1969).

(a) Cache Creek series - The aquifer potential of these rocks is poor and is dependant upon fracture permeability which, although variable, is typically low.

(b) Lower Lavas series - The flow potential of these soils has not been reported. It probably varies from little in the case of unweathered but highly deformed lavas to variable where intense weathering has occurred.

(c) Lower Series - These soils are characteristically fine-grained. The lignites are impermeable but the clays and silts exhibit varying degrees of permeability, depending upon the degree to which they are overconsolidated and fissured. Sand and gravel horizons are relatively rare.

(d) Middle series - The finer-grained "off-channel" materials probably inhibit subsurface flow except where the silts and clays may be fissured. According to McCullum, however, the main sand and gravel unit of the "channel" facies is an excellent water-bearing aquifer in the Pineview district (near Prince George) and presumably elsewhere also. In the Quesnel area, however, this unit may not be a reliable aquifer, perhaps because of lensing. Well logs indicate the presence of very few wells in the Quesnel area which are served by positively-identified Middle series aquifers.

(e) Upper Series - The diatomite is highly permeable and affords ready passage to any migrating groundwater. The relatively small sizes of diatomite deposits, however, limit their use asaquifers.

(f) Upper Lava Series - There are no reports on these materials. Water may be expected to penetrate the jointing networks which were established as the lavas cooled.

(g) Pleistocene soils - The tills are usually unsorted mixtures of sands, gravels, silts and clays which are so tightly packed that no water will pass through them. Occasional seams of sands or gravel within the tills are usually sealed and watertight. Interglacial sands and gravels may be locally water-bearing but tend to be sealed by tills. Glacio-fluvial materials which are associated with the most recent phase of deglaciation often include sands and gravels (in outwash plains, kames, eskers, etc.). These may be water-bearing locally. The glacio-lacustrine clays and silts are impermeable. Apparently a useful sand/gravel aquifer is often present between the varved silts and the till, probably of glacio-fluvial origin.

(h) Recent alluvial soils - Terrace silts are relatively impermeable but sands and gravels may retain water where they are underlain by an impervious substratum.

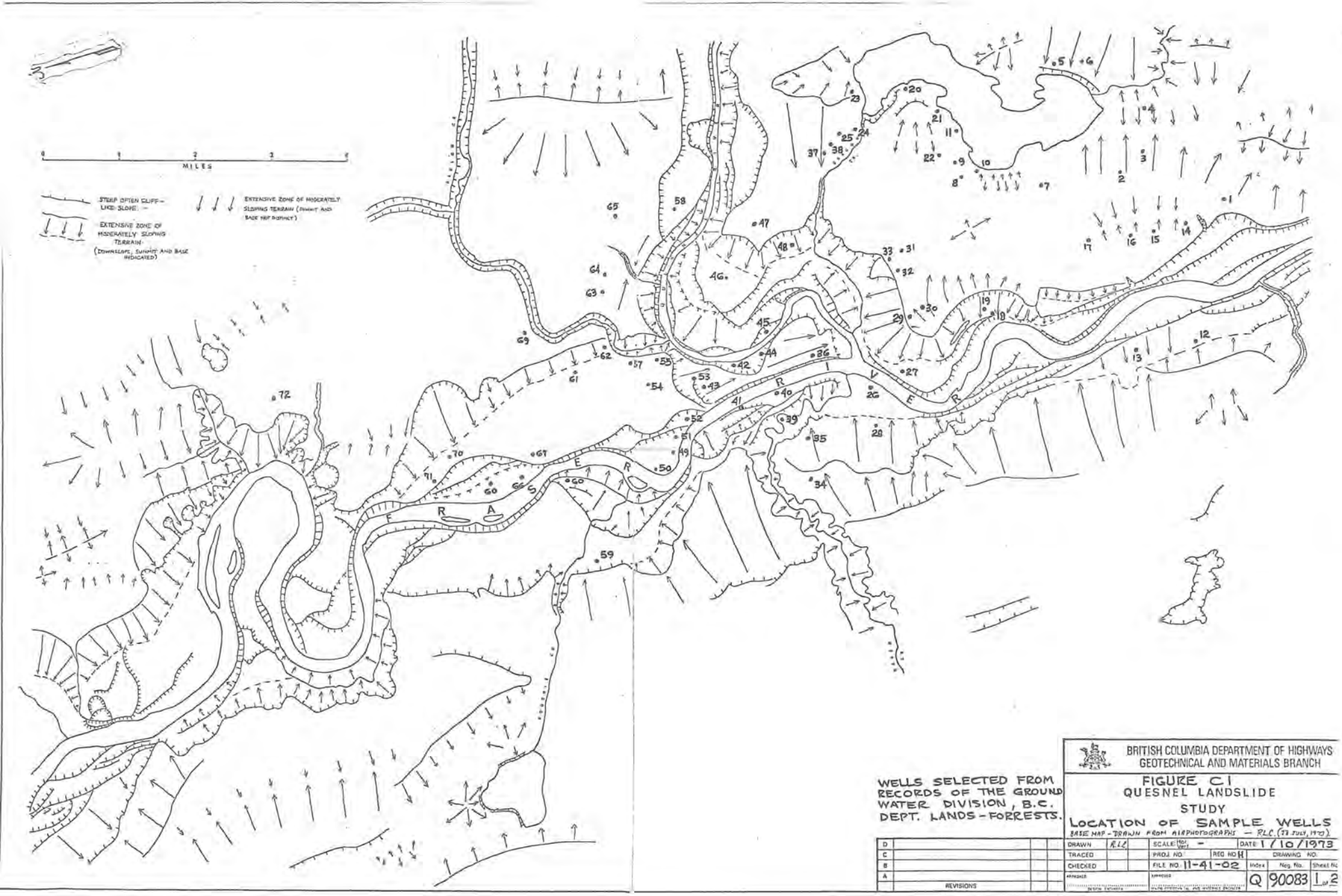
In order to obtain further information on groundwater supplies in the Quesnel region, a sample of 72 wells was selected for investigation from the well-log records of the Groundwater Division. The wells are located in Fig. C1. The sample was selected randomly but unfortunately, in large parts of the study area, especially to the west of the Fraser River, wells have not been drilled. The well logs record the sequence of soils which are drilled but since the identifications are usually unreliable, this information is not used. The most useful data were gained by plotting the elevation of the tops of the wells against the depth of the water-bearing strata (see Fig. C2).

The graph demonstrates that many wells do not encounter strata which bear adequate supplies of water until they have been drilled to depths below the level of the Fraser and Quesnel Rivers. Wells which fall below line AB are drilled to depths below the highest elevation of the Fraser River in the study area (1580 feet). The number of wells which are located on or close to line CD indicates that a major aquifer underlies the region at an elevation of approximately 1510 feet. Water from this aquifer probably cannot influence sliding since it is located below the lowest topographic points in the study area.

Wells which are situated above the line AB are served by aquifers which are higher in elevation than the Fraser and Quesnel Rivers. Within the shaded area, a whole series of high-level wells are served by aquifers which are close to the surface. These wells are located on the Fraser Plateau and on surfaces at the margins of the Plateau which slope downwards towards the valley sides. Many of these wells are located in the Dragon Lake area, for example. The depths of the aquifers which supply these wells rarely exceed 100 feet and it is possible that they are of Pleistocene age. Alternatively, the wells may have penetrated Middle soils. The soil descriptions in the well logs are not sufficiently detailed to permit a more informed prediction.

The high-level aquifers may be of great significance in promoting landslides. Considerable supplies of water must be present in order to be adequate for farm wells. The high static levels in many of the wells suggest that the water is under great pressure. Where these aquifers extend laterally into the upper surfaces of the Fraser valley slopes, seepage and spring activity may be expected to occur at least locally. For example, the Fraser Plateau surface grades into the summit of the Red Bluff Slide. Five wells which ring the summit of the slide (wells 29 - 33) are served by high-level aquifers which may discharge into the slide zone itself. A well to the east of the Big Slide (well 72) is served by water-bearing strata at 50 feet depth which may discharge into the upper slide zone where several minor seepage horizons were observed.

Apart from the high-level and low-level aquifers which are indicated by the graph, there are undoubtedly others which are locally capable of supplying farm wells. The elevation of the aquifer beneath wells 55 and 62 to the west of Barlow Creek is above 1700 feet. There are also numerous minor aquifers, many of which are not identified in the well-logs. At Plywood Hill, seepage zones are underlain by lignites, at Big Slide, by blue swelling clays.



WELLS SELECTED FROM RECORDS OF THE GROUND WATER DIVISION, B.C. DEPT. LANDS-FORRESTS.

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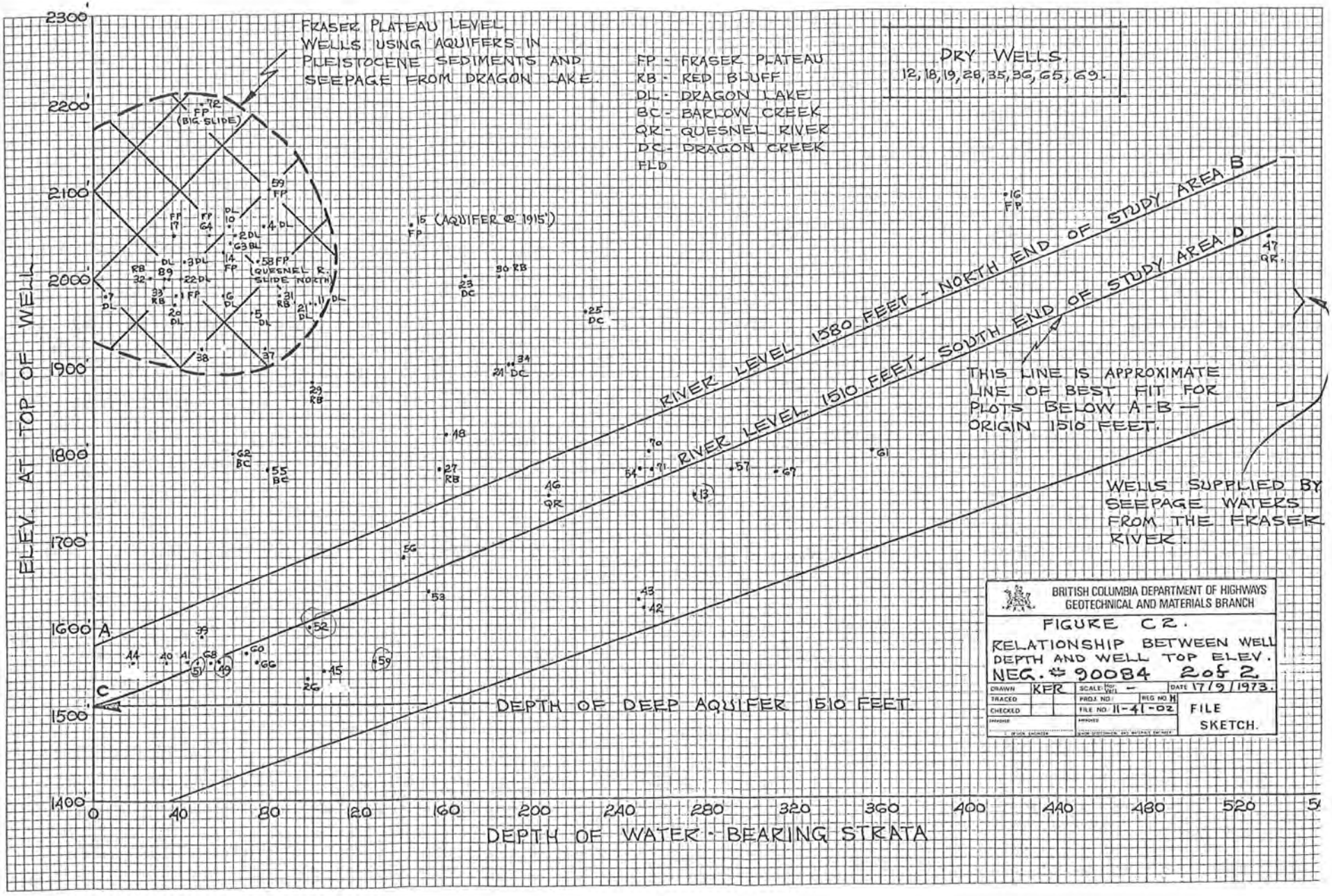
GEOTECHNICAL AND MATERIALS BRANCH

FIGURE C1
QUESNEL LANDSLIDE STUDY
LOCATION OF SAMPLE WELLS
BASE MAP - DRAWN FROM AIRPHOTOGRAPHS — R.L.C. (23 JULY, 1970).

D			DRAWN R.L.C.	SCALE Hor. Vert. -	DATE 1/10/1973		
C			TRACED	PROJ. NO.	REG. NO. H	DRAWING NO.	
B			CHECKED	FILE NO. 11-41-02	Index	Neg. No.	Sheet No.
A			REVIEWED	APPROVED	Q	90083	1 of 2
	REVISIONS						


FRASER PLATEAU LEVEL WELLS USING AQUIFERS IN PLEISTOCENE SEDIMENTS AND SEEPAGE FROM DRAGON LAKE.
FP - FRASER PLATEAU
RB - RED BLUFF
DL - DRAGON LAKE
BC - BARLOW CREEK
QR - QUESNEL RIVER
DC - DRAGON CREEK
FLD
DRY WELLS.
12, 18, 19, 28, 35, 36, 65, 69.
(BIG SLIDE)
QUESNEL R. SLIDE NORTH
15 (AQUIFER @ 1915')
RIVER LEVEL 1580 FEET - NORTH END OF STUDY AREA B
RIVER LEVEL 1510 FEET - SOUTH END OF STUDY AREA D
THIS LINE IS APPROXIMATE LINE OF BEST FIT FOR PLOTS BELOW A-B — ORIGIN 1510 FEET.
WELLS SUPPLIED BY SEEPAGE WATERS FROM THE FRASER RIVER.
DEPTH OF DEEP AQUIFER 1510 FEET
ELEV. AT TOP OF WELL
DEPTH OF WATER-BEARING STRATA
BRITISH COLUMBIA DEPARTMENT OF HIGHWAYS
GEOTECHNICAL AND MATERIALS BRANCH
FIGURE C2.
RELATIONSHIP BETWEEN WELL DEPTH AND WELL TOP ELEV.
NEG. # 90084 2 of 2
DRAWN KER
DATE 17/9/1973.
PROJ. NO. 11-41-02
FILE SKETCH.

APPENDIX D

TOPOGRAPHY

THE TERRACE AND BLUFF SEQUENCE

The terrace surfaces and bluffs which are located in Fig. D1 were identified from aerial photographs and topographic maps. They constitute much of the terrain below the Fraser Plateau and adjacent to Quesnel. The quasi-flat terraces are desirable zones for several types of development but many of the intervening bluffs are susceptible to sliding. Accordingly, special attention is focused on them in this section.

The terrace surfaces have been classified into five major groups which have been named, for convenience, the 1800 - foot, 1700 - foot, 1650 - foot, 1600 - foot and 1550 - foot surfaces. The assignment of individual terrace segments to these groups is, of necessity, tentative. The segments of one group may be widely separated. Furthermore, grouping is based on elevation which is susceptible to a variety of influences, notably warping, sliding and the normal downstream gradient which is common to all valleys.

The advantage of this classification procedure, however, is that the intervening bluffs may be placed within a relative time scale. The terrace at the base of each bluff is a measure of the minimum period which has elapsed since the bluff was abandoned by basal stream activity. The highest terraces are the oldest. The 1800 - foot surface could have been formed as long ago as the immediate post-glacial period (10,000 years ago). There has been no absolute dating of any of the terrace levels by radiocarbon or other means, however, so that one is confined to a relative time scale. Bluffs above the 1800 - foot surface have

experienced the longest periods of slope development without basal river interference. In contrast, bluffs above the 1550 - foot surface have only relatively recently been abandoned. By comparing and contrasting bluffs of different ages, much may be revealed concerning the characteristic patterns of slope development, surface processes, failure modes, etc., within the study area.

The most extensive terrace remnants belong to the 1800 - foot surface. They are located on both sides of the Fraser River between Quesnel and Big Bend. The sizes of these remnants are unusually large (4 - 5 square miles). Most surviving terrace segments are much smaller and are bounded above and beneath by steep bluffs. South of Quesnel, in particular, terraces are little more than ledges on the slopes of the Fraser Valley.

The forms of the bluffs reflect, to some extent, the terrace groups with which they are associated. For example, there is a tendency for mean slope angles to decline as the bluff ages. This relationship is masked, however, by influences such as slope height, which is a topographic variable, and other variables which are considered elsewhere (soil types, patterns of groundwater flow, vegetation cover).

The bluffs exhibit considerable height variations and therefore are subject to different loading stresses. The shortest bluffs may be termed "one-generation" bluffs, that is, the terraces above and below them are juxtaposed in the relative time scale. For example, the 1600 - foot surface may lie above the bluff, and the 1550 - foot surface beneath it. Most bluffs, however, are "multi-generation" bluffs which possess greater heights. For example, the basal terrace might be the 1550 - foot surface and the upper terrace, the 1800 - foot surface or, in exceptional cases, the Fraser Plateau. "Multi-generation" bluffs may have been actively modified by river processes at several stages of terrace formation.

Where they are present, it follows that one or more terrace levels is absent, either because of later erosion by a shifting river channel or because the terrace was never created at this point. It is obvious, from the activities of the Fraser River at present, that many terrace remnants are being eliminated by erosion as the river channel migrates.

Fig. D2 illustrates the locations of the most conspicuous bluffs in the Quesnel area. The most important distinction in the diagram is between slopes which are active (presently undercut) and those which have been abandoned. The abandoned bluffs are classified into "one-generation" and "multi-generation" types and the surfaces related to each bluff are indicated. The complexity of age and origin of the bluffs is apparent from this diagram.

In order to compare the bluffs, seventy-two slope profiles were measured from topographic maps of the area which were provided by the B.C. Department of Lands and Forests. These maps are the most detailed which were available for this purpose. Mapping is at a scale of 1" = 500 feet (1/6,000) and the contour interval is 10 feet. This means of gaining morphological data is obviously subject to some error but provides a preliminary basis for a general comparison of the bluffs. The locations of the slope profiles are plotted in Fig. D3. It should be noted that the detailed topographic coverage was available only for the area indicated on the map.

The measured slope profiles are shown in Fig. D4. The bluffs which are being undercut at present (Fig. D4a) are found to vary considerably. In profile, many are simple, straight slope units varying in angle between 23 and 40 degrees (6, 8, 9, 31, 42, 57, 70, 71). Such slopes are rarely greater than 85 feet in height, often rising only as far as the

1550 - foot or 1600 - foot surfaces. The forms of the higher undercut slopes are more complex. Several profiles are convex-upwards because of undercutting at the toe (1, 39, 43, 62, 68). The undercutting produces a steep cliff at the slope base where gradients often exceed 40 degrees. This process leads to particularly unstable conditions. Some slopes are largely concave-upwards (7, 46, 48, 58). These slopes are usually greater than 250 feet high. The forms of these slopes resemble the profiles of failure surfaces and all were measured in known slide areas. Six slopes exhibited particularly steep segments in midslope and were essentially convexo-concave upwards (23, 34, 35, 49, 67, 72). The steep zone may be a former erosion cliff or the upper segment of a surface of sliding. The low-gradient zones beneath them may represent scree or slide debris accumulations which have not been removed by the river.

The forms of the abandoned bluffs are reproduced in Fig. D4b. The bluffs above the 1550 - foot surface are characteristically simple in form. They rarely exceed 100 feet in height and are often "one-generation" bluffs. The slope beneath Red Bluff is an important exception, however, rising 360 feet and possessing a pronounced concave nick-point near the summit. Above the 1550 - foot surface, bluffs are often indistinct and, in several places, slip-off slopes have developed in their place (see Fig. D1). These indicate typical slope development on the inner bends of meanders.

The bluffs above the 1600 - foot surface are very variable in form. While some are simple (10, 30, 61, 69), others retain an overall convex form (22, 25, 54) and still others are concave (13, 21, 29, 53). Five of the profiles are convexo-concave (18, 28, 41, 47, 56). Most of the bluffs vary between 50 and 150 feet in height. The significance of

these variations in slope form is not clear. It may be that the convex and convexo-concave slopes have stabilized with essentially those forms which they possessed at the time of river abandonment. The concave forms suggest that failures have occurred at some time, replacing the old convexity.

Few survivals of the 1650 - foot and 1700 - foot surfaces remain. The segments of these surfaces are widely scattered and are often inconsistent in elevation so that each group might more reasonably represent a series of terrace-forming phases rather than a single phase. The bluffs above these surfaces were variable in form. Four were simple (15, 16, 19, 64), one was convex (55) and five were concave (2, 3, 26, 63, 65).

The bluffs above the 1800 - foot surface possibly represent the sides of the Fraser valley at the initiation of the post-glacial terrace-forming phase. These bluffs are typically long and high, stretching upwards to the Fraser Plateau or the high-level erosional bench. Forms are either dominantly convex (5, 51, 52) or dominantly concave (4, 45, 50).

The mean angles of the slope profiles are plotted on a frequency histogram in Fig. D5. The mean angle of slope of the 72 profiles is 26.1 degrees. As expected, the average mean angles of the undercut slopes are steepest (29.8 degrees). The mean angles of the abandoned slopes appear to be partially related to the age of the basal terrace surface. The average mean angles of the bluffs decline progressively with age from 26.6 degrees for bluffs above the 1550 - foot surface to 19.0 degrees for bluffs above the 1800 - foot surface. The average mean value of 26.6 degrees for bluffs above the 1700 - foot surface is higher than anticipated and may reflect the low sample size (N = 3).

The relationship between mean angle of slope and the elevation of the base of the slope is plotted on the bivariate graph in Fig. D6. The range of mean angle values declines as the bluffs become older. Furthermore, the maximum gradients also decline. Undercut slopes range in grade from 15 to 44 degrees. Bluffs above the 1550 - foot surface range in slope from 11 to 45 degrees, above the 1600 - foot surface, from 9 to 34 degrees, above the 1800 - foot surface, from 10 to 24 degrees.

A highly significant pattern emerges in Fig. D7 where mean slope angle is plotted against slope height. From the disposition of the data points, it appears that line AB marks a boundary condition in the relationship between mean angle and slope height. Slopes below the line may be stable at least in the short term. Slopes which, as they evolve, enter the zone above the line AB may be in a condition of imminent failure. The effect of failure would be to reduce slope angle and so relocate the slope below AB. The line AB is empirical in its significance and presumably applies to slopes which are being developed by undercutting within the Fraser River formation. It may be noted that practically all of the data points which occur on or close to this line represent slopes which are presently being undercut. The exceptional occurrence of profile 71 at the Paradise Road Slide above line AB may indicate the operation of factors not normal for the area, perhaps an unusually stress-resistant series of soils. The gravels here are well cemented and a lava cap-rock is also present.

Most of the undercut slopes are plotted close to the line AB. Among these profiles are many which traverse prominent slide zones of the Quesnel region (See Fig. D7 for identification). Not all slopes which are subject to basal river action approach the boundary (limiting) condition for slope angle and slope height. This is because the effectiveness

of a river in oversteepening its banks varies along its course. In a winding river, very little energy is expended in vertical downcutting. Most erosion occurs laterally (in a horizontal plane) and is concentrated on the outer bends of the meanders, and on the downstream side of these outer bends in particular. This explains the shifting of the channel in a meandering stream. The meanders migrate downstream. Their inner bends are zones of deposition which form slip-off slopes.

It is readily apparent from field observation and airphoto interpretation that the banks along straight sections and along the inner bends of the Fraser River are weakly undercut in the study area. Profiles of bluffs in these zones are most likely to be plotted well below line AB (as in the case of 6, 9, 46, 57, 62). Even along outer bends, undercutting varies in power, increasing as the rate of curvature of the meander increases. Thus, profiles 1, 8, 39, 68 and 70 are located along stretches of the river where rates of winding are low. The most unstable bluffs are located on the outer bends of tight curves (35, 48, 59, 71, 72). There are some exceptions to the above generalizations, presumably because of the operation of special circumstances. Profiles 7, 42 and 49 are located closer to the line AB than expected while profiles 27, 31 and 34 are more distant than expected.

It should not be presumed that the rates of meander migration are too slow to bring areas of appreciable size within the range of river erosion in the forseeable future. Marr's study of 1966 indicates a significant loss of land along the outer bend of that stretch of the Quesnel River which extends upstream from its confluence with the Fraser River - see Fig D8 which plots erosion between 1881 and 1966 along the river bank at A. Appreciable land losses have been suffered also at B and C. The situation at A was critical

when Marr conducted his study because erosion was approaching the toe of a terrace bluff above which were extensive residential subdivisions. The bank here is composed of an alluvial silty clay overlying a coarse, easily eroded, gravel - sand mixture of the Fraser River formation. The rates of erosion have been calculated as follows:

Period	Acres Lost	Acres per Year
1881-1948	11.6	.17
1948-1950	0	0
1950-1955	2.9	.58
1955-1959	0	0
1959-1961	1.32	.91
1961-1964 (June)	0	0
1964-1965 (Sept.)	3.25	1.63
	19.57	

In particular, the distance from the riverbank to the toe of the bluff decreased from over 300 feet in June, 1964 to less than 100 feet by September, 1965. Spur dykes which were designed to reduce erosion have not been entirely successful. Marr favoured a heavy rock rip-rap revetment which protected the bank directly and interfered less with actual stream flow.

The height/gradient relationships of abandoned bluffs are plotted in Fig. D7. Most plots are located well below the line AB. The disposition of the data points suggests the existence of another boundary condition along the line CD, but the location of this line is less sharply defined. It seems likely that slopes beneath it have assumed a relatively long term stability while abandoned bluffs above the line (10, 17, 44, 56) may yet be unstable in the short term.

From this graph, (Fig. D7), one is led to the conclusion that slope height is very important, perhaps more important than age, in controlling slope angles. The low mean angle of slopes above the 1800 - foot surface

is not surprising since these slopes are usually tall. Slopes above the 1550 - foot surface with their steep grades are usually less than 100 feet high. The height/angle relationships of slopes below line CD, therefore, may be relatively stable, whatever the age of the bluff.

It is interesting to note that the lowest observed gradients occur between 10 and 15 degrees. The latter figure occurs frequently (see Fig. D5). The significance of these values lies in the probability that given time, the bluff declines to a completely stable gradient which is attributable to the residual strength of the soil. Bluffs of all ages are found in this low-angle zone.

The maximum gradients to be found on the 72 slope profiles are plotted in Fig. D9. These values present a less consistent pattern than do those of mean angle. In general, the steepest maximum angles occur on undercut slopes (average maximum angle = 39.3 degrees). There is no systematic decline in average maximum angles with the age of the bluffs. These averages are very variable, ranging from 29.8 to 38.7 degrees. It is well known that maximum angles are susceptible to variations in local factors which do not influence mean angles to the same extent (Strahler, 1950). On abandoned slopes, the sequences of soil types, drainage, vegetation cover and microclimate dominate over regional considerations of age and relief in determining maximum angles.

PLATE D1
Typical subdued, forest terrain on the Fraser Plateau south of Baker Creek (top right).

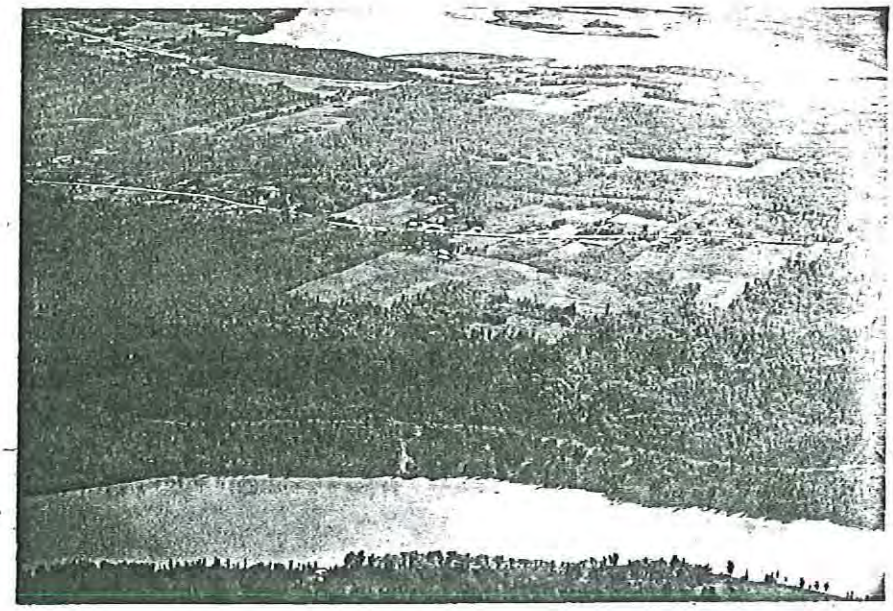


PLATE D2
Dragon Lake and the meadowlands of the 2000-foot erosional bench; note steep river bluff in foreground.

PLATE D3
Different terrace-levels inside meander loop at Big Bend; note Fraser Plateau and Paradise Road Slide (left).

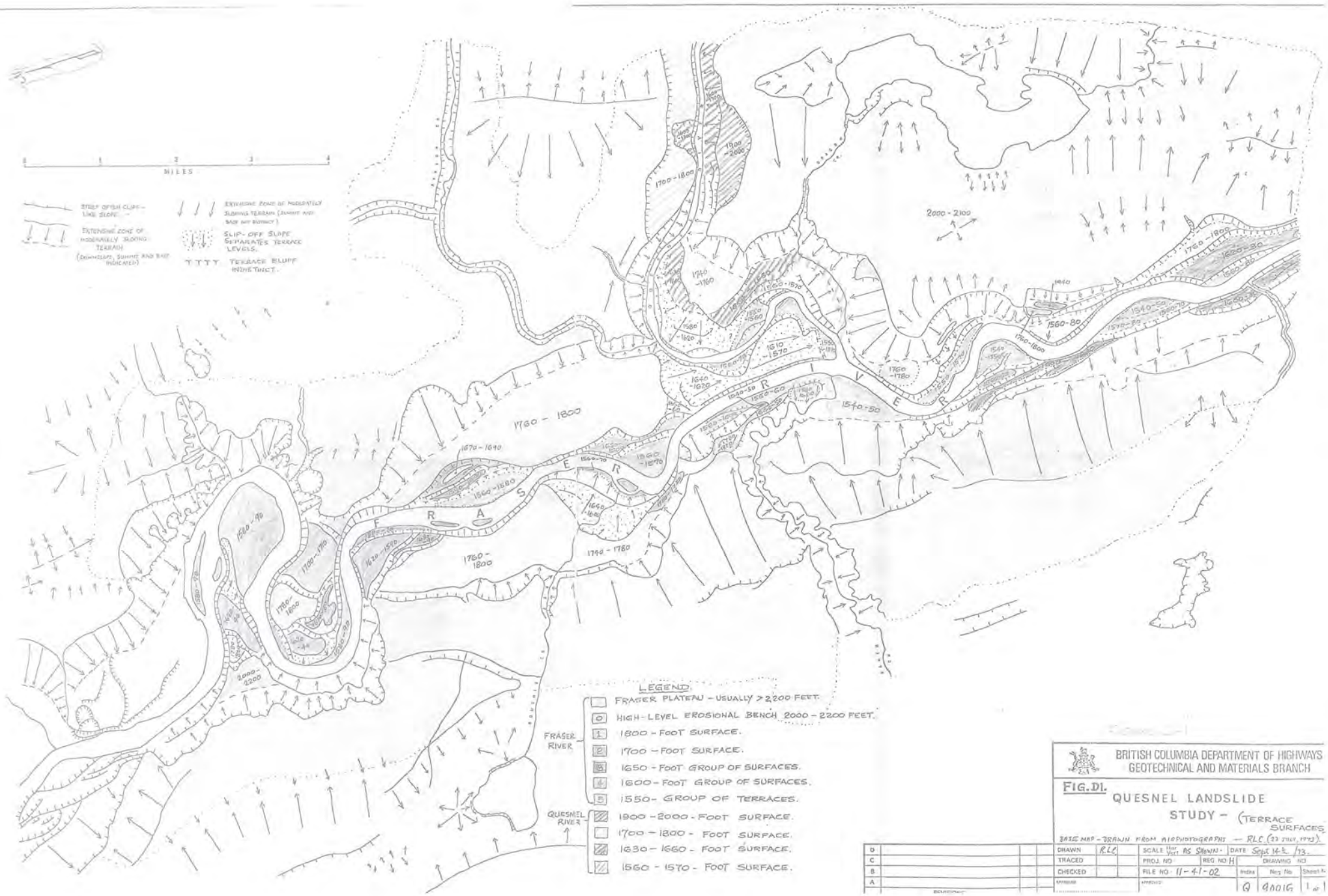


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FIG. D1.

QUESNEL LANDSLIDE STUDY - (TERRACE SURFACES)

BASE MAP - DRAWN FROM AIRPHOTOGRAPHS — RLC. (23 JULY, 1973).

D				DRAWN	R.L.C.	SCALE Hor. Vert. AS SHOWN	DATE Sept 14-k. /73.		
C				TRACED		PROJ. NO.	REG. NO. H	DRAWING NO.	
B				CHECKED		FILE NO. 11-41-02	Index	Reg. No.	Sheet No.
A				APPROVED		APPROVED	Q	9001G	1 of 1

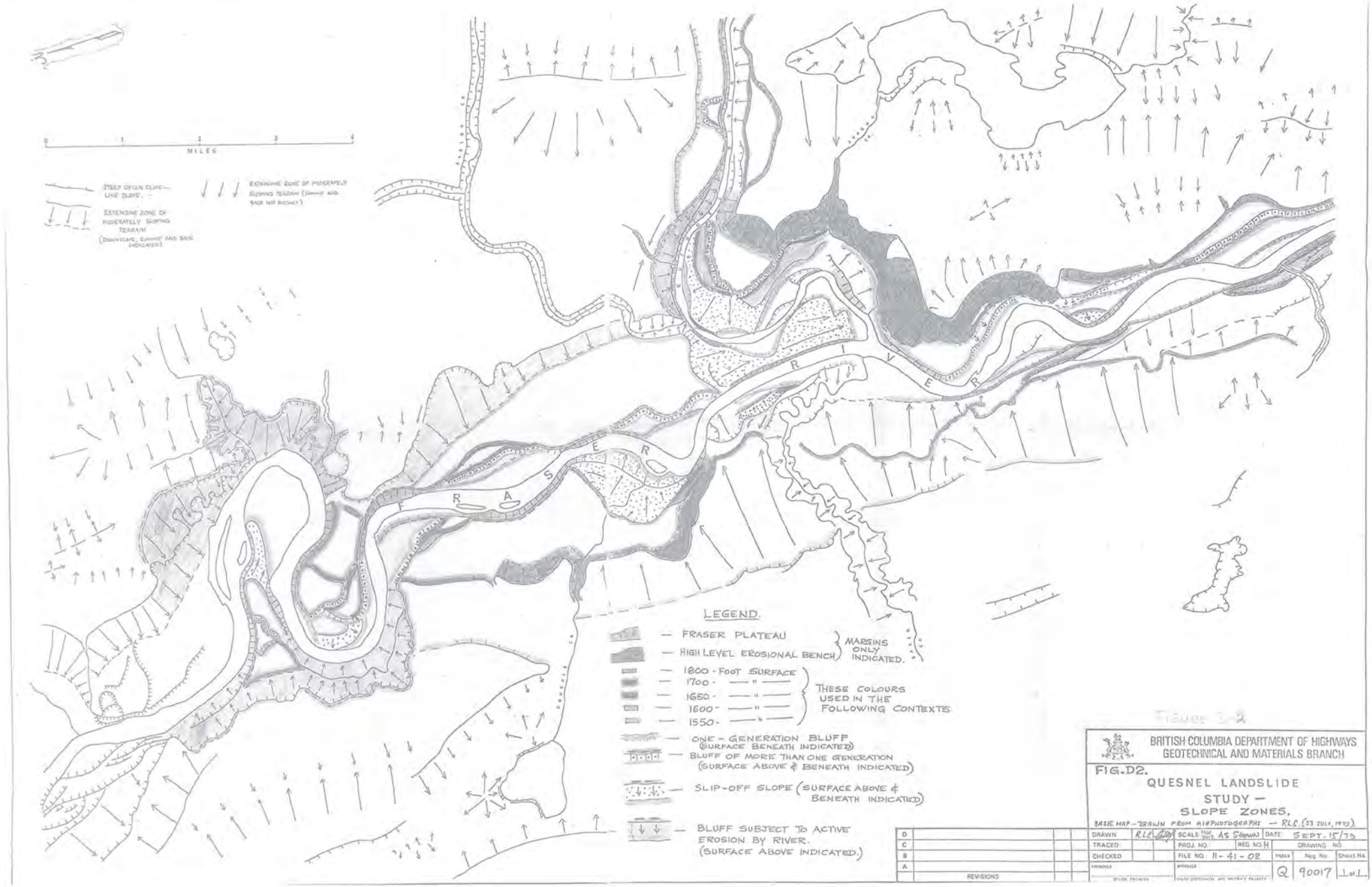
0 1 2 3 4
MILES
STEEP OFTEN CLIFF-LIKE SLOPE.
EXTENSIVE ZONE OF MODERATELY SLOPING TERRAIN (DOWNHILL, SUMMIT AND BASE INDICATED)
EXTENSIVE ZONE OF MODERATELY SLOPING TERRAIN (SUMMIT AND BASE NOT DISTINCT)
FRASER RIVER
LEGEND.
FRASER PLATEAU
HIGH LEVEL EROSIONAL BENCH
MARGINS ONLY INDICATED.
1800 - FOOT SURFACE
1700 - " "
1650 - " "
1600 - " "
1550 - " "
THESE COLOURS USED IN THE FOLLOWING CONTEXTS.
ONE - GENERATION BLUFF (SURFACE BENEATH INDICATED)
BLUFF OF MORE THAN ONE GENERATION (SURFACE ABOVE & BENEATH INDICATED)
SLIP-OFF SLOPE (SURFACE ABOVE & BENEATH INDICATED)
BLUFF SUBJECT TO ACTIVE EROSION BY RIVER. (SURFACE ABOVE INDICATED.)
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FIG. D2.
QUESNEL LANDSLIDE STUDY — SLOPE ZONES.
BASE MAP - DRAWN FROM AIRPHOTOGRAPHS — R.L.C. (23 JULY, 1973).
DRAWN R.L.C.
SCALE AS SHOWN
DATE SEPT. 15/73
TRACED
PROJ. NO.
REG. NO.
DRAWING NO.
CHECKED
FILE NO. 11-41-02
Q 90017 1 of 1
REVISIONS

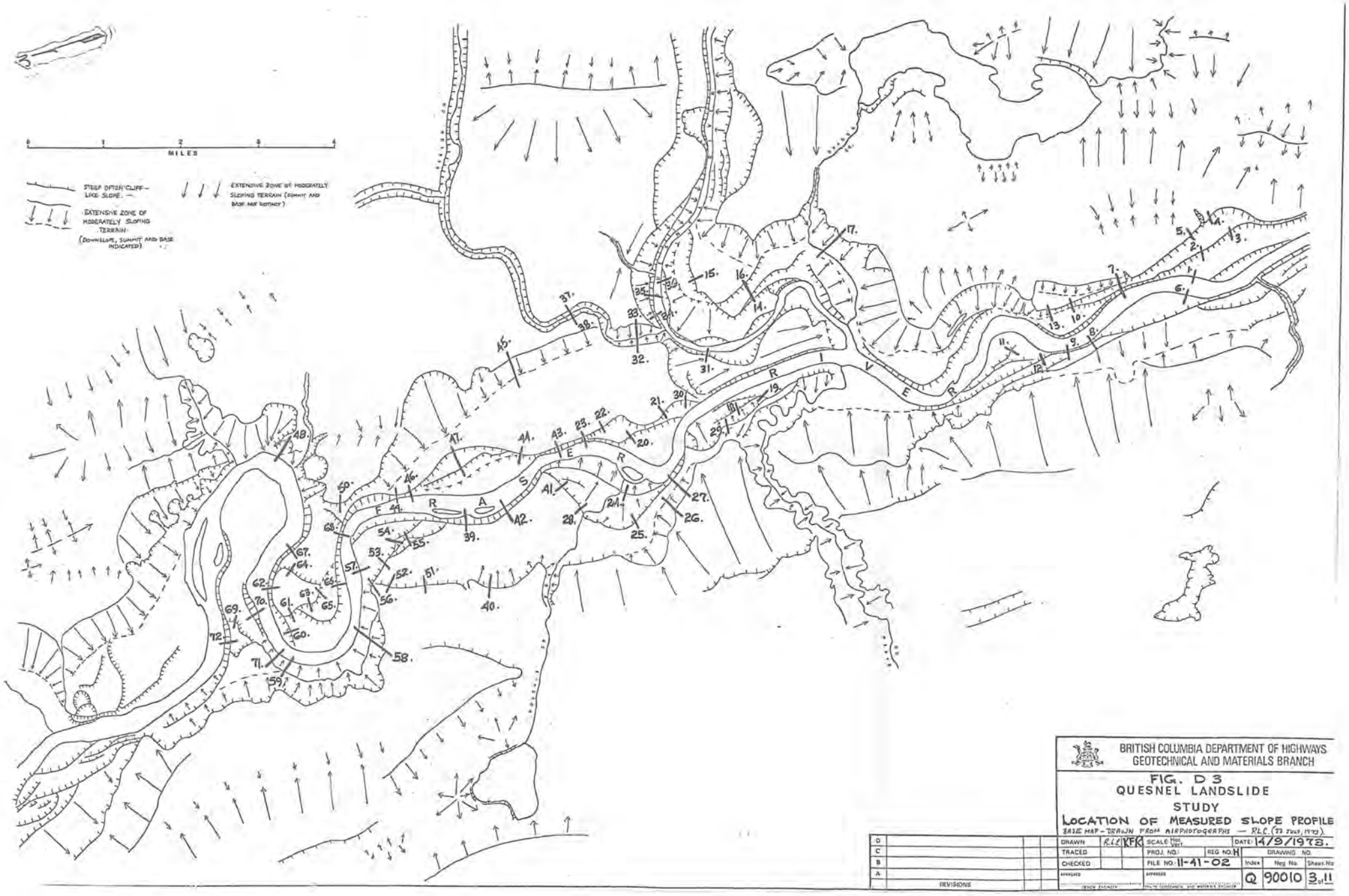

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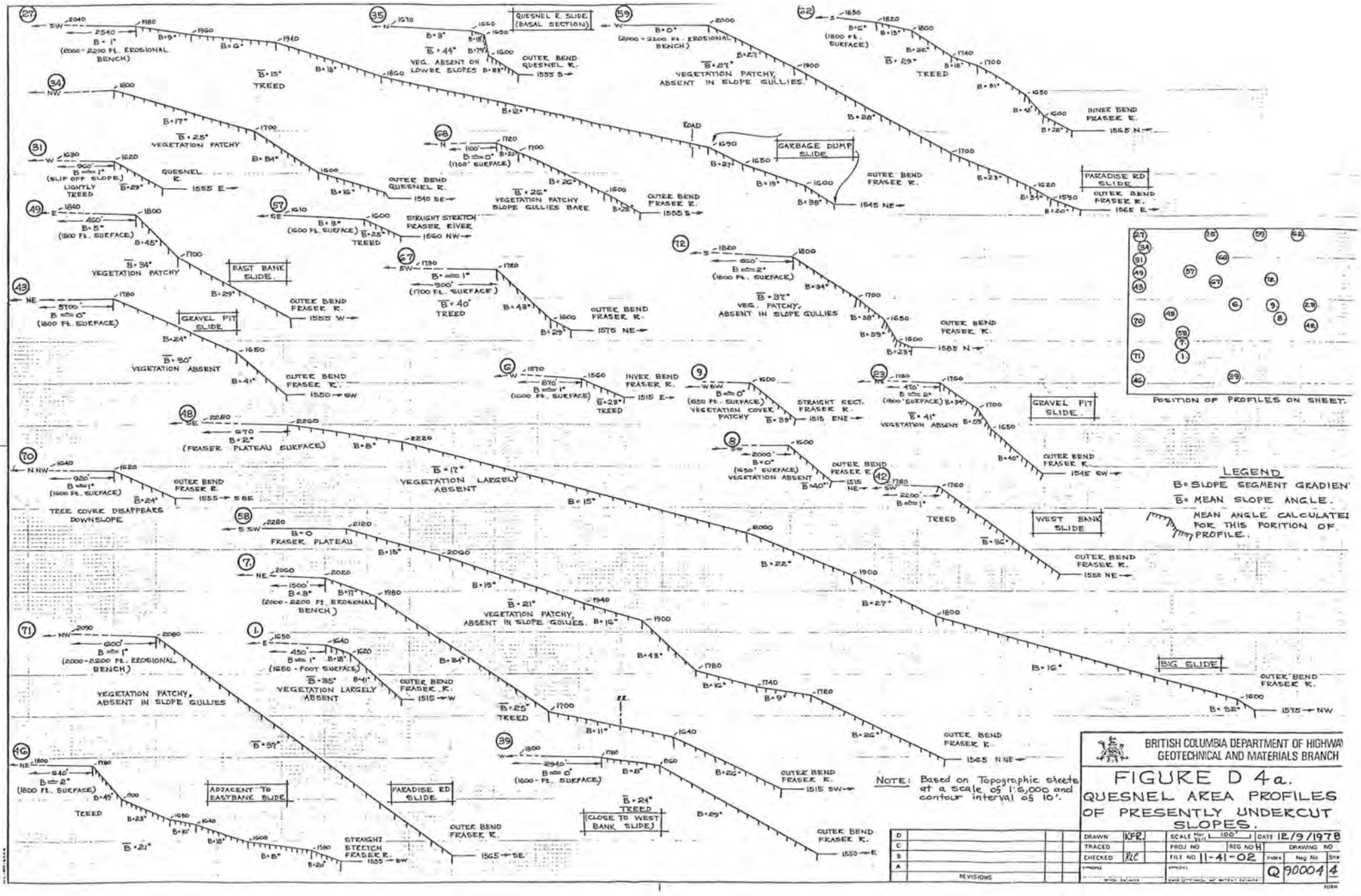
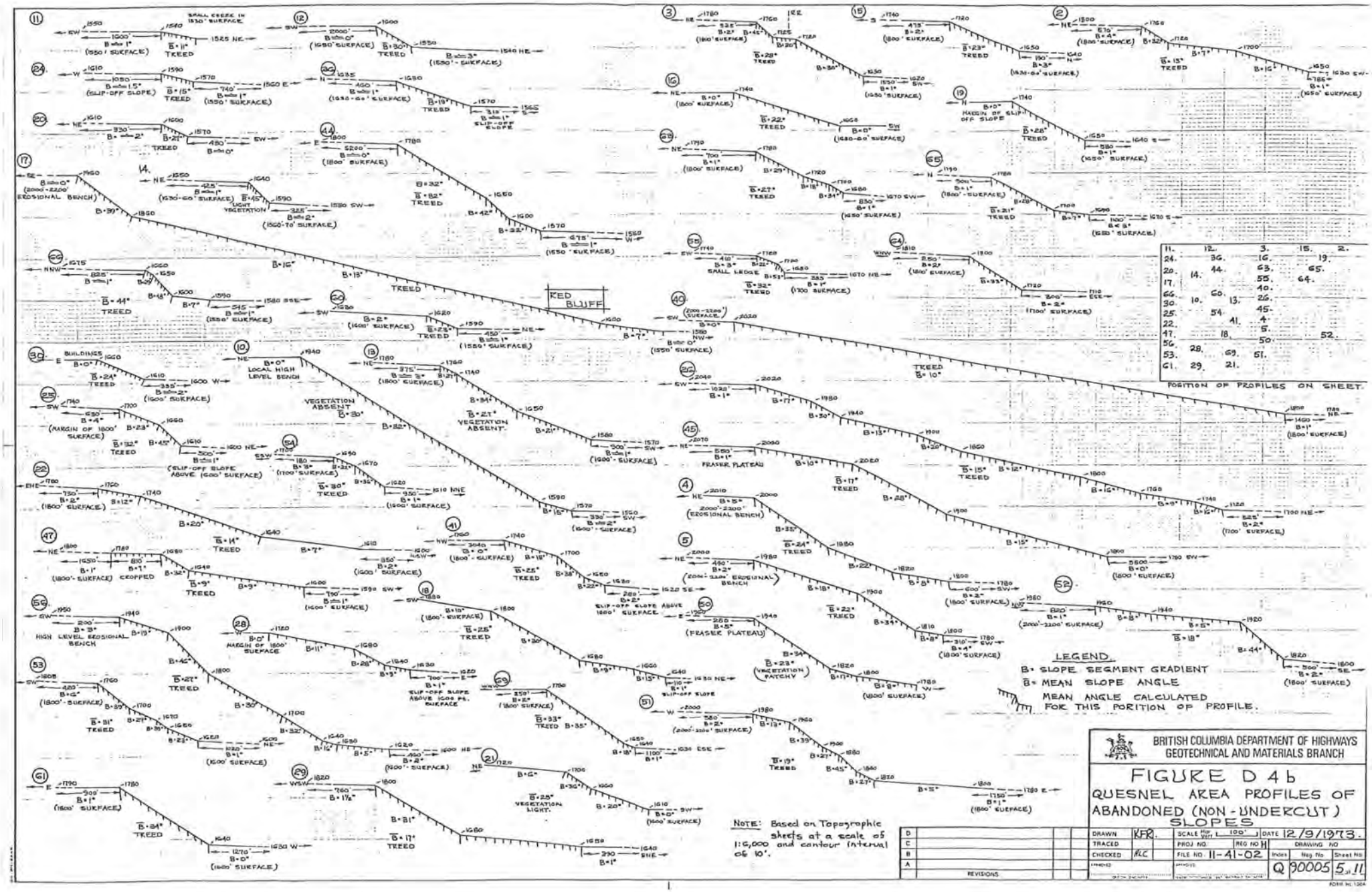
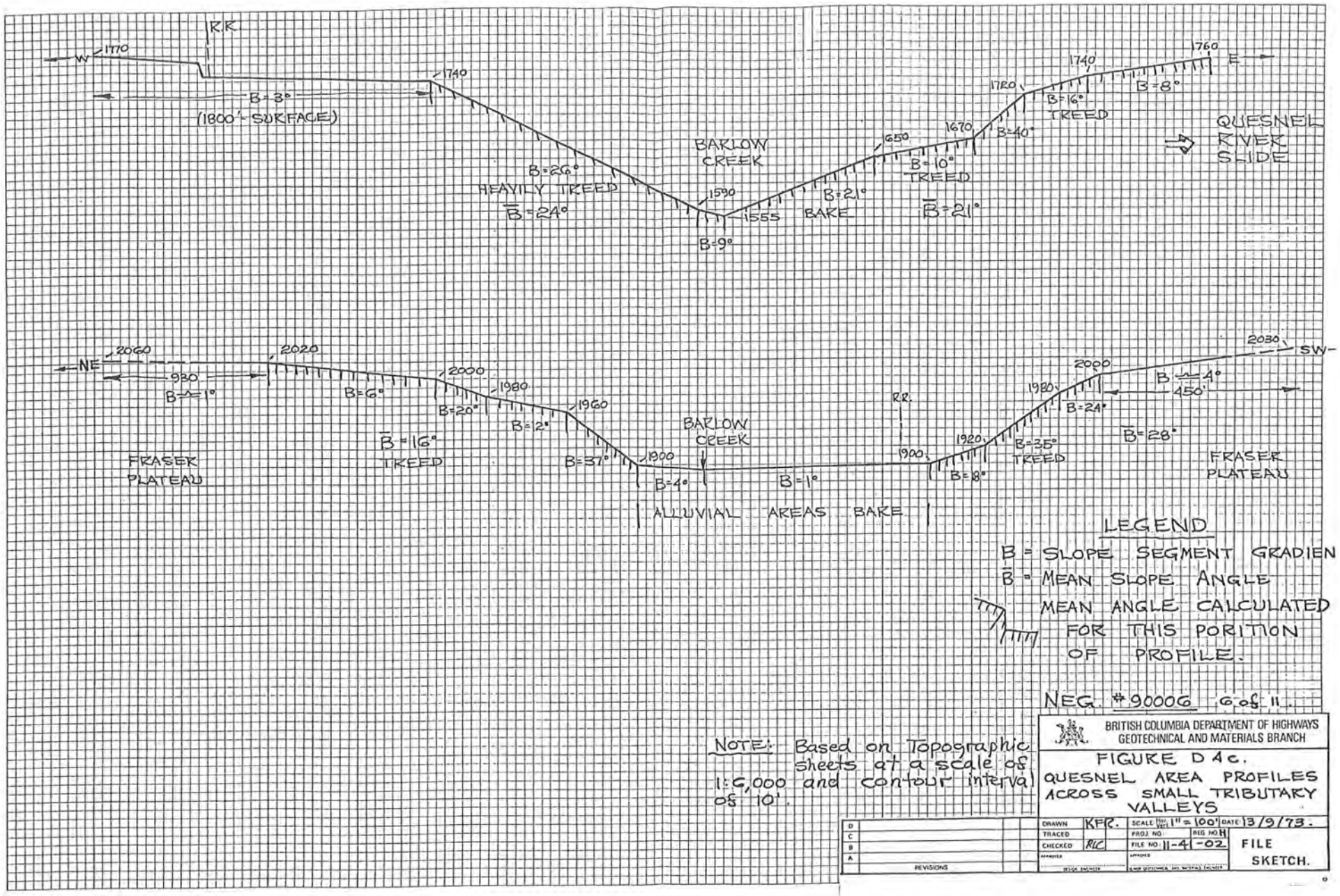
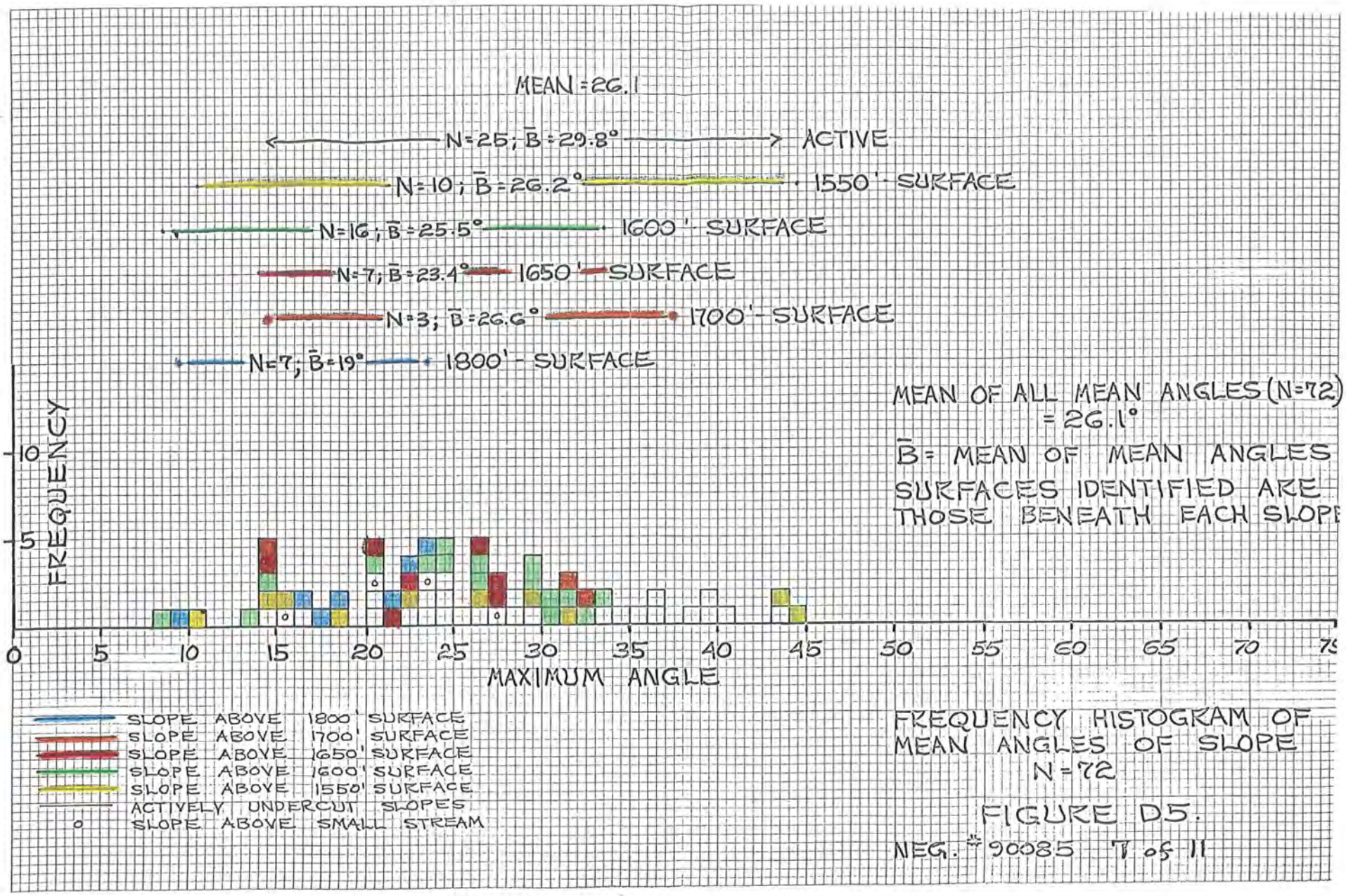
FIG. D 3
QUESNEL LANDSLIDE
STUDY
LOCATION OF MEASURED SLOPE PROFILE
BASE MAP - DRAWN FROM AIRPHOTOGRAPHS — RLC (23 July, 1979).

D			DRAWN	RLC	KFR	SCALE Hor. Vert.	DATE: 14/9/1978.	
C			TRACED			PROJ. NO.: REG. NO. H	DRAWING NO.	
B			CHECKED			FILE NO. 11-41-02	Index	Neg. No.	Sheet No.
A			APPROVED			APPROVED	Q	90010	3 of 11
	REVISIONS							


QUESNEL R. SLIDE (BASAL SECTION)
GARBAGE DUMP SLIDE
PARADISE RD SLIDE
EAST BANK SLIDE
GRAVEL PIT SLIDE
WEST BANK SLIDE
BIG SLIDE
ADJACENT TO EASTBANK SLIDE
(CLOSE TO WEST BANK SLIDE)
OUTER BEND QUESNEL R.
INNER BEND FRASER R.
OUTER BEND FRASER R.
STRAIGHT STRETCH FRASER RIVER
STRAIGHT SECT. FRASER R.
FRASER PLATEAU
(FRASER PLATEAU SURFACE)
VEGETATION PATCHY, ABSENT IN SLOPE GULLIES.
VEGETATION LARGELY ABSENT
TREED
LEGEND
B = SLOPE SEGMENT GRADIENT
B̄ = MEAN SLOPE ANGLE.
MEAN ANGLE CALCULATED FOR THIS PORTION OF PROFILE.
POSITION OF PROFILES ON SHEET.
NOTE: Based on Topographic sheets at a scale of 1:6,000 and contour interval of 10'.
BRITISH COLUMBIA DEPARTMENT OF HIGHWAYS
GEOTECHNICAL AND MATERIALS BRANCH
FIGURE D 4a.
QUESNEL AREA PROFILES OF PRESENTLY UNDERCUT SLOPES.
DRAWN KFRJ
TRACED
CHECKED RLC
SCALE Hor. 1" = 100'
DATE 12/9/1978
PROJ NO
REG NO H
FILE NO 11-41-02
DRAWING NO Q 90004 4
REVISIONS


RED BLUFF
POSITION OF PROFILES ON SHEET.
LEGEND.
B = SLOPE SEGMENT GRADIENT
B̄ = MEAN SLOPE ANGLE
MEAN ANGLE CALCULATED FOR THIS PORITION OF PROFILE.
NOTE: Based on Topographic sheets at a scale of 1:6,000 and contour interval of 10'.
BRITISH COLUMBIA DEPARTMENT OF HIGHWAYS
GEOTECHNICAL AND MATERIALS BRANCH
FIGURE D 4b
QUESNEL AREA PROFILES OF ABANDONED (NON-UNDERCUT) SLOPES
DRAWN KFR.
TRACED
CHECKED RLC
SCALE 1" = 100'
DATE 12/9/1973.
PROJ NO.
REG NO H
FILE NO. 11-41-02
DRAWING NO
Q 90005 5 of 11
REVISIONS


R.R.
W
1770
1740
B=3°
(1800'-SURFACE)
B=26°
HEAVILY TREED
$\bar{B}$=24°
BARLOW CREEK
1590
1555
B=9°
B=21°
BARE
1650
1670
B=10°
TREED
$\bar{B}$=21°
1720
B=40°
1740
B=16°
TREED
1760
B=8°
E
QUESNEL RIVER SIDE
NE
2060
2020
930
B=1°
B=6°
2000
1980
B=20°
B=2°
1960
$\bar{B}$=16°
TREED
FRASER PLATEAU
B=37°
1900
B=4°
BARLOW CREEK
B=1°
ALLUVIAL AREAS BARE
R.R.
1900
1920
B=8°
B=35°
TREED
1980
2000
B=24°
2030
SW
B=4°
450'
$\bar{B}$=28°
FRASER PLATEAU
LEGEND
B = SLOPE SEGMENT GRADIEN
$\bar{B}$ = MEAN SLOPE ANGLE
MEAN ANGLE CALCULATED FOR THIS PORITION OF PROFILE.
NEG. #90006 6 of 11.
NOTE: Based on Topographic sheets at a scale of 1:6,000 and contour interval of 10'.
BRITISH COLUMBIA DEPARTMENT OF HIGHWAYS
GEOTECHNICAL AND MATERIALS BRANCH
FIGURE D 4c.
QUESNEL AREA PROFILES ACROSS SMALL TRIBUTARY VALLEYS
DRAWN KFR.
TRACED
CHECKED RIC
SCALE 1" = 100'
DATE 3/9/73.
PROJ. NO.
REG. NO. H
FILE NO. 11-4 -02
FILE SKETCH.
REVISIONS



FREQUENCY HISTOGRAM OF MEAN ANGLES OF SLOPE N=72

FIGURE D5.

NEG. # 90085 7 of 11

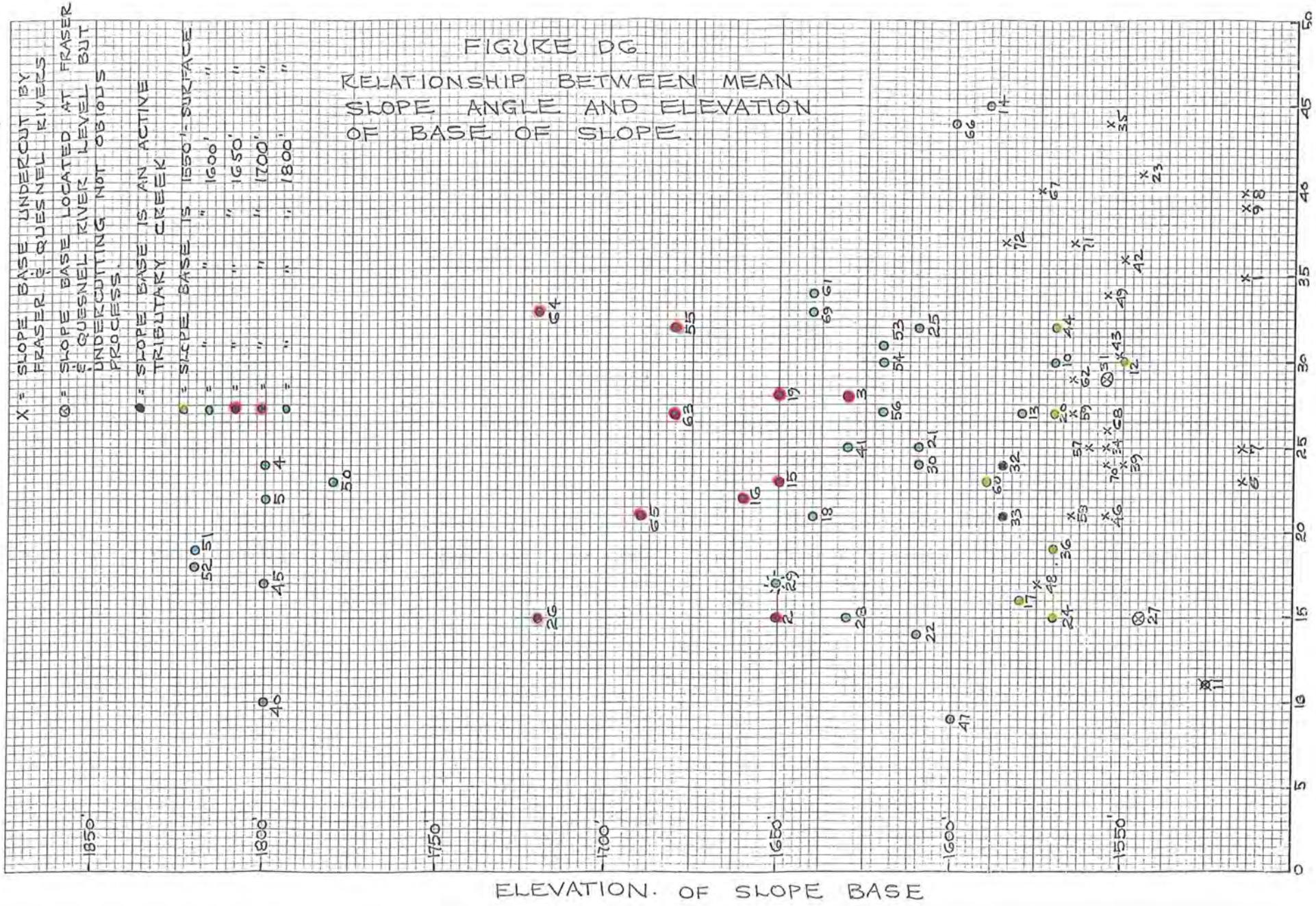


FIGURE D6

RELATIONSHIP BETWEEN MEAN SLOPE ANGLE AND ELEVATION OF BASE OF SLOPE.

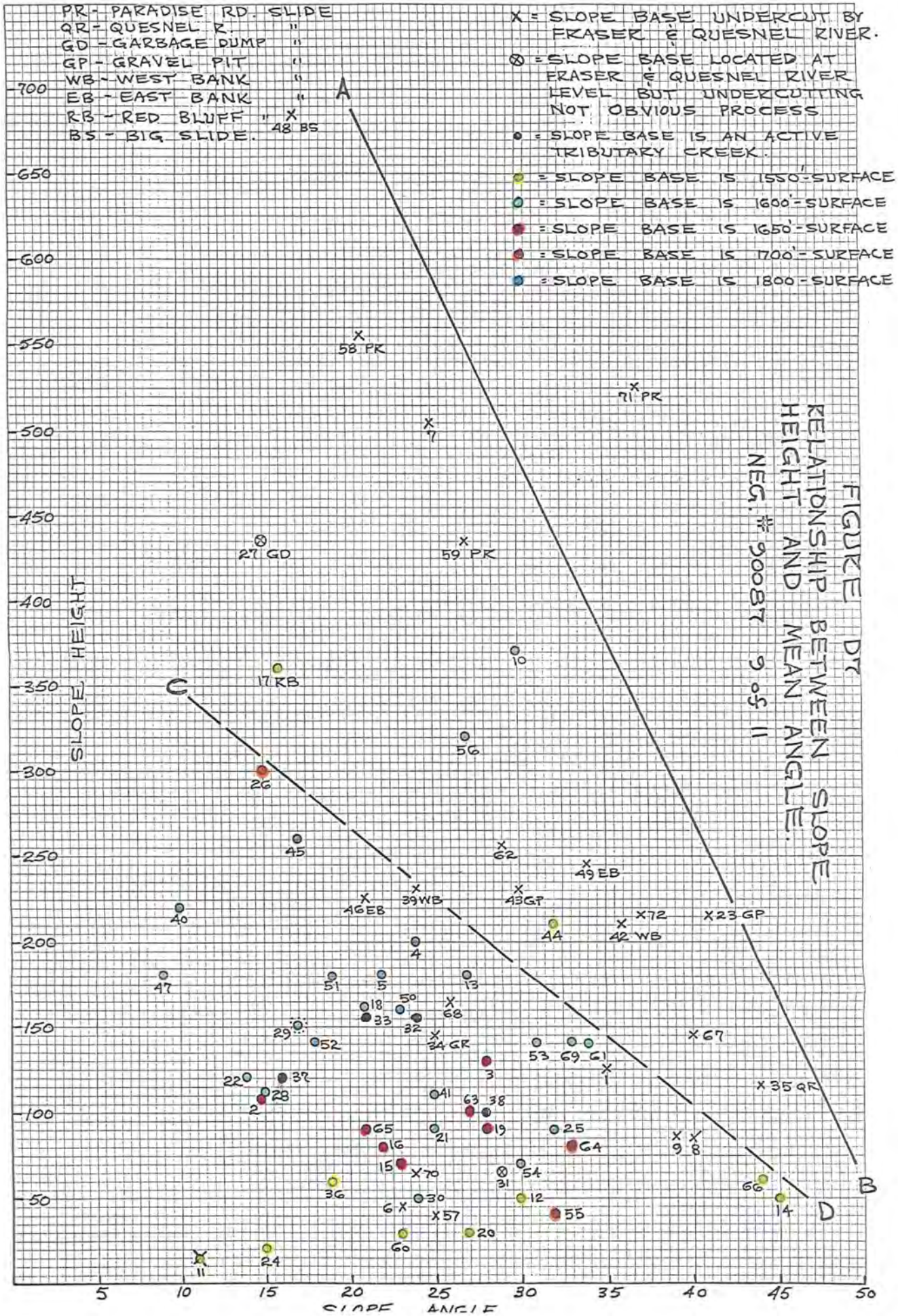


FIGURE D7
RELATIONSHIP BETWEEN SLOPE HEIGHT AND MEAN ANGLE.
NEG. # 900B7 9 of 11

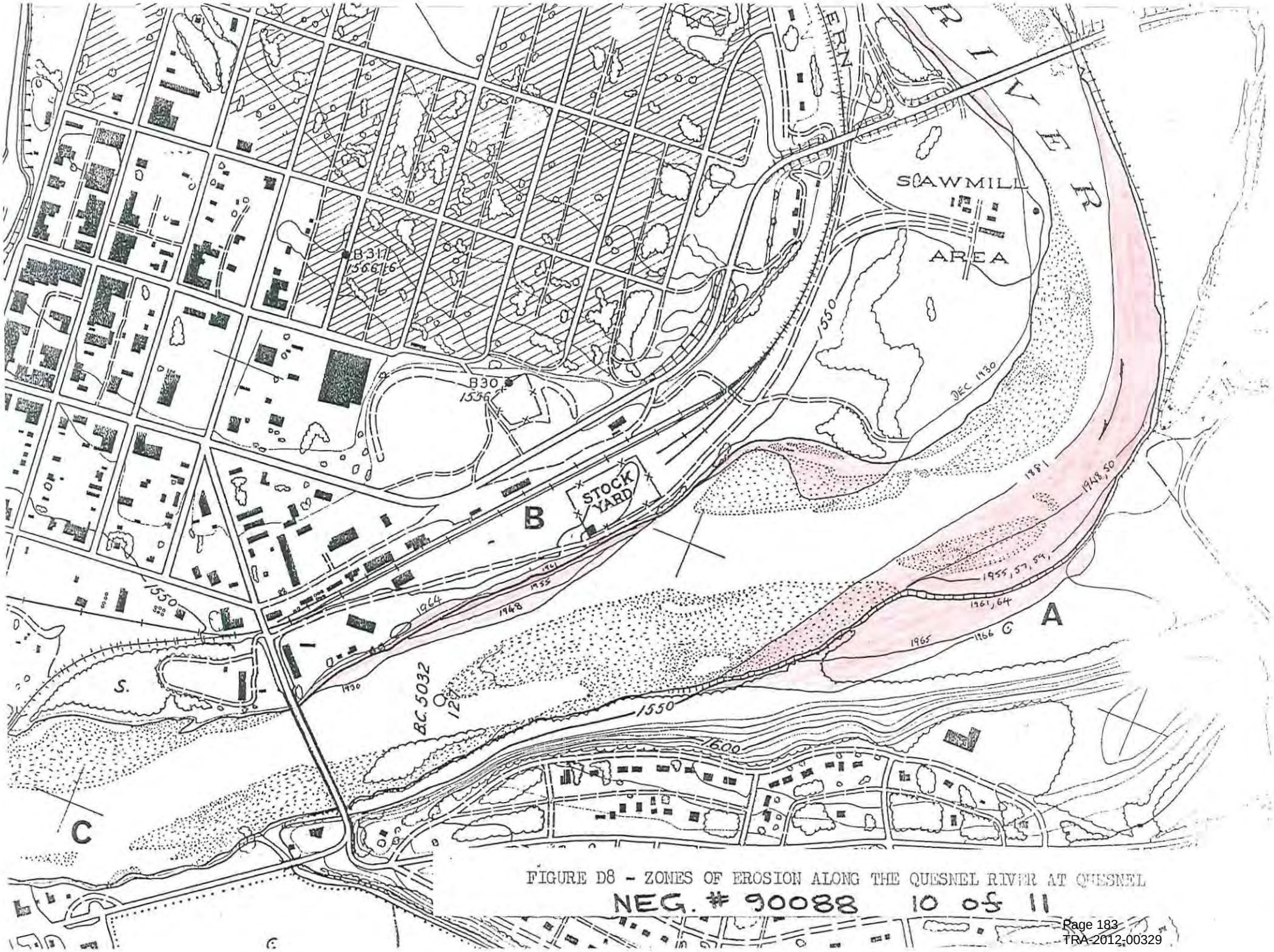
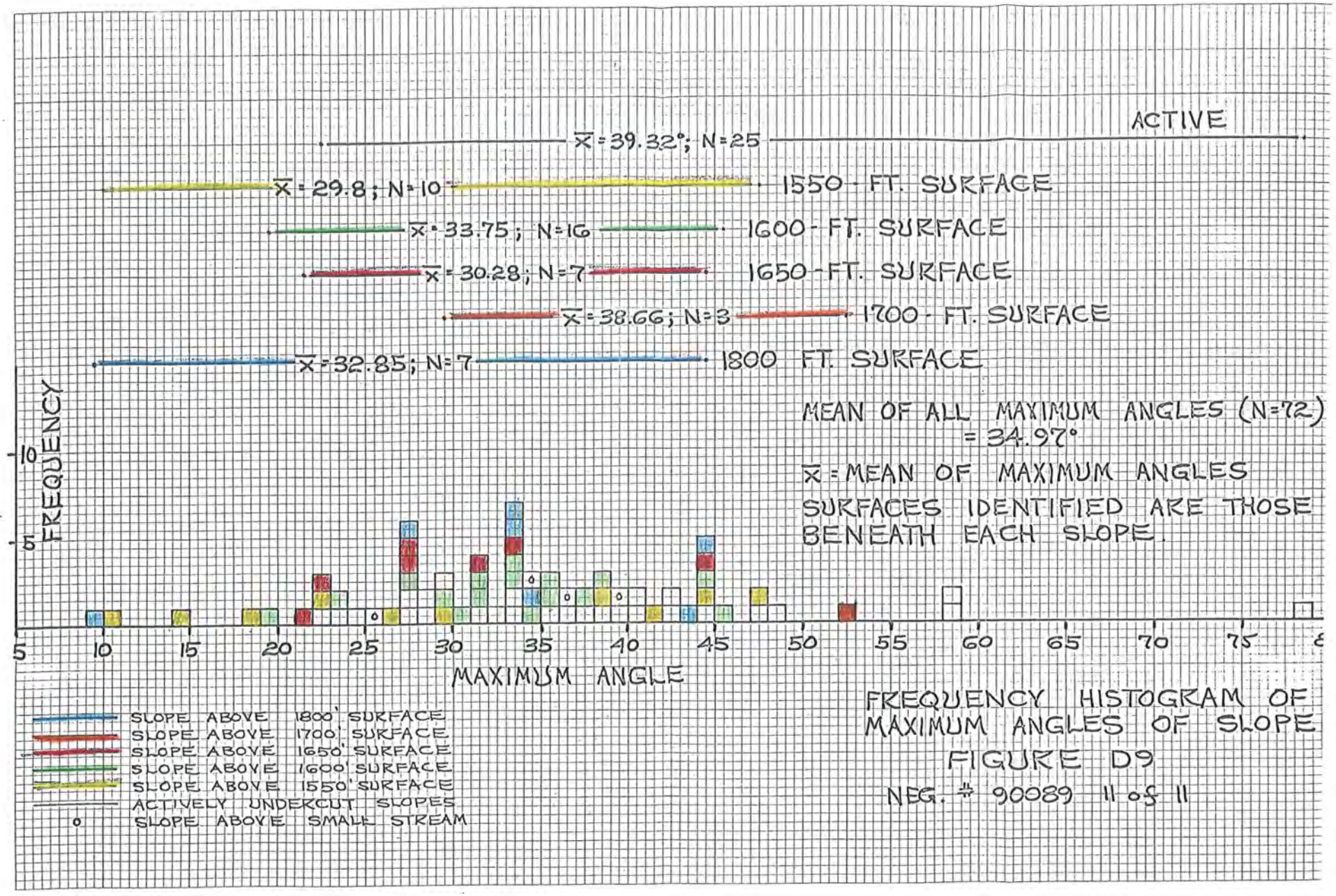


FIGURE D8 - ZONES OF EROSION ALONG THE QUESNEL RIVER AT QUESNEL

NEG. # 90088 10 of 11



FREQUENCY HISTOGRAM OF MAXIMUM ANGLES OF SLOPE

FIGURE D9

NEG. # 90089 11 of 11

APPENDIX E

FLOODING

Direct records concerning lands which are subject to flooding could not be obtained except within the built-up area of Quesnel. The Fraser River Board noted this lack of data in its report of 1956, and a search of the records of the Water Investigations Branch yielded little information. Six different series of aerial photographs from the Air Photo Library were not helpful because either (1) they were not flown during the season of flooding (May-July) or (2) they were flown during an unexceptional peak flood. The series which were examined were BC 940 (1949), BC 1143 (1950), BC 1649 (1953), BC 5070 (1963), BC 5328 (1969) and BC 5409 (1971). One flight series, BC 5462 may be useful with respect to flood-prone areas. The series was flown as a special project for the Land Inspection Division on May 29th, 1972, 17 days prior to the exceptionally high flood peak of that year. The only copies of these photographs are in use (as of August 1973) in the Land Inspector's Offices in Quesnel where they may be examined. The writers have not seen them.

One discharge-gauging station is maintained in the Quesnel area for continuous records by the Federal Government. Discharge volume and water elevation (stage) readings have also been collected for other locations close to Quesnel by the Water Investigations Branch. The later readings are not continuous and appear to be confined to a few flood seasons. Observations at the gauging stations are employed in this study as indirect evidence from which to obtain a preliminary indication of those areas which might experience flooding (see Fig. E1).

The federal observation station is listed in federal records as Station 08KE002. The gauge is located at the eastern end of the old bridge to West Quesnel. The river at this point is approximately 750 feet wide. Observations have been recorded since 1929. From 1929 to 1941, the gauge recorded average daily discharge volumes in c.f.s. Since 1941, the gauge has measured daily stages. Prior to 1972, the highest recorded stage was 1547.11 feet (May 30th-31st, 1948) and the lowest 1524.88 (March 28th, 1964), according to Water Survey of Canada, 1971. The maximum reading of 1547.80 for June 15th, 1972, is yet unconfirmed. The difference in elevation between the stage extremes is 22.23 feet.

White (1962) combined the discharge and stage data for this station and devised the flood frequency chart which is shown in Figure E2. The notes by the side of the diagram indicate that the curve is partly based on extrapolated data. The highest known water level, approximately 1549 feet, was experienced in the 1894 flood which, according to the diagram, may have a recurrence interval of 70-100 years. The highest confirmed flood stage (1948) is estimated to recur every 35 years. The flood stage of 1964 (1545.80) might be expected every six to ten years.

In Figure E3, White (1962) correlated the observations at Station 08KE002 with those at four observation stations of the Water Investigations Branch. Data have been added to White's graph which indicate estimated discharge volumes and the recurrence intervals of peak floods. It may be noted that the flood peak for 1948 at Station 08KE002 (1547.11 feet) is less than 5 feet above the average flood peak (1542.20 feet) which, in flood frequency studies, is conventionally assumed to be that stage which is equalled or exceeded every 2.33 years. Mapping of the 1948 and 1964 floods

at Quesnel is available and is reproduced in Figure E4.

The above information has been helpful in suggesting areas which may experience flooding and these are located in Figure E1. The base map for flood zoning was produced from 1961 air photographs. The map indicates that the water level at Station 08KE002 at the time of photography was between 1530 and 1540 feet. The exact elevation cannot be determined as the contour interval is 10 feet. The stage during the peak flood of 1894 (the 70/100 year flood) was approximately 1549 feet, or between 9 and 19 feet higher. From this fact, a ruling was developed for identifying potential flood zones. Upstream from the bridge to West Quesnel, the volume of discharge was presumed to be equal to or less than that at Station 08KE002. Where the river is at least 750 feet wide, as at the bridge, vertical fluctuations in stage should be equal to or less than at the bridge. In only a few places upstream is the river narrower. Along this stretch of the river, all zones which occur below the third contour above river level are zoned as possible flood areas. The elevation of the zone so defined varies between 20 and 30 feet above river level but ensures that at least the first 19 feet above river level are zoned. The zoning thus is conservative on the side of safety and the highest areas may not experience flooding once in 100 years.

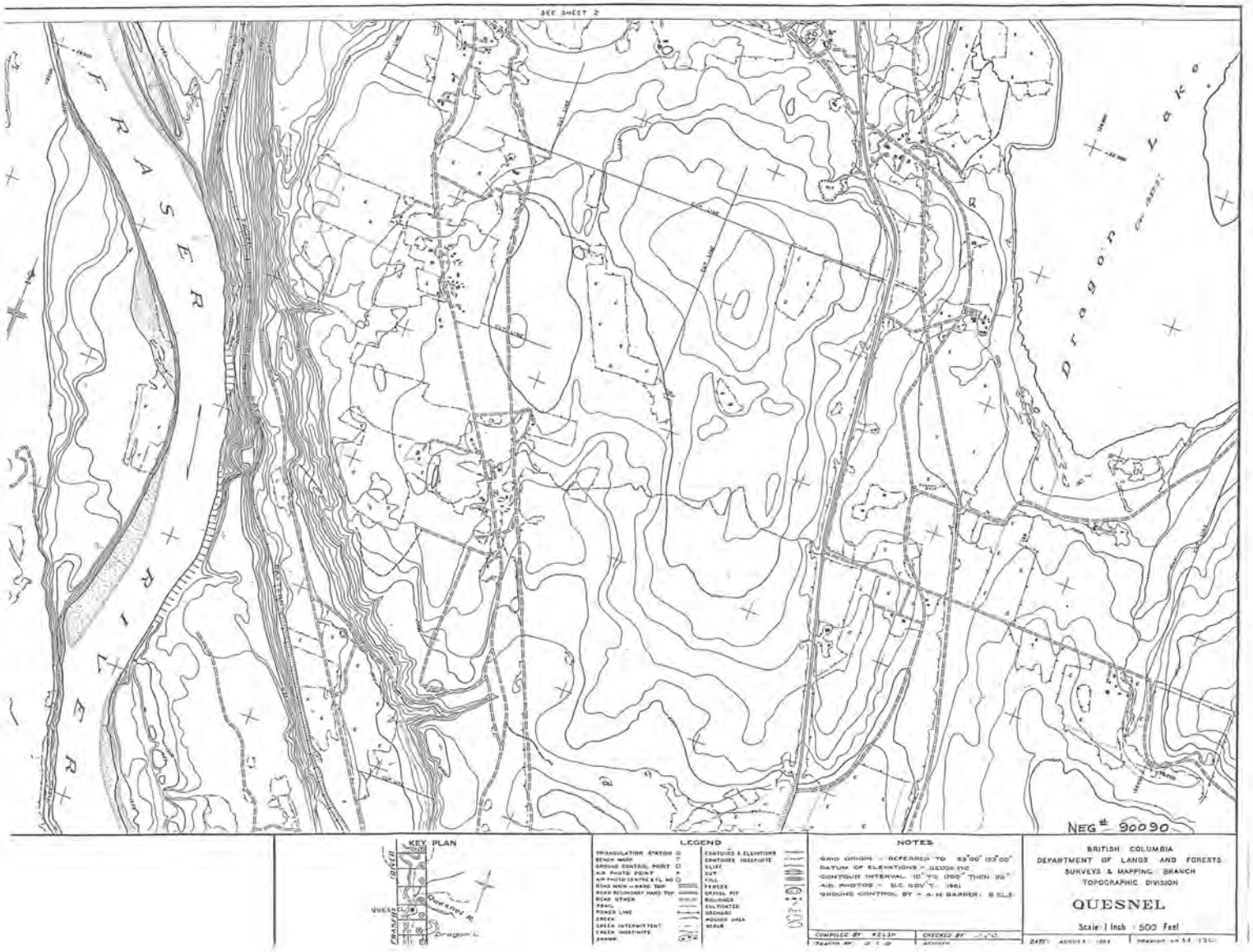
Downstream from the Quesnel River confluence, the discharge volume of the Fraser River is significantly greater than at Station 08KE002, having been augmented by as much as 20%. Station D (Figure E4) is located immediately downstream of the confluence. It appears, according to Figure E3, that the Fraser River at this point is subject to comparable stage fluctuations. The river channel at this point,

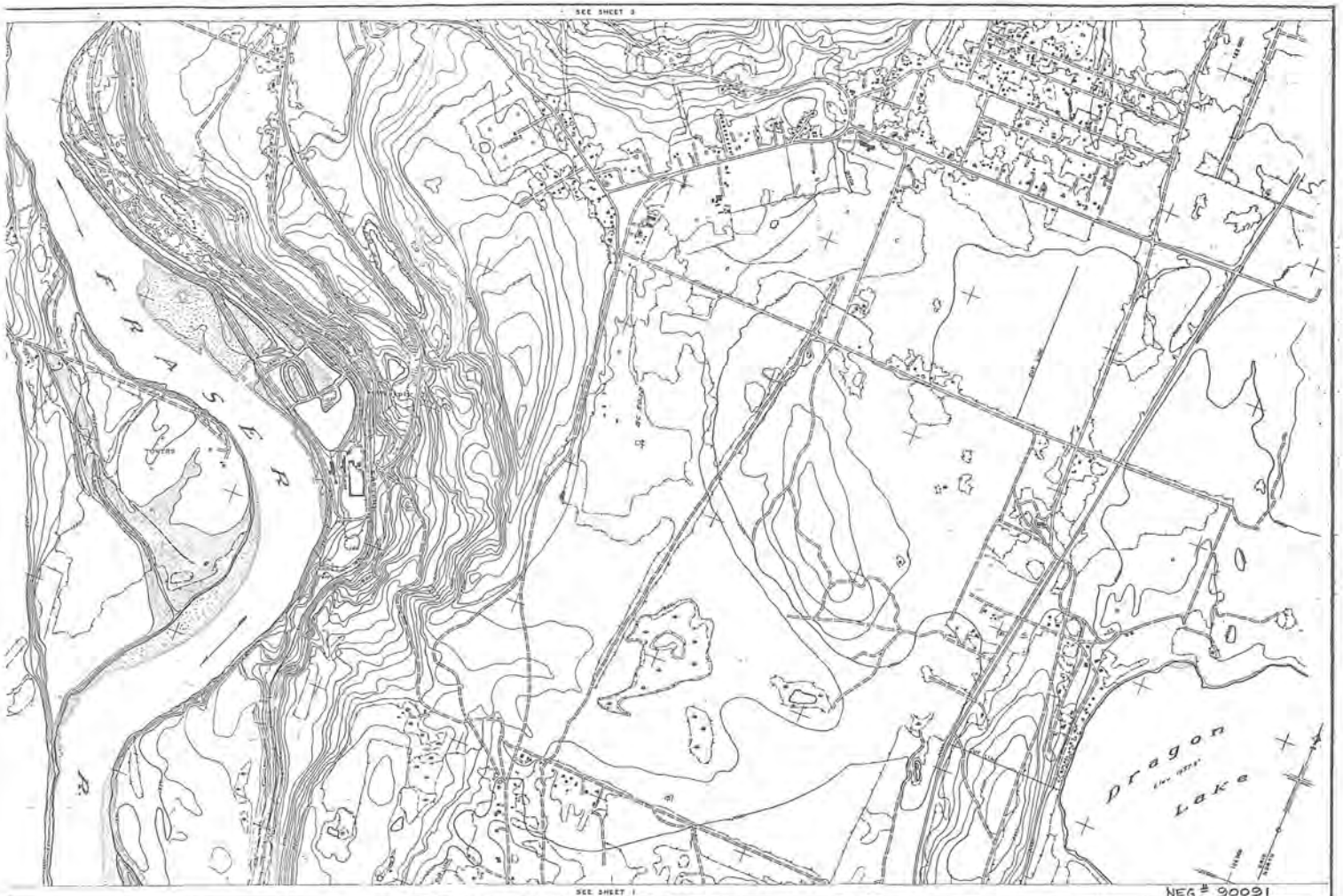
however, is exceptionally wide (greater than 900 feet across) and becomes narrower to the south so that stage fluctuations may become greater downstream. The ruling for zoning in the upstream area was very cautious, however, and was employed also in the downstream section. Lands along the Quesnel River were also zoned according to this ruling because readings at Station E (Figure E4) suggest stage fluctuations similar to those on the Fraser River (it is possible that the characteristic stage fluctuations along this river are masked at Station E by the Fraser River backwater).

It must be emphasized that this zoning is based on extrapolation from very limited data. A more accurate assessment requires detailed records from many points. The zoning procedure was designed to be conservative for this reason and the higher zoned land may be entirely free from flooding except during floods which recur only at greater than 70-to-100 year intervals.

FIG. E1 - AREAS OF FLOOD RISK

The Quesnel area is depicted on seven large-scale contour maps and zones which are within the range of the 100-year flood are shaded (in blue). Explanation of zoning methods is found in the text of Appendix E. Maps reduced to a scale of 1"=1,000' (1:12,000).


SEE SHEET 2
FRASER
RIVER
Dragon Lake
NEG # 90090
KEY PLAN
QUESNEL
Quesnel R.
Dragon L.
LEGEND
TRIANGULATION STATION
BENCH MARK
GROUND CONTROL POINT
AIR PHOTO POINT
AIR PHOTO CENTRE & FL. NO.
ROAD MAIN - HARD TOP
ROAD SECONDARY HARD TOP
ROAD OTHER
TRAIL
POWER LINE
CREEK
CREEK INTERMITTENT
CREEK INDEFINITE
SWAMP
CONTOURS & ELEVATIONS
CONTOURS INDEFINITE
BLUFF
CUT
FILL
FENCES
GRAVEL PIT
BUILDINGS
CULTIVATED
ORCHARD
MOUNDS AREA
SCRUB
NOTES
GRID ORIGIN - REFERRED TO 53°00' 123°00'
DATUM OF ELEVATIONS - GEODETIC
CONTOUR INTERVAL 10' TO 1000' THEN 20'
AIR PHOTOS - B.C. GOV'T. 1961
GROUND CONTROL BY - A. H. BARRER - B.C.L.S.
COMPILED BY
CHECKED BY
BRITISH COLUMBIA
DEPARTMENT OF LANDS AND FORESTS
SURVEYS & MAPPING BRANCH
TOPOGRAPHIC DIVISION
QUESNEL
Scale: 1 Inch = 500 Feet



NEG # 90091

KEY PLAN

LEGEND

TRIANGULATION STATION	CONTOURS & ELEVATIONS
BENCH MARK	CONTOURS INDEFINITE
GROUND CONTROL POINT	CLIFF
AIR PHOTO POINT	CUT
AIR PHOTO CENTRE & FL. NO.	FILL
ROAD MAIN or HARD TOP	FENCES
ROAD SECONDARY HARD TOP	GRAVEL PIT
ROAD OTHER	BUILDINGS
TRAIL	CULTIVATED
FOREST LINE	ORCHARD
CREEK	MARSH AREA
CREEK INTERMITTENT	SAND
CREEK INDEFINITE	
WATER	

NOTES

BASE ORIGIN - REFERRED TO 53°00' 123°00'
DATUM OF ELEVATIONS :- GEODETIC
CONTOUR INTERVAL 10' TO 1200' THEN 20'
AIR PHOTOS :- BC 604 "T" (1961)
GROUND CONTROL BY :- A.M. BARBER B.C.L.S.

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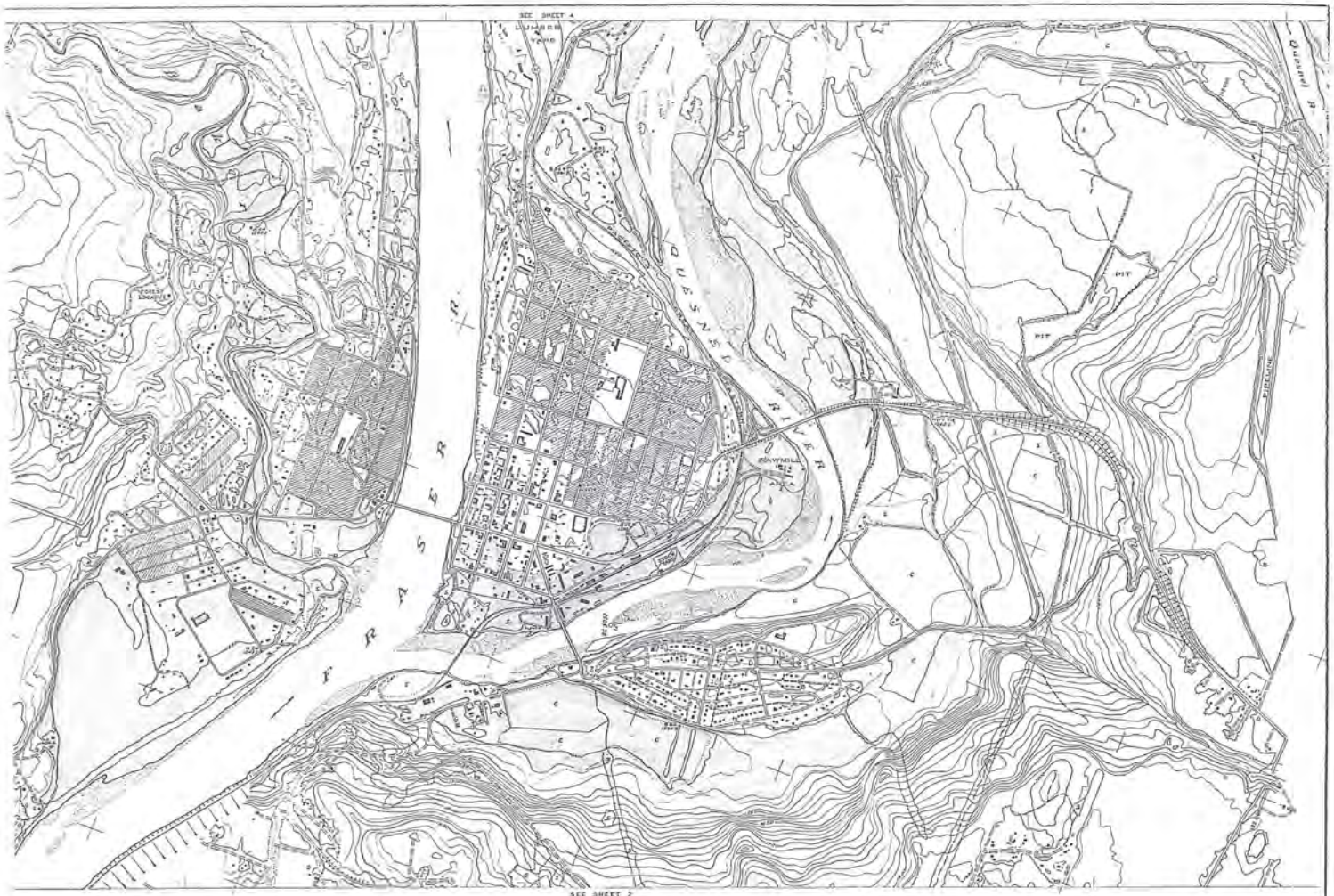
SURVEYS & MAPPING BRANCH
TOPOGRAPHIC DIVISION

QUESNEL

Scale: 1 Inch - 500 Feet

COMPILED BY KELSH	CHECKED BY J.S.C.	DATE JANUARY 1965	DRAWING NO M-135
TRACED BY M.J.P.	REVISED		

SHEET 2



KEY PLAN

LEGEND

TRIANGULATION STATION	CONTOURS & ELEVATIONS
BENCH MARK	CONTOURS INDEFINITE
GROUND CONTROL POINT	CLIFF
AIR PHOTO POINT	CUT
AIR PHOTO (LATS)	FILL
ROAD MAIN - GRAVEL TOP	FENCES
ROAD SECONDARY MAIN TOP	GRAVEL PIT
ROAD OTHER	BUILDINGS
TRAIL	CULTIVATED
POWER LINE	ORCHARD
CREEK	WOODED AREA
CREEK INTERMITTENT	SCRUB
CREEK INDEFINITE	OIL STORAGE TANKS
SWAMP	DENSELY POPULATED AREAS

NOTES

GRID ORIGIN - REFERRED TO 53°00' 122°00'
DATUM OF ELEVATIONS - GEODETIC
CONTOUR INTERVAL 10' TO 1700', THEN 20'
AIR PHOTOS - B.C. GOV'T. 1961
GROUND CONTROL BY - K.M. BARRER, B.C.L.S.

COMPILED BY WHITNEY | CHECKED BY
TRACED BY C.J.P. | REVISED

BRITISH COLUMBIA
DEPARTMENT OF LANDS AND FORESTS
SURVEYS & MAPPING BRANCH
TOPOGRAPHIC DIVISION

QUESNEL

Scale 1 inch : 500 Feet

DATE JANUARY 1966 | DRAWING NO. M-135

KEY PLAN

LEGEND

TRIANGULATION STATION	CONTOURS & ELEVATIONS
BENCH MARK	CONTOURS INDEFINITE
GROUND CONTROL POINT	CLIFF
AIR PHOTO POINT	CUT
AIR PHOTO CENTRE & NO.	FILL
ROAD MAIN - HARD TOP	FENCES
ROAD SECONDARY GRAD TOP	GRAVEL PIT
ROAD OTHER	BUILDINGS
TRAIL	CULTIVATED
POWER LINE	CROPPED
CREEK	WOODED AREA
CREEK INTERMITTENT	
CREEK INDEFINITE	
SWAMP	

NOTES

GRID ORIGIN - REFERRED TO 53° 123°
DATUM OF ELEVATIONS - GEODETIC
CONTOUR INTERVAL 10 TO 1000' THEN 20'
AIR PHOTOS - D.C. GOV'T. 1961
GROUND CONTROL BY - L.M. BARBER, B.C.L.S.

COMPILED BY: WILLIPLEE | CHECKED BY: J.C.C.
TRACED BY: J.D.H. | REVISED:

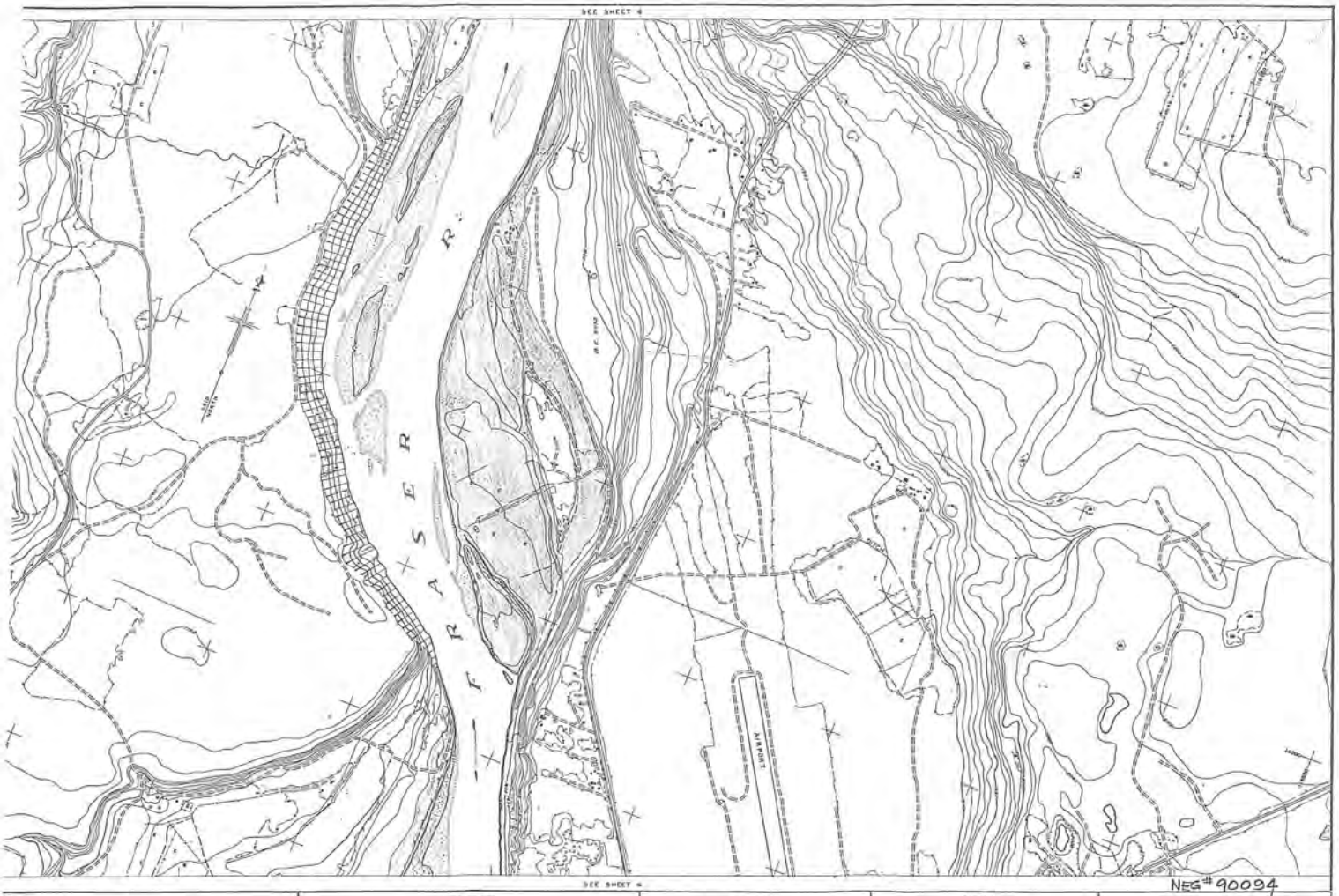
BRITISH COLUMBIA
DEPARTMENT OF LANDS AND FORESTS
SURVEYS & MAPPING BRANCH
TOPOGRAPHIC DIVISION

QUESNEL

Scale: 1 Inch = 500 Feet

DATE: JANUARY 1966 | DRAWING NO. M 135

SHEET 4



NEG# 90094

KEY PLAN

LEGEND

TRIANGULATION STATION	CONTOURS & ELEVATIONS
BENCH MARK	CONTOURS INDEFINITE
GROUND CONTROL POINT	BLUFF
AIR PHOTO POINT	CUT
AIR PHOTO CENTRE & EL. NO.	FILL
ROAD MAIN — HARD TOP	FENCES
ROAD SECONDARY MAIN'TAIN	GRAVEL PIT
ROAD OTHER	BUILDINGS
TRAIL	CULTIVATED
POWER LINE	ORCHARD
CREEK	WOODED AREA
CREEK INTERMITTENT	SWAMP
CREEK INDEFINITE	
SWAMP	

NOTES

GRID ORIGIN - REFERRED TO 53°00' 125°00'
DATUM OF ELEVATIONS - GEODETIC
CONTOUR INTERVAL 10' TO 1700' THEN 20'
AIR PHOTOS - B.C. 1424' T. 1946
GROUND CONTROL BY - A. McMANDRY, B.C.L.S.

COMPILED BY W.E.S.H.	CHECKED BY J.C.C.
TRACED BY R.J.P.	REVISED

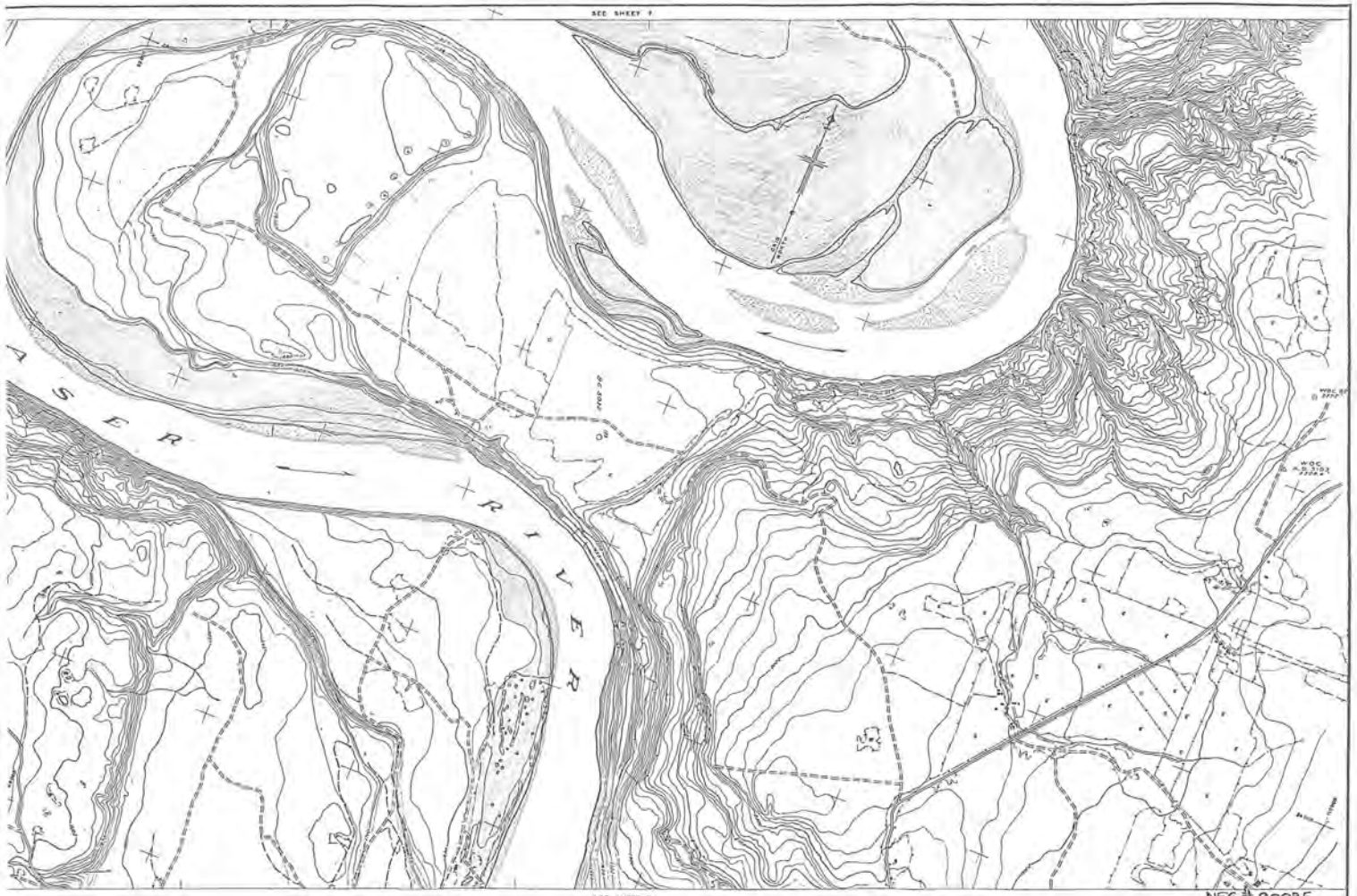
BRITISH COLUMBIA
DEPARTMENT OF LANDS AND FORESTS
SURVEYS & MAPPING BRANCH
TOPOGRAPHIC DIVISION

QUESNEL

Scale: 1 Inch - 500 Feet

DATE: OCTOBER 1955 | DRAWING NO. M 135

SHEET 3



KEY PLAN

LEGEND

TRIANGULATION STATION	CONTOURS & ELEVATIONS
BENCH MARK	CONTOURS INDEFINITE
GROUND CONTROL POINT	CLIFF
AIR PHOTO POINT	CUT
AIR PHOTO CENTRE & FL. NO.	FILL
ROAD MAIN—HARD TOP	FENCES
ROAD SECONDARY HARD TOP	GRAVEL PIT
ROAD OTHER	BUILDINGS
TRAIL	CULTIVATED
POWER LINE	ORCHARD
CREEK	WOODED AREA
CREEK INTERMITTENT	SCRUB
CREEK INDEFINITE	
SHRUB	

NOTES

GRID ORIGIN - REFERRED TO 53°00' 120°00'
DATUM OF ELEVATIONS - GEODETIC
CONTOUR INTERVAL 10' TO 1700' THEN 20'
AIR PHOTOS - B.C. 88V 7 1961
GROUND CONTROL BY - A.M. BARBER B.C.L.S.

COMPILED BY KELSH	CHECKED BY J.C.C.
TRACED BY K.S.P.	REVISED

BRITISH COLUMBIA
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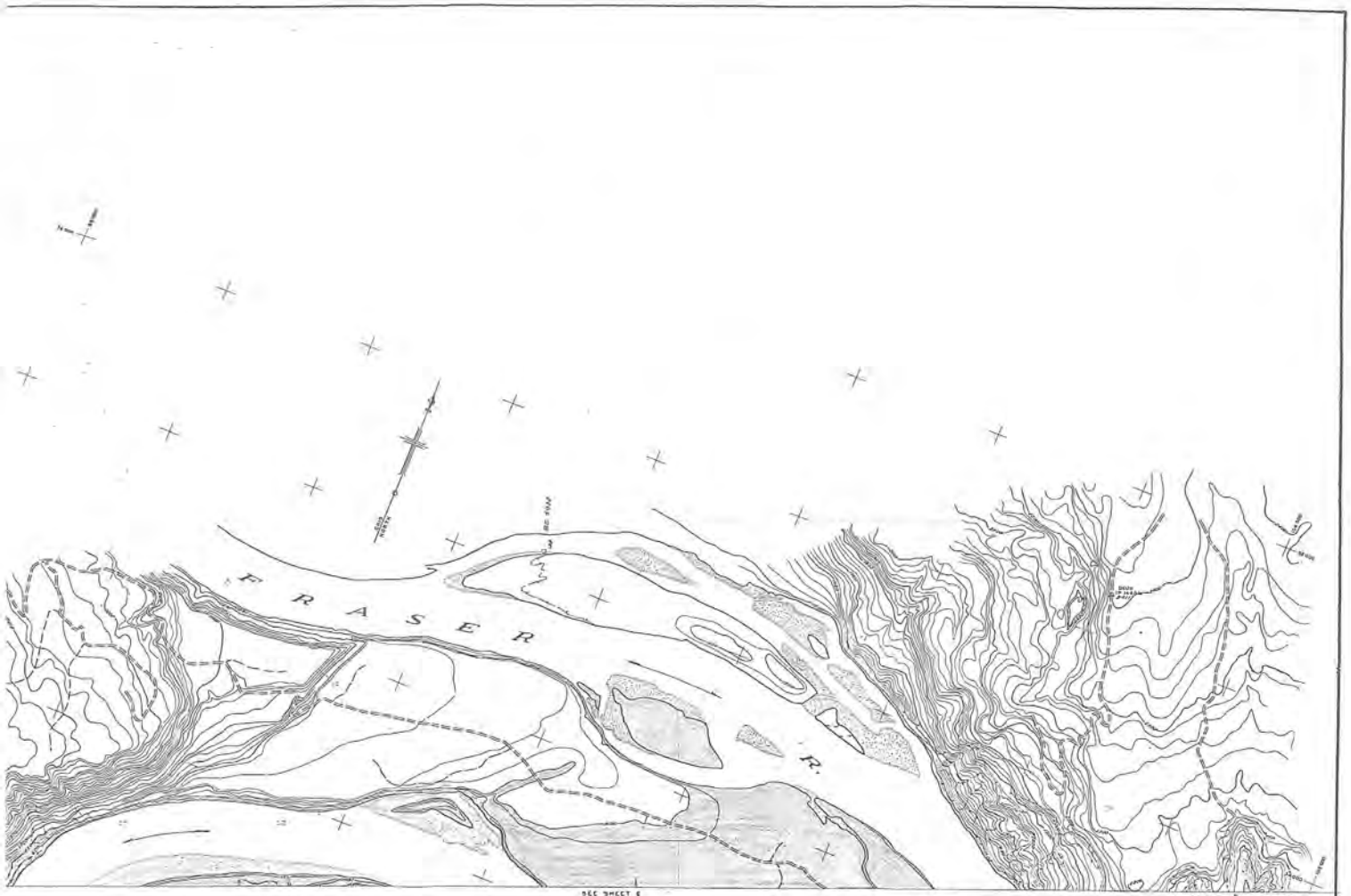
SURVEYS & MAPPING BRANCH
TOPOGRAPHIC DIVISION

QUESNEL

Scale: 1 Inch = 500 Feet

DATE OCTOBER 1963 | DRAWING NO. M 135

SHEET 6



NEG # 90096

KEY PLAN

LEGEND

TRIANGULATION STATION	CONTOURS & ELEVATIONS
BENCH MARK	CONTOURS INDEFINITE
GROUND CONTROL POINT	CLIFF
A.P. PHOTO POINT	CUT
A.P. PHOTO CENTRE & FL. NO.	FILL
ROAD MAIN - HARD TOP	FENCES
ROAD SECONDARY HARD TOP	GRAVEL PIT
ROAD OTHER	BUILDINGS
TRAIL	CULTIVATION
POWER LINE	ORCHARD
CREEK	WOODED AREA
CREEK INTERMITTENT	SCRUB
CREEK INDEFINITE	
SWAMP	

NOTES

GRID ORIGIN - REFERRED TO 53°00' 123°00'
DATUM OF ELEVATIONS - GEODETIC
CONTOUR INTERVAL 10' TO 1700' THEN 20'
AIR PHOTOS - B.C. GOV'T. 1981
GROUND CONTROL BY - A.M. BARBER, B.C.L.S.

COMPILED BY KELSH	CHECKED BY J.C.C.
TRACED BY R.S.P.	REVISED

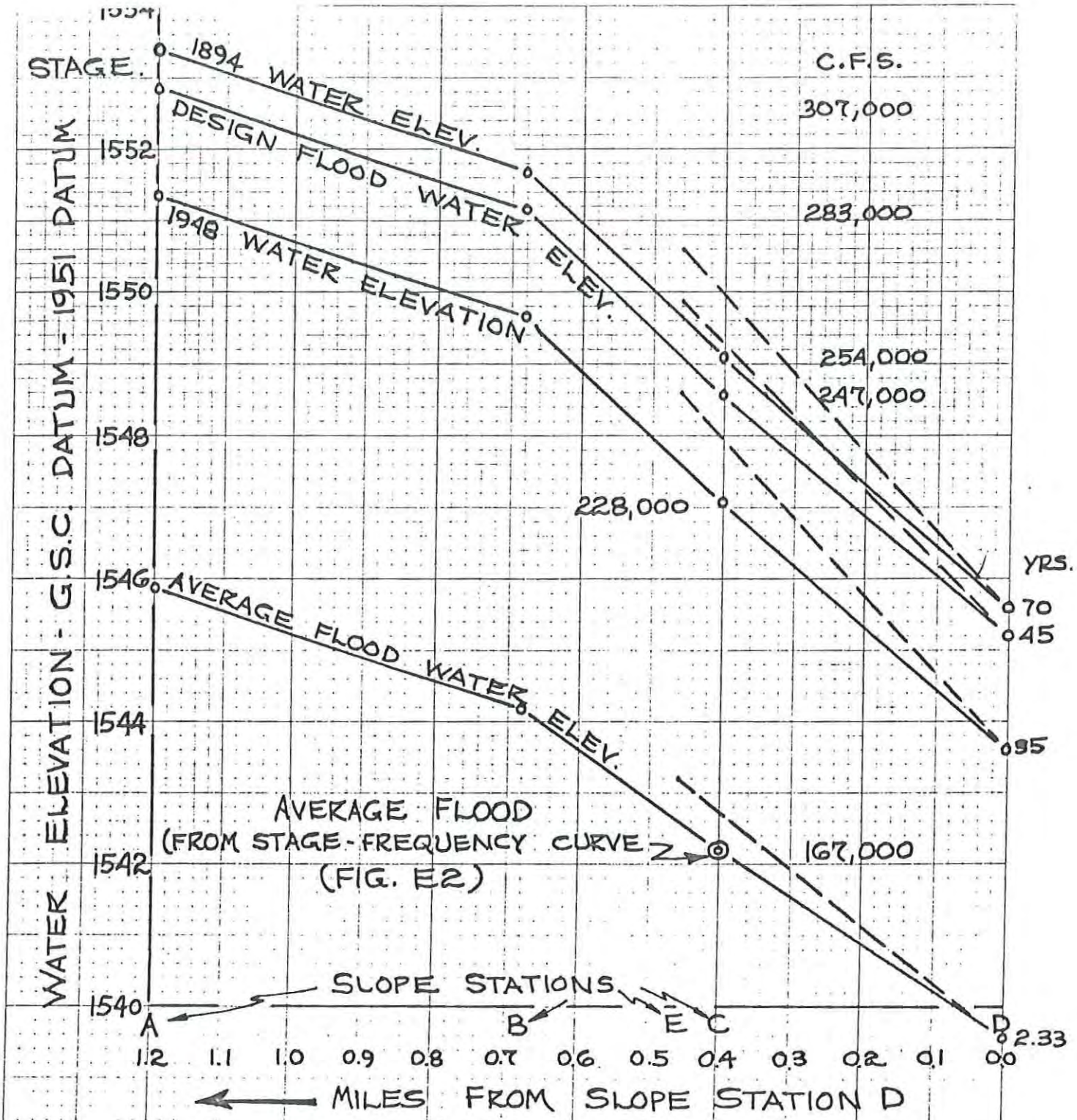
BRITISH COLUMBIA
DEPARTMENT OF LANDS AND FORESTS
SURVEYS & MAPPING BRANCH
TOPOGRAPHIC DIVISION

QUESNEL

Scale: 1 Inch = 500 Feet

DATE NOVEMBER 1985 | DRAWING NO. M 135

SHEET 7

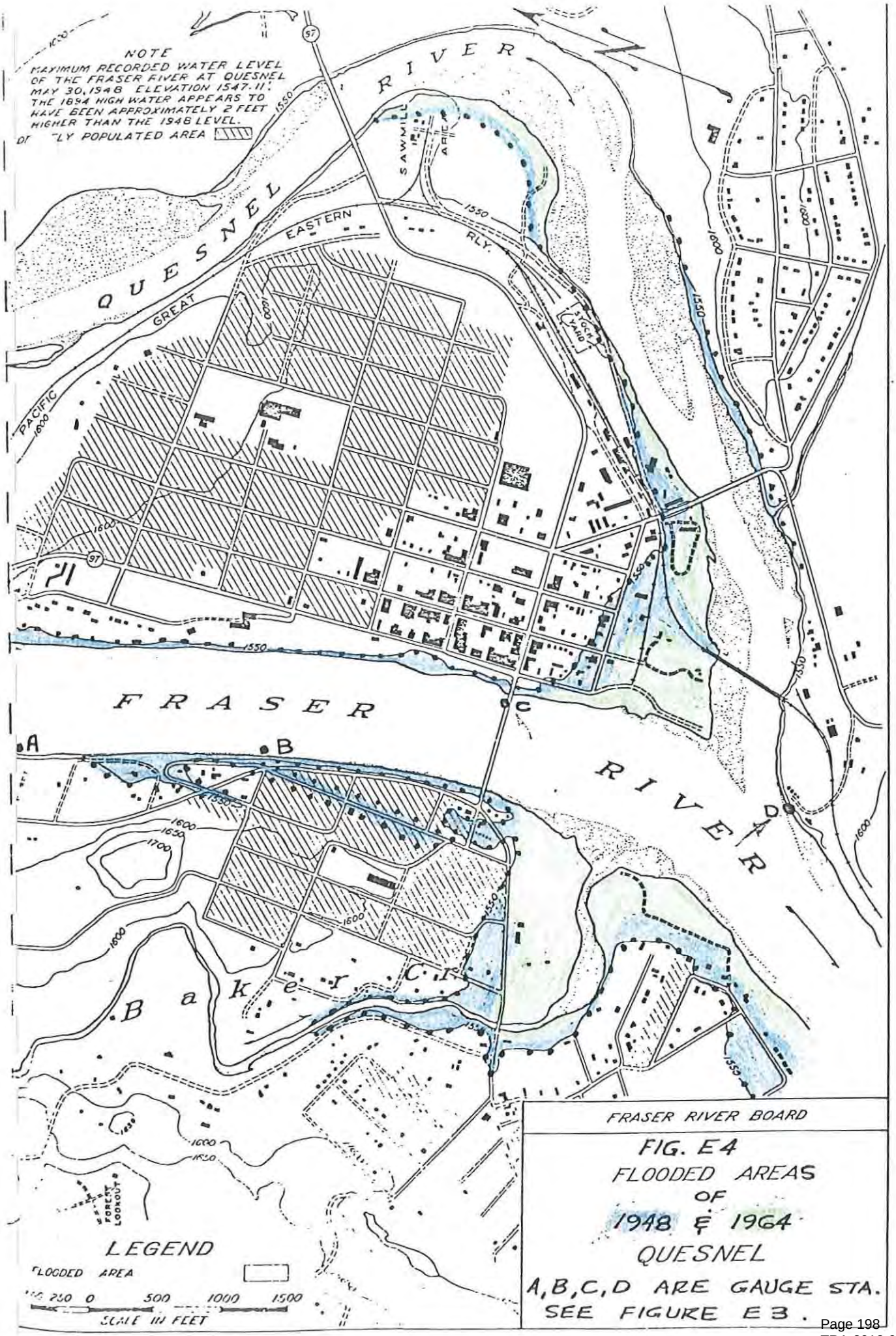


NOTE: STATIONS ARE LOCATED ON PLAN (FIGURE E4)

BRITISH COLUMBIA DEPARTMENT OF HIGHWAYS
GEOTECHNICAL AND MATERIALS BRANCH

FIGURE E3
FLOOD WATER ELEVATIONS FOR THE FRASER RIVER AT QUESNEL.

DRAWN	KFR.	SCALE Hor. Vert. –	DATE 17/9/1973.
TRACED		PROJ NO	REG NO 11
CHECKED		FILE NO 11-41-08	FILE SKETCH.


NOTE
MAXIMUM RECORDED WATER LEVEL OF THE FRASER RIVER AT QUESNEL MAY 30, 1948 ELEVATION 1547.11'. THE 1894 HIGH WATER APPEARS TO HAVE BEEN APPROXIMATELY 2 FEET HIGHER THAN THE 1948 LEVEL.
DENSELY POPULATED AREA
QUESNEL
RIVER
GREAT EASTERN RLY.
PACIFIC
SAWMILL AREA
STOCK YARD
FRASER
RIVER
A
B
C
D
Baker Cr.
FOREST LOOKOUT
LEGEND
FLOODED AREA
250 0 500 1000 1500
SCALE IN FEET
FRASER RIVER BOARD
FIG. E4
FLOODED AREAS
OF
1948 & 1964
QUESNEL
A, B, C, D ARE GAUGE STA.
SEE FIGURE E3.

APPENDIX F

INVENTORY OF LANDSLIDES

The intention in this Appendix is to provide a description and discussion of each slide with particular emphasis on the development, mode and incidence of movement and its potential for future sliding.

(A) LARGE MULTIPLE COMPLEX LANDSLIDES

(1) Big Slide, Paradise Road Slide

The slides at the Big Bend were some of the first to be noted in the region and are situated on the outside of two very involuted meanders. The slides both at Big Slide and Paradise Road Slide show a great complexity in their development which seems to reflect the heterogeneity in their constituent materials and the variety of processes at work.

(a) Big Slide, an omnibus word for the complex on the east bank of the Fraser is seen to be a collection of 14 slide sites (see Fig. F1). They are developed on a variety of materials (see Geological Sections B6 and B10) i.e. alternating clays, clay-shales, silts, sands and gravels of Miocene age of the Middle Fraser River formation capped by Pleistocene till. The geotechnical consequences of such a combination of materials has been discussed in Section IV.

There appear to be three groups of slide sites (Fig. F1), site B1 on the upstream side, sites B2-B7 located on the gully and sites B8-B14 on the downstream side of the point of inflection of the meander. Their occurrence is undoubtedly related to the erosion of the high slope flanking the Fraser River Plateau which at this point is about 600' above the river surface. An

additional factor that is key to the situation is the existence of a high-level aquifer in the area which is the source of seepage waters. The writers noted seepage right at the retreating head of B9.

In general, slope transformation seems to take place through a variety of processes which include gully erosion, flow slides and retrogressive slides. The formation of gullies appears to be the first stage of development followed by failure in the oversteepened gully side. This failure is sometimes a flow and sometimes a retrogressive failure which progressively eats its way back into the slope. Flow modes seem restricted to the lower half of the slope which may reflect changes in moisture content and/or material changes. The retrogressive failure mode is observed at the head of B9 (Plates F2 and F3).

With reference to the incidence and rate of erosion in general (including gully and slide activity) a comparison between airphotos flown in 1949, 1963 and 1969 is instructive (cf. Fig. F1). One of the most active has been slide B9 which since 1949 has completely devoured the field at its head. We have calculated that the annual loss through erosion is approximately 5000 sq. yds. The retreat distance of 100 yds. around the slide perimeter (1000 yds. long), indicates a rate of retreat per lineal yard of 5 yds./yr.

(b) Like Big Slide, Paradise Road Slide is a general name for a similar complex of slides downstream of Big Slide on

the western banks of the river. It is seen to be a collection of about 13 slides sites (see Fig. F1) and shares with Big Slide a complexity of geology (see Geological section B7) and slope transformation. There are two differences in the geology which tend to have an effect on the rate and type of landslide processes. First, the presence of a cap rock (basalt) beneath the till cover results in a steep slide scarp being maintained (Plate F6) and limits the amount of backward retrogressive sliding. Second, cemented gravels are present at the base of the slope, adjacent to the river which in turn results in reduced basal erosion of the slope (Plate F4). On the whole the slides at Paradise Road seem to be less active than those at Big Bend and there seems to be less gullying. It is noted that the same Middle Fraser River soils which are silts and fine sands at Big Bend are more gravelly at Paradise Road.

Many of the slides appear to be re-activated old ones. On the 1949 photos the outline of slide P13, for example, is apparent through thick vegetation cover but in the 1969 photos, it has lost all its vegetation and appears very active. (Cf. Plate F5).

(2) Quesnel River Slide

The Quesnel River Slide is another old slide that is associated with the Fraser Plateau surface. We may assume that similar factors such as heterogeneity of materials and ground water sources are present as at the Big Bend. The materials affected are once more the Middle Fraser River series and these sediments have been undercut by the Quesnel River,

causing the retrogressive failure situation which exists at the present. Vast amounts of seepage water were noted in the body of the slide which seems to have a large width relative to its length, indicating that sliding and not flowing is the dominant process. Recent slides at its east and west margins are still very active. (See Fig. F2 and Plates F7 and F8)

(3) Red Bluff Slide Complex

The very active Red Bluff Slide complex extends from Dragon Creek to Plywood Hill and is illustrative of the problem of landsliding in relation to both subdivision development and the high rate of slope transformation. A complex of about 12 slides (see Fig. F3 and Plate F9) has been developed on the flanks of the 2000' surface and was probably initiated when the Quesnel River flowed at the base of the slope where an abandoned channel now exists; the absence of the river has obviously had little effect on the incidence of sliding. The materials involved in the slides are Fraser River sediments, possibly from the Lower series. Section B4, although taken at Plywood Hill probably gives an indication of the complexity of materials. It is noted in Branch reports that deal with the possibility of constructing a by-pass through Red Bluff that the source of seepage was from "upslope". This would indicate that the high-level aquifer is an extremely important factor in the maintenance of sliding on Red Bluff.

Modes of failure range from retrogressive failure in the upper portion of the slope to flows in the lower portion of the slope. A noticeable scarp is seen at the head of the slide area which will probably be enveloped by further sliding. Much of the movement is caused by the blockage of granular drainage layers by mudflow material from above. The possibility of increasing landslide activity seems to be higher in the steeper section near Dragon Creek.

A demonstration of the incidence of sliding has been afforded by the virtual destruction of the old P.G.E. grade through the slide area.

It could not be located on the ground. A second line of communications has also been destroyed, at least partially, by landsliding, i.e. the old road up Red Bluff Hill (cf. Fig. F3). It was still workable up until, at least, the mid-fifties.

A slide on Red Bluff in 1958 destroyed some houses that were probably located on the rim of the slide area. It is thought that due to the proximity of other homes to the edge of the slide area, destruction of houses by continued retrogressive sliding is inevitable.

(4) Beaver House Lake Slide

Of all the slides examined, this is one of the more problematical. The existence of a large slide here is not in doubt; a distinct scarp can be detected on the fringe of the 2000' surface and slump topography in the form of hummocky ground can be made out between this scarp and the mill. The outline of the slide is far from clear (See Fig. F3). Beaver House Lake is apparently in one of the depressions that has formed between successive sliding blocks. The slide is probably in the complex sediments of the Lower Fraser River series and is likely to be affected by the high-level aquifer noted above in the discussion of Red Bluff.

(5) Westply Slide

The B.C.R. has negotiated the slide with some difficulty and the movement appears to take place on the southern margins of the bigger Beaver House Lake Slide area (Fig. F3). A creek drains the 2000' plateau to the east and seems to supply the slide with water. Railroad workers have endeavoured to drain the slide by an incredible assortment of pipes and culverts and have failed in their effort. Movement is of the retrogressive type with fairly large blocks being involved (see Plate F14). The materials involved in the slide are probably sediments of the Lower Fraser River formation and consist of alternating clays, gravels, silts and sands with lignitic layers at various horizons (See Geological Section B6 and Plate B8).

(6) West Quesnel Slide

The West Quesnel Slide is very similar to the slide at Westply. A similar type of movement seems to be operative, the materials are somewhat similar and seepage is an important factor. It is actively affecting the highway (relocation work was in progress when the writers were in the area) and also some houses that find themselves on the slide block. Continued erosion by the Fraser will ensure its movement in the future (Fig. F3).

(7) Quesnel Hill Slide

Yet another complex slide that appears on the flanks of the 2000' surface (Fig. F2). The factors of complex geology and the existence of the high-level aquifer seem to account for the slides which are traversed by Highway 97. Movement is reported on the highway and is probably related to continued movement in the slide. The toe of the slide area seems related to the 1800-foot surface and movement was probably initiated when either the Fraser or the Quesnel River was flowing at that elevation.

(8) Moose Heights Slide

Another complex, which seems inactive at present, is related to the Fraser Plateau; its toe appears to be related to the 1800-foot terrace level (Fig. F4).

(B) COMPLEX SLIDES

This group of slides includes those mass movements which clearly have a component of slump and flow (See Fig. 3 in text). The slide at Plywood Hill and the Pleateau Slide in West Quesnel are included in this group.

(1) Plywood Hill Slide

The Plywood Hill Slide (Fig. F3) has been extensively investigated by this Branch and for a detailed account of the slide reference should be made to Branch Reports. It is a good example of a complex slide exhibiting

both slump and earthflow modes of failure. It is a recent movement, the major displacement having occurred in the late summer of 1965 and a successive one in August, 1966. It took place in a gulley which formerly ran down from the Red Bluff plateau area to the Fraser River.

At the head of the slide the concentric cracks associated with slump movement are observed (Plate F10) whilst in the lower two-thirds, characteristics of flow are observed e.g. slickensides formed by side shear (Plate F12). Although horizontal drains have been placed in the slide to stabilize it, further movement has taken place (the same drains have become part of the slide debris). Movement has occurred as late as the Spring of this year when it blocked the railroad track and appears to be related to the development of excess pore-pressures in the vicinity of the impervious lignite layer.

The slide is related to the geometry of the underlying lignite strata and the mass appears to be moving on this stiffer sloping material (Fig. F5). The geology of the slide material can be seen in Fig. F5 and in Geological section B4.

(2) Plateau Slide

Plateau Slide is a similar movement to Plywood Hill Slide. However, due to the recent detection of this slide, it was not visited in the field. It appears from air photographs that the slump part of the slide is on the Fraser Plateau (Fig. F3) whilst the flow part is spread over the 1740 - 1780 foot surface below.

(C) COMPOUND SLIDES

These are distinguishable from the first group of slides since they involve a relatively simple movement (illustrated in Fig. 3 in the main text).

GROUP 1

Slides in this group show a striking similarity in the following respects:

(a) They affect either the 1800-foot surface (East Bank, West

Bank, Gravel Pit) or the lower 1700-foot surface (Garbage Dump).

(b) Wide dimensions in relation the length.

(c) Occurrence at the points of inflection on the outside of a meander.

(d) Seepage water is not in evidence i.e. not profuse.

(e) Causes seem to be undercutting of slope or sliding along a clay layer at depth.

(f) All in Middle Fraser River series with gravel cappings.

(1) East Bank Slide

The largest slide in the group. Probably existing slide area is located within an older slide mass (Fig. F4 and Plate F19) on the outside of a meander. Sliding will continue (for materials see Geological Section B8).

(2) West Bank Slide

A very recent slide on the West bank of the river which occurred between 1963 and 1969. The large body of the slide consists of gravels (see Fig. F4 and Plates F15A-B).

(3) Garbage Dump Slide

The Garbage Dump Slide continues to move although it appears to have failed over ten years ago. It is more complex than the others in the group and seems to be water-assisted. (See Fig. F4 and Plate F17)

(4) Gravel Pit Slide

Very similar to the West Bank Slide i.e. gravels at the top (which are being developed by the Department of Highways). Slide area seems to be moving downstream, a fact which may be related to meander migration. (See Fig. F4 and Plate F18)

GROUP 2

Group 2 involves the slides in the town of Quesnel itself i.e. the A & W Slide and the Front Street Slide. Both have been extensively investigated by this Branch.

(1) A & W Slide

Under a surficial cover of recent gravels, silty clay and clayey silts of Tertiary age failed along their boundary with a lignite seam (an impervious overconsolidated clay shale). The slide was caused by excess pore-pressures. Water coming from a car-wash on the slide site i.e. across the road, effluent from septic tanks and water from water mains broken in the initial movement were the source of excess water. As far as known, minor sliding is still taking place.

(2) Front Street Slide

The Front Street Slide is rather similar to the A & W Slide. It is a movement in extremely dense overconsolidated Tertiary silts. It appears (Brawner, 1956) that the slide site has had a long history of instability (See Section IV).

(D) SLUMPS

Many of the slides in this group have been induced by activity associated with construction, the exceptions being the Subdivision Slide and the slides along Baker Creek. A great deal of variation is found in the materials involved in movements that are relatively small and simple.

(1) Dragon Creek Fill Slide

A failure on Highway 97 which was investigated by this Branch. The apparent cause of failure was the loss of strength which certain clays experienced during saturation. Seepage occurred through sand layers and/or lenses within the clays. The surcharge of the fill also contributed to the movement. Materials involved were very probably silts and sands of Late-Pleistocene Age. (Fig. F2)

(2) Barkerville Road

Just before the second hairpin on the Barkerville Road (Fig. F2) a slump has occurred in a cut-slope consisting of Pleistocene lacustrine silts. The material is varved and relatively non-fissured. There are

indications that sliding is taking place deeper in the slope (cracking of the pavement was observed). Seepage from an aquiferous gravel capping and oversteepening of the slope appear to be the causes.

(3) Pipeline Slide

This slide was seen from the northern side of the Quesnel River (Fig. F2). High-level saturated silts (probably Pleistocene) seem to be the material involved. Stripping of the vegetation and seepage are the probable causes.

(4) Highways Slide

A slump which occurred on the West Quesnel Road. Materials involved are fine sands of the Fraser River formation which had been saturated by water from an upslope seepage line. There appears to be an element of flow in the debris.

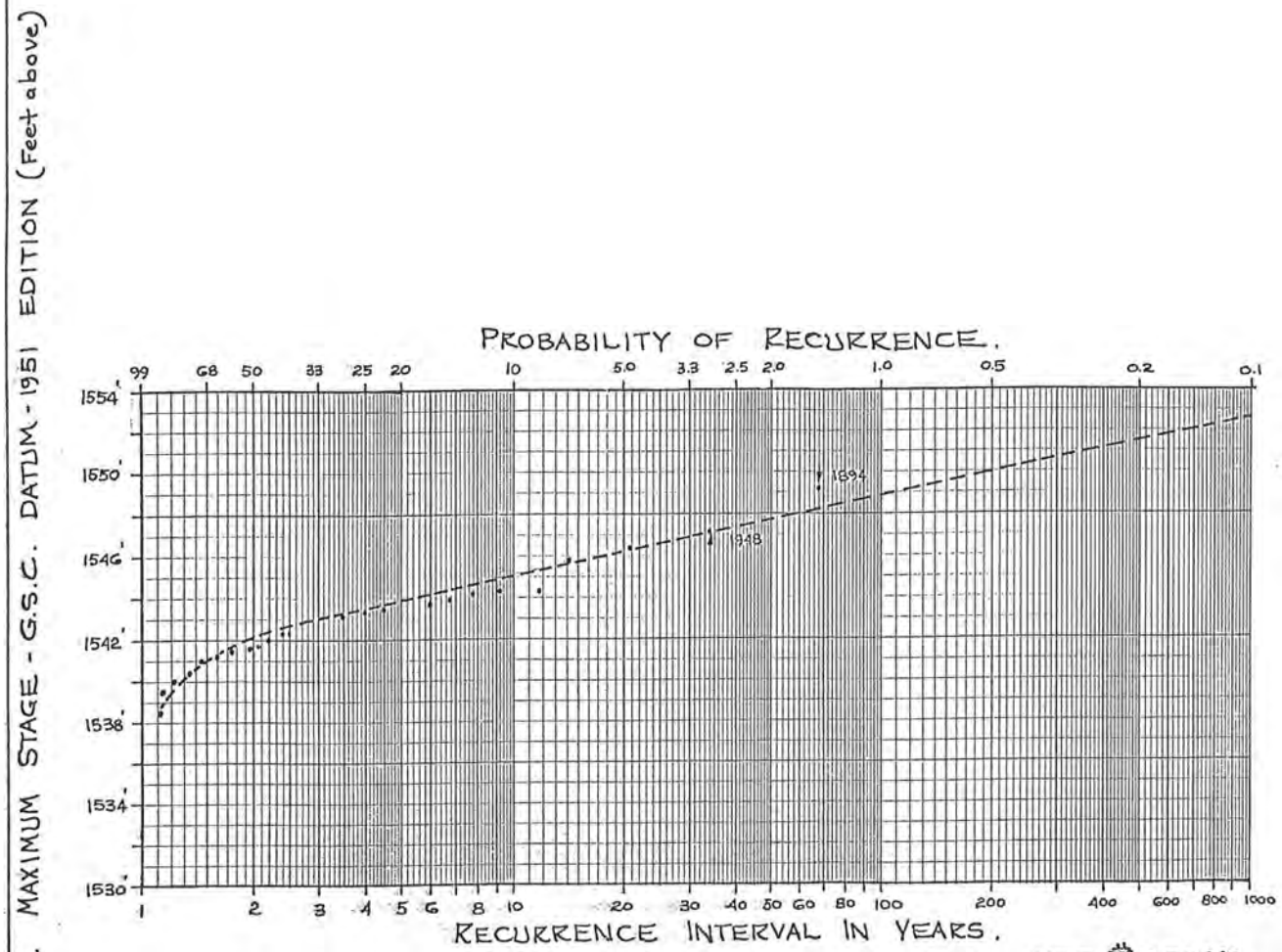
(5) Baker Creek Slides

Small slumps occur on the cut banks of the meandering Baker Creek. They are occurring in dirty gravels and sands of Pleistocene materials. Some houses are perilously near to parts of the Baker Creek channel and will inevitably collapse into the river unless rip-rapping is carried out on the banks.

(6) Subdivision Slide

This is a series of slides that has developed on the margins of the 2000' surface in West Quesnel. It is noted that five gullies have developed and have continued to expand by a combination of gully erosion and slumping (see Plates F20, F21, F22). It is a good example of how larger slides are initiated (cf. discussion on the slides at Big Bend). Seepage from silty layers was noted in the slide area, the source probably being the high-level aquifer. The materials in the slides are probably silts, dirty sands and gravels from the Lower series of the Fraser River Group. Rotted Lower Lavas were noted at the base of the slope and could

be a factor in the development and enlargement of the slide. As noted in Section VII, the danger both to houses at the top and houses on the bottom of the slope is substantial (Fig. F3).



NOTE:

1. STAGES FOR THE PERIOD 1929-1960 ARE FROM W.R.B. RECORDS. 1912-1928. STAGES WERE DERIVED TO ADJUST TIME BUT NOT PLOTTED.
2. STAGES 1953-1960 ADJUSTED TO OBTAIN UNREGULATED FLOWS DUE TO NECHAKO DIVERSION.
3. $n = 67$ $T = \frac{n+1}{m}$

   FLOOD FREQUENCY FORMULA

   N = number of years of record

   m = RANK, Highest rank being 1
4. EXTENDED IN TIME BY BENSON METHOD.

FRASER RIVER AT QUESNEL

STATION 08KE002.

NEG. # 90097
8 of 10

BRITISH COLUMBIA DEPARTMENT OF HIGHWAYS
GEOTECHNICAL AND MATERIALS BRANCH

FIGURE E2

FREQUENCY CURVE
PERIOD 1912-1960 + 1894.

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C		TRACED	PROJ NO. REG NO. H
B		CHECKED	FILE NO 11-41-02
A		APPROVED	APPROVED
	REVISIONS		

DATE 17/9/1973

FILE SKETCH.

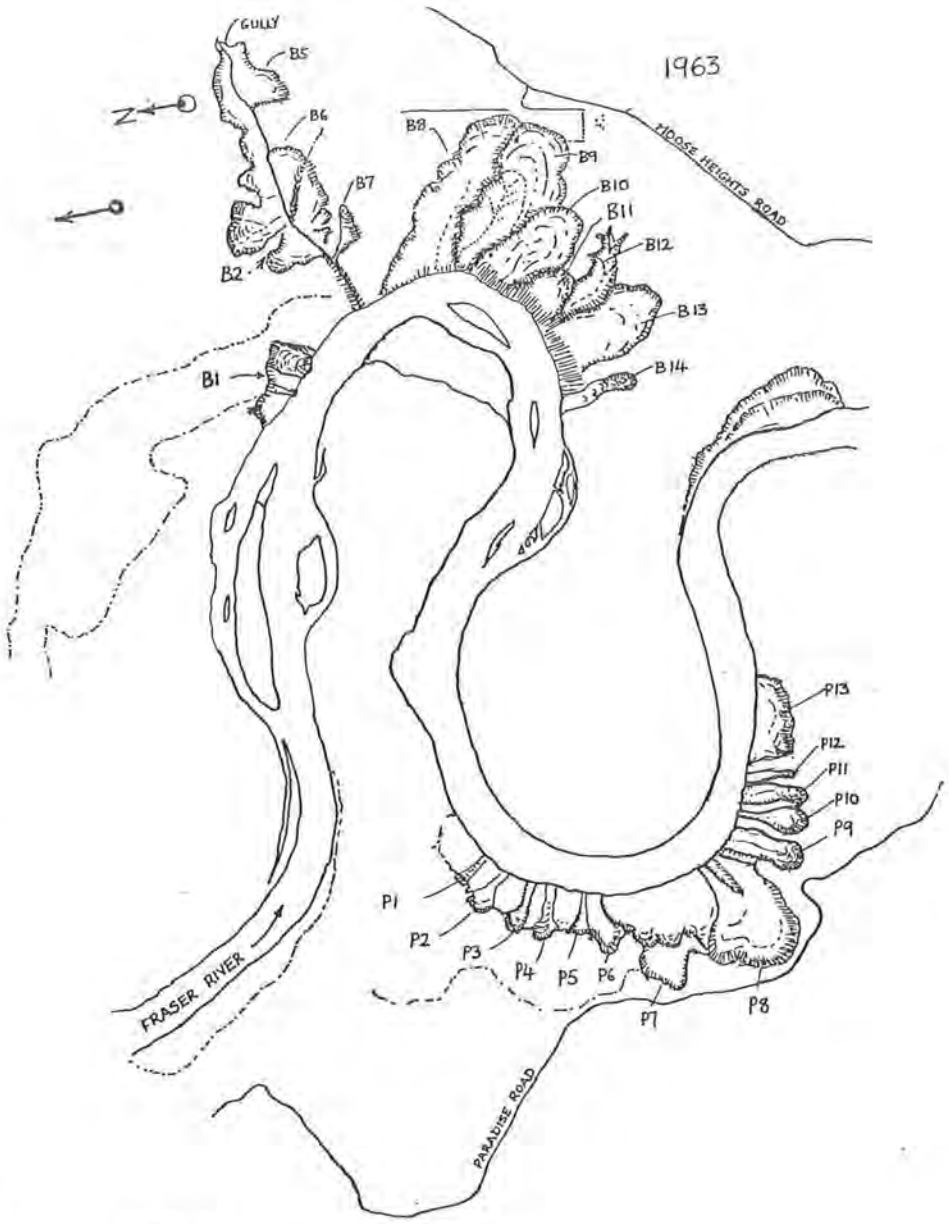
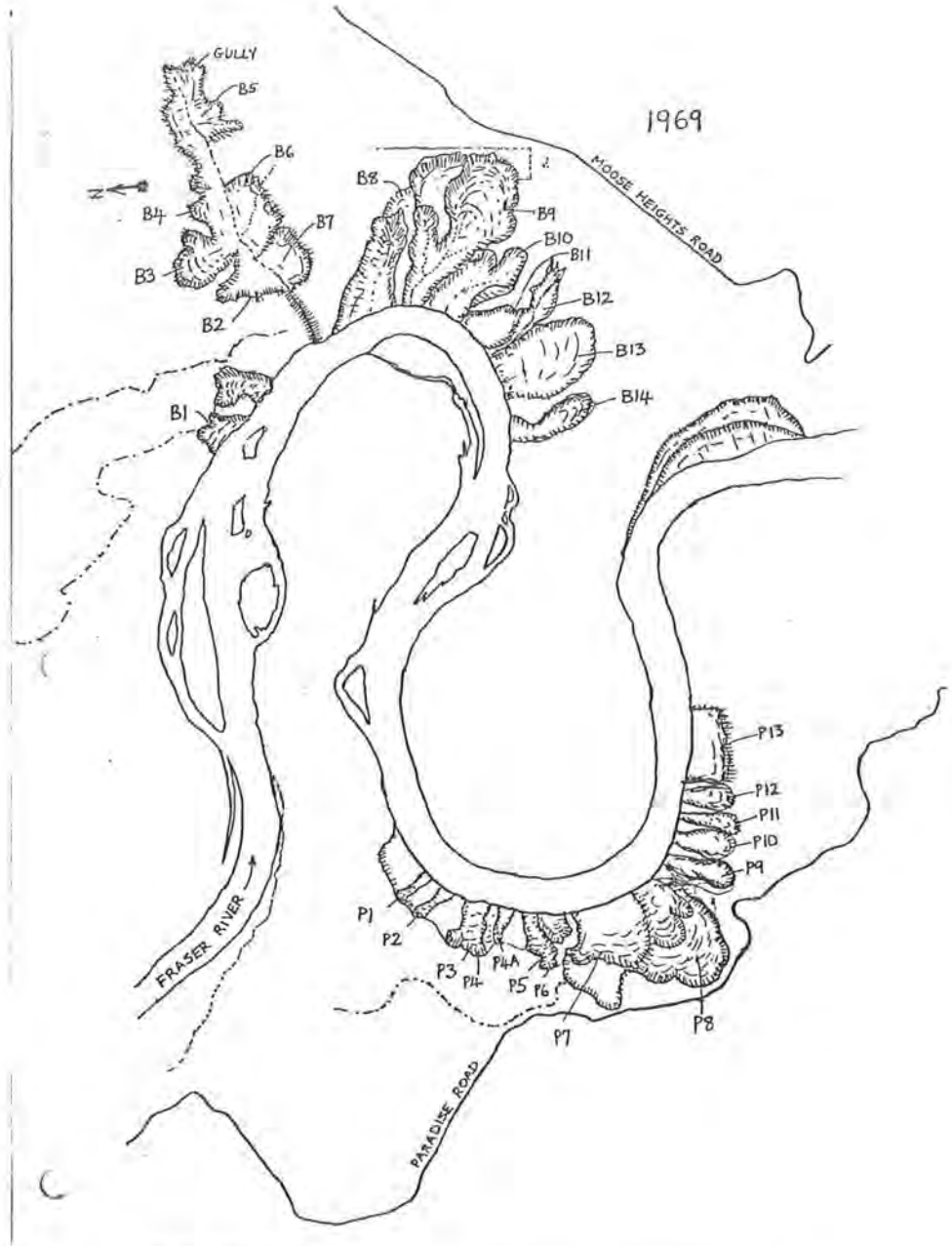


FIGURE F1

LANDSLIDES AT THE BIG BEND (DRAWN FROM B.C. AIR PHOTOS BC 5074-164 AND BC 5071-13, FLOWN MAY 17, 1963). SCALE 1" = 880 yds.



LANDSLIDES AT THE BIG BEND (DRAWN FROM BC AIRPHOTOS BC 5328-222 AND BC 5328-178 FLOWN MAY 9, 1969) SCALE 1" = 880 yds.

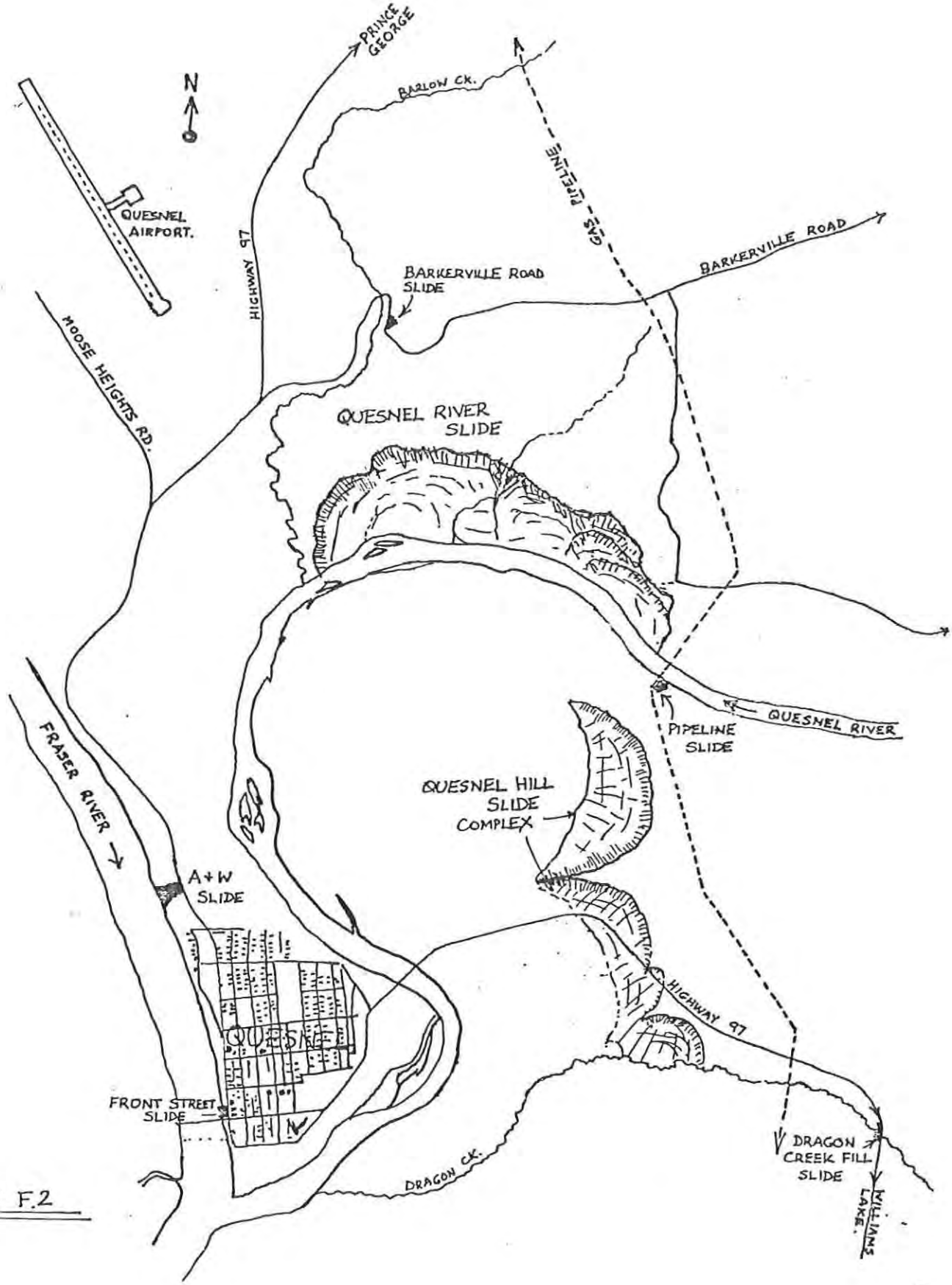


FIGURE F.2

LANDSLIDES IN QUESNEL AND ITS NORTH AND EASTERN VICINITIES. (DRAWN FROM B.C. AIRPHOTO B.C.5328-120, FLOWN MAY 9. 1969.) SCALE 1" - 880 yds.

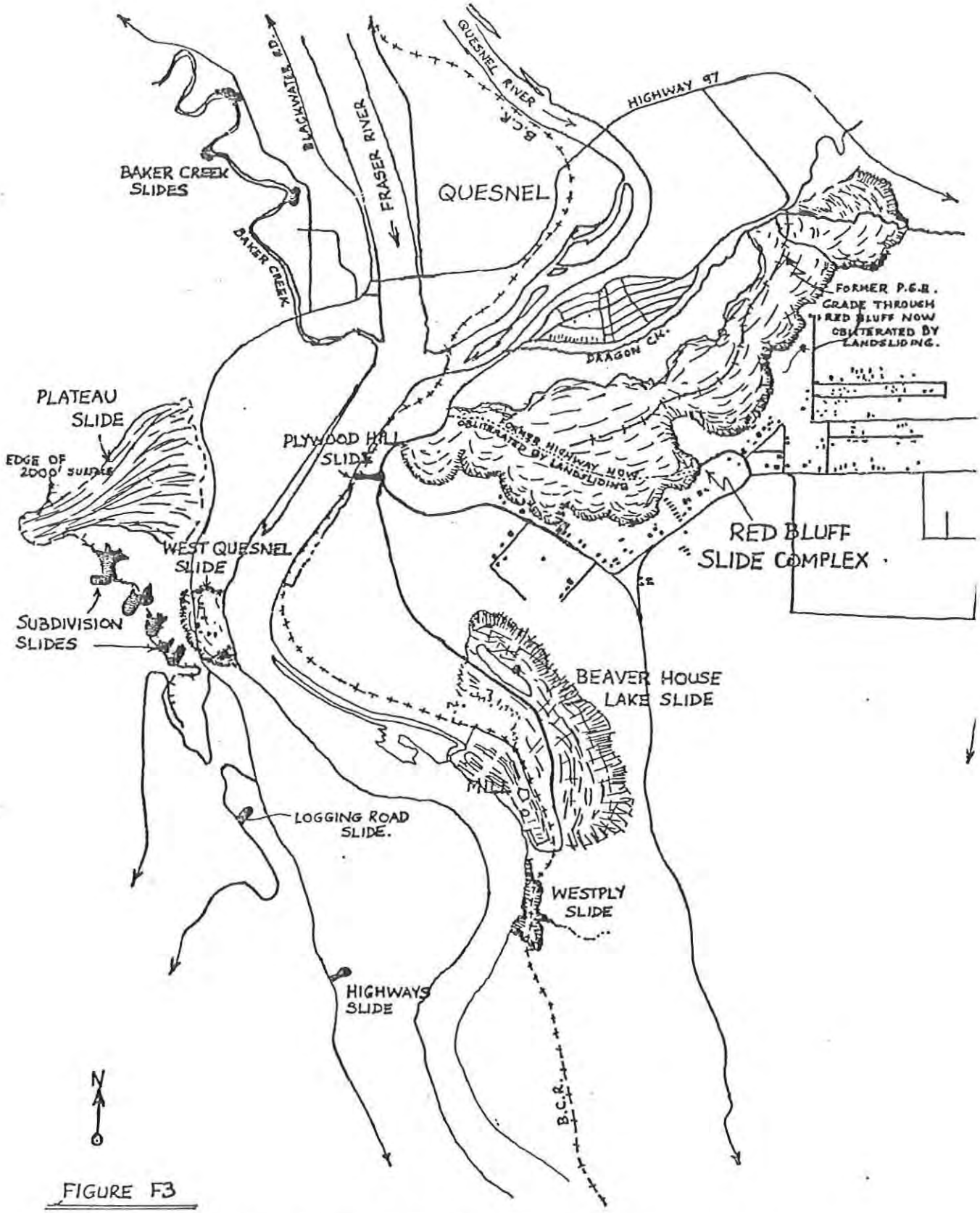


FIGURE F3

LANDSLIDES SOUTH OF QUESNEL (DRAWN FROM B.C. PHOTOGRAPHS B.C. 5328-122 AND BC 5328-226, FLOWN MAY 9. 1969) SCALE 1"-880 yds.

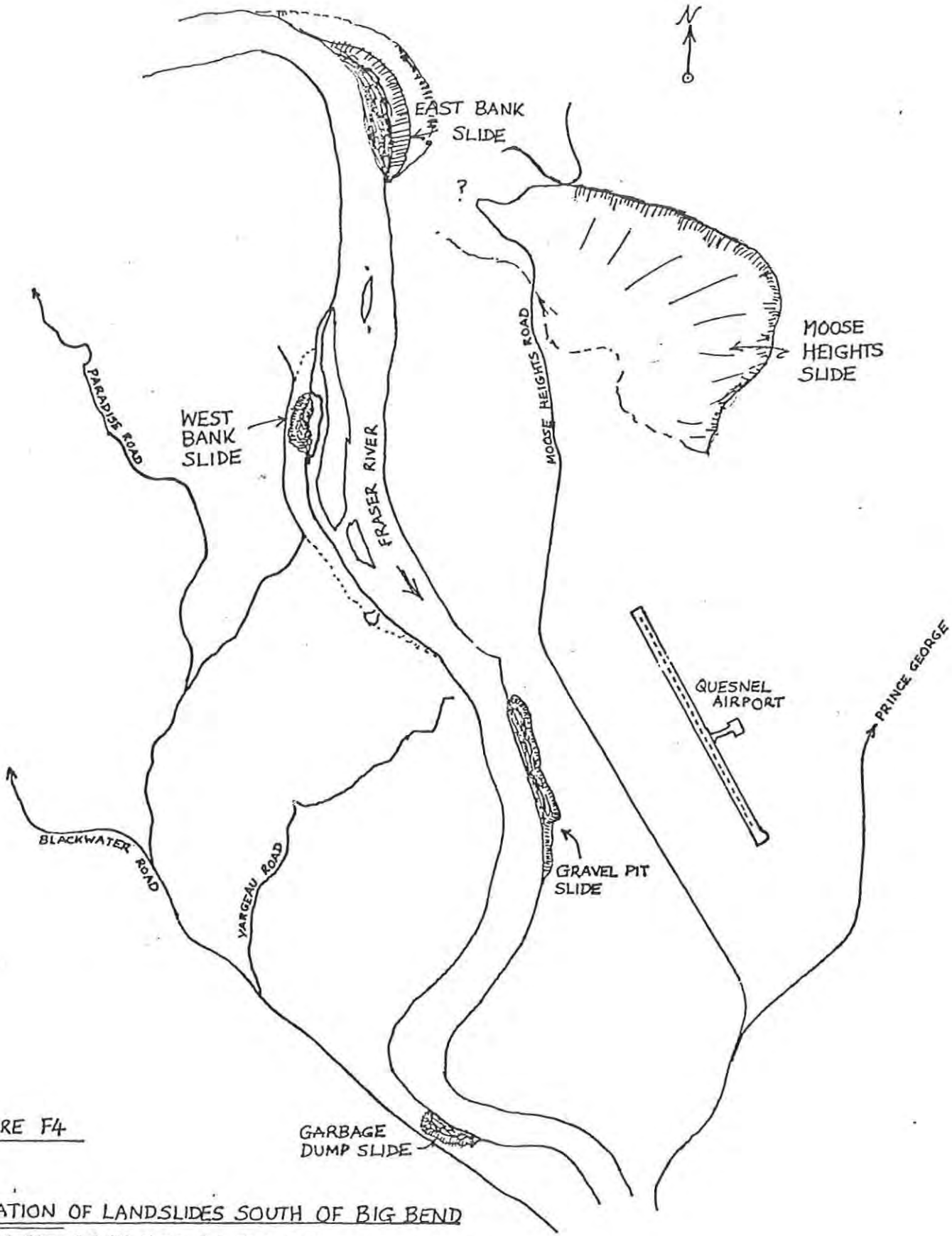
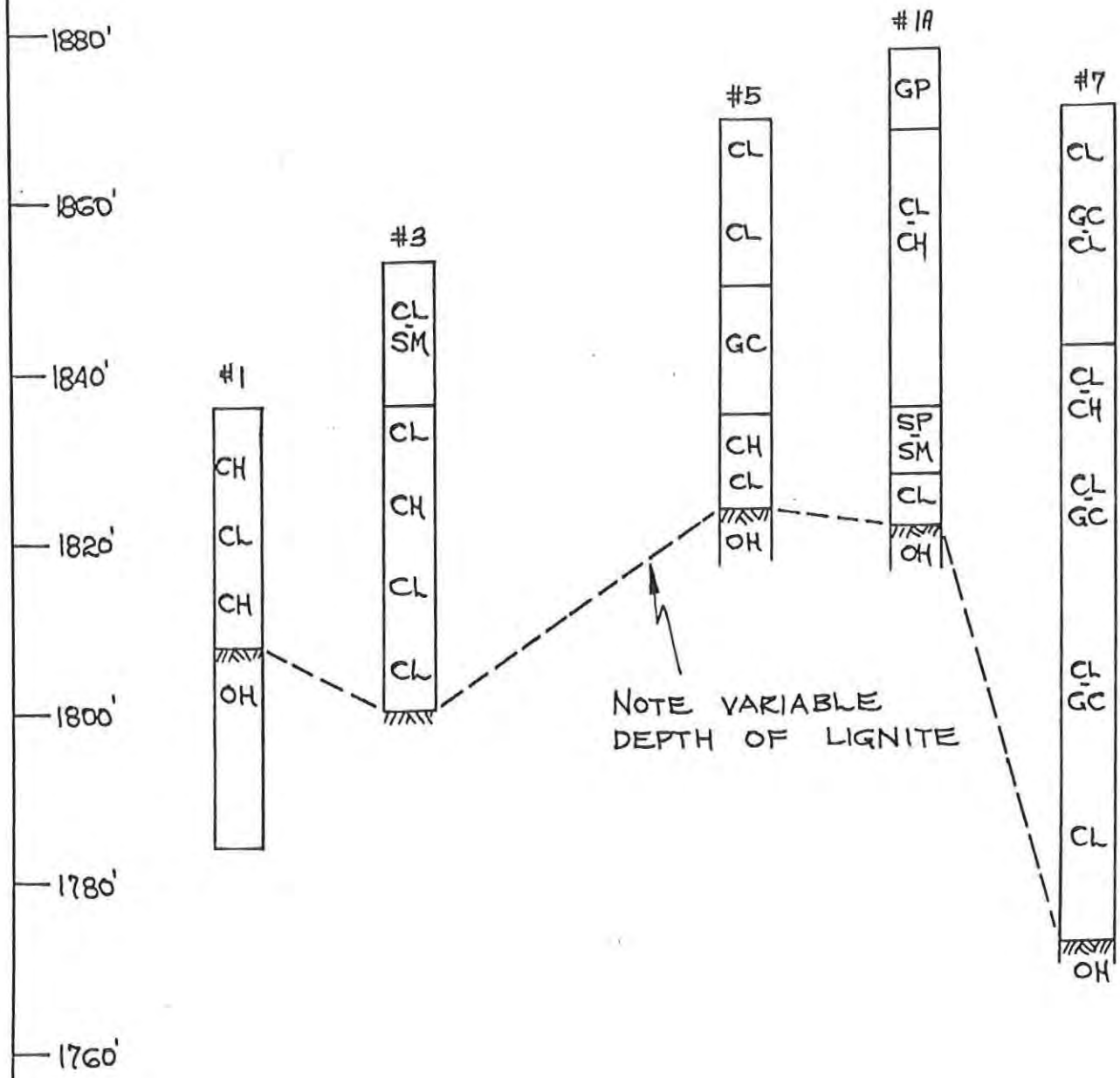


FIGURE F4

OCATION OF LANDSLIDES SOUTH OF BIG BEND

(DRAWN FROM B.C. AIR PHOTO B.C. 5328-224 FLOWN MAY. 9. 1969) SCALE 1"-880 yds.



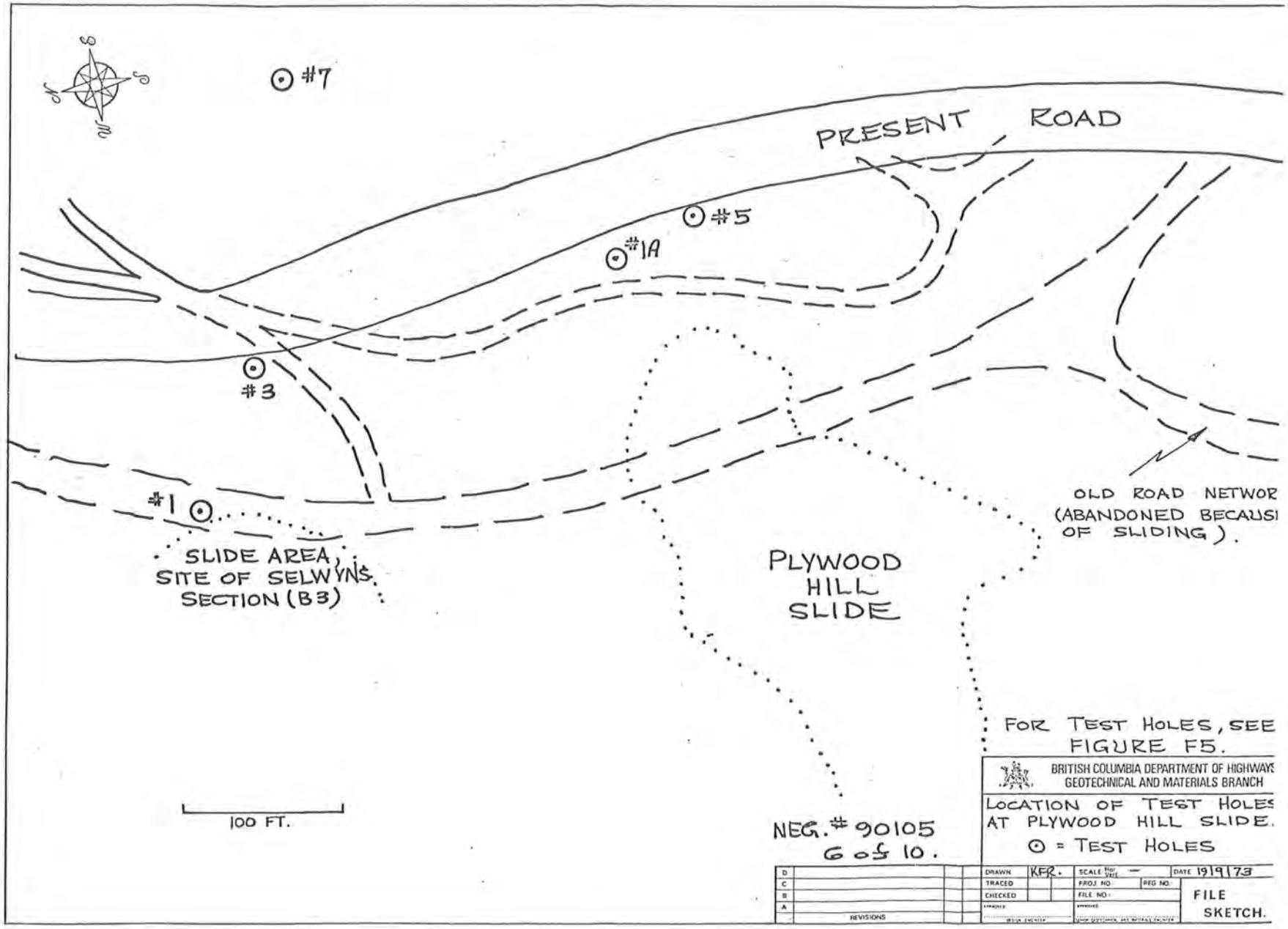
FROM: DWG'S P-1627
P-1629

SEE ACCOMPANYING
MAP FOR LOCATION

BRITISH COLUMBIA DEPARTMENT OF HIGHWAYS
GEOTECHNICAL AND MATERIALS BRANCH

FIGURE F5
PLYWOOD HILL SLIDE
TEST HOLES

KFR. 19/9/73
FILE


#7
PRESENT ROAD
#5
#1A
#3
#1
SLIDE AREA, SITE OF SELWYNS SECTION (B3)
PLYWOOD HILL SLIDE
OLD ROAD NETWOR (ABANDONED BECAUSI OF SLIDING).
100 FT.
FOR TEST HOLES, SEE FIGURE F5.
BRITISH COLUMBIA DEPARTMENT OF HIGHWAYS
GEOTECHNICAL AND MATERIALS BRANCH
LOCATION OF TEST HOLES AT PLYWOOD HILL SLIDE.
⊙ = TEST HOLES
NEG. # 90105
6 of 10.
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DATE 19/9/73
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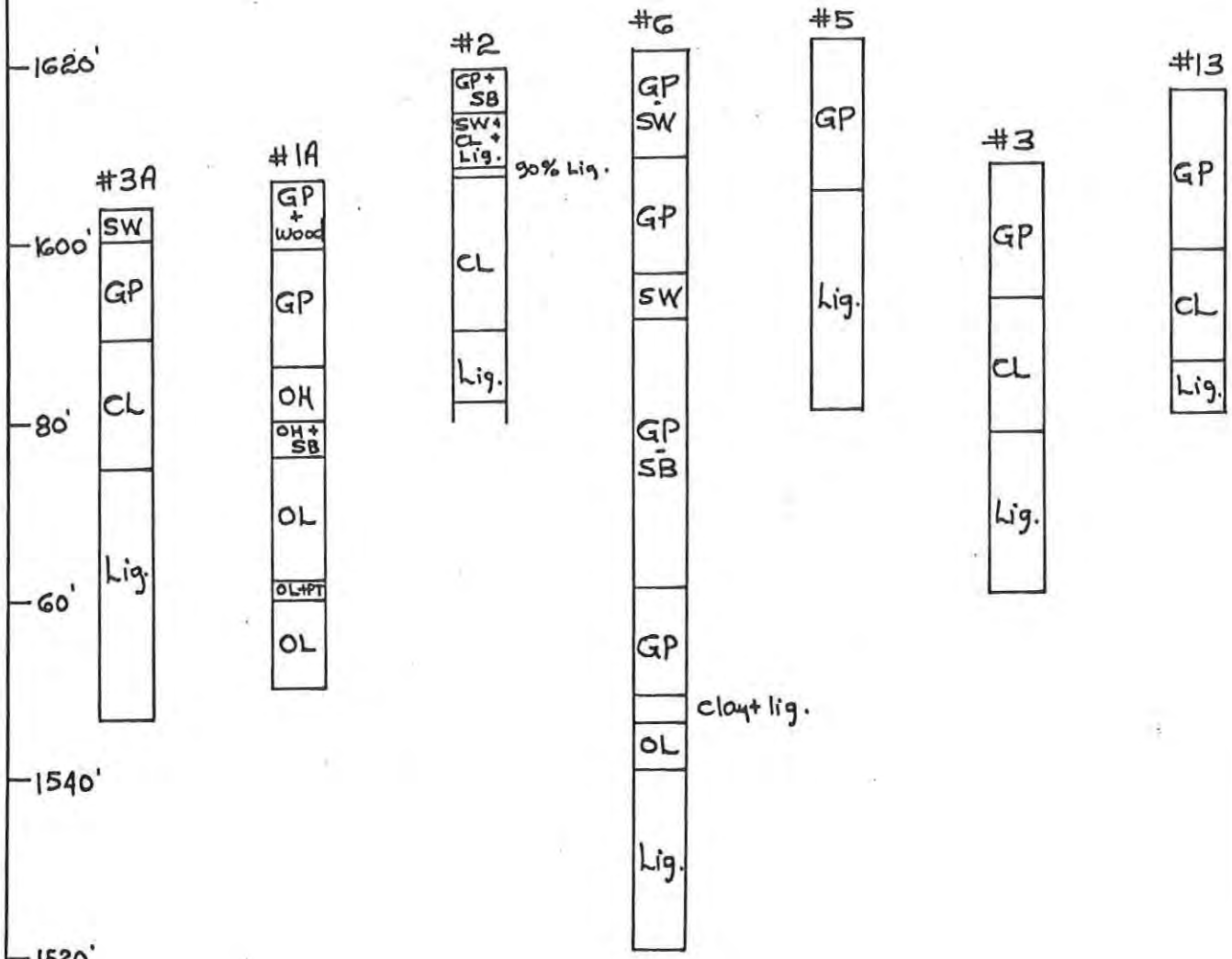


FROM DWG. Q-984/0

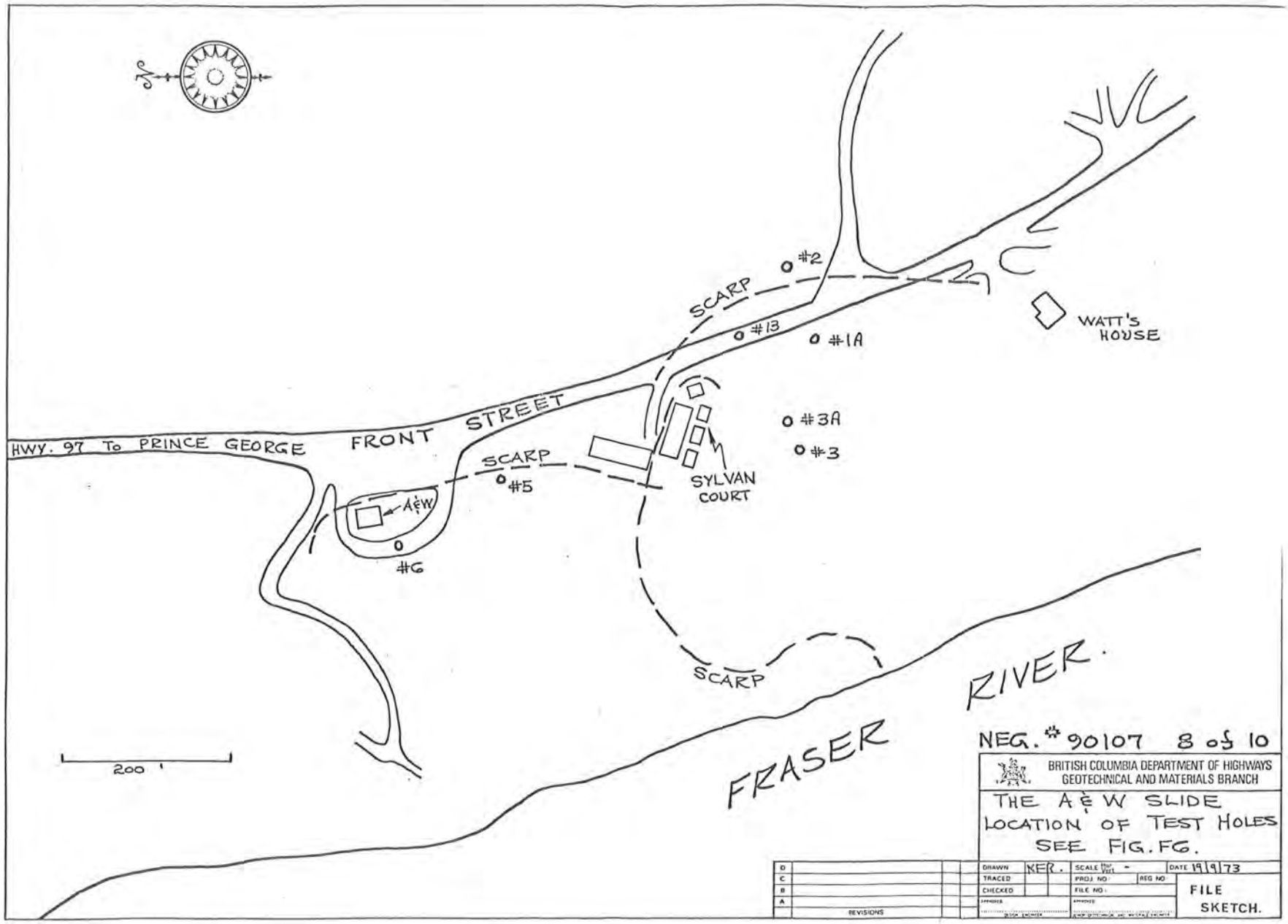
SEE ACCOMPANYING MAP FOR LOCATION

BRITISH COLUMBIA DEPARTMENT OF HIGHWAYS
GEOTECHNICAL AND MATERIALS BRANCH

FIGURE FG.
A & W SLIDE
TEST HOLES

KFR. 19/9/73

SKETCH


HWY. 97 To PRINCE GEORGE
FRONT STREET
SCARP
SCARP
SCARP
#2
#13
#1A
#3A
#3
#5
#6
A&W
SYLVAN COURT
WATT'S HOUSE
FRASER RIVER.
200 '
NEG. # 90107 8 of 10
BRITISH COLUMBIA DEPARTMENT OF HIGHWAYS
GEOTECHNICAL AND MATERIALS BRANCH
THE A & W SLIDE
LOCATION OF TEST HOLES
SEE FIG. F6.
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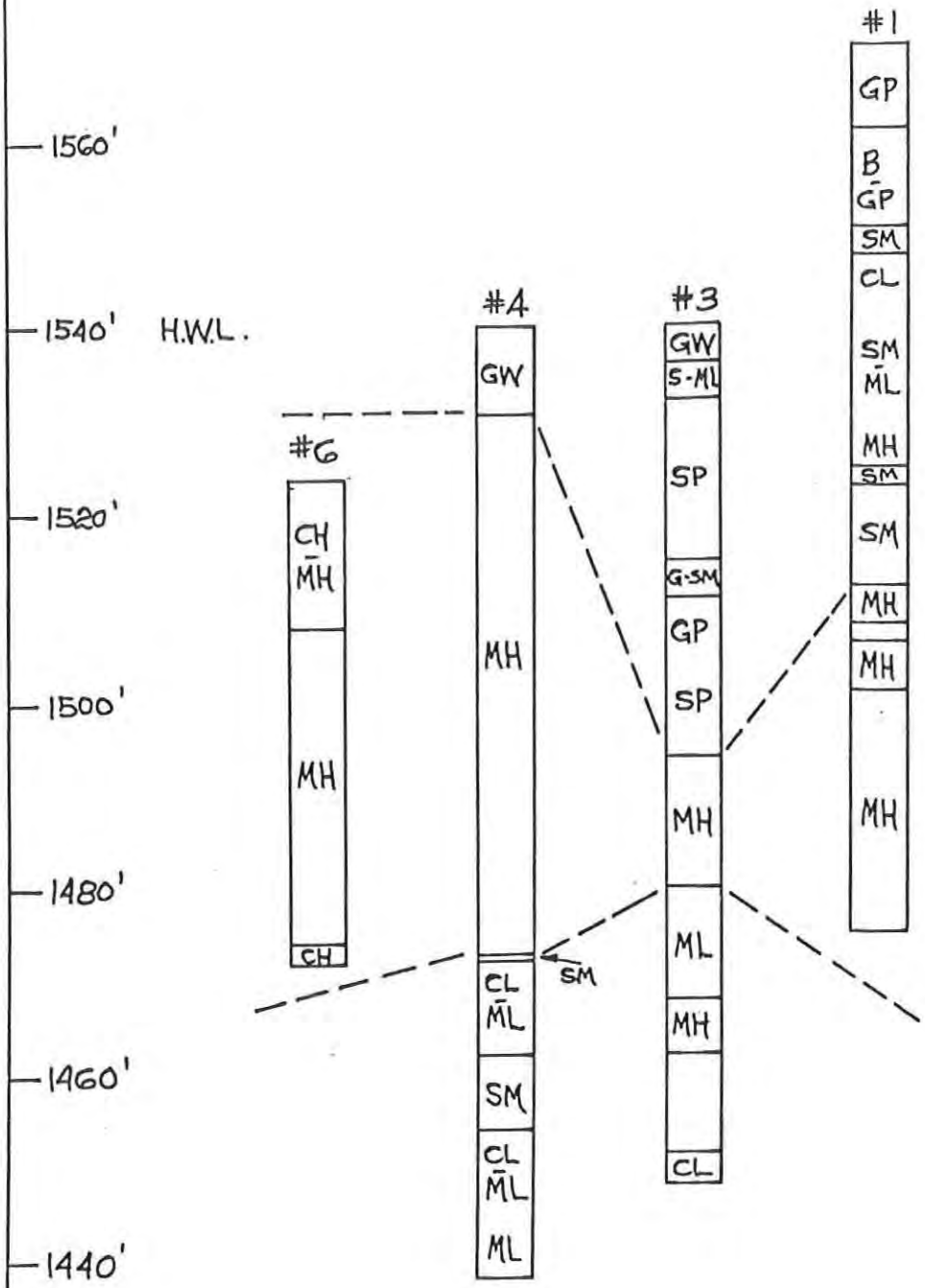

FROM DWG'S 1427
1303

BRITISH COLUMBIA DEPARTMENT OF HIGHWAYS
GEOTECHNICAL AND MATERIALS BRANCH

FIGURE F7
FRONT STREET SLIDE
TEST HOLES

SEE ACCOMPANYING
MAP FOR LOCATION

KFR

19/9/73

FILE
SKETCH

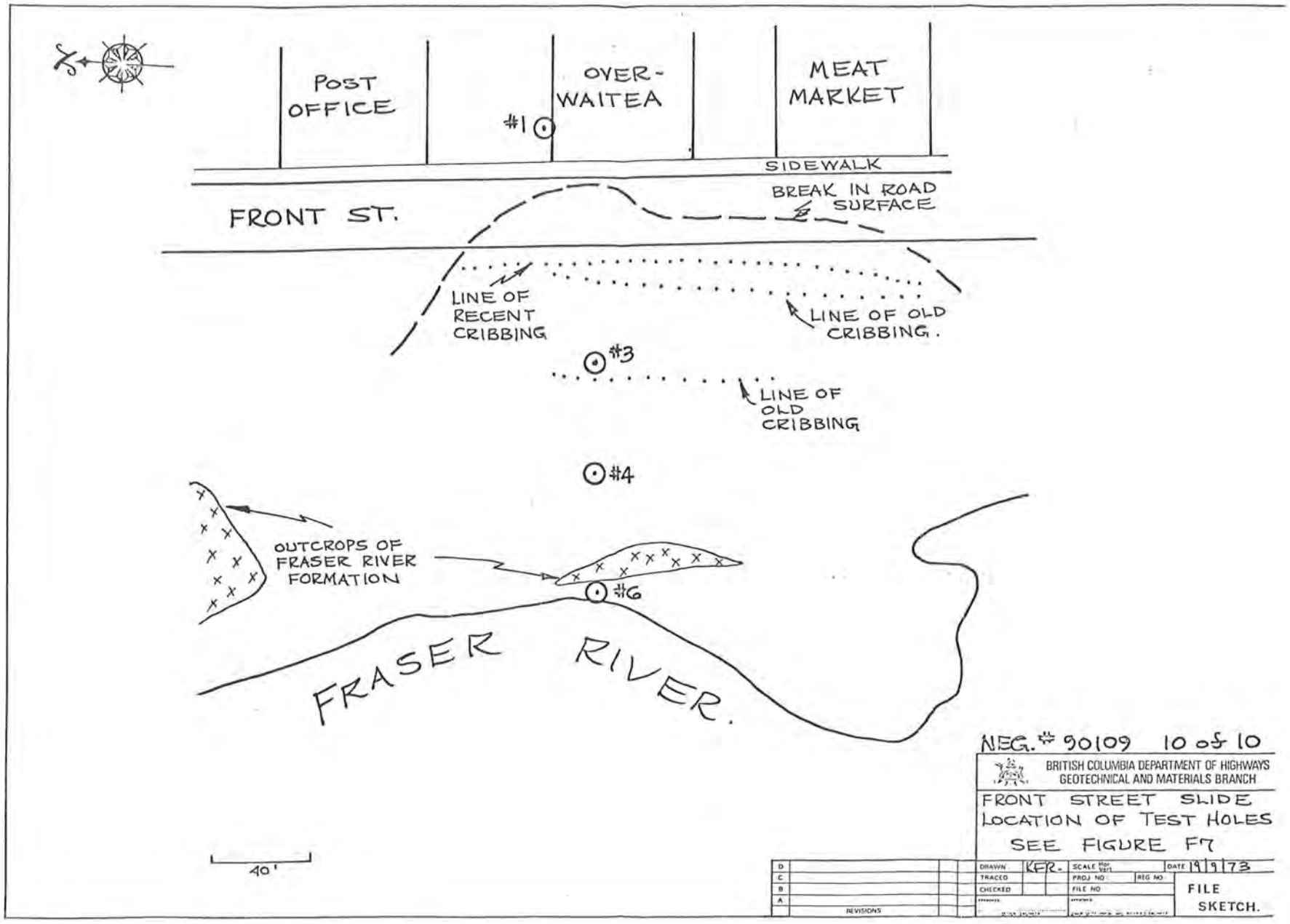
POST OFFICE
OVER-WAITEA
MEAT MARKET
#1
SIDEWALK
FRONT ST.
BREAK IN ROAD SURFACE
LINE OF RECENT CRIBBING
LINE OF OLD CRIBBING.
#3
LINE OF OLD CRIBBING
#4
OUTCROPS OF FRASER RIVER FORMATION
#6
FRASER RIVER.
40'
NEG. # 90109 10 of 10
BRITISH COLUMBIA DEPARTMENT OF HIGHWAYS
GEOTECHNICAL AND MATERIALS BRANCH
FRONT STREET SLIDE
LOCATION OF TEST HOLES
SEE FIGURE F7
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PLATE F1
Aerial view of slide B9 at Big Slide. The gulley-slide on the left was formed between 1963 and 1969. Note retrogressive failure at head of slide and flow mode downslope towards the Fraser; the stratification in river bank. Relief here is about 600' and the surface being affected is the Fraser Plateau (2200').

PLATE F2
Recent retrogressive failure at head of B9 on Big Slide. Notice rotational movement of intact slide wedges. Materials here are silts and clays; seepage was noted.

PLATE F3
Recent retrogressive failure at head of B9 on Big Slide.
As in F2 note rotational movement of intact slide wedges.
Note figure as scale.

PLATE F4
Paradise Road Slide (P9-P8). Note erosion of slide toes, surfaces of slide blocks marked by vegetation, and stratification in material. Cemented gravels occur at the base of the river bank.

PLATE F5
Paradise Road Slide (P13-10). Note slide scarps and slid masses. Progressive slope transformation can be appreciated from this view, Cf. modes of slope development in Section IV.

PLATE F6
Paradise Road Slide (18). Slide scarp formed at head of multiple retrogressive slide. Note fallen trees. Scarp is well preserved here (Cf. Plate F2) due to existence of basalt cap rock. Materials in slide are silts, clays and gravels. Scale of this movement is enormous.

PLATE F7
Quesnel River Slide: Although smoke is obscuring part of the slide, boundaries and type of slide can be appreciated. Note renewed sliding on left and at right. Surface affected is Fraser Plateau (2200'). Further involvement of lands at head of slide likely.

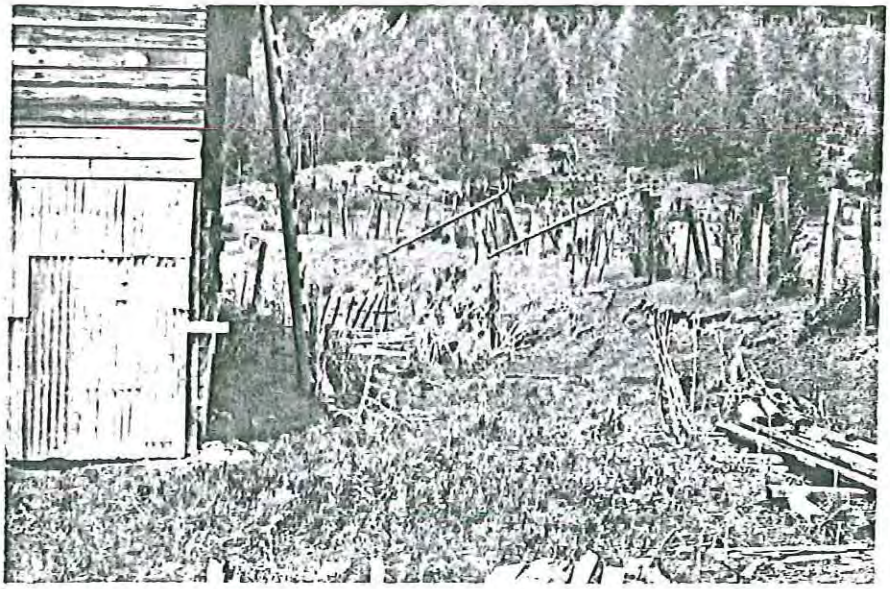


PLATE F8
Quesnel River Slide. Slide scarp of recent slide in amongst farm buildings of M. Veilleur.

PLATE F9
Aerial view of Red Bluff Hill. Slide area extends from Dragon Creek to Plywood Hill in foreground. Note Plywood Hill Slide in foreground and the proximity of houses to the rim of the slide. Area between base of slide slope and South Quesnel residential district on left is prone to flooding and represents an abandoned river channel. Dragon Lake is in the background.

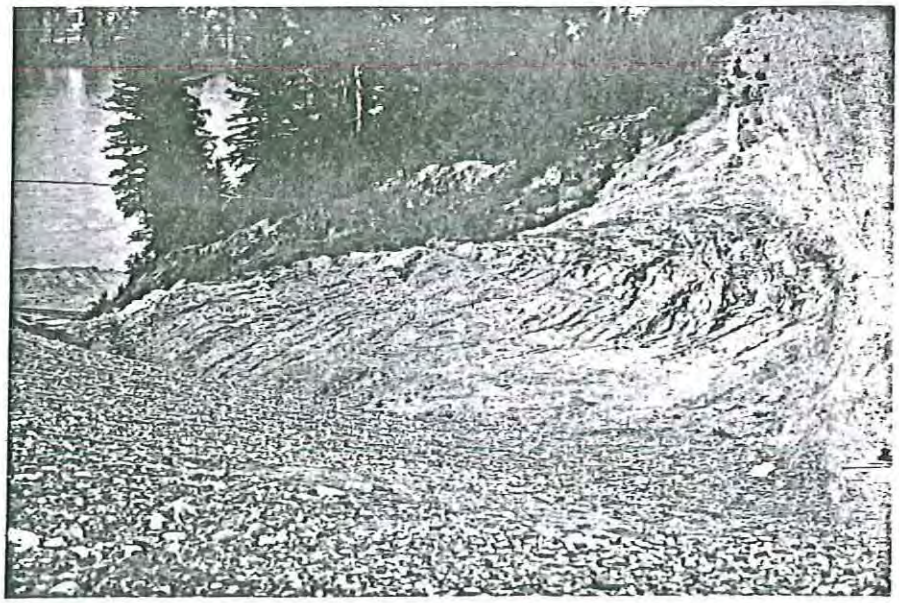


PLATE F10
Plywood Hill Slide. Concentric cracks at head.

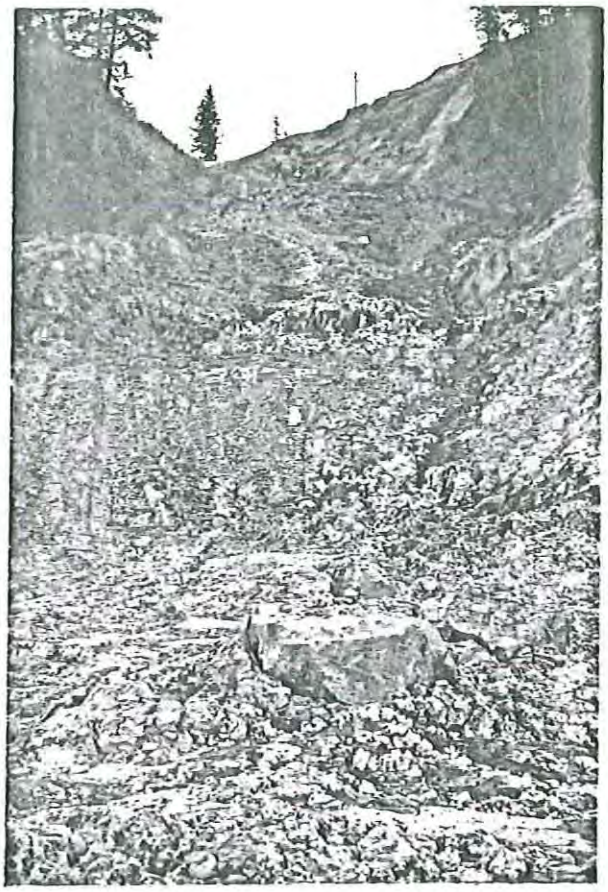


PLATE F11
View from railroad track up the gut of Plywood Slide. More movement similar to flow at this location. Note diatomite and seepage tracks and figures for scale.

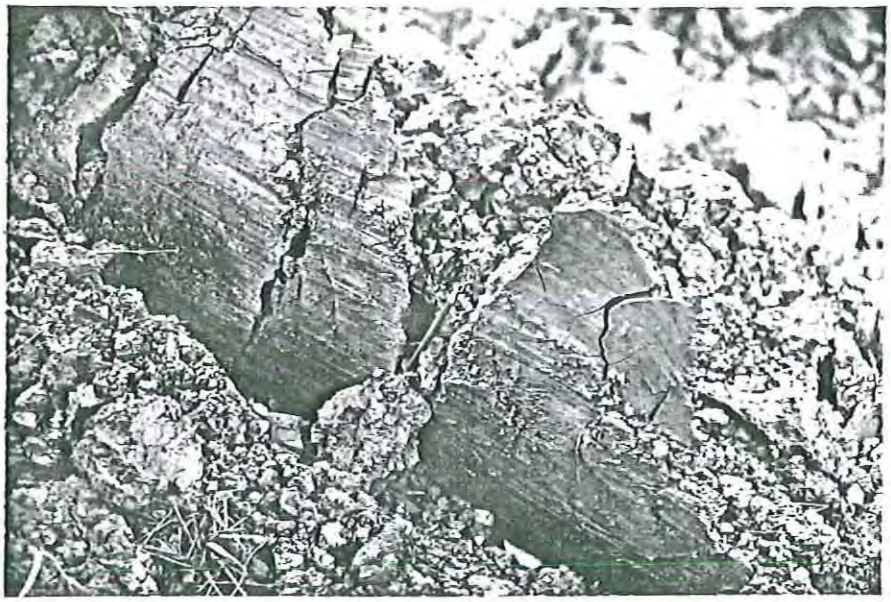


PLATE F12
Slickensides developed by side shear of mudflow mass at Plywood Hill Slide. Pencil is about 6" long.

PLATE F13A
View of slope at Plywood-P.G.E. Cut; slope in sands and gravels at south end is apparently stable at about 30°. Note Plywood Hill Slide in the more cohesive materials at the northern end of the section.

PLATE F13B
Angle of repose demonstrated in gravels in Plywood-P.G.E. Cut.

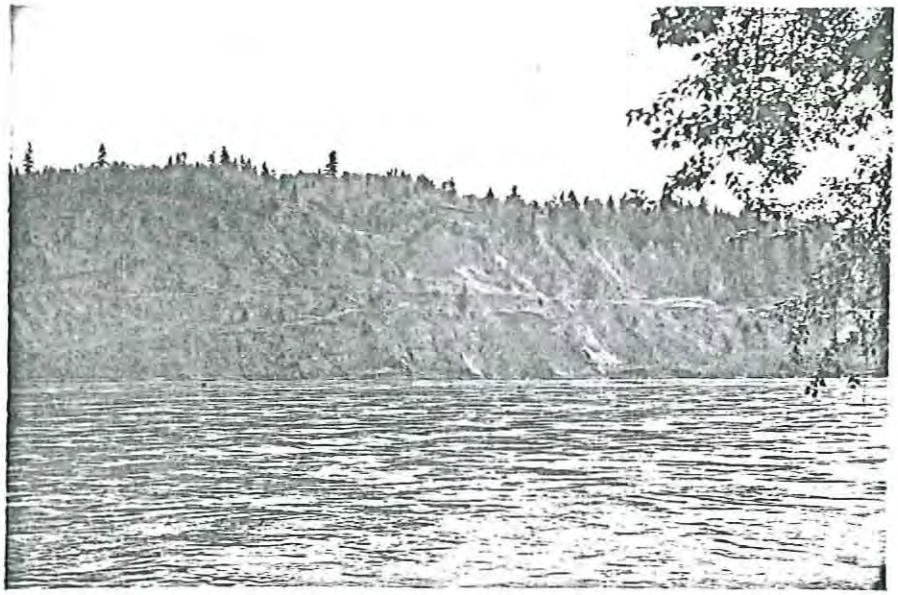


PLATE F14
Westply Slide. Note retrogressive mode of failure and boundary of slide blocks defined by vegetation.

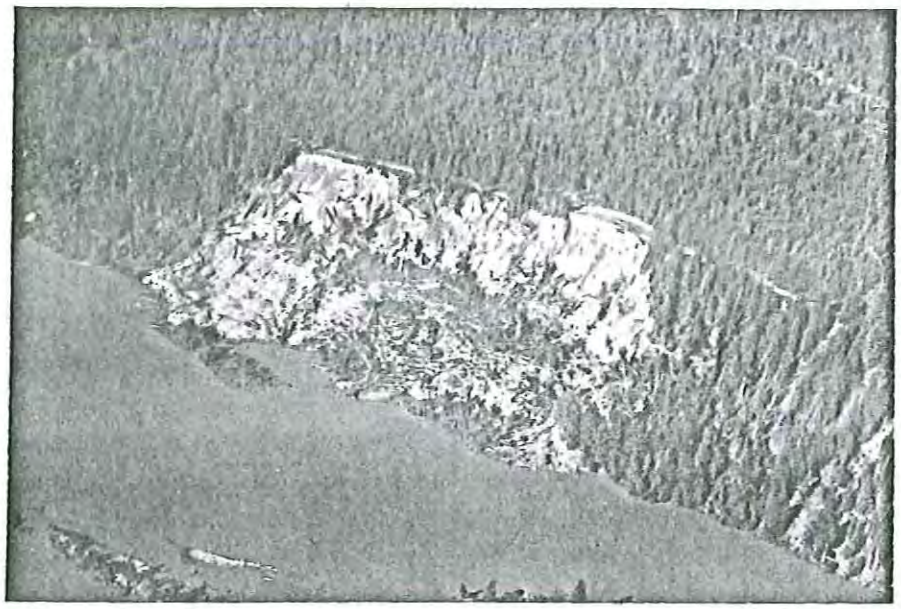


PLATE F15A
West Bank Slide. A compound mode of failure.

PLATE F15B
West Bank Slide with gravels and silts.

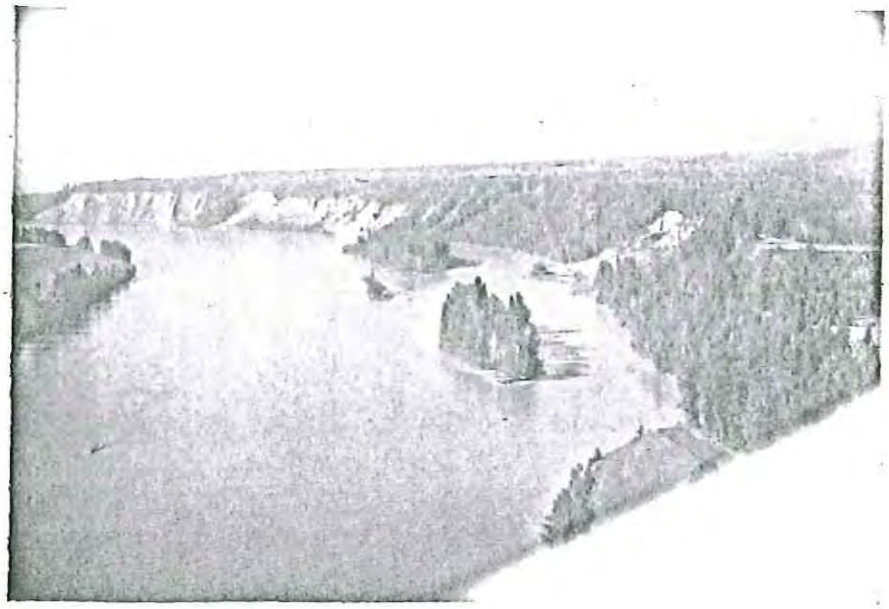


PLATE F16
West Bank Slide on right. Note steeper river cliffs downstream of the slide which are thought to have high slide potential and less steep cliffs in vicinity of slide, probably flattened by similar mode of transformation.

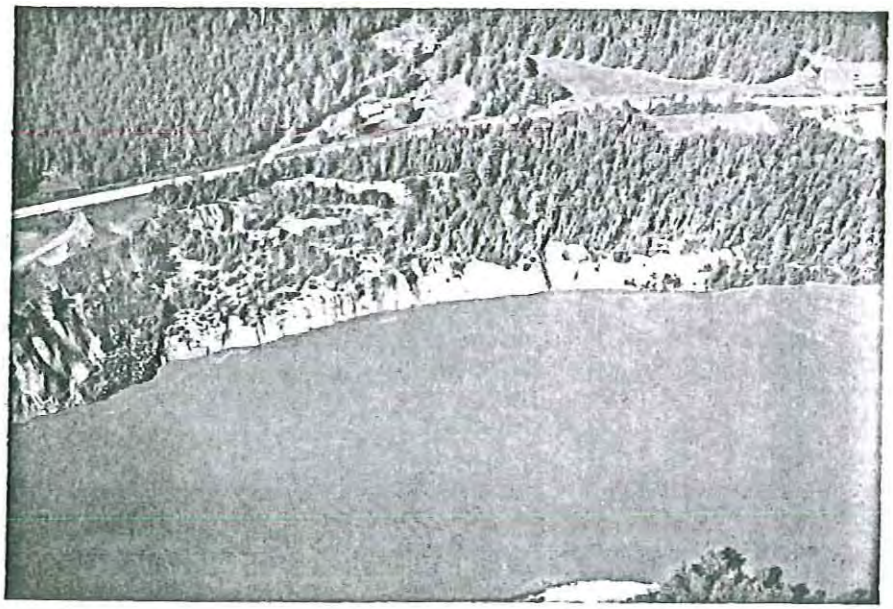


PLATE F17
Garbage Dump Slide. Note toe erosion which is probably a vital factor in its continued movement.

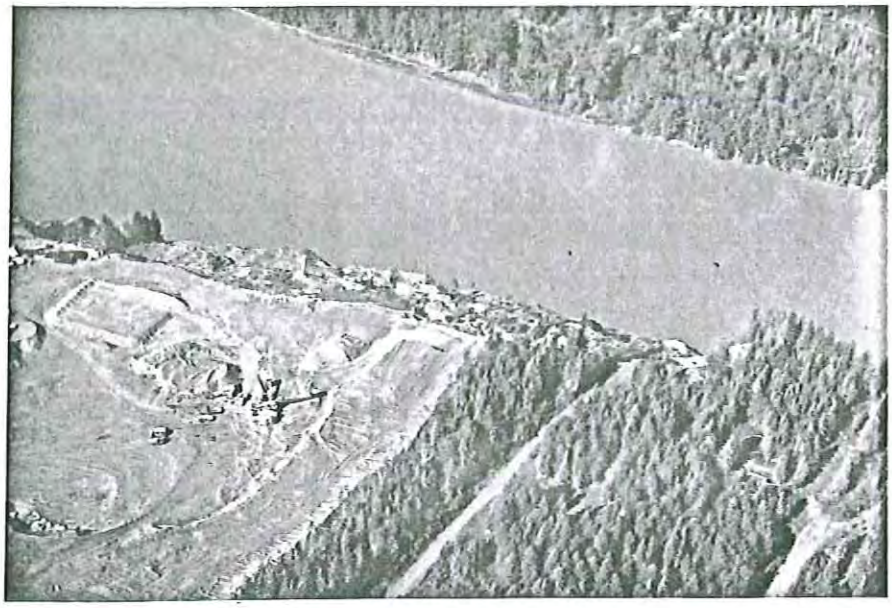


PLATE F18
Gravel Pit Slide. Note similar failure mode to West Bank Slide.

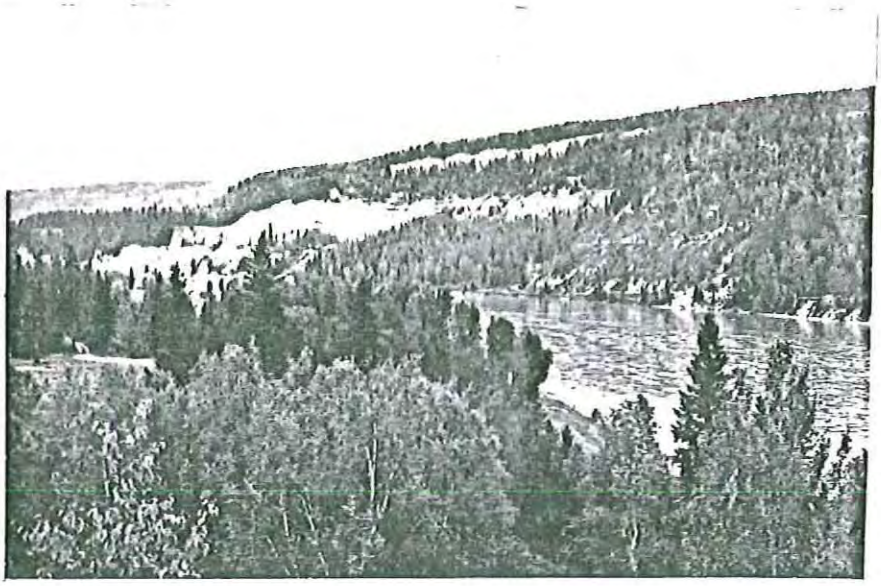


PLATE F19
East Bank Slide.

PLATE F20
Subdivision Slide. Debris, and silty gravels and sands in slope.

PLATE F21
View of Subdivision Slide, gulley-slump on margins of 2000' surface. Note houses near edge of slide (this land is offered for sale and is advertised as being "ideal for sub-dividing"). Note work in progress at base of slide, in fact they may have excavated part of the slide debris for building homes. Note West Quesnel Slide in foreground and vicinity of houses to the slide. Road is being relocated over main part of West Quesnel Slide.

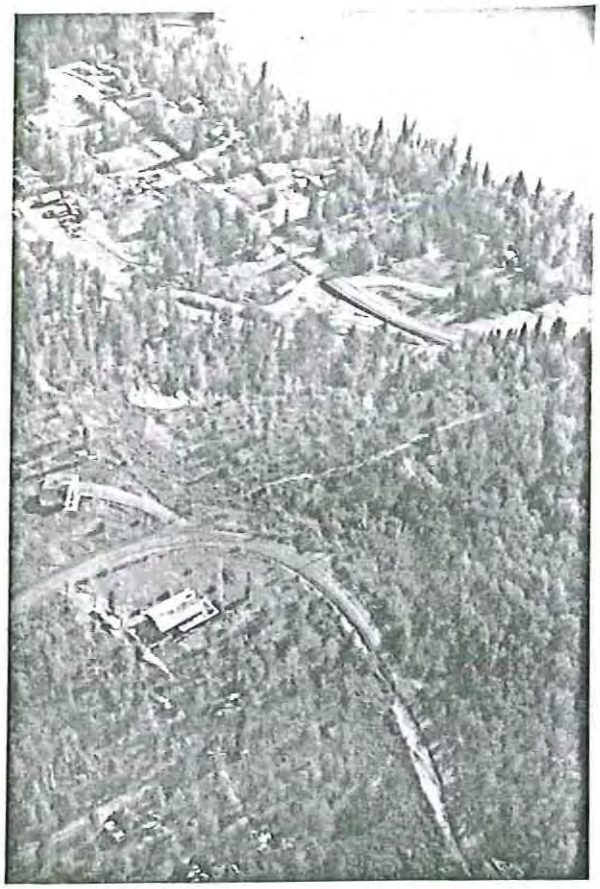


PLATE F22
Subdivision Slide. Houses near bottom and top. Further instability and development of unstable area is feared.

PLATE F23
Land cleared, presumably for subdivision, just south of Subdivision Slide. Note gulley system uncovered by vegetation stripping and slide on Logging Road (Logging Road Slide). The houses in the foreground seem to be dangerously near the toe of the slide. Further instability is forecast.

PLATE F24
Aerial view of Highways Slide showing slump-flow mode of failure.

PLATE F25
Baker Creek. One of the Baker Creek Slides in a meander bend.

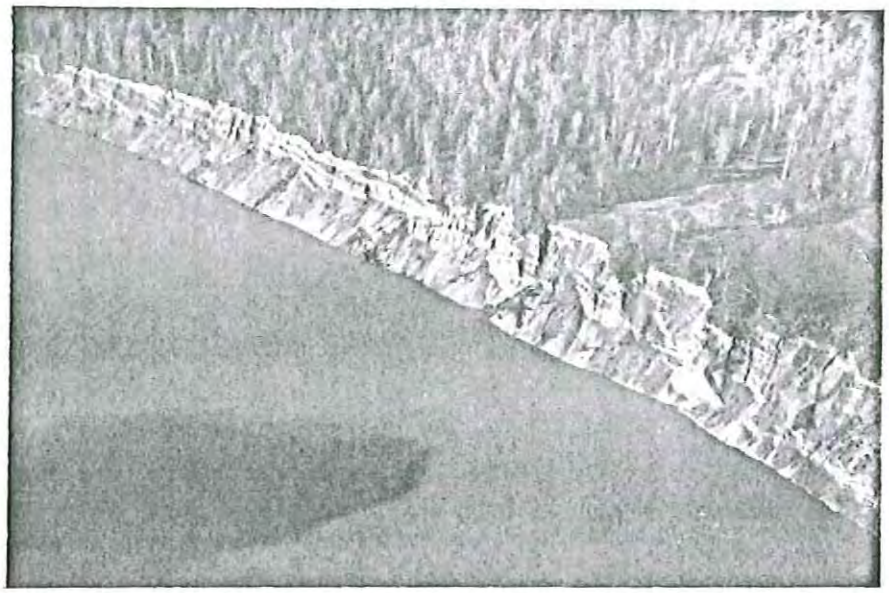


PLATE F26
River Cliff showing a Type C slope (see Slope Development, Section IVD).

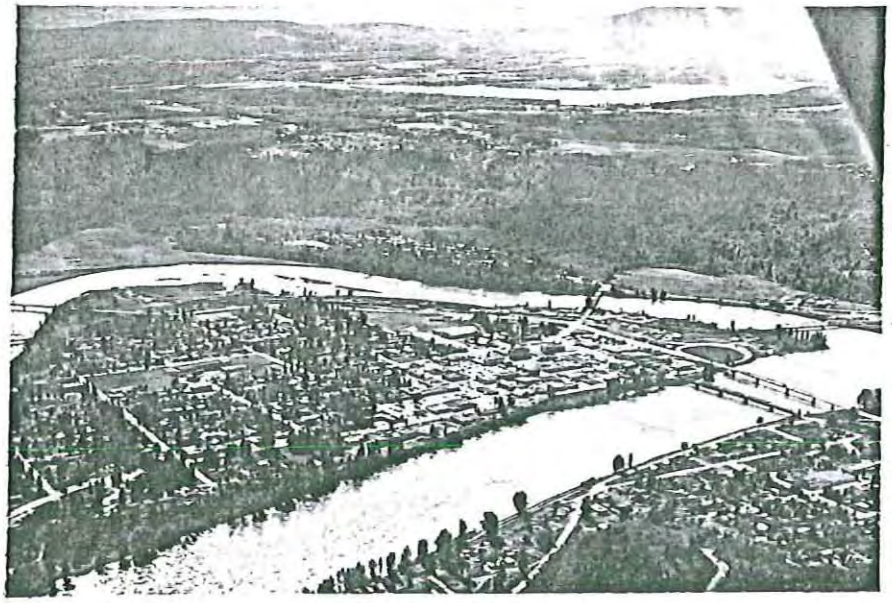


PLATE F27
Quesnel with Red Bluff in background and Front Street Slide near east end of old Fraser River Bridge.

APPENDIX G

MISCELLANEOUS

AIR PHOTO COVERAGE OF THE QUESNEL AREA

(A) 40 Chain

BC 940 --- August 29 and 30, 1949
BC 1143 --- August 19 to 21, 1950
BC 1649 --- May 15, 1953
BC 5070 --- May 17, 1963
BC 5328 --- May 9, 1969

(B) 20 Chain

BC 5409 --- May 4, 1971
BC 5463 --- May 29, 1972
BC 7510 --- July 29, 1973

(C) 10 Chain

BC 7499 -- July 29, 1973

MAP COVERAGE

(A) NTS - 1:50,000

93B-15 - unavailable
93B-16
93G-1
93G-2

(B) Dept. of Lands & Forests, Surveys & Mapping Branch, Topographic Div.

1:6000 -- 1963-1965
(Drawing M-135)
This series of seven large-scale maps (contour interval 10')
is best for large-scale work.

THIS IS AN ESTIMATE OF THE EARTHQUAKE PROBABILITY OF A SITE NEAR

QUESNEL AREA

THE GEOGRAPHICAL CO-ORDINATES OF THE SITE ARE
52 DEGREES 55 MIN NORTH LATITUDE
122 DEGREES 25 MIN WEST LONGITUDE

EARTHQUAKES BETWEEN 1899 AND 1963 INCLUSIVE ARE INCLUDED IN THE ANALYSIS.

DURING THIS PERIOD THERE ARE 1671 EARTHQUAKES IN THE EARTHQUAKE CATALOGUE FOR THIS REGION. THERE WERE 10 EARTHQUAKES WHICH COULD HAVE BEEN FELT AT THIS LOCATION DURING THIS 65 YEAR PERIOD

THIS SITE HAS EXPERIENCED A MAXIMUM ACCELERATION OF 1. PERCENT GRAVITY OR A MAXIMUM INTENSITY OF IV

TABLE 1 IS A LIST OF THE EARTHQUAKES WHICH REACHED AN INTENSITY OF II OR GREATER AT THIS SITE. ALL OF THE EVENTS IN THIS LIST MAY HAVE BEEN FELT.

TABLE 2 IS A LIST OF THE PREDICTIONS FOR THIS SITE. PLEASE READ THE FOLLOWING REMARKS BEFORE USING THE DATA.

THE VALUES FOUND IN TABLE 2 ARE BASED UPON A STATISTICAL ANALYSIS OF THE EARTHQUAKES WHICH HAVE OCCURRED OVER THE ABOVE INTERVAL OF TIME. THIS IS TOO SHORT A PERIOD OF OBSERVATION FOR ACCURATE PREDICTIONS ABOUT TECTONIC ACTIVITY. HOWEVER, THE DATA HAVE BEEN PROCESSED TO PROVIDE AN ESTIMATE OF THE POSSIBLE LEVEL OF EARTHQUAKE ACTIVITY IN THE NEAR FUTURE ASSUMING A CONTINUATION OF THE STATISTICAL PATTERN OF THE PAST YEARS. ALTHOUGH PREDICTIONS CAN BE MADE FOR MANY RETURN PERIODS, THE NUMBERS GIVEN FOR RETURN PERIODS GREATER THAN 100 YEARS ARE MORE LIKELY TO BE ALTERED BY CHANGING PATTERNS OF EARTHQUAKE ACTIVITY.

THE EXTREME VALUE METHODS OF STATISTICS ARE USED FOR THESE CALCULATIONS. THE SLOPE OF THE CURVE IS FOUND BY A LEAST SQUARES SOLUTION OF THE DATA FOR THE YEARS WHEN THERE WAS ACTIVITY ABOVE A FIXED THRESHOLD LEVEL. THE CURVE IS REPRESENTED BY THE EQUATION

$$LOG(ACC) = MODE + K(-LOG(-LOG(P)))$$

WHERE NATURAL LOGARITHMS ARE USED. P IS THE PROBABILITY THAT ACC WILL BE EXCEEDED IN 1 YEAR. R IS THE RETURN PERIOD (IN YEARS) OF ACCELERATION AMPLITUDE LOG(ACC) AND EQUALS 1/1-P .

FROM THIS THE ACCELERATION AMPLITUDE IS

$$ACC = EXP(LOG(ACC))$$

AND THE INTENSITY

$$I = 3\ LOG10(ACC) + 4.5$$

I IS THE INTENSITY BY THE MODIFIED MERCALLI INTENSITY SCALE OF 1931. IN THE TABLES THE VALUE IS ROUNDED TO THE NEAREST INTEGER AND PRINTED IN ROMAN NUMERALS. ACC IS THE ACCELERATION AS A PERCENTAGE OF GRAVITY.

THE VALUES OF ACCELERATION LISTED IN TABLE 2 ARE FOR FIRM SOIL. OTHER TYPES OF FOUNDATION MATERIAL MAY ALTER THE VALUES BY AT LEAST ONE UNIT OF I.

QUESNEL AREA

52 55 122 25

TABLE 1 DATA

YEAR	MAG	LAT	LONG	DISTANCE MILES	DISTANCE KMS	ACCELERATION PERCENT G	INTENSITY
1899	8.20	60.00	-142.00	888	1429	0	III
1899	8.60	60.00	-140.00	826	1329	1	IV
1900	8.20	60.00	-142.00	888	1429	0	III
1918	7.00	49.75	-126.50	280	451	0	III
1929	7.00	52.80	-129.50	295	475	0	III
1946	7.30	49.90	-124.90	234	376	1	IV
1949	7.00	47.20	-122.60	394	635	0	II
1949	8.00	53.75	-133.25	450	724	1	IV
1956	6.75	51.80	-129.20	296	476	0	II
1958	7.90	58.60	-137.10	690	1110	0	III

TABLE 2

52 55 122 25

MODE FOR THIS SITE = -3.68
K FOR THIS SITE = 0.91

ACC100 FOR THIS SITE = 1.6 PERCENT GRAVITY

PROBABILITY OF ACC BEING EXCEEDED IN ONE YEAR.	ACC IN PERCENTAGE GRAVITY	INTENSITY (MODIFIED MERCALLI)	EQUIVALENT RETURN PERIOD
0.333	0	I	3.
0.100	0	II	10.
0.033	1	IV	30.
0.020	1	IV	50.
0.010	2	V	100.
0.005	3	VI	200.
0.003	4	VI	300.
0.001	13	VIII	1000.

VALUES OF ACCELERATION OVER GRID PATTERN

LAT	LONG	MODE	SLOPE	ACC100	INT100
53.50	-123.00	-3.68	0.91	1.7	5.2
53.50	-122.80	-3.71	0.91	1.6	5.1
53.50	-122.60	-3.74	0.91	1.6	5.1
53.50	-122.40	-3.77	0.91	1.6	5.1
53.50	-122.20	-3.81	0.91	1.5	5.0
53.30	-123.00	-3.63	0.90	1.7	5.2
53.30	-122.80	-3.67	0.90	1.7	5.2
53.30	-122.60	-3.70	0.91	1.6	5.1
53.30	-122.40	-3.73	0.91	1.6	5.1
53.30	-122.20	-3.77	0.91	1.5	5.0
53.10	-123.00	-3.59	0.90	1.7	5.2
53.10	-122.80	-3.63	0.90	1.7	5.2
53.10	-122.60	-3.67	0.90	1.6	5.1
53.10	-122.40	-3.70	0.91	1.6	5.1
53.10	-122.20	-3.74	0.91	1.6	5.1
52.90	-123.00	-3.54	0.89	1.8	5.2
52.90	-122.80	-3.59	0.90	1.7	5.2
52.90	-122.60	-3.64	0.91	1.7	5.2
52.90	-122.40	-3.69	0.91	1.7	5.2
52.90	-122.20	-3.72	0.91	1.6	5.1
52.70	-123.00	-3.50	0.89	1.8	5.3
52.70	-122.80	-3.55	0.90	1.8	5.3
52.70	-122.60	-3.61	0.90	1.7	5.2
52.70	-122.40	-3.67	0.91	1.7	5.2
52.70	-122.20	-3.66	0.90	1.6	5.1

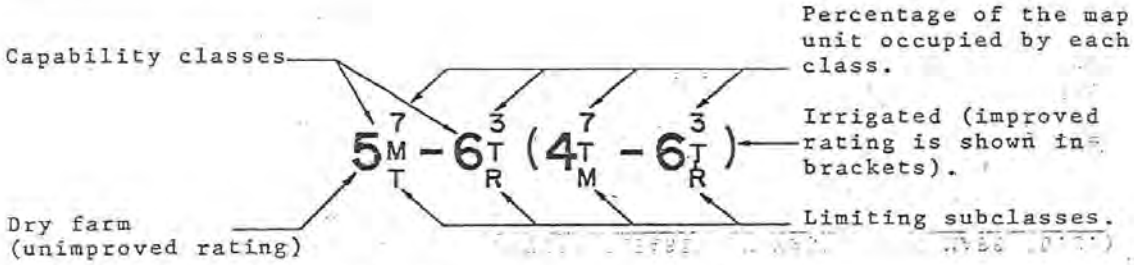
THE SEISMIC ZONING MAP IN THE NATIONAL BUILDING CODE OF CANADA (1970) USES THE ACCELERATION AMPLITUDES WITH RETURN PERIODS OF 100 YEARS AS TH CRITERIA FOR ZONE BOUNDARIES. THIS IS CALLED ACC100. THE FOLLOWING ARE THE ZONE BOUNDARIES IN THE 1970 CODE.

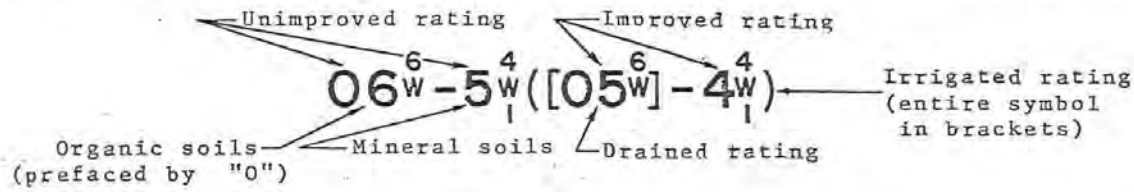
ZONE 0		ACC100 < 1.	R = 0
ZONE 1	1. <=	ACC100 < 3.	R = 1
ZONE 2	3. <=	ACC100 < 6.	R = 2
ZONE 3	6. <=	ACC100 <	R = 4

KEY FOR INTERPRETATION OF AGRICULTURE CAPABILITY MANUSCRIPT MAPS (B.C.)

There are 7 capability classes for agriculture with 1 representing the highest class and 7 representing the lowest. In some areas of the province, two ratings are shown: one for dry farming and a second for irrigated or drained (improved) conditions. The irrigated ratings are shown enclosed in round brackets while the drained ratings appear in square brackets. In all cases improved ratings have precedence over dry farm ratings.

Example Classifications





The agriculture capability classes are determined on the relative range of crops the land can produce.

a) Capability Classes

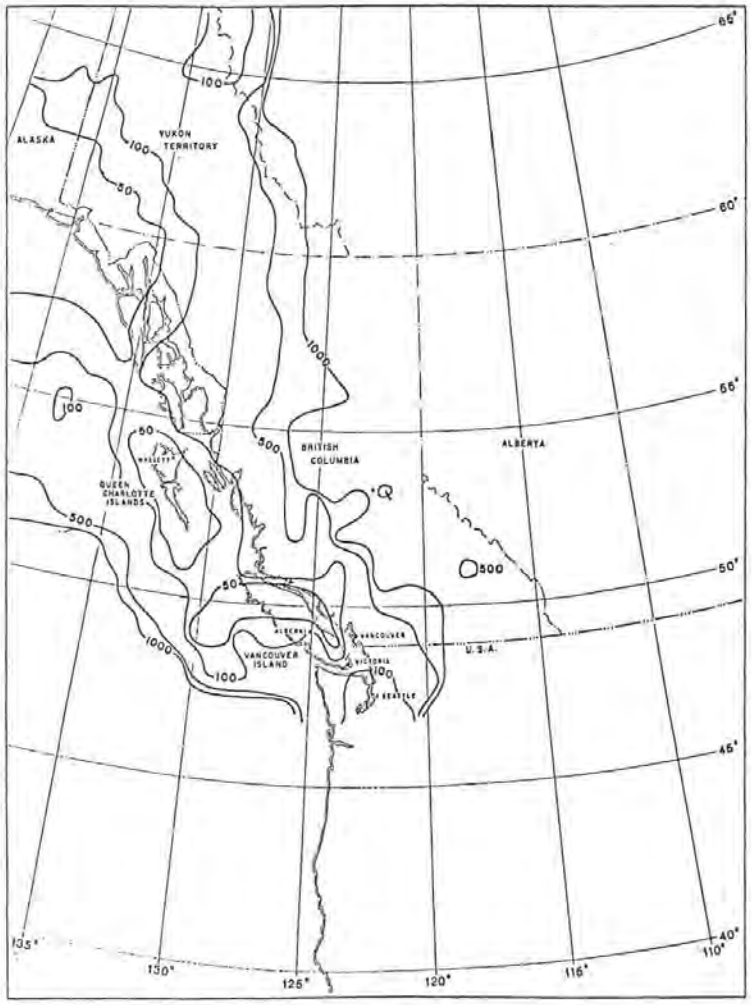
Class 1 - widest range of crops
Class 2
Class 3 } reduced range of crops caused by a number of limiting
Class 4 } factors (subclasses)
Class 5 - only permanent pasture or forage
Class 6 - natural grazing
Class 7 - no productivity

b) Limiting Subclasses

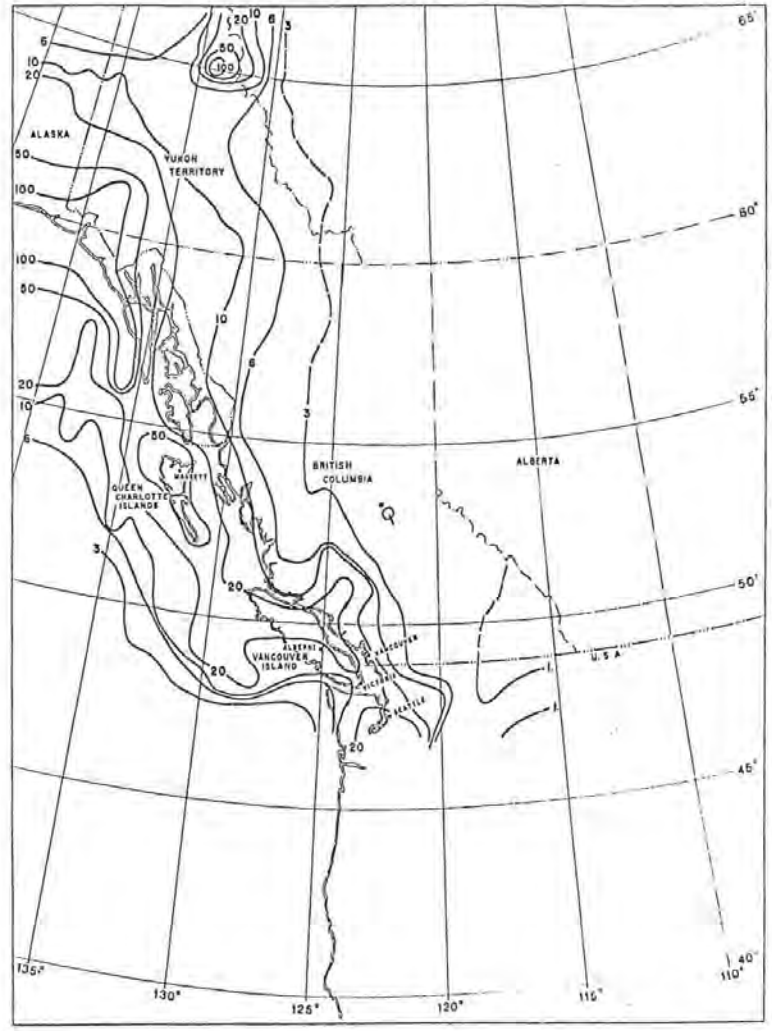
C - adverse climate
D - undesirable soil structure
E - erosion
F - low fertility
I - inundation (flooding)
M - moisture deficiency (droughtiness)
N - salts
P - stoniness
R - bedrock near the surface
T - topography (slope)
W - excess water
X - combination of soil factors

Tree fruit and grape growing areas: these crops are tolerant of soil conditions that limit field crops. Steep and stonier soils in suited climates have been upgraded to accommodate the expanded range of crops. e.g. A class 5T soil dry farmed becomes a 3T irrigated in an area climatically suited to tree fruits.

Note: A more detailed 16 page manual entitled Soil Capability Classification for Agriculture is available from the *Lands Directorate, Lands Forests and Wildlife Service, Department of the Environment, Ottawa, Ontario, K1A 0H3.*



Return periods in years for acceleration of 10 per cent gravity in western Canada



Accelerations as a per cent of g with a 100-year return period for western

PRINCE GEORGE SPECIAL SALES AREA (SOUTH)

AGRICULTURE

(PROVISIONAL COPY)

CANADA LAND INVENTORY (E