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THE UNIVERSITY OF ALBERTA

A REPORT ON SLOPE INSTABILITY ALONG THE OLDMAN RIVER AND TRIBUTARIES IN THE VICINITY OF LETHBRIDGE, ALBERTA

by

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SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING IN CIVIL ENGINEERING

EDMONTON, ALBERTA

SPRING, 1983

ABSTRACT

This report identifies areas of slope instability along the Oldman River and its tributaries in the vicinity of Lethbridge, Alberta. Based primarily on a review of vertical aerial photographs, the areas of slope instability have been analyzed with respect to the failure mode and the possible cause of instability.

In general, landslide activity occurs in two separate areas: either along the Oldman River valley walls or along the tributary valleys which drain into the Oldman River. The slides common to the Oldman River valley are relatively large and typically involve a translational type of failure. The slides formed along the tributary valleys are generally much smaller in areal extent and exhibit primarily a rotational type of movement.

The landslides along the main river valley are very old and relatively stable. It is suspected that the formation of the river valley slides are contemporaneous with the formation of the post-glacial river valley. The combined rotational-translational river valley slides are based along or in the Upper Cretaceous bedrock. Large alluvial terraces deposited within the valley floodplain provide natural toe erosion protection and stabilizing berms for a number of the river valley slides.

In addition to the naturally occurring river valley landslides, at least one slide area is suspected of being initiated by anthropogenic causes. A series of slumps and cracks along a stretch of the west bank of the Oldman River is believed to be due to subsidence over old coal mine workings.

ABSTRACT (continued)

The tributary valleys (commonly referred to as coulees) form a major part of the regional physiography in the plains portion of southern Alberta. The coulees are comprised of steep valley walls with flat bottoms and relatively steep gradients. In the Lethbridge area, the coulees are more pronounced on the east (or windward) side of the Oldman River valley. One of the most prominent characteristics of the coulees is their preferred orientation of N 70° E. The formation of the coulees have had an overall stabilizing effect on the Oldman River valley walls by reducing the average slope angle.

Instability along the coulees is relatively recent and consists primarily of shallow rotational landslides. In their natural state, the steep coulee walls (up to 40 degrees) are stable. Development along the crest of the coulees is one of the major causes of coulee landslide activity. Coulee landslides are typically caused by one or a combination of the following activities: a rise in the local groundwater table, fill placement along the crest of coulees, uncontrolled discharge of surface water runoff and irrigation water onto coulee slopes and ponding of water near the crest of slopes.

The recommendation of a safe setback distance from the river valley walls is a difficult task for general development along the prairie upland. As a result, a conservative approach regarding recommendations has been taken. For preliminary purposes, it is recommended that a setback distance equal to the depth of the valley be used for any proposed

ABSTRACT (continued)

developments adjacent to the Oldman River valley. With regard to development along the coulees, it is recommended that a perimeter road such as Scenic Drive be used to separate the coulees from any future residential or commercial development.

Final decisions for setback distances should be performed by a qualified geotechnical engineering firm with consideration given to loading or unloading of slopes and possible changes in the groundwater regime.

ACKNOWLEDGEMENTS

The financial assistance provided by Alberta Environment, Environmental Engineering Support Services, Design and Construction Division; the personal interest displayed by John Campbell, head of the Geotechnical Branch, Design and Construction Division, Alberta Environment; and the aid provided by the drafting department of Alberta Environment are all greatly appreciated. The support of EBA Engineering Consultants Ltd. with the secretarial services for the preparation of this report is also appreciated. The assistance and support of Professor S. Thomson is gratefully acknowledged.

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1.0 INTRODUCTION

1.1 PURPOSE

This report represents the results of a general slope stability evaluation along the Oldman River and its tributaries in the vicinity of Lethbridge, Alberta. The objectives of the evaluation were as follows:

- to identify areas along the river bank which exhibit signs of previous instability or are presently unstable.
- to identify failure modes and any geological factors presently affecting slope stability.
- to evaluate the effect of development along or adjacent to the river valley.
- to recommend a safe setback distance from the valley walls where developments will not be affected by slope instability.

1.2 SCOPE

The study incorporated an aerial photograph analysis and field investigation of the Oldman River in the vicinity of Lethbridge, Alberta. The stereoscopic examination of aerial photographs covered a period from 1950 to 1980. These aerial photographs were used to identify details of failure mode, location, size and present status of the slide. Inferences have been made with respect to groundwater conditions, surficial geology and bedrock stratigraphy.

A field reconnaissance was conducted for two weeks in May 1981 to provide verification of the features identified from the aerial photographs such as exposures of soils in backscarps, local seepage areas or springs, and confirmation of toe erosion, gullying and fill placement.

In addition to the aerial photographs and field reconnaissance, a review of published and unpublished reports and maps was conducted. These sources included bedrock geology, bedrock topography, hydrogeology, surficial geology, surface topography and local geotechnical reports.

1.3 LOCATION

The study area lies along a 13 kilometre reach of the Oldman River in the vicinity of Lethbridge, Alberta within Townships 8 and 9, Range 21 West of the Fourth Meridian and Townships 8 and 9, Range 22, West of the Fourth Meridian. The limits of the study area are shown on Drawing 1.

1.4 CLIMATE AND VEGETATION

The climate of southern Alberta is semi-arid with cold winters, frequent chinooks and hot summers. The mean annual precipitation at Lethbridge is 425 mm, with 62 percent of the precipitation falling as rain. Due to the hot summers and strong wind conditions, the monthly mean potential evapotranspiration rate exceeds the average monthly precipitation from May to October, yielding a moisture deficit of about 343 mm.

The proximity of the area to the Rocky Mountains results in rapid changes in the weather pattern. Warm chinook winds in winter can raise temperatures dramatically within a few hours, and in some instances melt all snow cover in several days.

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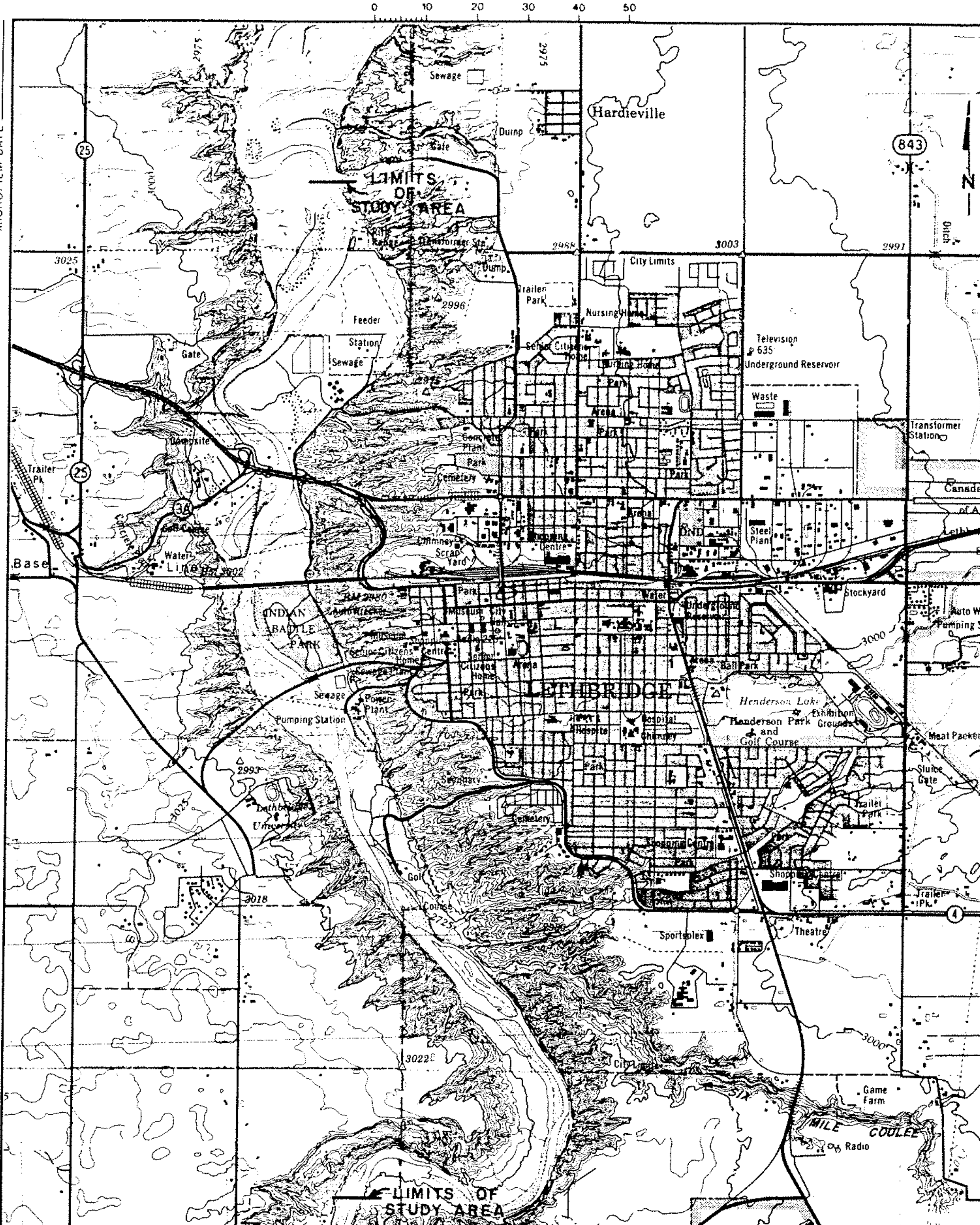

Alberta ENVIRONMENT

SLOPE STABILITY STUDY-LETHBRIDGE

LOCATION PLAN OF STUDY AREA

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Natural runoff is very low due to the flat lying topography away from the river valley. Rapid runoff occurs only in areas adjacent to the main river valley.

This area of southern Alberta forms part of the 'short grass prairie'. Apart from the major river valleys, no native trees grow in the area. The native vegetation includes blue grass, spear grass, sage and cactus. Today, little native vegetation remains, as most of the land is cultivated. Local crops include wheat, barley, oats, sugar beets and vegetables.

Irrigation is a vital component of the farming in the area. Extensive irrigation systems are used to sustain the needs of the local farming community.

On many valley slopes, the existence of shrubs and small trees (such as saskatoons and choke cherries) indicate areas of higher moisture content. This may be due to groundwater seepage, ponded water associated with surface runoff or possibly an area of snow drift accumulation just below the brow of a ridge or hill.

1.5 PHYSIOGRAPHY

The preglacial topography of the area has been modified considerably by the effects of glaciation. A mantle of drift has infilled the preglacial lows producing a landscape of gently rolling prairie.

The present-day river valleys were carved quite rapidly when large quantities of meltwater were available as the Laurentide glaciers made their final retreat from the area.

Near Lethbridge, the Oldman River valley is approximately 95 metres deep and varies in width from 1.5 to 3.0 kilometres. The river valley separates two different geomorphic units, indicating some form of glacial contact origin.

There is only one tributary stream within the limits of the study area which flows into the Oldman River. Referred to locally as 'Six Mile Coulee', this tributary system is situated south of the city on the east bank of the Oldman River (see Drawing 1). The stream which flows along the base of this flat bottom coulee undercuts the valley walls at meander bends, causing oversteeping of the banks and numerous cases of slope instability.

The tributary valley system in the area is of major importance when analyzing the landslide activity of the region. An examination of aerial photographs of the plains portion of southern Alberta reveals the existence of a series of short, narrow, parallel or subparallel coulees tributary to the main river valley. The distinctive pattern of alignment extends from Lethbridge to Pincher Creek in the Rocky Mountain Foothills. Several possible hypotheses regarding the possible formation of the coulees have been proposed, including: subsurface structural control, the role of regional slopes, the effect of lithological differences, and wind action.

The dominant feature of these coulees is their preferred alignment of N 70° E. Steep-walled valleys with a dendritic drainage pattern and relatively steep gradients are their notable characteristics. The coulees are generally dry, only carrying surficial runoff after heavy rains and occasionally during periods of abundant snowmelt. The addition of stormwater runoff or irrigation overflow has resulted in erosion and oversteeping along the base of a number of these coulees.

In the Lethbridge area, the coulees exhibit a more developed and mature appearance on the east (or windward) side of the Oldman River valley. The average length of the coulees on the east and west banks is 1.0 and 0.65 kilometres, respectively.

In a paper by Beaty (1975), three outstanding characteristics of these coulees were noted:

(1) their preferred orientation of N 70° E, which corresponds with the mean direction of the dominant chinook winds in southern Alberta

(2) the development of the these coulees only in the southwestern corner of Alberta which experiences the most pronounced effect of chinooks

(3) their dominant location on windward topographic surfaces.

The argument that the coulees are a reflection of structural features in bedrock beneath a veneer of unconsolidated materials is discounted by Beaty due to an inadequate explanation as to their existence primarily in the southwest corner of Alberta and also their dominant tendency to occur on windward valley walls. In a study by Babcock (1977) which compared bedrock joints and fractures in overlying Pleistocene lacustrine deposits, it was concluded that there was no relation between the two major joint sets and the development of the coulees.

Beaty proposed the following model to describe the origin of the coulees:

(1) the general drainage pattern was established 6,000 - 8,000 years ago and sufficient relief had developed for coulee formation

(2) strong southwesterly winds affected windward valley slopes by:
- retaining less snow
- the climate within a few centimetres of the surface was considerably drier because of solar radiation and strong winds.

These factors lead to decreased vegetation cover and surfaces which were much more susceptible to erosion.

(3) wind-driven snow and rain carved narrow, elongated surficial furrows on southwesterly facing slopes

(4) coulee enlargement was then continued by the erosional work of surface runoff.

Attempts to duplicate the process in a laboratory using an electric fan and a variety of soils and moisture contents have not proven successful.

Todate, there does not appear to be agreement regarding the process responsible for coulee formation.

Another interesting physiographic feature common to the area is the small step-like structures called terracettes, that develop on the valley walls. These terracettes or catsteps, vary in height from a few centimetres to two metres and average one half to one metre in width. They generally form on steep hillsides as a result of the development of slippage planes and subsequent slumping of the surficial soil (see Photo 1).

1.6 PREVIOUS WORK

The area was initially investigated by Dr. James Hector, a geologist, with the Palliser Expedition in the late 1850's. A more detailed geological investigation was undertaken by G.M. Dawson, in 1875. Dowling, in 1917, prepared a geological map of southern Alberta which broadly outlined the preglacial drainage pattern of the area. The physiographic development of southern Alberta was described by Williams and Dryer in 1930.

Horberg, in 1952, separated and mapped several till deposits in the Lethbridge area. In 1961, Stalker published the first map of the preglacial valleys in southern Alberta which was later modified and updated by Geiger in 1965. The quaternary stratigraphy of southern Alberta was described by Stalker in 1962.

Detailed bedrock and hydrogeologic studies were conducted by Geiger in 1965 and 1968, respectively. Additional groundwater studies were carried out by Nielsen in 1970 and a more general hydrogeologic study of the Lethbridge- Fernie area was completed by Tokarsky in 1974.

A summary of current geological maps of the Lethbridge area are listed in Table 1.

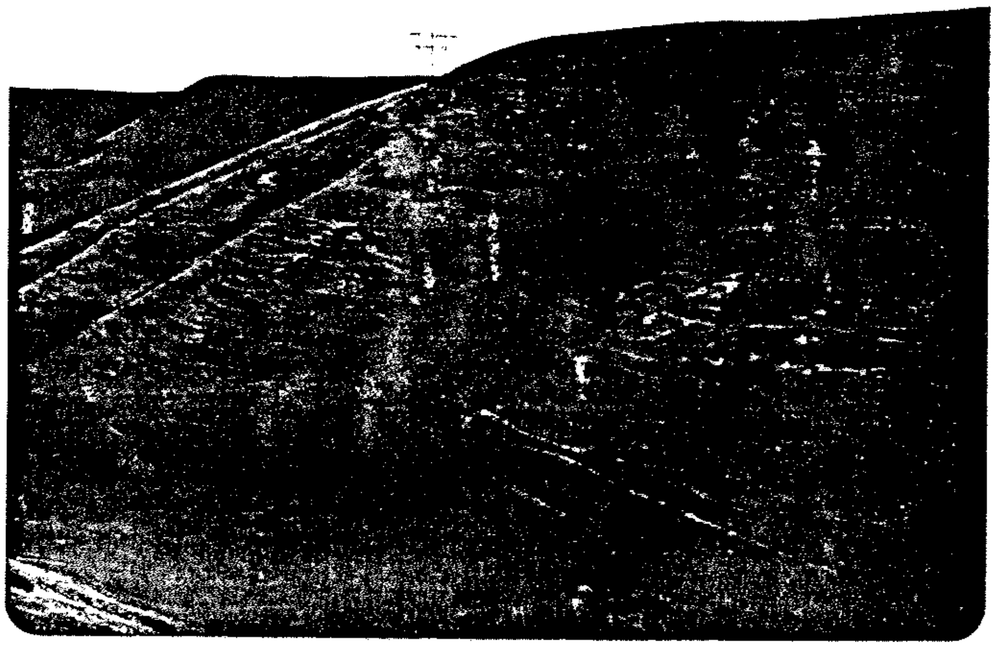


Photo 1: View of terracettes formed on many of the steep-walled coulees and valleys in the Lethbridge area.

TABLE 1

INDEX OF CURRENT GEOLOGICAL MAPS
OF THE LETHBRIDGE AREA

Hydrogeology

Tokorsky, O. 1974. Hydrogeology of the Lethbridge-Fernie Area, Alberta. A.R.C. Report 74-1 (Scale 1" = 4 miles)

Bedrock Topography

Geiger, K.W. 1965. Bedrock Topography of Southwestern Alberta. A.R.C. Report 65-1 (Scale 1" = 4 miles)

Surficial Geology

Stalker, A. MacS. 1962. Surficial Geology, Lethbridge (east half), Alberta. G.S.C. Map 41-1962 (Scale 1" = 4 miles)

Stalker, A. MacS. 1959. Surficial Geology, Fort McLeod, Alberta. G.S.C. Map 21-1958 with descriptive notes (Scale 1" = 4 miles)

Bedrock Geology

Irish, E.J.W. 1967. Geology, Lethbridge, Alberta. G.S.C. Preliminary Series Map 20-1967 with descriptive notes (Scale 1" = 4 miles)

NOTE: A.R.C. - Alberta Research Council
G.S.C. - Geological Survey of Canada

Detailed geotechnical studies by R.M. Hardy and Associates Ltd. (1977a, 1977b, 1978a, 1978b) have been conducted to assess the foundation conditions and the overall coulee stability for proposed residential developments on both the west and east banks of the Oldman River. Klohn Leonoff Consultants (1975) conducted a geotechnical investigation to evaluate slope instability in the Park Royal Subdivision for the City of Lethbridge and also a detailed geotechnical evaluation in 1970 for the University of Lethbridge.

Beginning in the late 1800's and continuing through to the mid 1900's, coal was mined extensively along the river valley in the Lethbridge area. Due to these coal mining operations, subsidence has occurred throughout the area contributing to numerous cracks, slumps and landslides along the Oldman River.

One of the slide areas has been identified by R.M. Hardy and Associates Ltd. (1977a) as being caused by subsidence. Although a detailed study of old mining records was not conducted, it is suspected that other areas near the river valley may have experienced subsidence due to coal mining and possibly triggered some form of landslide activity.

2.0 GEOLOGY

2.1 GEOLOGIC BACKGROUND

Widespread advances and regressions of epeiric seas during the Upper Cretaceous epoch provided the environment for deposition of sediments over the plains area of Western Canada. Sedimentation continued through the Cretaceous, Paleocene and Tertiary epochs. Formation of the Rocky Mountains occurred during the Eocene, which saw a period of major uplift followed by extensive erosion. It is estimated that up to 600 metres of sedimentary rock was eroded prior to the Quaternary and glaciation.

The Quaternary affected practically all of western Canada. Glacial ice and its associated processes deposited a mantle of drift over the entire study area. A significant modification of the drainage system occurred as the southwesterly advancing glaciers diverted the original river drainage channels. As the glacial ice retreated from the area, the diverted streams were often unable to recover their former channels due to infilling of the preglacial valleys with glacial deposits.

Four major glacial advances have been identified in the Lethbridge area. These are discussed in more detail in Section 2.5. Drift thickness in the study area is estimated to range up to 90 metres.

The exposed bedrock in the study area consists of Upper Cretaceous sediments deposited in both marine and fresh water environments. The bedrock deposits comprise gently dipping shale, siltstone and sandstone strata, with interspersed beds of coal and bentonite. For the most part, the exposed Upper Cretaceous rocks are poorly indurated and are often referred to as 'soft rocks' or 'hard clays'. Cementation by silica or carbonate have made some of the sandstone and siltstone strata competent.

2.2 REGIONAL GEOLOGY

Lethbridge is situated in the southern plains region of Alberta about 65 kilometres northeast of the eastern limit of the Foothills disturbed belt. The study area is located on the western limb of the Sweetgrass Arch Anticline, east of the Albert Syncline. The exposed formations are progressively younger from east to west with all strata dipping gently in a westerly or southwesterly direction. The magnitude of the dip increases from east to west, with the beds averaging 11.5 to 13 metres per kilometre in the Lethbridge area.

Several thrust faults have been identified and mapped by Irish (1967). One major fault, the Monarch fault zone, is an imbricate zone involving the uppermost beds of the Bearpaw, the Blood Reserve, and the lower beds of the St. Mary Formations. Another smaller thrust fault is known to cross the Oldman River in an area north of its confluence with the St. Mary River.

Numerous minor faults with vertical separations of about one metre are present in the area. These have caused many problems in the past during coal mining operations.

Two prominent joint sets are common throughout the region. The main joint direction lies in a general northeast-southwest direction, while a secondary set lies in a northwest-southeast direction.

2.3 BEDROCK GEOLOGY

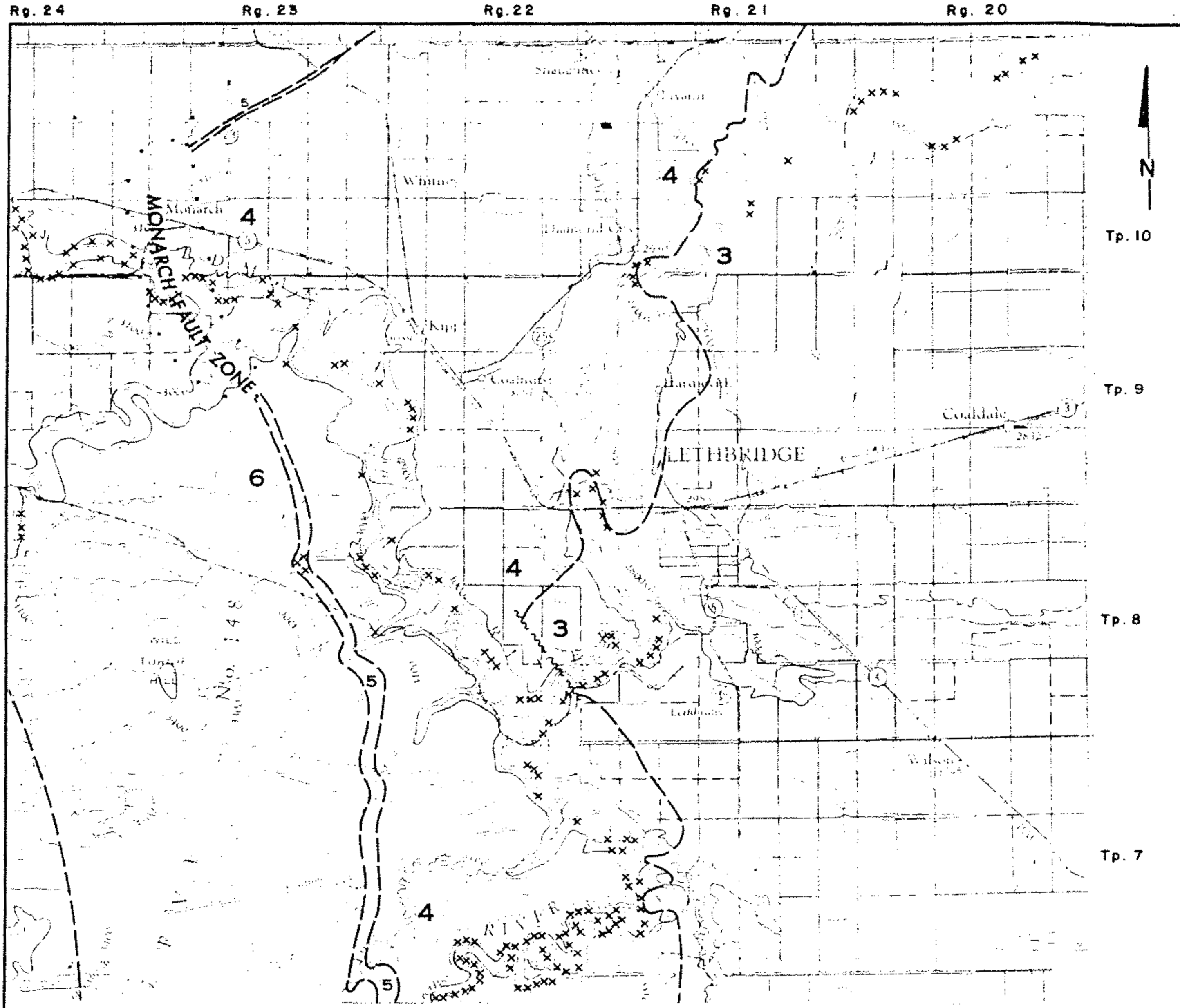
The stratigraphic column in the Lethbridge area, as described by Irish (1967), includes the following formations:

ERA	PERIOD	FORMATION
Cenozoic	Quaternary (Pleistocene)	River gravels & & glacial deposits
	Tertiary	Porcupine Hills Willow Creek
Mesozoic	Upper Cretaceous	Kneehills Tuff Zone St. Mary River Blood Reserve Bearpaw Oldman Foremost Pakowski Milk River

The geological formations that outcrop or occur immediately below the unconsolidated glacial deposits in the study area are of Upper Cretaceous age, and include the Oldman and Bearpaw Formations (Drawing 2). These two formations are discussed in the following sections.

Oldman Formation:

Beds of the Oldman Formation, which conformably overlie the Foremost Formation consist of interbedded and interlensed green, grey and light grey shale; silty shale; soft, grey and light grey weathered, argillaceous sandstone. Thin concretionary ironstone bands and limestone beds are present at some localities. Hard, grey, calcareous sandstone beds occur at some horizons and thick, crossbedded, light-grey weathering, lenticular sandstone units are typical of the upper part of the formation (Irish, 1967). Near the top of the formation are a series of coal beds and carbonaceous shales referred to as the Lethbridge Member. This member is generally used as a marker between the Oldman and overlying Bearpaw Shale Formation.



6 ST. MARY RIVER FORMATION : HARD, GREEN, GREY, AND BUFF-WEATHERING, GREY, FINE-GRAINED, CALCAREOUS SANDSTONE ; FRIABLE, GREEN AND GREY, SILTY SHALE ; FISSILE, GREY SHALE, COAL, AND COQUINOID LIMESTONE OCCURS IN BASAL PART (non-marine)

5 BLOOD RESERVE FORMATION: MASSIVE, BUFF TO YELLOW WEATHERING, GREY OR GREENISH GREY SANDSTONE (marine and non-marine)

4 BEARPAW FORMATION: DARK GREY AND BROWNISH-GREY, RUBBLY AND FLAKY SHALE ; SILTY SHALE ; GREY ARGILLACEOUS SANDSTONE ; IRONSTONE CONCRETIONARY BANDS ; BENTONITE LAYERS (marine)

3 OLDMAN FORMATION: MASSIVE, CROSSBEDDED, MEDIUM-TO COARSE-GRAINED, LIGHT-GREY WEATHERING SANDSTONE ; GREY, CLAYEY SILTSTONE ; GREY AND LIGHT-GREY WEATHERING, GREEN AND GREY SHALE ; DARK GREY AND BROWN, CARBONACEOUS SHALE ; IRONSTONE CONCRETIONARY BEDS (non-marine)

GEOLOGICAL BOUNDARY (approx.) . . . . ～～

ROCK OUTCROP . . . . ×

FAULT (position approximate) . . . . ~~~ ~~~ ~~~

Alberta ENVIRONMENT

SUBMITTED	DESIGNED	SLOPE STABILITY STUDY-LETHBRIDGE
DATE	CHECKED	**BEDROCK GEOLOGY OF THE LETHBRIDGE AREA** (AFTER IRISH, 1967)
APPROVED	DRAWN ....C.F....	SCALE 1 : 250 000 / SHEET 1 OF 1
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Outcrops of the Oldman Formation are exposed along the valley of the Oldman River north and south of the City of Lethbridge.

Bearpaw Formation:

The Bearpaw Formation rests conformably upon the beds of the Oldman Formation. Irish (1967) described the formation as:

> "grey-weathering, dark grey or brownish grey shale and silty shale; spheroidal ironstone concretions; fine-grained, clayey sandstone; and bentonite beds."

Most of the shale weathers to small angular fragments but fine flakes are produced in a similar manner. The upper 6.5 metres of the Bearpaw Formation contains numerous thin sandstone beds.

Excellent exposures of the Bearpaw strata are visible along the Oldman River valley from Township 9 downstream to a point about 8 kilometres north of Lethbridge (see Photo 2).

2.4 BEDROCK TOPOGRAPHY

A mature surficial topography was established during the extensive sub-aerial erosion period prior to the Quaternary. The bedrock channels that developed were broad with gentle valley slopes and widely separated by low, well rounded upland areas. The overall drainage pattern of the preglacial river system was similar to the present-day drainage which flows in a general northeasterly direction. Contour maps of the bedrock surface of southern Alberta (Geiger, 1965) permit an interpretation of the

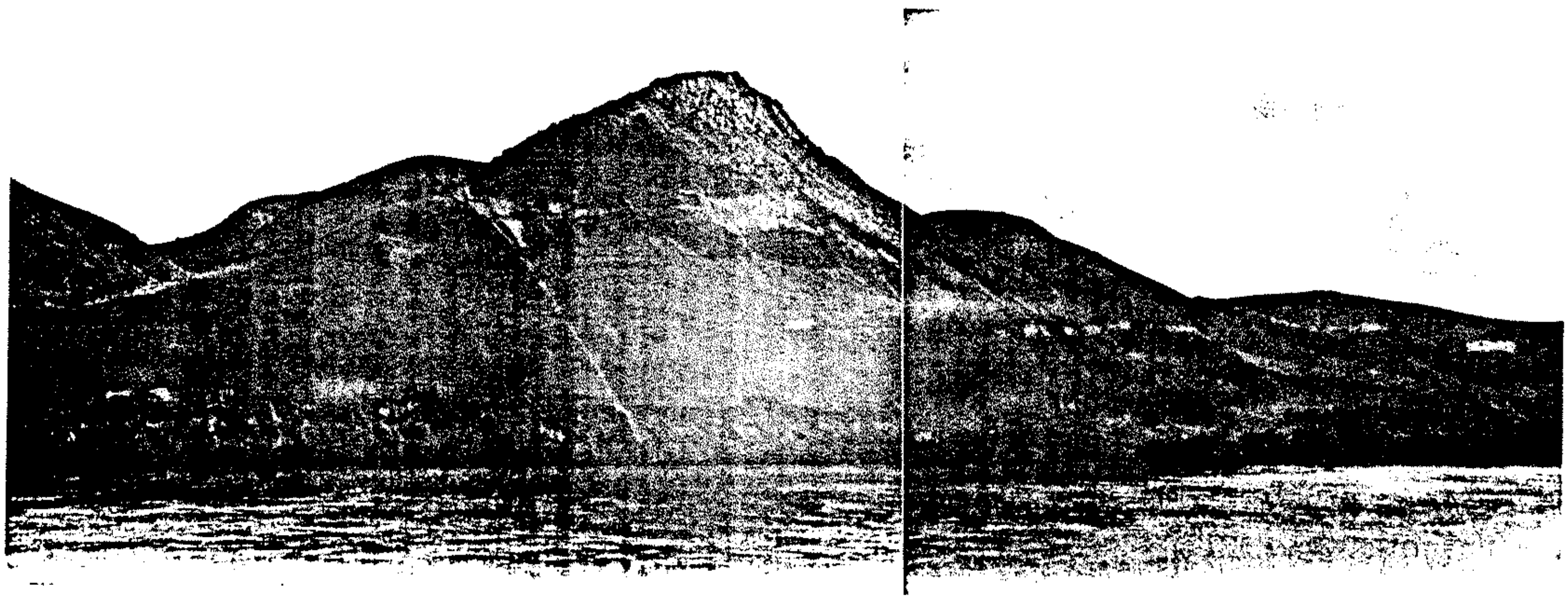


PHOTO 2: Exposure of Bearpaw Shale on east bank of Oldman River (LSD-7-Sec.13-Twp. 9 - Rge. 22-W4M).
Note layer of Saskatchewan Sand and Gravel between bedrock and overlying till.

preglacial drainage system. Drawing 3 illustrates the main preglacial valley thalwegs of southwestern Alberta.

The major preglacial valley traversing the study area is the Lethbridge Valley. The City of Lethbridge sits directly over the preglacial Lethbridge Valley which is 10 to 16 kilometres wide (Geiger, 1965). The centreline of the valley runs in an easterly direction under the city, intersecting the preglacial Blood and Whoop-Up Valleys at right angles, and then continues east-northeast.

The importance of the location of these preglacial valleys resides in the fact that they are typically floored with the Saskatchewan Sands and Gravels. In addition to being a major source of granular deposits, the sands and gravels have an overall stabilizing effect on the valley slopes. The highly permeable sands and gravels act as a drain lowering the groundwater table in the overburden, which decreases the porewater pressures in the adjacent valley slopes and increases the overall slope stability.

2.5 SURFICIAL GEOLOGY

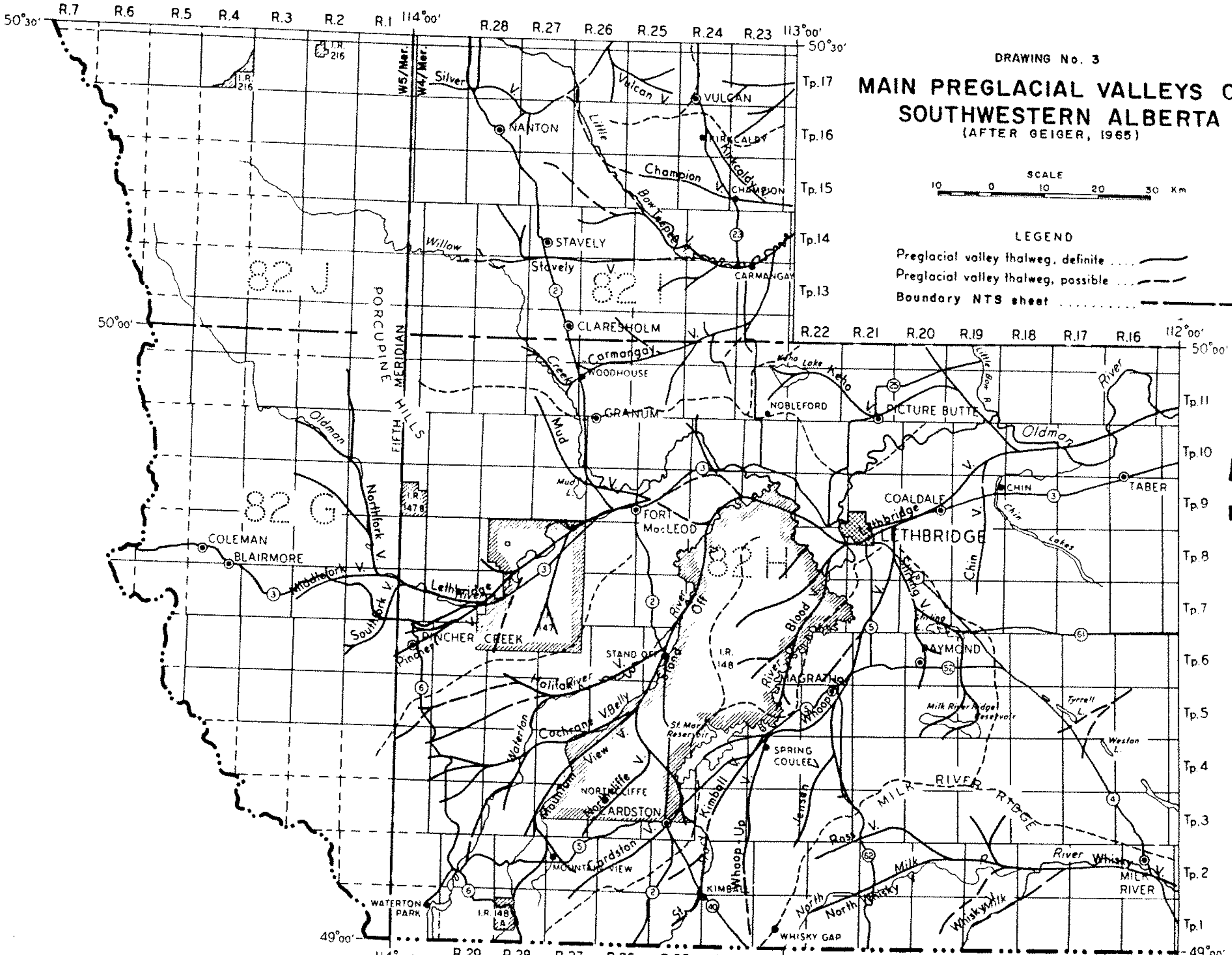
Numerous excellent exposures of the Pleistocene and more recent deposits occur along the Oldman River valley. They commonly include a bedrock base overlain by preglacial gravels, several till sheets and varying thicknesses of post-glacial deposits.

The Pleistocene deposits of the Lethbridge area are divided into the following stratigraphic units in order of decreasing age: Saskatchewan Sands and Gravels, Wolf Island sediments, basal till, lower till number 1, lower till number 2, Lenzie silts, upper till and upper silts and sands.

DRAWING No. 3

MAIN PREGLACIAL VALLEYS OF SOUTHWESTERN ALBERTA

(AFTER GEIGER, 1965)



Horberg (1952) provided the first detailed breakdown of the Pleistocene deposits in the Lethbridge area identifying three distinct till sequences: a basal till, a lower till and an upper till. The lower and upper tills are separated by a layer Horberg refers to as the 'Lenzie Silts'. More recently, this lower till has been subdivided into two separate till sheets by Geiger (1968) and Nielsen (1970).

Although not found in the Lethbridge area, further to the east, Westgate (1968) identified a sequence of lacustrine sands, silts and clays that conformably overlie the Saskatchewan Sands & Gravels. These Wolf Island sediments accumulated in elongated proglacial lakes that formed when the outlet of the preglacial rivers became blocked by ice. It would appear that these proglacial lakes did not extend as far back upstream as Lethbridge.

A correlation of the Lethbridge Pleistocene deposits as identified by Nielsen (1970), with the Foremost-Cypress Hills area studied by Westgate (1968) is shown in Table 2.

Five drift sheets have been identified by Westgate (1965) in the Foremost-Cypress Hills area. Of the five major glacial advances in southern Alberta, only four penetrated as far south as Lethbridge (Drawing 4).

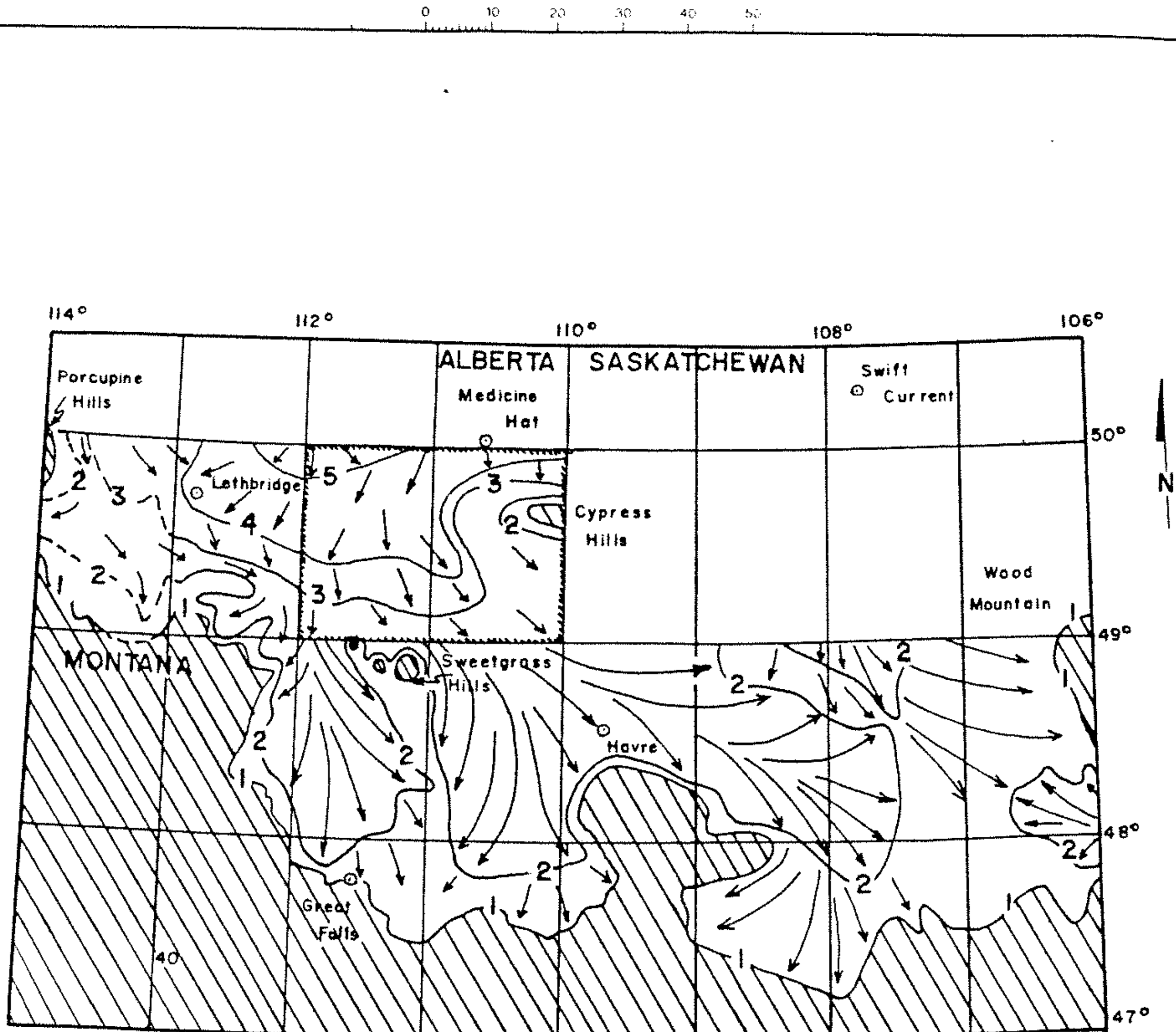
The individual Pleistocene deposits are discussed briefly in the following sections.

Underlying the Pleistocene glacial deposits and overlying the Upper Cretaceous bedrock are the Saskatchewan Sands and Gravels. Upstream of Lethbridge, outcrops of the sands and gravels have been observed above the Oldman Formation and downstream of Lethbridge, above the Bearpaw shales

STAGE	SUB STAGE	WESTGATE (1968)	NIELSEN (1970)
WISCONSIN GLACIAL STAGE	RECENT		MAZAMA ASH HORIZON 6600 YRS. B.P.
	CARY	OLDMAN DRIFT >13,000 YRS. B.P.	UPPER SILTS AND SANDS
		ETZIKOM DRIFT	UPPER TILL / LENZIE SILTS
		PAKOWKI DRIFT	LOWER TILL NO. 2 / BEDROCK MASSES HORZ.
	TAZEWELL	WILD HORSE DRIFT 20,000 - 24,000 YRS. B.P.	LOWER TILL NO. 1
	? IOWAN ?	ELKWATER DRIFT / WOLF ISLAND SEDIMENTS	BASAL TILL / ? WOLF ISLAND SEDIMENTS ?
NEBRASKAN TO WISCONSIN		SASKATCHEWAN GRAVEL > 36,000 YRS. B.P.	SASKATCHEWAN GRAVEL >54,500 YRS. B.P.

STRATIGRAPHY OF SURFICIAL DEPOSITS
(AFTER NIELSEN, 1970)

TABLE 2



(AFTER WESTGATE, 1965)

LEGEND

ICE FRONTAL POSITION
1. OUTER LIMIT OF BASAL TILL
2. OUTER LIMIT OF LOWER TILL NO. 1
3. OUTER LIMIT OF LOWER TILL NO. 2
4. OUTER LIMIT OF UPPER TILL

Alberta ENVIRONMENT	SLOPE STABILITY STUDY-LETHBRIDGE
SUBMITTED ... DATE ... DESIGNED ... CHECKED ...	SIGNIFICANT ICE FRONTAL POSITIONS IN SOUTHERN ALBERTA
APPROVED ... DATE ... DRAWN ... CHECKED ...	SCALE AS SHOWN · SHEET 1 OF 1
	DATE OCTOBER, 1982 · DRAWING No. 4

(see Photo 2). The Saskatchewan Sands and Gravels consist of a clean, well sorted, round to subrounded river gravel with a sand matrix. These granular deposits are generally confined to the floor of the preglacial valleys having been deposited by preglacial rivers flowing eastward from the mountains. The initiation of glaciation marked the end of deposition of the sand and gravel. Nielsen (1970) has estimated that these deposits vary in thickness up to 12 metres in the Lethbridge area.

The basal till is a well-indurated till lying directly on bedrock or on the Saskatchewan Sands and Gravels. It is brownish grey in colour, very hard, columnar structured, with salt deposits along the vertical joints. At the top of this basal till (which averages 1.3 metres in thickness), lies a thin layer of silt and sand of possible lacustrine or fluvial origin. Horberg (1952) concluded that the basal till is much older than the overlying tills, probably of early Wisconsin age.

The remaining tills are suspected to have been deposited during late or 'Classical' Wisconsin time. Overlying the basal till is a dense, hard, jointed, clayey, calcareous 'Lower Till' which varies in thickness from 4.5 to 41 metres (Nielsen, 1970). The lower, unoxidized part of the till is a dark grey colour, while the upper part has oxidized to a brown grey or buff colour to depths of about 3 metres. It is suspected that groundwater is responsible for much of the oxidization. Although the lower till does not exhibit a columnar structure which is as pronounced as the basal till, it still outcrops in near vertical exposures.

The lower till is separated into a Number 1 and a Number 2 till by a discontinuous layer of Cretaceous shale referred to as the 'Bedrock Masses' Layer, which varies in thickness up to one metre. Its presence within the drift is difficult to explain, but it is thought to have been frozen into the base of a readvancing glacier, indicating an interstadial period.

A distinct, stratified layer referred to as the 'Lenzie Silts' lies above the Lower Till. This clay, silt and sand layer of lacustrine and alluvial origin varies in thickness from 3 to 10 metres in the Lethbridge area (Nielsen, 1970). Horberg (1952) suggests that the sediments were laid down "as an off-lap deposit in proglacial lakes as the ice sheet that deposited the lower till withdrew from the area". These light brown silts provide an excellent marker between the grey lower till and the darker upper tills above the Lenzie silts.

The 'Upper Till' which overlies the Lenzie silts, is the final till sheet deposited in the area. The Lethbridge Moraine, south and east of Lethbridge marks the furthest readvance of the ice that deposited the upper till. Either dark grey in colour where unoxidized or buff where oxidized, the upper till is more massive in appearance than the lower till. The thickness of the upper till varies from 10 to 40 metres (Nielsen, 1970).

The surficial sediments overlying the upper till, referred to as the 'Upper Silts and Sands', were deposited during the final glacial retreat in glacial Lake Lethbridge. "They include a variety of sediments: lacustrine silts and clays, glaciofluvial sands and gravels, loess, alluvial wash, colluvium, volcanic ash, buried soils, dune sands, floodplain alluvium and surficial soils" (Horberg, 1952). Lacustrine silt and clay have a maximum thickness of approximately 13 metres in the Lethbridge area (Nielsen, 1970). After the glacial lakes had dried up, some lacustrine silts and sands were reworked by wind to form sand dunes and loess deposits.

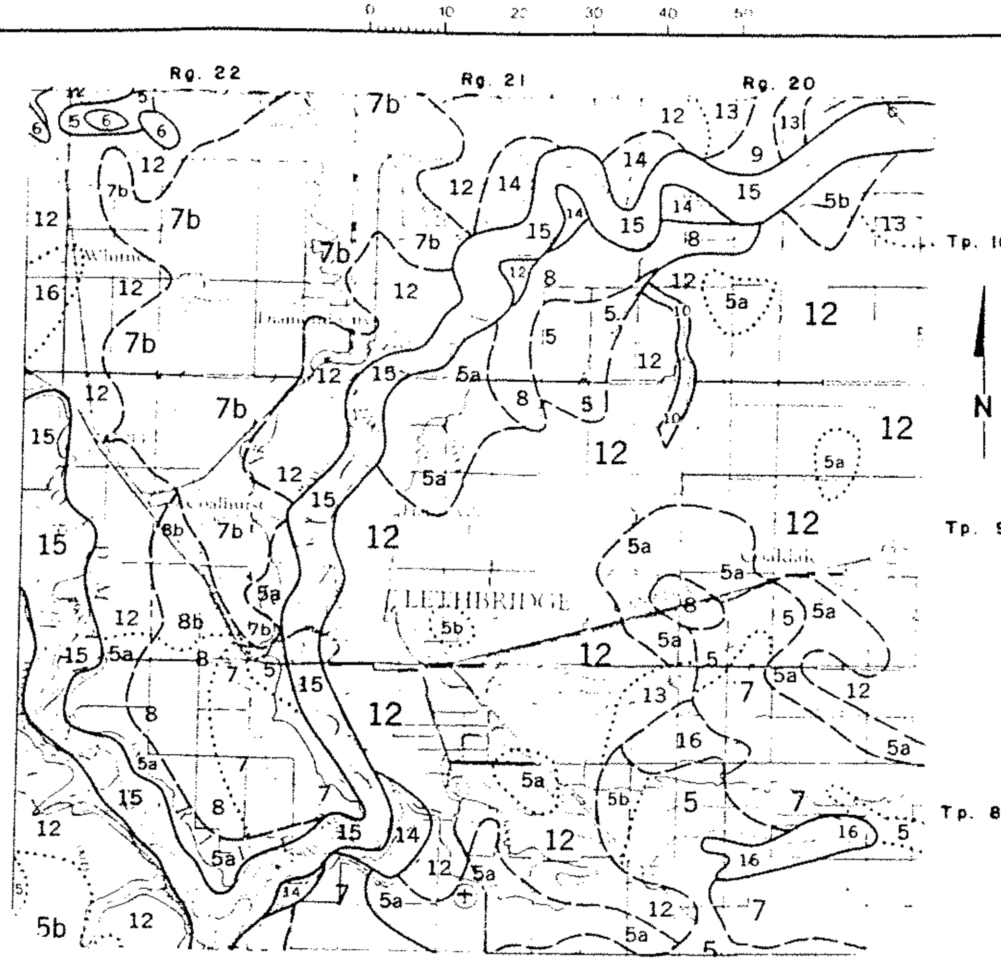
As the final glaciers retreated to the northeast, glacial meltwaters were trapped forming proglacial lakes. Lake levels fluctuated as their shorelines were breached, forming the numerous meltwater channels throughout the area.

Development of the major river valleys probably took place after the ice had retreated sufficiently far to the northeast that it no longer obstructed flow in the normal northeasterly downslope direction, but while there were still immense quantities of meltwater available to erode the very deeply incised major valleys of the present landscape. As post-glacial rivers began to establish their present day courses, numerous gravel terraces were deposited between the top and bottom of the valley. Presently, about 7 metres of gravel floors the bedrock along the Oldman River floodplain at Lethbridge.

A map identifying the present surficial deposits in the Lethbridge area is shown on Drawing 5.

2.6 HYDROGEOLOGY

The Milk River Formation is the major acquifer in southeastern Alberta. However, because it is located at depths between 300 and 400 metres, it is not an economically feasible water source. Other sources of groundwater include the Oldman Formation and the Saskatchewan Sands and Gravels. The Oldman Formation contains numerous sandstone layers and coal seams which can be possible acquifers. Although the sandstone is of considerable thickness, the permeability is low due to the montmorillinite



LEGEND

POST GLACIAL DEPOSITS

16. WIND DEPOSITS, INCLUDING AREAS OF BLOW-OUTS: SAND, SILT
15. ALLUVIUM (modern stream deposits): GRAVEL, SAND, SILT, MINOR TILL AND BEDROCK EXPOSURES
14. ALLUVIUM (immediately post-glacial terrace deposits of the modern streams): GRAVEL, SAND; LOCAL BEDROCK EXPOSURES

LATE-GLACIAL AND EARLY POST-GLACIAL DEPOSITS

13. LAKE DEPOSITS, COARSE: SAND, SILT
12. LAKE DEPOSITS, FINE: SILT, MINOR CLAY; LOCALLY VARVED

GLACIAL (LAURENTIDE) DEPOSITS

9. OUTWASH AND INWASH: GRAVEL, SAND, SILT; 9A, KAME DEPOSITS: MOSTLY GRAVEL
8. RECESSIONAL MORAINE (mostly deposited by active ice, commonly representing the limit of a minor glacial advance): CHIEFLY TILL, MINOR SAND AND GRAVEL; 8a, MODIFIED BY STREAMS DURING DEPOSITION: CHIEFLY COARSE GRAVEL; 8b, LOCALLY COVERED BY FINE LAKE DEPOSITS.
7. HUMMOCKY MORAINE (mostly deposited by stagnant ice, generally near the margin of the ice-sheet): TILL; 7a, LOCALLY OVERLAIN BY FINE LAKE DEPOSITS; 7b, MOSTLY OVERLAIN BY WIND-DEPOSITED SILT (loess)
6. DRUMLIN: TILL
5. GROUND MORAINE: TILL; 5a, LOCALLY COVERED BY FINE LAKE DEPOSITS; 5b, LOCALLY COVERED BY COARSE LAKE DEPOSITS OR ALLUVIUM; 5c, LARGELY EXPOSED THROUGH REMOVAL BY WIND OF OVERLYING OUTWASH AND INWASH.

GEOLOGICAL BOUNDARY (defined, approximate, assumed) . . . .

Alberta ENVIRONMENT	SLOPE STABILITY STUDY-LETHBRIDGE
SUBMITTED .... DATE .... / DESIGNED .... CHECKED	SURFICIAL GEOLOGY OF THE LETHBRIDGE AREA (AFTER A. MacS. STALKER, 1962)
APPROVED .... DATE .... / DRAWN C.F. CHECKED	SCALE 1:250 000 / SHEET 1 OF 1
	DATE OCTOBER, 1982 / DRAWING No. 5

MICROFILM DATE
DRAWING No
FILE No

which fills the intergranular cracks. Also within the Oldman Formation are numerous coal mine workings which have long been abandoned. An area north and west of Lethbridge involving an abandoned mine was investigated in the early 1960's as a potential groundwater source for the City of Lethbridge. A well was successfully located and completed in an abandoned coal mine tunnel. The top of the coal mine workings were found about 20 metres below the floodplain level in Section 12, Township 9, Range 22, West of the 4th Meridian (Beckie, 1963). The importance of these old coal mines with respect to slope stability is discussed in further detail in Section 4.3.

The Saskatchewan Sands and Gravels constitute the principal acquifer of the study area. These deposits have been exposed in several places by post glacial erosion permitting drainage of groundwater. Except for the Whoop-up and Stirling preglacial valleys (see Drawing 3), the Saskatchewan Sands and Gravels are mainly unsaturated and act as a drain carrying downward percolating groundwater. The continuous water table begins at or near the base of the Saskatchewan Sands and Gravel.

The overlying glacial and lacustrine deposits have a much lower permeability resulting in perched water tables over the unsaturated Saskatchewan Sands and Gravels. Transmissivity of the tills and lacustrine deposits as calculated by Nielsen (1970) from a number of field tests are shown on Table 3.

Table 3

Average Transmissivities of Pleistocene Deposits
(After Nielsen, 1970)

Horizon	Transmissivity (Imp.gal/day/ft)	Number of Measurements
Upper Till	1.2×10^{-5}	48
Lenzie Silts	6.9×10^{-5}	4
Lower Till	9.6×10^{-5}	6
Basal Till	4.0×10^{-4}	2

(Note: Transmissivity is the product of acquifer thickness and permeability).

The Upper Till, which is composed of reworked material from the earlier deposits is massive and relatively structureless. The Lenzie Silts consist primarily of silt and sand, and demonstrate a higher permeability than the Upper Till. These results indicate that jointing in the tills significantly increases the movement of groundwater. The lower permeability of the Upper Till controls the rate at which groundwater recharge occurs.

Irrigation in the rural districts has lead to perched water tables between 1.2 and 3.0 metres below grade (Nielsen, 1970). Watering of lawns and gardens combined with leaky sewer and water lines also contribute to produce a similar 'high' perched water table in the residential areas.

Infrared colour plates identify the river valley and coulees as natural discharge areas. Groundwater for the glacial drift is recharged in the Lethbridge Moraine area. From a groundwater study conducted by Nielsen, almost all piezometer installations indicated recharge conditions. Therefore, the majority of the upland area surrounding the river valley is a large recharge area.

Discharge areas are usually identified by one of the following features: springs, seepage, perennial sloughs, phreatophytic vegetation, salt precipitation and saline soils. Springs, which are not common in the study area, are generally confined to the coulees. Analysis performed on samples taken from some of the springs indicates a combination of groundwater and fresh irrigation water. The lack of springs in the area reflects the general low permeability of the tills.

'Phreatophytes are defined as plants that habitually obtain their water supply from the zone of saturation, either directly or through the capillary fringe' (Nielsen, 1970). They generally indicate the presence of shallow groundwater despite a lack of visible water at the land surface.

The major discharge areas are the floodplains adjacent to the Oldman River, which are typically vegetated with willows, cottonwood and white poplar.

Two major irrigation canals are present in the study area, one on either side of the Oldman River. Main irrigation canals and laterals operate from about May 1st to September 30th each year. The canal which services the St. Mary Irrigation District (on the east side of the river) runs in a northerly direction through the City of Lethbridge. This canal is located well back from the river (typically 5 kilometres) contributing minimally to seepage which exits into the coulees or river valley. Seepage from irrigation canals can cause problems if located within close proximity of any slopes by providing a constant source of water, increasing porewater pressures and decreasing overall slope stability.

Limited irrigation farming is practiced near the river valley on the east side of Oldman River due to the development of the city along the valley crest. On the west side of the river, irrigated farming is practiced on land which borders the Oldman River valley. A number of irrigation laterals which supply water for this area have overflows which empty directly into the coulees. This uncontrolled disposal of excess irrigation water has lead to serious erosion problems and contributed significantly to slope instability. This particular aspect is discussed in further detail in Section 4.0 as a major cause of slope instability.

Another water related problem which is presently being given more consideration by the Lethbridge City Engineering Department involves the disposal of stormwater runoff. With the increased development of residential areas, there is also a marked increase in areas which are impervious to surface water infiltration, such as paved roads, driveways, houses and parking lots. In the earlier years of Lethbridge's existence, the most convenient method of discharging the runoff from typical high intensity, short duration summer rainstorms was into the nearest coulee. Undisturbed, the coulees in the Lethbridge area have developed relatively stable slopes. Discharging high volumes of stormwater runoff into these coulees causes severe erosion, gullying and slope instability. The city is actively aware of the potential problems of uncontrolled surface runoff and presently ensures that all runoff is carried to the floodplain level of the Oldman River in large diameter culverts before being discharged.

Expansion of the city and development along the tops of the coulees is a major concern as landslide activity is not uncommon on these steep-walled coulees. In their natural state, the coulees are relatively stable, but interference from anthropogenic (man-made) sources has disturbed the delicate balance of equilibrium causing instability along the coulee walls.

3.0 AIRPHOTO ANALYSIS

3.1 PROCEDURE

An aerial photograph analysis of the study area was conducted using a number of various sources, including black and white stereo photos, colour stereo photos, false colour infrared photos and air photo mosaics. The information utilized, covered a period between 1950 and 1980. A list of the vertical aerial photographs used in the study is shown on Table 4. Airphoto pairs were viewed with a Nikon reflex stereoscope. The smaller scale aerial photographs (1:40,000) were used to provide an overview of the study area while the larger scale aerial photographs (1:10,000) permitted more detailed analysis of the individual slide areas.

Slides were typically identified by sharp breaks in slopes, barren areas on vegetated slopes, step-like topography, crescent shaped cracks near the crest and bulging debris in the toe area. Each slide was described with respect to the mode of failure and present state of stability. The evaluation of each slide also included areal extent, slope angle, slope height and trigger mechanism responsible for the slide. With the range of aerial photographs available (1950-1980), an estimation of whether the slide was active or quiescent could be determined.

Vegetation was used as a key indicator for possible seepage exiting the slope as well as ponded water near the crest or on the slide mass. The colour and false colour infrared photos were useful for identifying zones of high soil moisture.

After the aerial photographs had been reviewed, ground truthing was used to further identify subtle features of the individual slide areas, such as fill placement, seepage areas, erosion or other possible sources which could contribute to slope instability. Detailed geotechnical studies conducted by consultants was utilized to analyze specific slide areas.

TABLE 4

INDEX OF VERTICAL AERIAL PHOTOGRAPHS
OF THE LETHBRIDGE AREA

YEAR	SCALE	B&W OR COLOUR	SOURCE
1949 - 1950	1:40,000	B&W	Alberta Energy and Natural Resources
1961	1:31,680	B&W	Alberta Energy and Natural Resources
1970	1:12,000	B&W	Alberta Energy and Natural Resources
1975	1:12,000	B&W	Alberta Energy and Natural Resources
1975	1:12,000	B&W (I.R.)	Alberta Energy and Natural Resources
1978	1:10,000	Colour	City of Lethbridge
1979	1:20,000	Colour (I.R.)	National Air Photo Library (Energy, Mines and Resources Canada)
1980	1:10,000	B&W	Alberta Energy and Natural Resources

4.0 SLOPE STABILITY

4.1 INTRODUCTION

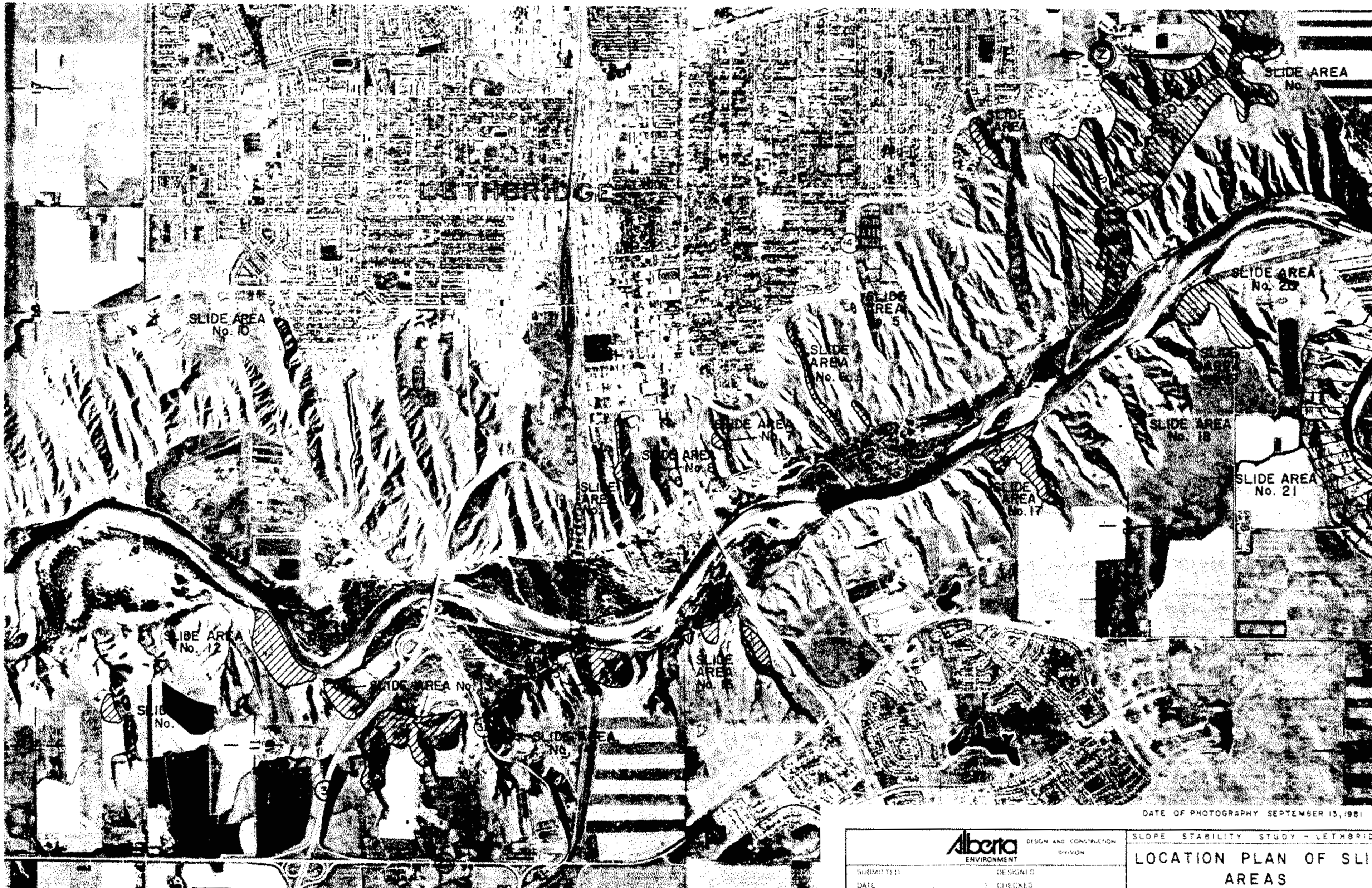
The slide areas located within the study area have been reviewed and analyzed with regard to their failure mode, the suspected trigger mechanism and their present state of stability. A detailed description of the slide areas is presented in the Appendix. Drawing 6 identifies all the slide areas analyzed within the study area. A summary of the slide areas is presented on Table 5.

The slide areas in some instances encompass one, two or several slides. In the case of Six Mile Coulee, the coulee walls along the entire length of the drainage channel are unstable resulting in the formation of 40 to 50 individual landslides.

It should be noted that only the larger, significant slides have been identified and analyzed. Numerous small slides were also identified but have not been included due to their relative insignificance to the overall slope stability of the study area.

4.2 GENERAL

Within the study region, the landslides observed occurred in two distinct areas: either along the Oldman River valley walls or along the coulees which drain into the Oldman River. Typically, the slides common to the Oldman River valley were relatively large and involved a translational type failure. The slides found along the coulees were generally much smaller in areal extent and exhibited primarily a rotational type movement.



DATE OF PHOTOGRAPHY SEPTEMBER 13, 1981

Alberta ENVIRONMENT — DESIGN AND CONSTRUCTION DIVISION

SLOPE STABILITY STUDY - LETHBRIDGE

LOCATION PLAN OF SLIDE AREAS

SUBMITTED	DESIGNED	SCALE 1:25 000	SHEET 1 OF 1
DATE	CHECKED	DATE Oct. 21, 1982	DRAWING No. 6
APPROVED	DRAWN M.G.Mc		
DATE	CHECKED		

CENTRAL FILE No. DRAWING FILE No. MICROFILM DATE

TABLE 5

SUMMARY OF SLIDE AREAS

SLIDE AREA	LOCATION	PRESENT STATE OF STABILITY	TRIGGER MECHANISM	FAILURE MODE	SLOPE HEIGHT (m)	SCARP LENGTH (m)	AVERAGE SLOPE ANGLE	COMMENTS
1	LSD 1 & 2-18-8-21-W4M	Inactive (Active in 1976)	Seepage	Rotational	-	120	20°	Slide involves only over-burden soils.
2	LSD 5 & 12-17-8-21-W4M; LSD 8-18-8-21-W4M	Active	Seepage	Flow	30 to 90	150 to 300	20° to 30°	Area is comprised of 3 individual slides, all precipitated by excess seepage into the slope.
3	Six Mile Coulee Sec. 16 & 17-6-21-W4M; Sec. 19 & 20-6-21-W4M	Active	Toe Erosion & Seepage	Shallow Rotational	Varies	-	-	Area comprised of 40-50 small slides along Six Mile Coulee.
3A	LSD 15-16-8-21-W4M	Inactive	Toe Erosion	Retrogressive Rotational	26	90	30°	
3B	Lethbridge Community College Slide LSD 6 & 7-20-8-21-W4M	Active	Dumping Near Crest, Seepage & Toe Erosion	Rotational	20 to 23	60 to 90	20° to 23°	Comprised of 3 separate slides. These slides are classified as active although some measures of stabilization appear to have been taken.
4	Park Royal Slide LSD 3 & 4-29-8-21-W4M	Inactive	Fill Placement At Crest & Seepage	Shallow Rotational	30	335	20°	
5	LSD 14-30-8-21-W4M	Inactive	Groundwater Seepage (?)	Shallow Rotational	-	10 to 15	-	2 shallow slides confined to the upper slope.

TABLE 5

SUMMARY OF SLIDE AREAS (Continued ...)

SLIDE AREA	LOCATION	PRESENT STATE OF STABILITY	TRIGGER MECHANISM	FAILURE MODE	SLOPE HEIGHT (m)	SCARP LENGTH (m)	AVERAGE SLOPE ANGLE	COMMENTS
6	LSD 9 & 16-25-8-22-W4M; LSD 13-30-6-21-W4M	Inactive	Toe Erosion	Toppling	-	200 to 760	-	Area consists of 3 coulees which have been exposed to severe erosion due to stormwater runoff.
7	LSD 8-36-8-22-W4M	Inactive	Seepage	Rotational	27	90	39°	
8	LSD 9 & 10-36-8-22-W4M	Inactive	Seepage	Rotational	26	50 to 60	26.5°	Area is comprised of 2 slides.
9	LSD 15 & 16-36-8-22-W4M	Inactive (Presently stabilized)	Toe Erosion	Rotational	Up to 38	120 to 180	28° to 38° (Prior to failure)	A major grading operation has presently stabilized this slide area.
10	Stafford Avenue Slide LSD 6-7-9-21-W4M	Active	Dumping Along Crest of Slope & Seepage	Combined Rotational-Translational	34	100	28° to 31°	
11	LSD 2-14-9-22-W4M	Inactive	Seepage	Rotational	35	90	29.5°	Slope instability developed by excessive irrigating on upland plain.
12	LSD 1 & 8-11-9-22-W4M	Inactive	Toe Erosion	Combined Rotational-Translational	87	600	22°	Very old slide.
13	LSD 2-11-9-22-W4M; LSD 10, 11, 14 & 15-2-9-22-W4M	Inactive (Minor gullying & slumping)	Toe Erosion	Combined Rotational-Translational; Rotational	80	130 to 300	17° to 32°	Comprised of 4 large inactive slides and 2 coulees subjected to gullying and small rotation failures.

TABLE 5

SUMMARY OF SLIDE AREAS (Continued ...)

SLIDE AREA	LOCATION	PRESENT STATE OF STABILITY	TRIGGER MECHANISM	FAILURE MODE	SLOPE HEIGHT (m)	SCARP LENGTH (m)	AVERAGE SLOPE ANGLE	COMMENTS
14	Nord Precast Concrete Slide LSD 7-2-9-22-W4M	Active	Dumping Along Crest of Slope	Rotational	-	70	33°	Majority of slide mass located in fill.
15	LSD 16-35-8-22-W4M	Inactive	Toe Erosion	Combined Rotational-Translational	99	400	10°-Upper Slope 12°-Lower Slope	C.P. railway trestle passes through north end of this old, inactive slide.
16	LSD 1, 8 & 9-35-8-22-W4M	Inactive	Subsidence	Combined Rotational-Translational	38 to 55	50 to 300	25° to 39°	The 2 slides and series of tension cracks in this area are suspected of being caused by subsidence over old coal mine workings.
17	LSD 1-25-8-22-W4M; LSD 15 & 16-24-8-22-W4M	Inactive	Subsidence (?)	Combined Rotational-Translational; Rotational	30 to 50	100 to 200	13° to 35°	Includes 4 separate slides: 2 rotational and 2 rotational-translational type failures.
18	LSD 5-19-8-21-W4M	Inactive	Seepage	Rotational	-	30	32°	Small slide confined to upper portion of slope. Breaks out partway down slope.
19	LSD 4-19-8-21-W4M	Active	Toe Erosion & Seepage	Rotational	30	130	29°	Water storage ponds near crest and irrigation water are suspected cause of instability.

TABLE 5

SUMMARY OF SLIDE AREAS (Continued ...)

SLIDE AREA	LOCATION	PRESENT STATE OF STABILITY	TRIGGER MECHANISM	FAILURE MODE	SLOPE HEIGHT (m)	SCARP LENGTH (m)	AVERAGE SLOPE ANGLE	COMMENTS
20	LSD 3-19-8-21-W4M; LSD 14-18-8-21-W4M	Inactive	Toe Erosion (?)	Combined Rotational-Translational(?)	40 to 78	200	22° to 25°	2 separate slides in this slide area. No obvious trigger mechanism.
21	Sec. 18-8-21-W4M; Sec. 13-8-22-W4M	Active	Seepage & Toe Erosion	Combined Rotational-Translational; Rotational; Flow	100	1900	10° to 20°	East portion of slide presently active. Irrigation canal supplies water which is major cause of present instability. West segment of slide is old and inactive.

Although the rotational and translational type landslides were the most common types of movement, flow and toppling failures were also observed in the study area. The following sections discuss the basic type of movements identifying the surficial features and mechanisms of the various slide types.

4.2.1 Rotational Slides

The most common type of failures in the study area are rotational slides. Rotational slides are generally confined to the overburden soils with failure occurring along a curved failure plane which is often curved upward in the toe area. In the head area, the movement may be primarily downward, with little apparent rotation; however, the top surface which forms the head area is usually tilted back towards the slope. If the failure surface is relatively shallow, the head area may tilt forwards. The toe area of a rotational slide is generally bulged out with the main body of the slide forming a distorted mass. Slide Area No. 7 is an example of a typical rotational failure.

After movement of a rotational failure has occurred, the main scarp at the head of a slump may be almost vertical. If the main mass of the slide moves down far enough, the steep main scarp is left unsupported and the stage set for a new failure at the crest of the slide. Tension cracks parallel to the crest of the slide and also within the slide mass are commonly formed prior to and after a slump has occurred. These tension cracks permit an ingress of free water, which results in an increase in porewater pressure and leads to further instability. Water may also tend to pond within the body of the slide, trapped by the backward tilting of sliding blocks which results in the formation of a local high groundwater table and high porewater pressures. By the successive creation of steep scarps and infiltrated water, slumps often become self-perpetuating areas of instability referred to as a multiple type movement.

Similar to multiple rotational slides are retrogressive rotational slides. The term retrogressive is used to describe a failure which begins in a local area and enlarges or retreats opposite to the direction of movement of the failed mass. Slide No. 3-A is an example of a typical retrogressive rotational slide. The initial instability was caused by erosion at the base of the slope by a stream which flows along the bottom of Six Mile Coulee. The first form of movement probably consisted of a shallow rotational slump near the base of the slope. This oversteepening of the slope combined with continued erosion at the toe would have precipitated a slightly larger rotational failure. In this manner, the main scarp would have retreated upslope to its present location.

The final type of rotational failures which are common in the study area are successive or stepped rotational slides. These types of movements are plainly visible along the coulee walls and have been identified earlier as terracettes. Successive rotational slips consist of an assembly of individual shallow rotational failures. It is suspected that successive slips generally spread up a slope from its base. Each individual slip is usually of considerable lateral extent, forming a step across the entire slope.

4.2.2 Translational Slides

In translational sliding the failed soil mass moves along a more or less planar surface with little or no rotational backward tilting. The majority of the translational type failures in the study area are combined rotational-translational slides. The upper portion of these slides occurs along a steeply curved backscarp through the overburden soils. The lower slide mass progresses outward either along the top or immediately beneath the top of the bedrock. Movement of translational slides is commonly controlled by geological planes of weakness such as faults, joints, bedding planes or the interface between overburden and hard bedrock. Contrary to rotational slides which exhibit a bulging deformed toe, the toe area of a translational slide slides out over the ground surface with little change in surface expression.

Frequently, when a combined rotational-translational failure occurs, a portion of the slide mass at the base of the backscarp is depressed in relation to the remainder of the lower slide mass. This sunken portion of the surface morphology is referred to as a graben. A slide which expressed this graben feature after failure is the Stafford Avenue Slide. It is suspected that the lower failure surface for this slide occured at the contact between the overburden and the bedrock. As the lower slide mass slid out over the bedrock, the head area of the slide slumped to a level lower than the main body of the slide. This graben feature is useful in identifying translational type failures.

4.2.3 Flow Slides

As inferred by the name, flow slides are failures which exhibit a viscous type of surficial expression due to an oversaturation of the soil mass. Although some flow slides can occur quite rapidly, the flow slides found within the study area are relatively slow moving and shallow in depth. Both Slides No. 2 and 21 exhibit typical flow type features within a portion of the slide mass. At Slide No. 21, overflow from an irrigation canal has been permitted to flow uncontrolled onto the slope face saturating the local overburden soils.

4.2.4 Toppling Failure

Toppling or slabbing is a relatively infrequent mode of failure within the study area. It is generally confined to the steep upper backscarps of either rotational or translational slides. The lacustrine sediments overlying the glacial tills are frequently shallow and after a slide has occurred, the till often stands in near vertical exposures. The upper exposed till forms a columnar pattern of vertical cracks which permits an ingress of water. The softening effect of water in summer and repeated freeze-thaw cycle in the winter weakens the base of the vertical blocks until a toppling failure occurs.

4.3 RIVERBANK INSTABILITY

The height of the Oldman River valley walls through the study area averages 95 metres and varies in width from 1500 to 3000 metres. The width of the river valley at the floodplain level varies from 350 to 1300 metres. The coulees draining into the Oldman river valley are much more pronounced on the east side of the river valley. As a result, the east side of the river valley is flatter and does not exhibit any landslides along the main river valley.

Along this reach of the river, the Oldman River has cut into the bedrock which presently controls the path of the river. Although the river meanders within the confines of the floodplain, active downcutting has practically ceased. Large alluvial terraces formed within the valley floodplain provide a stabilizing toe berm for a number of the large rotational-translational landslides.

Near the central portion of the study area, the bedrock changes from the Oldman to the Bearpaw Formation (see Drawing 2). The Oldman Formation is generally considered a relatively stable bedrock, while the Bearpaw is a more active formation. However, there does not appear to be a significant increase in landslide activity where the Bearpaw Formation is exposed along the river valley. A study conducted by Roggensack (1971) along the Oldman and South Saskatchewan Rivers concluded that bedrock type was one of the prime factors in initiating mass movement. River erosion and local groundwater conditions were also cited as major factors affecting slope stability.

In Roggensack's study, it was observed that greater than 90 percent of the landslides occurred in meander bends, generally downstream of the point of maximum curvature. This is where the effect of river erosion is most pronounced.

The landslides along the main river valley are typically very old and relatively stable. It is suspected that the majority of these slides occurred while the river was actively downcutting and the glaciers were retreating from the area. The regional groundwater table at the time of failure is also believed to be much higher than at present.

The majority of the slides along the Oldman River valley within the study area are combined rotational-translational failures. The Upper Cretaceous bedrock which forms the base for the translational movement, has several features which contribute to decreased bedrock shear strength. One of these features is the presence of 'bentonite' as a component of the bedrock minerals or in the form of a continuous layer. Bentonite possesses a frictional shear strength considerably less than non-bentonitic bedrock. As a result, bentonite rich bedrock provides a plane of weakness for translational movements.

Another factor which contributes to decreased shear strength along horizontally bedded rock underlying river valleys is the process of valley rebound. As the river valleys were formed after glaciation, the removal of overburden soils would have caused an elastic rebound of the material along the base of the valley. This process of valley rebound is described by Matheson and Thompson (1973) as an anticlinal rise below the valley bottom and an upwarping of the strata in the valley walls towards the valley edge which would have been accompanied by flexual slip between the originally flat lying beds. The flexual slip would have lowered the shear strength along the bedding planes in the valley walls, leading to a greater tendency for landslide activity.

The combined effect of high porewater pressures, weakened bedding planes and toe erosion are believed to have initiated the combined rotational-translational slides along the river valley banks.

Although most of the major landslide activity along the Oldman river valley is believed to have been caused by natural forces, some slide areas are suspected of being initiated by anthropogenic sources. Slide Area No. 16 on the west bank of the Oldman River was evaluated by R.M. Hardy and Associates Ltd. (1977a), with respect to the possibility of developing this area for residential housing. A detailed investigation of old coal mining records discovered that the workings for at least two separate coal mines were located beneath the proposed residential development.

Coal at Lethbridge was mined from a coal stratum (1.2 to 1.3 metres thick) near the upper part of the Oldman Formation. The depth of the coal mine workings are located approximately 100 metres below the prairie upland. Subsidence over the coal mines appears to be responsible for several series of major cracks and two slides located along the riverbank. Cracks produced by subsidence generally parallel the crests of coulees in the slide area. One major crack, some 90 metres in length, is suspected of forming the upper backscarp of a slide on the south side of one coulee. Vertical and horizontal displacements of up to 0.6 metres were noted across this crack. In addition, a number of sink holes and depressions on the prairie upland are also believed to have been caused by subsidence.

4.4 COULEE INSTABILITY

Instability along the coulees consists primarily of shallow rotational and retrogressive rotational landslides. In their natural state, the coulee walls although relatively steep (up to 40 degrees), are stable. However, interference from anthropogenic sources appears to be one of the major causes of landslide activity.

Landslides initiated by man in the study area are generally the result of one or a combination of the following activities:

- excessive watering of lawns and gardens in residential areas
- leakage of water from sewer and water mains
- irrigation of farmland in rural districts
- placement of fill along the crest of slopes
- uncontrolled discharge of surface water runoff and irrigation water onto slopes
- ponding of water near the crest of slopes.

Water plays an important role in the general stability of slopes. As discussed in Section 2.6, the low permeability of the upper till sheet controls the recharge rate of the underlying stratum. As a result, perched water tables are commonly formed in the lacustrine or glacial deposits overlying the upper till. Due to the low annual precipitation and high evaporation rate in the Lethbridge area, the natural groundwater table would not be anticipated to be in proximity of the ground surface. However, with the abundance of water supplied by rural irrigation and urban watering, the groundwater table is commonly situated within one or two metres of the ground surface. An increased groundwater table results in an increase in the porewater pressure, a decrease in the effective stress within the soil mass and a subsequent decrease in slope stability.

Slide Area No. 5 illustrates how watering of lawns and gardens along the crest of a slope can initiate landslide activity. Prior to 1970, the walls of this particular coulee were dry and stable. After construction of a convent near the crest of the coulee, watering of lawns and gardens is suspected to have raised the local groundwater table. By 1975, two small shallow slumps had developed along the crest of the slope. Lush vegetative growth indicative of groundwater discharge is visible within the slide mass.

Another area where slope instability was initiated by an increase in the local groundwater table is Slide Area No. 11. Irrigated farming is practiced extensively along the west bank of the river valley. An excessive amount of irrigation water applied to a field bordering the river valley resulted in a rise in the local groundwater table and the development of several shallow rotational slides.

Numerous other slides in the study area have been initiated by a combination of anthropogenic causes. The placement of fill near the crest of a slope combined with a rise in the groundwater table have triggered slides in Slide Areas No. 4 and 10. Slide Area No. 4 is a major landslide which occurred in the Park Royal Subdivision. This particular slide was analyzed by Klohn Leonoff in 1975. Fill was initially placed along the crest of a coulee to extend the backyards of homeowners. The placement of fill caused a blockage of natural subsurface drainage and a rise in the local groundwater table. Watering of lawns further increased porewater pressures and eventually resulted in a slope failure.

Slide Area No. 10 (Stafford Avenue Slide) is a similar example of instability initiated by dumping of fill along the crest of a coulee and a rise in the local groundwater table. Up to 1961, the coulee bank exhibited no signs of instability. Fill was placed along the crest of the coulee and appears to have initiated the first slide (evident in the 1970 aerial photographs). In the mid 1970's an expansion of the residential area adjacent to the coulee is suspected to have caused a rise in the local groundwater table. By 1978 a second slide had developed on the coulee bank. The two slides continued to move and by 1981 had coalesced into one large slide.

Uncontrolled discharge of surface runoff or excess irrigation water into the coulees has been a major source of gullying and instability on both sides of the river. Slide Area No. 6 exhibits the extensive erosive action of uncontrolled surface runoff. Surface runoff from Lethbridge was being discharged into 3 coulees on the east bank of the Oldman River for a number of years, extending back to before 1950. This uncontrolled discharge formed near vertical walls (10 metres high) at the base of the coulees. The length of erosion extended for a length of 760 metres along one of the coulees. Although the base of these three coulees was significantly downcut, no signs of major instability developed. The only type of instability which appears to have occurred are some toppling failures along the steep walls at the toe of the coulee slopes.

Numerous examples of erosion due to the discharge of excess irrigation water into coulees can be observed along the west bank of the Oldman River. The excess irrigation water erodes the base of the coulees forming a steep "V" notch along the base and saturates the surface of the slopes. Oversteepening of the slope leads to the formation of shallow slumps near the slope toe and in some cases develops into a retrogressive rotational slide.

An extreme case of uncontrolled irrigation water discharge is evident at Slide Area No. 21. This slide is located at the southern limit of the study area on the north bank of the Oldman River. The main irrigation canal which supplies water for farmers on the west side of the river terminates at the top of the slope. Surplus irrigation water has been discharged onto this slope face for many years, extending back to before the earliest set of air photos (1950). Steep-walled gullies formed by erosion display numerous shallow rotational failures. This continual supply of water has saturated the slope forming a series of retrogressive rotational slides and even a few flow slides.

Ponding of water near the crest of coulees is another cause of slope instability. Slide Areas No. 18 and 19, are suspected to have been caused at least partially by the construction of water reservoirs by local farmers along the crest of these slopes. The ponded water would have increased porewater pressures in the slope, decreased the effective stress and eventually lead to a slope failure. The slide mass of both these areas exhibits abundant vegetative growth, indicative of groundwater seepage.

Generally, unloading at the top of a bank tends to increase the stability of a slope. However, in the case of Slide Area No. 7, a slope failure appears to have been precipitated due to unloading. Approximately 10 metres of material were excavated from the top of a knoll for use as road fill, for the construction of Scenic Drive on the east bank of the Oldman River. Flattening of the knoll resulted in a tendency to collect rather than shed precipitation. In addition, the unloading effect resulted in an opening of vertical fractures in the till. The open vertical cracks would have permitted an ingress of water and an increase in porewater pressure. This increase in porewater pressure appears to have been sufficient to cause minor toe instability and eventually a large rotational failure.

Instability caused by toe erosion is responsible for numerous slides along the coulees. This type of instability is well displayed along the entire length of Six Mile Coulee. The stream which flows along the base of Six Mile Coulee has initiated a slide at almost every meander bend. Consisting primarily of shallow rotational failures at the base of the coulee walls, these shallow slumps generally retrogress upslope to the crest of the coulee. It is suspected that irrigation of the farmlands adjacent to Six Mile Coulee has also contributed to the instability by raising the local groundwater table.

5.0 SUMMARY

Slope stability within the study area has been identified as occurring in two main areas. These are located either along the Oldman River valley walls or along the coulees which drain into the Oldman River. The slides along the Oldman River are generally a combined rotational-translational failure and cover a relatively large area. Slides occurring along the coulees are smaller in areal extent and typically exhibit a rotational failure surface.

The river valley slides are all relatively old and stable, and have not shown any recent signs of movement other than occasional toppling block failures along the steep-walled backscarps. The formation of these large, deep seated slides are probably contemporaneous with the formation of the post-glacial river valley. Toe erosion and high groundwater conditions are suspected of being the primary trigger mechanisms for these river valley slides. Weakened bedding planes due to valley rebound and the presence of bentonite rich bedrock are other factors which contribute to the slope instability.

With the present topographic and hydrogeologic conditions, the possibility of reinitiated movement or the formation of new river valley slides does not appear to be a likely possibility. However, should dumping of fill or water on an inactive slide mass or excavation at the toe of the slope be permitted, then the reinitiation of slope movement is a possibility.

It is interesting to note that the formation of coulees on both the east and west sides of the Oldman River valley have had an overall stabilizing effect with respect to the stability of the river valley slopes. The formation of the coulees has resulted in a general slope flattening of the river valley walls. The coulees are much more prominent and well developed along the east side of the river. As a result, the major 'riverbank' slides are confined solely to the west side of the river valley.

The majority of recent landslide activity within the study area can be directly attributed to some form of anthropogenic interference. The following section outlines the effect of both rural and urban development on the stability of the coulees.

The coulees in their natural, undisturbed state have developed well rounded tops with steep side slopes and flat bottoms. Due to anthropogenic interference, the natural stable condition of these coulees has been significantly affected. The single most dominant factor which has altered the equilibrium condition of these slopes is the addition of water to the local groundwater regime.

Although the west side of the Oldman River is primarily used for agriculture and the east side for urban development, coulees on both sides of the river have been subjected to a decrease in stability due to a rise in the local groundwater table. As discussed in Sections 4.3 and 4.4, a rise in the groundwater table results in increased pore pressures and a decrease in overall stability.

Irrigation canals are used extensively to supply water for farming throughout the Lethbridge area. The effect of irrigation water is to raise the local groundwater table. At least one series of slides (Slide Area No. 11) can be directly attributed to excessive irrigation of farmland. Irrigation is believed to be one of the prime factors initiating slope failure in numerous other slide areas.

A major problem associated with the existing irrigation system is the method of disposing excess irrigation water. Presently, a number of irrigation canals terminate at the crest of a coulee or river valley slope. The excess irrigation water is permitted to flow uncontrolled onto the face of these slopes. This results in a saturation of the slope and also causes erosion along the base of the coulees. Erosion along the coulee base results in oversteepening of the slope and an increased possibility of failure. This problem of uncontrolled disposal of excess irrigation water is particularly evident at Slide Area No. 21.

In urban areas, the local groundwater table is raised by the watering of lawns and gardens and by leaky sewer and water mains. Residential developments adjacent to coulees or the main river valley are definitely a cause for concern. The Park Royal Slide is an excellent example of how the combined effect of high pore pressures and the placement of fill on a slope crest can initiate slope movement.

A major problem associated with existing and new residential development in the study area is the disposal of surface runoff. In the past, the surface runoff collected by the stormwater sewer system had been disposed directly into the coulees. This resulted in serious erosion along the base of the coulees as evidenced by Slide Area No. 6. Today, the City of Lethbridge uses large diameter culverts to carry the stormwater runoff down to the floodplain level of the Oldman River.

Other instances where man's intrusion has caused or contributed to slope instability include the placement of fill along the crest of valley slopes. The Stafford Avenue Slide, the Lethbridge Community College Slide and the Park Royal Slide are all examples where the placement of fill along the crest of a coulee has been one of the prime factors initiating slope failure.

6.0 RECOMMENDATIONS

An analysis of the study area has determined that slides along the Oldman River valley are relatively old and stable, with no significant signs of movement after 1950. Although apparently inactive, movement could be reinitiated within an old slide mass if precautions were not taken with regard to developments near these slides. If excavation at the toe of an old slide or dumping of fill or water onto an old slide mass was permitted, movement could be reinitiated. For these reasons, it is recommended that a conservative approach be used for determining setback distances from the valley walls for any developments. For preliminary purposes, it is considered that a setback distance equal to the depth of the valley be used for any developments on the prairie upland adjacent to the river valley.

With regard to development along the coulees, it is recommended that future developments be severely restricted. As has been evidenced with the Park Royal Slide, the potential for the initiation of slope failures is high. The coulees in the study area are presently in a state of quasi-equilibrium. It is apparent from the numerous failures that the coulees are sensitive to minor changes in loading, unloading or groundwater fluctuation.

It is recommended that a perimeter road, such as Scenic Drive, be used to separate the coulees from any residential or commercial development. This perimeter road should follow a line along the upland plain which connects the heads* of adjacent coulees. No development should be permitted between this perimeter road and the floodplain level of the Oldman River.

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* The head of a coulee in this text is defined as location where the upper end of a coulee valley intersects the upland plain.

Additional recommendations for existing and future developments adjacent to the river valleys or coulees include:

- a detailed geotechnical investigation of the area to determine the subsoil and groundwater conditions
- coal mining records should be reviewed to determine the possibility of abandoned coal mines beneath the prospective property
- several deep boreholes should be drilled to identify any recorded or uncharted coal mines
- the implementation of groundwater and slope monitoring programs to monitor any changes in the local groundwater system and slope condition
- a rigid control regarding the disposal of stormwater runoff. The present method used by the City of Lethbridge is effective and should continue to be utilized
- the control of excess irrigation water in a manner similar to that employed by the City of Lethbridge for surface runoff.

The recommendations presented within the report are solely intended for use as a guideline for future and existing developments. The degree of investigation and monitoring programs to be incorporated should be determined by the degree of risk associated with the proposed project. If the project involves a commercial or residential development, where human lives and costly structures are involved, then a detailed and extensive investigation and monitoring program should be incorporated. A lower risk project such as a roadway would require a less extensive drilling and monitoring program.

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APPENDIX

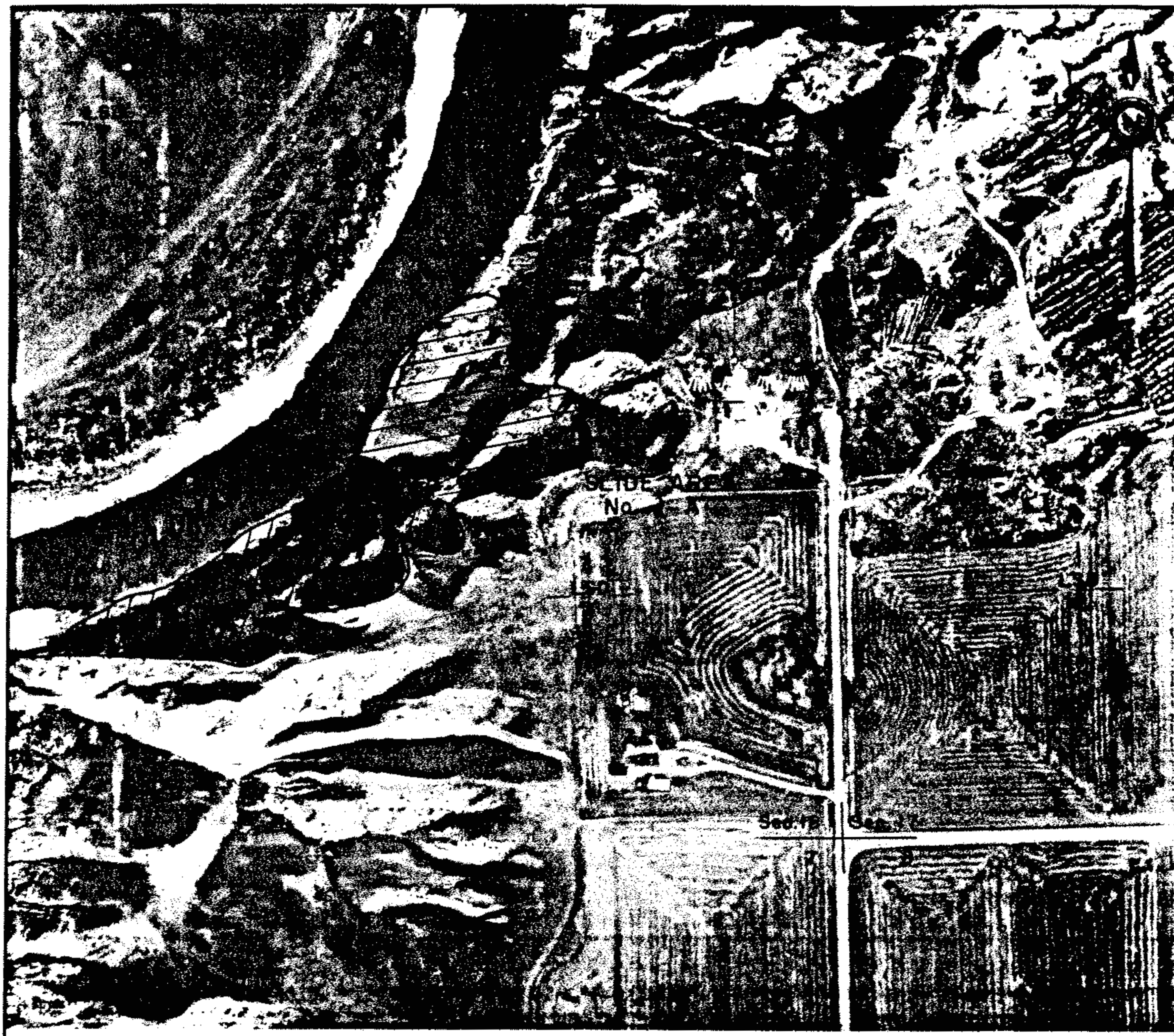
SLIDE AREA: No. 1

LOCATION: LSD 1 & 2 - Sec. 18 - Twp. 8 - Rge. 21 - W4M

DESCRIPTION:

This area consists of a series of failures (approximately 400 metres long) along the outside (east bank) of a meander bend of the Oldman River. The failures appear to have occurred as a movement of Pleistocene deposits across the top of the bedrock. Along this reach of the river, bedrock is exposed about two-thirds of the way up the valley wall. The steep banks below the failures are comprised of the Oldman Formation.

A recent movement (Slide 1-A) about 120 metres long, occurred between May 1975 and July 1977. A crack immediately down slope from the crest is visible on the 1975 aerial photographs. It is a dominantly rotational movement that is suspected to have been triggered by seepage at the Pleistocene-Upper Cretaceous contact. These failures appear to occur rapidly, since the failed material does not build up to a restraining mass, but rather cascades down the steep rock slope to the river forming a talus. The Oldman River, which flows along the base of the east bank, is presently eroding the talus deposited at the base. Failures prior to 1975 appear to be relatively old as the river has carried away any previously failed material.



PHOTOGRAPHED APRIL 16, 1980

Alberta
ENVIRONMENT

SUBMITTED	DESIGNED	SLOPE STABILITY STUDY – LETHBRIDGE	
DATE	CHECKED	SLIDE AREA No. 1 LSD. 1 & 2, Sec. 18, Tp. 8, Rg. 21, W/4 M	
APPROVED	DRAWN S. Y. C.	SCALE 1 : 5000	SHEET 1 OF 1
DATE	CHECKED	DATE OCT. 1982	DRAWING No. 7

SLIDE AREA: No. 2

LOCATION: LSD 5 & 12 - Sec. 17 - Twp. 8 - Rge. 21 - W4M;
LSD 8 - Sec. 18 - Twp. 8 - Rge. 21 - W4M

DESCRIPTION:

The slides in this area are located along the east bank of the Oldman River immediately downstream of Slide Area No. 1. The movements are dominated by flow type features. Flanked to the east, lies a deposit of fluvioglacial sands and gravels which are presently being mined. There are indications that this slide area also involves only Pleistocene deposits. The flow features suggest that there has been an excess amount of water which has saturated the soil mass.

The slide furthest upstream (2-A), has a flow feature extending down to the river, where it has deposited a colluvial fan. This fan has been deflected downstream and is presently being eroded by the river.

The adjacent slide downstream (2-B), shows similar flow features, which are less pronounced and exhibit only minor slump features.

Slide 2-C occupies the south bank of a coulee, north of Slide 2-B. This slide appears to be primarily a downward slumping of a water saturated mass. It includes almost the entire south side of the coulee.

Judging from the vegetation, these slides are old, but still actively creeping and could show a major movement during an intense rainstorm. The difference in the slides noted between the 1950 and 1980 air photos indicates a continuing increase in activity which may be due, in part, to the expansion of the gravel pit.

PHOTOGRAPHED APRIL 16, 1980

Alberta
ENVIRONMENT

SUBMITTED	DESIGNED	SLOPE STABILITY STUDY – LETHBRIDGE	
DATE	CHECKED	SLIDE AREA No. 2 LSD. 5 & 12, Sec. 17, Tp. 8, Rg. 21, W/4M LSD. 8, Sec. 18, Tp. 8, Rg. 21, W/4M	
APPROVED	DRAWN S. Y. C.	SCALE 1 : 5000	SHEET 1 OF 1
DATE	CHECKED	DATE OCTOBER, 1982	DRAWING No. 8

SLIDE AREA: No. 3, Six Mile Coulee

LOCATION: Sec. 16 & 17 - Twp. 6 - Rge. 21 - W4M;
Sec. 19 & 20 - Twp. 6 - Rge. 21 - W4M

DESCRIPTION:

This slide area comprises all the slides (40 to 50) along a major drainage channel (called Six Mile Coulee), which extends for several kilometres into the prairie upland. The flat bottom of the coulee which varies up to 15 metres in width, carries a stream which meanders slowly across the coulee base. The quantity and velocity of water within the stream are relatively insignificant, although during periods of high rainfall it is suspected that the volume of water increases appreciably. One of the major factors contributing to slope instability along Six Mile Coulee is the erosion at the base of the coulee walls.

The majority of the slides are located along the upper portion of the coulee where the banks consist of lacustrine or glacial till deposits. These slides are typically shallow rotational failures (see Photo 3) caused by a combination of toe erosion and an increase in porewater pressure.

It is suspected that the addition of irrigation water to the groundwater system has contributed significantly to slope instability along Six Mile Coulee. Firstly, the irrigation water would raise the local groundwater table, causing increased pore pressures and decreased slope stability. Furthermore, the amount of water carried by the stream is increased by the additional irrigation water, which in turn increases the toe erosion of the banks and results in further instability.

Another factor contributing to slope instability is the placement of debris and fill along the crest of the coulee walls. This practice of dumping was noted at several locations during the ground truthing inspection.

Two of the more prominent slide areas along Six Mile Coulee have been examined in greater detail and are discussed in the following two sections.

Photo 3:

Aerial and ground level views of typical sections along Six Mile Coulee. Note failures at almost every meander bend of the stream.

SLIDE AREA: No. 3-A

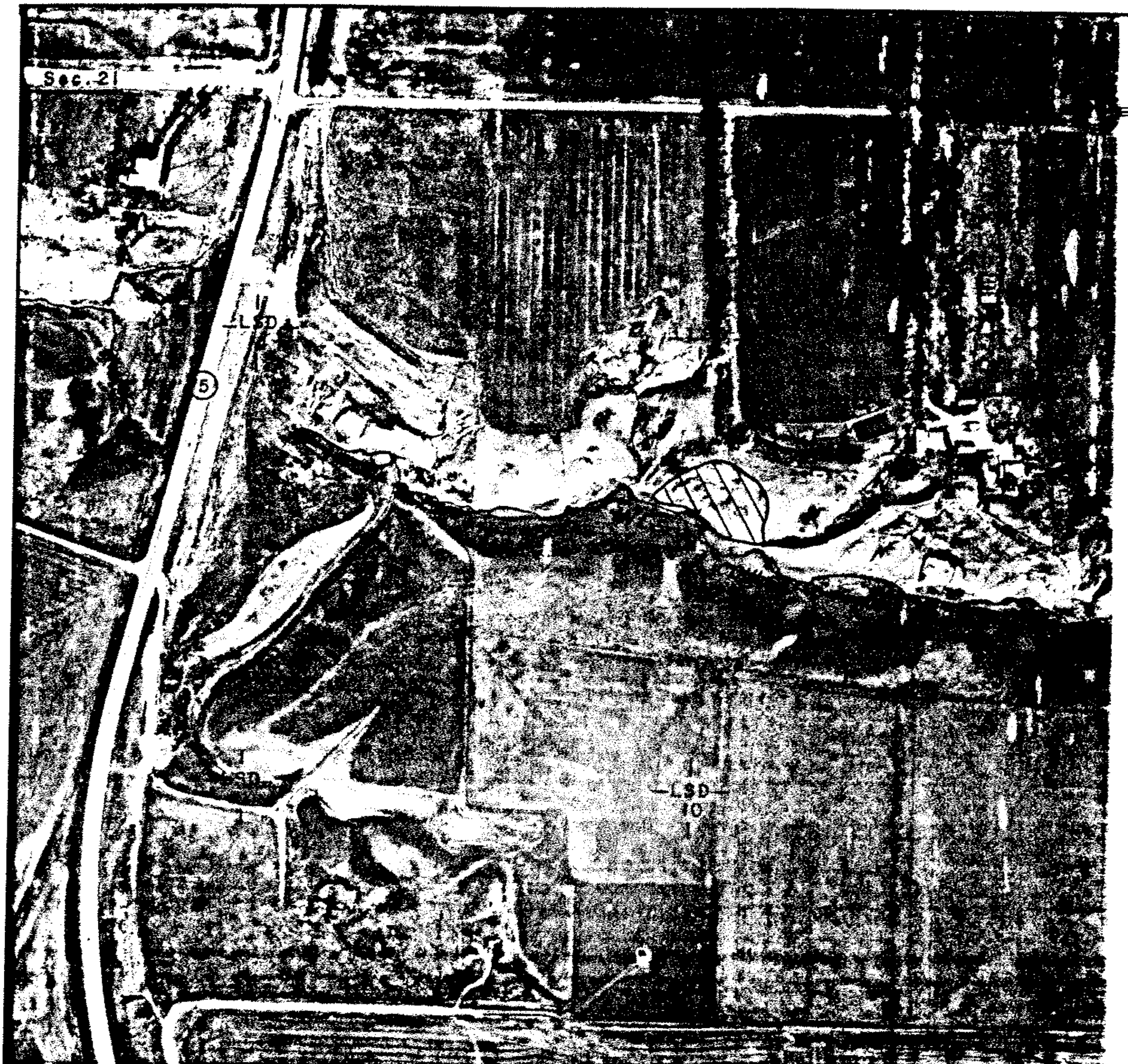
LOCATION: LSD. 15 - Sec. 16 - Twp. 8 - Rge. 21 - W4M

DESCRIPTION:

Located approximately 450 metres east of Highway 5 on the north bank of Six Mile Coulee, this slide is flanked by two smaller slides. It is approximately 26 metres high, 45 metres wide and 90 metres long, with an average slope angle of 30°. The slide is relatively old showing no signs of recent movement.

The existing slide morphology indicates a retrogressive rotational failure. Erosion at the toe of the slope is suspected as the trigger mechanism initiating failure at this location. The stream which is presently eroding at the toe, could eventually lead to further failure. However, the low flow velocities of the stream indicate only a minimal amount of erosion. It is speculated that the majority of the erosion occurs during the brief, high intensity rainstorms common in the area.

The surface of the slide appeared dry supporting little vegetation, indicative of a low groundwater table. Groundwater conditions at the time of failure are suspected to have been higher than at present.



PHOTOGRAPHED APRIL 16, 1980

Alberta ENVIRONMENT

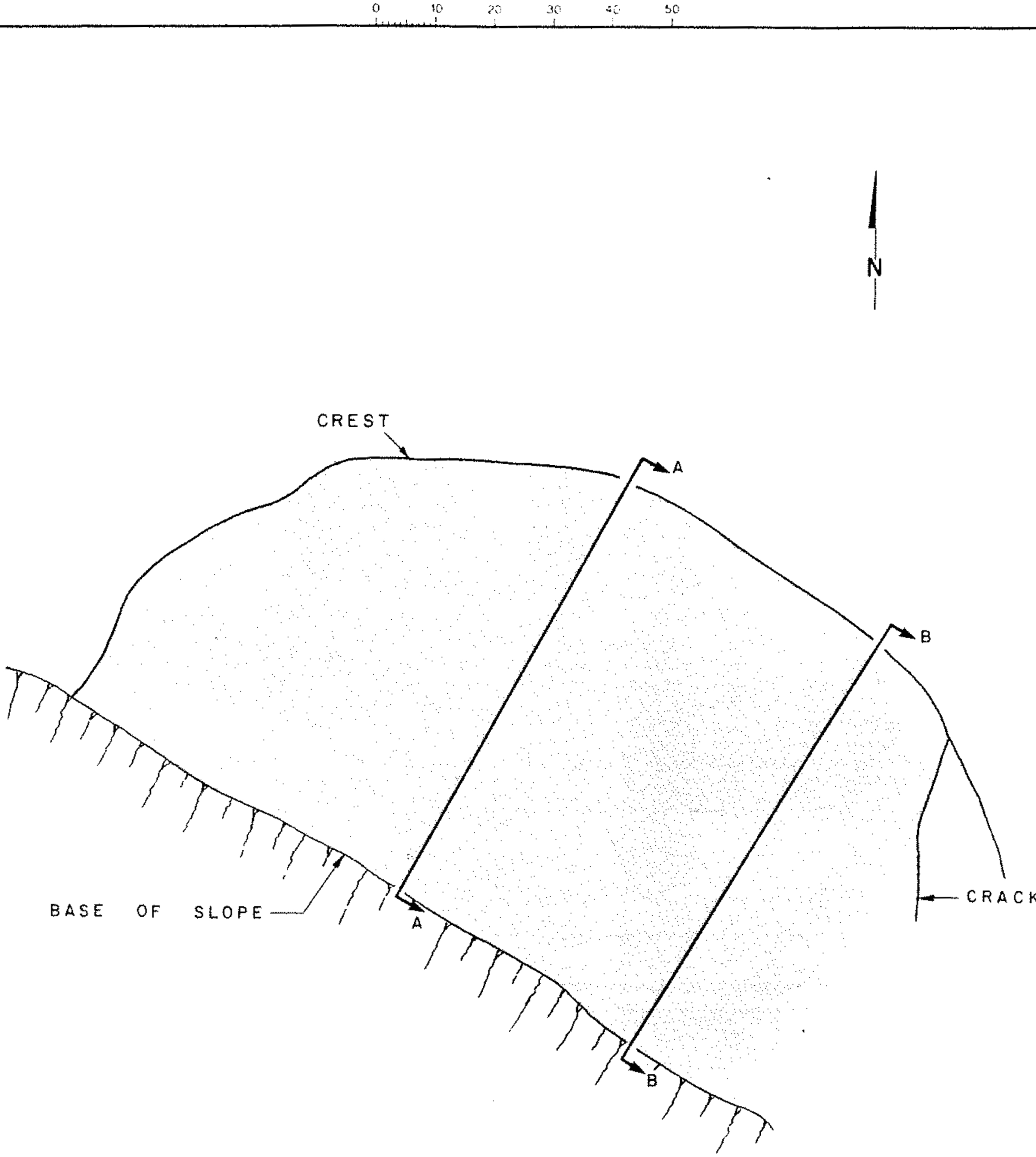
SUBMITTED	DESIGNED
DATE	CHECKED
APPROVED	DRAWN S. Y. C.
DATE	CHECKED

SLOPE STABILITY STUDY – LETHBRIDGE

SLIDE AREA No. 3-A

LSD. 15, Sec. 16, Tp. 8, Rg. 21, W/4 M

SCALE 1 : 5000	SHEET 1 OF 1
DATE OCTOBER, 1982	DRAWING No. 9



NORTH BANK OF SIX MILE COULEE

450m EAST OF HWY. 5

Alberta ENVIRONMENT

SUBMITTED	DESIGNED
DATE	CHECKED
APPROVED	DRAWN C. Bunlauer
DATE	CHECKED

SLOPE STABILITY STUDY - LETHBRIDGE

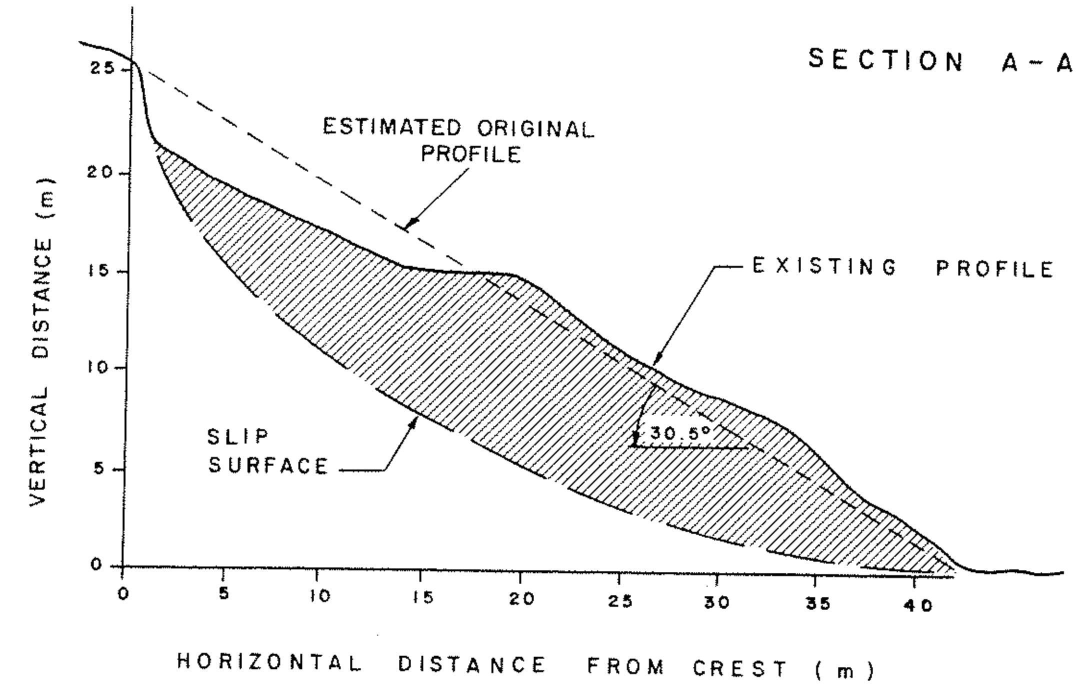
SLIDE AREA No. 3-A

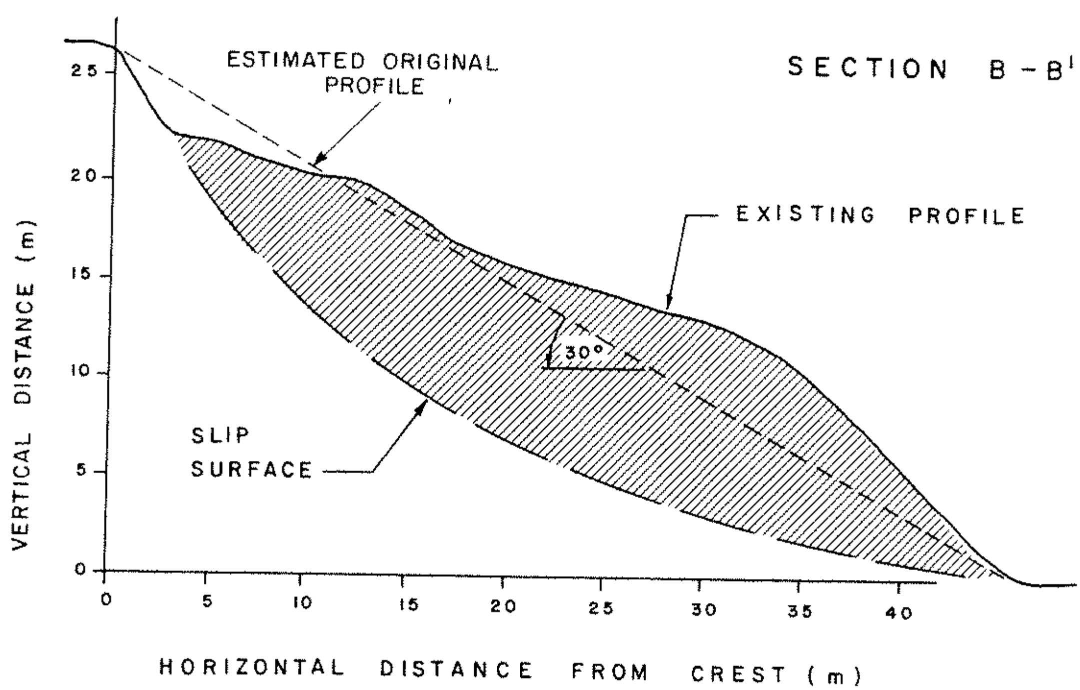
LSD. 15, SEC. 16, TP. 8, RG. 21, W4M

SCALE	1 : 720	SHEET 1	OF 1
DATE	OCT. 1982	DRAWING No.	10

MICROFILM DATE

DRAWING No





Alberta ENVIRONMENT

SUBMITTED	DESIGNED
DATE	CHECKED
APPROVED	DRAWN *E. [signature]*
DATE	CHECKED

SLOPE STABILITY STUDY - LETHBRIDGE

SECTION A-A' & B-B'

SLIDE AREA No. 3-A

LSD. 15, SEC. 16, TP. 8, RG. 21, W4M

SCALE	AS SHOWN	SHEET 1	OF 1
DATE	OCT. 1982	DRAWING No	11

FILE No

Photo 4: Aerial (above) and ground level (below) views of Slide No. 3-A. Note stream eroding toe of slope.

SLIDE AREA: No. 3-B, Lethbridge Community College Slide

LOCATION: LSD. 6 & 7 - Sec. 20 - Twp. 8 - Rge. 21 - W4M

DESCRIPTION:

This area consists of three separate slides along a small coulee west of the Lethbridge Community College. Fill was placed at the upper end of the coulee prior to 1975, possibly during the construction of the college. Some minor slope movement on the south coulee wall is detectable in the 1975 aerial photographs. The first slide 3-B(1), which involved undisturbed material, had developed by 1978.

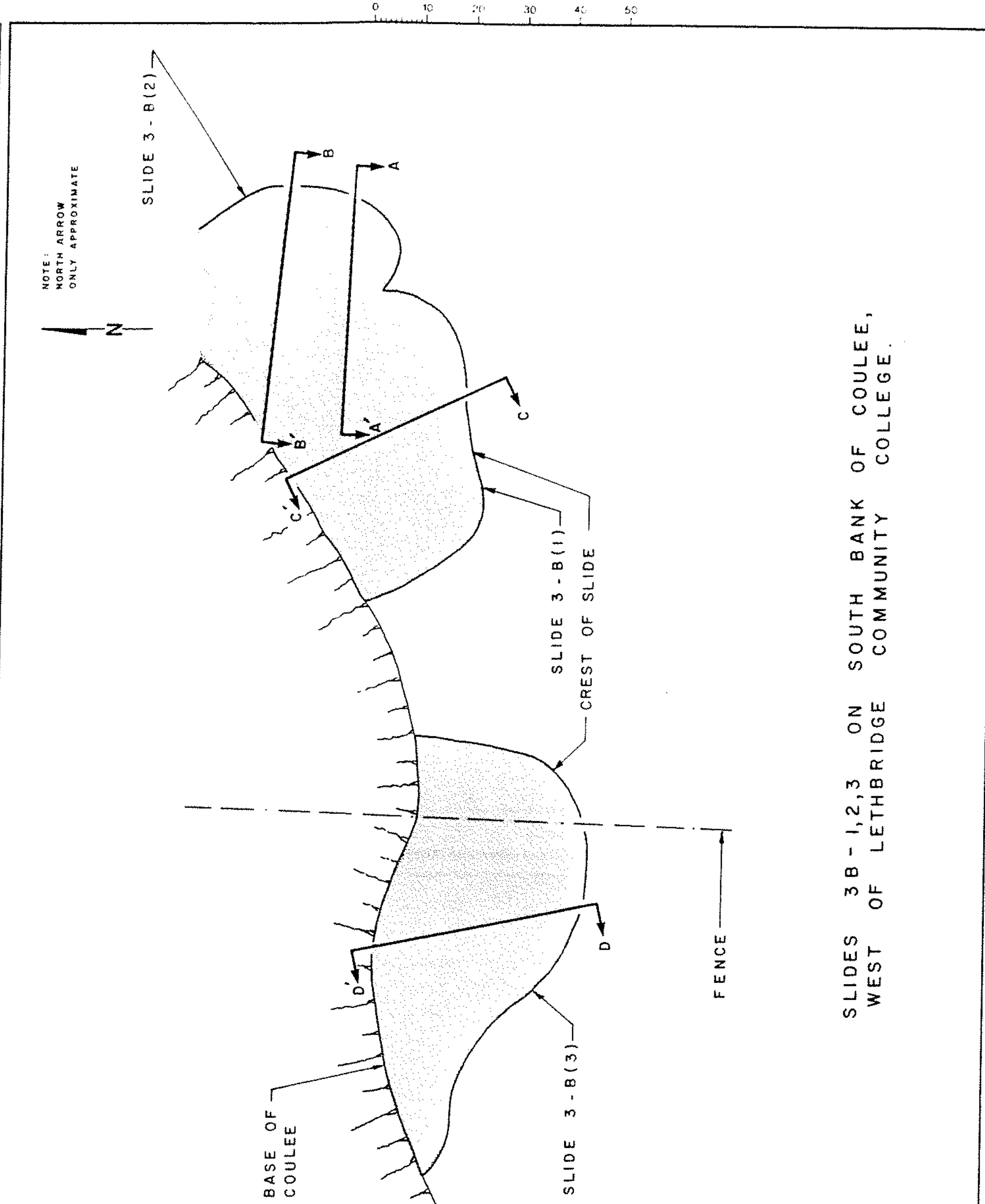
A second smaller scarp east of Slide 3-B(1) is also evident in the 1978 aerial photographs. A site visit confirmed that this second slide 3-B(2), was located through fill. Several wet zones in the slide face were also noted during the site inspection, indicative of groundwater seepage. The first two slides have presently coalesced but are still distinguishable as separate slide areas.

In the 1980 aerial photographs, fill was placed at the base of the first and second slides, possibly in an attempt to arrest future movement. Further west along the south coulee bank, another crack is visible on the 1980 aerial photographs. Several small toe failures appear to have proceeded this third slide, 3-B(3).

The estimated slope angle of the 3 slides prior to failure varies between 20° and 23°. The height of the slopes varies between 20 and 23 metres. A rotational type failure is common for all 3 slides. The cause of these slides is a combination of the following:

- fill placement at the top of the slope
- a rise in the local groundwater table due to watering of lawns
- erosion along the base of the coulee, which has increased between 1975 and 1980.

Alberta ENVIRONMENT		SLOPE STABILITY STUDY- LETHBRIDGE
SUBMITTED .... DATE	DESIGNED .... CHECKED	SLIDE AREA No. 3-B LETHBRIDGE COMMUNITY COLLEGE SLIDE LSD 6&7, Sec.20, Tp.8, Rg.21, W/4M
APPROVED .... DATE	DRAWN S. Y. C. CHECKED	SCALE 1 : 2500 — SHEET 1 OF 1 DATE OCTOBER, 1982 — DRAWING No. 12



MICROFILM DATE ________

DRAWING No ________

FILE No. ________

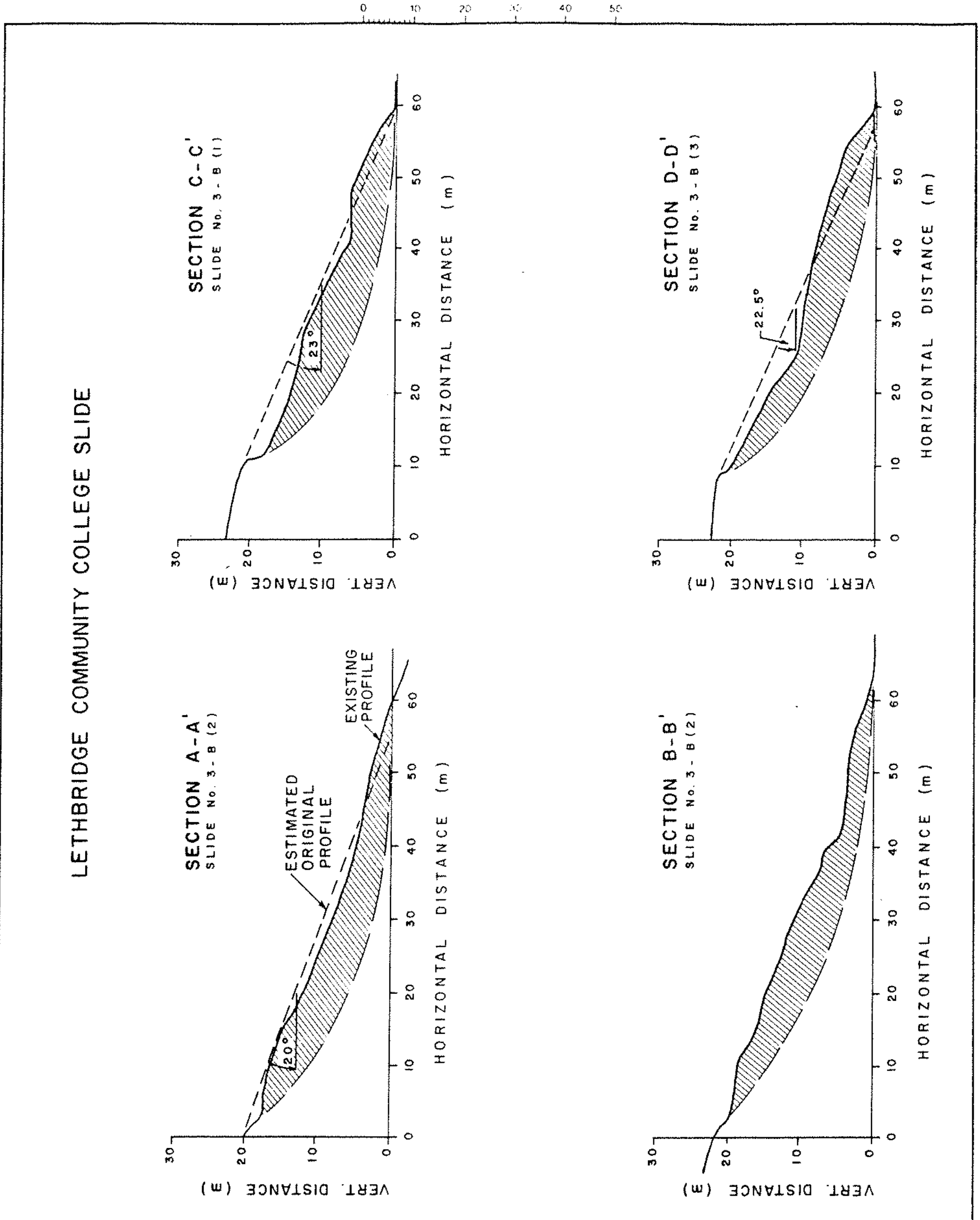
Alberta ENVIRONMENT

SLOPE STABILITY STUDY - LETHBRIDGE

SLIDE AREA No. 3-B

LSD. 6 & 7, Sec. 20, Tp. 8, Rg. 21, W/4

SUBMITTED	DESIGNED	SCALE 1 : 1250	SHEET 1 OF 1
DATE	CHECKED	DATE OCT. 1982	DRAWING No 13
APPROVED	DRAWN E. [signature]		
DATE	CHECKED		



MICROFILM DATE
DRAWING No.
FILE No.

Alberta ENVIRONMENT

SUBMITTED	DESIGNED
DATE	CHECKED
APPROVED	DRAWN *L. Bernhauser*
DATE	CHECKED

SLOPE STABILITY STUDY - LETHBRIDGE

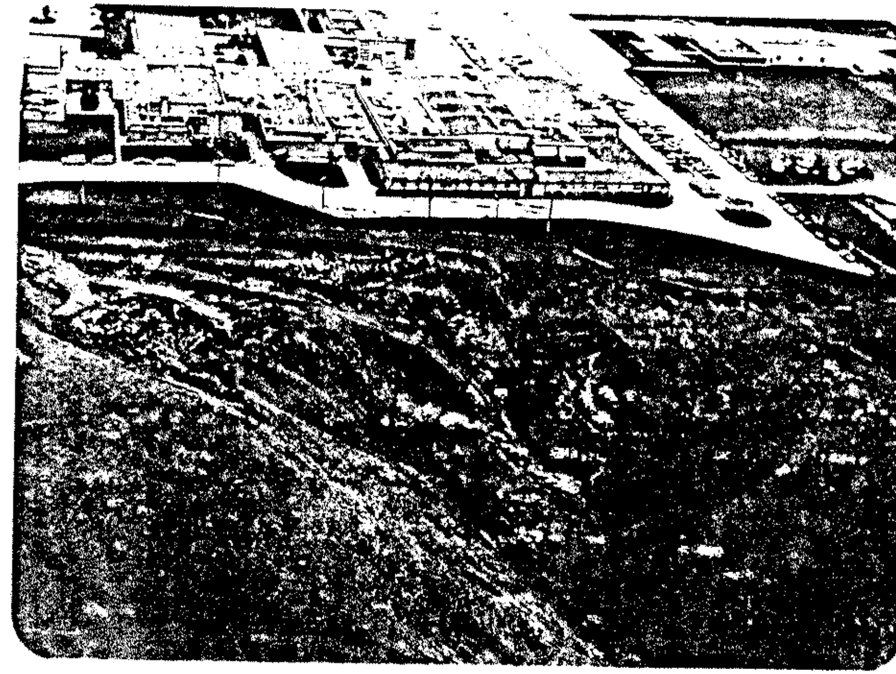
SECTIONS A-A', B-B', C-C', D-D'

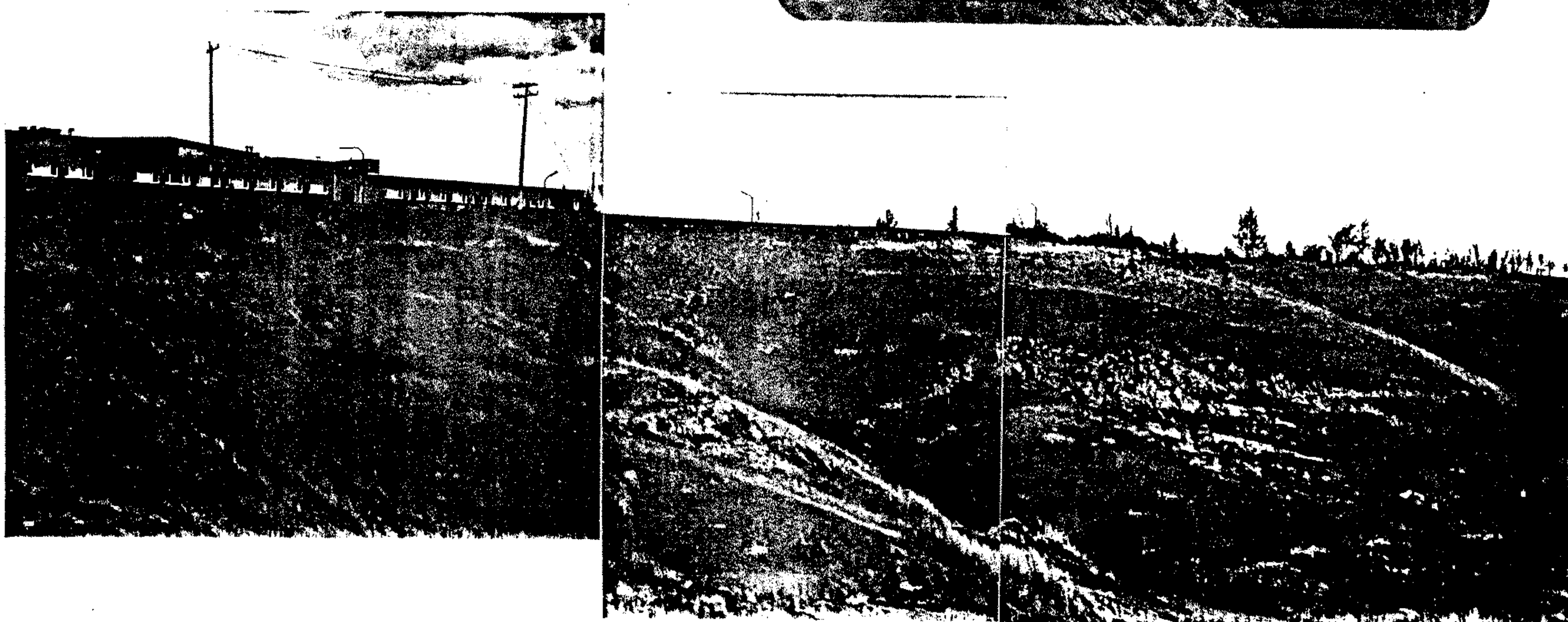
SLIDE AREA No. 3-B

LSD. 6 & 7, Sec. 20, Tp. 8, Rg. 21, W4/M

SCALE	AS SHOWN	SHEET 1	OF 1
DATE	OCT. 1982	DRAWING No.	14

Photo 5: Aerial and ground level views of Lethbridge Community College Slides 3-B(1) and 3-B(2).
Note additional placement of fill in top photo on left side along crest of coulee.
Slide 3-B(1) is situated on the right side of the photo and Slide 3-B(2) on the left side. Slide 3-B(3) is not visible on the photos.





SLIDE AREA: No. 4, Park Royal Slide

LOCATION: LSD. 3 & 4 - Sec. 29 - Twp. 8 - Rge. 21 - W4M

DESCRIPTION:

This slide area is located along a coulee on the east bank of the Oldman River and consists of two separate slide areas. The first slide traverses the south coulee wall and consists of a series of old retrogressive rotational slides which have shown no recent activity.

The second slide, which is relatively recent, is located on the north bank of the coulee. Basically a shallow rotational type failure, the slide consists of two separate centres of instability which have presently coalesced. The length of unstable slope along the north coulee bank is approximately 335 metres with scarps in excess of 3 metres. This slide has caused considerable damage to property along the top of the north coulee bank.

A major geotechnical investigation was conducted by Klohn Leonoff (1975) to analyze this particular slide. A brief summary of the events leading to the eventual failure as identified by Klohn Leonoff are as follows. Fill was initially placed along the top of the coulee to extend the homeowners' backyards. The placement of fill caused a blockage of the natural subsurface drainage, resulting in a rise of the local groundwater table. The level of the local groundwater table was further increased by the watering of lawns and gardens, and also possibly from leaky water and sewer lines. The combined effect of the additional weight at the top of the slope and the increase in the pore water pressure initiated a series of progressive landslide movements.

Alberta ENVIRONMENT

SLOPE STABILITY STUDY - LETHBRIDGE

SLIDE AREA No. 4

ROYAL PARK SLIDE

LSD. 3 & 4, Sec. 29, Tp. 8, Rg. 21, W4/M

SUBMITTED	DESIGNED	SCALE 1:2500	SHEET 1 OF 1
DATE	CHECKED	DATE OCTOBER, 1982	DRAWING No. 15
APPROVED	DRAWN S. Y. CHOW		
DATE	CHECKED		

SLIDE AREA: No. 5

LOCATION: LSD. 14 - Sec. 30 - Twp. 8 - Rge. 21 - W4M

DESCRIPTION:

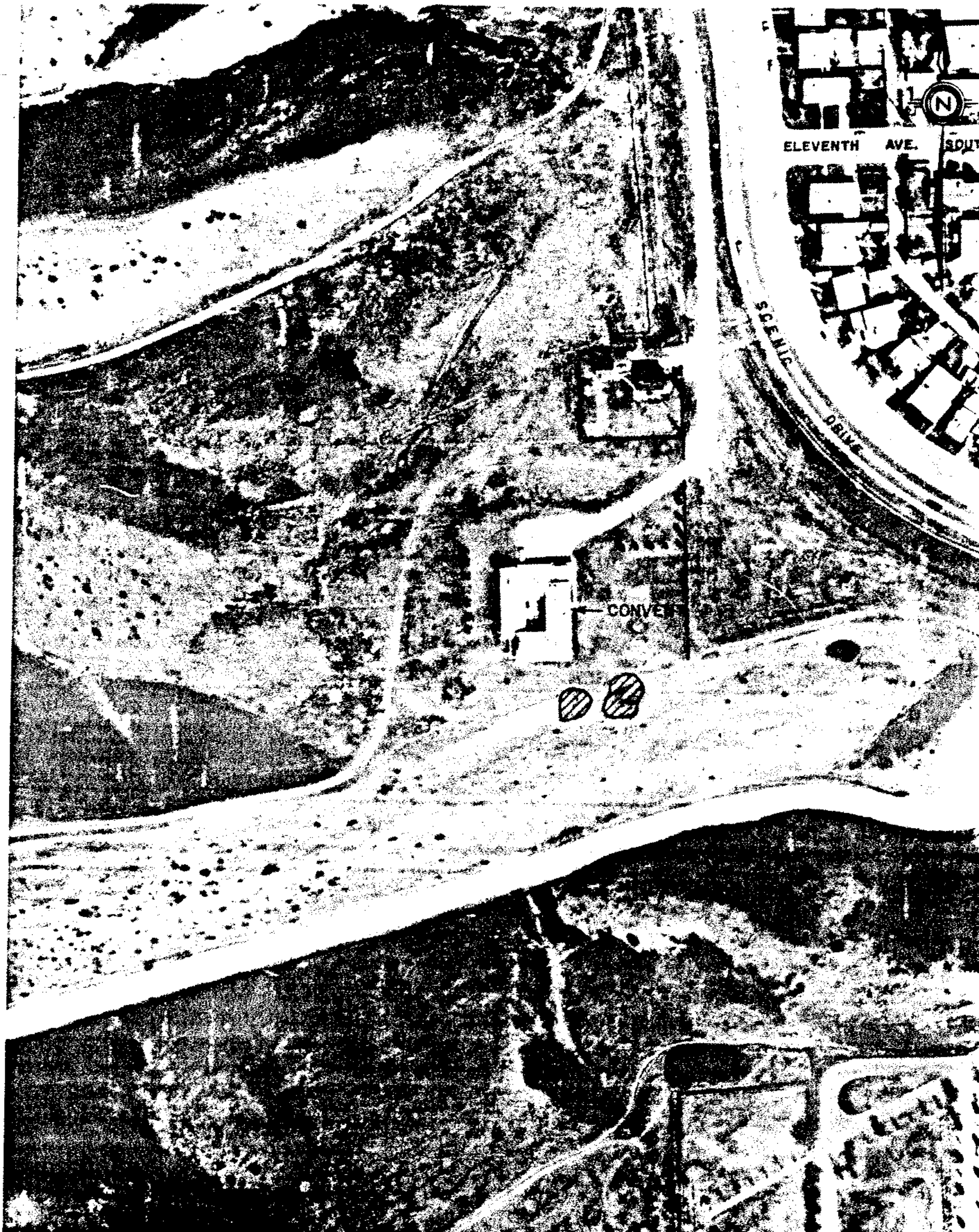
Two small slides have developed along the north bank of a 30 metre deep coulee on the east bank of the Oldman River, immediately west of 12th Avenue South. Although relatively small (only 10 and 15 metres in length), the presence of a convent only 10 metres from the crest greatly increases their significance.

These shallow rotational slides are confined to the upper portion of the slope involving surficial lacustrine/glacial deposits. Lush vegetation within the slide mass indicates groundwater seepage exiting the slope face.

Prior to construction of the convent, 1970 aerial photographs indicate a dry, stable slope, supporting only prairie grasses. After construction of the convent, watering of the lawns and gardens would have formed a local perched groundwater table. It is suspected that an increase in pore pressure is the probable cause of the slope failures. The slope failures are readily visible on the 1975 aerial photographs.

No deep seated movement is suspected and the existing slides do not appear to be regressing. However, should the situation be permitted to continue, these slides could increase in size and eventually pose a threat to the integrity of the building.

0 10 20 30 40 50



PHOTOGRAPHED APRIL 16, 1980

Alberta ENVIRONMENT

SUBMITTED	DESIGNED	SLOPE STABILITY STUDY - LETHBRIDGE	
DATE	CHECKED	SLIDE AREA No. 5 L.S.D. 14, Sec. 30, Tp. 8, Rg. 21, W4M	
APPROVED	DRAWN C.F.	SCALE 1:2000	SHEET 1 OF 1
DATE	CHECKED	DATE FEB, 1983	DRAWING No. 16

MICROFILM DATE

DRAWING No

FILE No.

SLIDE AREA: No. 6

LOCATION: LSD. 9 & 16 - Sec. 25 - Twp. 8 - Rge. 22 - W4M;
LSD. 13 - Sec. 30 - Twp. 6 - Rge. 21- W4M

DESCRIPTION:

This area consists of three separate parallel coulees on the east side of the Oldman River which have experienced extensive erosion. Stormwater runoff from the adjacent residential area has been directed into these coulees and allowed to erode the bases. The coulees are identified on Drawing 17 as areas 6-A, 6-B and 6-C.

Of the three coulees, erosion in the middle coulee (6-B) was the most severe. In the 1950 aerial photographs, erosion of the coulee bases extends back from the lower end of the coulee for a distance of approximately 200 metres, 440 metres and 200 metres for coulees 6-A, 6-B and 6-C, respectively. The 1961 aerial photographs indicate minimal increased erosion for areas 6-A and 6-C. However, the erosion in coulee 6-B had increased to a length of approximately 760 metres.

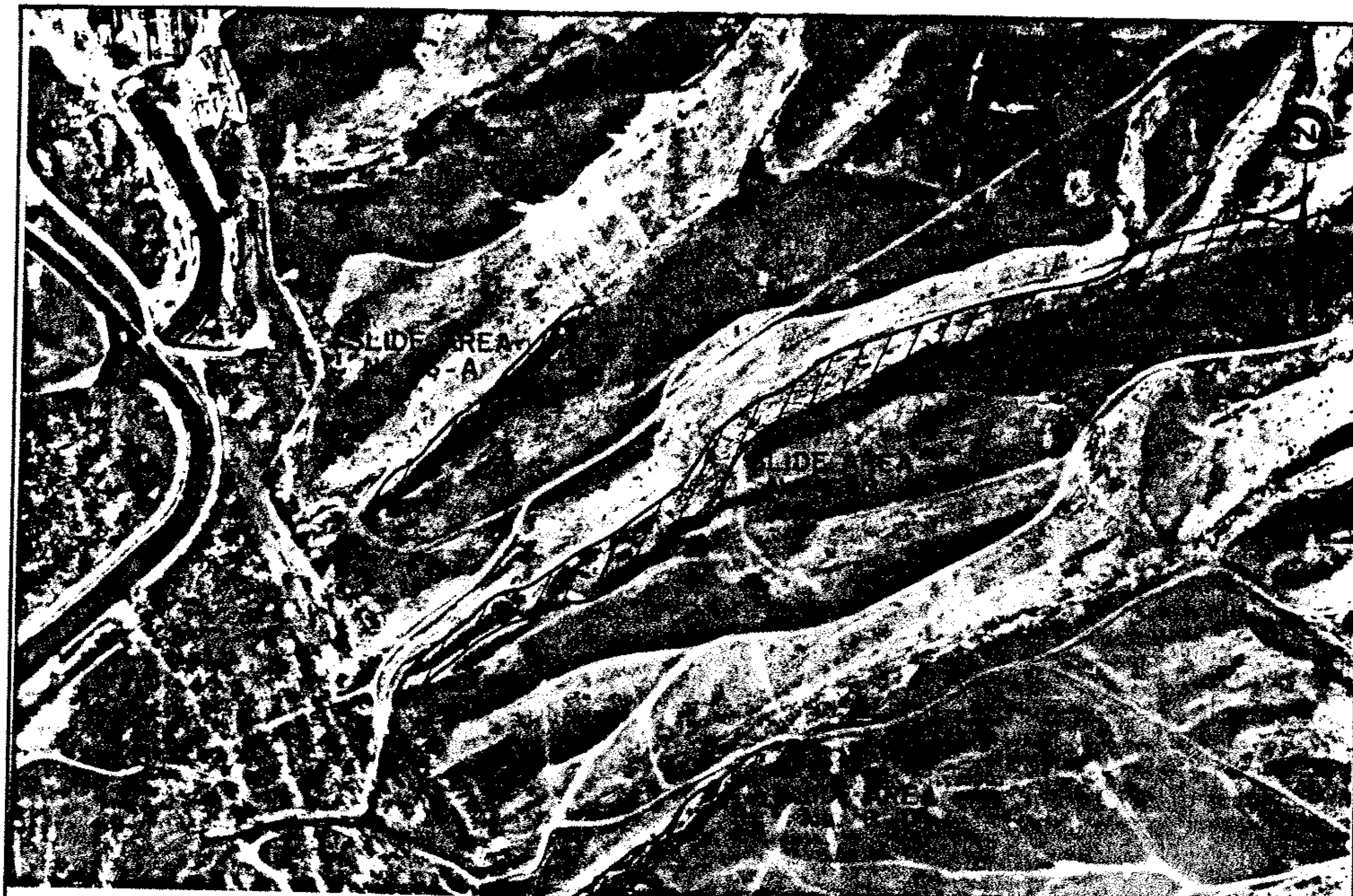
The erosion of the coulees by surface runoff resulted in the formation of near vertical walls at the coulee base, which are estimated to be 10 metres high. Although the base of these three coulees was significantly downcut and the overall slope angle increased, no signs of any major instability developed.

This practice of diverting stormwater runoff into the coulees is no longer permitted by the city. As a result there are no present gullying problems in this slide area. The only type of activity presently evident is an occasional toppling block failure along the steep walls at the base of the eroded coulees.

SLIDE AREA: No. 6 (Continued ...)

Between 1970 and 1975, the City of Lethbridge Engineering Department placed a large diameter culvert in the base of the middle coulee (6-B) and backfilled the upper half of the coulee. The culvert is used to carry surface runoff from the upland plain to the river level. This method of controlling surface runoff has worked effectively and is presently considered standard practice for the City Engineering Department.

1980 aerial photographs show that additional backfilling in the base of the coulee in 6-B has left only 230 metres of the middle coulee unfilled. No backfilling appears to have been performed in either areas 6-A or 6-C.



PHOTOGRAPHED APRIL 16, 1980

Alberta ENVIRONMENT

SUBMITTED	DESIGNED	SLOPE STABILITY STUDY – LETHBRIDGE	
DATE	CHECKED	**SLIDE AREA No. 6** LSD 9 & 16, Sec. 25, Tp. 8, Rg. 22, W/4 M LSD 13, Sec. 30, Tp. 6, Rg. 21, W/4M	
APPROVED	DRAWN S. Y. C.	SCALE 1 : 5000	SHEET 1 OF 1
DATE	CHECKED	DATE OCTOBER, 1982	DRAWING No. 17

SLIDE AREA: No. 7

LOCATION: LSD. 8 - Sec. 36 - Twp. 8 - Rge. 22 - W4M

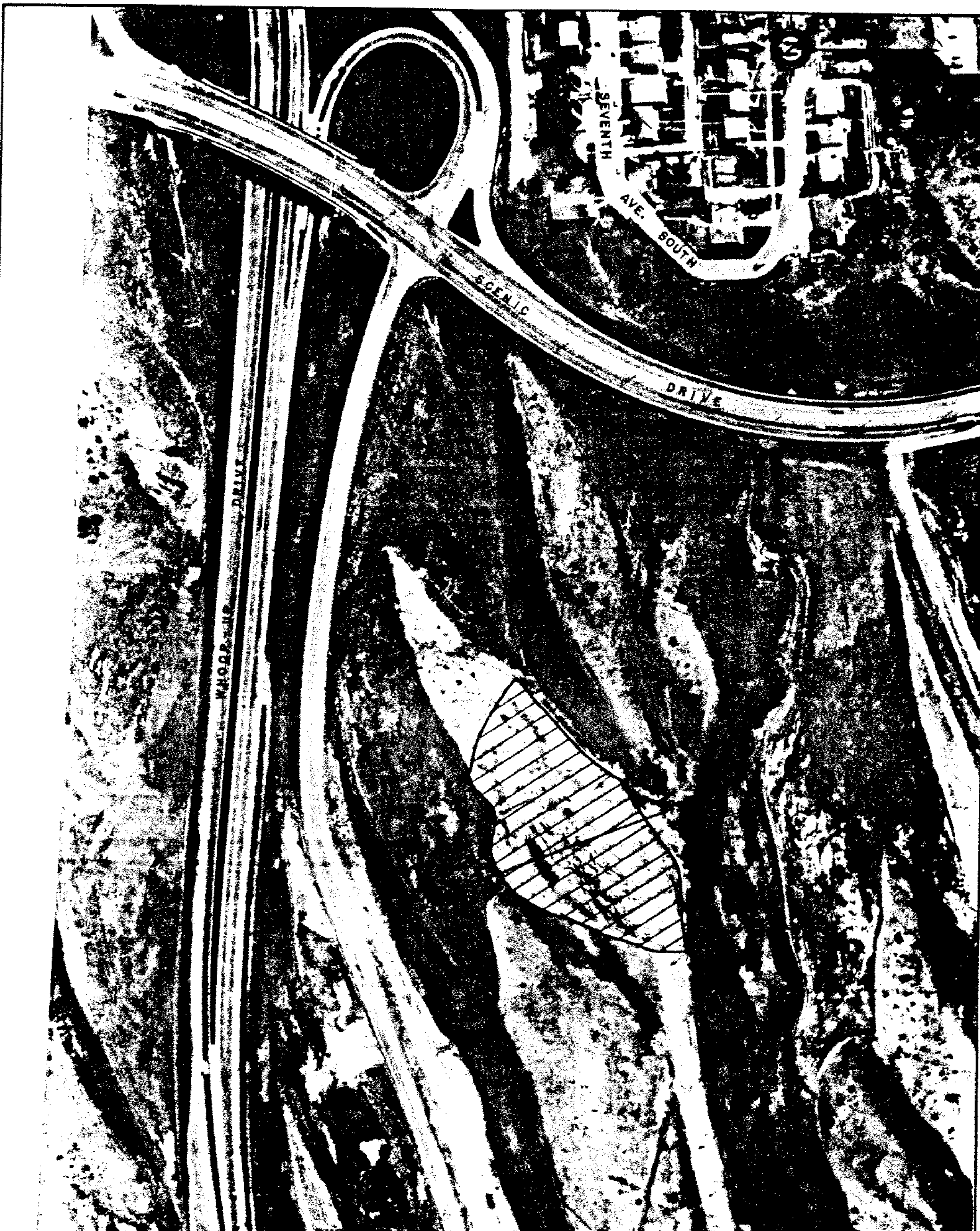
DESCRIPTION:

This slide is situated on the north bank of a coulee, on the east side of the Oldman River, south of Whoop-Up Drive. The top of the coulee was levelled off as part of a road construction program along Scenic Drive between 1961 and 1970. The 1950 and 1961 aerial photographs reveal ravelling along the lower portion of the steep coulee walls, indicating marginal coulee wall stability. Minor slumps in 1970, continued to increase in size until 1978 when a large slump block failed. No further movement is evident after 1978.

The slide is approximately 90 metres long and 27 metres high, with an estimated slope angle prior to failure of 39°. A section through the slide is presented on Drawing 19. A rotational type failure is suspected.

There are no signs of seepage on the slope, or any apparent erosion at the base. The coulee is well isolated from any form of anthropogenic interference, with the exception of the time period when the top of the coulee was levelled off.

Normally, unloading at the top of a bank would increase the stability of a slope. However, this does not appear to be the case with this particular slide. It is suspected that during the excavation process, more material would have been removed from the centre of the borrow area, rather than permitting heavy equipment too close to the edge of the coulee. This would have left a depression on top of the coulee, and subsequently tend to collect rainfall rather than shed it. In addition, the removal of the upper soil would have an unloading effect, which results in soil rebound and the opening of vertical fractures in the till. The opened vertical cracks would permit the ingress of surface runoff, causing a rise in the local ground-water table and increase in porewater pressure. The increase in porewater pressure appears to have been sufficient to intitiate the minor instability, which eventually lead to the larger slope failure.



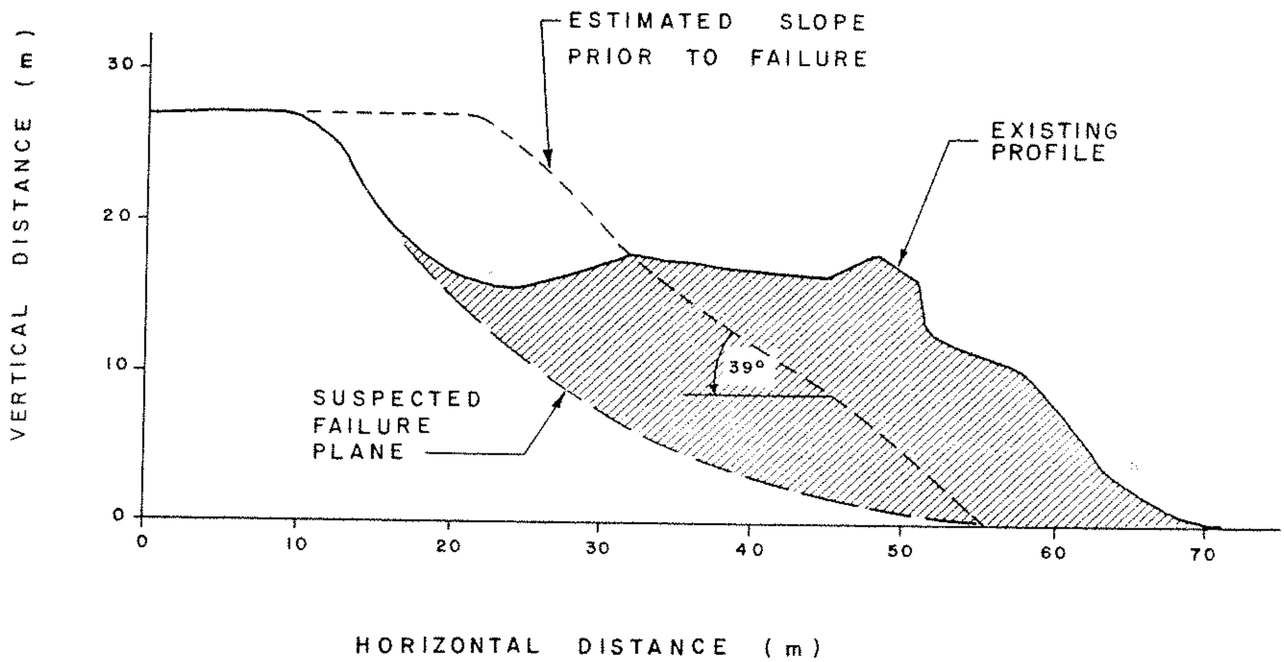
Alberta
ENVIRONMENT

SLOPE STABILITY STUDY - LETHBRIDGE

SLIDE AREA No. 7

LSD 8, Sec. 36, Tp. 8, Rg. 22 W/4 M

SUBMITTED	DESIGNED	SCALE 1:2500	SHEET 1 OF 1
DATE	CHECKED	DATE OCTOBER, 1982	DRAWING No. 18
APPROVED	DRAWN S. Y. C.		
DATE	CHECKED		



Alberta ENVIRONMENT

SUBMITTED	DESIGNED	SLOPE STABILITY STUDY - LETHBRIDGE	
DATE	CHECKED	SECTION A-A' SLIDE AREA No. 7 LSD 8, Sec. 36, Tp. 8, Rg. 22, W4/M	
APPROVED	DRAWN C. [illegible]	SCALE AS SHOWN	SHEET 1 OF 1
DATE	CHECKED	DATE OCT. 1982	DRAWING No. 19

FILE No. ___ DRAWING No. ___ MICROFILM DATE ___

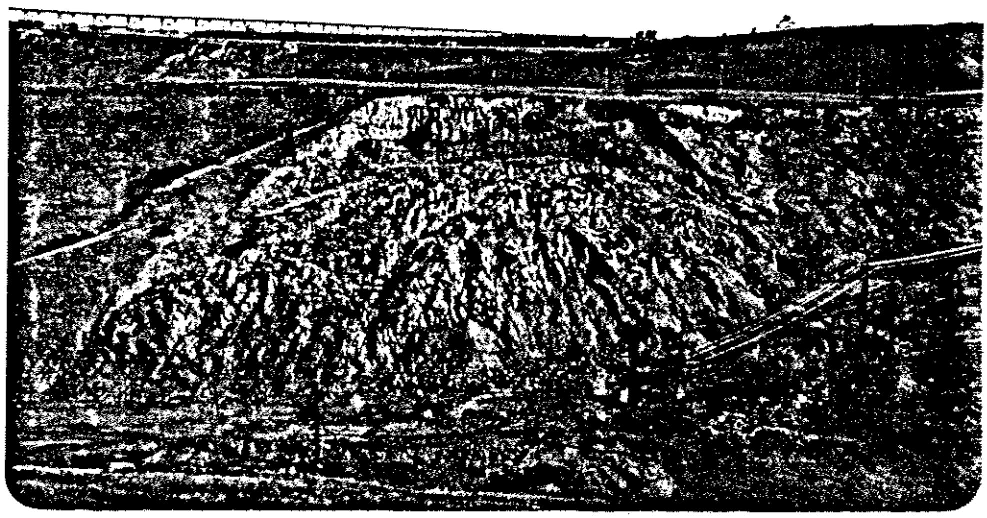


Photo 6: Ground level view of Slide No. 7. Note the flattened top of the coulee.

SLIDE AREA: No. 8

LOCATION: LSD. 9 & 10 - Sec. 36 - Twp. 8 - Rge. 22 - W4M

DESCRIPTION:

This area consists of two separate slides in adjacent coulees. These coulees are situated west of the Gault Museum on the east bank of the Oldman River. Both slides are presently inactive.

There are few signs that indicate a possible failure mechanism. However, similar to Slide No. 7, the top of the knoll which separates these 2 slides was levelled off between 1950 and 1961. The larger, older, north-facing slide (8-A), experienced movement prior to 1950 and additional movement after the knoll was levelled off.

Instability developed on the south side of the knoll (Slide 8-B) prior to 1970, but has not exhibited any additional movement after 1975.

The south-facing slide appears dry with little vegetation. The north-facing slide supports considerably more vegetation, particularly on the east edge of the slide mass. Similar to Slide No. 7, it is postulated that the soil experienced a rebound after the knoll was levelled, which permitted the opening of cracks, an ingress of water, and a rise in the local groundwater table. The rise in the groundwater table appears sufficient to have initiated slope instability.

A shallow rotational mode of failure is suspected for both of these slides. The size of these slides is similar, varying in length from 50 to 60 metres. The existing slope angle for Slide 8-A is 26.5° and the slope height 26 metres. A cross-section through Slide 8-A is shown on Drawing 21.

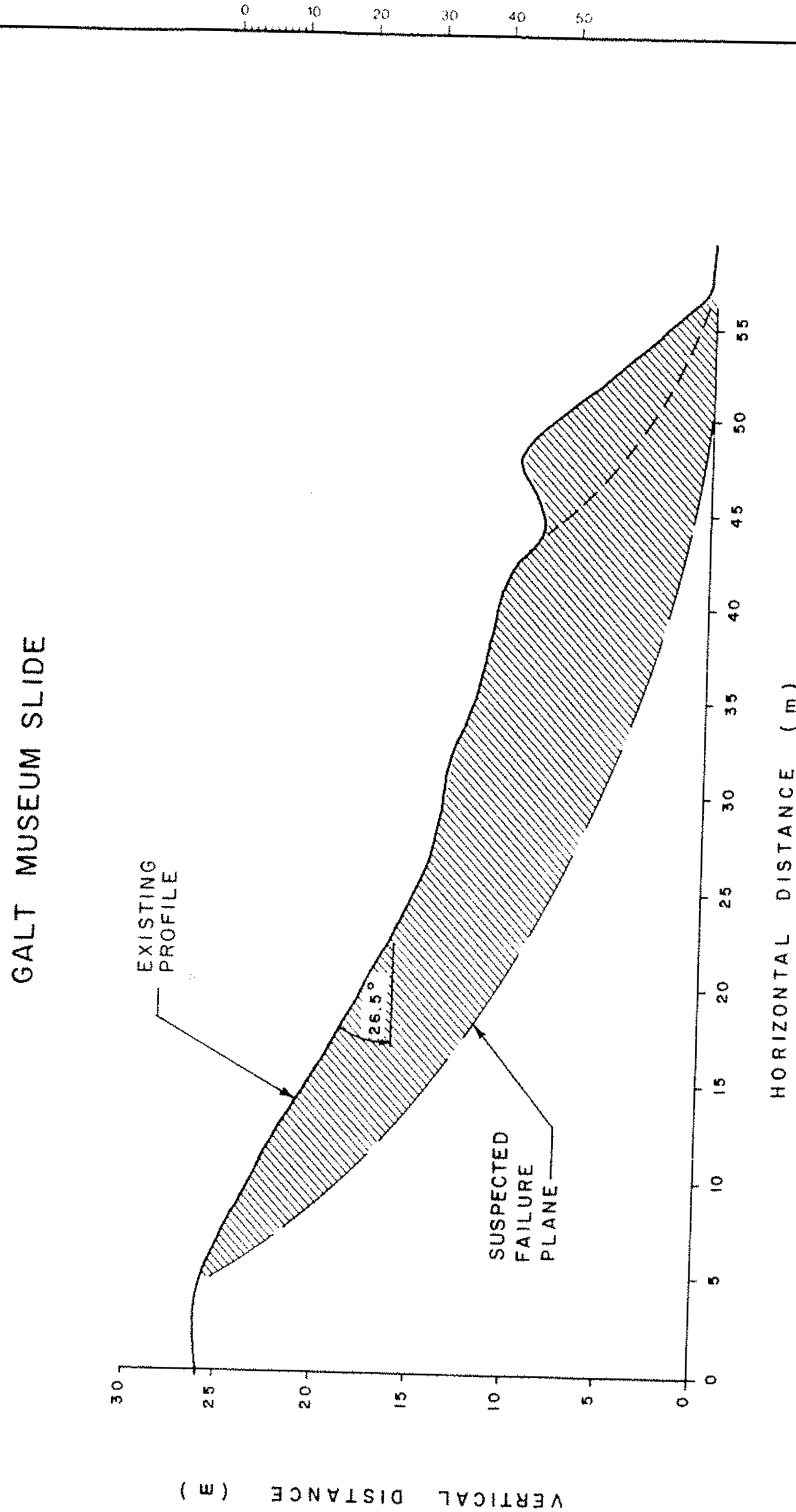
PHOTOGRAPHED MAY 18, 1975

Alberta ENVIRONMENT		SLOPE STABILITY STUDY – LETHBRIDGE	
SUBMITTED	DESIGNED	SLIDE AREA No. 8 & 9	
DATE	CHECKED	LSD 9&10, Sec.36, Tp.8, Rg.22, W/4 M LSD 15&16, Sec.36, Tp.8, Rg.22, W/4 M	
APPROVED	DRAWN S. Y. C.	SCALE 1:6000	SHEET 1 OF 1
DATE	CHECKED	DATE OCT. 1982	DRAWING No. 20

MICROFILM DATE

DRAWING No.

FILE No.



Alberta ENVIRONMENT

SUBMITTED	DESIGNED	SLOPE STABILITY STUDY - LETHBRIDGE
DATE	CHECKED	SECTION A-A'
APPROVED	DRAWN E. Beerbauer	SLIDE AREA No. 8-A
DATE	CHECKED	LSD 10, Sec. 36, Tp. 8, Rg. 22, W4/M
		SCALE AS SHOWN / SHEET 1 OF 1
		DATE OCT. 1982 / DRAWING No. 21

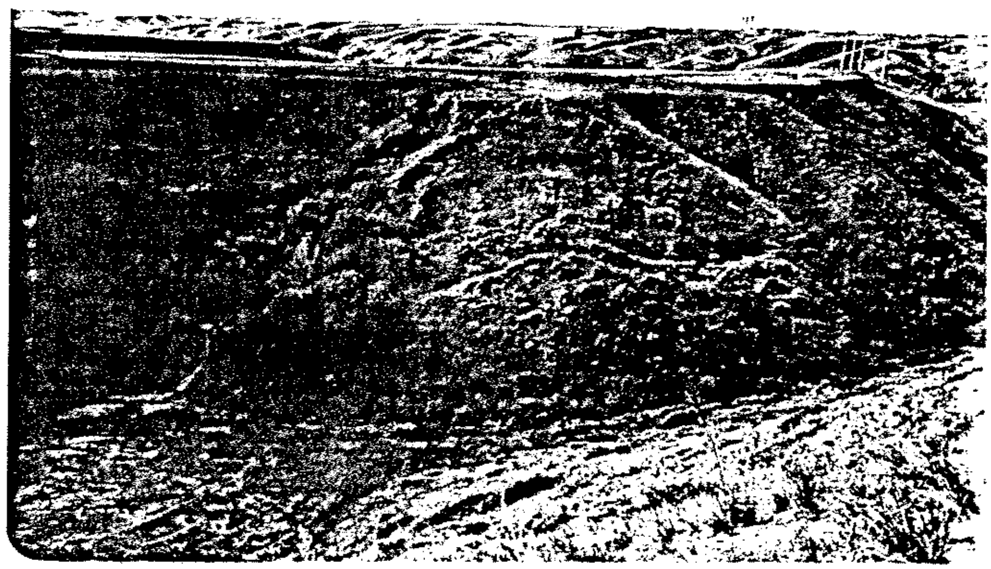


Photo 7: View looking south at Slide 8-A (Gault Museum Slide). Note shrub growth on left side of slide mass indicating groundwater seepage.

SLIDE AREA: No. 9

LOCATION: LSD. 15 and 16 - Sec. 36 - Twp. 8 - Rge. 22 - W4M

DESCRIPTION:

This area comprises slides on both the north and south banks of a coulee located immediately west of Third Avenue South, on the east bank of the Oldman River. The slides are not presently visible due to a major grading operation conducted between 1978 and 1980.

Severe gullying along the base of the coulee resulted in the formation of steep walls and a few small slides along the toe of the slopes. The cause of this gullying is probably due to the direction of stormwater runoff into the coulee. By 1961, the small slides had increased somewhat in size, but were not of major concern. In the 1970 aerial photographs, a significant rotational slide (9-A) had developed on the north bank of the coulee.

Between 1970 and 1975, a major slide approximately 180 metres in length occurred along the south bank of the coulee (9-B). The slope angle along the south bank prior to failure is estimated to vary from 28° to 38°. The height of the slope is approximately 38 metres. Three small retrogressive rotational failures are readily distinguishable at the toe of the slope preceding the major slope failure. Steepening at the base due to erosion appears to be the principle trigger mechanism.

A major grading program has presently stabilized both banks of the coulee. Stabilization comprised fill placement at the base of the coulee to eliminate the steep walls and provide toe support, levelling of the knoll which formed the north bank, and flattening of the south bank to a stable angle.

SLIDE AREA: No. 10, Stafford Avenue Slide

LOCATION: LSD. 6 - Sec. 7 - Twp. 9 - Rge. 21 - W4M

DESCRIPTION:

This slide area is located on a south coulee bank north of Stafford Avenue, on the east bank of the Oldman River. Slope instability appears to have been initiated by a combination of dumping along the crest of the coulee and a suspected rise in the local groundwater table.

Up to 1961, the south slope of the coulee was relatively stable. 1970 aerial photographs show the formation of a large crack approximately 40 metres long, on the south slope. Fill appears to have been placed along the crest of the slope prior to failure. This initial slide is flanked to the east by a very old slide.

1978 aerial photographs indicate that a second slide was developing immediately west of the first slide. This second slide exhibited a distinct 'graben' feature at the top and no noticeable bulging at the toe, inferring a translational failure mechanism. The suspected mode of failure is combined rotational-translational, with rotational movement occurring along the steep curved upper failure surface through the Pleistocene deposits and translational movement on the lower failure surface along the top of the Bearpaw Formation bedrock.

The trigger mechanism causing failure of the second slide is not readily apparent. There does not appear to have been any significant placement of fill in the vicinity of the slide area. It is suspected that a rise in the local groundwater table is the trigger mechanism.

SLIDE AREA: No. 10, Stafford Avenue Slide (Continued ...)

Between 1970 and 1975, an area west of Sixth Street North was developed for residential housing. The addition of these houses along the crest of the south coulee bank could have contributed to a rise in the local groundwater table due to watering of lawns and gardens and any leakage from sewers or water pipes. This increase in pore pressure appears to have been sufficient to initiate the second slide.

Although the 1980 aerial photographs show two separate slide masses, inspection of the slide mass in 1981, showed that the slides had coalesced into one larger slide. During the field reconnaissance it was noted that fill was still being placed at the top of slope. Presently the crest of the slide is only a few metres from Stafford Avenue (see Photo 8). Should dumping of fill along the crest of the slope be permitted to continue, there is a possibility that a portion of the road may be claimed by the slide.

The height of the slope is approximately 34 metres. The slope angle before failure is estimated to be between 28° and 31°. The length of slope involving the two most recent slides is approximately 100 metres.

Alberta
ENVIRONMENT

SLOPE STABILITY STUDY - LETHBRIDGE

SLIDE AREA No. 10

STAFFORD AVENUE SLIDE

LSD 6, Sec. 7, Tp. 9, Rg. 21, W/4 M

SUBMITTED		DESIGNED	
DATE		CHECKED	
APPROVED		DRAWN	S. Y. C.
DATE		CHECKED	

SCALE	1:2500	SHEET 1	OF 1
DATE	OCTOBER, 1982	DRAWING No.	22

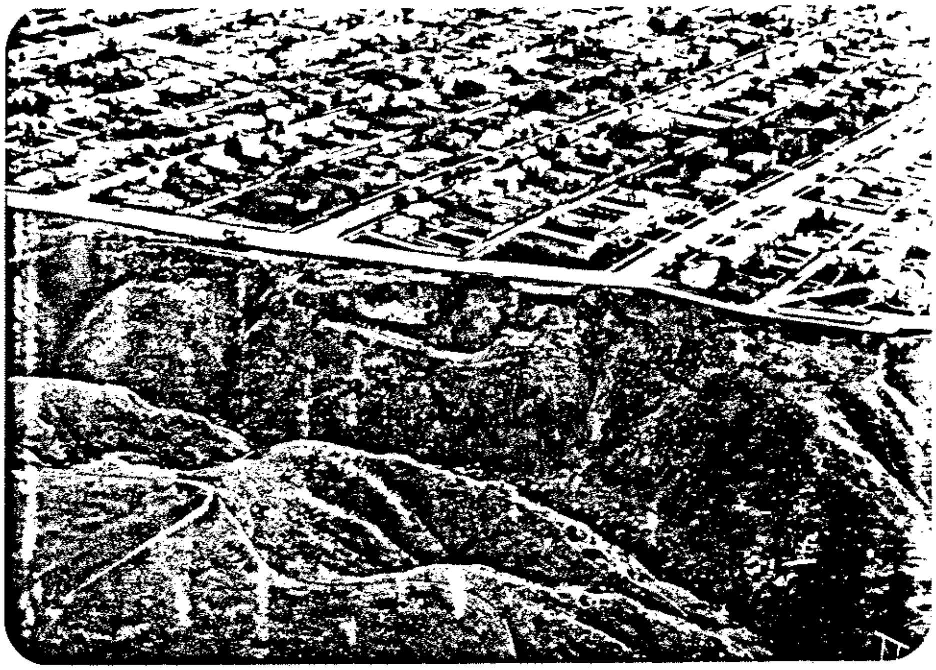


Photo 8: Aerial view (above) looking southeast, and ground level view (below) looking east at Slide Area No. 10. Note old inactive slide on left side of top photo and proximity of crest to Stafford Avenue. Lower photo shows recently placed fill at top of slope.

SLIDE AREA: No. 11

LOCATION: LSD. 2 - Sec. 14 - Twp. 9 - Rge. 22 - W4M

DESCRIPTION:

This area consists of a number of slides on both sides of a coulee on the west bank of the Oldman River. The drier north bank of the coulee contains only one old, inactive slide. The south bank on the other hand, displays three small slides and considerable vegetation. A section through the most recent of these slides (11-A) is shown on Drawing 24. The estimated slope angle prior to failure is 29.5°. The slide is approximately 35 metres high and 90 metres long.

The failure mode for the three north-facing slides is shallow rotational, characterized by steep backscarps and a bulging toe which breaks out partway up the slope. It is suspected that these slides are breaking out at the Pleistocene-Upper Cretaceous contact.

Discussions with the present property owner indicate that the previous farmer had over-irrigated the land and permitted the excess water to runoff into the coulees. This excessive irrigation would have caused a temporary local rise in the groundwater table, and is suspected of initiating the slope movements.

The most recent activity occurred between 1961 and 1970. Presently, the slides along the south bank are inactive and have not exhibited any recent signs of movement.

PHOTOGRAPHED APRIL 16, 1980

Alberta ENVIRONMENT

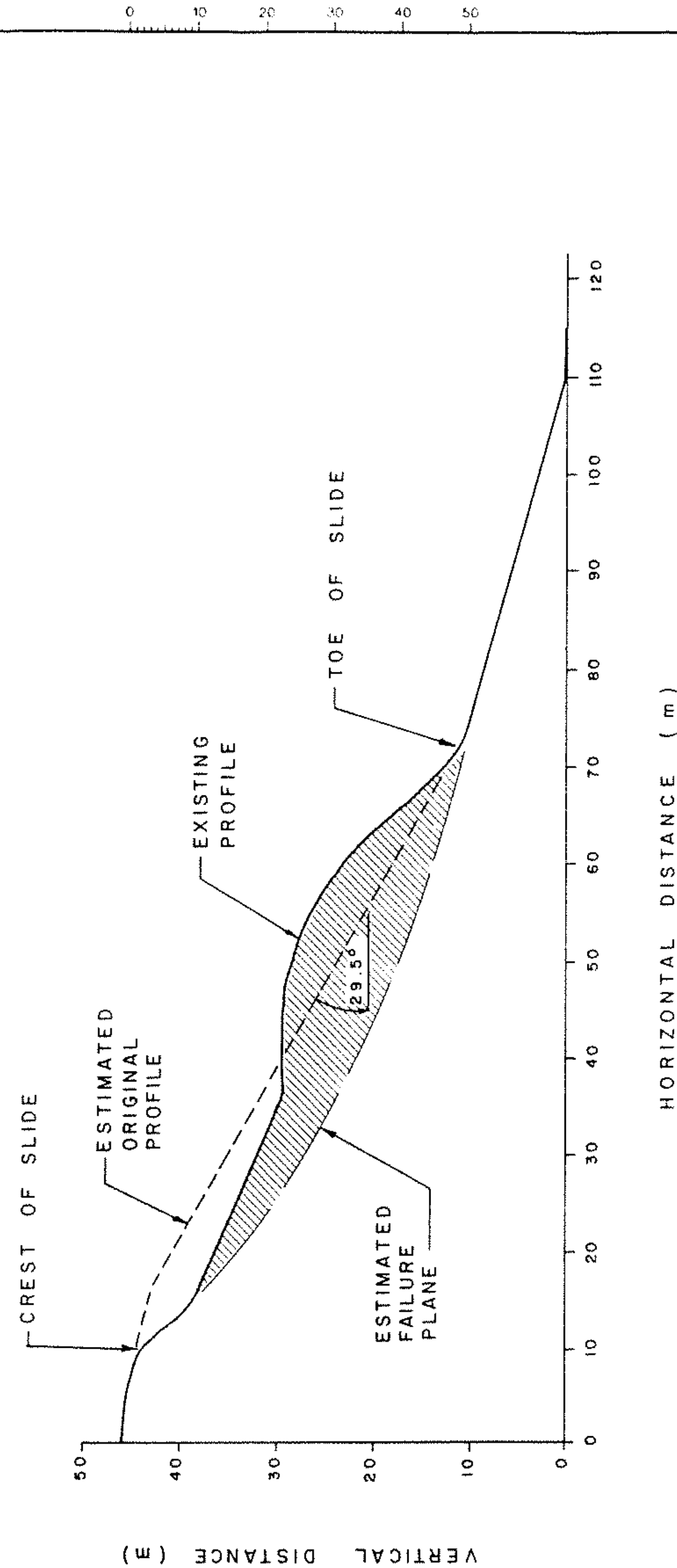
SUBMITTED	DESIGNED
DATE	CHECKED
APPROVED	DRAWN S. Y. C.
DATE	CHECKED

SLOPE STABILITY STUDY – LETHBRIDGE

SLIDE AREA No. 11

LSD 2, Sec. 14, Tp. 9, Rg. 22, W/4 M

SCALE 1 : 5000	SHEET 1 OF 1
DATE OCTOBER, 1982	DRAWING No. 23



Alberta ENVIRONMENT

SUBMITTED
DATE
APPROVED
DATE
DESIGNED
CHECKED
DRAWN C. Bernhauser
CHECKED

SLOPE STABILITY STUDY - LETHBRIDGE

SECTION A-A'

SLIDE AREA No. II-A

LSD 2, Sec. 14, Tp. 9, Rg. 22, W4/M

SCALE AS SHOWN
SHEET 1 OF 1
DATE OCT. 1982
DRAWING No. 24

MICROFILM DATE
DRAWING No.
FILE No.

Pho...

...ound level view of Slide No. 11-A, looking south.

SLIDE AREA: No. 12

LOCATION: LSD. 1 and 8 - Sec. 11 - Twp. 9 - Rge. 22 - W4M

DESCRIPTION:

This large, old landslide is located on the outside of a meander bend on the west bank of the Oldman River. Although subdued somewhat by surface erosion, the surface topography is extremely broken and irregular.

The postulated failure surface of this 600 metre long slide is a combined rotational-translational failure seated in the underlying Bearpaw Shale. The slide area averages 220 metres in width, 87 metres in height and a present slope angle of 22°. This slide is characterized by a steep backscarp and near-vertical banks at the toe. Having occurred along an outside meander bend of the river, the suspected trigger mechanism which initiated this slide is toe erosion. The slide is suspected of being formed while the river was actively downcutting through the Pleistocene sediments and carving the present day valley. Although the river is located directly along the toe of the slide, toe erosion is relatively insignificant.

No major movements have occurred during the period covered by the aerial photographs (1950 - 1980). Some minor slabbing is presently occurring along the steep-walled backscarp and also some minor erosion at the toe by the Oldman River.

PHOTOGRAPHED APRIL 16, 1980

Alberta ENVIRONMENT		SLOPE STABILITY STUDY – LETHBRIDGE
SUBMITTED	DESIGNED	SLIDE AREA No. 12 & 13
DATE	CHECKED	LSD 1,2 & 8, Sec. 11, Tp. 9, Rg. 22, W/4 M LSD 10,11,14 & 15, Sec. 2, Tp. 9, Rg. 22, W/4 M
APPROVED	DRAWN S. Y. C.	SCALE 1:10000 — SHEET 1 OF 1
DATE	CHECKED	DATE OCTOBER, 1982 — DRAWING No. 25

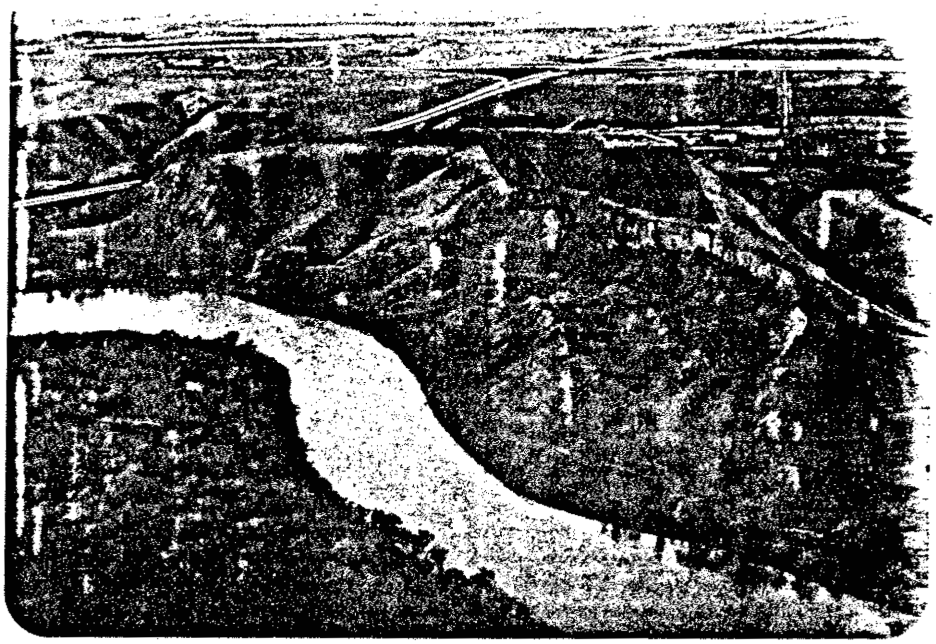


Photo 10: Aerial view of Slide No. 12 looking west.

SLIDE AREA: No. 13

LOCATION: LSD. 2 - Sec. 11 - Twp. 9 - Rge. 22 - W4M
LSD. 10, 11, 14 & 15 - Sec. 2 - Twp. 9 - Rge. 22 - W4M

DESCRIPTION:

This area involves a number of separate slides, which extend for a length of 1400 metres along the west bank of the Oldman River, beginning at a point south of Highway 3A West, to just north of Highway 3 West. The slide area consists of four major riverbank slides and two coulees exhibiting instability. A brief discussion of the four riverbank slides is presented, followed by a discussion of the instability along the two coulees.

The four major slides exhibit a similar morphology consisting of a steep backscarp with downdrop blocks in the lower slide zone. Similar to Slide No. 12, they were probably formed when the river was actively eroding the toe of the slope. A large terrace has formed along this reach of the west bank of the Oldman River which prevents further toe erosion.

The postulated mode of failure is combined rotational-translational with the lower failure surface seated at the bedrock - overburden interface. The top of the bedrock is estimated to be 10 metres above the present river level.

Along this reach of the Oldman River, the height of the valley walls from the upland plain to the river terrace level is approximately 80 metres. The most southerly of the slides (13-A), located south of Highway 3A is approximately 130 metres in length. Situated between Highways 3 and 3A are Slides 13-B and 13-C, which are approximately 300 and 170 metres long, respectively. Located north of Highway 3, Slide 13-D has been partially obscured by a major earthfill for Highway 3, which covers the southern

SLIDE AREA: No. 13 (Continued ...)

edge of the slide. These slides are all very old and presently inactive, with the exception of some minor slabbing which occurs along the steep upper backscarp.

The two coulees in this slide area are located between Highways 3 and 3A. One coulee separates Slides 13-B and 13-C and the other coulee is situated immediately south of Highway 3.

Both coulees exhibit similar surficial features. They both contain old, inactive landslides and are also presently experiencing active erosion along the base of the coulees. The erosion in the base of the coulees is caused by excess irrigation water spilling directly into the coulees. The surplus water has eroded the base of the coulees, forming steep banks at the toe of the slopes. Oversteeping at the toe of the slopes has initiated some minor slumping (see Photo 11).

Old inactive slides are located on the slopes of both coulees. It is suspected that these older slides were developed as the coulees were being formed and surface erosion was actively downcutting through the surficial sediments.

Photo 11: (Upper photo) Aerial view of Slide No. 13-B. Presently inactive.

(Lower photo) Small shallow failure caused by erosion and oversteepening of bank along base of coulee in Slide Area No. 13.

SLIDE AREA: No. 14, Nord Precast Concrete Slide

LOCATION: LSD. 7 - Sec. 2 - Twp. 9 - Rge. 22 - W4M

DESCRIPTION:

This slide occurs along the south coulee wall, which flanks Highway 3A on the west side of the Oldman River. Dumping along the crest of the valley wall at this site appears to have been common practice, even before 1950. In 1970 or shortly before, a small slide developed on the face of this slope. By 1975, the slide had increased in area to its present length of 70 metres. The slope angle before failure is estimated to be 33°.

This shallow rotational slide appears to have broken out near midslope and deposited a talus of material on the lower portion of the valley wall. Although difficult to state conclusively, the majority of the slide mass appears to consist of fill and may possibly not involve the native soils.

The headscarp does not appear to be retrogressing, however, the main body of the slide mass does indicate a slow downslope movement. The 1970 to the 1980 aerial photographs indicate an estimated horizontal component of movement in the order of 10 metres.

Alberta
ENVIRONMENT

SUBMITTED		DESIGNED			
DATE		CHECKED			
APPROVED		DRAWN	S. Y. C.		
DATE		CHECKED			

SLOPE STABILITY STUDY– LETHBRIDGE

SLIDE AREA No. 14

NORD PRECAST CONCRETE SLIDE
LSD 7, Sec. 2, Tp. 9, Rg. 22, W/4 M

SCALE	1 : 2500	SHEET 1	OF 1
DATE	OCTOBER, 1982	DRAWING No.	26

Photo 12: Aerial view of Slide Area No. 14. Fill placed at crest of slope has initiated shallow rotational slide.

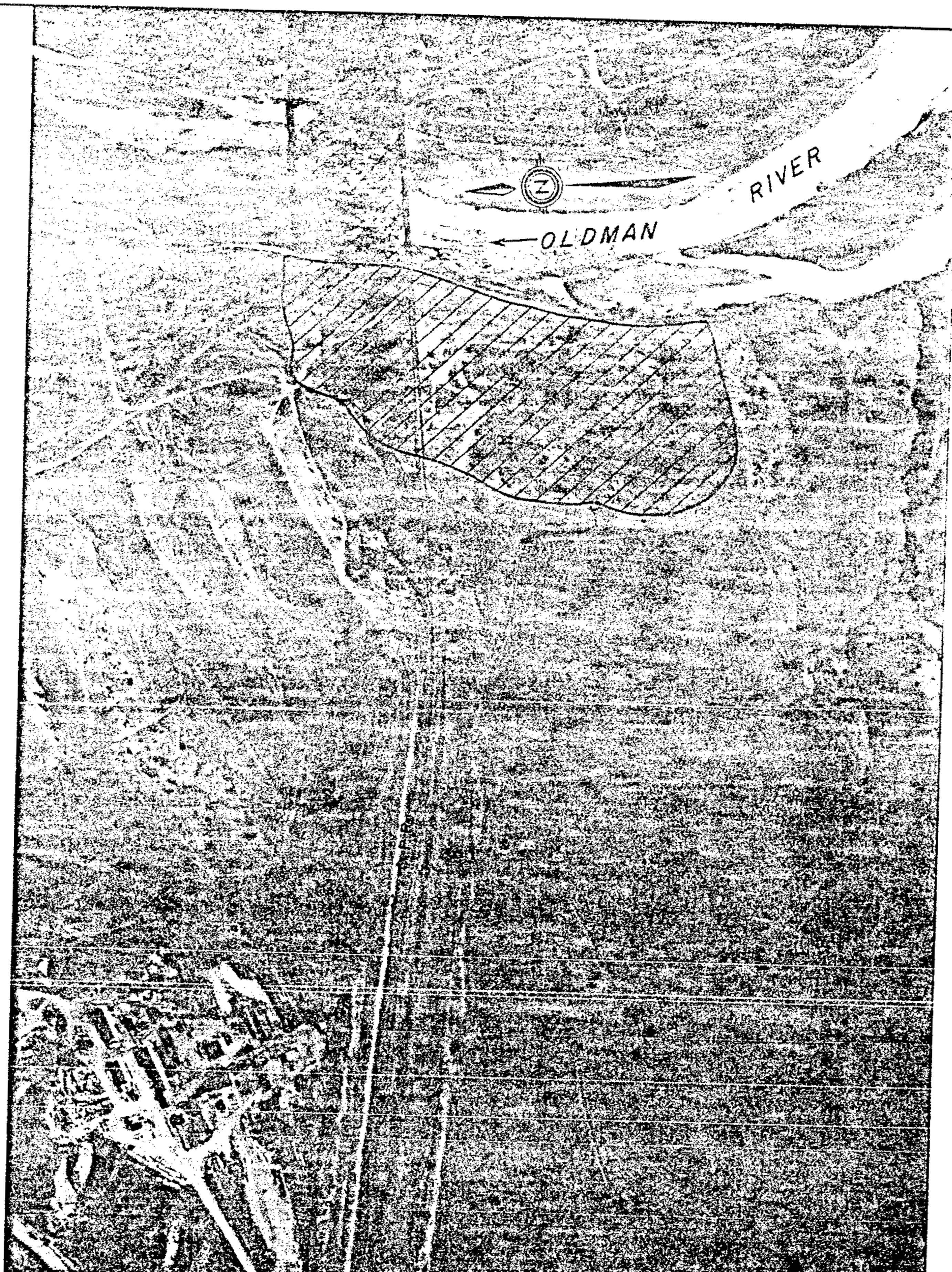
SLIDE AREA: No. 15

LOCATION: LSD. 16 - Sec. 35 - Twp. 8 - Rge. 22 - W4M

DESCRIPTION:

Located on the west bank of the Oldman River, the main Canadian Pacific Railway trestle crosses through the north end of this 400 metre long slide. Presently inactive, this old slide is a typical rotational-translational failure which probably failed when the river was actively degrading. The existing slide morphology consists of a steep upper backscarp with down drop blocks at the base of the slope.

The 70 year old railway trestle which traverses the slide demonstrates that the trestle has not upset the quasi-stable conditions of this landslide under the existing conditions.



Alberta
ENVIRONMENT

SUBMITTED .... DATE	DESIGNED .... CHECKED	SLOPE STABILITY STUDY - LETHBRIDGE
APPROVED .... DATE	DRAWN S. Y. C. CHECKED	SLIDE AREA No. 15 LSD 16, Sec. 35, Tp. 8, Rg. 22, W/4 M
		SCALE 1 : 5000 SHEET 1 OF 1

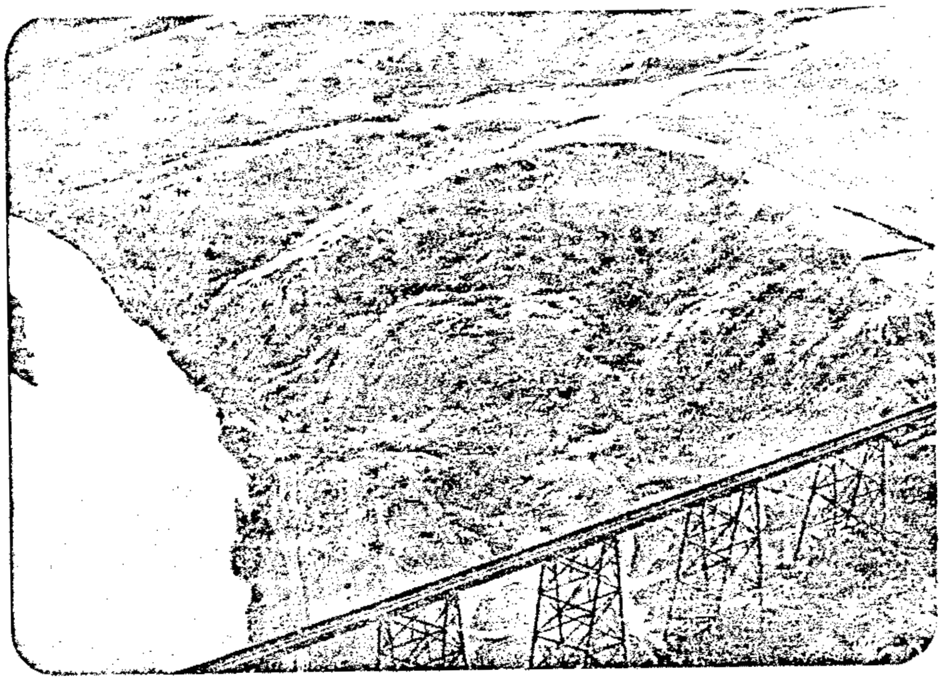


Photo 13: Aerial view of Slide No. 15, looking south. Slide is old and presently inactive. Note railway trestle crossing north end of slide.

SLIDE AREA: No. 16

LOCATION: LSD 1, 8 & 9 - Sec. 35 - Twp. 8 - Rge. 22 - W4M

DESCRIPTION:

Situated on the west bank of the Oldman River, this slide area involves a section of land which has been subjected to coal mining operations at a depth of approximately 100 metres below the crest of the west valley slope. The area comprises a slide in LSD 8, a slide in LSD 9 and an extensive series of tension cracks along the south bank of a major coulee in LSD 1.

A geotechnical study by R.M. Hardy and Associates Ltd. (1977a) evaluated this section of land with regard to a proposed residential development. Their investigation identified two major coal mine workings underlying this area. Subsidence due to the coal mining is responsible for a number of cracks, depressions and possibly the two slides. The tension crack on the south bank of the coulee (in LSD 1) forms a crescent shape extending for a length of over 90 metres, with vertical and horizontal displacements up to 0.6 metres.

The two slides occur at the ends of ridges or spurs where the floodplain and west valley wall intersect. It is postulated that the slides may have been triggered by subsidence over old mine workings and adits which underlie the ends of the spurs. Both slides are characterized by steep headscarps (up to 10 metres) and a hummocky lower slide morphology. No signs of recent movement are evident, although some activity periodically occurs from the steep headscarp by a toppling block type failure.

The general subsoil conditions identified by Hardy's investigation, are as follows: silty clay varying in thickness from 0.3 to 1.5 metres, a deposit of clay till 67 to 73 metres thick, underlain by Saskatchewan Sands and Gravels and bedrock.

Alberta ENVIRONMENT

SUBMITTED	DESIGNED	SLOPE STABILITY STUDY — LETHBRIDGE	
DATE	CHECKED	SLIDE AREA No. 16 LSD 1, 8 & 9, Sec. 35, Tp. 8, Rg. 22 W/4 M	
APPROVED	DRAWN S. Y. C.	SCALE 1:5000	SHEET 1 OF 1
DATE	CHECKED	DATE OCT. 1982	DRAWING No. 28

SLIDE AREA: No. 17

LOCATION: LSD 1 - Sec. 25 - Twp. 8 - Rge. 22 - W4M
LSD 15 & 16 - Sec. 24 - Twp. 8 - Rge. 22 - W4M

DESCRIPTION:

This area consists of two slides adjacent to the west bank of the Oldman River and two slides along a coulee. An interesting note regarding the landslides along the river is the fact that they occur along one of the few straight stretches of the river. As mentioned earlier in the text, slides adjacent to the river generally occur at a point immediately downstream of the maximum point of curvature in a meander bend of the river. The triggering mechanism for these two slides along the west bank of the Oldman River is not readily apparent. Although no detailed study of the coal mine workings in the area was undertaken, subsidence is suspected of being the most probable trigger mechanism.

The largest slide in this area (17-A) consists of down thrown blocks at the base of the slide and a series of blocks part way down the slope face, indicating a retrogressive series of failures. The suspected mode of failure is combined rotational-translational, with the translational movement occurring along the old mine tunnels and adits which were typically near river level.

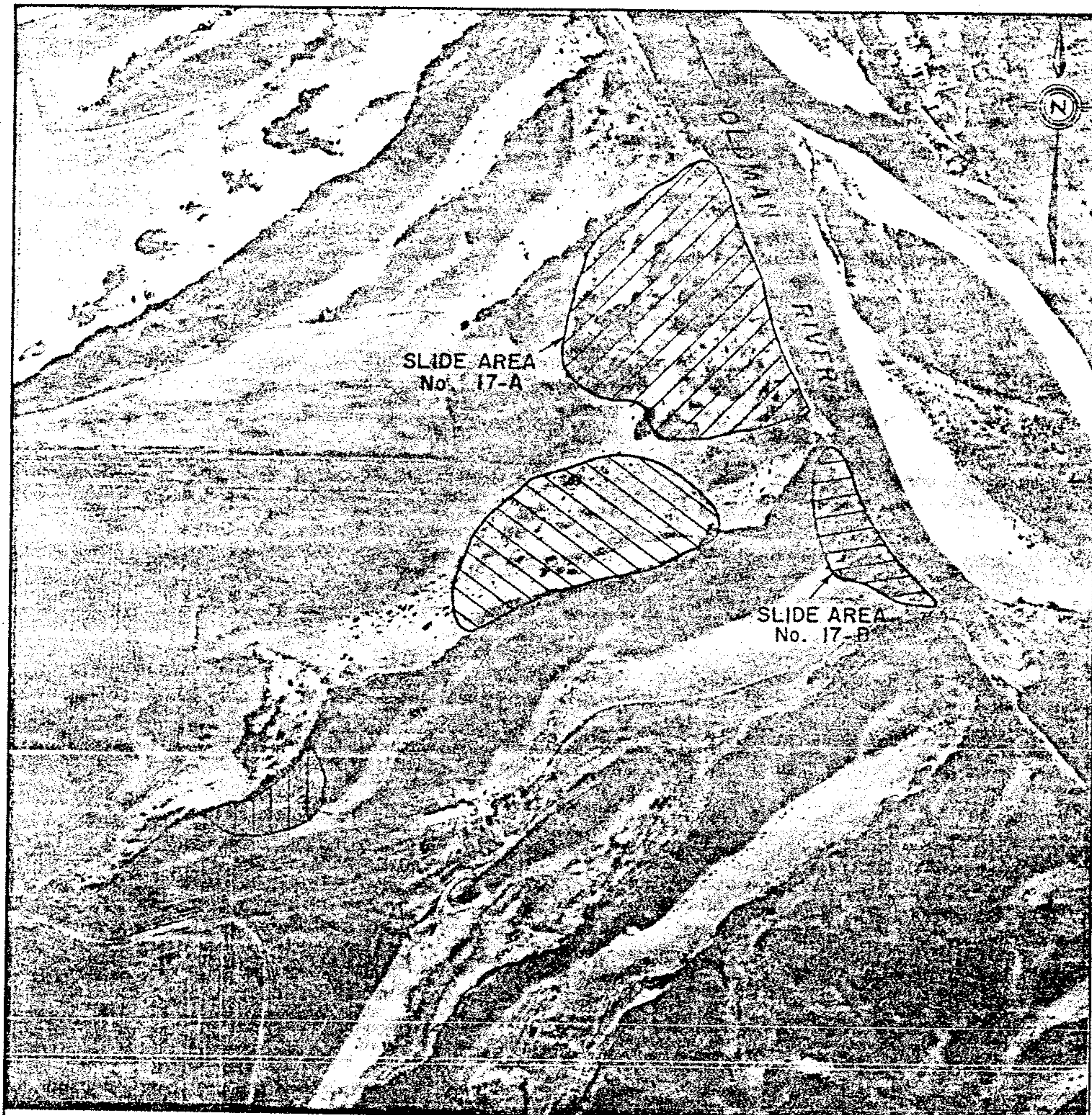
South of the larger slide is a similar, but smaller rotational-translational slide (17-B), which is also suspected of being initiated by subsidence over old mine tunnels and adits.

The remaining slides in this area are situated along a coulee which separates the two previously mentioned slides. On the north bank near the lower end of the coulee, are the remnants of an old rotational slide with mature, well rounded topographic features. It was probably initiated while the coulee was actively downcutting through the overburden tills.

SLIDE AREA: No. 17 (Continued ...)

The fourth slide in the area is located on the south bank near the upper end of the coulee. This smaller slide (approximately 60 metres in length) is also a shallow rotational failure confined to the overburden soils. A deeply eroded trench with near vertical walls forms the base of this V-shaped coulee. It is suspected that oversteepening at the base of the coulee is the probable triggering mechanism for this slide.

None of the coulee or riverbank slides are presently active.



PHOTOGRAPHED APRIL 16, 1980

Alberta ENVIRONMENT

SUBMITTED	DESIGNED	SLOPE STABILITY STUDY - LETHBRIDGE
DATE	CHECKED	SLIDE AREA No. 17 LSD 1, Sec. 25, Tp. 8, Rg. 22, W/4 M LSD 15 & 16, Sec. 24, Tp. 8, Rg. 22, W/4 M
APPROVED	DRAWN S. Y. C.	SCALE 1:5000 — SHEET 1 OF 1
DATE	CHECKED	DATE OCTOBER, 1982 — DRAWING No. 29

SLIDE AREA: No. 18

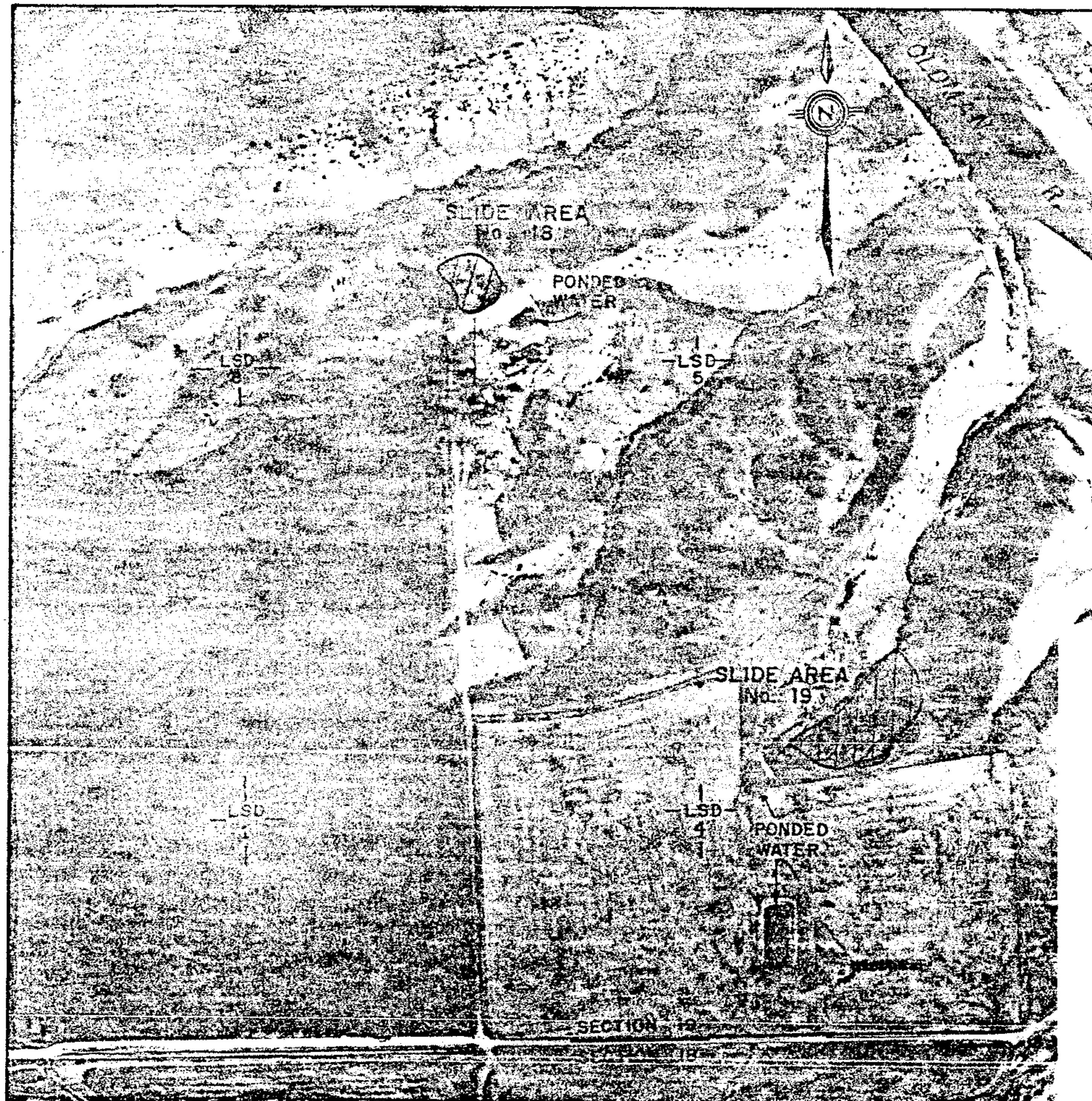
LOCATION: LSD. 5 - Sec. 19 - Twp. 8 - Rge. 21 - W4M

DESCRIPTION:

This rotational slide is located on the south bank of a coulee along the west bank of the Oldman River. Situated near the crest of the south coulee bank, this small slide (only about 30 metres in length) breaks out near the top of the slope spilling debris down the slope face. It is suspected that the failure is confined to the overlying lacustrine deposits and glacial tills.

A small irrigation canal exits onto the slope face immediately west of the slope failure. Excessive vegetative growth is evident at the point where the canal spills over onto the slope. In addition a water retaining dugout is located 20 metres back from the crest of the slope. It is suspected that water supplied for irrigation and leakage from the dugout have caused a local rise in the groundwater table, an increase in porewater pressure and an initiation of slope instability.

Aerial photographs indicate that the slide occurred between 1970 and 1975. Water appears to have been ponded in the dugout near the crest of the coulee since at least 1960. No additional slope movements are evident after the initial failure.



PHOTOGRAPHED APRIL 16, 1980

Alberta ENVIRONMENT

SUBMITTED	DESIGNED	SLOPE STABILITY STUDY – LETHBRIDGE	
DATE	CHECKED	SLIDE AREA No. 18 & 19 LSD 5, Sec. 19, Tp. 8, Rg. 21, W4/M LSD 4, Sec. 19, Tp. 8, Rg. 21, W4/M	
APPROVED	DRAWN S. Y. C.	SCALE 1:5000	SHEET 1 OF 1
DATE	CHECKED	DATE OCTOBER, 1982	DRAWING No. 30

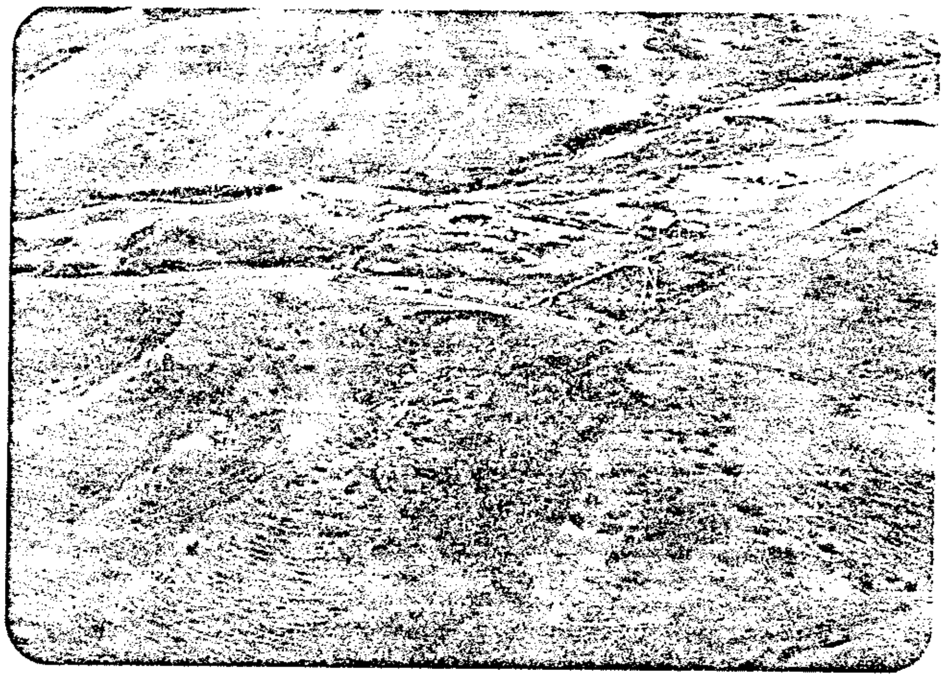


Photo 14: Aerial view of Slide No. 18. Note excessive vegetative growth alongside slump; also a dugout located just back of the crest.

SLIDE AREA: No. 19

LOCATION: LSD. 4 - Sec. 19 - Twp. 8 - Rge. 21 - W4M

DESCRIPTION:

Located on the south bank of a coulee on the west bank of the Oldman River, this slide appears to have been precipitated in a manner similar to Slide No. 18. The landowner constructed a small dyke at the top of the coulee, between 1970 and 1975 to retain surface runoff. In addition, there is a water-filled dugout approximately 100 metres south of the coulee. Land use along the crest of the coulee is irrigated farming. The base of the coulee appears to have been eroded, forming steep walls at the toe of the slope.

Small areas of lush vegetation on both sides of the coulee indicate groundwater seepage prior to construction of the dyke at the upper end of the coulee. The combined effect of irrigation, a water-filled dugout south of the coulee, plus the addition of another dugout at the top of the coulee resulted in a rise in the local groundwater table. The rise in the local groundwater table produced an increase in porewater pressure, a subsequent decrease in stability and the formation of a 130 metre long landslide between 1978 and 1980.

A smaller slide is evident at the toe of the main slide. It is suspected that failure of the major slide was preceded by movement of the smaller slide. This major rotational slide extends from the crest to the base of the coulee, a height of approximately 30 metres. The average slope angle before failure was approximately 29°. Due to the recent occurrence of the movement, this slide is classified as active.

Photo 15: Aerial view of Slide No. 19. Note water storage ponds near crest of coulee. Also small areas of lush vegetative growth, indicative of groundwater seepage.

SLIDE AREA: No. 20

LOCATION: LSD. 3 - Sec. 19 - Twp. 8 - Rge. 21 - W4M
LSD. 14 - Sec. 18 - Twp. 8 - Rge. - 21 - W4M

DESCRIPTION:

This area includes two old slides on the west bank of the Oldman River which were probably formed when the river was still actively downcutting and have long since been inactive. The first slide (in LSD. 3) is situated along the river valley wall. The second slide is located along the north bank of a coulee, immediately south of the first slide. The lower portion of the slope is relatively intact with only the overlying overburden apparently disturbed. A similar type of movement involving only the overburden is also suspected in the first slide. The thickness of overburden is estimated to be 30 metres.

The slope movements are very old with no obvious triggering mechanism. A possible explanation for the overburden movement may involve a bedrock surface which had eroded locally, leaving a dip towards the river and coulee. This local dipping surface would serve as a plane for a postulated combined rotational-translational failure.

PHOTOGRAPHED APRIL 16, 1980

Alberta ENVIRONMENT	SLOPE STABILITY STUDY – LETHBRIDGE
	SLIDE AREA No. 20
SUBMITTED .... DESIGNED	LSD 3, Sec. 19, Tp. 8, Rg. 21, W4/M
DATE .... CHECKED	LSD 14, Sec. 18, Tp. 8, Rg. 21, W4/M
APPROVED .... DRAWN S. Y. C.	SCALE 1:5000 / SHEET 1 OF 1
DATE .... CHECKED	DATE OCTOBER, 1982 / DRAWING No. 31

SLIDE AREA: No. 21

LOCATION: Sec. 18 - Twp. 8 - Rge. 21 - W4M;
Sec. 13 - Twp. 8 - Rge. 22 - W4M

DESCRIPTION:

This slide area has developed along an outside meander bend, over a 1900 metre stretch on the north bank of the Oldman River. The height of the valley walls are approximately 100 metres. The slide area is composed of a section of inactive slope which extends for a length of approximately 800 metres and another 1100 metres which is classified as presently active. The two areas of the slide mass are discussed separately.

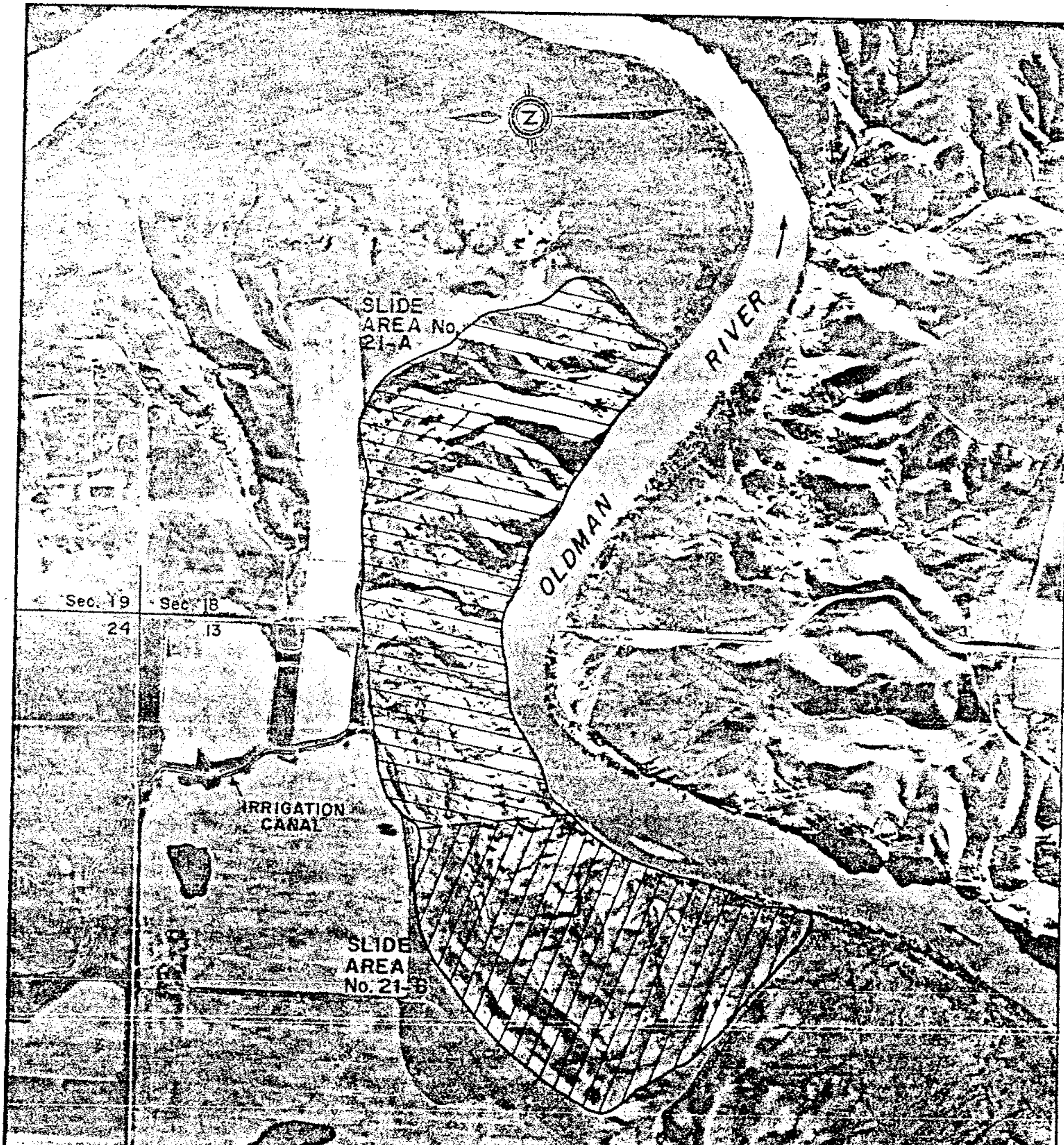
The active area (21-A) is presently experiencing several types of instability. The major source of the instability is excess irrigation water which has been dumped onto the slope and permitted to run uncontrolled down to the river level. The main irrigation canal which supplies water for the farmers on the west side of the Oldman River, terminates at the crest of the slope. Surplus irrigation water dumped onto the slope face has saturated the local Pleistocene sediments. The steep-walled gulleys formed by erosion have experienced a number of shallow rotational failures. This particular feature is most readily apparent along the east edge of the slide mass.

The continuous supply of water has formed a local perched groundwater table resulting in a series of retrogressive rotational slides, particularly in the central portion of the slide mass. In some places the soils have formed a flow type failure with the surface morphology expressing a viscous fluid type of movement. Several areas of ponded water are visible on the face of the slope.

SLIDE AREA: No. 21 (Continued ...)

The slope failures appear to be generally confined to the soils overlying the Upper Cretaceous bedrock. Near vertical exposures of the Oldman Formation along the eastern portion of the slide indicate the bedrock is relatively stable. In the central portion of the slide, debris has either fallen or flowed overtop of the bedrock forming a talus which varies up to 50 metres in width or more. Erosion at the base of the slope removes material which acts as a stabilizing toe berm. As the talus is slowly eroded, it no longer provides toe support for the material further upslope and results in further movement.

The western portion of the slide (21-B) exhibits a well rounded mature topography with no indication of recent activity. This section of the slide is estimated to have occurred while the river was downcutting. The slide morphology consists of a steep backscarp, backward rotated downdrop blocks on the upper and lower slide zone. The slide appears to be a combined multiple retrogressive rotational-translational type failure with the lower failure surface at the bedrock - overburden contact. The bedrock contact is estimated to be approximately 50 metres above river level. A substantial quantity of material is believed to be deposited at the toe of the slope forming a large talus at the base.



PHOTOGRAPHED MAY 18, 1975

Alberta ENVIRONMENT		SLOPE STABILITY STUDY - LETHBRIDGE	
SUBMITTED	DESIGNED	SLIDE AREA No. 21 Sec. 18, Tp. 8, Rg. 21, W/4 M Sec. 13, Tp. 8, Rg. 22, W/4 M	
DATE	CHECKED		
APPROVED	DRAWN S. Y. C.	SCALE 1: 12000	SHEET 1 OF 1
DATE	CHECKED	DATE OCTOBER, 1982	DRAWING No. 32