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THE UNIVERSITY OF ALBERTA

GLACIAL GEOMORPHOLOGY OF THE CATARACT BROOK VALLEY, YOHO NATIONAL PARK, BRITISH COLUMBIA.

by

JULIAN CHARLES FOX

A THESIS SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

DEPARTMENT OF GEOGRAPHY

EDMONTON, ALBERTA

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THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "Glacial Geomorphology of The Cataract Brook Valley, Yoho National Park, British Columbia." submitted by Julian Charles Fox in partial fulfilment of the requirements for the degree of Master of Science.

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Supervisor

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Date............................

ABSTRACT

The study was undertaken to map the surficial deposits and landforms in the Cataract Brook Valley, Yoho National Park, B.C., and to determine the glacial history of the valley. The study area lies just to the west of the Continental Divide, extending south from Kicking Horse Pass.

No stratigraphic sections were found that contain more than one till sheet, and the tills cannot be differentiated by grain [illegible] or lithologic characteristics. Therefore reliance was placed on geomorphic criteria and the areal relationships between tills and other glacial deposits and landforms. Field work was conducted to map the surficial deposits and landforms and to determine the relative ages of the tills. Laboratory work was conducted to describe and differentiate the tills.

Four glacial ice advances are recorded. The oldest advance, the earliest recorded in the study area, is indicated by high altitude remnants of lateral moraines and breaks in slope. This advance is tentatively correlated with Rutter's (1972) Eisenhower Junction advance, in the Bow Valley. A second advance, the Early Intermediate advance, is recorded by lower breaks in slope, two recessional moraines,

ground moraine and two kame terraces. This advance also extended out of the study area, via the Kicking Horse Pass, to the east. The next advance, the Late Intermediate advance, extended to the central portion of the Cataract Brook Valley. Evidence for this advance includes well preserved end moraine systems, deposited by four bodies of ice, erosional surfaces, fresh cirques and terminal moraines. The most recent advance was limited to the extreme upper portions of the cirques. The evidence for this recent advance includes six fresh, well-preserved terminal moraines and some lateral moraines.

The recent advance is dated from photographic evidence as achieving its maximum extent in the early part of this century. The Late Intermediate advance is probably of Neoglacial age (post-Altithermal -6500 - 4000 yrs B.P.) and the Early Intermediate and Oldest advances are probably pre-Altithermal in age.

Rock glaciers, block fields and pro-talus ramparts indicate two cold periods between the Late Intermediate and the most recent advance.

ACKNOWLEDGEMENTS

The writer wishes to thank Dr. J. Shaw, who supervised this thesis, especially for his careful reading of the drafts, and visits in the field. Thanks are also due to the National Parks, Western Regional Office, Calgary, for financial assistance, and the staff of Yoho National Park, who provided facilities and information in the field.

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CHAPTER 1

INTRODUCTION

Few studies have been completed in the small higher valleys of the Canadian Rocky Mountains. Most have been confined to the larger valleys such as the Bow and North Saskatchewan, where the preserved glacial deposits are more likely to represent a larger span of time.

The purpose of this study was to investigate the surficial deposits of the Cataract Brook valley, Yoho National Park, in order to describe the glacial deposits and landforms, and to arrive at an understanding of the glacial history of the valley. Not all the problems were solved. Nevertheless, a general scheme of the major events that occurred during recent time and the latter part of the Quaternary period is presented. Many of the erosional and depositional features of the surficial geology are explained.

Previous studies.

That the Rocky Mountains were formerly modified by glacial action was recognized in the latter part of the nineteenth century by G.M. Dawson of the Geological Survey of Canada and by the surveyor R.G. McConnell. Since this time there have been relatively few studies of glacial geomorphology and history in the Canadian Rockies. Horberg (1954) described the relationship between the Rocky Mountain and Continental Pleistocene deposits in Southern Alberta. McPherson (1963,1970) worked out a deglaciation sequence for the Upper Red Deer and the North Saskatchewan valleys. Rutter (1966) described the glacial landforms in the Bow Valley near Banff and proposed a chronology of events. A major work discussing the glacial chronology of the Rocky Mountains and the foothills of Southwestern Alberta is that of Wagner (1966). Dates of glacial events have been obtained from volcanic ash overlying ice contact glacial drift at Saskatchewan Crossing by Westgate and Dreimanis (1966) and by Stalker (1968) from a terrace sequence in the Bow Valley near Cockrane.

The work of Wagner (1966) presents the most detailed interpretation of the glacial history of the Canadian Rocky Mountains in Southwestern Alberta. Wagner working in the Castle, Crowsnest, Oldman and Belly rivers area established a glacial history on the basis of eight stratigraphic units and found evidence for two major ice advances from the mountains. lower mountain till is found in only a few sites, but in each case the till occurs below an upper mountain till. In one section a deep soil between the two tills provides evidence for differentiation between tills. Due to limited stratigraphic observations and absence of morphological expression of the till the extent of the ice which deposited the lower till is not known. The evidence for the second major advance which deposited the upper till is seen in stratigraphic and morphological evidence. The retreat of this ice left two sets of moraines - the outer moraines occurring in the foothills and the inner moraines, which occur behind the mountain front. The inner moraines are related to a stream terrace in their respective valleys, which grade into a lake at an elevation 1190 m (3900 ft.) (Lake Cardston). Horberg (1954) found that the lake levels in this area were relatively short lived, which leads to the conclusion that any geomorphic features closely related to a single lake level are likely to be of contemporaneous formation. So at least in south west Alberta it is possible to correlate morainic features between valleys.

Wagner showed that the lower till is older than the first continental ice event which Stalker (1963) has established to be earlier than 37,000 years B.P. The thick soil above the lower mountain till suggests a pre-Wisconsin date for this till and Wagner tentatively correlated this till with the Illinoian. The upper mountain till moraines have shallower depth of leaching, mostly unweathered surface stones, poor drainage integration, and bold form, all of which indicate a late Wisconsin age. Wagner considers the retreat of the second mountain advance to be confined to the early to middle Pinedale stades (20,000 to 12,000 yrs B.P.) of the Cordilleran chronology as outlined by Richmond (1965). However, Stalker (1969) has suggested that the terminal moraines which occur further downvalley than both the inner and foothill moraines of Wagner (1966) are of late Pinedale age (10,000-6000 yrs. B.P.) The age of the terminal moraines was obtained from radiocarbon dating of bison bones buried in outwash gravels. Wagner suggests that the bison could possibly have fallen from a cliff above the gravels and been incorporated into the gravels by the slumping of the cliff. However Stalker (1969) using radiocarbon dating has determined that the age of the beds overlying the gravels are younger than the the bone beds, therefore the bones could not have been incorporated into the gravels in the manner suggested by Wagner. Shaw (1972) states that the stratigraphic relationships between samples taken for radiometric dating and the terminal moraine in the Castle River valley identified by Stalker (1969) permits a much older deposition than Stalker suggests.

Rutter (1965) working in the mountain reaches of the Bow Valley in the Banff area has identified three ice advances- 1. Pre-Bow (Pre-Wisconsin) 2. Bow (Wisconsin) 3. Canmore (Wisconsin). The lowest and oldest Quaternary sediment recognised by Rutter is a stratified gravel occurring beneath the till of the Bow advance. Rutter identifies this with a glacial advance (Pre- Bow) although he presents no evidence of cold conditions (Shaw,1972). In a later publication (1972), Rutter considered a lower till to be of pre-Bow age because of its stratigraphic position, and high content of material derived directly from the local bedrock. It is dark grey, more than twenty feet thick, rests on bedrock, and underlies a sequence of two outwash units separated by buff coloured till. The dark colour of the till, caused by its high shale content, is different from any other observed in the mountain section of the Bow valley. It is possible that the lithological contrasts between the 'oldest' till and other tills are simply related to the low stratigraphic position and need not necessarily imply an older till. Stream diversion to the south of Banff townsite is considered to have taken place during the retreat phase of the pre-Bow advance. The later advances to be described are probably of Wisconsin age and, therefote, it is likely that the Bow Valley was glaciated several times prior to the Wisconsin.

The evidence for the Bow valley advance, which is more abundant, is based on stratigraphy and morphology. The basic record of this advance is a thick till, widespread on the floor of the Bow valley, which in the vicinity of Banff overlies the older outwash deposits mentioned above. Ice contact deposits indicate at least two intervals of equilibrium in the Bow valley during the retreat following the Bow advance.

Till patches overlying outwash are the principal evidence for the Canmore advance. Continuous ground moraine with erosional ridges found to the south east of the confluence of the Bow and Cascade Rivers, is also attributed to this advance. As Rutter (1972) points out this till could not be distinguished lithologicallly from the Bow Valley till. Breaks in slope on the south west side of the Bow ...lley are considered by Rutter to support the inference that the Canmore advance is in fact a Bow valley re-advance. The breaks in slope are more prominent than breaks associated with older advances and they occur at elevations compatible with the till patches over outwash. Rutter presents no evidence that suggests the till patches over outwash and the ... ...ade ground moraine is younger than the tills of the ... ... Also in light of glacier thinning during ... ...lins, 1957) and the evidence of the ice marginal chan... ...levels low than the maximum altitude, the Canmore ... as w... be related to stillstand during ... sin... ... to ...dvance.

A relatively complet... deg... ...ion occurred following the Canmore advance, as evide... ...t t... succeeding advance is found near the source of the ice.

Rutter (1972) presents evidence for a further ice advance (Eisenhower Junction advance) in the Banff area. The evidence includes well preserved ground and lateral moraines, breaks in slope, terminal moraines and fresh cirques. The Eisenhower Junction advance represents the last major advance, but Rutter gives evidence for a further minor readvance. The evidence being the occurrence of till over glacio-fluvial deposits of the Eisenhower Junction advance. But till over stratified deposits does not in itself imply a readvance (Boulton, 1968). Also it is difficult to imagine a thin glacier advancing further downstream than an earlier thicker one(Shaw, 1972).

McPherson (1970) working in the Upper Saskatchewan Valley identifies two major ice advances. Drilling for the Big Horn Dam revealed 36-39m (120-130 ft.) of gravel resting on a till which overlies bedrock. The till is associated with the Big Horn advance. The present day landscape is the result of the second major advance. Two major readvances or stillstands in the recession of the second advance are inferred from end moraines at Saskatchewan Crossing and at the junction of the North Saskatchewan and Alexandra rivers. A carbon 14 date was obtained on a charcoal layer occurring near the base of a deposit of loess, overlying ice-contact glacio-fluvial sands and gravels. The date of the charcoal layer, found a few hundred feet upstream from Saskatchewan Bridge, indicates that this section of the valley was ice free 9330 ± 170 C^{14} years B.P. (Westgate and Dreimanis, 1967).

Roed (1968) working in the Athabasca Valley in the Hinton and Edson area at the junction of the Laurentide and Cordilleran ice found that the oldest surficial deposit is a basal gravel orginating from the Rocky Mountains. Till is the most widespread deposit and Roed identified four Cordilleran tills. Cordilleran erratics at high altitude and several miles to the east of the above tills suggests a previous advance from the mountains. The oldest Cordilleran till (Marlboro) has an abrupt lateral contact with the Edson till of Laurentide origin. The orientation of drumlins in the area indicates the deflection of flow lines which occurred as a result of the two ice masses being contiguous. The Marlboro till is associated with end moraines, drumlins and flutings. The retreat of the Marlboro ice was accompanied by the development of glacier dammed lakes into which lacustrine sediments (Pedley) were deposited.

A further till (Obed) can only be distinguished from the Marlboro till where they are separated by the Pedley sediments. Associated with this till are drumlins and end moraines which truncate drumlins and end moraines of the

Marlboro advance. Two pauses in the recession of the ice which deposited the Obed till are associated with kame complexes and the development of two stream terrace levels.

Harris and Boydell (1972) discuss tills found in the valleys of the Clearwater and Ram rivers. Only a single till occurs in the Clearwater valley. The Ram river has two branches- the North and South Ram rivers. Glacial deposits are absent in the North Ram valley whereas in the South Ram river valley, deposits of three glacial advances occur. The oldest till (Hummingbird till) is cemented and a gorge cut into it. Below the gorge uncemented deltaic sands and gravels, correlated with about 20m (65 ft.) of tilted varves further downstream, represent the second glacial episode. These are separated by a depositional hiatus from the tills and gravels of the youngest advance. The latter appears to be the same age as the Spry Hill event in the Bow, Red Deer and Clearwater valleys. The Spry Hill event (Harris and Boydell, 1972) is thought to be part of the main Bow valley advance described by Rutter (1966, 1972). A further till exists on the 1200m (4000ft) plateau surface to the east of the Brazeau Range between the Clearwater and Ram river. It is deeply dissected and highly weathered. Since it is absent from the valleys cut into the surface of the plateau, it may be pre-Wisconsin in age.

In Southwestern Alberta Alley (1973) found evidence for three major and one minor Cordilleran advances. The first two advances are considered to be Pre-Wisconsin, the third Early Wisconsin, and the final minor advance to be Classical Wisconsin in age. The chronology of the above advances was determined by Alley (1973) and Alley and Harris (1973) on the basis of the following observations:

1. Stratigraphic relationships between the Cordilleran tills and Laurentide tills of known age.

2. Dates ranging between 25,000 and 54,000 C-14 years B.P. obtained from organic matter found in sands occurring between till of the third Cordilleran advance and an associated Laurentide till.

3. A C-14 date from a bone recovered in Crowsnest Pass from beneath gravelly outwash material, deposited during the minor Cordilleran advance. The bone was dated at 22,700 ± 1000 yrs B.P.

Alley concluded that the advances of the Cordilleran and Laurentide ice masses had non-synchronous maxima, whereas Wagner (1966) considered that the maxima were synchronous. However, these conclusions are based on interpretation of similar evidence. Both Wagner and Alley illustrate intercalated Laurentide and Cordilleran tills.

Wagner chooses to interpret the intercalations as representing fluctuating positions of the contact between contiguous ice masses. Alley considers that the sequence relates to out of phase advances between the two ice masses. The fact that lacustrine sediments commonly occur between the two tills indicates that the ice masses were not contiguous at all times during the accumulation of the interdigitating sequences. However, Alley's interpretation need not be the correct one as intercalated deposits could occur as a result of the emplacement of flow tills (Boulton, 1968), without the need to invoke fluctuating ice margins.

Many more studies have been conducted in the United States section of the Rocky Mountains than in the Canadian Rockies. Only the major studies will be discussed here. Earlier workers in Glacier National Park (Alden, 1912, 1932) and in the Wind River Mountains (Blackwelder, 1915) found evidence for three glaciations. The youngest being associated with the Wisconsin, the intermediate with th Illinoian and the oldest with the Kansan. Blackwelder (1931) in the Sierra Nevada and Basin Ranges, California found evidence for four and possibly five glaciations. The youngest of these (Tioga and Tahoe) he considered to be closely related in age and suggested that they may be but a subdivision of a single stage of the Wisconsin. However, Sharp and Birman (1963) found evidence for a glaciation intermediate between the Tioga and Tahoe substages at Mano Lake and correlated the intermediate glaciation with the Illinoian.

Blackwelder (1915) defined three glaciations in the Wind River Mountain area, which is now the type area for the Rocky Mountain succession. The three glaciations are 1. Buffalo-oldest 2. Bull Lake-intermediate 3. Pinedale-youngest. Blackwelder indicated that each of the tills may represent more than one glaciation. Richmond (1948) attributed two terrace levels in the north west Wind River Range to the Buffalo glaciation. Holmes and Moss (1955) working in the south west Wind River Mountains also suggested that the Buffalo glaciation can be divided into two sub-stages. Blackwelder showed the Bull Lake glaciation to be younger than the Buffalo glaciation on the basis of the degree of erosion, depth of weathering, the postion of the moraines in the valley and their relationships to outwash deposits. The younger Pinedale moraines are described as being rough, having slightly weathered boulders and mostly are undissected.

Deposits similar to those of the Bull Lake and Pinedale stades have been widely recognised throughout the United States Rocky Mountains. Richmond (1960) found deposits of two late Pleistocene glacial advances on the east slopes of

Glacier National Park, Montana. The older deposit being correlated with the Bull Lake stade in Wyoming, and the younger with the Pinedale.

In Rocky Mountain National Park, Ray (1940) recognized five Wisconsin glacial advances (I-V). Also in the same park Jones and Quam (1944) differentiated three main glacial stages. The older two (Old moraine remnants and Park border moraine) are correlated with the Wisconsin I and II, of Ray (1940) and the youngest advance with a distinctly younger stage. Ray believed that the younger moraine (Upper valley moraines) of Jones and Quam represented three separate glacial stages, namely his Wisconsin III, IV and V. Richmond (1960) reinterpreted the moraines of this area and correlated them with the Wind River sequence (table I).

Table I shows discrepancies in the correlations of moraines in the Rocky Mountains of Colorado. Flint (1957) and Antevs (1945) also interpreted the moraines of Rocky Mountain National Park as mapped by Ray, and again there are discrepancies in the interpretation of age.

A point that should be mentioned is that the mature zonal soil which separates the pre-Bull Lake and Bull Lake tills is believed by Richmond (1957) to represent a long period of interglaciation, but Ruhe (1965) states that the depth of weathering in tills and the development of soil is not necessarily a direct function of time.

Recent studies in the United States have improved the evidence for the Neoglacial chronology of the Rocky Mountains. Mahoney (1973) using lichenometrical, pedological and geological evidence established a Neolglacial chronology of three stades, for the Fourth of July Cirque, Central Colorado Front Range. The earliest stade (Temple Lake) was dated between 4500-2700 years B.P. The intermediate stade (Audubon) has a minimum age of 950 years B.P., and the youngest stade (Gannet Peak) was dated between 300-100 years B.P. The glacial and periglacial deposits of the cirque were assigned ages based on a growth-rate curve for the lichen Rhizocarpa geographium. The assigned ages are supported by pedological and geological studies, which provide data on soil profile development, weathered rhind thickness, weathered pit sizes on boulders, state of moraine crest, and soil polygon development.

Miller (1973) working in the Northern Sawatch Range, Colorado, has established a chronology of rock glacier development during the Neoglaciation. Miller used lichenometry to subdivided and date Neoglacial deposits. He recognises an early period of rock glacier development (Temple Lake I) which began more than 4000 years B.P. Formation of Temple Lake II deposits began between 3750 and

3500 years B.P., and they continued to accumulate until about 2500 years B.P. More recent (Audubon) rock glaciers began forming about 1900 years B.P. and continued to develop until 1000 to 900 years ago. The relative sizes of Temple Lake and Audubon rock glaciers indicate that the processes and conditions favouring rock glacier formation during the Temple Lake stade were more intense and/or lasted longer than during the Audubon stade. The Gannet Peak stade of Neoglaciation is represented in the cirque by talus alone.

Miller's study supports the conclusions of Richmond (1965) that Neoglaciation in the Rocky Mountains was characterized by three main intervals of glacier advance and rock glacier development.

a previous paper Miller (1969) using dendrochronological, lichenometrical and geological evidence established a chronology of glacier fluctuation during the Neoglacial in the Dome Peak area, North Cascade Range, Washington. The earliest recognized Neoglacial advance was that of the South Cascade glacier about 4900 years B.P. Other glaciers reached their maxima in the sixteenth century. In the Dome Peak area Miller found no evidence for the intermediate period of glacier expansion, which has been documented for other areas in the Rocky Mountains.

Curry (1974) working on the type Temple Lake moraine, Wyoming, has dated this moraine at 6500 ± 230 C-14 years B.P., and hence the moraine is of Pre-Neoglacial age. Curry also mapped and described two Neoglacial Moraines (Later and Earlier). Miller and Birkeland (1974), agree with Curry's division of the Neoglacial moraines and regard the Earlier moraine as being deposited by the first Post-Altithermal advance. Curry assigned the Late Neoglacial moraine to the Gannet Peak Stade. However, Miller and Birkeland found that this moraine partially overlies a small remnant of older till. On the basis of lichen and rock weathering characteristics they correlated the small remnant with Audubon deposits found in the Colorado Front Range (Mahoney, 1973) and in the Sawatch Range (Miller, 1973).

Absolute dates for early Pleistocene tills in the Cordillean region are scarce. A tuff deposit associated with Sherwin till has been dated at 710,000 years BP (Dalrymple and Cox, 1965). Using this Sharp (1968) placed the age of Sherwin till at approximately 750.000 years B.P.

Volcanic ash layers or tephra layers serve as stratigraphic marker horizons, particularly so, if they are widespread and mineralogically distinctive (Wilcox, 1965, and Westgate and Dreimanis, 1967). Tephra layers can be dated from associated carbonaceous material or by obtaining the potassium - argon age for certain primary constituents of the ash (Wilcox, 1965).

A number of tephra layers have been identified in the United States Cordilleran region. Of interest here are those found in the Canadian Rocky Mountains. On the basis of stratigraphic position, texture, chemical composition, minerology and C-14 age of associated charcoal three ash layers have been differentiated in Banff National Park (Westgate and Dreimanis, 1967). They are, in order of decreasing age, Mazama, St. Helens Y and Bridge River ashes. Mazama ash originates from Mt. Mazama at Crater Lake, Oregon. Several radiocarbon dates place the age of the ash at about 6600 C-14 years B.P. (Westgate, Smith and Tomlinson, 1970). Mazama ash was distributed over Washington, Idaho, Western Montana, Southern British Columbia and Alberta and Southwest Saskatchewan.

The second ash, St. Helens Y, originated from Mt. St. Helens in Washington. The fall-out area appears to be related to a narrow, northeasterly orientated plume, almost 1000 Km (600 miles) in length. The most distant recognized site of deposition is Entwistle, Alberta. Radiocarbon dates indicate the age of the ash as being between 3000-3500 C-14 years B.P.

Bridge River ash had a source near the Lillooet River area of British Columbia (Nasmith, Mathews and Rouse, 1967).

It occurs just below the surface over a narrow belt extending through British Columbia into adjacent Alberta. Its most eastern locale appears to be at Saskatchewan Crossing (Westgate and Dreimanis, 1967). The age of the ash has been détermined from a C-14 date on an associated peat, at 2440 ± 160 years B.P.

		Bull Lake glaciation.		Pinedale glaciation			Neoglaciation.	
Richmond (1964)	Wind River Mountains, Wy.	Early stade	Late stade	Early stade	Middle stade	Late stade	Temple Lake stade	Gannet Peak stade
Ray (1940)	Rocky Mtn. Nat. Park	I	II	II		III & IV	V	
Jones and Quam (1944)	Rocky Mtn. Nat. Park	Old Moraine Remnant		Park Border Mor.	Upper valley moraines.			
Richmond (1964)	Rocky Mtn.	Bull Lake		Pinedale			Neoglaciation	
Richmond (1965)	Rocky Mtn.	Early	Late	Early	Middle	Late	Temple lake	Gannet.

Table 1. Correlation of chronologies based on studies in the United States.

CHAPTER II.

STUDY AREA LOCATION AND DESCRIPTION.

Location.

The study area lies within the western watershed of the Canadian Rocky Mountains and is located on the extreme eastern boundary of Yoho National Park, B.C. (fig. 1). The main part of the study area lies within the Cataract Brook valley, which extends south from Wapta Lake in Kicking Horse Pass for approximately nine miles to Opabin Pass. The valley has a maximum width of some five miles. Other smaller basins included in the study area are 1. Lake McArthur basin which drains south west into McArthur Creek and eventually into the Ottertail Valley. 2. A small glaciated basin wedged between the Cataract Brook basin and the Great Divide. The mouth of this basin emerges into Kicking Horse Pass. This basin drains into Ross Lake and into Sink Lake which then drains to the west-see fig. 2.

The drainage of the Cataract Brook Valley is from north to south and emerges into Wapta Lake, which is drained by the Kicking Horse River to the west.

Description.

The mountains surrounding the Cataract Brook valley provide a great variety of such alpine landforms as cols,

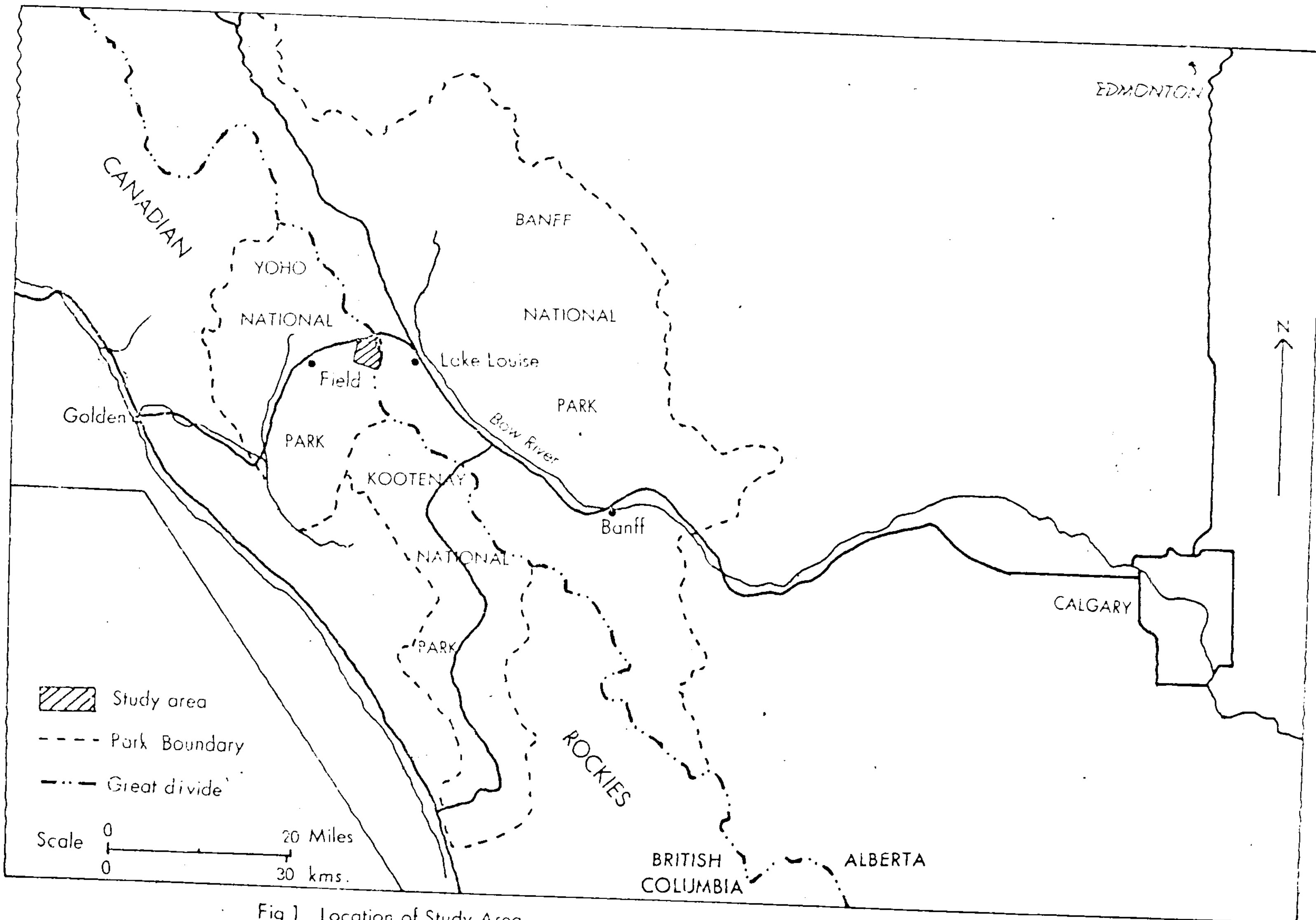


Fig 1 Location of Study Area.

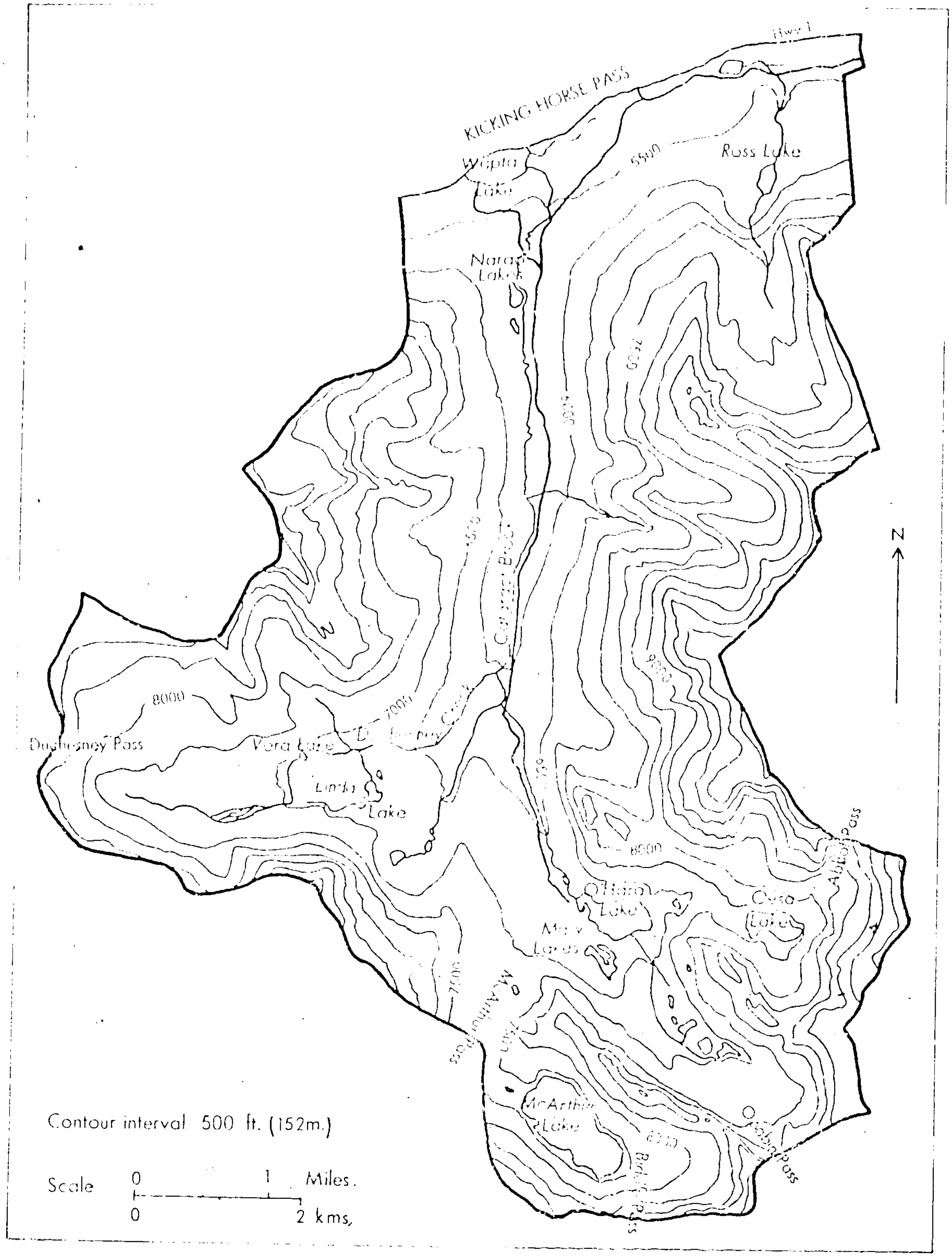


Fig 2 Contour Map of Study Area.

aretes, horns, cirques, hanging valleys, U-shaped valleys and glacially polished surfaces. The surrounding mountains such as Mt. Biddle, Hungabee Mountain, Mt. Lefroy, Odary Mountain and Cathedral Mountain generally have summits between 3050-3660m (10,000- 12,000 ft). The local relief varies between 1220-1830m (4000-6000 ft) with respect to the valley floor. Intense post-glacial sub-aerial erosion is rapidly modifying the existing landforms.

Approximately forty percent of the study area is tree covered and the tree line approximates to the 2135m (7000 foot) contour line.

Geology.

The study area lies within the Main Ranges Geologic Area. Lower Cambrian quartzitic rocks of the Gog Group are areally the most important. They are massive and are much more resistant to erosion than the overlying limestone, dolomite and shales of Middle Cambrian Age. Sixty percent of the study area is comprised of the quartzitic rock with limestone and dolomite accounting for approximately thirty seven percent. The shaly limestone of the Pika formation only occurs in the northeast of the study area and forms Narao Peaks (fig. 3, table 2).

Many faults cut the area, principally running in a

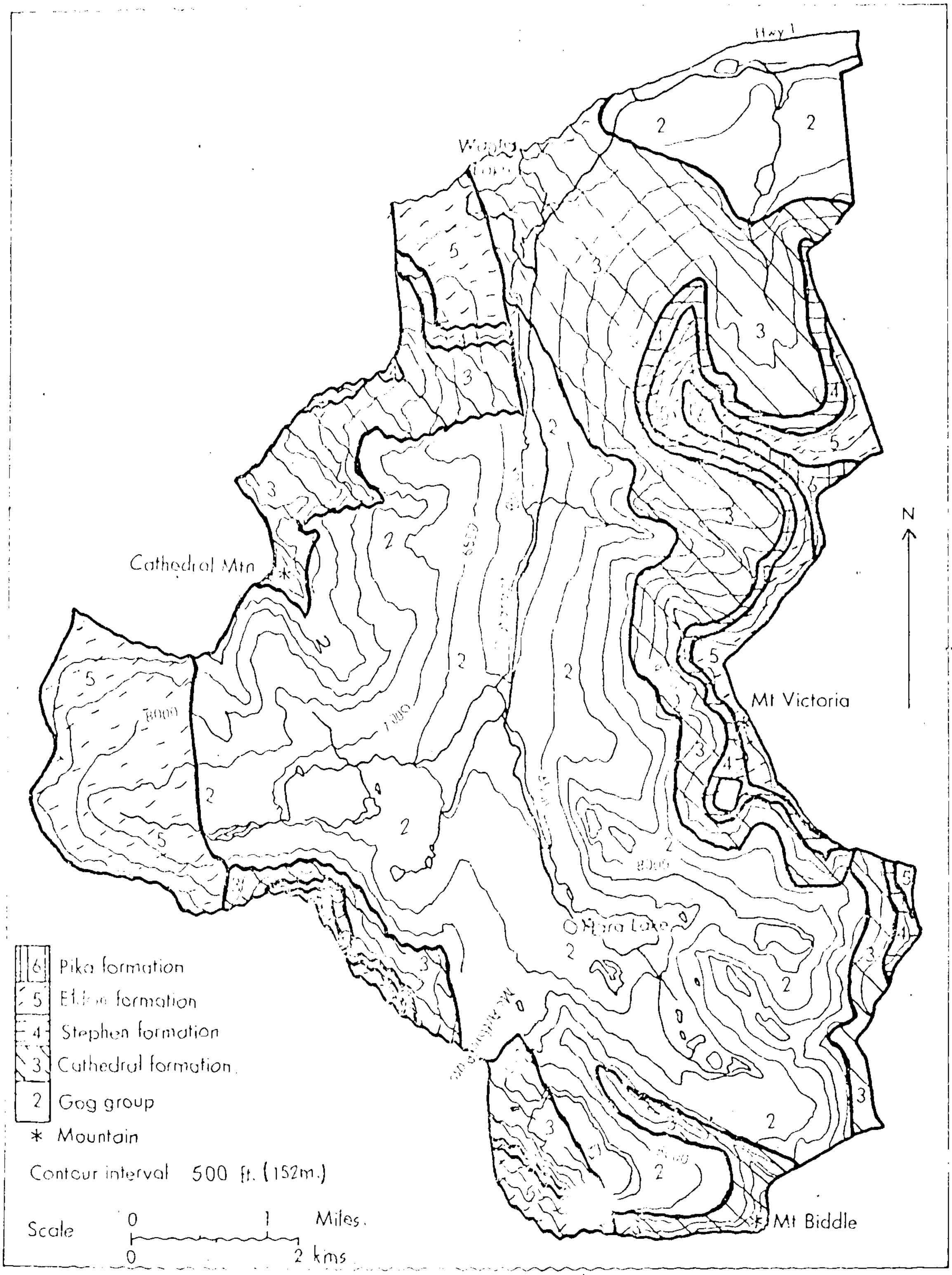


Fig. 3 Bedrock geology of the study area.

northwest/southeast direction.

Table 2. Rock formations found within the study area.

Pika formation (Shalely limestone)	
Eldon Formation (Limestone and dolomite)	Middle Cambrian
Stephen Formation (Mainly shale)	
Cathedral Formation (Dolomite and limestone)	
Gog Group (Quartzitic sandstone and shale)	Lower Cambrian

Occurrence of glaciers.

Glaciers in the study area are limited to the extreme upper portions of the cirques and are not as extensive as shown on the topographic map (Lake Louise, 82N/8 West, 1:50,000).

Generally speaking the glaciers in the south east portion of the study area extend down to the 2440metre (8000 foot) contour line. In Opabin Plateau glacial ice extends to the top of Opabin Pass. Glacial ice in Lake Oesa basin is present below Yukness Mountain, but confined principally to a steep narrow gully. Glacial ice is not present in Abbot Pass, nor in the small cirque to the north of L ke Oesa below Mt. Huber.

From Mt. Huber northwards along the eastern edge of the study area to Kicking Horse Pass and on the western side of the area glacial ice extends only to the 2592metre (8500 foot) contour line, whilst in Duchesney Basin ice is present only in the extreme north west of the basin. No ice is present in Cathedral Basin (fig. 6).

Place names.

Some place names used in the text occur on the topographic map of the area (Lake Louise, 82N/8 West, 1:50,000), others do not. For the sake of clarity other names have been added to the map (fig. 4). It should be noted that names on the map (fig. 4) other than those taken from the topographic map should not be taken as 'official' names.

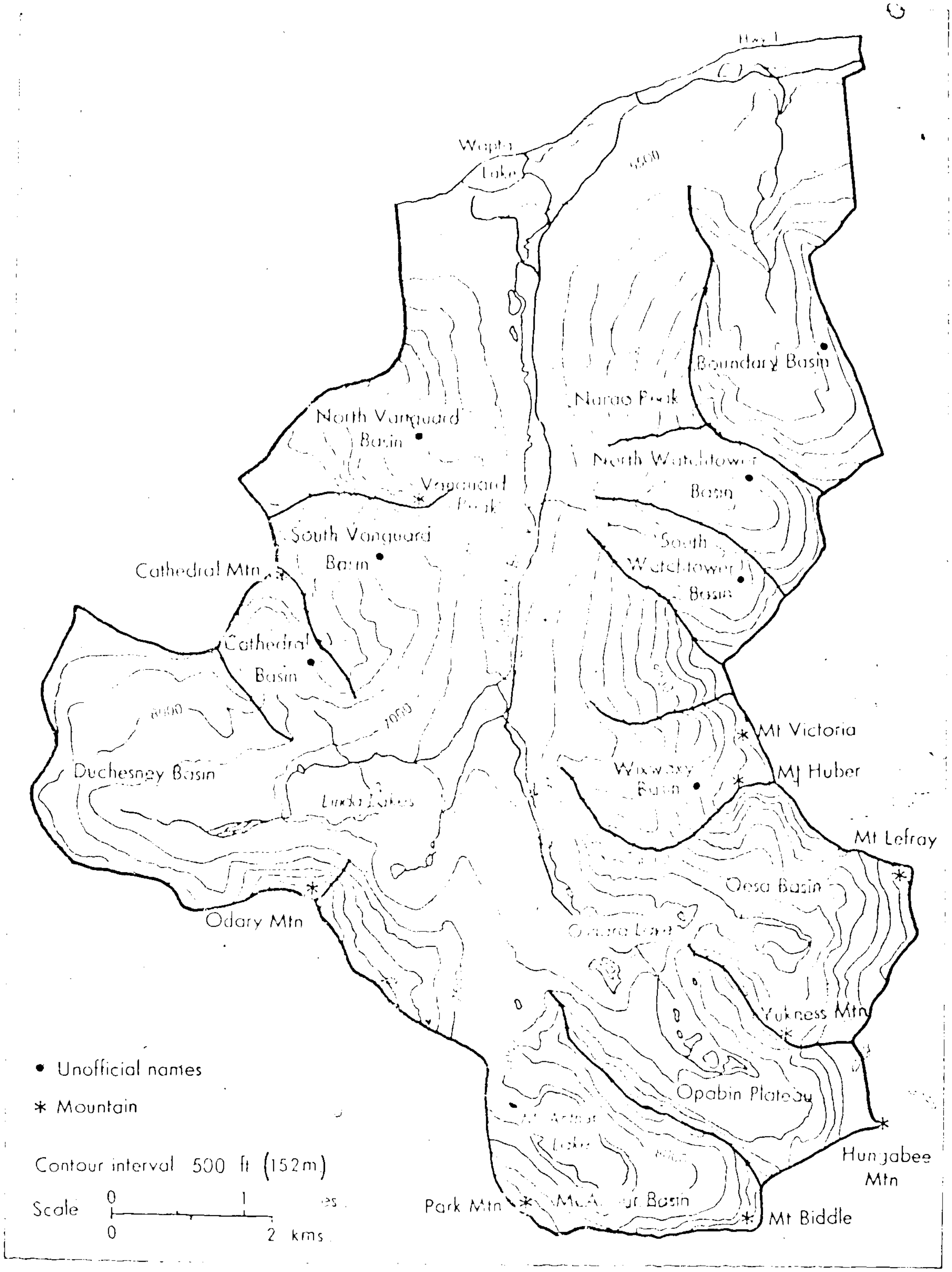


Fig. 4 Map of place names used in text

CHAPTER III

METHODOLOGY

A variety of techniques were employed to investigate the sequence of glacial events. These techniques included textural analysis, lithological composition, pebble roundness, carbonate content, relative age dating and field mapping of the surficial deposits and landforms. The techniques were used to 1. Describe the surficial deposits and landforms 2. Determine the sequence of glacial events.

The following is divided into field and laboratory techniques.

Field techniques.

1. Mapping.

The preliminary maps of surficial deposits and landforms were obtained from aerial photograph interpretation (scale 1:3333). The information gained from the photographs was limited; first by the scale of the photographs and their poor resolution, and secondly by the thick growth of trees that covered at least forty percent of the Cataract Brook Valley.

The preliminary maps were checked by means of a field mapping program. The field mapping allows for greater detail and confidence in the final map information. Much of the field examination was carried out from vantage points.

2. Sampling.

Each map unit was checked to verify that the landform unit was consistent with the surficial material. Representative samples were taken (fig. 5) and also descriptions made of the soil profile. Wherever possible more than one sample per unit was taken. In order to minimise the effects of weathering each sample was obtained at least two feet below the surface.

Determination of sample sizes was based on imformation from Krumbein and Pettijohn (1938), and depends on the size range of the material. Size of sample ranged from 2000-10,000 gm. Each sample was field sieved using sieves of size, 63 mm, 30 mm and 15 mm. The weight retained on each field sieve was obtained by a spring balance, the precision of which was checked before and after the field season. The material on the field sieves was then discarded and a portion of the fines was retained for laboratory analysis.

Exposures of surficial deposits were limited to road cuts along the O'Hara fire road and the old Banff road, and to a limited number of stream banks. None of the exposures contained more than one stratigraphic unit. As a result the glacial history was established on the basis of the

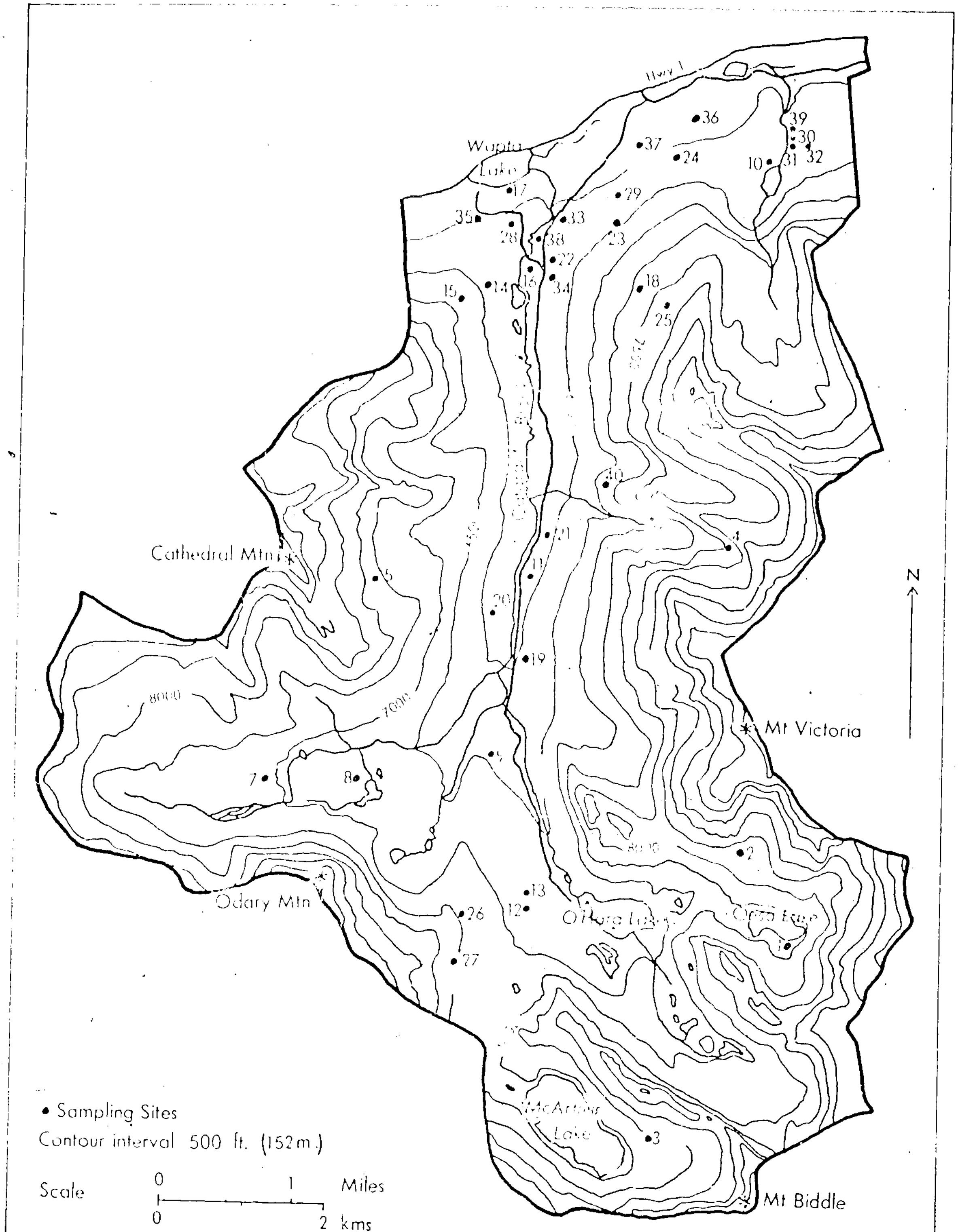


Fig. 5 Map of Sampling Sites.

relationship between glacial deposits and geomorphology. Sampling sites are shown in fig 5.

3. Relative age dating

Many field methods are available to determine the relative age of till deposits in order to trace the sequence of glacial events. Blackwelder (1931) developed many criteria for relative age determination and these were expanded by Sharp (1960) working in the same area. Birman (1964) applied Blackwelder's techniques with considerable success to the Trinity Alps in northern California. Sharp (1969) developed and tested semi-quantitative methods of temporal differentiation of tills. He termed the methods 'semi-quantative' as they involved subjectivity to some degree. Working near Convict Lake, Sierra Nevada, California, Sharp applied his semi-quantitative methods to a large lateral moraine that has been attributed by earlier workers to the early Pleistocene Sherwin glaciation, and to a massive moraine complex that has been regarded as a composite Late Pleistocene, Tahoe-Tioga feature. His data indicated that the moraine complex is a product of a single glaciation, the Tioga, and the large lateral moraine is primarily a Tahoe feature. The semiquantitative methods were not effective in defining the temporal position of a possibly older till.

Many of the relative age criteria depend upon the changes that have taken place since glacial action ceased. The following relative age criteria were used in this study.

A Topographic Position.

Sharp (1960) working in the Trinity Alps of northern California, and Nelson (1954) in the Frying Pan River drainage, Colorado, used topographic position of moraines to segregate deposits of differing age. Topographic position usually affords the primary basis for initial segregation of glacial deposits in a single valley. The older deposits are generally higher on valley walls or further downstream, as each successively younger ice advance destroys the features of earlier glaciations. The destruction of older moraines by more recent ice advance is not always the case. McPherson and Gardner (1969) observed a moraine in the Canadian Rocky Mountains recently exposed by ice. The moraine was known to have existed before the ice advance.

Recent moraines are found close to the heads of the valley and cirques. Successively older moraines are found progressively further down-valley. Where younger and older moraines are preserved in the same stretch of valley, the older moraines occur at higher altitudes.

B Topographic expression of moraines

With time, the relief of a moraine is reduced by running water and mass wasting processes. Older moraines are likely to have a more subdued topographic expression and lower mean slope angle than younger moraines.

Slope angles of various recessional and terminal moraines were taken on their distal slopes from base to crest. These slopes face a variety of directions and therefore possible variation in slope due to aspect is inherent in the data. Slope angles were taken to the nearest degree with an abney level. This criterion was only useful for differentiating the three youngest sets of moraines. The oldest moraines being remnants of lateral moraines could not be directly compared with the younger moraines.

C Weathering characteristics of moraines.

The following criteria were used to distinguish tills on the basis of weathering.

I Soil development - Nelson (1954) working in the Frying Pan River drainage, Colorado, found that conditions in high mountains areas are not so favourable to soil formation and preservation as in areas such as the middle west of America. Runoff, mass wasting and frost mixing tend to remove or disturb the soil profiles. He considered that colour, texture and humus content were the most valuable of the soil characteristics for the purpose of distinguishing between different age tills. Retzer (1954) on the other hand considered that soil development was an extremely useful criterion for distinguishing between deposits of different glacial advances on the Grand Mesa, Colorado. This criterion was useful as the surface erosion of the Mesa has been limited and there had been adequate time since the formation of the Mesa for the pedological processes to be fully developed. Because of its limited size all changes in climate and vegetation were presumed to have affected the entire mesa equally. Tweten (1971) found that soil development in the Ovando valley, Montana, proved to be one of the most useful methods for determining relative age.

In this study little importance was placed on soil development as a criterion of relative age because the moraines occurred in two different environments - forest and alpine - which makes comparison difficult. Also it was not possible to select sites suitable for comparative purposes. However within the forest zone, profile horizons, thickness of horizons and oxidation depth were recorded.

II Condition of surface boulders - The weathered condition of surface boulders is an indication of the duration of exposure to weathering. Weathering increases with time unless the boulder changes position on the moraine. Blackwelder (1931) and Birman (1964) used a three point classification system to obtain a granite weathering ratio. They considered this criterion an important one for distinguishing between tills of differing age.

In this study quartzite boulders were used due to their widespread occurrence. Unfortunately quartzite weathers slowly and does not show differences in weathering as clearly as would limestone. Information on the condition of surface boulders was gathered throughout the till areas. Three categories of weathering were used: 1. Almost unweathered 2. Decayed but solid 3. Greatly weathered, as used by Blackwelder (1931). Fifty boulders were used for each assessment of weathered condition. The number of boulders in each category for each assessment of surface condition was reduced to a percentage figure, giving a weathering ratio. Weathering was gauged principally by colour, spalling and fracturing. Boulders are defined as surface stones of diameter 30.5cm (1ft) or more. This criterion was found to be very useful.

III Weathered rhind - The weathered rhind of freshly broken stones is a distinctive band of weathered rock on the outer surface. The longer a stone or boulder has been exposed to the atmosphere the greater the thickness of the weathered rhind.

Sharp (1960) found that the degree of weathering of surface boulders had advanced to such a stage that even in the younger tills no easily expressed significant distinction could be made between weathered and unweathered boulders. Nelson (1954) found the weathered rhind of granitic surface boulders to be very useful in distinguishing various aged tills, provided that the degree of alteration of mineral constituents is slight and does not penetrate far into the rock. Textural variations he also considered important, as this has an effect on the rate of weathering.

Within the study area white and reddish coloured quartzites occur. The latter are infrequent and weather slightly more rapidly than the white quartzite. The white quartzite is common throughout the area wi[illegible] little variation in texture, and was used to measure the weathered rhind. Distinctive weathered rhinds were rare on quartzite stones and boulders, however, a change in colour could be noticed on freshly broken quartzite. The lower limit of discolouration was not distinctive and a number of measurements of thickness were needed to arrive at an average depth of discolouration. Where possible the weathered rhind on quartzite stones was correlated with that of slate, which was distin[illegible]ve. Measurements of the weathered rhind were taken throughout the area.

IV Boulder frequency - Boulder frequency is generally an inverse function of age owing to the progressive breakup and burial of surface stones (Sharp, 1969). For meaningful comparisons sites with similar topographic characteristics should be used e.g. crests of morainal ridges.

Surface boulder frequency has been treated in different ways by various investigators. Blackwelder (1931) counted along measured straight lines which could easily be reduced to terms of area. The method followed in this study is that of Sharp (1969). Boulder frequency was determined by counting all the surface boulders of thirty centimetres (one foot) or more in diameter within strips of thirty metres (one hundred feet) long and six metres (twenty feet) wide. Boulders that were above the general ground level but covered by moss were not included in the count. For comparative purposes moraine ridge crests were used for counting boulder frequency.

D Destruction of moraines by axial creeks.

This criterion must be used with discrimination. Creeks of different sizes and gradients excavate at different rates. Also, the texture of the moraine being eroded affects the rate of erosion. From a review of the literature this criterion does not appear to hdve been extensively used.

For the purpose of differentiating between moraines of different age this criterion was found to be of little use.

E General extent of gully growth in moraines.

On steep moraine slopes the degree of gullying can aid in relative age dating. A moraine with a few short gullies is probably younger than one with larger branching gullies (Blackwelder, 1931). This criterion has to be used with due regard to the origin of the gullies. Some gullies may have been excavated by drainage originating upstream from the moraine, others from water orginating on the moraine itself. This latter type of gully was used in this study. ifferences in texture and slope may also give rise to a variety of gully sizes and integration.

The width and depth of gullies were measured on the ne of the moraines from base to crest, and an average t re calculated. The degree of integration i.e. branching of gullies was estimated using three categories 1. Very little or no branching 2. Some branching with major tributaries 3. Branching with major tributaries. The estimation of integration was wholly subjective.

Estimation of the degree of gullying on the oldest moraines was not possible due to the fact that they only exist as small remnants.

Almost all these criteria have limitations dependent upon variations in geologic and environmental conditions. The processes used to determine relative age cannot be said to be strictly linear funtions of time. Usually, the application of a single criterion leaves uncertainties, but the accumulation of many and varied criteria support the differentiation of tills as propo by this study. Tree ring data and lichen growth may have been useful criteria, but were not used due to limitations of time and the lack of a lichen growth curve for the area.

Laboratory techniques.

Samples of till and fluvio-glacial material from forty locations in the Cataract Brook Valley were selected for laboratory analysis. The samples were obtained from undisturbed sites i.e. those sites not subjected to mass movement.

The following procedures were conducted in the laboratory.

1. Particle size analysis.

Particle size analysis can assist in determining the depositional environment of the materials sampled and as an aid in distinguishing between tills.

The slope of the cumulative curve of grain size distribution for a particular till is likely to be distinctive, making it possible to distinguish between two tills that are similar in appearance (Murray, 1953). Shepps (1953) used percentage composition of sand, silt and clay, median size and sorting factor. The percentage composition was found to be the most useful, particularly when plotted on a triangular diagram with each corner representing either one hundred percent of sand, silt or clay. Folk and Ward (1957) in a study of the significance of grain size parameters used mean, standard deviation, skewness and kurtosis of grain size ves of bi-modal material from a river bar in Texas, in order to determine if these four parameters had any value in determining sedimentary environments. They concluded that skewness and kurtosis are important distinguishing characteristics of bi-modal sediments and that changes in skewness, kurtosis and sorting are probably simple functions of the ratio between the two modes of the sediment. Landim and Frakes (1968) using the parameters of graphic mean, standard deviation, skewness and kurtosis, found that these parameters efficiently distinguish between tills, alluvial fans, outwash deposits and mudflows. However the problem in this study was to distin[illegible]ish between similar materials in order to trace the sequence of glacial events

Method of investigation:

a. Wet sieving the sample to the sand/silt boundary (4 phi).

b. Dry sieving of gravels at one phi intervals and sand at half phi intervals.

c. Pippette analysis of the silt-clay fraction using a constant temperature water bath. Samples were withdrawn at time intervals equivalent to one phi with a ten millilitre pippette. The analysis was continued to the silt/clay boundary (9 phi).

d. From the data gained above the mean, sorting, skewness and kurtosis were calculated for each sample (Folk and Ward 1957). These values provide a quantitative method for describing the material and also give an insight into the depositional environment. The sorting value is the amount of deviation from the mean by the extremes (95% and 5% points on the cumulative curve). Amount of skewness is indicated by the departure of the mean from the median (phi value which has an equal number of sizes below and above it). Skewness indicates whether there is an abundance of coarse or fine material, as compared to the mean. Kurtosis is a measure of the ratio of sorting in the extremes of the distribution compared with the sorting in the central part.

The use of the Folk and Ward statistical method requires that no more than five percent of the sample passes through the finest sieve used and that no more than five percent is retained on the coarsest sieve used. Of the forty sample six were not pipetted to within the five percent limit but they fell within the nine percent mark, so the extrapolation of the graph lines was fairly accurate. None of the samples were sieved to within the five percent retained point, due to the lack of suitable field sieves. The graph lines were extrapolated by means of a straight line to the one hundred percent point.

2. Roundness.

A study of the roundness of stones can give useful infomation concerning the nature of the deposit in which the stones were incorporated. Some information is also provided on the process of deposition and the nature of the last stage of transport (Embleton and King, 1971; Wadell, 1935).

Wadell (1935) and Krumbein (1961) differentiate clearly between shape and roundness. Krumbien concludes that roundness is strongly modified by abrasion and wear to which the particles have been subjected.

Cailleux (1945) developed a formula for measuring roundness hich was applied to a sample of fifty stones taken from a variety of glacial and fluvio-glacial features. Significant differences were found between outwash deltas, eskers, kames, moraines and solifluction materials. Cailleux used the parameters of minimum radius of curvature in the principle plane and the long axes of the stone to measure roundness. Wadell's (1935) method of measuring roundness entailed measuring the curvature of the pebble corners and edges, and expressing the data as a ratio of the average curvature of the particle as a whole. Krumbien's (1941) method was to compare visually pebbles of unknown roundness to those of known roundness as measured by Wadell's method. Statistical tests show that the average values of the two methods (Wadell's and Krumbeins's) agree well.

In this study the roundness of fifty pebbles per sample were measured using Krumbien's method of visual comparison. The pebbles investigated ranged in diameter from nine to seventy millimetres. Each pebble is held with its long axis between thumb and forefinger in such a manner that the largest re tion is visible. In this position it is compar bien's chart of visual roundness and a value is assi rom ta gained an arithmetic mean roundness is calcu ach sample.

3. Lithology.

The purpose of determining lithologic composition of the tills was to 1. Test for any major difference between samples or groups of samples, 2. Determine the provenançe of the tills.

Tests of hardness, colour, acid reaction and minerology were conducted to determine lithologic composition. The pebbles were grouped by the major lithologies of limestone, dolomite, shale and quartzite. Hardness of stones was obtained by scratching them with a knife blade. This distinguished between the softer limestone,dolomite and shale from the quartzite stones. Limestone and dolomite ranged in colour from grey to black. Shale was dark brown with a light brown inner core and quartzite was recognised by its white to reddish colour. The acid test using hydrochloric acid differentiated between carbonate and non carbonate rocks. Also acid reaction helps distinguish limestone and dolomite. Limestone reacts greatly with acid, dolomite very little. The crystals composing limestone and dolomite were too small to be distinguished. The quartzite stones contained larger crystals principally of quartz and feldspar. The quartz crystals were vitreous to greasy in luster and the feldspar crystals were pearly in luster.

Care was needed using the acid test due to carbonate encrustation on some stones. Fifty stones per sample were used to determine lithologic composition and the data is presented as percentage by weight.

4. Carbonate content and calcite-dolomite ratio.

Knowledge of carbonate content of tills is significant not only from the viewpoint of description but also for differentiating between deposits of different glacial advances and in stratigraphic and provenance studies (Dreimanis, 1960)

Dreimanis and Reavely (1953) found that carbonate content of tills was one of the most useful methods for differentiating between two tills occurring along the north shore of Lake Erie. At first they used the sample fraction of less than 0.84 mm (sand size and less) and obtained no difference between the two tills in spite of an obvious difference in the carbonate content of pebbles. This was due partially to the percentage of the sand fraction in the two tills being different, and also to the fact that quartz particles tend to show a coarser grain size than does calcite. The use of the less than 0.84mm fraction was discontinued as it was built up of unequal constituents in the two tills. Consequently they used the silt and clay fraction of the two tills as it was comprised of equal portions of silt and clay.

The procedure followed in this study to determine carbonate content and the calcite-dolomite ratio is that of Dreimanis (1962), using a quantitative gasometric method. Forty samples were analysed using the silt and clay fraction.

The method involves placing 1.7 gms of the sample with twenty millilitres of twenty percent hydrochloric acid. The quantity of carbon dioxide given off is measured in a burette by the displacement of a fluid. The different reaction times of dolomite and limestone enable the quantities of each to be found.

CHAPTER IV

DESCRIPTION OF SURFICIAL DEPOSITS AND LANDFORMS.

Surficial deposits are discussed first, together with their landform associations. In the section on tills the relative age data are presented and discussed. Any landforms not mentioned under surficial deposits will be discussed in the latter part of this chapter.

SURFICIAL DEPOSITS

The surficial deposits were mapped (fig. 6) first, on the basis of ground surface morphology as seen from a vantage point, and secondly by sampling the units so determined.

The deposits identified include 1. Till 2. Fluvio-glacial ice-contact deposits and outwash 3. Lacustrine 4. Recent-alluvium and colluvium 5. Ice and permanent snow.

1. TILL

Till is widespread in the area of investigation (fig. 6), and is mainly confined to the valley floor and the lower part of the valley walls. Till is defined as a sediment of diverse texture and structure, deposited by direct glacial action (Scott and St-Onge, 1969). This definition includes stratified material incorporated within till, but excludes deposits derived primarily from glacial meltwater.

A. Landform associations.

Landforms associated with till in the study area are terminal, recessional, ground and lateral moraines. These features are defined as follows (Flint 1971).

Terminal moraine - a ridge like accumulation of material built along the downstream or terminal margin of a glacier occupying a valley.

Recessional or end moraine - a ridge like accumulation of material built along any part of the margin of a glac which is in recession. A well defined complex of many ridges is an 'end moraine system.'

Lateral moraine - an end moraine built along the lateral margins of any glacier or glacier lobe occupying a valley.

Ground moraine - a moraine having low relief and devoid of transverse linear elements.

On the basis of spatial position the tills within the study area were subdivided into four possible age groups. These are called from the youngest to the oldest - Recent, Late Intermediate, Early Intermediate and Oldest.

(i) Recent

The landforms of the recent tills consist of terminal and lateral moraines, formed by a very limited ice advance. They occur in an altitude zone of 2257m (7400-8000 ft) feet in Oesa, Opabin, McArthur, Upper Duchesney, North and South Vanguard, North and South Watchtower and Boundary basins (figs. 7,8; Plate 1).

The moraines in Abbot Pass, South and North Watchtower and North Vanguard basins are lateral moraine remnants. In the other basins the terminal moraines are complete. One recessional moraine is present in Boundary basin and in the small cirque in Oesa basin below Mt. Huber.

In appearance these moraines are very fresh, with a dominant colour of grey, steep sided and sharp crested. No vegetation is established on the morai. s.

(ii) Late Intermediate

This till is mainly found in four end moraine systems, occurring in an altitude zone of 1982-2287m (6500-7500 ft), and downvalley from the recent moraines. Lateral moraines of this system occur in the cirques (figs. 7,8).

The end moraine systems occur in Upper and Lower Duchesney basin and in the vicinity of O'Hara Lake (fig. 7).

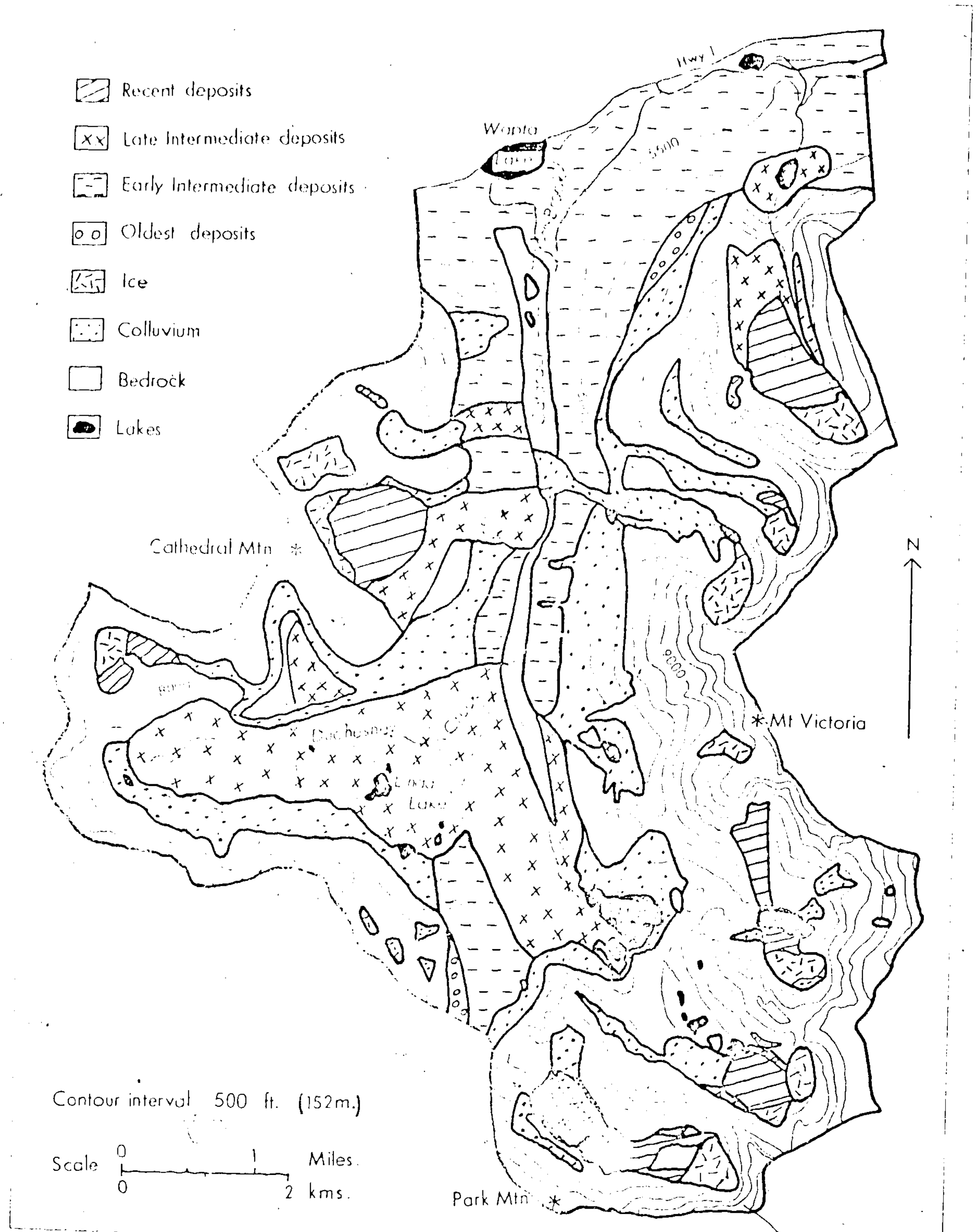


Fig. 8 Relative ages of the surficial deposits

Plate 1 Moraines in the northwestern part of Duchesney Basin

1. Recent moraine.
2. Ice smoothed bedrock.
3. Stoss and Ice topography.

The latter system (Plates 2,3) is comprised of a terminal moraine and four recessional moraines, formed by ice emerging from Oesa and Opabin basins. From the configuration of the moraines the Oe[illegible]pears to have had a greater influence on their deve[illegible]. Just upstream from the junction of Morning [illegible]k and the Cataract Brook, the terminal moraine rises steeply some 55-61m (180-200 ft) above the valley floor. The eastern portion of these moraines has been eroded by the Cataract Br[illegible].

Ice from the head of Duchesney basin formed a second end moraine system in the upper portion of the basin (fig. 7; Plate 4). It consists of a terminal moraine and a series of eight recessional moraines which extend diagonally down-valley from the north side of the basin with their ends turning across the basin floor. The moraines are not complete on the south side of the basin due to erosion by stream action. On the south side of the basin floor two lateral moraine remnants are present.

A third end moraine system is present in the lower portion of Duchesney basin, formed by ice flowing off the north buttress of Odary Mountain. The terminal moraine which dams Linda Lake (Plate 5) and the four recessional moraines which comprise this system are semi-circular in form. Hard under the buttress of Odary Mountain and encroaching upon

Plate 2 Late Intermediate moraines in the vicinity of O'Hara Lake.

1. O'Hara Lake.
2. Mary Lakes.
3. O'Hara Meadows
4. Late Intermediate moraines.

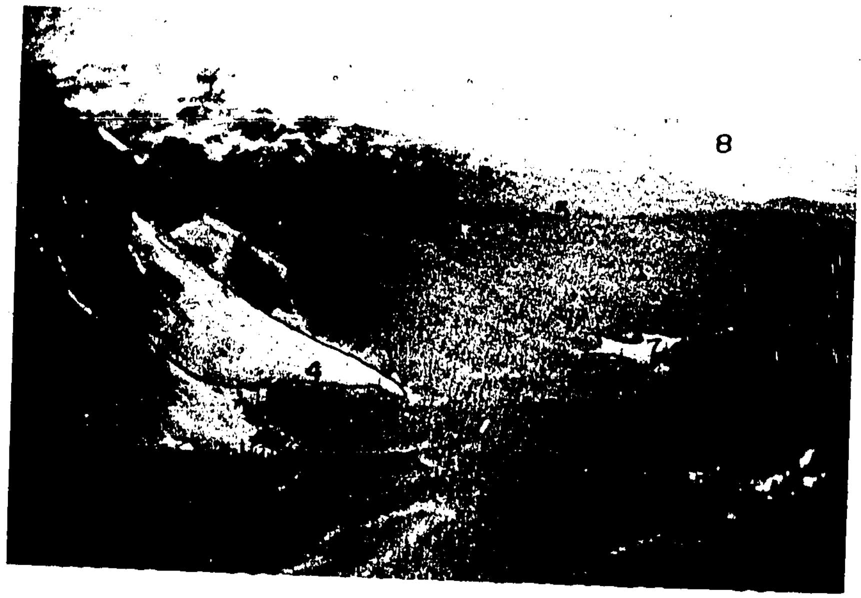


Plate 3 Late Intermediate moraines in the vicinity of the O'Hara Meadows.

1. Late Intermediate moraines.
2. O'Hara Lake.
3. Moraine dammed Mary Lakes.
4. Pro-takes ramparts.
5. Junction of Early and Late Intermediate tills.
6. Early Intermediate moraine.
7. O'Hara Meadows.
8. Ice Smoothed buttress of Odary Mountain.

Plate 4 Upper [illegible] Late Intermediate end moraine system.

1. Late Intermediate end moraine system.
2. Recent moraine.
3. Moraine dammed lake.

Plate 5 Lower Duchesney Late Intermediate end moraine system.

1. Linda Lake.
2. Late Intermediate end moraine system.
3. Mount Biddle.
4. Truncated arete with col.
5. Opabin Plateau hanging valley.

the south part of Linda Lake are three smaller, semi-circular ridges. They appear to be of more recent origin than the late Intermediate moraines with less soil development and vegetation. The boulders occurring on the surface are larger than those of the Late Intermediate moraines, and are mainly of limestone and dolomite originating from above, the ice smoothed quartzites of the north buttress of Odary Mountain. They could have been formed by an ice advance of more recent origin, but it is more likely that they are pro-talus ramparts. The growth of vegetation and the beginning of soil development preclude a Recent age for the semi-circular ridges. Also the rock fragments that comprise the ridges are sharp and angular, and did not appear to be abraded by glacial action. Further, is difficult to imagine a glacier extending down the vertical wall of Odary Mountain producing such regular ridges, so close to the base of the mountain.

The three end moraine systems occur just below the tree line and support a cover of spruce with a ground cover of moss and lichens.

A further end moraine system, although not as distinctive as those mentioned above, occurs at the mouth of South Vanguard basin (fig. 7; Plate 6) and extends to the Cataract Brook. This moraine is lobate in shape and is

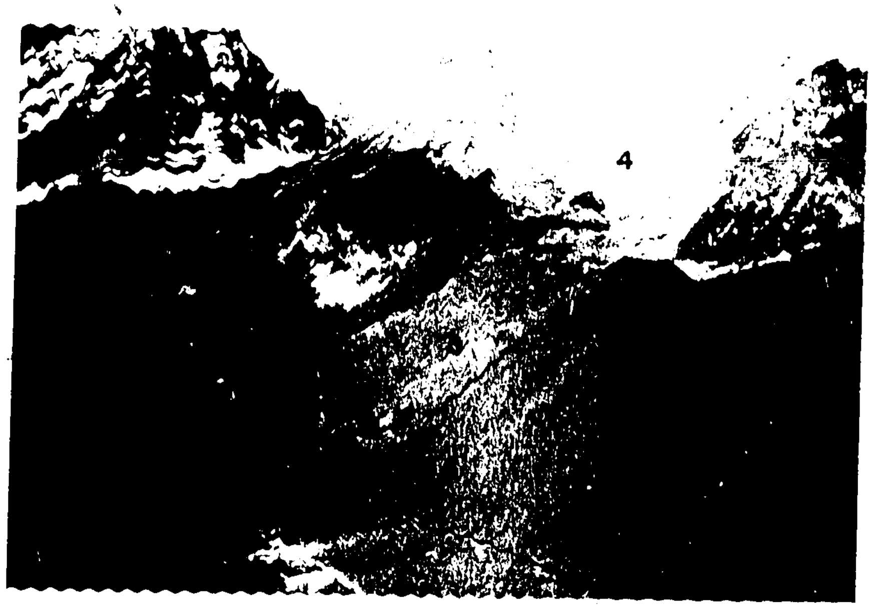


Plate 6 Late Intermediate lobe shaped moraine extending out from South Vanguard Basin.

1. Break in slope.
2. Oldest ground moraine.
3. Lobe Shaped Late Intermediate moraine.
4. South Vanguard Basin.

Plate 7 View downvalley to Narmo Lakes.

1. Break in slope.
2. Alluvial flats.
3. Watchtower kame.
4. Talus slopes.

mainly comprised of very large, weathered and broken limestone and dolomite boulders up to nine metres (thirty feet) in length. Above this moraine lobe on the extreme southeast edge of South Vanguard basin is a series of three recessional moraines. These also consist of very large boulders with very few fines.

Lateral moraines of the Late Intermediate age are present in McArthur, Boundary and South Watchtower basins (fig 7). They occur both above and down-valley from the recent moraines. For the most part they are more rounded and subdued than the recent moraines, darker in colour and support a thin vegetative cover of grasses, moss and stunted trees. The ice advance that formed the lateral moraines in Boundary basin appears to have flowed over the lip of the basin a short distance into Kicking Horse Pass to form a small end moraine system which dammed Ross Lake. This moraine overlies a kame terrace and rises some 6-8m (20-25 ft) above the level of the terrace.

(iii) Early Intermediate

Moraines of this age occur primarily down-valley from the late intermediate tills and consist for the most part of ground moraine (fig. 6,7; Plates 6,7). On the west valley side the ground moraine reaches an altitude of approximately 1982 m (6500 ft) and on the east side approximately 2074 m

(6800 ft).

Two moraine ridges, possibly recessional moraines, occur on the valley floor. One being approximately 140m (450 ft) downvalley from Narao Lakes (fig. 7) with a very round smooth appearance, which is probably due to water erosion. This will be discussed later. The other possible recessional moraine occurs some four hundred metres (quarter of a mile) up-valley from the Late Intermediate moraine lobe. It rises some 15 m (50 ft) above the valley floor with a gently sloping distal face and a steeper proximal side.

A very subdued lateral moraine is present on the east side of the valley bottom, extending from Wiwaxy basin to the exit of South Watchtower basin.

Throughout the area of Early Intermediate ground moraine the density of spruce is greater than on the Late Intermediate till and the ground cover of moss and lichens is thicker. Beneath this ground vegetative cover the surface has the appearance of being extremely bouldery.

Further areas of ground moraine occur in McArthur Pass and Odary Lookout. The junction of the Early and Late Intermediate moraines in the vicinity of McArthur Pass is approximately at the 2135 m (7000 ft) level.. Here there is a distinct break in slope and a change in vegetation from spruce on the lower Late Intermediate moraine to predomin tly larch on the Early Intermediate moraines. Also the Early Intermediate moraines are much more bouldery on the suface.

(iv) Oldest

Moraines of this age are limited to lateral moraine remnants on the northwest slopes of Narao Peaks (Plate 8) at an altitude of approximately 2318 m (7600 ft), and on the west side of McArthur Pass at 2287 m (7500 ft). The Narao Peaks Lateral moraine consists of two isolated mounds, 180 m (200 yds.) apart with a very subdued appearance. The outer valleyward faces are steep (table 3), with their upper surfaces sloping gently down into the valley wall (Plate 9). No boulders occur on their upper surfaces. The area surrounding the moraines is highly eroded and broken, and consists largely of coarse loose rock debris which is incised by gullies up to 15 m (50 ft) wide and 6 m (20 ft) deep. The survival of the moraine remnants is probably due to the relative stability of the debris slopes above them.

The lateral moraine remnants in McArthur Pass consist of three isolated mounds which are very similar in appearance to these on Narao Peaks.

Plate 8 View of north ridge of Narao Peak from Wapta Lake.

1. Oldest lateral moraine.

2. Early Intermediate ground moraine.

Plate 9 Close up of Oldest lateral moraine remnant on slopes of Narao Peaks.

B Sedimentalogical characteristics

In this section the grain size composition and fabric of the till units will be discussed. The tills of the study area exhibit no obvious structure. This is probably because the tills have a low percentage of silt and clay and therefore are not likely to show definite structu (Flint, 1971).

The six till fabrics recorded were limited to deposits of uncertain origin in an attempt to classify them.

(i) Grain size characteristics

The plots of the Folk and Ward statistics (figs 9, 10, 11, 12) and the triangular plots (figs. 13, 14) show no clear distinction between the till units. The only general pattern to emerge is one of decreasing gravel percent and increasing sand percent older the till.

The plots and diagrams show clearly that there is no possibility of using grain size as a criterion to distinguish between tills of the respective advances.

(ii) Fabric of the clasts.

Five till fabrics were recorded in order to help determine whether a deposit was in fact of glacial or glacio-fluvial origin rather than related to slope movement.

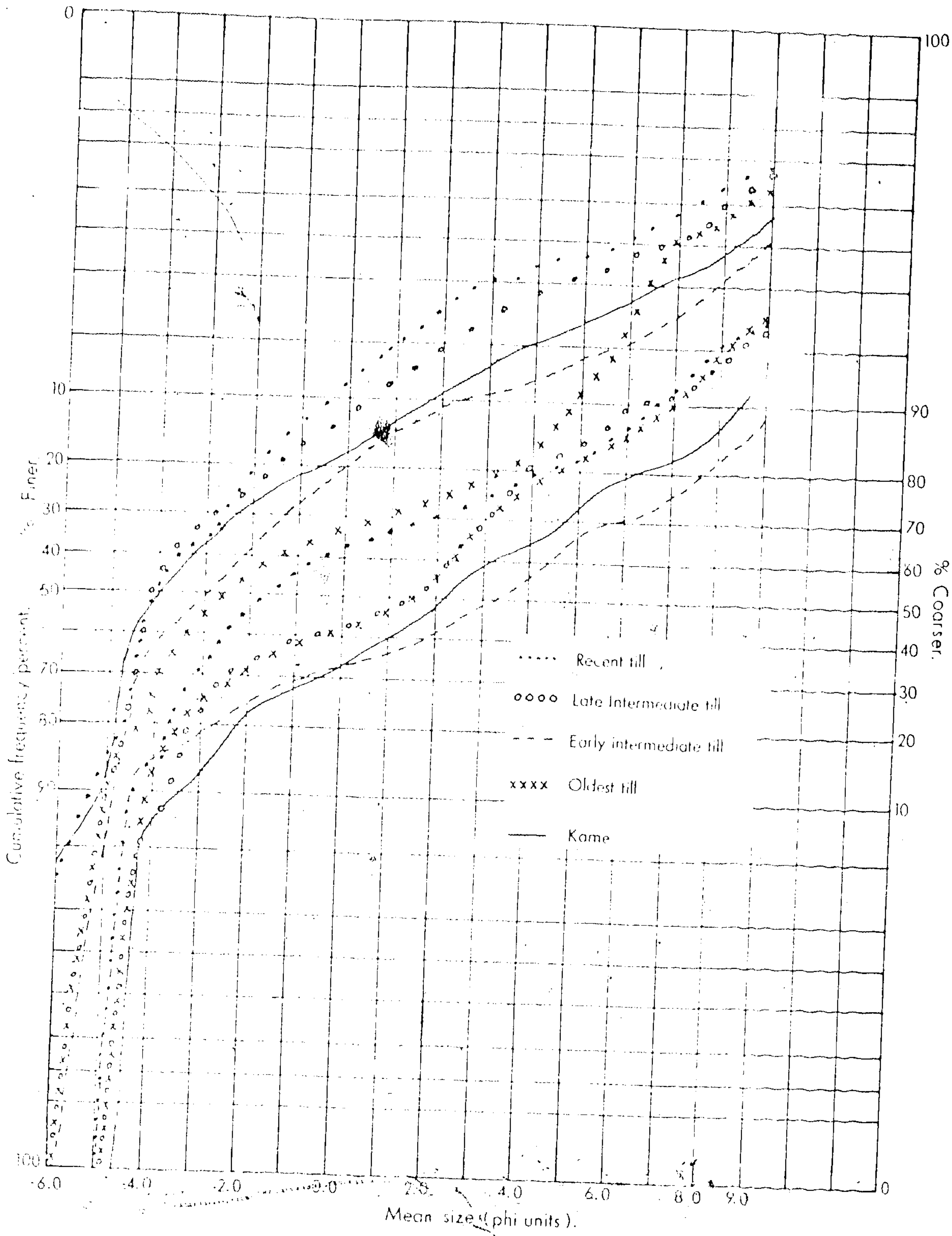


Fig. 9 Cumulative grain size frequency curves

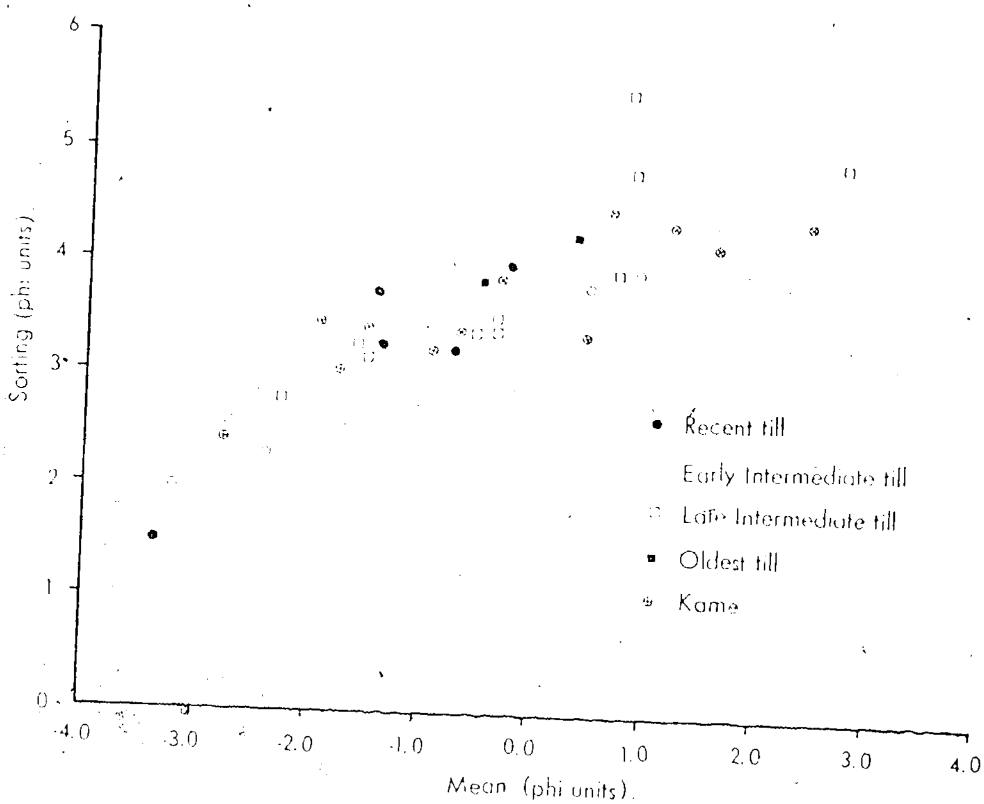


Fig 10 Values of mean versus sorting (Folk and Ward), all in phi units plotted for till and kame deposits.

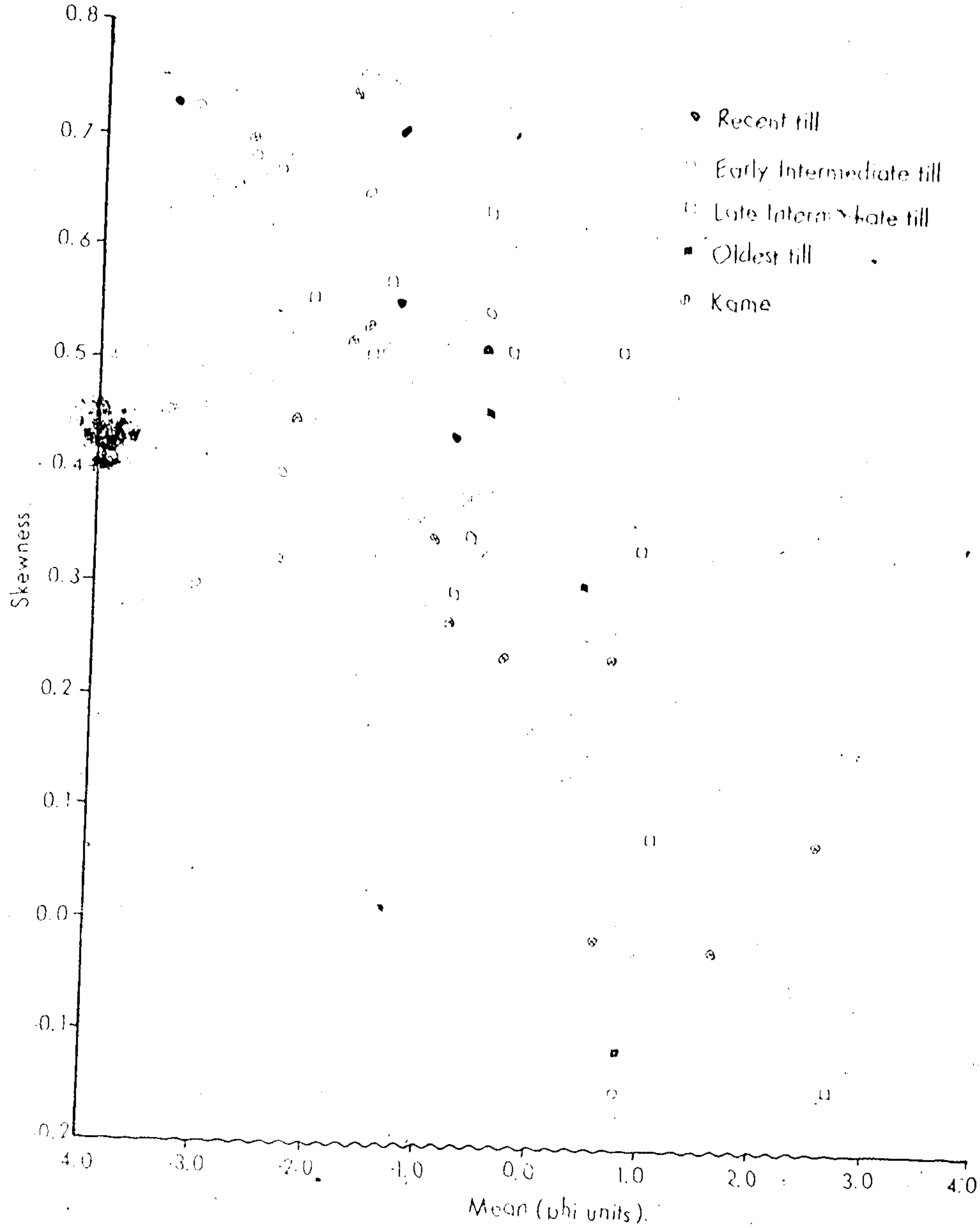


Fig. 11 Values of mean versus skewness (Folk and Ward), plotted for till and kame deposits.

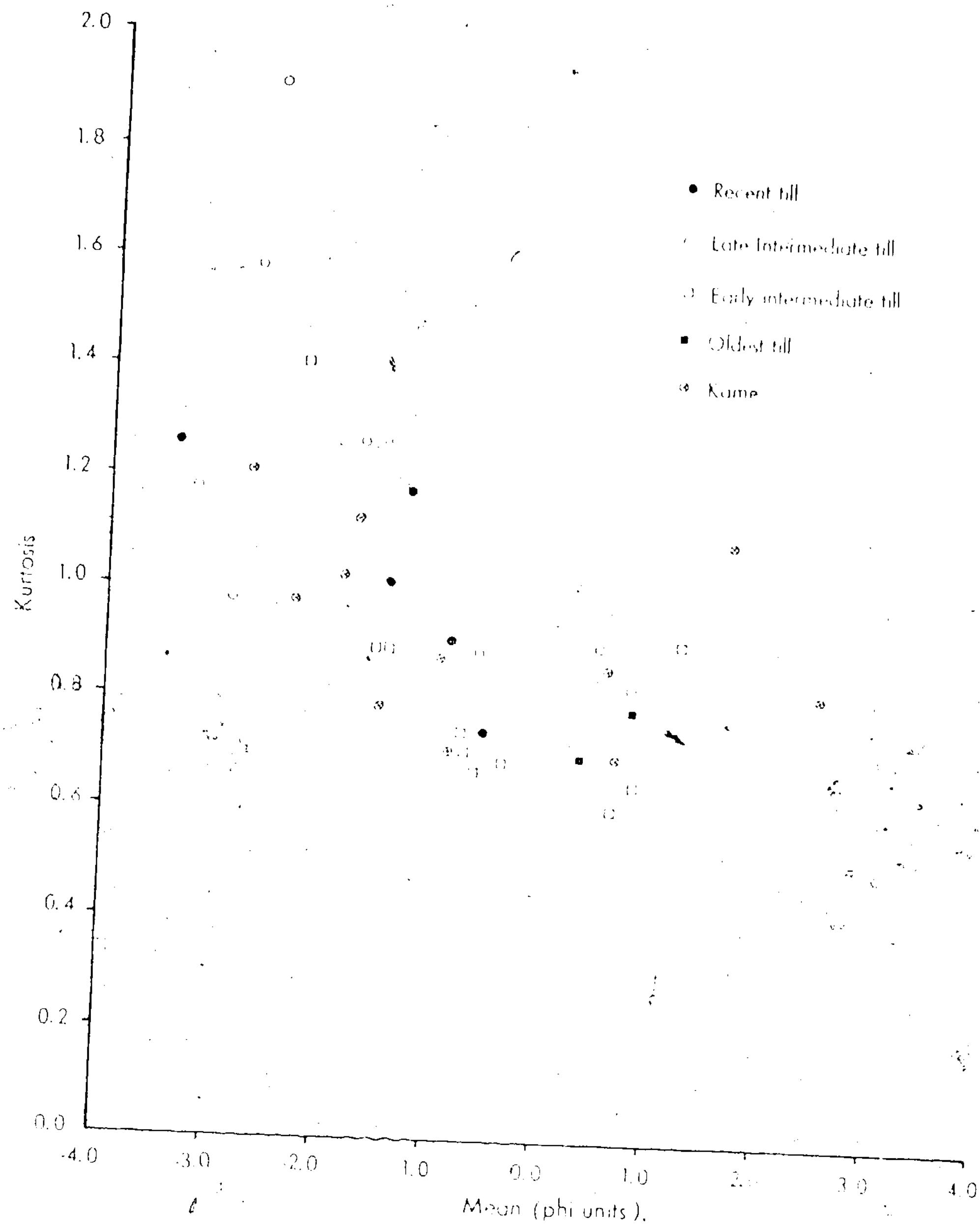


Fig. 12 Values of mean versus Kurtosis(Folk and Ward) plotted for till and kame deposits.

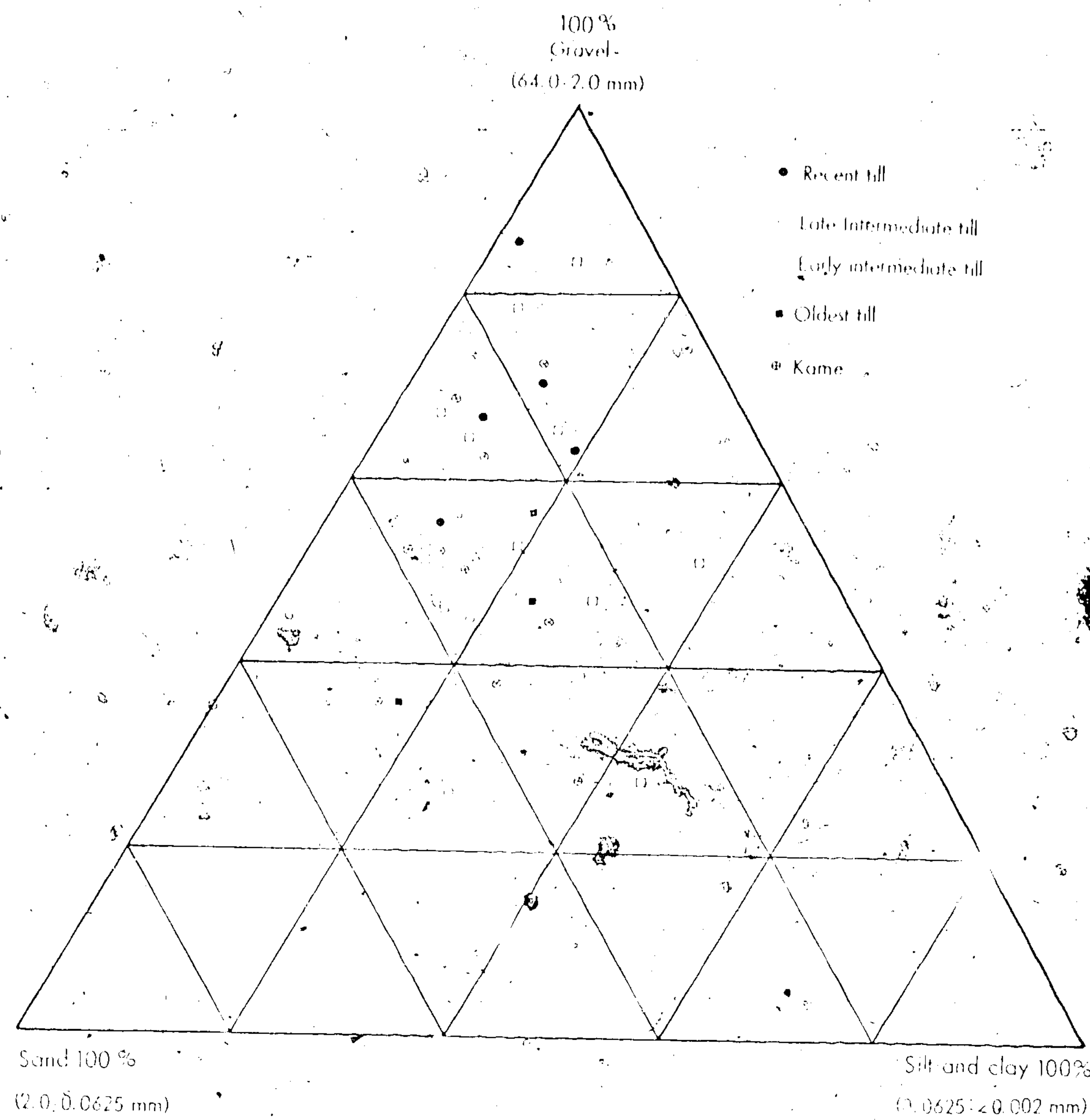


Fig. 13 Textural classification of the < 64 mm size fraction

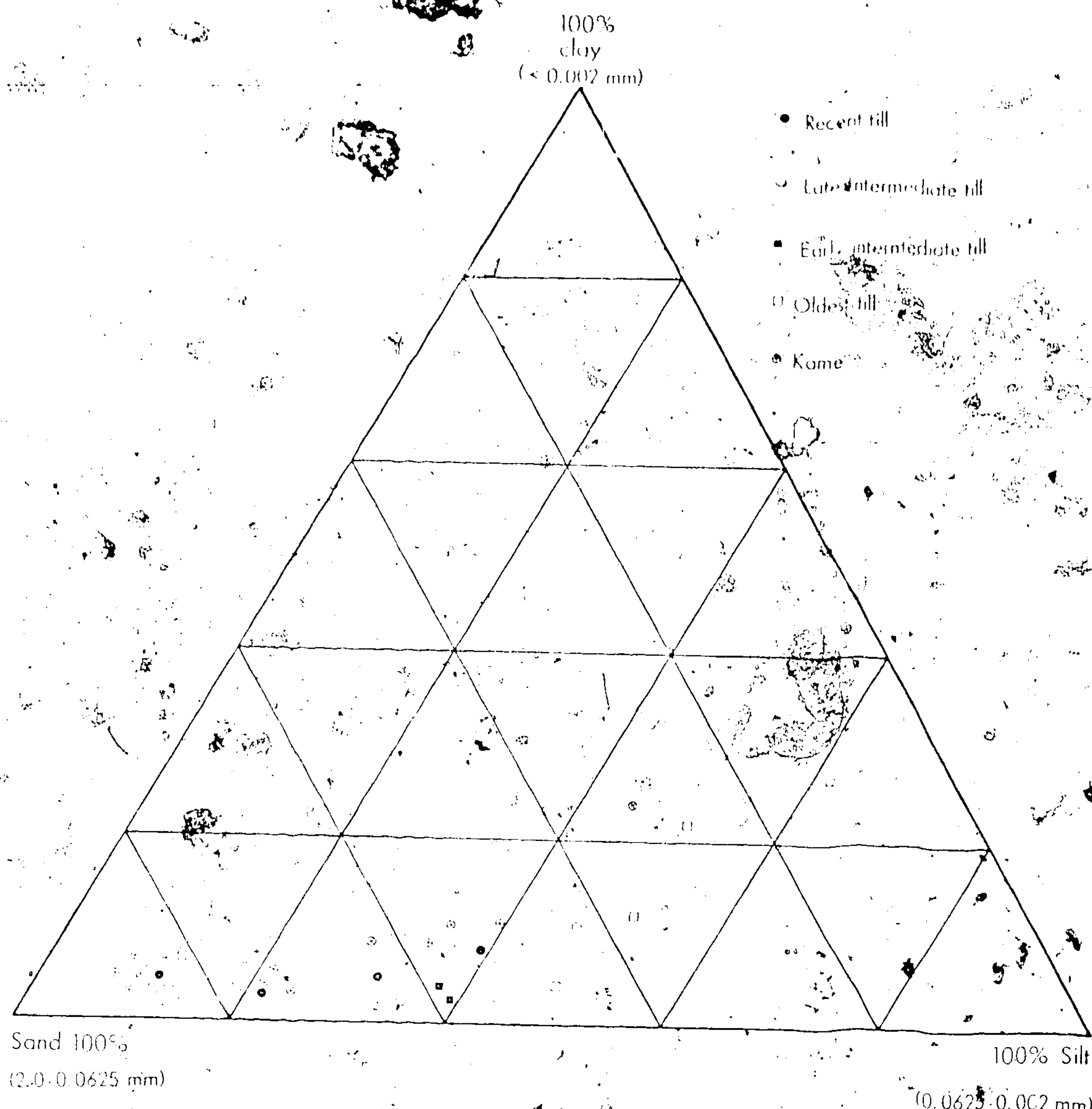


Fig. 14 Textural classification of the < 2.0 mm size fraction

It was considered unnecessary to use fabric measurements to determine ice flow direction, as ice in the study location would almost certainly have flowed downvalley.

Fabric measurements were taken in the two oldest tills, also in the Early Intermediate recessional moraine near Narao Lakes. This latter moraine had a fabric transverse across the valley. Another measurement of fabric was gained from the late intermediate moraine in South Watchtower basin.

All the deposits analysed have a preferred fabric (Appendix E). From the fabric data and other characteristics, i.e. roundness of the clasts, grain size distribution and morphology, it was concluded that the deposits were comprised of till.

Relative Age Criteria

The purpose of this section is to present further evidence for the age differentiation of the tills.

(i) Topographic expression of the moraines.

The difference in expression between the recent and late intermediate moraines is quite distinct. The data for the early intermediate moraines cannot be directly compared with the younger moraines due to lack of similar landforms.

Age	Range of slope	Average angle	Shape of crest.
Recent (distal slopes)	28°-35°	31°	Sharp
Late Intermediate (distal slopes)	20°-30°	27°	Rounded
Early Intermediate Lateral Moraine (Valleyward slope)	18°-21°	20°	Very rounded and subdued
Recession moraines (distal slopes)	9°-12°	10°	Very subdued. Proximal slope of upvalley moraine - 18°
Oldest (Valleyward slope)	25°-27°	26°	Flat

Table 3. [illegible]stal slope angles of moraines.

However their appearance in the field suggests an older age than the late intermediate moraines. Comparision of the data of the oldest moraines is difficult. First they occur in a different environment (Alpine) than the intermediate moraines (forest) and secondly their valleyward faces are actively eroding, but their very subdued, eroded appearance suggest an older age than the early intermediate.

Slope - data are analysed and compared using the Student-t test. The results (table 4) support the conclusions reached above. However, the number of slope

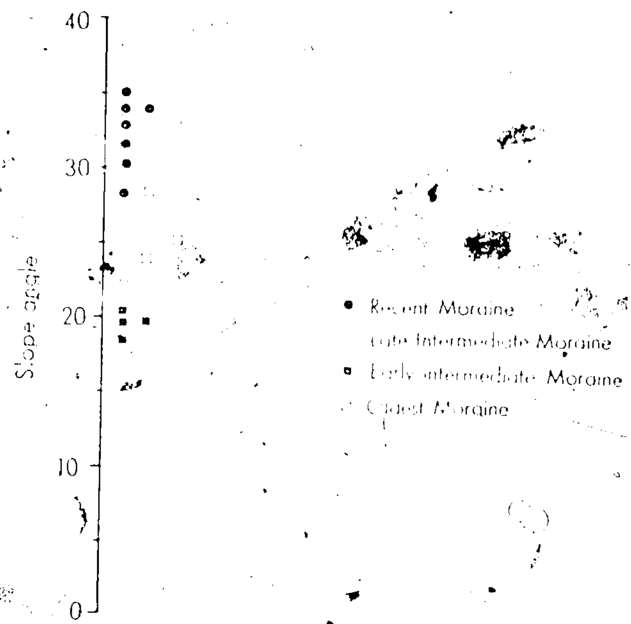


Fig. 15. Scatter diagram of slope angles (Degrees)

Age of Moraine	Mean slope	No. of Samples	P (0.05)	t	Difference at 95% Confidence level
Recent	31	7	2.145	2.176	Significant
Late Inter.	26	9			
Late Inter.	26	9	2.179	[illegible]2883	Significant
Early Inter.	20	5			
Early Inter.	20	5	.365	7.1261	Significant
Oldest	27	4			

Table 4. Analysis of slope data: Student-t test.

angles measured was small and hence the reliability of the data may be low.

(ii) Soil development

The recent moraines were differentiated from the other moraines in that they had no soil development. Although it was not possible to measure soil horizon thickness and oxida[illegible]pth for the two intermediate age moraines at com[illegible]ites the average thickness of horizons was greate[illegible]on the Early Intermediate moraines (table 5). Also the kame at the valley mouth of Early Intermediate age had a fairly constant oxidation depth of twenty three inches.

A regosolic soil has developed on the oldest moraines, and lacked horizons that could be compared with the soils developed on the other age moraines.

(iii) Condition of surface boulders

Using this criterion the age difference between the recent and late intermediate moraines is quite distinctive (table 6). However between the late and early intermediate moraines the difference is small but quite noticable in the field. The ratios obtained for the early intermediate moraine is based on fewer boulders than the two younger moraines, due to the thick ground cover of moss and lichens.

Age of Moraine	L-H thickness cm. (ins)		Ae thickness cm. (ins)		Ox. depth (ins)	
	Range	Average	Range	Average	Range	Average
Recent	Nil	Nil	Nil	Nil	Nil	
Late Intermediate	2.5-5.0 (1-2)	3.8 (1.5)	2.5-5.0 (1-2)	3.3 (1.3)	30.0-35.5 (12-14)	33 (13)
Early Intermediate	2.5-10.2 (1-4)	7.2 (2.8)	2.5-12.7 (1-5)	7.2 (2.8)	7.7-58.5 (3-23)	40.7 (16)
Kame					58.5 (23)	58.5 (23)
Oldest	Nil	Nil	Nil	Nil	Unknown	

Table 5.[illegible] Depth of organic, Ae and oxidation horizons in the soil profile of moraines.

Age	No. of Counts	Category 1	Category 2	Category 3	Ratio%	Av. Ratio%
[illegible]ent	1	x			100-0-0	100-0-0
	2	x			100-0-0	
	3	x			100-0-0	
Late Inter.	1		x		0-100-0	0-100-0
	2		x		0-100-0	
	3		x		0-100-0	
Early Inter.	1		x	x	0-96-4	0-93-7
	2		x	x	0-95-5	
	3		x	x	0-93-7	
	4		x	x	0-88-12	
Oldest.	No boulders present for measurement.					

Table 6. Weathered condition of surface boulders.
Category: 1. Almost unweathered.
2. Decayed but solid.
3. Greatly weathered.

Age	No. of counts	Frequency area=30.5x6m (100x20ft)	Av. Frequency
Recent	1	80	109
	2	115	
	3	125	
	4	118	
Late Inter	1	5	23
	2	17	
	3	30	
	4	41	
Early Inter	1	9	10
	2	11	
	3	6	
Oldest	Nil	Nil	Nil

Table 7. Frequency of boulders on moraine surfaces.

The slight difference between the two intermediate moraine counts is probably due to a short lapse of time between deposition.

(iv) Boulder frequency

This criterion again clearly distinguishes between the recent and the late intermediate moraines (table 7). But as in the previous criteria the difference between the two intermediate moraines is not distinctive. No boulders occurred on the surface of the oldest moraines.

(v) Weathered rhind

Age	Range of rhind thickness mm.	(in)	Av. rhind thickness mm.	(in)
Recent	Nil		Nil	
Late Inter.	2-6	(0.1-0.25)	5	(0.2)
Early Inter.	8-14	(0.3-0.55)	12	(0.45)
Oldest				

Table 8. Thickness of weathered rhind of surface boulders.

Age differences between the three youngest moraines is shown as well by this criterion (table 8). As discussed in the methodology chapter very few of the weathered rhind measurements were obtained from quartzite stones with a distinctive rhind. However, rhind measurements taken from large boulders in McArthur Pass in the proximity of, and at the the same altitude as, the oldest moraines had a very distinctive rhind averaging 9mm. (0.35 in.), the rhind being almost totally rotten. This suggests an older age than any of the other moraines in the study area. Unfortunately the oldest moraines on the slopes of Narao Peaks had no quartzite boulders. However, an erratic boulder of limestone or dolomite occurring at a slightly lower altitude than the moraine is extremely weathered, more so than any other limestone or dolomite boulder seen in the study area.

(vi) Gullying on Moraines

Age	Width cm. (ft)		Depth cm. (ft)		Integration
	Range	Av.	Range	Av.	
Recent	61-244 (2-8)	122 (4)	30-91 (1-3)	61 (2)	None
Late Inter	183-610 (6-20)	488 (11)	152-388 (5-16)	274 (9)	Partially
Early Inter	No comparable features.				
Oldest	No comparable features.				

Table 9. Width, depth and integration of gullies on moraines.

This criterion was only found to be useful in differentiating between the two youngest moraines (fig. 16 and table 9). The other moraines having no similar gullies for the purpose of comparison.

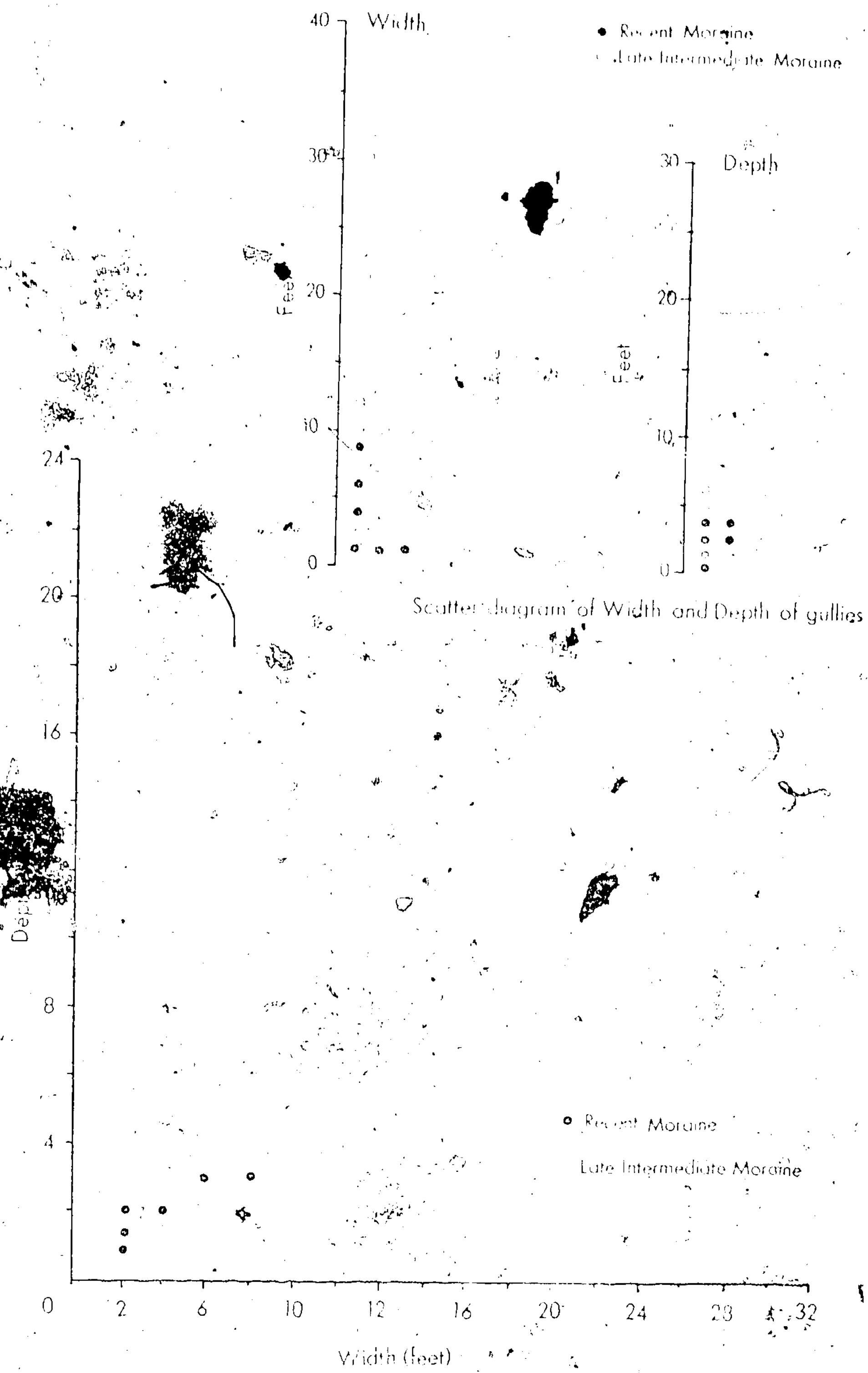


Fig. 16 Depth versus width of gullies.

A significant difference using the Student-T test was found between the width and depth of the gullies eroded into the Recent and Late Intermediate moraines (table 10).

(vii) Roundness

The graph (fig 17) does not clearly differentiate between kame deposits and tills, nor between the tills. The majority of the kame samples had a relatively high roundness. Some of the early intermediate samples were of high roundness, but these were associated with the recessional moraine near Narao Lakes which formed part of a lake shore at one time. Also the two samples gained on the slopes of Cathedral Crags had pebbles of high roundness. The lower sample (sample 14) was again situated at the edge of the former lake and the higher sample obtained from a ledge (sample 15) is possibly material deposited by meltwater flowing along the margin of the ice.

A comparison of the roundness data, using the Student-T test, for the different age moraines showed that the roundness of the clasts was not a good indicator of age difference. However between the two Intermediate age moraines the difference was significant.

Depth of Gullies					
Age of Moraines	Mean depth (ft) / width (ft)	No. of Samples	P(0.05)	t	Difference at 95% confidence level
Recent	2	6	2.201	4.4543	Significant
Late Inter.	9	7			
Width of Gullies					
Recent	4	6	2.201	3.6484	Significant
Late Inter.	16	7			

Table 10. Analysis of gully data: Student-t test.

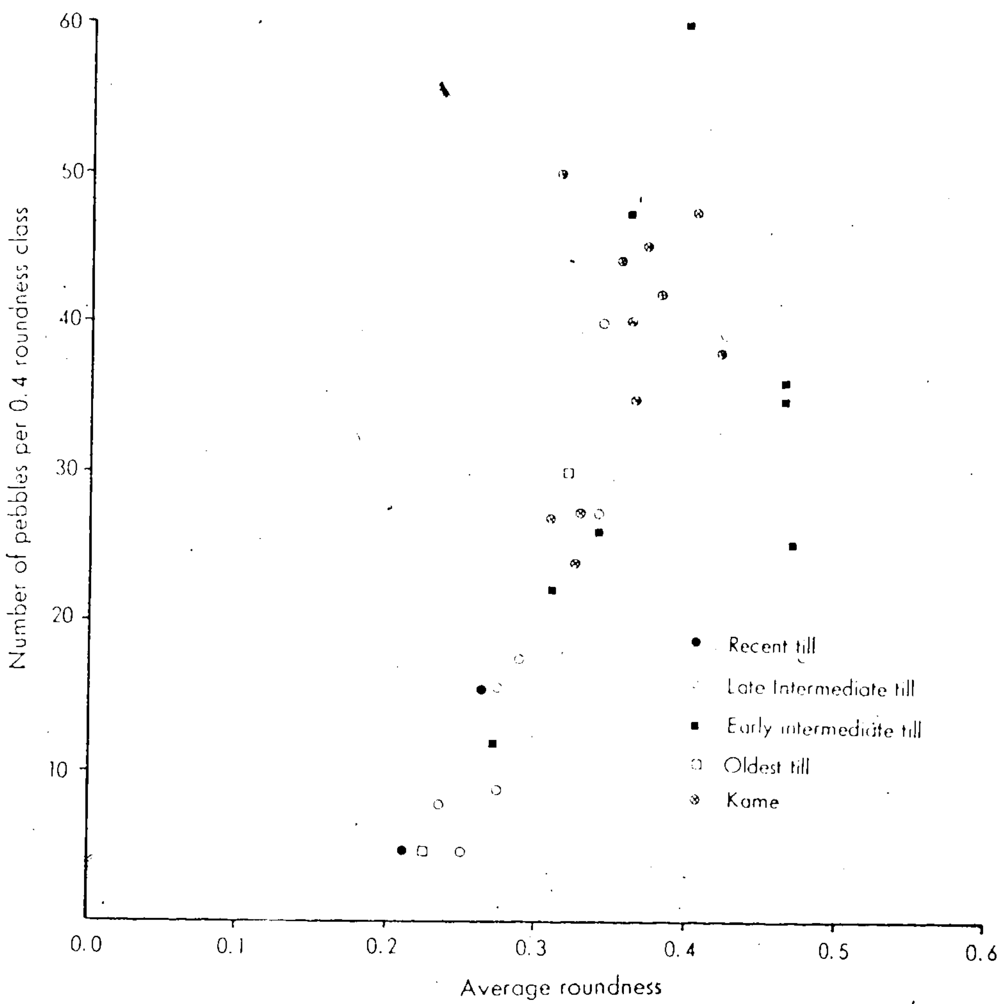


Fig. 17 Roundness of clasts in till and kame deposits.

(viii) Lithology

The lithologic composition of the tills (fig. 18) does not reflect age but rather the bedrock, which shows limestone and dolomite overlying quartzite (fig. 3). The samples containing mostly carbonate rocks were gained from a relatively high elevation, those with a composition of mainly quartzites were from the valley floor.

The lateral moraine of the oldest age in McArthur Pa contains mostly quartzite. Quartzite bedrock occurs within the study area, but in McArthur Creek basin, outside the study area, the bedrock is of limestone and dolomite (fig. 3). This perhaps indicates that ice moved southwest over McArthur Pass.

(ix) Carbonate content - calcite-dolomite ratio.

This criterion differentiates between the recent moraines, in terms of total carbonates, and the other tills (fig. 20). The lack of distinction (figs. 19,20) between the three oldest moraines is probably due to the strong localised influence of bedrock on the till and the incomplete mixing of the material derived from each bedrock type. Fig. 21 distinguishes between the Kicking Horse Kame deposits and till, and shows valley bottom deposits (mainly kame material) resting on the quartzite bedrock, on the left

Age of Moraines	Mean Roundness	No. of Samples	P(0.05)	t	Difference at 95% confidence level
Recent	24.00	2	2.306	0.4216	No significant difference
Late Inter.	27.75	8			
Late Inter.	27.75	8	2.145	3.6	Significant
Early Inter.	37.75	8			
Early Inter.	37.75	8	2.306	2.0271	No significant difference Significant at 90%
Oldest	27.00	2			

Table 11. Analysis of roundness data: Student-t test.

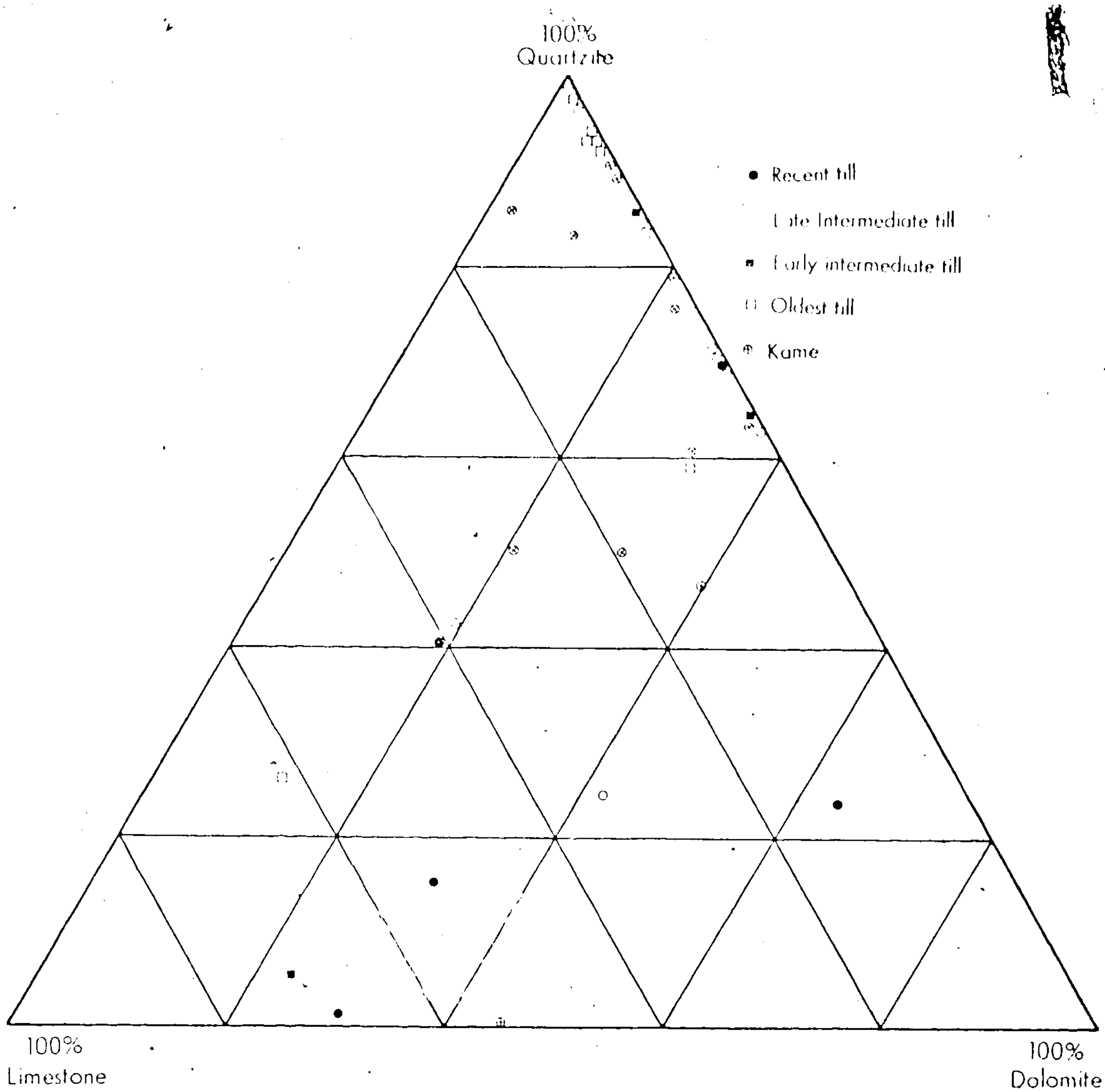


Fig. 18 Lithological composition of the samples

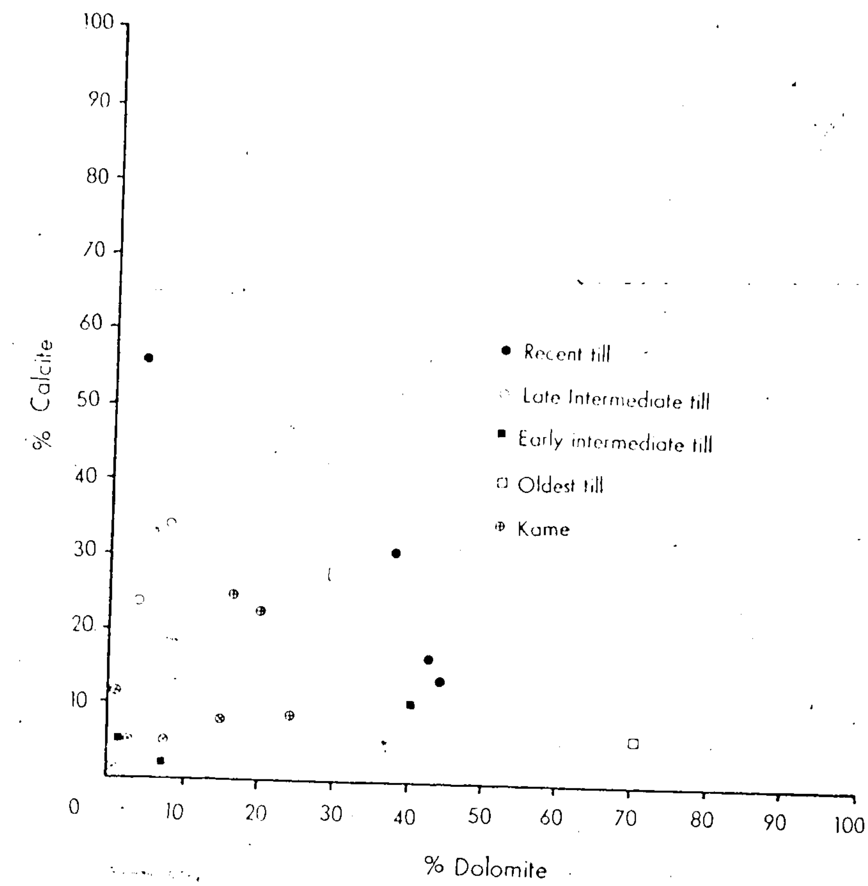


Fig. 19 Percent Dolomite versus percent Calcite.

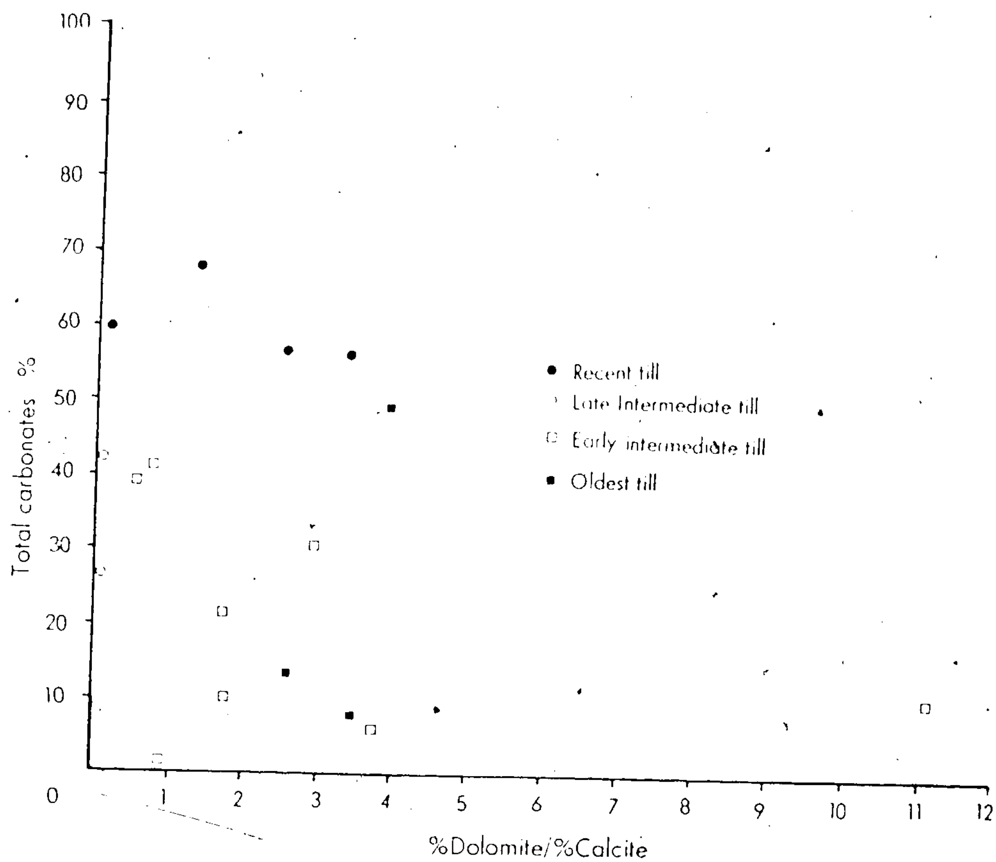


Fig. 20 Plot of % carbonates against %Dolomite/%Calcite

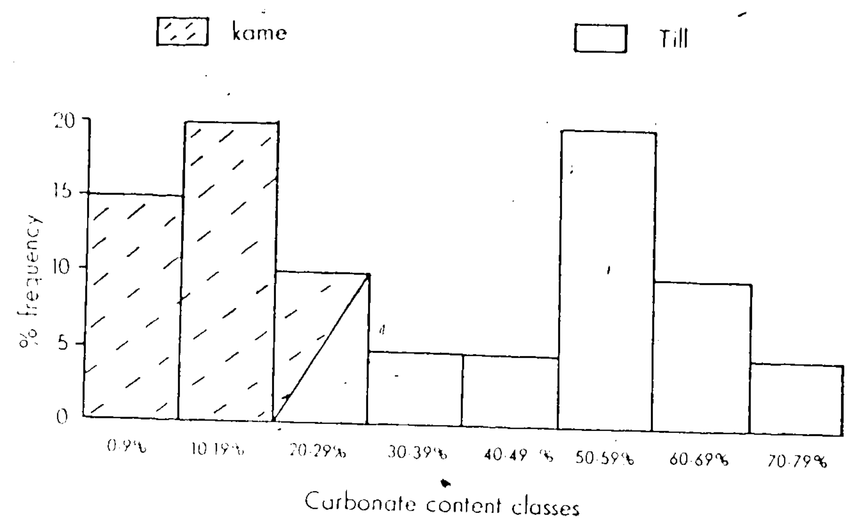


Fig. 21 Carbonate content versus frequency .

side of the graph. The tills found high on the valley walls occurring on or just below limestone and dolomite bedrock, occur on the right side of the graph. These tills have a high carbonate content, illustrating the strong localised influence of bedrock on the till lithology.

2. GLACIAL-FLUVIAL DEPOSITS

Two types of glacio-fluvial deposits occur within the study area 1. Kame terraces 2. Outwash sediments

A Kame terrace is an ice-contact stratified deposit built by stream deposition between a glacier and the side of a valley (Flint, 1971). They are commonly narrow and slope downstream. After the glacier melts, the sediment is often let down and the structure or sediments contorted. The top of the terrace is likely to be pitted by kettles, particularly so on its outer edge.

Outwash sediments consist of stratified material, mainly of sand and gravel. The outwash is built by streams beyond the glacier front and is usually well sorted. Often outwash takes the form of a valley train, which can be defined as a long narrow body of outwash filling the valley floor (Flint, 1971).

(i) Kame terraces

Two kame terraces are present in the study area, one associated with ice in the Cataract Brook Valley, the other with ice in Kicking Horse Pass.

The Cataract Brook kame terrace (Plate 7) occurs across the mouth of South Watchtower Basin at an elevation of approximately 1952m (6,400 ft). The stream draining the South Watchtower Basin has cut through the kame to a depth of twelve metres (forty feet). The kame terrace slopes downstream for just under half a mile (800 m) at an angle of 4°. Its upper surface slopes valleyward at 8° with a steep valley face of some 24°-26°. The top 45 cm. (1.5 ft) is comprised of a lag deposit of boulder and cobble size (Wentworth) stones. The grain size and lithological composition of the kame is shown in appendices A and C (sample 40). The average roundness is 0.31 and the surface stones have a weathered rhind averaging at 1cm (0.4 in).

The other kame terrace (Kicking Horse Kame) is associated with ice that flowed in an easterly direction through Kicking Horse Pass (fig 22). It traverses the mouth of the Cataract Brook Valley (Plate 10), and its upper surface is at an altitude of 1708m (5600 ft), sloping eastward to the head of the Pass. Across the Kicking Horse Pass is another less well defined kame terrace. The grain

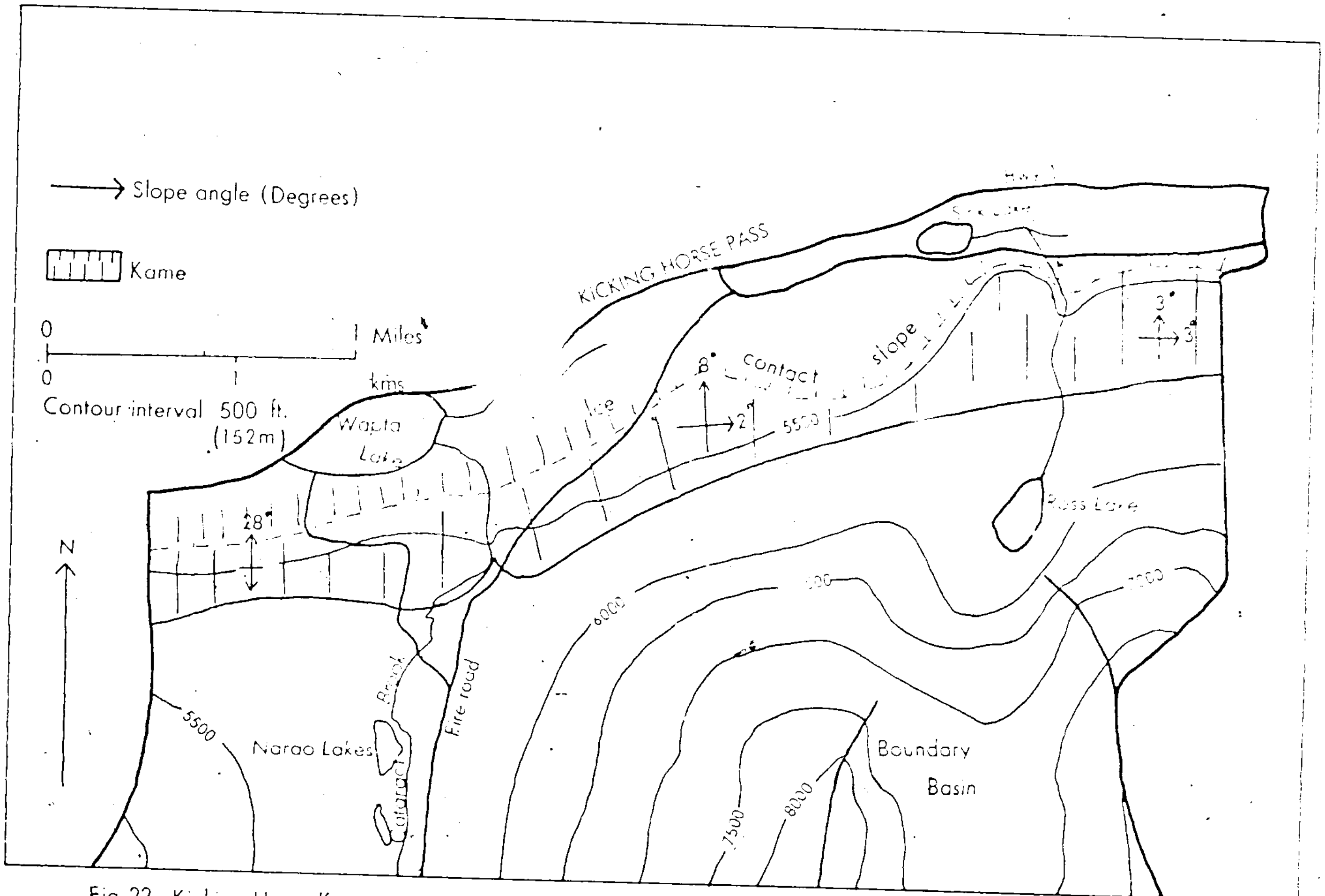


Fig. 22 Kicking Horse Kame

Plate 10 Kicking Horse Kame lying across the mouth of the Cataract Brook Valley.

size and lithologic composition can be found in appendixes A and C, (samples 28,29,30,31,32,33,34,35,36,37,38,39). To the west of the Cataract Brook the crest of the kame is flat and slopes at an angle of some 28°-30° towards the Kicking Horse Pass, and on the opposite side, slopes gently down to Narao Lakes. The roundness of the pebbles varies between 0.33 and 0.38 with the surface boulders having a weathered rhind averaging at 10mm (0.4 in.). Oxidation of the soil extends to 58m. (23 in).

To the east of the above section the Cataract Brook has eroded the kame terrace leaving remnants in the fo of elongate mounds running north and south. Further to the east the kame broadens out as far as the O'Hara car park (fig. 22). Here the kame has been exposed along the O'Hara fire road, and consists of sorted sands and well rounded gravels with some stratification. Pockets of silt, clay and fine sand, which are probably infilled kettle holes, are observable. Soil oxidation depths range between 53 cm and 58 cm (21-23 in.). Here the upper surface of the kame slopes down to the Kicking Horse Pass at an angle between 8° and 10°, with a steep frontal slope which is broken and appears to have slumped. At the outer edge of the broad section (fig. 22) pebble roundness is relatively high averaging 0.46. Patches of till occur with less rounded material.

Continuing eastwards there is a large indentation in the kame terrace, before the Ross Lake trail is reached (fig. 22). Here the outer face is some 15m (50 ft) high lying at an angle of 25°-30°. Its upper surface is narrow in width as it encroaches on the valley wall.

Still further east the kame terrace broadens, and has been cut through by the stream draining from Ross Lake. At this position the upper surface of the kame slopes down valleywards at an angle of 3°-4°, and the frontal face adjoining the Old Banff road lies at an angle of 27°-30° and is some 18-21 m (60-70 ft) high.

(ii) Outwash deposits

Outwash deposits are present in the valley bottom from Lake O'Hara to Narao Lakes, and exposed along the side of the O'Hara fire road some three to five metres (10-15 feet) above the Cataract Brook. The deposits consist of poorly to well sorted sands and gravels. The proportion of limestone and dolomite in the outwash increases downstream from the Watchtower basin alluvial fan. The strata dip gently downvalley, and the degree of sorting and roundness increases down-valley.

One hundred and eighty metres (200 yds) upstream from the Late Intermediate lobe shaped moraine extending from

South Vanguard Basin is a remnant of outwash. It occurs in the centre of the valley floor and is some three metres (10 ft.) high above the valley floor and thirty six square metres (400 sq. ft.) in area. Encroaching on the upstream side of the outwash remnant is an alluvial fan, which heads in an abandoned channel that cuts through a recessional moraine (fig. 7). Between the outwash remnant and the lobe shaped moraine are lacustrine deposits.

Upstream from the Kicking Horse kame is an area of outwash grading into Narao Lakes. It is comprised of eighty percent fire to coarse sand and twenty percent gravels. The soil on this outwash is relatively immature and appears to be younger in age than soils on the late intermediate moraines. Oxidation reaches to a depth of 12 cm (5 in) and the weathering rhind on the surface pebbles is less than 5mm (0.2 in.).

Outwash deposits in the form of a valley train, with a braided stream pattern, cover the valley floor of the South Watchtower basin from below the glacier snout to the lip of the basin. The surface of the valley train consists mainly of well rounded gravel size particles, with some large boulders.

In the Kicking Horse Pass section of the study area, outwash occurs throughout the valley bottom. It consists of stratified, moderately to well sorted sands and gravels.

3. RECENT DEPOSITS

Recent deposits within the study area consist of talus slopes and alluvial and colluvial fans. These are widespread throughout the area paticularly in the upper cirques. Since not all of the above features are of recent origin they will be described in the section on landforms.

4. GLACIAL ICE

At the present day, glaciers within the study area are very small in extent and restricted to upper portions of the cirques above the 2287 m (7500 ft) contour level.

Most of the glaciers are of the cirque type which are wholly confined to the cirque. The glaciers occurring on Mt. Huber and Mt. Victoria including the South Watchtower glacier are of the slab type, which lie outside the cirques on the mountain side.

LANDFORMS

The landform map(fig.7) is based on the interpretation of the surficial deposits and the ground surface morphology. The features identified are: 1. Ground, end and recessional moraines 2. Kames 3. Bedrock features 4. Lakes 5. Abandoned channels 6. Alluvial fans 7. Debris slopes 8. Breaks in slope 9. Periglacial features.

Ground, end and recessional moraines and kames have already been discussed under surficial deposits.

(i) Bedrock features

Cirques, rock steps, aretes, cols, horns, ice polished rock and U-shaped valleys are common throughout the study area, but are best developed in the upper portions of the Cataract Brook valley.

The Cataract Brook valley may be described as having a U-shape heading in upper cirque basins. The cirques are deep, ice-sculptured, bowl shaped basins with steep head and side walls. Examples of these are McArthur and Oesa basins, which occur at the head of the main valley. Other cirques, such as North and South Watchtower basins, occur as major indentations in the valley sides.

The coalescence of glaciers from the upper cirques formed a larger trunk glacier which widened and deepened the main valley. After the recession of the ice the tributary valleys (Vanguard, Duchesney, Oesa, Opabin, S. and N. Watchtower) were left as hanging valleys. The spurs on ridges between the tributaries having been truncated by ice erosion. A good example of a truncated ridge is seen on the east slopes of Mt. Biddle above Opabin Pass (Plate 5).

Growth of cirques by ice and frost erosion on opposite sides of a crest eventually reduces the crest to a knife edged form called an arete. Examples of aretes in the study area are the ridge between Popes Peak and Narao Peaks and the ridge between McArthur and Opabin basins.

Where two cirques enlarging towards each other cut through the ridge separating them, then a sharp edge gap or col with a smoothly curved profile results. Cols are found at the head of Opabin basin, one high up on the slopes of Mt. Biddle at 3050 m (10,000 ft) and a lower one which constitutes the present Opabin Pass. Biddle Pass, Odary Pass and Duchesney Pass are other examples of cols.

Three or more cirques being eroded inwards against a single high part of a mountain crest can sculpture the high part into a pyramid or horn, with several facets, each facet being the headwall of a cirque. Mt. Biddle and Cathedral Mountain are good examples of horns, each having four facets.

Smooth rock surfaces polished by ice movement over them can be seen in many places, particularly in Opabin, McArthur and the northwest corner of Duchesney basins. Stoss and lee topography can be observed in Opabin, McArthur and Oesa basins. Ice moving over a rock mass erodes a comparatively gentle slope on the upstream (stoss side) and a steeper, quarried slope on the lee side. Sometimes glacial material has been infilled on the lee side to present a smooth whaleback form with the long sloping tail of drift at the downstream end. An example of this form called crag and tail can be found in Cathedral basin.

A series of three rock steps is evident in Oesa basin, each tread containing a small lake. Probably these steps are not due wholly to glacial action, but also to bedrock structure.

The valley divides to the northeast and east of Oesa Basin and the arete forming the northeast wall of Cathedral Basin are very eroded and serrated. This appearance indicates that ice has not been at this elevation for a long period of time. This together with a truncated spur in the southeast corner of Oesa basin at 2897 m (9500 ft) and the truncated arete in Opabin Pass at 2865 m (9400 ft) approximately, indicates a possible ice elevation at between 2897-2865 m (9400-9500 ft) at the head of the valley. Also it is noticeable that ridges lying at or below 2897 m (9500 ft) eg. Mt. Schaffer - Mt. Biddle ridge, Yukness Mountain ridge and the divide at the head of Duchesney basin have a smoother appearance than the serrated divide and arete, even though the rock types of the ridges and skyline are in some instances the same. It is possible that the relative smoothness of these ridges resulted from ice erosion. An ice advance which had an elevation of 2680 m (9500 ft) at the head of the valley could possibly account for the lateral moraine remnant on the west slopes of Narao Peaks (sample 1)

(ii) Lakes

Lakes in the study area are of glacial origin and fall into two categories 1. Moraine dammed lakes 2. Rock basin lakes.

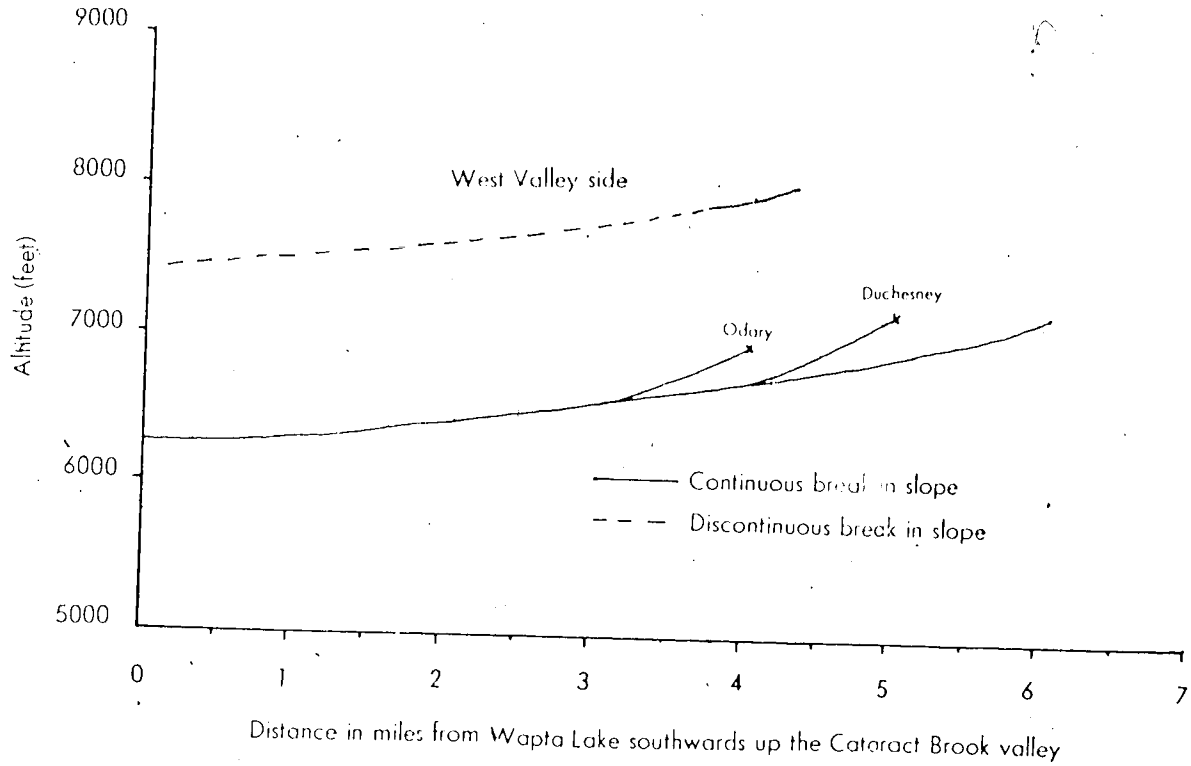
Examples of the former are Linda (Plate 5), Vera and Ross Lakes and of the latter category McArthur, Oesa and the lakes [illegible] Opabin Plateau. O'Hara Lake is likely a combination of the two categories of lakes. Its exit is dammed by moraine and a [illegible] ridge separates it from Mary Lakes but the other sid[illegible] lake are comprised of bedrock.

(iii) Break[illegible]

Breaks in slop[illegible] in[illegible] as [illegible] decrease in slope angle of the va[illegible] sed by either lateral stream action, or ice erodi[illegible] or [illegible] combination of the two.

Breaks in slope are be[illegible] pr[illegible]erved on the west and southwest facing sides of the [illegible]lley. On the southwest facing wall in Oesa basin and Opabin basin a break in slope can be observed at the 2440-2530 m (8000-8300 ft) level. The break can be traced almost continuously downvalley to the slopes of Narao Peaks where it is at an altitude of 2800 m (6100 ft), (fig.23). Generally the change in angle of the slope is from 23° on the upslope to 30° on the lower slope. On the ice smoothed buttress of Wixwaxy Peaks the break in slope is quite distinctive (Plate 11). Also on Narao Peaks another break in slope occurs at approximately 2074 m (6800 ft). Plate 12 shows a distinct change in colour. The line forming this change if continued southwards continues to the upper break in slope of Wixwaxy Buttress (Plate 11). The colour change was not viewed at close quarters, and so it is possible that the change is due to differing rock types.

On the western side of the study area a break in slope can be traced from the mouth of Cathedral basin at 2225 m (7300 ft) into the main valley. The change in slope is quite abrupt varying between 10°-15° on the gentler upslope to 30°-35° on the lower slope. This break cannot be traced continuously downvalley, but can be identified again on the lower slopes of Cathedral Crags, above Narao Lakes at 1890 m (6200 ft) (fig 23; Plate 7). A higher break in slope at 2440 m (8000 ft) is present on the S.E. ridge of Cathedral Mountain.



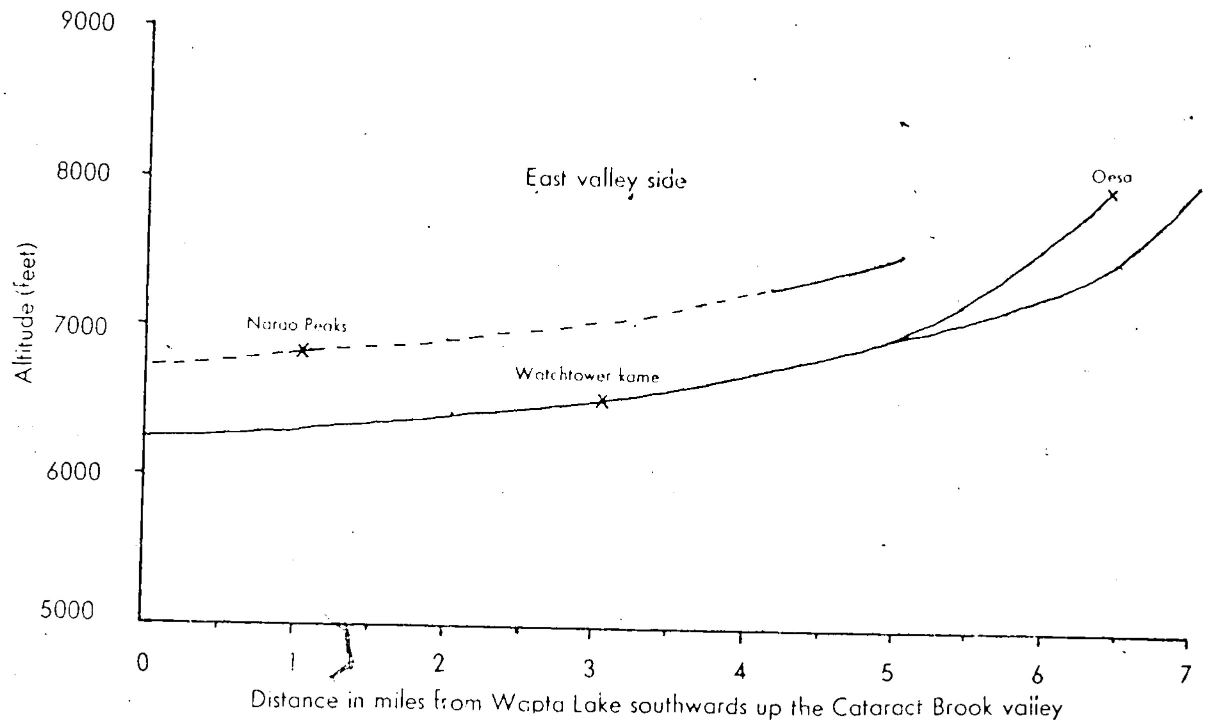


Fig. 23 Breaks in slope.

Plate 11 West buttress of Wixwaxy Peaks. Ice polished rock.

1. Breaks in slope.
2. Lateral channel.

Plate 12 West buttress of Wixwaxy Peaks, further to the south than plate 11. Colour change from light colour rock below to dark rock above.

1. Lighter coloured rock, less weathered and fresher than dark coloured rock.

2. Dark coloured rock.

The line forming the junction of the light and dark coloured rock is a continuation of the upper break in slope (Plate 11).

There is some doubt as to whether the breaks in slope can be attributed wholly to glacial action as the bedrock also dips northwards. However, the lower break in slope on the east side of the valley is associated with the kame terrace at the mouth of South Watchtower basin. Also the break on Wixwaxy Peaks buttress lies at a shallower angle than the dip of the strata. Further, the breaks if projected into the upper cirques are associated with slight colour changes on the cirque walls which are not related to changes in rock type. Both Opabin and McArthur basins show this colour change at approximately 2530 m (8300 ft). The rock above being darker than the fresher colour rock below. The line of the colour change slopes gently across the dip of the rock.

(iv) Abandoned channels

Two types of abandoned channels occur in the study area. 1. Lateral channels formed by meltwater along the edges of former glacial ice 2. Abandoned lake drainage channels formed during higher lake levels.

Two lateral channels are present in the area. One occurs on the west buttress of Wixwaxy Peaks slightly below the break in slope mentioned above (fig. 7; Plate 11). It slopes downvalley at a steeper angle than both the rock dip and the break in slope, and was probably formed close to the glacier snout during a pause in the ice retreat. In appearance it is quite fr a and its base is some three metres (10 ft) wide and water smoothed rock extends upwards for some six metres (20 ft). The preserved length of the channel is approximately 280 metres (300 yards).

A further lateral channel is situated at the extreme south east end of Yukness Ledge (Plate 13) at an elevation of 2395 m (7850 ft). Its length is 30 m (100 ft) and the water smoothed wall extends 6 m (20 ft) vertically (fig. 7; Plate 13).

On Opabin Plateau two abandoned spillways are present slightly above the present drainage lev . Both channels are eroded in bedrock and at present contain elongated lakes (fig.7).

Another abandoned lake channel, which runs in a northeast direction from Narao Lakes, was mapped It lies some 4-6 m (15-20 ft) above the present lake level and starts upstream from the recessional moraine. This channel can be traced to the valley floor in Kicking Horse Pass. A further channel can be traced at a lower elevation, but for only a short distance. Both channels are U-shaped and are incised into till and glacio- fluvial material.

Plate 13 Water smoothed rock of the lateral channel to the southeast of Yukness Ledge.

(v) Debris slopes

Talus slopes either in the form of cones or aprons are widespread throughout the study area, particularly in the upper cirques, and above the tree line.

Most of the talus is of recent origin, but two area of block fields composed of large angular blocks of bedrock up to three metres (10 ft) or more in diameter occur on either side of the mouth of Cathedral Basin, and at the base of the northwest arete of Yukness Mountain above O'Hara Lake. The block fields occur between 2287-2440m (7500-8000 ft) and appear to be older than the recent talus which is lighter in colour and has less lichen cover.

Pro-talus ramparts formed by the accumulation of debris at the base of snowbanks are present below the north buttress of Mt. Schaffer, and below Odary Mountain in Duchesney basin. Only the latter protalus rampart was visited. Its outer rim is semi-circular in shape and supports a thin soil with grasses and moss. Directly beneath the cliff, inside the rampart, the debris is quite fresh (fig. 7).

Three rock glaciers were mapped in the study area (fig. 7). Two are present below the north facing wall of Duchesney basin and are of the lobate type, with length less than width (Wahrhaftig and Cox, 1959). The third rock glacier occurs on Opabin Plateau at the base of the northeast facing wall and is of the spatulate type (tongue shaped but with enlargement at the front). They occur at an altitude between 2225-2287 m (7300-7500 ft), and are situated beneath active talus slopes, from which they derive their debris.

The rock glaciers consist at their frontal slopes of two layers; an upper layer consisting predominantly of coarse blockly rubble from 0.2-1.0 m (1.5-3.0 ft) in maximum diameter. The thicker lower layer is comprised of finer material with fewer boulders (Plate 14).

The micro-topography of the upper surfaces of the lower Duchesney rock glaciers consists of ridges and furrows which parallel the flow of the rock glacier. A series of ridges also run across the snout of the rock glacier transverse to the flow. The ridges are comprised of smaller stones than are found in the furrows. The other two rock glaciers exhibit a series of intersecting lobes on their upper surfaces.

The following evidence indicates that the rock glaciers are active:

1. Absence of vegetation on the upper surfaces.
2. Fresh appearance of the frontal slopes.

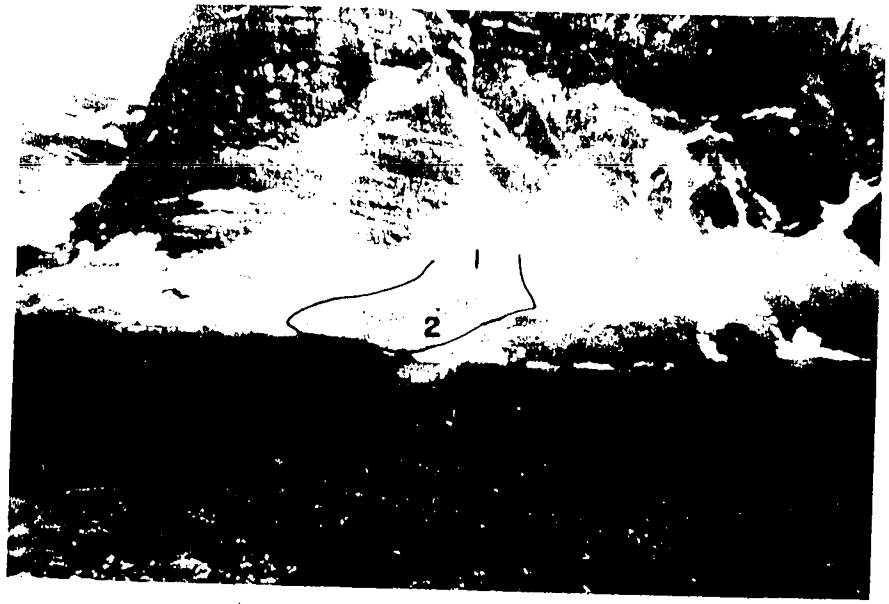


Plate 14 Rock glacier in Lower Duchesney Basin. Ridges on upper surface.

1. Rock glacier.

2. Fresh steep face of rock glacier.

3. The channel in front of the rock glacier separates the Late Intermediate moraine systems of Upper and Lower Duchesney Basin.

3. Sharp angle between the front and upper surface.

Water was observed flowing from the Lower Duchesney rock glacier at the end of the field season in August. The snow having melted from the upper surfaces in June. This perhaps indicates the presence of ice within the rock glacier.

The rock glaciers in Lower Duchesney and on Opabin Plateau appear to be overriding older rock glaciers which are darker in colour and show degraded frontal slopes.

The block fields, pro-talus ramparts and the older rock glacier suggest a period of time in the past that was colder, but in which ice was not present at the altitude of their location. They have since became inactive. The fresher more recent rock glaciers indicate a return to colder conditions in the not too distant past.

(vi) Alluvial fans

A large currently active fan has been built on the Cataract Brook valley floor by the stream from South Watchtower Basin. At its base it is some 823 m (2700 ft) in width with a height from base to apex of 15-18 m (50-60 ft). It is comprised of well-rounded, stratified sand and gravel.

The exposure in the gravel pit at its base shows 2.5-3.0 m (8-10 ft) of sand and gravel overlying 15 cm (0.5 ft) of fine sand. Below this fine layer further sand and gravel occurs.

A small alluvial fan occurs at the east end of O'Hara Lake (fig. 7) where the drainage from Oesa basin emerges. This fan consists of large boulders derived from the moraine above. It is older than the S. Watchtower fan being darker in colour with a ground cover of grasses and moss with some tree growth.

After the dep ition of the Late Intermediate moraines in the vicinity of O'Hara Lake, a small lake was formed at the present site of the O'Hara meadows. An alluvial fan (fig. 7), which slopes gently down to the east, was formed by drainage from McArthur pass. Old stream channels are present on the surface of the fan.

(vii) Periglacial features

Blockfields, rock glaciers and pro-talus ramparts are periglacial features and have been discussed under debris slopes.

Solifluction stripes consisting of alternating fine and coarse bands of debris occur above the treeline, on steep valley sides (25°-30°), on slopes that are not subjected to avalanches or snow slides. The solifluction stripes are particularly well developed on the east slopes of Narao Peaks and Wixwaxy Pass.

Solifluction lobes occur in Cathedral Basin on gently sloping ground (3°-8°). The steps of the lobes have a height ranging between 10-15cm. (4-6 in) with the length of the tread some 61-122cm. (2-4 ft). The lobes are predominantly of the turf bank type with treads relatively bare of vegetation and a thickly vegetated step.

Stone circles occur on the alluvial flats in Duchesney basin.

CHAPTER V

GLACIAL HISTORY

From the evidence presented in the previous chapter at least four glacial episodes have occurred in the Cataract Brook Valley. The evidence is based primarily on the characteristics of till and their associated landforms. In the following discussion a series of events is proposed to account for the surficial deposits and landforms.

Sometime during the Pleistocene ice advanced down the valley attaining an altitude at the head of the valley of approximately 2897m (9500 ft). Almost certainly the ice was not restricted entirely to the valley but was in contact with ice in adjacent valleys via McArthur, Opabin, Biddle and Duchesney Passes (fig. 24). During the recession of the ice the oldest moraines were deposited. A pause or minor readvance after the deposition of the oldest moraines on Narao Peaks is perhaps indicated by the break in slope at 2135m (7000 ft) below the oldest moraines on Narao Peaks, and in the central portion of the valley at 2440m (8000 ft) approximately. The position to which the ice retreated is not known.

A second relatively major advance followed (Early Intermediate) which joined ice in Kicking Horse Pass (fig. 25) and flowed to the east as shown by the easterly downward

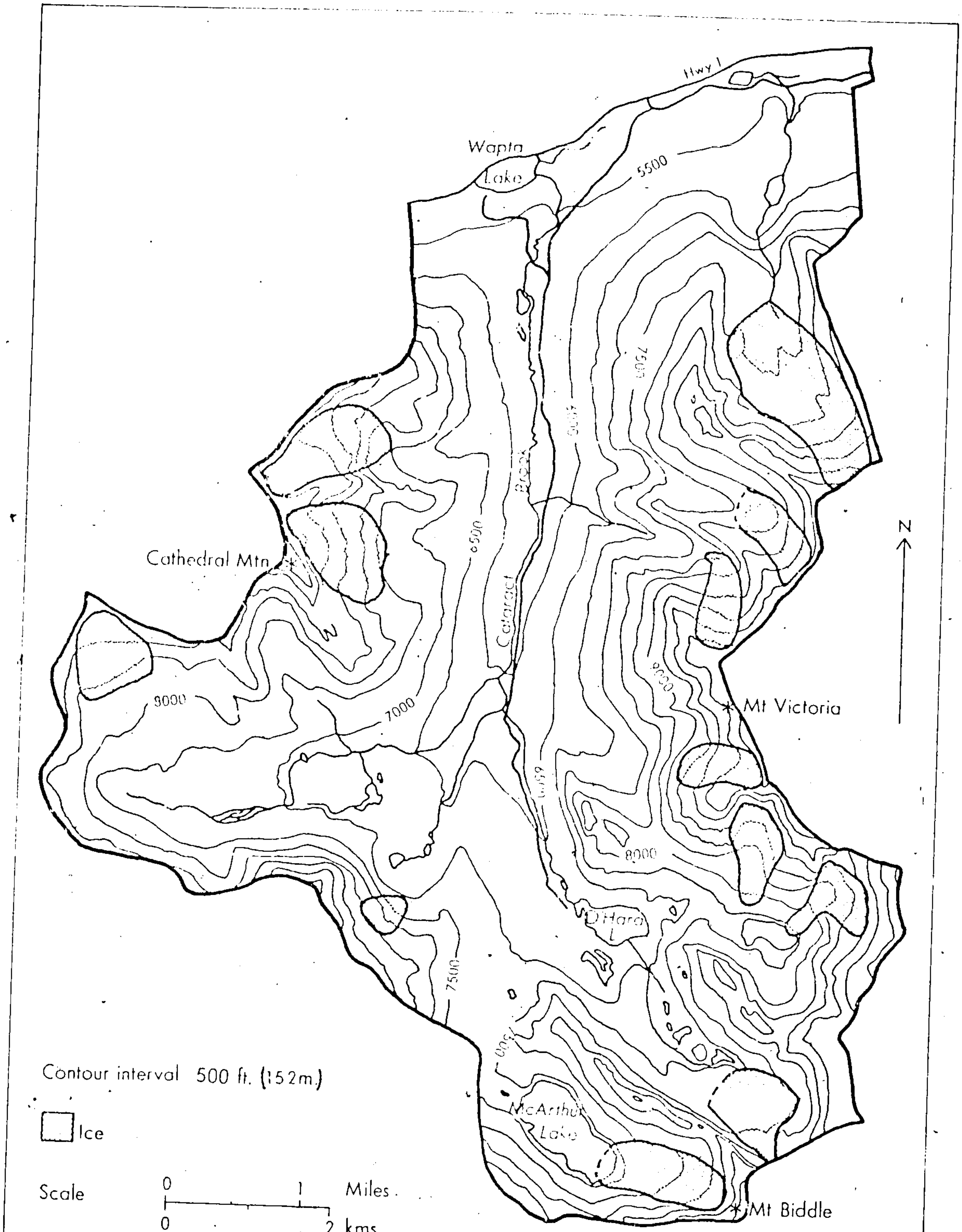


Fig. 24 Extent of Recent ice advance

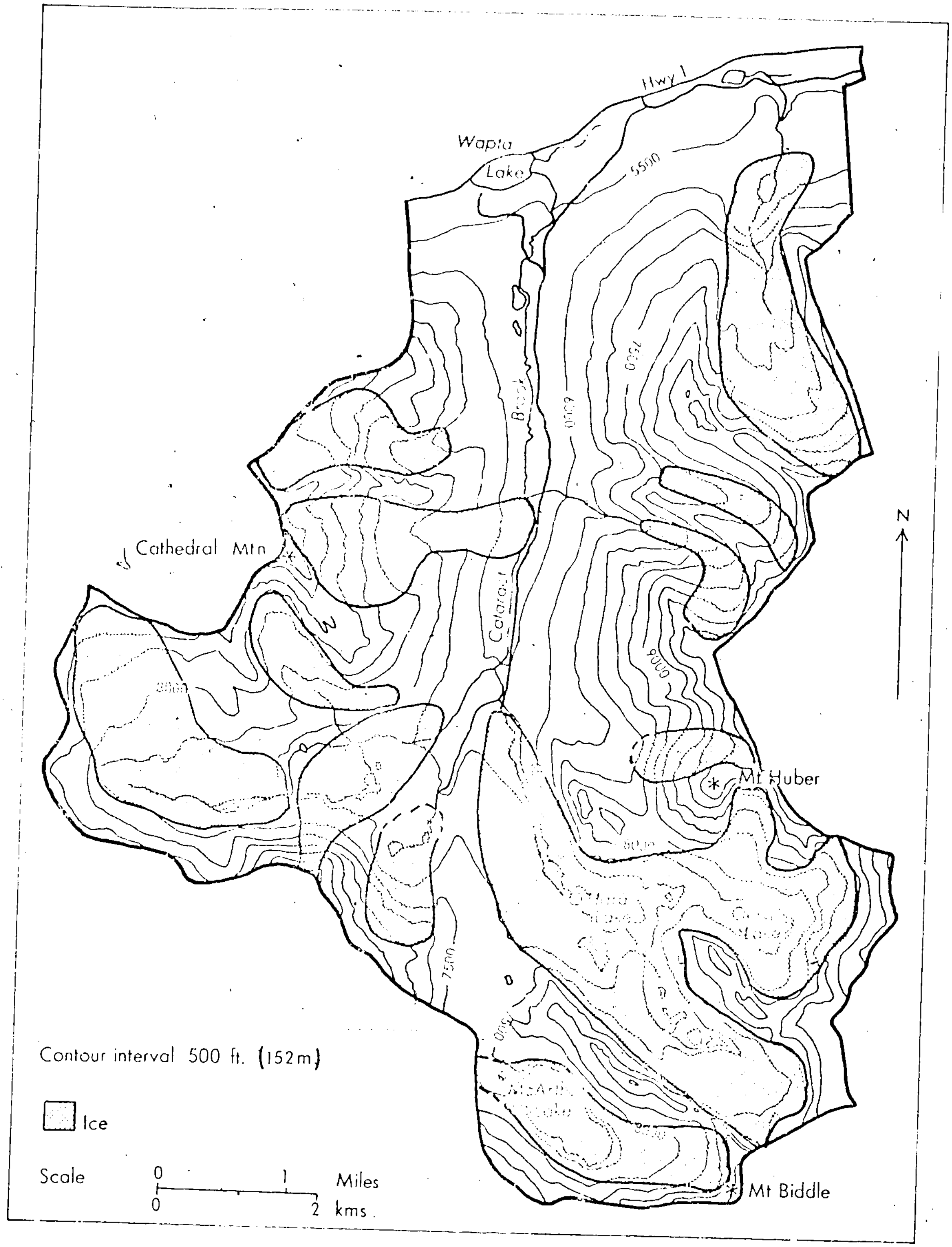


Fig. 25 Extent of Late Intermediate ice advance

slope of the kame. This ice also flowed out of the valley via McArthur Pass depositing till on the floor of the pass. The till is similar to the Early Intermediate till occurring in the northern portion of the study area. The ice in the pass was quite thin as it did not destroy the oldest moraines, so giving an altitude of ice at this position between 2195-2255m (7200-7400 ft). Colour changes on bedrock at the head of McArthur and Opabin basins indicate that the ice attained an elevation of 2440m (8000 ft), at least at its head. The lower, almost continuous, break in slope on the east side of the valley and the discontinuous break in slope on the west side probably indicates the maximum altitude of the ice. At the ice maximum, meltwater flowing between the ice and the valley sides deposited the kame terrace at the mouth of South Watchtower Basin.

Recession of the ice followed to a point where the Cataract Brook ice became separated from the ice in Kicking Horse Pass. At this time there was a stillstand or reduced rate of ice retreat, and the Kicking Horse Kame was deposited. Further recession followed, with another stillstand indicated by the recessional moraine in the central portion of the valley.

A lake was formed downvalley from the recessional moraine and extended to, and was dammed back by the kame across the valley mouth. The lake level was at least 4.5 m (15 ft) above the present level of Narao lakes, as shown by the abandoned channel, and drained away to the northeast. A lowering lake level is indicated by a second lower drainage channel also running to the northeast. Later the lake drained through the kame, as shown by abandoned stream channels cut through the kame. The kame remnants run in a north/south direction and indicate that the position at which the lake drainage entered the Kicking Horse Pass moved gradually westwards to its present position. Probably this movement of the lake drainage resulted from the drainage in Kicking Horse Pass ceasing to flow to the east and beginning to flow to the west. Presumably at this time ice had disappeared from Kicking Horse Pass. At its head the lake began to infill with glacio-fluvial material as shown by the remnant of outwash just downvalley from the recessional moraine. The extent to which the ice retreated is not known but the position of the Late Intermediate moraines indicates that the ice retreated to a position very close to its source.

A further relatively minor advance (Late Intermediate) of ice from Oesa and Opabin basins reached a position opposite the mouth of Wixwaxy basi.. (fig. 26). This ice reached an altitude of 2135m (7000 ft) between O'Hara Lake and McArthur Pass. Probably during the maximum extent

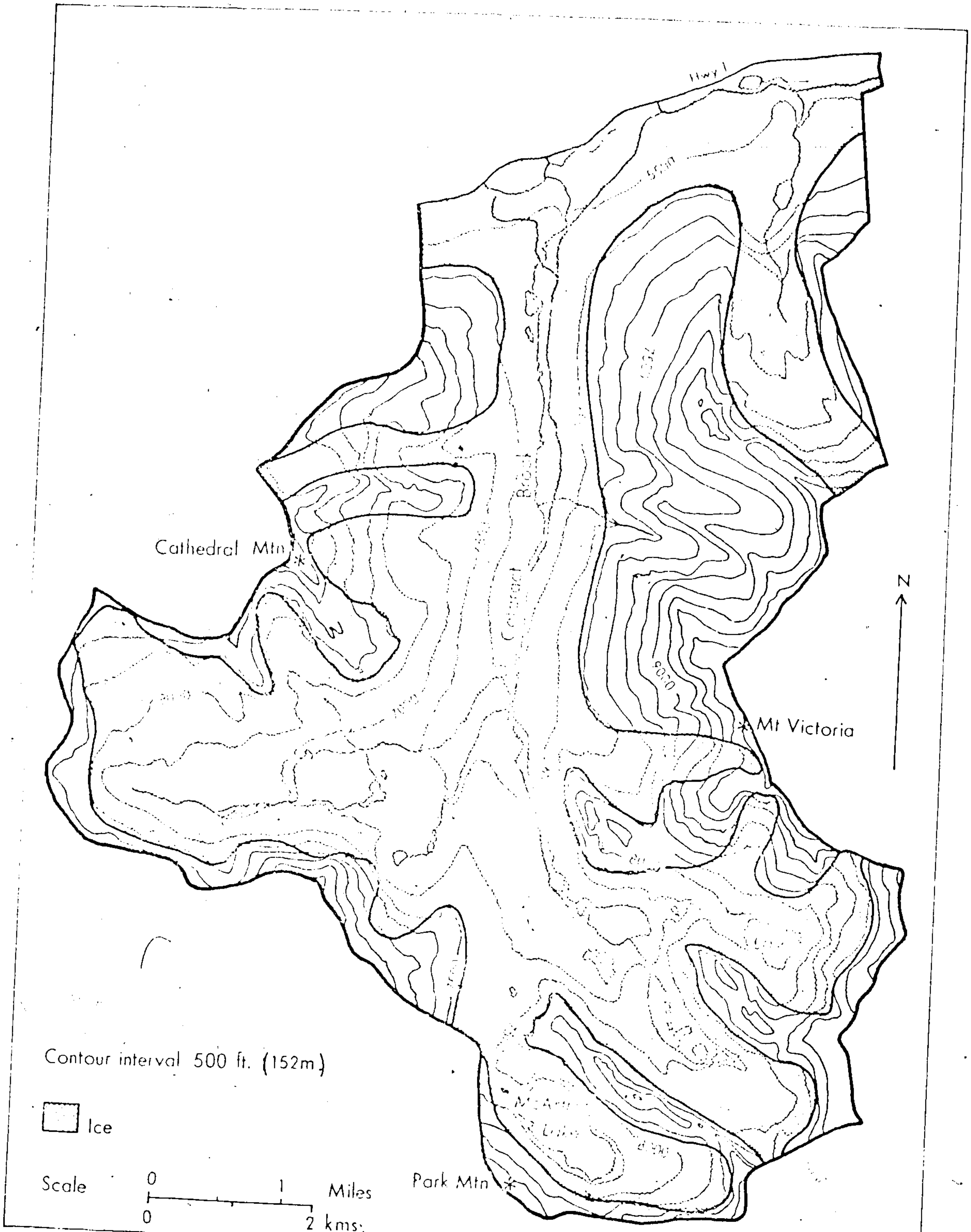


Fig. 26 Extent of Early Intermediate ice advance.

of this ice the two ice marginal channels were eroded in bedrock on Wixwaxy buttress and Yukness ledge. Also two bodies of ice advanced into Duchesney basin, one from the northwest, and the other from Odary Mountain. A further body of ice emerged from South Vanguard basin across the floor of the Cataract Brook valley, to abutt the east wall. Also ice from Boundary Basin emerged a short distance into Kicking Horse Pass. No evidence was found to indicate that ice in North and South Watchtower basins emerged into the main valley.

The recession of this ice occurred in a stop-go manner, with at least eight pauses or reductions in the rate of retreat as shown by the recessional moraines in Upper Duchesney basin. The other bodies of ice retreated in the same manner but the moraines indicate fewer stillstands. Alternatively some moraines may not have been deposited during each standstill or some of the recessional moraines may have been destroyed by erosion. The recessional moraines dammed Ross, Vera, Linda, O'Hara, Mary lakes and a lake on the site of the O'Hara meadows at this time. Meltwater draining in upper Duchesney follow the depressions between the moraine ridges and flowed into a lake on the southside of Duchesney basin. This lake has since been infilled. Drainage of the O'Hara end-moraine system also followed the depressions. The lake on the site of the O'Hara meadows has since drained through the two lower moraine ridges into Cataract Brook to form the present day drainage system. Also during the time the lake occupied the site of the O'Hara meadows it was partially infilled with alluvial sediments. Drainage from the O'Hara and Duchesney moraine systems probably flowed into a lake dammed by the Late Intermediate moraine across the valley from South Vanguard basin as indicated by the alluvial flats upvalley from this moraine. The lake was drained by a channel cut through the east end of the moraine. The channel is presently occupied by the Cataract Brook.

The final recession of the ice appears to have been relatively fast as very little moraine occurs on the floors of upper cirques, and the lateral moraines at the edges of McArthur and Opabin basins are quite small.

In the interval that followed before the advance of the recent ice the pro-talus ramparts, block fields and rock glaciers of two ages were formed, probably indicating two cold periods.

The most recent ice advance (fig. 24) is very small in extent, and limited to the extreme upper portions of the cirques. The gre st advance appears to have occurred in Boundary basin with ice advancing 1600 m (one mile) from the cirque headwall. The terminal moraines of this

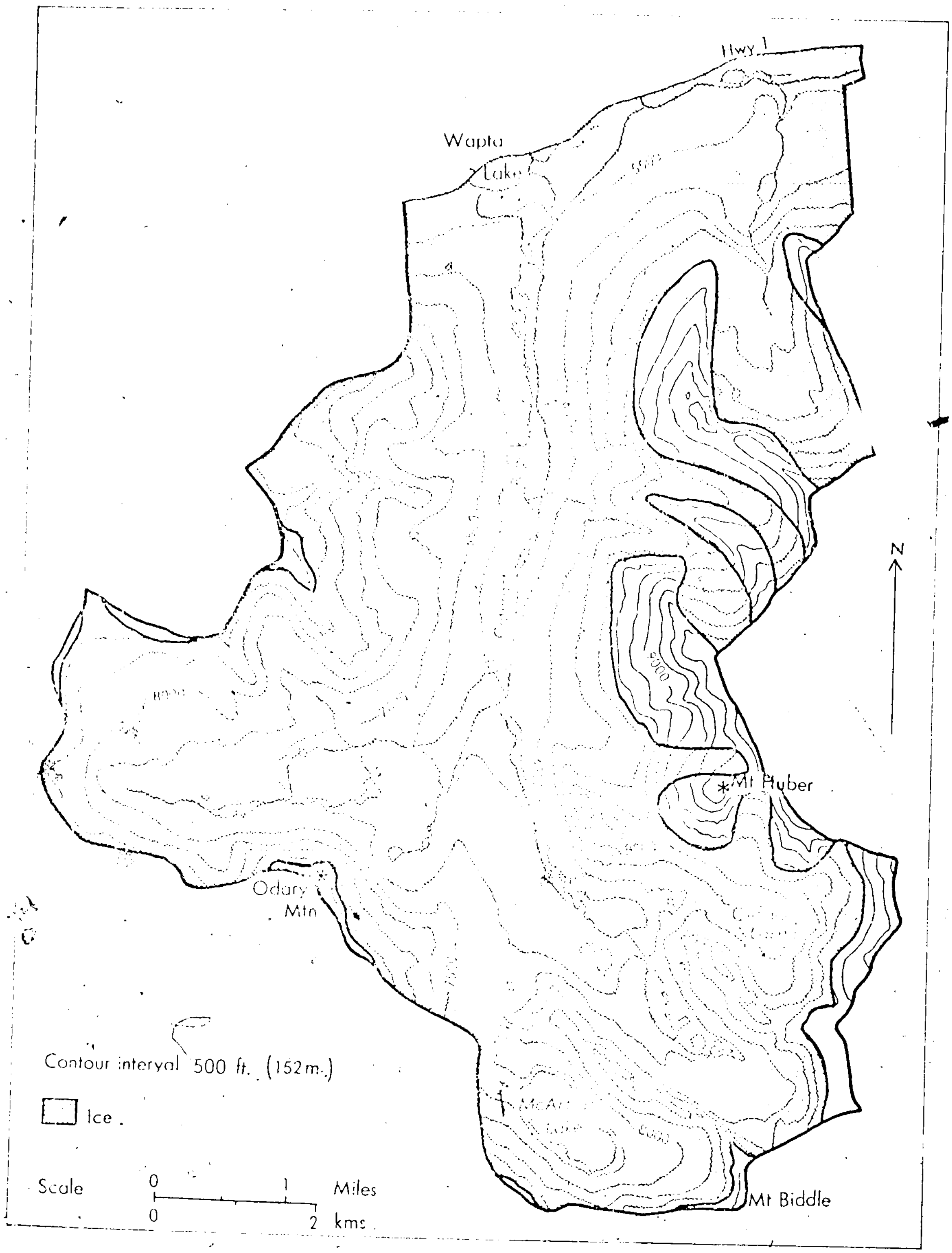


Fig. 27 Extent of Oldest ice advance

advance are quite distinctive and indicate a long pause before recession. Only one small pause in the ice retreat has occurred. The ice is at the present day still receeding.

Alluvial and colluvial fans and debris slopes began to form as the ice melted and areas were uncovered. These features are being modified at the present day.

Chronology

Only one date was determined for the ice advances. Photographs in the Canadian Alpine Journal (Vols.5,6,7,&9) show that the recent ice advance reached its maximum around the early part of the century or the late part of the last century.

Ash was found on McArthur Pass, and in the O'Hara meadows. The ash in McArthur Pass was incorporated with organic matter and mineral soil and was in a layer two inches thick almost at the surface. The ash in the meadows was throughly mixed with the mineral soil at least to a depth of six inches. This is probably due to washing of the ash from McArthur Pass together with other sediments, indicating that the late intermediate tills are probably younger than the age of the ash. Unfortunately the ash on McArthur Pass was mixed with the mineral soil to some extent, so the determination of the type of ash could not be undertaken with any degree of precision. An analysis of the glass shards gave a refraction of 1.50-1.51. These figures fall within the range of refraction of Mazama, Bridge River, and St. Helens Y ashes found in Banff National Park (Westgate and Dreimanis, 1967). However, the ash contains oxyhornblende, only small amounts of clinopyroxene and biotite is absent. This composition, together with the fine sand-silt texture, implies that the ash is Mazama (personal communication, J.A. Westgate). Westgate and Dreimanis (1967) found five inches of Mazama ash but only two inches of Bridge River ash. Westgate and Dreimanis reported a date for the Mazama ash at 6600 yrs. B.P.

Rutter (1966,1972) found an ash layer three inches thick near the Hoodoos east of Banff, and considered it most likely to be Mazama ash. It was incorporated within a wind blown deposit and appears to have fallen during a time of sparse vegetation. This could mean a drier, warm period, perhaps near the beginning of the altithermal, 6500-4000 yrs B.P. (Richmond, 1965).

If the ash found in the study area is Mazama then the oldest and early intermediate tills are of pre-Altithemal age and the late intermediate is of Neoglacial age (post-Altithemal).

The date of the possible Neoglacial moraines (Late

Intermediate) is not known. However Heusser (1956) dated a moraine beyond the recent moraine of the Yoho glacier, Yoho Natinal Park as at least 500 yrs. old. This moraine was clothed with Englemann spruce up to 38 m (125 ft) tall. The spruce trees on the late intermediate moraines were about 24-27m (80-90 ft) tall.

Correlation

Rutter (1966,1972) worked in the Bow valley, where his area of study extended to near Lake Louise, some eight miles down the Bow valley from the mouth of the Cataract Brook valley. A tentative correlation is made between Rutter's Eisenhower Junction advance with the oldest advance of this study on the basis of ice elevations (fig. 28). The oldest advance at least reached an elevation of 2315 m (7600 ft) on the slopes of Narao Peaks. Rutter's Eisenhower Junction advance attained an elevation of 2010 m (6600 ft) just downvalley from Lake Louise. Rutter considered the Eisenhower Junction advance as the last major advance in the Bow Valley. He gave a tentative minimum date for deglaciation of the Eisenhower Junction advance of 9330±170 yrs. B.P. which would agree with the pre-Mazama age of the oldest tills. Rutter placed the Eisenhower Junction advance in the latest stade of the Pinedale glaciation in late

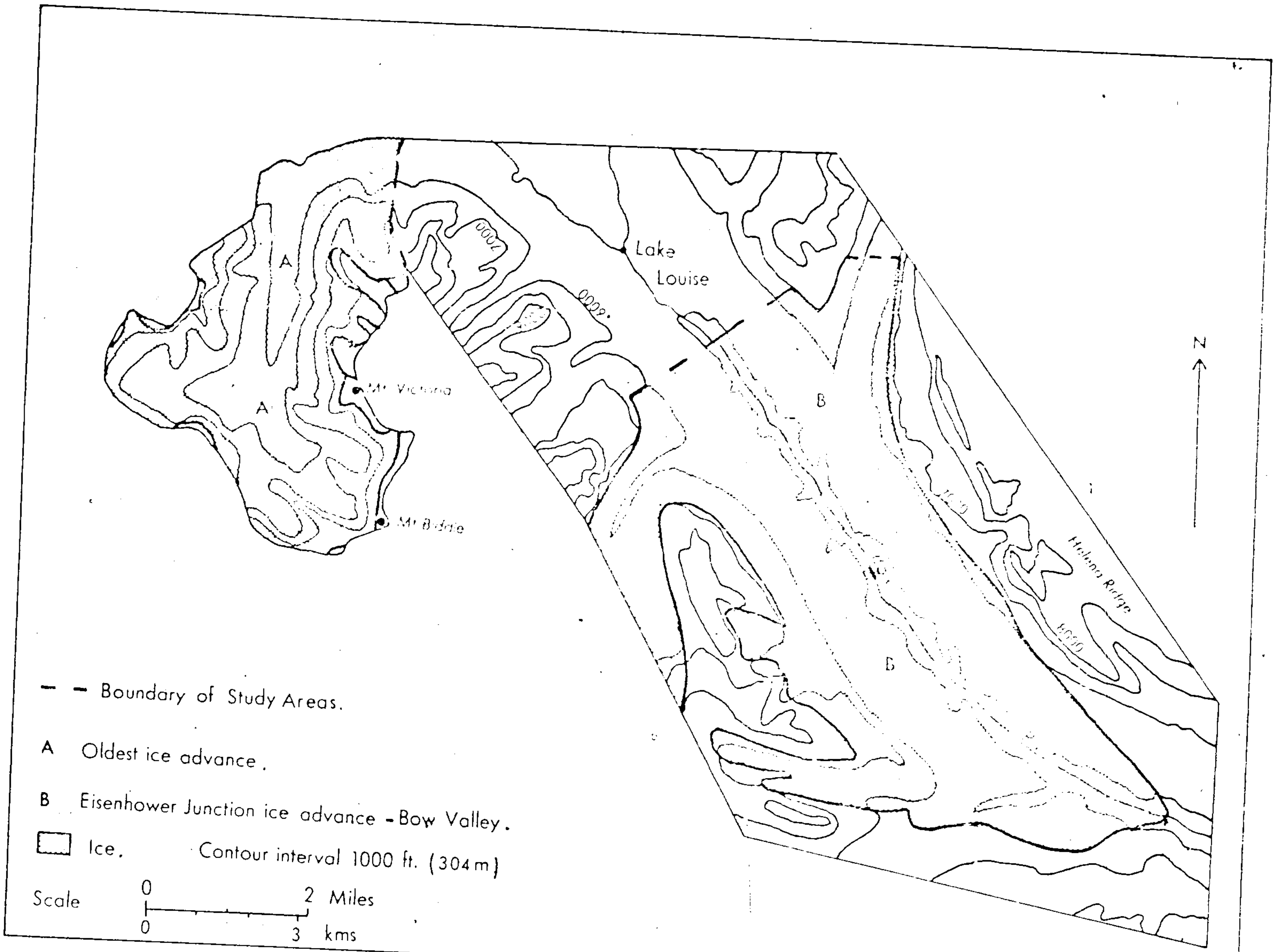


Fig. 28 Regional correlation of ice altitudes.

Wisconsin times.

It should be pointed out that the correlation is tentative and the ash on McArthur Pass is not known to be positively Mazama.

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APPENDICES

APPENDIX A

GRAIN SIZE ANALYSIS

Till Unit	Sample	Location	Gravel%	Sand%	Silt%	Clay%
Recent						
	1	Oesa	87	11.6	1.2	0.2
	2	Oesa	68	22	8.6	1.4
	3	S. Watchtower	60	20	16	4
	4	McArthur	70	19	10	1
	5	S. Varguard	57	32	9	2
Average			68.3	21.0	9.0	1.7
Later Inter.						
	7	Upper Duch.	46	34	18	2
	8	Lower Duch.	60	22	14	4
	9	O'Hara	79	13	7	1
	10	Boundary	37	43	16	4
	11	S. Watchtower	75	20	4	1
	12	O'Hara	83	14	2	1
	13	O'Hara	76	20	3	1
Average			65	24	9	2
Early Inter						
	14	[illegible]es of [illegible]n. Crags	67	26	6	1
	18	Slopes of Narao Pks	63	20	15.5	1.5
	19	Lat. Moraine	51	13	25	11
	20	Rec. Moraine	28	28	35	9
	22	Rec. Moraine	36	39	20	5
	23	Slopes of Narao Pks	53	35	11	1
Average			50.8	26.5	18.7	4.[illegible]
Oldest						
	25	Odary Lookout	36	46	16	2
	2	Slopes of Narao Pks	57	24.5	18.1	0.4
	27	McArthur Pass	48	30	20	2
Average			47	33.5	18.3	1.2

Kame

28	Kicking Horse	50	34	13	3
29	Kicking Horse	69	24	[illegible]	1
30	Kicking Horse	28	36	29	7
31	Kicking Horse	77	18	4	1
32	Kicking Horse	27	47	20	6
33	Kicking Horse	71	18	9	2
34	Kicking Horse	36	39	20	5
35	Kicking Horse	53	35	11	1
36	Kicking Horse	74	21	4	1
37	Kicking Horse	65	24	9	2
38	Kicking Horse	37	49	12	2
39	Kicking Horse	45	29	20	6
40	Cataract Brook	56	34	8	2

APPENDIX B

SLOPES (DISTAL) OF MORAINES

Age of Moraine	Degrees	Average Slope (degrees)
Recent	28	
	30	
	31	
	32	31
	33	
	33	
	35	
Late Inter.	20	
	22	
	23	
	24	
	25	27
	25	
	26	
	26	
	30	
Early Inter.	18	
	19	
	20	20
	20	
	21	
Oldest.	25	
	26	26
	27	
	29	

APPENDIX C

LITHOLOGY

Age	Sample	Shale%	Limst%	Dol%	Quartzite%	Shaly Limst%
Recent						
	1	50	0	27	23	0
	2	0	53	31	16	0
	3	0	40	20	40	0
	4	0	70	29	1	0
	5	4	11	64	21	
Late Inter.						
	7	0	26	18	56	0
	8	0	19	30	51	
					0	
	9	0	0	38	62	0
	10	0	0	1	99	0
	6	0	38	40	22	0
	12	0	0	32	69	0
	13	0	0	16	84	0
	11	0	37	27	36	0
Early Inter.						
	14	0	0	5	95	0
	15	0	0	8	92	0
	16	0	62	11	27	0
	17	0	0	18	82	0
	18	0	0	0	100	0
	19	0	11	2	86	0
	20	0	0	2	98	0
	21	0	0	6	94	0
	22	0	8	33	59	0
	23	0	0	4	96	0
	24					
Old						
	25	0	9	24	5	62
	26	0	0	15	85	0
	27		0	38	62	0

Kames

28	0	0	27	73	0
29	0	0	5	95	0
30	0	14	30	47	0
31	0	56	44	0	0
32	0	0	11	89	0
33	0	7	10	83	0
34		0			
		11	2	87	0
35	0	0	10	90	0
36	0	29	19	52	0
37	0	19	31	50	0
38	0	0	31	69	0
39	0	1	23	76	0
40	0	7	32	61	0

APPENDIX D

CARBONITE CONTENT - CALCITE-DOLMITE RATIO

Age	Sample	Calcite %	dolmite %	Total Carbonate %
Recent				
	1	0	0	0
	3	30	38	68
	4	56	4	60
	5	16	42	58
Late Inter.				
	6	23	4	27
	7	0	0	0
	8	0	0	0
	9	0	0	0
	10	0	0	0
	11	34	8	42
	12	0	0	0
	13	0	0	0
Early Inter.				
	14	0	0	0
	15	0	0	0
	16	0	0	0
	17	1.5	14	15.5
	18	10	40	50
	19	0	0	0
	20	0	0	0
	21	0	0	0
	22	2	7	9
	23	0	0	0
	23	0	0	0.
Oldest				
	25	6	0	6
	26	0	0	0
	27	0	0	0

Kame

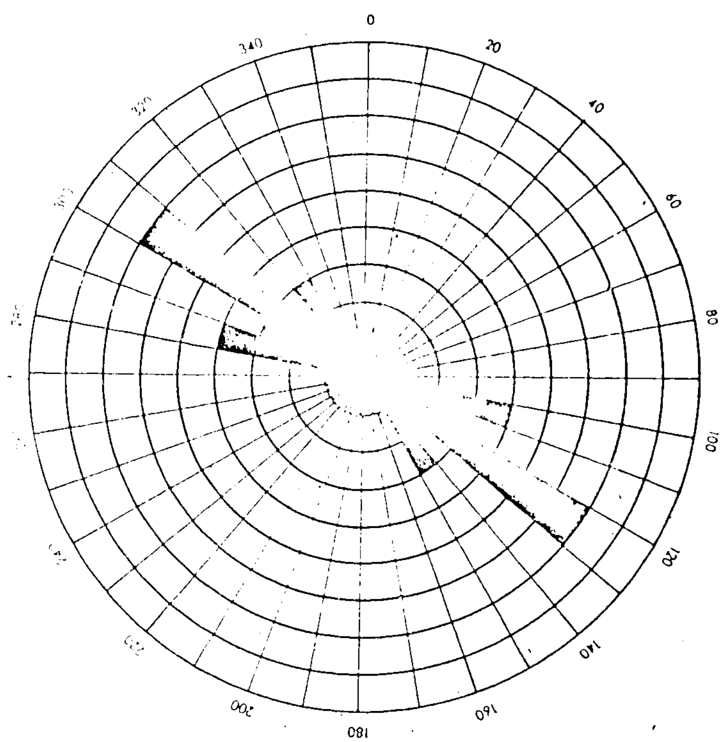
28	0	0	0
29	0	0	0
30	8	14	22
31	22	20	42
32	0	0	0
33	4	7	11
34	2	7	9
35	0	1	1
36	0	11	11
37	8	24	32
38	0	0	0
39	24	16	40
40	8	3	11

APPENDIX E

TILL FABRIC ROSE DIAGRAMS

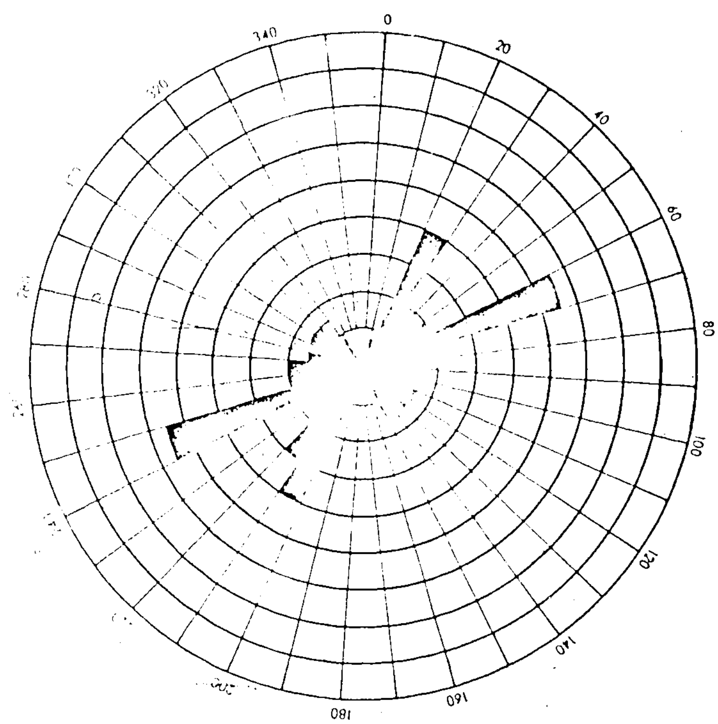
Till fabric of the recessional moraine downvalley from Narao Lakes. Fabric measured on moraine crest.

Circles at 2 pebble frequency.
50 observations.



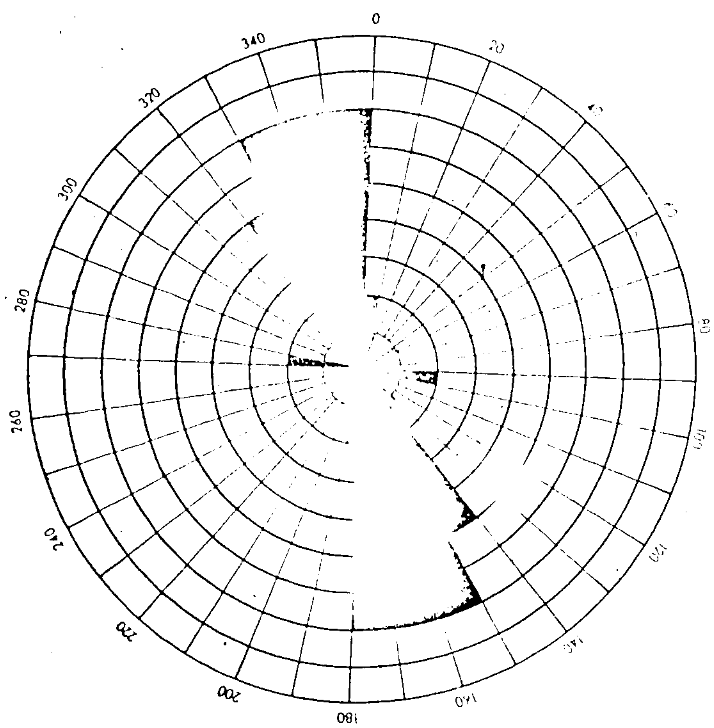
Till fabric of the Early Intermediate moraine 800m (0.5 mile) north of McArthur Pass. Fabric measured on moraine crest.

Circles at 2 pebble frequency.
50 observations.



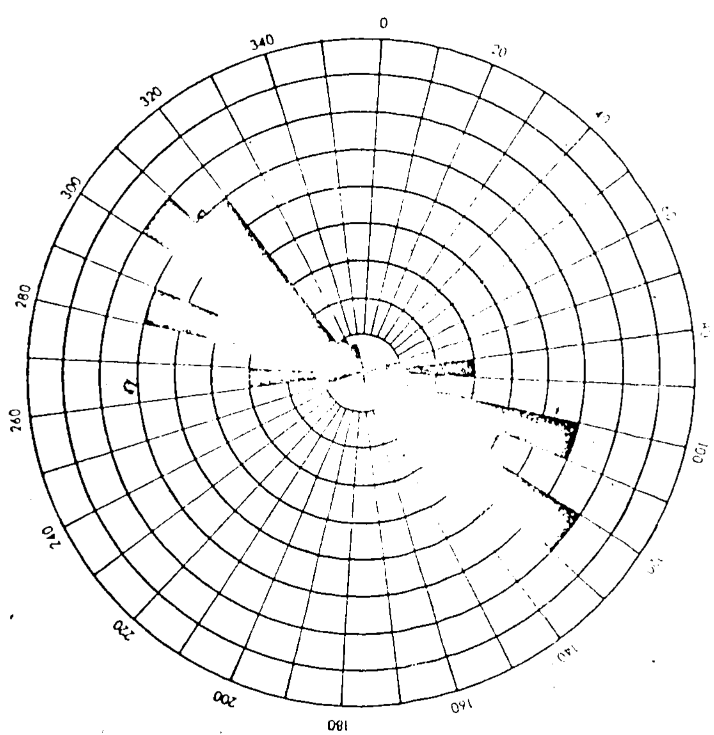
Till fabric of Oldest moraine above McArthur Pass. Fabric measured on moraine crest.

Circles at 2 pebble frequency.
50 observations.



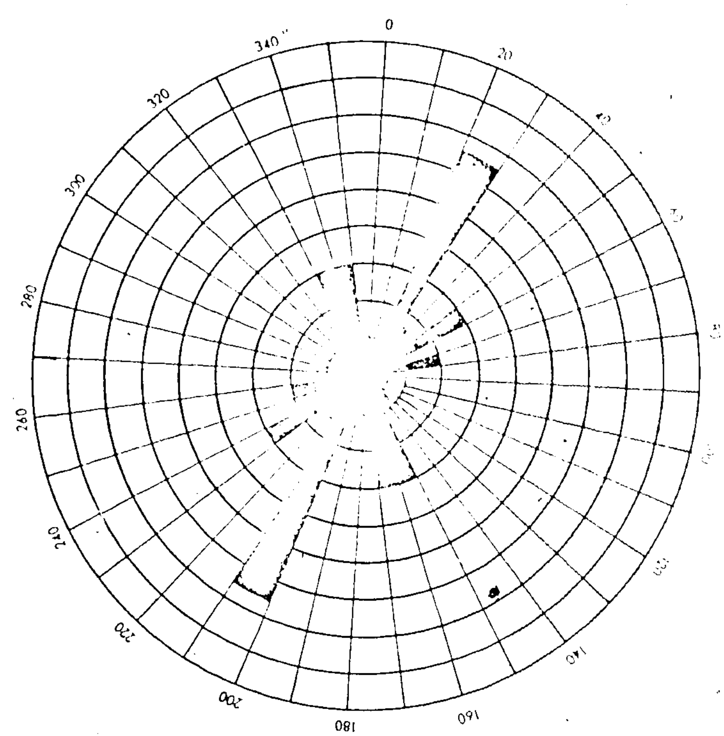
Till fabric of the Late Intermediate moraine at the mouth of Southwatchtower Basin. Fabric measured on moraine crest.

Circles at 2 pebble frequency.
50 observations.



Till fabric of the Oldest moraine on the west slope of Narao Peaks. Fabric measured on moraine crest.

Circles at 2 pebble frequency
50 observations.



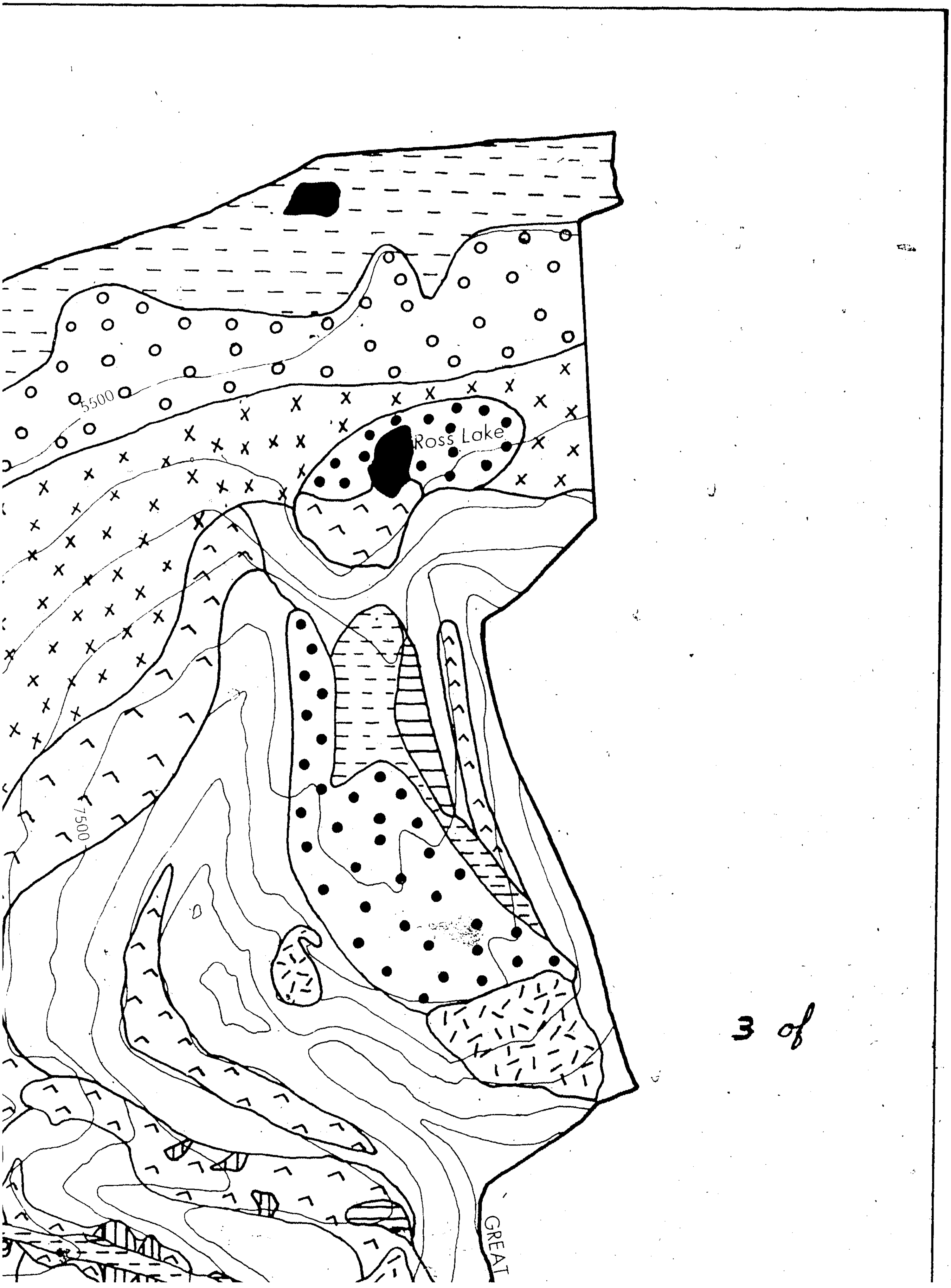
THE CATARACT BROOK VALLEY,

YOHO NATIONAL PARK,

B.C.

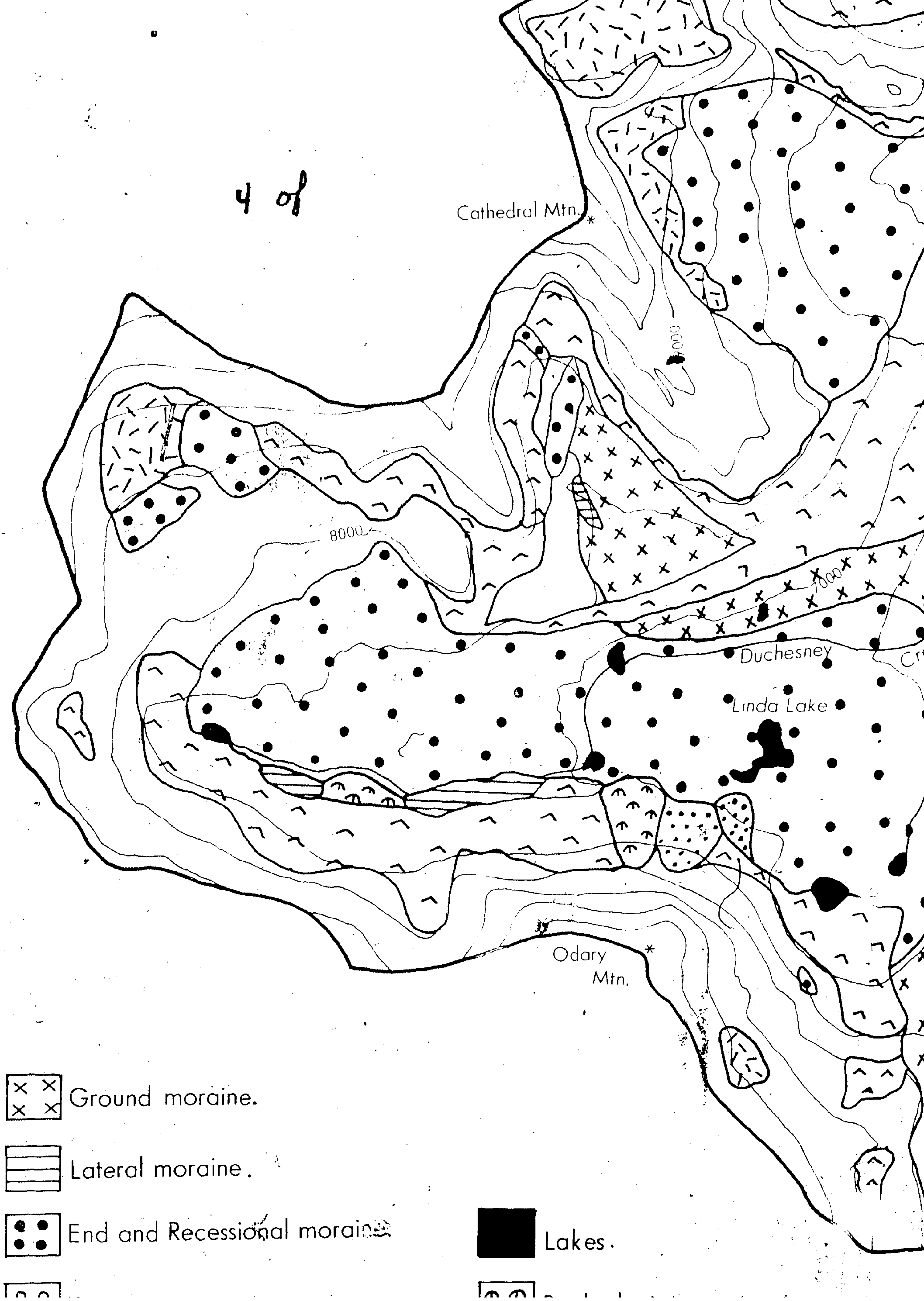
1 of

LEY,

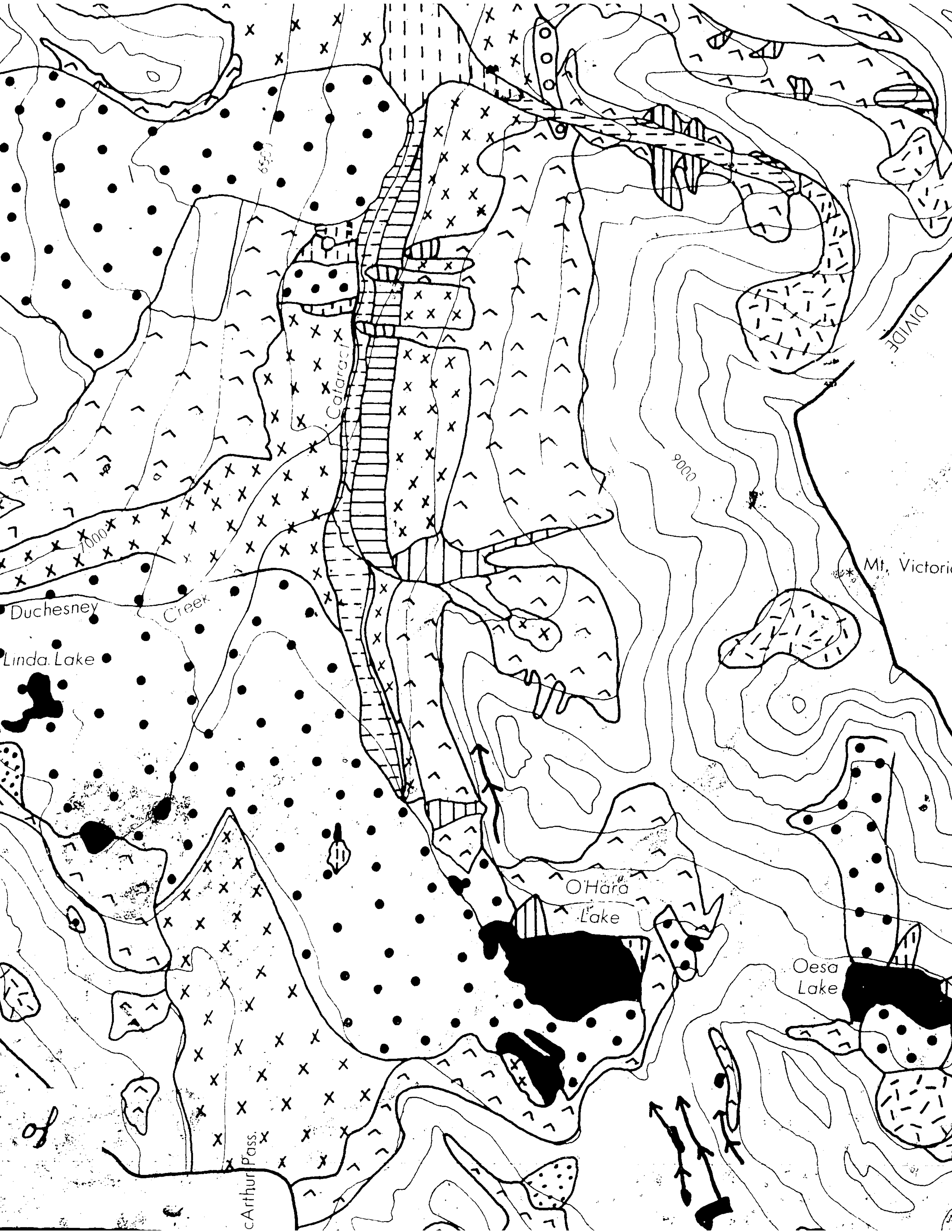


3 of

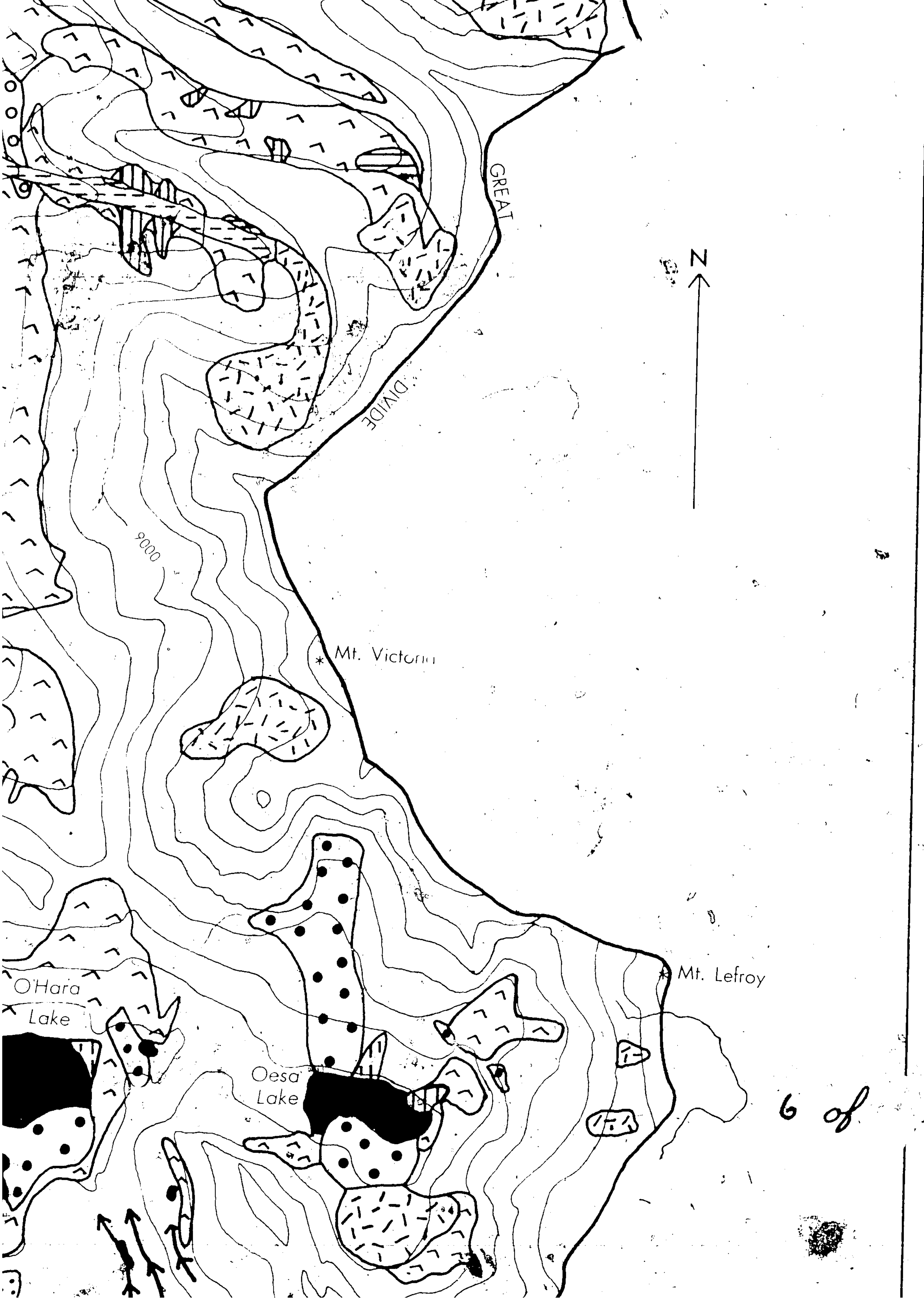
4 of



Cathedral Mtn.
8000
8000
7000
Duchesney
Linda Lake
Odary Mtn.
Ground moraine.
Lateral moraine.
End and Recessional moraine
Lakes.



Cataract
Duchesney
Creek
Linda Lake
7000
9000
DIVIDE
Mt. Victoria
O'Hara
Lake
Oesa
Lake
cArthur Pass.



GREAT
DIVIDE
N
9000
Mt. Victoria
Mt. Lefroy
O'Hara
Lake
Oesa
Lake

6 of

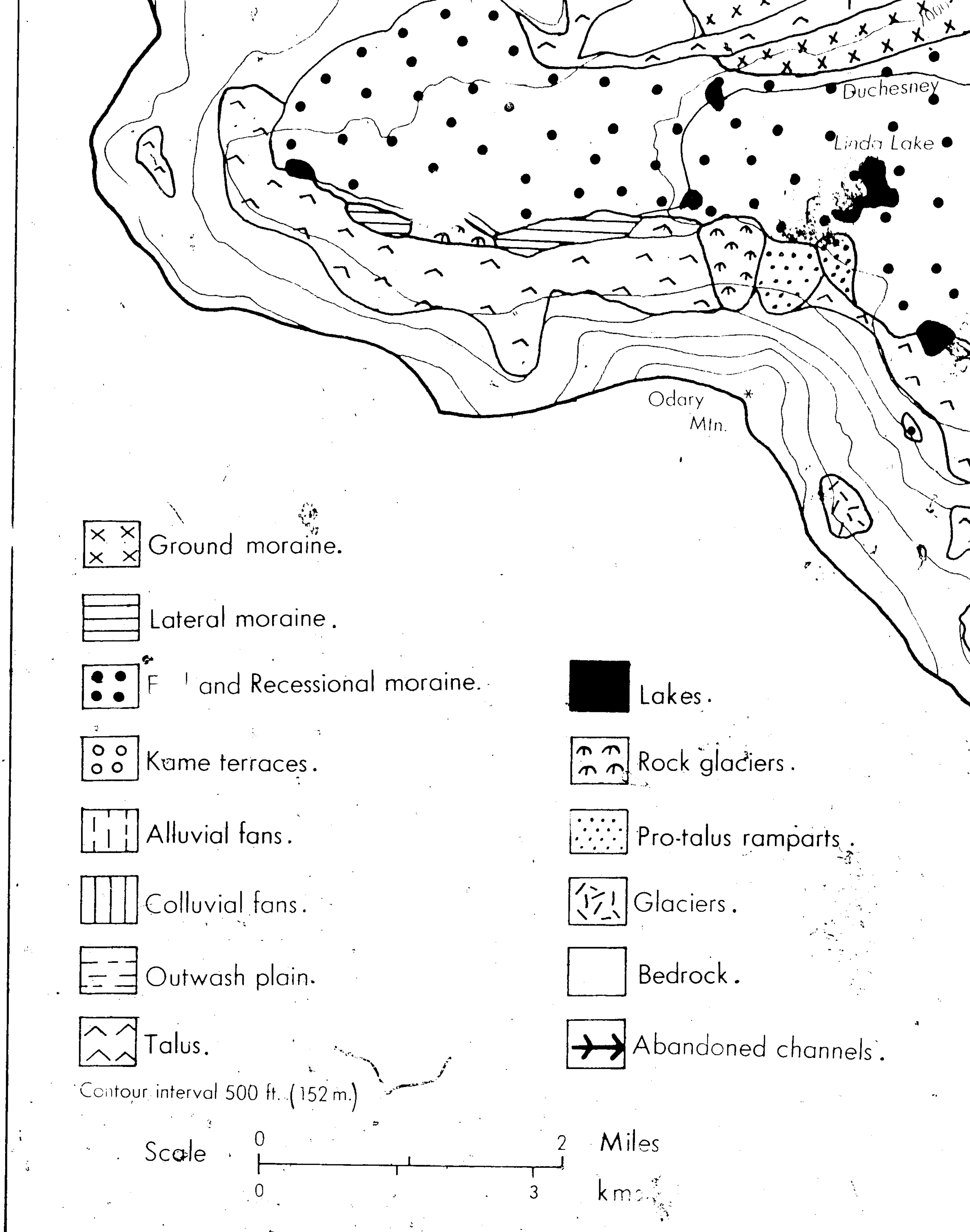
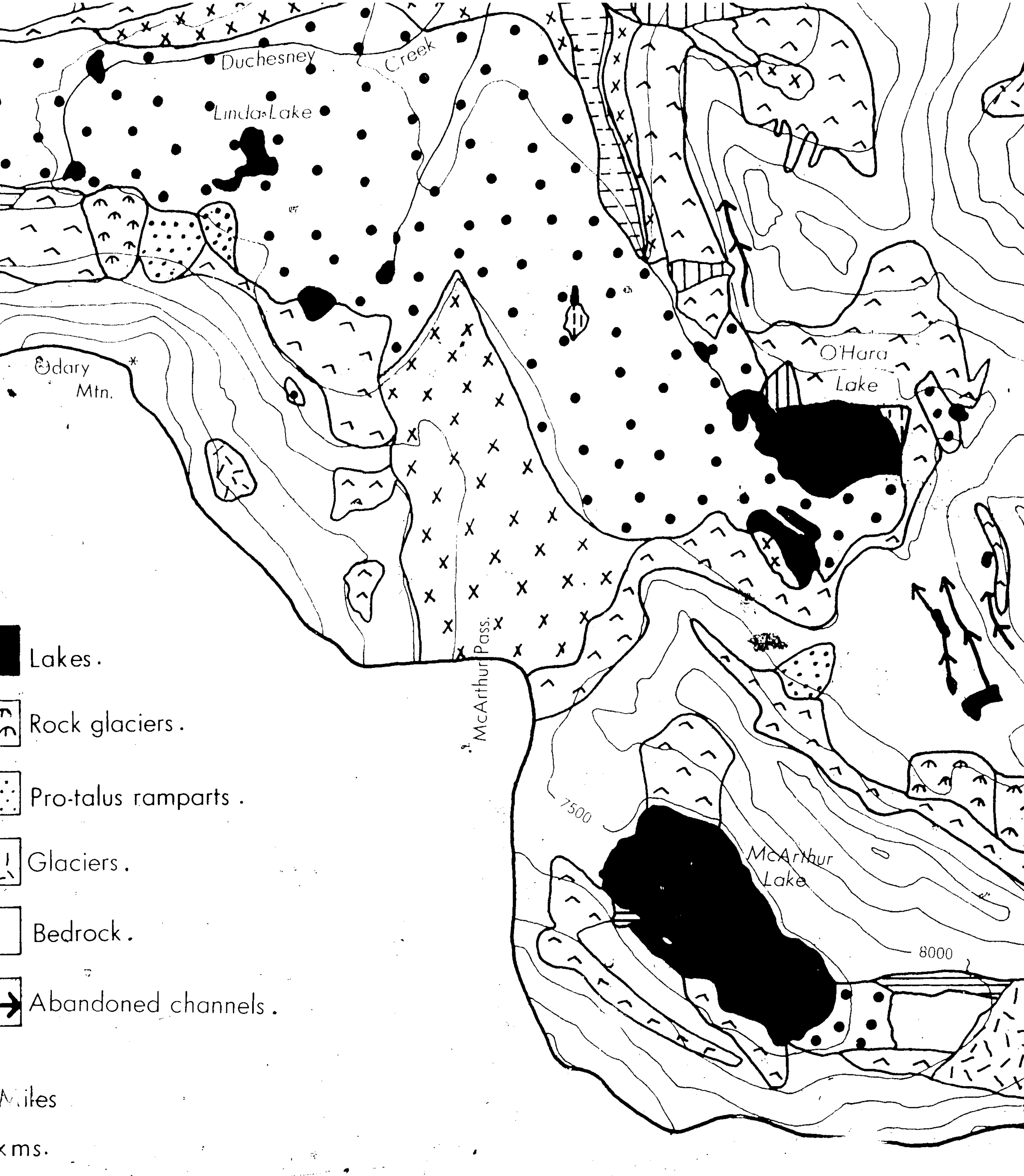
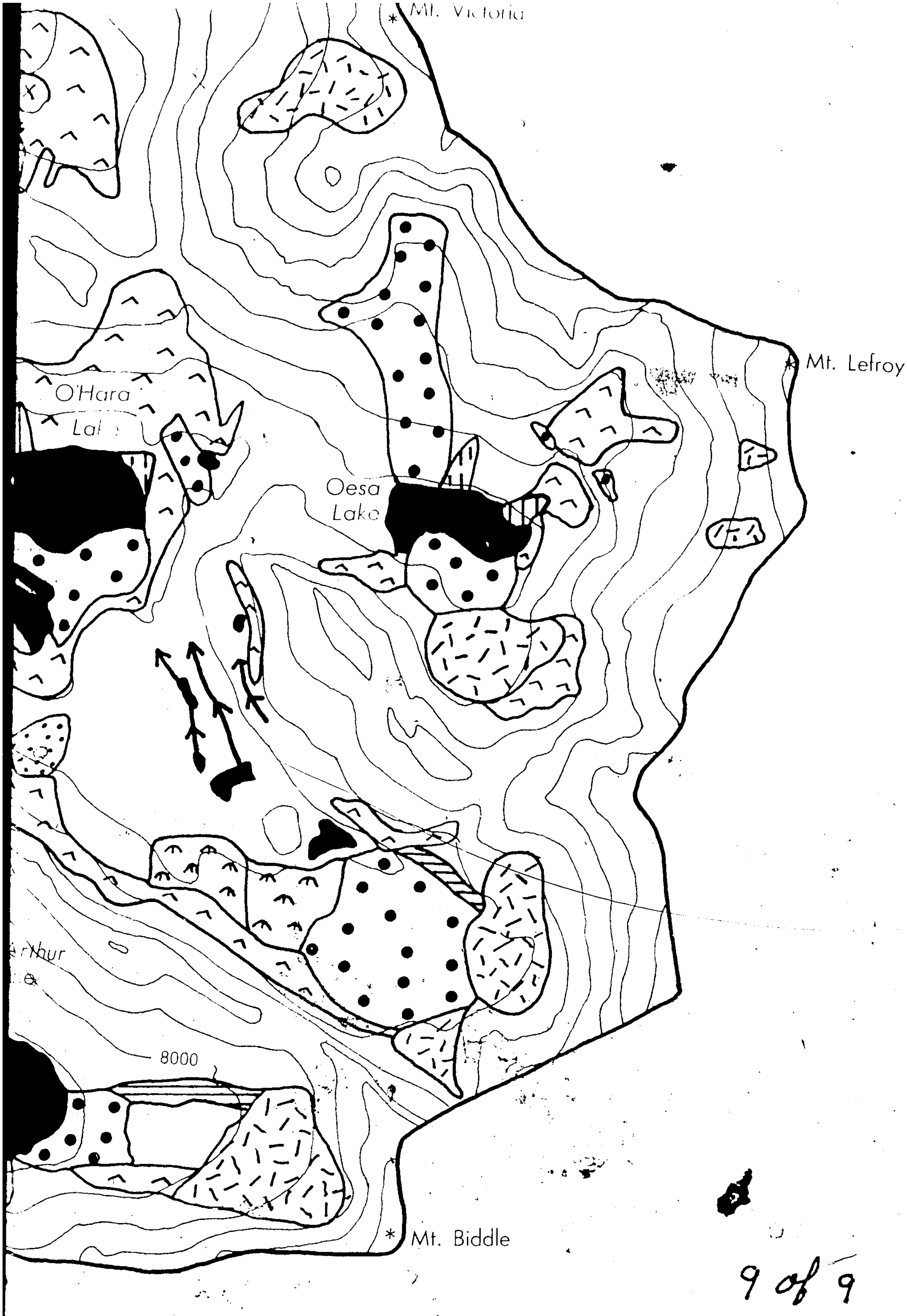


FIG. 7 LANDFORMS.


Duchesney Creek
Linda Lake
Odary Mtn.
O'Hara Lake
McArthur Pass.
McArthur Lake
7500
8000
Lakes.
Rock glaciers.
Pro-talus ramparts.
Glaciers.
Bedrock.
Abandoned channels.
Miles
kms.

8 of



Mt. Victoria
Mt. Lefroy
O'Hara
Lal
Oesa
Lake
Arthur
8000
Mt. Biddle

9 of 9

THE CATARACT BROOK VALLEY,

YOHO NATIONAL PARK,

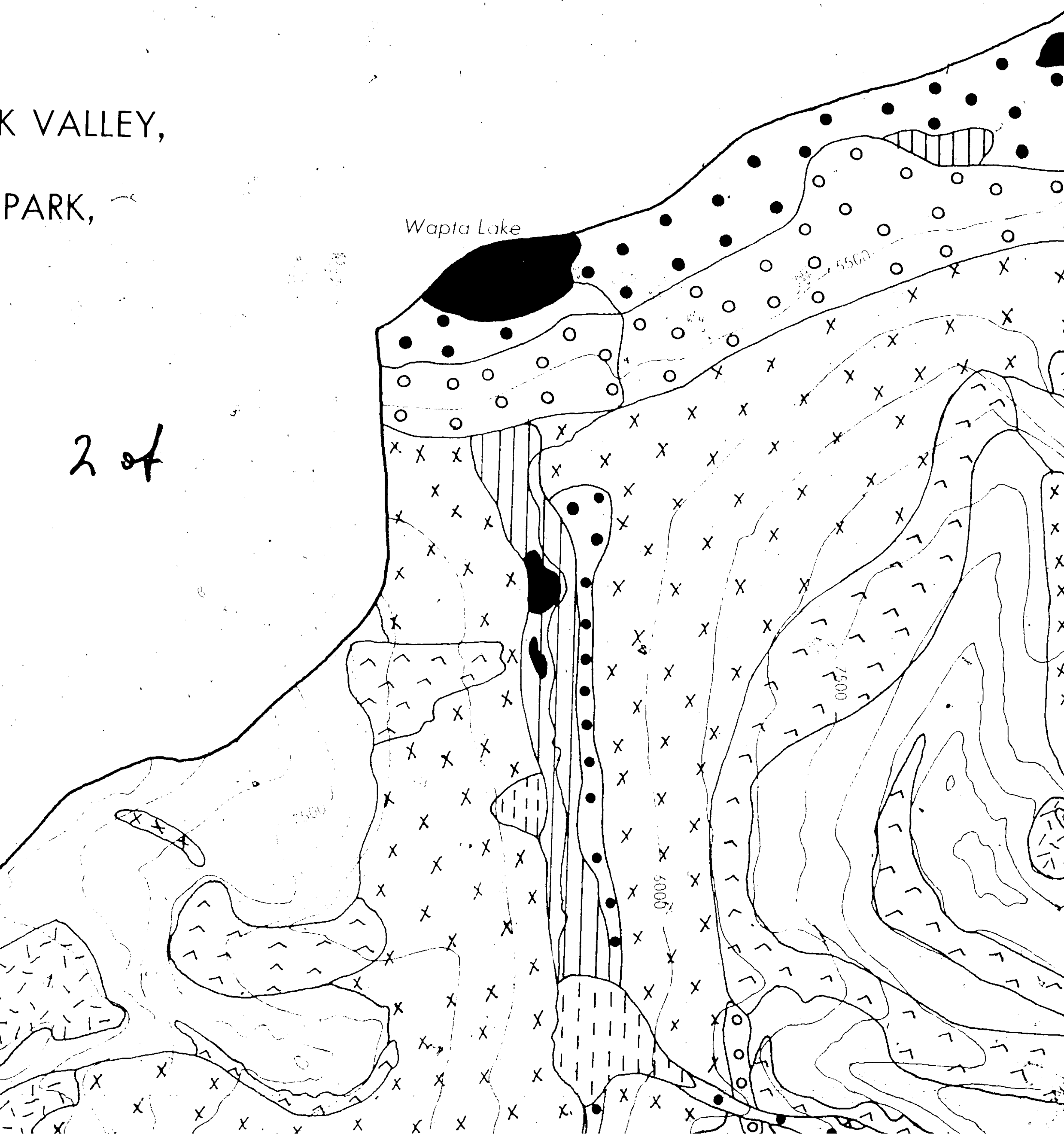
B.C.

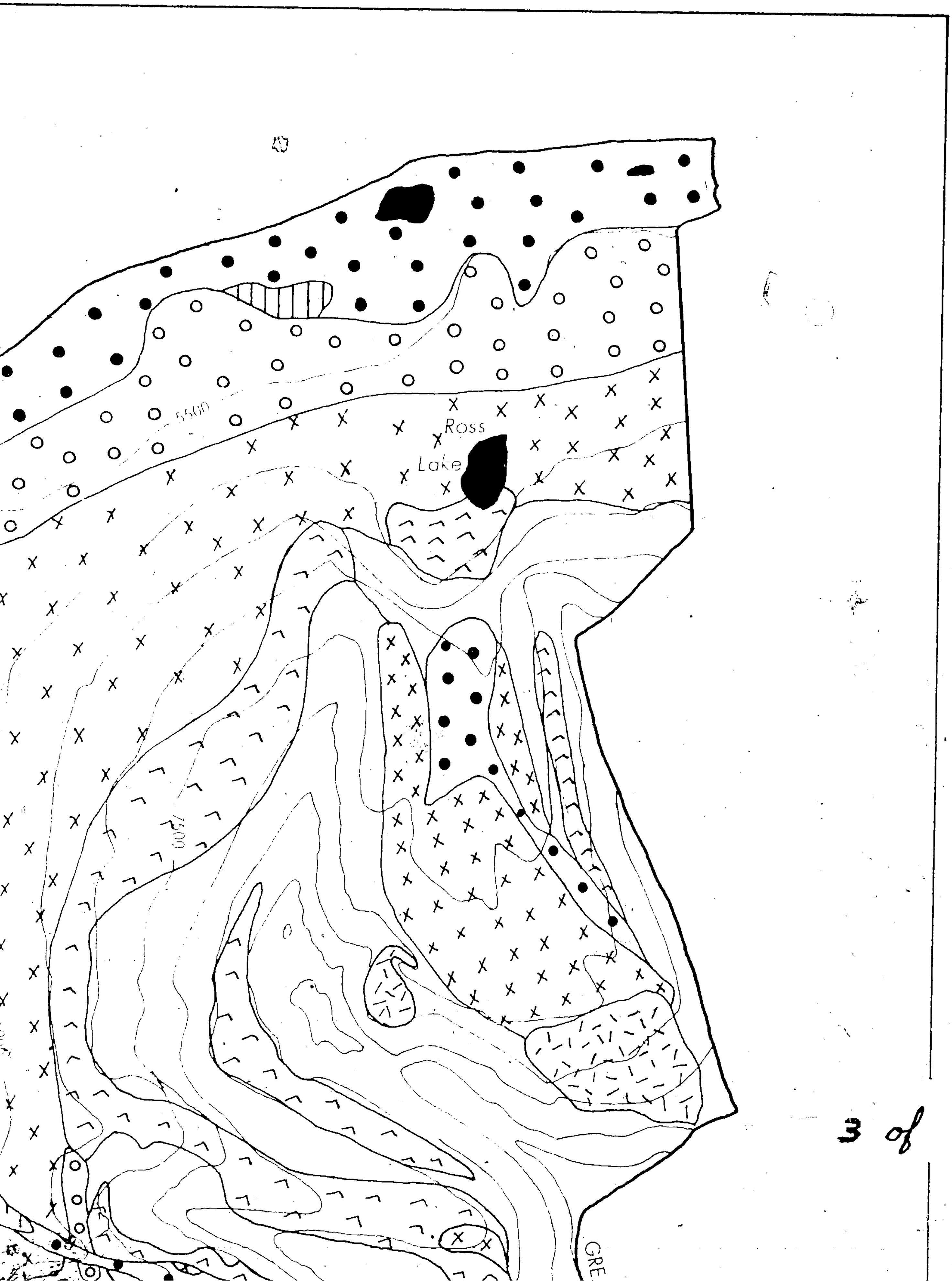
1 of

K VALLEY,

PARK,

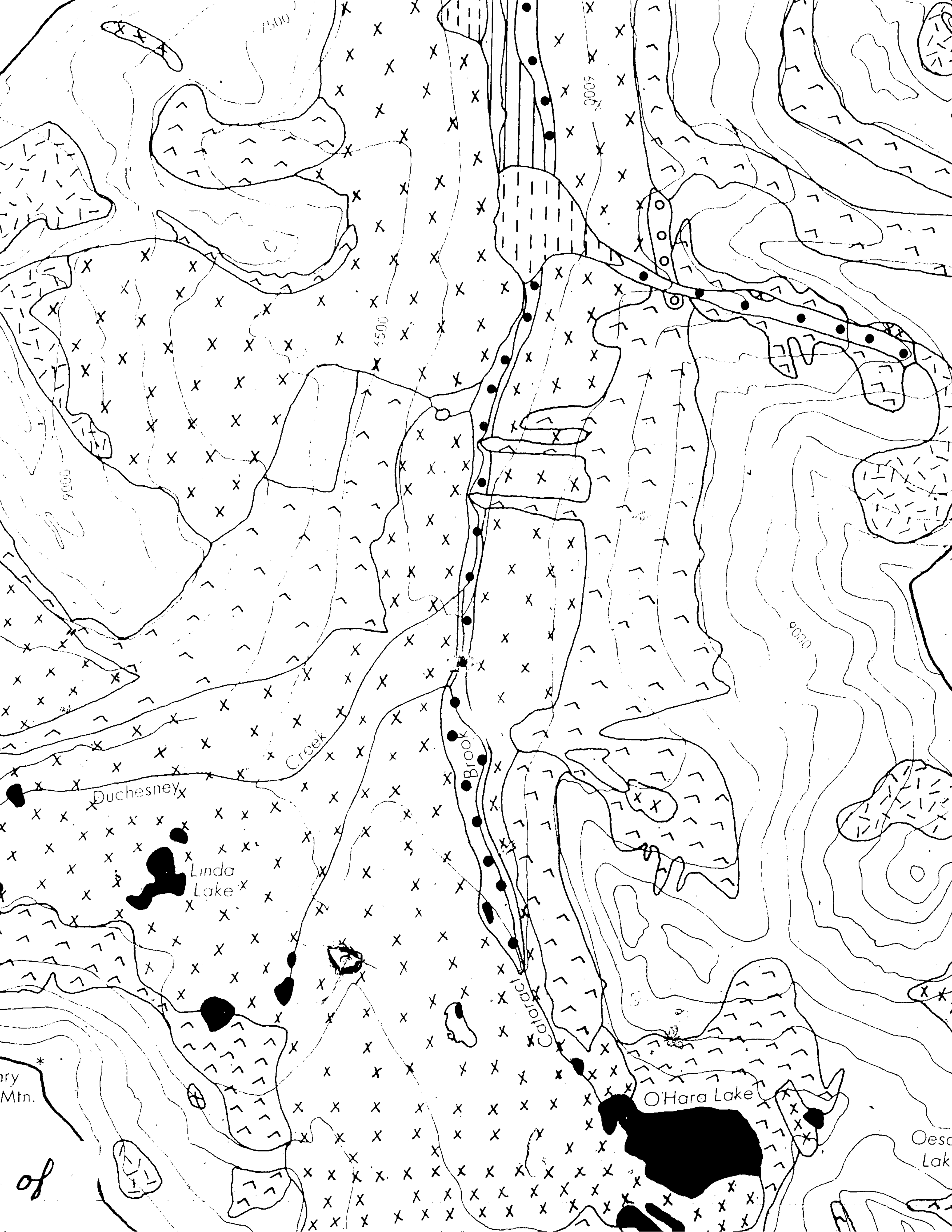
2 of



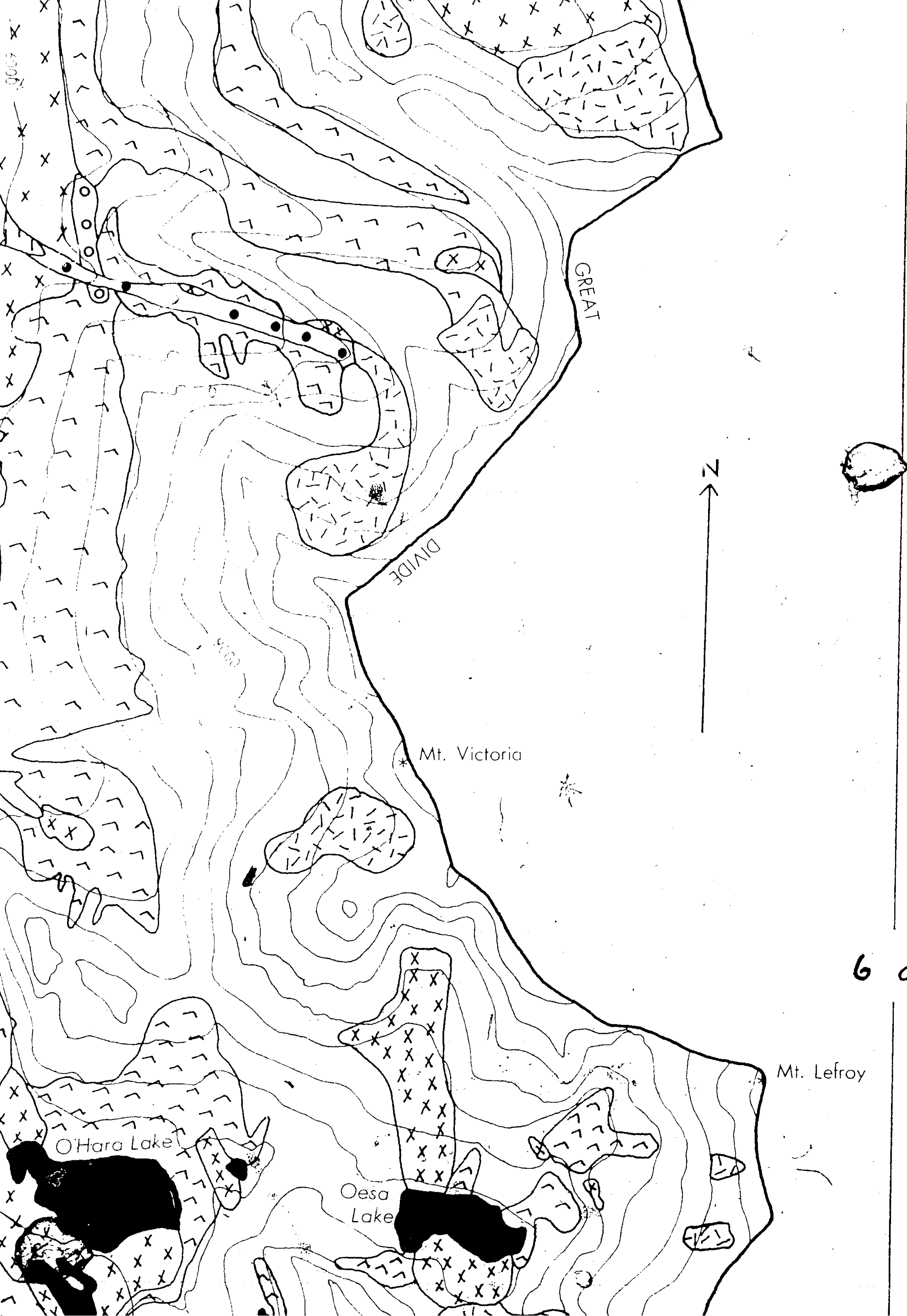


3 of


4 of
Cathedral Mtn.
9000
8000
Duchesney
Linda Lake
Odary Mtn.
Till
Ice contact glacio-fluvial deposits



7500
9000
8500
9000
9000
Duchesney
Creek
Brook
Linda Lake
Cataract
O'Hara Lake
Oesa Lake
ary Mtn.
of



6 of

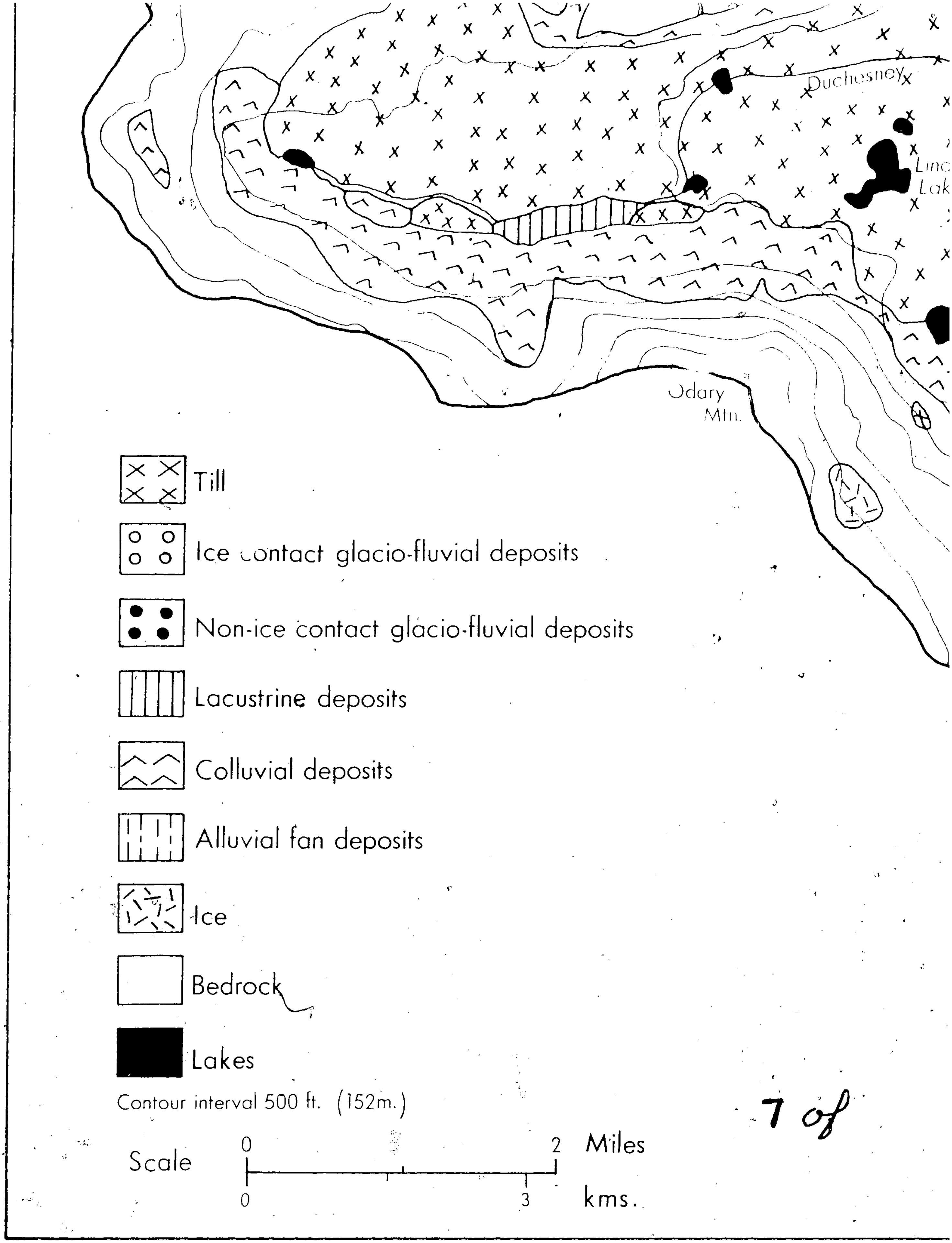
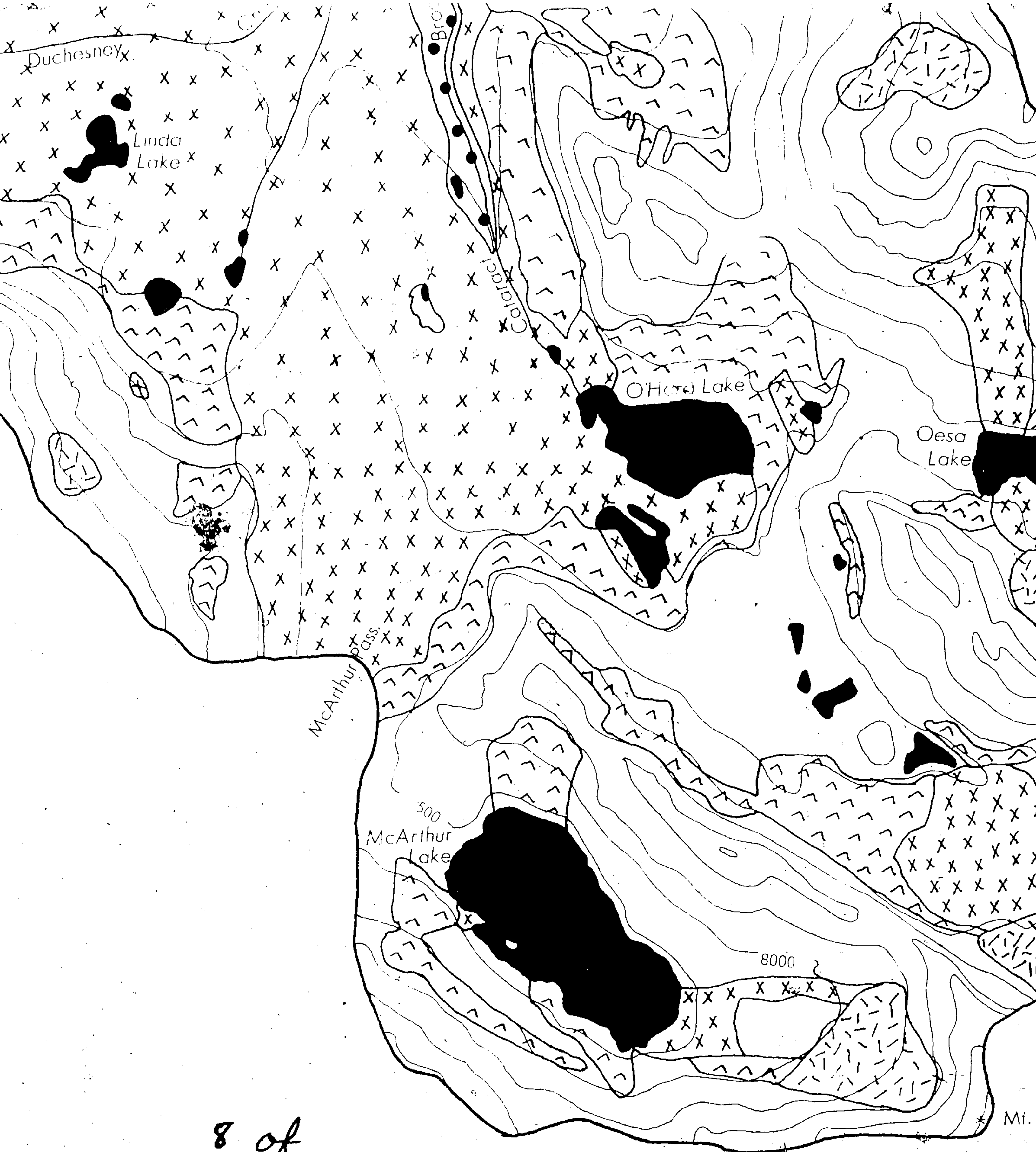
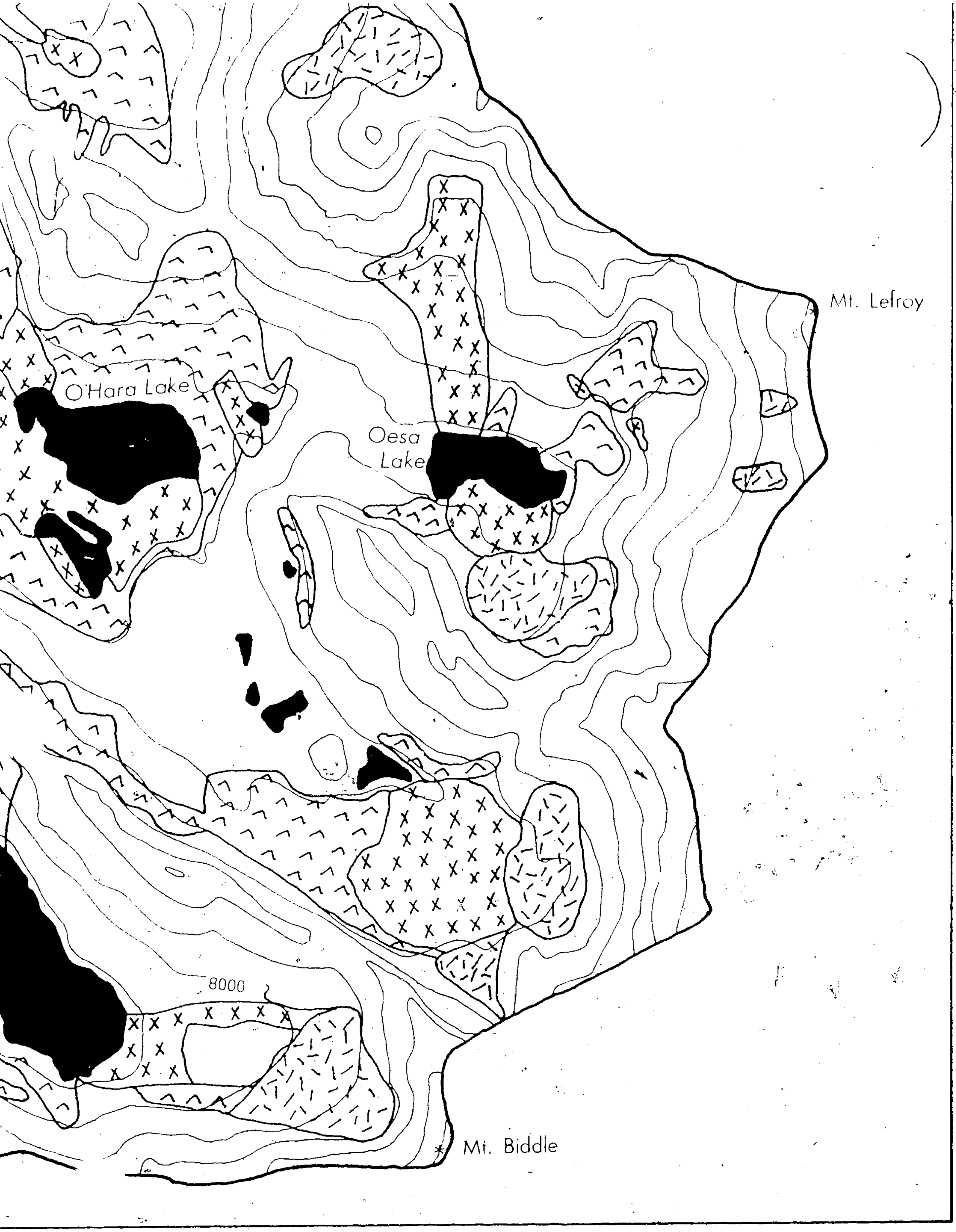


FIG. 6. SURFICIAL DEPOSITS.


Duchesney
Linda Lake
Cataract
O'Hara Lake
Oesa Lake
McArthur pass
500
McArthur Lake
8000
Mi.

8 of


Mt. Lefroy
O'Hara Lake
Oesa Lake
8000
Mt. Biddle