Mollard, J.D. 1972. Reconnaissance Study of Hydrogeology of the
Mackenzie River Valley Region - DRAFT

RECONNAISSANCE STUDY OF HYDROGEOLOGY
OF THE
MACKENZIE RIVER VALLEY REGION

Draft

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CONSULTING CIVIL ENGINEERS AND ENGINEERING GEOLOGISTS

Specializing in airphoto interpretation and ground-water studies

RECONNAISSANCE STUDY OF HYDROGEOLOGY
OF THE
MACKENZIE RIVER VALLEY REGION

Draft

Prepared for:

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April 18, 1972

RECONNAISSANCE STUDY OF HYDROGEOLOGY
OF THE
MACKENZIE RIVER VALLEY REGION

TERMS OF REFERENCE

Terms of reference for the present study were set out in a letter dated August 10, 1971, from Mr. W. J. DuBroy, Purchasing Operations Branch, Department of Supply and Services, Ottawa. Dr. R. L. Harlan, Groundwater Subdivision, Inland Branch, Hydrologic Sciences Division, Environment Canada, acted as Project Officer.

In Mr DuBroy's letter, it was stated that the final report on the groundwater investigation should include:

1) A summary of relevant groundwater and geologic investigations in the Mackenzie River Region and their findings, and

2) Reconnaissance hydrogeological maps prepared at a scale of 1:250,000 (approximately 1 inch = 4 miles) and reduced to 1 inch = 10 miles. These maps should reflect:

   a) General character and spatial distribution of the surficial deposits

   b) Areas of continuous and discontinuous permafrost

   c) Regional recharge and discharge patterns and probable groundwater flow regime

   d) Location of potentially developable groundwater supplies.

In a letter dated February 8, 1972, Dr. R. L. Harlan noted several additional points that he wanted us to consider in preparing our report on the hydrogeology of the Mackenzie Valley Region. In this connection we were requested to:

1) Select the locations of specific site-areas representative of varying groundwater recharge-discharge regimes in different permafrost environments in order to allow field inspection, limited drilling, and field instrumentation with observation wells and piezometers.

2) Comment on the research needs related to northern hydrogeology in general and pipeline construction and operation in particular.

3) Comment on possible applications of special-purpose aerial photography and other remote sensors in groundwater investigations in permafrost-affected regions.

SIZE OF AREA STUDIED

Size of study-area was determined firstly by the probable limits of a corridor that are believed to contain all likely transportation routes along the Mackenzie River Valley at the time of study and, secondly, by the need to show sufficient area to allow proper visualization of the regional geologic setting and regional topography and hydrography as they influence groundwater flow systems in permafrost-affected terrain.

The study-area selected is widest at the north, where the band of terrain is nearly 120 miles in width. At its narrow points, the study-area is roughly 70 miles wide, or 35 miles on each side of the Mackenzie River on the average.

Generalized surficial geology maps, surficial hydrogeology, and bedrock hydrogeology maps have been prepared to correspond with all or parts of the following map sheets in the National Topographic Series System (*see*, also, Fig 25).

Map number in this study	National Topographic Series map-sheet number	
1	Sibbeston Lake	95 G
2	Fort Simpson	95 H
3	Bulmer Lake	95 I
4	Camsell Bend	95 J
5	Root River	95 K
6	Dahadinni River	95 N
7	Wrigley	95 O
8	Blackwater Lake	96 B
9	Fort Norman	96 C
10	Carcajou Canyon	96 D
11	Upper Ramparts River	106 G
12	Sans Sault Rapids	106 H
13	Norman Wells	96 E
14	Mahoney Lake	96 F
15	Lac Belot	96 L
16	Fort Good Hope	106 I
17	Ontaratue	106 J
18	Martin House	106 K
19	Trail River	106 L
20	Fort McPherson	106 M
21	Arctic Red River	106 N
22	Travaillant Lake	106 O
23	Canot Lake	106 P

MAIN SOURCES OF REFERENCE AND ASSISTANCE USED IN THE PRESENT STUDY

The following persons were contacted in connection with groundwater studies in permafrost regions. Also mentioned briefly below is the purpose in making each private communication.

1. Mr. Paul Mascho
Department of Public Works
Government of Northwest Territories
Yellowknife, Northwest Territories

Purpose: Records of drilling and well installation for water supplies at Inuvik, Fort McPherson, Fort Good Hope, Norman Wells, Fort Norman, Wrigley, and Fort Simpson. Communications documented in this report -- see Appendix 'C'.

2. Mr. Sven Lund
Lund Drilling
Yellowknife, Northwest Territories

Purpose: Drilling problems and subsurface conditions at drill sites along the Mackenzie River Valley. Communications documented in this report -- see Appendix 'C'.

3. Mr. Lou Brears
M. R. Hall Drilling Ltd.
Regina, Saskatchewan

Purpose: Drilling results in vicinity of Fort Simpson, Northwest Territories. Communications documented in this report -- see Appendix 'C'.

4. Dr.J. Ross Mackay
Department of Geography
University of British Columbia

Purpose: Water-quality data pertaining to the Mackenzie River. Dr. Mackay's water-quality studies concerned the mixing of Liard and Great Bear River waters with those of the Mackenzie River (see Appendix 'H').

5. Mr. John Piart, Surveyor
Federal Department of Public Works
Edmonton, Alberta

Purpose: To determine the location of springs along the banks of Mackenzie River Valley since Mr Piart has spent nearly 20 summers on the river. Mr Piart had observed no springs that were not already mentioned in Brandon's paper.

6. Dr. Owen L. Hughes, Dr. Nat W. Rutter, Dr. Jim A. Code,
Dr. Pavel Kurfurst, Dr. Ralph M.S. Isaacs, Dr. Don K. Norris,
Dr. Chris Yorath
Geological Survey of Canada in Calgary and Ottawa

Purpose: Surficial and bedrock geology of the Mackenzie River Valley Region. The several communications from these people were helpful in preparing the surficial geology and bedrock hydrogeology maps.

7. Mr. Steve Zoltai and Dr. Colin Crampton
Northern Forestry Research Laboratory, Edmonton,
and
Dr. J. Stan Rowe
Department of Plant Ecology
University of Saskatchewan
Saskatoon

Purpose: Hydrology of peatlands in the discontinuous permafrost zone. See Appendix 'D' on measurements of thermokarst lakes and research on the geohydrology of peatlands.

8. a) Dr. Charles Slaughter
Water Resources Division
Department of Interior
Anchorage, Alaska

b) Mr. Don Morris
Water Resources Division
Department of Interior
Anchorage, Alaska

c) Dr. Bob Carlson
Institute of Water Resources
University of Alaska
College, Alaska

d) Dr. John R. Williams
U. S. Geological Survey
Boston, Mass.

e) Dr. Charles E. Sloan
Groundwater Geologist
Anchorage, Alaska

Purpose of enquiries: Groundwater publications and groundwater research in permafrost regions. See Appendix 'H', dealing with literature digest. Several references obtained from the above persons.

9. Mr. Leo V. Brandon
Regional Manager
Department of Indian Affairs and Northern Development
P. O. Box 1767
Whitehorse, Yukon Territories

Purpose: Past studies of groundwater in the Yukon and Northwest Territories. See section documenting private communication -- Appendix 'C'.

10. Mr. J. L. Jenness
Sidney River, Nova Scotia

Purpose: Report on drilling of water wells at Norman Wells, Northwest Territories. Referred to other sources of assistance.

11. Messrs. Stewart W. Reeder, Officer-in-charge,
Western Water Quality Region, and Paul Fee, in Calgary
and
Dave R. Silliphant in Regina
Water Quality Division
Inland Waters Branch
Environment Canada

12. Dr. L. Dennis Delorme and Dr. Robert O. Van Everdingen
Groundwater Subdivision, Hydrologic Sciences Division
Western Research Section
Inland Waters Branch
Environment Canada

13. Mr. J. N. Stein, Biologist
Pollution Control Section, Resource Development
Department of the Environment
Fisheries Service
Winnipeg

Purpose: Water-quality studies and analyses in the Mackenzie River Valley Region. See section on water-quality characteristics -- Appendix 'A.'

14. a) Mr. Rudy W. Klaubert, Ottawa
and
b) Mrs. V. Hewson, Calgary
Oil and Gas Land & Exploration Section
Oil and Gas Division
Northern Economic Development Branch
Ottawa and Calgary, respectively

Purpose: Publications and reports giving data based on oil-well drilling along the Mackenzie River Valley. See Appendix 'B' giving extracts from relevant data in oil-company geological reports filed with the Oil and Gas Division, Northern Economic Development Branch, Department of Indian Affairs and Northern Development, Calgary.

15. 1) Dr. Wayne Pettapiece, Pedologist
Soil Research Institute
Canada Department of Agriculture
Edmonton

Purpose: Groundwater chemistry of surface waters, Sans Sault Rapids to Fort McPherson region. Reported verbally that chemistry of collected surface waters indicated they are essentially rainfall and snowmelt in origin. Dr. Pettapiece ran about 50 specific conductivity tests on waters in peatland ponds. The values commonly ranged from 50 to 100 with an extreme low of 35 to 40 and with only one sample over 200 micromhos/cm.

2) Mr Orest Tokarsky, Hydrogeologist
Alberta Research Council

Purpose: Groundwater analyses in northern Alberta (see Fig 23).

3) Dr. Brian Hitchon
Alberta Research Council

Purpose: Water chemistry studies of northern regions.

4) Drs. George Ozoray and Joe Toth
Alberta Research Council

Purpose: Peatland hydrogeology in permafrost-affected terrain. See section on geohydrology of peatlands and Fig 23. Private communications with all five members of the Alberta Research Council.

16. 1) Dr. Les Lavkulich, Pedologist
University of British Columbia
Vancouver, British Columbia

Purpose: Soils in vicinity of Fort Simpson.

2) Mr. John H. Day, Pedologist
Soils Research Institute
Research Branch
Canada Department of Agriculture

Purpose: Soils along the Mackenzie River Valley. Communications useful in reconnaissance mapping of surficial geology.

17. 1) Mr. Robert W. May, District Engineer, Calgary
2) Mr. Kelt F. Davies, Area Engineer, Calgary
3) Mr. Walter N. Nemanishen, Study Engineer, Calgary
4) Mr. E. Dave Fowler, Officer-in-charge, Fort Smith, Northwest Territories
Environment Canada
Water Survey of Canada
Inland Waters Branch

Purpose: Streamflow data, riverbed erosion, water-quality data. See Appendix 'A.'

The following available reports and maps were consulted during preparation of this report and accompanying maps:

1. The Development of Sedimentary Basins in Western and Arctic Canada (1969), by P. A. Ziegler,Alberta Society of Petroleum Geologists, Calgary.

2. Regional Devonian Geology and Oil and Gas Possibilities, Upper Mackenzie River Area (1971), by James Law, Bull. of Can. Pet. Geol. Vol. 19, No. 2.

3. Facies and Faunal Relations at Edge of Early Mid-Devonian Carbonate Shelf South Nahanni River Area, N W T (1971),by J.P.A. Noble and R.D. Ferguson, Bulletin of Can. Pet. Geol. Vol. 19, No. 3.

4. Reconnaissance Geology, Southern Great Bear Plain, District of Columbia (1971), G S C Paper 71-11, by H.R. Balkwill.

5. The Lower Mackenzie River Area, N W T and Yukon (1954), G S C Memoir 273 and maps by G. S. Hume, Pub. No. 2513.

6. Virginia Falls and Sibbeston Lake Map-Area, Northwest Territories, G S C Paper 60-19, by R.J.W. Douglas and D. K. Norris; reprinted in 1970 along with Maps 22-1960 and 23-1960.

7. Camsell Bend and Root River Map-Areas, District of Mackenzie, Northwest Territories, Report, 2 maps, 2 figures, G S C Paper 61-13 by R.J.W. Douglas and D.K. Norris; reprinted in 1970 along with Maps 22-1961 and 23-1961.

8. Subsurface geology, Lower Mackenzie River and Anderson River Area, District of Mackenzie (1969), G S C Paper 68-25 by E.J. Tassonyi; includes report and 11 figures on stratigraphic correlation charts, cross-sections, and comparative formation nomenclature for the Upper and Lower Mackenzie River Valley Regions.

9. Hydrographic maps of the Mackenzie River from Mile 200 at Fort Simpson to the delta of the Mackenzie River (1970); published by the Canadian Hydrographic Service, Marine Sciences Branch, Department of Energy, Mines and Resources, Ottawa.

10. Glacial Lake McConnell and the Surficial Geology of Parts of Slave River and Redstone Map-Areas, District of Mackenzie (1965), G S C Bull. 122 and map, by B. G. Craig.

11. Reconnaissance Surficial Geology Maps, on open file at the Geological Survey of Canada, and covering the following National Topographic Series map sheets:

    Dr. O. L. Hughes: 106 H, 106 G, 96 C, 96 D, 96 E
    (scale: 1 inch = 4 miles)

    ✓ Dr. R. J. Fulton: 106 O, 96 E, 96 F, 96 L, 106 I, 106 J, 106 P
    (scale: 1 inch = 4 miles)

    ✓ Drs. O. L. Hughes and V. N. Rampton: 106 M, 106 N, 106 L, 106 K, 106 E, 106 F
    (scale: 1 inch = 4 miles)

12. Ground-Water Hydrology and Water Supply in the District of Mackenzie, Yukon Territory and Adjoining Parts of British Columbia (1965), by L. V. Brandon, G S C Paper 64-39; report includes 25 figures, 3 plates, and 14 tables.

13. Soils of the Upper Mackenzie River Area, N W T, by J. H. Day, Soils Research Institute, Central Experimental Farm, Research Branch, Canada Department of Agriculture, 1966.

14. Reconnaissance Soil Survey of the Liard River Valley, N W T, by J. H. Day, Soils Research Institute, Central Experimental Farm, Research Branch, Canada Department of Agriculture, 1966.

15. Schedules of Wells, Northwest Territories and Yukon Territory, Federal Department of Indian Affairs, Ottawa, Ontario.

The following scales of contact aerial photographs and mosaics were used to help prepare the accompanying generalized surficial-geology map, surficial-hydrogeology map, and bedrock-hydrogeology map:

1. Contact aerial photographs at an approximate scale of 1 inch = 3300 feet; obtained from the National Air Photo Library in Ottawa.

2. Two flight lines of colour infrared (false colour) aerial photographs that were taken along both sides of the Mackenzie River between Sans Sault Rapids and Fort Simpson, with a short gap in the photography near Wrigley; at an approximate scale of 1 inch = 2000 feet.

3. Aerial mosaics at scales varying from 1 inch = 4.5 miles to 1 inch = 6.5 miles, approximately.

4. Aerial mosaics at a scale of 1 inch = 2 miles, approximately.

As part of this reconnaissance groundwater study, an attempt was made to obtain available literature containing findings relevant to groundwater and related geological investigations in the Mackenzie River Valley Region of the Northwest Territories. Altogether over 80 literature references were obtained, and abstracts of this literature are summarized in an accompanying Appendix.

APPROACH TO PREPARATION OF THE ACCOMPANYING MAPS

All available non-confidential geological maps and reports that could be procured were used as a framework and guide to initial mapping of the surficial and bedrock geology. These were used in conjunction with the study of contact aerial photographs and aerial mosaics at one or more scales. An attempt was made to examine the more critical areas stereoscopically using 1 inch = 3300-foot contact aerial photographs. Generally such areas are located within what is likely to be the main transportation corridor, which follows lowland regions. On the other hand, highland watersheds likely to contribute groundwater recharge were also studied -- mainly in aerial mosaics and on regional geological maps. In other words, a large proportion of the 50,000 square mile study-area was examined only in mosaics and geological maps and not in stereoscopic pairs of contact airphotos.

Because of the significance of heat-flow and groundwater movement in areas underlain by widespread permafrost in the discontinuous permafrost zone, colour infrared photographs were purchased and studied because they frequently disclose the stress effects of plants that are affected by shallow active layer, fire, disease, insect, and other adverse environmental factors. It was suspected that the type, stature, density, and stressed condition of vegetation would all indicate something useful about the nature of local heat-flow patterns and prevailing groundwater flow regime.

Thus the three sets of maps that were produced from office study alone include material that was either traced or interpreted from different scales and types of geological, soil, and hydrographic maps as well as aerial mosaics, conventional panchromatic airphotos, and colour-infrared photography.

REGIONAL AND LOCAL CLIMATIC AND PERMAFROST CONDITIONS

Regional conditions (see Fig 24)

a) From Fort McPherson to Sans Sault Rapids across the Peel Plateau and Peel Plain

The mean daily temperature in January is less than -20°F and in April is between 10° and 15°F. There are about four months of growing season and an average of five months when the temperature is 0°F or lower. Mean annual number of days of measurable snowfall is 60; and of measurable precipitation, 110 days. Mean annual total snowfall is 50 inches, about the same as Calgary and Edmonton. Mean date of the last snow cover of 1 inch or more is May 20. One can expect about 220 days with 1 inch or more of snow cover and a maximum snow cover of around 30 inches. Mean annual precipitation ranges between 11 and 13 inches. Permafrost may be 300 to 400 ft thick in vicinity of Fort McPherson depending on the site tested.

The "Permafrost Map of Canada" shows the Peel Plateau and Peel Plain to be underlain by widespread permafrost in the discontinuous permafrost zone. However, in virtually all areas covered by Sphagnum moss,lichen (Cladonia spp.), and black spruce thepermafrost is continuous north of the 20°F mean annual air isotherm -- i.e., between Fort McPherson and Sans Sault Rapids. Yet wherever there has been long-standing water on the ground surface -- seemingly regardless of the size or depth of the water body -- the permafrost appears to have degraded to depths of 20 to 40 feet or greater. The great preponderance of these unfrozen "windows" are located below elevation 400 feet in what is believed to be essentially continuous permafrost.

b) From Sans Sault Rapids to Fort Simpson along the Mackenzie Plains

The January mean daily temperature varies from -20°F at Sans Sault Rapids to -15°F at Fort Simpson. Mean daily temperatures in April vary from 15°F at the north end to 25°F at the south end of the Mackenzie Plains.

Mean annual number of days with a minimum temperature of 0°F or lower varies from about 150 days at the north to about 110 days at the south end. The mean annual length of growing season varies from 120 days in vicinity of Sans Sault Rapids to 140 days in vicinity of Fort Simpson. Mean annual number of days with measurable snowfall is 60 and with measurable precipitation is 100. Mean annual total snowfall is 50 inches and mean annual total precipitation is about 12 inches. Mean date of the last snow cover of 1 inch or more is May 20 at Sans Sault Rapids and is April 30 at Fort Simpson. Mean annual maximum depth of snow is 30 inches and this is quite consistent along the entire Mackenzie Plains. But the mean annual number of days with snow cover of 1 inch or more varies from 230 days at the north end to 180 days in the south end of the Mackenzie Plains (see Fig 24).

The Mackenzie Plains lie between the 20° and 25°F mean air isotherms. This region is underlain by widespread permafrost in the northern part of the discontinuous permafrost zone. The mean annual air temperature at Norman Wells is 20.8°F and at Fort Simpson it is 20°F. Recorded mean annual ground temperatures at 0 to 5 feet at Fort Simpson range from 33.2° to 35.4°F. At a depth of 50 to 100 feet at Norman Wells, recorded mean annual ground temperatures range from 26° to 28.5°F. Permafrost thickness is 150 to 200 feet at Norman Wells and some 40 feet thick at Fort Simpson.

The active layer is 3 to 5 feet at Norman Wells and 5 and 10 feet at Fort Simpson. Under well insulated, densely shaded sites, however, the active layer is probably less than 2 or 3 feet thick --even at the very southern end of the Mackenzie Plains. But below more open stands of taller trees at this latitude, the active layer may be 4 to 6 feet below ground surface. Because there appears to be a noticeable change in tree species and canopy density in vicinity of Norman Wells, one might expect that permafrost is more widespread and that ground temperatures are colder between Sans Sault Rapids and Norman Wells than they are south of Norman Wells along the Mackenzie River Valley.

Local conditions

Although essentially continuous permafrost exists within several inches to a few feet of ground surface below vegetation-covered lowland areas between Fort McPherson and Fort Simpson, many localized areas and situations occur where permafrost either exists at several tens of feet or is absent altogether. It is important that these special terrain situations be recognized, for they are likely to have a bearing on groundwater hydrology. In fact, the three attached maps must be studied with these terrain settings in mind because most of the degraded permafrost sites are too small in size to show at map scales of 1 inch = 4 miles and 1 inch = 10 miles, respectively. These local topographic, drainage, geologic, and vegetation settings are listed below. While the list below may not be complete it is believed to represent the common occurrences of locally depressed permafrost tables and places where permafrost is absent within essentially continuous permafrost. These "windows" in the permafrost table may be sites of localized groundwater recharge or discharge. They may function as both recharge and discharge areas at different times of the year, depending on their local hydrologic setting within the regional groundwater flow system.

The following local hydrogeologic sites and settings correlate with significantly depressed permafrost tables and/or absence of permafrost (i.e., windows):

1. Large lakes and active river channels (Figs 1, 2, 4, 5, 6, 7, 11).

2. A variety of thermokarst depressions including small thaw lakes, pools, and ponds. They are characterized by standing still water or by sluggish surface and slow groundwater movement (Figs 3, 4, 5, 7, 8, 9, 10).

3. A variety of wetlands underlain by peat and supporting characteristic vegetation (peatlands), such as a) patterned fens and b) small windows and collapse scars in bogs that have a water table at or locally above ground surface for most of the year, the latter usually occurring in extensive peat plateaus. (The terms "wetland," "peatland," "fen," and "bog" are defined later in this report.)

4. Temporarily abandoned straight and serpentine back channels on floodplains, oxbow lakes, and active distributary channels on alluvial fans and deltas (Figs 4, 5, 6, 12).

5. Periodically inundated river point-bars that repeatedly receive a cover of fresh silt sediment and which support tall large-diameter white spruce and balsam poplar along with dense willow thickets (*see* Figs 1 and 5).

6. South-facing sunny slopes that receive unusually large amounts of solar radiation (*see* Fig 6).

7. Naturally or artificially cleared areas where the vegetation and underlying peat layer has been removed and the permafrost table has degraded. Special situations are landslides and sloughing banks, especially on south-facing and west-facing slopes, active lateral river erosion and undercutting of south- and west-facing valley banks, and roads, trails and village areas where the vegetation and peat have been stripped and the underlying mineral soil left exposed to the sun (*see* Figs 4 and 6).

8. Well-drained elevated landforms underlain by thick, clean and permeable granular materials. In these landscapes the water table is deep and the soils may be dry frozen on shaded slopes and unfrozen on sunny slopes (Figs 5 and 11).

9. Exposed bedrock outcrop with no soil or vegetation cover and mainly in topographic situations that receive large solar radiation inputs (Fig 1).

REGIONAL AND LOCAL GROUNDWATER RECHARGE AND DISCHARGE SYSTEMS

Regional groundwater flow systems along the Mackenzie River Valley are controlled mainly by large-scale topographic features like mountains, plateaus, lowland plains, and major river valleys (see Figs 14, 15, 16). On a regional scale the groundwater table is believed to mirror the surface topography, with highlands being dominantly groundwater recharge areas and lowlands and major river valleys being dominantly groundwater discharge areas (see Appendix 'A': water quality vs streamflow). Even though this seems to be the general situation, there can be exceptions. For example, at certain times of the year some of the rivers may discharge into underlying aquifers and build up groundwater mounds beneath the river -- the groundwater flowing away from the river channel rather than toward it (private communication from Dr. C. E. Sloan, concerning rivers in central Alaska). Any such groundwater mounding beneath large rivers usually builds in summer. In order to verify this condition in specific cases, piezometers measuring deep groundwater level measurements are necessary.

Examination of chemical analyses of river water quality reveals that the total dissolved solids increases with decreases in surface runoff -- that is, at times of the year when there is a proportionately greater contribution of groundwater containing higher concentrations of dissolved minerals. At least this seems to be the situation in the case of the Peel. Arctic Red, Liard, and other rivers (see Appendix 'A' on water quality versus streamflow). It may be that the lower reaches of the major tributaries are recharged by groundwater whereas parts of the Mackenzie River lose water to deep alluvial strata. One might suspect that part of a river channel may receive groundwater recharge whereas other parts of the same river channel may recharge aquifers beneath them -- and these recharge/discharge regions may operate seasonally. We consider such possibilities should be carefully studied. A proper understanding of them necessitates further research.

Based on our present knowledge it seems that major streams arising in the Mackenzie Mountains are fed primarily by rainfall and snowmelt runoff whereas streams and major rivers crossing the North Slope of Alaska and the Yukon are fed partly by thermal springs in watersheds along the north side of the Brooks Range and British Mountains -- well within the continuous permafrost zone (private communication from Dr Peter McCart, fish biologist). Thermal springs feeding rivers crossing the Arctic North Slope probably have a deep-seated bedrock source along lines of tectonic weakness; and while similar thermal springs exist along the Mackenzie River Valley (Mountain River at lat. 65°25'; long. 129°10'; Old Fort Island and Roche-qui-a-l'Eau) they seem to be much less common in occurrence. Temperature of groundwater at the spring at Roche-qui-Trempe-a-l'Eau, N W T, is 70° - 80°F; and temperature of the spring at Old Fort Island, 53°F (after L. V.Brandon). (<u>See</u>,also, "Groundwater in Canada," Economic Geology Report No. 24, edited by I.C. Brown (1967), pp. 185, 186.)

On a more local basis it is likely that there is little or no direct recharge to groundwater from areas underlying sloping fine-grained surficial deposits (lacustrine, till) that are relatively dry and support a tree cover of stunted black spruce and a ground cover of Sphagnum moss and/or <u>Cladonia</u>, the latter mainly reindeer lichen (Figs 2 and 10). This accounts for most of the mineral soil upland and extensive peat plateaus, excluding in the latter small unfrozen windows and collapse scars and, for the most part, elongate channelways occupied by ribbed fen. Within these latter isolated wet places in peatlands it is difficult to predict confidently if (and at what time of year) these unfrozen "windows" in the permafrost act as groundwater recharge or groundwater discharge areas. Nor is it perfectly clear just how such localized groundwater flow regimes change with changes in latitude and altitude between Fort McPherson and Fort Simpson. These are matters of continuing hydrogeological and geohydrological research in peatlands occurring within the discontinuous permafrost zone.

From inspection of conventional (panchromatic) aerial photography, black-and-white infrared aerial photography, false-colour (colour-infrared) aerial photography, and colour-infrared ground photography it would seem that the following hydrogeological relationships exist; but they must still be tested under varying field conditions:

1. There seems to be a noteworthy change in groundwater hydrology, natural vegetation, and peat depth in comparable geological, topographic, and drainage conditions between the continuous permafrost zone on the Peel Plateau west of Fort McPherson (say above about elevation 1500) and the discontinuous permafrost zone on the Peel Plain east of Fort McPherson.

2. On the Peel Plain and Peel Plateau between Fort McPherson and Sans Sault Rapids, many of the thermokarst features (lakes and ponds) seem to be reducing in size as a result of "new" permafrost aggradation around their shorelines. Thus there is probably very little groundwater recharge from standing water in the unfrozen "windows," the chimneylike cylindrical walls of which are likely to be nearly vertical (private communication from S. Zoltai and testhole logs and probings studied by the authors). Computations of changes in lake widths were made in area in vicinity of Fig 2 but results were inconclusive (see Appendix 'D').

3. The northern portion of the Mackenzie Plains extending from Sans Sault Rapids to roughly Great Bear River appears to be a transitional zone in which thawing (permafrost degradation) is occurring around some thermokarst features and freezing (formation of "new" permafrost) is occurring around others. In fact, we believe that segments of shoreline on a single thaw pond or lake (thermokarst depression) may be melting (naturally retrograding) whereas other segments of the shoreline on the same lake or pond may be stable (in equilibrium) or possibly freezing (permafrost aggradation). See Fig 3. These suspicions should be checked by properly controlled field research programs.

4. The southern portion of the Mackenzie Plains, especially around and south of Fort Simpson, seems to be situated in an area where the thermokarst features are actively melting (permafrost degradation). In this region, groundwater probably moves from ribbed fens and small treeless near-circular collapse scars out into unfrozen peat beneath frozen peat plateaus and underlying unfrozen mineral soils. Groundwaters within ribbed fens probably moves downslope within subsurface fen peat (see Figs 8 and 9).

Because it is possible that unfrozen "collapse scars" in frozen peat plateaus (ice-rich peat) and unfrozen ribbed fens surrounded by sloping frozen impermeable peatlands (Fig 9) may be either local groundwater discharge or recharge sites it will be necessary to install nests of piezometers in and around these thermokarst features and measure them several times a year to determine what is taking place seasonally and with regional changes in latitude and altitude. The groundwater and heat flow measurements should also be related to physical characteristics of the thermokarst feature.

Current differences of opinion as to the origin of thermokarst features may be related to seasonal effects, to latitude and altitude, soil texture and slope position and in turn to geohydrologic flow systems within the widespread permafrost region within the discontinuous permafrost zone (see section in this report dealing with suggested research).

EXPLANATION OF THE SURFICIAL GEOLOGY MAP AND LEGEND

The generalized surficial geology map shows the inferred origin, compositional character, and spatial distribution of surficial geological deposits. These deposits are shown on maps having scales of 1 inch = 4 miles and 1 inch = 10 miles, respectively, as well as on twenty-three (23) 8½-inch x 11-inch-sized pages at the back of the report. The assembled map sheets at scale 1 inch = 10 miles and covering the entire study-area are contained in a map pouch at the back of the report. This composite map has been made by splicing together the individual 1 inch = 10 mile maps. Four sets of the composite surficial geology maps have been coloured.

The mode and environment of sediment deposition as well as the lithology and stratigraphy of the various map-units may be inferred from the legend shown on each map-sheet. There are advantages to this kind of presentation for the hydrogeologist. For example, the map reader studying an area of ground moraine (G) exhibiting streamlined ice-flow features will know that if the till is derived from shale (from reference to the bedrock hydrogeology map) the subsoils will be homogeneous, exhibit very low permeability, and will act as an aquiclude or aquitard even though the till sheet may contain randomly distributed inclusions of sand and gravel. The map-unit G frequently contains patches of lacustrine silty clay and clayey silt to elevation 600 ft and even above this elevation locally. However, if well-defined glacially streamlined forms were apparent in the photos, we mapped the area as ground moraine. In the complex mapped as N it is not possible to separate the islands of till and surrounding waterlaid sand, silt and clay.

Lacustrine deposits (L) will be massive to varved and laminated,and even though predominately silt and clay in texture these sediments will contain some fine sand seams and partings. Map-unit L is finely layered, represents deposition in a deeper offshore glacial-lake environment, and generally occupies poorly-drained lowland areas. On slopes in former lakebed areas there are few thermokarst depressions; but in poorly drained flatlands they are numerous. These sediments do not contain commercial quantities of groundwater. They are finely stratified, exhibit low permeability, are only unfrozen where there is standing water (thermokarst lakes), and generally contain high and highly variable ice contents. Silty and clayey deposits in L interfinger with lake-deltaic sand and silt, marked D, and in many places it is difficult, if possible, to define the boundary between L and D without extensive testhole drilling and detailed sample inspection.

Surficial deposits marked F are subject to flooding, sudden changes in erosion and deposition, are permeable, and potentially may store large quantities of good quality groundwater. Glaciofluvial terraces and outwash plains appear to be dominantly sandy rather than gravelly.

The various surficial geology map-units have been grouped hydrogeologically (see following section). Descriptions below each map-unit allow such grouping.

Fig 25 is a key map showing the locations of individual 8½" x 11" surficial geology maps numbered 1 to 23, respectively.

EXPLANATION OF THE SURFICIAL HYDROGEOLOGY MAP AND LEGEND

An attempt has been made to group the surficial geology map-units into hydrogeology map-units, still retaining the symbols used on the surficial geology map showing the general character and distribution of the surficial deposits. Grouping is based on anticipated quality and quantity of groundwater that might be developed from individual wells assuming that a proper exploration, testing and well construction program is carried out. The inference here is that the groundwater investigation be carried out by a competent water-well driller under the supervision of an experienced hydrogeologist. The surficial hydrogeology map is intended as a groundwater probability map of surficial deposits and a guide to groundwater exploration.

It was considered desirable to retain the map-unit boundaries shown on the surficial geology map in preparing the surficial hydrogeology map because certain landforms that have been grouped together may, upon detailed drilling and well testing in the field, prove to yield slightly better quantities and qualities of water than other units in the group. The more promising map-units can then be easily recognized and separated out.

Because the number of tested water supplies are extremely limited for such a large area -- less than a dozen small sites in an area extending over 50,000 square miles -- the estimates given for probable maximum yields and anticipated water quality must of necessity be largely "educated guestimates." It should also be stressed that the safe yield figures given are not absolute maximum values but probable maximum estimates. Moreover, the figures do not refer to the safe yield from a well drilled at random in a particular map-unit, but rather to the results of a properly organized and conducted test-drilling program supervised by an experienced, competent hydrogeologist after he has first carried out a detailed field-geological reconnaissance of the study-area. This definition of hydrogeological map-units applies to groundwater exploration in the Mackenzie River Valley as it does to groundwater investigations on the Prairies, where as many as a dozen or more testholes may be drilled at carefully preselected test sites before the site for a permanent well site is discovered, and a well is installed, developed, and put into production. It is important that the reader interpret the hydrogeological map in this context.

Data in the map legend suggest that the best water-supply prospects are located in wide braided rivers -- especially below river bars on the active floodplain, beneath frequently inundated abandoned back channels on the inactive flood plain, and below wooded islands surrounded by coarse sand and gravel channel-lag alluvial deposits. This map-unit is marked F. The next best commercial sources of groundwater are probably large freshwater lakes (marked "lakes"), followed by sand and gravel outwash and terrace deposits where these glaciofluvial deposits are sufficiently low-lying to be recharged from lakes and rivers. These deposits are marked O and T. They are considered to be better groundwater prospects than the group of landforms that include A, E, D, W, I and C. These coarser-textured deposits are likely to yield small water supplies only where they happen to be unfrozen -- for example, a) below south-facing slopes, b) around the margins of large water bodies such as lakes, creeks, and rivers, and c) where the landforms are traversed frequently by surface runoff.

Springs should always be examined in the field; we were able to detect a very limited number only owing to the small scale of aerial photography examined. Twenty-three individual 8½" x 11" surficial hydrogeology maps follow the surficial geology maps and occupy similar areas (see key map in Fig 25).

EXPLANATION OF THE BEDROCK HYDROGEOLOGY MAPS AND LEGEND

An attempt was made to show generalized groups of sedimentary rock map-units considered significant in understanding regional groundwater flow systems (see Appendices 'F' and 'G'). The twenty-three 8½" x 11" maps at the end of this report contain information on 1) general topographic position of the various map-units, 2) tectonic history as related to degree of structural disturbance and thus secondary (fracture) porosity and permeability, 3) lithology and stratigraphy as they effect the primary (intergranular) permeability of varying strata (e.g., shale versus sandstone), 4) environment of sedimentary deposition as this affects rock type and quality of water that has migrated through these bedrock sediments. For example, one may anticipate sulphate waters in gypsiferous marine shale formations and carbonate-anhydrite formations, sulphate and chloride waters in formations that contain gypsum, anhydrite, and salt beds; and hard bicarbonate waters in dolomite and limestone beds. Better quality waters may occur in broken, brecciated, and basal zones in fresh-water (i.e., non-marine) sandstones having favorable secondary (fracture) porosity and permeability resulting from Early Tertiary crustal disturbances. Anticlinal and synclinal folds and major thrust faults are associated with Late Laramide orogeny, which occurred some 50 million years ago.

The bedrock hydrogeology map at a scale of 1 inch = 10 miles shows 1) contours, 2) different ages of the various sedimentary-rock formations, 3) lithology (rock type) and stratigraphy (layering and interbedding) of the map-units to the extent possible at a scale of 1 inch = 10 miles, 4) environment of sediment deposition such as mainly marine or mainly non-marine, 5) regional bedrock structures (synclines, anticlines, and major thrust faults).

The more productive aquifers are likely to occur in thick uncemented Tertiary sand and gravel (T); in thicker and coarser non-marine Cretaceous basal sandstone beds; in more fractured and porous zones in Devonian sandstone, limestone and dolomite rocks marked Dm, Dmk, Dmh, Dmbr, Duu, Duk, Dutt; and in Ordovician, Silurian and Cambrian strata shown as OS and OSk, Єca. Of these the Bear Rock, Nahanni and Kee Scarp Formations are probably the most permeable bedrock formations in the Mackenzie Valley region and they therefore represent potentially major bedrock aquifers. They show up on the bedrock hydrogeology maps as Dmbr, Dm, Dmk and Dmki map-units.

If the groundwaters have travelled very far through these rocks the water quality is likely to be poor (generally high in sulphates -- i.e., "sulphurous"), for it is believed that there is a close association between water quality and rock type through which the groundwater has migrated. Likewise, there appears to be a close correlation between water quality and magnitude of streamflow. Water quality and water temperature in bedrock also varies markedly with depth.

The occurrence of large flows of saline water in deep bedrock zones, as evidenced by deep boreholes, large saline springs, and well-developed sinkholes suggest groundwater movement within the deeper bedrock strata. One of the largest areas of widespread solution of carbonate and evaporite rocks occurs east of Fort Good Hope and north of Norman Wells. Here widespread collapse structures have been reported. Whether or not these structures result from the widespread solution of anhydrite beneath less soluble dolomite beds of the Bear Rock Formation is unknown; but this possibility is suspected by the writers (see, also, the location of sinkholes on the surficial-geology map).

Generally poor quality groundwater may be expected from the following formations Kl, Klf, K, Dur, Dus; Dm (sulphate waters), Dmc (sulphate waters), Dmki (sulphate waters), Dmbr (sulphate waters, locally), OSk (sulphate waters) and Єcs (sulphate and/or chloride waters).

GROUNDWATER DEVELOPMENT PROBLEMS

The following potential problems should be considered in exploring, testing, and developing groundwater sources along the Mackenzie River Valley (see, also, Appendix 'C' summarizing private communications from Mascho, Lund, and Brandon as well as literature digest, Appendix 'H'):

1. Much of the groundwater found in fine-grained glacial-drift deposits and in the underlying bedrock is likely to contain high sulphate, chloride, iron, and manganese contents.

2. Groundwater quality is likely to vary seasonally with stream discharge and also with the chemical composition of the rock strata through which the groundwaters have moved (see Figs 28 and 29).

3. Small groundwater sources located remote from major rivers and lakes may be depeted with continued pumpage because sources of recharge may be cut off by permafrost barriers.

4. Groundwater qualities may also deteriorate with continued usage and are likely to vary widely with depth below ground surface.

5. Freezing of water wells may be a problem in some localities; and in certain cases it may be necessary to operate the well continuously or, alternatively, install some suitable built-in heating unit.

6. Because suprapermafrost aquifers often tend to be thin and occur in local and regional topographic depressions, contamination of groundwater can be a serious problem.

7. Icing conditions at faults and joint fissures, at the contacts of water-bearing fissured sandstone or porous limestone over shale, and at springs at the contact of sand and gravel beds over clay, till or shale can build up ice mounds a few to several tens of feet thick. These ice mounds may even interfere with the normal pattern of surface runoff because of delayed runoff associated with temporary storage above the ice dams (private communication from Dr Charles Slaughter, Alaska).

8. The better groundwater prospects are located along major rivers that experience highly variable discharge and consequent shifting of the river channel along with excessive, and destructive, lateral erosion and temporary deep channel bed degradation. Probable maximum depth of riverbed degradation during high floods is therefore an important consideration in the installation of Ranney-type collector systems. Considerable ingenuity will be required in the design of collectors and wells to tap water in unfrozen deep sand and gravel strata and yet not be removed and destroyed by river erosion (private communications from L. V. Brandon, C.E. Sloan, and Appendix 'H').

SELECTION OF POSSIBLE SITES FOR HEAT-FLOW AND GROUNDWATER FLOW RESEARCH

Sites selected for the measurement of heat flow and groundwater movement are best illustrated by means of selected panchromatic and colour infrared aerial photographs. In this way, specific terrain features can be identified and discussed. If research programs are implemented, it will very likely be necessary to install nests of piezometers at different depths below ground level and at different distances back from the margins of thermokarst features as well as within some of these features. Accordingly, the recognition of these terrain features in airphotos is important.

Alternate site-areas for prospective groundwater research are shown on Figures 1 to 13 accompanying this report. Listed below are the figure numbers, hydrogeological research objectives, and general locations (*see*, also, Appendix 'B').

Fig 1. Determine size, shape, and hydrology of aquifer (thawed area) in sand dune (S) at Old Fort Point south of Fort Norman; on the east bank of the Mackenzie River. Panchromatic airphoto. Observe details of stratigraphy in exposed river bank and strata from which water is seeping.

Fig 2. Determine local heat-flow regime and possible permafrost aggradation around lakes on Peel Plain west of Arctic Red River. Panchromatic airphotos. Explain dark rims around these lakes.

Fig 3. Measure suspected localized permafrost melting (pink vegetation) around thaw lakes in vicinity of Wrigley. Colour-infrared airphoto.

Fig 4. Monitor heat flow and water movement and water/ice relationships on and around islands in the Mackenzie River near Norman Wells. Colour-infrared airphoto. Correlate man-induced effects and changes in the hydrology of the active layer.

Fig 5. Relate groundwater movement and heat flow to vegetation type, soil and rock type, hydrographic and topographic settings. Along the Lower Carcajou River east of West Mountain. Colour-infrared airphoto.

Fig 6. Compare groundwater regime and active-layer thickness in east-facing versus west-facing slopes and effects of differences in solar radiation on permafrost thawing, plant stress, and slope instability (at white arrow). This area is also located on the Carcajou River Valley, west of the Canol Road. Colour-infrared airphoto.

Figs 7, 8 and 9. Study the hydrology of 1) patterned (ribbed) fens (unfrozen), 2) wooded peat plateaus (frozen), and 3) small treeless collapse scars (unfrozen) in the peat plateaus. Figs 7 and 8 are colour-infrared airphotos and Fig 9 is a panchromatic airphoto. Research carried out here in summer of 1971 by Dr. L. Lavkulik, (pedologist), Dr. J. S. Rowe (plant ecologist), Prof. J. Murray (hydrologist), Dr. N. Rutter (geologist), Dr. C. Crampton (forest ecologist).

Fig 10. Determine possible reduction in size of thaw ponds having floating vegetation -- i.e., new permafrost around pond margins. Plot water content profiles for possible "new" versus "old" permafrost around these thermokarst features. Panchromatic airphoto. (Check with S. Zoltai about his research and findings in this field of endeavor.)

Fig 11. Attempt to measure differences in heat flow in warmer elevated sands (dunes) and colder low-lying finer soils north of Norman Wells. Colour-infrared airphoto.

Fig 12. Examine Sammon's Creek for places where river water goes underground and reappears as springs and check water quality vs source rock (Dmki?) and stream discharge.

Fig 13. Attempt to correlate chemistry of river water with chemistry of possible seeps and springs along valley walls opposite sinkholes and thus source rock (Middle Devonian carbonate and evaporite beds).

In addition to these prospective research studies of heat-flow and groundwater movement in different permafrost environments, we believe it would be useful to try and monitor regional groundwater flow systems. In this connection we suggest you consider installing piezometers along a long cross-valley (transverse) profile in an attempt to disclose regional groundwater flow patterns at Roche-qui-Trempe-a-l'eau or at Oscar Creek. An alternate piezometric profile might be considered at Norman Wells, extending from the limestone upland to the bars in the Mackenzie River -- either north or south of Bosworth Creek (see Fig 4).

Several alternate site-areas are shown and described in captions to the figures because it is difficult for us to know which research project or site-area you may favor for economic, research, or logistics reasons.

SOME NORTHERN HYDROGEOLOGY RESEARCH NEEDS

A Groundwater contribution to streamflow and its relation to fish biology

In subarctic and arctic regions the contribution of groundwater to streamflow is important in northern ecology as well as Arctic geotechnology. Based on our regional studies of aerial photographs and of relevant map and report data we believe that groundwater discharge into streams is probably relatively more important ecologically in the continuous permafrost zone than in the discontinuous permafrost zone. The major north-flowing rivers across the Arctic North Slope in Alaska and Yukon seem to be fed to a significantly much larger extent by thermal springs in the Brooks Range and British Mountains -- important in the spawning of certain species of fish, as Arctic Char -- than is the case with streams originating in the Mackenzie Mountains and Franklin Mountains, where runoff from rainfall and snowmelt is likely to be a more important factor. Springs are reported on islands in the Mackenzie River as well as such creeks and rivers as the Rabbitskin, Saline, Sammon's, Mountain, North Redstone, Great Bear, Beavertail and Mountain.

Research that is slanted toward the relative importance of groundwater flow in northern (arctic and subarctic) ecology (plants and animals including fishes) would likely prove useful.

B Relation of permafrost degradation/aggradation to latitude, altitude, changing climate

As may be noted elsewhere in this report, we suspect that permafrost may be presently aggrading on the Peel Plain and Peel Plateau, may be presently degrading from some point south of Norman Wells to Fort McMurray in northern Alberta, and may be nearly at equilibrium or may be either aggrading or degrading or both around the same thermokarst feature in vicinity of Norman Wells to Wrigley, or thereabouts. If these suspicions are correct, are these naturally-occurring present-day changes related not only to latitude, as indicated above, but also to altitude, to changes in climate, and to hydrogeological factors.

From a research standpoint there is need to obtain and analyze data on water-content vs depth profiles and groundwater-movement profiles and groundwater chemistry using suitably located piezometer nests in places where the permafrost is actively building (aggrading, building "new" ice) and where it is actively melting (degrading, only "old" ice).

Attempts to measure change in size of thermokarst features over a 20-year period proved inconclusive using medium-scale photography (see section of report dealing with such measurements -- i.e., Appendix 'D'.)

C Geometry of thermokarst features

We have long felt that thermokarst-feature size, depth, shape, shoreline configuration and presence or absence of floating, submergent, and emergent pond vegetation -- among other terrain features identifiable in airphotos -- should be systematically studied, possibly using computers, to determine which of these recognizable "indicators" yields the most useful data on type of mineral sediment in the substrate, b) age of the thermokarst features, c) relevant details of geomorphic/climatic/vegetational history, d) volume of subsurface ice present in different localities, e) existing thermal condition of the permafrost or the possibility of changing thermal conditions in the ground from locality to locality, f) relation of heat flow and movement and chemistry of groundwater. See thermokarst features on Figs 1 (upland), 2, 3 (white arrows), 4 (white arrow), 5 (S), 7 (white specks in PP), 8 (center of colour infrared photo), 9 (CS), 10 (W), 11 (upland north of Mackenzie River).

To oversimplify, one might suspect that

In the continuous permafrost zone:

1) Large, deep thaw depressions indicate a thick ice-rich silt layer over gravel or bedrock, and

2) Large, shallow thaw depressions indicate thin ice-rich silt layer of gravel or bedrock;

In the discontinuous permafrost zone:

1) Dark ground-cover vegetation rims around the shoreline of thaw ponds suggests permafrost aggradation (especially in vicinity of Arctic Red River)

2) Sharply outlined water basins and raw crumbling peat banks suggest active melting under existing natural (not man-induced) conditions.

D <u>Relation of erosion/sedimentation history within the Mackenzie River channel to groundwater flow and chemistry</u>

Deep boreholes for oil exploration disclose 200 to 300 feet of waterlaid silt and very fine sand in the vicinity of Camsell Bend. This would appear to place the base of waterlaid sediments in the Mackenzie Valley floodplain near Camsell Bend at or below elevation 90, which is well below the level of shale bedrock crossing the Mackenzie riverbed at Sans Sault Rapids. At Sans Sault Rapids, the shale in the riverbed occurs around elevation 140, or some 50 feet above the elevation of the base of waterlaid sediments (alluvial or lacustrine?) at Camsell Bend, even though Sans Sault Rapids is situated over 300 miles downstream in the same valley. Thus, one may ask: Did the bedrock in the riverbed at Sans Sault Rapids act as a plug in the regional groundwater flow system? Also, does this plug, if that is what it is, affect the chemistry of groundwater in the deeper alluvial sediments in the Mackenzie River bed. One would suspect that there has been very little change in the Mackenzie River channel since deglaciation some 10,000 to 13,000 years ago. (This view has also been mentioned by Dr. N.W. Rutter, G S C, Calgary -- private communication.)

We feel this is a possible groundwater research problem.

E Back flooding in lower reaches of major tributaries

Backflooding could very seriously and substantially affect the availability of usable groundwater supplies beneath floodplains along the lower 1 to 10 miles of major tributaries to the Mackenzie River. The length of reach affected depends on the gradient of the tributaries and the fact that the Mackenzie at flood discharge may back up water to depths of 20 to 30 feet in these tributaries and induce deposition of clay, silt, and very fine sand in their lower reaches. Ordinarily one would expect to find sand and gravel at the mouths of such high-energy rivers as the Mountain and Keele. But stratified fine sand and silt occur below the active flood plain at the mouth of the Mountain River (personal observation). Not only does such backflooding into low-gradient tributaries affect groundwater yield but also, possibly, the chemistry of groundwater in sections of tributary river valleys that may eventually be crossed by main transportation routes (highways, railways, pipelines). Thus the location of high-yielding water wells in the floodplains of these tributaries must consider backflooding effects.

F Relation of northern hydrogeology to pipeline construction and operation

There is little question that groundwater movement and pore-water pressure dissipation will have a marked bearing on the stability of a buried warm-oil pipeline in steeply sloping ice-rich fine-grained soils. An analysis of this problem must consider the interaction of many parameters over a period of time. The problem very likely necessitates computer programming and analysis in order to determine probable magnitude of the effects. The stability of a pipeline and surrounding ground is affected by many factors: density and permeability of the soil surrounding a warm-oil pipeline (both relate to rate of pore-water dissipation); ice content and its distribution in the subsurface; shape, size, and temperature of the heat source; various thermal characteristics and properties of the permafrost-affected soil; hydraulic gradients; strength of the unfrozen soil; and degree of slope (topography) across which a warm-oil pipeline traverses. There may be other factors that should be considered in computer programming and analysis. This type of heat flow and groundwater movement research could be useful as follow-up work on early studies undertaken by Dr Arthur Lachenbruch of the U S Geological Survey at Menlo Park, California, and recent computer studies by Dr. Norbert R. Morgenstern, Department of Civil Engineering, University of Alberta, Edmonton.

Because of the complexity of these interacting variables and the possible variations in procedures of constructing and operating warm-oil and chilled-gas pipelines, which are not fully known to us, we hesitate to comment on the hydrologic implications of construction and operation of a pipeline except to note that the implications require careful examination and study and attempts must be made to properly evaluate them.

G Geohydrology of northern peatlands

The role that groundwater hydrology and chemistry play in the formation of wetland fens versus deep ice-rich bogs along the Mackenzie Valley and south to Cold Lake, Alberta, is in our opinion a most important facet of northern hydrogeological research.

Terms frequently used by peatland ecologists should perhaps be defined because they may be unfamiliar to geologists, groundwater hydrologists, and engineers.

A WETLAND is an ecosystem having its water table near the surface of the main root system of plants growing in it. A PEATLAND is a wetland with substantial deposits of partially decomposed vegetal matter (i.e., peat). Peatland types can be differentiated into two main types -- fens and bogs -- according to the source of water supply promoting their accumulation.

In Dictionary of Ecology, Herbert C. Hanson defines a FEN as a tract of low marshy ground containing peat that is relatively rich in mineral salts, alkaline in reaction, often situated around or near freshwater lakes, and is vegetationally distinct from bogs. Hanson defines a BOG as an undrained or imperfectly drained depressional area that is covered with sedges and shrubs (Ericaeous, especially) and sphagnum mosses, is poor in mineral nutrients, is typically underlain by sphagnum peat, and is often dotted with islets of open water. Groundwater in bogs is usually highly acidic in reaction (pH of 3 to 4) whereas groundwater in fens is alkaline in reaction (pH over 7). Thus fens are usually found overlying calcareous parent materials (soils and rocks).

Ivan MacFarlane in "Muskeg Engineering Handbook" University of Toronto Press, 1969, describes FEN MUSKEG as peatland that is supplied by water previously in contact with mineral soil. He says that sloping fens are subject to groundwater flowing through the system -- as distinguished from bogs that are fed by precipitation that has been effectively isolated from passage through the mineral substrate. Bog vegetation is thus OMBROTROPHIC (i.e., rainfall-nourished) and fen vegetation is MINEROTROPHIC (i.e., mineral-nourished), or fed by water in contact with mineral materials.

In the Mackenzie Valley region the distinction between fens and bogs is significant in groundwater studies because fens and bogs are widespread, vary substantially in ice content (permafrost), and because the surface and near-surface water movement is different in each type of peatland, even though intergradations and transitions commonly occur between them. Thus, one may speak of "true fens" and "true bogs" and of transitions between them.

It appears that true fens tend to be wet; to form in elongate channelways; to develop on gentle slopes that follow concave slopes, and the lower parts of slopes and watersheds; to have pH values in the range of 7 or higher; to be relatively rich in nutrients, and particularly Ca and Mg ions; to support Hypnum mosses, sedges (Carex spp.), aquatic marsh grasses, dwarf or swamp birch, willows, and tamarack; to be generally unfrozen; and to be fed by groundwater that has migrated through a basic mineral substrate. On the other hand, true bogs (e.g., peat plateaus) tend to be relatively dry on the surface; to develop on convex surfaces near or at the crest of water-table divides; to have a pH of 3.5 to 4.5; be relatively poor in nutrients and especially in Ca and Mg ions; to be covered by a limited range of vegetation (Sphagnaceae, Ericaceae,and Black spruce), such as Sphagnum mosses, Reindeer lichen (Cladonia spp.), heath shrubs (Labrador tea, bog rosemary, leatherleaf, bog laurel, various blueberries, crowberries, cranberries and cowberries), and by stunted ragged spindly black spruce; to be generally frozen, often containing high ice contents; to be fed directly by rainfall and snowmelt -- not by groundwater that has passed through the mineral substrate; to be underlain by acidic rather than basic soil and rock types. In most peatlands the ground surface corresponds closely with the water table. Moreover, infertile sites (peat plateaus) tend to accumulate peat more rapidly and harbour more ground ice than fertile sites (e.g., fens).

A fundamental research question concerns whether collapse scars (windows) in peat plateaus originate from differences in vegetation, snow cover and standing water on ground surface or melting from below by artesian groundwaters.

The role of surface and groundwater hydrology and chemistry is fundamental to a proper understanding of northern peatlands and to the highly varying occurrence of permafrost in them. Probably no one has done more research in this field,as it applies to the Mackenzie Valley, than Mr. Steve Zoltai, presently at Edmonton. Other Canadian research workers interested in the hydrology and evolution of permafrost-affected northern peatlands are Dr. J. S. Rowe, Saskatoon, Dr. Wayne Pettapiece, Edmonton, Dr. Charles Tarnocai and Jean Thie, pedologists with the Canada Department of Agriculture, Research Station, Pedology Unit, in Winnipeg, and Dr Roger J. E.Brown, Permafrost Section, Division of Building Research, National Research Council, Ottawa. Mr. Zoltai has worked mainly on peatland stratigraphy and related vegetation; and it might be useful to supplement Mr. Zoltai's studies with detailed chemical profiles of the groundwater as well as with profiles of groundwater flow as determined from nests of precisely located piezometers.

SPECIAL-PURPOSE AIRBORNE REMOTE SENSING DEVICES

We feel that a balanced approach to the use of remote sensors is highly desirable in studying northern permafrost terrain. We believe the broader aspects of surficial geology, soils, vegetation, and permafrost are best interpreted from conventional (panchromatic) aerial photography, beginning with photos at a scale of 1 inch = 8000 feet and finally interpreting photos at a scale of 1 inch = 1000 feet to 1 inch = 2000 feet. Once this has been done, it is believed that refinements in data sensing can probably be achieved by recourse to airborne electrical-resistivity surveys (lateral and vertical variations in terrain resistivity), thermal-infrared imagery (the affecting variables of which must be carefully controlled and known for meaningful interpretation), black-and-white infrared photography(for surface drainage delineation and separation of deciduous and coniferous vegetation), and colour-infrared photography (for identification of plant stress that might be imposed by a thin active layer as well as other stress-generating factors). When the active layer is 4- to 6-feet thick, most trees are little if at all affected by underlying permafrost. We would like to have seen the colour-infrared aerial photography extended from Sans Sault Rapids to Fort McPherson and on northward into the continuous permafrost zone.

Thermal infrared, microwave radiometry, and side-looking radar imagery are all limited because of the high frequencies employed and limited depth penetration -- of the order of a few centimeters only.

Although each sensor has a contribution to make, we feel that colour-infrared aerial photography is perhaps as good as any, except possibly resistivity surveys. We have very little knowledge of electrical-resistivity surveys, some experimental work of which has been carried out by Barringer Research Limited of Rexdale, Ontario.

Main applications of the more esoteric remote sensors include the 1) detection of possible environmental relationships that might not otherwise be suspected; 2) selection of better field test sites, inasmuch as the sensors will shed light on what to look for in the field, where to sample in the field, and on preferable locations of piezometers and other field instrumentation.

SUMMARY OF FINDINGS AND RECOMMENDATIONS

1. We have prepared a) reconnaissance surficial geology, b) surficial hydrogeology, and c) bedrock hydrogeology maps covering some 50,000 square miles along the Mackenzie River Valley Region, beginning at a point south of Fort Simpson to and ending just north of Fort McPherson, Northwest Territories. The entire map-area is located within the widespread permafrost region of the discontinuous permafrost zone according to the "Permafrost Map of Canada." These maps have been explained in the body of this report.

2. We have described anticipated regional and local groundwater recharge and discharge systems and patterns in this region of widespread permafrost in the discontinuous permafrost zone and have sketched inferred regional groundwater flow systems.

3. We have pointed out a number of alternate research sites and types of northern hydrogeological research problems that we feel should be carefully considered. We recommend that the suggested alternate sites and research projects be carefully examined because, owing to possible limited available time and budget controls, it may be that only a few test sites and research projects can be undertaken. We have tried to include a wide enough range of site-areas and research projects to provide for reasonable selection. These are summarized in Appendix 'E'.

4. There is a paucity of existing data, sufficiently relevant and complete, to allow clearcut hydrogeological relationships to be disclosed for every situation that may be encountered along the Mackenzie River Valley. Gaps in existing data -- which would otherwise make the data more useful to the research hydrogeologist and geohydrologist -- could we believe be obtained at relatively little extra time and expense. In this connection we recommend that the Ground-Water Subdivision of Inland Waters explore the possibilities and costs of:

1) Getting the Fisheries Branch to include a complete chemical analysis of river and lake waters. The present method of chemical analyses and reporting does not allow a proper cation and anion balance to be made in order to confidently identify groundwater recharge/discharge areas and relationships.

2) Getting oil companies running drill-stem tests to collect water samples and run chemical analyses on all boreholes drilled. Temperatures of groundwater in boreholes could also be readily reported and these would be useful.

The existing partial data is frustrating because it is difficult to do more than suspect groundwater recharge-discharge relationships. A set of regulations suitable for the Fisheries Branch and for oil companies alike would go a long way toward overcoming this situation, and add a great deal to the knowledge of northern hydrogeology at comparatively little extra cost.

5. Appendices A, B, C, D, E, and H are included to document our own studies as well as sources of assistance. These include evidences of groundwater discharge, Appendix 'A'; extracts from oil-company geological reports, Appendix 'B'; documentation of private communications concerning water-well drilling, water supply and groundwater development problems, Appendix 'C'; attempts to measure thermokarst aggradation and degradation, Appendix 'D'; potential research site-areas and projects, Appendix 'E'; digest of relevant literature, Appendix 'H'; and one set of xerox copies of water quality data sent to us by Dr L. D. Delorme, Appendix 'I'; and use of drillstem tests to interpret the groundwater flow system, Appendix 'J'.

Groundwater recharge appears to be occurring in highlands with local groundwater discharge in lowlands -- notably the Mackenzie River and its main tributaries. Major differences in permeability between rock strata result in exceptions to this general flow regime (see Appendix 'J').

Deeper-lying groundwater and groundwater in older formations generally show higher total dissolved solids, even though there are exceptions, as indicated on the stratigraphic cross-section D-D' near Wrigley (Fig 21) and cross-section B-B' near the Arctic Red River (Fig 19).

Localized groundwater discharge into creeks and rivers is suggested by an increase in specific conductivity of the water during low-flow periods (see Appendix 'A'). Yet surface waters in ponds and lakes on the Peel Plain, Peel Plateau, and Mackenzie Plain appear to have very low dissolved mineral contents -- generally much lower than lakes and ponds on the Prairies.

CHEMICAL ANALYSES OF WATER SUPPLIES AT FORT GOOD HOPE AND FORT NORMAN, NORTHWEST TERRITORIES

1. Fort Good Hope. Water taken from spring in esker on October 30, 1970.

Constituent	Concentration in ppm
Total hardness as $CaCO_3$	215
Phenolphthalein alkalinity as $CaCO_3$	nil
Total alkalinity as $CaCO_3$	218
Iron	1.6
Manganese	<0.01
Nitrate nitrogen	0.22
Free-ammonia nitrogen	0.01
Calcium	58
Magnesium	17
Sodium	6
Bicarbonate	131
Carbonate	nil
Sulphate	4
Chloride	313
Fluoride	0.09
Total dissolved solids	252
pH	7.75

2. Fort Good Hope. Water taken from the water-distribution system on October 2, 1970.

Constituent	ppm
Total dissolved solids	284
Hardness (as $CaCO_3$)	198
Iron	0.02
Total alkalinity (as $CaCO_3$)	224
Sulphate	122
Chloride	2

3. Fort Norman. Water taken from village well.

Constituent	Concentration in ppm after 12 hrs pumping at 18 Igpm in July 1970	Concentration in ppm after 24 hrs pumping at 18 Igpm in July 1970	Concentration in ppm on January 5, 1971
Total dissolved solids	1209	1250	1316
Nitrate	0.09	0.10	0.10
Iron	3.3	5.4	1.20
Phenolphthalein alkalinity as $CaCO_3$	0	0	0
Total alkalinity as $CaCO_3$	110	112	118
Total hardness as $CaCO_3$	218	226	220
Calcium	57	64	62
Magnesium	18	16	11
Sodium and potassium	363	366	398
Carbonate	0	0	0
Bicarbonate	134	137	71
Sulphate	132	135	132
Chloride	539	546	573
pH	8.0	7.9	7.8

APPENDIX 'D'

MEASUREMENTS OF DIAMETERS OF LAKES IN THERMOKARST AREAS SHOWN ON 1950 AND 1970 AERIAL PHOTOGRAPHY VICINITY OF MARTIN HOUSE AND FORT SIMPSON, NORTHWEST TERRITORIES

Previous airphoto studies in Alaska, in the Mackenzie River Valley region, in northern Ontario, Manitoba, Saskatchewan, Alberta and British Columbia by the authors indicates that permafrost aggradation might be taking place at a measurable rate in some areas whereas permafrost degradation is occurring in other places. This suspicion was given support in talks with Mr Steve Zoltai, Federal Forestry Research Laboratory in Edmonton on October 14, 1971 and in Ottawa on February 3, 1972. Perhaps the best available evidence is that collected by Jean Thie, Department of Soil Science, University of Manitoba and documented in his report titled "Air Photo Analysis and Description of Surficial Deposits of An Area North of Lake Winnipeg, with Special Reference to the Occurrence and Melting of Permafrost," April, 1971.

A number of measurements of lake diameters were made on medium-scale aerial photography showing two selected locations along the Mackenzie River Valley in an attempt to determine whether or not permafrost has been discernibly aggrading or discernibly degrading over the past 20 years. The northern site selected is located in essentially continuous permafrost near Martin House on the Arctic Red River; the second site chosen is located in discontinuous permafrost near Fort Simpson. In carrying out this office-based study we followed the procedure outlined briefly below:

1. We acquired two sets of aerial photographs showing the same area but taken 20 years apart -- 1950 and 1970.

2. Then, as accurately as possible, we established the scale of each set of airphotos. We made certain that the difference in airphoto scales was accurate by measuring the distance between identical points on the airphotos taken in 1950 and 1970 and then calculating the precise scale of one set of airphotos using the other set as a measurement base.

3. We selected lakes in ice-rich peatlands; the lakes were about one-half mile in diameter and located in ice-rich peatland. We then attempted to make accurate measurements of changes in the shorelines of the lakes over a period of 20 years.

4. We selected several sections across the lakes. Sections across were taken at places where lake shorelines were especially well defined, so that precise measurements could be made.

5. Then, at the selected sections, we accurately measured the widths of lakes on the 1950 and 1970 airphotos. This was done using the 1/50-inch divisions on a standard engineer's scale and the airphotos which varied in scale from about 1 inch = 2000 ft to 1 inch = 3300 ft.

Locations of features selected for the determination of possible permafrost aggradation and degradation were as follows:

In the continuous permafrost zone: Latitude: 66°55'
Longitude: 133°25'
Location: Martin House, Northwest Territories
National Topographic Series mapsheet: 106 K

In the discontinuous permafrost zone: Latitude: 61°45'
Longitude: 121°08'
Location: Across the Liard River from the Fort Simpson Airport
National Topographic Series mapsheet: 95 H.

Based on several comparative airphoto measurements at each location we reached the conclusion that it was not possible to confidently establish whether or not thermokarst has been actively aggrading or degrading over the last 20 years. Some lake shorelines showed small increases over the 20-year period whereas others showed a similar magnitude of decreases in lake diameter. Lake diameters ranged between 2000 feet and 3000 feet in width. Differences in lake width measured on the 1950 and 1970 airphotos fell in the 25-foot to 75-foot range. Therefore, it appears that field measurements and observations are needed in order to establish reliable permafrost aggradation and degradation trends within the selected study-areas. Scales of two sets of aerial photography were 1 inch =

2000 feet and 1 inch = 3000 feet, approximately; and it is felt that these scales are too small to permit detection of small amounts of lake shoreline advance or retreat. Scales of 1 inch = 1000 feet to 1500 feet would have been much better. Also, at larger scales it would be preferable to measure windows or thermokarst collapse scars rather than lakes occupying ice-rich peatland.

Regarding Jean Thie's work north of Lake Winnipeg in Manitoba, in his conclusions he states:

1) Most permafrost in this area could have been formed after 600 years BP and before 200 years BP (= before the present time).

2) Collapsing in peat plateaus from melting of permafrost has been going on for some time -- from 200 to 100 years BP, and most likely from 120 to 100 years BP, when the climate is alleged to have begun to ameliorate.

3) Some segments of the rims of the collapse scars showed melting rates as low as 0 to 5 meters in 20 years. The rate of degradation on collapse scars 100 to 750 meters across ranged from 5 to 20 meters in 20 years; and collapse scars smaller than 100 meters across showed collapsing rates of 15 to 30 meters in 20 years.

Mr Jean Thie discusses the melting of permafrost bodies within the southern fringe of the discontinuous permafrost zone of Manitoba (equivalent to south of a line through Fort Simpson and Camsell Bend, Northwest Territories) in relation to relatively alleged recent changes in climate. In this connection, it is instructive to study Dr. J. Terasmae's graph showing changes in climate during the Wisconsin glaciation and postglacial time as related to present average annual temperature (see Fig 30). Mr. Thie's studies would lead one to speculate that the greatest chance of detecting permafrost degradation using comparative low-level airphotos (say 20 years apart) would occur in peatlands located south of about Camsell Bend in the Northwest Territories.

APPENDIX 'E'

ALTERNATE HYDROGEOLOGIC RESEARCH SITE-AREAS AND RESEARCH PROJECTS

Fig No. 1

Geographic location

Old Fort Point

Relevant airphoto

A11973 -- 210

National Topographic Map Series (1 inch = 4 miles)

96 C

Latitude

64°40'

Longitude

124°50'

Potential northern hydrogeological heat-flow and ground-water movement research project

To determine the nature of ground-water flow at the spring emanating from sand dune in vicinity of Old Fort Point.

Fig No. 2

Geographic location

West of the Arctic Red River near Martin House

Relevant airphoto

A12702 -- 56

National Topographic Map Series (1 inch = 4 miles)

106 K

Latitude

66°55'

Longitude

133°25'

Potential northern hydrogeological heat-flow and ground-water movement research project

To determine potential rate of advance of permafrost face around margin of large lakes on the Peel Plain.

Fig No. 3

Geographic location

Hodgson Creek near Wrigley

Relevant airphoto

A30366 -- 201

National Topographic Map Series (1 inch = 4 miles)

95 O

Latitude

$63^{o}20'$

Longitude

$123^{o}30'$

Potential northern hydrogeological heat-flow and ground-water movement research project

To determine the rate of retreat of permafrost around the margins of thermokarst ponds.

Fig No. 4

Geographic location

Norman Wells and Bear Island

Relevant airphoto

A30366 -- 114

National Topographic Map Series (1 inch = 4 miles)

96 E

Latitude

$65^{o}15'$

Longitude

$126^{o}50'$

Potential northern hydrogeological heat-flow and ground-water movement research project

To determine pattern of heat flow and ground-water movement in permafrost-affected islands in the Mackenzie River channel.

Fig No. 5

Geographic location

Carcajou River east of West Mountain

Relevant airphoto

A30366 -- 13

National Topographic Map Series (1 inch = 4 miles)

106 H

Latitude

65°30'

Longitude

128°15'

Potential northern hydrogeological heat-flow and ground-water movement research project

To monitor heat flow and ground-water movement in relation to different types of vegetation, soil and rock type, and drainage/topographic settings.

Fig No. 6

Geographic location

Carcajou River near the old Canol road

Relevant airphoto

A30366 -- 35

National Topographic Map Series (1 inch = 4 miles)

96 E

Latitude

65°10'

Longitude

127°20'

Potential northern hydrogeological heat-flow and ground-water movement research project

To determine the relation existing among slope aspect, solar radiation, ground-water regimes and slope stability in south-facing versus north-facing river banks.

Fig No. 7

Geographic location

South Blackwater River on the east side of the Mackenzie River

Relevant airphoto

A30366 -- 187

National Topographic Map Series (1 inch = 4 miles)

95 O

Latitude

63°45'

Longitude

124°00'

Potential northern hydrogeological heat-flow and ground-water movement research project

To determine the geohydrologic aspects of frozen wooded peat plateaus and unfrozen small treeless collapse scars in these peat plateaus.

Fig No. 8

Geographic location

Near Bear Rock, north of Great Bear River

Relevant airphoto

A30366 -- 129

National Topographic Map Series (1 inch = 4 miles)

96 C

Latitude

65°05'

Longitude

125°35'

Potential northern hydrogeological heat-flow and ground-water movement research project

To determine the geohydrologic aspects of ribbed fen (e.g., ground-water discharg vs ground-water recharge, or seasonally both).

LIST OF APPENDICES

APPENDIX 'A'

EVIDENCES OF GROUNDWATER DISCHARGE ALONG THE MACKENZIE VALLEY FROM PLOTS OF STREAMFLOW AND SPECIFIC CONDUCTANCE OF THE WATER

Groundwater discharge into some lakes, creeks, and rivers is suggested by an increase in specific conductance of the water during low-flow periods. Figs 28 and 29 show plots of specific conductance against stream discharge for the Mackenzie River and five tributary rivers to the Mackenzie.

It is worth noting that the quality of water in the more northerly streams is influenced to a smaller degree by the inflow of groundwater, presumably because of thicker and more continuous permafrost the farther north one goes. As an example, the Peel River shows less influence of groundwater inflow than the Liard River (see Fig 28); likewise, the Arctic Red River shows relatively less groundwater inflow than the South Nahanni River (see Fig 29). Chemical analyses of Mackenzie River water samples collected during winter months, when the river flow comes almost entirely from the Great Slave and Great Bear Lakes, show little change in quality. During summer months, however, there is evidence of substantial groundwater inflow. This aspect of the Mackenzie River chemistry was noted in a paper by A.A. Levinson, Brian Hitchon, and S.W. Reeder when they report (see reference below): "The results show, quite surprisingly, that during periods of high discharge the Mackenzie carries more total dissolved solids per unit volume than it does during periods of low discharge." These data strongly suggest that groundwater discharge is retarded by freezing temperatures during winter months. Even though it is evident that further research data and analyses are needed,the data gathered to date seem to indicate that there is substantial regional groundwater movement and that notably less groundwater discharge occurs during the winter months.

The following table shows a comparison of the specific conductance of water samples collected from three creeks in the vicinity of Norman Wells during the period June 25 to October 3, 1971.

Specific conductance in micromhos/cm

Date sampled	Vermilion Creek	Prohibition Creek	Oscar Creek
25/6/71	800	255	
9/7/71	1120	210	
16/7/71			560
25/7/71	450		
1/8/71			535
17/8/71	560	275	
22/8/71	312		
27/8/71			241
3/9/71	880		
11/9/71			382
17/9/71	970		
25/9/71			392
3/10/71	1040		

Vermilion and Prohibition Creeks are approximately six miles apart. Oscar Creek is located approximately 40 miles downstream of these two creeks on the east side of the Mackenzie River. Vermilion Creek waters show a markedly higher specific conductance than Prohibition Creek, even though in several instances both creeks were sampled on the same days. This comparison suggests greater groundwater discharge along Vermilion Creek and/or the presence of more readily dissolved gypsum and anhydrite strata in the Bear Rock Formation (see sinkholes adjoining Vermilion Creek on the accompanying surficial-geology maps).

The following three publications were studied and found to be pertinent in our study of water quality in the Mackenzie Valley Region:

1) "Groundwater Hydrology and Water Supply in the District of Mackenzie, Yukon Territory, and adjoining parts of British Columbia," Geological Survey of Canada Paper 64-39, by L. V. Brandon.

2) "Regional Variations of River Water Composition Resulting from Halite Solution, Mackenzie River Drainage Basin, Canada," by Brian Hitchon, A. A. Levinson, and S. W. Reeder; in Water Resources Research Vol 5, No. 6, Dec. 1969.

3) "Major Element Composition of the Mackenzie River at Norman Wells, N.W.T., Canada," Contribution No. 424, Research Council of Alberta, by A. A. Levinson, Brian Hitchon and S.W. Reeder, 1969.

Surface water samples collected from lakes and ponds along the Mackenzie River Valley by Dr. L. D. Delorme show specific conductances generally below 300 micromhos/cm, with the exception of one lake located approximately three miles northeast of Little Chicago (lat. 67°14'; long. 130°10'), which shows a specific conductance in the range of 900 to 1000 micromhos/cm (see, also, page 6, item 15 under Pettapiece). The low specific conductivity values suggest that there is little groundwater movement into surface ponds because of a deep permafrost layer, which acts as an impermeable boundary.

For comparison purposes the following total dissolved solids values, obtained from the Saskatchewan Water Resources Commission, show mineral concentrations in lake waters in southern Saskatchewan:

Lake	Approximate total dissolved solids (ppm)
Last Mountain Lake	2000
Fishing Lakes	1600
Madge Lake	500
Jackfish Lake	2000
Big Quill Lake	42,000
Little Quill Lake	5000 to 8000

Specific conductance of a small pond of snowmelt water in the Kerrobert, Saskatchewan, district approximately one week after spring thawing began was 5000 micromhos/cm. These values are markedly higher than those of surface waters collected in the Mackenzie River Valley Region.

From inspection of 100-foot contour maps, many of the surface-water samples collected along the Mackenzie River Valley and in northwestern Alberta appear to be located in areas that, theoretically, should be groundwater-discharge areas. Comparison of water qualities from northwestern Alberta and the Mackenzie Valley suggest lower concentrations of dissolved minerals in ponded surface waters along the Mackenzie Valley compared to northwestern Alberta, where, however, the climate is significantly different. This analysis again suggests that the permafrost layer, as suspected, acts as a deterrent to the movement of groundwater.

Preliminary findings by the Alberta Research Council indicate that the concentrations of dissolved minerals occurs in the mineral soil at shallow depths below ground surface whereas surface waters ponded in kettlehole and thermokarst lakes and ponds are relatively low in total dissolved solids (see Fig 23).

A detailed study of the several indicators of groundwater discharge is beyond the scope of this report. It seems certain, however, that groundwater discharge in the form of springs and seepages contributes substantial volumes of water to the Mackenzie River drainage basin. By following the method of J. D. Hem* of plotting stream discharge versus variation in specific conductance, one might obtain a general indication of groundwater flow.

Copies of chemical analyses of water and streamflow data used in this study are included in Appendix 'I'. They were obtained from Dr. L D Delorme in Calgary; from Paul Fee with the Water Quality Division, Inland Waters Branch; and from J N Stein, Pollution Control Section, Resource Development Department of the Environment and the Alberta Research Council.

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*USGS Water Supply Paper 1473, "Study and Interpretation of the Chemical Characteristics of Natural Water."

APPENDIX 'B'

EXTRACTS FROM OIL COMPANY SUBSURFACE GEOLOGICAL DATA FILED WITH THE OIL AND GAS EXPLORATION SECTION OIL AND GAS DIVISION NORTHERN ECONOMIC DEVELOPMENT BRANCH DEPARTMENT OF INDIAN AFFAIRS AND NORTHERN DEVELOPMENT, CALGARY

Most oil-company geological reports on deep borehole drilling contain relatively little data that is pertinent to the present study. However, some items of information are worth noting and these have been extracted and listed below. The report number is given along with what is considered to be the more significant subsurface geological information as it relates to regional hydrogeological studies. Descriptions of geographic locations and subsurface geological materials are sometimes vague and difficult to tie down.

1 60-4-4 Upper Devonian flat-lying limestone outcrops along the Trout River approximately 8 miles above the confluence of the Trout and Mackenzie Rivers. Extensive glacial drift covers the Upper Devonian strata in this locality.

2 508-1-4-8 A testhole drilled at latitude 60°51' and longitude 117°17' is reported to have encountered artesian groundwater.

3 508-1-4-8 Structure-test drilling in National Topographic Series mapsheets 85 D and 95 A encountered between 3 and 144 ft of glacial drift overlying Devonian strata.

4 509-1-4-1(4) a) The following composite stratigraphic section is given for the region in vicinity of Wrigley:

Depth (ft)	Materials
0 - 100	dark fissile shale
100 - 300	yellow limestone with grey shale interbeds
300 - 800	red shale and massive red limestone
800 - 1300	grey shale and dense grey limestone

b) The following composite stratigraphic section is given for the Great Slave Lake area:

Depth (ft)	Materials
0 - 300	Hay River Formation hard dolomitic limestone
300 - 700	Hay River Formation shale with limestone and sandstone interbeds
700 - 795	Fort Simpson Formation shale

5 352-1-4-17 Soft Upper Devonian shale is said to outcrop along the Mackenzie River banks between latitude 62°00' and 63°00'.

6 86-1-4-7 Following data are recorded for the upper Mckenzie River Valley area:

a) A borehole at latitude 60°52' and longitude 120°36' showed 280 ft of glacial drift.

b) Boreholes 18 miles east-southeast of Fort Simpson showed between 43 and 500 ft of glacial drift over bedrock.

c) The presence of salt water was noted in the Fort Providence area.

d) The Martin Hills are reported to be an Upper Cretaceous erosional remnant, which consists of salt-and-pepper sandstone and silty shale at a point 24 miles west of Fort Simpson.

e) The immediate Fort Simpson area is underlain by Upper Devonian Fort Simpson Formation shale.

7 45-1-5-14(151) Area: National Topographic Series mapsheet 95 N.

a) Springs were observed along the North Redstone River at latitude 63°32' and longitude 125°43'. They are said to emanate from a fault zone between Cambrian-Ordovician gypsum beds and the Silurian-Ordovician Mt Kindle Formation.

8 96-1-5-1 (218) Lower Root River area: latitude 123°15' to 124°00'; longitude 62°20' to 62°55'.

a) In this locality, glacial drift was seen on mountain sides as far up as elevation 3300 ft. Moreover, glacial erratics were found on the tops of all highlands. Alluvial sediments in lowland areas are said to reach 300 ft in thickness.

b) Upper Devonian strata (shale, limestone, siltstone) are over 10,000 ft thick.

c) Underlying Middle Devonian limestone strata are said to be 1500 to 2200 ft thick.

9 7-11-5-11 (142) Data extracted from several subsurface geological reports is as follows:

a) Structurally, Franklin Mountains are an anticlinorium, in which anticlinal axes plunge to the south.

b) Near Wrigley, Devonian limestones are seen to outcrop and to dip below the Willowlake River.

c) The Franklin Mountains east of the Mackenzie between Ochre River and Blackwater River are composed of heterogeneous limestone strata that form high erosional-remnant ridges and hills.

d) Over 150 ft of interbedded shale, limestone, and underlying gypsum beds occur three miles from the Mackenzie River along Saline River. These beds are part of the Saline River Formation. Small creeks in the vicinity are said to be salty and salt encrustations were seen to collect on rocks in creek and river bottoms.

e) A Cretaceous sandstone ridge with a gentle regional dip to the west occurs in the Dahadinni River area and is said to be overlain by thick deposits of Quaternary sand and gravel.

f) In the Lower Carcajou River area, Sammons Creek is reported to disappear underground of a distance of "several" miles at one point (lat. 65°28'; long. 28°15'), where the strata consist of porous dolomite in the Bear Rock Formation. Anhydrite is interbedded with dolomite and limestone, and the strata are said to be locally cavernous.

g) Oscar Creek basin (lat. 65°30'; long. 127°00') near Mount Morrow is said to cover an area of about two square miles that are occupied by small lakes having no outlet. The lakes are believed to discharge into the underlying limestone bedrock. Nearby, deep sinkholes occur in salt and gypsum beds in the lower part of the Bear Rock Formation. Sinkholes occur in evaporites under Bear Rock Formation conglomerate in Mount Richard and Mount Thomas. In the Oscar Creek basin area, the Kee Scarp limestone is reported to be porous and coralline.

h) Slater River - Bogg Creek - Halfway Islands area (lat. 65°00'; long. 126°15'). A stratum of 5 ft of silty clay was observed on top of a terrace at the mouth of Slater River.

i) Shiltee Rock, located seven miles above the confluence of Stony Creek and the Peel River, is a hard Cretaceous sandstone and conglomerate pillar that is 20 feet high.

j) Discovery Ridge (east of Norman Wells) consists of Devonian and Silurian limestone and dolomite. Norman Wells oilfield is developed in coral-reef limestone.

k) Alluvial coarse sand and gravel occur along the upper Redstone River (foothills region). Pleistocene and Recent (Holocene) deposits in this area are said to be over 200 ft thick.

l) Warm sulphur springs issue from coarse brecciated Bear Rock Formation where the Mountain River cuts the Imperial Range (lat. 65°25'; long. 129°10').

m) In vicinity of the headwaters of the East Fork of Little Bear River (across the Mackenzie River from Fort Norman), sediments consist of thick, coarse, massive Tertiary conglomerate and gravel. A borehole on Hoosier Ridge (lat. 65°25'; long. 127°35'; elev: 744) struck salt water at depth of 2817 ft. The water rose to within 100 ft of ground surface. This borehole shows 1600 ft of soft carbonaceous sand, gravel, conglomerate, shale, and lignite.

n) Two sulphur springs occur on the south bank of the Great Bear River downstream from the lower end of portage road (probably at the rapids section). Exposures along the Great Bear River Valley consist almost entirely of Pleistocene sediments.

o) In the Beavertail Point region (NTS: 106 H), both Devonian limestone and overlying basal Cretaceous sandstone are reported to be porous and permeable and many sulphur springs occur in the area. The report states that 20 ft of sand (deltaic) over lacustrine silt and clay occur in the lower Donnelly River area.

p) There is a strong odour of sulphur in waters of the Mackenzie River near Beavertail Point (NTS 106 H).

q) Depth of glacial drift in the Wrigley area is said to vary from 10 to 1000 ft in thickness.

r) Two islands in the Mackenzie River opposite Norman Wells -- Goose Island and Bear Island -- are underlain by stratified alluvial silt and sand that is several hundred feet in thickness. Heavy drilling mud is said to be required to drill through glacial drift in the Norman Wells area.

10 508-1-46(252). Cameron Hills area in northeastern Alberta and adjoining

Northwest Territories.

a) Glacial drift in the Cameron River Valley south of Tathlina Lake is reported to be 700 ft thick.

b) In vicinity of Bistcho Lake in northwestern Alberta, the glacial drift is 865 ft thick, with a gravel stratum from 600 to 865 ft below ground surface.

APPENDIX 'C'

DOCUMENTATION OF PRIVATE COMMUNICATIONS FROM MASCHO, LUND, BRANDON, BREARS, WILDERMAN

1. Mr. Paul Mascho, Department of Public Works
Yellowknife, Northwest Territories

a) Fort Norman. The well here is 160 feet deep, and yields approximately 12 Igpm. Chloride content of the water is said to have been high initially and, in addition, has increased with water use.

b) Fort Providence. Two water wells are in use but the main source of municipal water is the Mackenzie River. The motel is said to have a "good well."

c) Fort Simpson. Main water supply for Fort Simpson is taken from the Mackenzie River.

d) Wrigley. The Department of Transport uses groundwater from a well near the Wrigley Airport. Approximately one-quarter of the village water consumption comes from wells.

e) Fort Good Hope. This community developed a groundwater supply by installing a crib in a spring in an esker. Well depth reported to be 16 to 18 feet and the crib size, 6 feet x 6 feet. The iron content varies from 3 to 4 ppm; otherwise, the water quality is good. However, the spring froze over in 1970, apparently because of traffic along a nearby road. The well has been relocated in order to overcome this problem. It is suspected that the spring may be recharged through shallow sand and gravel from a lake 3 to 4 miles away.

f) Inuvik. River water is pumped directly from the Mackenzie River into Hidden Lake in order to settle out a silt content of approximately 250 ppm in the summer and a silt content of 20 to 25 ppm in the winter. Inuvik is presently experimenting with settling tanks to remove the river silt.

2. Mr. Sven Lund, water-well drilling contractor at
Yellowknife, Northwest Territories

a) Lund owns three drilling rigs, and requently uses a Nodwell-mounted combination of rotary and cable-tool rigs.

b) Lund has installed water wells at Fort Norman and Wrigley and has test drilled at Norman Wells in connection with groundwater exploration there. At Fort Norman, elevation of the well is approximately 40 to 60 feet above river level. The glacial drift aquifers are 4 to 5 feet thick and wells in the overburden tap several sections of sand. Water quality has deteriorated with usage. At Wrigley, testholes drilled for the Department of Transport encountered cemented gravel below a high terrace. The well at Wrigley is approximately 200 feet deep. Static water level is approximately 100 feet below ground surface. Quantity of water developed is said to be sufficient for local needs.

c) Lund says that groundwater temperatures range from $38^{\circ}F$ to $40^{\circ}F$ in northern localities where water wells have been installed.

d) Lund commonly uses 5- or 7-inch well casing, and frequently installs surface casing.

e) At Norman Wells, the top 100 feet of drift overburden contains zones of frozen sand and gravel that yield no water. Where encountered, shale bedrock below the overburden is hard and contains no significant water-bearing fractures or fissures.

f) Lund has done most of what little water-well drilling and installation work that has been carried out along the Mackenzie River Valley. Considerable shallow testhole drilling has been done by Big Indian Drilling; and Hall Drilling has done a limited amount of drilling for seismic investigations in vicinity of Fort Simpson.

g) Lund says that frozen sand and gravel is difficult to drill through owing to caving problems.

3. Mr. Leo V. Brandon, Regional Manager
Department of Indian Affairs and Northern Development
Whitehorse, Yukon

a) Probably the best aquifers occur in thick alluvium along the larger rivers, even though some bedrock formations -- such as Middle Devonian Bear Rock Formation limestone, locally -- may yield potable water.

b) Permafrost is not necessarily a barrier to groundwater development because in the past numerous groundwater supplies have been developed in permafrost regions.

c) Existing northern communities are not necessarily located in good locations from an engineering, economic, or environmental standpoint. Future northern communities and northern camp-site locations should give more consideration to such factors as water supply, drainage, and, if located on or near a major water course, the velocity of the river water and consequent serious problems of bank erosion and riverbed scour.

d) Mr. Brandon has observed many locations in the field that would be favorable for the development of groundwater supplies. However, he notes, groundwater development should be done by experienced well-drilling contractors under the supervision of competent groundwater hydrologists.

e) Rivers tributary to the Mackenzie River from the west carry a much higher silt load than rivers draining into the Mackenzie River from the east.

f) Mr. Brandon has observed numerous springs along the Rabbitskin River.

g) Mr. Brandon believes that the deeper groundwater flow system passes below the Mackenzie River and surfaces along the contact of sedimentary rock strata and the Precambrian Shield. Evidence to support this contention is the apparently more highly mineralized waters in Marian Lake (west of Fort Rae, NWT), and shown on National Topographic Series mapsheet 85 K) and the lower reaches of Little Buffalo River above Great Slave Lake (shown on National Topographic Series mapsheet 85A).

h) Available well logs and drilling records, as at 1964, are contained in Mr. Brandon's paper titled "Groundwater Hydrology and Water Supply in the District of Mackenzie, Yukon Territory, and Adjoining Parts of British Columbia," Geological Survey of Canada, Paper 64-39.

4. Mr. Lou Brears, water-well driller with M R Hall Drilling, Regina

a) When drilling for seismic investigations in the area immediately west of Fort Simpson, Mr Brears said he encountered up to 100 feet of unconsolidated stratified (deltaic) sand. The testhole that encountered this thick section of sand is located about 4 miles north of Antoine Lake. This would indicate that the community of Fort Simpson might possibly investigate groundwater supplies in these deltaic sands -- rather than treat Mackenzie River water. A good location to test for potential groundwater supplies would be in vicinity of nearby Martin River.

b) Some of the testholes drilled by Mr Brears along the Mackenzie River lowland encountered weakly artesian pressures in the groundwater. Boreholes would flow from 4 to 12 hours -- that is, until the pressure was sufficiently reduced. The discharging water would then freeze, indicating that permafrost restricts groundwater flow.

c) Mr Brears encountered loss-of-circulation problems frequently when drilling in permafrost. This situation was most evident, he said, when unfrozen soil zones occurred between frozen soil layers.

5. Mr. Giles Wilderman
Big Indian Drilling Co. Ltd.,
Calgary

a) Shallow drilling between Fort McPherson and Fort Simpson was conducted using a rotary-air combination. Compressed air was initially cooled from 150°F to 45° to 50°F, which was a sufficient reduction in temperature if drilling progress was relatively fast. However, it became necessary to drop the air-drilling temperature to 10°F to 15°F if drilling progress was relatively slow. Also where adverse drilling problems were encountered, it became necessary to drop the temperature to 10°F to 15°F to eliminate thawing.

b) Permafrost-affected soils are best drilled with a combination of rotary-air and cable-tool rig. Refrigeration of compressed air used in drilling is not economical on most small jobs.

c) Most seismic shotholes along the Mackenzie River Valley are 60 to 100 feet deep. Consequently, they frequently do not pass through the permafrost layer.

d) Wilderman says that Dr Ralph Isaacs of the Geological Survey of Canada in Ottawa is drilling relatively shallow testholes along the Mackenzie River Valley, and it may be desirable to extend these testholes to depths of several hundred feet (400 to 500 ft), which can be accomplished with the drilling equipment on the job.

e) Mr Wilderman says that they did not encounter any groundwater artesian conditions (flowing holes) in their shallow (10 to 50 ft) testhole drilling program that extended from north of Fort McPherson and to south of Fort Simpson.

CAMBRIAN

Єcs	Saline River Formation evaporites (salt, anhydrite gypsum, and red beds) and underlying Mt Cap Formation green shale and Mt Clark Formation reddish-purple sandstone. Mainly ground-water recharge areas at higher elevations in the Franklin Mountains and ground-water discharge areas at lower elevations near the Mackenzie River. Expect large quantities of poor quality sulphate and chloride waters in the Saline River Formation.

PROTEROZOIC

Ᵽ	Precambrian argillite, quartzite and dolomite. Only one small area is shown.

(Geology is modified after GSC Map 30-1963; GSC Memoir 273; GSC Papers 60-19, 61-13, 68-25, 71-11, with accompanying maps and figures; The Development of Sedimentary Basins in Western and Arctic Canada, by P.A. Ziegler (1969), Alberta Society of Petroleum Geology; J. Law in Bull. Can. Pet. Geol. Vol. 19, No. 2, 1971; and J.P.A. Noble and R.D. Ferguson in Bull. Can. Pet. Geol. Vol. 19, No. 3, 1971.)

APPENDIX 'G'

LEGEND OF RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP

(Note: The entire study-area is underlain by widespread permafrost in the discontinuous permafrost zone; also estimates of yields refer to probable, not absolute, maximum figures)

Symbol	Explanation
T	Tertiary non-marine sand, gravel, conglomerate, shale, sandstone, coal. Expect maximum yields of 50 Igpm of fair to good quality waters
Ku	Upper Cretaceous mainly non-marine sandstone and shale. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
Kl	Lower Cretaceous mainly marine shale and sandstone. Expect maximum yields of 1 Igpm of poor quality sulphate waters
Klf	Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
K	Upper and Lower Cretaceous unnamed and undivided mainly marine shale and sandstone. Expect maximum yield of 5 Igpm of generally poor quality waters
CPa	Carboniferous (Pennsylvanian) and Permian sandstone and conglomerate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
Dur	Upper Devonian Redknife Formation mainly marine shale and sandstone. Expect maimum yields of 1 Igpm of generally poor quality waters
Duu	Upper Devonian unnamed mainly non-marine shale, siltstone, limestone, and sandstone. Expect maximum yields of 5 Igpm of poor to fair quality waters
Dui	Upper Devonian Imperial Formation mainly non-marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
Duk	Upper Devonian Kakisa Formation limestone. Expect maximum yields of 5 Igpm of poor to fair quality bicarbonate waters
Dutt	Upper Devonian Trout River and Tetcho Formations consisting mainly of limestone with some shale and sandstone. Expect maximum yields of 5 Igpm of poor to locally fair quality generally bicarbonate waters
Dus	Upper Devonian Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igpm of generally poor quality sulphate waters
Dm	Middle Devonian mainly carbonate strata with minor shale and anhydrite. Expect maximum yields of 25 Igpm of variable quality waters

Symbol	Explanation
Dmk	Middle Devonian Kee Scarp Formation reefal limestone and other limestones. Expect maximum yields of 100 Igpm of poor to locally fair quality generally bicarbonate waters
Dmki	Middle Devonian Kee Scarp Formation limestone and Hare Indian calcareous shale. Expect maximum yields of 25 Igpm of variable quality generally bicarbonate waters
Dmh	Middle Devonian Hume Formation limestone. Expect maximum yields of 10 Igpm of variable quality generally bicarbonate waters
Dmc	Middle Devonian Canol Formation shale. Expect maximum yield of 1 Igpm of poor quality sulphate waters
Dmci	Middle Devonian Canol and Hare Indian Formations consisting mainly of shale. Expect maximum yields of 1 Igpm of poor quality bicarbonate-sulphate waters
Dmbr	Middle Devonian Bear Rock Formation dolomite, limestone, and anhydrite. Expect maximum yields of 250 Igpm of very poor quality generally bicarbonate-sulphate waters
Dmhi	Middle Devonian Hare Indian Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
OS	Undivided and unnamed Ordovician and Silurian dolomite and limestone. Expect maximum yields of 10 Igpm of highly variable quality generally biacrbonate-sulphate waters
OSk	Ordovician and Silurian Mt. Kindle Formation dolomite and anhydrite, Franklin Mtn. Formation dolomite and shale. Expect maximum yields of 100 Igpm of poor to fair quality generally bicarbonate-sulphate waters
Єcs	Cambrian Saline River Formation anhydrite gypsum and salt, Cap Mt. Formation shale and Mt. Clark Formation sandstone. Expect maximum yields of 100 Igpm of poor quality generally sulphate-chloride waters from the Saline River salt and anhydrite, 1 Igpm of poor quality waters from the Cap Mt. Formation shale, and 10 Igpm of poor to fair quality waters from the Mt. Clark Formation sandstone
P̲	Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of fair quality waters

APPENDIX 'H'

SUMMARY OF FINDINGS OF GROUND-WATER AND GEOLOGICAL INVESTIGATIONS IN PERMAFROST REGIONS AS THEY APPLY TO THE MACKENZIE VALLEY REGION -- A LITERATURE ABSTRACT

Abu-Lughod, J., W. J. Roberts and J. B. Stall (1957) "Industrial Operations under Extremes of Weather," Part 5, Problems of Industrial Water in Areas of Extreme Weather Conditions, Meteorol. Mon., Vol. 2, No. 9, pp. 66-86

Abstract

Large yields of potable water are found in aquifers beneath permafrost, particularly in river valleys. Temperature of the ground water is commonly high enough to prevent freezing of the distribution system. Ground water occurs in bedrock fissures, at contacts, and in structural depressions beneath permafrost.

Alaska's Health (1951) "Safe Wells Need Careful Plans," Alaska's Health, Vol. 9, p. 7

Abstract

Suggestions for the proper location of wells with respect to sewage disposal facilities and a detailed plan for a safe well suitable for Arctic conditions are given.

Alter, A. J. (1949) "Water Supply Problems of the Arctic," Alaska's Health, Vol. 7, No. 3, pp. 1-3

Abstract

Brief discussion of water supply in permafrost regions, including the utilization of ground water.

Alter, A. J. (1950a) "Arctic Sanitary Engineering," Washington Federal Housing Administration, p. 106

Abstract

Shallow suprapermafrost water provides a seasonal supply that is easily contaminated. Rarely, water is entrapped with the permafrost in the southern part of the permafrost zone; but the yield is variable. Subpermafrost water supplies are difficult to locate, costly to develop, and commonly highly mineralized. In the Arctic, where permafrost extends into bedrock, circulation of ground water beneath permafrost is hindered by impermeable bedrock formations, and recharge through the permafrost is impossible. At Fairbanks, several wells tap subpermafrost water; the warmest water is available at some distance below the base of permafrost.

Barnes, D. F., and G. R. MacCarthy (1956) "Tests of Geophysical Prospecting Techniques in areas of Sporadic Permafrost in Interior Alaska," Geological Society of America Bulletin, Vol. 67, No. 12, Part 2, p. 1805

Abstract

Tests were made of resistivity and seismic refraction techniques in prospecting for ground water near Fairbanks, Big Delta, and Tok. The seismic refraction method proved excellent for detecting permafrost and mapping its upper surface, but was not successful in mapping the lower boundary of permafrost or the upper surface of bedrock. Resistivity techniques were fairly reliable in indicating the presence of permafrost and estimating its thickness; lack of adequate interpretation curves and the effects of severe lateral variations in surface resistivity limited the accuracy of depth measurements.

Bateman, J. D. (1949) "Permafrost at Giant Yellowknife," Royal Soc. Canada Trans., Vol. 43, Ser. 3, Sec. 4, pp. 7-11

Abstract

Permafrost, which is not present in outcrops, extends to a depth of 280 feet where the thickness of the overlying lacustrine clay approaches 60 feet. The clay overburden is regarded as an insulating blanket that has preserved ancient permafrost, and was deposited during a late glacial or Recent high level of Great Slave Lake. The age of the permafrost, therefore, is greater than that of the overburden, and is late glacial or interglacial.

Benninghoff, W. S. (1952) "Interaction of Vegetation and Soil Frost Phenomena," Arctic, Vol. 5, No. 1, pp. 34-44

Abstract

Distribution of permafrost beneath a river flood plain is sketched. Spruce-covered cut banks are underlain by permafrost at shallow depth, but river channels and bars are lacking in permafrost or have a deep permafrost table. Ground which permits the greatest degree of water penetration usually thaws to the greatest depth each summer, but root systems tend to restrict the downward penetration of water.

Billings, C. H. (1953) "Protecting Underground Utilities Located in Arctic Regions," Water and Sewerage Works, Vol. 100, No. 11, pp. 441-447

Abstract

Ground water occurs above, within, or beneath permafrost; the water below permafrost is like that in other climatic regions and is the most dependable source of supply. The water within permafrost is in passages like those in limestone and is generally under pressure, because the free level of its source is likely to be that of a lake or stream above ground. The water above permafrost in summer moves by gravity, percolating down the slope of the frost table; in winter, when the water begins to freeze, it becomes confined and moves under pressure. If under sufficient hydrostatic head, the water may burst through the top of the ground to form icings.

Black, R. F. (1950) "Permafrost, in Trask, P.D.," Applied Sedimentation, John Wiley and Sons, New York, pp. 247-275

Abstract

Definitions, summaries of terminology, distribution, character, temperature, relation to terrain features, origin, and geologic, engineering, and biologic significance of permafrost are given.

Large year-round supplies of water in the continuous-permafrost zone are found only in deep lakes or large rivers which do not freeze to the bottom in winter. In the U.S.S.R. artesian water has been found beneath 700 to 1,500 ft of permafrost. In the discontinuous-permafrost zone large supplies of ground water are found perched on top of permafrost or in unfrozen zones within or beneath the permafrost. Water-supply problems in the sporadic permafrost zone are comparable to those of the temperate regions. Quality of water is generally inferior to that of temperate regions.

Black, R. F. (1957) "Some Problems in Engineering Geology Caused by Permafrost in the Arctic Coastal Plain, Northern Alaska," Arctic, Vol. 10, No. 7, pp. 230-240

Abstract

Potable ground water is absent except in the beds of larger rivers and lakes. Shallow wells have encountered only saline water within and below permafrost. Potable water is trapped on permafrost in many lakes of the coastal plain. Lakes deeper than 6 ft do not freeze to the bottom and may provide a limited supply of water throughout the year. Very limited quantities of water may be obtained in summer from the active layer and from some of the offshore bars, but the water contains organic material and dissolved salts.

Black, R. F. (1958) "Permafrost, Water-Supply, and Engineering Geology of Point Spencer Spit, Seward Peninsula, Alaska," Arctic, Vol. 11, No. 2, pp. 102-116

Abstract

Point Spencer is the northern tip of a spit that separates Port Clarence from the Bering Sea and is located 69 miles northwest of Nome. Gravel and sand that compose the spit deposits are perennially frozen and cemented with ice; frozen ground underlies most of the area and extends several feet beyond the shore. In many places there is more ice than normal pore space in the sediments. The top of permafrost generally parallels topographic form. The base of permafrost determined in two wells was 12.5 and 17 ft below the surface, or 7.5 and 8 ft below sea level; the base of permafrost probably conforms roughly to topography. An icing mound 30 ft in diameter was underlain by a lens of ice 1 ft thick; polygonal patterns on the older part of the spit seem analogous to ice-wedge polygons elsewhere in the Arctic, but they were not investigated.

Fresh water is derived from rain and snow melt and is trapped as perched ground water in irregularities on the top of the permafrost. In winter much of the water is frozen. Water is most abundant in the borrow pits excavated in permafrost between the runway and Port Clarence, and in fresh-water ponds.

Boyd, W. L. and J. W. Boyd (1959) "Water Supply Problems at Point Barrow," American Water Works Association Journal, Vol. 51, No. 7, pp. 890-896

Abstract

Attempts to utilize ground water at Point Barrow, Alaska, have been unsuccessful. Drilling during exploration for oil in the Naval Petroleum Reserve produced subpermafrost water with a salinity of several thousand parts per million. Treatment of lake water, used as a supply, is necessary because the concentration of minerals in unfrozen water increases with increased ice thickness.

Brandon, L. V. (1960) "Northern Settlements," No. 1, Preliminary Notes: Canada Geological Survey Topical Report 28, 29 pp.

Abstract

A study of ground-water conditions at most of the settlements in the District of Mackenzie, Northwest Territories, was made in 1960 as part of a study of the occurrence of ground water in the permafrost regions of Canada. Most of the Paleozoic dolomite and limestone in the western Great Slave Lake region and Mackenzie Valley are aquifers containing water that is high in salt and sulfur. Precambrian rocks are satisfactory aquifers for domestic supplies only where fractured. The best aquifers are sand and gravel of alluvial and glacial deposits. Permafrost, where continuous and deep north of the Arctic Circle makes utilization of wells difficult. In relatively thin permafrost little heat is required from the water in the aquifer, or from a built-in heating unit, to keep the well open. Wells offer a potential means of supplying water where surface water has high turbidity, or required expensive intakes, filtration, plants, or pipelines.

Brandon, L. V. (1963) "Evidences of Ground Water Flow in Permafrost Regions," Proceedings: Permafrost International Conference, National Academy of Sciences - National Research Council, Publication 1287, pp. 176-177

Abstract

Springs and drilled wells provide evidence for ground water flow. Three other forms of evidence are apparent in ground-water discharge areas. These are base flow of rivers, variations in the chemical composition of river waters, and vegetation peculiar to an area as a consequence of ground water discharge. Resources do provide evidence of winter flow which can, in part, be attributed to ground water discharge.

Brandon, L. V. (1965) "Groundwater Hydrology and Water Supply in the District of Mackenzie, Yukon Territory, and Adjoining Parts of British Columbia," Geological Survey of Canada Paper 64-39, 102 pp.

Abstract

This report is based on a reconnaissance study of the ground-water hydrology of the District of Mackenzie (527,490 square miles), Yukon Territory (207,076 square miles), and a small adjacent part of British Columbia.

Field work was carried out during the summers of 1960 and 1961, when the writer travelled by aeroplane, canoe, and car over part of the area and visited settlements, type locations, and places where springs are known to occur.

The report is in three parts. The first part outlines the groundwater hydrology of the area and indicates the effect of physiography and geology on streamflow. The second part describes a number of thermal springs in the area. The third part describes the availability of groundwater in many towns and settlements.

Brewer, M. C. (1955) "Geothermal Investigations of Permafrost in Northern Alaska," American Geophysical Union Transactions, Vol. 36, No. 3, p. 503

Abstract

Maximum depth of permafrost is 1,330 ft, and the minimum temperature is -10.6°C, recorded below the depth of seasonal temperature fluctuation (70-100 ft). Lakes deeper than 7 ft do not freeze to the bottom in winter and may have an unfrozen zone approaching several hundred feet in depth beneath them. Frozen ground within the upper 100 ft of depth probably does not extend outward more than a few tens of feet from the shore of Arctic Ocean, although frozen ground may be present at greater depths.

Brewer, M. C. (1958a) "The Thermal Regime of an Arctic Lake," American Geophysical Union Transactions, Vol. 39, No. 2, pp. 278-284

Abstract

Permafrost underlies the shallow lakes, but an unfrozen basin several hundred feet deep may extend beneath the deep lakes.

Brewer, M. C. (1958b) "Some Results of Geothermal Investigations of Permafrost in Northern Alaska," American Geophysical Union Transactions, Vol. 39, No. 1, pp. 19-26

Abstract

Depth of permafrost varies with latitude, length of seasons, surface cover, proximity to the ocean, and distribution of rivers and large lakes that do not freeze to the bottom. Depth of permafrost decreases from 1,330 ft 8 miles from the ocean to indicated depths of 1,045 ft at a point 1,200 ft from the sea, and 670 ft at a point 400 ft from the ocean; the latter depths are slightly modified by nearby lakes. Permafrost temperature increases rapidly toward the ocean. At a point 390 ft from land, data suggest that permafrost is present to more than 400 ft below the sea bottom. Ocean bottom temperatures are below 0°C until ocean depths at 500-1,000 ft are reached, and therefore permafrost must extend seaward to ocean depths of 500-1,000 ft. The driller's log of the hole drilled in the ocean floor indicated no frozen material to 100 ft and the possibility of frozen ground from 100 to 205 ft and the unfrozen layers from 205 to 326 ft below the ocean floor. However, all the formations but the upper few feet have temperatures below 0°C, and are by definition perennially frozen.

Lakes are divided into two groups: (1) those that are 2-3 ft deep and freeze to the bottom in winter, and thaw to a few feet beneath their beds each summer, and (2) those that are 6-9 ft deep, do not freeze to the bottom each winter, and have much deeper thawed zones beneath their beds. Lakes having a diameter of half a mile and a depth of at least 7 ft may have thawed basins beneath them to a depth of 200 ft or more. If the lakes are underlain by sand or gravel of favorable water-bearing characteristics, they could provide a small year-round supply of fresh water. Within 5 miles of the coast, the sediments beneath such lakes may contain saline water.

Permafrost temperatures beneath small rivers that freeze to the bottom each winter are modified by the warming action of river water. Drilling on a bar along the Shaviovik River and at sites one-quarter mile on either side of the river show that the river produced a 3°C warming of permafrost temperature to a depth of 135 ft. Temperatures of these holes are expected to converge with the normal permafrost temperature gradient at greater depth.

The best year-round water source in the Arctic is an uncontaminated lake or stream, having a minimum water depth of at least 7 or 8 ft.

Broadwell, J. A. (1945) "How CAA Engineers Meet Construction Problems North of the Arctic Circle," Pacific Builder and Engineer, Vol. 51, No. 4, pp. 55-56

Abstract

The Civil Aeronautics Administration airstrip at Kotzebue, Alaska, is on a sandy beach ridge about 50 ft from Kotzebue Sound. Fresh water

was obtained by digging a shallow well only 100 ft from the sound. Water level in the well was 5 or 6 ft below sea level. Permafrost between the site of the well and the sound formed a barrier to encroachment of salt water. Softening and chlorination of the well water was necessary. At Shungnak, Alaska, a well was dug less than 100 ft from the riverbank of the Kobuk River. The well passed from sandy soil into gravel, but it was entirely in frozen ground. No water was found at least 15 ft below the level of the river. The hole was filled with gravel and converted into a cistern into which river water was pumped.

Brooks, A. H. (1907) "The Circle Precinct (Alaska)," U.S. Geological Survey Bulletin 314-K, pp. 187-204

Abstract

On Harrison Creek the gravel deposits are not frozen, and water circulates freely throughout the year. Creek-valley alluvium along Eagle Creek is 8-20 ft thick, of which 5-15 ft is muck; the gravel is not frozen and contains freely circulating water all winter. Similar water-bearing unfrozen zones occur in the alluvial deposits on Deadwood Creek.

Brown, I. C. (1958) "Geological Map of the District of Mackenzie, Northwest Territories," Map 1055A, Geological Survey of Canada

Abstract

Map relevant to the geology of the Mackenzie River Valley Region, N.W.T.

Brown, R. J. E. (1967) "Permafrost in Canada," Map 1246A, Publication No. NRC 9769, A Joint Publication of The Geological Survey of Canada and The Division of Building Research

Abstract

This map shows the areal distribution of continuous and discontinuous permafrost in Canada.

Brown, R. J. E. (1969) "Factors Influencing Discontinuous Permafrost in Canada," The Periglacial Environment, Edited by Troy L. Pewe, McGill-Queens University Press, Montreal, pp. 11-55

Abstract

Discontinuous permafrost forms a broad transition between areas with no permafrost and the continuous zone. From a study of available literature and field observations over the past decade, the approximate distribution and nature of the discontinuous zone in Canada has been established. East of Hudson Bay, discontinuous permafrost extends from the Laurentide Scarp, north to about 58° north. Between Hudson Bay and the Cordillera it extends northwesterly in a broad band several hundred miles wide to include the northern portions of the provinces and the southern portions of the territories. In the Cordillera, permafrost occurs at high elevations south to the 49th parallel and farther. Climatic control of the broad pattern of permafrost distribution is borne out by its relation to mean annual air temperature. Between the 30°F and 25°F mean annual air isotherms permafrost islands vary from a few feet to several acres in extent, to a maximum of about 50 feet in thickness, having temperatures between 30°F and 32°F. Between the 25°F and 20°F mean annual air isotherms, permafrost is widespread, 50 to 200 feet thick having temperatures down to approximately 23°F. Permafrost is virtually continuous north of the 20°F mean annual air isotherm. Climate is responsible generally for the existence of permafrost but the distribution of individual islands is conditioned by variations in microclimate and terrain features such as relief, drainage, vegetation, and snow cover. The extent of permafrost fluctuates in response to changes in climatic and terrain features with time. The permafrost in Canada's discontinuous zone probably formed after the final retreat of Pleistocene ice sheets or post-glacial inundations, except in the unglaciated portion of the Yukon Territory where its formation was periglacial.

Cederstrom, D. J. (1951) "Ground Water in Palmer, Anchorage, and Fairbanks Areas, Alaska," U.S. Geological Survey Open-File Report, 6 p.

Abstract

The Fairbanks area consists of a low plain underlain by silt, sand, and gravel, which is perennially frozen in form of wedges ranging in thickness from 0 to 250 ft, and silt-mantled bedrock hills. In the plain at Fairbanks small-diameter wells, 15 to 250 ft deep, obtain water from above or below permafrost. The wells are constructed by the jet-drive method, and no real difficulty is experienced in keeping them in operation. Two-inch diameter wells produce as much as 40 gpm, and the large-diameter wells yield more than 800 gpm. Water quality is poor, largely because of a high-iron content.

Cederstrom, D. J. (1952) "Summary of Ground-Water Development in Alaska, 1950," U.S. Geological Survey Circular 169, 37 p.

Abstract

This report discusses present and possible future ground-water development in a number of localities through Alaska. Substantial development of ground-water supplies is found only in Anchorage, Palmer, and Fairbanks. Elsewhere, few wells are present and possibilities of ground-water development have been almost entirely unexplored. Large quantities of ground water of good to poor quality are available in extensive areas of intermontane sandy fill and sandy glacial deposits. Nothing specific is known of possible yields in hardrock areas, or in rocks of any kind in southeastern Alaska. Much remains to be learned about ground-water occurrence, particularly with reference to the needs of growing communities, military establishments, and some areas of potential industrial activity.

Permafrost is a factor to be dealt with in development of water supplies in many northerly localities. In the north, permafrost is thick; but it thins southward and becomes more and more discontinuous until it is entirely absent. Except where thick and continuously distributed, permafrost does not preclude ground-water development, for it occurs in many places beneath permafrost or in thawed zones between permafrost. Permafrost is a serious problem north and west of the Alaska Range. Near Fairbanks permafrost is as much as 200 ft thick in the valley flat, but is discontinuous. In the vicinity of major streams and rivers permafrost is ordinarily absent, particularly on the "slip-off" side of the meander, but it is present in the steep face of cut banks on the opposite shore. Even near the cut bank, permafrost may be thin, and it is commonly absent beneath abandoned channels a half mile or more from the river. North of the Brooks Range permafrost many hundreds of feet thick makes ground-water development impracticable, except possibly along the Colville River.

Cable-tool drilling offers no special problems; frozen materials generally stand well in the hole, but casing is required to shut off thawed running sand or silt and to prevent caving due to thawing as the hole warms during the drilling. Casing will freeze to the walls of holes only where permafrost is several degrees below freezing or during periods of idleness. A productive well will not freeze if pumped regularly, and the plug of ice that sometimes forms inside the casing during idle periods can be thawed by hot water, steam, or salt.

Thicknesses of permafrost greater than 150 ft have been penetrated by 2-in. driven wells using cone-shaped drive head, above which are 1/4-in. perforations and through which a 1/2-in. thaw line projects as much as 18 in. The thaw line delivers water at 33° to 40°F which melts sufficient permafrost to permit driving the pipe. At shallow depths skilled drillers can make 30-40 ft per day, but progress below 80-100 ft may be as little as 1 or 2 ft a day.

Shallow wells dug in materials above permafrost supply a small amount of poor-tasting water, but the wells decrease in yield or freeze completely in winter. Supplies are obtained in some places where a depression in the permafrost formed beneath stripped ground or heated buildings.

Cederstrom, D. J., P. M. Johnston and Seymour Subitzky (1953) "Occurrence and Development of Ground Water in Permafrost Regions," U.S. Geological Survey Circular 275, 30 pp.

Abstract

Ground water in permafrost regions occurs mainly in unfrozen ground which is (a) under and adjacent to large rivers; (b) in or near the smaller streams; (c) in or near standing bodies of water, such as lakes occupying abandoned channels or muskeg lakes; (d) in newly deposited alluvium formed on the concave side of present river meanders but not necessarily adjacent to the river; (3) in dry abandoned channel scars or lakebeds; (f) in places where insulating vegetation mat has been stripped, allowing deep thaw; and (g) on south-facing hillsides. The procedure for surveying ground-water resources follows that of Muller (1945). Description of ground-water recovery includes discussion of drilling methods, drilling fluids, and winterization of drill rigs employed by Government agencies, petroleum and mining companies, and water-well drillers in Alaska and northern Canada.

Water distribution systems and water sources are described for Fairbanks, Nome, Dawson, Yellowknife, Donjek River, Kluane Lake, and Fort Chemo.

Further studies of the occurrence of ground water in permafrost regions should be undertaken along the following lines: (a) Continuation of literature search; (b) establishment of a research investigation, including drilling in some area north of the Arctic Circle in Alaska to obtain data on occurrence within the continuous-permafrost zone; and (c) development of geophysical methods and use of them in alluvial valleys where geologic information and drilling information make checking of the results possible.

Cederstrom, D. J., Clyde Wahrhaftig and F. F. Barnes (1959) "Ground Water Hydrology in Alaska," First International Symposium on Arctic Geology, Calgary, Canada, Vol. 12, No. 12

Abstract

Ground-water studies, begun in 1947, have been made at Fairbanks, Anchorage, Matanuska Valley, Kotzebue, Pribilof Islands, and Bethel. The Tanana Valley, in which Fairbanks is located, with its gravelly fill was found to be one of the most prolific sources of ground water in the world. In this area, permafrost is a minor problem in developing ground water, as is high iron content in the water. Central Alaska may be characterized as an area where large alluvial valley fills contain much ground water. Northward, however, permafrost becomes more and more of a problem.

Chernyshev, M. IA (1935) "Search for Underground Water in Perpetually Frozen Areas," American Water Works Association Journal, Vol. 27, pp. 581-593

Abstract

Finding water in perpetually frozen ground offers difficulties, and the methods used to find it are different from those ordinarily used. They are closely associated with common geologic practice and with the climate in a given region and are difficult to use in other regions. Three types of water occurrence are considered.

1. Subsoil water found in thick alluvium above perpetually frozen ground is the result of infiltration of precipitation and condensation of moisture during the frost-free season. Because of underlying permafrost

the subsoil water is not a source of large supplies, and tends to be erratic in quantity and to dry up toward the end of winter. In winter, when the water-bearing layer is compressed between the downward penetration of winter freezing and permafrost, the water under hydrostatic pressure breaks through to the surface at the weakest point in the seasonally frozen layer. The water forms an icefield; under heated buildings the water can emerge with less difficulty and may inundate the building, freezing and filling the structure with ice. Subsoil water trapped between the seasonal frost and the permafrost is not an abundant and dependable supply of water, and the springs formed are not dependable. It is best developed by erection of shallow wells with timbered frames or underground drain galleries; however, withdrawal of water may exhaust the water-bearing layer and permit freezing of the galleries; so the wells and galleries should be protected from freezing air temperatures, possibly by an earth embankment around well or gallery. The water in regions of perpetually frozen ground is characteristically soft, and sometimes contains high amounts of iron.

2. Springs are a more constant and abundant supply of water, which rises from very deep strata through the permafrost. They occur in the cracks of the scarps and are common in areas underlain by granite and crystalline schists. Springs are of either fresh or mineral water; some hot and warm waters are of the nitrous-acid type, most cold waters are of the carbonic-acid type. Springs are common on sunny slopes and even on mountaintops; their waters saturate the soil downslope, providing sufficient moisture for growth of thickets of trees (some tilted) on ice hillocks. Some springs, when localized, form "ice-volcanoes" at the surface; others, composed of warm water, form open-water channels that pass downslope into icefields. The best time to search for springs is February or March, when they can be recognized by icefields, or "heaps," and because at this time of year a flow probably indicates a spring origin, not an origin in subsoil water.

Reconnaissance investigation of a spring should be made in March to fix its limits, with detailed exploitation of the water source in the summer. During reconnaissance, a topographic survey of the outlet should be made, and the icefield sketched. Velocity of the running water is measured. Where the outlet is under water, the highest temperature measurement will be closest to the spring outlet, and measurement of the direction of currents in an icefield may enable location of the outlet. Shallow borings and excavations to locate the deepest thawed ground and rise of ground temperatures toward the source of water also show the position of the spring outlet. Heads of springs commonly form ice cones in late winter. Definition of the limits of the funnel within which the spring occurs is done during the detailed investigation by a system of "chessboard" borings and pits made near the outlet. From these excavations and borings, geologic maps with notations of permafrost and ground-water level can be made. In the center of the funnel in permafrost, an excavation is made suitable for pumping water. Where the spring outlet is discovered, the whole thawed layer and outlet may be intersected at several points by a collection gallery. Where there are several outlets separated by permafrost, each outlet is blocked and its water diverted to the lowest. Pumping tests and water-level observations should be made, and the waste water led away by way of gutters downslope; at the beginning of pumping the water yield is always more than that established later.

3. Artesian water from beneath the permafrost comes generally from horizons in alluvium in which impermeable confining layers are above and below the water-bearing layer and cause hydrostatic pressure (head). Artesian water occurs, in some places, in perpetually frozen ground, and may also consist of juvenile water; artesian water is found only in comparatively young sedimentary and volcanic formations (Jurassic and Tertiary) and in volcanic formations of Jurassic, Cretaceous, and Tertiary age.

Investigation of artesian water requires detailed geologic examination and deep boring. Temperatures of perpetually frozen ground and of the water are measured to insure that the water passing through the borehole in permafrost will not freeze. Water should be kept flowing through the borehole rapidly to enable the water to warm the pipes and thaw sufficient frozen ground around the pipes. It is also advisable to heat the hole, at the beginning of work, by steam through pipes from the boiler. Further special heating measures are generally not required.

Clark, L. K. and A. J. Alter (1956) "Water Supply in Arctic Areas; Design Features," Journal of Sanitary Engineering Division, Vol. 82, No. SA-2, Paper 931, pp. 931-1-931-11

Abstract

Ground water obtained from wells through permafrost is subject to freezing in the withdrawal pipe from underpumping and to freezing in the aquifer from overpumping. Well and pump installations are subject to damage by frost heaving. Ground water is warmer than surface water in winter and requires less heating before distribution. Water levels fluctuate, reaching the lowest level in late winter and early spring; in some places, well supplies have been entirely depleted at this time of year. Test pumping during the spring low water period will aid in determining reliability of yield.

Craig, B. G. (1957) "Glacial Lake McConnell, and the Surficial Geology of Parts of Slave River and Redstone River Map-areas, District of Mackenzie," Geological Survey of Canada Bulletin 122, p. 33

Abstract

The area was completely glaciated by the Wisconsin Laurentide ice-sheet, which extended westward into Mackenzie Mountains. There is no evidence that Cordilleran ice entered the area from the west.

A vast glacial lake, Glacial Lake McConnell, which extended from Great Bear Lake through Great Slave Lake to Lake Athabasca, was formed during deglaciation as a result of differential isostatic depression toward the east. This lake originated as three separate lakes in the three basins but became one vast lake as the topographic low between Great Bear Lake and the northwest arm of Great Slave Lake, and the Slave River Lowland became ice-free. Elevations of lacustrine features that formed during the maximum stand of the lake are about 925 feet above sea-level along its eastern boundary and decrease westward. Subsequent isostatic readjustment lowered water levels until the large glacial lake separated into smaller lakes, one of which was ancestral to Great Slave Lake. The minimum amount of readjustment indicated in this basin is slightly over 2 feet per mile.

During the earliest phases of ice-retreat, flow was diverted to the north and south by the mountain barrier along Mackenzie and Liard Rivers. Subsequent marginal thinning and eastward retreat produced a radial pattern of flow features in the western part of the area. Stagnation on Horn Plateau while ice was flowing actively on either side of it formed two lobes in the east-central part of the map-area. During the last phases of deglaciation flow was to the southwest and the ice-margin was almost parallel with the edge of the Precambrian Shield.

Cronkwright, A. E. (1947) "Water Supply Problems of the Arctic," Public Works, Vol. 78, No. 8, pp. 18-20

Abstract

In Arctic and subarctic regions abundant surface water of good quality can be obtained from rivers and lakes in summer; but in winter surface water is scarce, for rivers freeze nearly to the bottom and have restricted flow, and only the deeper lakes have water beneath the ice cover. At an unspecified Army post on Baffin Island plans were made for obtaining winter water supply from a river that in summer was one-quarter mile wide and 10 to 20 ft deep. Restricted streamflow, thick ice, and drifting snow on the access road rendered these plans impracticable, and water that was mineralized and of high color was obtained from a lake. Permafrost extends into bedrock at least 100 ft below the ground surface at this base and is hard to drill. The possibility of using high-speed rock drills in frozen rock should be investigated. At a large subarctic base, water was distributed by pipelines laid on the surface in insulated boxes. At small bases, a location close to water, such as a deep lake, is required or else snow and ice can be melted for camp use.

Day, J. H. (1968) "Soils of the Upper Mackenzie River Area, Northwest Territories," Research Branch, Canada Department of Agriculture, Ottawa, p. 77

Abstract

The surveyed area consists of approximately 4,787,500 acres in the southwestern part of the Northwest Territories. It includes the lands west of the Hay River in a wide band around the west end of Great Slave Lake and down the Mackenzie River to Green Island. The area is part of the Great Slave Lake Plain. The terrain is mostly level and gently sloping near the lakes and the river, but farther away there are steep slopes. The steepest slopes, which in some places are sheer rock escarpments, mark the highest stand of Glacial Lake McConnell along the south border of the area.

The climate is the continental type. The mean annual temperature is about 25 F; the mean annual precipitation varies from 10 to 14 inches.

The frost-free period (32F) varies from 75 to 106 days, and the growing season (42F) from 130 to 140 days. The Thornthwaite moisture deficiency during the growing season varies from 5.5 to 7.9 inches.

Forest growth covers the area. White spruce and balsam poplar form the main cover types on the river benches. At levels above the river benches, pines, aspen, and in the moist or wet positions, black spruce and tamarack are the tree species.

The most commonly occurring soils are Brown Wooded (30.3%) followed by Organic soils (24.3%), Gleysols (21.5%), Regosols (4.1%), Gray Wooded (2.7%), Podzo Regosols (2.2%), and Humic Gleysols (0.7%). About 1% of the land is moderately and strongly sloping, and about 1.1% is very steeply sloping and hilly. About 40% of the soils are well or imperfectly drained, but 47% are poorly drained. About 27% of the soils have sufficient stones on the surface to hinder cultivation.

About 12% of the soils belong to soil capability class 3 for agriculture, and about 16% belong to capability class 4. The soils in these classes have limitations for agriculture, but are capable of producing cereal and forage crops. About 14% of the soils belong in class 5 and are best suited to the production of forage crops and pasture. About 24% of the soils belong to class 7 and are not capable of use for arable agriculture or permanent pasture.

The soil map, printed on a scale of 1:250,000 (nearly 4 miles-inch), identifies soil areas by colors and symbols. The map also indicates the location of settlements, roads, lakes, and rivers. The report and the map are complementary and both should be studied to obtain information about the soils.

Dickens, H. B. (1959) "Water Supply and Sewage Disposal in Permafrost Areas of Northern Canada," Polar Record, Vol. 9, No. 62, pp. 421-432

Abstract

Permafrost restricts the movement of ground water and limits its use. Supplies obtained from above or within the permafrost are of variable quantity and of doubtful purity. Wells drilled through permafrost are costly and may require controlled pumping or auxiliary heat to prevent freezing of the well. Overpumping may result in freezing of the aquifer.

Dickens, H. B. (1960) "Construction in Permafrost; Obstacles of Soil and Climate," Canadian Consulting Engineer, Vol. 2, No. 1, pp. 33-37

Abstract

The author explains the basic properties of permafrost and discusses the problems of water supply and sewage disposal.

Douglas, R. J. W. and D. K. Norris (1961) "Camsell Bend and Root River Map-Areas, District of Mackenzie, Northwest Territories," Geological Survey of Canada Paper 61-13, p. 36

Abstract

Camsell Bend and Root River map-areas extend from the western Interior Plains on the east to deep within Mackenzie Mountains on the west. The nature and thickness of the stratigraphic succession varies considerably, depending on position relative to the plains or the mountains. In general, about 2,000 to 3,000 feet of strata underlies the plains east of the map-areas. Along the mountain front in McConnell Range of Franklin Mountains, some 6,000 feet is present between the top of the Middle Devonian and the Proterozoic. In Whittaker and Delorme Ranges of Mackenzie Mountains, however, some 15,000 feet of strata was measured below the top of the Middle Devonian; in spite of this great thickness it is unlikely that the top of the Proterozoic was reached.

The succession in Franklin Mountains in McConnell Range and in the vicinity of Root and North Nahanni Rivers has been known for some time through the work of Williams (1922, 1923) and Hume (1922). Several of their rock units were named, and insofar as possible at this time, they are recognized in this report. The thick succession in Mackenzie Mountains and Liard Plateau has been described in previous reports (Douglas and Norris, 1959, 1960) and additional data is presented here. The succession has been divided into a large number of map-units, some of formational status. Other map-units have been introduced to avoid implying correlation of strata in the different ranges where uncertainties exist, and still others to embrace sequences of rocks that were undivided or indivisible.

In this report, names are proposed for some map-units that are considered to have formational status. These units comprise rocks of Ordovician, Silurian and Devonian age exposed in Mackenzie Mountains. The new formations -- the Whittaker, Delorme, Camsell, Sombre, Arnica, Manetoe, Funeral, Landry and Headless -- are established primarily on the basis of gross lithology and general mappability in these and adjacent map-areas to the south and north; their designation does not fully take into consideration the results of stratigraphic and palaeontological studies still in progress.

Douglas, R. J. W. and D. K. Norris (1963) "Dahadinni and Wrigley Map-areas, District of Mackenzie, Northwest Territories," Geological Survey of Canada Paper 62-33, p. 34

Abstract

The stratigraphic succession beneath the Plains is probably more like that in Franklin Mountains than that of the more easterly Plains (Douglas and A. W. Norris, 1960). The succession in McConnell Range of Franklin Mountains was established by Williams (1922, 1923) at Cap

Mountain and Mount Kindle within Wrigley map-area and at Mount Clark and Saline River just north of the area. He proposed the following Cambrian to Silurian formations: Mount Clark, Mount Cap, Saline River Franklin Mountain and Mount Kindle. Their use here is as close as possible to their original definition, although it has been found necessary to raise the base of the Mount Clark Formation to correspond with an unconformity and the Mount Kindle Formation is now considered to be late Ordovician and early Silurian in age. Most of the formations of the Mackenzie Mountain sequence as established in adjacent Camsell Bend and Root River map-area (Douglas and D. K. Norris, 1961) extend into Dahadinni River map-area. These are the Whittaker, Delorme, Sombre, Arnica, Funeral, Manetoe, Landry and Headless Formations, of Ordovician to Middle Devonian age.

Ellsworth, C. A. (1910) "Water Supply of the Yukon-Tanana Region (Alaska), 1909," U.S. Geological Survey Bulletin 442-F, pp. 251-283

Abstract

Impermeability of the frozen ground prevents significant underground storage of water and makes uniform distribution of the total runoff impossible. Water derived from thawing of frozen ground during summer is of minor importance.

Fernald, A. T. (1959) "Geomorphology of the Upper Kuskokwim Region, Alaska," U.S. Geological Survey Bulletin 1071-G, pp. 191-279

Abstract

Wells at McGrath on the flood plain of the meandering Kuskokwim River provide subsurface data on frozen ground in the lowland. On the older parts of the meander scrolls 5 wells passed through the bottom of permafrost at depths ranging from 15 to 40 ft, and 6 wells at depths of 40-50 ft. Wells on the newer parts of the meander scrolls, including the 262-ft Federal Aviation Agency well, are free of permafrost. At Farewell Federal Aviation Agency airstrip a 360-ft well passed through a zone of permafrost the bottom of which is reported as both 12 and 125 ft by different sources.

Ferrians, Jr., Oscar J., Reuben Kachodoorian, and Gordon W. Greene (1969) "Permafrost and Related Engineering Problems in Alaska," U.S. Geological Survey Professional Paper 678, p. 37

Abstract

Permafrost, or perennially frozen ground, is a widespread natural phenomenon. It underlies approximately 20 percent of the land area of the world. The permafrost region of Alaska, which includes 85 percent of the State, is characterized by a variety of permafrost-related geomorphic features including patterned ground, pingos, thaw lakes, beaded drainage, thaw or thermokarst pits, and muck deposits. Known permafrost thickness ranges from about 1,300 feet near Barrow in northern Alaska to less than a foot at the southern margin of the permafrost region. The distribution of permafrost is controlled by climatic, geologic, hydrologic, topographic, and botanic factors.

The extensive permafrost region of Alaska poses special engineering problems for the design, construction, and maintenance of all types of structures. Lack of knowledge about permafrost has resulted in tremendous maintenance costs and even in relocation or abandonment of highways, railroads, and other structures. Because of the unique geologic-environmental conditions that exist in permafrost areas, special engineering procedures should be used, not only to minimize disruption of the natural environment, but also to provide the most economical and sound methods for developing the natural resources of the permafrost region of Alaska.

Fraser, J. K. (1956) "Physiographic Notes on Features in the Mackenzie Delta Area," Canadian Geographer, No. 8, pp. 18-23

Abstract

Associated with landslide debris on the slopes of low hills bordering the eastern margin of the Richardson Mountains, near Aklavik, Northwest Territories, are three pingolike features. Pingos, according to most workers, are formed by hydrostatic pressure in a subsurface layer of unfrozen soil confined by frozen layers. This pressure forces a mixture of water and fine materials upward through a rupture in the upper permafrost layer; their formation appears to require fine homogeneous material saturated with water, as, for example, occurs in shallow ponds or old lake beds. The pingos on the slopes of Mount Goodenough (Black Mtn.) are (1) a conical hill 60 ft high containing a crater with a pool 25 ft across, (2) a circular pool 40 ft across in which the ice was cracked and arched, with mud showing in the crack, and (3) a circular crater about 85 ft in diameter contained by a low rim about 18 ft high and breached downslope. Two theories of origin are advanced: (1) that they are of thermokarst origin, and (2) that their formation is similar to that of pingos.

Feulner, Alvin J. and John R. Williams (1967) "Development of a Ground-Water Supply at Cape Lisburne, Alaska, by Modification of the Thermal Regime of Permafrost," U.S. Geological Survey Professional Paper 575-B, pp. B199-B202

Abstract

A water supply has been developed in formerly frozen alluvium beneath a small intermittent stream by modification of the thermal regime of permafrost. The modification, largely a byproduct of road and reservoir construction, was effected by: (1) removal of tundra vegetation and the upper few feet of alluvium, which allows warming of gravel and water in the summer; (2) construction of a reservoir upvalley, from which water recharges the alluvium during the summer; and (3) installation of galleries downvalley from the reservoir to collect the water. Similar methods may make it possible to obtain water supplies elsewhere in arctic regions where stream alluvium extends below the depth of winter freezing.

Grainger, J. W. (1958) "Water and Sewer Facilities in Permafrost Regions," *Municipal Utilities Magazine*, Vol. 96, No. 10, pp. 29, 62-67

Abstract

Water in permafrost regions may be obtained from wells, rivers, lakes, ice, and the ocean. River water can be exploited by standard methods or with portable pumps where permafrost, unstable soil conditions, or the problem of ice erosion of river banks exist. Water can be obtained from lakes by extending intake pipe out into the lake. It can be obtained from just below the ice of the Arctic Ocean near the mouths of rivers because the fresh river water floats on the heavier salt water.

Hitchon, Brian, A. A. Levinson and S. W. Reeder (1969) "Regional Variations of River Water Composition Resulting from Halite Solution, Mackenzie River Drainage Basin, Canada," *Water Resources Research Vol. 5, No. 6*, pp. 1395-1403

Abstract

The composition of surface waters in the Mackenzie River drainage basins falls into three general groups: (1) rivers entering the Slave-Mackenzie system from the west which have sum-of-constituents 100-200 mg/l and chloride in the range <1 mg/l in their headwaters to 2-5 mg/l at their mouths; (2) surface waters on the Canadian Shield which have lower sum-of-constituents (<100 mg/l) and chloride (<1 mg/l); and (3) the Slave and Mackenzie rivers and the Great Bear and Great Slave Lakes, which have sum-of-constituents 100-200 mg/l and chloride 5-10 mg/l. Hydraulic head cross sections with evidence of solution collapse structures and anomalous depositional thicknesses indicate extensive solution of Middle Devonian halite and movement of the resulting brines to discharge areas at the principal Devonian outcrop near the Slave River. Chemical and isotopic analysis of saline springs in the discharge area confirms an origin by solution of halite (and gypsum) by meteoric water.

Hopkins, David M., Thor N. V. Karlstrom and Others (1955) "Permafrost and Groundwater in Alaska," *U.S. Geological Survey Paper 264-F*, pp. 113-145

Abstract

The distribution of ground water in Alaska affects and is affected by the distribution of permafrost. Present knowledge of permafrost and groundwater conditions is summarized for the following representative areas of Alaska: The Arctic slope and northern Seward Peninsula in the continuous-permafrost zone; southern Seward Peninsula, the Yukon Flats, the middle Tanana Valley, and the upper Kuskokwim Valley in the discontinuous-permafrost zone; the Britol Bay region in the sporadic-permafrost zone; and the Kenai lowland in the no-permafrost zone. The application and limitations of aerial-photograph interpretation in permafrost studies also are discussed.

Regional climatic differences result in a transition from thick, continuous permafrost in northern Alaska to permafrost-free terrain in southern Alaska. However, local differences in topography, lithology, and drainage result in sharp local differences in the character and distribution of permafrost that tend to obscure the regional zonation. Moreover, frozen ground formed during past cold periods persist to the present time in many areas, so that the distribution pattern is not exclusively the product of present-day climates.

Much of the ancient frozen ground is differentially thawing today. Recently formed frozen ground also thaws locally where natural or artificial alteration of the landscape alters the thermal regimen of the ground. Thus, both recent and ancient permafrost are interrupted horizontally and vertically by thawed zones through which ground water may circulate. Conditions that favor active circulation of water, both at the surface and at depth, promote thawing of permafrost and retard formation of new permafrost. Consequently, potential aquifers are similar in character but more restricted in size and abundance in permafrost areas than in areas of no permafrost.

Aerial photographs are almost indispensable to geomorphic studies in Arctic and subarctic regions. Their use permits recognition of many features and geomorphic relationships difficult to discern on the ground and allows controlled extrapolation of field data into nearby areas.

Hubbs, G. L. (1963) "Water Supply Systems in Permafrost Areas," Proceedings: Permafrost International Conference, National Academy of Sciences -- National Research Council, Publication No. 1287, pp. 426-429

Abstract

Adequate water supply is basic for the continued growth of any community. In permafrost areas the attendant difficulties in providing this supply are numerous and complicated. The main concern here is to find workable solutions for safe and plentiful water supplies that are economically feasible for both large and small communities.

Hughes, O. L., V. N. Rampton and R. J. Fulton (1968, 1969, 1970) "Reconnaissance Maps of Surficial Geology along the Lower Mackenzie Valley and adjoining Coastal Plains," on open file in the Geological Survey of Canada Office in Calgary.

Abstract

These maps comprise a generalized overview of the surficial materials along the lower portion of the Mackenzie River Valley and Arctic lower coastal plain.

Hume, G. S. (1954) "The Lower Mackenzie River Area, Northwest Territories and Yukon," Geological Survey of Canada Memoir 273, p. 118

Abstract

This publication contains three maps on the geology of the Mackenzie River Area.

Hyland, W. L. and M. H. Mellish (1949) "Steam Heated Conduits -- Utilidors -- Protect Pipes from Freezing," Civil Engineer, Vol. 19, No. 1, pp. 27-29

Abstract

Churchill, Manitoba, Canada, obtains its water by way of pipeline from a lake; the subsoil is not suitable for wells. At Fairbanks, Alaska, individual domestic wells are as deep as 200 ft; the sandy and gravelly soil is perennially frozen, but is water-bearing below and between layers of permafrost.

Hyland, W. L. and G. M. Reece, (1951a) "Water Supplies for Army Bases in Alaska," New England Water Works Association Journal, Vol. 65, No. 1, pp. 1-16

Abstract

Near Fairbanks, shallow lakes and streams, deep freezing in winter, flat terrain, and high suspended load of some streams make development of surface-water supplies impracticable. Adequate supplies of ground water are found below permafrost at depths of 60-180 ft. The water is about 35°F and does not meet the U.S. Public Health Service standards for iron and manganese content. The high iron and manganese content seems characteristic of permafrost regions. Because of the high cost of shipment of dry chemicals, and because base regulations required 0.4 ppm chlorine in the treated water, the chlorine method was found most practicable for removing the iron and manganese and at the same time adding chlorine to the water. Chlorine is applied to the water and is followed by settling and sand filtration.

Janson, Lars-Eric (1963) "Water Supply Systems in Frozen Ground," Proceedings: Permafrost International Conference, National Academy of Sciences -- National Research Council Publication No. 1287, pp. 430-433

Abstract

Consideration must be given to several factors when determining an underground layout depth for water pipelines and sewers. In northern Sweden, the zero-isotherm or frost-free depth, is in most cases the only determining factor.

In these areas, the frost depth is very uncertain and, to a large extent, extremely sensitive to variations in the mean annual temperature, especially in snow-cleared ground. As stated in an earlier publication, a succession of years with cold winters along with cool summers and autumns or little precipitation may result in lowering of the mean annual temperature of the ground to 0° or below. This implies that the frost depth may, at a certain critical mean annual temperature in the ground, suddenly go much deeper than normal.

Mean temperature variations in these areas make it difficult to establish a frost depth which will be decisive in choosing a laying depth for water pipelines. A 2.4 to 2.6 m laying depth has been adopted for the present; it corresponds to the frost depth of most cold winters. Because frost depth may be considerably greater, freezing in pipelines will be fairly frequent. This is confirmed by the fact that every year large sums are spent on repair and thawing of frozen water pipelines and sewers.

Jenness, J. L. (1949) "Permafrost in Canada," Arctic, Vol. 2, No. 1, pp. 13-27

Abstract

The bed of the Mackenzie River near Norman Wells is unfrozen. Wells 100 ft, 200 ft, and 350 ft from the water encountered permafrost thicknesses of 60 ft, 135 ft, and 267 ft, respectively. The beds of Great Bear, Great Slave and other lakes are unfrozen.

Two theories may account for the presence of an unfrozen zone separating the permafrost from the active layer: 1) that the permafrost below the unfrozen zone is a relic of past harsher climate and that the present climate is not severe enough to form permafrost; and 2) that the unfrozen zone may be a recent aquifer developed on or near the top of permafrost, in which freezing of the active layer may compress the aquifer, giving rise to hydrostatic pressure that prevents its water from freezing, even when its temperature falls below 0°C. The second theory is unlikely because it is hard to imagine that ground water could force its way through already frozen soil to form such unfrozen zones. However, some unfrozen zones may result from the failure of permafrost to form in aquifers having a high mineral content. A map shows the distribution of permafrost in Canada.

Kamenskii, G. N. (1947) "Hydrogeological Investigations of the Sources of Water Supply Under Permafrost Conditions," Poiski i Razvedka Podzemnykh Vod: Moscow-Lenigrad, Gosgeolizdat, Chapter 6, pp. 196-201 and pp. 281-283

Abstract

Prospect drilling for water in ground having negative temperatures is complicated by freezing of the drilling tools in the hole; this problem can be eliminated by using heated water, steam, and brine sollutions during drilling. Systematic measurement of temperatures should be made during drilling, either with slow-recording or electric thermometers, in order to determine the depth of the lower boundary of permafrost and the presence of talik, as shown by positive temperatures. Test-pumping experiments are made to determine the efficiency and reserves of ground-water reservoirs.

Of the various types of suprapermafrost water, that confined in thick alluvial deposits which do not completely freeze in winter is of significance. Yield of suprapermafrost waters is subject to fluctuation

Throughout the year, and the maximum and minimum yield must be determined by research work. Determination of maximum production is made during the summer when thawing is at its maximum pumping is done by using the "Tim method" (Thiem?) in conjunction with calculations of the distribution of flow, or by practical exploration methods of interaction of drill holes. In summer, it is important to consider influence of surface water on productivity of aquifers, especially those connected hydraulically with rivers. Determination of minimum flow is made during the maximum freezing period in late winter when the weak suprapermafrost supplies freeze; even the better aquifers are reduced to a minimum. Test pumping in this case must be prolonged 10 to 15 days, or even 1 to 2 months. Under these conditions recharge of the aquifer is stopped and the reserves diminished. The estimate of reserves should not be based solely on the natural distribution of flow, but on the measure of temporary reserves that are recharged during the period of summer thawing. Methods of test pumping of suprapermafrost waters for productivity are the same as for artesian waters and shallow aquifers. Investigations are recommended of icings and hydrolaccoliths originating from subpermafrost and suprapermafrost waters. The flow of water that forms icings can be determined by measurements of the volume of ice. Information on the thickness of permafrost is given, and the increase in temperature is cited as 1°C per 100 m depth in permafrost regions.

Mining operations are commonly facilitated by permafrost which maintains stability. However, in the Amderma region, the mines are infiltrated by salt water which has a temperature of -5°C near the surface. The permafrost layer, about 400 m thick, has a temperature of -4.8°C at a depth of 215 m. Comparison of chemical analyses of sea water and water from mines near the coastline shows that salt water will penetrate permafrost layers and hamper mining operations.

Krynine, D. P. and W. R. Judd (1957) "Principles of Engineering Geology and Geotechnics," McGraw-Hill, New York-London-Toronto, p. 730

Abstract

Ground water above permafrost in summer may be a limited source of supply, but because of its shallowness, it is subject to contamination and commonly disappears in winter. If the active layer is in impervious materials, ground water trapped between the active zone and permafrost may move horizontally to contribute to formation of hydrolaccoliths, or it may form a conduit through the active zone or appear in thawed zones beneath heated buildings or along streams and abandoned stream channels.

Water within permafrost occurs in alluvium near rivers, abandoned river channels, or in thawed gravel beds, and even in thawed areas between masses of permafrost, near standing water, on south-facing hillsides, and where vegetation has been stripped.

Water below permafrost occurs in large quantities and generally satisfies sanitary requirements; it is located in alluvium beneath permafrost and in joints and other space in bedrock. In hilly regions water under permafrost may be under high pressure and flowing wells may result.

Icings formed at points of ground-water emergence upslope from places where deep freezing has taken place can be controlled by construction of frost belts at some distance upslope from the road or other structure. Icings may be controlled also by ice fences and heating.

Law, James (1971) "Regional Devonian Geology and Oil and Gas Possibilities, Upper Mackenzie River Area," Bulletin of Canadian Petroleum Geology, Vol. 19, No. 2, pp. 437-486

Abstract

The upper Mackenzie River area is homoclinal in the east, with broad gentle uplifts. In the west there are large anticlines and thrust faults.

Devonian sediments thicken westwards from zero to over 10,000 ft. Early Devonian carbonates of the Delorme, Camsell and Sombre formations are present in the west. Early Eifelian rocks consist of basinal shales and limestones of the Funeral Formation and dolomites of the Arnica and Manetoe formations in the west, and evaporites of the Bear Rock and lower Chinchaga formations in the east. Late Eifelian rocks consist of Hume, Headless and lower Nahanni limestones and shales in the west and upper Chinchaga evaporites in the east. The name Willow Lake Formation is proposed for the dolomites lying between the lower Hume and the upper Chinchaga, and the name Ebbutt Member is proposed for the terrigenous clastic unit occurring at the base of the Willow Lake and extending into the basal Hume and middle Chinchaga.

Givetian rocks are mostly limestones and shales with important reef developments in the upper Nahanni and Kee Scarp carbonates. A major uplift, the Upper Mackenzie River Uplift, which affected most of the area, caused thinning of the early Givetian, upper Nahanni limestones and Horn River shales, and may have caused a mid-Givetian unconformity.

Upper Devonian rocks consist of shales with subsidiary silstones, sandstones and limestones.

Many anticlinal, reef and stratigraphic pinch-out traps remain to be tested.

Lebedev, A. F. (1936) "Soil and Ground Waters," Akad. Nauk SSSR Izd., Moscow, p. 314

Abstract

Old and new theories of ground-water formation are summarized and discussed. The laws of free, oriented and bound water migration in the soil both up and down are discussed. Problems of soil moisture accumulation and the role of evaporation and condensation of water in the formation of ground ice in permafrost are explained. The soil composed of solid or loose rock strata, frozen or unfrozen, is always porous to water vapour to a certain degree. Water condensing in permafrost in the form of ice layers comes from lower strata where vapour pressure is greater.

Levinson, A. A., Brian Hitchon and S. W. Reeder (1968) "Major Element Composition of the Mackenzie River at Norman Wells, N.W.T. Canada," Geochemica et Cosmochimica Acta, Permagon Press, Vol. 33, pp. 133-138

Abstract

The Mackenzie River at Norman Wells (about 88 per cent of the total Mackenzie drainage) has an average annual flow of 306,000 cfs, with great seasonal variations, and a discharge-weighted average dissolved solids content of 173 ppm which varies seasonally in the narrow range of 162-176 ppm. The previously observed chemical similarity between the Mackenzie and the Mississippi is confirmed.

MacKay, B. R. (1945) "Canada's Ground Water Resources from a Geological Aspect," American Water Works Association Journal, Vol. 37, pp. 84-100

Abstract

This introduction to the report is a statement of the past studies of the Water Supply and Borings Section, Geological Survey of Canada, the materials available for study, and a sketch of the physiography and geology of Canada. Most of the ground water utilized comes from unconsolidated deposits.

Canada is divided into three major structural units, the Laurentia, Cordillera, and Appalachia units, which are subdivided into stratigraphic units, and further subdivided into ground-water provinces. Permafrost is mentioned in discussion of certain units and provinces, as follows.

In the Arctic Islands Paleozoic ground-water province, the glacial drift is frozen, and water supplies are developed from either streams or wells that penetrate the frost zone into underlying bedrock. In the Arctic Islands Mesozoic province, water could be obtained from porous sandstone aquifers below the frostline. The Appalachia structural unit lies south of the permafrost zone, and the Cordillera unit is not subdivided.

MacKay, J. R. (1955) "The Anderson River Map-Area, N.W.T.," Canada Department of Mines and Technical Surveys, Geographical Branch Memoir 5, p. 137

Abstract

Even though the area lies within the permafrost zone, underground drainage occurs. In 1951 underground drainage was observed passing through a sand and gravel terrace near Rummy Lake, and the flow, in the form of perennial springs, fed a creek that built an ice fan each winter. The source of the flow was probably a lake a few hundred yards away. Another example of drainage through sand and gravel was seen on July 4, 1951, on the east side of Stopover Lake near the source of Horton River. The entire flow of a stream 10 ft. wide and several inches deep discharged into a lake 100 ft. across. The lake had no outlet, but conical pits in the bottom were seen to be the places through which water drained into the ground.

Ground ice in the region forms tundra polygons like those described by Leffingwell (1919) and Black (1953); the broad ice wedges are 5-10 ft across and probably go down 20-30 ft or more. Some ice wedges in permafrost extend below sea level. Polygons in the tundra flats bordering the old channel leading from Horton River to Harrowby Bay are hardly more than 150 years old, and some are younger because they have kept pace with continuous infilling of the channel. Pingos occur at the foot of Parry Peninsula, 4 miles south of Langton Bay, at 68°13' N. 122°35' W. and at 69°3' N. 120°15' W.; they are as much as 150 ft high. In 1955, storm waves intersecting a pingo on the east side of McKinley Bay exposed the core of clear white bubbly large-crystalled ice which was overlain by 4-5 ft of brown sand, locally containing small clam shells.

Moore, E. W. (1949) "A Summary of Available Data on Quality of Arctic Waters," National Research Council, Division of Medical Science Report to Subcommittee on Water Supply of the Committee on Sanitary Engineering and Environment, p. 14

Abstract

Wells in Yukon Territory, Canada, near rivers yield water of good Quality; those in permanently frozen ground freeze up in winter and cannot be relied on for permanent water supplies. Analyses of ground water from sandpoints in permafrost near Mayo and from a shallow well near Klondike River (Dawson area) show, respectively, 132 and 148 ppm dissolved solids, including 0.07 and 0.02 ppm iron.

Analyses of shallow ground water in permafrost regions of Northwest Territories, Canada, are given for Fort Resolution and Sawmill Bay, and other sites in which total calculated dissolved solids range from 486.7 to 3,600 ppm. The waters are hard and contain much iron; they contain organic matter, ammonia, and albuminoid nitrogen. Wells in permafrost seem to be unreliable in both yield and quality of the water.

Analyses of ground waters at Ladd A.F.B. (well 6), Tanana, Anvik, and Sinuk, Alaska, are given; dissolved solids range from 178 to 458 ppm, including iron content of 0.03-11.8 ppm. The waters are apparently moderate to high in hardness and mineralization.

Norris, D. K., R. A. Price and E. W. Mountjoy (1963) "Geology, Northern Yukon Territory and Northwestern District of Mackenzie," Geological Survey of Canada Map 10-1963

Abstract

Map showing geology of Northern Yukon Territory and Northwestern District of Mackenzie.

"Northwest Territories and Yukon Territory, Schedule of Wells, 1965," *Department of Indian Affairs and Northern Development Schedule No. 5*, p. 59

Abstract

The Fifth Schedule of Wells, compiled and annotated by Officers of the Resource Management Division, is a report of all wells drilled and completed in the Yukon and Northwest Territories, from 1920 to the end of 1965. Pursuant to Section 107 of the Canada Oil and Gas Land Regulations, the information contained is compiled from Well Completion Data Forms, and released from confidential status two years after the completion or abandonment of an exploratory well, and thirty days for a development well. Basic information on wells such as location, elevation and depth is released at any time. Further details on non-confidential wells and structure test holes can be obtained at the office of the Oil Conservation Engineer in Calgary.

Ponomarev, V. M. (1956) "The Main Characteristics of Ground Water Formation in Permafrost Regions," *Tezisy i Plany Dokladov -- k Soveshchaniiu 1956 g. Merzlotovedeniiu*, Akad. Nauk SSSR. Inst. Merzlotoveneniia, No. 2, pp. 29-32

Abstract

The characteristics of ground-water circulation, exchange, and chemical composition in permanently frozen rock are discussed. These types of water are distinguished: fresh water at the surface, saline water in the middle layer, and water vapour in the bottom zone. The distribution of ground water in permafrost in given areas is closely related to their Quaternary history. Areas of young rock folds correspond to areas of the most intense ground- and surface-water exchange, plateaus to those of medium water exchange, and lowlands to those of very weak water exchange. Surface water forms the water-bearing horizon of the active layer and remains in the liquid state only a limited period of time, while ground water above the local erosion level is usually always frozen. The upper artesian water horizons in the north are frozen, while the temperature of those in large geological basins is depressed. Artesian water supply occurs through unfrozen areas under rivers, lakes, and along tectonic faults. In north coastal regions the ground water is high in marine mineral content and is in constant motion due to geothermal gradients.

Ponomarev, V. M. and N. I. Tolstikhin (1959) "Ground Water in Permafrost Areas," *Osnovy Geokriologii,* Pt. 1, Chap. 10, Akad. Nauk SSSR, Inst. Merzlotovedeniia, pp. 328-364

Abstract

The origin and characteristics of ground water in permafrost areas and their interaction with the permafrost are discussed in detail. The various types of ground and artesian waters are described individually, and a table is presented giving for each type the state of the water (whether liquid or solid), its temperature, pressure, quality, mode of alimentation, and possible use. A map showing the distribution of various types of ground water in the permafrost regions of the USSR is included.

Porfir'yev, M. M. and G. V. Porkhayev (1963) "Utility Networks in Permafrost Regions," Proceedings: Permafrost International Conference, National Academy of Sciences -- National Research Council, Publication No. 1287, pp. 455-458

Abstract

The severe climate in permafrost areas makes it necessary to provide maximum comforts for human habitation. Therefore, all modern facilities -- water works, sewerage, central heating, power, as well as gas supply in a number of localities -- are widely used. In some areas where natural fuels are scarce, all domestic needs, including heating systems, are electric.

The main problems in designing utility nets are dependability and continuous operation. Accordingly, their design and operating conditions must be chosen to prevent damage to the networks by soil subsidence after thawing, heaving, frost cracks, icing, and solifluction processes, and to preclude the possibility of freezing of fluids in pipes.

Reed, I. McK. (1943) "How Dawson Keeps its Water Mains from Freezing," Pacific Builder and Engineer, Vol. 49, No. 8, p. 554

Abstract

Water for Dawson, Yukon Territory, is obtained from a well, supplemented at extra demand from the Klondike River.

Sargent, Charles (1963) "Water Works Supply Systems in Permafrost Areas," Proceeding: Permafrost International Conference, National Academy of Sciences -- National Research Council, Publication No. 1287, pp. 440-441

Abstract

Abundant potable water is necessary to comfortable living in any environment; a population's health depends on pure water for all domestic uses, and almost any modern industry uses water in quantities equal to or exceeding the tonnage of its product. Civilization cannot thrive where an adequate supply of good water cannot be made available.

In about one-fifth of the land area of the world, the ground remains at a temperature below the freezing point of water throughout the year. Where such a condition exists, the area is classified as a permafrost area in this paper, regardless of whether ice exists in the ground.

Industrial, commercial, or domestic habitation of permafrost areas requires special consideration of water supply and distribution problems beyond those necessary in more temperate areas. The water source may be frozen, water may freeze in the distribution system, or both. Available water may be of such poor quality that special conditions must be considered for its treatment. The availability of a water supply may be the greatest single factor in selecting community sites in permafrost areas.

Schultz, J. R. and A. B. Cleaves (1955) "Geology in Engineering," John Wiley and Sons, New York, p. 522

Abstract

In permafrost regions of the northern hemisphere ground water is the best source of supply in the south, but ground water becomes increasingly difficult to obtain in the north, where permafrost attains great thickness. The water that lies above permafrost is called suprapermafrost water and is fed by rain and melt water, surface water, water condensed by contact with the cold ground surface, and seepage from within or below permafrost. A year-round supply is available only in the parts of the suprapermafrost zone in which permafrost lies below the depth of seasonal frost penetration, particularly along banks of large rivers and lakes with constant inflow and outflow; supplies may occur also at the mouths of valleys and at the heads of alluvial fans. Suprapermafrost water is subject to contamination. In winter the ground freezes from the top downward and the water is subjected to pressure, with the result that water emerges at the surface to form icings or is wedged between frozen and unfrozen layers and frozen in place to form ground ice.

Intrapermafrost water is derived from sources above and below the permafrost. It occurs mainly in thick alluvial deposits near rivers, in old river channels, and, to a lesser degree, in strongly fissured and jointed rocks. Along the Arctic Coast saline water within the permafrost is probably of marine origin; such mineralized water remains liquid at temperatures well below 0°C. Care must be taken to maintain circulation of intrapermafrost water in permeable layers or in pipelike openings, for freezing will result if flow is retarded or if the well is subjected to excessive or accelerated pumping. Intrapermafrost water may locally be under pressure.

Subpermafrost water is always liquid, being beneath permafrost, and is generally under considerable hydrostatic pressure. It furnishes the most dependable supply of ground water, usually of good quality. In some areas, however, subpermafrost water is highly mineralized. Generally, it is difficult to locate because of scarcity of surface indications.

In addition to the discussion of ground water in permafrost regions, a description of pingos, frost blisters, icing mounds, and peat mounds are included in this publication.

Silin-Bekchurin, A. I. (1951b) "Methods Employed in Studying Underground Waters in Permafrost," Spetsial'naia Gidrogeologia: Moscow, Gosgeolizdat, pp. 277-280

Abstract

Methods for selecting and drilling for water supply in permafrost regions are described. Drilling for suprapermafrost water is similar to the methods used under nonpermafrost conditions. Test drilling for subpermafrost water in alluvial deposits should be placed near the river channel and extended into areas receiving maximum insolation. Drilling should be started wherever seepage of water from alluvial deposits occurs. Drill holes should be placed from 50 to 200 m and should be arranged in a checkerboard pattern. Test drills in stratified bedrock should be placed along and across the axis of the syncline depending on the structure of the bedrock. The deepest water vein should be tapped for relatively warm water whenever several veins are available.

Sumgin, M. I., N. N. Geniev and A. M. Chekotillo (1939) "Water Supply of Railroads in Permafrost Regions," Moscow, Transzheldorizdat, p. 251

Abstract

The book contains chapters on thermophysics, thermodynamics of the ground, permafrost, water sources, methods of investigating water sources, organization of water-source studies, water-intake structures, construction of water-conduit network, thermal technique for the water system, laying pipe during winter, supplementary structures for water conduits, thermometry, experimental determination of heat loss in water lines and thermal regime of an operating water-supply system.

Outlets of subpermafrost water are found along the boundaries of different rock strata and along faults. Locating these narrow zones in the subsurface by drilling is difficult, and it is usually done by developing the surface seepages. The best time to prospect for springs is February or March when they can be recognized by icings and icing mounds. The water outlet may be determined approximately by the direction of the flow of the water and by an increase in temperatures toward the source. Water source is usually located at the uphill edge of icings. Taliks are usually found by shallow drill holes; decreased thickness of seasonal frost and greater depth to permafrost may indicate the proximity of a spring. Discharge of the spring is concentrated in channels and measured, or is estimated from the volume of the icing divided by 100 days the time usually required to form ice up to early March in the region under study.

A more detailed study of the springs specifies the geologic conditions of the water outlets for correct construction of the spring capping, makes a more precise discharge measurement during various seasons, and determines the quality of water. During this stage further drilling and test-pitting are done to define the contours of the talik in which the spring occurs.

"Summary Report, 1921, Part B" Geological Survey of Canada No. 1959, p. 104

Abstract

This publication contains several reports and maps covering the geology of the Mackenzie River Valley Region.

Tassonyi, E. J. (1969) "Subsurface Geology, Lower Mackenzie River and Anderson River Area, District of Mackenzie," Geological Survey of Canada Paper 68-25, 207 pp.

Abstract

This report deals with the subsurface stratigraphy of the Mackenzie River region between 64 degrees north latitude and the Arctic coast, and between the Canadian Shield and the west border of Yukon Territory. The study is based on the examination of well samples, cores, and mechanical logs of all important exploratory wells drilled prior to March, 1961, and on published information to that date. References are made to surface geology and paleontology, and to published stratigraphic concepts in order to substantiate the suggested nomenclature and stratigraphy. Several informal lithologic units and one new formation are introduced. The economic potential of each formation (principally with regard to hydrocarbon production) is examined.

The Macdougal Group comprises: (1) the Mount Clark Formation consisting of red sandstone, red shale, ferruginous sandstone and hematite; (2) the Mount Cap Formation consisting of green and red sandstone with some rusty shale; and (3) the Saline River Formation consisting of red and green shales with salt casts. It includes Lower and Middle Cambrian rocks and probably includes Upper Cambrian strata as well. A disconformity between this group and the overlying beds is postulated.

At some places within the study-area the Macdougal Group is overlain by stratigraphic equivalents of the Franklin Mountain Formation. In the subsurface study the exact stratigraphic equivalents of the Franklin Mountain Formation could not be recognized but are probably included in the upper part of the Saline River Formation and lower part of the Ronning Formation.

The Ronning Formation, as defined in this report, includes strate equivalent to the Mount Kindle Formation and part of the underlying Franklin Mountain Formation but the detailed relationships between these units are not yet known. In the subsurface the Ronning Formation consists principally of dolomites. It overlies the shaly, semievaporitic facies of the Saline River Formation with assumed disconformity and is considered, tentatively, to be Early Ordovician to Late Silurian in age.

The Ronning Formation is overlain disconformably either by the Early and Middle Devonian (Eifelian) Bear Rock Formation consisting of brecciated dolomites and interbedded evaporites or by equivalent strata within the Gossage Formation composed of non-brecciated, bedded limestones and dolomites. In the study-area, the Bear Rock Formation (restricted) grades laterally into the Gossage Formation. In the subsurface, the Bear Rock Formation is divided informally into a lower, evaporitic member and an upper, brecciated member. The Gossage Formation comprises three informal members.

The Hume Formation of Middle Devonian age, consisting of fossiliferous limestones with some shale, overlies the Bear Rock or Gossage Formations. The upper contact with the Hare Indian Formation is abrupt but conformable, whereas the lower contact is probably disconformable.

Overlying the Hume limestones is the Hare Indian Formation which is divided informally into two members. The lower, or spore-bearing member, consists of dark brown to black, bituminous shales containing trilete spore cases. The upper, unnamed member of the formation, is composed of grey to green, calcareous shales with interbedded, thin, limestone beds.

Within the overlying Ramparts Formation two informal members are recognized: the lower, or platform member, consists of fossiliferous, bedded, brown and grey, argillaceous limestone, and includes at the top the shaly Carcajou marker; the overlying reef member consists of massive, clean, grey to buff limestone characterized by corals and stromatoporoids. A Givetian (Middle Devonian) age has been accepted with reservation for this formation.

The Ramparts beds are overlain unconformably by the Canol Formation, which is composed of about 75 feet of dark grey, greenish and yellowish weathering, non-calcareous shales. A tentative Upper Devonian (Frasnian) age is assigned to this formation.

In the study-area, the Imperial Formation includes all Upper Devonian shales, siltstones and sandstones overlying the Canol Formation and overlain unconformably by Cretaceous strata. It is divided informally into a lower member of Frasnian and Fammenian ages.

The presently accepted Cretaceous formations comprise the following in ascending order: (1) the Sans Sault Formation, consisting of marine sandstone and shale; (2) the Slater River Formation, consisting of dark grey to black shale with ironstone concretionary layers and thin bentonite bands; (3) the Little Bear Formation, comprising sandstone, sandy shale, conglomerate and coal; and (4) the East Fork Formation, composed mainly of dark grey, marine shale.

In the wells studied, the youngest Cretaceous formation, the East Fork Formation, is missing and the Little Bear Formation is incomplete. In the subsurface, division and correlation of the Cretaceous strata is attempted by using the described surface formations. This is considered to be tentative until such time as Cretaceous stratigraphy is revised through surface studies.

Tertiary sands, gravels, shales and lignites overlie the Cretaceous East Fork Formation locally. In the subsurface medium-grained, porous, friable sandstones and silty shales are tentatively assigned to the Tertiary.

Coal seams have been reported from the Cretaceous and Tertiary strata but are of little economic value at this time. No coal or lignite seams are present in the examined wells, either in the Cretaceous or in the tentatively identified Tertiary strata.

Halite occurs in the Cambrian but the depth and location of the occurrences make its recovery prohibitive at this time. There is no indication of potassium salts and reported gypsum occurrences are too impure to be commercial.

The primary economic interest in the study-area has been and remains the exploration for oil and natural gas and the potential for these minerals appears to be greater than for any others. At present, oil and gas are being produced only from the reef member of the Ramparts Formation although other formations have productive potential.

Thomas, J. F. J. (1956) "Interim Report-Hardness of Major Canadian Water Supplies," Canada Department of Mines and Technical Surveys, Mines Branch, Memo. Series 132

Abstract

Report includes data on Dawson, Yukon River, Whitehorse, Aklavik, and other places in the permafrost zone.

Wilson, J. D. (1949) "Arctic Construction," Military Engineer, Vol. 41, pp. 258-260

Abstract

Permafrost underlies much of the Arctic from depths of a few feet to as much as 700 ft. Permafrost can exist where mean air temperature is only a degree or two below freezing. Ground water may exist above, within or below permafrost. Practically all destructive effects of freezing and thawing are related to ground water. Heat is conveyed by ground water to thaw permafrost. Ground water may be present, at all seasons, between the permafrost table and the base of seasonal frost.

Williams, John R. (1970) "A Review of Water Resources of the Umiat Area, Northern Alaska," U.S. Geological Survey Circular 636, p. 8

Abstract

Surface-water supplies from the Colville River, small tributary creeks, and lakes are abundant in summer but limited in winter by low or zero flow in streams and thick ice cover on lakes.

Fresh ground water occurs in unfrozen zones in alluvium and in the upper part of bedrock beneath the Colville River and beneath lakes that do not freeze to the bottom in winter. These unfrozen zones, forming depressions in the upper surface of permafrost, are maintained by flow of heat from bodies of surface water into subjacent alluvium and bedrock.

Brackish or saline ground water occurs in bedrock beneath as much as 1,055 feet of permafrost in the Arctic foothills and beneath 750 to 800 feet of permafrost beneath low terraces of the Colville River valley. The foothill area is unfavorable for developing supplies of potable ground water because of the great depth to water, predominance of brackish or saline water, and low potential yield of the bedrock. In the Colville River Valley, shallow unfrozen alluvium beneath the river and deep lakes will yield abundant year-round supplies of ground water, but the bedrock below permafrost yields less than 10 gpm (gallons per minute) of saline or brackish water.

Williams, John R. (1970) "Groundwater in Permafrost Regions of Alaska," U.S. Geological Survey Professional Paper 696, p. 83

Abstract

Although ground water in permafrost regions in Alaska occurs according to the same geologic and hydrologic principles prevailing in temperate regions, subfreezing temperatures result in profound modification of ground-water flow systems. Frozen ground is an impermeable layer which: (1) Restricts recharge, discharge, and movement of ground water, (2) acts as a confining layer, and (3) limits the volume of unconsolidated deposits and bedrock in which liquid water may be stored. Frozen ground in many areas eliminates shallow aquifers and requires that wells be drilled deeper than in similar geologic environments having no permafrost. Although little is known about the effect of permafrost and low water temperatures on quality of ground water, the restricted circulation imposed by permafrost boundaries may increase the concentration of dissolved solids in ground water in some areas. Low ground temperatures above and below permafrost result in groundwater temperatures ranging from 0° to 4.5°C (Celsius). At these temperatures, ground water is more viscous and moves more slowly than in temperate regions.

Permafrost is defined as unconsolidated deposits of bedrock that continuously have had a temperature below 0°C for 2 years to thousands of years. It formed when the balance between net heat lost to the atmosphere at the surface and that received from sources within the earth produced

Williams, M. Y. (1922) "Exploration East of Mackenzie River, between Simpson and Wrigley," Canada Geological Survey Summary Report, 1921, Part B, pp. 56 - 66

Abstract

The soil is generally frozen in the area. Mineral springs occur near Old Fort Wrigley where water issues from the surface of the smaller island 15 ft above river level and leaves a deposit of lime. Lime deposits also occur on the mainland across the river. Mineral springs occur also at Roche-qui-trempe-a-l'Eau, where warm waters emerging from a travertine cone about 50 ft above the river have deposited calcareous material. The springs are related to a fault.

Yates, A. B. and D.R. Stanley (1963) "Domestic Water Supply and Sewage Disposal in the Canadian North," Proceedings: Permafrost International Conference, National Academy of Sciences - National Research Council Publication No. 1287, pp. 413 - 419

Abstract

This paper deals with water supply and sewage disposal in the Yukon and Northwest Territories of northern Canada. These cover 1,511,979 square miles or 39.3% of the total Canadian land and water mass, lie above 60° latitude, and are populated as far north as Alert at the 83° latitude.

The problem of water supply and sewage disposal in northern Canada is twofold: First, to obtain adequate water supplies for drinking, culinary, and minimum sanitation requirements and dispose of human waste, garbage, and wash water in a satisfactory, sanitary manner. Second, to provide modern water and sewerage systems so that inhabitants can enjoy normal amenities at reasonable cost.

Zoltai, S. C. and C. Tarnocai (1971) "Properties of a wooded palsa in Northern Manitoba," Arctic and Alpine Research, Vol. 3, No. 2, pp. 115 - 129

Abstract

A palsa complex, 106 m in diameter, having a maximum height of 224 cm above the water table is described in detail. Permafrost occurred under the elevated, densely wooded palsa, extending into the underlying clay. The height of doming was largely due to ice accumulation in the clay and peat. The thickness of the active layer was least under the densest black spruce stands and greatest in the openings. The cumulative depth of snow was greatest in openings and least in dense stands. The volumetric moisture content of the peat in the active layer was about 30% in the fall, but this figure nearly doubled in the winter; the moisture content of the frozen core remained constant at over 90%. The peat material was largely mesic sedge peat near the bottom with mesic forest peat closer to the surface.

Mackay, J. Ross (1966) "The Mixing of the Waters of the Liard and Great Bear Rivers with those of the Mackenzie," Geographical Bulletin, Vol. 8, No. 2, pp. 166 - 173

Abstract

The interpretation of temperature and Secchi disk transparency readings for the right and left banks of the Mackenzie River below its junction with the Liard at Fort Simpson, N.W.T. are discussed. The measurements, made in 1963 and 1964, were taken in June after break-up. In both years the results show that, 200 miles downstream, the warmer and more turbid waters of the Liard had not fully mixed with those of the Mackenzie. Similarly, a study of the Great Bear River below Fort Norman, N.W.T. shows that the mixing of its waters with those of the Mackenzie was not fully completed 50 miles below their confluence.

Dingman, S. L., H. R. Samide, D.L. Saboe, M.J. Lynch & C.W. Slaughter (1970) "Hydrologic reconnaissance of the Delta River and its drainage basin, Alaska." U.S. Army Cold Regions Research and Engineering Laboratory, Research Report 262, 81 pp, 22 tables, 74 refs, appendices, map.

Abstract

Estimates of the water balance, flow duration curves and sediment characteristics of this large braided glacial river are reported. The catchment is 1665 square miles in the east central part of the Alaska Range. The general geomorphology of the basin is outlined and references to further studies are given. Of the mean annual precipitation of 40.4" (the mean annual loss of permanent storage is about 1") some 30% leaves as evapotranspiration, 50% as stream flow and 20% as groundwater flow. Characteristics in the response to glacial melt are outlined. Peak flow at foothill stations occurs within 24 hours of the rainfall if greater than 0.5"/day - amounts less than this do not generally produce a measurable stream response. The stream geometry is described in detail and the response to glacial melt and rain, channel geometry and processes are described. Lower floodplain channels are asymmetric and roughly triangular or parabolic and have a high width/depth ratio. Gauging station hydraulic geometry is described together with channel changes.

APPENDIX 'J'

USE OF DRILLSTEM TESTS TO INTERPRET THE GROUNDWATER FLOW SYSTEM

Dr. R. O. van Everdingen, Groundwater Subdivision, Inland Waters Branch, Environment Canada, provided us with a computer record of drillstem tests run by oil companies. They represent data on non-confidential boreholes located in the general Mackenzie River Valley region. Data available on individual boreholes include borehole location, elevation, variations in water quality and temperature with depth, hydrostatic head from shut-in pressures, formation age, stratigraphy, and lithology.

Using these data we plotted five cross-sections showing hydrostatic heads, total dissolved solids, and the geological formations penetrated in the drill holes. Two generalized cross-sections -- one located near Camsell Bend and the other near Norman Wells -- have also been constructed to show the regional groundwater-flow pattern. A few tentative conclusions are suggested from analysis of the limited data available:

1 The groundwater flow system appears to conform to the generally accepted theory that groundwater recharge occurs in highland and mountain regions and that groundwater discharge occurs in lowland regions, which in the present study-area comprises the Mackenzie River Valley and its main tributaries. Data contained in Appendix 'A' deal with evidence of groundwater discharge; they suggest that most groundwater flow discharges into the Mackenzie River. From examination of Figs 15 and 16, it would appear likely that the Franklin Mountains on the east side of the Mackenzie River Valley present an obstacle to groundwater flow to the northeast and to the Precambrian Shield. We believe that the existence of the Franklin Mountains lying to the east of the Mackenzie Valley is the main reason that most groundwater west of the Mackenzie River discharges into that river valley -- rather than discharging along the margin of the Precambrian Shield to the east. On the other hand, any groundwater recharge on the east side of the Franklin Mountains does in all likelihood discharge along the margin of the Precambrian Shield. Similarly, groundwaters in relatively gently dipping strata south and southwest of Great Slave Lake probably flow toward that major water body.

2 The groundwater flow system is markedly influenced by differences in permeability between different rock types -- for example, tight shale strata versus highly permeable zones in the Bear Rock Formation. In the generalized Camsell Bend cross-section (Fig 15), the Bear Rock Formation is interpreted as a major regional drain. Unfortunately we have not been able to identify the Bear Rock Formation in any of the drillstem tests. Most of the drillstem tests were run on Devonian Formations considered to offer better oil-bearing prospects. Consequently, the groundwater-flow pattern in detail in any area is far from complete and clear.

3 Groundwater qualities generally become more saline with increasing depth and with increasing age of geological formations. An exception, which probably can be attributed to the local groundwater flow system, can be seen on cross-section D-D' near Wrigley, where the deepest water in two boreholes is less saline than it is in a zone immediately above. Cross-section B-B' near the Arctic Red River also shows surprisingly good quality water to depths of 2000 feet.

4 Groundwater temperatures have not been included on the cross-sections. We were not able to arrive at any firm conclusion concerning the significance of the temperature values reported. Considerably more study is required to make a valid assessment. However, one might suspect that the high water temperatures at depth represent a potential source of thermal energy for the Mackenzie River Valley region. An attempt was made to arrive at a probable geothermal gradient; but the values studied were too erratic and scattered.

One water temperature observation at a depth of about 11,000 ft in a borehole extending below the Mackenzie River Delta was reported to be 71°C whereas another water temperature at a depth of 7000 ft below ground surface along the Northwest Territories - British Columbia boundary was reported to be 121°C.

LIST OF FIGURES

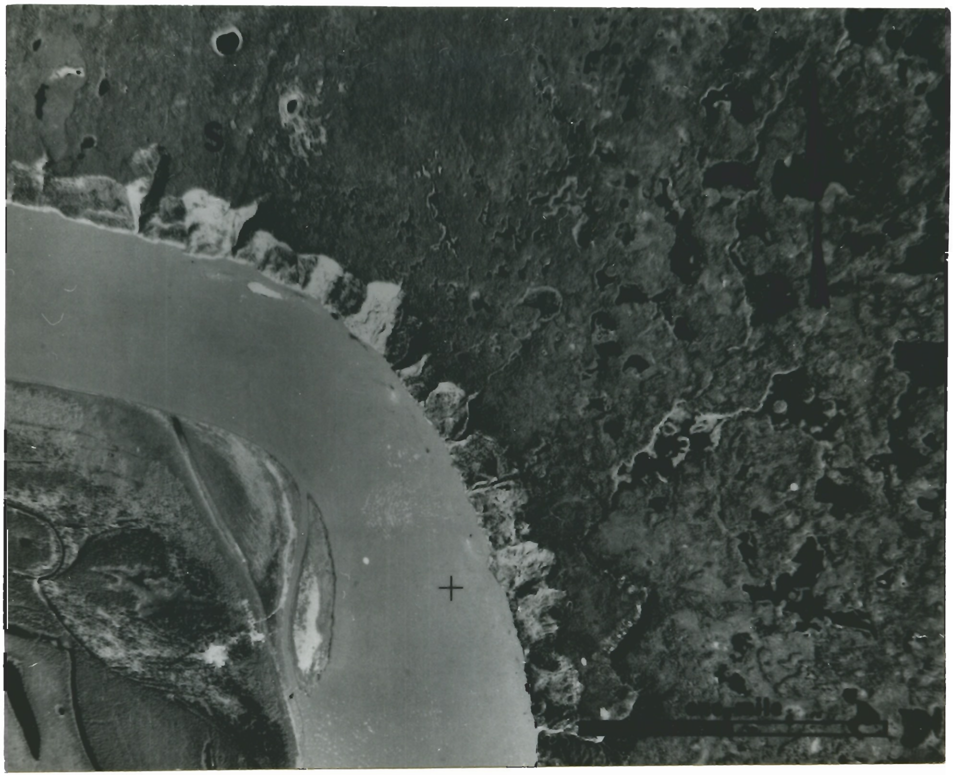


Fig 1. View of Mackenzie River bank opposite Old Fort Point. Airphoto shows active slides on the riverbank and a spring at "S." Note extensive thermokarst topography on the right side of this airphoto. Melting of ice in exposed subsoils, continual lateral river erosion, and springs all contribute to bank instability. Panchromatic airphoto.

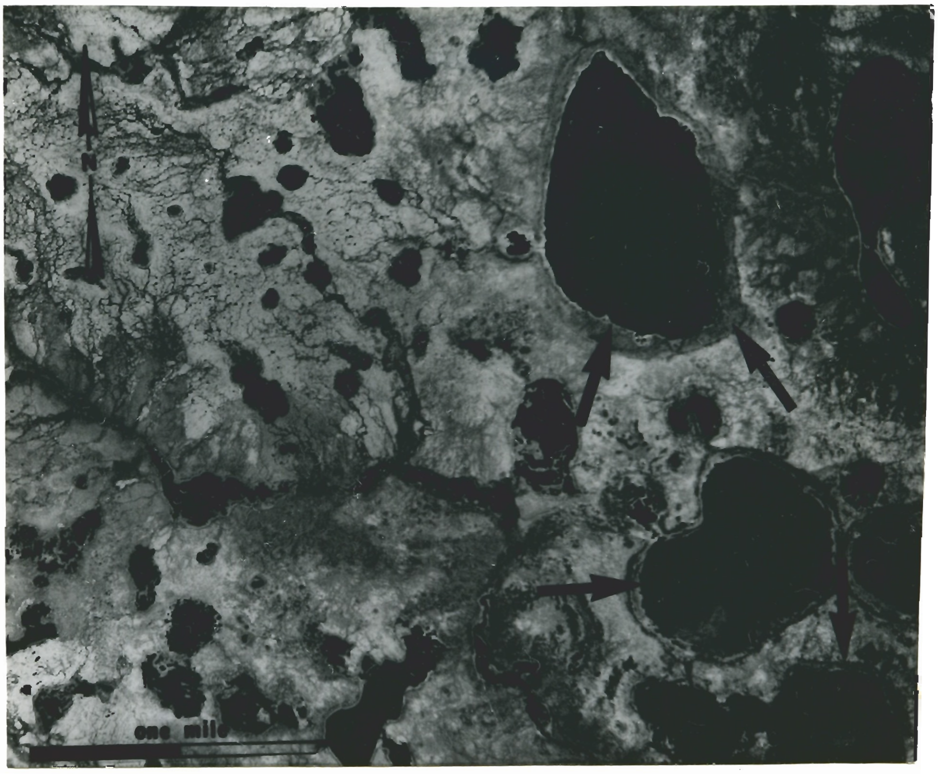


Fig 2. It is suspected that the dark rims around the large lakes seen here represent "new" ice in peat as the near-vertical permafrost face moves in toward the center of the lakes. The "whitish" upland area is a lichen-covered (<u>Cladonia spp.</u>) woodland carrying stunted black spruce. It is a typical lichen-black spruce open woodland, which is commonly underlain by 5 to 15 feet of ice-rich peat. Panchromatic airphoto.

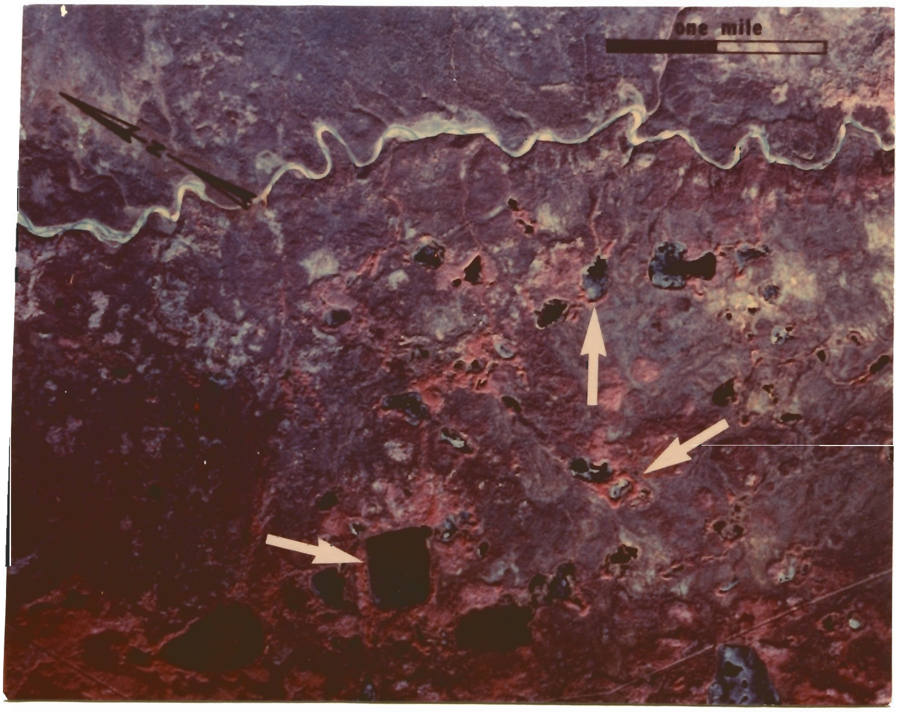


Fig 3. Colour-infrared airphoto showing pinkish-coloured rendition of vegetation around small thermokarst ponds (see arrows). It is believed that the pinkish tones indicate less-stressed vegetation (i.e., a thicker active layer or deep unfrozen ground) and melting around the periphery of these thermokarst features.

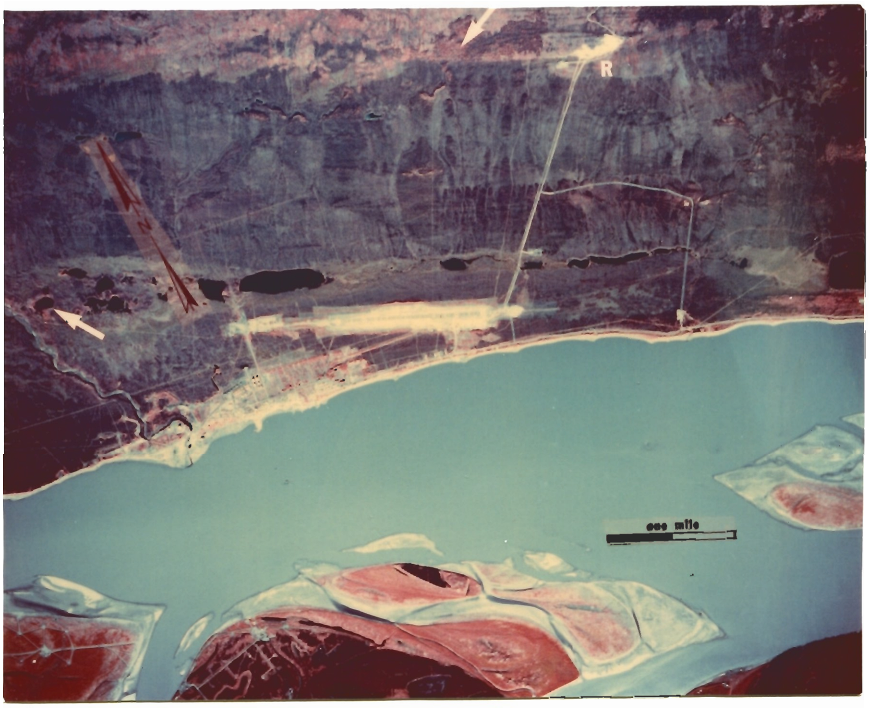


Fig 4. Colour-infrared airphoto of the Norman Wells area showing either a thick active layer or deep unfrozen ground a) on frequently-flooded parts of islands in the Mackenzie River channel, b) in the village of Norman Wells, c) along the sides of the airstrip, d) on thin patchy drift overlying limestone near a rock quarry in the upper right. Highly variable ice contents are expected in the former meltwater channel north-northwest of the airstrip. Thickness of active layer and availability of moisture may be correlated here with flooding, man-made disturbances, and differences in subsurface materials.

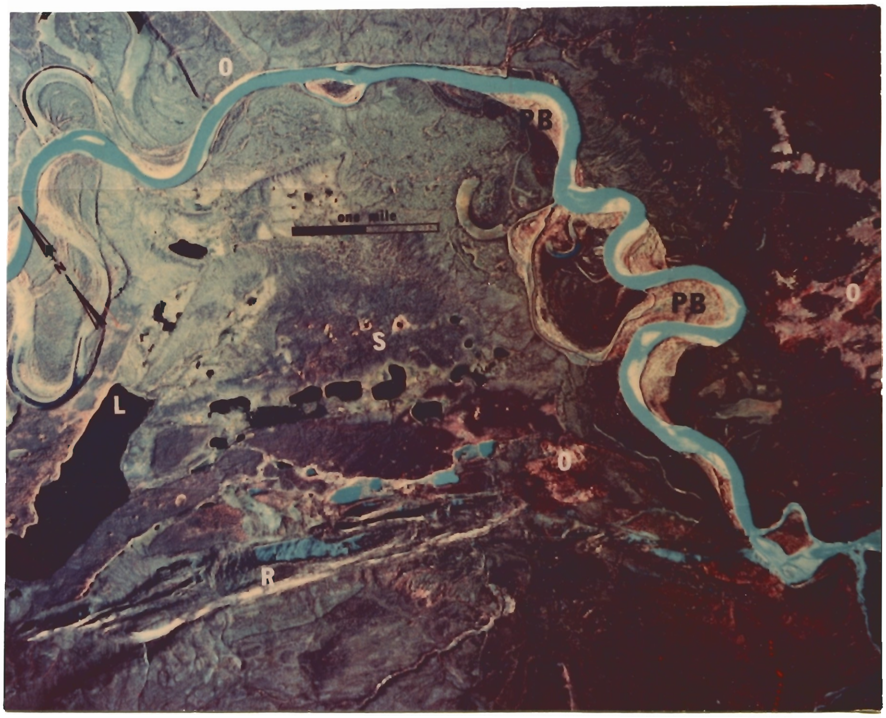


Fig 5. Colour-infrared airphoto along the lower reaches of the Carcajou River showing exposed bedrock (R), vigorous plant growth on outwash ("O" to the right of the river on right side of photo), a thin active layer over thick gravels ("O" north of river), unfrozen alluvium below active pointbars (PB), and narrow rims of thawed ground around small depressions marked "S" and along the side of the lake (L) that is subject to wind and wave action and to a larger input of heat. In this region varying colours on the colour-infrared print are related largely to both type and stressed condition of vegetation.

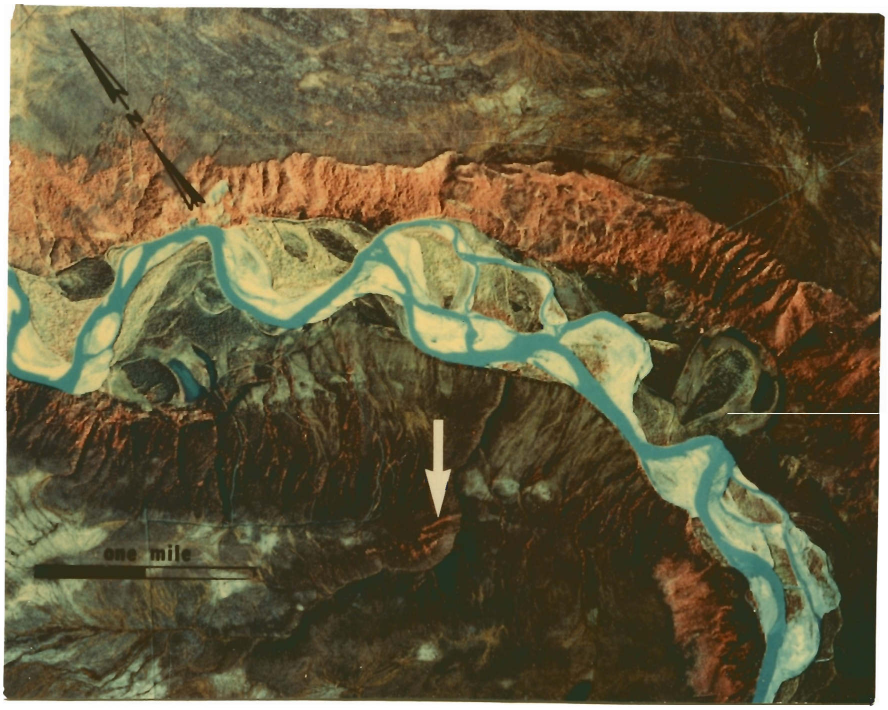


Fig 6. Colour-infrared airphoto showing the marked affect of solar insolation on colour rendition of natural vegetation. Note the light whitish tones of Sphagnum moss and Reindeer lichen in poorly drained areas, and dark pinkish hue on a finger-shaped detachment slide (white arrow to the right of the scale bar). Surface runoff in small creekbeds also has a marked effect on increasing the thickness of the active layer, improving growth conditions and plant vigour. Unfortunately, colour-infrared hues seem to vary somewhat from one area to another, and with laboratory processing as well as with the type of film used. This sensor is most useful as a guide to differences in thermal conditions as reflected by plant type and plant vigour.

Fig 7. Colour infrared airphoto showing brownish olive green hues (see arrows) on wooded portions of ice-rich peat plateaus and whitish speckles in unfrozen treeless collapse scars, which are covered with Sphagnum mosses and heath plants. These colours show up more clearly on the original pictures.

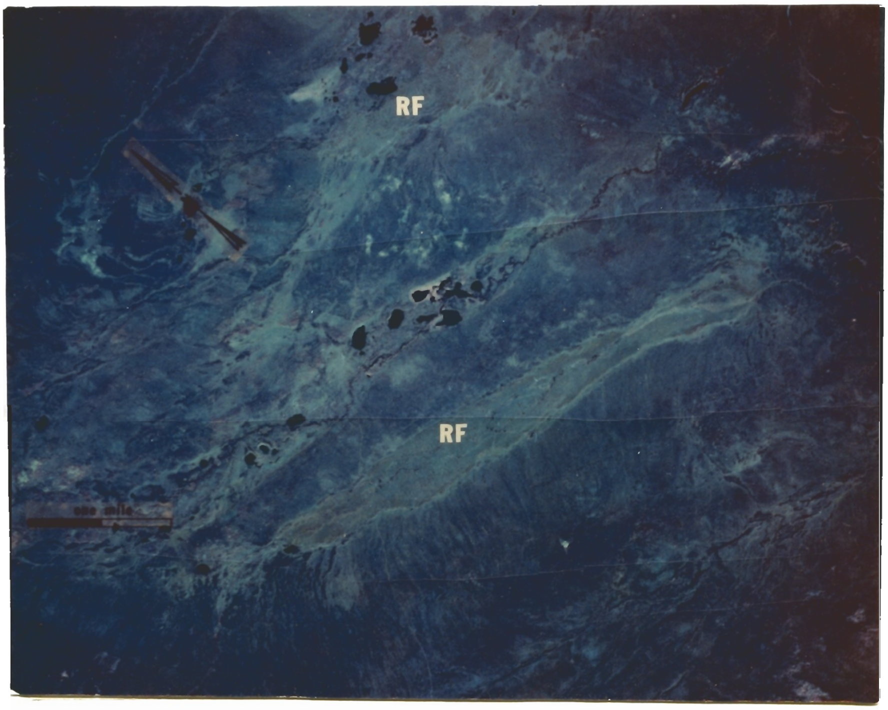


Fig 8. These poorly expressed ribbed fens (RF) in light blue depressions near Bear Rock, north of the Great Bear River, do not show the pinkish hues seen in colour-infrared photographs taken near Fort Simpson using a hand-held camera using colour infrared film. One wonders if the difference is due to depth of unfrozen ground, type of film used, or to laboratory processing. Normally the fens are unfrozen -- at least in vicinity of Fort Simpson. However, transitions occur between "true" fens and "true" bogs.

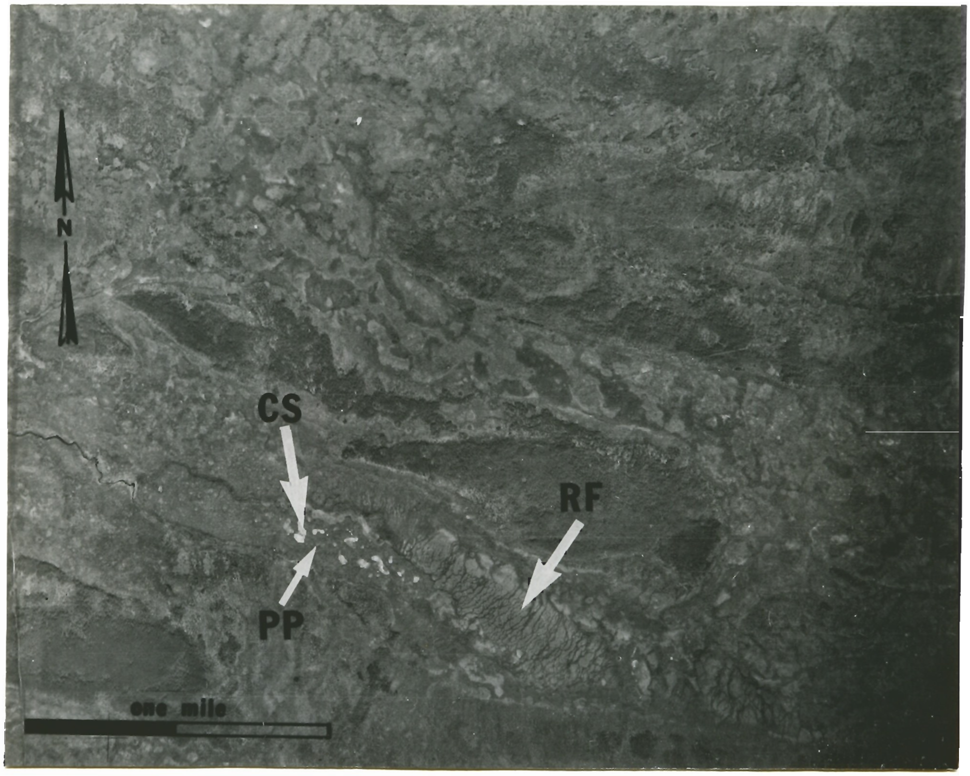


Fig 9. Panchromatic aerial photograph showing frozen ice-rich wooded peat plateaus (PP) with unfrozen treeless collapse scars (CS), and unfrozen ribbed fen (RF) in vicinity of Fort Simpson, N W T. The prevailing ground-water flow (recharge/discharge) system and ground-water chemistry is believed to be different in these two adjoining but different peatland types. This difference in ground-water flow regime and ground-water chemistry may account for the marked differences in permafrost occurrence in these two different peatland types.

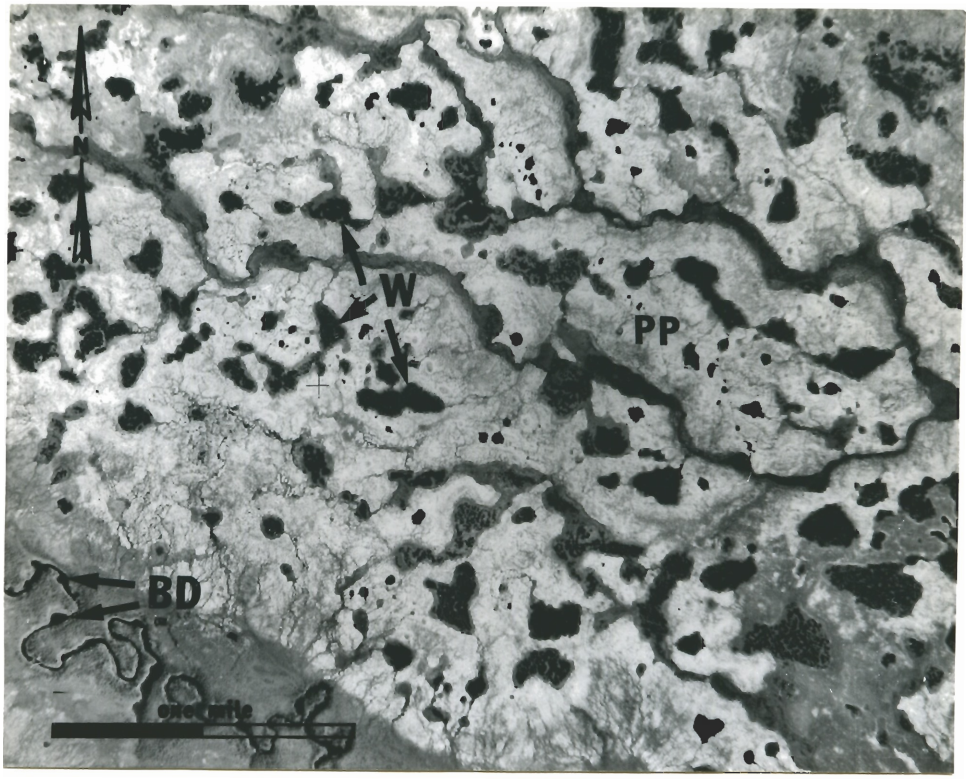


Fig 10. Panchromatic aerial photograph showing beaded drainage (BD) in a region of extensive, thick, stratified, fine-grained glaciolacustrine sediments covered by thick (5 to 15 feet) ice-rich peat in sparsely treed peat plateaus (PP) surrounding unfrozen windows (W) that are believed to be shrinking, rather than enlarging, in size.

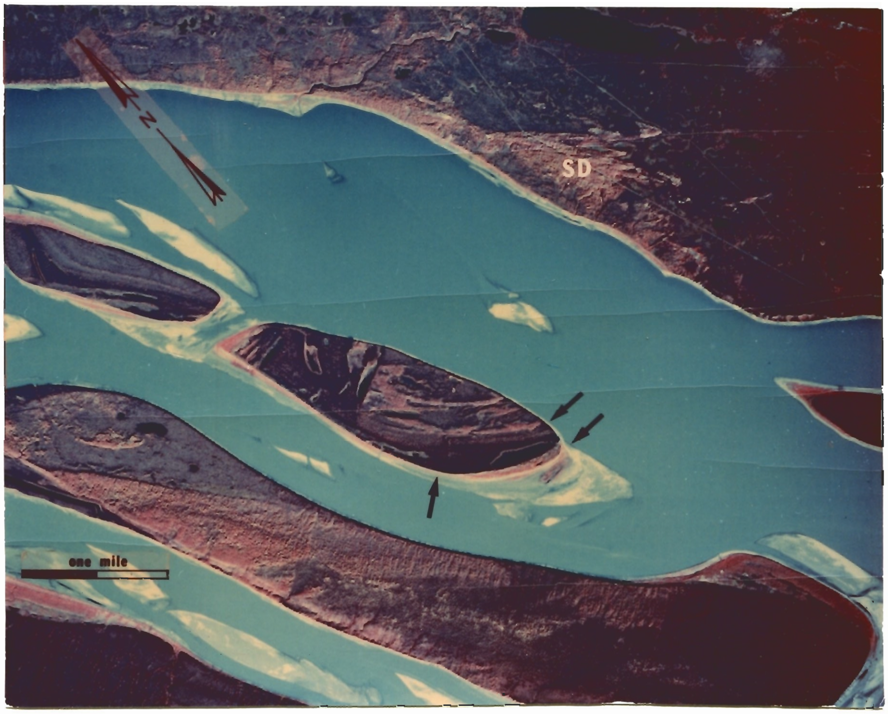


Fig 11. Colour-infrared airphoto showing pinkish hues in vegetation (thicker active layer) on a) sand dunes (SD), b) better-drained ridges (lower water table) on the small island, c) frequently flooded margins of islands, d) better drained slopes on Perry Island (large island). Note that, even at this latitude, thermokarst features occur on poorly-drained areas underlain by fine-grained alluvial deposits that are insulated by some 12 to 18 inches of dry peat and ground cover.

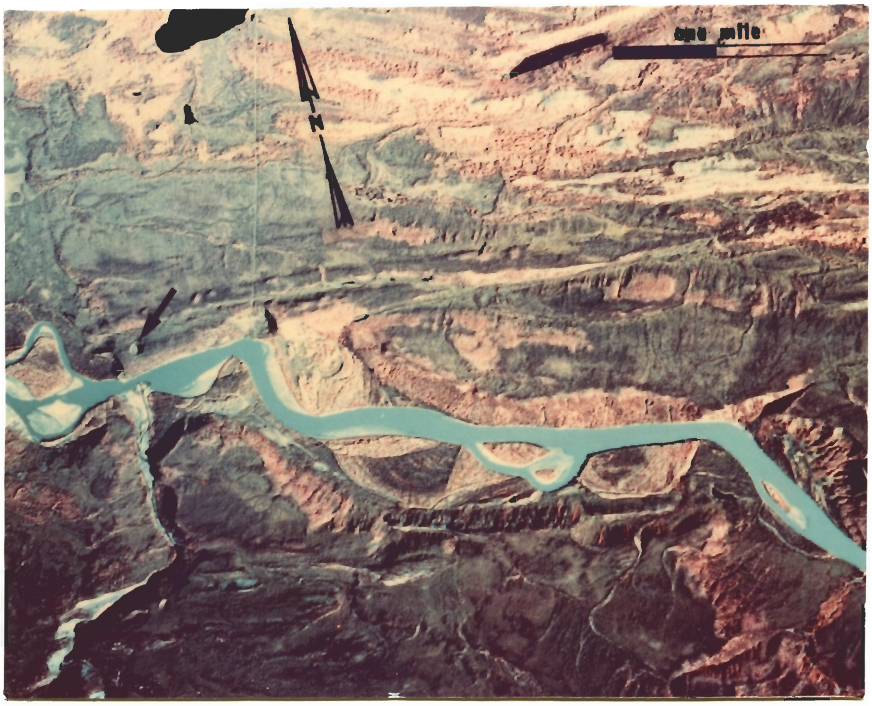
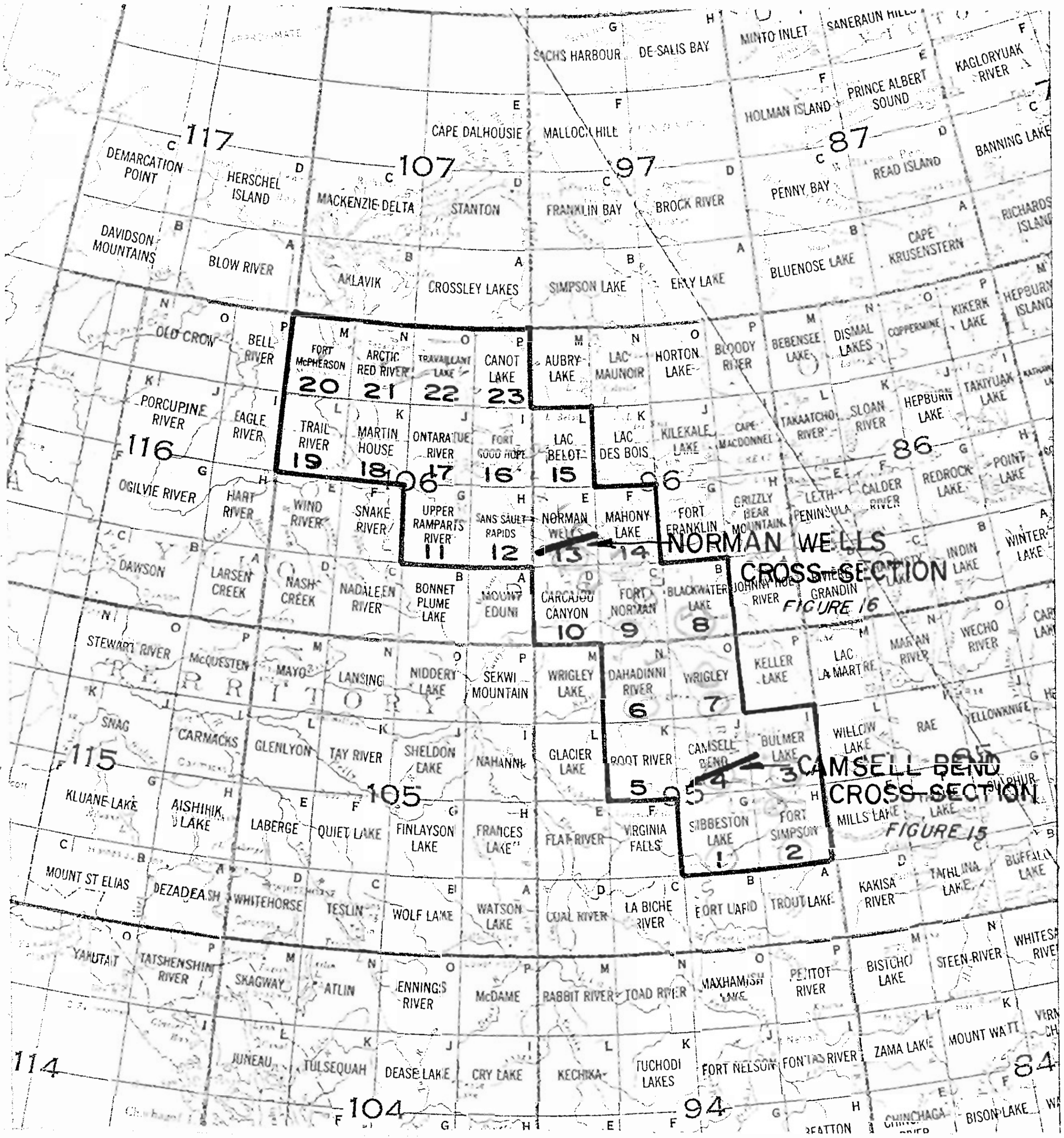


Fig 12. Black arrows on opposite sides of the Carcajou River (about 1¼ miles apart) point to small sinkholes in karstic bedrock. These localities might be inspected visually for evidence of groundwater flow and seepages along nearby slopes. Note that both sinkholes appear to be postglacial in age and situated near high river banks. Colour infrared airphoto.

Fig 13. Black arrows point to postglacial sinkholes on opposite sides of Vermilion Creek southeast of Norman Wells. Note the standing water and vertical walls in the sinkhole on the west side of Vermilion Creek.

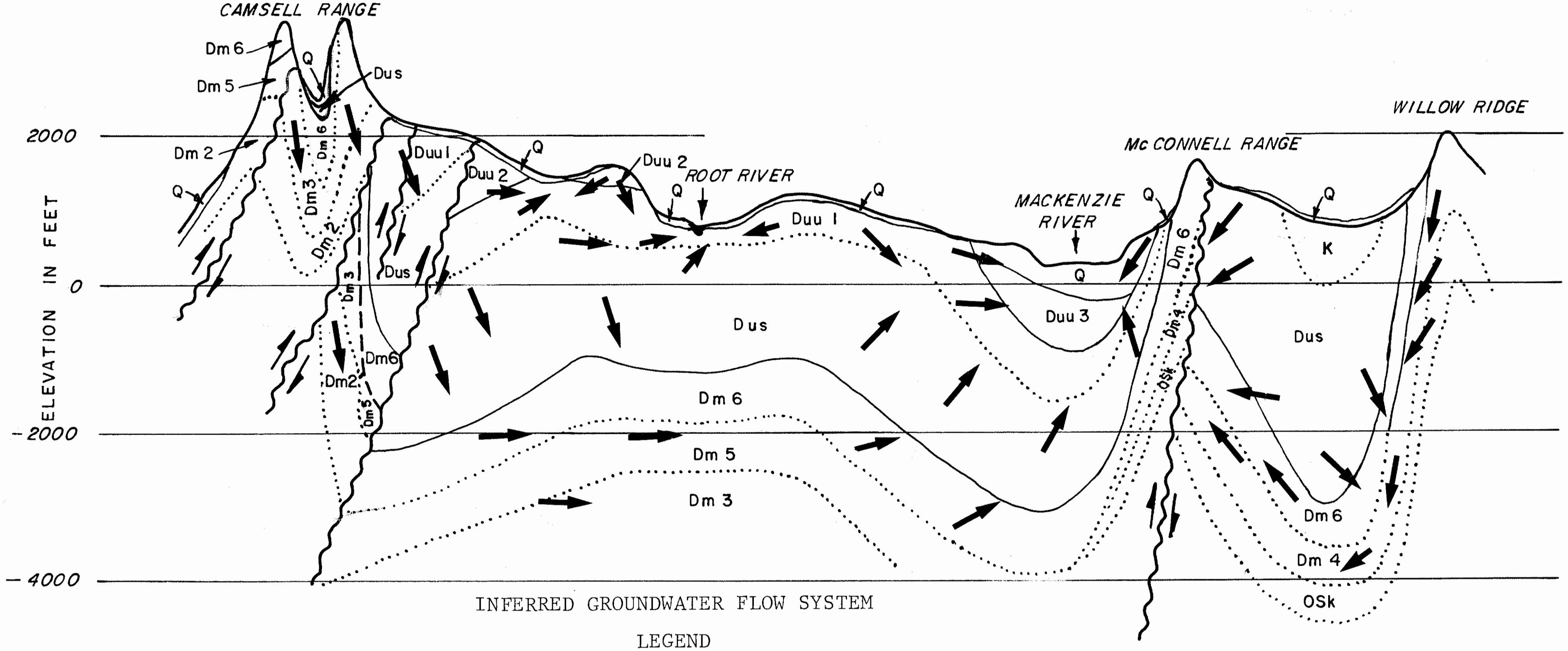


REGIONAL STRATIGRAPHY AND INFERRED GROUNDWATER FLOW REGIME

LOCATION OF CROSS-SECTIONS
ALONG
MACKENZIE RIVER VALLEY, N.W.T.
AND
SHOWN IN FIGURES
15, 16

FIGURE 14

CAMSELL BEND CROSS-SECTION



INFERRED GROUNDWATER FLOW SYSTEM

LEGEND

Symbol	Geological formations
Q	Quaternary, glacial drift, alluvium, and peat
K	Cretaceous, undivided and unnamed (shale, sandstone)
Duu 3	Upper Devonian, unnamed (shale, limestone)
Duu 2	Upper Devonian, unnamed (shale)
Duu 1	Upper Devonian, unnamed (mainly limestone and shale)
Dus	Upper Devonian, Fort Simpson Formation (shale)
Dm 6	Middle Devonian Nahanni Formation (limestone)
Dm 5	Headless Formation (shale, limestone)
Dm 4	Bear Rock Formation (dolomite, anhydrite)
Dm 3	Manetoe Formation (limestone, dolomite)
Dm 2	Arnica Formation (limestone, dolomite)
OSk	Mount Kindle Formation (dolomite)

Formation contact and fault symbols

Geological formation contact (approximate ——— uncontrolled ···········)

Thrust fault (arrows indicate relative movement) ⇌

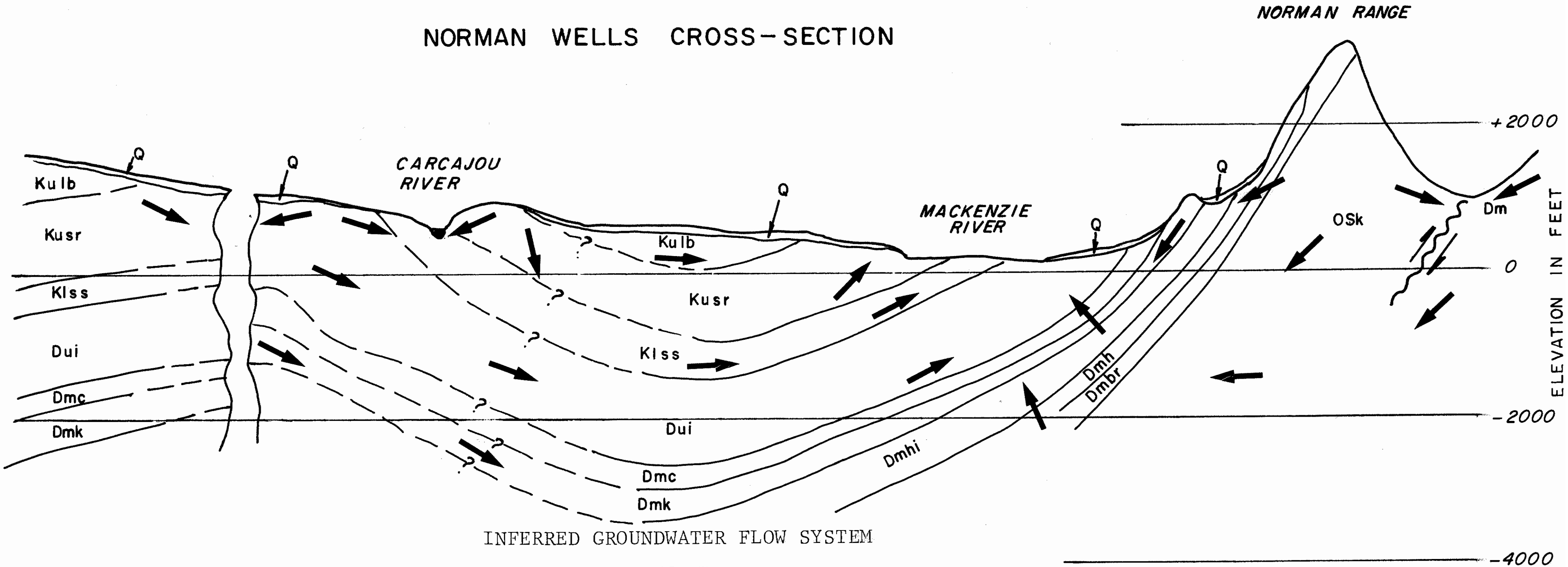
Inferred groundwater flow symbol

Arrow indicates inferred regional groundwater-flow direction ➡

Horizontal scale: 1 inch = 4 miles
Vertical scale: as shown

FIGURE 15

NORMAN WELLS CROSS-SECTION



INFERRED GROUNDWATER FLOW SYSTEM

LEGEND

Symbol	Geological formations
Q	Quaternary, glacial drift, alluvium, and peat
Kulb	Upper Cretaceous Little Bear Formation (sandstone, siltstone, shale)
Kusr	Upper Cretaceous Slater River Formation (shale, siltstone)
Klss	Lower Cretaceous Sans Sault Formation (sandstone, shale)
Dui	Upper Devonian Imperial Formation (sandstone, siltstone)
Dm	Middle Devonian, unnamed and undivided; includes Arnica, Manetoe, Landry, Nahanni, Headless, Funeral, Bear Rock, and Hume Formations (limestone, dolomite, anhydrite, shale)
Dmc	Middle Devonian Canol Formation (shale)
Dmk	Middle Devonian Kee Scarp Formation (reefal and other limestones)
Dmhi	Middle Devonian Hare Indian Formation (calcareous shale)
Dmh	Middle Devonian Hume Formation (limestone, shale)
Dmbr	Middle Devonian Bear Rock Formation (dolomite, anhydrite, gypsum)
OSk	Ordovician-Silurian Mount Kindle Formation (dolomite)

Geological contact and fault symbols

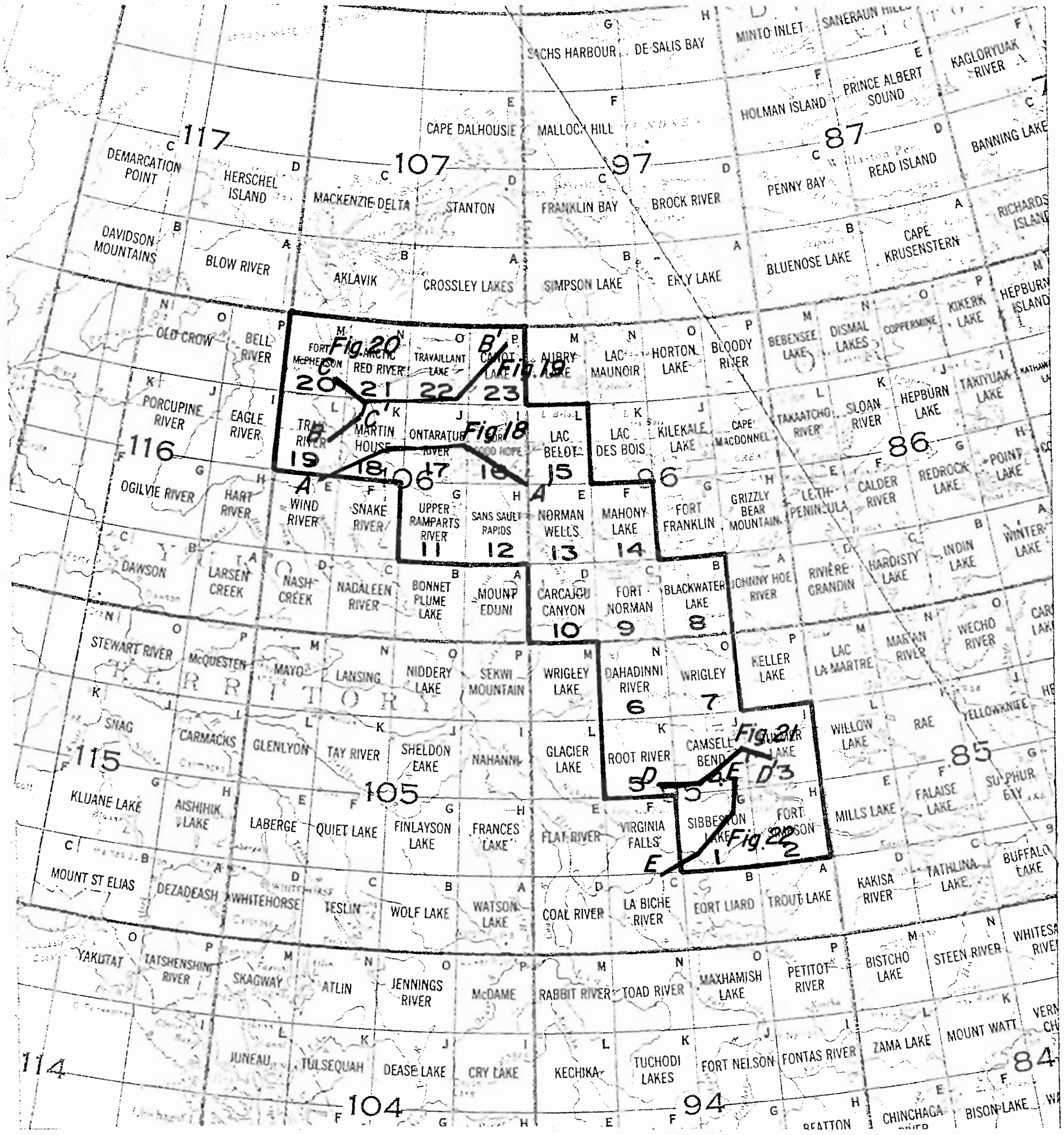
Geological formation contact (approximate ———, questioned ——?——)
Thrust fault (arrows indicate relative movement) ⇌

Inferred groundwater flow symbol

Arrow indicates inferred regional groundwater-flow direction ➡

Horizontal scale: 1 inch = 4 miles
Vertical scale: as shown

FIGURE 16



PETROLEUM EXPLORATION DRILLHOLE LOGS SHOWING STATIC WATER LEVEL, TOTAL DISSOLVED SOLIDS AND DIRECTION OF HYDRAULIC GRADIENT IN HOLE

LOCATION OF CROSS-SECTIONS
ALONG
MACKENZIE RIVER VALLEY, N.W.T.
AND
SHOWN IN FIGURES
18, 19, 20, 21, 22

FIGURE 17a

LEGEND FOR FIGURES 18, 19, 20, 21, 22

Cretaceous

K	Unnamed and undivided: shale, sandstone

Mississippian

Cm	Limestone, phyllite, chert

Upper Devonian

Dui	Imperial Formation: sandstone, siltstone, shale
Duhr	Hay River Formation: shale, siltstone
Dus	Fort Simpson Formation: shale, siltstone

Middle Devonian

Dm	Unnamed and undivided; includes Landry, Arnica, and Headless Formations: limestone, dolomite, shale
Dmh	Hume Formation: limestone, dolomite, shale
Dmn	Nahanni Formation: limestone, dolomite, shale
Dmk	Kee Scarp Formation: reefal and other limestones, dolomite, shale
Dmc	Canol Formation: shale, siltstone, limestone
Dmf	Funeral Formation: shale, siltstone, limestone
Dmhr	Horn River Formation: shale, siltstone, limestone
Dmhi	Hare Indian Formation: shale, siltstone, limestone
Dmch	Chinchaga Formation: anhydrite, salt, breccia

Ordovician and Silurian

OSk	Mount Kindle and Franklin Mountain: dolomite, limestone

Cambrian

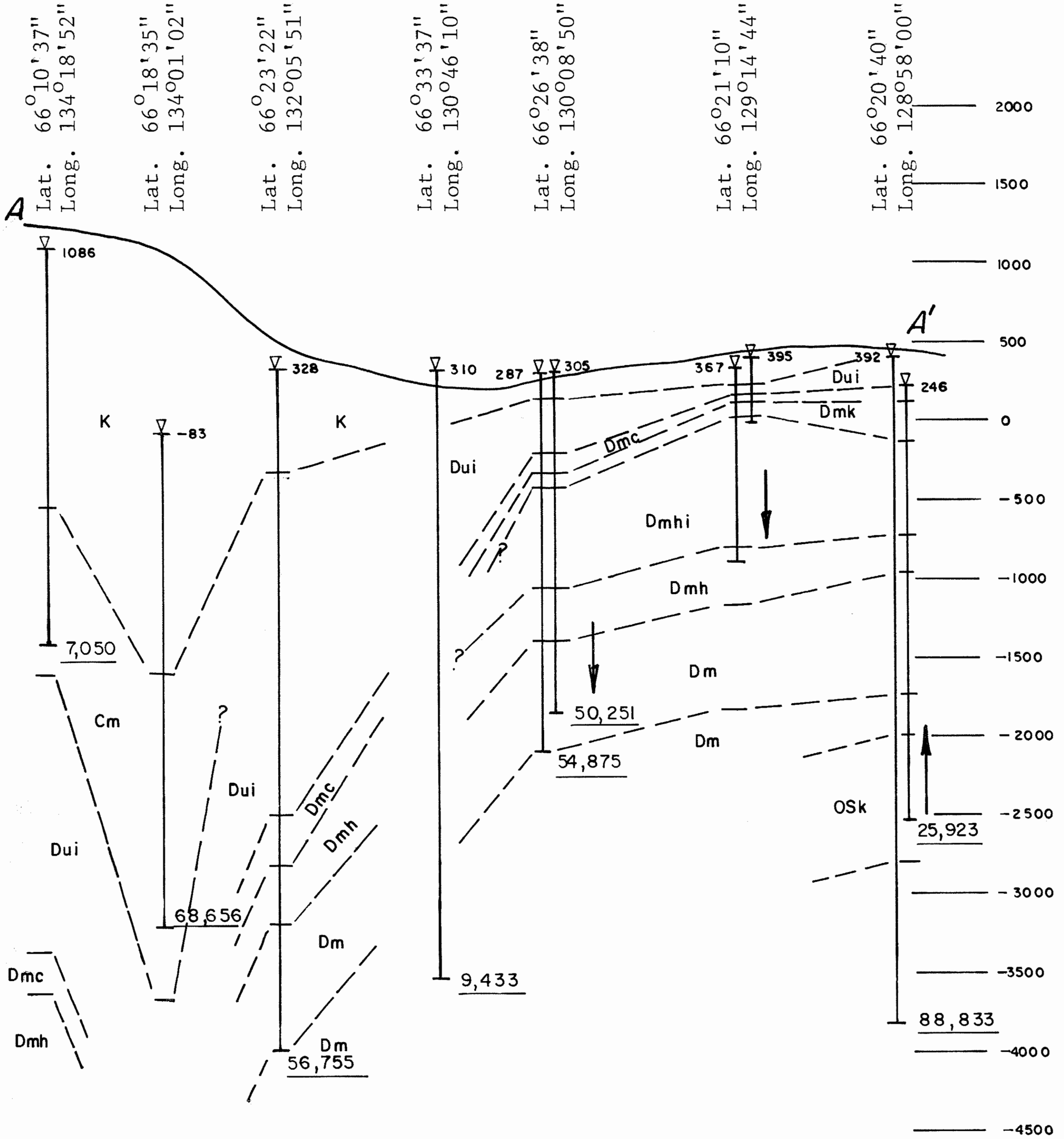
Єcs	Saline River Formation: sandstone, shale, dolomite, gypsum, salt

Precambrian

P̲	Precambrian crystalline rocks: gneisses, schists, granitic rocks
▽ 382	Elevation of static water level in borehole
138,768	Total dissolved solids content of water in section of borehole tested
↓↑	Direction of hydraulic gradient

FIGURE 17b

STRATIGRAPHIC
CROSS-SECTION IN VICINITY OF
ARCTIC RED RIVER
(see Key Map for location)



CROSS-SECTION OF OIL-EXPLORATION DRILLHOLE LOGS SHOWING DEPTH OF SECTIONS TESTED, STATIC WATER LEVEL, TOTAL DISSOLVED SOLIDS, AND DIRECTION OF GROUNDWATER FLOW IN HOLE (HYDRAULIC GRADIENT) -5000

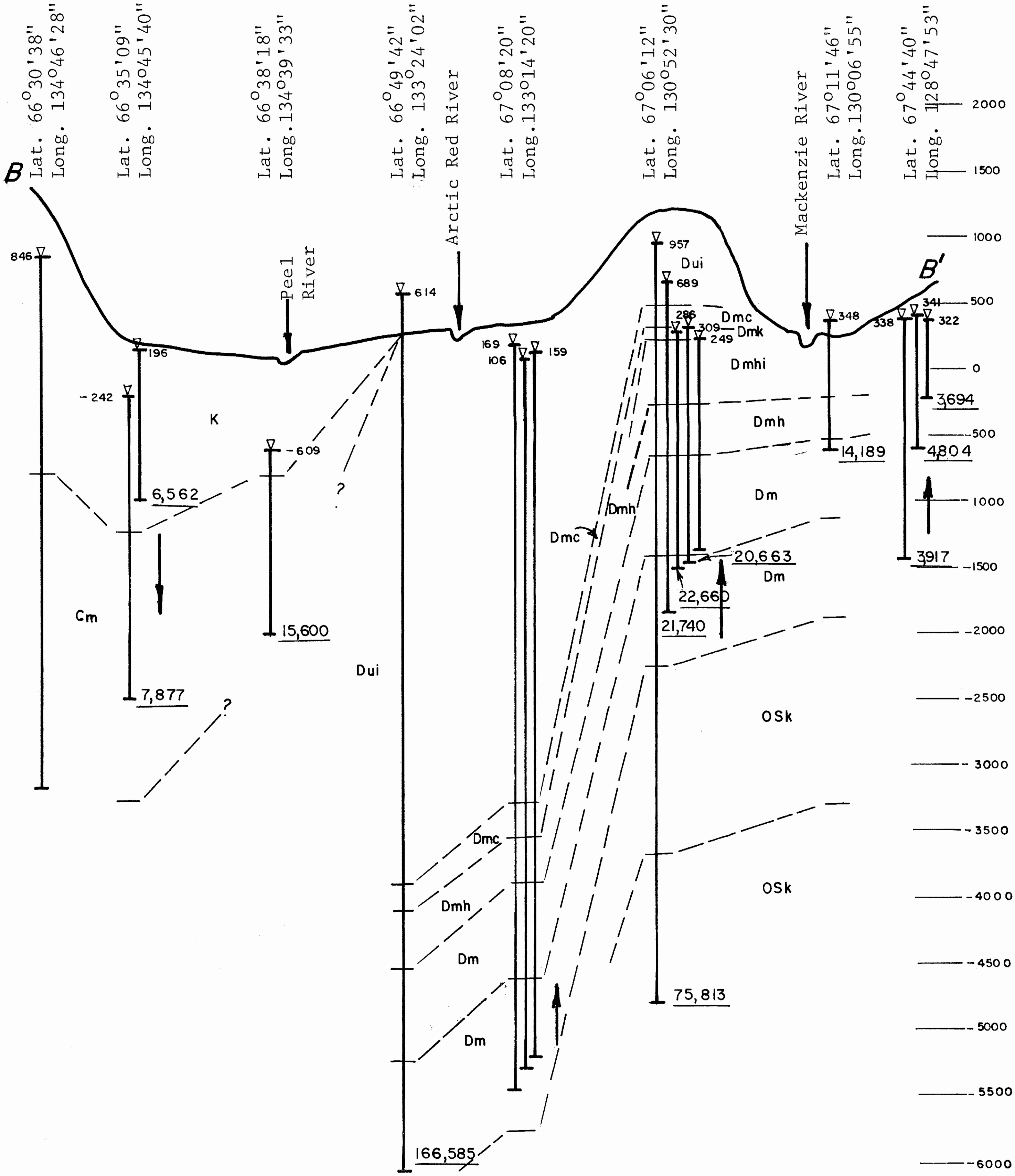
Vertical scale: as shown
Horizontal scale: not to scale

J D Mollard and Associates Limited
April, 1972

FIGURE 18

STRATIGRAPHIC CROSS-SECTION IN VICINITY OF ARCTIC RED RIVER, NORTHWEST TERRITORIES

(see Key Map for location)



CROSS-SECTION OF OIL-EXPLORATION DRILLHOLE LOGS SHOWING DEPTH OF SECTIONS TESTED, STATIC WATER LEVEL, TOTAL DISSOLVED SOLIDS, AND DIRECTION OF GROUNDWATER FLOW IN HOLE (HYDRAULIC GRADIENT)

Vertical scale: as shown
Horizontal scale: not to scale

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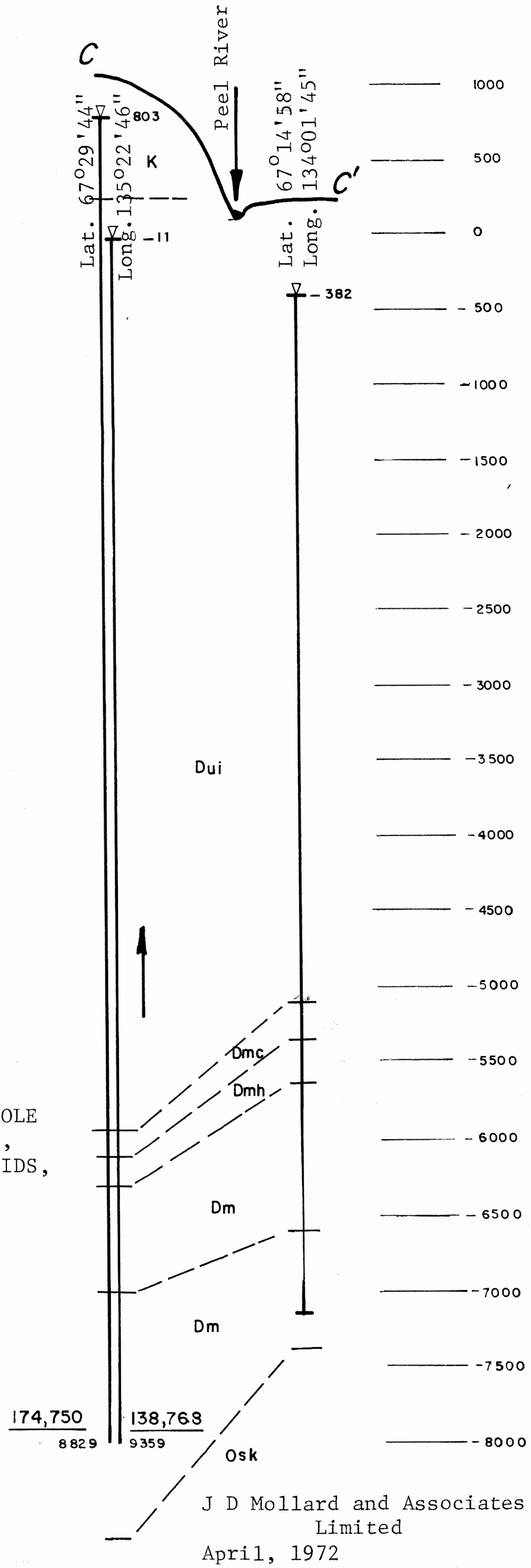
April, 1972

FIGURE 19

STRATIGRAPHIC
CROSS-SECTION IN VICINITY OF ARCTIC RED RIVER, NORTHWEST TERRITORIES



CROSS-SECTION OF OIL-EXPLORATION DRILLHOLE LOGS SHOWING DEPTH OF SECTIONS TESTED, STATIC WATER LEVEL, TOTAL DISSOLVED SOLIDS, AND DIRECTION OF GROUNDWATER FLOW IN HOLE (HYDRAULIC GRADIENT)

Vertical scale: as shown
Horizontal scale: not to scale

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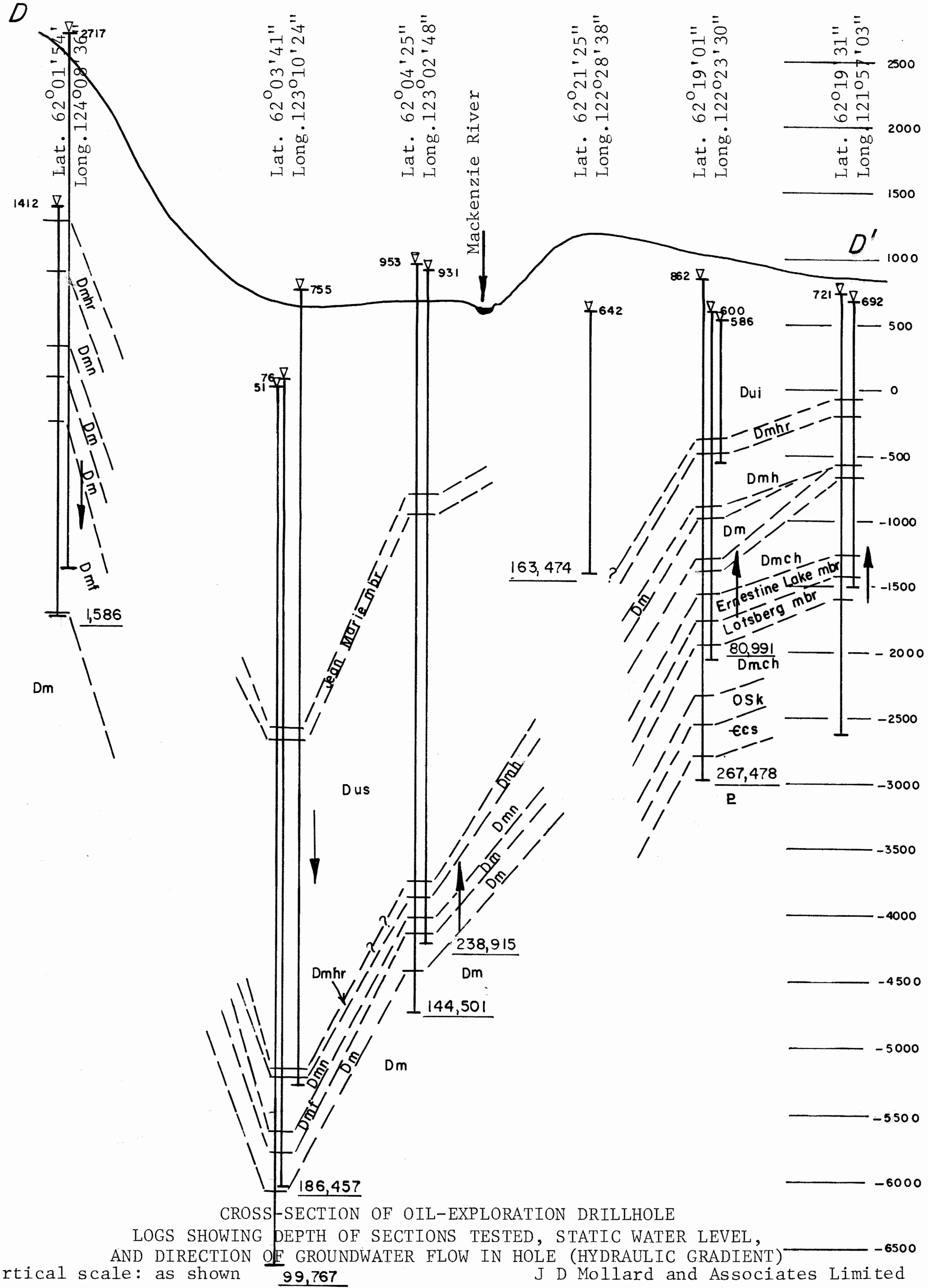
Limited
April, 1972

FIGURE 20

STRATIGRAPHIC
CROSS-SECTION IN VICINITY OF
WRIGLEY, NORTHWEST TERRITORIES
(see Key Map for location)



CROSS-SECTION OF OIL-EXPLORATION DRILLHOLE
LOGS SHOWING DEPTH OF SECTIONS TESTED, STATIC WATER LEVEL,
AND DIRECTION OF GROUNDWATER FLOW IN HOLE (HYDRAULIC GRADIENT)

Vertical scale: as shown
Horizontal scale: not to scale

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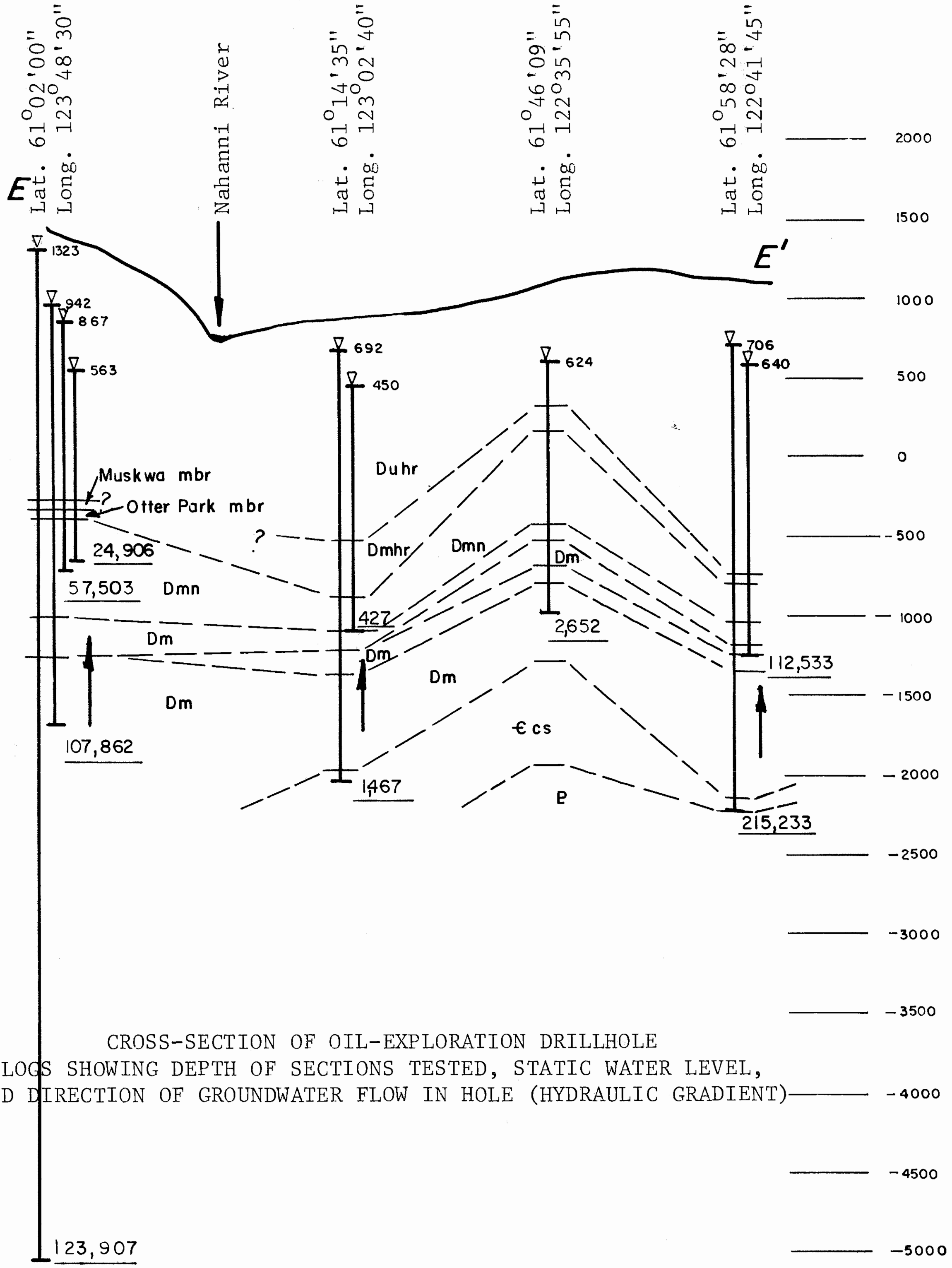
FIGURE 21

STRATIGRAPHIC
CROSS-SECTION VICINITY OF
SOUTH NAHANNI -- LIARD RIVERS
(see Key Map for location)



CROSS-SECTION OF OIL-EXPLORATION DRILLHOLE
LOGS SHOWING DEPTH OF SECTIONS TESTED, STATIC WATER LEVEL,
AND DIRECTION OF GROUNDWATER FLOW IN HOLE (HYDRAULIC GRADIENT)

Vertical scale: as shown
Horizontal scale: not to scale

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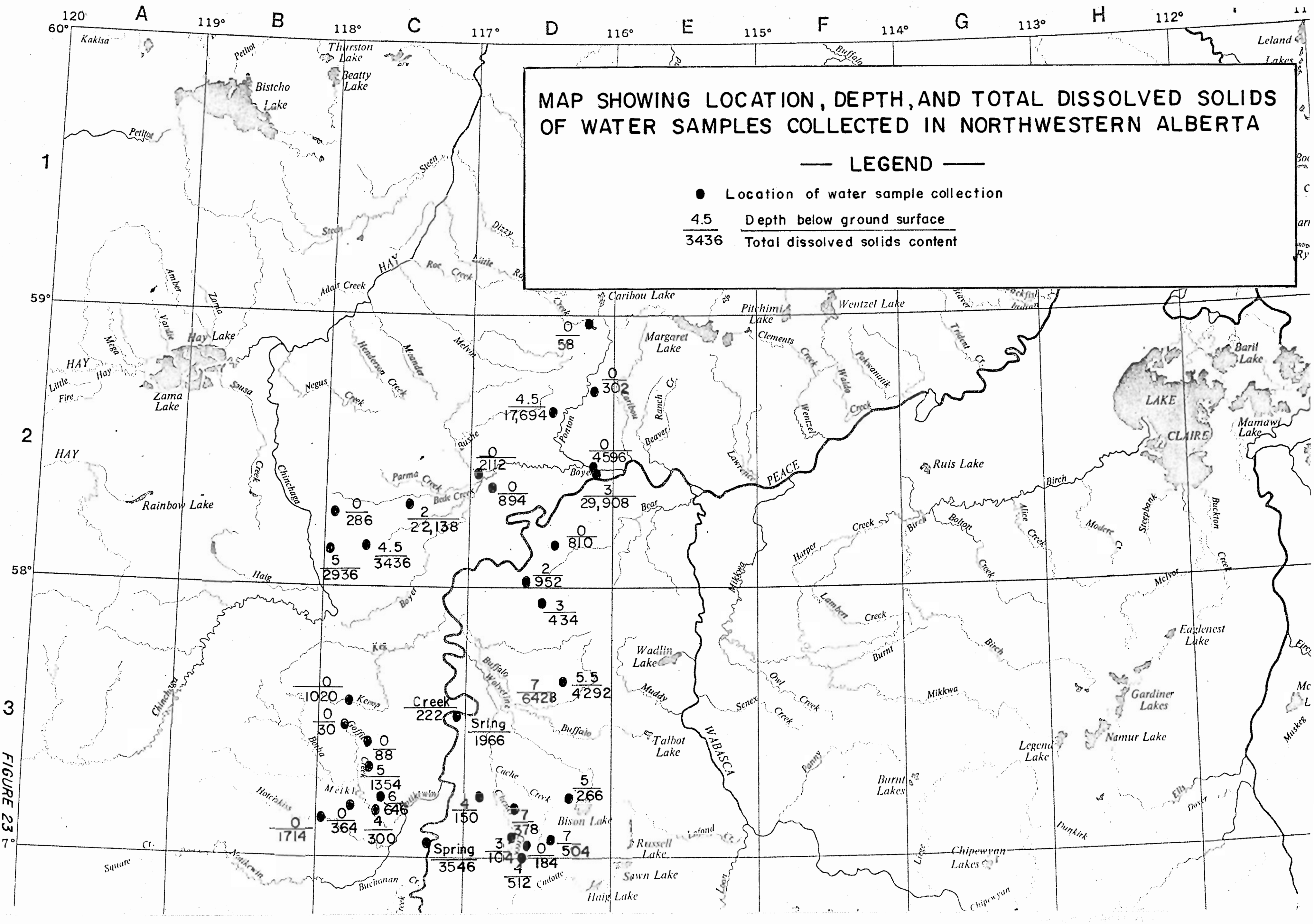
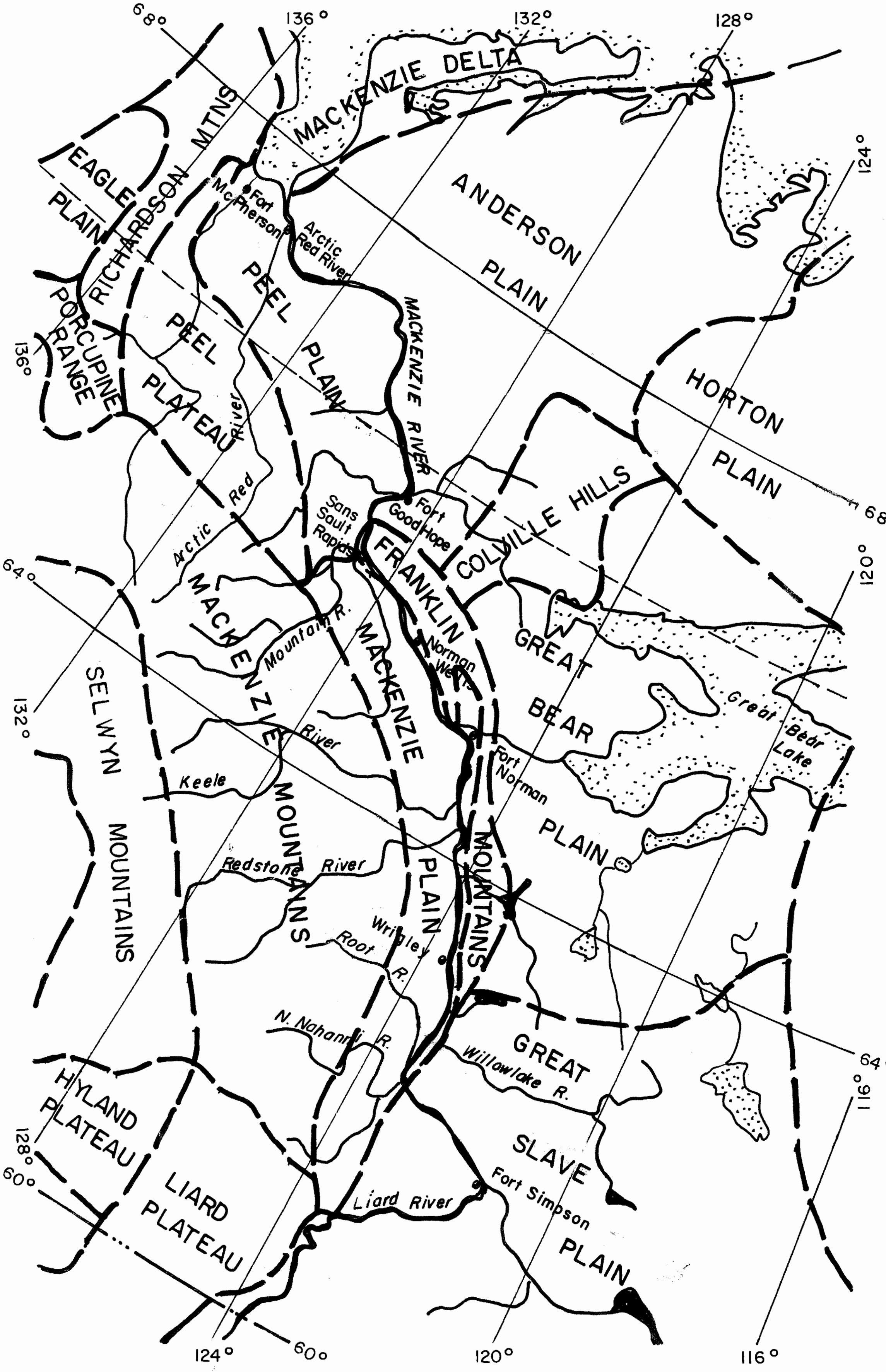
FIGURE 22



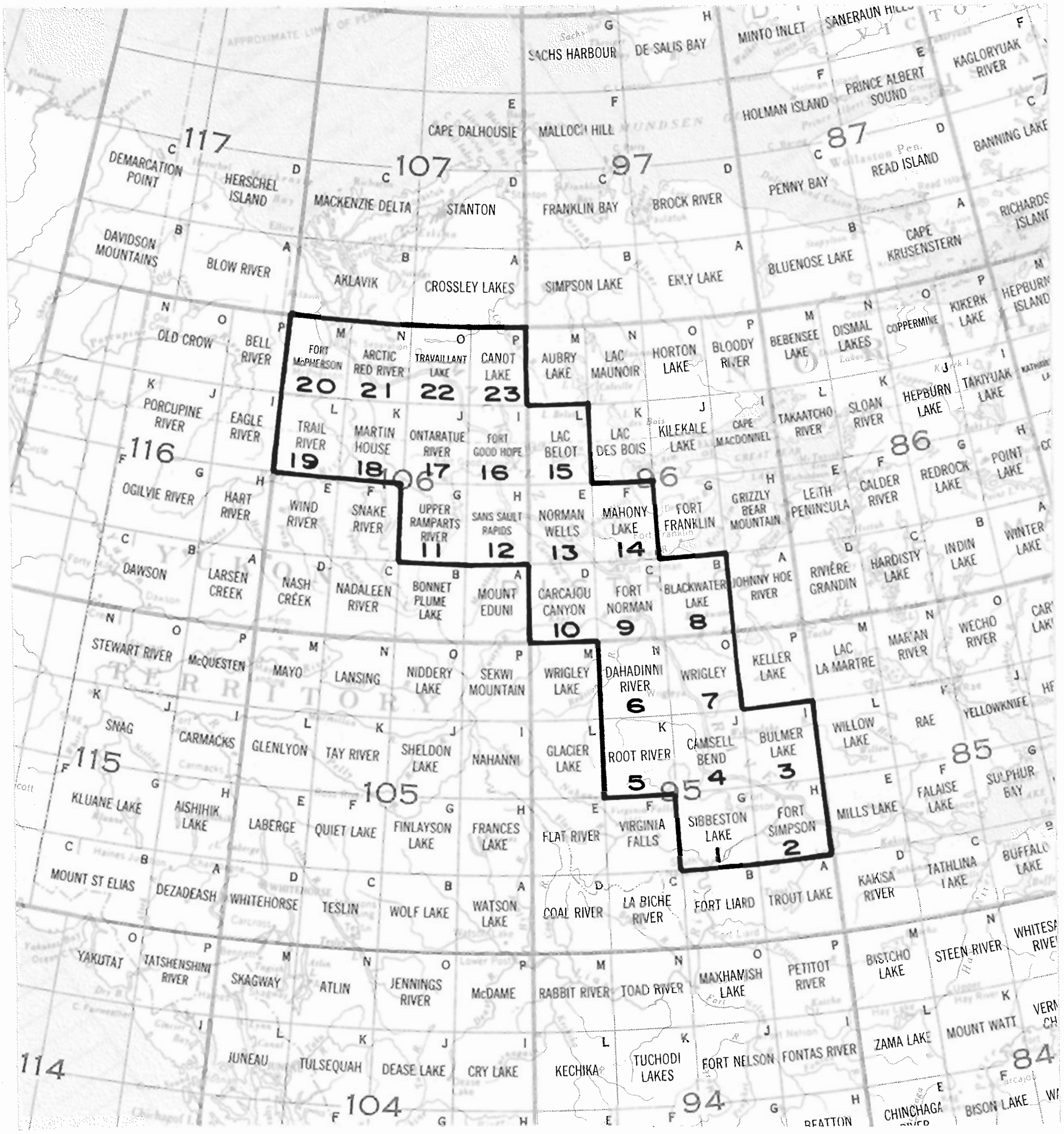
MAP SHOWING LOCATION, DEPTH, AND TOTAL DISSOLVED SOLIDS OF WATER SAMPLES COLLECTED IN NORTHWESTERN ALBERTA
— LEGEND —
● Location of water sample collection
4.5 Depth below ground surface
3436 Total dissolved solids content
A
B
C
D
E
F
G
H
1
2
3
120°
119°
118°
117°
116°
115°
114°
113°
112°
60°
59°
58°
57°
0 / 58
0 / 302
4.5 / 17,694
0 / 4596
0 / 2112
0 / 894
3 / 29,908
0 / 286
2 / 22,138
5 / 2936
4.5 / 3436
0 / 810
2 / 952
3 / 434
7 / 6428
5.5 / 4292
0 / 1020
0 / 30
Creek / 222
Sring / 1966
0 / 88
5 / 1354
6 / 646
0 / 364
4 / 300
0 / 1714
4 / 150
Spring / 3546
7 / 378
3 / 104
0 / 184
4 / 512
7 / 504
5 / 266
Kakisa
Petitot
Bistcho Lake
Thurston Lake
Beatty Lake
Steen
HAY
Adair Creek
Roe Creek
Little
Dizzy
Amber
Zama
Vardie
Hay Lake
Mega
Hay
Little
Fire
Zama Lake
Sousa
Negus
Henderson Creek
Meander
Creek
Melvin
Chinchaga
Creek
Rainbow Lake
Haig
Parma Creek
Bede Creek
Bushe
Boyer
Keg
Kemp
Goffitt
Botha
Creek
Meikle
Hotchkiss
Chinchaga
Square
Cr.
Notikewin
Buchanan Cr.
Caribou Lake
Creek
Ponton
Caribou
Margaret Lake
Ranch Cr.
Beaver
Boyer
Bear
Pitchimi Lake
Clements
Creek
Wentzel Lake
Waldo
Pakwanutik
Wentzel
Creek
Lawrence
PEACE
Trident Cr.
Beaver
Buffalo
Wolverine
Buffalo
Cache
Creek
Chester
Bison Lake
Cadotte
Haig Lake
Sawn Lake
Russell Lake
Lafond Cr.
Wadlin Lake
Muddy
Talbot Lake
WABASCA
Loon
Mikkwa
Harper
Creek
Lambert
Creek
Senex
Owl
Creek
Creek
Panny
Burnt
Burnt Lakes
Mikkwa
Birch
Ruis Lake
Birch
Bolton
Creek
Alice Creek
Birch
Legend Lake
Chipewyan Lakes
Chipewyan
Loon
Dunkirk
Modere Cr.
Steepbank
Buckton Creek
McIvor
Eaglenest Lake
Gardiner Lakes
Namur Lake
Ells
Dover
LAKE CLAIRE
Baril Lake
Mamawi Lake
Leland Lakes
Muskeg

FIGURE 23



PHYSIOGRAPHIC REGIONS
ALONG
MACKENZIE RIVER VALLEY, N.W.T.

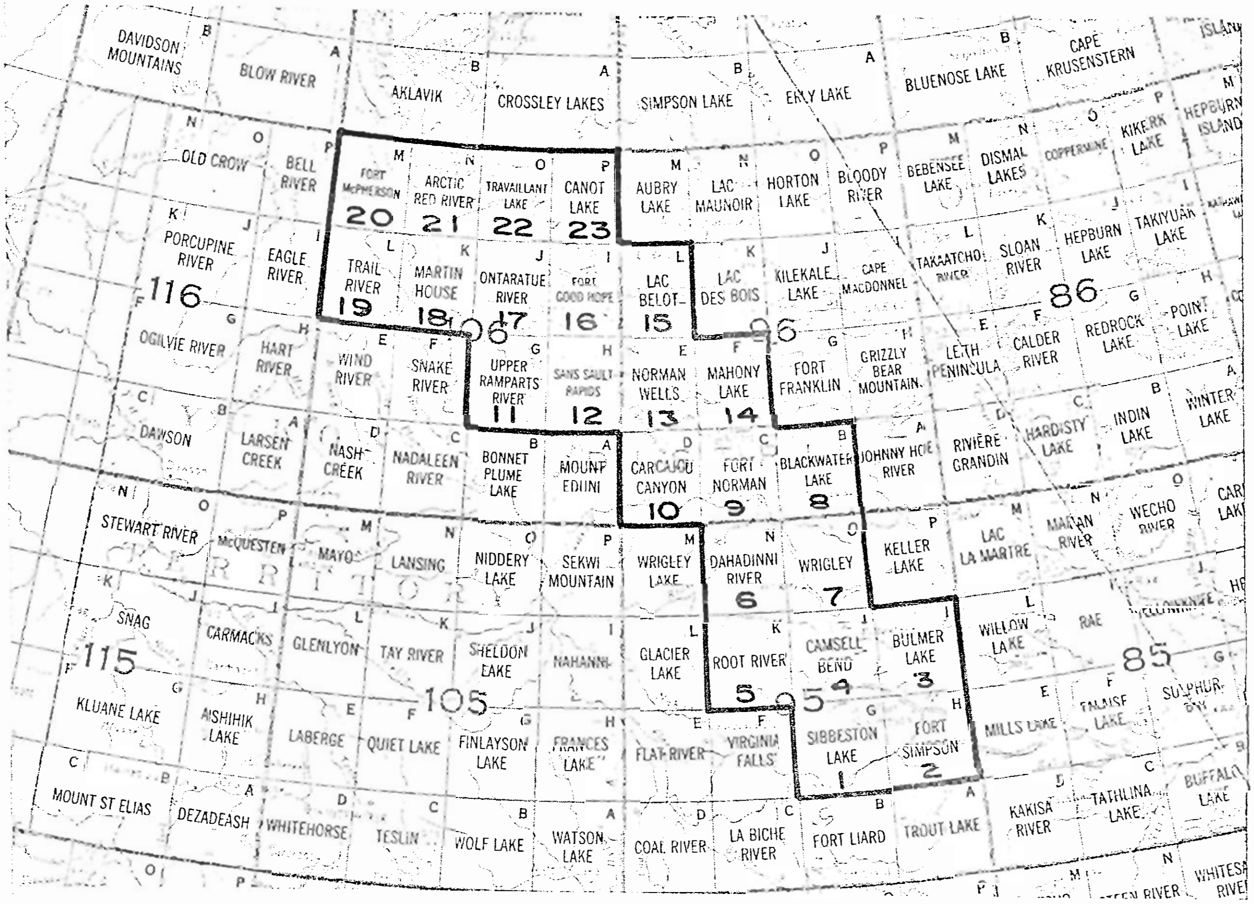
FIGURE 24



LOCATION OF MAPS
ALONG
MACKENZIE RIVER VALLEY, N.W.T.

ACCOMPANYING 23 SURFICIAL GEOLOGY, 23 SURFICIAL HYDROGEOLOGY, AND 23 BEDROCK HYDROGEOLOGY MAPS AND CORRESPONDING NATIONAL TOPOGRAPHIC MAP SHEET NUMBERS

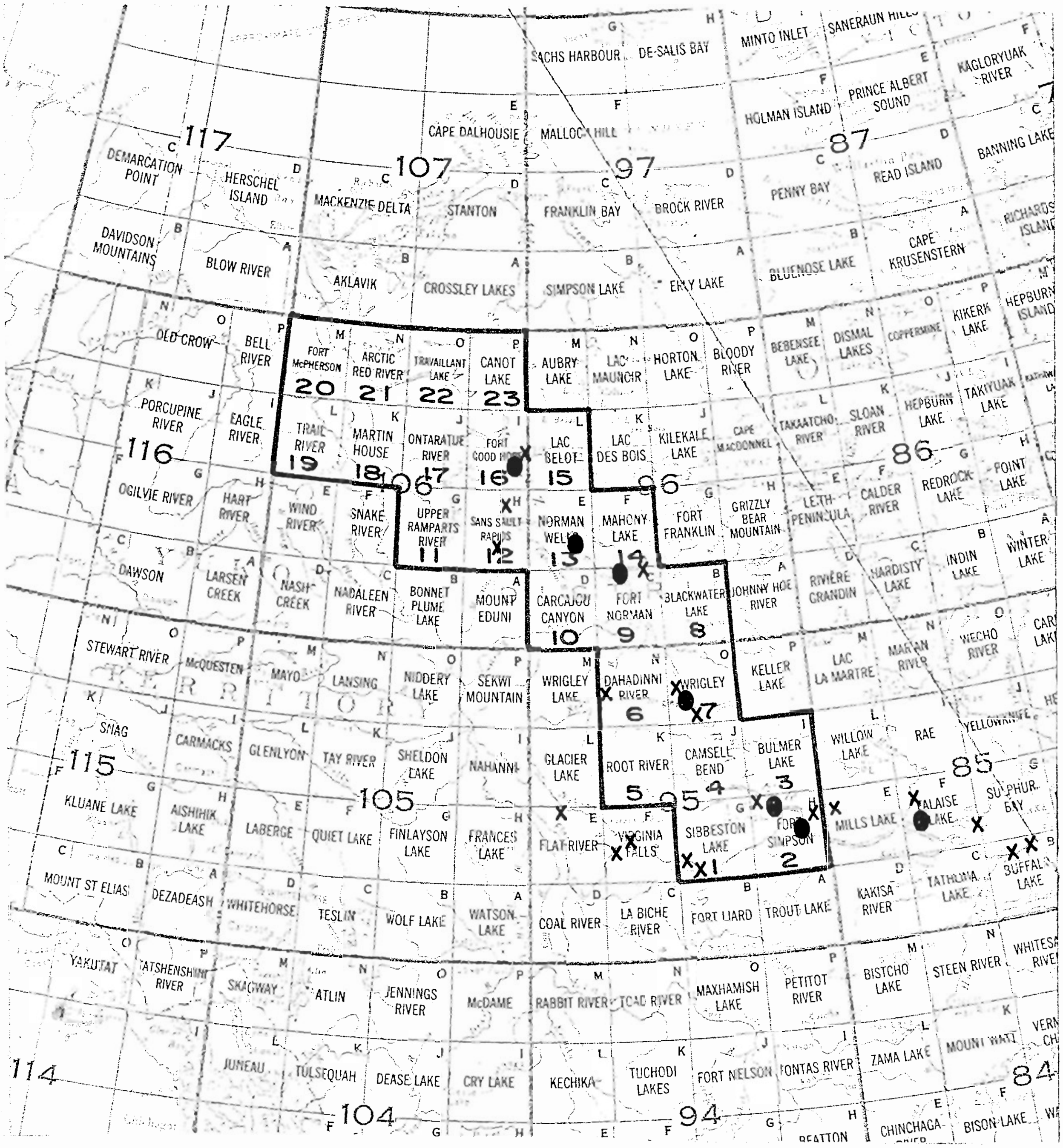
FIGURE 25



KEY MAP CORRELATING LOCATIONS OF GEOGRAPHIC PLACE NAMES REFERRED TO IN REPORT WITH CORRESPONDING MAP NUMBERS (FIG 25) AND NATIONAL TOPOGRAPHIC SERIES MAP SHEETS (NTS WHERE SHOWN)

Antoine Lake	2
Arctic Red River	21
Bear Rock	9
Beavertail Point	12
Bistcho Lake (Alta)	NTS: 84 M
Blackwater River	6
Bogg Creek	13
Bosworth Creek	13
Camsell Bend	4
Cap Mountain	7
Carcajou River	10
Dahadinni River	6
Discovery Ridge	13
Fort Good Hope	16
Fort Providence	NTS: 85 F
Fort McPherson	20
Fort Simpson	2
Franklin Mountains	7, 8, 9
Goose Island and Bear Island	13
Great Bear River (rapids section)	14
Halfway Islands	13
Hare Indian River	16
Hoosier Ridge	13
Kee Scarp	13
Keele River	10
Liard River	1, 2
Little Chicago	22
Lower Carcajou River	10
Lower Donnelly River	12
Martin Hills	1
Martin House	18
Martin River	1, 2
Mountain River and Imperial Hills	12
Mt. Clark	9
Mount Kindle	7
Mt. Thomas and Mt.Richard	13
Mount Morrow	13
Norman Wells	13
North Redstone River	6
North and South Nahanni Rivers	1,4,5
Ochre River	7
Old Fort Island	4
Old Fort Point	9
Oscar Creek	13
Oscar Creek Basin	13
Prohibition Creek	13
Rabbitskin River	2
Redstone River	6,9
Roche-qui-Trempe-a-l'Eau	7
Root River	4,5
Saline River	9
Sammon's Creek	12
Sans Sault Rapids	12
Shiltee Rock (Fort McPherson)	20
Slater River	10
Tathlina Lake	NTS: 85
Trout River	NTS:85 and 95
Vermilion Creek	13
West Mountain	12
Wrigley	7

FIGURE 26



LOCATION OF WATER-WELL DRILLING SITES AND SPRINGS OBSERVED IN FIELD ALONG MACKENZIE RIVER VALLEY, N.W.T.

● Water-well drilling sites

x Springs observed in field

FIGURE 27

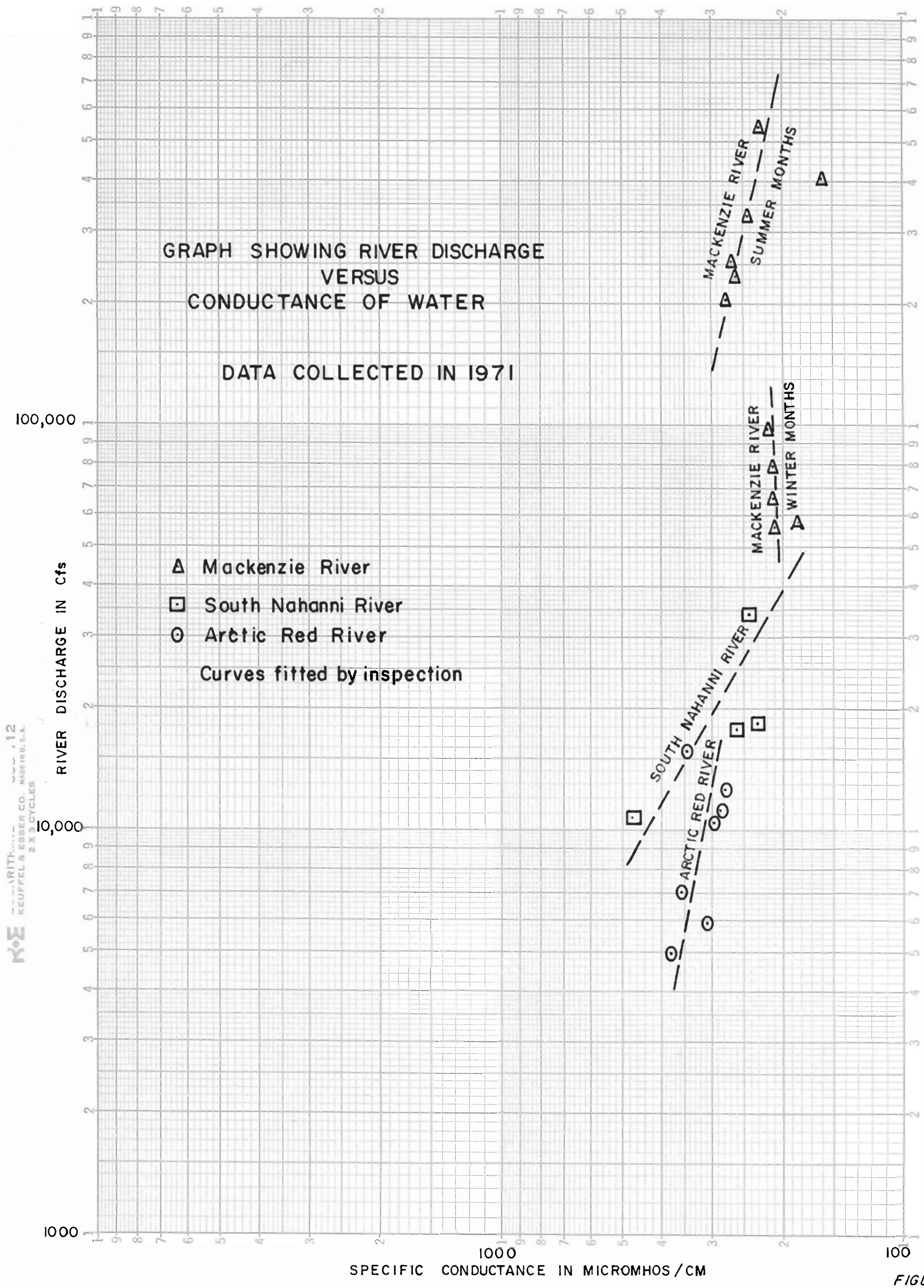

GRAPH SHOWING RIVER DISCHARGE VERSUS CONDUCTANCE OF WATER
DATA COLLECTED IN 1971
Δ Mackenzie River
⊡ South Nahanni River
⊙ Arctic Red River
Curves fitted by inspection
MACKENZIE RIVER SUMMER MONTHS
MACKENZIE RIVER WINTER MONTHS
SOUTH NAHANNI RIVER
ARCTIC RED RIVER
RIVER DISCHARGE IN Cfs
100,000
10,000
1000
SPECIFIC CONDUCTANCE IN MICROMHOS / CM
1000
100
K&E KEUFFEL & ESSER CO. MADE IN U.S.A. 2 X 3 CYCLES

FIGURE 28

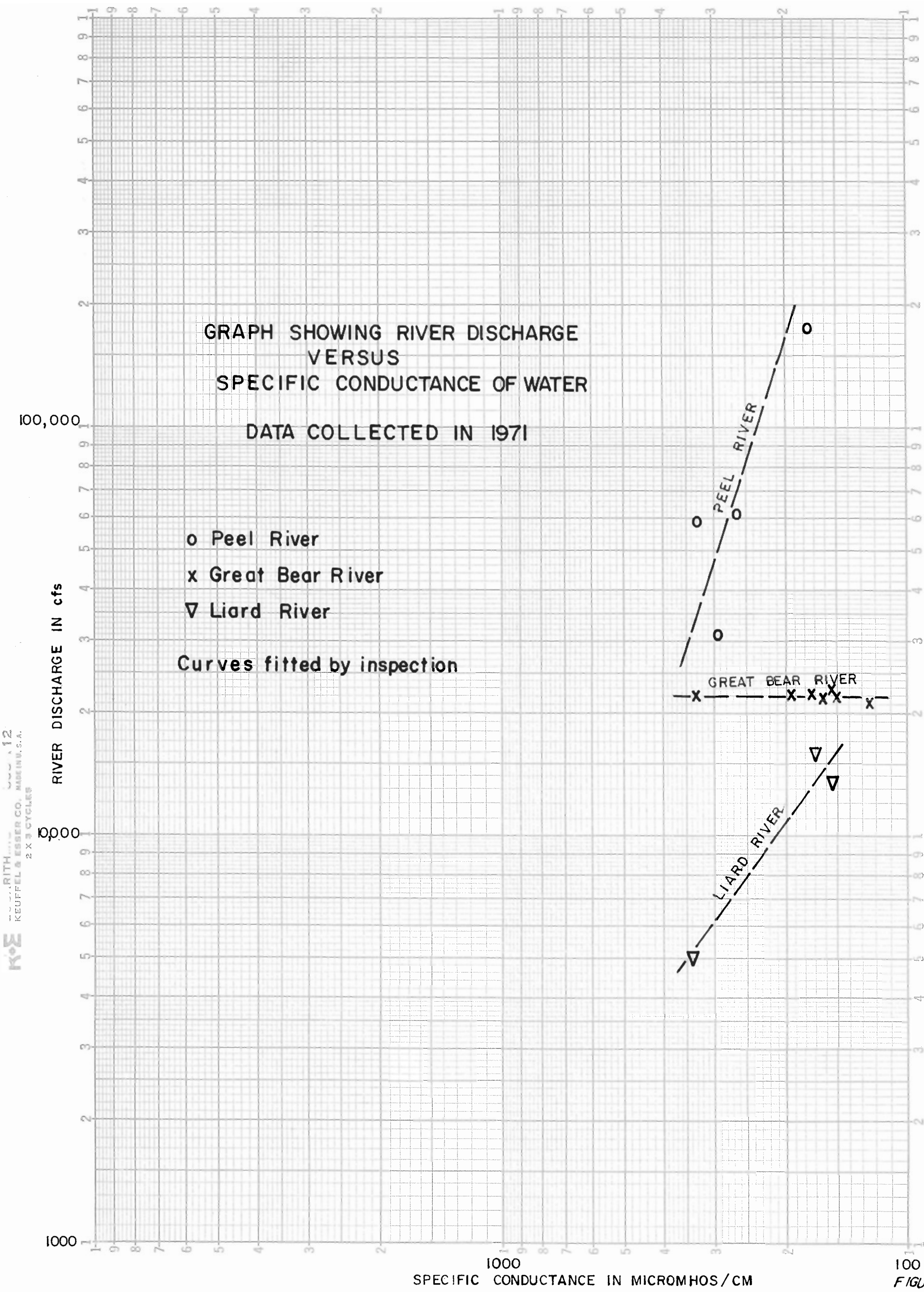

GRAPH SHOWING RIVER DISCHARGE
VERSUS
SPECIFIC CONDUCTANCE OF WATER
DATA COLLECTED IN 1971
o Peel River
x Great Bear River
∇ Liard River
Curves fitted by inspection
PEEL RIVER
GREAT BEAR RIVER
LIARD RIVER
RIVER DISCHARGE IN cfs
100,000
10,000
1000
SPECIFIC CONDUCTANCE IN MICROMHOS/CM
1000
100

FIGURE 29

CHANGING CLIMATE DURING WISCONSIN AND POSTGLACIAL TIME (after J. Terasmae, Proceedings 14th Muskeg Research Conference 10 and 11 May 1971, p 158)

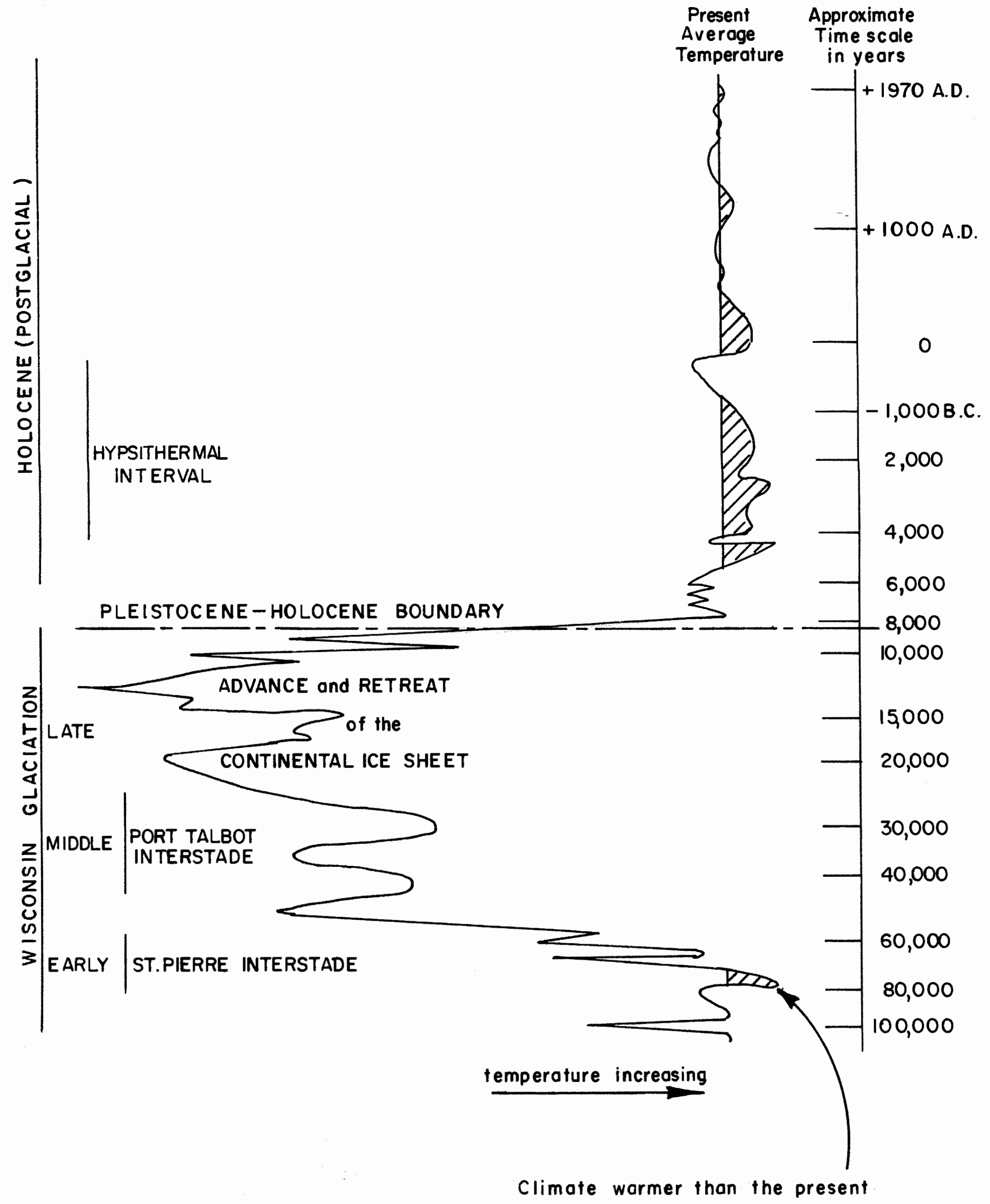
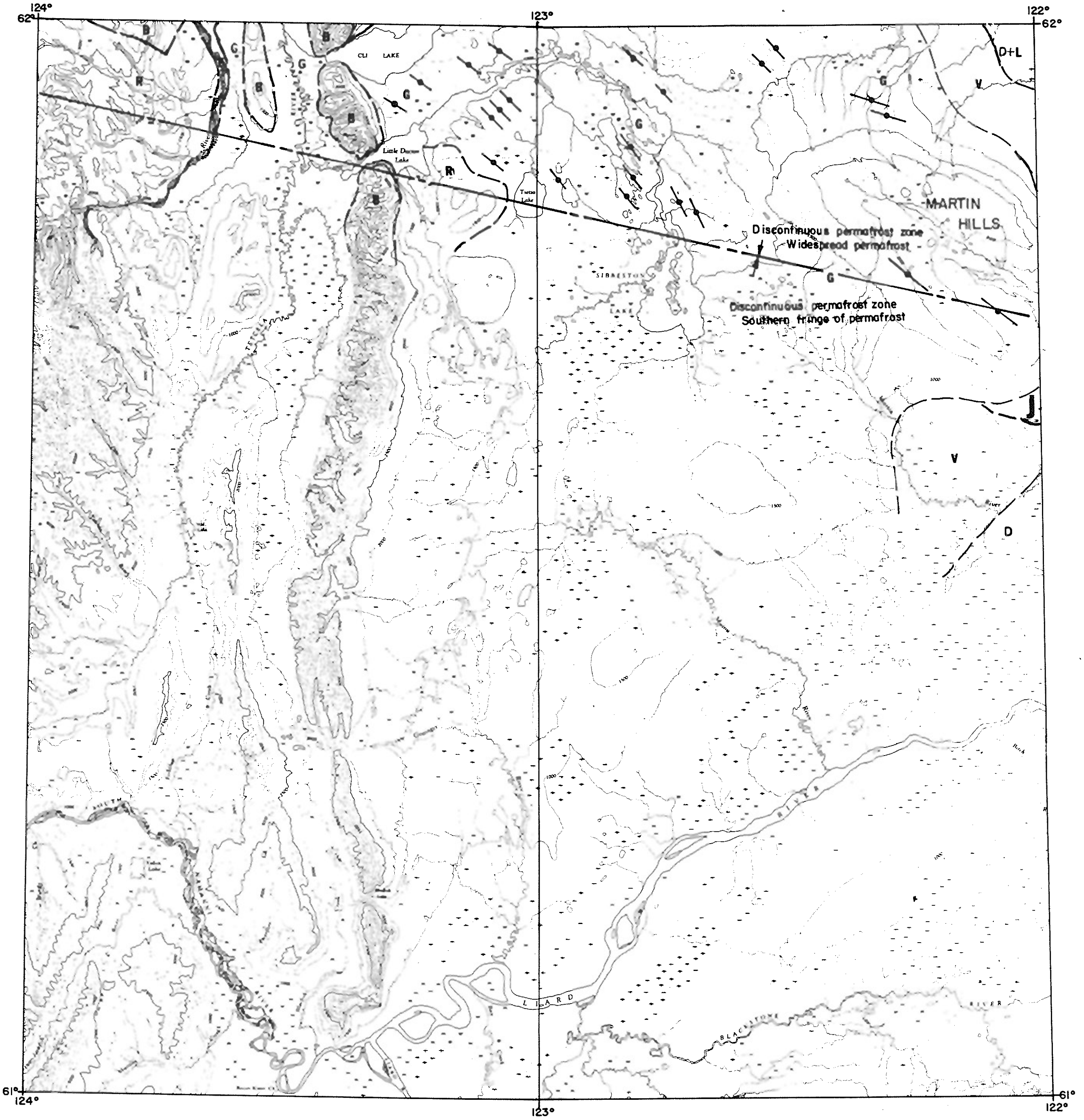


FIGURE 30



SIBBESTON LAKE

95G

RECONNAISSANCE SURFICIAL . GEOLOGY MAP

LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT Mc PHERSON , NWT

RECENT

NONGLACIAL DEPOSITS

PEATLAND ENVIRONMENT

⍦	ORGANIC DEPOSITS: Mainly peat, some muck; fens, bogs, marshes, and swamps

FLUVIAL ENVIRONMENT

F	FLOODPLAIN DEPOSITS: Mainly exposed gravel and sand, with thin topstratum of silt and fine sand on the wooded inactive portions of floodplains; the Mackenzie River modern floodplain and up to 5 miles in the lower reaches of flat-gradient tributary rivers consist mainly of stratified silt and fine sand, with minor clay, gravel, and stones
A	ALLUVIAL FAN AND CONE DEPOSITS: Mainly poorly sorted silty gravel and sand; lesser silt, clay and cobbles
E	ESTUARINE DELTAIC AND FLOODPLAIN DEPOSITS: Mainly complexly intergrading and interfingering silt, clay, fine sand, and peat with commonly a thick peat cover

EOLIAN ENVIRONMENT

W	DUNE DEPOSITS: Mainly fine sand, silty fine sand

PLEISTOCENE

GLACIAL-DRIFT DEPOSITS

GLACIOLACUSTRINE ENVIRONMENT

D	LAKE-DELTAIC DEPOSITS (includes widely scattered sand dunes): Mainly stratified silty fine sand, fine sand, silt, and clayey silt deposited in nearshore lake waters and where major meltwater streams entered temporary glacial lakes; somewhat less extensive thermokarst development that map-unit L
L	LACUSTRINE DEPOSITS: Mainly stratified and massive silt, silty clay, clayey silt, and minor fine sand deposited in deeper offshore waters; this map-unit L sometimes overlies map-unit D; extensive thermokarst development in poorly drained, ponded water areas
V	LACUSTRINE VENEER OVER MORAINE DEPOSITS: Mainly silt, clayey silt, and silty clay over till

GLACIOFLUVIAL ENVIRONMENT

T	HIGH TERRACE DEPOSITS: Mainly sand with some gravelly beds; mostly with a silt and surficial peat cover up to 15 feet thick locally
O	OUTWASH PLAIN, OUTWASH DELTA, VALLEY TRAIN DEPOSITS--LOCALLY CHANNELLED AND KETTLED: Mainly stratified fine to coarse sand, gravelly sand, gravel; minor cobbles and silt
I	ICE-CONTACT FEATURES INCLUDING ESKERS, CREVASSE FILLINGS, KAMES, KAME TERRACES, KAME DELTAS DEPOSITS: Mainly sand and gravel cored ridges and mounds; with minor silt, till, and boulders occurring as inclusions and overburden

GLACIAL ENVIRONMENT

H	HUMMOCKY MORAINE DEPOSITS (includes a thin cover of fine-grained waterlaid and windlaid deposits locally as well as fine ponded and slopewash sediments beneath partly peat-filled deep depressions): Mainly till
G	GROUND MORAINE DEPOSITS, GENERALLY SHOWING STREAMLINED FORMS:(includes thin cover of silty to sandy slopewash deposits locally): Mainly clay-rich till over shale strata, sandy till over sandstone strata, and silty till over carbonate rocks; peat deposits on gentle slopes and in undrained hollows; some V below 600'
J	GROUND MORAINE DEPOSITS WITH DEEPER SILTY TO SANDY SLOPEWASH OVERLAY(Classic areas are the slopes of the Ebbutt and Martin Hills and the Horn Plateau): Mainly silt and sand over till
N	BEVELLED TILL DEPOSITS (includes pockets of fine waterlaid material and peat): Mostly a lag concentrate of boulders and cobbles with frequent patches and pockets of sand and gravel, waterlaid silt and clay, and peat

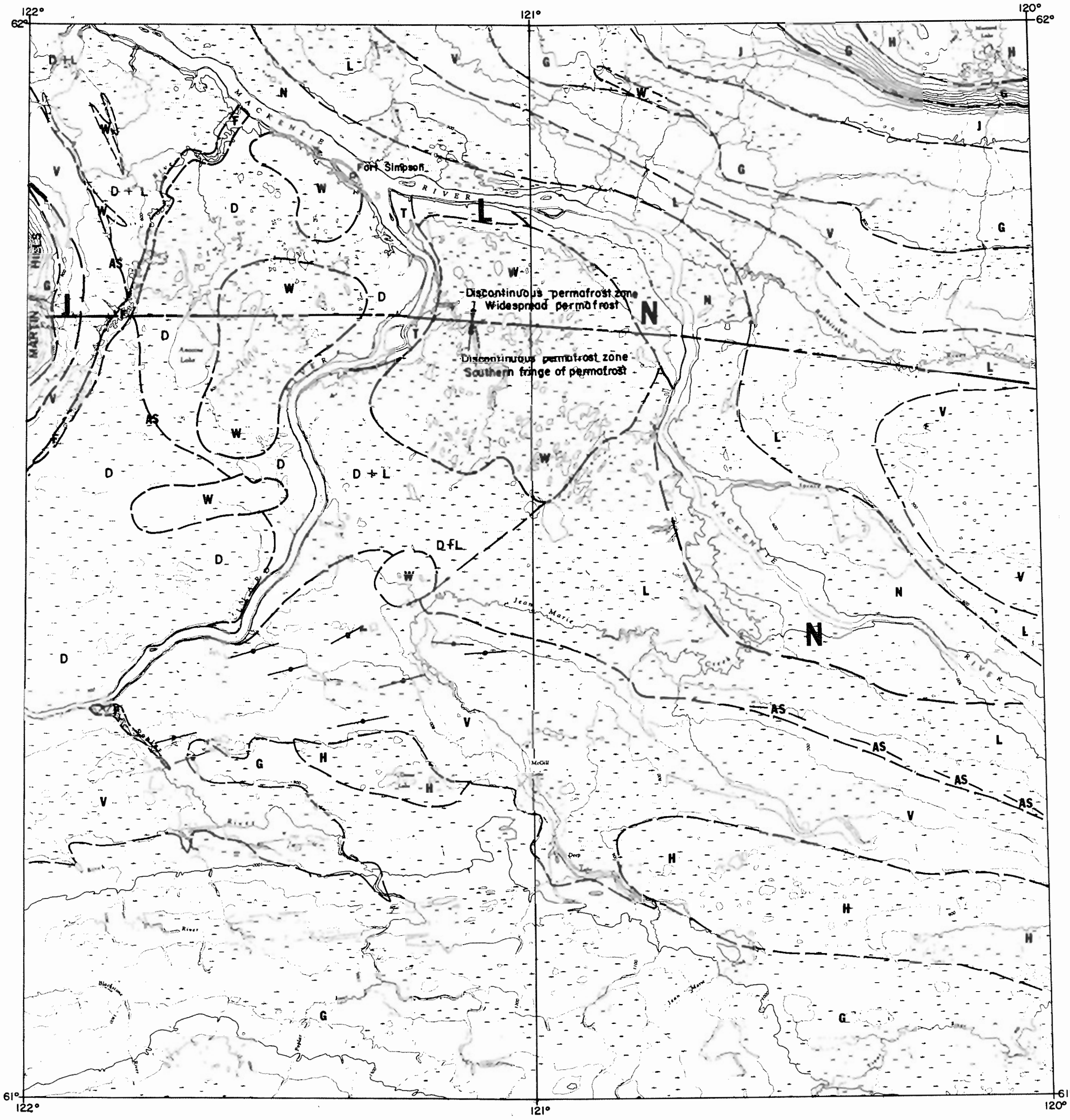
BEDROCK-DOMINATED TERRAIN

B	WIDELY EXPOSED BEDROCK TERRAIN: Mainly exposed bedrock and bedrock with a thin, discontinuous veneer of drift; often having rugged topography; includes very rugged eroded topography
R	VENEERED BEDROCK-DOMINATED RELIEF: Mainly a thin, but variable and locally thick, cover of drift; chiefly till

M	Meltwater and spillway channels
AS	Abandoned strandlines; includes minor raised beaches
○K○	Karstic topography; sinkholes in soluble rocks (gypsum, anhydrite, dolomite, limestone)
⦵	Ice-flow features; includes glacial grooves, glacial fluting, drumlinoid ridges, streamlined hills and ridges, drumlinized landscapes, crag-and-tail hills
C	Rock glaciers, talus, and thick colluvium on steep slopes
S	Springs

NOTE: The same legend is shown on all map sheets; but rarely are all map-units used and shown on each individual sheet

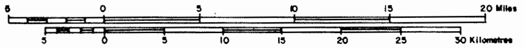
Map 1



FORT SIMPSON

95H

RECONNAISSANCE SURFICIAL GEOLOGY MAP



LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT Mc PHERSON , NWT

RECENT

NONGLACIAL DEPOSITS

PEATLAND ENVIRONMENT

ORGANIC DEPOSITS: Mainly peat, some muck; fens, bogs, marshes, and swamps

FLUVIAL ENVIRONMENT

F FLOODPLAIN DEPOSITS: Mainly exposed gravel and sand, with thin topstratum of silt and fine sand on the wooded inactive portions of floodplains; the Mackenzie River modern floodplain and up to 5 miles in the lower reaches of flat-gradient tributary rivers consist mainly of stratified silt and fine sand, with minor clay, gravel, and stones

A ALLUVIAL FAN AND CONE DEPOSITS: Mainly poorly sorted silty gravel and sand; lesser silt, clay and cobbles

E ESTUARINE DELTAIC AND FLOODPLAIN DEPOSITS: Mainly complexly intergrading and interfingering silt, clay, fine sand, and peat with commonly a thick peat cover

EOLIAN ENVIRONMENT

W DUNE DEPOSITS: Mainly fine sand, silty fine sand

PLEISTOCENE

GLACIAL-DRIFT DEPOSITS

GLACIOLACUSTRINE ENVIRONMENT

D LAKE-DELTAIC DEPOSITS (Includes widely scattered sand dunes): Mainly stratified silty fine sand, fine sand, silt, and clayey silt deposited in nearshore lake waters and where major meltwater streams entered temporary glacial lakes; somewhat less extensive thermokarst development that map-unit L

L LACUSTRINE DEPOSITS: Mainly stratified and massive silt, silty clay, clayey silt, and minor fine sand deposited in deeper offshore waters; this map-unit L sometimes overlies map-unit D; extensive thermokarst development in poorly drained, ponded water areas

V LACUSTRINE VENEER OVER MORAINE DEPOSITS: Mainly silt, clayey silt, and silty clay over till

GLACIOFLUVIAL ENVIRONMENT

T HIGH TERRACE DEPOSITS: Mainly sand with some gravelly beds; mostly with a silt and surficial peat cover up to 15 feet thick locally

O OUTWASH PLAIN, OUTWASH DELTA, VALLEY TRAIN DEPOSITS--LOCALLY CHANNELLED AND KETTLED: Mainly stratified fine to coarse sand, gravelly sand, gravel; minor cobbles and silt

I ICE-CONTACT FEATURES INCLUDING ESKERS, CREVASSE FILLINGS, KAMES, KAME TERRACES, KAME DELTAS DEPOSITS: Mainly sand and gravel cored ridges and mounds; with minor silt, till, and boulders occurring as inclusions and overburden

GLACIAL ENVIRONMENT

H HUMMOCKY MORAINE DEPOSITS (Includes a thin cover of fine-grained waterlaid and windlaid deposits locally as well as fine ponded and slopewash sediments beneath partly peat-filled deep depressions): Mainly till

G GROUND MORAINE DEPOSITS, GENERALLY SHOWING STREAMLINED FORMS (Includes thin cover of silty to sandy slopewash deposits locally): Mainly clay-rich till over shale strata, sandy till over sandstone strata, and silty till over carbonate rocks; peat deposits on gentle slopes and in undrained hallows; some V below 600'

J GROUND MORAINE DEPOSITS WITH DEEPER SILTY TO SANDY SLOPEWASH OVERLAY (Classic areas are the slopes of the Ebbutt and Martin Hills and the Horn Plateau): Mainly silt and sand over till

N BEVELLED TILL DEPOSITS (Includes pockets of fine waterlaid material and peat): Mostly a lag concentrate of boulders and cobbles with frequent patches and pockets of sand and gravel, waterlaid silt and clay, and peat

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M Meltwater and spillway channels

AS Abandoned strandlines; includes minor raised beaches

K Karstic topography; sinkholes in soluble rocks (gypsum, anhydrite, dolomite, limestone)

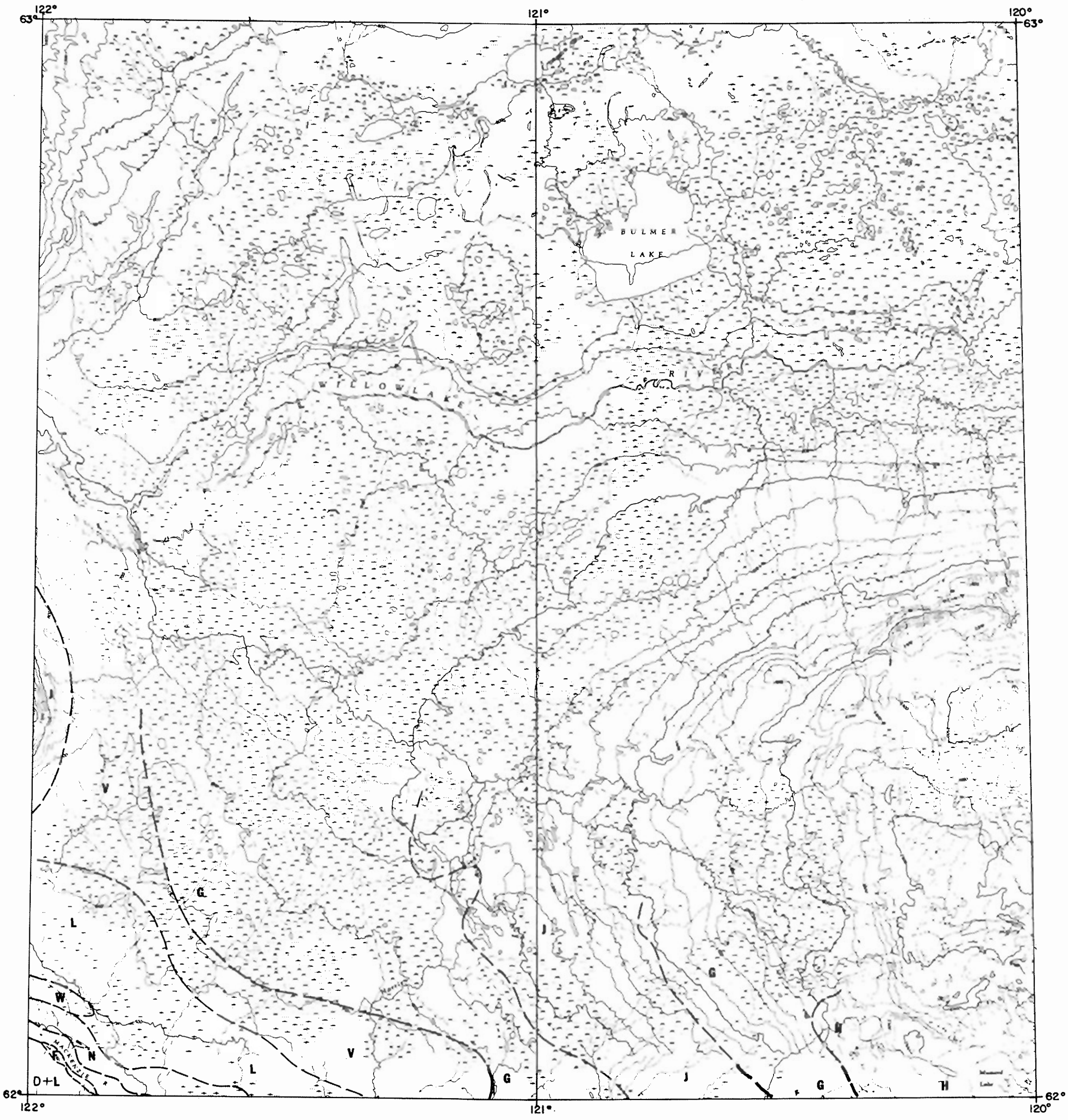
Ice-flow features; includes glacial grooves, glacial fluting, drumlinoid ridges, streamlined hills and ridges, drumlinized landscapes, crag-and-tail hills

C Rock glaciers, talus, and thick colluvium on steep slopes

S Springs

NOTE: The same legend is shown on all map sheets; but rarely are all map-units used and shown on each individual sheet

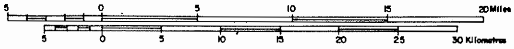
Map 2



BULMER LAKE

95 I

RECONNAISSANCE SURFICIAL GEOLOGY MAP



LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT Mc PHERSON, NWT

RECENT

NONGLACIAL DEPOSITS

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FLUVIAL ENVIRONMENT

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EOLIAN ENVIRONMENT

W	DUNE DEPOSITS: Mainly fine sand, silty fine sand

PLEISTOCENE

GLACIAL-DRIFT DEPOSITS

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C	Rock glaciers, talus, and thick colluvium on steep slopes
S	Springs

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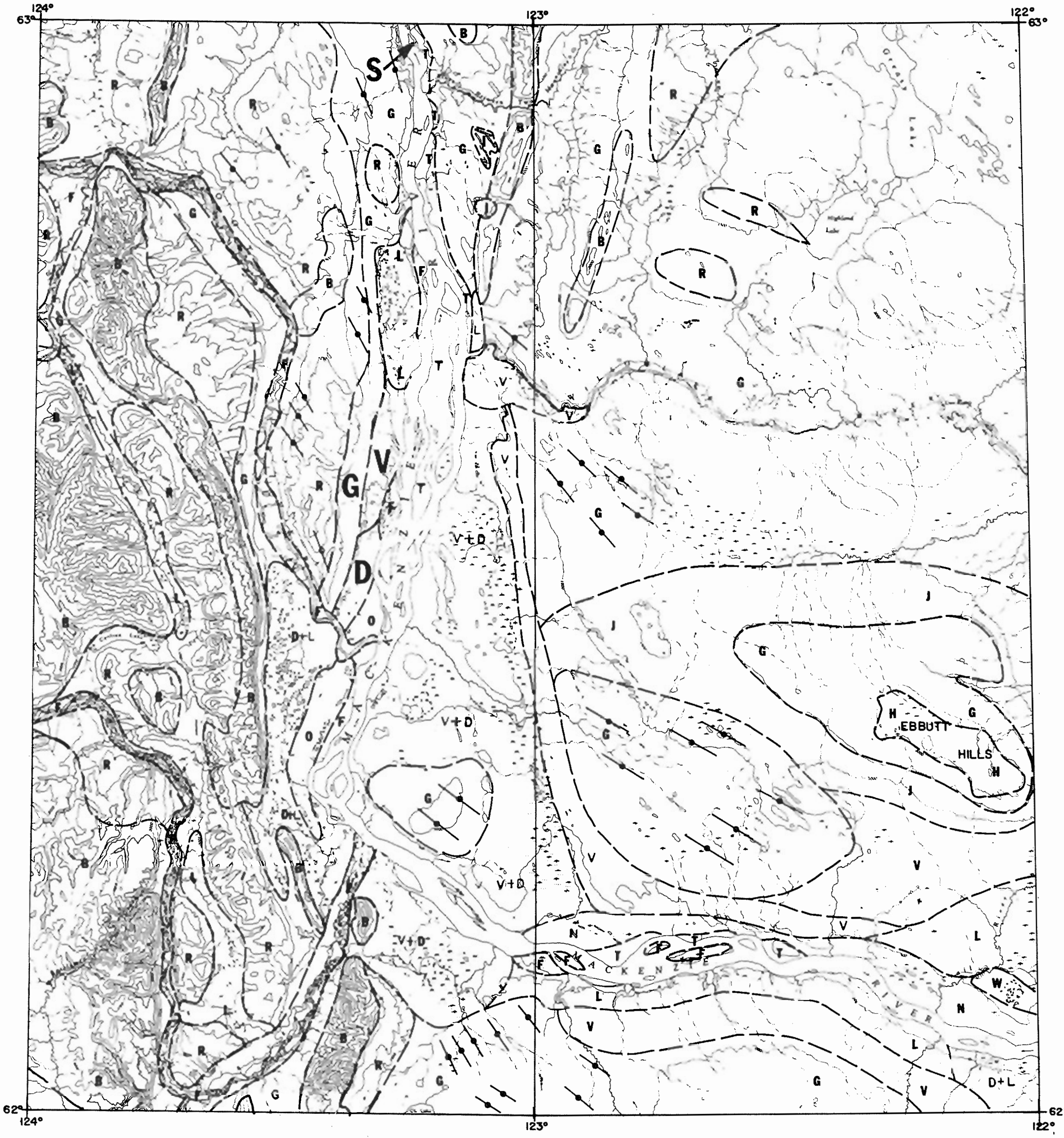
Map 3



CAMSELL BEND
95J
RECONNAISSANCE SURFICIAL GEOLOGY MAP

5 0 5 10 15 20 Miles
5 0 5 10 15 20 25 30 Kilometres

LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT Mc PHERSON, NWT

RECENT

NONGLACIAL DEPOSITS

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EOLIAN ENVIRONMENT

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PLEISTOCENE

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C Rock glaciers, talus, and thick colluvium on steep slopes

S Springs

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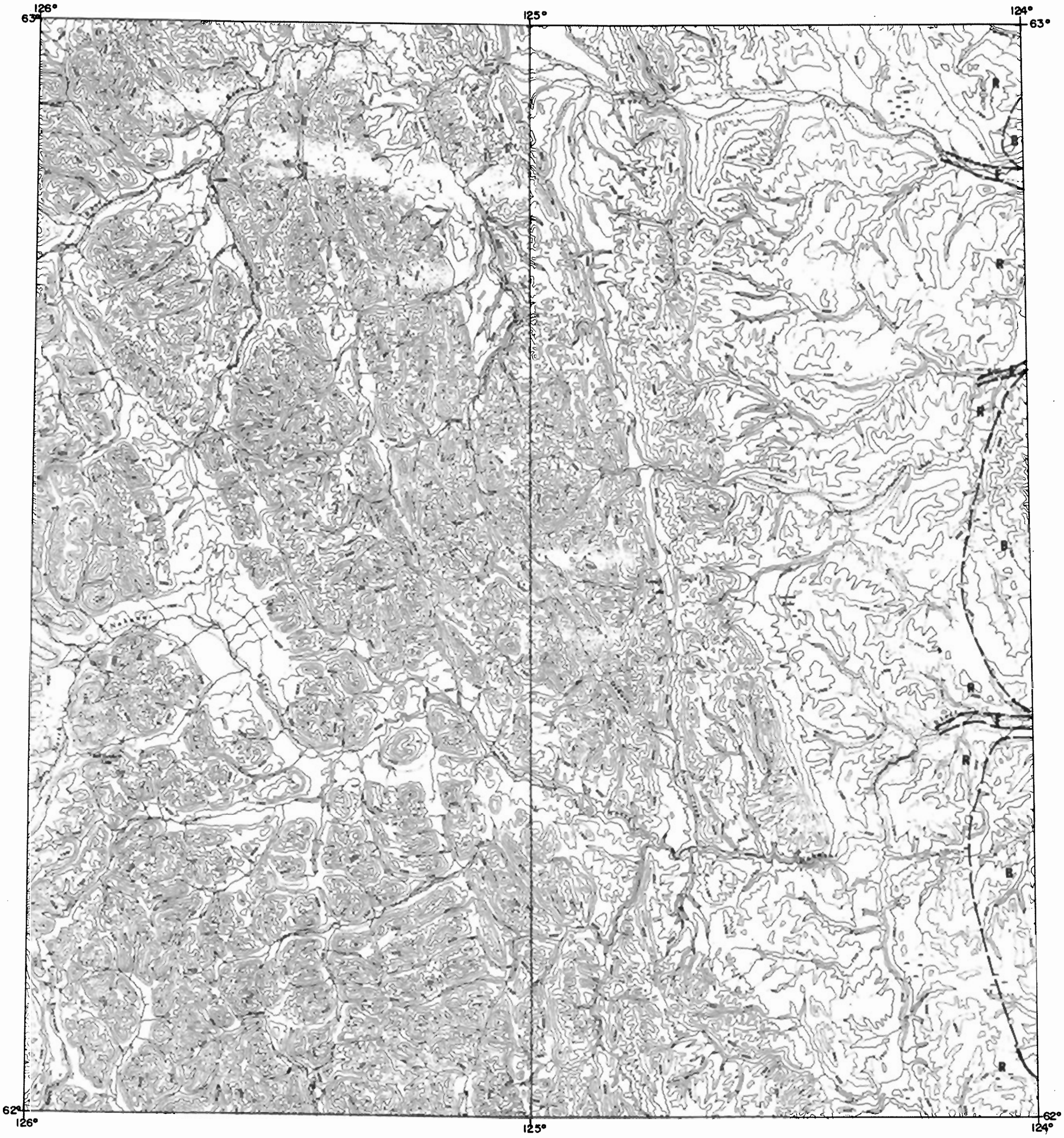
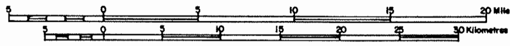
Map 4



ROOT RIVER

95K

RECONNAISSANCE SURFICIAL GEOLOGY MAP



LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT Mc PHERSON, NWT

RECENT

NONGLACIAL DEPOSITS

PEATLAND ENVIRONMENT

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FLUVIAL ENVIRONMENT

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EOLIAN ENVIRONMENT

W	DUNE DEPOSITS: Mainly fine sand, silty fine sand

PLEISTOCENE

GLACIAL-DRIFT DEPOSITS

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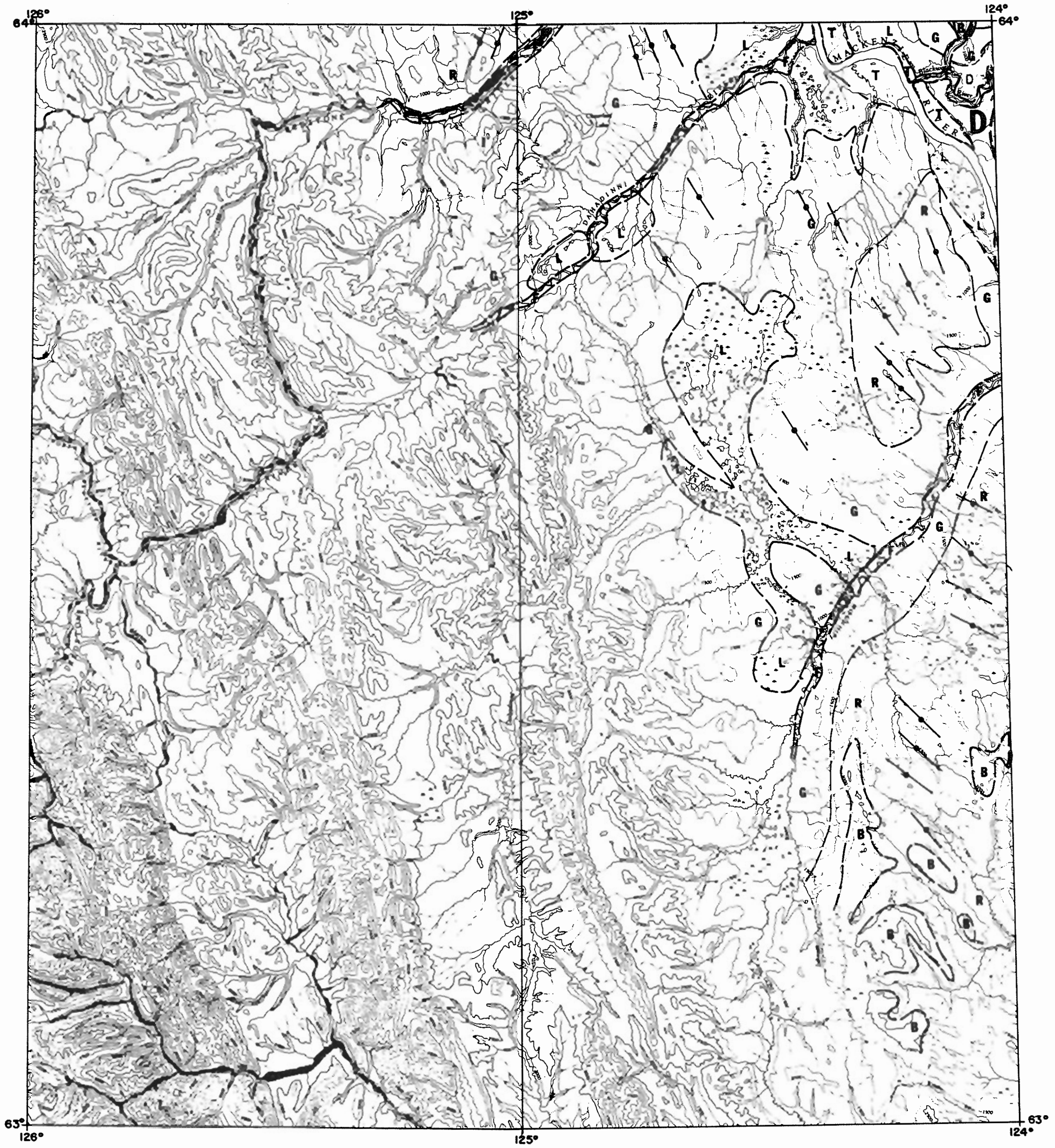
C	Rock glaciers, talus, and thick colluvium on steep slopes
S	Springs

NOTE: The same legend is shown on all map sheets; but rarely are all map-units used and shown on each individual sheet

Map 5



DAHADINNI RIVER

95N

RECONNAISSANCE SURFICIAL GEOLOGY MAP

LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT Mc PHERSON , NWT

RECENT

NONGLACIAL DEPOSITS

PEATLAND ENVIRONMENT

⫛	ORGANIC DEPOSITS: Mainly peat, some muck; fens, bogs, marshes, and swamps

FLUVIAL ENVIRONMENT

F	FLOODPLAIN DEPOSITS: Mainly exposed gravel and sand, with thin topstratum of silt and fine sand on the wooded inactive portions of floodplains; the Mackenzie River modern floodplain and up to 5 miles in the lower reaches of flat-gradient tributary rivers consist mainly of stratified silt and fine sand, with minor clay, gravel, and stones
A	ALLUVIAL FAN AND CONE DEPOSITS: Mainly poorly sorted silty gravel and sand; lesser silt, clay and cobbles
E	ESTUARINE DELTAIC AND FLOODPLAIN DEPOSITS: Mainly complexly intergrading and interfingering silt, clay, fine sand, and peat with commonly a thick peat cover

EOLIAN ENVIRONMENT

W	DUNE DEPOSITS: Mainly fine sand, silty fine sand

PLEISTOCENE

' GLACIAL-DRIFT DEPOSITS

GLACIOLACUSTRINE ENVIRONMENT

D	LAKE-DELTAIC DEPOSITS (includes widely scattered sand dunes): Mainly stratified silty fine sand, fine sand, silt, and clayey silt deposited in nearshore lake waters and where major meltwater streams entered temporary glacial lakes; somewhat less extensive thermokarst development that map-unit L
L	LACUSTRINE DEPOSITS: Mainly stratified and massive silt, silty clay, clayey silt, and minor fine sand deposited in deeper offshore waters; this map-unit L sometimes overlies map-unit D; extensive thermokarst development in poorly drained, ponded water areas
V	LACUSTRINE VENEER OVER MORAINE DEPOSITS: Mainly silt, clayey silt, and silty clay over till

GLACIOFLUVIAL ENVIRONMENT

T	HIGH TERRACE DEPOSITS: Mainly sand with some gravelly beds; mostly with a silt and surficial peat cover up to 15 feet thick locally
O	OUTWASH PLAIN, OUTWASH DELTA, VALLEY TRAIN DEPOSITS--LOCALLY CHANNELLED AND KETTLED: Mainly stratified fine to coarse sand, gravelly sand, gravel; minor cobbles and silt
I	ICE-CONTACT FEATURES INCLUDING ESKERS, CREVASSE FILLINGS, KAMES, KAME TERRACES, KAME DELTAS DEPOSITS: Mainly sand and gravel cored ridges and mounds; with minor silt, till, and boulders occurring as inclusions and overburden

GLACIAL ENVIRONMENT

H	HUMMOCKY MORAINE DEPOSITS (includes a thin cover of fine-grained waterlaid and windlaid deposits locally as well as fine ponded and slopewash sediments beneath partly peat-filled deep depressions): Mainly till
G	GROUND MORAINE DEPOSITS, GENERALLY SHOWING STREAMLINED FORMS (includes thin cover of silty to sandy slopewash deposits locally): Mainly clay-rich till over shale strata, sandy till over sandstone strata, and silty till over carbonate rocks; peat deposits on gentle slopes and in undrained hollows; some V below 600'
J	GROUND MORAINE DEPOSITS WITH DEEPER SILTY TO SANDY SLOPEWASH OVERLAY (Classic areas are the slopes of the Ebbutt and Martin Hills and the Horn Plateau): Mainly silt and sand over till
N	BEVELLED TILL DEPOSITS (includes pockets of fine waterlaid material and peat): Mostly a lag concentrate of boulders and cobbles with frequent patches and pockets of sand and gravel, waterlaid silt and clay, and peat

BEDROCK-DOMINATED TERRAIN

B	WIDELY EXPOSED BEDROCK TERRAIN: Mainly exposed bedrock and bedrock with a thin, discontinuous veneer of drift; often having rugged topography; includes very rugged eroded topography
R	VENEERED BEDROCK-DOMINATED RELIEF: Mainly a thin, but variable and locally thick, cover of drift; chiefly till

M	Meltwater and spillway channels
AS	Abandoned strandlines; includes minor raised beaches
○**K** ○	Karstic topography; sinkholes in soluble rocks (gypsum, anhydrite, dolomite, limestone)
⟋	Ice-flow features; includes glacial grooves, glacial fluting, drumlinoid ridges, streamlined hills and ridges, drumlinized landscapes, crag-and-tail hills
C	Rock glaciers, talus, and thick colluvium on steep slopes
S	Springs

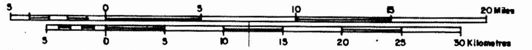
NOTE: The same legend is shown on all map sheets; but rarely are all map-units used and shown on each individual sheet

Map 6

WRIGLEY

950

RECONNAISSANCE SURFICIAL GEOLOGY MAP



LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT Mc PHERSON , NWT

RECENT

NONGLACIAL DEPOSITS

PEATLAND ENVIRONMENT

ψ	ORGANIC DEPOSITS: Mainly peat ,some muck ; fens,bogs, marshes,and swamps

FLUVIAL ENVIRONMENT

F	FLOODPLAIN DEPOSITS: Mainly exposed gravel and sand, with thin topstratum of silt and fine sand on the wooded inactive portions of floodplains ; the Mackenzie River modern floodplain and up to 5 miles in the lower reaches of flat-gradient tributary rivers consist mainly of stratified silt and fine sand ,with minor clay, gravel, and stones
A	ALLUVIAL FAN AND CONE DEPOSITS: Mainly poorly sorted silty gravel and sand; lesser silt, clay and cobbles
E	ESTUARINE DELTAIC AND FLOODPLAIN DEPOSITS: Mainly complexly intergrading and interfingering silt, clay, fine sand ,and peat with commonly a thick peat cover

EOLIAN ENVIRONMENT

W	DUNE DEPOSITS: Mainly fine sand, silty fine sand

PLEISTOCENE

GLACIAL-DRIFT DEPOSITS

GLACIOLACUSTRINE ENVIRONMENT

D	LAKE-DELTAIC DEPOSITS (includes widely scattered sand dunes): Mainly stratified silty fine sand, fine sand, silt, and clayey silt deposited in nearshore lake waters and where major meltwater streams entered temporary glacial lakes; somewhat less extensive thermokarst development that map-unit L
L	LACUSTRINE DEPOSITS: Mainly stratified and massive silt , silty clay ,clayey silt, and minor fine sand deposited in deeper offshore waters ; this map-unit L sometimes overlies map-unit D ; extensive thermokarst development in poorly drained , ponded water areas
V	LACUSTRINE VENEER OVER MORAINE DEPOSITS: Mainly silt, clayey silt,and silty clay over till

GLACIOFLUVIAL ENVIRONMENT

T	HIGH TERRACE DEPOSITS: Mainly sand with some gravelly beds ; mostly with a silt and surficial peat cover up to 15 feet thick locally
O	OUTWASH PLAIN, OUTWASH DELTA, VALLEY TRAIN DEPOSITS--LOCALLY CHANNELLED AND KETTLED: Mainly stratified fine to coarse sand , gravelly sand, gravel ; minor cobbles and silt
I	ICE-CONTACT FEATURES INCLUDING ESKERS, CREVASSE FILLINGS, KAMES, KAME TERRACES, KAME DELTAS DEPOSITS: Mainly sand and gravel cored ridges and mounds ; with minor silt , till, and boulders occurring as inclusions and over-burden

GLACIAL ENVIRONMENT

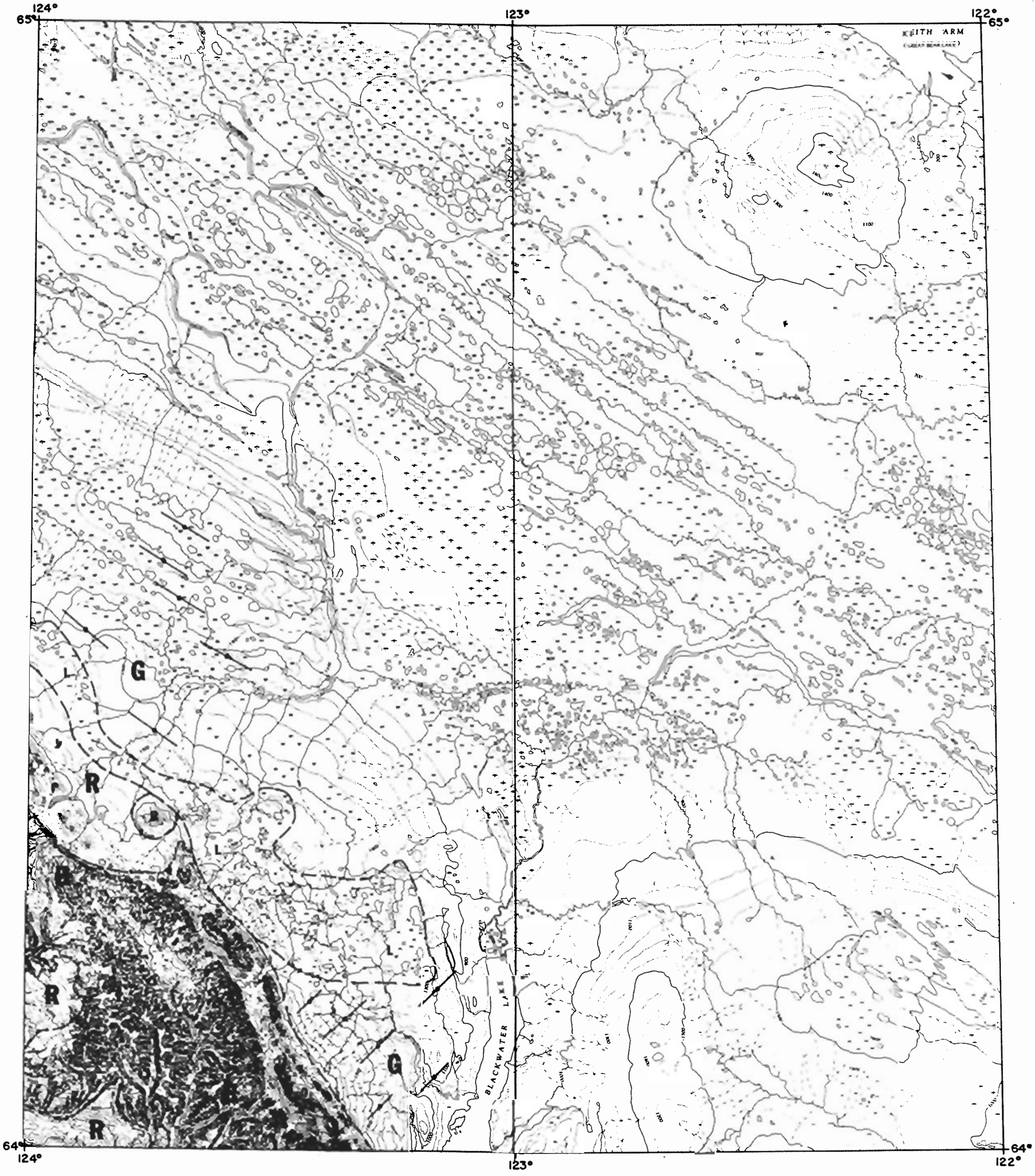
H	HUMMOCKY MORAINE DEPOSITS (includes a thin cover of fine-grained waterlaid and windlaid deposits locally as well as fine ponded and slopewash sediments beneath partly peat-filled deep depressions): Mainly till
G	GROUND MORAINE DEPOSITS, GENERALLY SHOWING STREAMLINED FORMS :(includes thin cover of silty to sandy slopewash deposits locally): Mainly clay-rich till over shale strata, sandy till over sandstone strata ,and silty till over carbonate rocks ; peat deposits on gentle slopes and in undrained hollows; same Vbelow600'
J	GROUND MORAINE DEPOSITS WITH DEEPER SILTY TO SANDY SLOPEWASH OVERLAY(Classic areas are the slopes of the Ebbutt and Martin Hills and the Horn Plateau):Mainly silt and sand over till
N	BEVELLED TILL DEPOSITS (includes pockets of fine waterlaid material and peat): Mostly a lag concentrate of boulders and cobbles with frequent patches and pockets of sand and gravel , waterlaid silt and clay, and peat

BEDROCK-DOMINATED TERRAIN

B	WIDELY EXPOSED BEDROCK TERRAIN: Mainly exposed bedrock and bedrock with a thin, discontinuous veneer of drift ; often having rugged topography ; includes very rugged eroded topography
R	VENEERED BEDROCK - DOMINATED RELIEF: Mainly a thin, but variable and locally thick, cover of drift ; chiefly till
M	Meltwater and spillway channels
AS	Abandoned strandlines ; includes minor raised beaches
○K○	Karstic topography ; sinkholes in soluble rocks (gypsum , anhydrite , dolomite , limestone)
⟋	Ice-flow features ; includes glacial grooves , glacial fluting , drumlinoid ridges , streamlined hills and ridges , drumlinized landscapes, crag-and-tail hills
C	Rock glaciers , talus ,and thick colluvium on steep slopes
S	Springs

NOTE : The same legend is shown on all map sheets ; but rarely are all map-units used and shown on each individual sheet

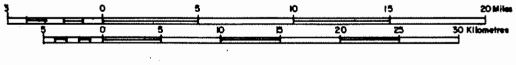
Map 7



BLACK WATER LAKE

96 B

RECONNAISSANCE SURFICIAL GEOLOGY MAP



LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT Mc PHERSON , NWT

RECENT

NONGLACIAL DEPOSITS

PEATLAND ENVIRONMENT

ѱ ORGANIC DEPOSITS: Mainly peat, some muck; fens, bogs, marshes, and swamps

FLUVIAL ENVIRONMENT

F FLOODPLAIN DEPOSITS: Mainly exposed gravel and sand, with thin topstratum of silt and fine sand on the wooded inactive portions of floodplains; the Mackenzie River modern floodplain and up to 5 miles in the lower reaches of flat-gradient tributary rivers consist mainly of stratified silt and fine sand, with minor clay, gravel, and stones

A ALLUVIAL FAN AND CONE DEPOSITS: Mainly poorly sorted silty gravel and sand; lesser silt, clay and cobbles

E ESTUARINE DELTAIC AND FLOODPLAIN DEPOSITS: Mainly complexly intergrading and interfingering silt, clay, fine sand, and peat with commonly a thick peat cover

EOLIAN ENVIRONMENT

W DUNE DEPOSITS: Mainly fine sand, silty fine sand

PLEISTOCENE

GLACIAL-DRIFT DEPOSITS

GLACIOLACUSTRINE ENVIRONMENT

D LAKE-DELTAIC DEPOSITS (includes widely scattered sand dunes): Mainly stratified silty fine sand, fine sand, silt, and clayey silt deposited in nearshore lake waters and where major meltwater streams entered temporary glacial lakes; somewhat less extensive thermokarst development that map-unit L

L LACUSTRINE DEPOSITS: Mainly stratified and massive silt, silty clay, clayey silt, and minor fine sand deposited in deeper offshore waters; this map-unit L sometimes overlies map-unit D; extensive thermokarst development in poorly drained, ponded water areas

V LACUSTRINE VENEER OVER MORAINE DEPOSITS: Mainly silt, clayey silt, and silty clay over till

GLACIOFLUVIAL ENVIRONMENT

T HIGH TERRACE DEPOSITS: Mainly sand with some gravelly beds; mostly with a silt and surficial peat cover up to 15 feet thick locally

O OUTWASH PLAIN, OUTWASH DELTA, VALLEY TRAIN DEPOSITS--LOCALLY CHANNELLED AND KETTLED: Mainly stratified fine to coarse sand, gravelly sand, gravel; minor cobbles and silt

I ICE-CONTACT FEATURES INCLUDING ESKERS, CREVASSE FILLINGS, KAMES, KAME TERRACES, KAME DELTAS DEPOSITS: Mainly sand and gravel cored ridges and mounds; with minor silt, till, and boulders occurring as inclusions and over-burden

GLACIAL ENVIRONMENT

H HUMMOCKY MORAINE DEPOSITS (includes a thin cover of fine-grained waterlaid and windlaid deposits locally as well as fine ponded and slopewash sediments beneath partly peat-filled deep depressions): Mainly till

G GROUND MORAINE DEPOSITS, GENERALLY SHOWING STREAMLINED FORMS (includes thin cover of silty to sandy slopewash deposits locally): Mainly clay-rich till over shale strata, sandy till over sandstone strata, and silty till over carbonate rocks; peat deposits on gentle slopes and in undrained hollows, some V below 600'

J GROUND MORAINE DEPOSITS WITH DEEPER SILTY TO SANDY SLOPEWASH OVERLAY (Classic areas are the slopes of the Ebbutt and Martin Hills and the Horn Plateau): Mainly silt and sand over till

N BEVELLED TILL DEPOSITS (includes pockets of fine waterlaid material and peat): Mostly a lag concentrate of boulders and cobbles with frequent patches and pockets of sand and gravel, waterlaid silt and clay, and peat

BEDROCK-DOMINATED TERRAIN

B WIDELY EXPOSED BEDROCK TERRAIN: Mainly exposed bedrock and bedrock with a thin, discontinuous veneer of drift; often having rugged topography; includes very rugged eroded topography

R VENEERED BEDROCK-DOMINATED RELIEF: Mainly a thin, but variable and locally thick, cover of drift; chiefly till

M Meltwater and spillway channels

AS Abandoned strandlines; includes minor raised beaches

○K○ Karstic topography; sinkholes in soluble rocks (gypsum, anhydrite, dolomite, limestone)

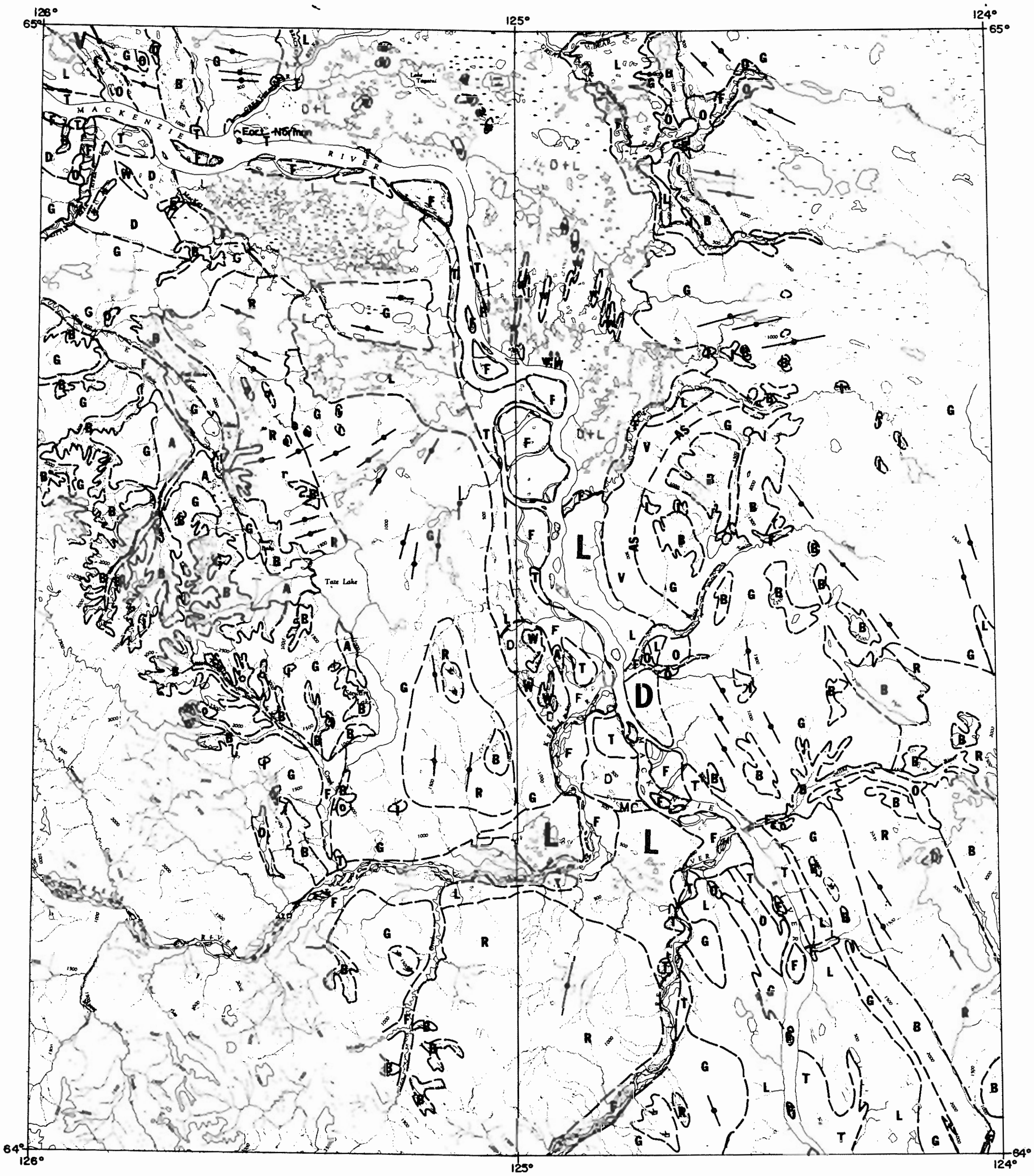
⟋ Ice-flow features; includes glacial grooves, glacial fluting, drumlinoid ridges, streamlined hills and ridges, drumlinized landscapes, crag-and-tail hills

C Rock glaciers, talus, and thick colluvium on steep slopes

S Springs

NOTE: The same legend is shown on all map sheets; but rarely are all map-units used and shown on each individual sheet

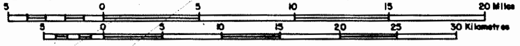
Map 8



FORT NORMAN

96C

RECONNAISSANCE SURFICIAL GEOLOGY MAP



LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT Mc PHERSON, NWT

RECENT

NONGLACIAL DEPOSITS

PEATLAND ENVIRONMENT

⩛	ORGANIC DEPOSITS: Mainly peat, some muck; fens, bogs, marshes, and swamps

FLUVIAL ENVIRONMENT

F	FLOODPLAIN DEPOSITS: Mainly exposed gravel and sand, with thin topstratum of silt and fine sand on the wooded inactive portions of floodplains; the Mackenzie River modern floodplain and up to 5 miles in the lower reaches of flat-gradient tributary rivers consist mainly of stratified silt and fine sand, with minor clay, gravel, and stones
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E	ESTUARINE DELTAIC AND FLOODPLAIN DEPOSITS: Mainly complexly intergrading and interfingering silt, clay, fine sand, and peat with commonly a thick peat cover

EOLIAN ENVIRONMENT

W	DUNE DEPOSITS: Mainly fine sand, silty fine sand

PLEISTOCENE

GLACIAL-DRIFT DEPOSITS

GLACIOLACUSTRINE ENVIRONMENT

D	LAKE-DELTAIC DEPOSITS (includes widely scattered sand dunes): Mainly stratified silty fine sand, fine sand, silt, and clayey silt deposited in nearshore lake waters and where major meltwater streams entered temporary glacial lakes; somewhat less extensive thermokarst development that map-unit L
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V	LACUSTRINE VENEER OVER MORAINE DEPOSITS: Mainly silt, clayey silt, and silty clay over till

GLACIOFLUVIAL ENVIRONMENT

T	HIGH TERRACE DEPOSITS: Mainly sand with some gravelly beds; mostly with a silt and surficial peat cover up to 15 feet thick locally
O	OUTWASH PLAIN, OUTWASH DELTA, VALLEY TRAIN DEPOSITS--LOCALLY CHANNELLED AND KETTLED: Mainly stratified fine to coarse sand, gravelly sand, gravel; minor cobbles and silt
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GLACIAL ENVIRONMENT

H	HUMMOCKY MORAINE DEPOSITS (includes a thin cover of fine-grained waterlaid and windlaid deposits locally as well as fine ponded and slopewash sediments beneath partly peat-filled deep depressions): Mainly till
G	GROUND MORAINE DEPOSITS, GENERALLY SHOWING STREAMLINED FORMS: (includes thin cover of silty to sandy slopewash deposits locally): Mainly clay-rich till over shale strata, sandy till over sandstone strata, and silty till over carbonate rocks; peat deposits on gentle slopes and in undrained hollows; some V below 600'
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AS	Abandoned strandlines; includes minor raised beaches
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⟋	Ice-flow features; includes glacial grooves, glacial fluting, drumlinoid ridges, streamlined hills and ridges, drumlinized landscapes, crag-and-tail hills
C	Rock glaciers, talus, and thick colluvium on steep slopes
S	Springs

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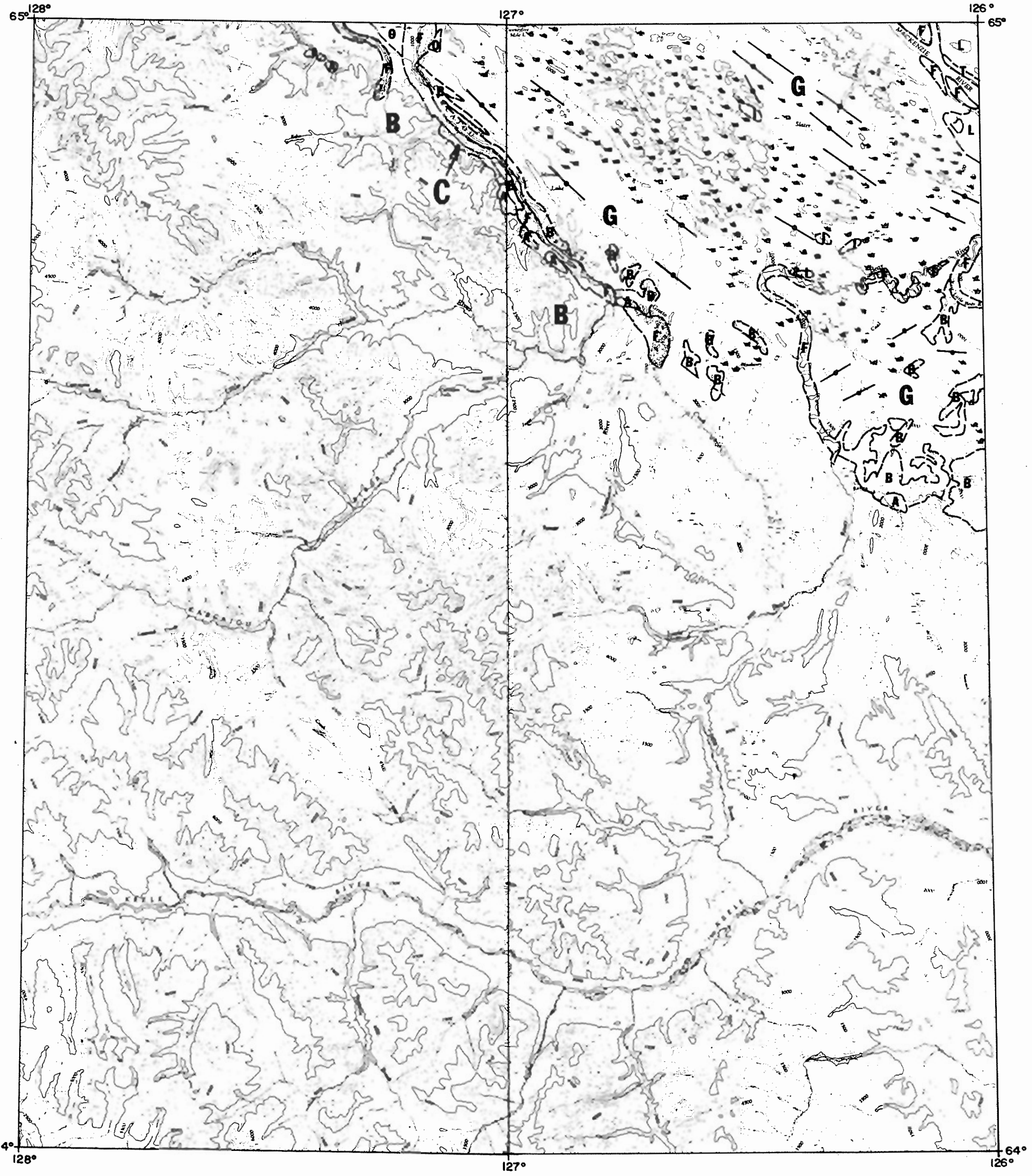
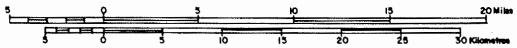
Map 9



CARCAJOU CANYON

96D

RECONNAISSANCE SURFICIAL GEOLOGY MAP



LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT Mc PHERSON, NWT

RECENT

NONGLACIAL DEPOSITS

PEATLAND ENVIRONMENT

⚲	ORGANIC DEPOSITS: Mainly peat, some muck; fens, bogs, marshes, and swamps

FLUVIAL ENVIRONMENT

F	FLOODPLAIN DEPOSITS: Mainly exposed gravel and sand, with thin topstratum of silt and fine sand on the wooded inactive portions of floodplains; the Mackenzie River modern floodplain and up to 5 miles in the lower reaches of flat-gradient tributary rivers consist mainly of stratified silt and fine sand, with minor clay, gravel, and stones
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EOLIAN ENVIRONMENT

W	DUNE DEPOSITS: Mainly fine sand, silty fine sand

PLEISTOCENE

GLACIAL-DRIFT DEPOSITS

GLACIOLACUSTRINE ENVIRONMENT

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GLACIOFLUVIAL ENVIRONMENT

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GLACIAL ENVIRONMENT

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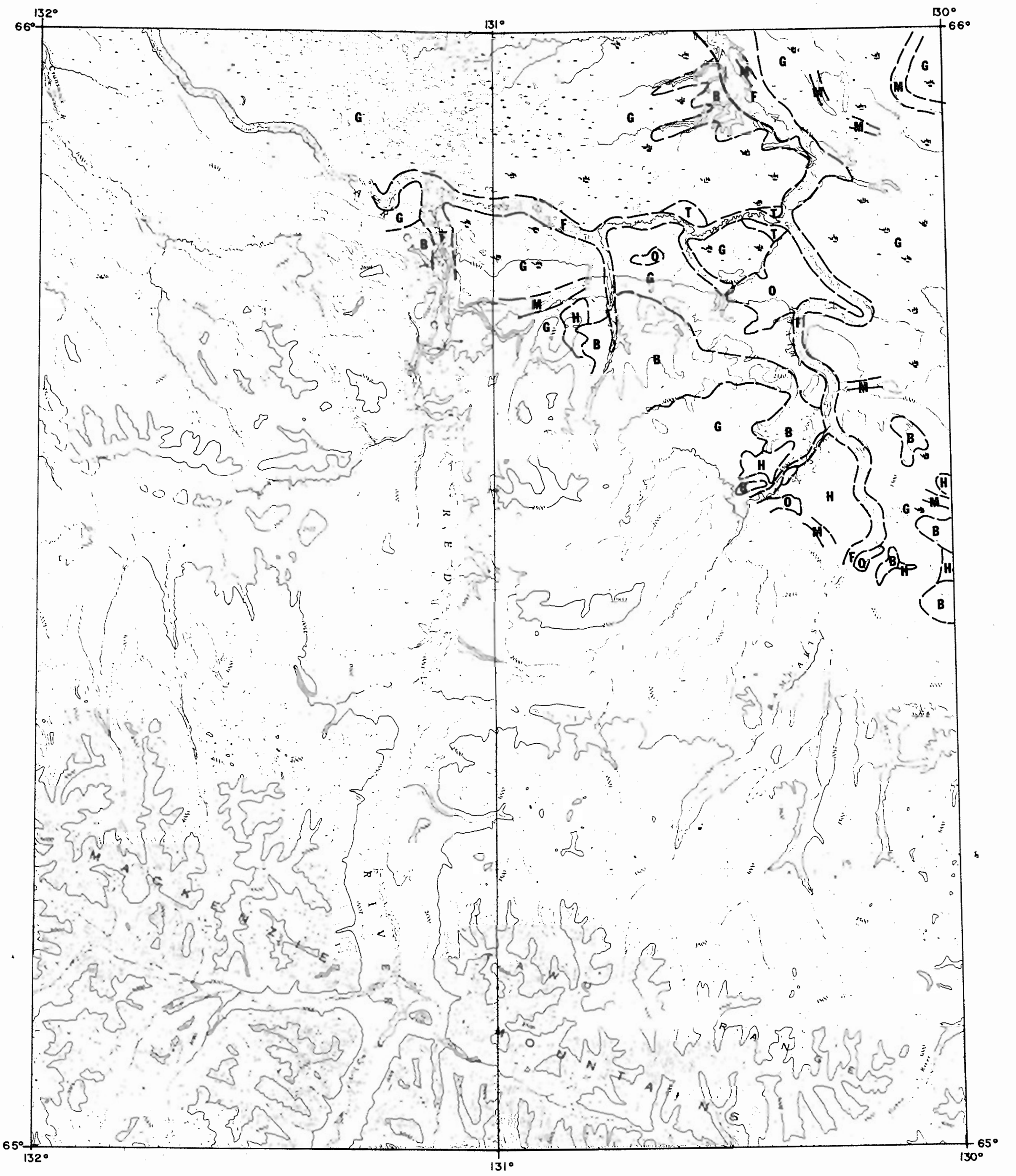
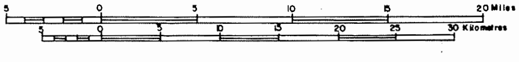


UPPER RAMPARTS RIVER

106 G

RECONNAISSANCE SURFICIAL GEOLOGY MAP



LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT Mc PHERSON, NWT

RECENT

NONGLACIAL DEPOSITS

PEATLAND ENVIRONMENT

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FLUVIAL ENVIRONMENT

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EOLIAN ENVIRONMENT

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PLEISTOCENE

GLACIAL-DRIFT DEPOSITS

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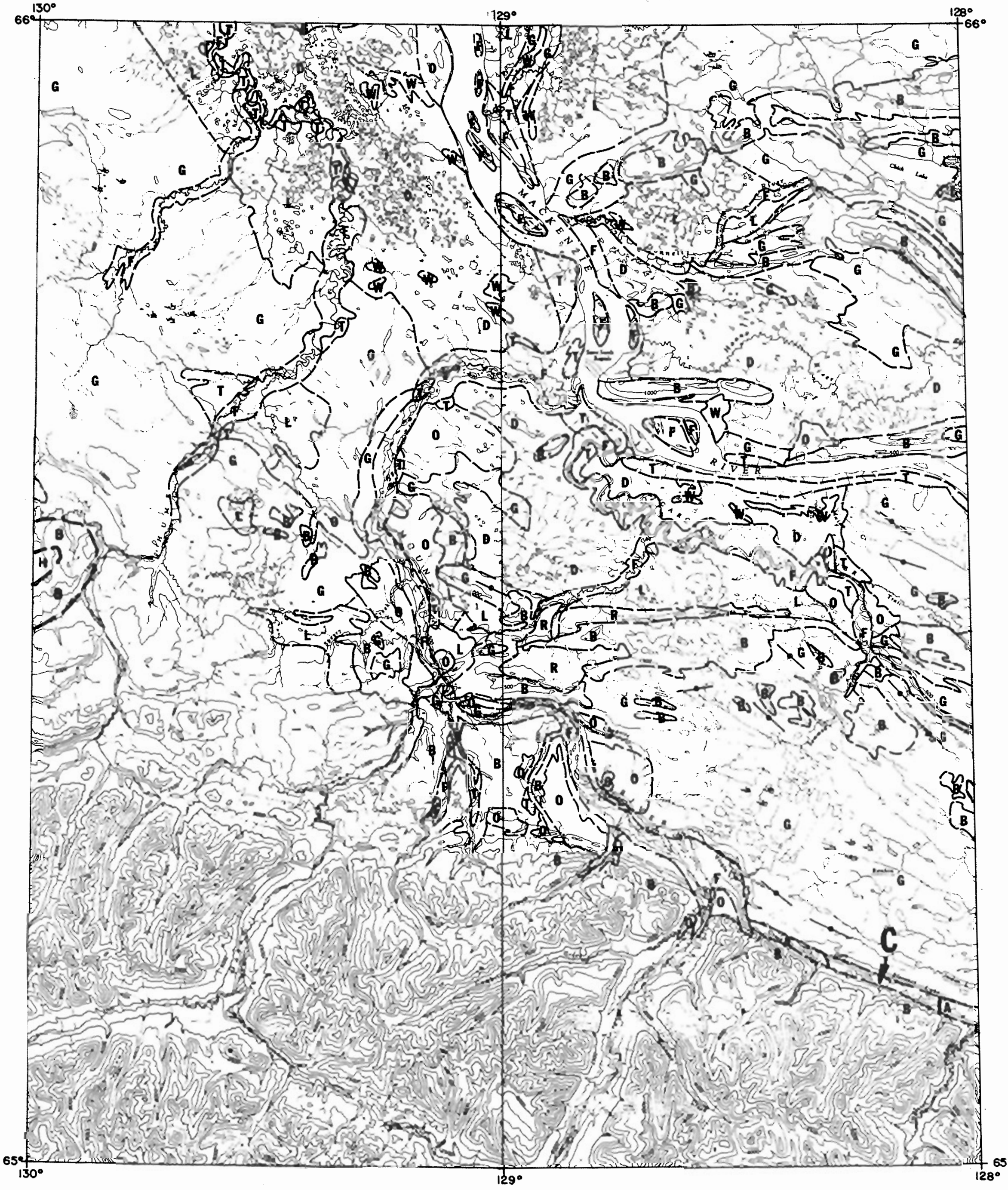
M	Meltwater and spillway channels
AS	Abandoned strandlines; includes minor raised beaches
○**K**○	Karstic topography; sinkholes in soluble rocks (gypsum, anhydrite, dolomite, limestone)
⟋	Ice-flow features; includes glacial grooves, glacial fluting, drumlinoid ridges, streamlined hills and ridges, drumlinized landscapes, crag-and-tail hills
C	Rock glaciers, talus, and thick colluvium on steep slopes
S	Springs

NOTE: The same legend is shown on all map sheets; but rarely are all map-units used and shown on each individual sheet



SANS SAULT RAPIDS

106 H

RECONNAISSANCE SURFICIAL GEOLOGY MAP

LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT Mc PHERSON, NWT

RECENT

NONGLACIAL DEPOSITS

PEATLAND ENVIRONMENT

⺌	ORGANIC DEPOSITS: Mainly peat, some muck; fens, bogs, marshes, and swamps

FLUVIAL ENVIRONMENT

F	FLOODPLAIN DEPOSITS: Mainly exposed gravel and sand, with thin topstratum of silt and fine sand on the wooded inactive portions of floodplains; the Mackenzie River modern floodplain and up to 5 miles in the lower reaches of flat-gradient tributary rivers consist mainly of stratified silt and fine sand, with minor clay, gravel, and stones
A	ALLUVIAL FAN AND CONE DEPOSITS: Mainly poorly sorted silty gravel and sand; lesser silt, clay and cobbles
E	ESTUARINE DELTAIC AND FLOODPLAIN DEPOSITS: Mainly complexly intergrading and interfingering silt, clay, fine sand, and peat with commonly a thick peat cover

EOLIAN ENVIRONMENT

W	DUNE DEPOSITS: Mainly fine sand, silty fine sand

PLEISTOCENE

GLACIAL-DRIFT DEPOSITS

GLACIOLACUSTRINE ENVIRONMENT

D	LAKE-DELTAIC DEPOSITS (includes widely scattered sand dunes): Mainly stratified silty fine sand, fine sand, silt, and clayey silt deposited in nearshore lake waters and where major meltwater streams entered temporary glacial lakes; somewhat less extensive thermokarst development that map-unit L
L	LACUSTRINE DEPOSITS: Mainly stratified and massive silt, silty clay, clayey silt, and minor fine sand deposited in deeper offshore waters; this map-unit L sometimes overlies map-unit D; extensive thermokarst development in poorly drained, ponded water areas
V	LACUSTRINE VENEER OVER MORAINE DEPOSITS: Mainly silt, clayey silt, and silty clay over till

GLACIOFLUVIAL ENVIRONMENT

T	HIGH TERRACE DEPOSITS: Mainly sand with some gravelly beds; mostly with a silt and surficial peat cover up to 15 feet thick locally
O	OUTWASH PLAIN, OUTWASH DELTA, VALLEY TRAIN DEPOSITS--LOCALLY CHANNELLED AND KETTLED: Mainly stratified fine to coarse sand, gravelly sand, gravel; minor cobbles and silt
I	ICE-CONTACT FEATURES INCLUDING ESKERS, CREVASSE FILLINGS, KAMES, KAME TERRACES, KAME DELTAS DEPOSITS: Mainly sand and gravel cored ridges and mounds; with minor silt, till, and boulders occurring as inclusions and overburden

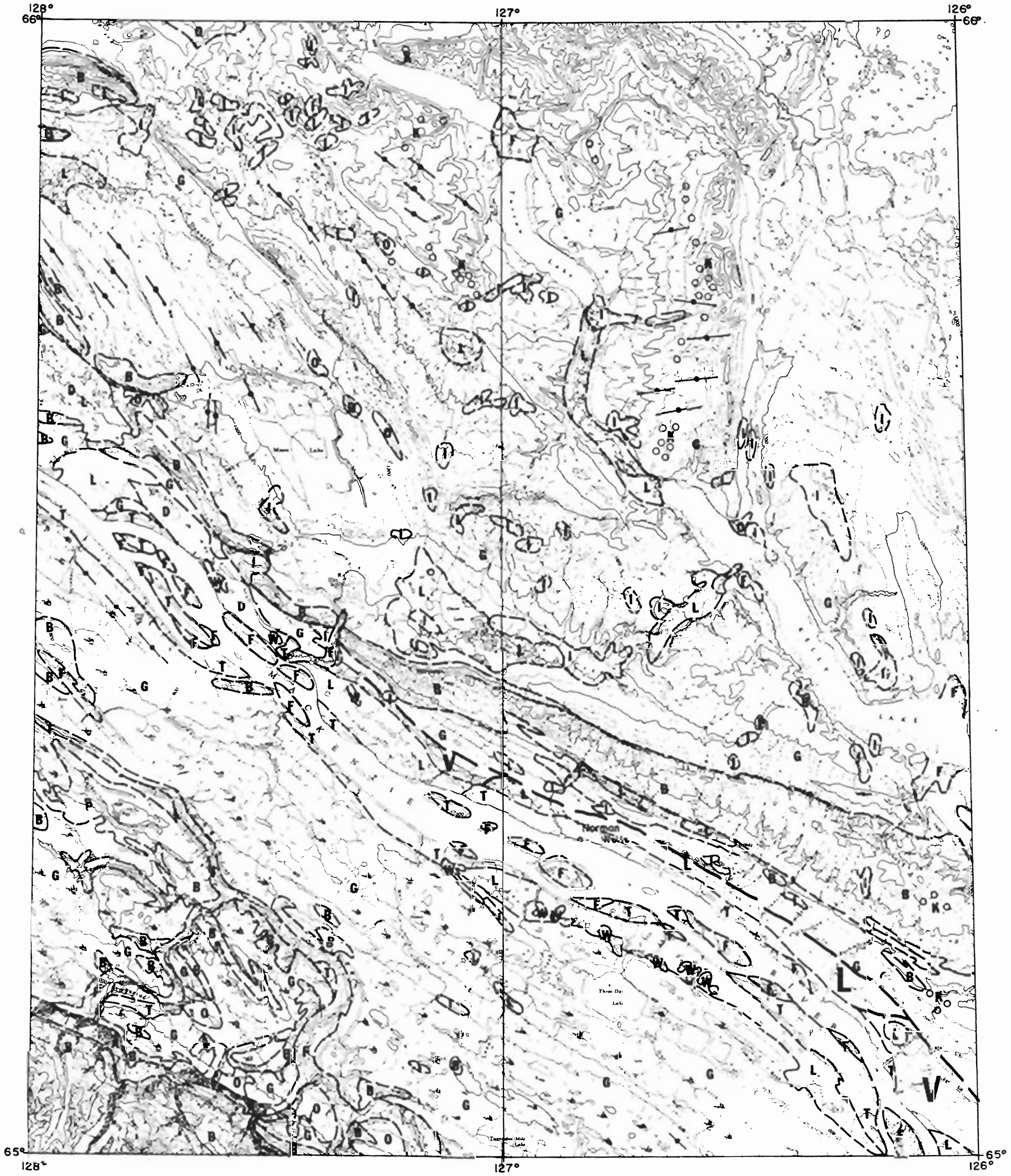
GLACIAL ENVIRONMENT

H	HUMMOCKY MORAINE DEPOSITS (includes a thin cover of fine-grained waterlaid and windlaid deposits locally as well as fine ponded and slopewash sediments beneath partly peat-filled deep depressions): Mainly till
G	GROUND MORAINE DEPOSITS, GENERALLY SHOWING STREAMLINED FORMS: (includes thin cover of silty to sandy slopewash deposits locally): Mainly clay-rich till over shale strata, sandy till over sandstone strata, and silty till over carbonate rocks; peat deposits on gentle slopes and in undrained hollows, some V below 600'
J	GROUND MORAINE DEPOSITS WITH DEEPER SILTY TO SANDY SLOPEWASH OVERLAY (Classic areas are the slopes of the Ebbutt and Martin Hills and the Horn Plateau): Mainly silt and sand over till
N	BEVELLED TILL DEPOSITS (includes pockets of fine waterlaid material and peat): Mostly a lag concentrate of boulders and cobbles with frequent patches and pockets of sand and gravel, waterlaid silt and clay, and peat

BEDROCK-DOMINATED TERRAIN

B	WIDELY EXPOSED BEDROCK TERRAIN: Mainly exposed bedrock and bedrock with a thin, discontinuous veneer of drift; often having rugged topography; includes very rugged eroded topography
R	VENEERED BEDROCK-DOMINATED RELIEF: Mainly a thin, but variable and locally thick, cover of drift; chiefly till
M	Meltwater and spillway channels
AS	Abandoned strandlines; includes minor raised beaches
○K○	Karstic topography; sinkholes in soluble rocks (gypsum, anhydrite, dolomite, limestone)
⟋	Ice-flow features; includes glacial grooves, glacial fluting, drumlinoid ridges, streamlined hills and ridges, drumlinized landscapes, crag-and-tail hills
C	Rock glaciers, talus, and thick colluvium on steep slopes
S	Springs

NOTE: The same legend is shown on all map sheets; but rarely are all map-units used and shown on each individual sheet



NORMAN WELLS

96 E

RECONNAISSANCE SURFICIAL GEOLOGY MAP

LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT Mc PHERSON , NWT

RECENT

NONGLACIAL DEPOSITS

PEATLAND ENVIRONMENT

	ORGANIC DEPOSITS: Mainly peat , some muck ; fens,bogs, marshes, and swamps

FLUVIAL ENVIRONMENT

F	FLOODPLAIN DEPOSITS: Mainly exposed gravel and sand, with thin topstratum of silt and fine sand on the wooded inactive portions of floodplains ; the Mackenzie River modern floodplain and up to 5 miles in the lower reaches of flat-gradient tributary rivers consist mainly of stratified silt and fine sand , with minor clay, gravel, and stones
A	ALLUVIAL FAN AND CONE DEPOSITS: Mainly poorly sorted silty gravel and sand; lesser silt, clay and cobbles
E	ESTUARINE DELTAIC AND FLOODPLAIN DEPOSITS: Mainly complexly intergrading and interfingering silt, clay, fine sand, and peat with commonly a thick peat cover

EOLIAN ENVIRONMENT

W	DUNE DEPOSITS: Mainly fine sand, silty fine sand

PLEISTOCENE

GLACIAL-DRIFT DEPOSITS

GLACIOLACUSTRINE ENVIRONMENT

D	LAKE-DELTAIC DEPOSITS (includes widely scattered sand dunes): Mainly stratified silty fine sand, fine sand, silt, and clayey silt deposited in nearshore lake waters and where major meltwater streams entered temporary glacial lakes; somewhat less extensive thermokarst development that map-unit L
L	LACUSTRINE DEPOSITS: Mainly stratified and massive silt , silty clay , clayey silt, and minor fine sand deposited in deeper offshore waters ; this map-unit L sometimes overlies map-unit D ; extensive thermokarst development in poorly drained, ponded water areas
V	LACUSTRINE VENEER OVER MORAINE DEPOSITS: Mainly silt, clayey silt, and silty clay over till

GLACIOFLUVIAL ENVIRONMENT

T	HIGH TERRACE DEPOSITS: Mainly sand with some gravelly beds ; mostly with a silt and surficial peat cover up to 15 feet thick locally
O	OUTWASH PLAIN, OUTWASH DELTA , VALLEY TRAIN DEPOSITS-- LOCALLY CHANNELLED AND KETTLED: Mainly stratified fine to coarse sand , gravelly sand, gravel; minor cobbles and silt
I	ICE-CONTACT FEATURES INCLUDING ESKERS, CREVASSE FILLINGS, KAMES, KAME TERRACES, KAME DELTAS DEPOSITS: Mainly sand and gravel cored ridges and mounds ; with minor silt , till, and boulders occurring as inclusions and over-burden

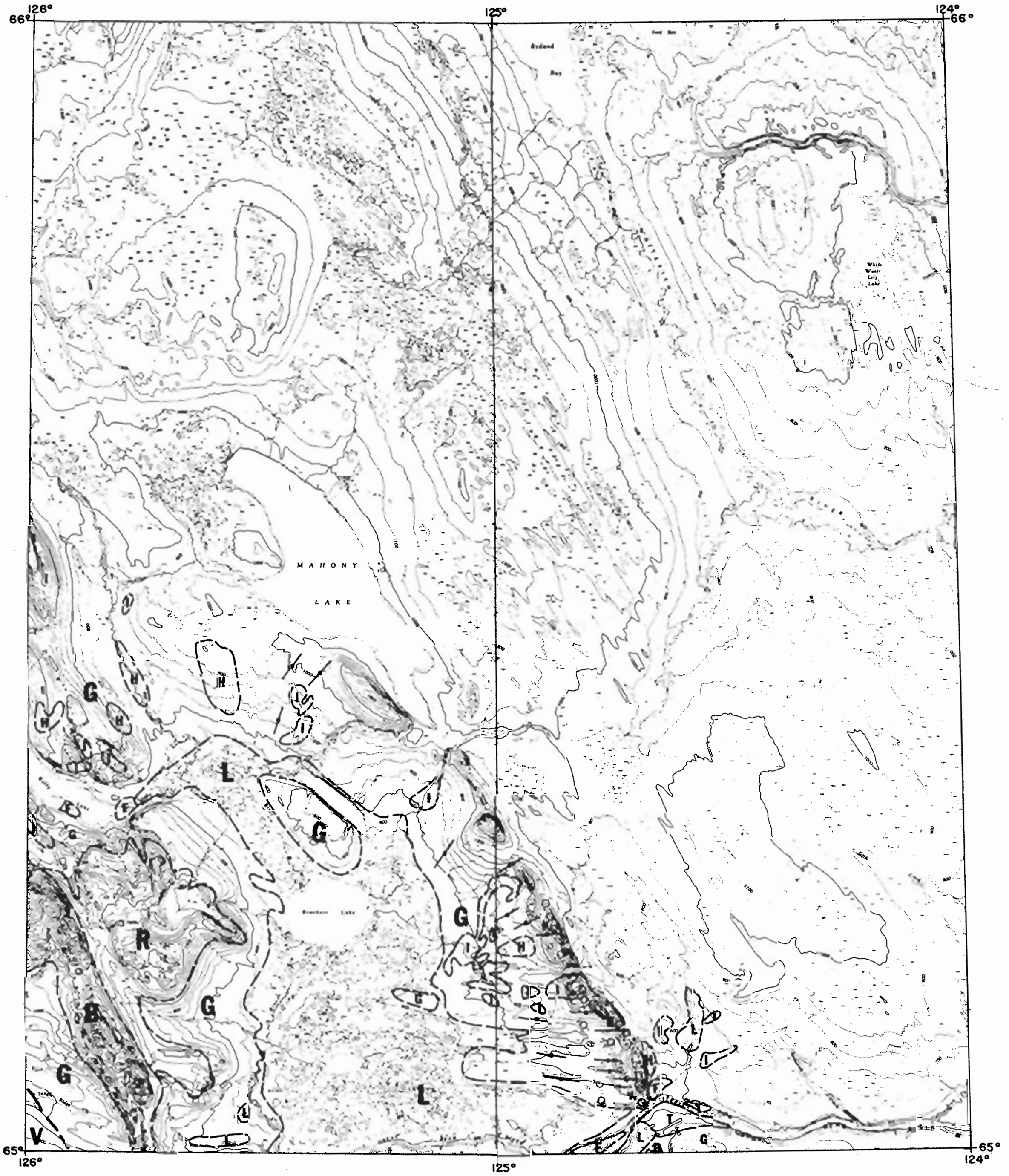
GLACIAL ENVIRONMENT

H	HUMMOCKY MORAINE DEPOSITS (includes a thin cover of fine-grained waterlaid and windlaid deposits locally as well as fine ponded and slopewash sediments beneath partly peat-filled deep depressions): Mainly till
G	GROUND MORAINE DEPOSITS, GENERALLY SHOWING STREAMLINED FORMS :(includes thin cover of silty to sandy slopewash deposits locally): Mainly clay-rich till over shale strata, sandy till over sandstone strata, and silty till over carbonate rocks ; peat deposits on gentle slopes and in undrained hollows;**zone V below 600'**
J	GROUND MORAINE DEPOSITS WITH DEEPER SILTY TO SANDY SLOPEWASH OVERLAY(Classic areas are the slopes of the Ebbutt and Martin Hills and the Horn Plateau):Mainly silt and sand over till
N	BEVELLED TILL DEPOSITS (includes pockets of fine waterlaid material and peat): Mostly a lag concentrate of boulders and cobbles with frequent patches and pockets of sand and gravel, waterlaid silt and clay, and peat

BEDROCK-DOMINATED TERRAIN

B	WIDELY EXPOSED BEDROCK TERRAIN: Mainly exposed bedrock and bedrock with a thin, discontinuous veneer of drift ; often having rugged topography ; includes very rugged eroded topography
R	VENEERED BEDROCK-DOMINATED RELIEF: Mainly a thin, but variable and locally thick, cover of drift ; chiefly till
M	Meltwater and spillway channels
AS	Abandoned strandlines ; includes minor raised beaches
o**K** o	Karstic topography; sinkholes in soluble rocks (gypsum , anhydrite , dolomite , limestone)
⟋	Ice-flow features ; includes glacial grooves , glacial fluting , drumlinoid ridges , streamlined hills and ridges , drumlinized landscapes , crag-and-tail hills
C	Rock glaciers , talus , and thick colluvium on steep slopes
S	Springs

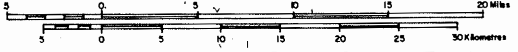
NOTE : The same legend is shown on all map sheets ; but rarely are all map-units used and shown on each individual sheet



MAHONY LAKE

96 F

RECONNAISSANCE SURFICIAL GEOLOGY MAP



LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT Mc PHERSON, NWT

RECENT

NONGLACIAL DEPOSITS

PEATLAND ENVIRONMENT

╨	ORGANIC DEPOSITS: Mainly peat, some muck; fens, bogs, marshes, and swamps

FLUVIAL ENVIRONMENT

F	FLOODPLAIN DEPOSITS: Mainly exposed gravel and sand, with thin topstratum of silt and fine sand on the wooded inactive portions of floodplains; the Mackenzie River modern floodplain and up to 5 miles in the lower reaches of flat-gradient tributary rivers consist mainly of stratified silt and fine sand, with minor clay, gravel, and stones
A	ALLUVIAL FAN AND CONE DEPOSITS: Mainly poorly sorted silty gravel and sand; lesser silt, clay and cobbles
E	ESTUARINE DELTAIC AND FLOODPLAIN DEPOSITS: Mainly complexly intergrading and interfingering silt, clay, fine sand, and peat with commonly a thick peat cover

EOLIAN ENVIRONMENT

W	DUNE DEPOSITS: Mainly fine sand, silty fine sand

PLEISTOCENE

GLACIAL-DRIFT DEPOSITS

GLACIOLACUSTRINE ENVIRONMENT

D	LAKE-DELTAIC DEPOSITS (includes widely scattered sand dunes): Mainly stratified silty fine sand, fine sand, silt, and clayey silt deposited in nearshore lake waters and where major meltwater streams entered temporary glacial lakes; somewhat less extensive thermokarst development that map-unit L
L	LACUSTRINE DEPOSITS: Mainly stratified and massive silt, silty clay, clayey silt, and minor fine sand deposited in deeper offshore waters; this map-unit L sometimes overlies map-unit D; extensive thermokarst development in poorly drained, ponded water areas
V	LACUSTRINE VENEER OVER MORAINE DEPOSITS: Mainly silt, clayey silt, and silty clay over till

GLACIOFLUVIAL ENVIRONMENT

T	HIGH TERRACE DEPOSITS: Mainly sand with some gravelly beds; mostly with a silt and surficial peat cover up to 15 feet thick locally
O	OUTWASH PLAIN, OUTWASH DELTA, VALLEY TRAIN DEPOSITS--LOCALLY CHANNELLED AND KETTLED: Mainly stratified fine to coarse sand, gravelly sand, gravel; minor cobbles and silt
I	ICE-CONTACT FEATURES INCLUDING ESKERS, CREVASSE FILLINGS, KAMES, KAME TERRACES, KAME DELTAS DEPOSITS: Mainly sand and gravel cored ridges and mounds; with minor silt, till, and boulders occurring as inclusions and overburden

GLACIAL ENVIRONMENT

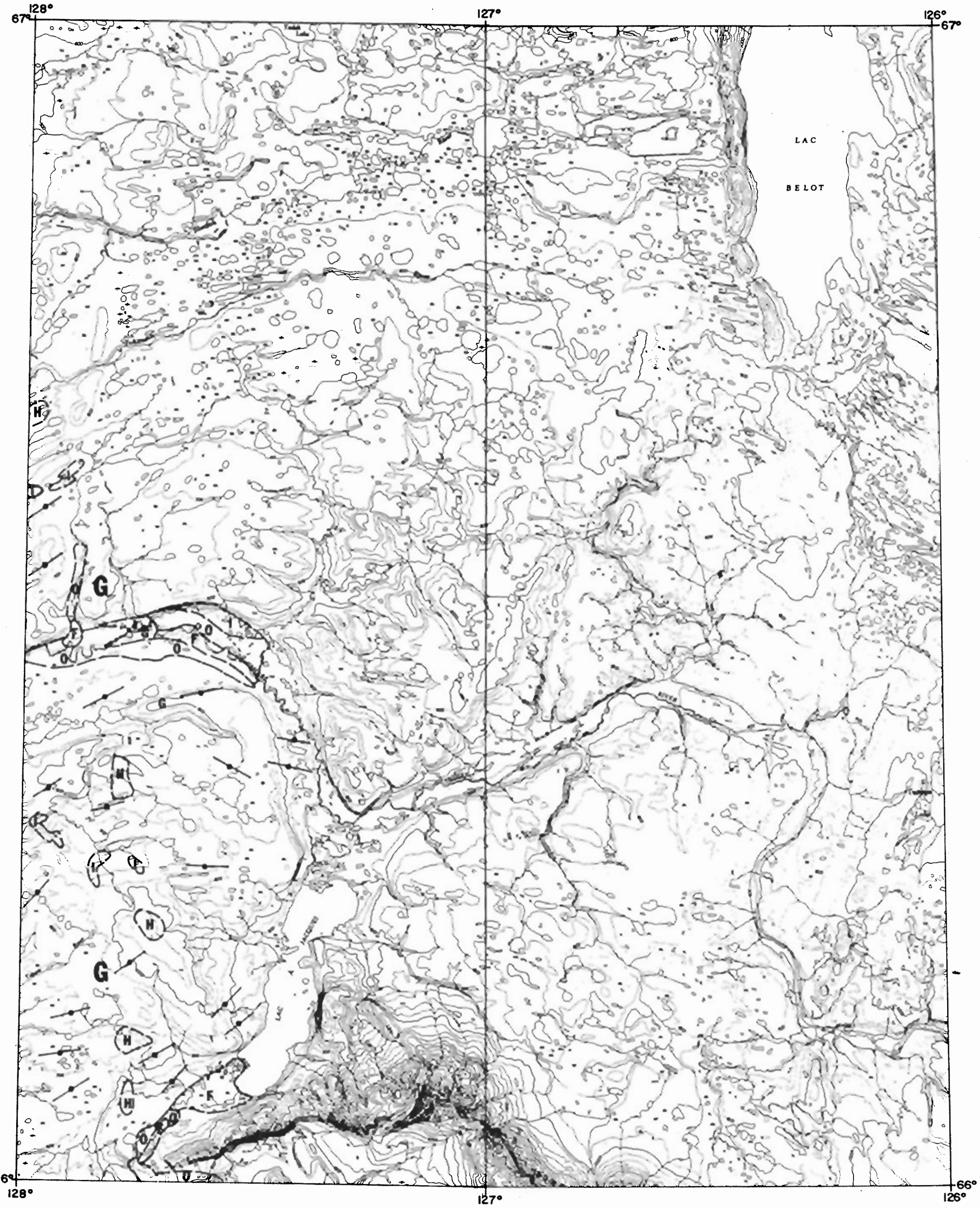
H	HUMMOCKY MORAINE DEPOSITS (includes a thin cover of fine-grained waterlaid and windlaid deposits locally as well as fine ponded and slopewash sediments beneath partly peat-filled deep depressions): Mainly till
G	GROUND MORAINE DEPOSITS, GENERALLY SHOWING STREAMLINED FORMS: (includes thin cover of silty to sandy slopewash deposits locally): Mainly clay-rich till over shale strata, sandy till over sandstone strata, and silty till over carbonate rocks; peat deposits on gentle slopes and in undrained hollows; **some V below 600'**
J	GROUND MORAINE DEPOSITS WITH DEEPER SILTY TO SANDY SLOPEWASH OVERLAY (Classic areas are the slopes of the Ebbutt and Martin Hills and the Horn Plateau): Mainly silt and sand over till
N	BEVELLED TILL DEPOSITS (includes pockets of fine waterlaid material and peat): Mostly a lag concentrate of boulders and cobbles with frequent patches and pockets of sand and gravel, waterlaid silt and clay, and peat

BEDROCK-DOMINATED TERRAIN

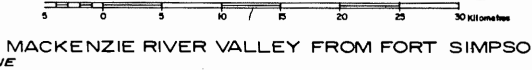
B	WIDELY EXPOSED BEDROCK TERRAIN: Mainly exposed bedrock and bedrock with a thin, discontinuous veneer of drift; often having rugged topography; includes very rugged eroded topography
R	VENEERED BEDROCK-DOMINATED RELIEF: Mainly a thin, but variable and locally thick, cover of drift; chiefly till

M	Meltwater and spillway channels
AS	Abandoned strandlines; includes minor raised beaches
○K ○	Karstic topography; sinkholes in soluble rocks (gypsum, anhydrite, dolomite, limestone)
⟋	Ice-flow features; includes glacial grooves, glacial fluting, drumlinoid ridges, streamlined hills and ridges, drumlinized landscapes, crag-and-tail hills
C	Rock glaciers, talus, and thick colluvium on steep slopes
S	Springs

NOTE: The same legend is shown on all map sheets; but rarely are all map-units used and shown on each individual sheet



LAC BELOT
96L
RECONNAISSANCE SURFICIAL GEOLOGY MAP



LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT Mc PHERSON , NWT

RECENT

NONGLACIAL DEPOSITS

PEATLAND ENVIRONMENT

⫫	ORGANIC DEPOSITS: Mainly peat, some muck; fens, bogs, marshes, and swamps

FLUVIAL ENVIRONMENT

F	FLOODPLAIN DEPOSITS: Mainly exposed gravel and sand, with thin topstratum of silt and fine sand on the wooded inactive portions of floodplains; the Mackenzie River modern floodplain and up to 5 miles in the lower reaches of flat-gradient tributary rivers consist mainly of stratified silt and fine sand, with minor clay, gravel, and stones
A	ALLUVIAL FAN AND CONE DEPOSITS: Mainly poorly sorted silty gravel and sand; lesser silt, clay and cobbles
E	ESTUARINE DELTAIC AND FLOODPLAIN DEPOSITS: Mainly complexly intergrading and interfingering silt, clay, fine sand, and peat with commonly a thick peat cover

EOLIAN ENVIRONMENT

W	DUNE DEPOSITS: Mainly fine sand, silty fine sand

PLEISTOCENE

GLACIAL-DRIFT DEPOSITS

GLACIOLACUSTRINE ENVIRONMENT

D	LAKE-DELTAIC DEPOSITS (includes widely scattered sand dunes): Mainly stratified silty fine sand, fine sand, silt, and clayey silt deposited in nearshore lake waters and where major meltwater streams entered temporary glacial lakes; somewhat less extensive thermokarst development that map-unit L
L	LACUSTRINE DEPOSITS: Mainly stratified and massive silt, silty clay, clayey silt, and minor fine sand deposited in deeper offshore waters; this map-unit L sometimes overlies map-unit D; extensive thermokarst development in poorly drained, ponded water areas
V	LACUSTRINE VENEER OVER MORAINE DEPOSITS: Mainly silt, clayey silt, and silty clay over till

GLACIOFLUVIAL ENVIRONMENT

T	HIGH TERRACE DEPOSITS: Mainly sand with some gravelly beds; mostly with a silt and surficial peat cover up to 15 feet thick locally
O	OUTWASH PLAIN, OUTWASH DELTA, VALLEY TRAIN DEPOSITS--LOCALLY CHANNELLED AND KETTLED: Mainly stratified fine to coarse sand, gravelly sand, gravel; minor cobbles and silt
I	ICE-CONTACT FEATURES INCLUDING ESKERS, CREVASSE FILLINGS, KAMES, KAME TERRACES, KAME DELTAS DEPOSITS: Mainly sand and gravel cored ridges and mounds; with minor silt, till, and boulders occurring as inclusions and over-burden

GLACIAL ENVIRONMENT

H	HUMMOCKY MORAINE DEPOSITS (includes a thin cover of fine-grained waterlaid and windlaid deposits locally as well as fine ponded and slopewash sediments beneath partly peat-filled deep depressions): Mainly till
G	GROUND MORAINE DEPOSITS, GENERALLY SHOWING STREAMLINED FORMS: (includes thin cover of silty to sandy slopewash deposits locally): Mainly clay-rich till over shale strata, sandy till over sandstone strata, and silty till over carbonate rocks; peat deposits on gentle slopes and in undrained hollows; some V below 600'
J	GROUND MORAINE DEPOSITS WITH DEEPER SILTY TO SANDY SLOPEWASH OVERLAY (Classic areas are the slopes of the Ebbutt and Martin Hills and the Horn Plateau): Mainly silt and sand over till
N	BEVELLED TILL DEPOSITS (includes pockets of fine waterlaid material and peat): Mostly a lag concentrate of boulders and cobbles with frequent patches and pockets of sand and gravel, waterlaid silt and clay, and peat

BEDROCK-DOMINATED TERRAIN

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R	VENEERED BEDROCK-DOMINATED RELIEF: Mainly a thin, but variable and locally thick, cover of drift; chiefly till
M	Meltwater and spillway channels
AS	Abandoned strandlines; includes minor raised beaches
○K○	Karstic topography; sinkholes in soluble rocks (gypsum, anhydrite, dolomite, limestone)
⟋	Ice-flow features; includes glacial grooves, glacial fluting, drumlinoid ridges, streamlined hills and ridges, drumlinized landscapes, crag-and-tail hills
C	Rock glaciers, talus, and thick colluvium on steep slopes
S	Springs

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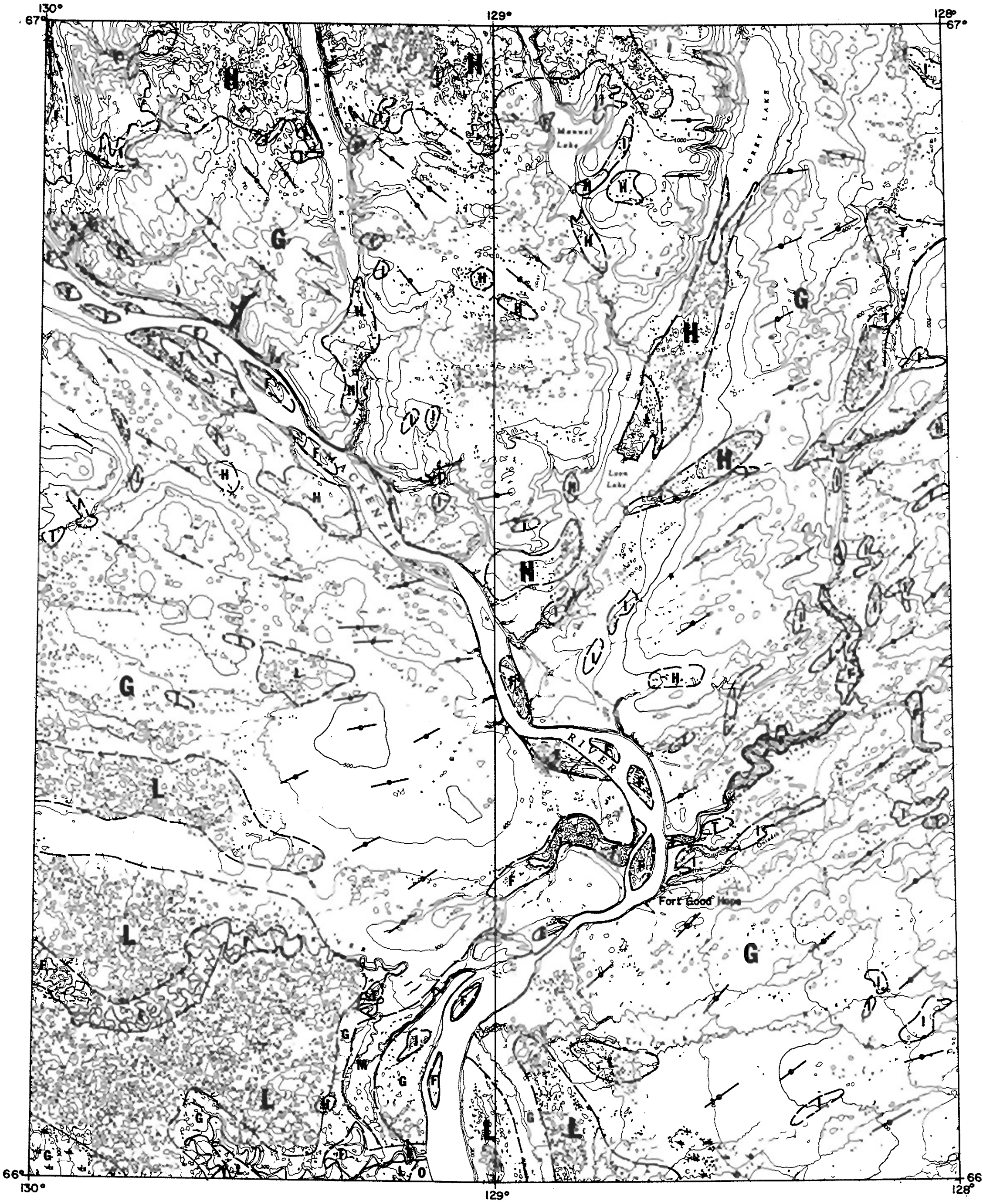
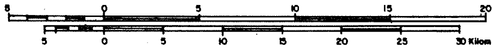
Map 15



FORT GOOD HOPE

106 I

RECONNAISSANCE SURFICIAL GEOLOGY MAP



LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT Mc PHERSON, NWT

RECENT

NONGLACIAL DEPOSITS

PEATLAND ENVIRONMENT

🝖	ORGANIC DEPOSITS: Mainly peat, some muck; fens, bogs, marshes, and swamps

FLUVIAL ENVIRONMENT

F	FLOODPLAIN DEPOSITS: Mainly exposed gravel and sand, with thin topstratum of silt and fine sand on the wooded inactive portions of floodplains; the Mackenzie River modern floodplain and up to 5 miles in the lower reaches of flat-gradient tributary rivers consist mainly of stratified silt and fine sand, with minor clay, gravel, and stones
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EOLIAN ENVIRONMENT

W	DUNE DEPOSITS: Mainly fine sand, silty fine sand

PLEISTOCENE

GLACIAL-DRIFT DEPOSITS

GLACIOLACUSTRINE ENVIRONMENT

D	LAKE-DELTAIC DEPOSITS (includes widely scattered sand dunes): Mainly stratified silty fine sand, fine sand, silt, and clayey silt deposited in nearshore lake waters and where major meltwater streams entered temporary glacial lakes; somewhat less extensive thermokarst development that map-unit L
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V	LACUSTRINE VENEER OVER MORAINE DEPOSITS: Mainly silt, clayey silt, and silty clay over till

GLACIOFLUVIAL ENVIRONMENT

T	HIGH TERRACE DEPOSITS: Mainly sand with some gravelly beds; mostly with a silt and surficial peat cover up to 15 feet thick locally
O	OUTWASH PLAIN, OUTWASH DELTA, VALLEY TRAIN DEPOSITS--LOCALLY CHANNELLED AND KETTLED: Mainly stratified fine to coarse sand, gravelly sand, gravel; minor cobbles and silt
I	ICE-CONTACT FEATURES INCLUDING ESKERS, CREVASSE FILLINGS, KAMES, KAME TERRACES, KAME DELTAS DEPOSITS: Mainly sand and gravel cored ridges and mounds; with minor silt, till, and boulders occurring as inclusions and over-burden

GLACIAL ENVIRONMENT

H	HUMMOCKY MORAINE DEPOSITS (includes a thin cover of fine-grained waterlaid and windlaid deposits locally as well as fine ponded and slopewash sediments beneath partly peat-filled deep depressions): Mainly till
G	GROUND MORAINE DEPOSITS, GENERALLY SHOWING STREAMLINED FORMS (includes thin cover of silty to sandy slopewash deposits locally): Mainly clay-rich till over shale strata, sandy till over sandstone strata, and silty till over carbonate rocks; peat deposits on gentle slopes and in undrained hollows; some V below 600'
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N	BEVELLED TILL DEPOSITS (includes pockets of fine waterlaid material and peat): Mostly a lag concentrate of boulders and cobbles with frequent patches and pockets of sand and gravel, waterlaid silt and clay, and peat

BEDROCK-DOMINATED TERRAIN

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R	VENEERED BEDROCK-DOMINATED RELIEF: Mainly a thin, but variable and locally thick, cover of drift; chiefly till

M	Meltwater and spillway channels
AS	Abandoned strandlines; includes minor raised beaches
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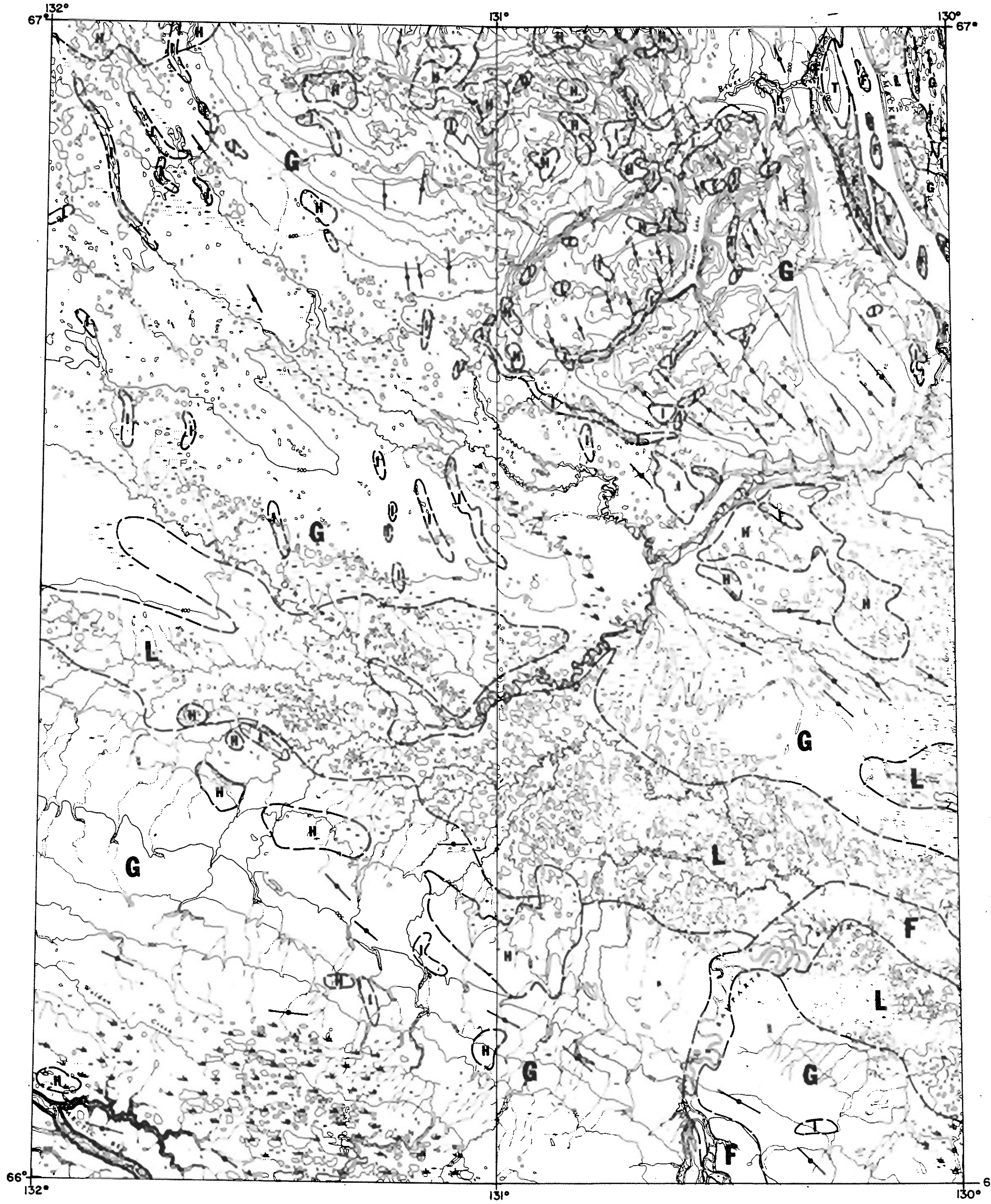
⟋	Ice-flow features; includes glacial grooves, glacial fluting, drumlinoid ridges, streamlined hills and ridges, drumlinized landscapes, crag-and-tail hills
C	Rock glaciers, talus, and thick colluvium on steep slopes
S	Springs

NOTE: The same legend is shown on all map sheets; but rarely are all map-units used and shown on each individual sheet

Map 16



ONTARATUE RIVER

106 J

RECONNAISSANCE SURFICIAL GEOLOGY MAP

LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT Mc PHERSON, NWT

RECENT

NONGLACIAL DEPOSITS

PEATLAND ENVIRONMENT

ψ ORGANIC DEPOSITS: Mainly peat, some muck; fens, bogs, marshes, and swamps

FLUVIAL ENVIRONMENT

F FLOODPLAIN DEPOSITS: Mainly exposed gravel and sand, with thin topstratum of silt and fine sand on the wooded inactive portions of floodplains; the Mackenzie River modern floodplain and up to 5 miles in the lower reaches of flat-gradient tributary rivers consist mainly of stratified silt and fine sand, with minor clay, gravel, and stones

A ALLUVIAL FAN AND CONE DEPOSITS: Mainly poorly sorted silty gravel and sand; lesser silt, clay and cobbles

E ESTUARINE DELTAIC AND FLOODPLAIN DEPOSITS: Mainly complexly intergrading and interfingering silt, clay, fine sand, and peat with commonly a thick peat cover

EOLIAN ENVIRONMENT

W DUNE DEPOSITS: Mainly fine sand, silty fine sand

PLEISTOCENE

GLACIAL-DRIFT DEPOSITS

GLACIOLACUSTRINE ENVIRONMENT

D LAKE-DELTAIC DEPOSITS (includes widely scattered sand dunes): Mainly stratified silty fine sand, fine sand, silt, and clayey silt deposited in nearshore lake waters and where major meltwater streams entered temporary glacial lakes; somewhat less extensive thermokarst development that map-unit L

L LACUSTRINE DEPOSITS: Mainly stratified and massive silt, silty clay, clayey silt, and minor fine sand deposited in deeper offshore waters; this map-unit L sometimes overlies map-unit D; extensive thermokarst development in poorly drained, ponded water areas

V LACUSTRINE VENEER OVER MORAINE DEPOSITS: Mainly silt, clayey silt, and silty clay over till

GLACIOFLUVIAL ENVIRONMENT

T HIGH TERRACE DEPOSITS: Mainly sand with some gravelly beds; mostly with a silt and surficial peat cover up to 15 feet thick locally

O OUTWASH PLAIN, OUTWASH DELTA, VALLEY TRAIN DEPOSITS--LOCALLY CHANNELLED AND KETTLED: Mainly stratified fine to coarse sand, gravelly sand, gravel; minor cobbles and silt

I ICE-CONTACT FEATURES INCLUDING ESKERS, CREVASSE FILLINGS, KAMES, KAME TERRACES, KAME DELTAS DEPOSITS: Mainly sand and gravel cored ridges and mounds; with minor silt, till, and boulders occurring as inclusions and over-burden

GLACIAL ENVIRONMENT

H HUMMOCKY MORAINE DEPOSITS (includes a thin cover of fine-grained waterlaid and windlaid deposits locally as well as fine ponded and slopewash sediments beneath partly peat-filled deep depressions): Mainly till

G GROUND MORAINE DEPOSITS, GENERALLY SHOWING STREAMLINED FORMS: (includes thin cover of silty to sandy slopewash deposits locally): Mainly clay-rich till over shale strata, sandy till over sandstone strata, and silty till over carbonate rocks; peat deposits on gentle slopes and in undrained hollows; some V below 600'

J GROUND MORAINE DEPOSITS WITH DEEPER SILTY TO SANDY SLOPEWASH OVERLAY (Classic areas are the slopes of the Ebbutt and Martin Hills and the Horn Plateau): Mainly silt and sand over till

N BEVELLED TILL DEPOSITS (includes pockets of fine waterlaid material and peat): Mostly a lag concentrate of boulders and cobbles with frequent patches and pockets of sand and gravel, waterlaid silt and clay, and peat

BEDROCK-DOMINATED TERRAIN

B WIDELY EXPOSED BEDROCK TERRAIN: Mainly exposed bedrock and bedrock with a thin, discontinuous veneer of drift; often having rugged topography; includes very rugged eroded topography

R VENEERED BEDROCK-DOMINATED RELIEF: Mainly a thin, but variable and locally thick, cover of drift; chiefly till

M Meltwater and spillway channels

AS Abandoned strandlines; includes minor raised beaches

K Karstic topography; sinkholes in soluble rocks (gypsum, anhydrite, dolomite, limestone)

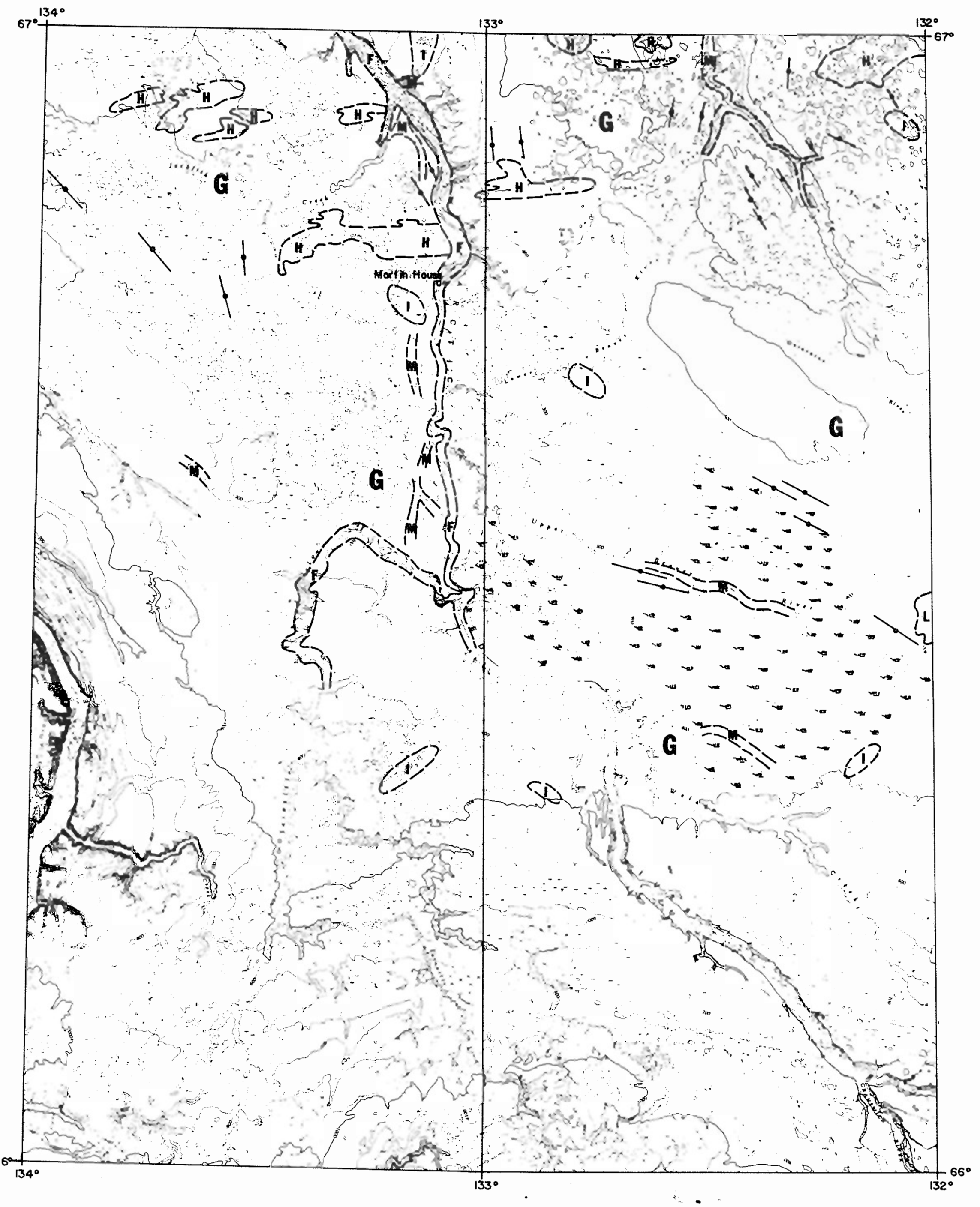
/ Ice-flow features; includes glacial grooves, glacial fluting, drumlinoid ridges, streamlined hills and ridges, drumlinized landscapes, crag-and-tail hills

C Rock glaciers, talus, and thick colluvium on steep slopes

S Springs

NOTE: The same legend is shown on all map sheets; but rarely are all map-units used and shown on each individual sheet

Map 17



MARTIN HOUSE
106 K

RECONNAISSANCE SURFICIAL GEOLOGY MAP

5 0 5 10 15 20 Miles

5 0 5 10 15 20 25 30 Kilometres

LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT Mc PHERSON, NWT

RECENT

NONGLACIAL DEPOSITS

PEATLAND ENVIRONMENT

ψ	ORGANIC DEPOSITS: Mainly peat, some muck; fens, bogs, marshes, and swamps

FLUVIAL ENVIRONMENT

F	FLOODPLAIN DEPOSITS: Mainly exposed gravel and sand, with thin topstratum of silt and fine sand on the wooded inactive portions of floodplains; the Mackenzie River modern floodplain and up to 5 miles in the lower reaches of flat-gradient tributary rivers consist mainly of stratified silt and fine sand, with minor clay, gravel, and stones
A	ALLUVIAL FAN AND CONE DEPOSITS: Mainly poorly sorted silty gravel and sand; lesser silt, clay and cobbles
E	ESTUARINE DELTAIC AND FLOODPLAIN DEPOSITS: Mainly complexly intergrading and interfingering silt, clay, fine sand, and peat with commonly a thick peat cover

EOLIAN ENVIRONMENT

W	DUNE DEPOSITS: Mainly fine sand, silty fine sand

PLEISTOCENE

GLACIAL-DRIFT DEPOSITS

GLACIOLACUSTRINE ENVIRONMENT

D	LAKE-DELTAIC DEPOSITS (includes widely scattered sand dunes): Mainly stratified silty fine sand, fine sand, silt, and clayey silt deposited in nearshore lake waters and where major meltwater streams entered temporary glacial lakes; somewhat less extensive thermokarst development that map-unit L
L	LACUSTRINE DEPOSITS: Mainly stratified and massive silt, silty clay, clayey silt, and minor fine sand deposited in deeper offshore waters; this map-unit L sometimes overlies map-unit D; extensive thermokarst development in poorly drained, ponded water areas
V	LACUSTRINE VENEER OVER MORAINE DEPOSITS: Mainly silt, clayey silt, and silty clay over till

GLACIOFLUVIAL ENVIRONMENT

T	HIGH TERRACE DEPOSITS: Mainly sand with some gravelly beds; mostly with a silt and surficial peat cover up to 15 feet thick locally
O	OUTWASH PLAIN, OUTWASH DELTA, VALLEY TRAIN DEPOSITS--LOCALLY CHANNELLED AND KETTLED: Mainly stratified fine to coarse sand, gravelly sand, gravel; minor cobbles and silt
I	ICE-CONTACT FEATURES INCLUDING ESKERS, CREVASSE FILLINGS, KAMES, KAME TERRACES, KAME DELTAS DEPOSITS: Mainly sand and gravel cored ridges and mounds; with minor silt, till, and boulders occurring as inclusions and over-burden

GLACIAL ENVIRONMENT

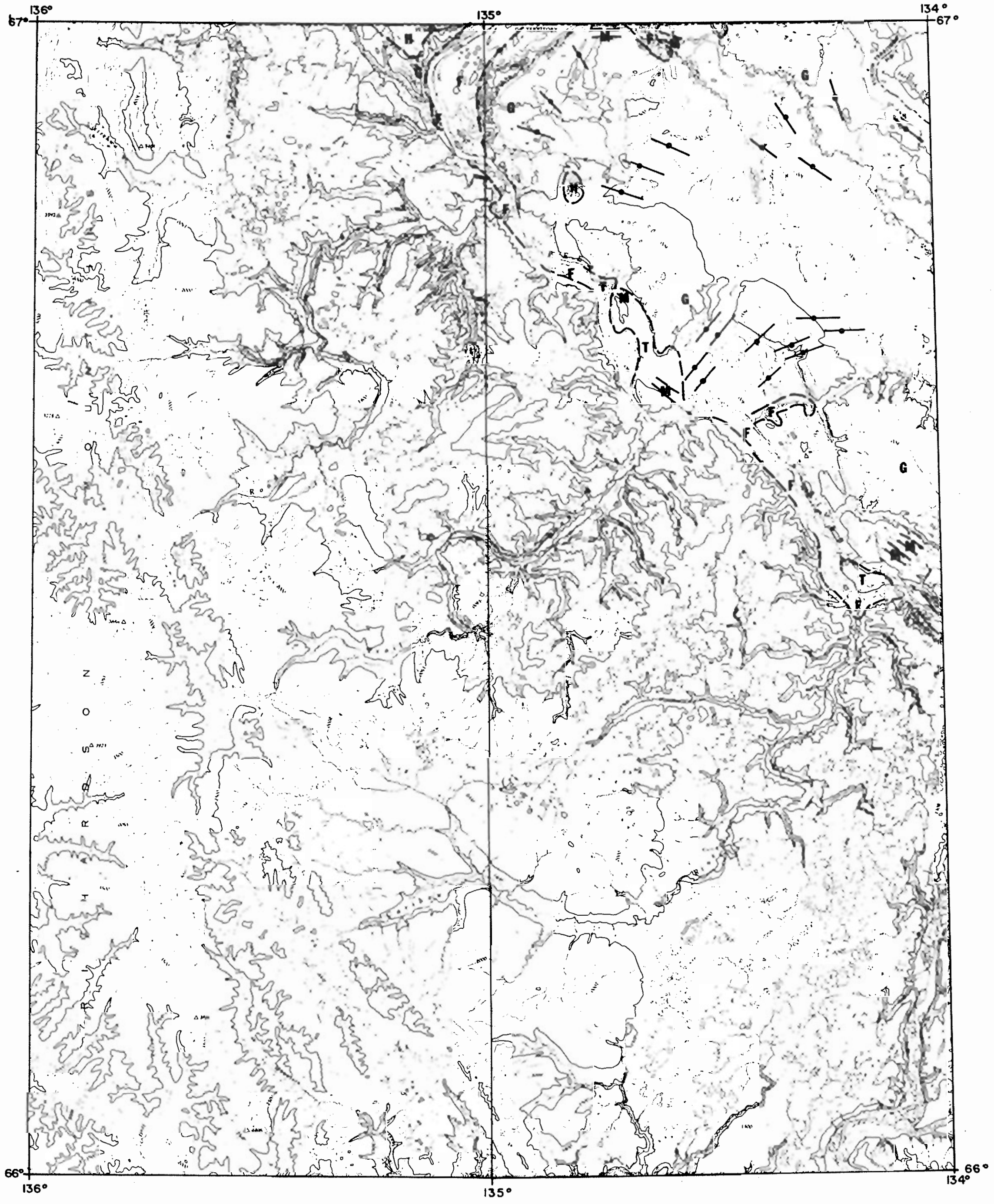
H	HUMMOCKY MORAINE DEPOSITS (includes a thin cover of fine-grained waterlaid and windlaid deposits locally as well as fine ponded and slopewash sediments beneath partly peat-filled deep depressions): Mainly till
G	GROUND MORAINE DEPOSITS, GENERALLY SHOWING STREAMLINED FORMS (includes thin cover of silty to sandy slopewash deposits locally): Mainly clay-rich till over shale strata, sandy till over sandstone strata, and silty till over carbonate rocks; peat deposits on gentle slopes and in undrained hollows; some V below 600'
J	GROUND MORAINE DEPOSITS WITH DEEPER SILTY TO SANDY SLOPEWASH OVERLAY (Classic areas are the slopes of the Ebbutt and Martin Hills and the Horn Plateau): Mainly silt and sand over till
N	BEVELLED TILL DEPOSITS (includes pockets of fine waterlaid material and peat): Mostly a lag concentrate of boulders and cobbles with frequent patches and pockets of sand and gravel, waterlaid silt and clay, and peat

BEDROCK-DOMINATED TERRAIN

B	WIDELY EXPOSED BEDROCK TERRAIN: Mainly exposed bedrock and bedrock with a thin, discontinuous veneer of drift; often having rugged topography; includes very rugged eroded topography
R	VENEERED BEDROCK-DOMINATED RELIEF: Mainly a thin, but variable and locally thick, cover of drift; chiefly till
M	Meltwater and spillway channels
AS	Abandoned strandlines; includes minor raised beaches
○K ○	Karstic topography; sinkholes in soluble rocks (gypsum, anhydrite, dolomite, limestone)
⧸	Ice-flow features; includes glacial grooves, glacial fluting, drumlinoid ridges, streamlined hills and ridges, drumlinized landscapes, crag-and-tail hills
C	Rock glaciers, talus, and thick colluvium on steep slopes
S	Springs

NOTE: The same legend is shown on all map sheets; but rarely are all map-units used and shown on each individual sheet

Map 18



TRAIL RIVER

106 L

RECONNAISSANCE SURFICIAL GEOLOGY MAP

5 0 5 10 15 20 Miles

5 0 5 10 15 20 25 30 Kilometres

LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT Mc PHERSON, NWT

RECENT

NONGLACIAL DEPOSITS

PEATLAND ENVIRONMENT

ѱ	ORGANIC DEPOSITS: Mainly peat, some muck; fens, bogs, marshes, and swamps

FLUVIAL ENVIRONMENT

F	FLOODPLAIN DEPOSITS: Mainly exposed gravel and sand, with thin topstratum of silt and fine sand on the wooded inactive portions of floodplains; the Mackenzie River modern floodplain and up to 5 miles in the lower reaches of flat-gradient tributary rivers consist mainly of stratified silt and fine sand, with minor clay, gravel, and stones
A	ALLUVIAL FAN AND CONE DEPOSITS: Mainly poorly sorted silty gravel and sand; lesser silt, clay and cobbles
E	ESTUARINE DELTAIC AND FLOODPLAIN DEPOSITS: Mainly complexly intergrading and interfingering silt, clay, fine sand, and peat with commonly a thick peat cover

EOLIAN ENVIRONMENT

W	DUNE DEPOSITS: Mainly fine sand, silty fine sand

PLEISTOCENE

GLACIAL-DRIFT DEPOSITS

GLACIOLACUSTRINE ENVIRONMENT

D	LAKE-DELTAIC DEPOSITS (includes widely scattered sand dunes): Mainly stratified silty fine sand, fine sand, silt, and clayey silt deposited in nearshore lake waters and where major meltwater streams entered temporary glacial lakes; somewhat less extensive thermokarst development that map-unit L
L	LACUSTRINE DEPOSITS: Mainly stratified and massive silt, silty clay, clayey silt, and minor fine sand deposited in deeper offshore waters; this map-unit L sometimes overlies map-unit D; extensive thermokarst development in poorly drained, ponded water areas
V	LACUSTRINE VENEER OVER MORAINE DEPOSITS: Mainly silt, clayey silt, and silty clay over till

GLACIOFLUVIAL ENVIRONMENT

T	HIGH TERRACE DEPOSITS: Mainly sand with some gravelly beds; mostly with a silt and surficial peat cover up to 15 feet thick locally
O	OUTWASH PLAIN, OUTWASH DELTA, VALLEY TRAIN DEPOSITS--LOCALLY CHANNELLED AND KETTLED: Mainly stratified fine to coarse sand, gravelly sand, gravel; minor cobbles and silt
I	ICE-CONTACT FEATURES INCLUDING ESKERS, CREVASSE FILLINGS, KAMES, KAME TERRACES, KAME DELTAS DEPOSITS: Mainly sand and gravel cored ridges and mounds; with minor silt, till, and boulders occurring as inclusions and overburden

GLACIAL ENVIRONMENT

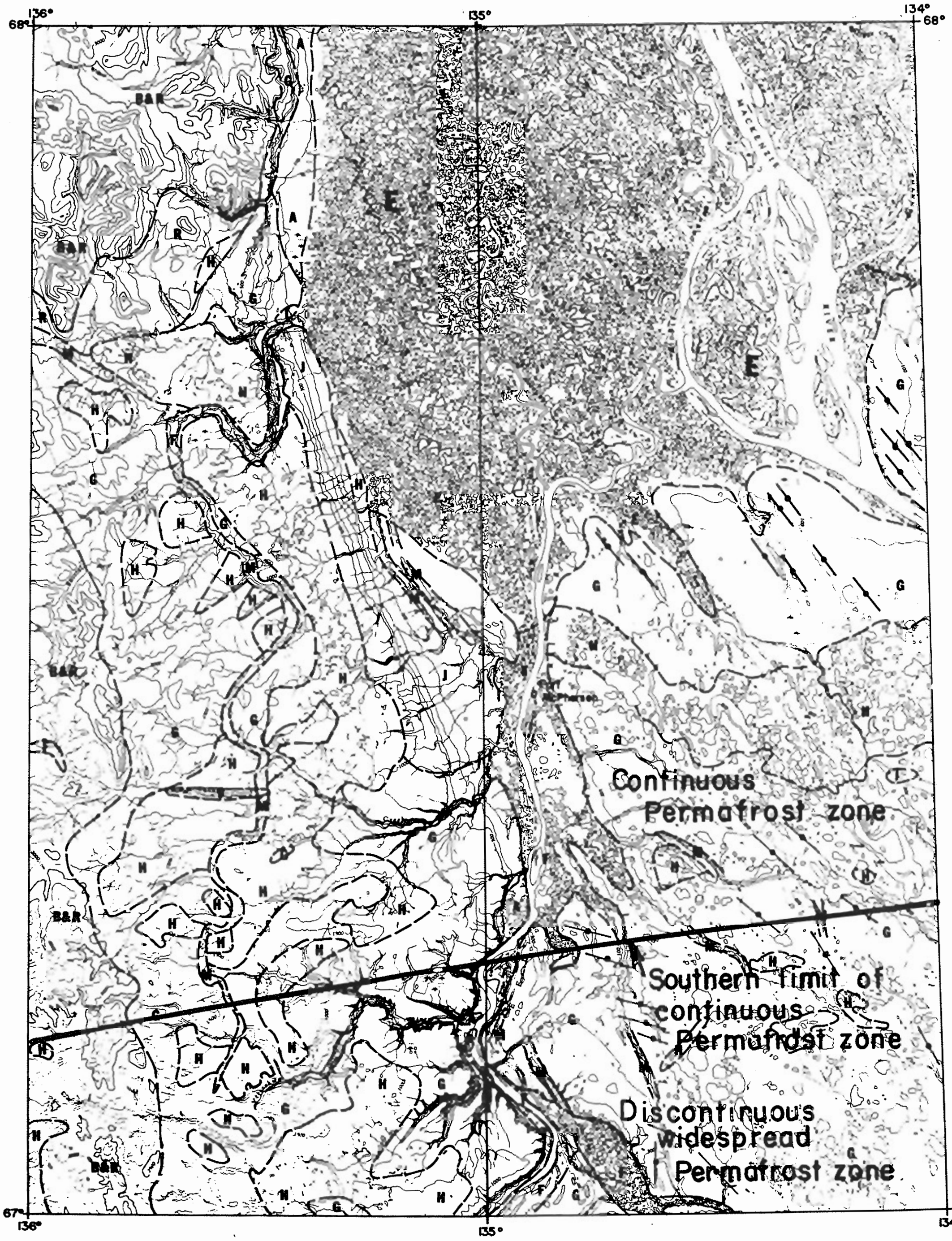
H	HUMMOCKY MORAINE DEPOSITS (includes a thin cover of fine-grained waterlaid and windlaid deposits locally as well as fine ponded and slopewash sediments beneath partly peat-filled deep depressions): Mainly till
G	GROUND MORAINE DEPOSITS, GENERALLY SHOWING STREAMLINED FORMS: (includes thin cover of silty to sandy slopewash deposits locally): Mainly clay-rich till over shale strata, sandy till over sandstone strata, and silty till over carbonate rocks; peat deposits on gentle slopes and in undrained hollows; some V below 800'
J	GROUND MORAINE DEPOSITS WITH DEEPER SILTY TO SANDY SLOPEWASH OVERLAY (Classic areas are the slopes of the Ebbutt and Martin Hills and the Horn Plateau): Mainly silt and sand over till
N	BEVELLED TILL DEPOSITS (includes pockets of fine waterlaid material and peat): Mostly a lag concentrate of boulders and cobbles with frequent patches and pockets of sand and gravel, waterlaid silt and clay, and peat

BEDROCK-DOMINATED TERRAIN

B	WIDELY EXPOSED BEDROCK TERRAIN: Mainly exposed bedrock and bedrock with a thin, discontinuous veneer of drift; often having rugged topography; includes very rugged eroded topography
R	VENEERED BEDROCK-DOMINATED RELIEF: Mainly a thin, but variable and locally thick, cover of drift; chiefly till
M	Meltwater and spillway channels
AS	Abandoned strandlines; includes minor raised beaches
○**K**○	Karstic topography; sinkholes in soluble rocks (gypsum, anhydrite, dolomite, limestone)
⟋	Ice-flow features; includes glacial grooves, glacial fluting, drumlinoid ridges, streamlined hills and ridges, drumlinized landscapes, crag-and-tail hills
C	Rock glaciers, talus, and thick colluvium on steep slopes
S	Springs

NOTE: The same legend is shown on all map sheets; but rarely are all map-units used and shown on each individual sheet

Map 19



FORT McPHERSON

106M

RECONNAISSANCE SURFICIAL GEOLOGY MAP

LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT McPHERSON, NWT

RECENT

NONGLACIAL DEPOSITS

PEATLAND ENVIRONMENT

ORGANIC DEPOSITS: Mainly peat, some muck; fens, bogs, marshes, and swamps

FLUVIAL ENVIRONMENT

F FLOODPLAIN DEPOSITS: Mainly exposed gravel and sand, with thin topstratum of silt and fine sand on the wooded inactive portions of floodplains; the Mackenzie River modern floodplain and up to 5 miles in the lower reaches of flat-gradient tributary rivers consist mainly of stratified silt and fine sand, with minor clay, gravel, and stones

A ALLUVIAL FAN AND CONE DEPOSITS: Mainly poorly sorted silty gravel and sand; lesser silt, clay and cobbles

E ESTUARINE DELTAIC AND FLOODPLAIN DEPOSITS: Mainly complexly intergrading and interfingering silt, clay, fine sand, and peat with commonly a thick peat cover

EOLIAN ENVIRONMENT

W DUNE DEPOSITS: Mainly fine sand, silty fine sand

PLEISTOCENE

GLACIAL-DRIFT DEPOSITS

GLACIOLACUSTRINE ENVIRONMENT

D LAKE-DELTAIC DEPOSITS (includes widely scattered sand dunes): Mainly stratified silty fine sand, fine sand, silt, and clayey silt deposited in nearshore lake waters and where major meltwater streams entered temporary glacial lakes; somewhat less extensive thermokarst development that map-unit L

L LACUSTRINE DEPOSITS: Mainly stratified and massive silt, silty clay, clayey silt, and minor fine sand deposited in deeper offshore waters; this map-unit L sometimes overlies map-unit D; extensive thermokarst development in poorly drained, ponded water areas

V LACUSTRINE VENEER OVER MORAINE DEPOSITS: Mainly silt, clayey silt, and silty clay over till

GLACIOFLUVIAL ENVIRONMENT

T HIGH TERRACE DEPOSITS: Mainly sand with some gravelly beds; mostly with a silt and surficial peat cover up to 15 feet thick locally

O OUTWASH PLAIN, OUTWASH DELTA, VALLEY TRAIN DEPOSITS--LOCALLY CHANNELLED AND KETTLED: Mainly stratified fine to coarse sand, gravelly sand, gravel; minor cobbles and silt

I ICE-CONTACT FEATURES INCLUDING ESKERS, CREVASSE FILLINGS, KAMES, KAME TERRACES, KAME DELTAS DEPOSITS: Mainly sand and gravel cored ridges and mounds; with minor silt, till, and boulders occurring as inclusions and overburden

GLACIAL ENVIRONMENT

H HUMMOCKY MORAINE DEPOSITS (includes a thin cover of fine-grained waterlaid and windlaid deposits locally as well as fine ponded and slopewash sediments beneath partly peat-filled deep depressions): Mainly till

G GROUND MORAINE DEPOSITS, GENERALLY SHOWING STREAMLINED FORMS :(includes thin cover of silty to sandy slopewash deposits locally): Mainly clay-rich till over shale strata, sandy till over sandstone strata, and silty till over carbonate rocks; peat deposits on gentle slopes and in undrained hollows; some V below 600'

J GROUND MORAINE DEPOSITS WITH DEEPER SILTY TO SANDY SLOPEWASH OVERLAY (Classic areas are the slopes of the Ebbutt and Martin Hills and the Horn Plateau): Mainly silt and sand over till

N BEVELLED TILL DEPOSITS (includes pockets of fine waterlaid material and peat): Mostly a lag concentrate of boulders and cobbles with frequent patches and packets of sand and gravel, waterlaid silt and clay, and peat

BEDROCK-DOMINATED TERRAIN

B WIDELY EXPOSED BEDROCK TERRAIN: Mainly exposed bedrock and bedrock with a thin, discontinuous veneer of drift; often having rugged topography; includes very rugged eroded topography

R VENEERED BEDROCK-DOMINATED RELIEF: Mainly a thin, but variable and locally thick, cover of drift; chiefly till

M Meltwater and spillway channels

AS Abandoned strandlines; includes minor raised beaches

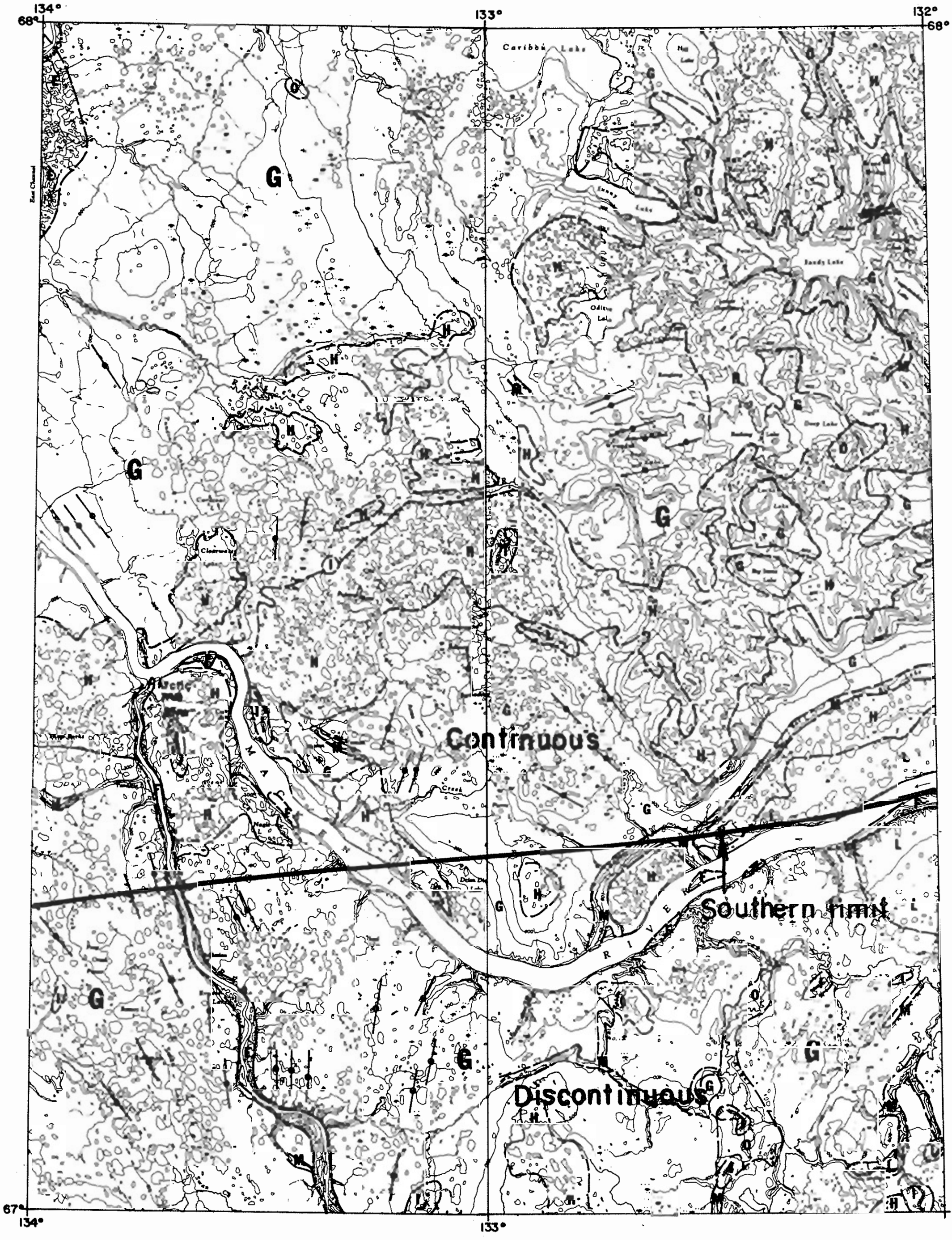
○K○ Karstic topography; sinkholes in soluble rocks (gypsum, anhydrite, dolomite, limestone)

/ Ice-flow features; includes glacial grooves, glacial fluting, druminoid ridges, streamlined hills and ridges, druminized landscapes, crag-and-tail hills

C Rock glaciers, talus, and thick colluvium on steep slopes

S Springs

NOTE: The same legend is shown on all map sheets; but rarely are all map-units used and shown on each individual sheet



ARCTIC RED RIVER
106N
RECONNAISSANCE SURFICIAL GEOLOGY MAP

LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT M.c PHERSON , NWT

RECENT

NONGLACIAL DEPOSITS

PEATLAND ENVIRONMENT

♆	ORGANIC DEPOSITS: Mainly peat, some muck; fens, bogs, marshes, and swamps

FLUVIAL ENVIRONMENT

F	FLOODPLAIN DEPOSITS: Mainly exposed gravel and sand, with thin topstratum of silt and fine sand on the wooded inactive portions of floodplains; the Mackenzie River modern floodplain and up to 5 miles in the lower reaches of flat-gradient tributary rivers consist mainly of stratified silt and fine sand, with minor clay, gravel, and stones
A	ALLUVIAL FAN AND CONE DEPOSITS: Mainly poorly sorted silty gravel and sand; lesser silt, clay and cobbles
E	ESTUARINE DELTAIC AND FLOODPLAIN DEPOSITS: Mainly complexly intergrading and interfingering silt, clay, fine sand, and peat with commonly a thick peat cover

EOLIAN ENVIRONMENT

W	DUNE DEPOSITS: Mainly fine sand, silty fine sand

PLEISTOCENE

GLACIAL-DRIFT DEPOSITS

GLACIOLACUSTRINE ENVIRONMENT

D	LAKE-DELTAIC DEPOSITS (includes widely scattered sand dunes): Mainly stratified silty fine sand, fine sand, silt, and clayey silt deposited in nearshore lake waters and where major meltwater streams entered temporary glacial lakes; somewhat less extensive thermokarst development that map-unit L
L	LACUSTRINE DEPOSITS: Mainly stratified and massive silt, silty clay, clayey silt, and minor fine sand deposited in deeper offshore waters; this map-unit L sometimes overlies map-unit D; extensive thermokarst development in poorly drained, ponded water areas
V	LACUSTRINE VENEER OVER MORAINE DEPOSITS: Mainly silt, clayey silt, and silty clay over till

GLACIOFLUVIAL ENVIRONMENT

T	HIGH TERRACE DEPOSITS: Mainly sand with some gravelly beds; mostly with a silt and surficial peat cover up to 15 feet thick locally
O	OUTWASH PLAIN, OUTWASH DELTA, VALLEY TRAIN DEPOSITS--LOCALLY CHANNELLED AND KETTLED: Mainly stratified fine to coarse sand, gravelly sand, gravel; minor cobbles and silt
I	ICE-CONTACT FEATURES INCLUDING ESKERS, CREVASSE FILLINGS, KAMES, KAME TERRACES, KAME DELTAS DEPOSITS: Mainly sand and gravel cored ridges and mounds; with minor silt, till, and boulders occurring as inclusions and overburden

GLACIAL ENVIRONMENT

H	HUMMOCKY MORAINE DEPOSITS (includes a thin cover of fine-grained waterlaid and windlaid deposits locally as well as fine ponded and slopewash sediments beneath partly peat-filled deep depressions): Mainly till
G	GROUND MORAINE DEPOSITS, GENERALLY SHOWING STREAMLINED FORMS: (includes thin cover of silty to sandy slopewash deposits locally): Mainly clay-rich till over shale strata, sandy till over sandstone strata, and silty till over carbonate rocks; peat deposits on gentle slopes and in undrained hollows; some V below 600'
J	GROUND MORAINE DEPOSITS WITH DEEPER SILTY TO SANDY SLOPEWASH OVERLAY (Classic areas are the slopes of the Ebbutt and Martin Hills and the Horn Plateau): Mainly silt and sand over till
N	BEVELLED TILL DEPOSITS (includes pockets of fine waterlaid material and peat): Mostly a lag concentrate of boulders and cobbles with frequent patches and pockets of sand and gravel, waterlaid silt and clay, and peat

BEDROCK-DOMINATED TERRAIN

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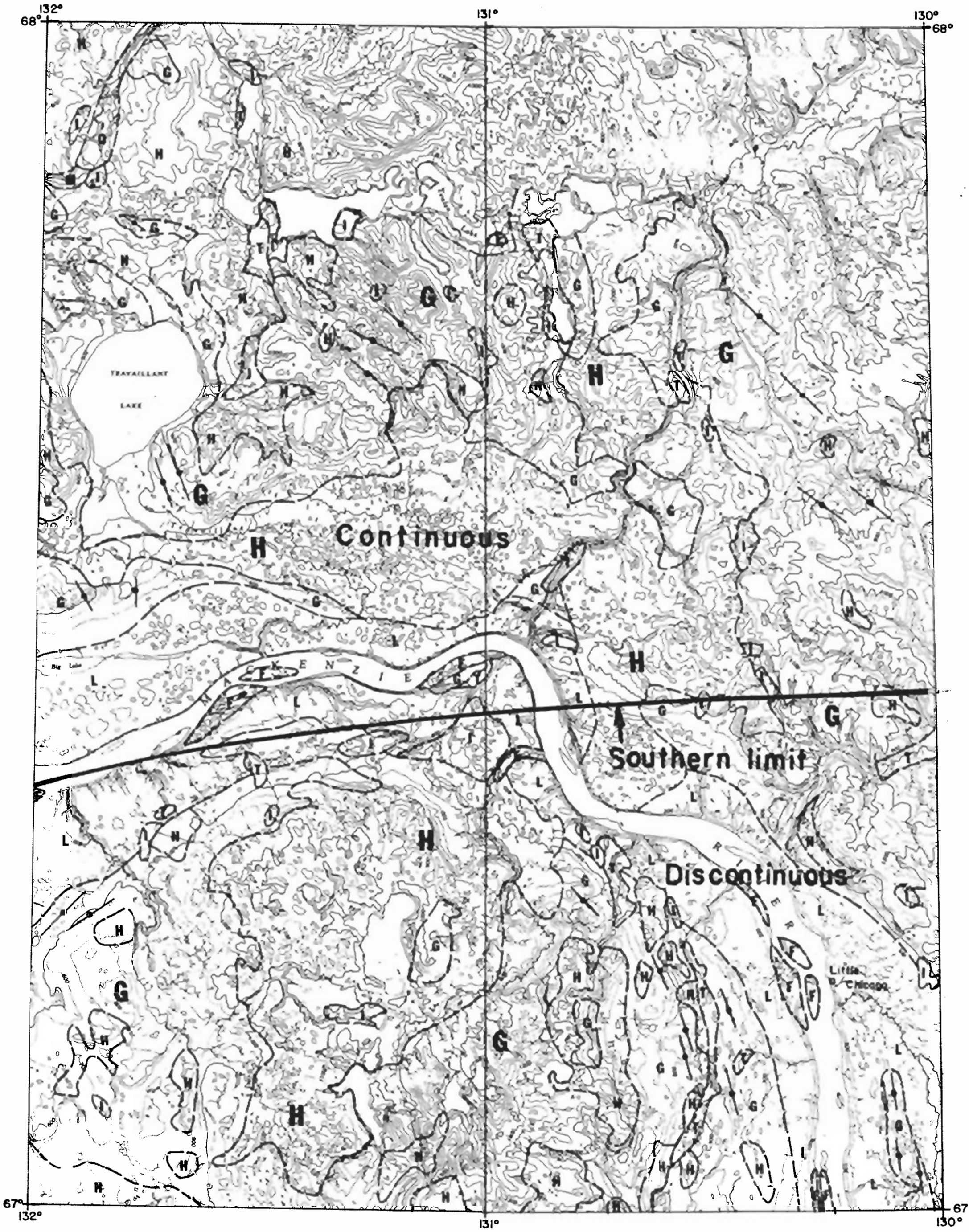
R	VENEERED BEDROCK-DOMINATED RELIEF: Mainly a thin, but variable and locally thick, cover of drift; chiefly till
M	Meltwater and spillway channels
AS	Abandoned strandlines; includes minor raised beaches
○K○	Karstic topography; sinkholes in soluble rocks (gypsum, anhydrite, dolomite, limestone)
⟋	Ice-flow features; includes glacial grooves, glacial fluting, druminoid ridges, streamlined hills and ridges, druminized landscapes, crag-and-tail hills
C	Rock glaciers, talus, and thick colluvium on steep slopes
S	Springs

NOTE: The same legend is shown on all map sheets; but rarely are all map-units used and shown on each individual sheet

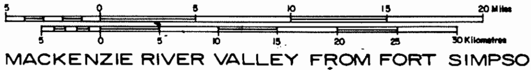
Map 21



TRAVAILLANT LAKE

106 O

RECONNAISSANCE SURFICIAL GEOLOGY MAP



LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT Mc PHERSON , NWT

RECENT

NONGLACIAL DEPOSITS

PEATLAND ENVIRONMENT

ψ	ORGANIC DEPOSITS: Mainly peat, some muck; fens, bogs, marshes, and swamps

FLUVIAL ENVIRONMENT

F	FLOODPLAIN DEPOSITS: Mainly exposed gravel and sand, with thin topstratum of silt and fine sand on the wooded inactive portions of floodplains; the Mackenzie River modern floodplain and up to 5 miles in the lower reaches of flat-gradient tributary rivers consist mainly of stratified silt and fine sand, with minor clay, gravel, and stones
A	ALLUVIAL FAN AND CONE DEPOSITS: Mainly poorly sorted silty gravel and sand; lesser silt, clay and cobbles
E	ESTUARINE DELTAIC AND FLOODPLAIN DEPOSITS: Mainly complexly intergrading and interfingering silt, clay, fine sand, and peat with commonly a thick peat cover

EOLIAN ENVIRONMENT

W	DUNE DEPOSITS: Mainly fine sand, silty fine sand

PLEISTOCENE

GLACIAL-DRIFT DEPOSITS

GLACIOLACUSTRINE ENVIRONMENT

D	LAKE-DELTAIC DEPOSITS (includes widely scattered sand dunes): Mainly stratified silty fine sand, fine sand, silt, and clayey silt deposited in nearshore lake waters and where major meltwater streams entered temporary glacial lakes; somewhat less extensive thermokarst development that map-unit L
L	LACUSTRINE DEPOSITS: Mainly stratified and massive silt, silty clay, clayey silt, and minor fine sand deposited in deeper offshore waters; this map-unit L sometimes overlies map-unit D; extensive thermokarst development in poorly drained, ponded water areas
V	LACUSTRINE VENEER OVER MORAINE DEPOSITS: Mainly silt, clayey silt, and silty clay over till

GLACIOFLUVIAL ENVIRONMENT

T	HIGH TERRACE DEPOSITS: Mainly sand with some gravelly beds; mostly with a silt and surficial peat cover up to 15 feet thick locally
O	OUTWASH PLAIN, OUTWASH DELTA, VALLEY TRAIN DEPOSITS--LOCALLY CHANNELLED AND KETTLED: Mainly stratified fine to coarse sand, gravelly sand, gravel; minor cobbles and silt
I	ICE-CONTACT FEATURES INCLUDING ESKERS, CREVASSE FILLINGS, KAMES, KAME TERRACES, KAME DELTAS DEPOSITS: Mainly sand and gravel cored ridges and mounds; with minor silt, till, and boulders occurring as inclusions and overburden

GLACIAL ENVIRONMENT

H	HUMMOCKY MORAINE DEPOSITS (includes a thin cover of fine-grained waterlaid and windlaid deposits locally as well as fine ponded and slopewash sediments beneath partly peat-filled deep depressions): Mainly till
G	GROUND MORAINE DEPOSITS, GENERALLY SHOWING STREAMLINED FORMS: (includes thin cover of silty to sandy slopewash deposits locally): Mainly clay-rich till over shale strata, sandy till over sandstone strata, and silty till over carbonate rocks; peat deposits on gentle slopes and in undrained hallows; **some V below 600'**
J	GROUND MORAINE DEPOSITS WITH DEEPER SILTY TO SANDY SLOPEWASH OVERLAY (Classic areas are the slopes of the Ebbutt and Martin Hills and the Horn Plateau): Mainly silt and sand over till
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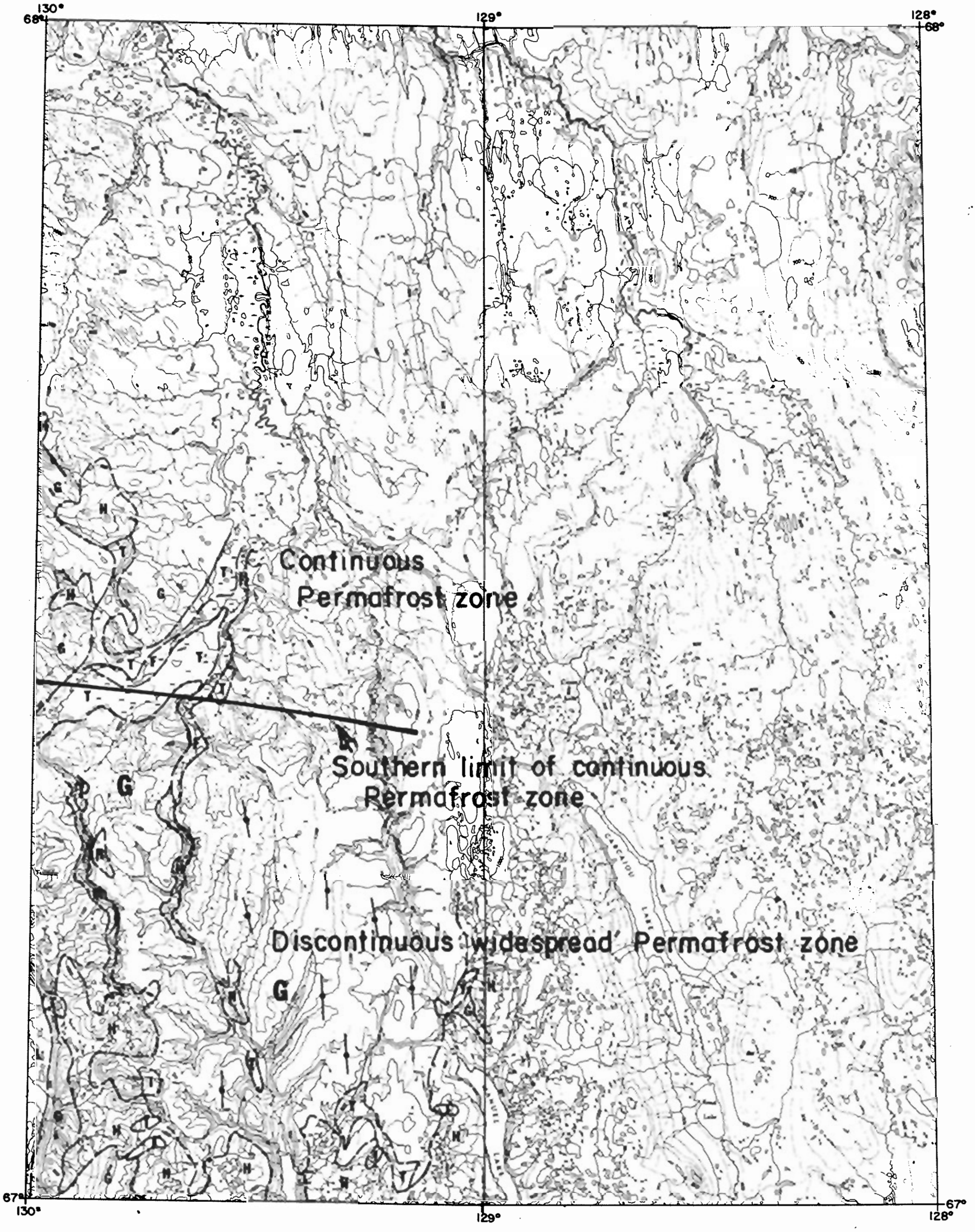
M	Meltwater and spillway channels
AS	Abandoned strandlines; includes minor raised beaches
○K ○	Karstic topography; sinkholes in soluble rocks (gypsum, anhydrite, dolomite, limestone)
⟋	Ice-flow features; includes glacial grooves, glacial fluting, drumlinoid ridges, streamlined hills and ridges, drumlinized landscapes, crag-and-tail hills
C	Rock glaciers, talus, and thick colluvium on steep slopes
S	Springs

NOTE: The same legend is shown on all map sheets; but rarely are all map-units used and shown on each individual sheet

Map 22



CANOT LAKE

106 P

RECONNAISSANCE SURFICIAL GEOLOGY MAP

LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT Mc PHERSON , NWT

RECENT

NONGLACIAL DEPOSITS

PEATLAND ENVIRONMENT

	ORGANIC DEPOSITS: Mainly peat, some muck; fens, bogs, marshes, and swamps

FLUVIAL ENVIRONMENT

F	FLOODPLAIN DEPOSITS: Mainly exposed gravel and sand, with thin topstratum of silt and fine sand on the wooded inactive portions of floodplains; the Mackenzie River modern floodplain and up to 5 miles in the lower reaches of flat-gradient tributary rivers consist mainly of stratified silt and fine sand, with minor clay, gravel, and stones
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E	ESTUARINE DELTAIC AND FLOODPLAIN DEPOSITS: Mainly complexly intergrading and interfingering silt, clay, fine sand, and peat with commonly a thick peat cover

EOLIAN ENVIRONMENT

W	DUNE DEPOSITS: Mainly fine sand, silty fine sand

PLEISTOCENE

GLACIAL-DRIFT DEPOSITS

GLACIOLACUSTRINE ENVIRONMENT

D	LAKE-DELTAIC DEPOSITS (includes widely scattered sand dunes): Mainly stratified silty fine sand, fine sand, silt, and clayey silt deposited in nearshore lake waters and where major meltwater streams entered temporary glacial lakes; somewhat less extensive thermokarst development that map-unit L
L	LACUSTRINE DEPOSITS: Mainly stratified and massive silt, silty clay, clayey silt, and minor fine sand deposited in deeper offshore waters; this map-unit L sometimes overlies map-unit D; extensive thermokarst development in poorly drained, ponded water areas
V	LACUSTRINE VENEER OVER MORAINE DEPOSITS: Mainly silt, clayey silt, and silty clay over till

GLACIOFLUVIAL ENVIRONMENT

T	HIGH TERRACE DEPOSITS: Mainly sand with some gravelly beds; mostly with a silt and surficial peat cover up to 15 feet thick locally
O	OUTWASH PLAIN, OUTWASH DELTA, VALLEY TRAIN DEPOSITS--LOCALLY CHANNELLED AND KETTLED: Mainly stratified fine to coarse sand, gravelly sand, gravel; minor cobbles and silt
I	ICE-CONTACT FEATURES INCLUDING ESKERS, CREVASSE FILLINGS, KAMES, KAME TERRACES, KAME DELTAS DEPOSITS: Mainly sand and gravel cored ridges and mounds; with minor silt, till, and boulders occurring as inclusions and overburden

GLACIAL ENVIRONMENT

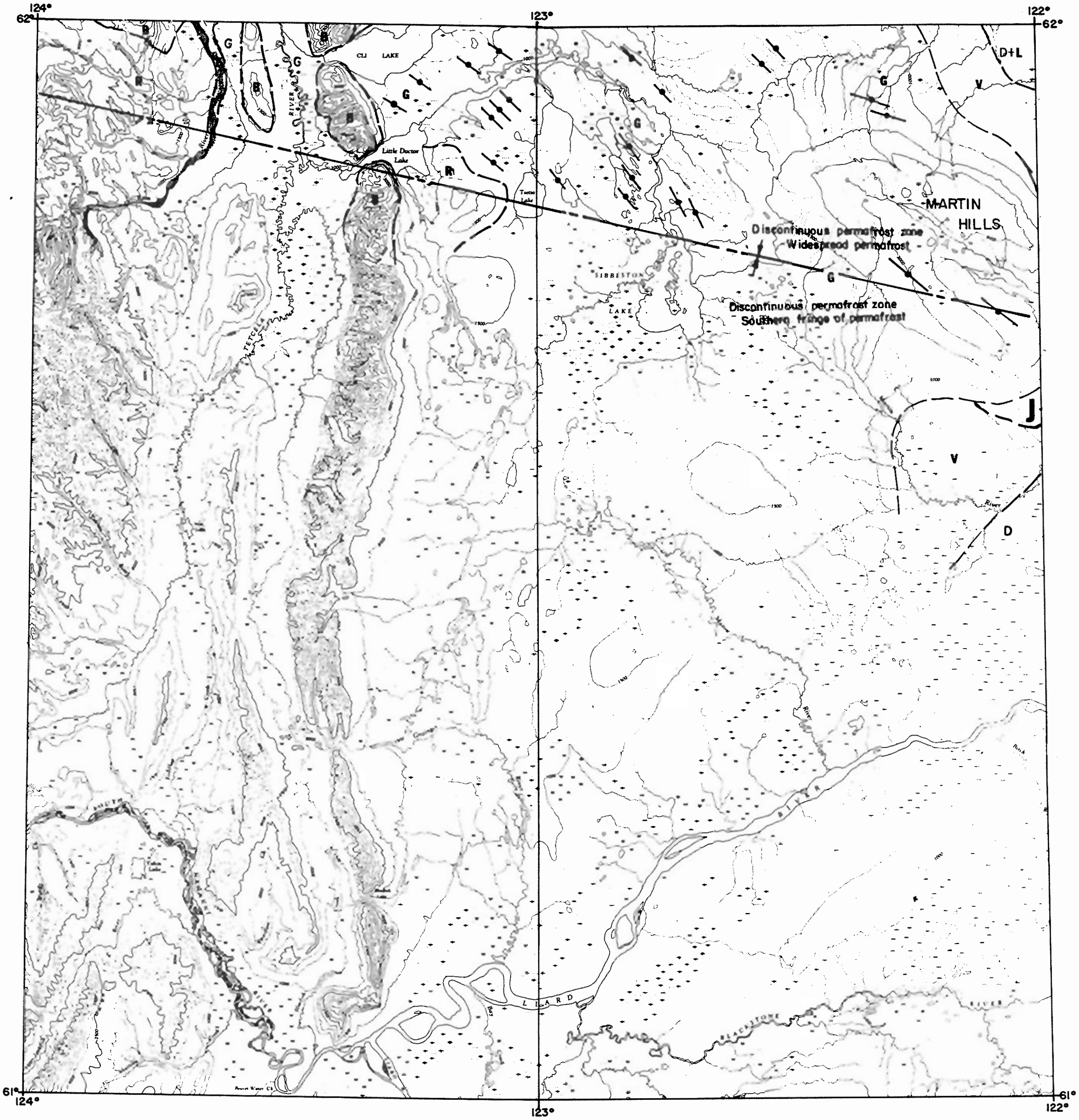
H	HUMMOCKY MORAINE DEPOSITS (includes a thin cover of fine-grained waterlaid and windlaid deposits locally as well as fine ponded and slopewash sediments beneath partly peat-filled deep depressions): Mainly till
G	GROUND MORAINE DEPOSITS, GENERALLY SHOWING STREAMLINED FORMS (includes thin cover of silty to sandy slopewash deposits locally): Mainly clay-rich till over shale strata, sandy till over sandstone strata, and silty till over carbonate rocks; peat deposits on gentle slopes and in undrained hollows; zone V below 600'
J	GROUND MORAINE DEPOSITS WITH DEEPER SILTY TO SANDY SLOPEWASH OVERLAY (Classic areas are the slopes of the Ebbutt and Martin Hills and the Horn Plateau): Mainly silt and sand over till
N	BEVELLED TILL DEPOSITS (includes pockets of fine waterlaid material and peat): Mostly a lag concentrate of boulders and cobbles with frequent patches and pockets of sand and gravel, waterlaid silt and clay, and peat

BEDROCK-DOMINATED TERRAIN

B	WIDELY EXPOSED BEDROCK TERRAIN: Mainly exposed bedrock and bedrock with a thin, discontinuous veneer of drift; often having rugged topography; includes very rugged eroded topography
R	VENEERED BEDROCK-DOMINATED RELIEF: Mainly a thin, but variable and locally thick, cover of drift; chiefly till

M	Meltwater and spillway channels
AS	Abandoned strandlines; includes minor raised beaches
○K○	Karstic topography; sinkholes in soluble rocks (gypsum, anhydrite, dolomite, limestone)
⟋	Ice-flow features; includes glacial grooves, glacial fluting, drumlinoid ridges, streamlined hills and ridges, drumlinized landscapes, crag-and-tail hills
C	Rock glaciers, talus, and thick colluvium on steep slopes
S	Springs

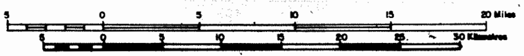
NOTE: The same legend is shown on all map sheets; but rarely are all map-units used and shown on each individual sheet



SIBBESTON LAKE

95G

RECONNAISSANCE SURFICIAL HYDROGEOLOGY MAP



GENERALIZED HYDROGEOLOGY MAP OF SURFICIAL DEPOSITS
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

(Note: Estimates of yield are probable, not absolute, maximum figures, which also exclude possible buried bedrock valleys partly filled with granular strata but having no surface expression)

LEGEND

Symbol — Explanation

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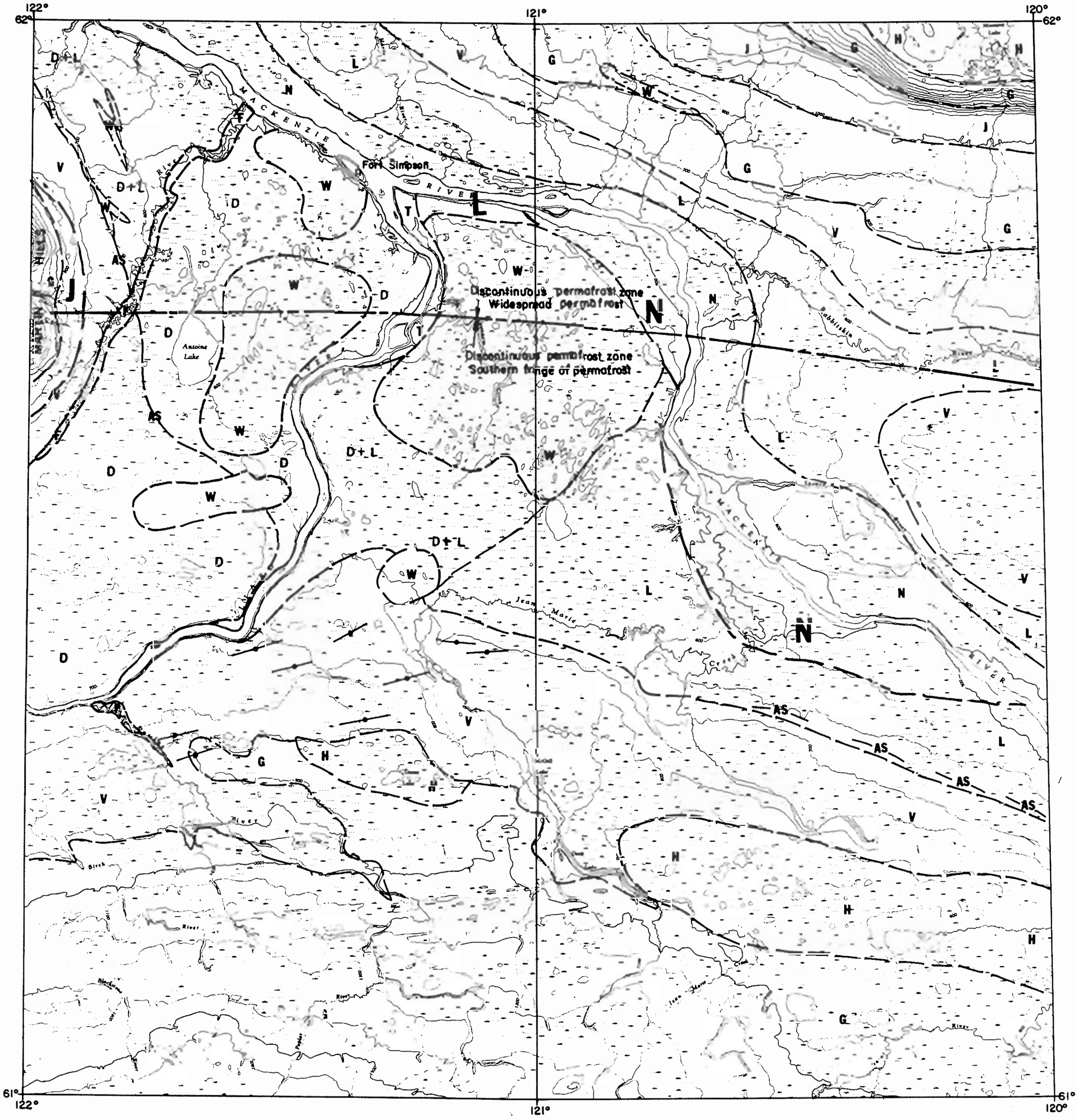
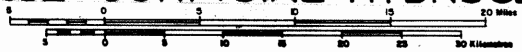
Map 1



FORT SIMPSON

95H

RECONNAISSANCE SURFICIAL HYDROGEOLOGY MAP



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FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

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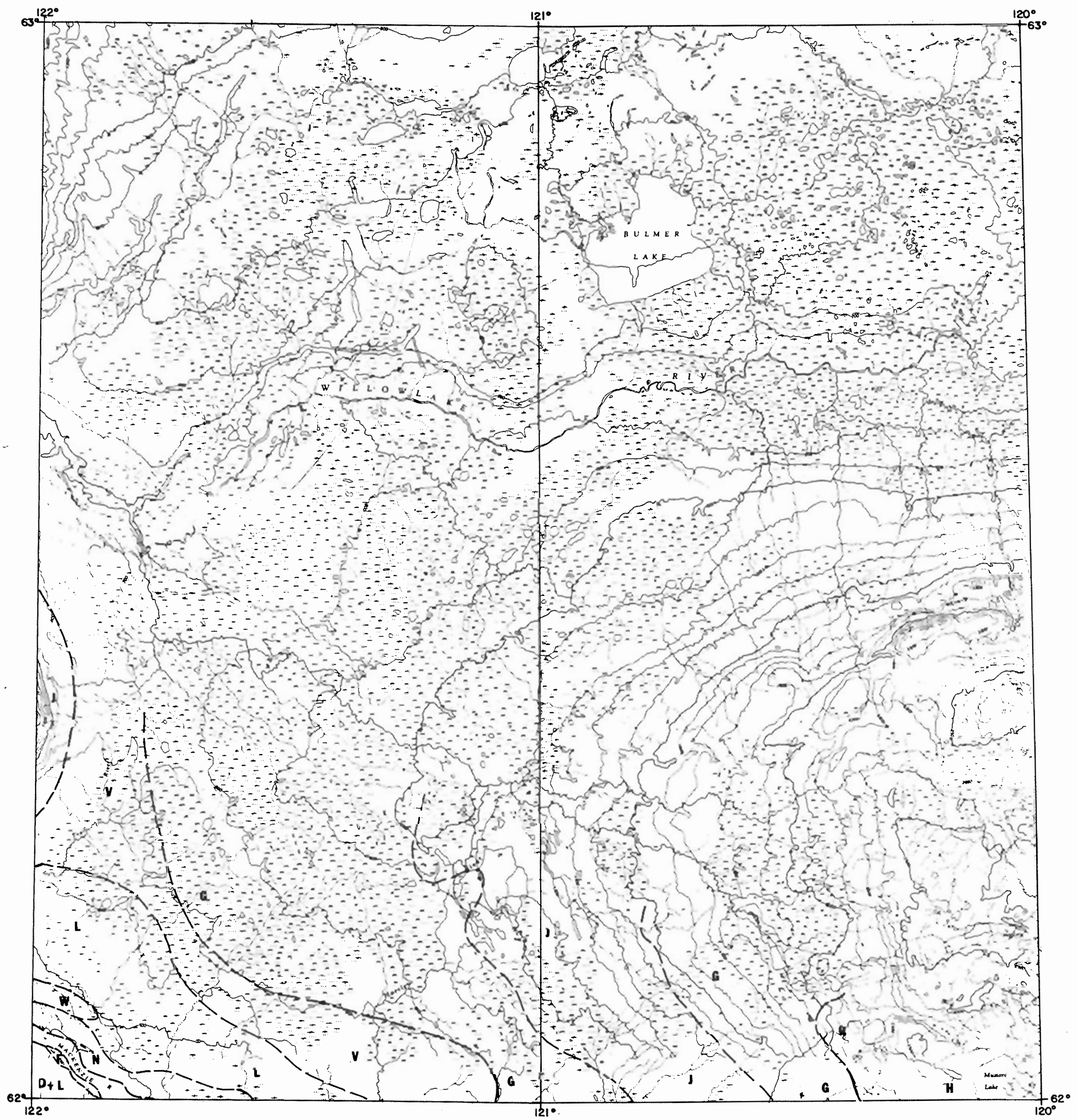
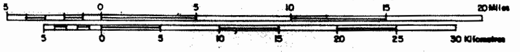


BULMER LAKE

95 I

RECONNAISSANCE SURFICIAL HYDROGEOLOGY MAP



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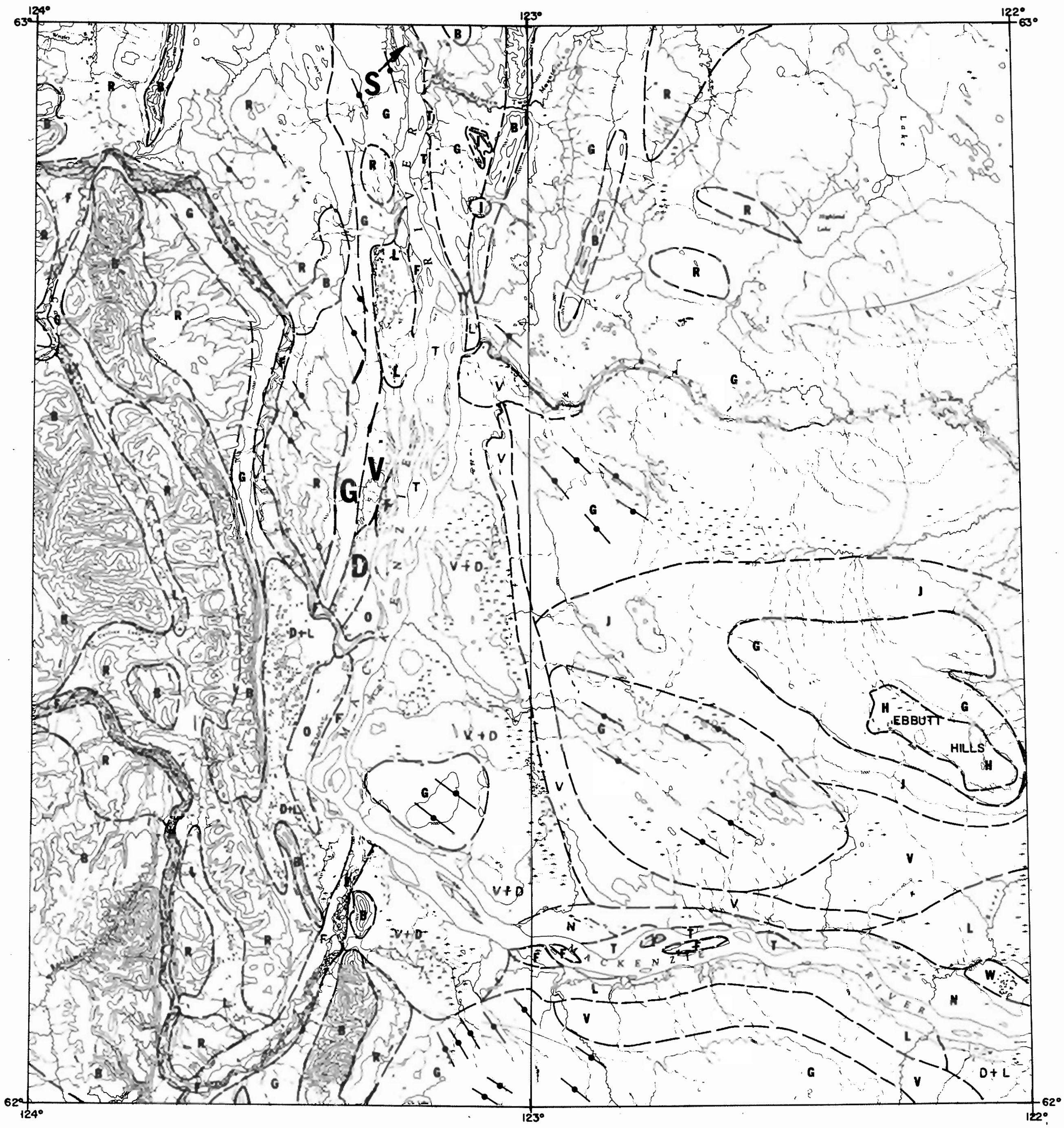

CAMSELL BEND

95J

RECONNAISSANCE SURFICIAL HYDROGEOLOGY MAP

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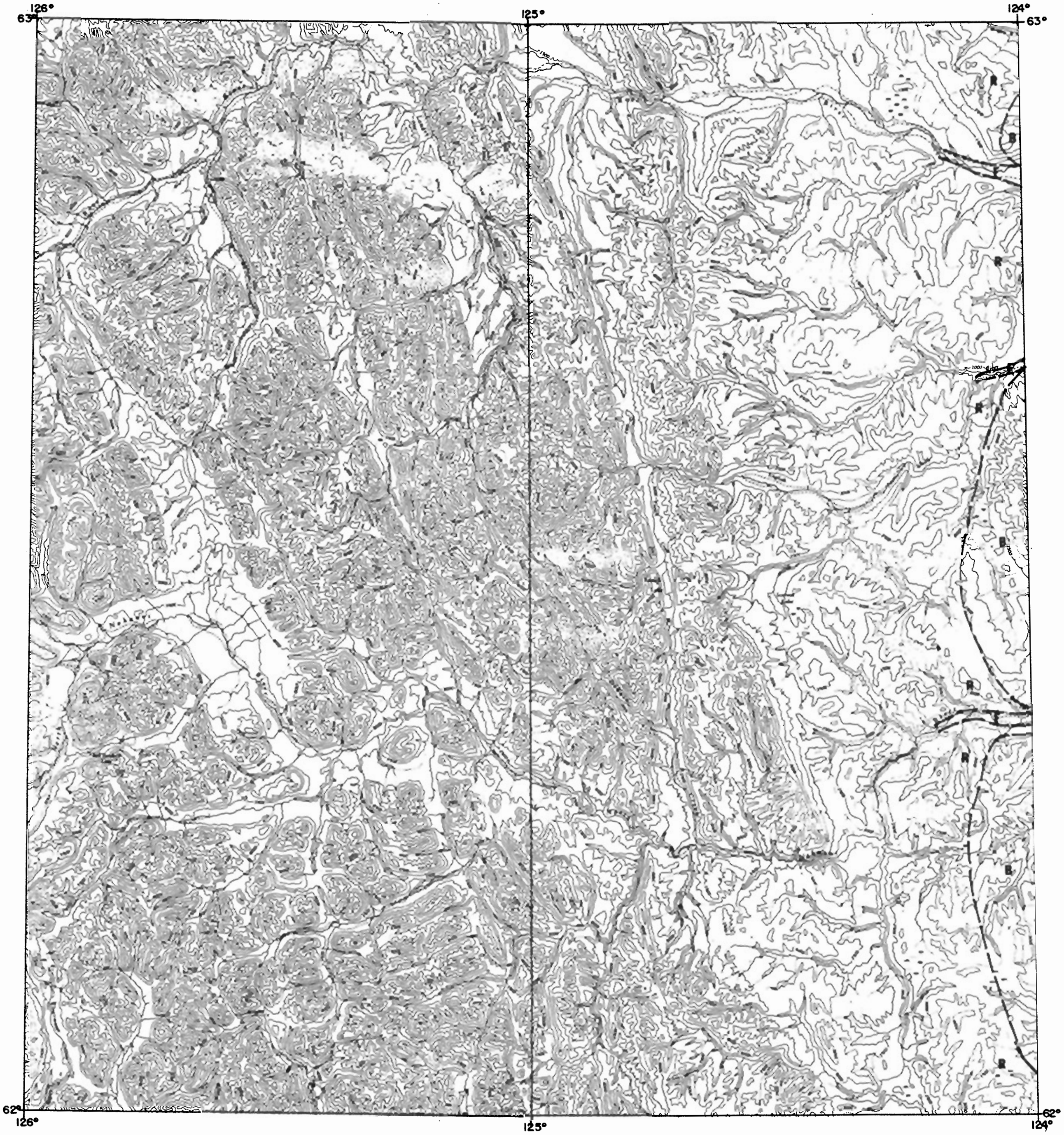
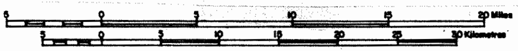


ROOT RIVER

95K

RECONNAISSANCE SURFICIAL HYDROGEOLOGY MAP



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O,T PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS MAY YIELD UP TO 35 IGPM OF GOOD QUALITY WATER WHERE THESE GRANULAR SEDIMENTS ARE UNFROZEN AND CONTINUALLY RECHARGED; BETTER PROSPECTS OCCUR SOUTH OF NORMAN WELLS, ESPECIALLY THICKER LOW-LYING SECTIONS OF SAND AND GRAVEL COVERED BY JACKPINE, WHITE SPRUCE, BALSAM POPLAR, AND TALL WILLOWS Potentially fair to good possibilities for tourist camps, domestic use (washing, drinking) at construction camps, and small native settlements. Consists mainly of sandy outwash and terrace deposits containing minor gravelly and silt interbeds.

A,C E,D W,I PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS MAY YIELD UP TO 5 IGPM OF POOR TO FAIR QUALITY WATER; BETTER PROSPECTS (COMMONLY MAP-UNITS A AND I) OCCUR IN LOCALITIES THAT BORDER WATER, ARE FREQUENTLY FLOODED, OR ARE SITUATED ON SOUTH-FACING EXPOSURES Generally poor to locally fair water supplies for domestic use. Detailed airphoto study coupled with thorough field geological reconnaissance is needed to pinpoint preferred testhole-exploration sites. Expect limited ground-water recharge. Ground water will likely require some treatment, such as removal of iron and manganese. The more promising well sites are commonly restricted to places on active distributaries and abandoned channels on larger alluvial and colluvial fans marked A and C, the margins of larger ponds and creekbeds in areas marked E and D, and south-facing slopes on higher larger wooded ridges marked W and I in regional lowland areas receiving recharge.

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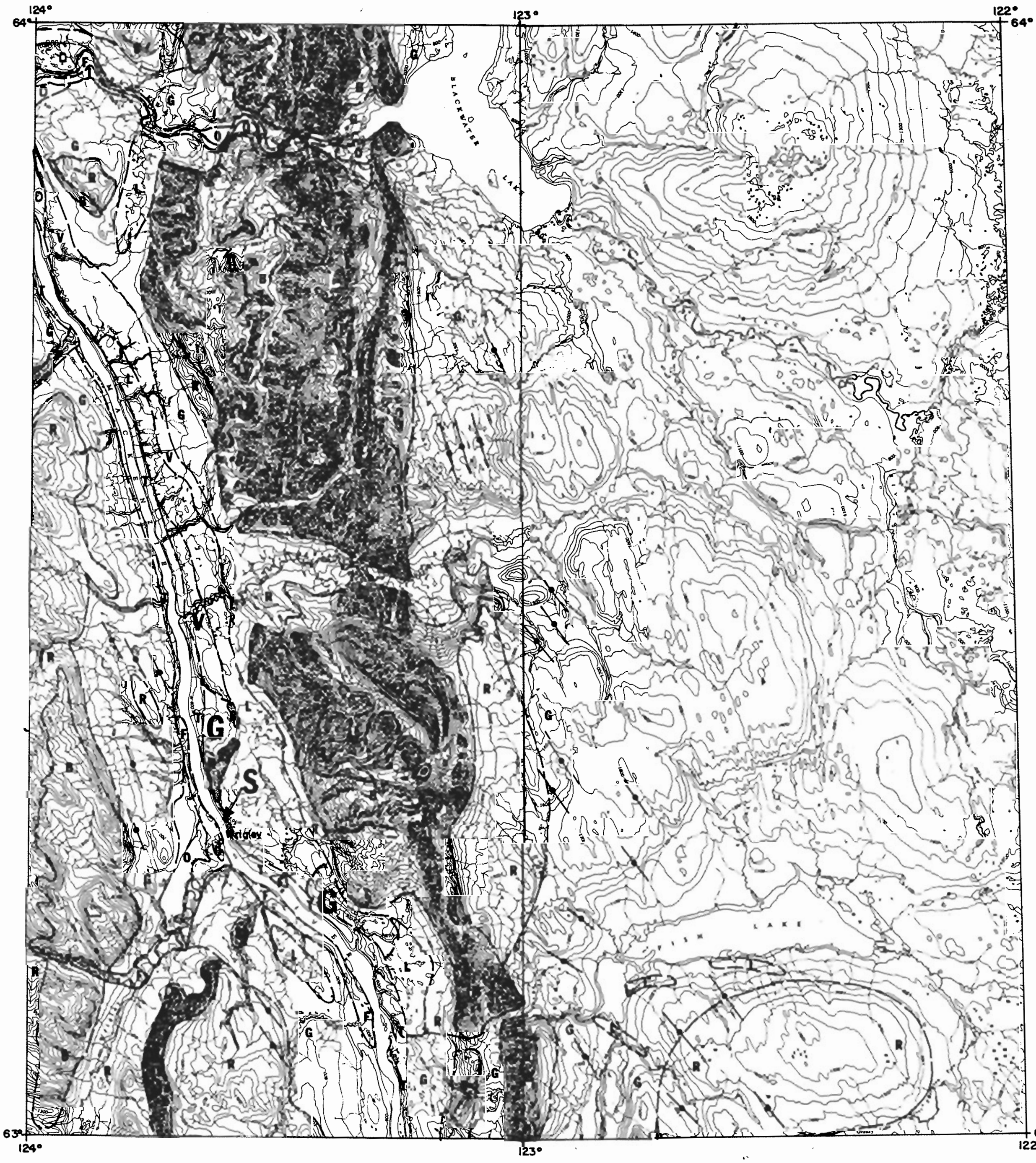
B,R,K YIELDS FROM PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS ARE EXPECTED TO VARY FROM LESS THAN 1 IGPM IN THICK SHALE SEQUENCES TO POSSIBLY 250 IGPM AT SELECT LOCATIONS IN HIGHLY DISTURBED AND FRACTURED NON-MARINE SANDSTONE AND POROUS CARBONATE ROCKS AND IN THICK UNCEMENTED TERTIARY SAND AND GRAVEL (SEE, ALSO, THE ACCOMPANYING GENERALIZED BEDROCK HYDROGEOLOGY MAP) Highly variable ground-water source, both from the standpoints of water quality and quantity. Potentially suitable for domestic supplies, villages and some industries in certain localities.

S SPRINGS YIELDING LARGE QUANTITIES OF HIGHLY VARIABLE QUALITY GROUND WATER Generally springs occur in lowland areas along valley banks where permeable soil or rock materials overlie impermeable strata. The springs may be artesian or water-table. Potentially suitable for towns, industries, and construction campsites depending on water quality.

⚘ INDIVIDUAL WELLS IN ORGANIC (PEAT) DEPOSITS ARE EXPECTED TO YIELD LESS THAN 1 IGPM OF POOR QUALITY WATER Generally poor water supplies for all users because of the typical tea colour of the water, potentially high manganese and iron contents and common boggy taste and odour. Includes fens, bogs, marshes, and swamps. Generally patterned fens are unfrozen in vicinity of Fort Simpson whereas only the small, roundish, treeless collapse scars in peat plateaus are unfrozen.

Lake PROPER INTAKES INTO LARGE LAKES MAY YIELD UP TO 100 IGPM OF GOOD QUALITY WATER; DEPTH OF WATER (PREFERABLY OVER 10 FEET) AND SIZE OF LAKE ARE IMPORTANT CONSIDERATIONS, THE LARGER AND DEEPER LAKES BEING BETTER Consists of larger and deeper permanent lakes in Mackenzie River Valley upland, such as Tate and Stewart Lakes. Potentially fair to good water supplies for villages, industries, and construction camps. Treatment for iron, manganese, and organic matter may be necessary. Because of potentially thick ice cover on smaller shallow lakes, the availability of this water source may vary seasonally.

Map 5



WRIGLEY

950

RECONNAISSANCE SURFICIAL HYDROGEOLOGY MAP

GENERALIZED HYDROGEOLOGY MAP OF SURFICIAL DEPOSITS
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

(Note: Estimates of yield are probable, not absolute, maximum figures, which also exclude possible buried bedrock valleys partly filled with granular strata but having no surface expression)

LEGEND

Symbol	Explanation
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O,T	PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS MAY YIELD UP TO 25 IGPM OF GOOD QUALITY WATER WHERE THESE GRANULAR SEDIMENTS ARE UNFROZEN AND CONTINUALLY RECHARGED; BETTER PROSPECTS OCCUR SOUTH OF NORMAN WELLS, ESPECIALLY THICKER LOW-LYING SECTIONS OF SAND AND GRAVEL COVERED BY JACKPINE, WHITE SPRUCE, BALSAM POPLAR, AND TALL WILLOWS Potentially fair to good possibilities for tourist camps, domestic use (washing, drinking) at construction camps, and small native settlements. Consists mainly of sandy outwash and terrace deposits containing minor gravelly and silt interbeds.
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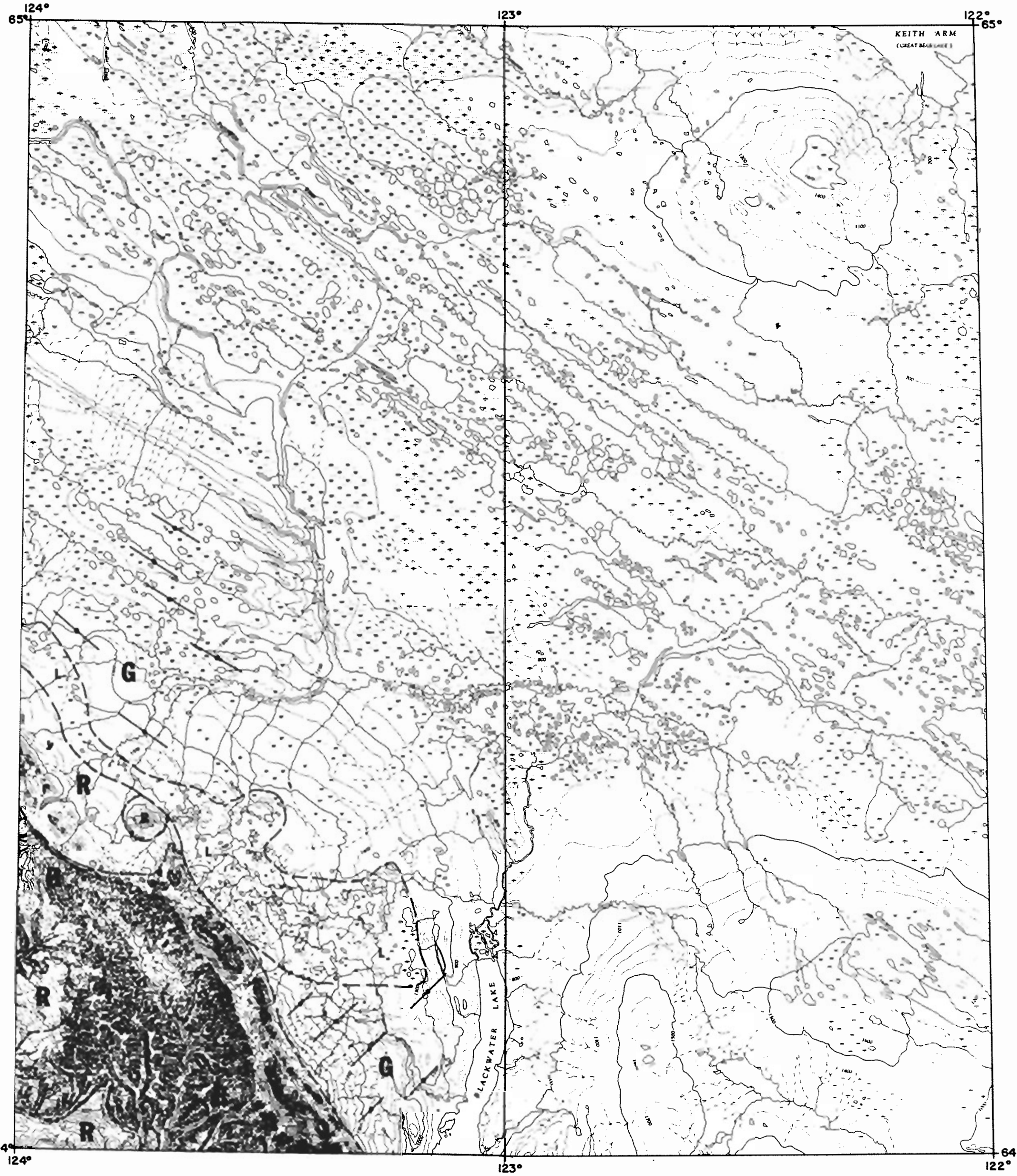
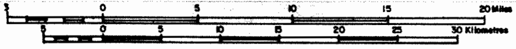
Map 7



BLACK WATER LAKE

96 B

RECONNAISSANCE SURFICIAL HYDROGEOLOGY MAP



GENERALIZED HYDROGEOLOGY MAP OF SURFICIAL DEPOSITS
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

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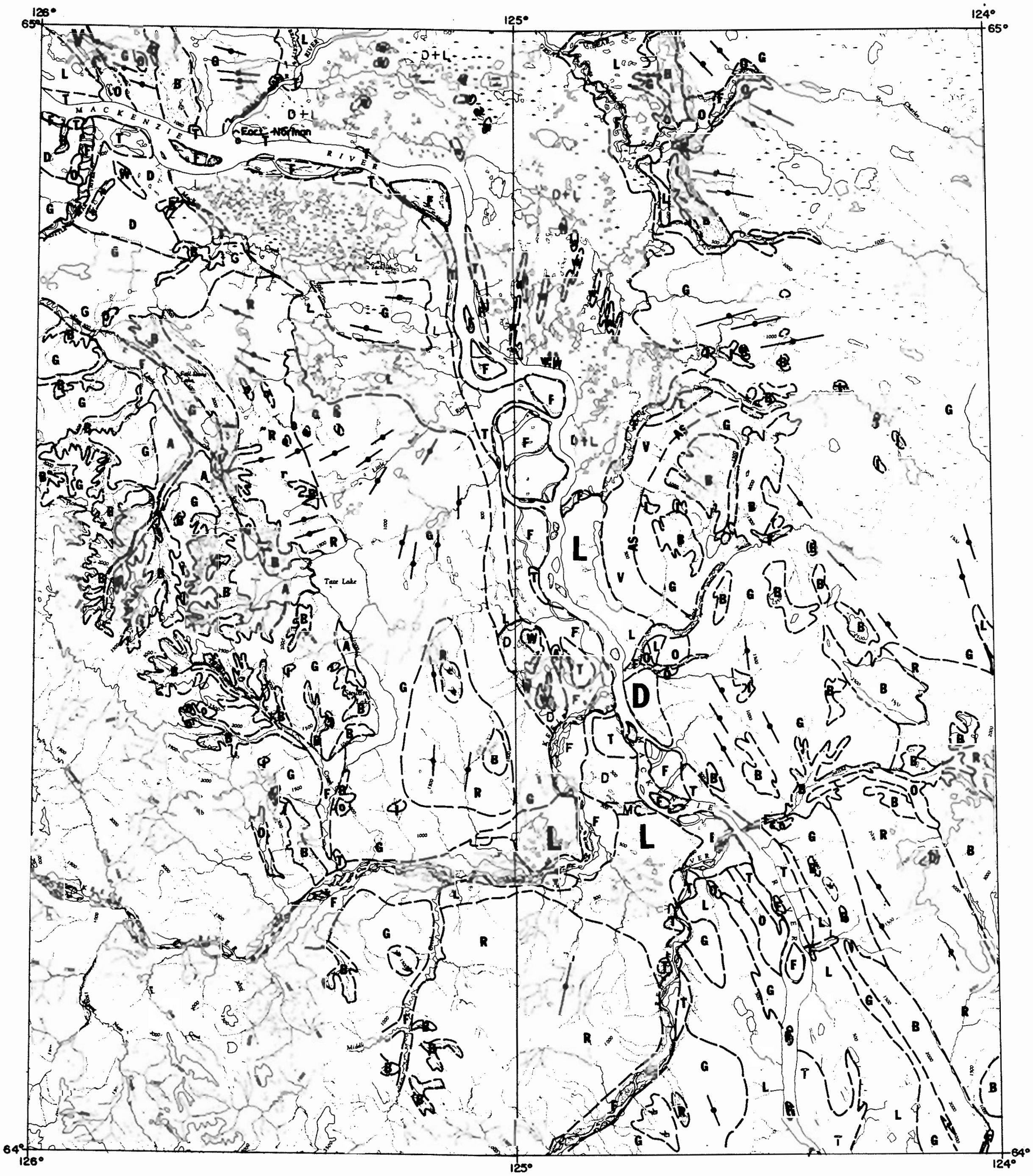
Map 8



FORT NORMAN

96C

RECONNAISSANCE SURFICIAL HYDROGEOLOGY MAP

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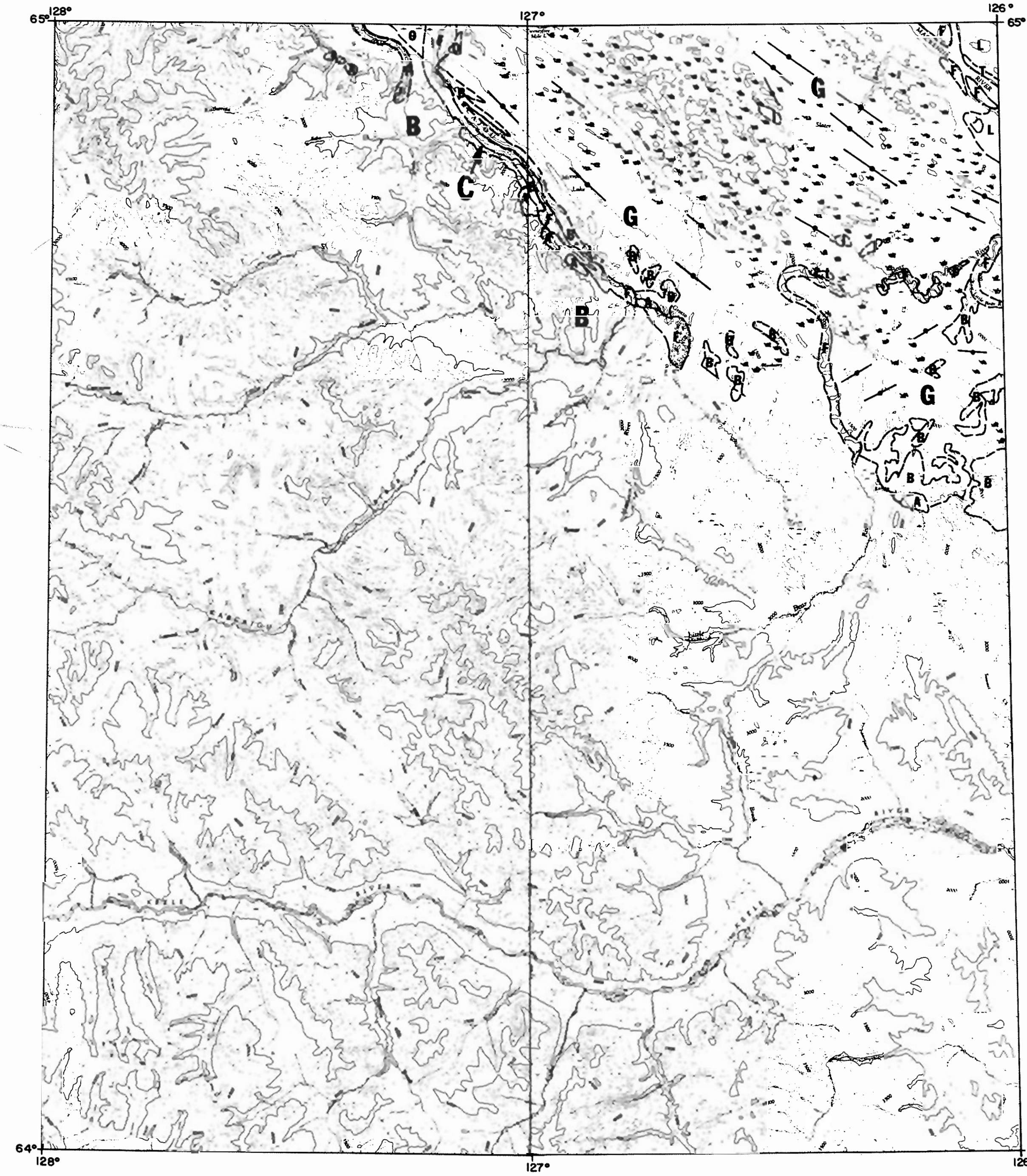

CARCAJOU CANYON
96D
RECONNAISSANCE SURFICIAL HYDROGEOLOGY MAP

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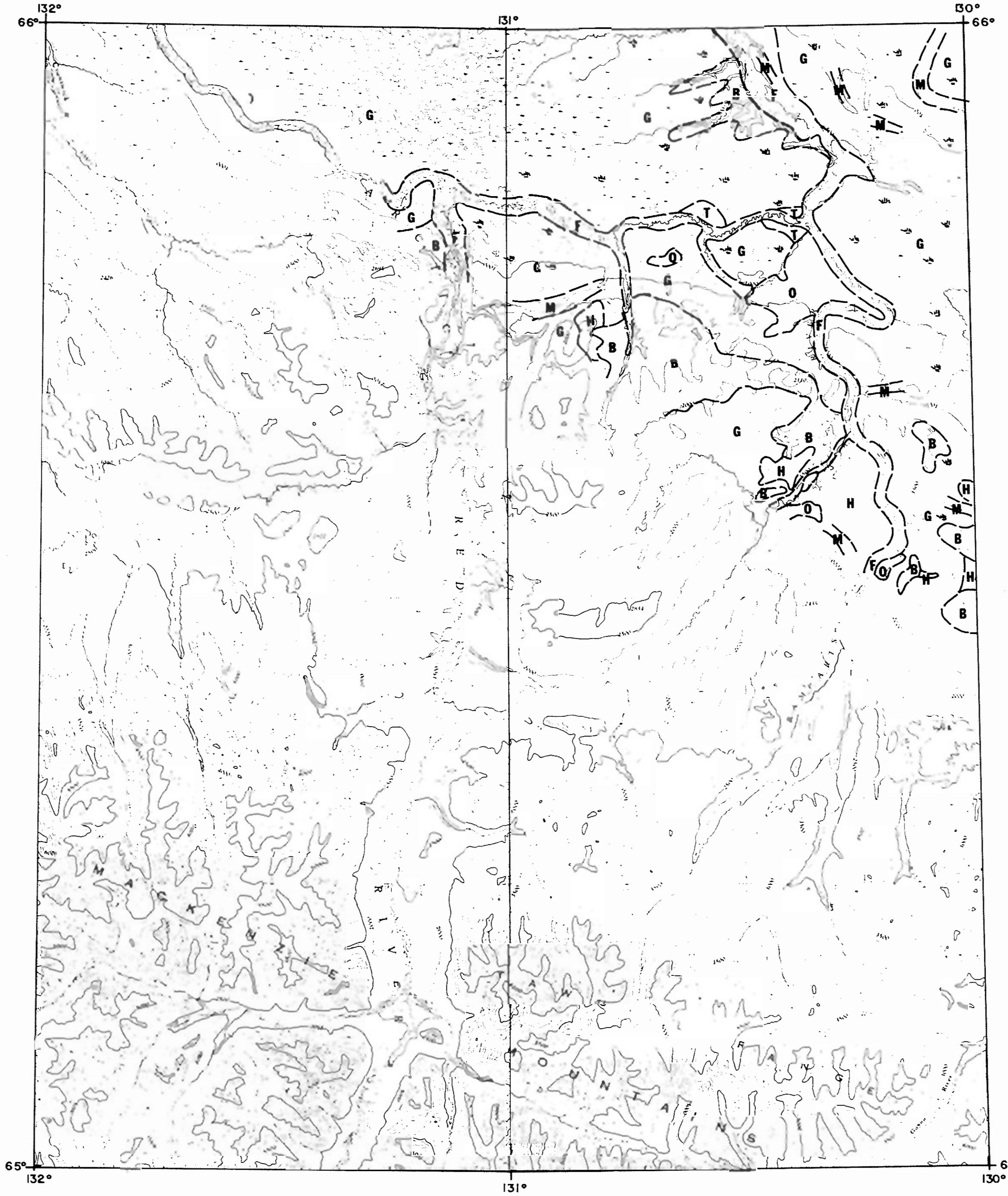
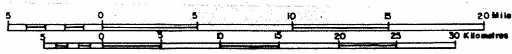


UPPER RAMPARTS RIVER

106 G

RECONNAISSANCE SURFICIAL HYDROGEOLOGY MAP



GENERALIZED HYDROGEOLOGY MAP OF SURFICIAL DEPOSITS
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

(Note: Estimates of yield are probable, not absolute, maximum figures, which also exclude possible buried bedrock valleys partly filled with granular strata but having no surface expression)

LEGEND

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F	PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS MAY YIELD UP TO 50 TO 100 IGPM AND LOCALLY, IN THICKER MORE PERMEABLE AQUIFERS, 100 TO 500 IGPM OF GOOD QUALITY WATER Potentially good water supplies for tourist and construction camps, villages and towns, and industries -- especially those thick coarse aquifers in major river valleys tributary to the Mackenzie River. Consists mainly of alluvial sand and gravel below the active and wooded (inactive) floodplains and below coarse sandy and gravelly point-bar deposits on steeper-gradient sections of larger meandering rivers. Considerable test drilling may be required to locate large aquifers in the lower reaches of tributaries and in the Mackenzie River flood plain. Chief well installation problems are flooding and excessive lateral and vertical river erosion. Rivers with headwaters in the Mackenzie Mountains are extremely flashy and floods can be highly destructive.
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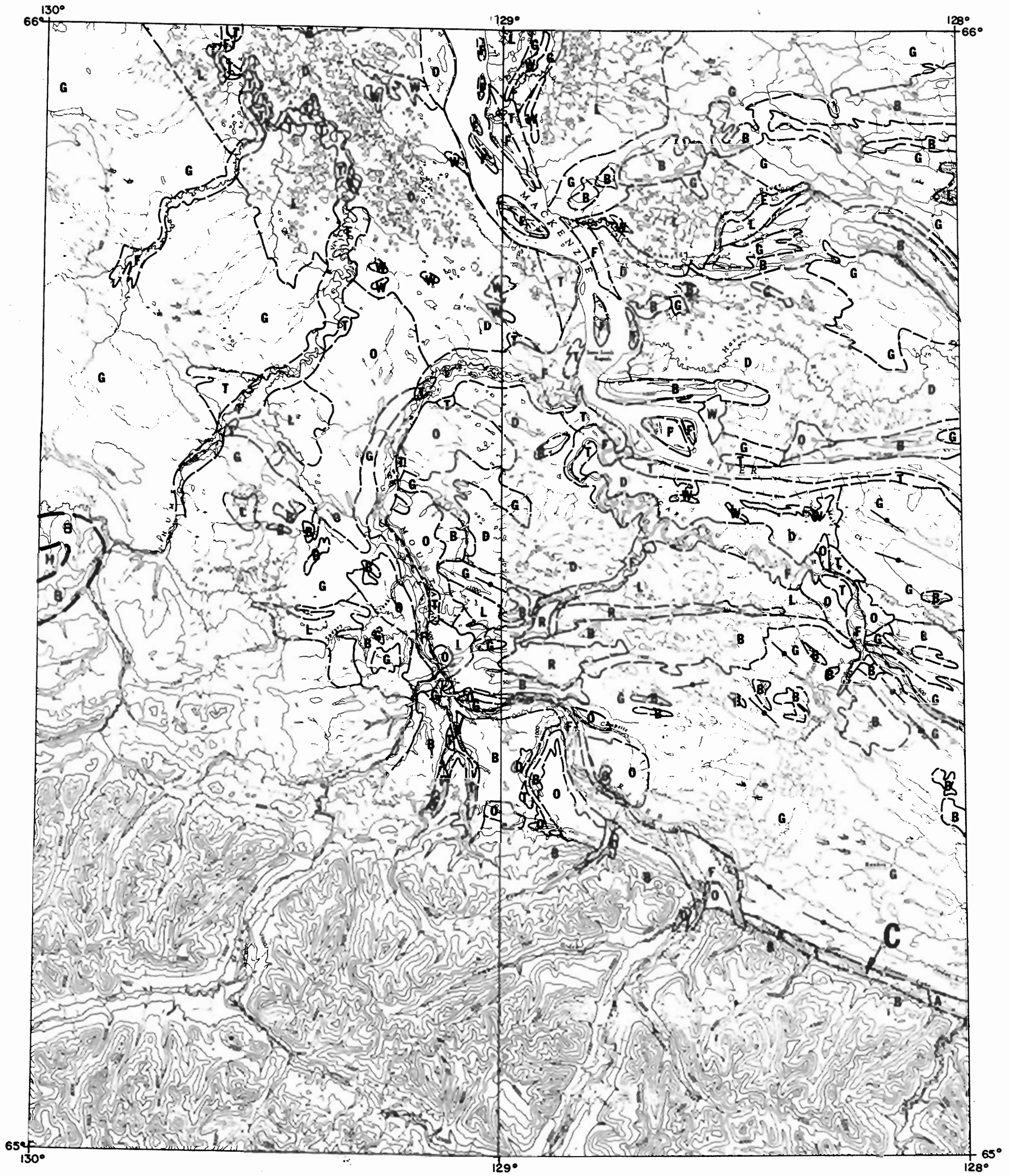

SANS SAULT RAPIDS

106 H

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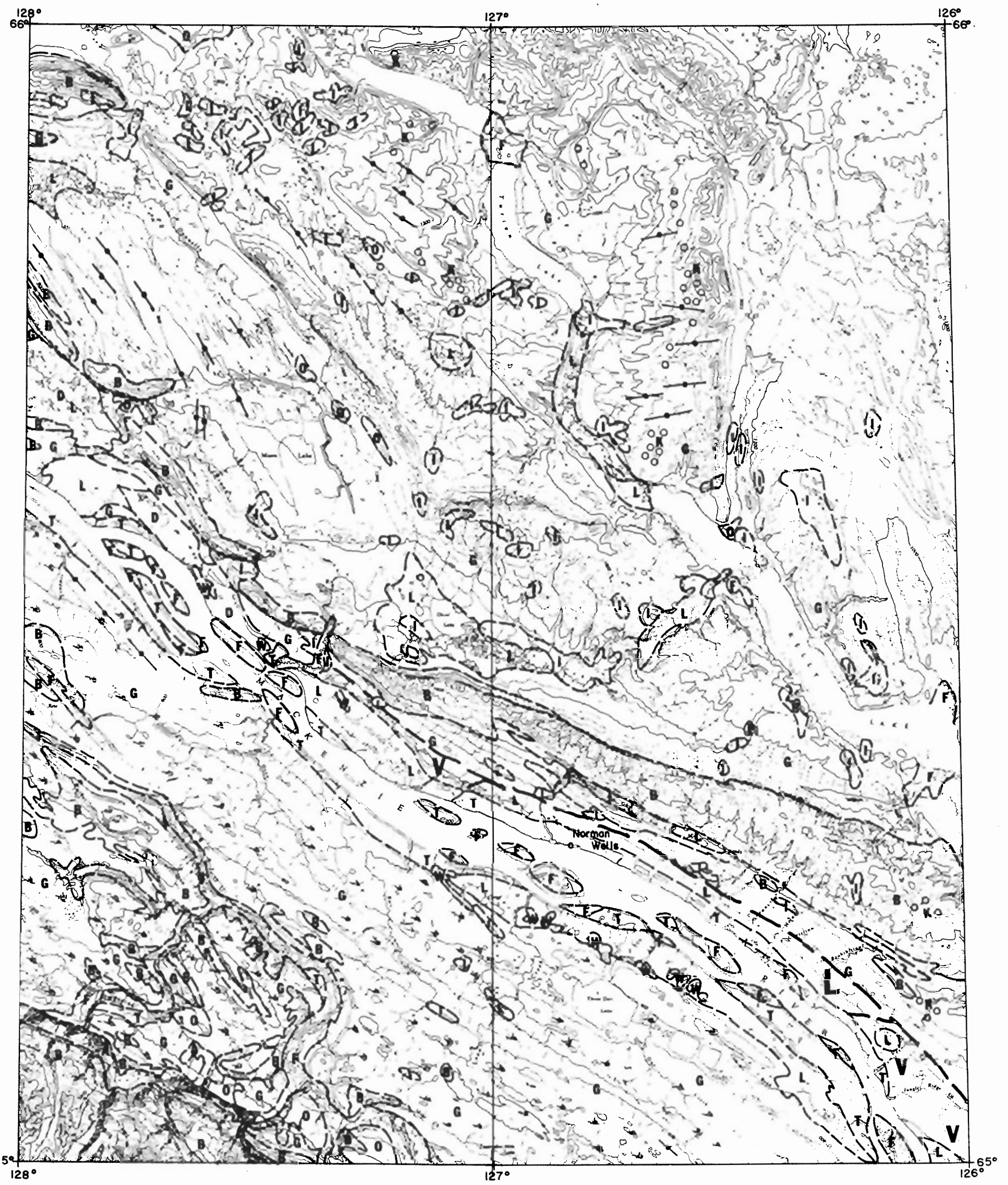

NORMAN WELLS

96 E

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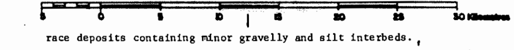

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Map 13

MAHONY LAKE

96 F

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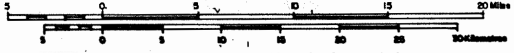

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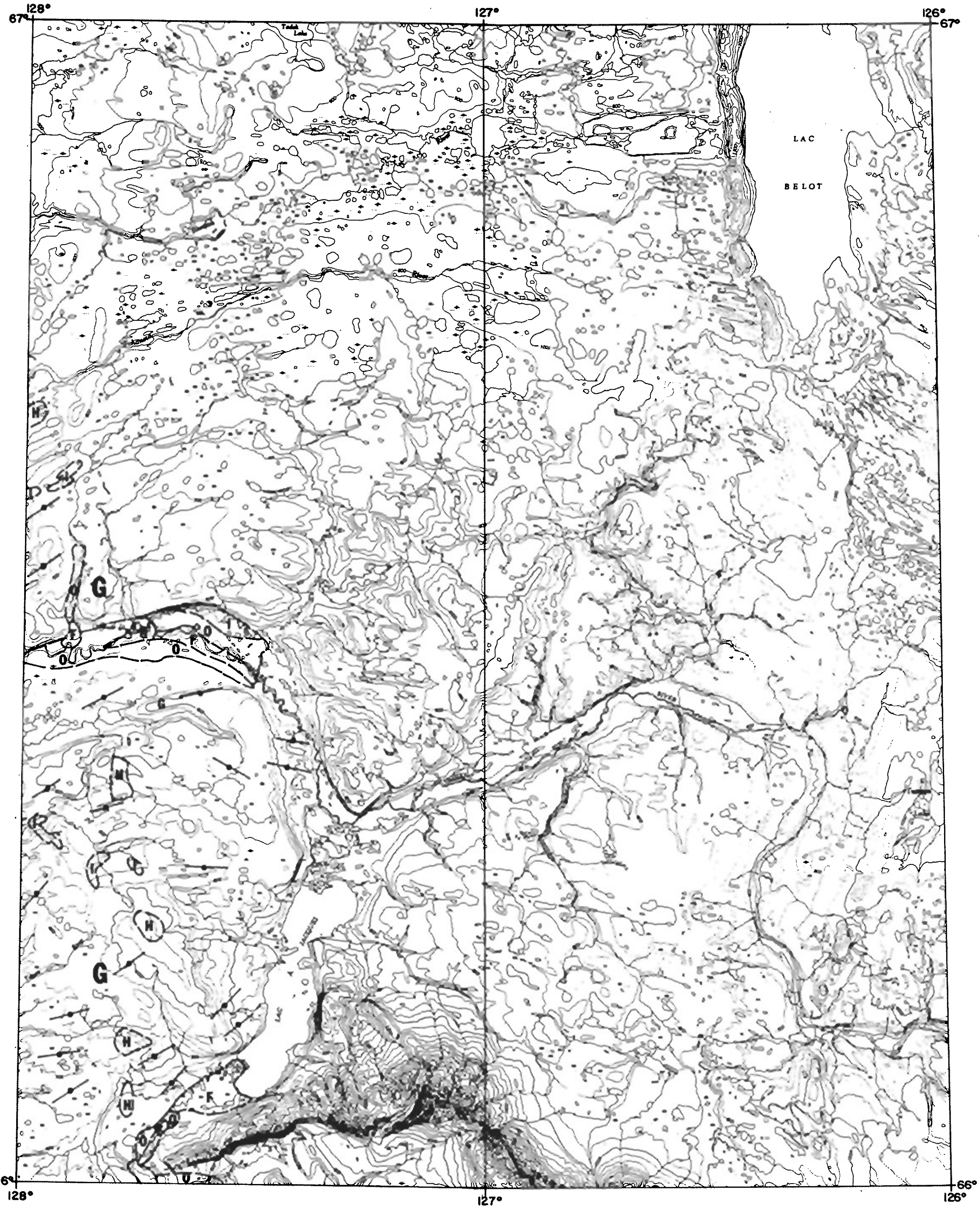

LAC BELOT

96L

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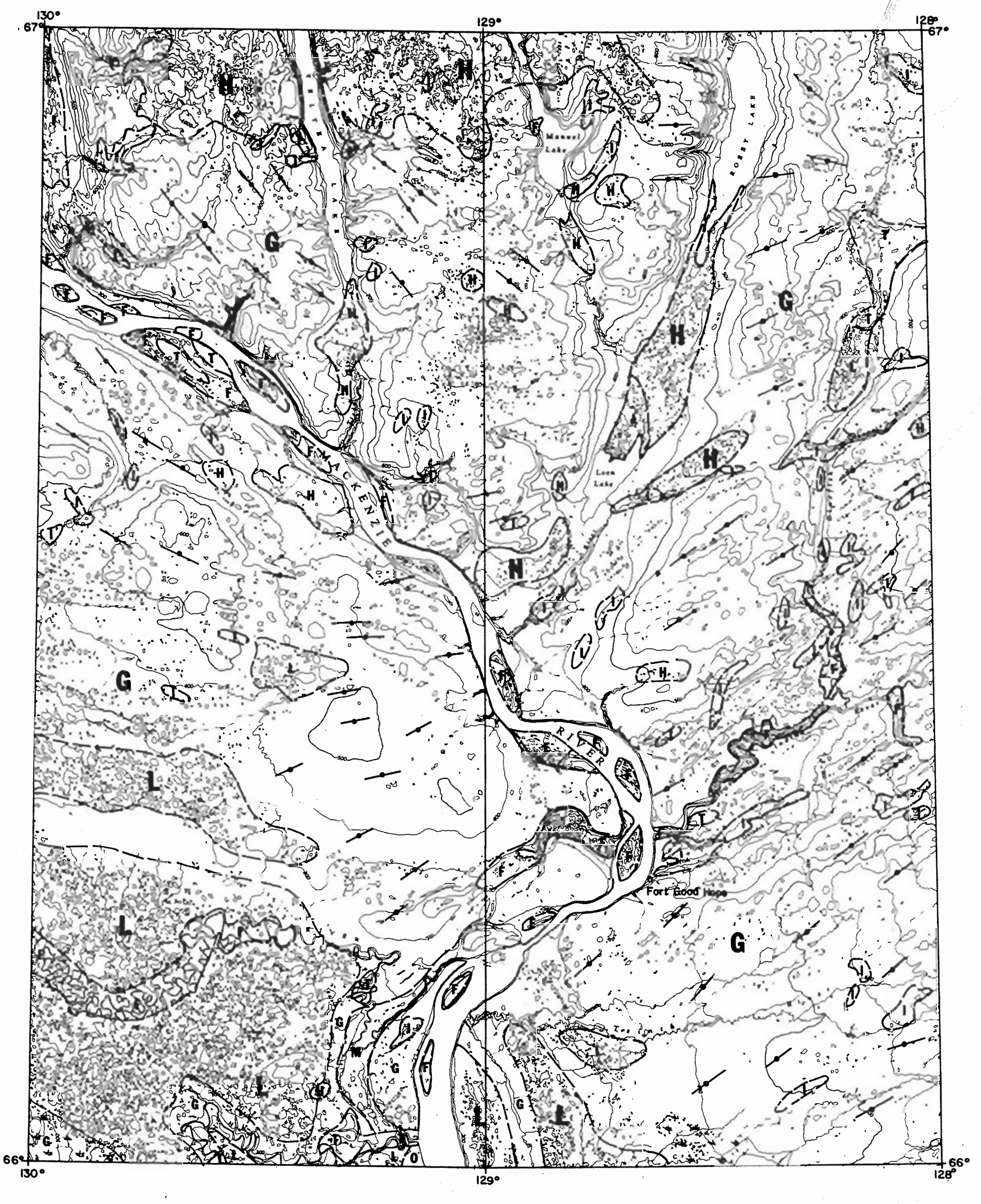

FORT GOOD HOPE

106 I

RECONNAISSANCE SURFICIAL HYDROGEOLOGY MAP

GENERALIZED HYDROGEOLOGY MAP OF SURFICIAL DEPOSITS
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

(Note: Estimates of yield are probable, not absolute, maximum figures, which also exclude possible buried bedrock valleys partly filled with granular strata but having no surface expression)

LEGEND

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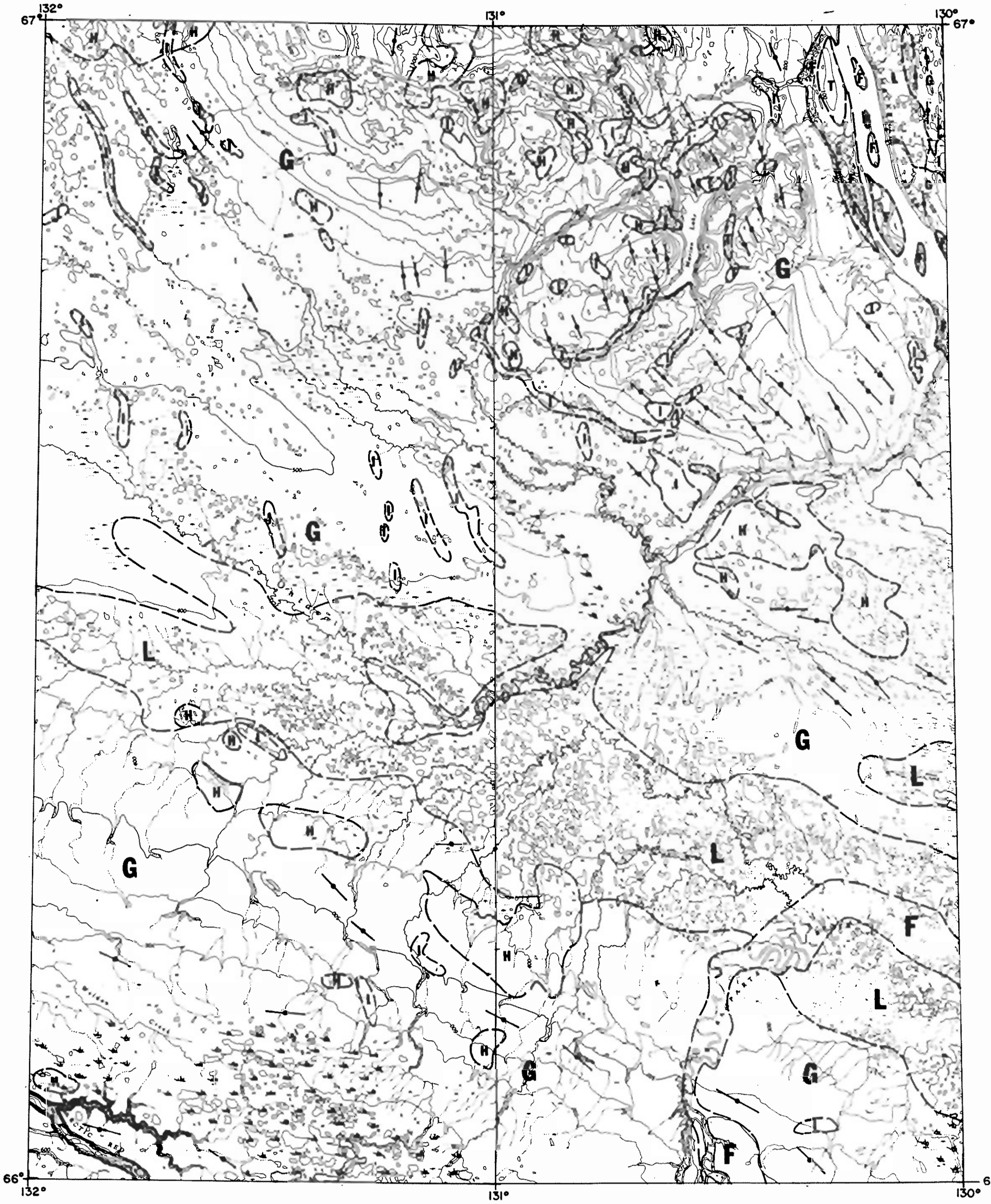

ONTARATUE RIVER

106 J

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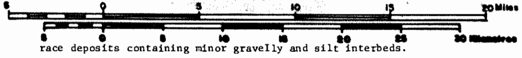
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES



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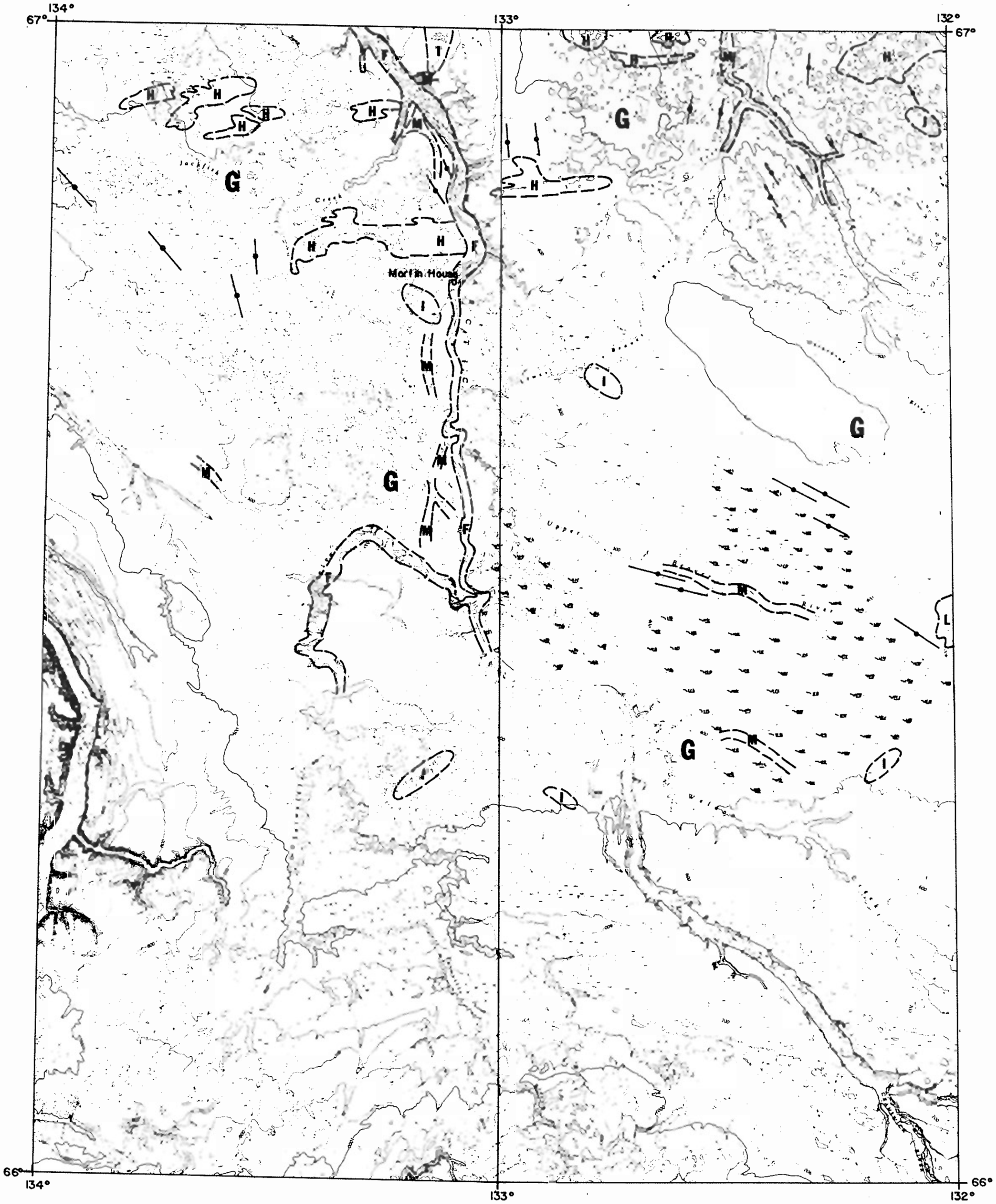

MARTIN HOUSE

106 K

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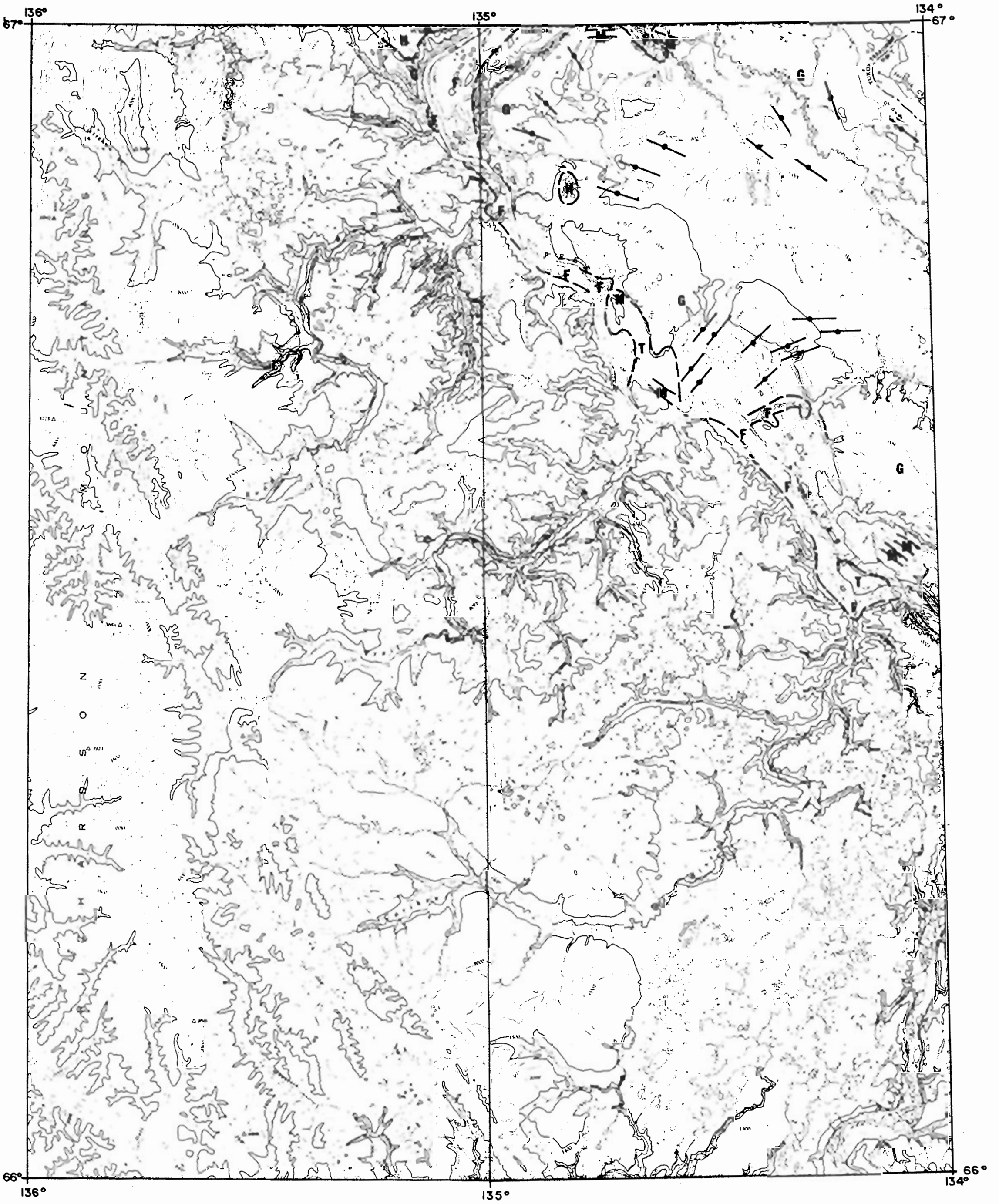
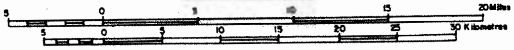


TRAIL RIVER

106 L

RECONNAISSANCE SURFICIAL HYDROGEOLOGY MAP



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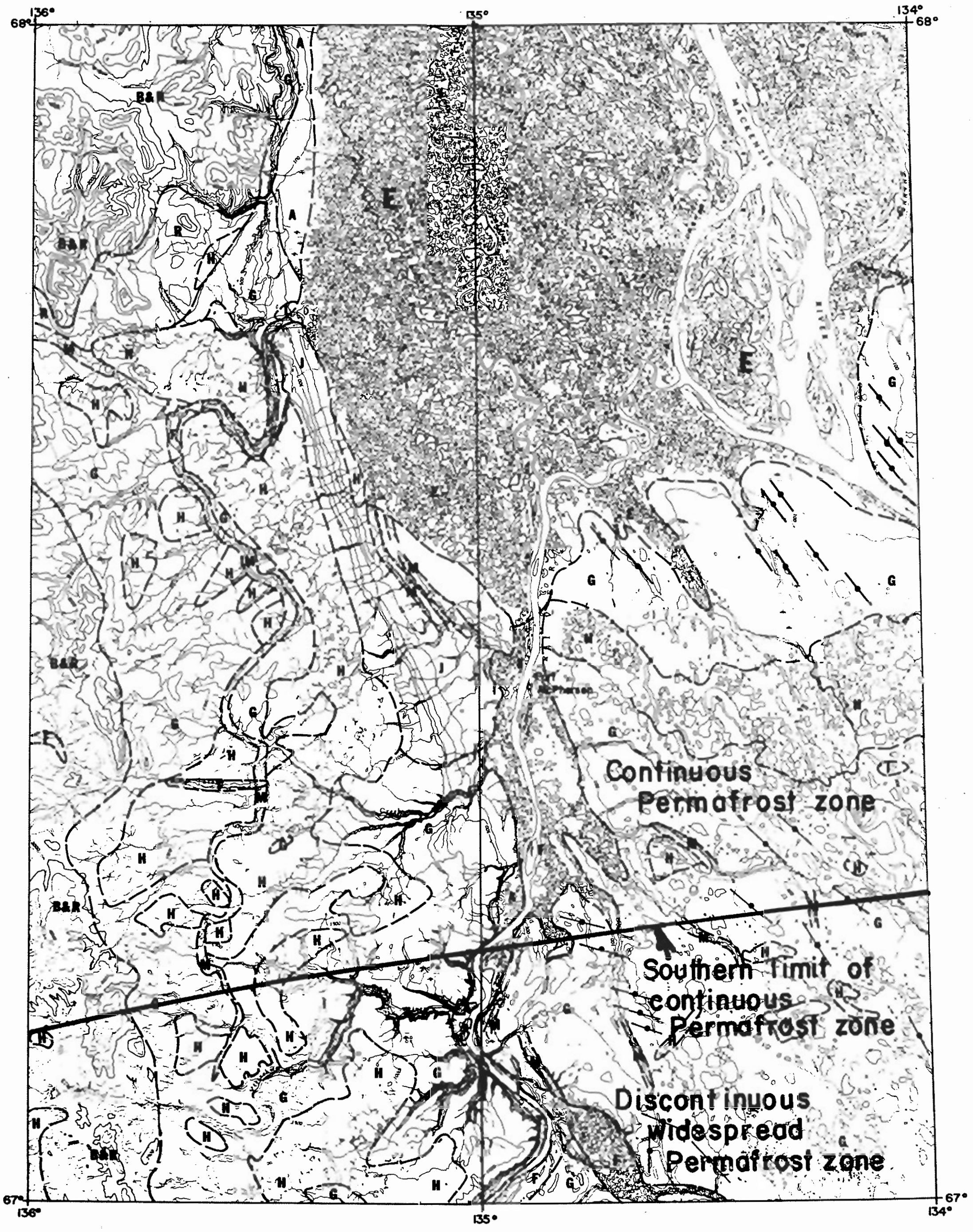

FORT McPHERSON

106M

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B,R,K YIELDS FROM PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS ARE EXPECTED TO VARY FROM LESS THAN 1 IGPM IN THICK SHALE SEQUENCES TO POSSIBLY 250 IGPM AT SELECT LOCATIONS IN HIGHLY DISTURBED AND FRACTURED NON-MARINE SANDSTONE AND POROUS CARBONATE ROCKS AND IN THICK UNCEMENTED TERTIARY SAND AND GRAVEL (SEE, ALSO, THE ACCOMPANYING GENERALIZED BEDROCK HYDROGEOLOGY MAP) Highly variable ground-water source, both from the standpoints of water quality and quantity. Potentially suitable for domestic supplies, villages and some industries in certain localities.

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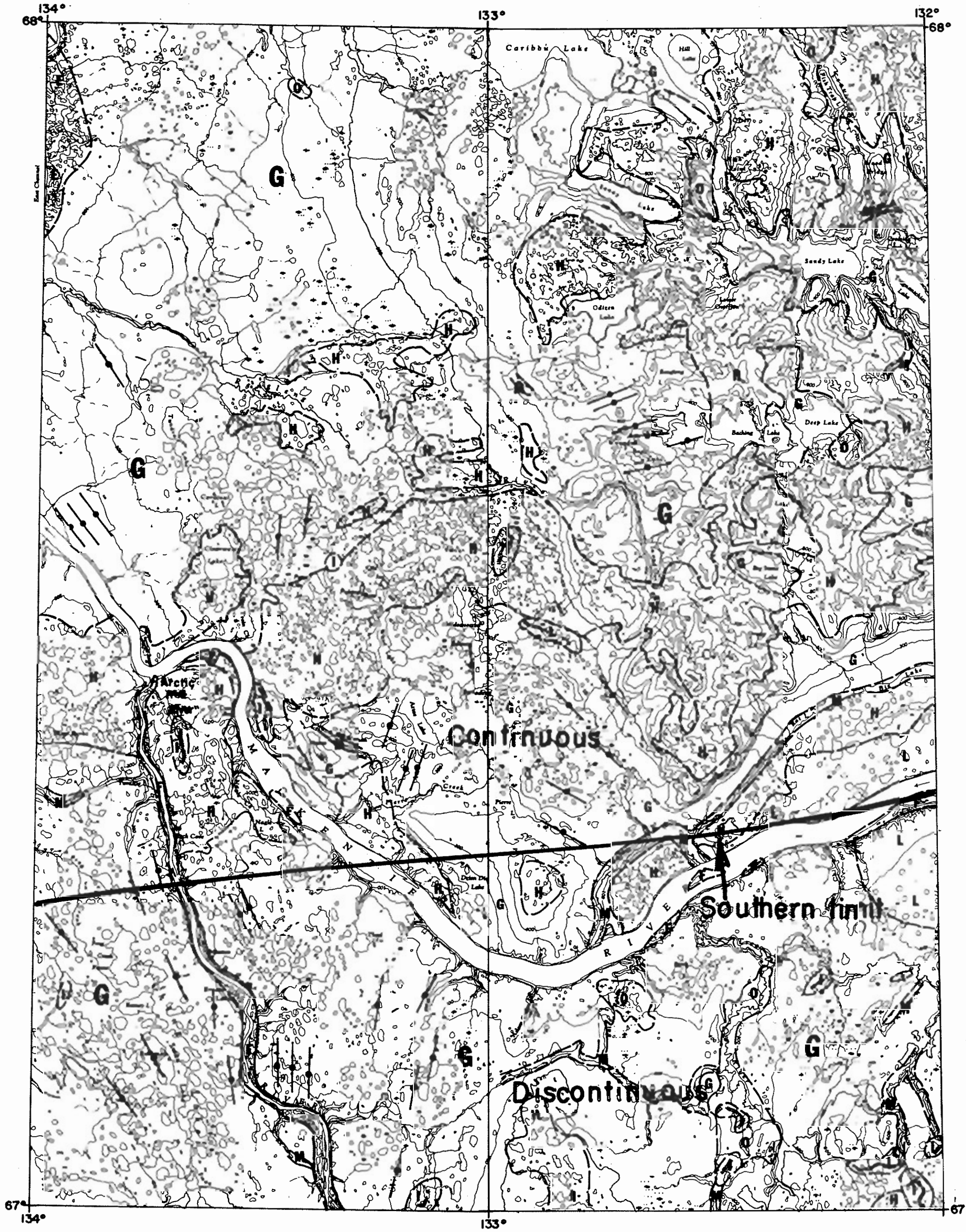
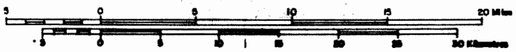


ARCTIC RED RIVER

106N

RECONNAISSANCE SURFICIAL HYDROGEOLOGY MAP



GENERALIZED HYDROGEOLOGY MAP OF SURFICIAL DEPOSITS
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

(Note: Estimates of yield are probable, not absolute, maximum figures, which also exclude possible buried bedrock valleys partly filled with granular strata but having no surface expression)

LEGEND

Symbol	Explanation
F	PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS MAY YIELD UP TO 50 TO 100 IGPM AND LOCALLY, IN THICKER MORE PERMEABLE AQUIFERS, 100 TO 500 IGPM OF GOOD QUALITY WATER Potentially good water supplies for tourist and construction camps, villages and towns, and industries -- especially those thick coarse aquifers in major river valleys tributary to the Mackenzie River. Consists mainly of alluvial sand and gravel below the active and wooded (inactive) floodplains and below coarse sandy and gravelly point-bar deposits on steeper-gradient sections of larger meandering rivers. (Considerable test drilling may be required to locate large aquifers in the lower reaches of tributaries and in the Mackenzie River flood plain. Chief well installation problems are flooding and excessive lateral and vertical river erosion. Rivers with headwaters in the Mackenzie Mountains are extremely flashy and floods can be highly destructive.
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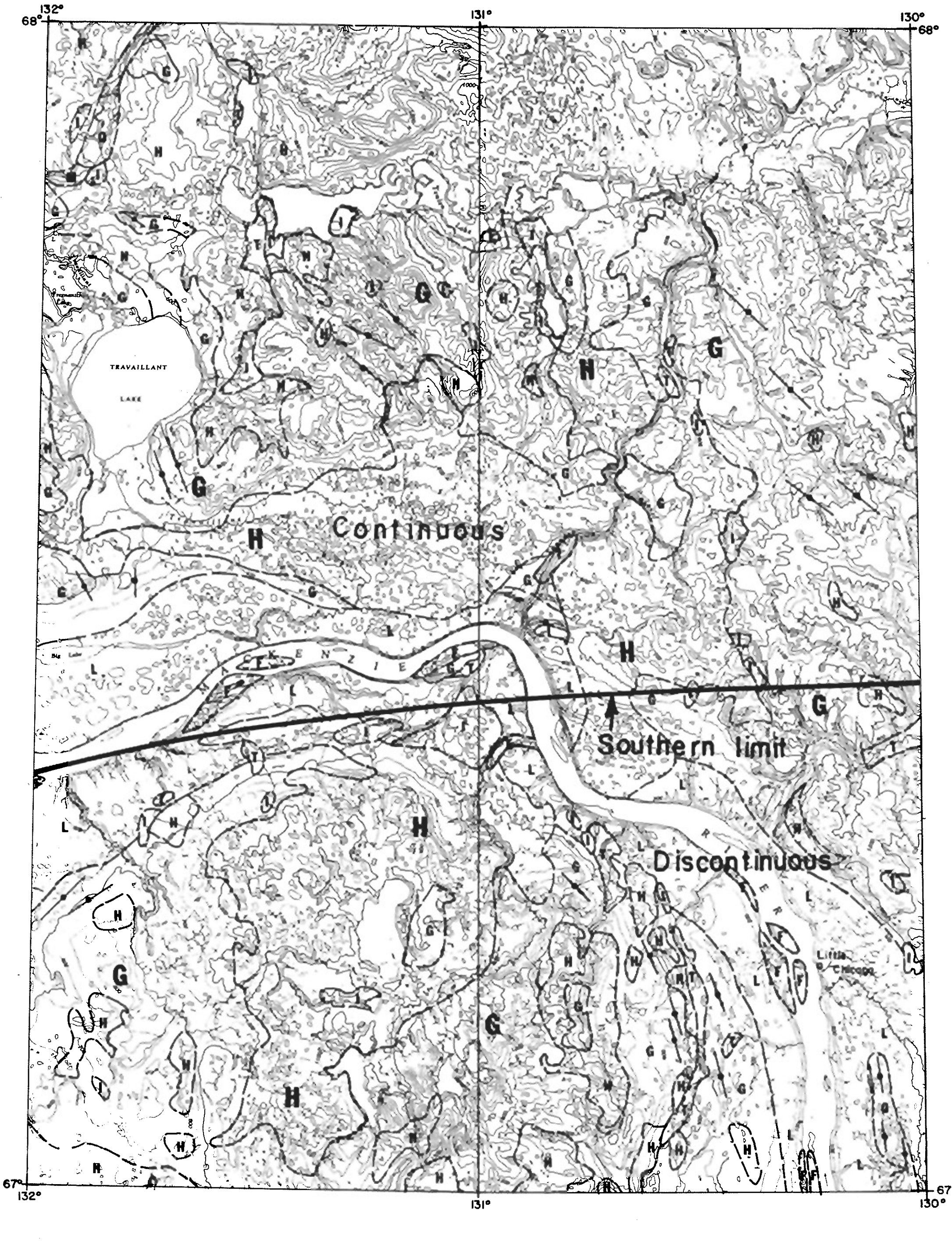
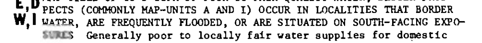


TRAVAILLANT LAKE

106 O

RECONNAISSANCE SURFICIAL HYDROGEOLOGY MAP



GENERALIZED HYDROGEOLOGY MAP OF SURFICIAL DEPOSITS
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FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

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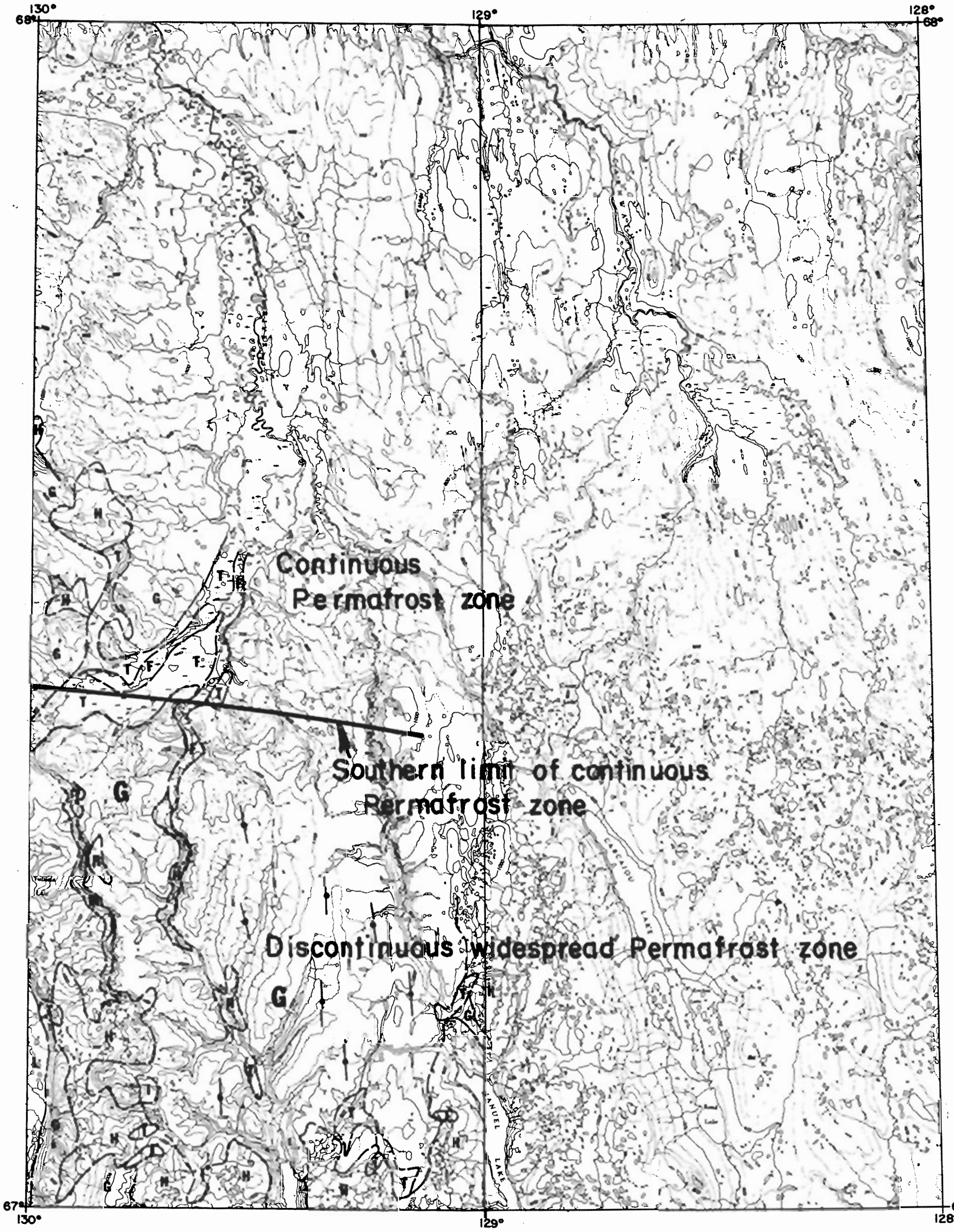
Map 22



CANOT LAKE

106 P

RECONNAISSANCE SURFICIAL HYDROGEOLOGY MAP

GENERALIZED HYDROGEOLOGY MAP OF SURFICIAL DEPOSITS
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

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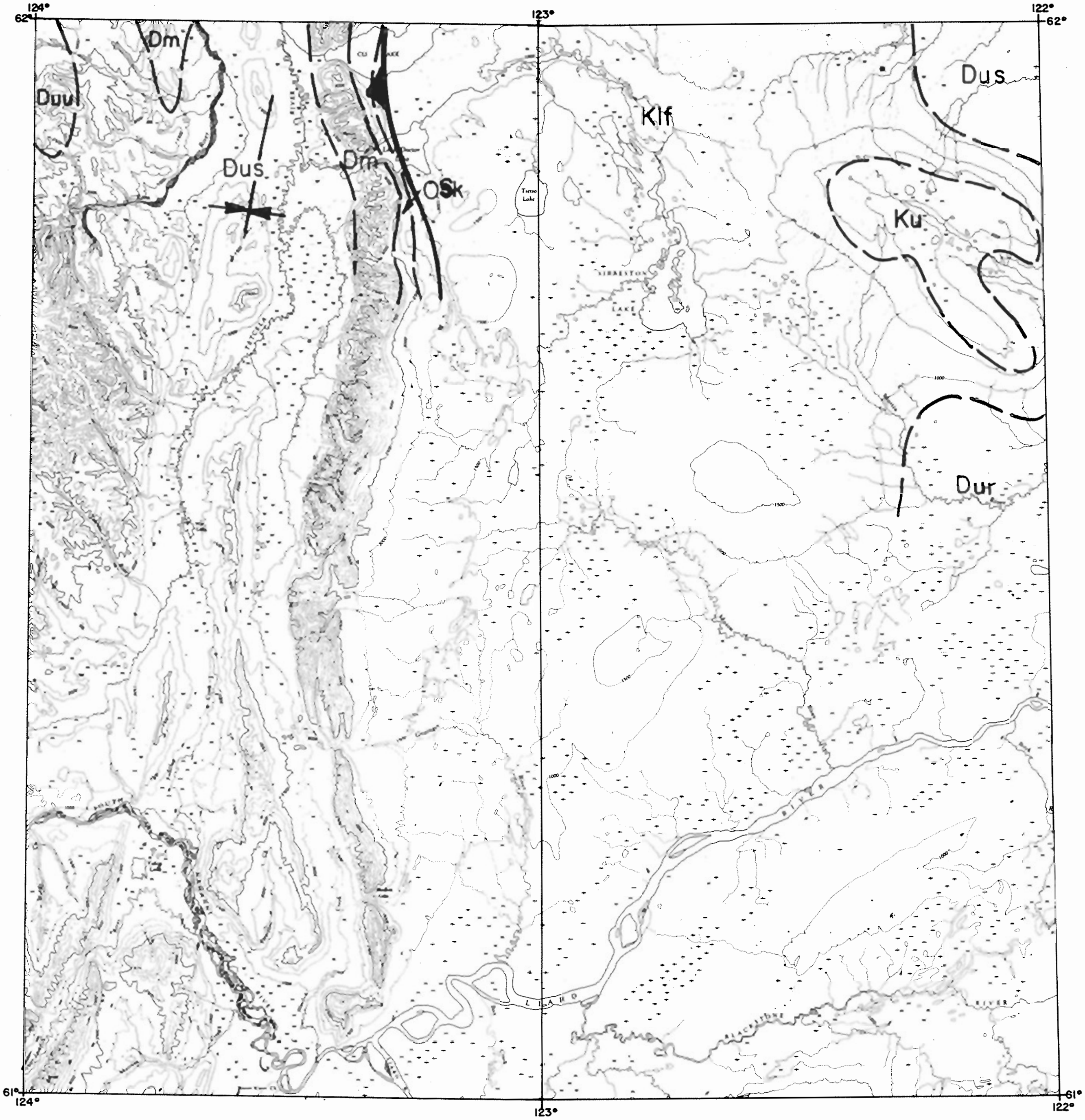
Map 23



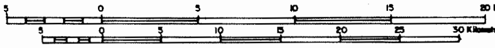
SIBBESTON LAKE

95G

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP

LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

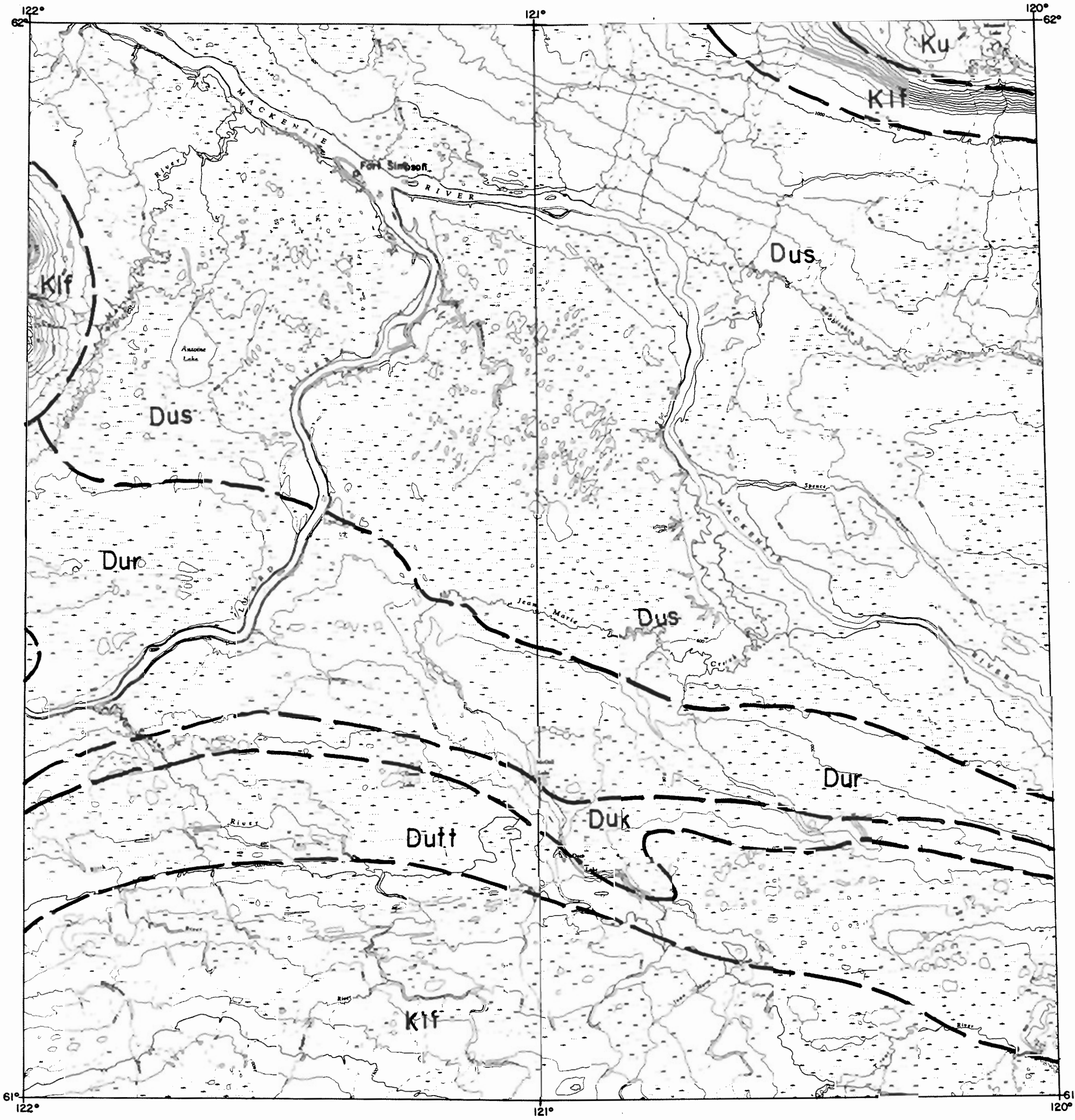
(Note: The entire study-area is underlain by widespread permafrost in the discontinuous permafrost zone; also, estimates of yields refer to probable, not absolute, maximum figures and to generally more highly disturbed, fractured, and porous zones within the formations)



Symbol	Explanation
T	Tertiary non-marine sand, gravel, conglomerate, shale, sandstone, coal. Expect maximum yields of 50 Igpm of generally fair to good quality waters
Ku	Upper Cretaceous mainly non-marine sandstone and shale. Expect maximum yields of 25 Igpm of generally poor to locally fair quality waters
Kl	Lower Cretaceous mainly marine shale and sandstone. Expect maximum yields of 1 Igpm of poor quality sulphate waters
Klf	Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
K	Upper and Lower Cretaceous unnamed and undivided mainly marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor quality waters
CPa	Carboniferous (Pennsylvanian) and Permian unnamed and undivided sandstone and conglomerate. Expect maximum yields of 25 Igpm of poor to locally *fair* quality waters
Dur	Upper Devonian Redknife Formation mainly marine shale with minor sandstone and limestone. Expect maximum yields of 1 Igpm of generally poor quality waters
Duu	Upper Devonian unnamed mainly non-marine shale, siltstone, limestone, and sandstone. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters
Dui	Upper Devonian Imperial Formation mainly non-marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
Duk	Upper Devonian Kakisa Formation limestone. Expect maximum yields of 5 Igpm of poor to locally fair quality bicarbonate waters
Dutt	Upper Devonian Trout River and Tetcho Formations consisting mainly of limestone with minor shale and sandstone. Expect maximum yields of 5 Igpm of poor to locally fair quality generally bicarbonate waters
Dus	Upper Devonian Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igpm of generally poor quality sulphate waters
Dm	Middle Devonian unnamed and undivided mainly carbonate strata with minor shale and anhydrite. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate waters
Dmk	Middle Devonian Kee Scarp Formation reefal and other limestones. Expect maximum yields of 100 Igpm of poor to locally fair quality generally bicarbonate, hard waters
Dmki	Middle Devonian Kee Scarp Formation limestone and Hare Indian calcareous shale. Expect maximum yields of 25 Igpm of variable quality generally bicarbonate, hard waters
Dmh	Middle Devonian Hume Formation limestone. Expect maximum yields of 10 Igpm of variable quality generally bicarbonate, hard waters
Dmc	Middle Devonian Canol Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
Dmci	Middle Devonian Canol and Hare Indian Formations consisting mainly of shale. Expect maximum yields of 1 Igpm of poor quality bicarbonate-sulphate waters
Dmbr	Middle Devonian Bear Rock Formation dolomite, limestone, and anhydrite. Expect maximum yields of 250 Igpm of very poor quality generally bicarbonate-sulphate waters
Dmhi	Middle Devonian Hare Indian Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
OS	Ordovician and Silurian unnamed and undivided dolomite and limestone. Expect maximum yields of 10 Igpm of highly variable quality generally bicarbonate-sulphate waters
OSk	Ordovician and Silurian Mount Kindle Formation dolomite and anhydrite and Franklin Mtn. Formation dolomite and shale. Expect maximum yields of 100 Igpm of generally poor to locally fair quality bicarbonate-sulphate waters
€cs	Cambrian Saline River Formation anhydrite gypsum and salt, Cap Mt. Formation shale and Mt. Clark Formation sandstone. Expect maximum yields of 100 Igpm of poor quality sulphate-chloride waters from the Saline River salt and anhydrite, 1 Igpm of poor quality sulphate waters from the Cap Mt. Formation shale, and 25 Igpm of fair quality waters from the Mt. Clark Formation sandstone
P€	Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

Tectonic symbols: ▲▲ thrust fault with teeth indicating direction of dip; ✛ anticline; ✛ syncline

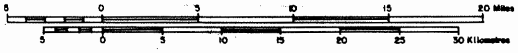
Map 1



FORT SIMPSON

95H

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP



LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

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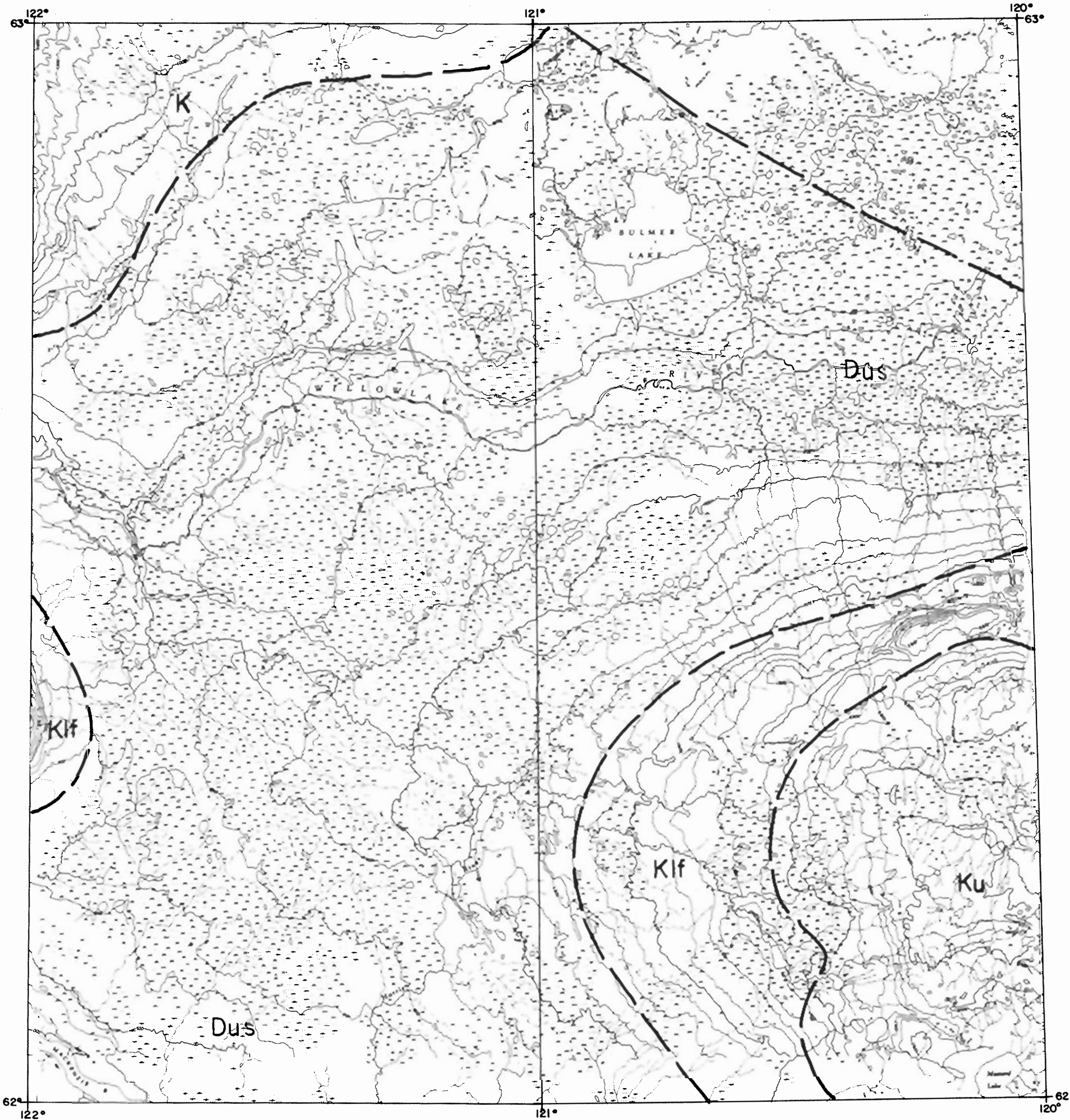
Duk	Upper Devonian Kakisa Formation limestone. Expect maximum yields of 5 Igpm of poor to locally fair quality bicarbonate waters
Dutt	Upper Devonian Trout River and Tetcho Formations consisting mainly of limestone with minor shale and sandstone. Expect maximum yields of 5 Igpm of poor to locally fair quality generally bicarbonate waters
Dus	Upper Devonian Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igpm of generally poor quality sulphate waters
Dm	Middle Devonian unnamed and undivided mainly carbonate strata with minor shale and anhydrite. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate waters
Dmk	Middle Devonian Kee Scarp Formation reefal and other limestones. Expect maximum yields of 100 Igpm of poor to locally fair quality generally bicarbonate, hard waters
Dmki	Middle Devonian Kee Scarp Formation limestone and Hare Indian calcareous shale. Expect maximum yields of 25 Igpm of variable quality generally bicarbonate, hard waters
Dmh	Middle Devonian Hume Formation limestone. Expect maximum yields of 10 Igpm of variable quality generally bicarbonate, hard waters
Dmc	Middle Devonian Canol Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
Dmci	Middle Devonian Canol and Hare Indian Formations consisting mainly of shale. Expect maximum yields of 1 Igpm of poor quality bicarbonate-sulphate waters
Dmbr	Middle Devonian Bear Rock Formation dolomite, limestone, and anhydrite. Expect maximum yields of 250 Igpm of very poor quality generally bicarbonate-sulphate waters
Dmhi	Middle Devonian Hare Indian Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
OS	Ordovician and Silurian unnamed and undivided dolomite and limestone. Expect maximum yields of 10 Igpm of highly variable quality generally bicarbonate-sulphate waters
OSk	Ordovician and Silurian Mount Kindle Formation dolomite and anhydrite and Franklin Mtn. Formation dolomite and shale. Expect maximum yields of 100 Igpm of generally poor to locally fair quality bicarbonate-sulphate waters
€cs	Cambrian Saline River Formation anhydrite gypsum and salt, Cap Mt. Formation shale and Mt. Clark Formation sandstone. Expect maximum yields of 100 Igpm of poor quality sulphate-chloride waters from the Saline River salt and anhydrite, 1 Igpm of poor quality sulphate waters from the Cap Mt. Formation shale, and 25 Igpm of fair quality waters from the Mt. Clark Formation sandstone
P€	Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

Tectonic symbols: ▲▲ thrust fault with teeth indicating direction of dip; ┼ anticline; ┼ syncline

Map 2



BULMER LAKE

95 I

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP

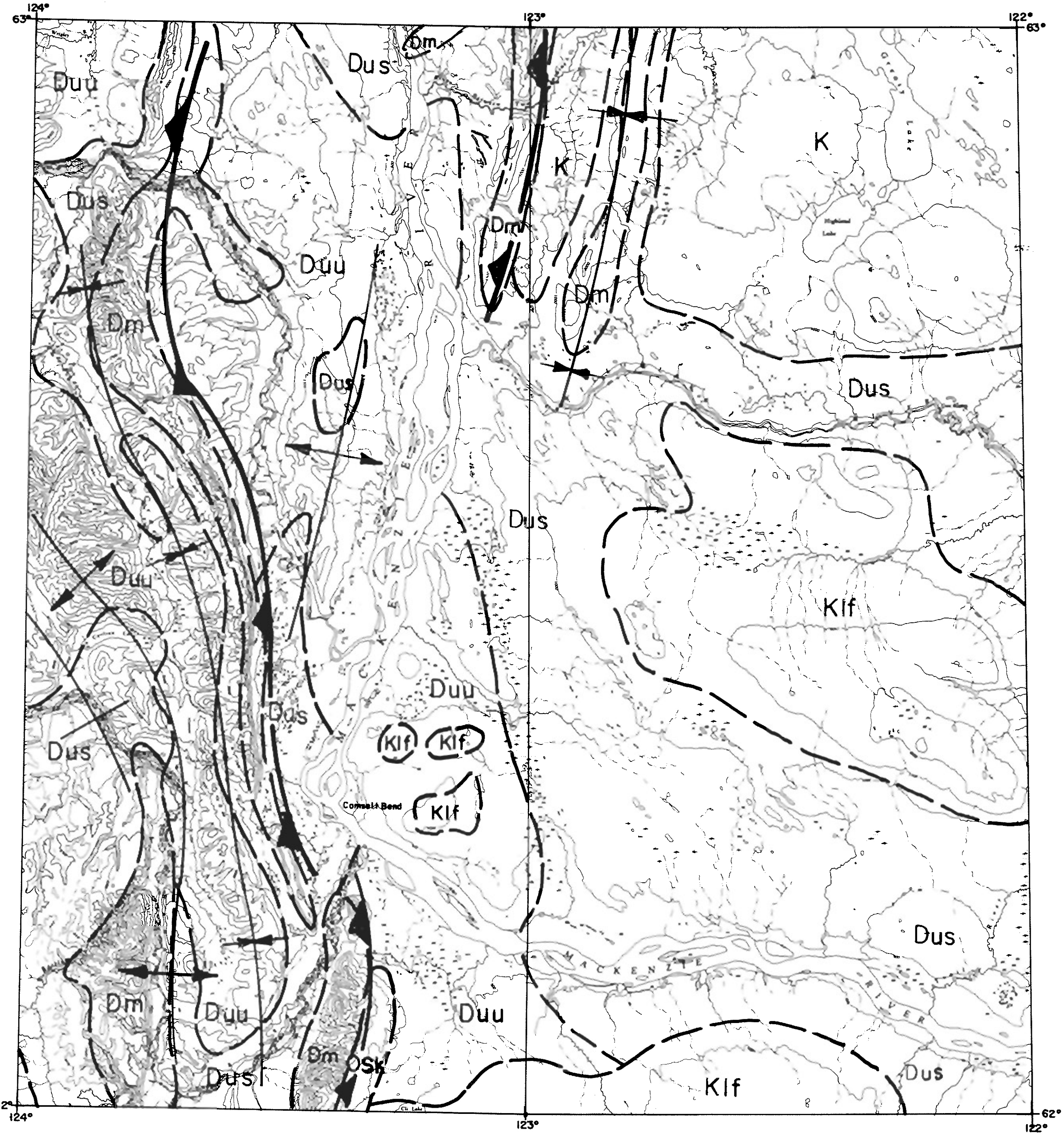
LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

(Note: The entire study-area is underlain by widespread permafrost in the discontinuous permafrost zone; also, estimates of yields refer to probable, not absolute, maximum figures and to generally more highly disturbed, fractured, and porous zones within the formations)

Symbol	Explanation
T	Tertiary non-marine sand, gravel, conglomerate, shale, sandstone, coal. Expect maximum yields of 50 Igpm of generally fair to good quality waters
Ku	Upper Cretaceous mainly non-marine sandstone and shale. Expect maximum yields of 25 Igpm of generally poor to locally fair quality waters
Kl	Lower Cretaceous mainly marine shale and sandstone. Expect maximum yields of 1 Igpm of poor quality sulphate waters
Klf	Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
K	Upper and Lower Cretaceous unnamed and undivided mainly marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor quality waters
CPa	Carboniferous (Pennsylvanian) and Permian unnamed and undivided sandstone and conglomerate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
Dur	Upper Devonian Redknife Formation mainly marine shale with minor sandstone and limestone. Expect maximum yields of 1 Igpm of generally poor quality waters
Duu	Upper Devonian unnamed mainly non-marine shale, siltstone, limestone, and sandstone. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters
Dui	Upper Devonian Imperial Formation mainly non-marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
Duk	Upper Devonian Kakisa Formation limestone. Expect maximum yields of 5 Igpm of poor to locally fair quality bicarbonate waters
Dutt	Upper Devonian Trout River and Tetcho Formations consisting mainly of limestone with minor shale and sandstone. Expect maximum yields of 5 Igpm of poor to locally fair quality generally bicarbonate waters
Dus	Upper Devonian Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igpm of generally poor quality sulphate waters
Dm	Middle Devonian unnamed and undivided mainly carbonate strata with minor shale and anhydrite. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate waters
Dmk	Middle Devonian Kee Scarp Formation reefal and other limestones. Expect maximum yields of 100 Igpm of poor to locally fair quality generally bicarbonate, hard waters
Dmki	Middle Devonian Kee Scarp Formation limestone and Hare Indian calcareous shale. Expect maximum yields of 25 Igpm of variable quality generally bicarbonate, hard waters
Dmh	Middle Devonian Hume Formation limestone. Expect maximum yields of 10 Igpm of variable quality generally bicarbonate, hard waters
Dmc	Middle Devonian Canol Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
Dmcl	Middle Devonian Canol and Hare Indian Formations consisting mainly of shale. Expect maximum yields of 1 Igpm of poor quality bicarbonate-sulphate waters
Dmbr	Middle Devonian Bear Rock Formation dolomite, limestone, and anhydrite. Expect maximum yields of 250 Igpm of very poor quality generally bicarbonate-sulphate waters
Dmhi	Middle Devonian Hare Indian Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
OS	Ordovician and Silurian unnamed and undivided dolomite and limestone. Expect maximum yields of 1.0 Igpm of highly variable quality generally bicarbonate-sulphate waters
OSk	Ordovician and Silurian Mount Kindle Formation dolomite and anhydrite and Franklin Mtn. Formation dolomite and shale. Expect maximum yields of 100 Igpm of generally poor to locally fair quality bicarbonate-sulphate waters
€cs	Cambrian Saline River Formation anhydrite, gypsum and salt, Cap Mt. Formation shale and Mt. Clark Formation sandstone. Expect maximum yields of 100 Igpm of poor quality sulphate-chloride waters from the Saline River salt and anhydrite, 1 Igpm of poor quality sulphate waters from the Cap Mt. Formation shale, and 25 Igpm of fair quality waters from the Mt. Clark Formation sandstone
P̶	Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

Tectonic symbols: ▲▲ thrust fault with teeth indicating direction of dip; ┼ anticline; ┼ syncline

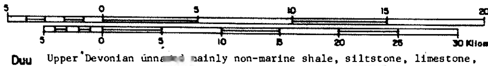
Map 3.



CAMSELL BEND

95J

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP



LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

(Note: The entire study-area is underlain by widespread permafrost in the discontinuous permafrost zone; also, estimates of yields refer to probable, not absolute, maximum figures and to generally more highly disturbed, fractured, and porous zones within the formations)

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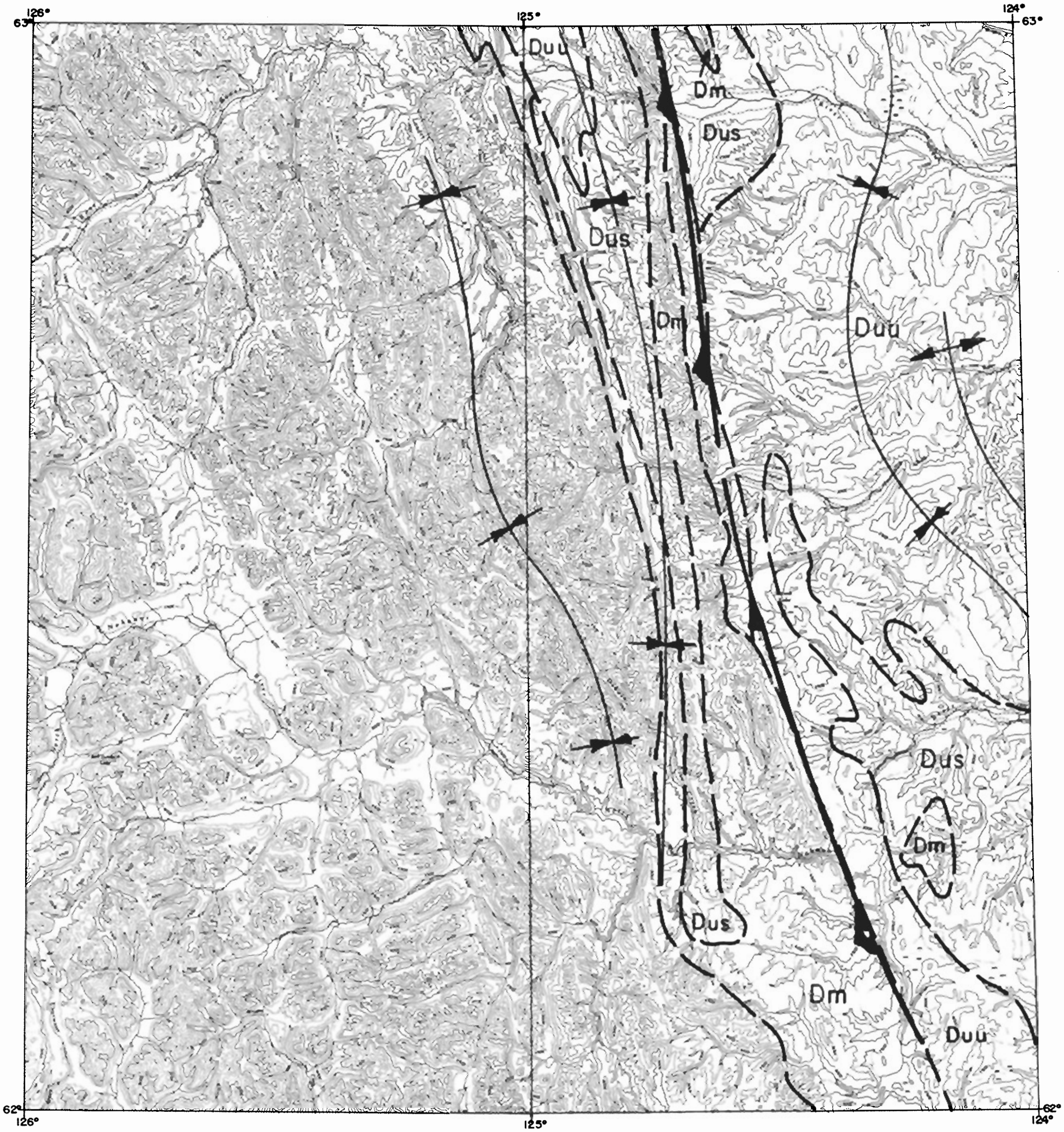
Kl	Lower Cretaceous mainly marine shale and sandstone. Expect maximum yields of 1 Igpm of poor quality sulphate waters
Klf	Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
K	Upper and Lower Cretaceous unnamed and undivided mainly marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor quality waters
CPa	Carboniferous (Pennsylvanian) and Permian unnamed and undivided sandstone and conglomerate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
Dur	Upper Devonian Redknife Formation mainly marine shale with minor sandstone and limestone. Expect maximum yields of 1 Igpm of generally poor quality waters
Duu	Upper Devonian unnamed mainly non-marine shale, siltstone, limestone, and sandstone. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters
Dui	Upper Devonian Imperial Formation mainly non-marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
Duk	Upper Devonian Kakisa Formation limestone. Expect maximum yields of 5 Igpm of poor to locally fair quality bicarbonate waters
Dutt	Upper Devonian Trout River and Tetcho Formations consisting mainly of limestone with minor shale and sandstone. Expect maximum yields of 5 Igpm of poor to locally fair quality generally bicarbonate waters
Dus	Upper Devonian Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igpm of generally poor quality sulphate waters
Dm	Middle Devonian unnamed and undivided mainly carbonate strata with minor shale and anhydrite. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate waters
Dmk	Middle Devonian Kee Scarp Formation reefal and other limestones. Expect maximum yields of 100 Igpm of poor to locally fair quality generally bicarbonate, hard waters
Dmki	Middle Devonian Kee Scarp Formation limestone and Hare Indian calcareous shale. Expect maximum yields of 25 Igpm of variable quality generally bicarbonate, hard waters
Dmh	Middle Devonian Hume Formation limestone. Expect maximum yields of 10 lgpm of variable quality generally bicarbonate, hard waters
Dmc	Middle Devonian Canol Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
Dmci	Middle Devonian Canol and Hare Indian Formations consisting mainly of shale. Expect maximum yields of 1 Igpm of poor quality bicarbonate-sulphate waters
Dmbr	Middle Devonian Bear Rock Formation dolomite, limestone, and anhydrite. Expect maximum yields of 250 Igpm of very poor quality generally bicarbonate-sulphate waters
Dmhi	Middle Devonian Hare Indian Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
OS	Ordovician and Silurian unnamed and undivided dolomite and limestone. Expect maximum yields of 10 Igpm of highly variable quality generally bicarbonate-sulphate waters
OSk	Ordovician and Silurian Mount Kindle Formation dolomite and anhydrite and Franklin Mtn. Formation dolomite and shale. Expect maximum yields of 100 Igpm of generally poor to locally fair quality bicarbonste-sulphate waters
€cs	Cambrian Saline River Formation anhydrite gypsum and salt, Cap Mt. Formation shale and Mt. Clark Formation sandstone. Expect maximum yields of 100 Igpm of poor quality sulphate-chloride waters from the Saline River salt and anhydrite, 1 Igpm of poor quality sulphate waters from the Cap Mt. Formation shale, and 25 Igpm of fair quality watera from the Mt. Clark Formation sandstone
P€	Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

Tectonic symbols: ▲▲ thrust fault with teeth indicating direction of dip; ┼ anticline; ┼ syncline

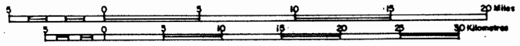
Map 4



ROOT RIVER

95K

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP



LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

(Note: The entire study-area is underlain by widespread permafrost in the discontinuous permafrost zone; also, estimates of yields refer to probable, not absolute, maximum figures and to generally more highly disturbed, fractured, and porous zones within the formations)

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Kl	Lower Cretaceous mainly marine shale and sandstone. Expect maximum yields of 1 Igpm of poor quality sulphate waters
Klf	Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
K	Upper and Lower Cretaceous unnamed and undivided mainly marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor quality waters
CPa	Carboniferous (Pennsylvanian) and Permian unnamed and undivided sandstone and conglomerate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
Dur	Upper Devonian Redknife Formation mainly marine shale with minor sandstone and limestone. Expect maximum yields of 1 Igpm of generally poor quality waters
Duu	Upper Devonian unnamed mainly non-marine shale, siltstone, limestone, and sandstone. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters
Dui	Upper Devonian Imperial Formation mainly non-marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
Duk	Upper Devonian Kakisa Formation limestone. Expect maximum yields of 5 Igpm of poor to locally fair quality bicarbonate waters
Dutt	Upper Devonian Trout River and Tetcho Formations consisting mainly of limestone with minor shale and sandstone. Expect maximum yields of 5 Igpm of poor to locally fair quality generally bicarbonate waters
Dus	Upper Devonian Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igpm of generally poor quality sulphate waters
Dm	Middle Devonian unnamed and undivided mainly carbonate strata with minor shale and anhydrite. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate waters
Dmk	Middle Devonian Kee Scarp Formation reefal and other limestones. Expect maximum yields of 100 Igpm of poor to locally fair quality generally bicarbonate, hard waters
Dmki	Middle Devonian Kee Scarp Formation limestone and Hare Indian calcareous shale. Expect maximum yields of 25 Igpm of variable quality generally bicarbonate, hard waters
Dmh	Middle Devonian Hume Formation limestone. Expect maximum yields of 10 Igpm of variable quality generally bicarbonate, hard waters
Dmc	Middle Devonian Canol Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
Dmci	Middle Devonian Canol and Hare Indian Formations consisting mainly of shale. Expect maximum yields of 1 Igpm of poor quality bicarbonate-sulphate waters
Dmbr	Middle Devonian Bear Rock Formation dolomite, limestone, and anhydrite. Expect maximum yields of 250 Igpm of very poor quality generally bicarbonate-sulphate waters
Dmhi	Middle Devonian Hare Indian Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
OS	Ordovician and Silurian unnamed and undivided dolomite and limestone. Expect maximum yields of 10 Igpm of highly variable quality generally bicarbonate-sulphate waters
OSk	Ordovician and Silurian Mount Kindle Formation dolomite and anhydrite and Franklin Mtn. Formation dolomite and shale. Expect maximum yields of 100 Igpm of generally poor to locally fair quality bicarbonate-sulphate waters
€cs	Cambrian Saline River Formation anhydrite gypsum and salt, Cap Mt. Formation shale and Mt. Clark Formation sandstone. Expect maximum yields of 100 Igpm of poor quality sulphate-chloride waters from the Saline River salt and anhydrite, 1 Igpm of poor quality sulphate waters from the Cap Mt. Formation shale, and 25 Igpm of fair quality waters from the Mt. Clark Formation sandstone
Ꝑ	Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

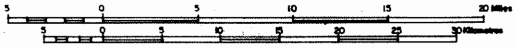
Tectonic symbols: ▲▲ thrust fault with teeth indicating direction of dip; ✛ anticline; ✛ syncline

Map 5

DAHADINNI RIVER

95N

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP



LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

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Ku	Upper Cretaceous mainly non-marine sandstone and shale. Expect maximum yields of 25 Igpm of generally poor to locally fair quality waters
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Klf	Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
K	Upper and Lower Cretaceous unnamed and undivided mainly marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor quality waters
CPa	Carboniferous (Pennsylvanian) and Permian unnamed and undivided sandstone and conglomerate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
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Duu	Upper Devonian unnamed mainly non-marine shale, siltstone, limestone, and sandstone. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters
Dui	Upper Devonian Imperial Formation mainly non-marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
Duk	Upper Devonian Kakisa Formation limestone. Expect maximum yields of 5 Igpm of poor to locally fair quality bicarbonate waters
Dutt	Upper Devonian Trout River and Tetcho Formations consisting mainly of limestone with minor shale and sandstone. Expect maximum yields of 5 Igpm of poor to locally fair quality generally bicarbonate waters
Dus	Upper Devonian Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igpm of generally poor quality sulphate waters
Dm	Middle Devonian unnamed and undivided mainly carbonate strata with minor shale and anhydrite. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate waters
Dmk	Middle Devonian Kee Scarp Formation reefal and other limestones. Expect maximum yields of 100 Igpm of poor to locally fair quality generally bicarbonate, hard waters
Dmki	Middle Devonian Kee Scarp Formation limestone and Hare Indian calcareous shale. Expect maximum yields of 25 Igpm of variable quality generally bicarbonate, hard waters
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Dmci	Middle Devonian Canol and Hare Indian Formations consisting mainly of shale. Expect maximum yields of 1 Igpm of poor quality bicarbonate-sulphate waters
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P€	Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

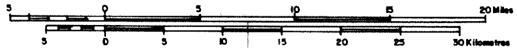
Tectonic symbols: ▲▲ thrust fault with teeth indicating direction of dip; ┼ anticline; ┼ syncline

Map 6

WRIGLEY

950

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP



LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

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Klf	Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
K	Upper and Lower Cretaceous unnamed and undivided mainly marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor quality waters
CPa	Carboniferous (Pennsylvanian) and Permian unnamed and undivided sandstone and conglomerate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
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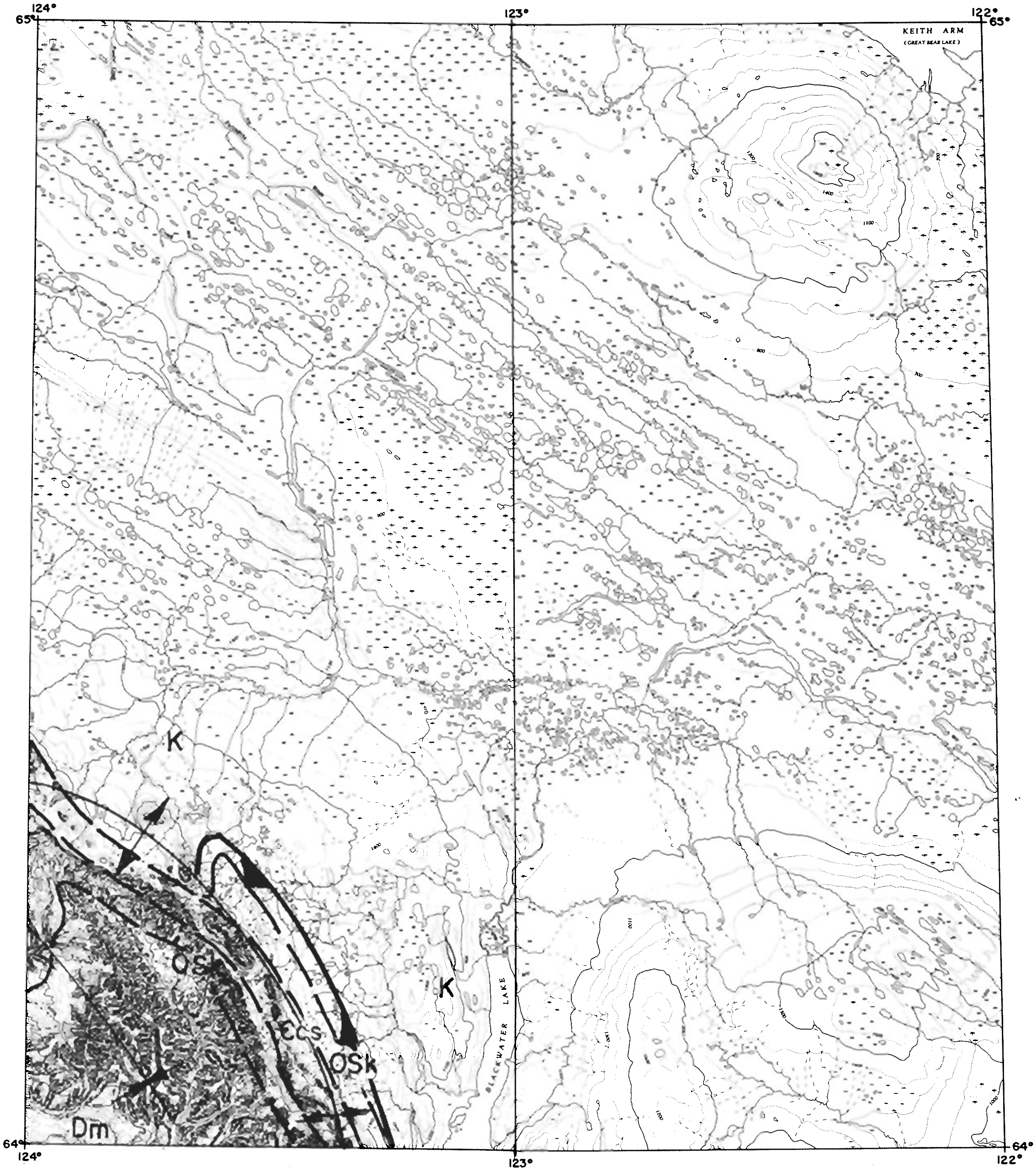
Ᵽ	Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

Tectonic symbols: ▲▲ thrust fault with teeth indicating direction of dip; ┼ anticline; ┼ syncline

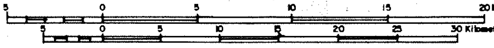
Map 7



BLACK WATER LAKE

96 B

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP



LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

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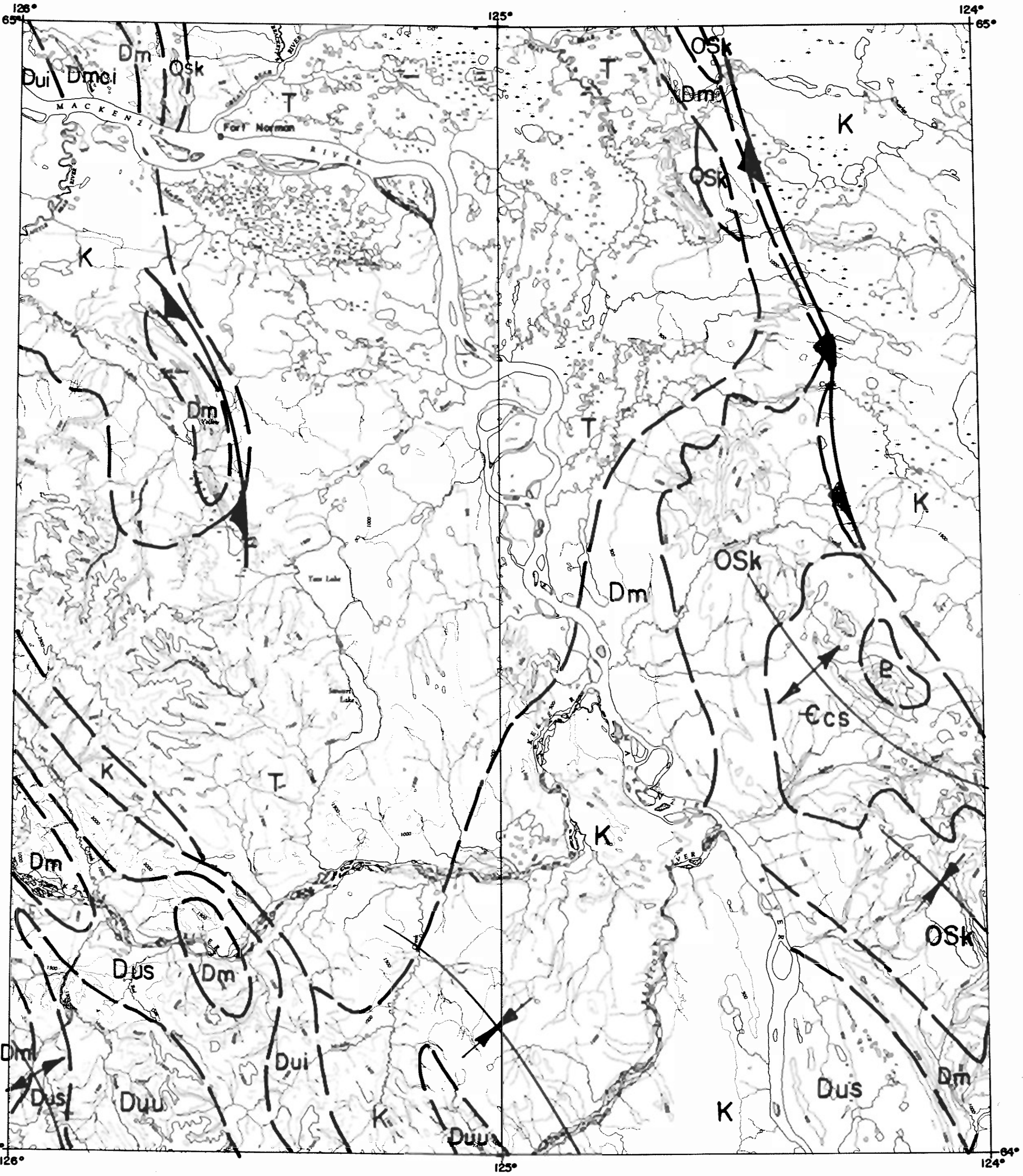
Dmk	Middle Devonian Kee Scarp Formation reefal and other limestones. Expect maximum yields of 100 Igpm of poor to locally fair quality generally bicarbonate, hard waters
Dmki	Middle Devonian Kee Scarp Formation limestone and Hare Indian calcareous shale. Expect maximum yields of 25 Igpm of variable quality generally bicarbonate, hard waters
Dmh	Middle Devonian Hume Formation limestone. Expect maximum yields of 10 Igpm of variable quality generally bicarbonate, hard waters
Dmc	Middle Devonian Canol Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
Dmcl	Middle Devonian Canol and Hare Indian Formations consisting mainly of shale. Expect maximum yields of 1 Igpm of poor quality bicarbonate-sulphate waters
Dmbr	Middle Devonian Bear Rock Formation dolomite, limestone, and anhydrite. Expect maximum yields of 250 Igpm of very poor quality generally bicarbonate-sulphate waters
Dmhi	Middle Devonian Hare Indian Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
OS	Ordovician and Silurian unnamed and undivided dolomite and limestone. Expect maximum yields of 10 Igpm of highly variable quality generally bicarbonate-sulphate waters
OSk	Ordovician and Silurian Mount Kindle Formation dolomite and anhydrite and Franklin Mtn. Formation dolomite and shale. Expect maximum yields of 100 Igpm of generally poor to locally fair quality bicarbonate-sulphate waters
€cs	Cambrian Saline River Formation anhydrite gypsum and salt, Cap Mt. Formation shale and Mt. Clark Formation sandstone. Expect maximum yields of 100 Igpm of poor quality sulphate-chloride waters from the Saline River salt and anhydrite, 1 Igpm of poor quality sulphate waters from the Cap Mt. Formation shale, and 25 Igpm of fair quality waters from the Mt. Clark Formation sandstone
P	Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

Tectonic symbols: ▲▲ thrust fault with teeth indicating direction of dip; ┼ anticline; ┼ syncline

Map 8



FORT NORMAN
96C
RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP

5 0 5 10 15 20 Miles
5 0 5 10 15 20 25 30 Kilometres

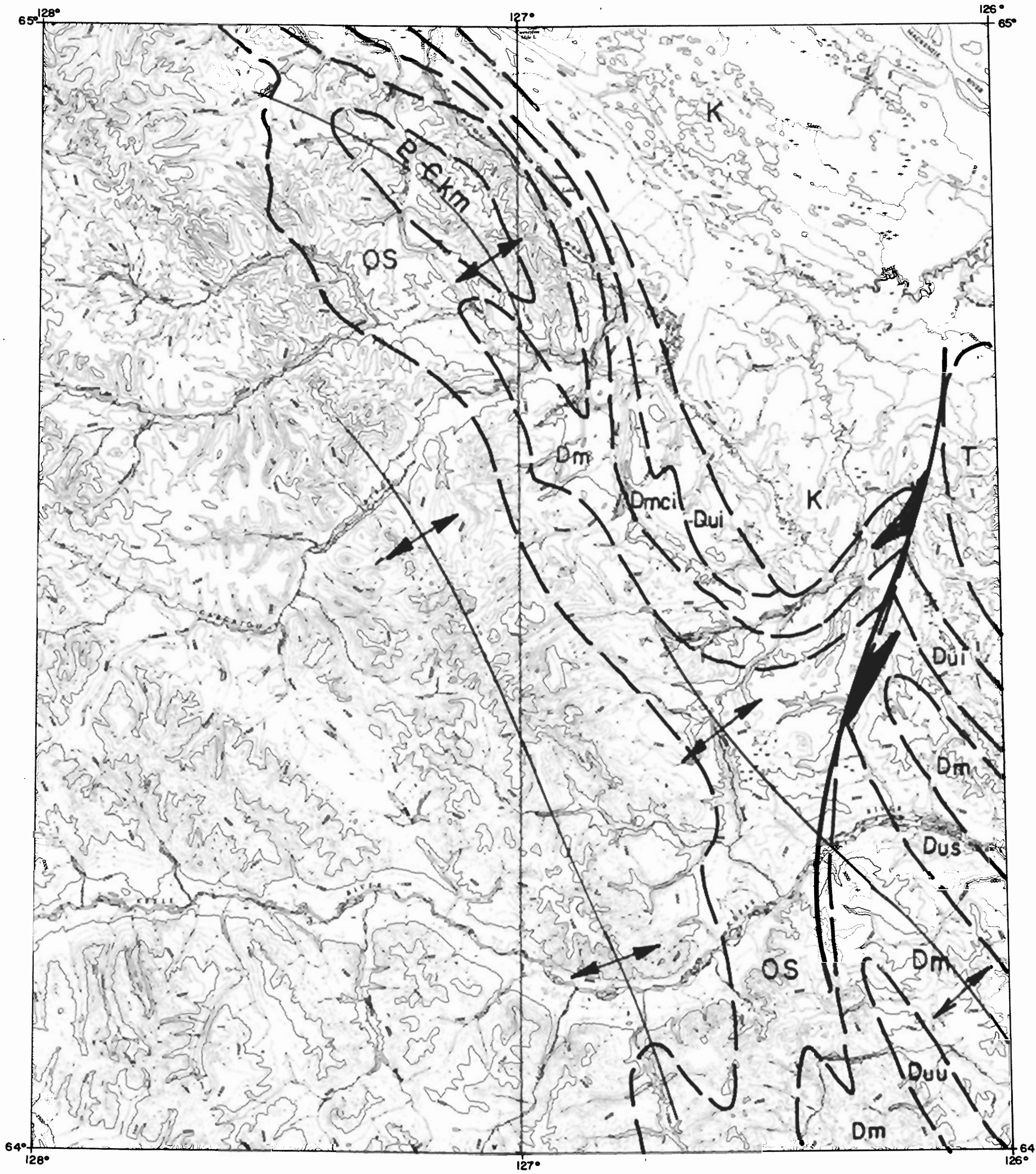
LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

(Note: The entire study-area is underlain by widespread permafrost in the discontinuous permafrost zone; also, estimates of yields refer to probable, not absolute, maximum figures and to generally more highly disturbed, fractured, and porous zones within the formations)

Symbol	Explanation
T	Tertiary non-marine sand, gravel, conglomerate, shale, sandstone, coal. Expect maximum yields of 50 Igpm of generally fair to good quality waters
Ku	Upper Cretaceous mainly non-marine sandstone and shale. Expect maximum yields of 25 Igpm of generally poor to locally fair quality waters
Kl	Lower Cretaceous mainly marine shale and sandstone. Expect maximum yields of 1 Igpm of poor quality sulphate waters
Klf	Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
K	Upper and Lower Cretaceous unnamed and undivided mainly marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor quality waters
CPa	Carboniferous (Pennsylvanian) and Permian unnamed and undivided sandstone and conglomerate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
Dur	Upper Devonian Redknife Formation mainly marine shale with minor sandstone and limestone. Expect maximum yields of 1 Igpm of generally poor quality waters
Duu	Upper Devonian unnamed mainly non-marine shale, siltstone, limestone, and sandstone. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters
Dui	Upper Devonian Imperial Formation mainly non-marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
Duk	Upper Devonian Kakisa Formation limestone. Expect maximum yields of 5 Igpm of poor to locally fair quality bicarbonate waters
Dutt	Upper Devonian Trout River and Tetcho Formations consisting mainly of limestone with minor shale and sandstone. Expect maximum yields of 5 Igpm of poor to locally fair quality generally bicarbonate waters
Dus	Upper Devonian Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igpm of generally poor quality sulphate waters
Dm	Middle Devonian unnamed and undivided mainly carbonate strata with minor shale and anhydrite. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate waters
Dmk	Middle Devonian Kee Scarp Formation reefal and other limestones. Expect maximum yields of 100 Igpm of poor to locally fair quality generally bicarbonate, hard waters
Dmki	Middle Devonian Kee Scarp Formation limestone and Hare Indian calcareous shale. Expect maximum yields of 25 Igpm of variable quality generally bicarbonate, hard waters
Dmh	Middle Devonian Hume Formation limestone. Expect maximum yields of 10 Igpm of variable quality generally bicarbonate, hard waters
Dmc	Middle Devonian Canol Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
Dmci	Middle Devonian Canol and Hare Indian Formations consisting mainly of shale. Expect maximum yields of 1 Igpm of poor quality bicarbonate-sulphate waters
Dmbr	Middle Devonian Bear Rock Formation dolomite, limestone, and anhydrite. Expect maximum yields of 250 Igpm of very poor quality generally bicarbonate-sulphate waters
Dmhi	Middle Devonian Hare Indian Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
OS	Ordovician and Silurian unnsmed and undivided dolomite and limestone. Expect maximum yields of 10 Igpm of highly variable quality generally bicarbonate-sulphate waters
OSk	Ordovician and Silurian Mount Kindle Formation dolomite and anhydrite and Franklin Mtn. Formation dolomite and shale. Expect maximum yields of 100 Igpm of generally poor to locally fair quality bicarbonate-sulphate waters
€cs	Cambrian Saline River Formation anhydrite gypsum and salt, Cap Mt. Formation shale and Mt. Clark Formation sandstone. Expect maximum yields of 100 Igpm of poor quality sulphate-chloride waters from the Saline River salt and anhydrite, 1 Igpm of poor quality sulphate waters from the Cap Mt. Formation shale, and 25 Igpm of fair quality waters from the Mt. Clark Formation sandstone
e	Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

Tectonic symbols: ▲▲ thrust fault with teeth indicating direction of dip; ⨁ anticline; ⨁ syncline

Map 9



CARCAJOU CANYON

96D

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP

LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

(Note: The entire study-area is underlain by widespread permafrost in the discontinuous permafrost zone; also, estimates of yields refer to probable, not absolute, maximum figures and to generally more highly disturbed, fractured, and porous zones within the formations)

Symbol	Explanation
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Kl	Lower Cretaceous mainly marine shale and sandstone. Expect maximum yields of 1 Igpm of poor quality sulphate waters
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K	Upper and Lower Cretaceous unnamed and undivided mainly marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor quality waters
CPa	Carboniferous (Pennsylvanian) and Permian unnamed and undivided sandstone and conglomerate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
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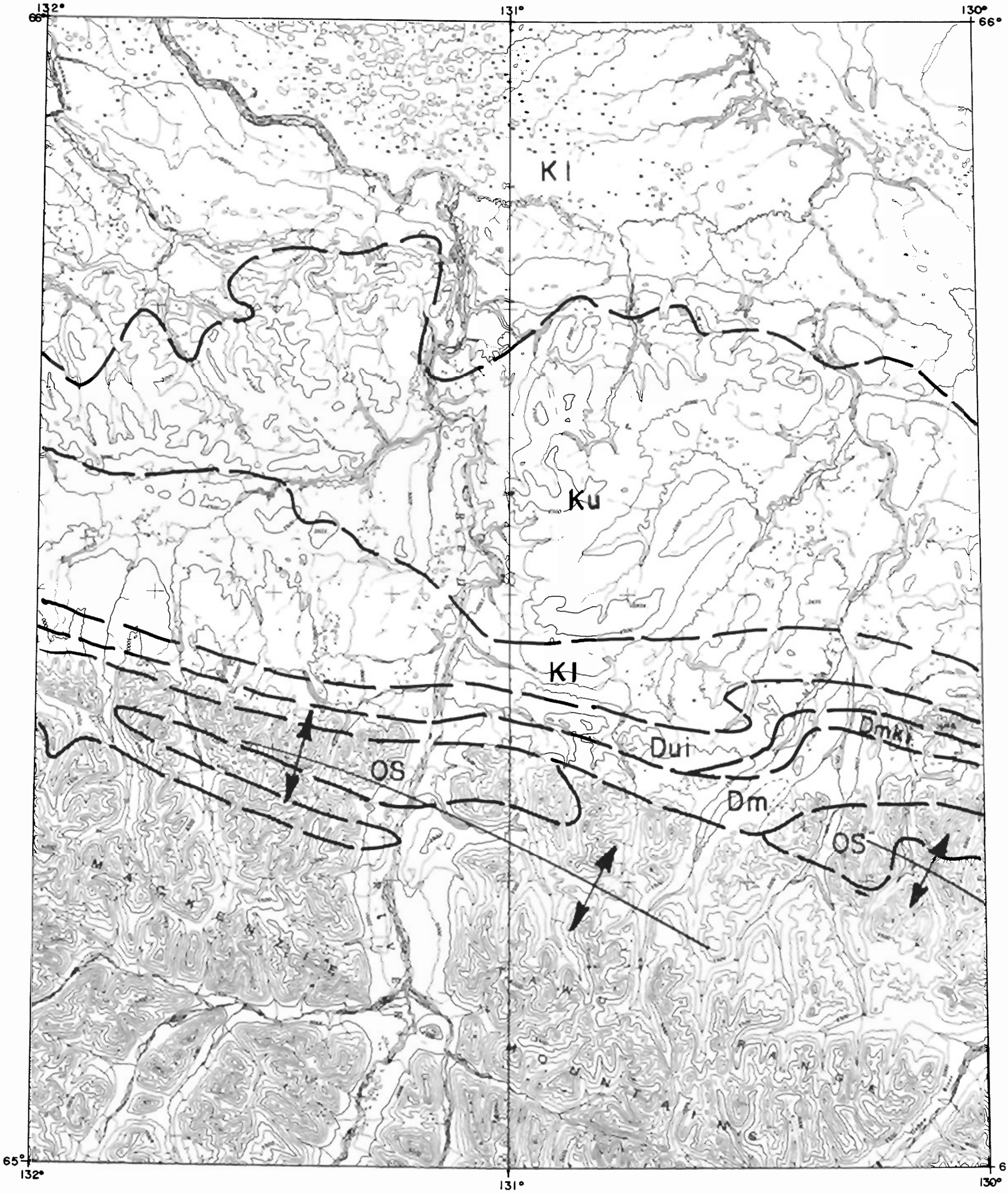
Duu	Upper Devonian unnamed mainly non-marine shale, siltstone, limestone, and sandstone. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters
Dui	Upper Devonian Imperial Formation mainly non-marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
Duk	Upper Devonian Kakisa Formation limestone. Expect maximum yields of 5 Igpm of poor to locally fair quality bicarbonate waters
Dutt	Upper Devonian Trout River and Tetcho Formations consisting mainly of limestone with minor shale and sandstone. Expect maximum yields of 5 Igpm of poor to locally fair quality generally bicarbonate watera
Dus	Upper Devonian Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igpm of generally poor quality sulphate waters
Dm	Middle Devonian unnamed and undivided mainly carbonate strata with minor shale and anhydrite. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate waters
Dmk	Middle Devonian Kee Scarp Formation reefal and other limestones. Expect maximum yields of 100 Igpm of poor to locally fair quality generally bicarbonate, hard waters
Dmki	Middle Devonian Kee Scarp Formation limestone and Hare Indian calcareous shale. Expect maximum yields of 25 Igpm of variable quality generally bicarbonate, hard waters
Dmh	Middle Devonian Hume Formation limestone. Expect maximum yields of 10 Igpm of variable quality generally bicarbonate, hard waters
Dmc	Middle Devonian Canol Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
Dmci	Middle Devonian Canol and Hare Indian Formations consisting mainly of shale. Expect maximum yields of 1 Igpm of poor quality bicarbonate-sulphate waters
Dmbr	Middle Devonian Bear Rock Formation dolomite, limestone, and anhydrite. Expect maximum yields of 250 Igpm of very poor quality generally bicarbonate-sulphate waters
Dmhi	Middle Devonian Hare Indian Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
OS	Ordovician and Silurian unnamed and undivided dolomite and limestone. Expect maximum yields of 10 Igpm of highly variable quality generally bicarbonate-sulphate waters
OSk	Ordovician and Silurian Mount Kindle Formation dolomite and anhydrite and Franklin Mtn. Formation dolomite and shale. Expect maximum yields of 100 Igpm of generally poor to locally fair quality bicarbonate-sulphate waters
Ꞓcs	Cambrian Saline River Formation anhydrite gypsum and salt, Cap Mt. Formation shale and Mt. Clark Formation sandstone. Expect maximum yields of 100 Igpm of poor quality sulphate-chloride waters from the Saline River salt and anhydrite, 1 Igpm of poor quality sulphate waters from the Cap Mt. Formation shale, and 25 Igpm of fair quality waters from the Mt. Clark Formation sandstone
P	Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

Tectonic symbols: ▲▲ thrust fault with teeth indicating direction of dip; ┼ anticline; ┼ syncline

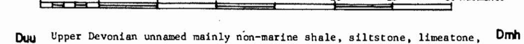
Map 10



UPPER RAMPARTS RIVER

106 G

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP



LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

(Note: The entire study-area is underlain by widespread permafrost in the discontinuous permafrost zone; also, estimates of yields refer to probable, not absolute, maximum figures and to generally more highly disturbed, fractured, and porous zones within the formations)

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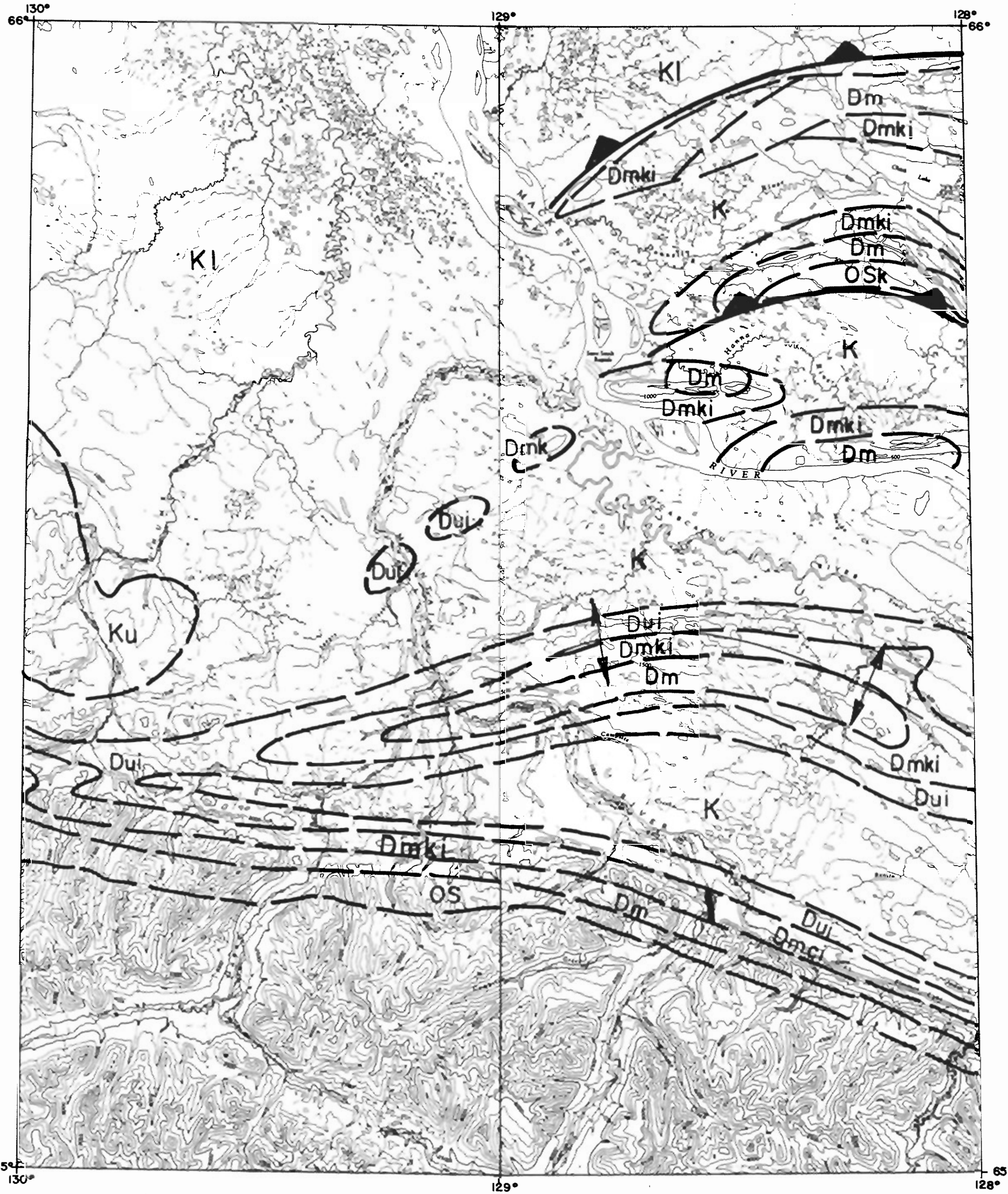
Klf	Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
K	Upper and Lower Cretaceous unnamed and undivided mainly marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor quality waters
CPa	Carboniferous (Pennsylvanian) and Permian unnamed and undivided sandstone and conglomerate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
Dur	Upper Devonian Redknife Formation mainly marine shale with minor sandstone and limestone. Expect maximum yields of 1 Igpm of generally poor quality waters
Duu	Upper Devonian unnamed mainly non-marine shale, siltstone, limestone, and sandstone. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters
Dui	Upper Devonian Imperial Formation mainly non-marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
Duk	Upper Devonian Kakisa Formation limestone. Expect maximum yields of 5 Igpm of poor to locally fair quality bicarbonate waters
Dutt	Upper Devonian Trout River and Tetcho Formations consisting mainly of limestone with minor shale and sandstone. Expect maximum yields of 5 Igpm of poor to locally fair quality generally bicarbonate waters
Dus	Upper Devonian Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igpm of generally poor quality sulphate waters
Dm	Middle Devonian unnamed and undivided mainly carbonate strata with minor shale and anhydrite. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate waters
Dmk	Middle Devonian Kee Scarp Formation reefal and other limestones. Expect maximum yields of 100 Igpm of poor to locally fair quality generally bicarbonate, hard waters
Dmki	Middle Devonian Kee Scarp Formation limestone and Hare Indian calcareous shale. Expect maximum yields of 25 Igpm of variable quality generally bicarbonate, hard waters
Dmh	Middle Devonian Hume Formation limestone. Expect maximum yields of 10 Igpm of variable quality generally bicarbonate, hard waters
Dmc	Middle Devonian Canol Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
Dmci	Middle Devonian Canol and Hare Indian Formations consisting mainly of shale. Expect maximum yields of 1 Igpm of poor quality bicarbonate-sulphate waters
Dmbr	Middle Devonian Bear Rock Formation dolomite, limestone, and anhydrite. Expect maximum yields of 250 Igpm of very poor quality generally bicarbonate-sulphate waters
Dmhi	Middle Devonian Hare Indian Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
OS	Ordovician and Silurian unnamed and undivided dolomite and limestone. Expect maximum yields of 10 Igpm of highly variable quality generally bicarbonate-sulphate waters
OSk	Ordovician and Silurian Mount Kindle Formation dolomite and anhydrite and Franklin Mtn. Formation dolomite and shale. Expect maximum yields of 100 Igpm of generally poor to locally fair quality bicarbonate-sulphate waters
€cs	Cambrian Saline River Formation anhydrite gypsum and salt, Cap Mt. Formation shale and Mt. Clark Formation sandstone. Expect maximum yields of 100 Igpm of poor quality sulphate-chloride waters from the Saline River salt and anhydrite, 1 Igpm of poor quality sulphate waters from the Cap Mt. Formation shale, and 25 Igpm of fair quality waters from the Mt. Clark Formation sandstone
P€	Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

Tectonic symbols: ▲▲ thrust fault with teeth indicating direction of dip; ╪ anticline; ╪ syncline

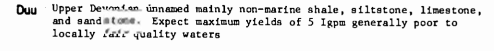
Map 11



SANS SAULT RAPIDS

106 H

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP



LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

(Note: The entire study-area is underlain by widespread permafrost in the discontinuous permafrost zone; also, estimates of yields refer to probable, not absolute, maximum figures and to generally more highly disturbed, fractured, and porous zones within the formations)

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Kl	Lower Cretaceous mainly marine shale and sandstone. Expect maximum yields of 1 Igpm of poor quality sulphate waters
Klf	Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
K	Upper and Lower Cretaceous unnamed and undivided mainly marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor quality waters
CPa	Carboniferous (Pennsylvanian) and Permian unnamed and undivided sandstone and conglomerate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
Dur	Upper Devonian Redknife Formation mainly marine shale with minor sandstone and limestone. Expect maximum yields of 1 Igpm of generally poor quality waters
Duu	Upper Devonian unnamed mainly non-marine shale, siltstone, limestone, and sandstone. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters
Dui	Upper Devonian Imperial Formation mainly non-marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
Duk	Upper Devonian Kakisa Formation limestone. Expect maximum yields of 5 Igpm of poor to locally fair quality bicarbonate waters
Dutt	Upper Devonian Trout River and Tetcho Formations consisting mainly of limestone with minor shale and sandstone. Expect maximum yields of 5 Igpm of poor to locally fair quality generally bicarbonate waters
Dus	Upper Devonian Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igpm of generally poor quality sulphate waters
Dm	Middle Devonian unnamed and undivided mainly carbonate strata with minor shale and anhydrite. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate waters
Dmk	Middle Devonian Kee Scarp Formation reefal and other limestones. Expect maximum yields of 100 Igpm of poor to locally fair quality generally bicarbonate, hard waters
Dmki	Middle Devonian Kee Scarp Formation limestone and Hare Indian calcareous shale. Expect maximum yields of 25 Igpm of variable quality generally bicarbonate, hard waters
Dmh	Middle Devonian Hume Formation limestone. Expect maximum yields of 10 Igpm of variable quality generally bicarbonate, hard waters
Dmc	Middle Devonian Canol Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
Dmci	Middle Devonian Canol and Hare Indian Formations consisting mainly of shale. Expect maximum yields of 1 Igpm of poor quality bicarbonate-sulphate waters
Dmbr	Middle Devonian Bear Rock Formation dolomite, limestone, and anhydrite. Expect maximum yields of 250 Igpm of very poor quality generally bicarbonate-sulphate waters
Dmhi	Middle Devonian Hare Indian Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
OS	Ordovician and Silurian unnamed and undivided dolomite and limestone. Expect maximum yields of 10 Igpm of highly variable quality generally bicarbonate-sulphate waters
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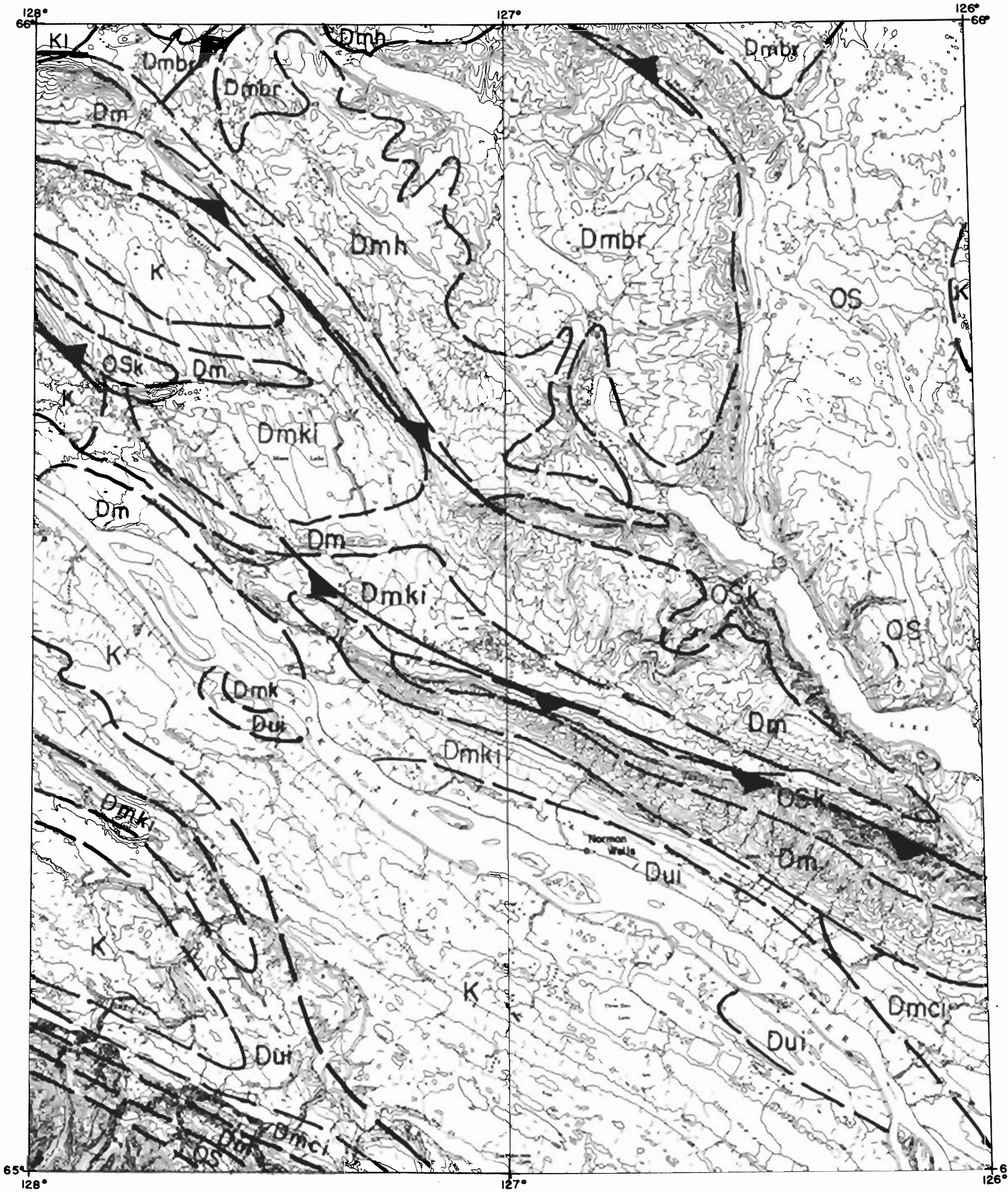
€cs	Cambrian Saline River Formation anhydrite gypsum and salt, Cap Mt. Formation shale and Mt. Clark Formation sandstone. Expect maximum yields of 100 Igpm of poor quality sulphate-chloride waters from the Saline River salt and anhydrite, 1 Igpm of poor quality sulphate waters from the Cap Mt. Formation shale, and 25 Igpm of fair quality waters from the Mt. Clark Formation sandstone
P€	Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

Tectonic symbols: ▲▲ thrust fault with teeth indicating direction of dip; ┼ anticline; ┼ syncline

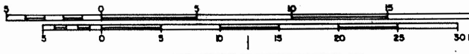
Map 12



NORMAN WELLS

96 E

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP



LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

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CPa	Carboniferous (Pennsylvanian) and Permian unnamed and undivided sandstone and conglomerate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
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Dui	Upper Devonian Imperial Formation mainly non-marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
Duk	Upper Devonian Kakisa Formation limestone. Expect maximum yields of 5 Igpm of poor to locally fair quality bicarbonate waters
Dutt	Upper Devonian Trout River and Tetcho Formations consisting mainly of limestone with minor shale and sandstone. Expect maximum yields of 5 Igpm of poor to locally fair quality generally bicarbonate waters
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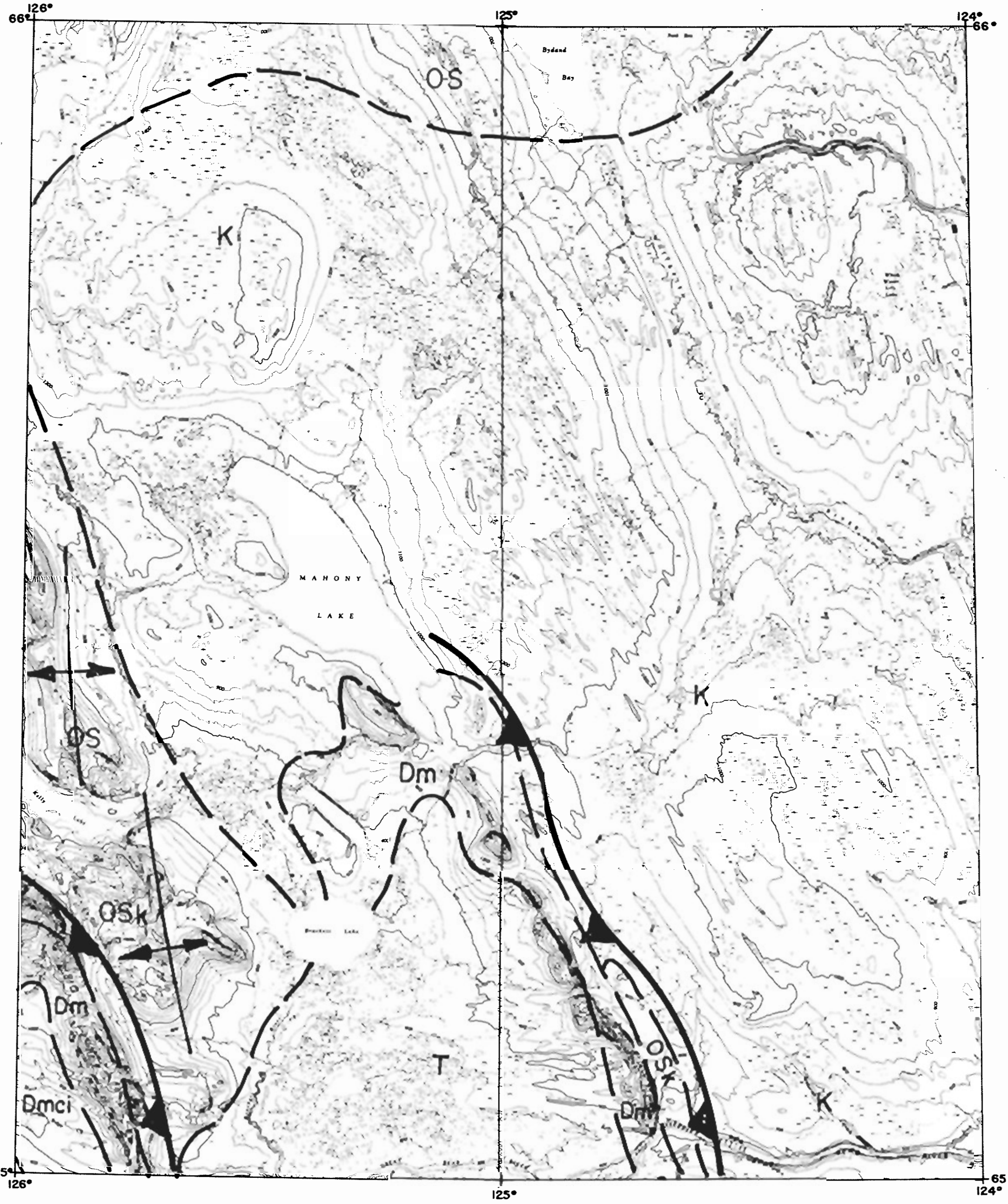
P€	Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

Tectonic symbols: ▲▲ thrust fault with teeth indicating direction of dip; ✝ anticline; ✝ syncline

Map 13



MAHONY LAKE

96 F

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP

LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

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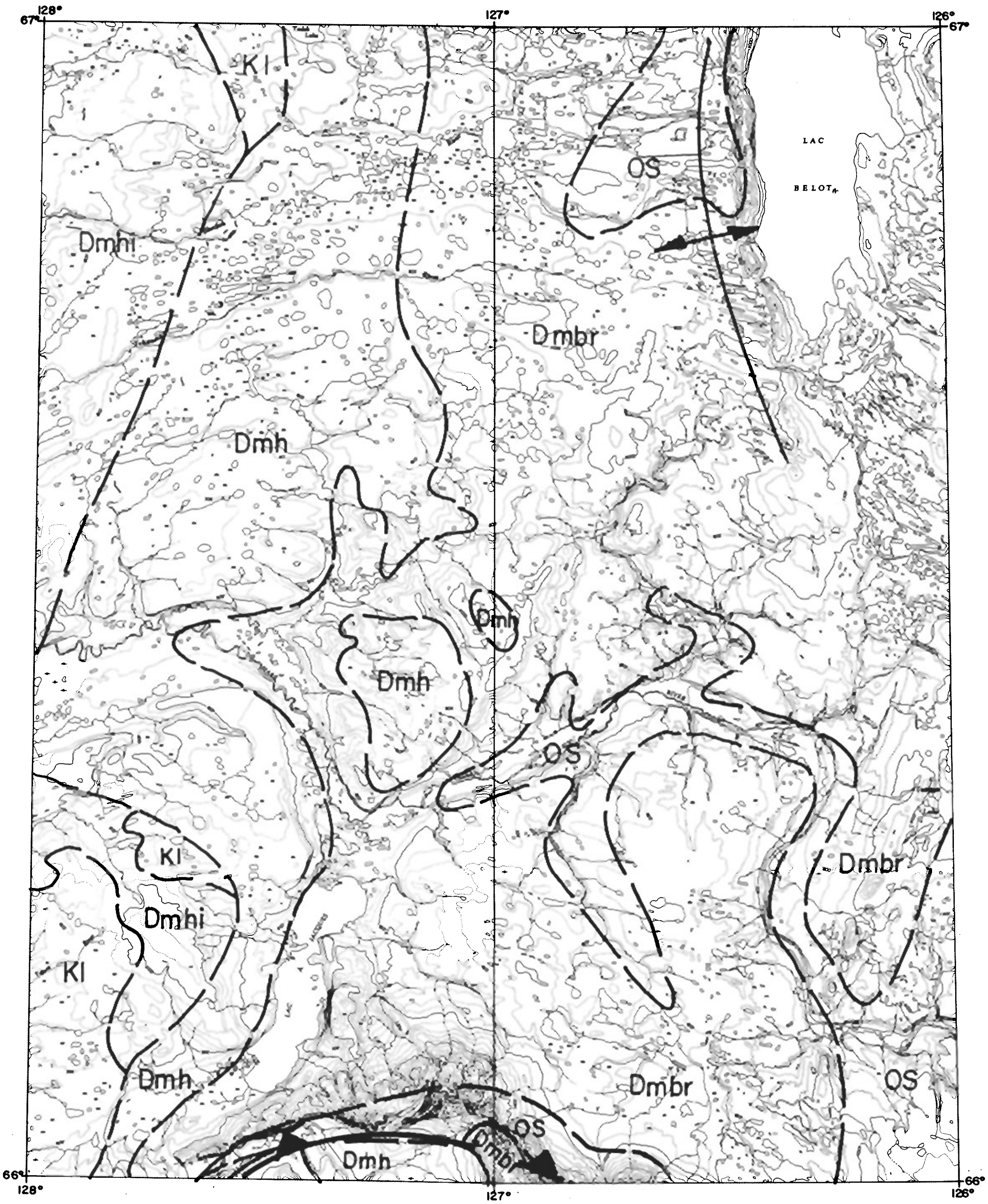
Dmbr	Middle Devonian Bear Rock Formation dolomite, limestone, and anhydrite. Expect maximum yields of 250 Igpm of very poor quality generally bicarbonate-sulphate waters
Dmhi	Middle Devonian Hare Indian Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
OS	Ordovician and Silurian unnamed and undivided dolomite and limestone. Expect maximum yields of 10 Igpm of highly variable quality generally bicarbonate-sulphate waters
OSk	Ordovician and Silurian Mount Kindle Formation dolomite and anhydrite and Franklin Mtn. Formation dolomite and shale. Expect maximum yields of 100 Igpm of generally poor to locally fair quality bicarbonate-sulphate waters
€cs	Cambrian Saline River Formation anhydrite gypsum and salt, Cap Mt. Formation shale and Mt. Clark Formation sandstone. Expect maximum yields of 100 Igpm of poor quality sulphate-chloride waters from the Saline River salt and snhydrite, 1 Igpm of poor quality sulphate waters from the Cap Mt. Formation shale, and 25 Igpm of fair quality waters from the Mt. Clark Formation sandstone
Ᵽ	Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

Tectonic symbols: ▲▲ thrust fault with teeth indicating direction of dip; ┼ anticline; ┼ syncline

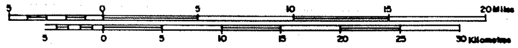
Map 14



LAC BELOT

96L

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP



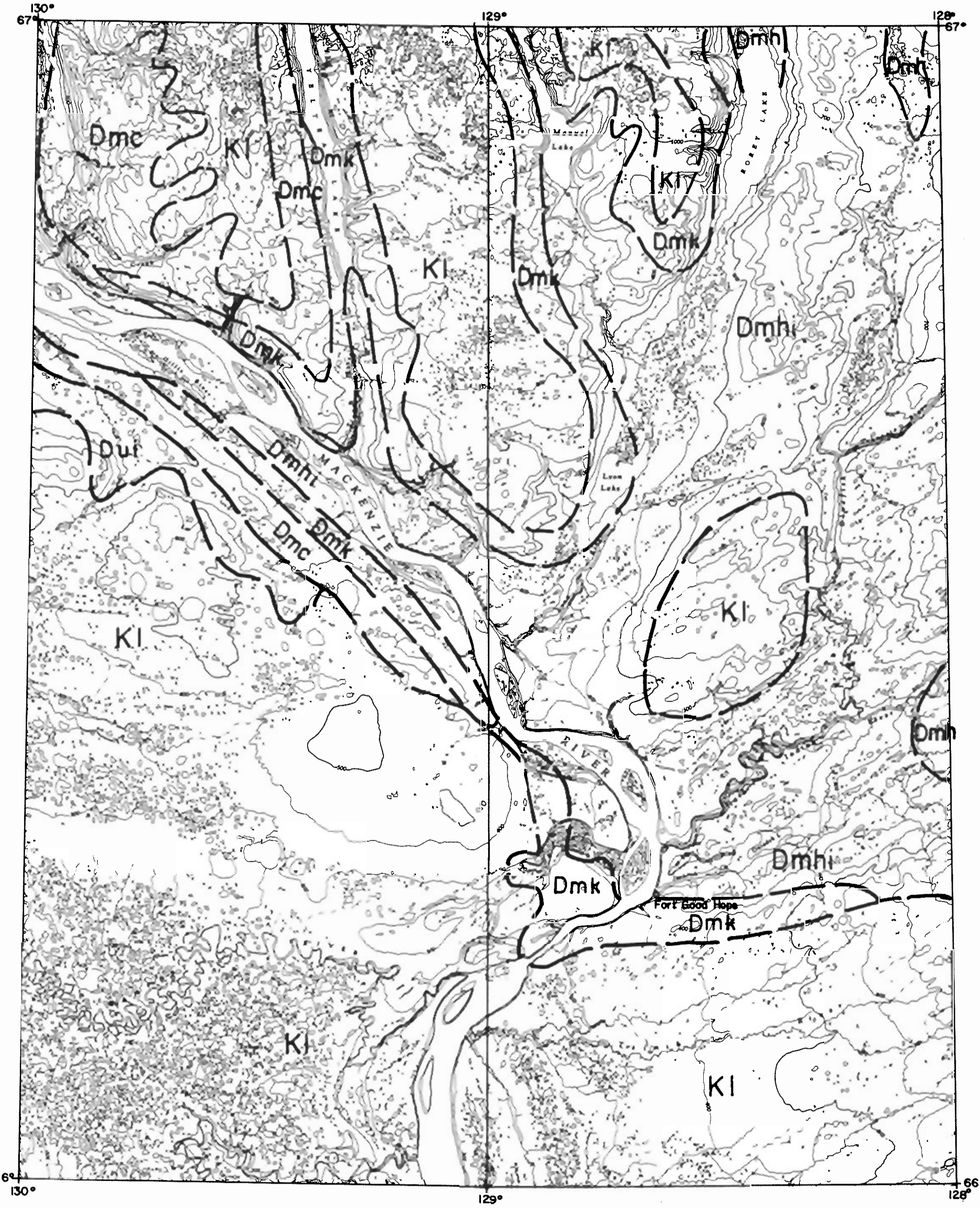
LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

(Note: The entire study-area is underlain by widespread permafrost in the discontinuous permafrost zone; also, estimates of yields refer to probable, not absolute, maximum figures and to generally more highly disturbed, fractured, and porous zones within the formations)

Symbol	Explanation
T	Tertiary non-marine sand, gravel, conglomerate, shale, sandstone, coal. Expect maximum yields of 50 Igpm of generally fair to good quality waters
Ku	Upper Cretaceous mainly non-marine sandstone and shale. Expect maximum yields of 25 Igpm of generslly poor to locally fair quality waters
Kl	Lower Cretaceous mainly marine shale and sandstone. Expect maximum yields of 1 Igpm of poor quality sulphate waters
Klf	Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
K	Upper and Lower Cretaceous unnamed and undivided mainly marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor quality waters
CPa	Carboniferous (Pennsylvanian) and Permian unnamed and undivided sandstone and conglomerate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
Dur	Upper Devonian Redknife Formation mainly marine shale with minor sandstone and limestone. Expect maximum yields of 1 Igpm of generally poor quality waters
Duu	Upper Devonian unnsmed mainly non-marine shale, siltstone, limestone, and sandstone. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters
Dui	Upper Devonian Imperial Formation mainly non-marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
Duk	Upper Devonian Kakisa Formation limestone. Expect maximum yields of 5 Igpm of poor to locally fair quality bicarbonate waters
Dutt	Upper Devonian Trout River and Tetcho Formations consisting mainly of limestone with minor shale and sandstone. Expect maximum yields of 5 Igpm of poor to locally fair quality generally bicarbonate waters
Dus	Upper Devonian Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igpm of generally poor quality sulphate waters
Dm	Middle Devonian unnamed and undivided mainly carbonate strata with minor shale and anhydrite. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate waters
Dmk	Middle Devonian Kee Scarp Formation reefal and other limestones. Expect maximum yields of 100 Igpm of poor to locally fair quality generally bicarbonate, hard waters
Dmki	Middle Devonian Kee Scarp Formation limestone and Hare Indian calcareous shale. Expect maximum yields of 25 Igpm of variable quality generally bicarbonate, hard waters
Dmh	Middle Devonian Hume Formation limestone. Expect maximum yields of 10 Igpm of variable quality generally bicarbonate, hard waters
Dmc	Middle Devonian Canol Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
Dmcl	Middle Devonian Canol and Hare Indian Formations consisting mainly of shale. Expect maximum yields of 1 Igpm of poor quality bicarbonate-sulphate waters
Dmbr	Middle Devonian Bear Rock Formation dolomite, limestone, and anhydrite. Expect maximum yields of 250 Igpm of very poor quality generally bicarbonate-sulphate waters
Dmhi	Middle Devonian Hare Indian Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
OS	Ordovician and Silurian unnamed and undivided dolomite and limestone. Expect maximum yields of 10 Igpm of highly variable quality generally bicarbonate-sulphate waters
OSk	Ordovician and Silurian Mount Kindle Formation dolomite and anhydrite and Franklin Mtn. Formation dolomite and shale. Expect maximum yields of 100 Igpm of generally poor to locally fair quality bicarbonate-sulphate waters
Ꞓcs	Cambrian Saline River Formation anhydrite gypsum and salt, Cap Mt. Formation shale and Mt. Clark Formation sandstone. Expect maximum yields of 100 Igpm of poor quality sulphate-chloride waters from the Saline River salt and anhydrite, 1 Igpm of poor quality sulphate waters from the Cap Mt. Formation shale, and 25 Igpm of fair quality waters from the Mt. Clark Formation sandstone
Ᵽ	Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

Tectonic symbols: ▲▲ thrust fault with teeth indicating direction of dip; ┼ anticline; ┼ syncline

Map 15



FORT GOOD HOPE

106 I

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP

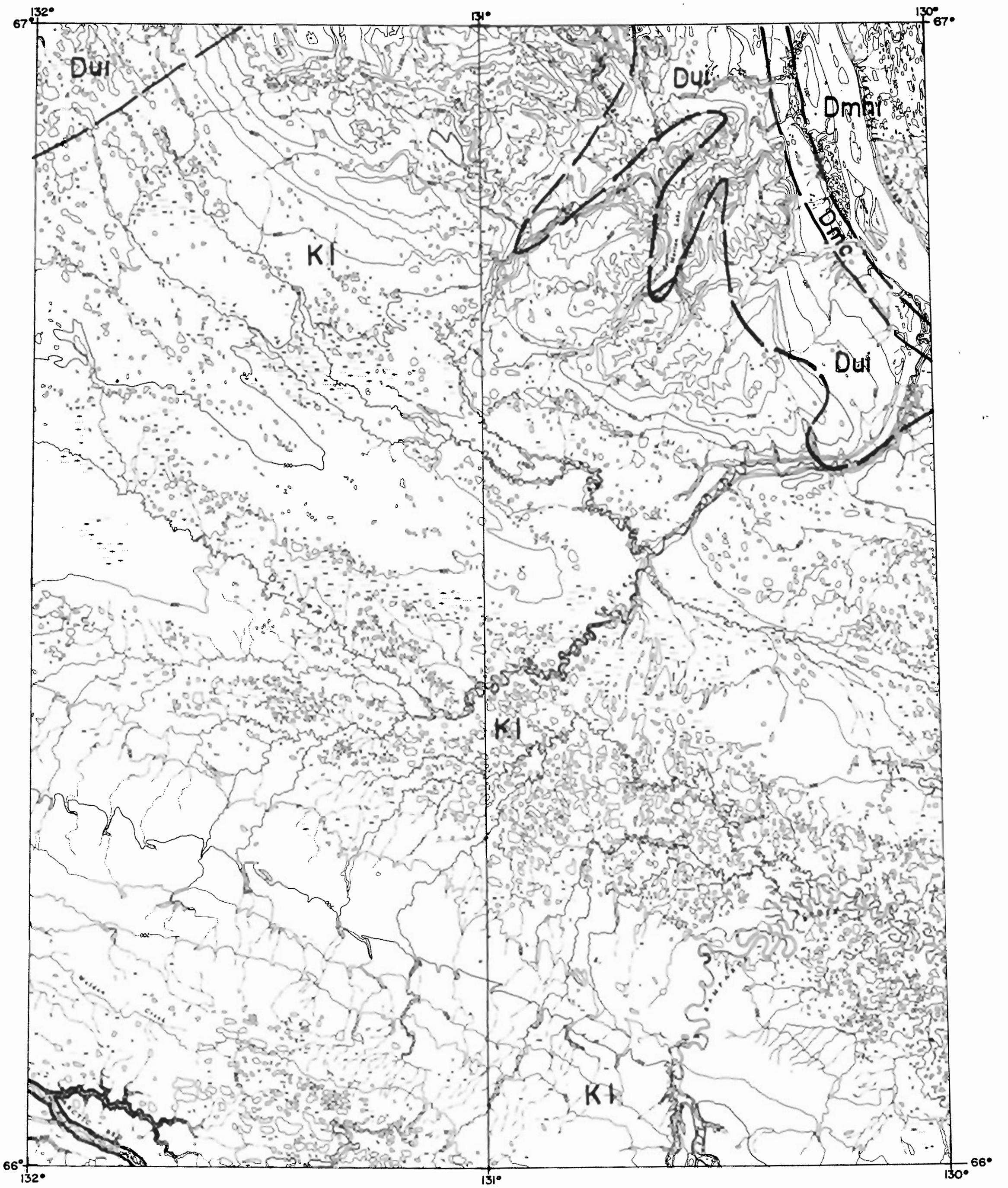
LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

(Note: The entire study-area is underlain by widespread permafrost in the discontinuous permafrost zone; also, estimates of yields refer to probable, not absolute, maximum figures and to generally more highly disturbed, fractured, and porous zones within the formations)

Symbol	Explanation
T	Tertiary non-marine sand, gravel, conglomerate, shale, sandstone, coal. Expect maximum yields of 50 Igpm of generally fair to good quality waters
Ku	Upper Cretaceous mainly non-marine sandstone and shale. Expect maximum yields of 25 Igpm of generally poor to locally fair quality waters
Kl	Lower Cretaceous mainly marine shale and sandstone. Expect maximum yields of 1 Igpm of poor quality,sulphate waters
Klf	Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
K	Upper and Lower Cretaceous unnamed and undivided mainly marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor quality waters
CPa	Carboniferous (Pennsylvanian) and Permian unnamed and undivided sandstone and conglomerate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
Dur	Upper Devonian Redknife Formation mainly marine shale with minor sandstone and limestone. Expect maximum yields of 1 Igpm of generally poor quality waters
Duu	Upper Devonian unnamed mainly non-marine shale, siltstone, limestone, and sandstone. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters
Dui	Upper Devonian Imperial Formation mainly non-marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
Duk	Upper Devonian Kakisa Formation limestone. Expect maximum yields of 5 Igpm of poor to locally fair quality bicarbonate waters
Dutt	Upper Devonian Trout River and Tetcho Formations consisting mainly of limestone with minor shale and sandstone. Expect maximum yields of 5 Igpm of poor to locally fair quality generally bicarbonate waters
Dus	Upper Devonian Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igpm of generally poor quality sulphate waters
Dm	Middle Devonian unnamed and undivided mainly carbonate strata with minor shale and anhydrite. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate waters
Dmk	Middle Devonian Lee Scarp Formation reefal and other limestones. Expect maximum yields of 100 Igpm of poor to locally fair quality generally bicarbonate, hard waters
Dmki	Middle Devonian Lee Scarp Formation limestone and Hare Indian calcareous shale. Expect maximum yields of 25 Igpm of variable quality generally bicarbonate, hard waters
Dmh	Middle Devonian Hume Formation limestone. Expect maximum yields of 10 Igpm of variable quality generally bicarbonate, hard waters
Dmc	Middle Devonian Canol Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
Dmci	Middle Devonian Canol and Hare Indian Formations consisting mainly of shale. Expect maximum yields of 1 Igpm of poor quality bicarbonate-sulphate waters
Dmbr	Middle Devonian Bear Rock Formation dolomite, limestone, and anhydrite. Expect maximum yields of 250 Igpm of very poor quality generally bicarbonate-sulphate waters
Dmhi	Middle Devonian Hare Indian Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
OS	Ordovician and Silurian unnamed and undivided dolomite and limestone. Expect maximum yields of 10 Igpm of highly variable quality generally bicarbonate-sulphate waters
OSk	Ordovician and Silurian Mount Kindle Formation dolomite and anhydrite and Franklin Mtn. Formation dolomite and shale. Expect maximum yields of 100 Igpm of generally poor to locally fair quality bicarbonate-sulphate waters
€cs	Cambrian Saline River Formation anhydrite, gypsum and salt, Cap Mt. Formation shale and Mt. Clark Formation sandstone. Expect maximum yields of 100 Igpm of poor quality sulphate-chloride waters from the Saline River salt and anhydrite, 1 Igpm of poor quality sulphate waters from the Cap Mt. Formation shale, and 25 Igpm of fair quality waters from the Mt. Clark Formation sandstone
P€	Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

Tectonic symbols: ▲▲ thrust fault with teeth indicating direction of dip; ┼ anticline; ┼ syncline

Map 16



ONTARATUE RIVER
106 J
RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP

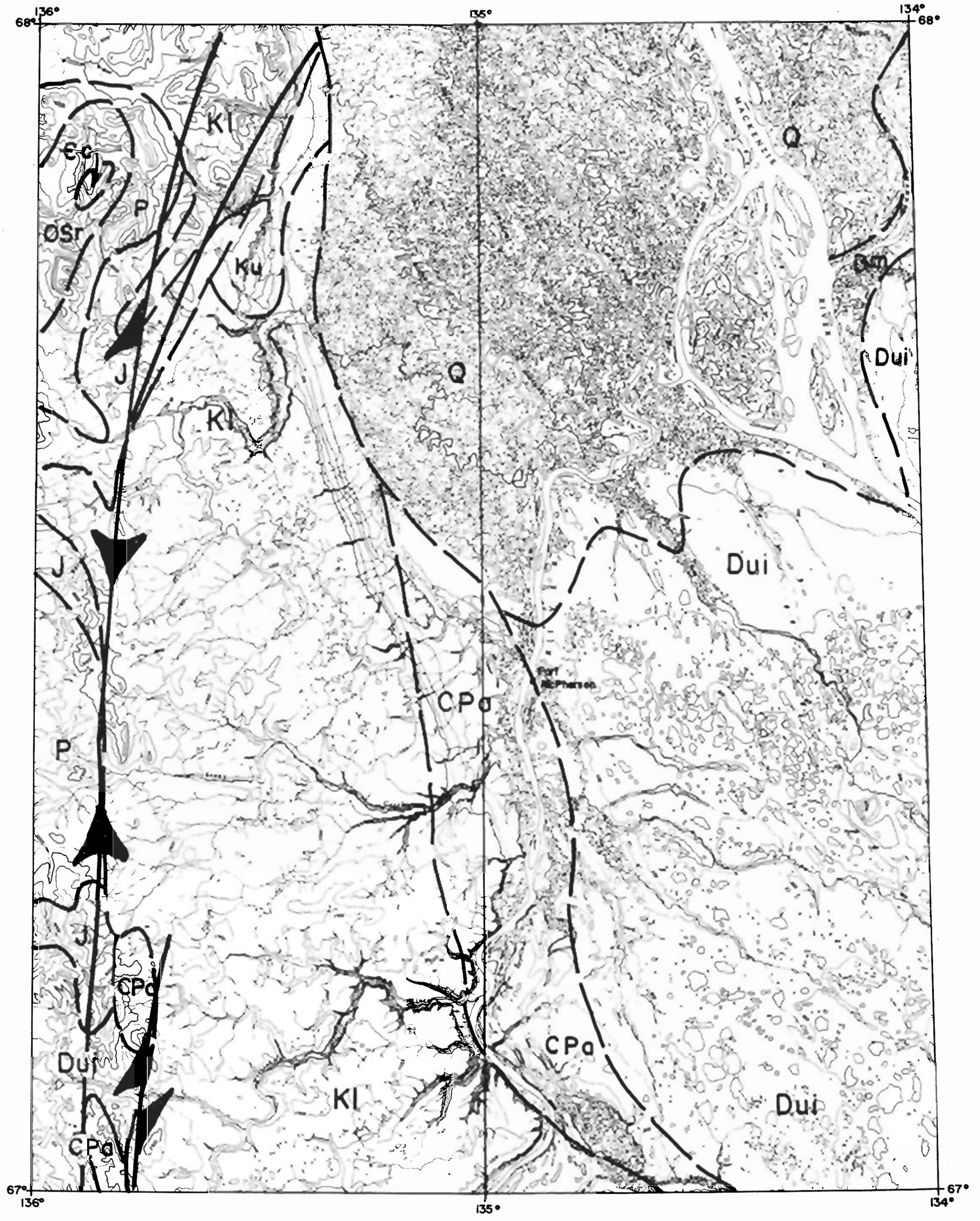
LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

(Note: The entire study-area is underlain by widespread permafrost in the discontinuous permafrost zone; also, estimates of yields refer to probable, not absolute, maximum figures and to generally more highly disturbed, fractured, and porous zones within the formations)

Symbol	Explanation
T	Tertiary non-marine sand, gravel, conglomerate, shale, sandstone, coal. Expect maximum yields of 50 Igpm'of generally fair to good quality waters
Ku	Upper Cretaceous mainly non-marine sandstone and shale. Expect maximum yields of 25 Igpm of generally poor to locally fair quality waters
Kl	Lower Cretaceous mainly marine shale and sandstone. Expect maximum yields of 1 Igpm of poor quality sulphate waters
Klf	Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
K	Upper and Lower Cretaceous unnamed and undivided mainly marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor quality waters
CPa	Carboniferous (Pennsylvanian) and Permian unnamed and undivided sandstone and conglomerate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
Dur	Upper Devonian Redknife Formation mainly marine shale with minor sandstone and limestone. Expect maximum yields of 1 Igpm of generally poor quality waters
Duu	Upper Devonian unnamed mainly non-marine shale, siltstone, limestone, and sandstone. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters
Dui	Upper Devonian Imperial Formation mainly non-marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
Duk	Upper Devonian Kakisa Formation limestone. Expect maximum yields of 5 Igpm of poor to locally fair quality bicarbonate waters
Dutt	Upper Devonian Trout River and Tetcho Formations consisting mainly of limestone with minor shale and sandstone. Expect maximum yields of 5 Igpm of poor to locally fair quality generally bicarbonate waters
Dus	Upper Devonian Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igpm of generally poor quality sulphate waters
Dm	Middle Devonian unnamed and undivided mainly carbonate strata with minor shale and anhydrite. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate waters
Dmk	Middle Devonian Kee Scarp Formation reefal and other limestones. Expect maximum yields of 100 Igpm of poor to locally fair quality generally bicarbonate, hard waters
Dmki	Middle Devonian Kee Scarp Formation limestone and Hare Indian calcareous shale. Expect maximum yields of 25 Igpm of variable quality generally bicarbonate, hard waters
Dmh	Middle Devonian Hume Formation limestone. Expect maximum yields of 10 Igpm of variable quality generally bicarbonate, hard waters
Dmc	Middle Devonian Canol Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
Dmci	Middle Devonian Canol and Hare Indian Formations consisting mainly of shale. Expect maximum yields of 1 Igpm of poor quality bicarbonate-sulphate waters
Dmbr	Middle Devonian Bear Rock Formation dolomite, limestone, and anhydrite. Expect maximum yields of 250 Igpm of very poor quality generally bicarbonate-sulphate waters
Dmhi	Middle Devonian Hare Indian Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
OS	Ordovician and Silurian unnamed and undivided dolomite and limestone. Expect maximum yields of 10 Igpm of highly variable quality generally bicarbonate-sulphate waters
OSk	Ordovician and Silurian Mount Kindle Formation dolomite and anhydrite and Franklin Mtn. Formation dolomite and shale. Expect maximum yields of 100 Igpm of generally poor to locally fair quality bicarbonate-sulphate waters
€cs	Cambrian Saline River Formation anhydrite gypsum and salt, Cap Mt. Formation shale and Mt. Clark Formation sandstone. Expect maximum yields of 100 Igpm of poor quality sulphate-chloride waters from the Saline River salt and anhydrite, 1 Igpm of poor quality sulphate waters from the Cap Mt. Formation shale, and 25 Igpm of fair quality waters from the Mt. Clark Formation sandstone
P	Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

Tectonic symbols: ▲▲ thrust fault with teeth indicating direction of dip; ┼ anticline; ┼ syncline

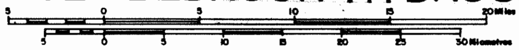
Map 17



FORT McPHERSON

106M

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP



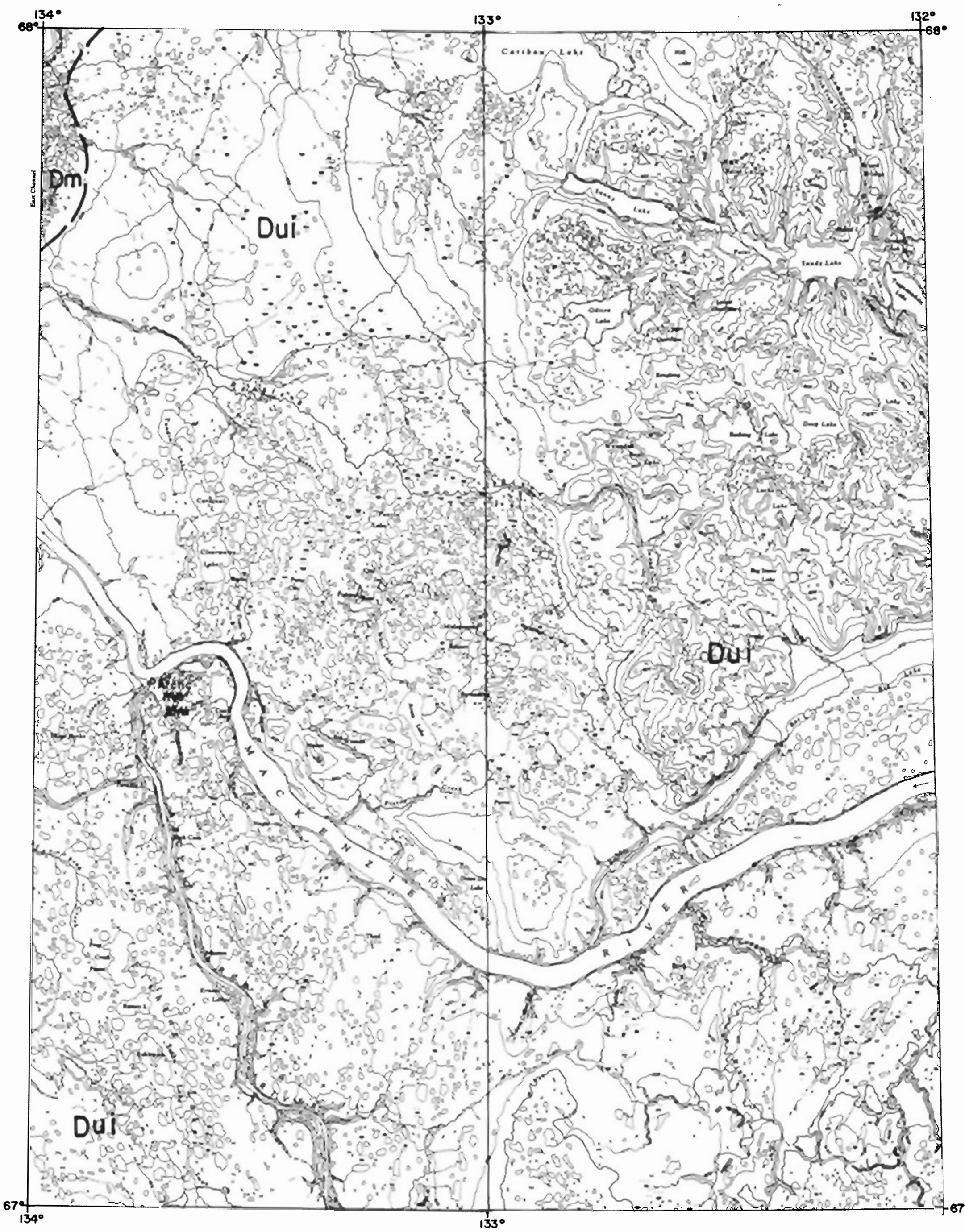
LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

(Note: The entire study-area is underlain by widespread permafrost in the discontinuous permafrost zone; also, estimates of yields refer to probable, not absolute, maximum figures and to generally more highly disturbed, fractured, and porous zones within the formations)

Symbol	Explanation
T	Tertiary non-marine sand, gravel, conglomerate, shale, sandstone, coal. Expect maximum yields of 50 Igpm of generally fair to good quality waters
Ku	Upper Cretaceous mainly non-marine sandstone and shale. Expect maximum yielda of 25 Igpm of generally poor to locally fair quality waters
Kl	Lower Cretaceous mainly marine shale and sandstone. Expect maximum yields of 1 Igpm of poor quality sulphate waters
Klf	Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
K	Upper and Lower Cretaceous unnamed and undivided mainly marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor quality waters
CPa	Carboniferous (Pennsylvanian) and Permian unnamed and undivided sandstone and conglomerate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
Dur	Upper Devonian Redknife Formation mainly marine shale with minor sandstone and limestone. Expect maximum yields of 1 Igpm of generally poor quality waters
Duu	Upper Devonian unnamed mainly non-marine shale, siltstone, limestone, and sandstone. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters
Dui	Upper Devonian Imperial Formation mainly non-marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
Duk	Upper Devonian Kakisa Formation limestone. Expect maximum yields of 5 Igpm of poor to locally fair quality bicarbonate waters
Dutt	Upper Devonian Trout River and Tetcho Formations consisting mainly of limestone with minor shale and sandstone. Expect maximum yields of 5 Igpm of poor to locally fair quality generally bicarbonate watera
Dus	Upper Devonian Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igpm of generally poor quality sulphate waters
Dm	Middle Devonian unnamed and undivided mainly carbonate strata with minor shale and anhydrite. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate waters
Dmk	Middle Devonian Keele Scarp Formation reefal and other limestones. Expect maximum yields of 100 Igpm of poor to locally fair quality generally bicarbonate, hard waters
Dmki	Middle Devonian Keele Scarp Formation limestone and Hare Indian calcareous shale. Expect maximum yields of 25 Igpm of variable quality generally bicarbonate, hard waters
Dmh	Middle Devonian Hume Formation limestone. Expect maximum yields of 10 Igpm of variable quality generally bicarbonate, hard waters
Dmc	Middle Devonian Canol Formation shsle. Expect maximum yields of 1 Igpm of poor quality sulphate waters
Dmcl	Middle Devonian Canol and Hare Indian Formations consisting mainly of shale. Expect maximum yields of 1 Igpm of poor quality bicarbonate-sulphate waters
Dmbr	Middle Devonian Bear Rock Formation dolomite, limestone, and anhydrite. Expect maximum yields of 250 Igpm of very poor quality generally bicarbonate-sulphate waters
Dmhi	Middle Devonian Hare Indian Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
OS	Ordovician and Silurian unnamed and undivided dolomite and limestone. Expect maximum yields of 10 Igpm of highly variable quality generally bicarbonate-sulphate waters
OSk	Ordovician and Silurian Mount Kindle Formation dolomite and anhydrite and Franklin Mtn. Formation dolomite and shale. Expect maximum yields of 100 Igpm of generally poor to locally fair quality bicarbonate-aulphate waters
€cs	Cambrian Saline River Formation anhydrite gypsum and salt, Cap Mt. Formation shale and Mt. Clark Formation sandstone. Expect maximum yields of 100 Igpm of poor quality sulphate-chloride waters from the Saline River salt and anhydrite, 1 Igpm of poor quality sulphate waters from the Cap Mt. Formation shale, and 25 Igpm of fair quality waters from the Mt. Clark Formation sandstone
p€	Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

Tectonic symbols: ▲▲ thrust fault with teeth indicating direction of dip; ┼ anticline; ┼ syncline

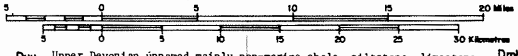
Map 20



ARCTIC RED RIVER

106N

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP



LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

(Note: The entire study-area is underlain by widespread permafrost in the discontinuous permafrost zone; also, estimates of yields refer to probable, not absolute, maximum figures and to generally more highly disturbed, fractured, and porous zones within the formations)

Symbol	Explanation
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Kl	Lower Cretaceous mainly marine shale and sandstone. Expect maximum yields of 1 Igpm of poor quality sulphate waters
Klf	Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
K	Upper and Lower Cretaceous unnamed and undivided mainly marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor quality waters
CPa	Carboniferous (Pennsylvanian) and Permian unnamed and undivided sandstone and conglomerate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
Dur	Upper Devonian Redknife Formation mainly marine shale with minor sandstone and limestone. Expect maximum yields of 1 Igpm of generally poor quality waters
Duu	Upper Devonian unnamed mainly non-marine shale, siltstone, limestone, and sandstone. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters
Dui	Upper Devonian Imperial Formation mainly non-marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
Duk	Upper Devonian Kakisa Formation limestone. Expect maximum yields of 5 Igpm of poor to locally fair quality bicarbonate waters
Dutt	Upper Devonian Trout River and Tetcho Formations consisting mainly of limestone with minor shale and sandstone. Expect maximum yields of 5 Igpm of poor to locally fair quality generally bicarbonate waters
Dus	Upper Devonian Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igpm of generally poor quality sulphate waters
Dm	Middle Devonian unnamed and undivided mainly carbonate strata with minor shale and anhydrite. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate waters
Dmk	Middle Devonian Kee Scarp Formation reefal and other limestones. Expect maximum yields of 100 Igpm of poor to locally fair quality generally bicarbonate, hard waters
Dmki	Middle Devonian Kee Scarp Formation limestone and Hare Indian calcareous shale. Expect maximum yields of 25 Igpm of variable quality generally bicarbonate, hard waters
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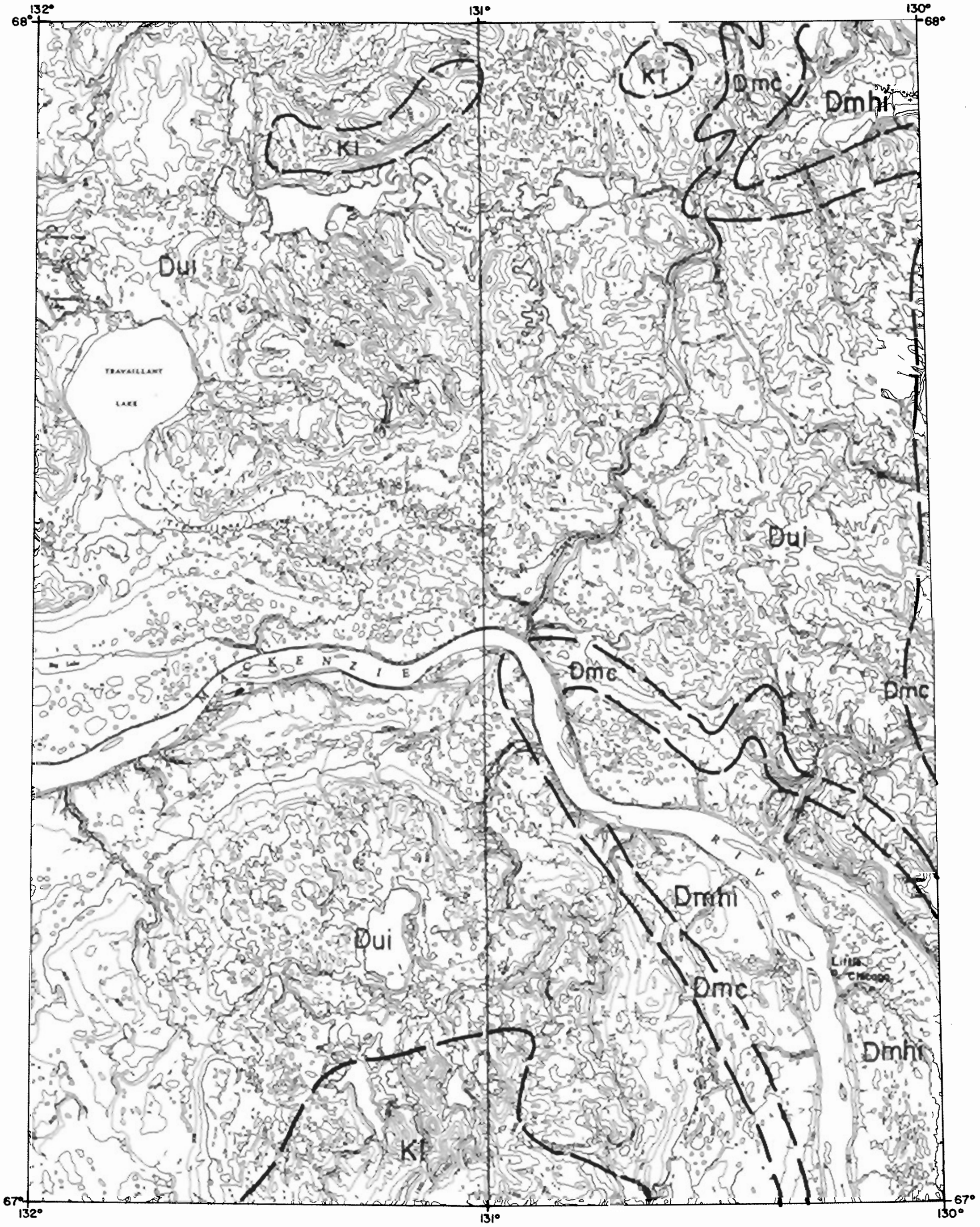
Ᵽ	Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

Tectonic symbols: ▲▲ thrust fault with teeth indicating direction of dip; ╋ anticline; ╋ syncline

Map 21



TRAVAILLANT LAKE

106 0

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP

LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

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Dm	Middle Devonian unnamed and undivided mainly carbonate strata with minor shale and anhydrite. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate waters
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Dmki	Middle Devonian Kee Scarp Formation limestone and Hare Indian calcareous shale. Expect maximum yields of 25 Igpm of variable quality generally bicarbonate, hard waters
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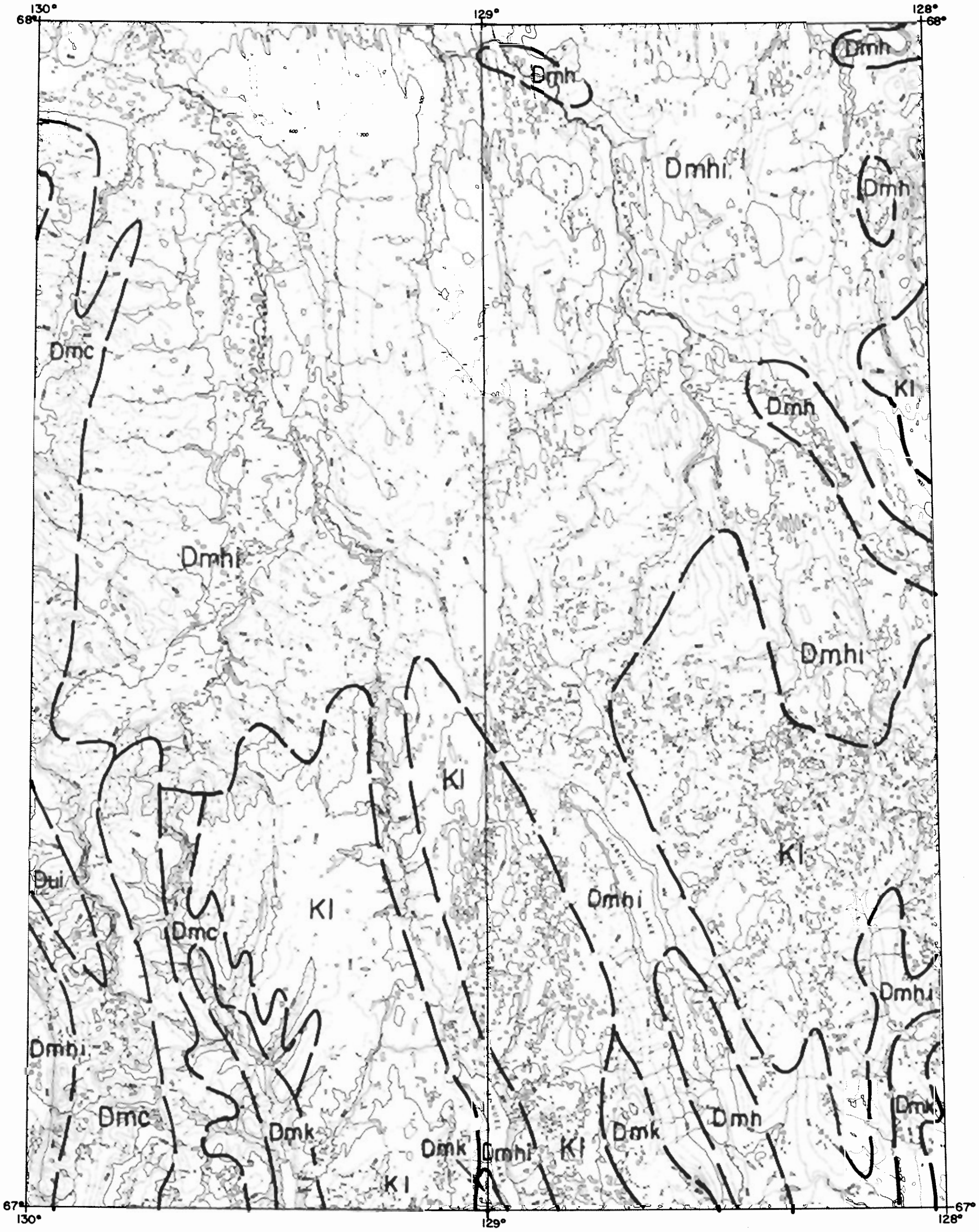
OS	Ordovician and Silurian unnamed and undivided dolomite and limestone. Expect maximum yields of 10 Igpm of highly variable quality generally bicarbonate-sulphate waters
OSk	Ordovician and Silurian Mount Kindle Formation dolomite and anhydrite and Franklin Mtn. Formation dolomite and shale. Expect maximum yields of 100 Igpm of generally poor to locally fair quality bicarbonate-sulphate waters
€cs	Cambrian Saline River Formation anhydrite gypsum and salt, Cap Mt. Formation shale and Mt. Clark Formation sandstone. Expect maximum yields of 100 Igpm of poor quality sulphate-chloride waters from the Saline River salt and anhydrite, 1 Igpm of poor quality sulphate waters from the Cap Mt. Formation shale, and 25 Igpm of fair quality waters from the Mt. Clark Formation sandstone
P	Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

Tectonic symbols: ▲▲ thrust fault with teeth indicating direction of dip; ╋ anticline; ╋ syncline

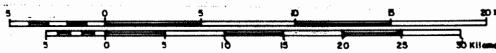
Map 22



CANOT LAKE

106 P

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP



LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

(Note: The entire study-area is underlain by widespread permafrost in the discontinuous permafrost zone; also, estimates of yields refer to probable, not absolute, maximum figures and to generally more highly disturbed, fractured, and porous zones within the formations)

Symbol	Explanation
T	Tertiary non-marine sand, gravel, conglomerate, shale, sandstone, coal. Expect maximum yields of 50 Igpm of generally fair to good quality waters
Ku	Upper Cretaceous mainly non-marine sandstone and shale. Expect maximum yields of 25 Igpm of generally poor to locally fair quality waters
Kl	Lower Cretaceous mainly marine shale and sandstone. Expect maximum yields of 1 Igpm of poor quality aulphate waters
Kft	Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
K	Upper and Lower Cretaceous unnamed and undivided mainly marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor quality waters
CPa	Carboniferous (Pennsylvanian) and Permian unnamed and undivided sandstone and conglomerate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
Dur	Upper Devonian Redknife Formation mainly marine shale with minor sandstone and limestone. Expect maximum yields of 1 Igpm of generally poor quality waters
Duu	Upper Devonian unnamed mainly non-marine shale, siltstone, limestone, and sandstone. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters
Dui	Upper Devonian Imperial Formation mainly non-marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
Duk	Upper Devonian Kakisa Formation limestone. Expect maximum yields of 5 Igpm of poor to locally fair quality bicarbonate waters
Dutt	Upper Devonian Trout River and Tetcho formations consisting mainly of limestone with minor shale and sandstone. Expect maximum yields of 5 Igpm of poor to locally fair quality generally bicarbonate waters
Dus	Upper Devonian Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igpm of generally poor quality sulphate waters.
Dm	Middle Devonian unnamed and undivided mainly carbonate strata with minor shale and anhydrite. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate waters
Dmk	Middle Devonian Kee Scarp Formation reefal and other limestones. Expect maximum yields of 100 Igpm of poor to locally fair quality generally bicarbonate, hard waters
Dmki	Middle Devonian Kee Scarp Formation limestone and Hare Indian calcareous shale. Expect maximum yields of 25 Igpm of variable quality generally bicarbonate, hard waters
Dmh	Middle Devonian Hume Formation limestone. Expect maximum yields of 10 Igpm of variable quality generally bicarbonate, hard waters
Dmc	Middle Devonian Canol Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
Dmci	Middle Devonian Canol and Hare Indian Formations consisting mainly of shale. Expect maximum yields of 1 Igpm of poor quality bicarbonate-sulphate waters
Dmbr	Middle Devonian Bear Rock Formation dolomite, limestone, and anhydrite. Expect maximum yields of 250 Igpm of very poor quality generally bicarbonate-sulphate waters
Dmhi	Middle Devonian Hare Indian Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
OS	Ordovician and Silurian unnamed and undivided dolomite and limestone. Expect maximum yields of 10 Igpm of highly variable quality generally bicarbonate-sulphate waters
OSk	Ordovician and Silurian Mount Kindle Formation dolomite and anhydrite and Franklin Mtn. Formation dolomite and shale. Expect maximum yields of 100 Igpm of generally poor to locally fair quality bicarbonate-sulphate waters
€cs	Cambrian Saline River Formation anhydrite gypsum and salt, Cap Mt. Formation shale and Mt. Clark Formation sandstone. Expect maximum yields of 100 Igpm of poor quality sulphate-chloride waters from the Saline River salt and anhydrite, 1 Igpm of poor quality sulphate waters from the Cap Mt. Formation shale, and 25 Igpm of fair quality waters from the Mt. Clark Formation sandstone
P	Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

Tectonic symbols:: ▲▲ thrust fault with teeth indicating direction of dip; + anticline; + syncline

Map 23

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RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP

LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

(Note: The entire study-area is underlain by widespread permafrost in the discontinuous permafrost zone; also, estimates of yields refer to probable, not absolute, maximum figures and to generally more highly disturbed, fractured, and porous zones within the formations)

Symbol	Explanation
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Ku	Upper Cretaceous mainly non-marine sandstone and shale. Expect maximum yields of 25 Igpm of generally poor to locally fair quality waters
Kl	Lower Cretaceous mainly marine shale and sandstone. Expect maximum yields of 1 Igpm of poor quality sulphate waters
Klf	Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
K	Upper and Lower Cretaceous unnamed and undivided mainly marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor quality waters
CPc	Carboniferous (Pennsylvanian) and Permian unnamed and undivided sandstone and conglomerate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
Dur	Upper Devonian Redknife Formation mainly marine shale with minor sandstone and limestone. Expect maximum yields of 1 Igpm of generally poor quality waters
Duu	Upper Devonian unnamed mainly non-marine shale, siltstone, limestone, and sandstone. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters
Dui	Upper Devonian Imperial Formation mainly non-marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
Duk	Upper Devonian Kakisa Formation limestone. Expect maximum yields of 5 Igpm of poor to locally fair quality bicarbonate waters
Dutt	Upper Devonian Trout River and Tetcho Formations consisting mainly of limestone with minor shale and sandstone. Expect maximum yields of 5 Igpm of poor to locally fair quality generally bicarbonate waters
Dus	Upper Devonian Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igpm of generally poor quality sulphate waters
Dm	Middle Devonian unnamed and undivided mainly carbonate strata with minor shale and anhydrite. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate waters
Dmk	Middle Devonian Kee Scarp Formation reefal and other limestones. Expect maximum yields of 100 Igpm of poor to locally fair quality generally bicarbonate, hard waters
Dmki	Middle Devonian Kee Scarp Formation limestone and Hare Indian calcareous shale. Expect maximum yields of 25 Igpm of variable quality generally bicarbonate, hard waters
Dmh	Middle Devonian Hume Formation limestone. Expect maximum yields of 10 Igpm of variable quality generally bicarbonate, hard waters
Dmc	Middle Devonian Canol Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
Dmci	Middle Devonian Canol and Hare Indian Formations consisting mainly of shale. Expect maximum yields of 1 Igpm of poor quality bicarbonate-sulphate waters
Dmbr	Middle Devonian Bear Rock Formation dolomite, limestone, and anhydrite. Expect maximum yields of 250 Igpm of very poor quality generally bicarbonate-sulphate waters
Dmhi	Middle Devonian Hare Indian Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
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P	Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

Tectonic symbols: thrust fault with teeth indicating direction of dip; anticline; syncline

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP

LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

(Note: The entire study-area is underlain by widespread permafrost in the discontinuous permafrost zone; also, estimates of yields refer to probable, not absolute, maximum figures and to generally more highly disturbed, fractured, and porous zones within the formations)

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CPa	Carboniferous (Pennsylvanian) and Permian unnamed and undivided sandstone and conglomerate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
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Duu	Upper Devonian unnamed mainly non-marine shale, siltstone, limestone, and sandstone. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters
Dui	Upper Devonian Imperial Formation mainly non-marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
Duk	Upper Devonian Kakisa Formation limestone. Expect maximum yields of 5 Igpm of poor to locally fair quality bicarbonate waters
Dutf	Upper Devonian Trout River and Tetcho Formations consisting mainly of limestone with minor shale and sandstone. Expect maximum yields of 5 Igpm of poor to locally fair quality generally bicarbonate waters
Dus	Upper Devonian Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igpm of generally poor quality sulphate waters
Dm	Middle Devonian unnamed and undivided mainly carbonate strata with minor shale and anhydrite. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate waters
Dmk	Middle Devonian Kee Scarp Formation reefal and other limestones. Expect maximum yields of 100 Igpm of poor to locally fair quality generally bicarbonate, hard waters
Dmki	Middle Devonian Kee Scarp Formation limestone and Hare Indian calcareous shale. Expect maximum yields of 25 Igpm of variable quality generally bicarbonate, hard waters
Dmh	Middle Devonian Hume Formation limestone. Expect maximum yields of 10 Igpm of variable quality generally bicarbonate, hard waters
Dmc	Middle Devonian Canol Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
Dmci	Middle Devonian Canol and Hare Indian Formations consisting mainly of shale. Expect maximum yields of 1 Igpm of poor quality bicarbonate-sulphate waters
Dmbr	Middle Devonian Bear Rock Formation dolomite, limestone, and anhydrite. Expect maximum yields of 250 Igpm of very poor quality generally bicarbonate-sulphate waters
Dmhi	Middle Devonian Hare Indian Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
OS	Ordovician and Silurian unnamed and undivided dolomite and limestone. Expect maximum yields of 10 Igpm of highly variable quality generally bicarbonate-sulphate waters
OSk	Ordovician and Silurian Mount Kindle Formation dolomite and anhydrite and Franklin Mtn. Formation dolomite and shale. Expect maximum yields of 100 Igpm of generally poor to locally fair quality bicarbonate-sulphate waters
€cs	Cambrian Saline River Formation anhydrite gypsum and salt, Cap Mt. Formation shale and Mt. Clark Formation sandstone. Expect maximum yields of 100 Igpm of poor quality sulphate-chloride waters from the Saline River salt and anhydrite, 1 Igpm of poor quality sulphate waters from the Cap Mt. Formation shale, and 25 Igpm of fair quality waters from the Mt. Clark Formation sandstone
P	Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

Tectonic symbols: ▲ thrust fault with teeth indicating direction of dip; ↕ anticline; ✕ syncline

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RECONNAISSANCE SURFICIAL HYDROGEOLOGY MAP

GENERALIZED HYDROGEOLOGY MAP OF SURFICIAL DEPOSITS
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

(Note: Estimates of yield are probable, not absolute, maximum figures, which also exclude possible buried bedrock valleys partly filled with granular strata but having no surface expression)

LEGEND

Symbol	Explanation
F	PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS MAY YIELD UP TO 50 TO 100 IGPM AND LOCALLY, IN THICKER MORE PERMEABLE AQUIFERS, 100 TO 500 IGPM OF GOOD QUALITY WATER Potentially good water supplies for tourist and construction camps, villages and towns, and industries — especially those thick coarse aquifers in major river valleys tributary to the Mackenzie River. Consists mainly of alluvial sand and gravel below the active and wooded (inactive) floodplains and below coarse sandy and gravelly point-bar deposits on steeper-gradient sections of larger meandering rivers. Considerable test drilling may be required to locate large aquifers in the lower reaches of tributaries and in the Mackenzie River flood plain. Chief well installation problems are flooding and excessive lateral and vertical river erosion. Rivers with headwaters in the Mackenzie Mountains are extremely flashy and floods can be highly destructive.
O,T	PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS MAY YIELD UP TO 25 IGPM OF GOOD QUALITY WATER WHERE THESE GRANULAR SEDIMENTS ARE UNFROZEN AND CONTINUALLY RECHARGED; BETTER PROSPECTS OCCUR SOUTH OF NORMAN WELLS, ESPECIALLY THICKER LOW-LYING SECTIONS OF SAND AND GRAVEL COVERED BY JACKPINE, WHITE SPRUCE, BALSAM POPLAR, AND TALL WILLOWS Potentially fair to good possibilities for tourist camps, domestic use (washing, drinking) at construction camps, and small native settlements. Consists mainly of sandy outwash and terrace deposits containing minor gravelly and silt interbeds.
A,C E,D W,I	PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS MAY YIELD UP TO 5 IGPM OF POOR TO FAIR QUALITY WATER; BETTER PROSPECTS (COMMONLY MAP-UNITS A AND I) OCCUR IN LOCALITIES THAT BORDER WATER, ARE FREQUENTLY FLOODED, OR ARE SITUATED ON SOUTH-FACING EXPOSURES Generally poor to locally fair water supplies for domestic use. Detailed airphoto study coupled with thorough field geological reconnaissance is needed to pinpoint preferred testhole-exploration sites. Expect limited ground-water recharge. Ground water will likely require some treatment, such as removal of iron and manganese. The more promising well sites are commonly restricted to places on active distributaries and abandoned channels on larger alluvial and colluvial fans marked A and C, the margins of larger ponds and creekbeds in areas marked E and D, and south-facing slopes on higher larger wooded ridges marked W and I in regional lowland areas receiving recharge.
L,V H,G N,J M,AS	INDIVIDUAL WELLS ARE EXPECTED TO YIELD LESS THAN 1 IGPM OF POOR QUALITY WATER Generally poor ground-water sources for all prospective water users because of low permeability, low recharge possibilities, and a high permafrost table. Recharge is limited to larger thermokarst features — mainly in map-units L and H. Expect sulphate waters having potentially high iron and manganese contents. Consists mainly of fine-grained, low-permeability lacustrine and till deposits, the latter containing minor and randomly occurring inclusions of sand and, less commonly, gravel. Expect subsoils to be widely frozen (permafrost).
B,R,K	YIELDS FROM PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS ARE EXPECTED TO VARY FROM LESS THAN 1 IGPM IN THICK SHALE SEQUENCES TO POSSIBLY 250 IGPM AT SELECT LOCATIONS IN HIGHLY DISTURBED AND FRACTURED NON-MARINE SANDSTONE AND POROUS CARBONATE ROCKS AND IN THICK UNCEMENTED TERTIARY SAND AND GRAVEL (SEE, ALSO, THE ACCOMPANYING GENERALIZED BEDROCK HYDROGEOLOGY MAP) Highly variable ground-water source, both from the standpoints of water quality and quantity. Potentially suitable for domestic supplies, villages and some industries in certain localities.
S	SPRINGS YIELDING LARGE QUANTITIES OF HIGHLY VARIABLE QUALITY GROUND WATER Generally springs occur in lowland areas along valley banks where permeable soil or rock materials overlie impermeable strata. The springs may be artesian or water-table. Potentially suitable for towns, industries, and construction campsites depending on water quality.
ψ	INDIVIDUAL WELLS IN ORGANIC (PEAT) DEPOSITS ARE EXPECTED TO YIELD LESS THAN 1 IGPM OF POOR QUALITY WATER Generally poor water supplies for all users because of the typical tea colour of the water, potentially high manganese and iron contents and common boggy taste and odour. Includes fens, bogs, marshes, and swamps. Generally patterned fens are unfrozen in vicinity of Fort Simpson whereas only the small, roundish, treeless collapse scars in peat plateaus are unfrozen.
Lake	PROPER INTAKES INTO LARGE LAKES MAY YIELD UP TO 100 IGPM OF GOOD QUALITY WATER; DEPTH OF WATER (PREFERABLY OVER 10 FEET) AND SIZE OF LAKE ARE IMPORTANT CONSIDERATIONS, THE LARGER AND DEEPER LAKES BEING BETTER Consists of larger and deeper permanent lakes in Mackenzie River Valley upland, such as Tate and Stewart Lakes. Potentially fair to good water supplies for villages, industries, and construction camps. Treatment for iron, manganese, and organic matter may be necessary. Because of potentially thick ice cover on smaller shallow lakes, the availability of this water source may vary seasonally.

END OF REPORT