Earth Sciences Report 81-1

Guidebook
for use with Soil Survey Reports of
Alberta Provincial Parks and Recreation Areas

by

G.M. Greenlee

Alberta
RESEARCH COUNCIL

ERRATA : Earth Sciences Report 81-1

Page 13 Figure 4 - Lower right corner. "Medium Columnar Flat or Road Top" should read "Medium Columnar Flat or Round Top".

Page 23 Plate 17 - is upside down.

Page 55 Paragraph 4, last sentence - "Textures of unconsolidated mineral materials, and fiber content of organics are recognized in a category called Mineral Modifiers." should read "Textures of unconsolidated mineral materials, and fiber content of organics are recognized in a category called Material Modifiers".

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PREFACE

This guidebook has been prepared as a companion text to soil survey reports of Alberta provincial parks and recreation areas. Most of the information is pertinent to all the reports, and the guidebook is frequently cited in them. Some terms defined or explained in various figures, tables, appendices and the glossary of the guidebook are not used in all reports; however all the terms are used in one or more reports.

PLATE 2. Scenic stream in an Alberta Provincial Park.

INTRODUCTION

Soil is a basic resource, the key consideration in any form of land use. Outdoor recreation areas must be designed for use without undue deterioration of soil, vegetation, and water resources. Pertinent soil and landscape characteristics need to be recognized.

Soil surveys provide for the systematic examination of soils in the field and laboratory. Each kind of soil occurring in the landscape is classified, defined, and delineated on a map. The scientific basis of a soil survey is that the locations of soils in the landscape have a degree of predictability. Soil surveys are reasonably accurate because this soil-landscape association possesses a degree of correlation that is high enough to allow inference and predictions of soil behavior under different types of land use.

The objective of a soil survey is to delineate the landscape into soil units that contain less variable soil conditions than the total population of soils. The utility of the resulting soil map depends upon the precision of the statements that can be made about the behavior of the delineated units versus the area as a whole.

A soil survey can be one of the most useful tools available to management in planning a proper design of an area for recreational use. Knowledge of soil problems enables planners to use careful conservation practices or to direct traffic away from areas not suitable for heavy use. By using a soil survey, a design can be made that is compatible with natural land features. Both initial investment and maintenance after site development can be reduced.

This guidebook contains background material that should assist users of soil survey information to understand reports written for Alberta provincial park and recreation areas. Various subjects discussed include the following:

1. Soil formation;

2. An outline of the Canadian soil classification system;

3. Soil characteristics and other factors that affect the use of soils for various recreational and related purposes;
4. Three special problem soils;
5. Soil erosion;
6. Methodology used in conducting the soil surveys;
7. Soil and landscape maps that are produced for the soil survey reports ;
8. An explanation of the various soil interpretations and guidelines used for developing the interpretations;
9. An appendix dealing with chemical and physical properties of soils;
10. An appendix outlining the landform classification system used by Canadian pedologists.

It is hoped that information in the guidebook and soil reports will be useful in planning future development of provincial parks and recreation areas in Alberta.

SOILS

The pedologist defines soil as the naturally occurring, unconsolidated, mineral or organic material at the earth's surface that is capable of supporting plant growth. It extends from the surface to 15 cm below the depth at which properties produced by soil forming processes can be detected (Canada Department of Agriculture, 1976).

SOIL FORMATION

Soil is continuous over the land surface of the earth, except for the steep and rugged mountain peaks and the lands of ice and snow (Simonson, 1957); and in areas where it has been moved or covered by man's activities. Soils may be regarded as products of their environment. They are not static, but dynamic, and will change with modifications in the environment. The most important factors in determining the kinds of soil that develop are climate, vegetation, organisms, relief, time, and parent material.

Soils have been formed from the original parent material. Processes involved are the physical breakdown or weathering of rock fragments; the chemical weathering or alteration

PLATE 3. Lake and beach in an Alberta Provincial Park.

and solution of rock and mineral particles; biological activities including the growth of plants and the decomposition of plant material; and the production of humus (soil organic matter) by the work of macro and micro soil organisms.

IDENTIFICATION OF SOIL HORIZONS AND PROFILES

The soil profile as viewed in vertical cross-section is a succession of layers or horizons approximately parallel to the land surface, and extending from the surface of the soil down into the underlying and relatively unchanged geological material. The processes of soil formation involve changes in material, transferral from one part of the soil to another, and development of soil structure. Each soil horizon differs from adjacent genetically related layers in properties such as texture, structure, consistence, color; and chemical, biological, and mineralogical composition.

The A horizon, the uppermost layer in the mineral soil profile, usually is the part of the soil in which organic matter is most plentiful. In soils formed under forest cover, the A horizon has been leached of substances, both in suspension and in solution-clay particles, organic matter, iron and aluminum oxides.

The B horizon, when present, lies immediately beneath the A, and the color is often transitional between that of the A and C horizons. The B frequently has more clay than either the A or the C horizons, and may have a blocky or prismatic structure. Concentrations of iron or aluminum oxides, usually in combination with organic matter, mark the B horizons of some soils.

The C horizon is the deepest of the three major horizons, and constitutes the parent material of soils. It may have accumulated in place from the breakdown and weathering of hard rock, or it may have been moved to its present location by water, wind, or ice. The C is comparatively unaltered by soil-forming processes, except gleying; and the accumulation of calcium and magnesium carbonates, and water soluble salts. It is commonly lighter colored than the A or B horizons.

A particular soil is recognized by identifying the various layers or horizons that make up its profile, and a system has been devised to facilitate this recognition (Canada Soil Survey Committee, 1978). Figure 1 gives generalized definitions of the soil horizons, and the symbols used to designate them in profile descriptions. Table 1 gives a generalized outline of the Canadian soil classification system. Figure 2 gives diagrammatic horizon patterns of some representative soil profiles from the various orders.

IMPORTANT SOIL CHARACTERISTICS

Soils comprise probably the most basic resource to consider when planning land-use activities. Proper use and management of the soil resources is required to accommodate recreational activities and facilities at optimal cost, both in terms of construction and maintenance, and in terms of impairment to the environment. Each kind of soil has its own particular set of characteristics and is described in terms of observable properties. Soil properties affecting various recreational uses include permeability, texture, structure, consistence, color, reaction, organic matter content, salinity, free lime content, thickness of topsoil, surface organic horizons, soil depth, and productive capacity. These factors are discussed in the following paragraphs.

Permeability

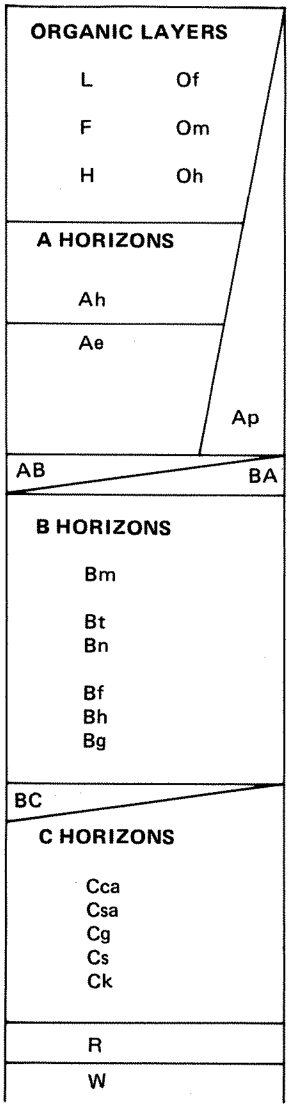
Permeability is that quality of a soil that enables it to transmit water or air. Accepted as a measure of this quality is the rate at which soil will transmit water under saturated conditions. The classes of soil permeability are shown in Table 2.

Since field measurements are not made, soil permeability is estimated from a consideration of soil characteristics observed in the field, particularly texture, structure, and depth to an impeding horizon in the profile.

In general, soils with very rapid to moderately rapid permeability have no limitations for recreational uses if a groundwater contamination hazard does not exist; and soils with slow and very slow permeability may have severe limitations. However, the degree of limitation may vary with climate. For example, in high rainfall areas, slow permeability may result in surface water ponding, and is a more serious limitation than in low rainfall areas. In low rainfall areas, rapid permeability may result in dry soils, and is a more serious limitation than in high rainfall areas.

Texture

Texture refers to the relative proportions of fine, medium, and coarse particles (clay, silt, and sand) that make up the



NOTE: The lower case letters shown above in the A, B and C horizons are sometimes combined to express combinations of characteristics. Other lower case letters not listed above are:

- b - a buried soil horizon
- j - a modifier of suffixes e, f, g, n and t to denote expression of, but failure to meet, the specified limits of the suffix it modifies.
- u - a horizon markedly disrupted by physical or faunal processes other than cryoturbation.
- y - a horizon affected by cryoturbation.
- z - a perennially frozen layer.

L-F-H	well drained decomposing plant litter, primarily leaves, twigs, woody materials. L - slightly decomposed, F - partly decomposed, H - well decomposed.
O	poorly drained decomposing peat, mainly mosses, rushes, woody materials. Of - fibric - least decomposed; Om - mesic - moderately decomposed; Oh - humic - most highly decomposed.
A	Organic-mineral horizons at or near the surface. Ah - dark colored, humus-rich horizon Ae - light colored, eluviated horizon, characterized by removal of clay, iron, aluminium or organic matter, alone or in combination. Ap - horizons disturbed by man's activities, that is, by cultivation, or pasturing, or both.
AB, BA	horizons transitional to A and B.
B	a mineral horizon differing from A and C by the following characteristics: m - slightly altered by hydrolysis, oxidation, or solution or all three, to give a change in color, or structure or both. t - a significant accumulation of silicate clay. n - a columnar or prismatic structure, hard consistence when dry and significantly high exchangeable sodium. f - a significant accumulation of Fe + Al combined with organic matter. h - a significant accumulation of illuvial organic matter. g - a significant expression of gleying.[2]
BC	a horizon transitional to B and C.
C	a horizon comparatively unaffected by soil forming processes, except for: ca - an accumulation of lime. sa - an accumulation of water-soluble salts. g - a significant expression of gleying.[2] s - denotes the presence of salts, including gypsum ($CaSO_4$). k - denotes the presence of lime.
R	a consolidated bedrock layer.
W	a layer of water.

[1] Diagram copied from the National Atlas of Canada (Energy, Mines and Resources, 1973).

[2] "Gleying" refers to a soil forming process operating under poor drainage conditions, which results in the reduction of iron and other elements, in gray colors, and mottles.

FIGURE 1. Diagram[1] of a soil profile and definitions of soil horizon symbols (Canada Soil Survey Committee, 1978).

TABLE 1.
Outline of the Canadian Soil Classification System
(Canada Soil Survey Committee, 1978)

ORDER	GREAT GROUP	DISTINGUISHING CHARACTERISTICS
Brunisolic (Sufficient development to exclude them from the Regosolic order, but lack degrees or kinds of development specified for other orders)	Melanic Brunisol	Ah>10 cm, pH>5.5
	Eutric Brunisol	Ah<10 cm, pH>5.5
	Sombric Brunisol	Ah>10 cm, pH<5.5
	Dystric Brunisol	Ah<10 cm, pH<5.5
Chernozemic (Surface horizons darkened by accumulation of organic matter from decomposition of xerophytic or mesophytic plants representative of grasslands or grassland-forest with associated plants)	Brown	Brownish Ah, subarid to semiarid climate
	Dark Brown	Dark Brown Ah, semiarid climate
	Black	Black Ah, subhumid climate
	Dark Gray	Surface L-H, eluvial Ah, subhumid climate
Cryosolic (Permafrost within 1 m of surface, or 2 m if >1/3 of pedon strongly cryoturbated)	Turbic Cryosol	Mineral soil, cryoturbation, permafrost within 2 m of surface, usually patterned ground
	Static Cryosol	Mineral soil, no cryoturbation, permafrost within 1 m of surface
	Organic Cryosol	Organic soil, permafrost within 1 m of surface
Gleysolic (Features indicative of periodic or prolonged water saturation, and reducing conditions - mottling and gleying)	Humic Gleysol	Ah≥10 cm, no Bt
	Gleysol	Ah<10 cm, no Bt
	Luvic Gleysol	Has a Btg, usually has an Ahe or an Aeg
Luvisolic (Light colored eluvial horizons - Ae, illuvial B horizons of silicate clay accumulation - Bt, developed under forest vegetation)	Gray Brown Luvisol	Forest mull Ah, Ae and Bt, MAST[1] ≥8°C
	Gray Luvisol	May or may not have Ah, has Ae and Bt, usually MAST[1]< 8°C.
Organic (Composed dominantly of organic materials, and most are water saturated for prolonged periods)	Fibrisol	Dominantly fibric
	Mesisol	Dominantly mesic
	Humisol	Dominantly humic
	Folisol	Forest leaf litter over rock or fragmental material, rarely water saturated.
Podzolic (Accumulation in B horizons of amorphous material, composed mainly of humified organic matter combined in varying degrees with Al and Fe)	Humic Podzol	Bh≥10 cm, OC[2]>1%, Fe<0.3% OC[2]/Fe≥20.
	Ferro-Humic Podzol	Bhf≥10 cm, OC[2]>5%, Fe+Al≥0.6% (0.4% for sands)
	Humo-Ferric Podzol	Bf or thin Bhf + Bf≥10 cm, OC[2] = 0.5 - 5% Fe + Al≥0.6% (0.4% for sands)
Regosolic (Development too weak to meet requirements of any other order)	Regosol	Ah<10 cm, Bm absent or<5 cm
	Humic Regosol	Ah≥10 cm, Bm absent or<5 cm
Solonetzic (Solonetzic B horizon - Bn or Bnt - columnar or prismatic structure, hard to extremely hard when dry, exchangeable Ca/Na≤10)	Solonetz	Lack a continuous Ae≥2 cm
	Solodized Solonetz	Ae≥2 cm, intact columnar Bnt or Bn
	Solod	Ae≥2 cm, distinct AB or BA (disintegrating Bnt)

[1] MAST - mean annual soil temperature

[2] OC - organic carbon

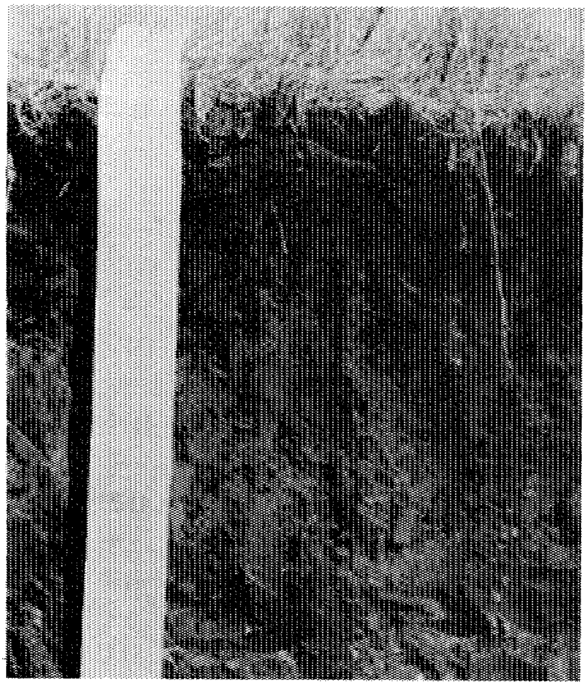


PLATE 4. A Chernozemic Black soil is characterized by a thick black surface Ah horizon.

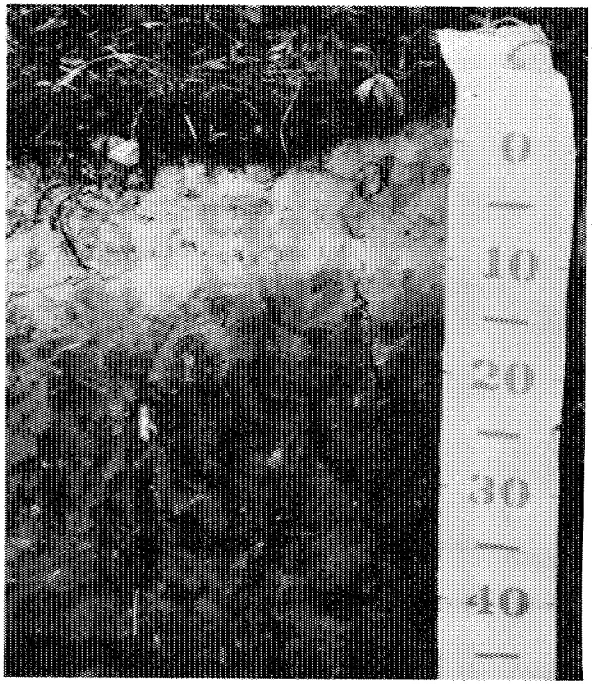


PLATE 5. A Gray Luvisol soil is characterized by a light-colored "leached" horizon (Ae), underlain by a darker colored horizon of accumulation (Bt).

PLATE 6. Very little profile development is evident in a Brunisolic soil.

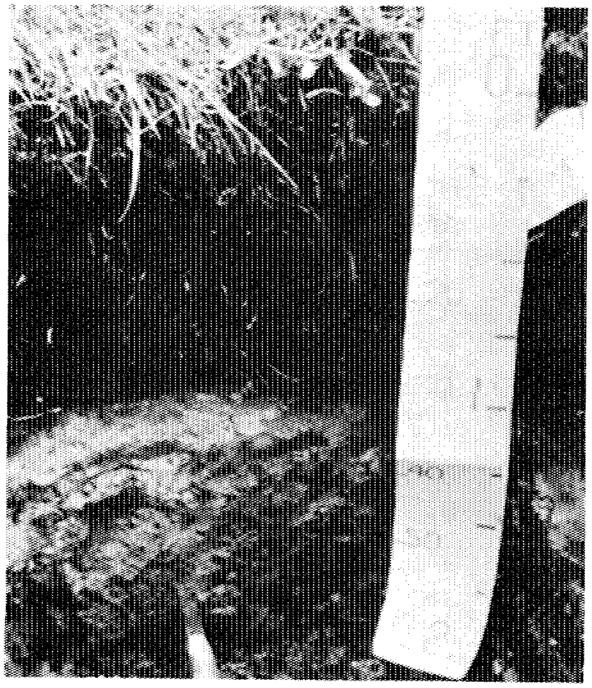


PLATE 7. Gleysolic soils often have considerable surface accumulations of peat, and are typified by dull colors and mottling, indicative of poor drainage.

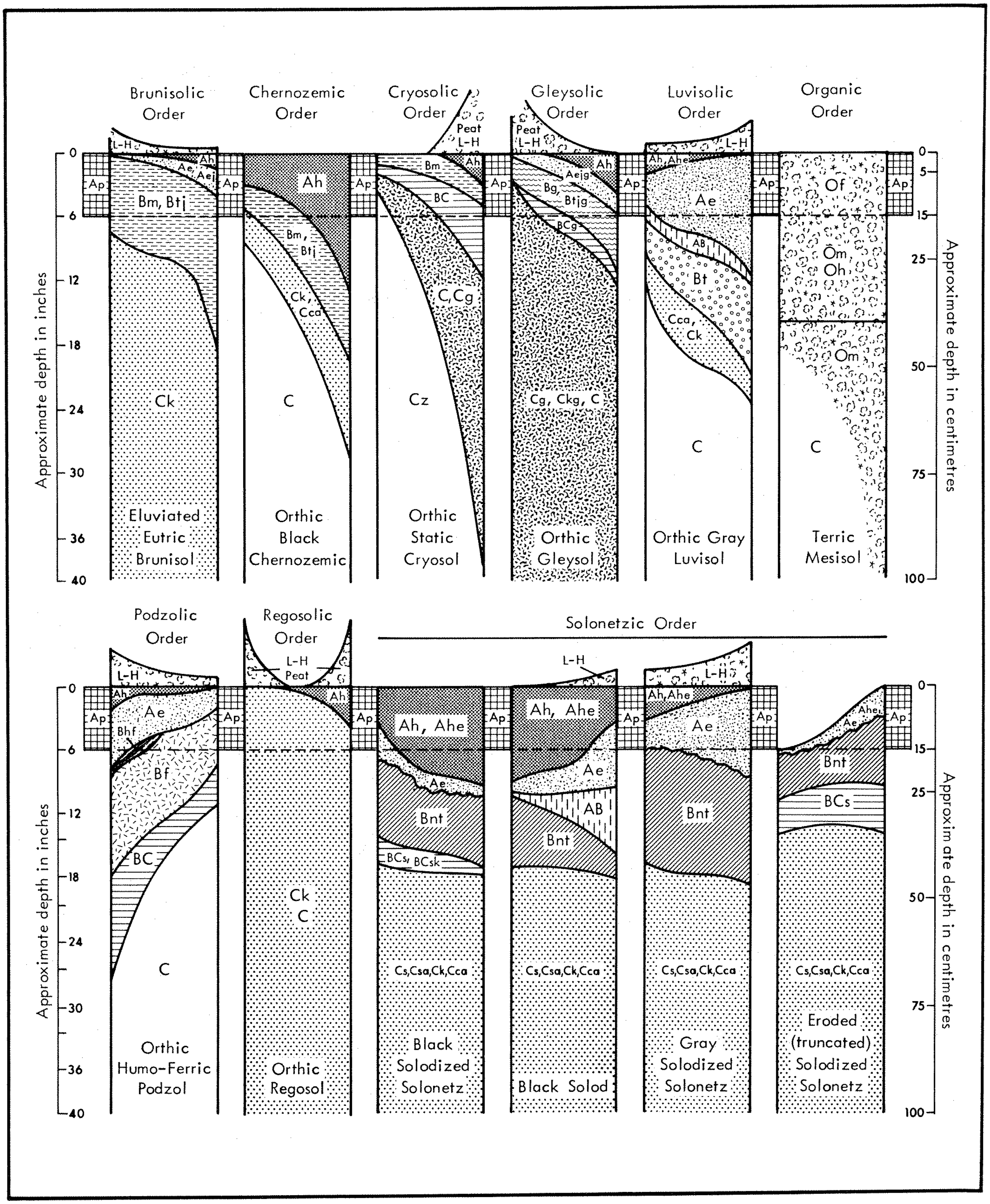


FIGURE 2. Diagrammatic horizon patterns of some representative soil profiles (Canada Department of Agriculture, 1974).

TABLE 2.
Soil permeability classes
(United States Department of Agriculture, undated)

Permeability Class	Rate of Permeability
Very slow	<0.15 cm/hr
Slow	0.15 - 0.5 cm/hr
Moderately slow	0.5 - 1.5 cm/hr
Moderate	1.5 - 5.0 cm/hr
Moderately rapid	5.0 - 15.0 cm/hr
Rapid	15.0 - 50.0 cm/hr
Very rapid	>50.0 cm/hr

soil matrix. Figure 3 shows the various textural classes of the Canada Soil Survey Committee (1978) system. The sand, loamy sand, and sandy loam classes are further subdivided on the basis of the proportions of the various sand separates present. In field mapping it is often necessary to group the textural classes as indicated because of the variability in soils and parent materials.

In determining the potential of an area for recreational uses, texture is one important property to consider, because it influences many other soil characteristics (Table 3).

High clay content in surface soil horizons constitutes a severe limitation for any uses that involve heavy foot traffic by people or horses. Soils high in clay become

TABLE 3.
The effect of texture on some important soil characteristics
(Leskiw, 1976)

Soil Characteristics	Soil Texture Coarse	 Fine
Permeability	high	low
Erodibility (water)	low	high
Erodibility (wind)	high	variable
Water holding capacity	low	high
Shrink-swell potential	low	high
Susceptibility to frost heave	low	high

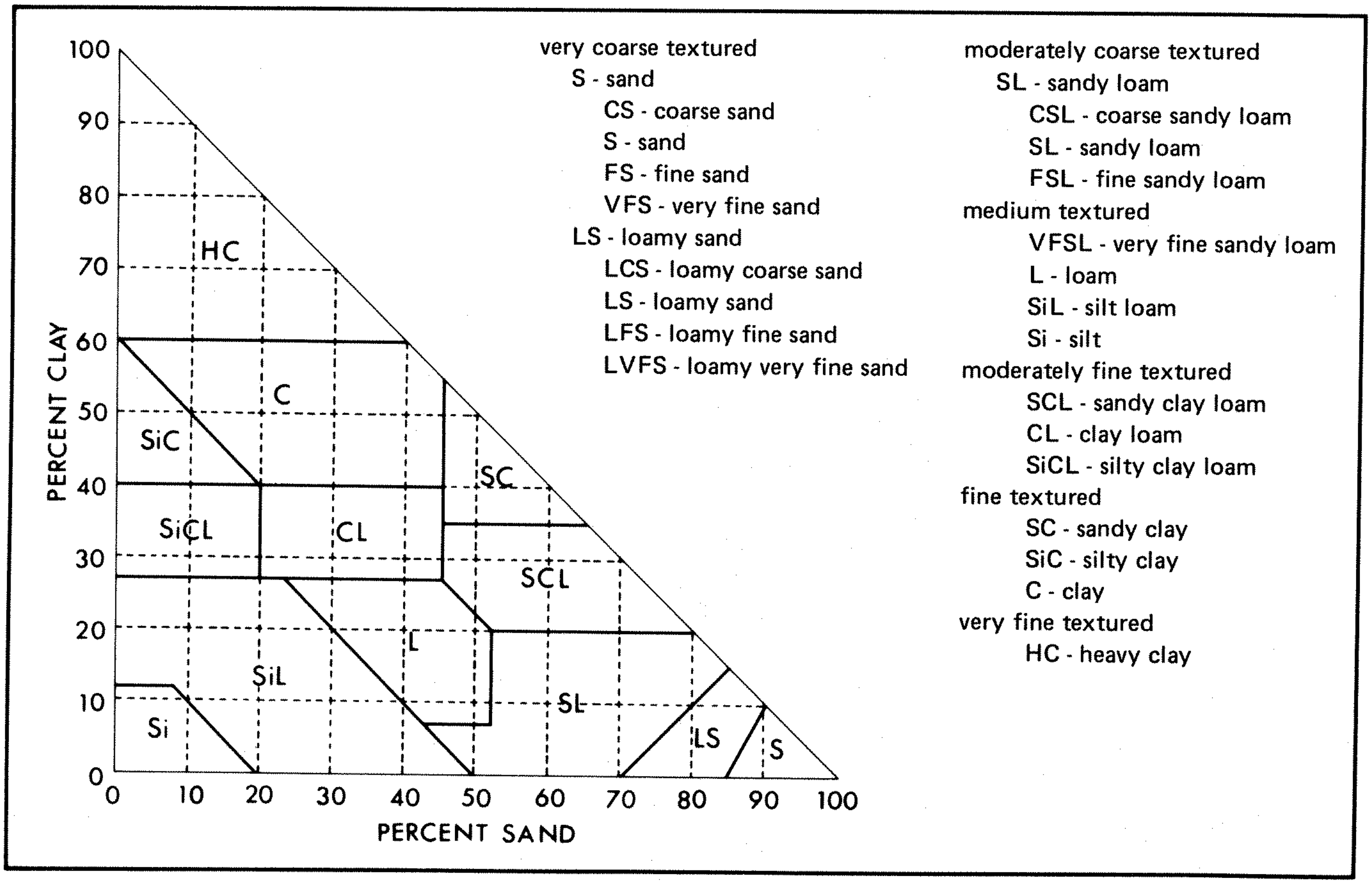


FIGURE 3. Soil textural classes: percentages of clay and sand in the main textural classes of soil; the remainder of each class is silt (Canada Soil Survey Committee, 1978).

slippery and sticky when wet, and dry out slowly after rainfalls. Also they may be highly susceptible to water erosion when situated on moderate to steep slopes. Soils high in silt become very slippery when wet, are also very susceptible to water erosion, and extremely dusty when dry. Loose sandy soils are unstable when dry, resulting in rapid deterioration, and the disappearance of natural vegetation under concentrated foot traffic. Due to a lack of available moisture in very rapidly drained soils, grass cover needed for lawns, picnic sites, and playgrounds is difficult to establish and maintain. Sandy soils may be highly susceptible to wind erosion, vehicles can easily become stuck, and roads may be excessively dusty. The binding ability of clay-sized particles is very important for soil stability. In general, medium- to moderately coarse-textured soils, such as loams and sandy loams, are the most suitable for recreational uses.

Soil texture is also important for sewage disposal fields. Construction of subsurface seepage beds in slowly permeable soils and poorly drained soils (Gleysolic) results in surface seepage of effluent, and surface water contamination. Coarse-textured soils constitute relatively poor filtering materials, and permit unfiltered sewage to travel long distances. Water supplies, streams, ponds, lakes, or water courses may receive seepage of unfiltered sewage if they are situated near an absorption field constructed in sandy soils. Well-drained medium-textured soils with moderate permeability are the most desirable for sewage disposal, and also sanitary landfills.

Shrink-swell potential is defined as susceptibility to volume change due to loss or gain in moisture content, and is directly proportional to the clay content of soils. Soils with high shrink-swell potentials tend to be unstable with

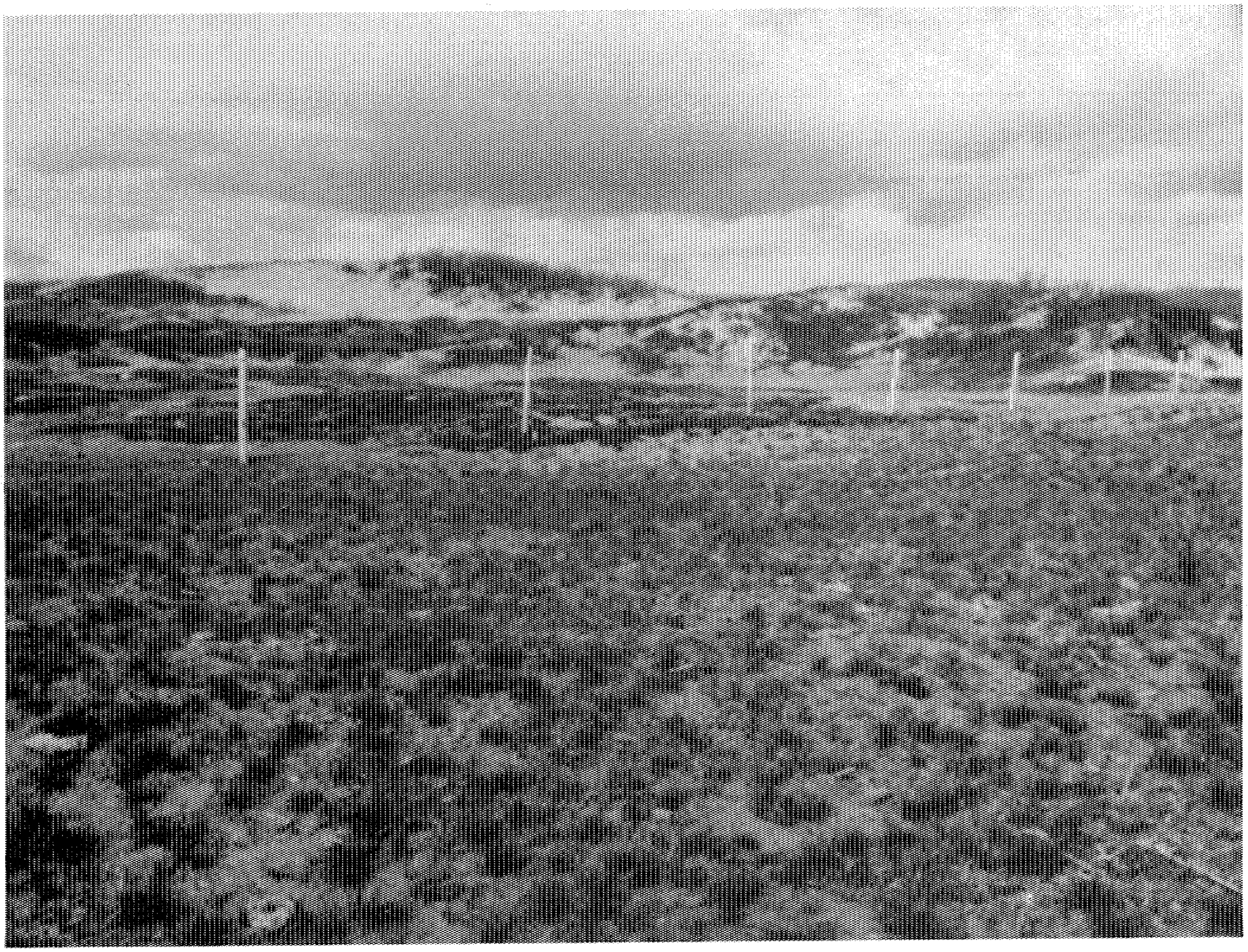


PLATE 8. Very sparse vegetation and dune formation on a very sandy soil.

changing moisture conditions, and when wet may fail to support access roads, trails, and building foundations.

Susceptibility to frost heave refers to the effects on structures or roads resulting from freezing and subsequent thawing of soil materials. Such action pertains not only to heaving as freezing progresses, but also to excessive wetting and loss of soil strength upon thawing. Generally, soils high in silt are highly susceptible to frost action. The availability of water also has a large effect, and this is dependent upon climatic conditions and water table depths. Frost heaving of foundations occurs only where frost penetrates to the assumed depths of basement footings, and the soil is moist during freezing weather. Frost heaving is generally not considered a serious problem for roads in Alberta, except in imperfectly or poorly drained locations, or when high amounts of rainfall are received shortly before freezing (Greenlee, 1976). A frost design soil classification is shown in Table 4.

Structure

Soil structure refers to the aggregation of primary soil particles into peds that are separated from adjoining aggregates by surfaces of weakness. Soil structure is classified in terms of grade or distinctness (weak, moderate, strong), class or size (fine, medium, coarse, very coarse), and type (granular, platy, prismatic, blocky). These are explained and illustrated in Figure 4 and Table 5.

The stability of the peds in a soil is very important, since soil conditions and characteristics such as water movement, heat transfer, aeration, bulk density, and porosity are much influenced by structure. Soil aggregates at the

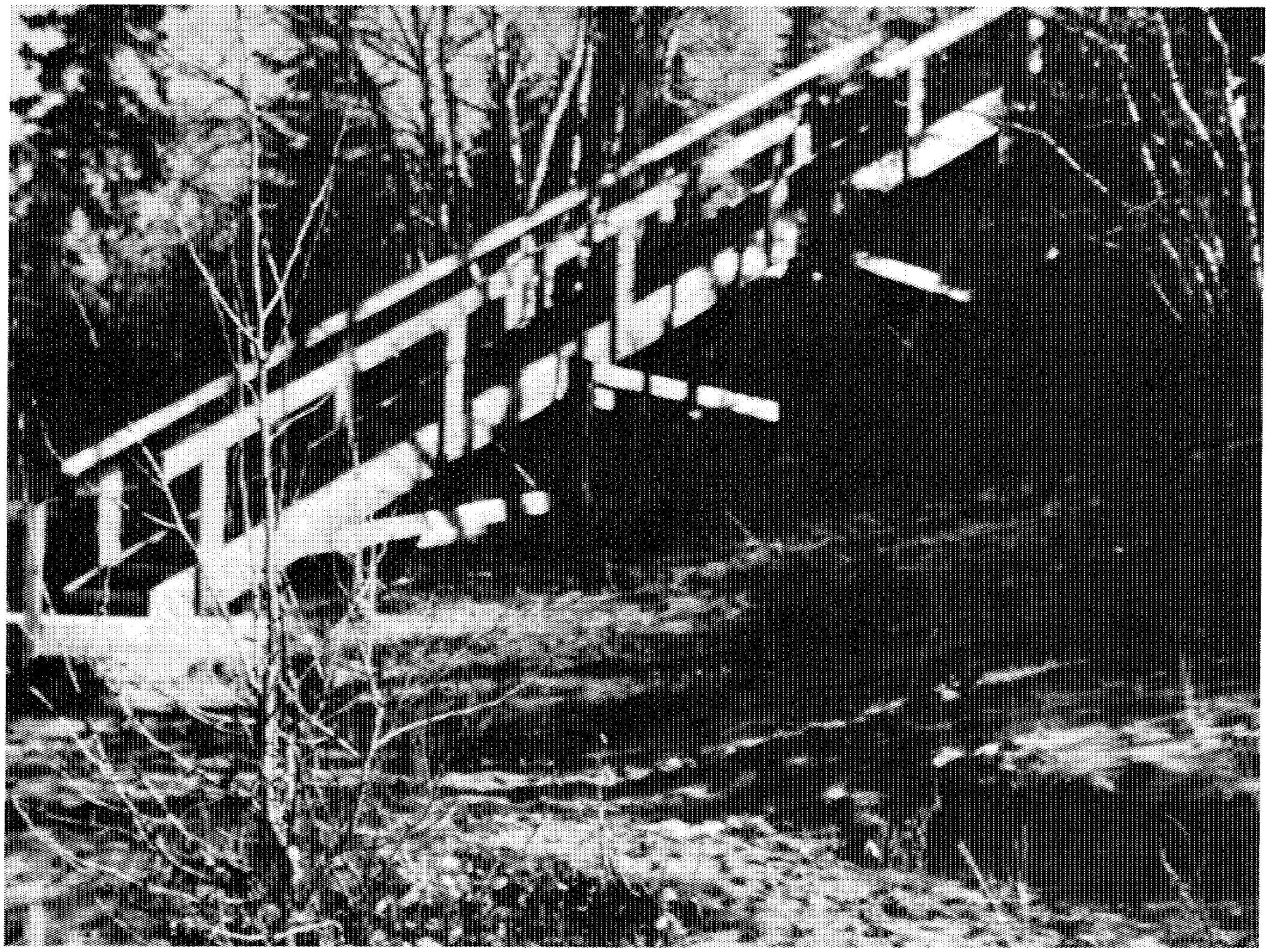


PLATE 9. Stairway constructed over a sand dune to protect the vegetation in one of Alberta's Provincial Parks.

TABLE 4.
Frost design soil classification
(United States Army Corps of Engineers, 1962)

Frost group	Kind of soil	Percentage by weight, finer than 0.02 mm	Typical soil types under Unified Soil Classification System
F1	Gravelly soils	3 to 10	GW, GP, GW-GM, GP-GM
F2	(a) Gravelly soils	10 to 20	GM, GW-GM, GP-GM
	(b) Sands	3 to 15	SW, SP, SM, SW-SM, SP-SM
F3	(a) Gravelly soils	Over 20	GM, GC
	(b) Sands, except very fine silty sands	Over 15	SM, SC
	(c) Clays, PI>12	----	CL, CH
F4	(a) All silts	----	ML, MH
	(b) Very fine silty sands	Over 15	SM
	(c) Clays, PI<12	----	CL, CL-ML
	(d) Varved clays and other fine-grained, banded sediments	---- ----	CL, and ML; CL, ML, and SM; CL, CH, and ML; CL, CH, ML, and SM

TABLE 5.
Types, kinds, and classes of soil structure (Canada Soil Survey Committee, 1978)

Type	Kind	Class	Size mm
1. Structureless: no observable aggregation or no definite orderly arrangement around natural lines of weakness.	A. Single grain structure: loose, incoherent mass of individual particles as in sands.		
	B. Amorphous (massive) structure: a coherent mass showing no evidence of any distinct arrangement of soil particles.		
2. Blocklike: soil particles are arranged around a point and bounded by flat or rounded surfaces.	A. Blocky (angular blocky): faces rectangular and flattened, vertices sharply angular.	Fine blocky	<10
		Medium blocky	10-20
		Coarse blocky	20-50
		Very coarse blocky	>50
	B. Subangular blocky: faces subrectangular, vertices mostly oblique, or subrounded.	Fine subangular blocky	<10
		Medium subangular blocky	10-20
		Coarse subangular blocky	20-50
		Very coarse subangular blocky	>50
	C. Granular: spheroidal and characterized by rounded vertices	Fine granular	<2
		Medium granular	2-5
		Coarse granular	5-10
3. Platelike: soil particles are arranged around a horizontal plane and generally bounded by relatively flat horizontal surfaces.	A. Platy structure: horizontal planes more or less developed.	Fine platy	<2
		Medium platy	2-5
		Coarse platy	>5
4. Prismlike: soil particles are arranged around a vertical axis and bounded by relatively flat vertical surfaces.	A. Prismatic structure: vertical faces well-defined, and edges sharp.	Fine prismatic	<20
		Medium prismatic	20-50
		Coarse prismatic	50-100
		Very coarse prismatic	>100
	B. Columnar structure: vertical edges near top of columns are not sharp. (Columns may be flat topped, round-topped, or irregular.)	Fine columnar	<20
		Medium columnar	20-50
		Coarse columnar	50-100
		Very coarse columnar	>100

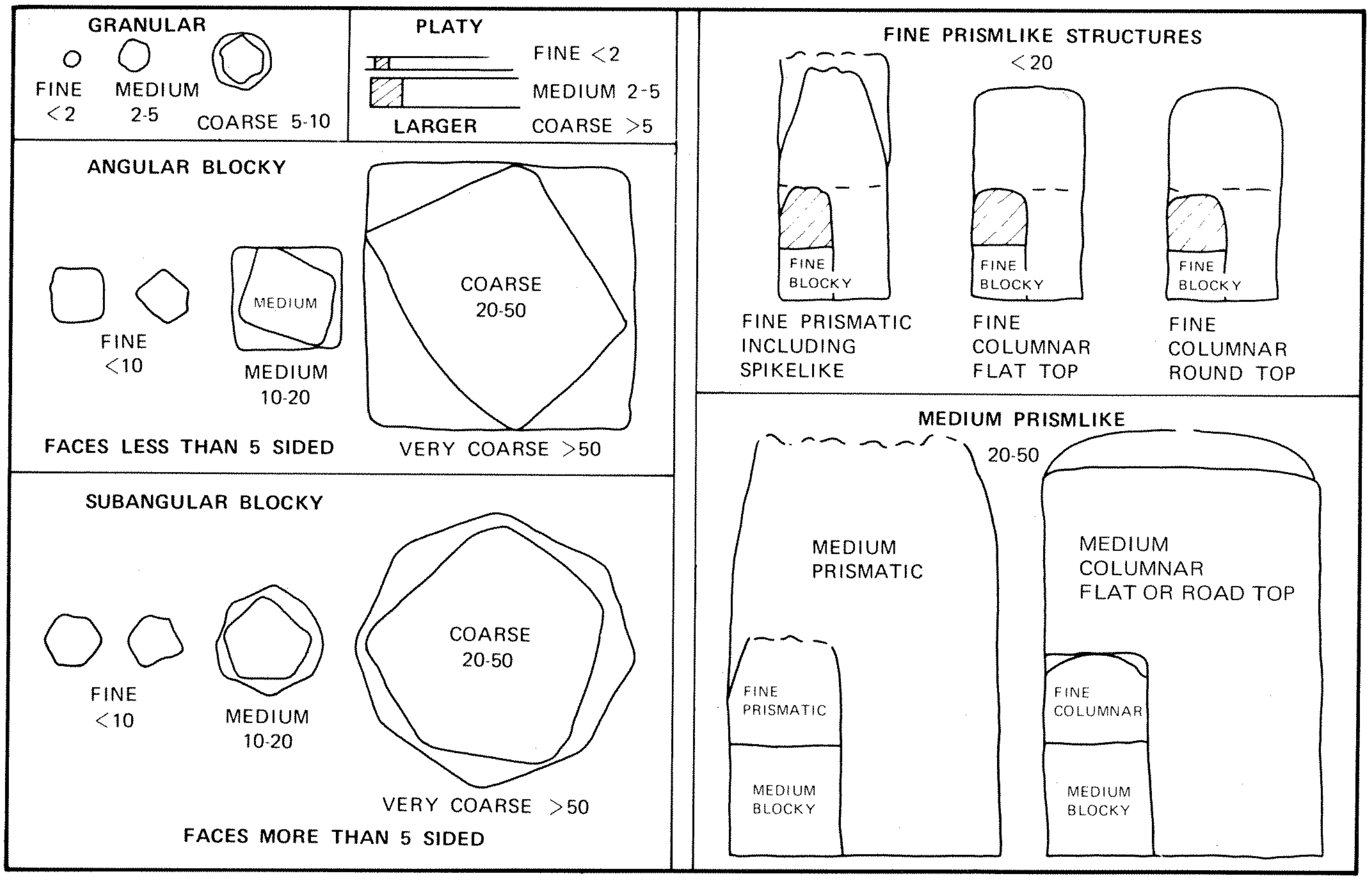


FIGURE 4. Types, kinds, and classes of soil structure (Canada Soil Survey Committee, 1978).

surface, which resist the force of raindrops or disruptive actions of cultivation or foot traffic, ensure a stable system of pores for water and air movement. This is usually beneficial for plant growth and helps minimize surface erosion. Structure is not a stable property of the soil and will vary considerably with different moisture conditions.

Consistence

Soil consistence refers to its resistance to deformation or rupture and its degree of cohesion and adhesion. Consistence of wet soil is classified in terms of stickiness (nonsticky, slightly sticky, sticky, very sticky), and plasticity (nonplastic, slightly plastic, plastic, very plastic) (Canada Soil Survey Committee, 1978). Consistence is classified for moist soil as loose, very friable, friable, firm, or very firm; and for dry soil as loose, soft, slightly hard, hard, very hard, and extremely hard. Cementation refers to brittle, hard consistence due to some cementing substance. The classes of cementation are weakly cemented, strongly cemented, and indurated.

The consistence of a soil is commonly associated with the textural class. For example, sands usually have a loose consistence when either wet or dry. However, many clays are hard when dry, firm when moist, and sticky and plastic when wet.

Consistence is important in determining the practical utilization of soils. The terms used to describe it are meaningful as applied to soil workability and tilth; soil manipulation such as tillage or road construction; and surface compaction by farm machinery or human foot traffic.

Color

Color is the most obvious property of any soil, and to a varying degree a well-drained soil will reflect the color of the geological or other material from which it has formed. Color of the surface soil is important in terms of fertility and favorable tilth, in that dark colors generally indicate relatively high amounts of organic matter. Subsoil colors are important in that bright colors indicate well-drained conditions; and dull colors and mottling or gleying usually indicate slow internal drainage and a shallow or fluctuating water table.

Soil color descriptions are made using a Munsell soil color chart, and the color is described in terms of hue, value, and chroma (Munsell, undated).

Reaction

Reaction is the degree of acidity or alkalinity of a soil, usually expressed as a pH value. Acid soils have pH values of 5.5 or less; neutral soils have pH values between 5.5 and 7.4; and alkaline soils have pH values of 7.4 or more.

The availability of several essential nutrients and the solubility of certain elements toxic to plant growth are drastically affected by soil pH. For example, iron, manganese, and zinc become less available as the pH is raised from 5 to 8. Molybdenum availability is higher at the higher pH levels. Phosphorus is never readily soluble in the soil, but seems to be most available to plants at a soil pH of about 6.5. At pH values below 5, aluminum, iron, and manganese are often soluble in sufficient quantities to be toxic to some plants. At very high pH values, bicarbonate ion is sometimes present in sufficient quantities to interfere with the normal uptake of other ions. These examples of the indirect effects of soil pH show why much importance is placed on this characteristic in diagnosing fertility problems. The best pH range for most crops in Alberta is 5.5 to 7.5 (Alberta Soil and Feed Testing Laboratory, O. S. Longman Building, Edmonton).

The common ranges in pH shown by soils of humid regions is slightly below 5 to above 7; and that for soils of arid regions is slightly below 7 to about 9 (Brady, 1974).

Organic Matter Content

Organic matter content refers to the percent by weight of plant, animal, and microorganism residues in various stages of decomposition in the soil. Organic Matter influences physical and chemical properties of soils far out of proportion to the small quantities present (Brady, 1974). It commonly accounts for at least half the cation exchange capacity of soils and is responsible, perhaps more than any other single factor, for the stability of soil aggregates. It supplies energy and body building constituents for the soil microorganisms, and in forest soils, the surface organic litter is a major source of nutrient elements for plants. The following examples illustrate the important influences of soil organic matter on soil properties. 1. Effect on color of topsoil – brown to black; 2. Influence on physical properties: a) granulation is encouraged; b) plasticity and stickiness are reduced; c) water holding capacity is increased. 3. High cation adsorption capacity: a) 2 to 30 times as great as mineral soil colloids; b) accounts for 30 to 90 percent of the adsorbing power of mineral soils. 4. Supply and availability of nutrients: a) easily replaceable cations are present; b) nitrogen, phosphorus, and sulfur are held in organic forms; c) elements are extracted from minerals by acid humus, and made available to plants.

A relatively high organic matter content in soils is desirable for growing plants, but not for construction purposes. Topsoil tends to compress when loaded and does not provide favorable support for structures, or a good base for roads. Often it is advisable to remove topsoil prior to construction operations.

Salinity and Free Lime Content

Soil salinity and free lime content affect soil suitabilities for plant growth. Soluble salts are present to some degree in all soils. When the salt concentration is high, plant growth is reduced, and the soil is considered saline. In general, the growth of lawn grass is affected on soils having electrical conductivity readings as outlined in Table 6.

Free lime is present in some soils and may reduce nutrient availability in the following ways (Brady, 1974); deficiencies of available iron, manganese, copper, or zinc may be induced; phosphate availability may be decreased due to the formation of complex and insoluble calcium phosphates; the uptake and utilization of boron may be hindered; the high pH in itself may be detrimental.

Free lime cannot readily be removed from the soil. The only practical way to counteract its effect is to increase soil organic matter content.

The soluble sulfate content of subsoils is an important factor for buildings with concrete foundations, and for underground conduits. Categories for sulfate attack on concrete recognized by the Canadian Standards Association are outlined in Table 7. Foundations may require sulfate resistant cement when constructed in soils which have a high sulfate content. If severe sulfate attack is expected, sulfate resistant cement should be used.

Thickness of Topsoil

The meaning commonly conveyed by the term topsoil is that of fertile soil material used to topdress roadbanks,

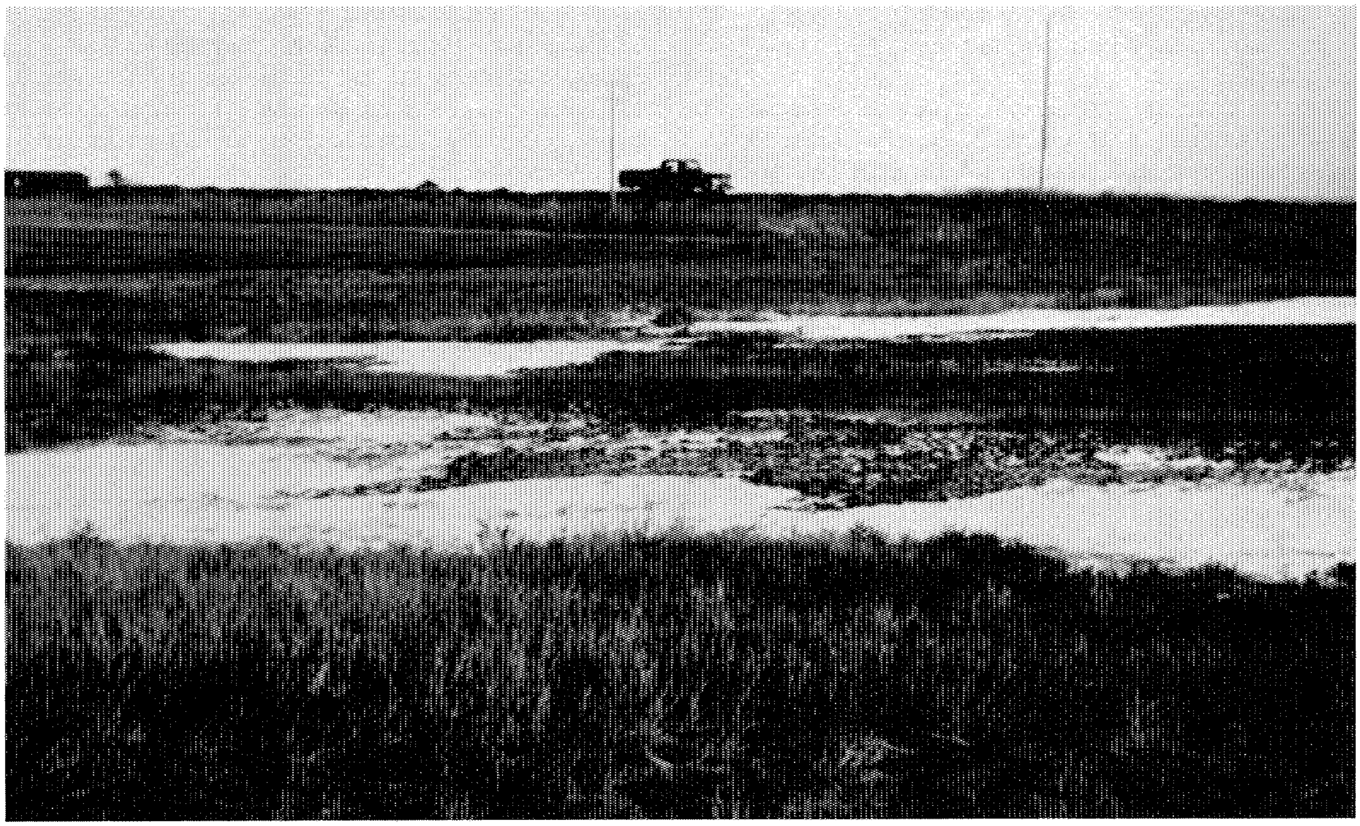


PLATE 10. The presence of a surface white salt crust and salt-tolerant vegetation indicate a saline soil.

TABLE 6.
Effects of soil salinity on lawn growth
(Alberta Soil and Feed Testing Laboratory, O.S. Longman Building, Edmonton)

Conductivity	Effect
0 - 1	negligible salt effects
1.1 - 3	lawn growth noticeably restricted
>3	lawn growth considerably restricted

TABLE 7.
Attack on concrete by soils and waters containing sulfates
(Swenson, 1971)

Relative degree of SO_4 attack	% water soluble SO_4 in dry soil (on a weight basis)	ppm SO_4 in water samples
Negligible	0.00 - 0.10	0 - 150
Positive	0.10 - 0.20	150 - 1000
Considerable	0.20 - 0.50	1000 - 2000
Severe	>0.50	>2000

gardens, lawns, and other landscaped areas. As such it can be considered synonymous with the definition of an Ah horizon.

The rating of a site for recreational uses in general increases with increasing thickness of an Ah horizon (Lesko, 1973). An Ah horizon generally has a high content of organic matter and available nutrients, is well aggregated, and is resilient to compaction. The most suitable soils for lawns and landscaping have an Ah horizon of at least 8 cm, although lack of an Ah is not considered a severe limitation in itself.

Surface Organic Horizon

The accumulation of leaf litter (L-H horizon) on the surface of forested soils is important for its cushioning effect on trampling, and is a protection against the impact of raindrops on the soil (Lesko, 1973). It also serves as a storage of nutrients, which are slowly released for plant growth. Up to a certain thickness (5 to 8 cm), the L-H horizon enhances site capability for recreational uses. However, if it is much thicker, a large percentage of tree and other plant roots are located in this layer. Under conditions of heavy use and concentrated foot traffic, the L-H horizon is rapidly worn away and compacted, thus destroying ground vegetation and exposing tree roots.

Gleysolic or poorly drained soils often have surface layers of peat more than 15 cm thick. Adverse properties of these peat layers can be expected to approach the properties of Organic soils, which are discussed under the heading of Special Problem Soils.

Soil Depth

Soil depth is an important factor for many uses. Soils underlain by bedrock or sand and gravel at shallow depths cannot be levelled for campsites except at high cost. Roads and basements are very difficult to construct in soils with shallow bedrock, and soils with sand and gravel at shallow depths are undesirable for sewage disposal, where a groundwater contamination hazard exists. Also, shallow depths of soil overlying bedrock are very limiting for use as septic tank absorption fields.

Difficulties may be encountered in establishing vegetation on shallow soils overlying impervious soil layers, rock, or sand and gravel, thus rendering them poor locations for intensive uses. In general, deep friable soils are desirable to provide plants with adequate rooting depth and to promote healthy vigorous growth. Any site with a rooting depth of less than 15 cm is regarded as unsuitable for campground use because the upper 15 cm of soil suffer heavily from compaction, and any erosion would severely damage the site.

PLATE 11. Heavy use and concentrated foor traffic in this campground have destroyed the ground vegetation and resulted in numerous exposed tree roots.

It should also be noted that the degree of limitation for hiking trails imposed by an area of bedrock outcroppings can vary greatly with the nature of the outcroppings (Epp, 1977). Flat lying bedrock may impose only slight to moderate limitations, but cliffs may impose severe limitations. Occasionally it may be possible and desirable to route trails over rock outcroppings due to the resistance of the bedrock to environmental damage.

Productive Capacity

The term fertility refers to the inherent capacity of a soil to supply nutrients to plants in adequate amounts and suitable proportions. Productive capacity refers to the capacity of a soil, in its normal environment, to produce a specific plant or sequence of plants under a specified system of management. Productive capacity is the broader term since fertility is only one factor that determines crop yields. Other soil properties may alter the availability of nutrient elements to a plant. For example, soil pH values can affect the form and solubility of several nutrient elements. Also, moisture and aeration levels can affect the uptake of nutrients, or their availability, to various degrees.

The surface soil is the major zone of root development, carries much of the nutrient supply available to plants, and supplies a large share of the water used by crops. Also, it can be plowed and cultivated, manipulated and managed, both physically and chemically. Its fertility, and to a lesser degree its productive capacity, may be altered in accordance with economic crop production. The productive capacity of a soil is affected also by the nature of its subsoil, even though this is normally subject to little field alteration other than drainage. The permeability and chemical nature of the subsoil influence the surface soil in its role as a medium for plant growth. Plant roots often penetrate deeply into the subsoil to obtain moisture and nutrients.

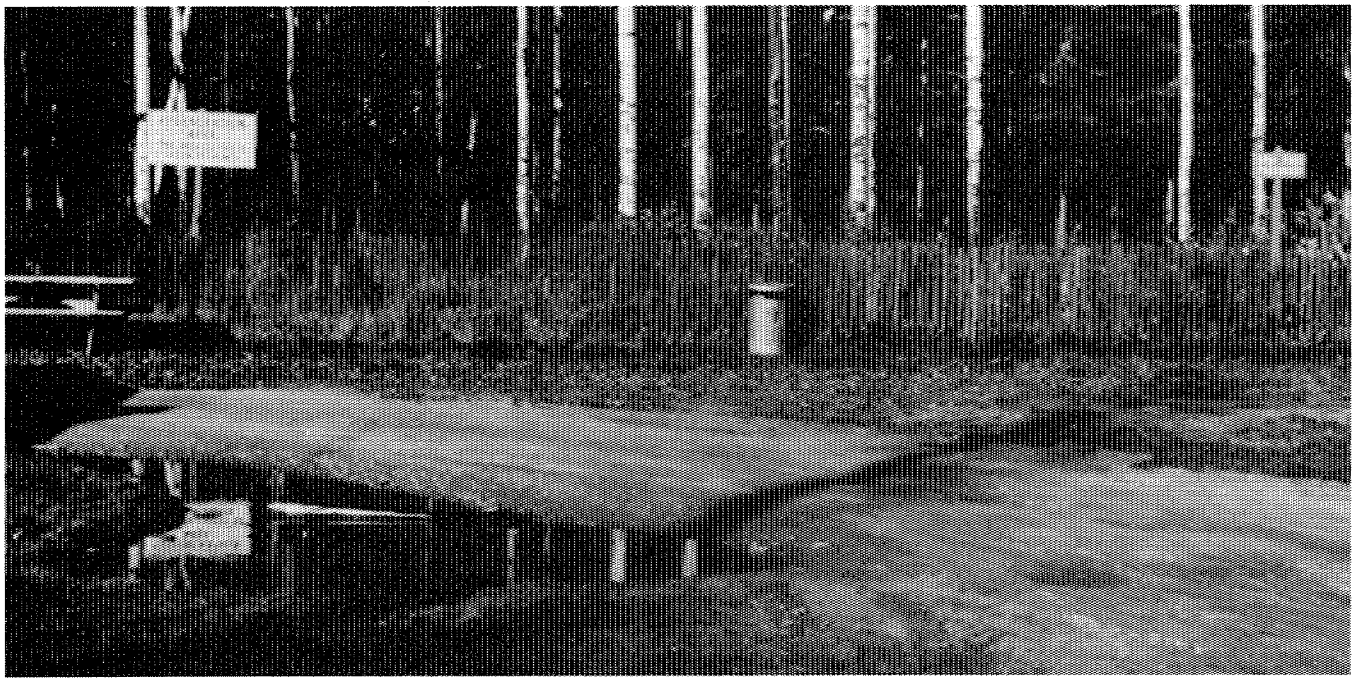


PLATE 12. A portion of this campground has been closed to public use to allow for the regeneration of ground vegetation, destroyed by heavy use and concentrated foot traffic.

Productive capacity of soils for vegetation of different kinds is closely related to the feasibility of many recreational enterprises (Montgomery and Edminster, 1966). The ability of soils to produce sods that can take concentrated human foot traffic is an important factor in campgrounds and playgrounds. The development of conservation practices, such as planting shade trees, living fences, plant screens, and barriers to trespass, is guided by soil conditions. The capacity of an area to produce economically harvestable crops of game also depends in part upon the productive capacity of its soils.

OTHER FACTORS AFFECTING RECREATIONAL USES

Other important factors that have significant effects on the use of soils for recreational purposes include drainage, slope, surface stoniness and coarse fragments, and susceptibility to flooding. These factors are discussed in the following paragraphs.

Drainage

Soil drainage refers to the rapidity and extent of removal of water from soils in relation to additions. It is affected by a number of factors acting separately or in combination, including texture, structure, organic matter content, slope gradient, length of slope, position in landscape, water holding capacity, and evapotranspiration. Seven soil drainage classes are recognized by the Canada Soil Survey Committee (1978). These are defined in terms of available water storage capacity (AWSC) and source of water, as follows.

Very Rapidly Drained. Water is removed from the soil very rapidly in relation to supply. Excess water flows downward very rapidly if underlying material is pervious. There may be very rapid subsurface flow during heavy rainfall if there is a steep gradient. Soils have very low AWSC (usually <2.5 cm) within the control section and are usually coarse textured, shallow, or both. Water source is precipitation.

Rapidly Drained. Water is removed from the soil rapidly in relation to supply. Excess water flows downward if underlying material is pervious. Subsurface flow may occur on steep gradients during heavy rainfall. Soils have low AWSC (2.5 to 4 cm) within the control section, and are usually coarse textured, or shallow, or both. Water source is precipitation.

Well Drained. Water is removed from the soil readily but not rapidly. Excess water flows downward readily into underlying pervious material or laterally as subsurface flow. Soils have intermediate AWSC (4 to 5 cm) within the control section, and are generally intermediate in texture and depth. Water source is precipitation. On slopes subsurface flow may occur for short durations but additions are equalled by losses.

Moderately Well Drained. Water is removed from the soil somewhat slowly in relation to supply. Excess water is removed somewhat slowly due to low perviousness, shallow water table, lack of gradient, or some combination of these. Soils have intermediate to high AWSC (5 to 6 cm) within the control section and are usually medium to fine textured. Precipitation is the dominant water source in medium- to fine-textured soils; precipitation and significant additions by subsurface flow are necessary in coarse-textured soils.

Imperfectly Drained. Water is removed from the soil sufficiently slowly in relation to supply to keep the soil wet for a significant part of the growing season. Excess water moves slowly downward if precipitation is the major supply. If subsurface water or groundwater, or both, are the main sources, flow rate may vary but the soil remains wet for a significant part of the growing season. Precipitation is the main source if AWSC is high; contribution by subsurface flow or groundwater flow, or both, increases as AWSC decreases. Soils have a wide range in available water supply, texture, and depth, and are gleyed phases of well-drained subgroups.

Poorly Drained. Water is removed so slowly in relation to supply that the soil remains wet, for a comparatively large part of the time the soil is not frozen. Excess water is evident in the soil for a large part of the time. Subsurface flow or groundwater flow, or both, in addition to precipitation are the main water sources; there may also be perched water tables with precipitation exceeding evapotranspiration. Soils have a wide range in AWSC, textures and depths, and are gleyed subgroups, Gleysols and Organic soils.

Very Poorly Drained. Water is removed from the soil so slowly that the water table remains at or on the surface, for the greater part of the time the soil is not frozen. Excess water is present in the soil for the greater part of the time. Groundwater flow and subsurface flow are the major water sources. Precipitation is less important except where there is a perched water table with precipitation exceeding evapotranspiration. Soils have a wide range in AWSC, texture, and depth, and are either Gleysolic or Organic.

Well-drained sites are needed for most types of recreational development. Wetness affects bearing strength, compactibility, and erodibility of soils. Wetness may result from proximity to streams or late spring snowmelt areas, ponding of surface runoff water, groundwater seepage, or high water tables. Soils that are wet all year, even if not flooded, have severe limitations for campgrounds, picnic areas, playgrounds, hiking trails, and roads. High water tables also affect buildings (especially those with basements) and the proper functioning of septic tank absorption fields. Soils that are wet only part of the year, or those with a water table that fluctuates without actually reaching the surface, are not easily detected. However, soil properties (such as mottles), and often vegetation, reflect the high moisture conditions, even at a time of year when the soil is dry. These soils are considered to have moderate to severe limitations for most recreational uses, and if possible should be avoided for the more permanent facilities, such as campgrounds and buildings. Soils that dry out slowly after rains (those with a high clay content or an impeding horizon near the surface) also present problems where intensive use is contemplated. With careful planning, design, and management, however, these soils can be used for most recreational facilities.

Overcoming limitations due to wetness may involve costly construction such as extensive drainage; or special maintenance such as sump pumps. The soils that are dry during the season of use and have a water table deeper than 75 cm are considered to have slight to no limitations for most recreational uses.

Slope

Slope is an important factor in areas used for recreation. Steeply sloping areas have obvious limitations for such uses as playgrounds or campgrounds, especially where bedrock is close to the surface. Steep slopes cause increased construction costs, create a need for careful design requirements, and are a major factor influencing erosion potential. Some loss in vegetation cover is expected in any campground, and this can initiate accelerated soil erosion on the steeper slopes (Lesko, 1973). Steep, moderately sloping, and gently sloping soils can be levelled for campsites, playgrounds, and building sites, where the cost is justified; but effective soil conservation practices must be maintained. Special care must be given to revegetation requirements.

Mechanical problems of layout and construction of sewage filter fields, and therefore expense, increase with increasing steepness of slope. Lateral seep, re-surfacing of sewage, and downslope flow may occur on steep slopes.

Surface Stoniness and Coarse Fragments

Surface stones and coarse fragments on the soil surface present obstacles for playgrounds, campgrounds, picnic areas, and trails. Rounded gravels and stones present hazards on steep slopes used for foot trails. In some instances it is feasible to remove the stones, thus eliminating the limitation, but often the expense is considered prohibitive.

Coarse fragments in a soil also influence its workability and the difficulty in making excavations. This is important for all types of excavations, as well as where soil is used in road construction and as a covering material in trench-type sanitary landfills. A close correlation commonly exists between surface stoniness and the content of coarse fragments in the soil solum.

Susceptibility to Flooding

Flooding hazard can be predicted from soil properties and landscape position. Soils that are subject to flooding during

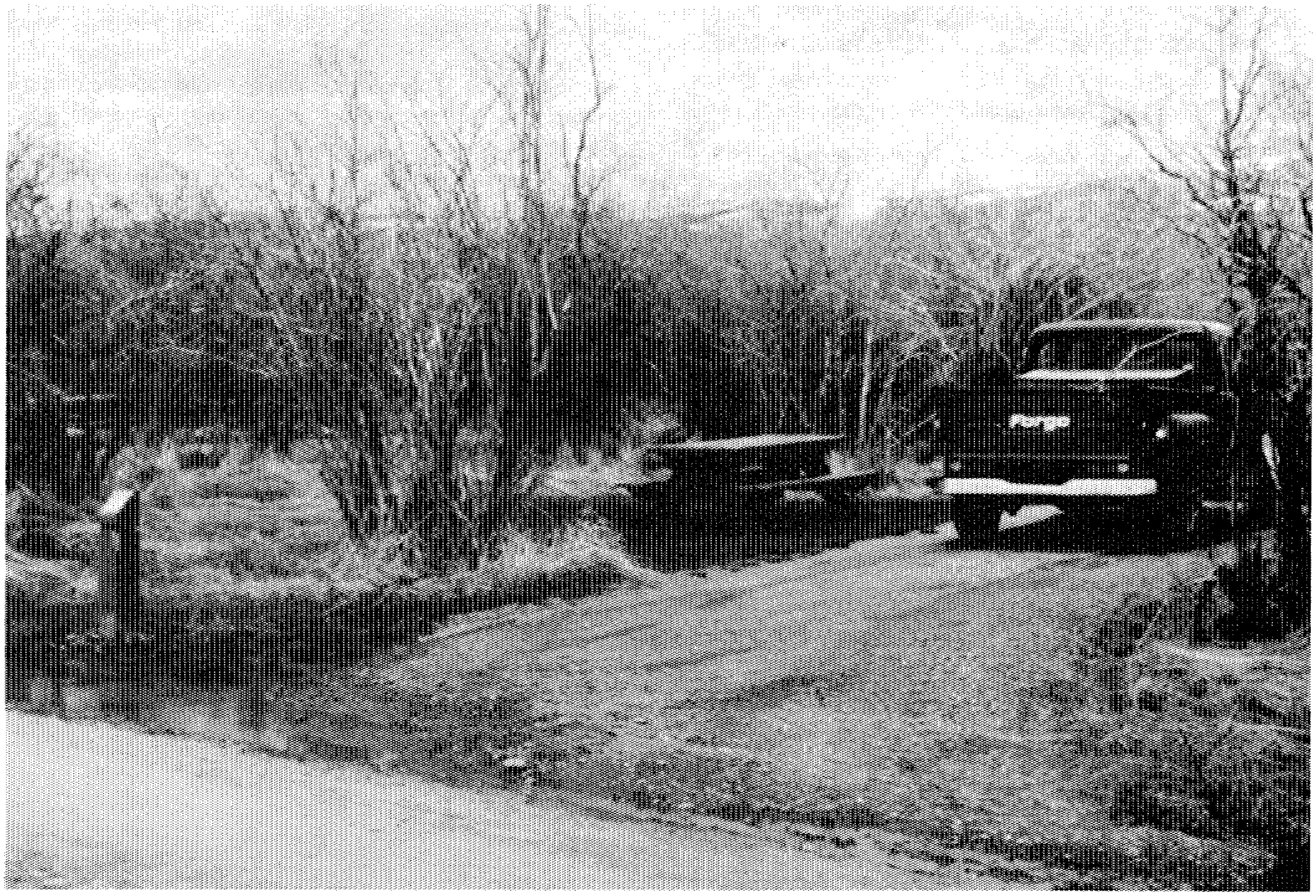


PLATE 13. This campsite constructed on a gleyed soil is unduly wet in late spring.

PLATE 14. Aspen forest *(Populus tremuloides)* is the typical vegetation of many Gray Luvisol soils.

the season of use are considered to have severe limitations for facilities such as campgrounds, building sites, and roads. These facilities require permanent design considerations and should not be developed unless protected by dikes, levees, or other flood prevention structures. These soils may be better suited for hiking or nature study areas, or for greenbelt open space, if the flooding is not too frequent. Montgomery and Edminster (1966) suggest one or two floodings during the season of use constitute only a moderate limitation for picnic areas, playgrounds, and hiking trails. These are less permanent facilities that can be shifted or moved with relative ease. Flood waters also seriously interfere with the functioning of sewage filter fields, and carry away unfiltered sewage.

SPECIAL PROBLEM SOILS

Some widespread soils in Alberta possess distinctive features that warrant special consideration. These include Luvisolic, Organic, and Solonetzic soils, and are discussed in the following paragraphs.

Luvisolic Soils

In general, Luvisolic soils are the most common and widespread soils throughout the forested regions of Alberta, and are the most prevalent soils in many of Alberta's provincial parks.

A Luvisolic soil in its natural state has a surface L-H horizon, which may vary from 2 to 12 cm or more in thickness. Underlying this is an Ah horizon, which in Orthic Gray Luvisols is always less than 5 cm thick, and often absent altogether. The Ae horizon below is the most distinctive, and is the cause of many problems encountered in managing these soils (Bentley *et al.,* 1971). The Ae horizon is gray colored, low in organic matter (humus) and plant nutrients, and has a platy structure. It generally varies from 7 to 30 cm in thickness. The Bt horizon or subsoil lies below the Ae, and commonly has a high clay content. The Cca horizon or lime layer is usually 1 m or more below the soil surface. Some of the special management problems encountered with Luvisolic soils are summarized as follows.

Climatic Hazards. Frost free periods in Luvisolic soil areas range downward from an average of about 90 days in the most favored locations. Also, in some districts, drought during the main growing season of June and early July is common, followed by rains in late July and August.

Poor Soil Tilth. The L-H and Ah horizons rapidly become broken down under heavy foot traffic in recreation areas, and often disappear completely from a combination of physical destruction and surface erosion. Thus the Ae is exposed at the surface. Because of the low organic matter content of most Luvisolic soil Ae horizons, tilth is usually poor and serious physical problems are common. When thoroughly dry, the soil surface is often baked and hard, making plant growth difficult. High intensity rain showers may puddle the surface, and subsequent drying may create severe crusting. Under such circumstances small seeded crops such as grasses and clovers may be unable to penetrate the crust. Surface soil puddling and crusting have other adverse effects as well. Entry of moisture from subsequent rains is hampered, and runoff may be increased, causing soil erosion. Soil pore spaces may become plugged with soil particles, thus reducing aeration and causing adverse effects on some plants.

The compact fine-textured subsoils (Bt horizons) of most Luvisolic soils are so hard when dry that plant root penetration is hampered, thereby reducing the depth of soil from which plants can obtain moisture and nutrients. Fortunately, tap root crops such as alfalfa can penetrate such layers, and over time will usually improve conditions for other plants.

Drainage Problems. Drainage problems are more common in Luvisolic soil areas than in many other areas of Alberta some instances the Bt horizon is so enriched with clay that moisture has difficulty percolating downward. The spring thaw or heavy rains during summer may saturate the surface soil, so that it becomes semi-fluid. This condition has an adverse effect on plants because the soil remains cold and soil air content is reduced. Also surface soils are very susceptible to erosion.

Soil Acidity. Luvisolic soil sola are commonly acidic. The primary cause of plant damage is the high solubility of aluminum and manganese at a pH of less than 5. These elements are harmful when present to excess in a soluble form. Also, at such a low pH the ability of clovers to fix nitrogen may be reduced. Calcium or magnesium deficiencies may sometimes result, and the availability of phosphorus and molybdenum tends to be reduced.

Liming is the only practical way to correct soil acidity, so that sensitive crops can be grown. The amount of lime required ranges from less than one ton per acre to several tons, depending on the nature of the soil. Materials commonly used include calcite lime (calcium carbonate) and dolomitic lime (calcium magnesium carbonate). Others which may be used are hydrated lime, marl, or some types of industrial slag. An economic factor favoring the use of lime in Alberta is that under western Canadian conditions, the effect of a single lime application will last many years.

Organic Soils

Organic soils consist of an accumulation of undecomposed or partly decomposed plant material, and are commonly called bogs, muskegs, peats, or mucks. They are water saturated for most of the year, unless artificially drained, and possess at least 30 percent organic matter to certain specified depths. They are highly variable in stage of decomposition, depth, acidity, fertility, and depth to water table. In their natural state, organic soils act as natural reservoirs, delaying runoff and releasing water slowly to natural water courses. Thus, large peat areas are important regulators of stream flow in districts where they occur (Bentley *et al.,* 1971).

Organic soils have severe limitations for most recreational uses, due mainly to their excessive wetness. Other adverse properties are extremely low bulk density, high compressibility, irreversible shrinkage when drained, continual subsidence after drainage due to biochemical oxidation, susceptibility to fire, low bearing strength, and susceptibility to frost heave (Slusher *et al.,* 1974).

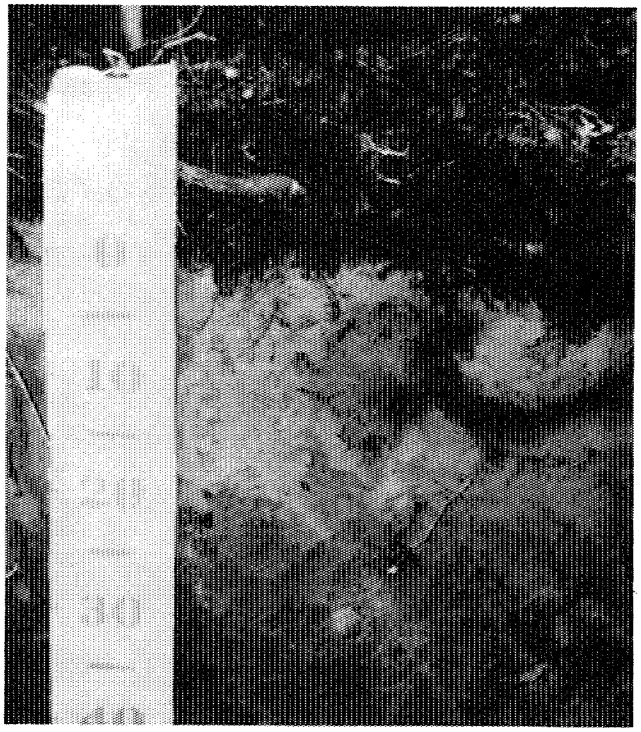


PLATE 15. The distinctive gray-colored Ae horizon is very prominent in this Gray Luvisol soil.

Because of the extreme acidity of most Organic soils, and their runoff waters, concrete and metal structures in such an environment are subject to corrosion and precautionary measures may be necessary (MacFarlane and Williams, 1974). Alkaline runoff waters also occur, and these may also be corrosive.

Limitations of Organic soils for lawns and landscaping are a short growing season and complexities of plant nutrient deficiencies, including micro elements. Fertilizer requirements are high, and exceedingly variable; high rates of nitrogen are frequently required. Drainage is usually necessary, and shallow ditches at quarter mile intervals are often sufficient.

Solonetzic Soils

Solonetzic soils have characteristics that adversely affect their productivity, and result in special management problems (Toogood and Cairns, 1973). These are summarized as follows.

Impermeable B Horizon. The hard, compact B horizon limits water, air, and root penetration. In many Solonetzic soil areas, a large proportion of the rainwater remains on

PLATE 16. Black spruce (*Picea mariana*) is the typical vegetation of many Organic soils.

the surface, and much is lost by evaporation. Plant roots become concentrated near the surface, and plants cannot withstand long periods of drought.

Ae Horizon. Most Solonetzic soils have a platy structured Ae horizon, low in organic matter. When found at the surface, this horizon crusts readily, and the penetration of plant seedlings is adversely affected.

Chemical Composition. The particular chemical composition of many Solonetzic soils adversely affects nutrient uptake by plant roots. These soils often require the addition of much greater than average amounts of nitrogen fertilizer. Also, the Ah horizons of Solonetzic soils are usually thinner than those of other associated soils.

Low pH. The A horizons of many Solonetzic soils have low pH values, which may adversely affect the growth of sensitive crops, such as some clovers.

Variability. Solonetzic soils commonly vary erratically over short distances, and this makes any kind of soil management or land use difficult.

Solonetzic soils also have properties that adversely affect their use for construction purposes, and these are summarized as follows.

Sulfates. Sulfates present in subsoils of most Solonetzic soils cause deterioration of ordinary cement. Sulfate resistant concrete is required in the construction of building foundations and underground conduits.

High Sodium Content. Because of a high sodium content, soil aggregates are unstable, causing Solonetzic soils to be highly erodible. This factor is important in the construction of recreation facilities and in road building.

Low Permeability. Because of the low permeability of Solonetzic soils, they are usually inferior as sewage disposal sites.

SOIL EROSION

Soil susceptibility to erosion refers to the expected rate and amount of soil loss by either wind or water following removal of vegetation (Knapik and Coen, 1974). It is a function of many variables, both soil properties and other factors. The main soil properties to consider are texture, structure, infiltration rate, permeability, soil depth, organic matter content, and thickness of Ah horizon. Most of these are closely interrelated in the way they influence soil erodibility.

Texture and Structure

Since detachment and transport are the essential steps in surface soil erosion, large soil particles are much more resistant than smaller ones (Swanston and Dyrness, 1973). However, even though clay particles are readily carried by

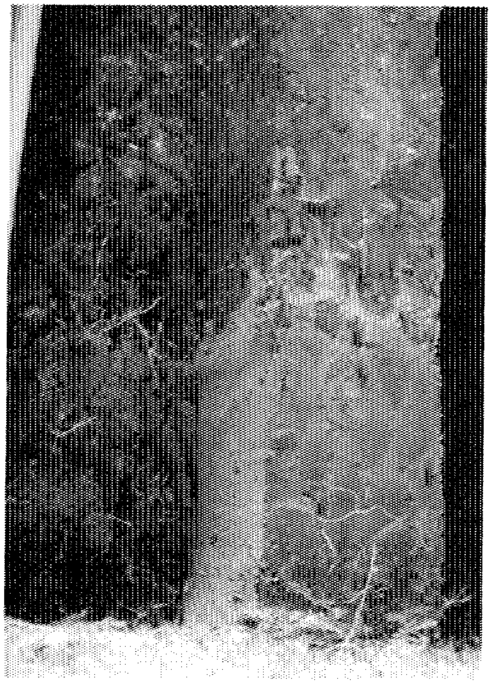


PLATE 17. A typical Solonetzic soil profile, showing the sharp contrast between the surface horizons and the hard compact B horizon.

PLATE 18. Dust storm caused by wind erosion of soil.

running water, soils high in clay are often not the most erodible. This is because fine-textured soils generally possess far more water stable aggregates than coarse-textured soils, due mainly to the cementing capacities of the clay particles. Other important cementing agents which promote stable aggregates in various soils are organic matter, iron and aluminum oxides, and calcium carbonate.

Sandy and silty soils seldom have well aggregated structure because organic matter and clay are usually so low that the aggregates are poorly cemented (Toogood and Newton, 1955). However, the large sand particles offer more resistance than silt or clay particles to movement by water, and coarse-textured soils have high infiltration rates and permeabilities. Therefore, sandy soils are often not highly erodible. Silty soils are often highly erodible, because the particles are readily transported, aggregation is usually poor and weak, and infiltration rates and permeabilities are relatively low.

Infiltration Rate and Permeability

Infiltration rate and permeability, which are influenced mainly by soil texture, structure, and depth, have a marked influence on soil erodibility. While clay soils have a greater total pore space than sands, the individual pores are much smaller, and as a result infiltration rates and permeabilities are usually lower. This general rule may be modified by soil structure, however, and some clay soils may have high infiltration rates and permeabilities due to the presence of large stable aggregates.

Soil Depth

Shallow soils overlying bedrock, or soils with heavy clay subsoils, especially Luvisolic and Solonetzic soils, are often very susceptible to erosion. These subsoils are very impervious, resulting in low infiltration rates and hence high amounts of runoff, especially on sloping land. The eluvial (Ae) horizons of Luvisolic soils situated on sloping land are often very susceptible to erosion, due to a lack of fines (clay-sized particles) and an absence of other cementing agents. Luvisolic soils are by far the most prevalent mineral soils in the forested regions of Alberta, where numerous parks are situated.

Organic Matter Content

Organic matter is a very important cementing agent in soil aggregate formation. Also, all forms of organic matter in soils have high water holding capacities. A high soil organic matter content therefore usually promotes a low incidence of water runoff, and correspondingly low rates of soil erosion.

Thickness of AH Horizon

Ah horizons generally have high organic matter contents, are well aggregated, have high infiltration rates, and are resilient to compaction. The erodibility of soils with thick Ah horizons is generally relatively low. Exceptions are soils with impervious horizons near the surface, such as Solonetzic soils.

Other factors which have a marked influence on soil susceptibility to erosion are slope, vegetation, and fire.

Slope

Steepness of slope is a major factor affecting the rate of soil erosion (Rutter, 1968). Water velocity is about doubled when the slope (expressed as a percentage) is quadrupled. Doubling the velocity of water increases its erosive or cutting capacity four times, and increases the size of particle it can roll or push along 64 times (Toogood and Newton, 1955). Slope length also affects the rate of soil erosion. As slope length increases, water velocity also increases, thus increasing the erosive capacity of the water.

Vegetation

Vegetation, including both plant and litter cover, is a very effective means of erosion prevention and control. The rate of erosion is negligible at full vegetation cover, even on steep slopes (Lesko, 1973). Tremendous amounts of kinetic energy are expended by falling raindrops as they hit the earth's surface, and most of this is absorbed by vegetation and litter in undisturbed forests. Shrub cover is also beneficial, because the woody stems are resistant to wear and protect the ground from trampling by restricting or discouraging foot traffic. The presence of shrubs also helps in the retention of litter, and in the maintenance of a favorable infiltration rate in the surface soil. Loss of vegetation cover can lead to accelerated soil erosion on steeper slopes.

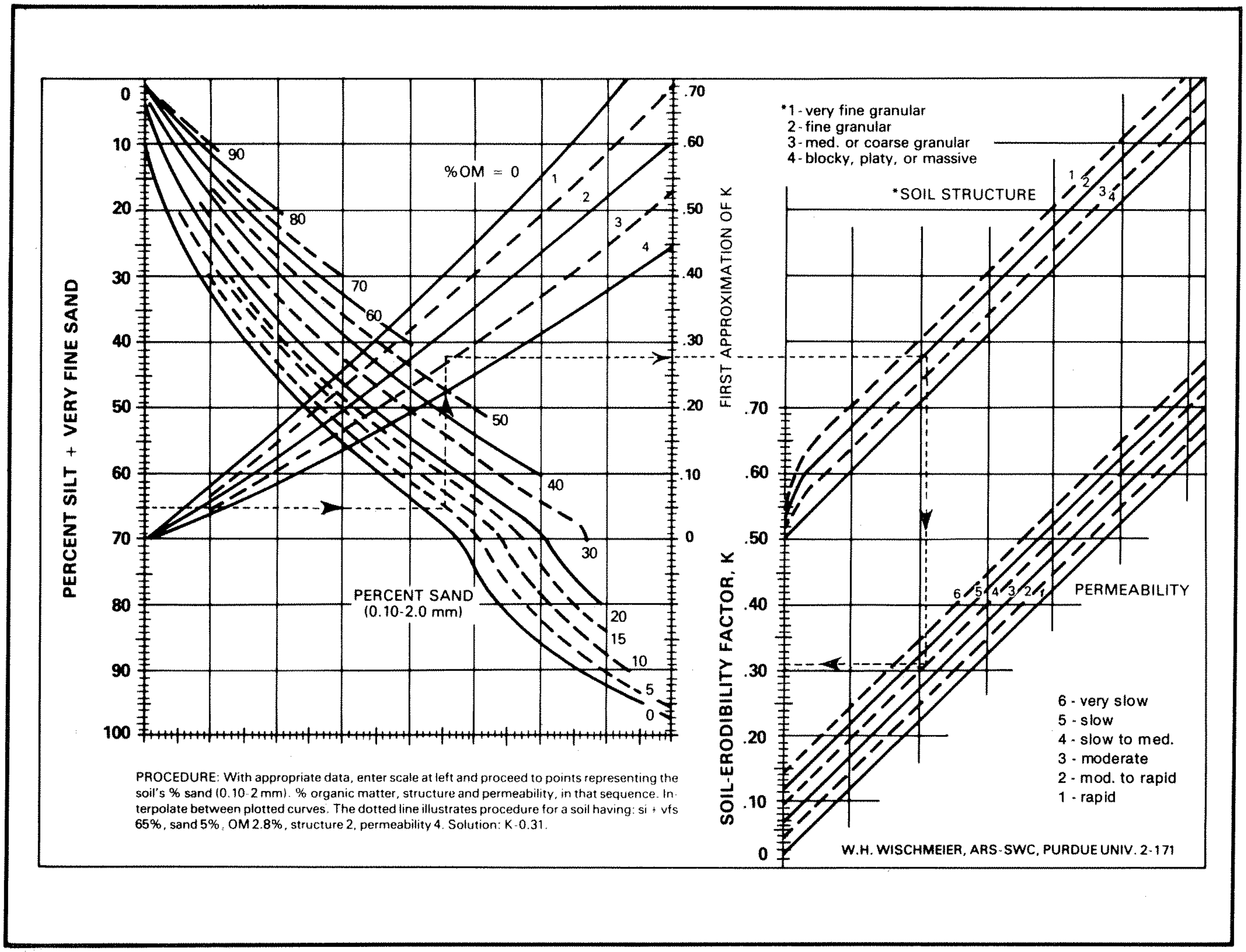
Fire

Fires can lead to an increase in surface erosion, primarily through the removal of protective vegetation and litter. Sufficiently hot fires may also cause changes in surface soil properties, such as a reduction in organic matter content and a resulting breakdown of water stable aggregates.

An overall evaluation of soil susceptibility to erosion is very difficult to derive, because of the many influencing variables. An assessment of soil susceptibility to water erosion can be obtained by applying soils to Figures 5 and 6.

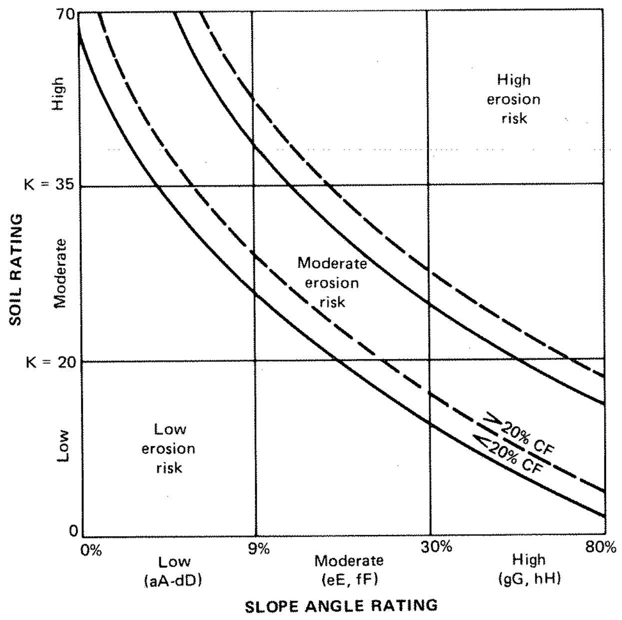
The evaluations of soil susceptibility to water erosion are based on the assumption that natural geologic water erosion is expected and accepted. Thus, the predicted erosion potential applies only when man's activities (including fires) cause a loss of vegetation on the soil surface which can lead to accelerated erosion of that surface. The five parameters needed to read numerical soil erodibility values directly from the nomograph (Fig. 5) can be obtained from routine laboratory determinations and standard soil profile descriptions.

The relative permeability classes as coded for the erodibility formula (Fig. 5) refer to the soil profile as a whole. Usually these can be estimated from a consideration of soil characteristics observed in the field, particularly texture, structure, and depth to an impeding horizon in the profile. The controlling soil layer most often is below the surface layer. For greater uniformity of soil permeability estimates, Wischmeier *et al.* (1971) followed several rules of thumb for codes 4, 5, and 6: when more permeable surface soils were underlain by massive clay or silty clay, they were coded 5. Moderately permeable surface soils underlain by a silty clay or silty clay loam having a weak subangular blocky or blocky structure were coded 4. If the subsoil structure grade was moderate or strong, or texture was coarser than silty clay loam, the code was 3.



PROCEDURE: With appropriate data, enter scale at left and proceed to points representing the soil's % sand (0.10-2 mm). % organic matter, structure and permeability, in that sequence. Interpolate between plotted curves. The dotted line illustrates procedure for a soil having: si + vfs 65%, sand 5%, OM 2.8%, structure 2, permeability 4. Solution: K-0.31.

FIGURE 5. Soil erodibility nomograph (taken from Wischmeier *et al.,* 1971).



Soils with >20 percent coarse fragments (CF>2 mm) are less susceptible to erosion and the band between the dashed lines indicates moderate erosion risk in such cases.

FIGURE 6. Erosion hazard of soils. This graph was originally derived in part by Rutter (1968), and modified by Coen *et al.* (1977).

CONCLUDING STATEMENT

Basic soil properties have a large influence on the types of outdoor recreational activities that can be supported by any particular area. With the knowledge of the different soil types and their properties, and with the aid of a soil map, soil scientists and other specialists can develop soil interpretations for recreational uses. These interpretations can best be made locally by people familiar with the soils and conditions in an area. Soil interpretations are not recommendations for land use. Rather they can be used as inputs into the planning process, and as such provide valuable tools for planners.

METHODOLOGY

FIELD TECHNIQUES

The areas surveyed are traversed by motor vehicle along all roads and negotiable trails, and on foot along cut lines and trails not suitable for vehicles. An outboard motor boat is utilized along lake shores and rivers in some areas of otherwise limited access, and foot traverses are made as necessary across areas lacking trails.

Soil pits are dug at frequent intervals to depths of 0.5 to 1 m, to examine and describe soil horizons and to classify the soils. The usual procedure is to excavate the upper 0.5 m with a shovel, and to examine the lower depths by sampling with a soil auger.

The frequency of soil inspections varies with the mapping intensity. In general, inspections are made at half mile intervals along all road allowances for reconnaissance mapping, at quarter mile intervals for semi-detailed mapping, and at much higher frequencies for detailed mapping. The pattern varies according to the availability of roads, trails, and cut lines; and soil and landform variations encountered in the field. When delineating soil and landform patterns in the field, soil inspections are made in numerous dispersed locations in addition to the general grid pattern, to determine boundaries accurately.

In general, soil boundaries are determined along lines of traverse, then projected between these on panchromatic black and white aerial photographs of scales varying from 1:31 680 (2 in = 1 mi) to 1:12 000 (5.25 in = 1 mi) with the aid of a pocket stereoscope. The dependency on air photo interpretation varies inversely with the level of mapping intensity. Most soil boundaries are projected between lines of traverse through air photo interpretation in reconnaissance soil mapping, whereas in detailed mapping, soil inspections are made at much closer intervals to locate more accurately the boundaries.

Soil areas are delineated on velox copies of photomosaics at a scale of 1:8 000 (8 in = 1 mi) for detailed and semi-detailed mapping, and at a scale of 1:24 000 (2.6 in = 1 mi) for reconnaissance mapping. The final maps are printed at similar scales.

Horizon samples are collected from representative soil profiles for chemical and physical analyses, and subsurface samples are collected at depths of 0.5 to 1.5 m for engineering tests. In addition, surface and subsurface samples to depths as great as 60 cm are collected from representative areas for chemical soil tests.

CHEMICAL AND PHYSICAL ANALYSES

The following chemical and physical analyses are carried out in the Alberta Institute of Pedology laboratories, using standard procedures. These analyses help to characterize and finalize the classification of soils that have been described and tentatively classified in the field.

Soil Reaction

pH is determined with a Beckman model Zeromatic pH meter equipped with a glass and calomel electrode. The pH in $CaCl_2$ is determined using a 2:1 0.01 M $CaCl_2$ solution to soil ratio (Peech, 1965), and the pH in water is determined on a saturated soil paste (Doughty, 1941).

Exchangeable Cations and Cation Exchange Capacity

The cation exchange capacity is determined by displacement of ammonium with sodium chloride (Chapman, 1965). Exchangeable cations are extracted by the Association of Official Agricultural Chemists (1955) method and Na, K, Ca, and Mg are determined by atomic absorption spectrophotometry.

Organic Carbon

Organic carbon is determined by dry combustion using an induction furnace with a gasometric detection of evolved CO_2 (Leco Carbon Analyzer Model 577-100) (Allison *et al.,* 1965).

Calcium Carbonate Equivalent

The calcium carbonate equivalent is determined by the inorganic carbon manometric method of Bascomb (1961).

Mechanical Analysis

The mechanical analysis is carried out by the pipette method of Kilmer and Alexander, as modified by Toogood and Peters (1953).

Free Iron and Aluminum

Free iron and aluminum are extracted with sodium pyrophosphate by the McKeague (1967) method. The determination of Fe and Al is done by atomic absorption spectrophotometry.

Electrical Conductivity

A saturated soil paste is prepared according to the procedure outlined in USDA Handbook 60 (Richards, 1954). The saturation extract is obtained by suction, and the conductivity of the extract is measured with a direct reading YSI Model 31 Conductivity Bridge.

Soluble Sulfates

Sulfates are determined by the turbidimetric method of the Association of Official Agricultural Chemists (1955), where sulfate is precipitated with $BaCl_2$ crystals. A Bausch and Lomb Spectronic 20 spectrophotometer is used for the determination, at a wavelength of 490 mu.

Engineering Tests

These are done according to American Society for Testing and Materials (1970) procedures, and include field moisture content, liquid limit, plastic limit, sieve analysis, and particle-size analysis (hydrometer method). Values for optimum moisture content and maximum dry density are obtained from charts prepared by the Alberta Transportation Laboratory, Edmonton.

SOIL TESTS

The following chemical analyses are conducted by the Alberta Soil and Feed Testing Laboratory (O.S. Longman Building, Edmonton), according to routine procedures. Each soil sample consists of five separate samples taken at random locations and mixed together into one composite sample. Fertilizer recommendations are based on these analyses.

Available Nutrients

Nitrogen and phosphorus are extracted simultaneously with 0.03 N NH_4F + 0.03 N H_2SO_4 (medium strength Bray, modified)(Miller and Axley, 1956). Available nitrogen (N) is determined by the Technicon (Technicon International of Canada Limited, Calgary, Alberta) Method number 100-700W as modified by the Alberta Soil and Feed Testing Laboratory. Available phosphorus (P) is determined by the Technicon Method number 155-71W.

Potassium is extracted with 1 N NH_40Ac adjusted to a pH of 7, (Chapman, 1965) and available potassium (K) is determined by flame photometry (Jackson, 1958).

Sulfate is extracted with 0.1 M $CaCl_2$, (Johnson and Nishita, 1952) and available sulfur is determined by the Technicon Industrial Method number 226-72W as modified by the Alberta Soil and Feed Testing Laboratory.

Soil Reaction

pH is determined with a glass and calomel electrode, using a 2:1 water to soil ratio (Jackson, 1958).

Electrical Conductivity

The electrical conductivity is measured by a dip electrode procedure whereby the electrodes are placed in the supernatant liquid on the surface of a 2:1 water to soil mixture. The result is converted to the saturated soil paste method outlined in the USDA Handbook 60 (Richards, 1954) by means of a correlation coefficient.

Soluble Sulfates

Soluble sulfates (SO_4) are determined on soil samples having electrical conductivities of one or more. A saturated soil paste is prepared according to the procedure outlined in the USDA Handbook 60 (Richards, 1954). A saturation extract is obtained by suction, and sulfates are precipitated with $BaCl_2$ crystals by the turbidimetric method and estimated by a visual inspection.

Exchangeable Sodium

Sodium is extracted with 1 N NH_40Ac adjusted to a pH of 7 (Chapman, 1965), and exchangeable sodium (Na) is determined by flame photometry (Jackson, 1958).

Organic Matter

The organic matter content is estimated by a visual inspection of the soil sample.

Free Lime

The free lime content is estimated by a visual inspection of the degree of effervescence when a solution of dilute HCl (10%) is added to the soil sample.

Available Aluminum and Manganese

Available aluminum (Al) and manganese (Mn) are determined on soil samples having a pH of 5.5 or less. They are extracted with 0.1 M $CaCl_2$ and determined by atomic adsorption spectrophotometry (Hoyt and Nyborg, 1971).

DISCUSSION OF SOIL MAP

The soils are classified according to the Canadian System of Soil Classification (Canada Soil Survey Committee, 1978) (Table 1). The areal extent of each map unit is indicated on the soil map. An explanation of the map symbol follows:

$$\text{topographic class (Table 8)} \rightarrow \frac{4}{e2} \begin{array}{l} \leftarrow \text{map unit (Soil Report)} \\ \leftarrow \text{surface stoniness rating (Table 9)} \end{array}$$

The map units indicate single soil series, groupings of series (complexes), or catenas. A soil series consists of soils that are essentially alike in all major profile characteristics except the texture of the surface (Canada Department of Agriculture, 1976). Where a map unit consists of a complex, the different series occur together in characteristic and repetitive patterns within the landscape and it is not feasible to outline each separately at the scale of mapping employed. A catena consists of a sequence of soils of about the same age, derived from similar parent materials, and occurring under similar climatic conditions; but having unlike characteristics because of variations in relief and drainage.

Where a map unit consists of a single series, other series may be found in close proximity. However, the dominant series constitutes roughly 60 to 90 percent of the map unit; the other series are present in such minor amounts that their occurrence is not considered significant with respect to recreational use.

Where a map unit consists of a complex, the different series generally possess very similar properties. The approximate percentage of each series is indicated in the soil reports. Insignificant inclusions of other series may be present but are not mentioned and do not have a significant effect on the use of a particular map unit for recreation.

Where a map unit consists of a catena, the approximate percentages of only the dominant members (which may also be series) are indicated. Insignificant inclusions of other members often occur, but are not indicated.

Soil interpretations are for the most dominant member of a map unit, and interpretations for the less dominant members are often very different.

Other miscellaneous symbols appearing on the soil map are defined or explained in the soil reports.

DISCUSSION OF LANDFORM MAP

The landform map is included to provide additional information about the mapped area. The landforms do not have any direct bearing on soil interpretations in the soil reports.

The symbols on the landform map refer to local landforms. A local landform comprises a unique assemblage of slopes which are constantly repeated in nature, and which generally owe their unique form to the composition and mode of origin of a surficial deposit (Acton, 1975). This

TABLE 8.
Topographic classes and symbols
(Canada Department of Agriculture, 1974)

Simple topography single slopes (regular surface)	Complex topography Multiple slopes (irregular surface)	Slope %
A depressional to level	a nearly level	0 to 0.5
B very gently sloping	b gently undulating	>0.5 to 2
C gently sloping	c undulating	>2 to 5
D moderately sloping	d gently rolling	>5 to 9
E strongly sloping	e moderately rolling	>9 to 15
F steeply sloping	f strongly rolling	>15 to 30
G very steeply sloping	g hilly	>30 to 60
H extremely sloping	h very hilly	>60

repetitive landform pattern may be associated with different major geologic structures, the result being similar local landforms or repetitive landform patterns occurring in different regional landform units. An outwash fan of a valley glacier as contrasted to a similar local form associated with continental glaciation would serve as an example of one repetitive landform pattern in regionally different landform units.

An abridged version of the landform classification system is outlined in Appendix II.

EXPLANATION OF SOIL INTERPRETATIONS

With a knowledge of soil properties and behavior, interpretations can be made for various land uses. Both external and internal characteristics are summarized regarding the behavior or potential of soils for various uses. The purpose is to provide the best information possible in a form that can be used by people not familiar with soils. Through the use of a soil map, the interpretations can be geographically related to a particular planning area.

Soil limitation or suitability ratings are for evaluating each soil for a particular use. Interpretations are based on evaluation of the soil to a depth of about 1 m; however, some interpretations can be extrapolated to a depth of more than 1.5 m. The interpretations are based on soil descriptions and field observations made during the soil mapping program; supplemented by laboratory data on soil samples collected for chemical and physical analyses, past experience, and available published information.

It is important that the proper perspective be placed on the use of soil interpretations in recreation planning. The interpretations are for soil in the natural state, and not for disturbed areas. Nor do they include such factors as location, aesthetic values, and nearness to population centres. A soil survey properly interpreted is a useful guide for general recreation planning and site selection. However, all soil differences which occur in the field cannot be shown on a soil map, however detailed. Due to the variable nature of soils, small inclusions of unmappable (due to scale) soil types may be present in an area where a development is planned. It must also be recognized that low intensity mapping is often done in wooded areas of limited access. This decreases the accuracy of soil interpretations for some of the more intensive land uses. Therefore, an on-site investigation by a person familiar with soils is often needed to facilitate the design of specific recreational facilities, before construction.

TABLE 9.
Surface stoniness ratings[1]
(Canada Soil Survey Committee, 1978)

Stony 0 - (non stony phase) - very few stones (<0.01% of surface, stones>30 m apart).
Stony 1 - (slightly stony phase) - some stones that hinder cultivation slightly or not at all (0.01 to 0.1% of surface, stones 10 to 30 m apart).
Stony 2 - (moderately stony phase) - enough stones to cause some interference with cultivation (0.1 to 3% of surface, stones 2 to 10 m apart).
Stony 3 - (very stony phase) - sufficient stones to handicap cultivation seriously; some clearing is required (3 to 15% of surface, stones 1 to 2 m apart).
Stony 4 - (exceedingly stony phase) - sufficient stones to prevent cultivation until considerable clearing is done (15 to 50% of surface, stones 0.1 to 0.5 m apart).
Stony 5 - (excessively stony phase) - too stony to permit cultivation; boulder or stone pavement (>50% of surface, stones <0.1 m apart).

[1] Phases of stoniness are defined on the basis of the percentage of the land surface occupied by fragments coarser than 15 cm in diameter.

The planner can use interpretations to help predict the type and degree of potential problems, and plan the kind and amount of on-site investigation needed. However, the number of investigations can be reduced considerably by the use of a soil map and accompanying interpretations.

The soil map units are evaluated by considering the various properties that affect the degree of limitation or suitability for specific uses. Soils in the provincial parks are used mainly for recreational pursuits, as building sites, and as road construction materials.

Definitions of the soil limitation and suitability ratings follow (United States Department of Agriculture, undated).

NONE TO SLIGHT

A none to slight soil limitation is the rating given soils that

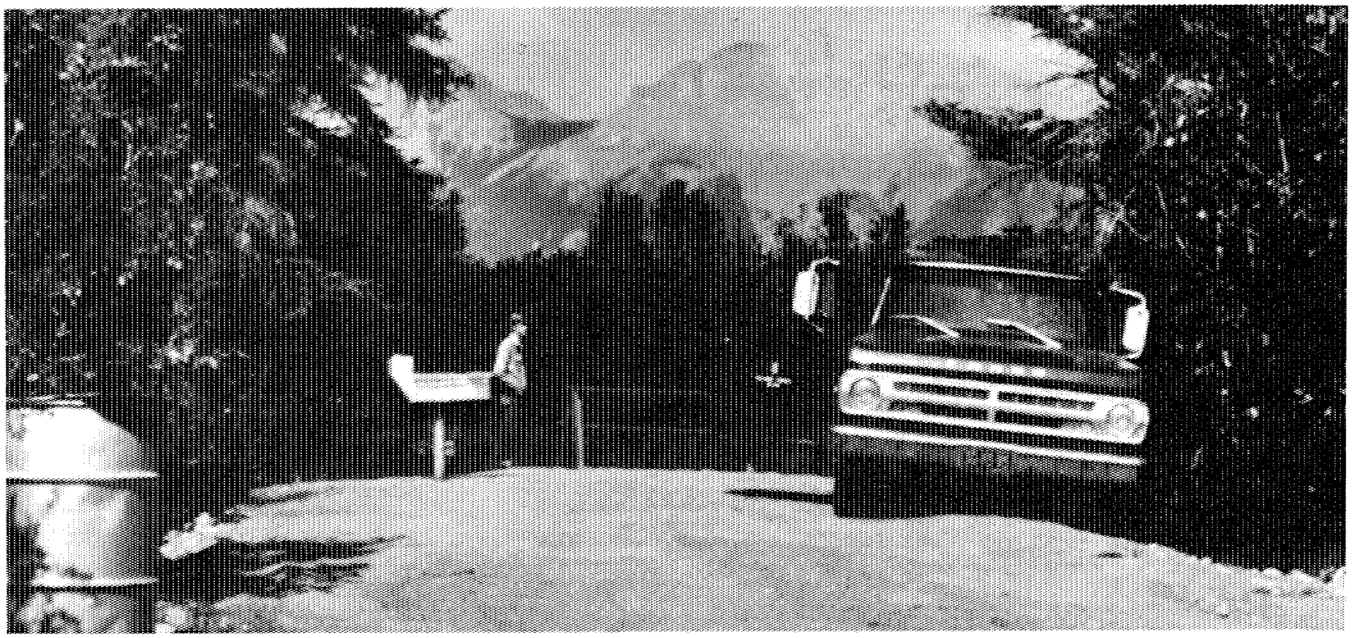


PLATE 19. A gravelled campsite in an Alberta Provincial Park.

have properties favorable for the rated use. The degree of limitation is minor and can be easily overcome. Good performance and low maintenance can be expected.

MODERATE

A moderate soil limitation is the rating given soils that have properties moderately favorable for the rated use. This degree of limitation can be overcome or modified by special planning, design, or maintenance. During some part of the year, the performance of the planned use is somewhat less desirable than for soils rated slight. Some soils rated moderate require treatment such as artificial drainage, runoff control to reduce erosion, extended sewage absorption fields, extra excavation, or some modification is needed for construction plans generally used for soils of slight limitation. Modification may include special foundations, extra reinforcement of structures, sump pumps, and the like.

SEVERE

A severe soil limitation is the rating given soils that have one or more properties unfavorable for the rated use, such as steep slopes, bedrock near the surface, flooding hazard, high shrink-swell potential, a seasonal high water table, or a sandy surface texture. This degree of limitation generally requires major soil modification, special design or intensive maintenance. Modification might require the soil material to be removed or replaced. Some of these soils can be improved by reducing or removing the soil feature that limits its use, but in most situations it is difficult and costly to alter the soil or design a structure so as to compensate for a severe degree of limitation.

VERY SEVERE

A very severe limitation is the rating given soils that have one or more properties which are so unfavorable for the proposed use that the soils cannot physically be used for that purpose or it is thought to be economically impractical to do so. Examples of such properties are very steep slopes, bedrock very near the surface, frequent flooding, permanently wet soils, excessively stony soils, or organic soils.

GOOD

A rating of good means the soils have properties favorable for the rated use. Good performance and low maintenance can be expected.

FAIR

A rating of fair means the soils are moderately favorable for the rated use. One or more soil properties make these soils less desirable than those rated good.

POOR

A rating of poor means the soils have one or more properties unfavorable for the rated use. Overcoming the unfavorable property requires special design, extra maintenance, or costly alteration.

VERY POOR

A rating of very poor means the soils have one or more properties which are so unfavorable for the proposed use that the soils cannot physically be used for that purpose or it is thought to be economically impractical to do so.

DEFINITIONS OF SELECTED USES AND SOIL INTERPRETATION GUIDES

Tables 10 through 23 are guides that can be used in developing soil interpretations for selected recreational and other uses. Information in the tables presents the nature and degree of limitations or suitabilities for the various uses. The guides are useful in evaluating each kind of soil mapped in parks and recreation areas. Interactions among some soils and other properties may in some cases be great enough to change ratings by one class. However, the class rating is usually determined by the most limiting property which affects the rating, and lesser limitations are indicated as well. Usually only a maximum of three are listed. Limitations due to slope are not further subdivided once the limitation is rated very severe for a specified use. It follows however, that the steeper the slope, the more severe is the limitation; and this fact should be borne in mind when using the soil interpretation tables.

GUIDE FOR DEVELOPING SOIL INTERPRETATIONS FOR PRIMITIVE CAMPING AREAS

This guide applies to soils which will undergo relatively light use in areas used for tents only. Access will be by hike in, canoe in, or horse; and pit toilets will be provided. A maximum of only seven sites per ha, and probably only three or four; and a maximum of 20 sites per facility, usually only five, will be provided (per. comm. D. Perraton, Provincial Parks Division of Alberta Recreation and Parks). It is assumed that little site preparation will be done, other than some minimum shaping, levelling, and gravel pads for tents. The soil should be suitable for relatively concentrated foot traffic by humans.

TABLE 10.
Soil limitation classes for primitive camping areas

		Degree of Limitation		
Properties Affecting Use	None to Slight	Moderate	Severe	Very Severe
Flooding	None	Very occasional during season of use. Once in 5-10 years.	Occasional during season of use. Once in 2-4 years.	Flooding during every season of use.
Wetness[1] (soil drainage class)	Very rapidly, rapidly, well & moderately well drained soils - no seepage or ponding. WT$>$75 cm during season of use.	Moderately well drained soils - occasional seepage or ponding, imperfectly drained soils - no seepage or ponding. WT$>$50 cm during season of use.	Imperfectly drained soils - seepage or ponding, poorly & very poorly drained soils. WT$<$50 cm during season of use.	Permanently wet soils.
Slope	0-15% (aA-eE)	$>$15-30% (fF)	$>$30-60% (gG)	$>$60% (hH)
Permeability[2]	Very rapid to moderate inclusive $>$1.5 cm/hr	Moderately slow and slow 0.15-1.5 cm/hr	Very slow $<$ 0.15 cm/hr	
Surface Stoniness[3]	0 and 1	2	3 and 4	5
Rockiness[4]	Rock exposures$>$25 m apart & cover$<$10% of the area.	Rock exposures 10-25 m apart & cover 10-25% of the area.	Rock exposures$<$10 m apart & cover$>$25% of the area.	Rock exposures too frequent to permit campground location.
Surface Soil Texture[5]	SL, FSL, VFSL, L and LS with textural B. Not subject to soil blowing.	SiL, CL, SCL, SiCL, LS and sand other than loose sand.	SC, SiC, C, Si	Sand subject to severe blowing. Organic soils.

[1] Soil drainage classes are defined in this guidebook. [2] In low rainfall areas, soils may be rated one class better. Soil permeability classes are defined in this guidebook. [3] Surface stoniness for the purpose of this table includes gravels and cobbles, or any coarse fragments$>$2mm in diameter. Some gravelly soils may be rated none to slight when the gravel content exceeds 20% by only a small margin, if a) the gravel is embedded in the soil matrix, or b) the fragments are $<$2 cm in diameter. Surface stoniness classes are defined in this guidebook. [4] Very shallow soils are rated severe for rockiness. Rockiness classes are defined in the Canadian System of Soil Classification (Canada Soil Survey Committee, 1978). [5] The soil textural classes are defined in this guidebook.

GUIDE FOR DEVELOPING SOIL INTERPRETATIONS FOR FULLY SERVICED CAMPGROUNDS

This guide applies to soils to be used intensively for tents and camp trailers of various sizes; and the accompanying activities of outdoor living. A maximum of 17 to 25 sites per ha will be provided and campsites will be gravelled or paved (per. comm., D. Perraton, Provincial Parks Division of Alberta Recreation and Parks). Modern sewage facilities will also be provided. The soil should be suitable for heavy foot traffic by humans, since natural areas will be left between campsites. Soil suitability for growing and maintaining vegetation is not a part of this guide, but is an important item to consider in the final evaluation of a site (see Table 15, Soil limitation classes for lawns and landscaping).

TABLE 11.
Soil limitation classes for fully serviced campgrounds

	Degree of Limitation			
Properties Affecting Use	None to Slight	Moderate	Severe	Very Severe
Flooding	None	Very occasional during season of use. Once in 5-10 years.	Occasional during season of use. Once in 2-4 years.	Flooding during every season of use.
Wetness[1] (soil drainage class)	Very rapidly, rapidly, well & moderately well drained soils - no seepage or ponding. WT >75 cm during season of use.	Moderately well drained soils - occasional seepage or ponding, imperfectly drained soils - no seepage or ponding. WT >50 cm during season of use.	Imperfectly drained soils - seepage or ponding, poorly & very poorly drained soils. WT< 50 cm during season of use.	Permanently wet soils.
Slope	0-9% (aA-dD)	>9-15% (eE)	>15-30% (fF)	>30% (gG, hH)
Permeability[2]	Very rapid to moderate inclusive >1.5 cm/hr	Moderately slow and slow 0.15-1.5 cm/hr	Very slow < 0.15 cm/hr	
Surface Stoniness[3]	0 and 1	2	3 and 4	5
Rockiness[4]	No rock exposures.	Rock exposures >25 m apart & cover< 10% of the area.	Rock exposures 10-25 m apart & cover 10-25% of the area.	Rock exposures too frequent to permit campground location.
Surface Soil Texture[5]	SL, FSL, VFSL, L and LS with textural B. Not subject to soil blowing.	SiL, CL, SCL, SiCL, LS and sand other than loose sand.	SC, SiC, C, Si	Sand subject to severe blowing. Organic soils.

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[1] Soil drainage classes are defined in this guidebook. [2] In low rainfall areas, soils may be rated one class better. Soil permeability classes are defined in this guidebook. [3] Surface stoniness for the purpose of this table includes gravels and cobbles, or any coarse fragments >2mm in diameter. Some gravelly soils may be rated none to slight when the gravel content exceeds 20% by only a small margin, if a) the gravel is embedded in the soil matrix, or b) the fragments are <2 cm in diameter. Surface stoniness classes are defined in this guidebook. [4] Very shallow soils are rated severe for rockiness. Rockiness classes are defined in the Canadian System of Soil Classification (Canada Soil Survey Committee, 1978). [5] The soil textural classes are defined in this guidebook.

GUIDE FOR DEVELOPING SOIL INTERPRETATIONS FOR PICNIC AREAS

This guide applies to soils considered for intensive use as park type picnic areas, which are subject to heavy foot traffic by humans. It is assumed that most vehicular traffic will be confined to access roads and parking areas (see Table 20, Soil limitation classes for road location). Soil suitability for growing and maintaining vegetation is not a part of this guide, but is an important item to consider in the final evaluation of a site (see Table 15, Soil limitation classes for lawns and landscaping).

TABLE 12.
Soil limitation classes for picnic areas

	Degree of Limitation			
Properties Affecting Use	None to Slight	Moderate	Severe	Very Severe
Flooding	None during season of use.	May flood 1 or 2 times per year for short periods during season of use.	Floods >2 times during season of use.	Prolonged flooding during season of use.
Wetness[1] (soil drainage class)	Very rapidly, rapidly, well & moderately well drained soils - no seepage or ponding. WT >50 cm during season of use.	Moderately well drained soils - occasional seepage or ponding, imperfectly drained soils - no seepage or ponding. WT< 50 cm for short periods during season of use.	Imperfectly drained soils - seepage or ponding, poorly & very poorly drained soils. WT< 50 cm & often near surface for a month or more during season of use.	Permanently wet soils.
Slope	0-9% (aA-dD)	>9-15% (eE)	>15-30% (fF)	>30% (gG, hH)
Permeability[2]	Very rapid to moderately slow inclusive > 0.5 cm/hr	Slow and very slow <0.5 cm/hr		
Surface Stoniness[3]	0, 1 and 2	3	4	5
Rockiness[4]	Rock exposures >25 m apart and cover <10% of the area.	Rock exposures 10-25 m apart and cover 10-25% of the area.	Rock exposures <10 m apart and cover >25% of the area.	Rock exposures too frequent to permit location of picnic areas.
Surface Soil Texture[5]	SL, FSL, VFSL, L and LS with textural B. Not subject to soil blowing.	SiL, CL, SCL, SiCL, LS and sand other than loose sand.	SC, SiC, C, Si	Loose sand subject to severe blowing. Organic soils.

[1] Soil drainage classes are defined in this guidebook. [2] In low rainfall areas, soils may be rated one class better. Restricted permeability is not considered a severe limitation for picnic areas. Soil permeability classes are defined in this guidebook. [3] Surface stoniness for the purpose of this table includes gravels and cobbles, or any coarse fragments≥2 mm in diameter. Some gravelly soils may be rated none to slight when the gravel content exceeds 20% by only a small margin, if a) the gravel is embedded in the soil matrix, or b) the fragments are≤2 cm in diameter. Surface stoniness classes are defined in this guidebook. [4] Very shallow soils are rated as having a severe limitation for rockiness. The nature and topography of bedrock exposures may significantly alter these ratings. On site investigations may be needed. Rockiness classes are defined in the Canadian System of Soil Classification (Canada Soil Survey Committee, 1978). [5] The soil textural classes are defined in this guidebook.

GUIDE FOR DEVELOPING SOIL INTERPRETATIONS FOR PATHS

This guide applies to soils to be used for local and cross country footpaths, generally in relatively level areas. If built in rougher areas, they will be placed along contours; some soil excavating may be done, and some stairways may be used (per. comm., D. Perraton, Provincial Parks Division of Alberta Recreation and Parks). The steeper the slope upon which a path is to be built, the more miles of trail that will be needed to cover a given horizontal distance, and the more soil that will have to be moved to obtain a level tread (Coen and Holland, 1976). The paths will be covered by pavement, wood chips, fine gravel, or some other material. Soil features, such as texture and structure, that affect erodibility, stability, and dust, should be given special emphasis.

TABLE 13.
Soil limitation classes for paths

	Degree of Limitation			
Properties Affecting Use	None to Slight	Moderate	Severe	Very Severe
Flooding	None during season of use.	May flood 1 or 2 times for short periods during season of use.	Floods>2 times during season of use.	Prolonged flooding during season of use.
Wetness[1] (soil drainage class)	Very rapidly, rapidly, well & moderately well drained soils - no seepage or ponding. WT>50 cm during season of use.	Moderately well drained soils - occasional seepage or ponding, imperfectly drained soils - no seepage or ponding. WT<50 cm for short periods during season of use.	Imperfectly drained soils - seepage or ponding, poorly & very poorly drained soils. WT<50 cm & often near surface for a month or more during season of use.	Permanently wet soils.
Slope[2]	0-9% (aA-dD)	>9-15% (eE)	>15-30% (fF)	>30% (gG, hH)
Surface Stoniness[3]	0 and 1	2	3 and 4	5
Rockiness[4]	Rock exposures>25 m apart and cover<10% of the area.	Rock exposures 10-25 m apart and cover 10-25% of the area.	Rock exposures<10 m apart and cover >25% of of the area.	Rock exposures too frequent to permit location of paths.
Surface Soil Texture[5]	SL, FSL, VFSL, and L	SiL, SiCL, SCL, CL, and LS	SC, SiC, C, Si and sand other than loose sand.	Loose sand subject to severe blowing. Organic soils.

[1] Soil drainage classes are defined in this guidebook. [2] Slope in this context refers to the slope of the ground surface, not the slope of the tread. Soil erodibility is closely related to slope. Some adjustments in slope range may be needed in different climatic zones. [3] Surface stoniness for the purpose of this table includes gravels and cobbles, or any coarse fragments>2mm in diameter. Gravels tend to cause unstable footing when present in high amounts, and are also associated with increased erosion. Cobbles and stones must be removed from the trail tread, increasing construction and maintenance difficulties. Some gravelly soils may be rated none to slight when the content of gravel exceeds 20% by only a small margin, if a) the gravel is embedded in the soil matrix, or b) the fragments are<2 cm in diameter. Surface stoniness classes are defined in this guidebook.
[4] Very shallow soils are rated as having a severe limitation for rockiness. The nature and topography of bedrock exposures may significantly alter these ratings. On site investigations may be necessary. Rockiness classes are defined in the Canadian System of Soil Classification (Canada Soil Survey Committee, 1978). [5] Texture refers to the soil texture which will form the tread texture. This is the surface texture on level areas, but may be a subsurface texture on slopes. The soil textural classes are defined in this guidebook.

GUIDE FOR DEVELOPING SOIL INTERPRETATIONS FOR TRAILS

This guide applies to soils to be used for primitive hiking trails. It is assumed that these areas will be used as they occur in nature, and that little or no soil will be moved (excavated or filled). It is also assumed that a dry stable tread is desirable and that muddy, dusty, worn, or eroded trail treads are undesirable. Hiking and riding trails are not treated separately, but as the design requirements for riding trails are more stringent, a given limitation will be more difficult to overcome. Only minimum preparation will be done, such as the clearing of trees and removal of a few boulders if necessary (per. comm., D. Perraton, Provincial Parks Division of Alberta Recreation and Parks). Soil features, such as surface texture and structure, that affect trafficability, dust, and design and maintenance of trails, should be given special emphasis.

TABLE 14.
Soil limitation classes for trails

	Degree of Limitation			
Properties Affecting Use	None to Slight	Moderate	Severe	Very Severe
Flooding	None during season of use.	May flood 1 or 2 times for short periods during season of use.	Floods>2 times during season of use.	Prolonged flooding during season of use.
Wetness[1] (soil drainage class)	Very rapidly, rapidly, well & moderately well drained soils - no seepage or ponding. WT>50 cm during season of use.	Moderately well drained soils - occasional seepage or ponding, imperfectly drained soils - no seepage or ponding. WT<50 cm for short periods during season of use.	Imperfectly drained soils - seepage or ponding, poorly & very poorly drained soils. WT<50 cm & often near surface for a month or more during season of use.	Permanently wet soils.
Slope[2]	0-15% (aA-eE)	>15-30% (fF)	>30-60% (gG)	>60% (hH)
Surface Stoniness[3]	0, 1 and 2	3	4	5
Rockiness[4]	Rock exposures>25 m apart and cover<10% of the area.	Rock exposures 10-25 m apart and cover 10-25% of the area.	Rock exposures<10 m apart and cover >25% of of the area.	Rock exposures too frequent to permit location of trails.
Surface Soil Texture[5]	SL, FSL, VFSL, and L	SiL, SiCL, SCL, CL, and LS	SC, SiC, C, Si and sand other than loose sand.	Loose sand subject to severe blowing. Organic soils.

[1] Soil drainage classes are defined in this guidebook. [2] Slope in this context refers to the slope of the ground surface, not the slope of the tread. Soil erodibility is closely related to slope. Some adjustments in slope range may be needed in different climatic zones. [3] Surface stoniness for the purpose of this table includes gravels and cobbles, or any coarse fragments >2 mm in diameter. Gravels tend to cause unstable footing when present in high amounts, and are also associated with increased erosion. Cobbles and stones must be removed from the trail tread, increasing construction and maintenance difficulties. Some gravelly soils may be rated none to slight when the content of gravel exceeds 20% by only a small margin, if a) the gravel is embedded in the soil matrix, or b) the fragments are <2 cm in diameter. Surface stoniness classes are defined in this guidebook.

[4] Very shallow soils rated as having a severe limitation for rockiness. The nature and topography of bedrock exposures may significantly alter these ratings. On site investigations may be necessary. Rockiness classes are defined in the Canadian System of Soil Classification (Canada Soil Survey Committee, 1978). [5] Texture refers to the soil texture which will form the tread texture. This is the surface texture on level areas, but may be a subsurface texture on slopes. The soil textural classes are defined in this guidebook.

GUIDE FOR DEVELOPING SOIL INTERPRETATIONS FOR LAWNS AND LANDSCAPING

This guide applies to soils to be used for lawn turf, shrubs and trees. It is assumed that the addition of topsoil will not be needed for good establishment, and that some land grading or smoothing may be required. Irrigation is an assumed management practice.

TABLE 15.

Soil limitation classes for lawns and landscaping

	Degree of Limitation			
Properties Affecting Use	None to Slight	Moderate	Severe	Very Severe
Flooding	None during growing season.	May flood 1 or 2 times for short periods during growing season.	Subject to flooding>2 times during growing season.	Prolonged flooding during growing season.
Wetness[1] (soil drainage class)	Very rapidly, rapidly, well & moderately well drained soils - no seepage or ponding. WT>50 cm during growing season.	Moderately well drained soils - occasional seepage or ponding, imperfectly drained soils - no seepage or ponding. WT<50 cm for short periods during growing season.	Imperfectly drained soils - seepage or ponding, poorly & very poorly drained soils. WT<50 cm & often near surface or ponded for a month or more during growing season.	Permanently wet soils.
Slope	0-9% (aA-dD)	>9-15% (eE)	>15-30% (fF)	>30% (gG, hH)
Surface Stoniness[2]	0 and 1	2	3 and 4	5
Rockiness[3]	Rock exposures>75 m apart and cover<2% of the area.	Rock exposures 25-75 m apart and cover 2-10% of the area.	Rock exposures 2-25 m apart and cover 10-50% of the area.	Rock exposures<2m apart and cover>50% of the area.
Surface Soil Texture[4]	SL, FSL, VFSL, L, SIL, and LS with textural B. Not subject to soil blowing.	CL, SCL, SiCL, and LS not subject to soil blowing	SC, SiC, C, Si, Organic soils, sand other than loose sand.	Loose sand subject to severe blowing.
Thickness of Ah Horizon[5]	>8 cm	0-8 cm	Lack of Ah horizon not a severe limitation by itself.	
Topsoil Salinity	EC[6] 0-1	EC>1-3	EC>3-8[7]	EC>8[7]
Depth to Bedrock, Sand or Gravel	>100 cm	50-100 cm[8]	25-50 cm	<25 cm
Permeability[9]	Moderately rapid to moderately slow inclusive 0.5-15.0 cm/hr	Slow and very slow <0.5 cm/hr	Rapid and very rapid >15.0 cm/hr	

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[1] Soil drainage classes are defined in this guidebook. [2] Surface stoniness for the purpose of this table includes gravels and cobbles, or any coarse fragments>2 mm in diameter. Cobbles and stones must be removed from areas to be landscaped, increasing development and maintenance difficulties. Some gravelly soils may be rated none to slight when the content of gravel exceeds 20% by only a small margin, if a) the gravel is embedded in the soil matrix, or b) the fragments are <2 cm in diameter. Surface stoniness classes are defined in this guidebook. [3] Very shallow soils are rated as having a severe limitation for rockiness. Rockiness classes are defined in the Canadian System of Soil Classification (Canada Soil Survey Committee, 1978). [4] The soil textural classes are defined in this guidebook. [5] Also known as topsoil, which is defined in this guidebook under the heading "Thickness of Topsoil." [6] EC means Electrical Conductivity, and is explained in Appendix 1. [7] These limits are taken from Richards (1954). [8] May be rated none to slight on 0-2% slopes. [9] In low rainfall areas finer textured soils may be rated one class better, and coarser textured soils may be rated one class lower. Soil permeability classes are defined in this guidebook.

GUIDE FOR DEVELOPING SOIL INTERPRETATIONS FOR PLAYGROUNDS

This guide applies to soils to be used intensively for playgrounds for baseball, football, and other similar organized games. These areas are subject to intensive foot traffic. A nearly level surface, good drainage, and a soil texture and consistence that gives a firm surface generally are required. The most desirable soils are free of rock outcrops and coarse fragments. Soil suitability for growing and maintaining vegetation is not a part of this guide, but is an important item to consider in the final evaluation of a site (see Table 15, Soil limitation classes for lawns and landscaping).

TABLE 16.
Soil limitation classes for playgrounds

	Degree of Limitation			
Properties Affecting Use	None to Slight	Moderate	Severe	Very Severe
Flooding	None during season of use.	Occasional. Once in 2-3 years during season of use.	Every year.	Prolonged flooding during season of use.
Wetness[1] (soil drainage class)	Very rapidly, rapidly, well & moderately well drained soils - no seepage or ponding. WT >75 cm during season of use.	Moderately well drained soils - occasional seepage or ponding, imperfectly drained soils - no seepage or ponding. WT >50 cm during season of use.	Imperfectly drained soils - seepage or ponding, poorly & very poorly drained soils. WT <50 cm during season during season of use.	Permanently wet soils.
Slope	0-2% (aA, bB)	>2-5% (cC)	>5-9% (dD)	>9% (eE-hH)
Permeability[2]	Very rapid to moderate inclusive ≥1.5 cm/hr	Moderately slow and slow 0.15-1.5 cm/hr	Very slow <0.15 cm/hr	
Surface Stoniness[3]	0 and 1	2	3 and 4	5
Rockiness[4]	Rock exposures >75 m apart and cover <2% of the area.	Rock exposures 25-75 m apart and cover 2-10% of the area.	Rock exposures <25 m apart and cover >10% of of the area.	Rock exposures too frequent to permit playground location.
Depth to bedrock	>100 cm	50-100 cm[5]	<50 cm[5]	
Surface Soil Texture[6]	SL, FSL, VFSL, L	SiL, CL, SCL, SiCL, LS	SC, SiC, C, S, Si	S and LS subject to blowing. Organic soils.
Depth to Sand or Gravel[7]	>100 cm	50-100 cm	<50 cm	

[1] Soil drainage classes are defined in this guidebook. [2] In low rainfall areas soils may be rated one class better. Soil permeability classes are defined in this guidebook. [3] Surface stoniness for the purpose of this table includes gravels and cobbles, or any coarse fragments >2 mm in diameter. Surface stoniness classes are defined in this guidebook. [4] Very shallow soils are rated as severe for rockiness. Rockiness classes are defined in the Canadian System of Soil Classification (Canada Soil Survey Committee, 1978). [5] Downgrade to very severe if slope >5%. [6] Surface soil texture influences soil ratings as it affects foot trafficability, surface wetness, dust, and maintenance. Adverse soil textures may be partially or completely overcome with the addition of topsoil. The soil textural classes are defined in this guidebook. [7] Depth to sand or gravel is considered a limitation in that levelling operations may expose sand or gravel, thereby bringing about adverse surface textures and undesirable amounts of coarse fragments. The addition of topsoil after levelling would overcome this limitation.

GUIDE FOR DEVELOPING SOIL INTERPRETATIONS FOR PERMANENT BUILDINGS

This guide provides ratings for undisturbed soils that are evaluated for single family dwellings and other structures with similar foundations. Slope, susceptibility to flooding, and seasonal wetness, that have effects beyond those related exclusively to foundations, are also considered. The properties affecting foundation support are those that affect bearing capacity and settlement under load, and those that affect excavation and construction costs. The properties affecting bearing strength and settlement of the natural soil are density, wetness, plasticity, texture, and shrink-swell behavior. Shrink-swell potential and plasticity (Atterberg limits) are inferred from the Unified Soil Classification. Properties influencing the ease and amount of excavation are wetness, slope, depth to bedrock and sand or gravel, stoniness and rockiness. These properties also affect the ease of installing underground utilities. Excluded are limitations for septic tank absorption fields (see Table 18, Soil limitations classes for septic tank absorption fields) and lawns and landscaping (see Table 15, Soil limitation classes for lawns and landscaping). On site investigations are needed for specific placement of buildings and utility lines, and for detailed design of foundations. All ratings are based on undisturbed soils to a depth of 1 to 2 m.

TABLE 17.

Soil limitation classes for permanent buildings

	Degree of Limitation			
Properties Affecting Use	None to Slight	Moderate	Severe	Very Severe
Flooding	None	None	Occasional (once in 5 years).	Frequent (every year).
Wetness[1] (soil drainage class)	WITH BASEMENTS: very rapidly, rapidly & well drained soils. WT>150 cm. WITHOUT BASEMENTS: very rapidly, rapidly, well & moderately well drained soils - no seepage or ponding. WT>75 cm.	WITH BASEMENTS: moderately well drained soils - no seepage or ponding. WT 75-150 cm. WITHOUT BASEMENTS: moderately well drained soils - occasional seepage or ponding, imperfectly drained soils - no seepage or ponding. WT 50-75 cm.	WITH BASEMENTS: imperfectly drained soils - no seepage or ponding, poorly & very poorly drained soils. WT 25-75 cm 1 month or more during year. WITHOUT BASEMENTS: poorly & very poorly drained soils. WT 25-50 cm 1 month or more during year.	WITH BASEMENTS: permanently wet soils. WT<25 cm. WITHOUT BASEMENTS: permanently wet soils. WT<25 cm.
Slope[2]	0-9% (aA-dD)	>9-15% (eE)	>15-30% (fF)	>30% (gG, hH)
Shrink-swell Potential[3]	Low - Unified Groups GW, GP, SW, SP, GM, GC, SM, SC, & CL with P.I.[4] <15.	Moderate[5] - Unified Groups ML, & CL with P.I.≥15.	High[5] - Unified Groups CH, MH, OL & OH	Very High[5] - Unified Group Pt.
Potential Frost Action[6]	Low (F1, F2)	Moderate (F3)[5]	High (F4)[5]	
Depth to Bedrock[7]	WITH BASEMENTS: >150 cm WITHOUT BASEMENTS: >100 cm	WITH BASEMENTS: 100-150 cm WITHOUT BASEMENTS: 50-100 cm	WITH BASEMENTS: 50-100 cm WITHOUT BASEMENTS: <50 cm	WITH BASEMENTS: <50 cm
Potential Sulfate Attack[8] on Concrete	0-1000 ppm[9] or 0-0.20%	1000-2000 ppm or 0.20 - 0.50%[5]	>2000 ppm or >0.50%[5]	
Surface Stoniness[10]	0 and 1	2	3 and 4	5
Rockiness[7, 11]	Rock exposures >75 m apart and cover <2% of the area.	Rock exposures 25-75 m apart and cover 2-10% of the area.	Rock exposures < 25 m apart and cover >10% of the area.	Rock exposures too frequent to permit location of permanent buildings.

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[1] Soil drainage classes are defined in this guidebook. [2] Reduce the slope limits by one-half for soils subject to hillside slippage. [3] This item estimates the strength of the soil, that is, its ability to withstand applied loads. [4] P.I. means Plasticity Index, and is defined in Appendix I. [5] These factors are limitations only where basements and underground utilities are planned. [6] Frost heave only applies where frost penetrates to the assumed depth of the footings and the soil is moist. The potential frost action classes are outlined in Table 4. [7] If bedrock is soft enough to be dug with light power equipment, such as a backhoe, moderate & severe limitations may be reduced by 1 class. [8] Categories for sulfate attack on concrete are outlined in Table 7. [9] ppm means parts per million. [10] Surface stoniness classes are outlined in this guidebook. [11] Very shallow soils are rated as having a severe limitation for rockiness. Rockiness classes are defined in the Canadian System of Soil Classification (Canada Soil Survey Committee, 1978).

GUIDE FOR DEVELOPING SOIL INTERPRETATIONS FOR SEPTIC TANK ABSORPTION FIELDS

The septic tank absorption field is a subsurface tile system laid out in such a way that effluent from the septic tank is distributed with reasonable uniformity into the natural soil. When the effluent is percolated into the ground, the impurities it contains are attacked by a myriad of biological organisms, naturally present in the soil (Alberta Department of Manpower and Labour, 1972).

Absorption fields are influenced by the ease of downward movement of effluent through the soil. This guide provides ratings for undisturbed soils that are evaluated on their ability to absorb and filter the liquid or effluent passed through the tile field. Soils with slow permeability are rated severe. Clean sands and gravels with rapid permeability have slight limitations, unless a hazard exists for contaminating nearby water supplies. A rating of severe does not necessarily mean that a septic system should not be installed in a given soil, but rather suggests difficulty, in terms of installation and maintenance, which can be expected.

TABLE 18.
Soil limitation classes for septic tank absorption fields

	Degree of Limitation			
Properties Affecting Use	None to Slight	Moderate	Severe	Very Severe
Flooding	None	None	Occasional (once in 5 years)	Floods every year.
Wetness[1] (soil drainage class)	Very rapidly, rapidly & well drained soils. Seasonal[2] WT>180 cm	Moderately well drained soils - no seepage or ponding. Seasonal WT 120-180 cm.	Moderately well drained soils - occasional seepage or ponding, imperfectly drained soils - no seepage or ponding. Seasonal WT 60-120 cm. Very rapidly & rapidly drained soils if groundwater contamination hazard.	Imperfectly drained soils - seepage or ponding, poorly & very poorly drained soils, permanently wet soils. Seasonal WT<60 cm.
Slope	0-9% (aA-dD)	>9-15% (eE)	>15-30% (fF)	>30% (gG, hH)
Permeability[3]	Very rapid to moderately rapid inclusive >5.0 cm/hr	Moderate 1.5-5.0 cm/hr	Moderately slow & slow 0.15-1.5 cm/hr. Very rapid & rapid if groundwater contamination hazard >15.0 cm/hr.	Very slow < 0.15 cm/hr
Percolation Rate[4] (Auguer hole method)	About 8-18 min/cm	18-24 min/cm	Slower than 24 min/cm	
Depth to Bedrock[5] or Other Impervious Material	>180 cm	120-180 cm[6]	60-120 cm	<60 cm
Depth to Sand or Gravel[5]	>180 cm	120-180 cm[6,7]	60-120 cm[7]	<60 cm[7]

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[1] Water table depth based on the assumption that tile depth is 60 cm in the soil. Soil drainage classes are defined in this guidebook. [2] Seasonal means for more than one month. It may with caution be possible to make some adjustment for the severity of a water table limitation where seasonal use of the facility does not coincide with the period of high water table. A seasonal water table should be at least 120 cm below the bottom of the trench at all times for soils having a slight limitation (United States Department of Health, Education and Welfare, 1969). Where relief permits, the effective depth above a water table or rock can be increased by adding appropriate amounts of fill. [3] The limitation ratings should be based on the permeability of soil layers at and below the depth of the tile line. Soil permeability classes are defined in this guidebook. [4] Soils having a percolation rate faster than about 8 min/cm are likely to present a pollution hazard to adjacent waters. This hazard must be noted, but the degree must be assessed in each case by examining the proximity of the proposed installation to water bodies, water table, and related features. Refer to Alberta Manpower and Labour, 1972 for details of the auger hole procedure. [5] Based on an assumed tile depth of 60 cm in the soil. [6] Where the slope is >9%, a depth to bedrock, sand or gravel of 120-180 cm is considered a severe limitation. [7] Limitation if a groundwater contamination hazard exists.

GUIDE FOR DEVELOPING SOIL INTERPRETATIONS FOR TRENCH-TYPE SANITARY LANDFILLS

The trench-type sanitary landfill is a dug trench in which refuse is buried. Successive layers of refuse and soil material are put into the trench and compacted. Soil material excavated when digging the trench is used. The cover of soil material keeps the refuse in place and controls odors, fires, and rodents. A final cover of soil material at least 1 m thick is placed on the landfill when the trench is full.

This guide provides ratings for evaluating undisturbed soils on their suitability as sites for good sanitary landfills that should be usable all year, and should operate without contaminating water supplies or causing a health hazard. Because routine soil investigations are normally confined to depths of about 1 to 2 m, and many landfill operations use trenches as deep as 4 m or more, geological and hydrological information are needed to determine the potential for pollution of groundwater, as well as to obtain the design of a sanitary landfill. The presence of hard nonrippable bedrock, creviced bedrock, sandy or gravelly strata within or immediately underlying the proposed trench bottom is undesirable from the standpoint of excavation, and from the standpoint of the potential for groundwater pollution.

TABLE 19.

Soil limitation classes for trench-type sanitary landfills [1]

	Degree of Limitation			
Properties Affecting Use	None to Slight	Moderate	Severe	Very Severe
Flooding	None	Rare	Occasional	Frequent
Wetness[2] (soil drainage class)	Very rapidly, rapidly & well drained soils. Seasonal[3] high WT>180 cm.	Moderately well drained soils - no seepage or ponding. Seasonal high WT 120-180 cm.	Moderately well drained soils - occasional seepage or ponding, imperfectly drained soils - no seepage or ponding. Seasonal high WT 60-120 cm. Very rapidly & rapidly drained soils if groundwater contamination hazard.	Imperfectly drained soils - seepage or ponding, poorly & very poorly drained soils, permanently wet soils. Seasonal high WT<60 cm.
Slope	0-15% (aA-eE)	>15-30% (fF)	>30-60% (gG)	>60% (hH)
Permeability[4]	Moderate to very slow inclusive <5.0 cm/hr	Moderate to very slow inclusive <5.0 cm/hr	Moderately rapid 5.0-15.0 cm/hr	Rapid and very rapid >15.0 cm/hr
Soil Texture[5] (dominant to a depth of 150 cm)	SL, FSL, VFSL, L, SiL, SCL	SiCL, CL, SC, LS, Si[6]	SiC	C, S, gravel, peat, muck
Depth to Bedrock				
Hard -	>180 cm	>180 cm	100-180 cm	<100 cm
Rippable -	>150 cm	100-150 cm	<100 cm	
Surface Stoniness[7]	0 and 1	2	3 and 4	5
Rockiness[8]	No rock exposures	No rock exposures	Rock exposures present	Rock exposures too frequent to permit location of sanitary landfills.
Nature of Bedrock	Impermeable	Permeable[9]	Highly permeable[9], fractured, easily soluble.	
Depth to Sand or Gravel[5]	>180 cm	>180 cm[9]	100-180 cm[9]	<100 cm[9]

[1] Based on soil depth (120 cm) commonly investigated in making soil surveys. If it is probable that the soil material to a depth of 3-4 m will not alter a rating of slight or moderate, indicate that by an appropriate footnote such as "Probably slight to 4 m," or "Probably moderate to 4 m."

[2] Soil drainage classes are defined in this guidebook.

[3] Seasonal means for more than 1 month.

[4] Reflects ability of soil to retard movement of landfill leachate from the landfills; may not be a limitation in arid and semiarid areas. Soil permeability classes are defined in this guidebook.

[5] Reflects the ease of digging and moving soil material (workability) and trafficability in the immediate area of the trench that may not have surfaced roads. Soil textural classes are defined in this guidebook.

[6] Soils high in expansive clays may need to be given a limitation rating of severe.

[7] Surface stoniness classes are defined in this guidebook.

[8] Rockiness classes are defined in the Canadian System of Soil Classification (Canada Soil Survey Committee, 1978).

[9] Limitations only if a groundwater contamination hazard exists.

GUIDE FOR DEVELOPING SOIL INTERPRETATIONS FOR ROAD LOCATION

This guide applies to soils evaluated for construction and maintenance of local roads, streets, and parking areas. These are improved roads and streets having some kind of all-weather surfacing, commonly asphalt or gravel, and are expected to carry automobile traffic all year. They consist of:

1. underlying local soil material (either cut or fill) called the subgrade;
2. the base material of gravel, crushed rock or lime, or soil cement stabilized soil called the subbase; and
3. the actual road surface or pavement, either flexible or rigid.

They also are graded to shed water, and have ordinary provisions for drainage. With the probable exception of the hardened surface layers, the roads and streets are built mainly from the soil at hand, and cuts and fills are limited, usually less than 2 m. Excluded from consideration in this guide are highways designed for fast moving, heavy trucks.

Properties that affect design and construction of roads and streets are:

1. those that affect the load supporting capacity and stability of the subgrade; and
2. those that affect the workability and amount of cut and fill.

The AASHO and Unified Classifications, and the shrink-swell potential give an indication of the traffic supporting capacity. Wetness and flooding affect stability. Slope, depth to bedrock, stoniness, rockiness, and wetness affect the ease of excavation and the amount of cut and fill required to reach an even grade.

TABLE 20.
Soil limitation classes for road location

	Degree of Limitation			
Properties Affecting Use	None to Slight	Moderate	Severe	Very Severe
Flooding[1]	None	Infrequent (once in 5 years)	Occasional (once in 2-4 years)	Frequent (every year)
Wetness[2] (soil drainage class)	Very rapidly, rapidly, well & moderately well drained soils - no seepage or ponding. Seasonal[3] WT>150 cm.	Moderately well drained soils - occasional seepage or ponding, imperfectly drained soils - no seepage or ponding. Seasonal WT 100-150 cm.	Imperfectly drained soils - seepage or ponding, poorly & very poorly drained soils Seasonal WT 50-100 cm.	Permanently wet soils. WT<50 cm.
Slope[1]	0-9% (aA-dD)	>9-15% (eE)	>15-30% (fF)	>30% (gG,hH)
Shrink-Swell Potential[4]	Low - Unified Groups GW, GP, SW, SP, GM, GC[5], SM, SC[5]	Moderate - Unified Groups CL with P.I.[6]<15, ML	High - Unified Groups CL with P.I.≥15, CH, MH, OH, OL, Pt.	
AASHO Group Index	0-4	5-8	>8	
Potential Frost Action[7]	Low (F1, F2)	Moderate (F3)	High (F4)	
Depth to Bedrock[8]	>100 cm	50-100 cm	<50 cm	
Surface Stoniness[9]	0, 1 and 2	3	4	5
Rockiness[10]	Rock exposures>75 m apart & cover<2% of the surface.	Rock exposures 25-75 m apart & cover 2-10% of the surface.	Rock exposures<25 m apart & cover >10% of the surface.	Rock exposures too frequent to permit location of roads and streets.

[1] Applies to road location. [2] Soil drainage classes are defined in this guidebook. [3] Seasonal means for more than one month. [4] This item estimates the strength of the soil as it applies to roadbeds. The limitations were estimated assuming that the roads would be surfaced. On unsurfaced roads, rapidly drained, very sandy, poorly graded soils may cause washboard or rough roads. [5] Downgrade to moderate if content of fines (<200 mesh) is greater than about 30%. [6] P.I. means plasticity index and is defined in Appendix I. [7] Frost heave is important where frost penetrates below the paved or hardened surface layer, and moisture transportable by capillary movement is sufficient to form ice lenses at the freezing point. The potential frost action classes are outlined in Table 4. [8] If bedrock is soft enough to be dug with light power equipment and is rippable by machinery, reduce moderate and severe limitations by one class. [9] Surface stoniness classes are outlined in this guidebook. [10] Rockiness classes are outlined in the Canadian System of Soil Classification (Canada Soil Survey Committee, 1978).

GUIDE FOR DEVELOPING SOIL INTERPRETATIONS FOR SOURCES OF ROADFILL

Since soil survey interpretations are oriented to local roads and streets rather than to super highways, suitability ratings are assumed to be evaluations of the soils as sources of roadfill for low embankments, generally less than 2 m high, and less exacting in design than high embankments.

Generally, the rating is given for the whole soil, from the surface to a depth of 1 to 2 m, based on the assumption that soil horizons will be mixed in loading, dumping, and spreading. If the surface layer from a few cm to as much as about 30 cm in thickness is poorly suited for roadfill, disregard the surface layer in establishing the rating. If the thickness of suitable material is less than about 1 m because of shallow depth to bedrock or other unsuited or poorly suited material, the whole soil is given a rating of poor, regardless of the material less than 1 m thick.

These ratings reflect how well a soil performs after it is removed from its original location and placed in a road embankment elsewhere. They also reflect evaluation of other characteristics, such as slope, that determine the ease or difficulty in getting the soil out.

Since roadfill is soil materials used for making embankments for roads and because low embankments or the upper part of high embankments serve as the subgrade for the road, soil material good for roadfill must also be good for subgrade. Most of the comments pertaining to soil material used for road location are also pertinent to soil material used for sources of roadfill.

TABLE 21.
Soil suitability classes for sources of roadfill

	Degree of Suitability			
Properties Affecting Use[1]	Good	Fair	Poor	Very Poor
Shrink-Swell Potential	Low - Unified Groups GW, GP, SW, SP, GM, GC[2], SM, SC[2]	Moderate - Unified Groups CL with P.I.[3]<15, ML	High - Unified Groups CL with P.I.≥15, CH, MH[4]	Very High - Unified Groups OL, OH, Pt.
AASHO Group Index	0-4	5-8	>8	
Potential Frost Action[5]	Low (F1, F2)	Moderate (F3)	High (F4)	
Flooding	Infrequent (once in 5 years)	Occasional (once in 2-4 years)	Frequent (every year)	Constantly flooded
Wetness[6] (soil drainage class)	Very rapidly, rapidly, well & moderately well drained soils - no seepage or ponding. Seasonal[7] WT>150 cm.	Moderately well drained soils - occasional seepage or ponding, imperfectly drained soils - no seepage or ponding. Seasonal WT 100-150 cm.	Imperfectly drained soils - seepage or ponding, poorly & very poorly drained soils. Seasonal WT 50-100 cm.	Permanently wet soils. WT<50 cm.
Slope	0-15% (aA-eE)	>15-30% (fF)	>30-60% (gG)	>60% (hH)
Depth to Bedrock	>100 cm	50-100 cm	20-50 cm	<20 cm
Surface Stoniness[8]	0, 1 and 2	3	4	5
Rockiness[9]	Rock exposures>25 m apart & cover<10% of the surface.	Rock exposures 10-25 m apart & cover 10-25% of the surface.	Rock exposures 2-10 m apart & cover 25-50% of the surface.	Rock exposures 2 m or less apart & cover 50-90% of the surface.

[1] The first three items pertain to soil after it is placed in a fill; the last six items pertain to soil in its natural condition before excavation for roadfill. [2] Downgrade to fair if content of fines (<200 mesh) is more than about 30%. [3] P.I. means Plasticity Index and is defined in Appendix I. [4] Upgrade to fair if MH is largely Kaolinitic, friable, and free of mica. [5] Frost heave is important where frost penetrates below the paved or hardened surface layer, and moisture transportable by capillary movement is sufficient to form ice lenses at the freezing point. The potential frost action classes are outlined in Table 4. [6] Soil drainage classes are defined in this guidebook. [7] Seasonal means for more than one month. [8] Surface stoniness classes are outlined in this guidebook. [9] Rockiness classes are outlined in the Canadian System of Soil Classification (Canada Soil Survey Committee, 1978).

GUIDE FOR DEVELOPING SOIL INTERPRETATIONS FOR SOURCES OF SAND OR GRAVEL

The purpose of this interpretation is to provide guidance on the probable supply of sand or gravel.

Ratings are based on the probability that soils contain sizeable quantities of sand or gravel, excluding soft materials such as shale or siltstone. The interpretation pertains mainly to the characteristics of the soil substratum to a depth of 150 cm and to qualify as either a good or fair probable source, the layer should be at least 1 m thick. All of this, however, need not be in the top 1 to 2 m. If the approximate lowest 15 cm of this section is sand or gravel, and observations of deep cuts, geological information, or other evidence suggest that the sand or gravel at the bottom of this section extends downward for several metres, the thickness requirement is satisfied.

Only the suitability as a *source* of sand or gravel is rated. No attempt is made to rate the quality of the sand or gravel for specific uses, such as road base or concrete. The general relative quality for many uses in terms of grain size is indicated in Table 24 by classes in the Unified Soil Classification System. However, quality determinations should be made at the site of the source, since both grain sizes, and shapes of sand and gravel determine the suitability for specific uses (Olsen *et al.,* 1971).

A particular area outlined on the soil map can be identified as predominantly sand or predominantly gravel by consulting the soil report for a description of the map unit under consideration.

TABLE 22.
Soil suitability classes for sources of sand or gravel

Properties Affecting Use	Degree of Suitability Good			
	Good	Fair	Poor	Very Poor
Flooding[1]	Infrequent (once in 5 years)	Occasional (once in 2-4 years)	Frequent (every year)	Constantly flooded
Wetness[1,2] (soil drainage class)	Very rapidly, rapidly, well & moderately well drained soils - no seepage or ponding. Seasonal[3] WT>150 cm.	Moderately well drained soils - occasional seepage or ponding, imperfectly drained soils - no seepage or ponding. Seasonal WT 100-150 cm.	Imperfectly drained soils - seepage or ponding, poorly & very poorly drained soils Seasonal WT 50-100 cm.	Permanently wet soils. WT<50 cm.
Unified Soil Group	SW, SP, GW, GP	SW-SM, SP-SM, GW-GM, GP-GM	SM, SW-SC, SP-SC, GM, GW-GC, GP-GC	All other groups and bedrock.
Depth to Sand and Gravel	<50 cm	50-100 cm[4]	>100 cm[4]	
Rockiness[5]	Rock exposures>25 m apart & cover<10% of the surface.	Rock exposures 10-25 m apart & cover 10-25% of the surface.	Rock exposures 2-10 m apart & cover 25-50% of the surface.	Rock exposures 2 m or less apart & cover 50-90% of the surface.

[1] Affects accessibility and ease of excavation. [2] Soil drainage classes are defined in this guidebook. [3] Seasonal means for more than one month. [4] Rated good if it is known that the underlying gravel or sand deposit is thick (>150 cm). [5] Rockiness classes are outlined in the Canadian System of Soil Classification (Canada Soil Survey Committee, 1978).

GUIDE FOR DEVELOPING SOIL INTERPRETATIONS FOR SOURCES OF TOPSOIL

The purpose of this interpretation is to provide information for use by engineers, landscapers, nurserymen, planners, and others who make decisions about selection, stockpiling, and use of topsoil.

Topsoil has several meanings, but in soil survey interpretations it means soil material to spread over barren surfaces, usually made barren by construction, so as to improve soil conditions for re-establishment and maintenance of adapted vegetation; and to improve soil conditions for lawns, gardens, and flower beds where vegetation already may exist.

The physical, chemical, and biological characteristics of good topsoil favor the establishment and growth of adapted plants. It is friable and easy to handle and spread. While a high content of plant nutrients in good balance is desirable, it is less important than responsiveness to fertilization and to liming if pH adjustments are necessary (United States Department of Agriculture, undated).

A soil that qualifies as a good source not only provides a source of topsoil for removal, but also has characteristics such that, with material stripped off for topsoil, the remaining soil can be reclaimed. Some damage to a borrow area is to be expected, but if the damage is great enough so that revegetation and erosion control become major problems, the soil should be rated as a poor source of topsoil regardless of the quality of the surface materials. This constraint does not apply to construction sites where the soils are drastically disturbed in the construction process; and topsoil ratings of soils for such places therefore may be different. Unless otherwise specified, however, the assumption is made that localities from which topsoil is taken are to be restored.

Also considered in rating soil as a source of topsoil are certain features that affect the ease or difficulty of excavating the material, particularly the slope, wetness, and thickness of suitable material. Usually, only the surface layer is rated; but if this is less than about 15 cm thick, assume that it will be mixed with the adjacent layer to make up a thickness of at least 15 cm and rate this mixture.

TABLE 23.
Soil suitability classes for sources of topsoil

	Degree of Suitability			
Properties Affecting Use	Good	Fair	Poor	Very Poor
Moist Consistence[1]	Very friable, friable	Loose, firm	Very firm	Cemented
Flooding	None	May flood occasionally for short periods.	Frequent flooding	Constantly flooded
Wetness[2] (soil drainage class)	Wetness not determining if better than poorly drained.		Poorly drained soils	Very poorly drained and permanently wet soils.
Slope[3]	0-9% (aA-dD)	>9-15% (eE)	>15-30% (fF)	>30% (gG, hH)
Surface Stoniness[4]	0 and 1	2	3 and 4	5
Texture[5]	FSL, VFSL, L, SiL, SL; SC if 1:1 clay is dominant.	CL, SCL, SiCL; SC if 2:1 clay is dominant; C & SiC if 1:1 clay is dominant.	S, LS; C & SiC if 2:1 clay is dominant. Organic soils.[6]	
Thickness[7] of Ah Horizon	>25 cm	15-25 cm	8-15 cm	<8 cm
Topsoil Salinity	EC[8] - 0-1	EC>1-3	EC>3-8[9]	EC>8[9]

[1] Terms used to describe soil consistence are defined in this guidebook. [2] Soil drainage classes are defined in this guidebook. [3] Influences ease of excavation, and susceptibility to soil erosion after topsoil has been removed. See section entitled "Soil Susceptibility to Erosion." [4] Surface stoniness for the purpose of this table includes gravels and cobbles, or any coarse fragments >2 mm in diameter. Some gravelly soils may be rated none to slight when the content of gravel exceeds 20% by only a small margin if (a) the gravel is embedded in the soil matrix, or (b) the fragments are <2 cm in diameter. Surface stoniness classes are defined in this guidebook. [5] The soil textural classes are defined in this guidebook. [6] Non-woody organic materials are assessed as good sources for topsoil if mixed with or incorporated into mineral soil. [7] Defined in this guidebook under the heading "Thickness of Topsoil." [8] EC means electrcity conductivity and is explained in Appendix I. [9] These limits are taken from Richards (1954).

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APPENDIX I
CHEMICAL AND PHYSICAL PROPERTIES OF SOILS

Most of the important chemical and physical properties of soils were discussed in the SOILS section of this guidebook. Some are discussed further in Appendix I.

EXCHANGEABLE CATIONS AND CATION EXCHANGE CAPACITY

The cation exchange capacity of a soil is a measure of the total amount of exchangeable cations that the soil can absorb, and is an important factor influencing fertility. The higher the exchange capacity, the greater is the ability of the soil to retain certain plant nutrients against the action of leaching. The capacity increases with increased clay and organic matter content, and is less in sandy soils. High concentrations of exchangeable sodium are characteristic of Solonetzic B horizons.

ORGANIC CARBON

The determination of organic carbon in soil is considered the best method of estimating the amount of organic matter. Generally, soil organic matter is assumed to contain 58 percent carbon, and an estimate of organic matter is made by multiplying the amount of organic carbon by the factor 1.7.

MECHANICAL ANALYSIS

The mechanical analysis of a soil sample is carried out to determine its texture, or the relative proportions of clay, silt, and sand particles present.

FREE IRON AND ALUMINUM

The dominant accumulation product in Podzolic B horizons is amorphous material composed mainly of humified organic matter combined in varying degrees with aluminum and iron (Canada Soil Survey Committee, 1978). The concentration of iron and aluminum is used as the basis for differentiating Podzolic B horizons from other soil horizons.

ELECTRICAL CONDUCTIVITY

Conductivity is a measure of the total soluble salt concentration in a soil. Soluble salts are present in soils at all times; however, when the salt concentration is high, plant growth is reduced and the soil is considered saline. Sulfates and sodium are determined to identify specific salts commonly causing salinity.

AVAILABLE NUTRIENTS

An available nutrient is the portion of any element or compound in the soil that can be readily absorbed and assimilated by growing plants. Plant growth may be retarded because certain essential elements are lacking in the soil, because they become available too slowly, or because they are not adequately balanced by other nutrients.

Nitrogen

Nitrogen is of special importance because plants need it in rather large amounts, and it is easily lost from the soil through leaching, erosion, and as gases. Moreover, it is usually present in comparatively small amounts in mineral soils. In general, low nitrogen levels are likely in soils low in organic matter, and soils that are cold or poorly drained.

Nitrogen tends primarily to encourage above ground vegetative growth, and to impart a deep green color to the leaves. Plants deficient in nitrogen are stunted in growth and have restricted root systems. The leaves turn yellow or yellowish green, and tend to drop off.

Soil nitrogen supply can be markedly affected by climatic conditions, native vegetation, and soil texture. In humid areas, where forests predominate, the higher rainfall causes much leaching with the removal of most soil nitrogen from upper horizons. In contrast, in areas of somewhat limited rainfall where grass predominates, much more nitrogen remains near the soil surface. A clay or clay loam textured soil commonly contains two to three times as much nitrogen as does a very sandy soil under similar climatic conditions. Poorer aeration and less leaching favor the retention of nitrogen in the finer textured soils.

General soil test ratings for supplies of available nitrogen, expressed in pounds per acre, are: low, 0 to 20; medium, 21 to 50; and high, 51 or more (Alberta Soil and Feed Testing Laboratory, O.S. Longman Building, Edmonton).

The primary natural source of soil nitrogen is air. Ammonium and nitrate salts are brought down by precipitation, and atmospheric nitrogen is fixed by certain microorganisms. Important artificial sources are commercial fertilizers, animal manures, green manures, and various crop residues.

Phosphorus

An inadequate supply of phosphorus is especially serious, since it may prevent other nutrients from being acquired by plants. Phosphorus has beneficial effects on the following aspects of plant growth: flowering and fruiting, including seed formation; plant maturation; root development, particularly of lateral and fibrous rootlets; stem strength; and resistance to certain diseases. A phosphorus deficiency is usually accompanied by reduced plant size, and a deep green color of the plant.

As phosphorus does not move appreciably in the soil, accumulations are found primarily in the surface 30 cm. Most of the total phosphorus supply is chemically bound in a form that is not usable by plants, and as such is not available to the growing plant. Available soil phosphorus originates from the breakdown of soil minerals and soil organic matter, or from the addition of phosphate fertilizer. The available soil phosphorus is usually only about 1 percent of the total soil phosphorus.

Soil tests show that most Alberta soils are low in available phosphorus. General soil test ratings for supplies, expressed in pounds per acre are: low, 0 to 30; medium, 31 to 70; and high, 71 or more (Alberta Soil and Feed Testing Laboratory, O.S. Longman Building, Edmonton).

Potassium

Plants need large amounts of potassium, which has a beneficial effect on their general tone and vigor. It increases plant resistance to certain diseases, and encourages strong root systems. It is supplied to roots by soil minerals, artificial fertilizers, manure, and crop residues.

Potassium is essential for photosynthesis, starch formation, the translocation of sugars, and the development of chlorophyll. The leaves of plants suffering from a potassium deficiency appear dry and scorched at the edges, and the surfaces are irregularly chlorotic (yellowish). In some plants, these symptoms are preceded by the appearance of small dots arranged more or less regularly around the edges of the leaves.

Most Alberta soils contain adequate amounts of potassium. Deficiencies occur most frequently on peat soils or poorly drained soils. General soil test ratings for supplies of available potassium, expressed in pounds per acre, are: low, 0 to 150; medium, 151 to 300; and high, 301 or more (Alberta Soil and Feed Testing Laboratory, O.S. Longman Building, Edmonton).

Sulfur

Many plants use about as much sulfur as they do phosphorus. The maturity of fruits and seeds is delayed in the absence of adequate sulfur. Plants that are sulfur deficient are characteristically small and spindly, and the younger leaves are light green to yellowish. Plants obtain sulfur from the soil, rain and irrigation water, artificial fertilizers, and sulfur gases in the atmosphere.

General soil test ratings for supplies of available sulfur as indicated by the Alberta Soil and Feed Testing Laboratory (O.S. Longman Building, Edmonton) are: low (L), medium (M), high (H), and none (nil). The degree within each category is indicated by a + or a - sign. The soil test determines whether adequate amounts of sulfur are available for normal plant growth. Where the sulfur test is low, a fertilizer containing sulfur should be applied; where it is medium, a field test using sulfur and non-sulfur fertilizers should be conducted. Plant needs for sulfur fertilizer can vary considerably over very small areas.

AVAILABLE ALUMINUM AND MANGANESE

Soils with pH of 5.5 or lower may contain soluble aluminum and manganese in sufficient quantities to be toxic to plants (Alberta Soil and Feed Testing Laboratory, O.S. Longman Building, Edmonton). Aluminum in toxic quantities restricts root growth, reducing the plant's ability to take up nutrients and water. Excess manganese accumulates in all tissues and interferes with their proper metabolism (Russell, 1961).

ENGINEERING TESTS

Engineering properties of soils determine their suitabilities for engineering uses. These properties are influenced most by soil texture, its gradation, and composition. A brief description of the significance of each analytical parameter follows.

Field Moisture Percentage

This is a determination of the natural moisture content of the soil as it occurs in the field.

For any potential borrow material, it is essential to know in advance of construction whether, for the compaction procedure likely to be specified, the moisture content in the field is excessive or deficient with respect to the optimum value for that procedure (Terzaghi and Peck, 1967).

Particle-Size Analysis

The particle-size distribution within a soil is determined by laboratory tests. The amounts of gravel and sand are determined by sieving, while silt and clay contents are determined by sedimentation techniques. The particle-size analysis provides part of the information needed to classify soils in the Unified and AASHO systems, discussed in this guidebook.

Plasticity

In soil mechanics, plasticity is defined as that property of a material which allows it to be deformed rapidly, without rupture, without elastic rebound, and without volume change (Means and Parcher, 1964).

Tests have been devised to determine the moisture content of a soil at which it changes from one major physical condition to another (Portland Cement Association, 1962). These tests, conducted on the material passing the number 40 sieve (0.42 mm), have been used as key factors in classifying soils for structural purposes.

The tests used for estimating plasticity are plastic limit (PL) and liquid limit (LL). The plasticity index (P.I.) is defined as the numerical difference between the liquid and plastic limits.

The plastic limit of soils is the moisture content at which a soil changes from a semisolid to a plastic state. This condition is said to prevail when the soil contains just enough moisture so that it can be rolled into 1/8 in diameter threads without breaking. Some silty and sandy soils that cannot be rolled into 1/8 in threads at any moisture content have no plastic limit, and are termed "nonplastic." The test is of no value in judging the relative load carrying capacity of nonplastic soils. Soils having plastic limits contain silt and clay, and the moisture contents of such soils have a direct bearing on their load carrying capacities. Load carrying capacity increases very rapidly as the moisture content is decreased below the plastic limit. On the other hand, load carrying capacity decreases very rapidly as the moisture content is increased above the plastic limit. Soils will generally reach or exceed their plastic limit moisture contents at some season of the year, even in regions of semiarid climate. Therefore, the bearing capacity of the subgrade, and pavement design requirements should be based on this low load carrying capacity condition, rather than on drier and correspondingly higher load carrying conditions unless specific long-range field data show that the better conditions prevail.

The liquid limit is the moisture content at which a soil passes from a plastic to a liquid state. The test is made by determining, for a number of moisture contents, the number of blows of a standard cup at which two halves of a soil cake will flow together for a distance of about 0.5 in. These data are then plotted, and the moisture content at which the plotted line (called flow curve) crosses the 25-blow line is the liquid limit. Since the cohesion of soil retards flow, this test is an index of cohesion. Cohesion has been largely overcome at the liquid limit. Sandy soils have low liquid limits, in the order of 20. In these soils, the test is of little significance in judging load carrying capacity. Silts and clays have significant liquid limits that may run as high as 80 to 100. High liquid limits indicate soils of high clay content and low load carrying capacity.

The plasticity index gives the range of moisture contents at which a soil is in a plastic condition. A small plasticity index, such as 5, shows that a small change in moisture content will change the soil from a semisolid to a liquid condition. Such a soil is very sensitive to moisture changes unless the silt and clay content combined is less than 20 percent. A large plasticity index, such as 20, show that considerable water can be added before the soil becomes liquid.

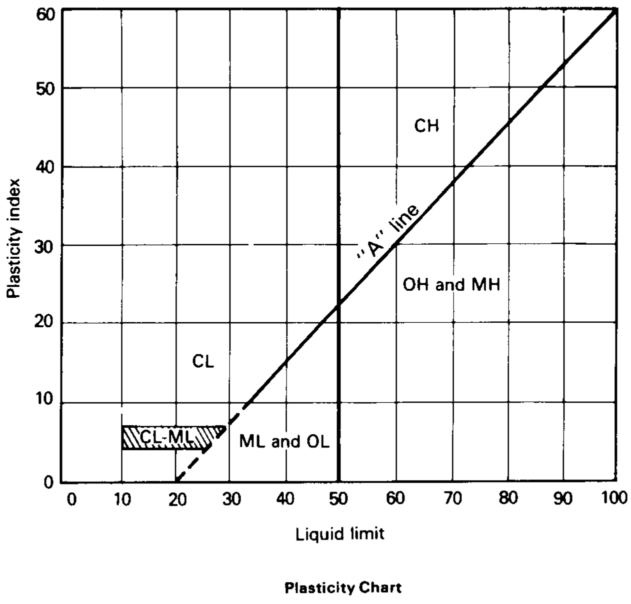
When the liquid limit or plastic limit cannot be determined, or when the plastic limit equals or is higher than the liquid limit, the plasticity index is reported as nonplastic (NP).

These moisture conditions – liquid limit, plastic limit, and plasticity index – are often called the Atterberg limits after the originator of the test procedures.

Moisture-Density Relationships

The purpose of every laboratory compaction test is to determine a moisture density curve comparable to that for the same material when compacted in the field by means of the equipment and procedures likely to be used (Terzaghi and Peck, 1967). Most of the current methods are derived from the procedure known as the Standard Proctor Test. A sample of soil is dried, pulverized, and separated into two size fractions, using a number four sieve. The finer fraction is divided into six or eight equal portions. Each portion is mixed thoroughly with a different quantity of water so that each has a different water content, ranging from nearly zero to about midway between the liquid and plastic limits. Each portion is compacted in a container with exactly the same compactive

TABLE 24.
Unified Soil Classification System (Portland Cement Association 1962).

Major divisions			Group symbols		Typical names	Laboratory classification criteria		
Coarse-grained soils (More than half of material is larger than No. 200 sieve size)	Gravels (More than half of coarse fraction is larger than No. 4 sieve size)	Clean gravels (Little or no fines)	GW		Well-graded gravels, gravel-sand mixtures, little or no fines	Determine percentages of sand and gravel from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size), coarse-grained soils are classified as follows: Less than 5 percent .... GW, GP, SW, SP More than 12 percent .... GM, GC, SM, SC 5 to 12 percent .... Borderline cases requiring dual symbols**	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			GP		Poorly graded gravels, gravel-sand mixtures, little or no fines		Not meeting all gradation requirements for GW	
		Gravels with fines (Appreciable amount of fines)	GM*	d	Silty gravels, gravel-sand-silt mixtures		Atterburg limits below "A" line or P.I. less than 4	Above "A" line with P.I. between 4 and 7 are borderline cases requiring use of dual symbols
				u				
			GC		Clayey gravels, gravel-sand-clay mixtures		Atterberg limits above "A" line with P.I. greater than 7	
	Sands (More than half of coarse fraction is smaller than No. 4 sieve size)	Clean sands (Little or no fines)	SW		Well-graded sands, gravelly sands, little or no fines		$C_u = \frac{D_{60}}{D_{10}}$ greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			SP		Poorly graded sands, gravelly sands, little or no fines		Not meeting all gradation requirements for SW	
		Sands with fines (Appreciable amount of fines)	SM*	d	Silty sands, sand-silt mixtures		Atterburg limits below "A" line or P.I. less than 4	Limits plotting in hatched zone with P.I. between 4 and 7 are borderline cases requiring use of dual symbols.
				u				
			SC		Clayey sands, sand-clay mixtures		Atterburg limits above "A" line with P.I. greater than 7	
Fine-grained soils (More than half of material is smaller than No. 200 sieve)	Silts and clays (Liquid limit less than 50)		ML		Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity	 **Plasticity Chart**		
			CL		Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays			
			OL		Organic silts and organic silty clays of low plasticity			
	Silts and clays (Liquid limit greater than 50)		MH		Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts			
			CH		Inorganic clays of high plasticity, fat clays			
			OH		Organic clays of medium to high plasticity, organic silts			
	Highly organic soils		Pt		Peat and other highly organic soils			

*Division of GM and SM groups into subdivisions of d and u are for roads and airfields only. Subdivision is based on Atterburg limits; suffix d used when L.L. is 28 or less and the P.I. is 6 or less; the suffix u used when L.L. is greater than 28.

**Borderline classifications, used for soils possessing characteristics of two groups, are designated by combinations of group symbols. For example: GW-GC, well-graded gravel-sand mixture with clay binder.

effort; its water content and weight of solids per cubic foot of compacted soils, usually termed the dry density, are determined. The dry density after compaction decreases conspicuously with increasing water content, and a curve is plotted showing the relation between dry density and water content. The optimum moisture content, according to the Standard Proctor Test, is the water content at which the dry density is a maximum (maximum dry density).

Soil Classification

In order that soils may be evaluated, it is necessary to devise systems or methods for identifying soils with similar properties and then to follow this identification with a grouping or classification of soils that perform in a similar manner when their densities, moisture contents, textures, and other properties are similar (Portland Cement Association, 1962). A brief description of three widely used soil classification systems follows.

Unified Soil Classification System. In this system, soils are identified according to their textures and plasticities, and are grouped according to their performance as engineering construction materials. Soil materials are divided into coarse-grained soils, fine-grained soils, and highly organic soils. The coarse-grained soils contain 50 percent or less of material smaller than the number 200 sieve, and are subdivided into eight classes. The fine-grained soils contain more than 50 percent of material smaller than the number 200 sieve, and are subdivided into six classes. There is only one class of highly organic soils, and they can generally be identified visually.

The coarse-grained soils are divided into gravels (G) and sands (S). The gravels have the greater percentage of the coarse fraction (that portion retained on the number 200 sieve) retained on the number four sieve, and the sands have the greater portion passing the number four sieve. The four secondary divisions of each group depend upon the amount and type of fines, and how well graded the soil material is.

Fine-grained soils are subdivided into silts (M) and clays (C), depending upon their liquid limit and plasticity index. Silts are those fine-grained soils with a liquid limit and plasticity index that plot below the 'A' line in the diagram in Table 24, and clays are those that plot above the 'A' line. The foregoing definition is not valid for organic clays, since their liquid limit and plasticity index plot below the 'A' line. The silt and clay groups are divided into secondary divisions based on whether the soils have a relatively low (L) or high (H) liquid limit. In addition, the letter 'O' is used to designate organic silts and clays (OL and OH).

Highly organic soils, usually very compressible and with undesirable construction characteristics, are classified into one group designated by the symbol Pt.

The designation CL for example, indicates inorganic clays of low to medium plasticity; SW indicates well-graded sands; and SC indicates clayey sands and sand-clay mixtures.

AASHO Classification System. The American Association of State Highway Officials system is an engineering property classification based on field performance of highways, in which soil material is classified into seven basic groups. Soil materials within each group have about the same general load carrying capacity and service. The groups are designated A-1 to A-7; the best soils for road subgrades are classified as A-1 and the next best as A-2, with the poorest soils being classified as A-7.

These seven basic groups are further divided into subgroups with a group index that was devised to approximate within group evaluations. Group indexes range from zero for the best subgrades to 20 for the poorest.

The charts and tables used in this classification system are shown in Figures 7 and 8, and in Table 25.

The soils are divided into two major groups, as shown in Table 25: the granular materials containing 35 percent or

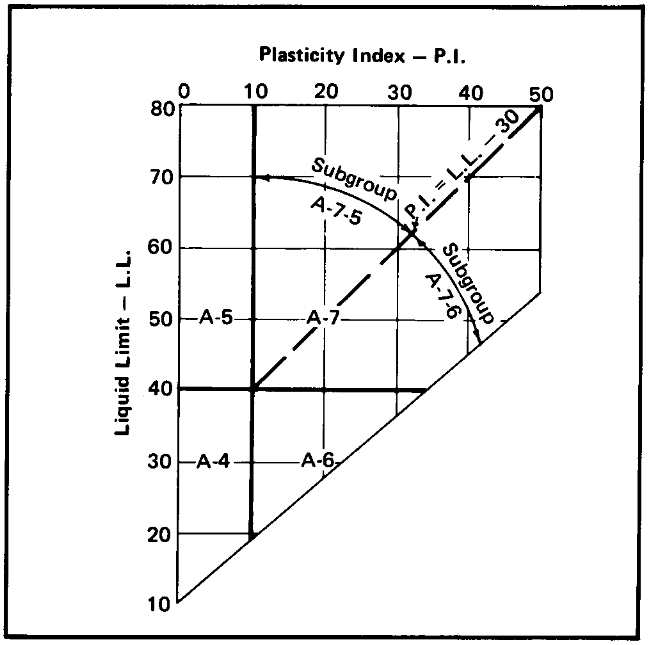


FIGURE 7. Liquid limit and plasticity index ranges for A-4, A-5, A-6, and A-7 subgrade groups (Portland Cement Association, 1962).

less of material passing the number 200 sieve, and the silt-clay materials containing more than 35 percent passing the number 200 sieve. Five soil fractions are recognized: boulders, gravel, coarse sand, fine sand, and combined silt and clay. The limiting boundaries between the various size fractions are given in Figure 9. Boulders constitute fragments larger than 76 mm in diameter.

Whether a soil is silty or clayey depends upon its plasticity index. Silty is applied to fine material having a plasticity index of 10 or less, and clayey is applied to fine material having a plasticity index of more than 10.

A-2 soils for example are composed of a wide range of granular materials that cannot be classified as A-1 or A-3 because of their fines content, plasticity, or both; A-4 soils, very common in occurrence, are composed predominantly of silt, with only moderate to small amounts of clay; and A-6 soils, also very common in occurrence, are composed predominantly of clay, with moderate to negligible amounts of coarse material.

United States Department of Agriculture Soil Classification System. The system of textural soil classification, used by Canadian soil scientists, is known as the USDA system. It is described in the SOILS section of this guidebook under the heading of texture. Some variations occur in the particle-size limits between the USDA and the two engineering systems, but the differences are not great. A comparison is given in Figure 9.

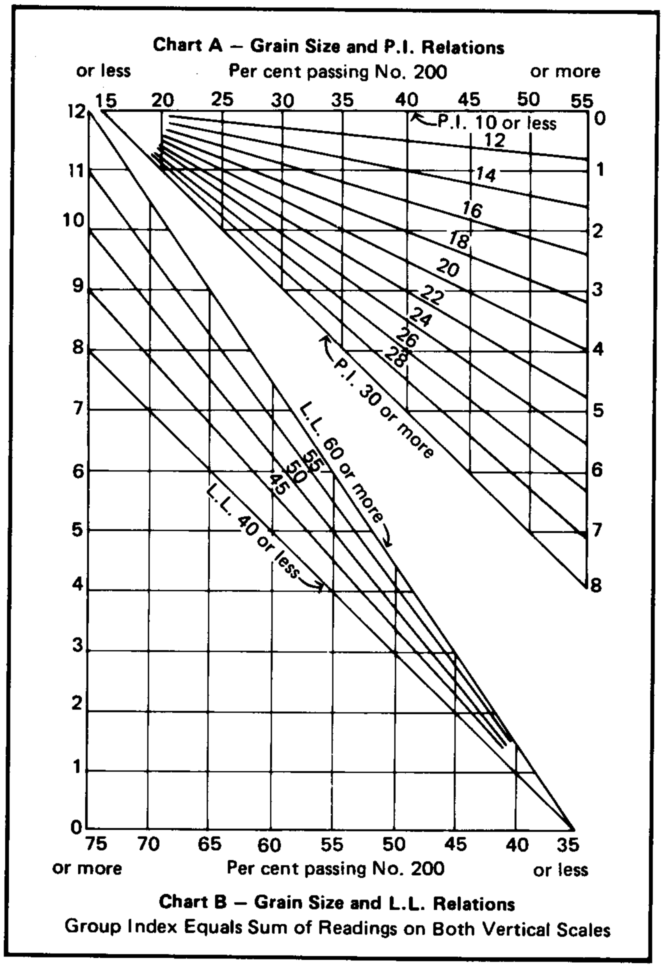


FIGURE 8. Group index charts (Portland Cement Association, 1962).

TABLE 25.
Classification of Highway Subgrade Materials (with Suggested Subgroups). (Portland Cement Association 1962)

General classification	Granular materials (35 per cent or less of total sample passing No. 200)							Silt-clay materials (More than 35 per cent of total sample passing No. 200)			
Group classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5, A-7-6
Sieve analysis, per cent passing:											
No. 10	50 max.										
No. 40	30 max.	50 max.	51 min.								
No. 200	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.	36 min.	36 min.	36 min.	36 min.
Characterisics of fraction passing No. 40:											
Liquid limit				40 max.	41 min.	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.
Plasticity index	6 max.		NP	10 max.	10 max.	11 min.	11 min.	10 max.	10 max.	11 min.	11 min.*
Group Index**	0		0	0		4 max.		8 max.	12 max.	16 max.	20 max.

Classification procedure: With required test data available, proceed from left to right on chart; correct group will be found by process of elimination. The first group from the left into which the test data will fit is the correct classification.

*P.I. of A7-5 subgroup is equal to or less than L.L. minus 30 P.I. of A-7-6 subgroup is greater than L.L. minus 30 (see Fig. 7).

**See group index formula or Fig. 8 for method of calculation. Group index should be shown in parentheses after the group symbol as: A-2-6(3), A-4(5),, A-6(12), A-7-5(17,) etc.

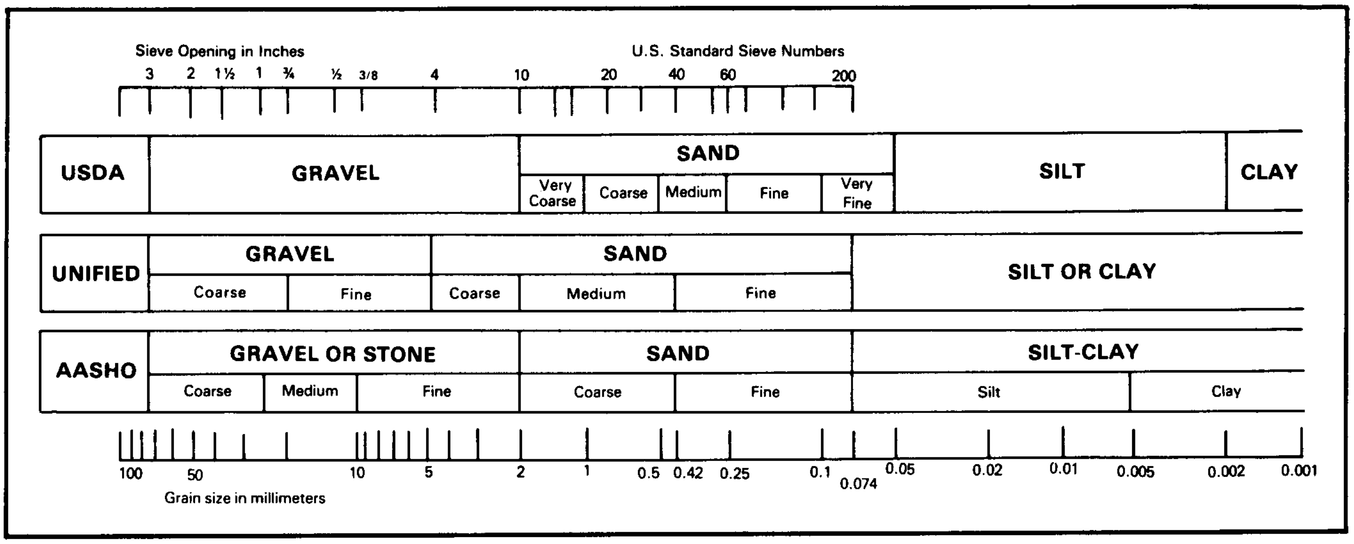


FIGURE 9. Soil separate size limits of USDA, Unified, and AASHO Soil Classification Systems (Diagram developed by Soil Conservation Service, United States Department of Agriculture).

APPENDIX II
ABRIDGED LANDFORM CLASSIFICAITON SYSTEM

This is an outline of the landform classification system used in soil mapping by Canadian pedologists. For a more complete description see the Canadian System of Soil Classification (Canada Soil Survey Committee, 1978).

SCOPE

This landform classification system is categorical in nature but does not involve a rigid hierarchy. It is intended to be a field classification system rather than a theoretical taxonomic one.

Landforms in this system are considered to include materials and form. Emphasis is placed on objectivity whereby the two basic attributes are recognized in terms of their inherent properties rather than on inferred genesis. The system attempts to map comprehensively all landforms rather than stress prominent features of importance to the interpretation of glacial history.

The Material category recognizes four groups of materials: unconsolidated mineral, organic, consolidated, and ice. Classes of unconsolidated mineral and organic materials have been established, but classes of consolidated materials (bedrock) and ice have not been recognized. Textures of unconsolidated mineral materials, and fiber content of organics are recognized in a category called Mineral Modifiers.

Surface expression, or form, associated with a material or deposit is considered in the first instance on the basis of the primary depositional form. Post depositional forms, essentially erosional, as well as processes, are recognized by a category called Modifying Processes.

A category named Qualifying Descriptors makes possible futher qualification of the kinds of materials and the current state of processes as to whether they are active or inactive.

GENETIC MATERIALS

Materials are classified according to their essential properties within a general framework of their mode of formation. Four components have been recognized and these are presented below.

Unconsolidated Mineral Component

The unconsolidated mineral component consists of clastic sediments that may or may not be stratified, but whose particles are not cemented. They are essentially of glacial or post glacial origin but may include poorly consolidated and weathered bedrock. The classes and abbreviated definitions follow.

A - Anthropogenic (man made, including materials associated with mineral exploitation and waste disposal).
C - Colluvial (sediments that have reached their present position by direct, gravity-induced movement).
E - Eolian (materials transported and deposited by wind action).
F - Fluvial (materials transported and deposited by streams and rivers).
L - Lacustrine (materials that have settled from suspension in bodies of standing fresh water, or beach and other nearshore sediments transported and deposited by wave action).
M - Morainal (heterogeneous mixture of sediments that have been transported beneath, beside, on, within, and in front of a glacier, and not modified by an intermediate agent).
V - Volcanic (unconsolidated pyroclastic sediments).
U - Undifferentiated (a layered sequence of more than three types of genetic material outcropping on a steep erosional escarpment).

Organic Component

The organic component consists of peat deposits containing >30% organic matter by weight that may be as thin as 10 cm if they overlie bedrock, but otherwise >40 cm and generally >60 cm thick. The classes are listed as follows:
B - Bog (sphagnum peat)
N - Fen (fen or sedge peat)
O - Organic, undifferentiated
S - Swamp (forest peat)

Consolidated Component

The consolidated component consists of tightly packed, indurated materials of bedrock origin including igneous, metamorphic, sedimentary, and consolidated volcanic rocks. The only class is bedrock (R), which is undifferentiated.

Ice Component

The ice component includes areas of snow and ice where evidence of active glacier movement is present within the boundary of the defined unit area. Ice (I) is the only class, and it is undifferentiated.

MATERIAL MODFIERS

Material modifiers are used to qualify unconsolidated mineral and organic deposits. Particle-size classes indicate the size, roundness, and sorting of unconsolidated mineral deposits. Fiber classes indicate the degree of decomposition and fiber size of organic materials.

Particle-Size Classes for Unconsolidated Materials

a - blocky (angular particles >256 mm in size).
b - bouldery (rounded particles >256 mm in size).
c - clayey (fine earth fraction contains 35% or more clay - <0.002 mm - by weight and particles >2 mm are <35% by volume).
k - cobbly (rounded particles of diameter 64-256 mm).
g - gravelly (rounded particles ranging in size from pebbles to boulders).
l - loamy (fine earth fraction contains <35% clay - <0.002 mm - by weight and particles >2 mm are <35% by volume).
p - pebbly (rounded particles of diameter 2-64 mm).
r - rubbly (angular fragments of diameter 2-256 mm).
s - sandy (fine earth fraction contains >70% by weight of fine sand or coarser particles and particles >2 mm are <35% by volume).
si - silty (fine earth fraction contains <15% of fine sand or coarser particles and has <35% clay; particles >2 mm are <35% by volume).

Fiber Classes for Organic Materials

The amount of fiber and its durability are important characterizing features of organic deposits because they reflect the degree of decomposition of the material. The prevalence of woody materials in peats is also important.

f - Fibric (least decomposed of all organic materials).
m - Mesic (organic material in an intermediate stage of decomposition).
h - Humic (highly decomposed organic material).
w - Woody (organic material containing >50% of woody fibers).

SURFACE EXPRESSION

The surface expression of genetic materials is their form (assemblage of slopes) and patterns of forms.

Classes for Unconsolidated and Consolidated Mineral Components

a - Apron (a relatively gentle slope at the foot of a steeper slope, and formed by materials from the steeper upper slope).
b - Blanket (a mantle of unconsolidated materials thick enough to mask minor irregularities in the underlying unit, but still conforming to the general topography).
f - Fan (a fan shaped form similar to the segment of a cone and having a perceptible gradient from the apex to the toe).
h - Hummocky (a very complex sequence of slopes extending from somewhat rounded depressions or kettles of various sizes to irregular and conical knolls or knobs - slopes are generally 9 to 70%).
i - Inclined (a sloping unidirectional surface with a generally constant slope not broken by marked irregularities - slopes are 2 to 70%).
l - Level (a flat or very gently sloping unidirectional surface with a generally constant slope not broken by marked elevations and depressions - slopes are generally <2%).
m - Rolling (a very regular sequence of moderate slopes and depressions, producing a wave-like pattern of moderate relief - slope length is often approximately 1.6 km and gradients are >5%).
r - Ridged (a long narrow elevation of the surface, usually sharp crested with steep sides - the ridges may be parallel, subparallel, or intersecting).
s - Steep (erosional slopes >70% on both consolidated and unconsolidated materials).
t - Terraced (scarp face and the horizontal or gently inclined surface or tread above it).
u - Undulating (a very regular sequence of gentle slopes producing a wave-like pattern of low local relief - slope length is generally <0.8 km and the dominant gradient of slopes is 2 to 5%).
v - Veneer (unconsolidated materials too thin to mask the minor irregularities of the underlying unit surface - ranges in thickness from 10 cm to 1 m).

Classes for Organic Component

b - Blanket (a mantle of organic materials thick enough to mask minor irregularities in the underlying unit, but still conforms to the general underlying topography).
o - Bowl (a bog or fen occupying concave shaped depressions).
d - Domed (a bog with an elevated convex central area much higher than the margin).
f - Floating (a level organic surface associated with a pond or lake and not anchored to the lake bottom).

h - Horizontal (a flat peat surface not broken by marked elevations and depressions).
p - Plateau (a bog with an elevated flat central area only slightly higher than the margin).
r - Ribbed (a pattern of parallel or reticulate low ridges associated with fens).
s - Sloping (a peat surface with a generally constant slope not broken by marked irregularities).

SLOPE

A set of slope classes has been provided to make possible a quantification of the dominant but not necessarily most abundant slopes within a mapped unit of a local landform. These are outlined in Table 26.

MODIFYING PROCESSES

Terms that describe the geological processes that have modified or are currently modifying genetic materials and their surface expression are considered here.

A - Avalanched (slopes modified by frequent avalanche activity).
B - Beveled (surface cut or planed by running water but not underlain by fluvial materials).
C - Cryoturbated (surface modified by processes of frost action).
D - Deflated (modified by the sorting out, lifting, and removal of loose, dry, fine-grained particles - clay and silt - by the turbulent eddy action of the wind).
E - Eroded (channeled)(surface crossed by a series of abandoned channels).
F - Failing (modification of surface by the formation of tension fractures or by large consolidated or unconsolidated masses moving slowly downslope).
H - Kettled (deposit or feature modified by depressions left by melting ice blocks).
K - Karst modified (modification of carbonate and other rocks by processes of solution, and of overlying unconsolidated materials by collapse resulting from that solution).
N - Nivated (surface modified by frost action, erosion, and mass wasting beneath and around a snowbank so as to produce transverse, longitudinal, and circular hollows).
P - Piping (surface modified by small hollows, commonly aligned along routes of subsurface drainage, and resulting from the subsurface removal of particulate matter in unconsolidated materials).
S - Solifluction (surface modified by the process of slow gravitational downslope movement of saturated non-frozen earth material behaving apparently as a viscous mass over a surface of frozen ground).

TABLE 26.
Slope classes of local landforms

Slope Class	Percent Slope	Approximate Degrees	Terminology
1	0-0.5	0	level
2	0.5-2.5	0.3-1.5	nearly level
3	2-5	1-3	very gentle slopes
4	6-9	3.5-5	gentle slopes
5	10-15	6-8.5	moderate slopes
6	16-30	9-17	strong slopes
7	31-45	17-24	very strong slopes
8	46-70	25-35	extreme slopes
9	71-100	35-45	steep slopes
10	>100	>45	very steep slopes

V - Gullied (the modification of surface by fluvial erosion resulting in the development of parallel and sub-parallel, steep-sided, and narrow ravines in both consolidated and unconsolidated materials).
W - Washed (modification of a deposit or feature by wave action in a body of standing water resulting in lag deposits, beaches of lag materials, and wave cut platforms).

QUALIFYING DESCRIPTORS

A number of descriptors have been introduced to qualify either the genetic materials or the modifying process terms. The descriptors supply additional information about the mode of formation or depositional environment.

G - Glacial: Used to qualify non-glacial genetic materials or process modifiers where there is direct evidence that glacier ice exerted a strong but secondary or indirect control upon the mode of origin of the materials or mode of operation of the process. Implied is that glacier ice was close to the site of the deposition of material or the site of operation of a process. The three glacial qualifying descriptors are glaciofluvial, glaciolacustrine, and meltwater channels.

Included in the definitions of the qualifying descriptor categories are statements concerning the commonly assumed status of their processes. Where the process status is contrary to the common assumption, it is indicated. The processes are A - Active (to indicate any evidence of the recurrent nature of a modifying process or of the contemporary nature of the process forming a genetic material), and I - Inactive (to indicate no evidence that the modifying process is recurrent and that the processes of formation of the genetic materials have ceased).

MAPPING CONVENTIONS

Composite Units

Because terrain units commonly occur that are of small areal extent and cannot be delimited individually at the scale of mapping, a system of composite units is employed whereby up to three types of terrain may be designated within a common unit boundary. The relative amounts of each terrain type are indicated by using the symbols =, /, and //. The components are indicated in decreasing order of abundance. = components on either side of this symbol are approximately equal; each represents 45 to 55 percent of the area. / the component in front of this symbol is more abundant than the one that follows; the first represents 55 to 70 percent of the area and the second 30 to 45 percent. // the component in front of the symbol is considerably more abundant than the component that follows; the first represents 70 to 90 percent and the second 10 to 30 percent of the area.

Stratigraphic Data

Stratigraphic data may be presented to supplement surficial data, and should be given for veneers and blankets.

For map presentation a horizontal bar is used to separate the components that are arranged in stratigraphic order, and surface expressions may be attached to underlying units if appropriate.

If the type of unconsolidated material underlying a blanket of different genetic material is not known, only the surface expression of the underlying material is given.

Map Symbols

The following example illustrates a hypothetical landform symbol, assuming that all components of the system (genetic materials and their particle size or fiber class, surface expression and related slope, modifying processes, and qualifying descriptors) are to be utilized.

$$\frac{tG^{Q}{}_{e}{}^{Q}/tG^{Q}{}_{e}{}^{Q}{}_{1}\text{-}P^{Q}}{G^{Q}{}_{e}}$$

$tG^{Q}{}_{e}{}^{Q}$ is the dominant (55 to 70 percent) surficial material and $tG^{Q}{}_{e}{}^{Q}{}_{1}\text{-}\ P^{Q}$ is the subdominant material (30 to 45 percent). $G^{Q}{}_{e}$ in the denominator represents an underlying stratigraphic unit.

t - genetic material modifier (particle size of clastic materials and fiber content of organic materials).
G - genetic material
e - surface expression
1 - slope qualifier (numeric)
P - modifying process
Q - qualifying descriptor (superscript)

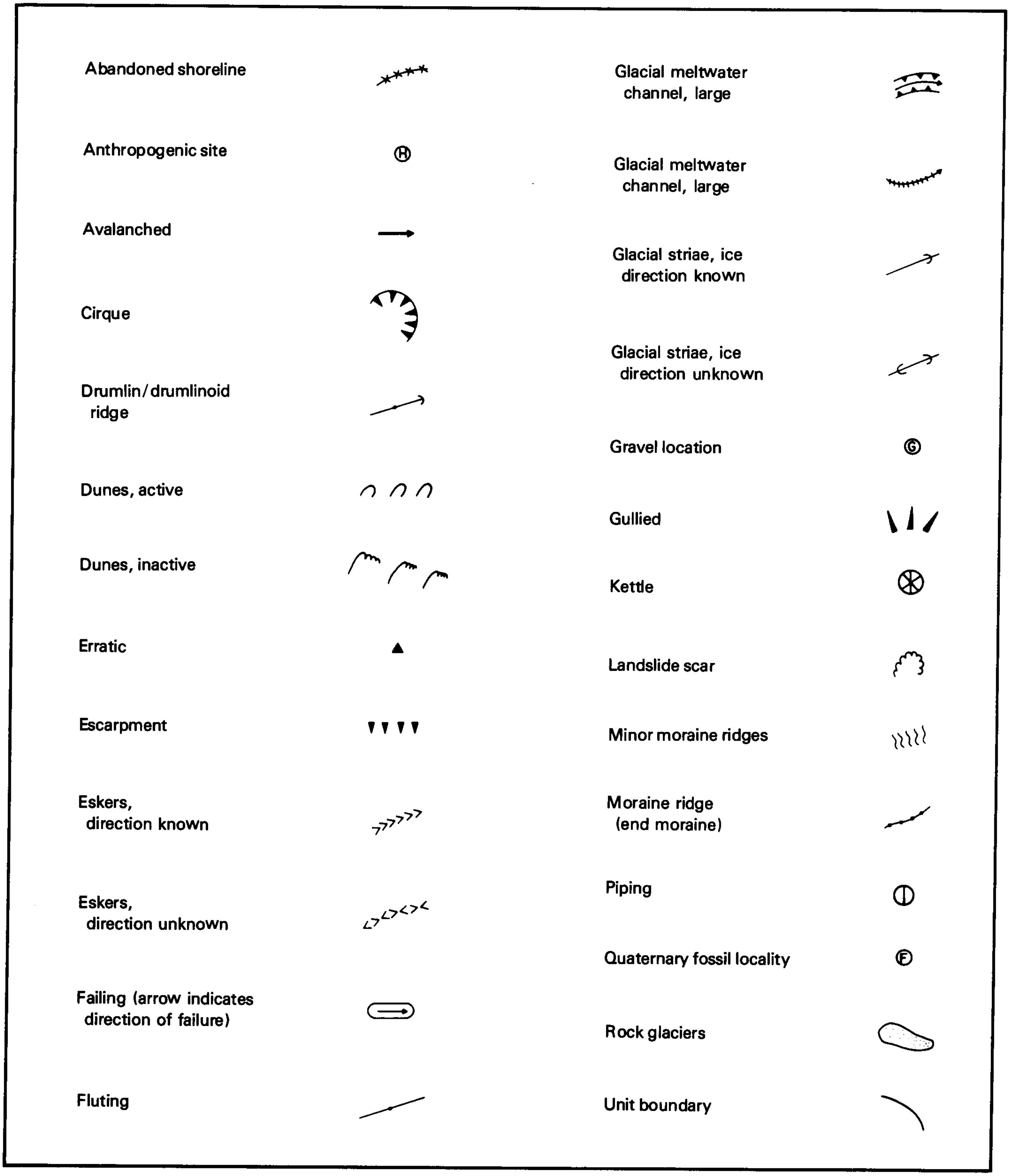
The following hypothetical examples further illustrate use of the system.

Mh	- indicates hummocky morainal deposits
$F^{G}{}_{u}$	- indicates undulating glaciofluvial materials
$\frac{L^{G}{}_{v}}{Mu}$	- indicates a glaciolacustrine veneer overlying undulating morainal materials
Ft-V	- indicates fluvial terraces modified by gullying
$\frac{Cb}{Rr\text{-}F}$	- indicates a colluvial blanket overlying ridged rock modified by failing
$Mu/\frac{F^{G}{}_{v}}{Mu}$	- indicates a mixture of undulating morainal deposits (55 to 90 percent of the area) and a glaciofluvial veneer overlying undulating morainal materials (30 to 45 percent of the area)
$Mm//\frac{L^{G}{}_{b}}{Mh}$	- indicates a mixture of rolling morainal deposits (70 to 90 percent of the area) and a glaciolacustrine blanket overlying hummocky materials (10 to 30 percent of the area)
$\frac{L^{G}{}_{b}}{h}$	- indicates hummocky unconsolidated material of unkown specific type underlying a glaciolacustrine blanket.

On Site Symbols

On site symbols or map symbols are used to describe features or processes in the terrain that express either a limited (by scale) areal function, or are simply point observations. The size of on site symbols will vary with the type of symbol and the areal extent of the feature depicted. The on site symbols are illustrated in Figure 10.

FIGURE 10. On site landform symbols.



GLOSSARY

adsorption complex: The group of substances in the soil capable of adsorbing water and nutrients.

aeration, soil: The process by which air in the soil is replaced by air from the atmosphere.

aggregate, soil: A group of soil particles cohering so as to behave mechanically as a unit.

alluvium: A general term for all detrital material deposited or in transit by streams, including gravel, sand, silt, clay, and all variations and mixtures of these.

anion: An ion carrying a negative charge of electricity. The common soil anions are carbonate, sulfate, chloride, and hydroxyl.

available nutrient: That portion of any element or compound in the soil that can readily be absorbed and assimilated by growing plants.

avalanche: A large mass of snow or ice that falls from higher to lower parts of mountains.

base saturation percentage: The extent to which the adsorption complex of a soil is saturated with exchangeable cations other than hydrogen and aluminum.

beach: The relatively thick and temporary accumulation of loose water-borne material (usually well-sorted sand and pebbles accompanied by mud, cobbles, boulders, and smoothed rock and shell fragments) that is in active transit or deposited between the limits of low and high water along the shore of a body of water.

bearing capacity: The maximum load that a material can support before failing.

bedrock: The solid rock underlying soils and the regolith in depths ranging from zero (where exposed by erosion) to several hundred feet.

boulders: Stones which are larger than 60 cm in diameter.

bulk density, soil: The mass of dry soil per unit bulk volume.

cation: An ion carrying a positive charge of electricity. The common soil cations are calcium, magnesium, sodium, potassium, and hydrogen.

cation exchange: The interchange between a cation in solution and another on the surface of any surface-active material in the soil such as clay or organic matter.

cirque: A deep, steep-walled, flat or gentle-floored, half-bowl-like, recess or hollow, semicircular in plan, situated high on the side of a mountain and commonly at the head of a glacial valley, and produced by the erosive activity of mountain glaciers. It often contains a small round lake, and it may or may not be occupied by ice or snow.

clastic: Composed of broken fragments of rocks and minerals.

clod: A compact, coherent mass of soil produced artificially, usually by the activity of man by plowing, digging, etc., especially when these operations are performed on soils that are either too wet or too dry for normal tillage operations.

coarse fragments: Rock or mineral fragments greater than 2.0 mm in diameter.

cobbly: Containing appreciable quantities of rounded or subrounded coarse rock or mineral fragments 8 to 25 cm in diameter. "Angulary cobbly" is used when the fragments are less rounded.

colloid, soil: Organic or inorganic matter having very small particle size and a correspondingly large surface area per unit of mass. Most colloidal particles are too small to be seen with the ordinary compound microscope.

conglomerate: The consolidated equivalent of gravel, both in size range and in the essential roundness and sorting of its constituent particles.

conservation, soil: (1) Protection of the soil against physical loss by erosion or against deterioration; that is excessive loss of fertility by either natural or artificial means. (2) A combination of all methods of management and land use that safeguard the soil against depletion or deterioration by natural or man-induced factors.

control section, soil: The vertical section upon which the taxonomic classification of soil is based. The control section usually extends to a depth of 100 cm in mineral materials and to 160 cm in organic materials.

creep: The slow downward movement of soil and rock fragments on a slope.

crevasse fillings: Ridges or hummocks formed from glacial sediments that were deposited by water in the cracks and crevasses of the ice.

cryoturbation: Frost action, including frost heaving.

delta: The accumulation of sediments where a stream empties into a body of quiet water, resulting in the building out of the shoreline.

deposition: The accumulation of material left in a new position by a natural transporting agent such as water, wind, ice, or gravity; or by the activity of man.

drainage: The removal of excess surface water or groundwater from land by natural runoff and percolation, or by means of surface or subsurface drains.

drift, glacial: Rock debris transported by glaciers and deposited either directly from the ice or from the meltwater.

droughty soil: Sandy or very rapidly drained soil.

drumlin: An elongated or oval hill of glacial drift, commonly till, deposited by glacier ice with its long axis parallel to the direction of ice movement.

dune: A mound or ridge of sand piled up by the wind.

edaphic: (1) Of or pertaining to the soil. (2) Resulting from or influenced by factors inherent in the soil or other substrata, rather than by climatic factors.

eluvial horizon: A soil horizon that has been formed by the process of eluviation.

eluviation: The transportation of soil material in suspension or in solution within the soil by the downward or lateral movement of water.

end moraine: A moraine that has been deposited at the lower or outer end of a glacier.

ericaceous: Of or relating to the heath family.

erosion: The wearing away of the land surface by running water, wind, ice, or other geological agents, including such processes as gravitational creep.

erratic: A rock fragment carried by glacier ice or floating ice, and deposited when the ice melted at some distance from the outcrop from which the fragment was derived.

escarpment: A steep face or ridge of high land.

esker: A winding ridge of irregularly stratified sand, gravel, and cobbles deposited under the ice by a rapidly flowing glacial stream.

eutrophic: Rich in nutrients.

evapotranspiration: The combined loss of water from a given area and during a specific period of time, by evaporation from the soil surface and by transpiration from plants.

exchangeable cation: A cation that is held by the adsorption complex of the soil and is easily exchanged with other cations of neutral salt solutions.

fan: An accumulation of debris brought down by a stream on a steep gradient and debouching on a gently sloping plain in the shape of a fan, forming a section of a very low cone.

fertilizer: Any organic or inorganic material of natural or synthetic origin that is added to a soil to supply elements essential to plant growth.

field capacity: The percentage of water remaining in the soil two or three days after the soil has been saturated, and free drainage has practically ceased.

floodplain: The land bordering a stream, built up of sediments from overflow of the stream and subject to inundation when the stream is at flood stage.

flowtill: A superglacial till that is modified and transported by plastic mass flow.

flutings: Groups of ridge-like and groove-like glacial landforms combining to impart a fluted pattern to the surface.

forb: A herbaceous plant which is not a grass, sedge, or rush.

fossil: Any remains, trace, or imprint of a plant or animal that has been preserved by natural processes in the earth's crust since some past geologic time.

frost-free period: The period or season of the year between the last spring frost and the first autumn frost.

frost heave: The raising of a surface due to the accumulation of ice in the underlying soil.

grain size: The effective diameter of a particle measured by sedimentation, sieving, or micrometric methods.

grass: Plant of a large family characterized by rounded and hollow jointed stems, narrow sheathing leaves, flowers borne in spikes, and hard grain-like seeds.

gravel: Rock or mineral fragments 2 mm to 8 cm in diameter.

gravelly: Containing appreciable quantities of rounded or subrounded coarse rock or mineral fragments 2 mm to 8 cm in diameter. 'Angular gravelly' is used when the fragments are less rounded.

great group: A category in the Canadian system of soil classification. It is a taxonomic grouping of soils having certain morphological features in common and a similar pedogenic environment.

green manure: Plant material incorporated into the soil to improve it, while the plant material is still green.

ground moraine: The rock debris deposited or released from glacial ice during ablation, to form an extensive, fairly even thin layer of till, having a gently rolling surface and low relief.

groundwater: Water that is passing through or standing in the soil and the underlying strata in the zone of saturation. It is free to move by gravity.

hardpan layers: Horizons or layers in soils that are strongly compacted, indurated, or very high in clay content.

herb: Any flowering plant except those developing persistent woody bases and stems above ground.

humification: The processes by which organic matter decomposes to form humus.

hummocky moraine: An area of knob and kettle topography that may have been formed either along a live ice front or around masses of stagnant ice.

humus: (1) The fraction of the soil organic matter that remains after most of the added plant and animal residues have decomposed. It is usually dark colored. (2) Humus is also used in a broader sense to designate the humus forms referred to as forest humus. (3) All the dead organic material on and in the soil that undergoes continuous breakdown, change and synthesis.

hydric layer: A layer of water in the control section of Organic soils, extending from a depth of not less than 40 cm to a depth of more than 160 cm.

hydrophyte: A plant that grows in water, or in wet or saturated soils.

igneous rock: Rock formed by solidification from a molten or partially molten state.

illuvial horizon: A soil horizon in which material carried from an overlying layer has been precipitated from solution or deposited from suspension as a layer of accumulation.

illuviation: The process of depositing soil material removed from one horizon in the soil to another, usually from an upper to a lower horizon in the soil profile. Illuvial substances include silicate clay, hydrous oxides of iron and aluminum, and organic matter.

impeding horizon: A horizon which hinders the movement of water by gravity through soils.

infiltration: The downward entry of water into the soil.

irrigation: The artificial application of water to the soil for the benefit of growing crops.

kame: A conical hill or short irregular ridge of stratified gravel or sand deposited by glacial meltwater in contact with glacier ice.

kame terrace: A terrace-like ridge consisting of stratified sand and gravel deposited by a meltwater stream between a melting glacier or a stagnant ice lobe and a higher valley wall or lateral moraine, and left standing after the disappearance of the ice.

kettle: A steep-sided, usually basin- or bowl-shaped hole or depression without surface drainage in glacial drift deposits.

lacustro till: A glacial deposit that looks like lacustrine material, has a texture of clay, and contains a few stones.

laminations: Layering or bedding less than 1 cm thick in a stratified sequence.

landslide: A mass of material that has slipped down hill by gravity, often assisted by water when the material is saturated.

lateral moraine: An end moraine built along the side margin of a glacial lobe occupying a valley.

leaching: The downward movement within the soil of materials in solution.

lime (in soil): A soil constituent consisting principally of calcium carbonate; and including magnesium carbonate, and perhaps the oxide and hydroxide of calcium and magnesium.

limestone: A sedimentary rock composed of calcium carbonate.

lithic phase (of soil): Any mineral soil having consolidated bedrock within the control section below a depth of 10 cm.

loess: Material transported and deposited by wind, and consisting of predominantly silt-sized particles.

macrostructure (primary structure): Refers to the larger peds of soil horizons that break down to smaller peds.

map unit: A kind of soil (soil series), a combination of kinds of soil, or miscellaneous land type or types that can be shown at the scale of mapping for the defined purpose and objectives of a particular soil survey. (Combination of kinds of soil includes groupings of soil series, soil associations, soil catenas, or undifferentiated soils appropriate for use at the scale of mapping being carried out.) Soil map units are the basis for the delineations of a soil survey map, and are most commonly set up where two or more defined soil units are so intimately intermixed geographically that it is impractical, because of the scale used, to separate them. Map units normally contain inclusions of soils outside the limits of the taxonomic name or names used to define the map unit. Map units are generally designed to reflect significant differences in use and management.

marsh: Periodically flooded or continually wet areas having the surface not deeply submerged. They are covered dominantly with sedges, cattails, rushes, or other hydrophytic plants.

matrix, soil: The main soil constituent or material that encloses other soil features, for example, concretions embedded in a fine-grained matrix.

meander: One of a series of looplike bends in the course of a stream.

meander scar: An abandoned meander that has been cut off from the main course of a stream by erosion.

mesophyte: A plant that grows under intermediate moisture conditions, between the two extremes of dry and wet.

mesostructure (secondary structure): Refers to the smaller peds of soil horizons that result from the breakdown of larger peds.

metamorphic rock: Rock derived from pre-existing rocks but that differs from them in physical, chemical, and mineralogical properties as a result of natural geological processes, principally heat and pressure, originating within the earth.

mineral: A naturally formed chemical element or compound having a definite chemical composition, and usually a characteristic crystal form.

mineral soil: A soil consisting predominantly of, and having its properties determined predominantly by, mineral matter.

moraine: A mound, ridge, or other distinct accumulation of unsorted, unstratified glacial drift, predominantly till, deposited chiefly by direct action of glacial ice in a variety of topographic landforms.

morphology, soil: The physical constitution, particularly the structural properties, of a soil profile as exhibited by the kinds, thickness, and arrangement of the horizons in the profile; and by the texture, structure, consistence, and porosity of each horizon.

mottling: Spotting and blotching of different color or shades of color interspersed with the dominant color.

net fen: Same as string fen, except that the parallel ridges are interlocked and form a net-like pattern.

nonsoil: The aggregate of surficial materials that do not meet the definition of soil.

ombrotrophic: Acidic and low in nutrients.

order, soil: A category in the Canadian system of soil classification. All the soils within an order have one or more characteristics in common.

orthic: A subgroup referring to the modal or central concept of various great groups in the Brunisolic, Chernozemic, Cryosolic, Gleysolic, Luvisolic, Podzolic, and Regosolic orders of the Canadian system of soil classification.

outcrop: That part of a geological formation or structure that appears at the surface of the earth.

outwash: Stratified detritus (chiefly sand and gravel) washed out from a glacier by meltwater streams and deposited in front of or beyond the terminal moraine of an active glacier.

paleosol (fossil soil): A soil of the geologic past that was buried subsequent to its formation.

palsa: Mound of peat with a frozen peat or mineral core.

parent material: The unconsolidated and more or less chemically weathered mineral or organic matter from which the solum of a soil has developed by pedogenic processes.

peat: Unconsolidated soil material consisting largely of undecomposed, or only slightly decomposed, organic material.

ped, soil: A unit of soil structure such as a prism, block, or granule, which is formed by natural processes.

pediment: A broad, flat or gently sloping erosion surface or plain of low relief, typically developed by subaerial agents (including running water) in an arid or semiarid region at the base of an abrupt and receding mountain front or plateau escarpment, and underlain by bedrock (occasionally by older alluvial deposits) that may be bare but more often partly mantled with a thin and discontinuous veneer of alluvium derived from the upland masses and in transit across the surface.

pedogenic: Pertaining to the mode of origin of the soil, especially the processes or soil forming factors responsible for the development of the solum.

pedologist: A person who specializes in those aspects of soil science dealing with the origin, morphology, genesis, mapping, and taxonomy of soils; and classification in terms of their use.

pedon: A three-dimensional soil unit. Its lower limit is the vague and arbitrary depth between soil and nonsoil, and the upper limit is its contact with air or water. The lateral dimensions are large enough to permit study of the nature of the range in horizon variability that occurs within a small area.

perched water table: A water table due to the 'perching' of water on a relatively impermeable layer at some depth within the soil. The soil within or below the impermeable layer is not saturated with water.

percolation: The downward movement of water through saturated or nearly saturated soil.

pitted outwash plain: An outwash plain marked by many irregular depressions such as kettles, shallow pits, and potholes.

plain: Any flat area, large or small, of low elevation.

polygonal peat plateau: Peat plateau with polygonal pattern of trenches and adjacent shoulders, caused by ice wedge formation.

porosity, soil: The volume percentage of the total bulk not occupied by solid particles.

productivity, soil: The capacity of a soil, in its normal environment, to produce a specified plant or sequence of plants under a specified system of management.

Quaternary: The second period of the Cenozoic era, thought to cover the last two or three million years.

reed: A type of tall grass that grows in wet places.

regolith: The unconsolidated mantle of weathered rock and soil material on the earth's surface.

relief: The elevations or inequalities of the land surface when considered collectively.

residual material: Unconsolidated and partly weathered mineral materials formed by the disintegration of consolidated rock in place.

rock: Any naturally formed, consolidated or unconsolidated material, other than soil, composed of two or more minerals or occasionally of one mineral, and having some degree of chemical and mineralogic constancy.

rock glacier: A tongue-shaped mass of angular boulders that creeps slowly from high rugged terrain with the aid of interstitial ice.

rotten rock: Any highly decomposed but still coherent rock.

runoff: The portion of the total precipitation on an area that flows away through stream channels. Surface runoff does not enter the soil. Groundwater runoff or seepage flow from groundwater enters the soil before reaching the stream.

rush: A grass-like herb growing in marshy ground, and having cylindrical leafless stems.

salinization: The process of salt accumulation in soil.

sandstone: A sedimentary rock composed predominantly of sand-sized grains of minerals and rock fragments cemented together.

saturation extract: The extract from a soil sample that has been saturated with water.

scarp: An escarpment or a cliff.

sedge: Grass-like herb that grows in marshy places.

sediment: Solid material, both mineral and organic, that is in suspension, is being transported; or has been removed from its site of origin by air, water, gravity or ice, and has come to rest on the earth's surface either above or below sea level.

sedimentary rock: Rock formed by the lithification of mechanical, chemical, or organic sediments.

seepage, soil: The emergence of water from the soil along an extensive line of surface.

separates, soil: Mineral particles, less than 2.0 mm in equivalent diameter, ranging between specified size limits. The names and size limits of separates recognized by soil pedologists in Canada and the United States are: very coarse sand, 2.0 to 1.0 mm; coarse sand, 1.0 to 0.5 mm; medium sand, 0.5 to 0.25 mm; fine sand, 0.25 to 0.10 mm; very fine sand, 0.10 to 0.05 mm; silt, 0.05 to 0.002 mm; clay, less than 0.002 mm; and fine clay, less than 0.0002 mm.

shale: A laminated, detrital sedimenatry rock in which the particles are predominantly of clay size.

shrub: A woody perennial plant differing from a tree by its low stature and by generally producing several basal shoots instead of a single trunk.

sieve analysis: A laboratory test to determine the amounts of gravel and sand fractions in a soil.

slump: A landslide characterized by a shearing and rotary movement of a generally independent mass of rock or earth along a curved slip surface (concave upward) and about an axis parallel to the slope from which it descends, and by backward tilting of the mass with respect to that slope so that the slump surface often exhibits a reversed slope facing uphill.

solum, soil (plural = sola): The upper horizons of a soil in which the parent material has been modified and in which most plant roots are contained. It usually consists of A and B horizons.

spit: A small point or narrow embankment of land commonly consisting of sand or gravel deposited by longshore drifting, and having one end attached to the mainland with the other terminating in open water.

spring: A place where groundwater flows naturally from a rock or the soil onto the land surface or into a body of surface water.

striae: A series of long, delicate, finely cut, usually straight and parallel furrows or lines inscribed on a bedrock surface by the rasping and rubbing of rock fragments embedded at the base of a moving glacier, and usually oriented in the direction of the ice movement.

string fen: More or less parallel low ridges, separated by water saturated hollows oriented across the slope, at right angles to water movement.

subgroup, soil: A category in the Canadian system of soil classification. These soils are subdivisions of the great groups, and therefore each soil is defined more specifically.

subsoil: The B horizons of soils with distinct profiles. In soils with weak profile development, the subsoil can be defined as the soil below the plowed soil (or its equivalent of surface soil), in which roots normally grow.

superglacial: Carried upon, deposited from, or pertaining to the top surface of a glacier or ice sheet.

supraglacial: Situated or occurring at or immediately above the surface of a glacier or ice sheet.

talus: A sloping heap of loose rock fragments lying at the foot of a cliff or steep slope.

terminal moraine: An end moraine, extending across a glacial valley as an arcuate or crescentic ridge, that marks the farthest advance or maximum extent of a glacier.

terric layer: An unconsolidated mineral substratum underlying organic soil material.

till: Unstratified glacial drift deposited directly by the ice and consisting of clay, sand, gravel, and boulders intermingled in any proportion.

tilth, soil: The physical condition of a soil as related to its ease of tillage, fitness as a seedbed, and impedence to seedling emergence and root penetration.

tonguing: Interfingering of one soil horizon into another situated below, vertical dimensions of the tongued portion usually greater than horizontal dimensions.

topography: The physical features of a district or region, such as those represented on a map, taken collectively; especially the relief and contours of the land.

trafficability: The capacity of a soil to withstand traffic by people, horses, or vehicles.

truncated: Having lost all or part of the upper soil horizon or horizons.

turfy: Grassy, with matted roots.

turgidity: Distended firm state of a plant due to water uptake.

type, soil: A unit in the natural system of soil classification; a subdivision of a soil series consisting of or describing soils that are alike in all characteristics including the texture of the A horizon.

valley train: An outwash terrace extending down a valley away from the ice front.

washboard moraine: Several small, parallel, regularly spaced ridges that are oriented transverse to the ice movement in a general sense and that collectively resemble a washboard in pattern.

watershed: A term used loosely to mean both a drainage basin and a drainage divide.

water table: The upper surface of groundwater or that level below which the soil is saturated with water.

water track fen: Patterned fen occupying a concave tract of peatland which marks the path of subsurface mineral water flow.

weathering: The physical and chemical disintegration, alteration and decomposition of rocks and minerals at or near the earth's surface by atmospheric agents.

wilting point: The moisture content of a soil at which plants wilt and fail to recover their turgidity when placed in a dark, humid atmosphere.

xerophyte: A plant capable of surviving periods of prolonged moisture deficiency.

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Hydrogeology of the Peace River Area, Alberta

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Alberta
RESEARCH COUNCIL

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ABSTRACT

The Peace River area, located in northwestern Alberta, has little relief with the exception of the Whitemud Hills in the northwestern quarter of the map area. The Peace River valley cuts deeply into shales and sandstones of Upper Cretaceous age. Total annual precipitation varies from 355 to nearly 480 mm (14 to nearly 19 in) and the lowest amount of precipitation falls in the area immediately surrounding the town of Peace River.

Yields range from 0.4 L/s (5 igpm) in Upper Cretaceous sandstones to possibly 38 L/s (500 igpm) in the Grimshaw gravels to the northwest of the town of Peace River. Coarse alluvial sediments found in the Peace River valley at several locations may prove capable of yields of up to 7.6 L/s (100 igpm), and possibly higher.

Water of better quality is found generally in areas of recharge and in the Grimshaw gravels; however, this is not true of all surficial sediments. No data are available for most of the area east of the Peace River.

The main types of water encountered in the Peace River area are calcium-magnesium sulfate and calcium-magnesium bicarbonate with total dissolved solids ranging from 200 to almost 5000 mg/L. Surficial aquifers of the Manning region are of poor quality with total dissolved solids ranging from 1410 to slightly over 11 000 mg/L. The water is the sodium sulfate type with nitrates present in many of the shallow wells.

INTRODUCTION

The Peace River area, located in the northwestern part of Alberta, lies between longitudes 116° and 118° west and latitudes 56° and 57° north. The area contains all or parts of Tps 81 to 92 and Rs 13 to 26, W 5th Mer (dominion land survey system).

The map area, which covers approximately 13 000 km^2 (5000 sq mi), was mapped in conjunction with the Winagami map area to the south, during the summer of 1973.

Approximately one-third of the area is settled, mostly in the Peace River-Grimshaw, Manning, and Clear Hills areas. The largest community in the area is the town of Peace River, which has a population of 5754 (Canadian Almanac, 1981). Other small towns are Grimshaw (pop. 2209) and Manning (pop. 1166), which are respectively about 19 km (12 mi) west and 80 km (50 mi) north of the town of Peace River (Canadian Almanac, 1981).

Previous hydrogeological and related studies were conducted in the general area by Rutherford (1930), Kidd (1946), Jones (1966), Tokarsky (1967, 1971), and Marciniuk and Kerr (1971). A map of the bedrock topography was prepared by Tokarsky (1967) for the Grimshaw-Cardinal Lake area.

Wyatt (1935) prepared a preliminary soil survey of the Peace River-High Prairie-Sturgeon Lake area.

Geology of the bedrock sediments has been studied by many authors: McLearn (1918, 1919), Warren (1939), Crickmay (1944), Wickenden (1951), Alberta Study Group (1954), Gleddie (1954), Stelck and Wall (1954), Stelck (1955), Stelck and Wetter (1958), MacDonald (1957), Wall (1960), and Energy Resources Conservation Board (1963). Geological maps of the area were prepared by Jones (1966) and Green (1972).

Cultivation takes place in the southwestern part of the map area in the Peace River-Grimshaw area, at the foot of the Whitemud Hills in the west central portion of the map area, and around Manning.

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TOPOGRAPHY AND DRAINAGE

The eastern part of the area has flat to gently rolling topography; elevations range from 490 m (1600 ft) to slightly over 730 m (2400 ft) above mean sea level. In the western part, the topography is more diverse; elevations range from 490 m (1600 ft) to 817 m (2700 ft) in the Whitemud Hills.

The area has a multitude of lakes. East of the Peace River the largest lakes, from north to south, are Cadotte, Otter, and Haig Lakes. West of the Peace River, they are the Cardinal, St. Germain, Leddy, Flood, Pluvius, and Driftwood Lakes.

The main drainage in the area is provided by the Peace River valley, which is also the area's most striking morphological feature. The valley bottom elevation ranges from 335 m (1100 ft) at the southern boundary of the study area to 300 m (1000 ft) at the northern boundary. The valley is incised to depths of from slightly over 210 m (700 ft) to 150 m (500 ft) over the same range.

The Peace River is 1200 m (¾ mi) wide just north of the town of Peace River and its average width is slightly over 400 m (¼ mi). The northern part of the map area has large meanders with radii up to 2.4 km (1.5 m). Terraces formed by the changing Peace River course are composed of sediments such as sands, gravels, and boulders, and therefore are potentially excellent aquifers.

The main rivers and creeks joining the Peace River on the left bank are, from north to south: Whitemud River, Rousseau and Buchanan Creeks, and the Notikewin River, which joins the Peace River just past the northern boundary of the study area. On the right bank, in downstream order, the Smoky, Heart, Cadotte, and Little Cadotte Rivers join the Peace. The Smoky River, which joins the Peace River about 4.8 km (3 mi) upstream of the town of Peace River, has a 210 m (700 ft) deep valley. The Heart River, which joins the Peace at the south end of town, despite its small size, has a valley ranging from 180 m (600 ft) at the mouth to 120 m (400 ft), 12.8 km (8 mi) upstream of the town of Peace River. The Cadotte and the Little Cadotte Rivers join before their confluence with the Peace River.

ACCESS

Access is fair to good west of the Peace River. This area constitutes about one third of the study area and contains the towns of Peace River, Grimshaw, and Manning, as well as developed land around and between these towns. In the two thirds of the study area that lies east of the Peace River, access is very poor to nonexistent. The landscape is mainly muskeg and boreal forest and development consists of a few, small settlements and some activity related to the Peace River tar sands at Three Creeks and Simon Lakes.

CLIMATE

According to Koeppen's climate classification (Longley, 1972), the map area can be divided into two climatic zones:

1. the southwest corner of the map area is microthermal with an average temperature of the warmest month above 10°C (50°F) and the coldest month below -3°C (27°F); this area has warm summers with a mean temperature of 10°C (50°F) or more;
2. the remainder of the map area is microthermal with the average temperature of the warmest month above 10°C (50°F) and the coldest month below -3°C (27°F); this area has cool summers with the mean temperature of the warmest month below 22°C (72°F) and less than four months with a mean temperature of 10°C (50°F) or more.

Few weather stations exist in the area. The towns of Peace River and Grimshaw, which have the longest records (10 years), have an average annual total precipitation of about 355 mm (14 in). Other settlements such as Berwyn, Clear Hills, and Notikewin have either short (less than 10 years) or interrupted records.

From 355 mm (14 in) in the area immediately surrounding the town of Peace River, the average annual precipitation increases eastward to almost 480 mm (19 in) and westward to slightly above 460 mm (18 in). As a general rule, the lower precipitation values follow the Peace River valley and increase from there to the maxima indicated on the meteorological side map.

Snow accounts for 25 percent of the total precipitation at Peace River and 29 percent at Berwyn southwest of the town.

Potential evapotranspiration (using the Thornthwaite method, 1957) is about 400 mm (16 in) at the town of Peace River and about 380 mm (15 in) at Berwyn.

GEOLOGY

BEDROCK GEOLOGY

The bedrock formations found within the limits of the cross-sections are of Lower and Upper Cretaceous age and, in ascending order, the succeeding formations are the Peace River, Shaftesbury, Dunvegan, Kaskapau and the Smoky Group. The following bedrock geology description is from Green (1972).

The Peace River Formation of Lower Cretaceous age outcrops in the Peace River valley. It is mainly composed of fine-grained quartzose sandstone (Cadotte member), dark gray silty shale (Harmon member), fine-grained glauconitic sandstone, silty interbeds in lower part (Notikewin member); shoreline complex.

The Shaftesbury Formation of Upper and Lower Cretaceous age is composed of dark gray, fish-scale bearing shale, silty in upper part, numerous nodules and thin beds of concretionary ironstone, bentonite partings, lower part with thin silty and sandy intervals; marine.

The Dunvegan Formation of Upper Cretaceous age consists of gray, fine-grained, feldspathic sandstone with hard calcareous beds, laminated siltstone and gray silty shale; deltaic to marine.

The Kaskapau Formation of Upper Cretaceous age consists of dark gray silty shale, thin concretionary ironstone beds, interbedded in lower part with fine-grained quartzose sandstone and thin beds of ferruginous oolithic mudstone; marine.

The Smoky Group of Upper Cretaceous age to the east of the Peace River is composed of dark gray shale and silty shale, nodules and thin beds of concretionary ironstone; marine.

SURFICIAL SEDIMENTS

Relatively permeable shallow surficial sediments such as sands and gravels were outlined for the western portion of the map area on the basis of seismic shotholes and water well lithologs. Fairly large areas of sands or gravels are found west of the Peace River in the general area of Cardinal Lake. As previously indicated by Tokarsky (1967, 1971), the Grimshaw gravels are significant both in areal extent and in thickness. Other types of gravels and sands are also present and have been outlined on the map. These are either surficial or very shallow or present as gravel and sand terraces in the valley of the Peace River.

BEDROCK TOPOGRAPHY AND BEDROCK CHANNELS AQUIFERS

A bedrock topography map was prepared for part of the western portion of the study area by Tokarsky (1967, 1971). This map was extended northward on the basis of additional data obtained during the course of the present study. These data included bedrock elevations obtained from shothole logs, previous Alberta Research Council testholes and a study by Marciniuk and Kerr (1971). The bedrock topography shows three main buried channels which could prove to contain good aquifers. These channels could be important as potential aquifers despite the fact that the water quality is likely to be poor because of high sulfates or chlorides. Such chemistry has been observed in similar channels in other parts of the province.

The main and best known bedrock channel in the map area is the Shaftesbury, which runs north of and parallel to the Peace River in a southwest-northeast direction. This channel is filled with up to 240 m (800 ft) of sediments, including gravels and sands. This channel is believed to cross the Peace River valley towards the east where available data show the presence of a bedrock channel in the Three Creeks area.

Also indicated on the map is a deep (210 to 240 m or 700 to 800 ft) bedrock channel, which has been named l'Hirondelle channel (referring to a small Métis community in the area). This channel runs probably from west to east in the eastern part of the map area, and passes underneath Lubicon Lakes, then continues east and possibly follows the Loon River valley on the Peerless Lake map area to the east. Another branch runs possibly to the west and merges with the Shaftesbury channel. Little information is available on this area, but three oil wells at the eastern boundary of the map area report the presence of 210 to 240 m (700 to 800 ft) of surficial material. Also, the base of the fish scale marker is eroded in that same area at about the same depth.

The Manning channel, first recognized by Tokarsky (pers. comm.), was outlined and described by Marciniuk and Kerr (1971). The Alberta Research Council and the Department of the Environment conducted test drilling to outline its extent. This channel is filled with over 150 m (500 ft) of surficial sediments in the center. Gravel, resting on the bedrock surface, is fairly extensive and can be found over several townships around Manning. The testholes that were drilled in the channel by the Alberta Research Council and the Department of the Environment yielded large quantities of water that were, unfortunately, of poor quality.

YIELDS OF DRIFT AQUIFERS

The Grimshaw gravels, found in the area surrounding Cardinal Lake, have a probable yield range up to 8 L/s (100 igpm) and possibly exceeding 38 L/s (500 igpm). Other gravel units have a probable yield ranging from 2 to possibly more than 8 L/s (25 to 100 igpm). Other deposits such as surficial and deeper sands and gravels found north of Cardinal Lake were assigned a 20-year safe yield of 0.4 to 2 L/s (5 to 25 igpm).

The Manning bedrock channel sediments were assigned a yield range of 2 to 8 L/s (25 to 100 igpm) due to the presence of gravels and sands found during test drilling and in structure testhole logs.

A few pump tests or bail tests were conducted in the deepest gravels or sands to be found in this channel.

- A testhole (Lsd 15, Sec 11, Tp 91, R 23, W 5th Mer) drilled by the Department of the Environment in 1969, encountered gravels between 161 and 167 m (529 and 548 ft). The well was pump tested for four days at 1.3 L/s (17 igpm) and showed 0.66 m (2 ft) of drawdown. Calculation of the transmissivity yielded a value of 6000 igpd/ft and a 20-year safe yield of about 23 L/s (300 igpm).

- A second testhole (Lsd 7, Sec 18, Tp 92, R 21, W 5th Mer) drilled by the Department of the Environment in 1970, found boulders, clay, and gravels between 109 and 111 m (358 and 365 ft). An attempt to pump test it showed that no appreciable amount of water was available at that depth.

- A testhole (Lsd 13, Sec 28, Tp 91, R 22, W 5th Mer) drilled by the Alberta Research Council in 1967 found an appreciable amount of saturated sands and gravels at a depth between 104 and 145 m (340 and 475 ft). Caving problems due to the fineness of the sand did not allow a proper pump test.

On the basis of such tests and from the presence of gravels recognized in structure testholes over a large area, this channel has been given a yield range of 2 to 8 L/s (25 to 100 igpm). The water quality in this aquifer is quite poor since total dissolved solids in the three previous testholes were 2941, 11 627, and 1410 mg/L respectively.

Unconsolidated sediments of l'Hirondelle bedrock channel are expected to yield 2 to 8 L/s (25 to 100 igpm). Only when thicknesses and distribution of gravel and sand horizons are defined through drilling and pump tests are conducted, can more accurate yield figures be attributed to the channel.

YIELDS OF BEDROCK AQUIFERS

Yield areas have been defined by Tokarsky (1971) in the Grimshaw-Cardinal Lake areas. Some changes to the yield values were made in that area and yields are not expected to be higher than 8 L/s (100 igpm). In the remainder of the map area where transmissivity control is poor to nonexistent, the assigned yield ranges reflect the lithology of the bedrock sediments. To the east of the Peace River, bedrock yields are expected to be in the range of 0.4 to 2 L/s (1 to 25 igpm).

RECHARGE – DISCHARGE

Water levels closely follow the surface topography. Gradients become steeper closer to streams and river valleys. Some water levels are quite deep (130 m or 420 ft) in the Manning bedrock channel where water level measurements taken during the drilling of one Alberta Research Council testhole (Lsd 13, Sec 28, Tp 91, R 22, W 5th Mer) suggest a downward groundwater movement through the channel sediments.

Recharge occurs in the Whitemud Hills west of the map area. It occurs also in low-lying areas where relatively high permeabilities are encountered at or near the surface, as is the case for that part of the Grimshaw gravels north and west of the town of Peace River.

Flowing conditions were used to define the main discharge areas. These conditions are found south and southwest of Cardinal Lake and also along the base of the northern slopes of the Whitemud Hills. Usually these flowing conditions occur at shallow depths with the exception of flowing wells that are between 45 and 80 m (150 to 250 ft) deep in an area directly south of Cardinal Lake (Tp 82, R 25). These wells are completed in sands, gravels, or even quicksand and flow at discharge rates ranging from less than 0.075 L/s (<1 igpm) to about 3.8 L/s (50 igpm).

HYDROCHEMISTRY

Groundwater chemical data are sparse for the map area and nonexistent for the area east of the Peace River. Most of the data used for the chemistry were found in the area west of the Peace River, and half of that area was described in detail by Tokarsky (1967, 1971). The portion described was added to the chemical side map in order to give a better picture of the chemistry.

Aquifers in the Manning region contain waters of mixed types. As mentioned in the previous discussion of the Manning channel, the groundwater quality is quite poor and often unfit for human consumption (Manning uses surface water for its water supply). Many shallow wells in the Manning channel area show the presence of nitrates; it is not known why the nitrate content is high. Deeper wells are of the sodium sulfate type with total dissolved solids ranging from 1410 to about 11 000 mg/L.

Groundwater of various chemical types is found in the Whitemud Hills. At higher elevations one can find sodium-calcium magnesium-bicarbonate waters with total dissolved solids ranging from 300 to 2000 mg/L. Downslope, the waters are a calcium-magnesium-sulfate type with total dissolved solids ranging from 700 to more than 7000 mg/L. At the foot of the hills, sodium-sulfate waters are found with total dissolved solids ranging from 700 to 7000 mg/L.

The Grimshaw-Peace River area has groundwater of mixed types, calcium-magnesium sodium-sulfate. In groundwaters found near Cardinal Lake, the bicarbonate anion is dominant. Total dissolved solids increase downslope from about 500 mg/L in Cardinal Lake to about 3000 mg/L south and southwest of the lake.

CONCLUSIONS

Aquifers in the Peace River map area are found both in surficial and bedrock sediments. Yields vary greatly from as little as 0.07 L/s (1 igpm) up to a possible high of 38 L/s (500 igpm). Some aquifers, such as the river valley gravels of the Peace River valley, are small in extent. Induced infiltration wells may produce over 7 L/s (100 igpm). Water quality is good in the area of the Grimshaw gravels to poor in the bedrock channels.

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LEGEND

Isohyet, mean annual precipitation in inches (mm)
- defined .... —15(380)—
- approximate .... --15(380)--

Mean annual precipitation in inches (mm):
- 🟨 less than 15 inches (less than 380 mm)
- 🟩 15 to 20 inches (380 to 510 mm)

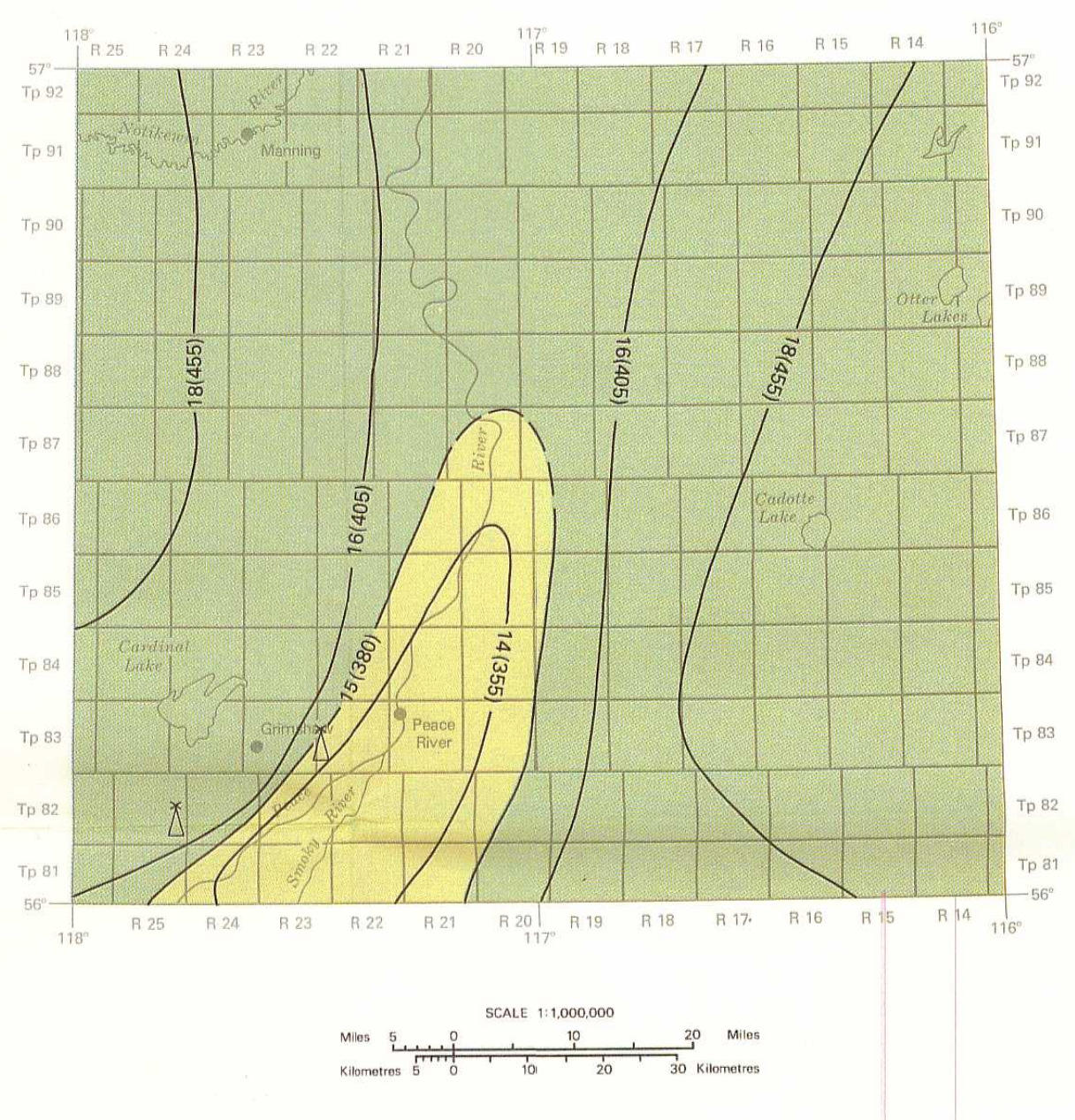
Meteorological station ....

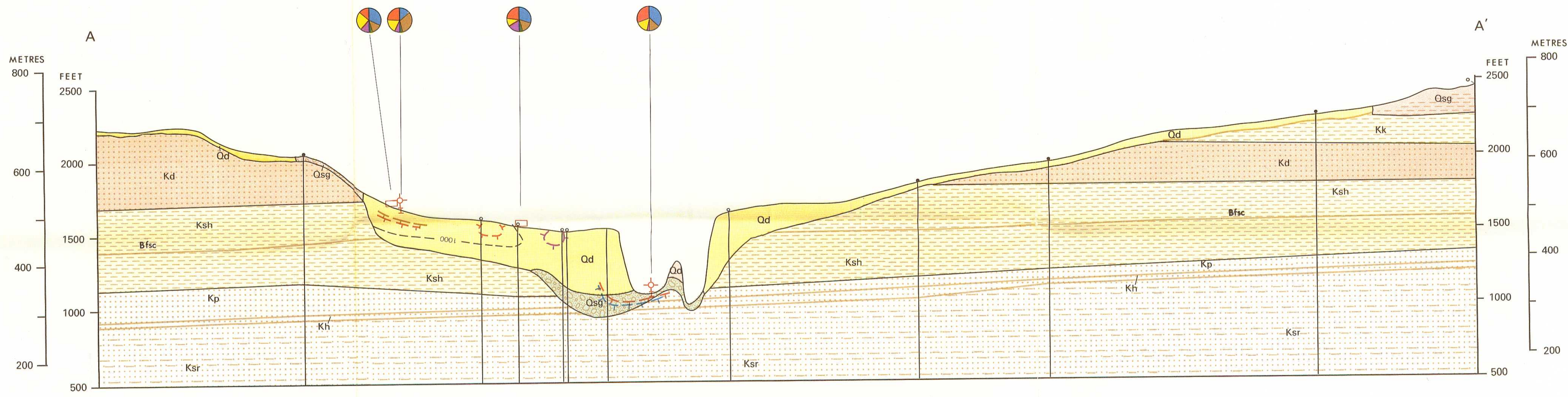
Precipitation data:
- Mean annual precipitation estimated in inches 12.26
- Year of commencement of observations 1944
- Number of years in average 30
- Mean monthly precipitation ....
- Period when surface is usually snow covered ....
- Period when mean daily temperatures is below freezing ....
- Figure indicates percentage of mean annual precipitation falling as rain

Source: Climatic maps for Alberta (R. W. Langley)

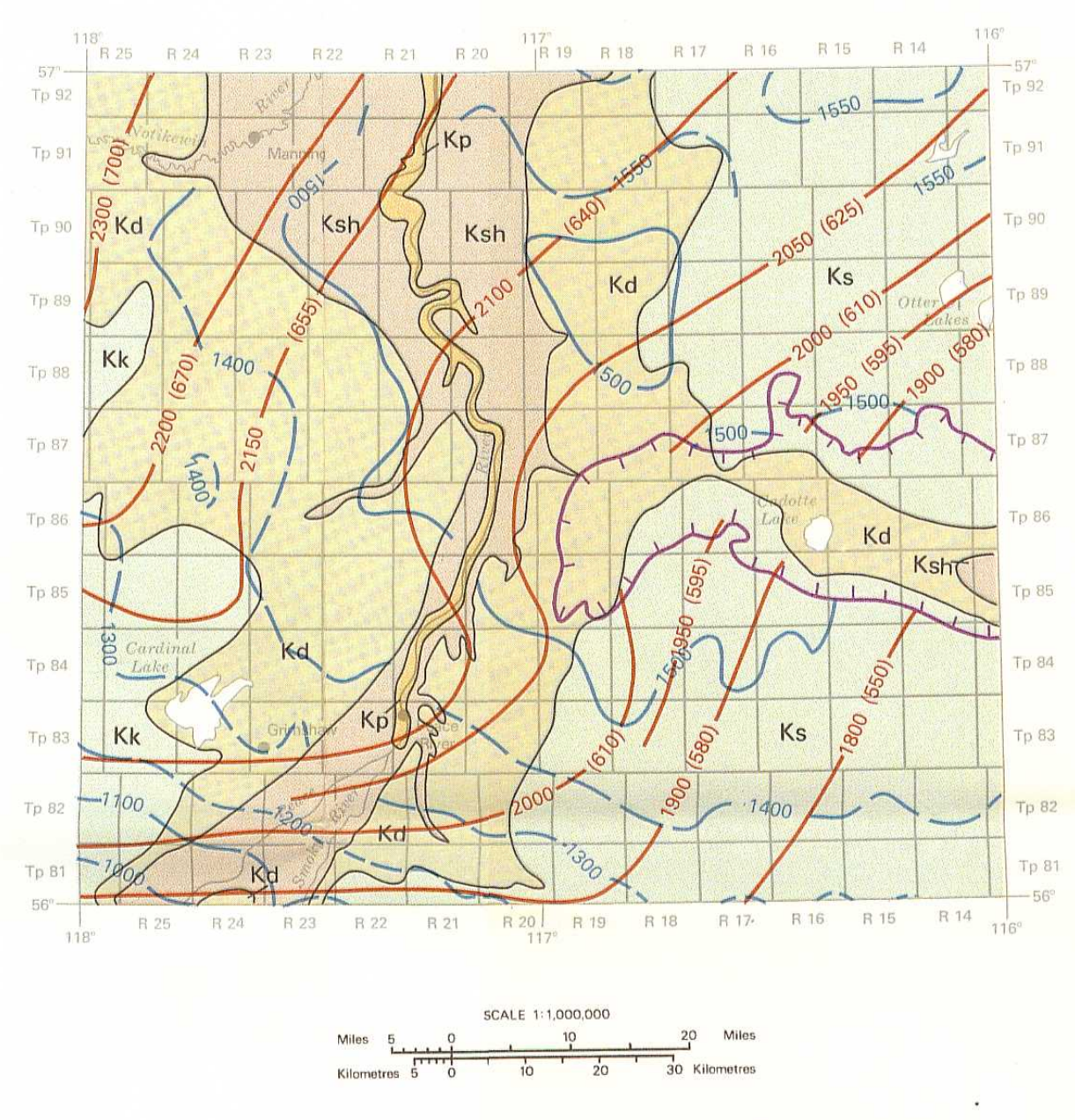
ERRATA
Section D-D¹ Ks shales should be yellow (pale).

METEOROLOGY





GEOLOGY



LEGEND

Smoky Group: *dark grey shale and silty shale, nodules and thin beds of concretionary*
Ks *ironstone; include unnamed dark grey shale unit on Caribou Mountains and Buffalo Head Hills: marine*

Kaskapau Formation: *dark grey silty shale, thin concretionary ironstone beds; interbedded*
Kk *in lower part with fine grained quartzose sandstone and thin beds of ferruginous oolitic mudstone; marine*

Peace River Formation: *fine-grained quartzose sandstone (Cadotte Member); dark grey*
Kp *silty shale (Harmon Member); fine-grained glauconitic sandstone; silty interbeds in lower part (Notikewin Member); shoreline complex*

Dunvegan Formation: *grey, fine-grained, feldspathic sandstone with hard calcareous beds;*
Kd *laminated siltstone and grey silty shale; deltaic to marine*

Shaftesbury Formation: *dark grey fish-scale bearing shale, silty in upper part; numerous*
Ksh *nodules and thin beds of concretionary ironstone; bentonite partings; lower part with thin silty and sandy intervals; marine*

Rock unit boundary ....
Structure contour on top of Dunvegan Formation .... —2000(610)—
Structure contour on Base of Fish Scale Zone .... —1500—
Boundary of area with no Base of Fish Scale ....

MAIN MAP LEGEND

Topography

Surface contours and elevation in feet (interval 500 feet) 3000
Sides and slumps ....

Geology

Geological boundary:
- defined ....
- approximate ....

Thalweg of buried valley ....

QUATERNARY

Qd	Unconsolidated deposits
Qsg	Unconsolidated sand and gravel

CRETACEOUS

Ks	Smoky Group
Kd	Dunvegan Formation
Ksh	Shaftesbury Formation
Kp	Peace River Formation
Ksr	Spirit River Formation
Kk	Kaskapau Formation
Kh	Harmon Member
Bfsc	Base of Fish Scale

Lithology

Grimshaw Gravel ....
Buried Gravel ....
Surficial Sand and Gravel or River Terrace Gravel ....
Sand ....
Sandstone ....
Shale ....
Sandstone and Shale ....
Shale and Sandstone ....

Hydrography

Lake or slough, perennial ....
Lake or slough, seasonal ....
Marsh, muskeg ....
Stream, perennial ....
Stream, intermittent ....
Surface water divide ....

Hydrogeology

Spring flow rate unknown ....

Nonpumping water level contour in the bedrock (elevation in feet followed by metres in brackets) and vertical component of groundwater movement .... Upward flow 2000(610) Downward flow

Boundary of area of artesian flow ....

GROUNDWATER PROBABILITY

Range of average expected yield of wells in imperial gallons per minute (l/sec)

Probable: estimated from quantitative information (pump tests, bail tests, etc).
Possible: estimated from qualitative information (flow regime, lithology, etc)

🟦	100-500	(8-38)
🟩	25-100	(2-8)
🟥	5-25	(0.4-2)
🟧	1-5	(0.1-0.4)
🟨	1	(0.1)

Yield area boundary ....

+ The indicated expected yields to wells are predictions based on the best data available at the time of map compilation; due to data shortcomings and special conditions, local discrepancies between predicted and actual yields are inevitable. Multiaquifer completion may be necessary to obtain the yield indicated.

WELLS AND OTHER ARTIFICIAL WORKS

Depth Scale

FEET
0
100
200
300
400

Depth to water
Depth of well or seismic shot hole

Water well, nonflowing ....
Water well, flowing ....
Water well with estimates of safe yield and apparent transmissivity ....
Flowing shotholes ....
Oil well ....
Burning gas well .... ☆
Structure test hole .... ○
Depth of exploratory well ....
Dugout or borrow pit ....

The vertical line portion of oil, gas or other exploratory test well symbols indicates the well depth; the dashed portion indicates the surface casing interval where applicable or where known (otherwise, a solid line is used).
Note: On the main map exploratory wells appear as point symbols only.

Line of hydrogeological profile .... A A'

Hydrochemistry

note: when the yellow Mg pie sector is absent Ca & Mg are represented as a unit by the red sector

Total dissolved solid in parts per million:
- approximate .... -- 3000 --

Isogram along which calcium & magnesium constitute 60 percent of total cations*; teeth indicate direction of lesser calcium & magnesium content
- defined ....
- approximate ....

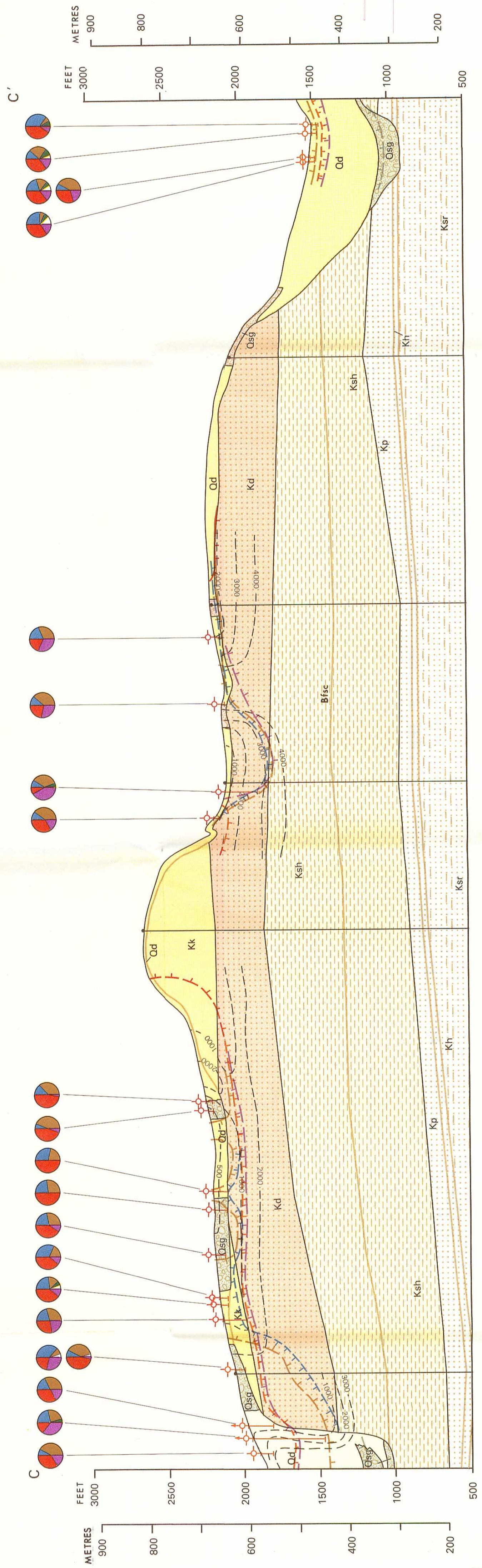
Isogram along which sodium & potassium constitute 60 percent of total cations*; teeth indicate direction of lesser sodium & potassium content:
- defined ....
- approximate ....

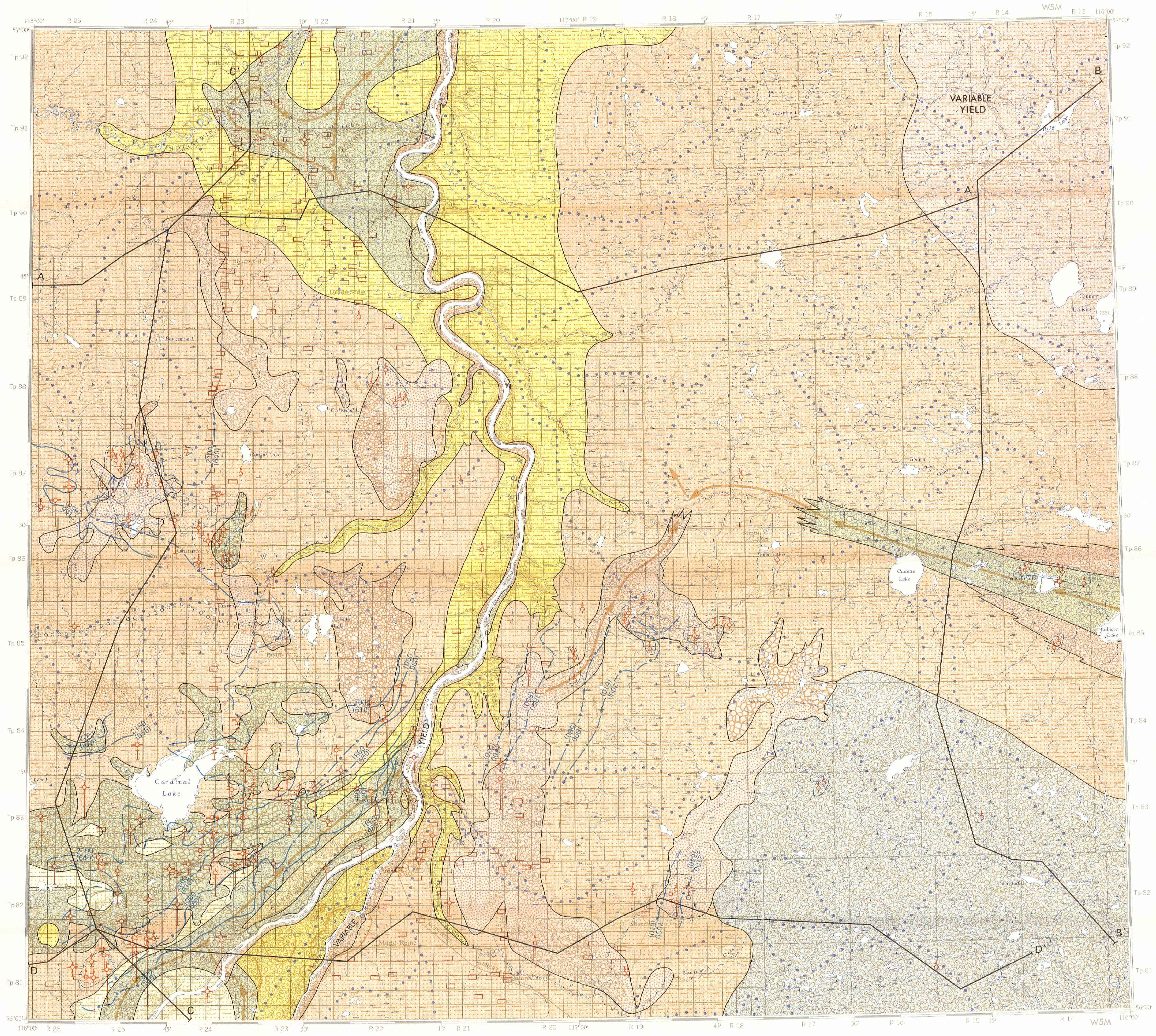
Isogram along which chloride constitutes 60 percent of total anions*; teeth indicate direction of lesser chloride content:
- defined ....
- approximate ....

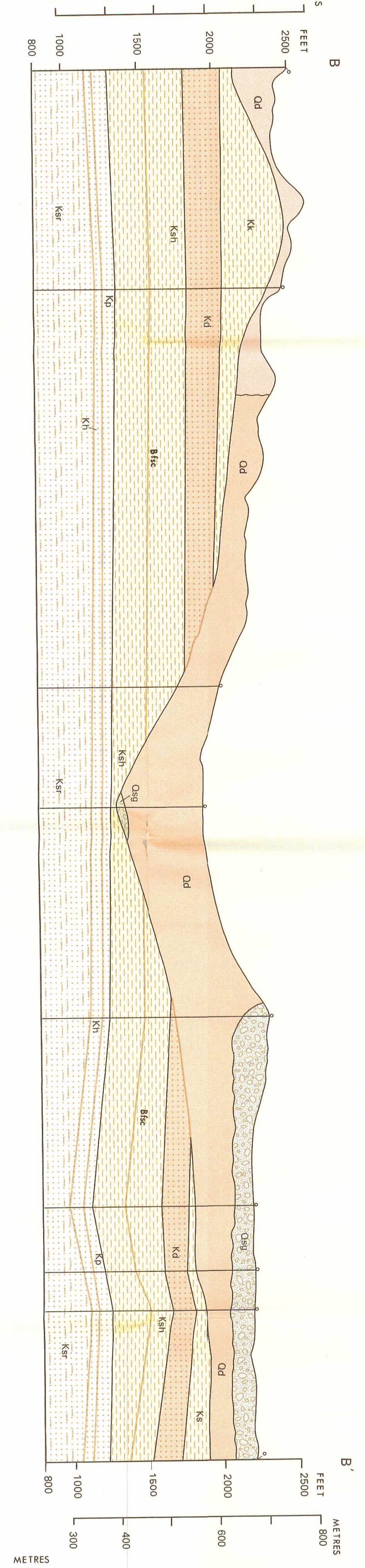
Isogram along which carbonate & bicarbonate constitute 60 percent of total anions*; teeth indicate direction of lesser carbonate & bicarbonate content:
- defined ....
- approximate ....

Isogram along which sulfate constitutes 60 percent of total anions*; teeth indicate direction of lesser sulfate content:
- defined ....
- approximate ....

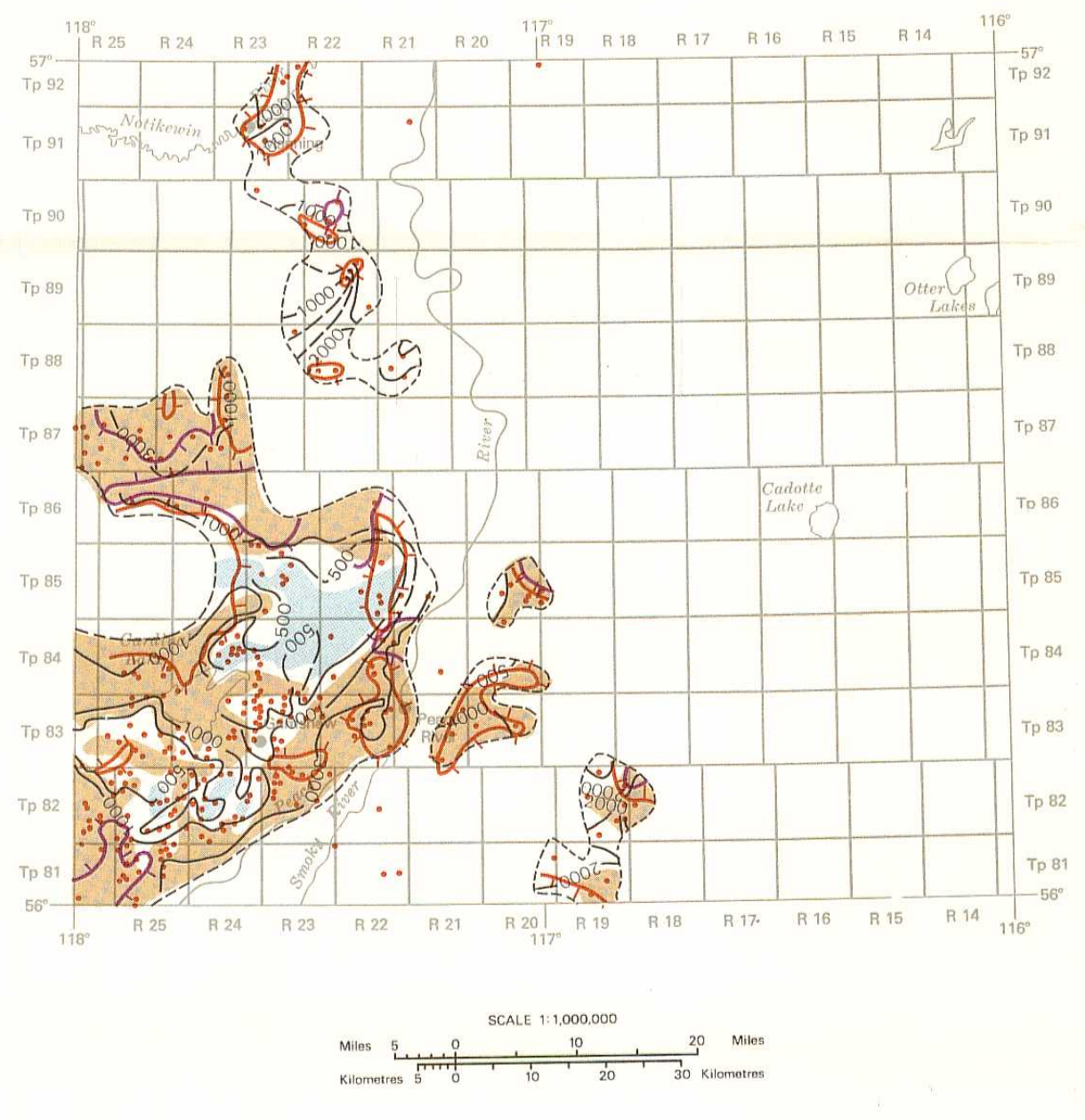
Determined on equivalents per million basis.







HYDROCHEMISTRY

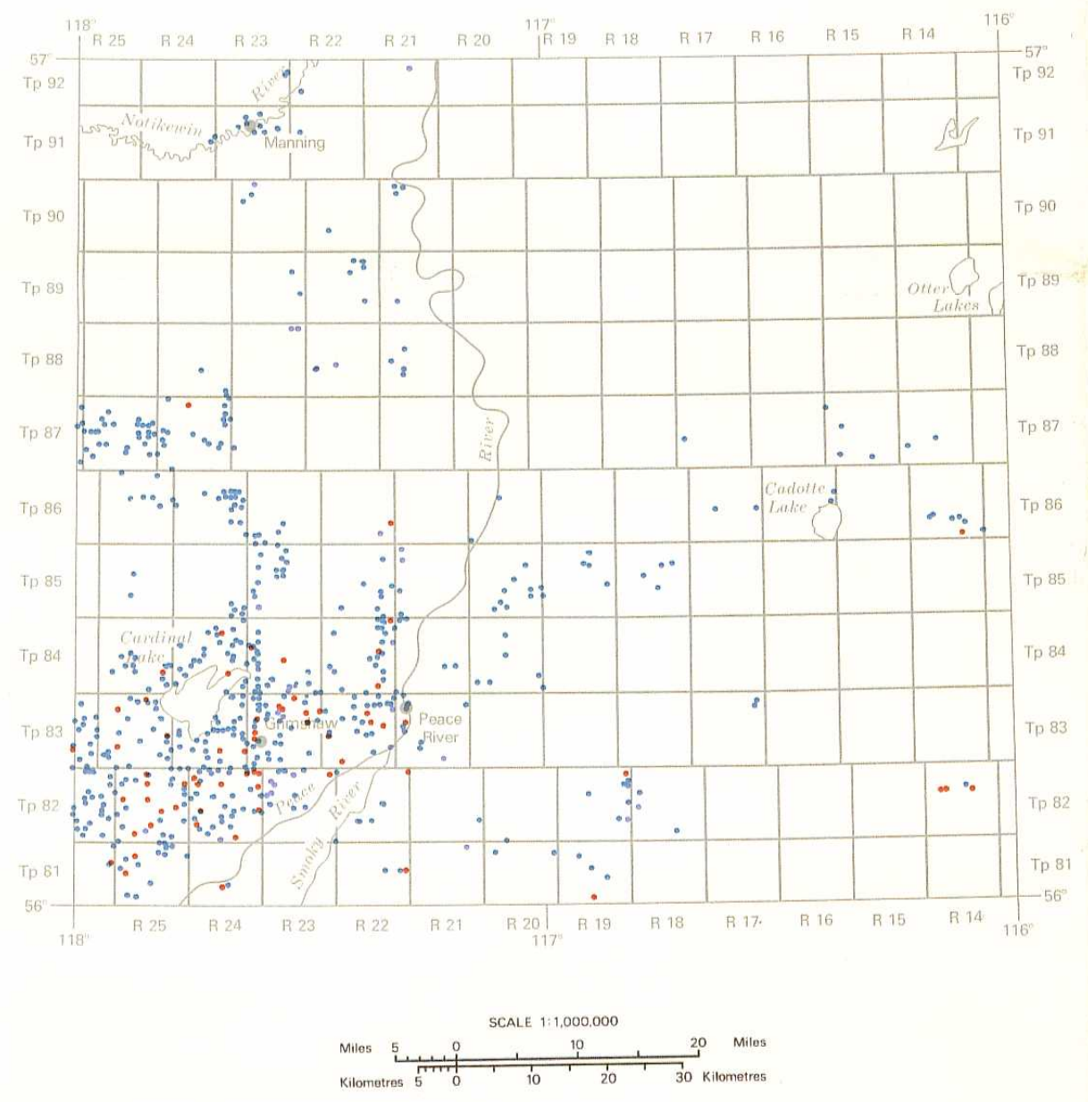


LEGEND

Data control point ....
Total dissolved solids in mg/L:
- defined .... — 3000 —
- approximate .... -- 3000 --

Carbonate & bicarbonate constituting of 60 percent of total anions* .... 🟦
Sulfate constituting over 60 percent of total anions* .... 🟧
Isogram along which calcium & magnesium constitute 60 percent of total cations*; teeth indicate direction of lesser calcium & magnesium content ....
Isogram along which sodium & potassium constitute 60 percent of total cations*; teeth indicate direction of lesser sodium & potassium content ....
Boundary of insufficient data ....
Determined on equivalents per million basis.

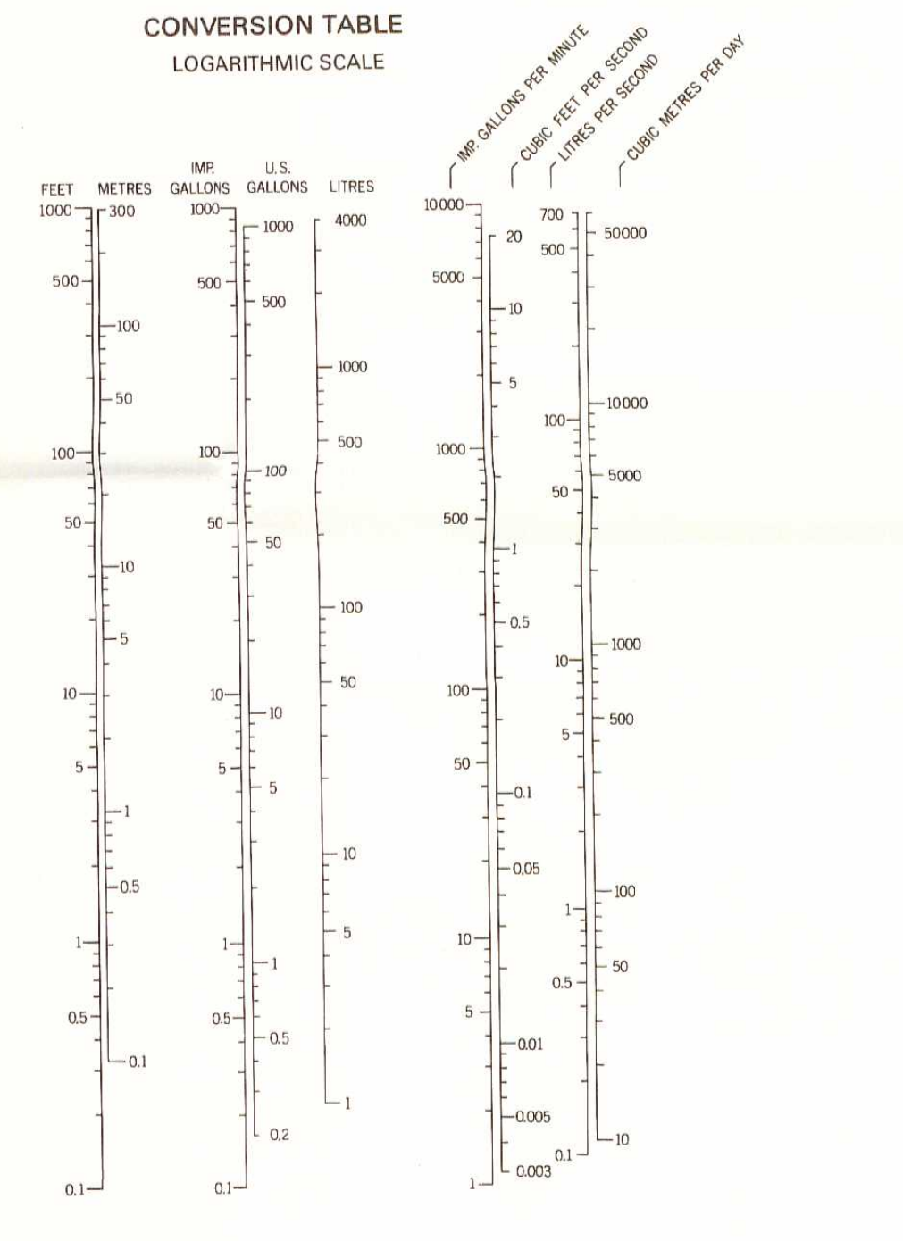
DATA DENSITY

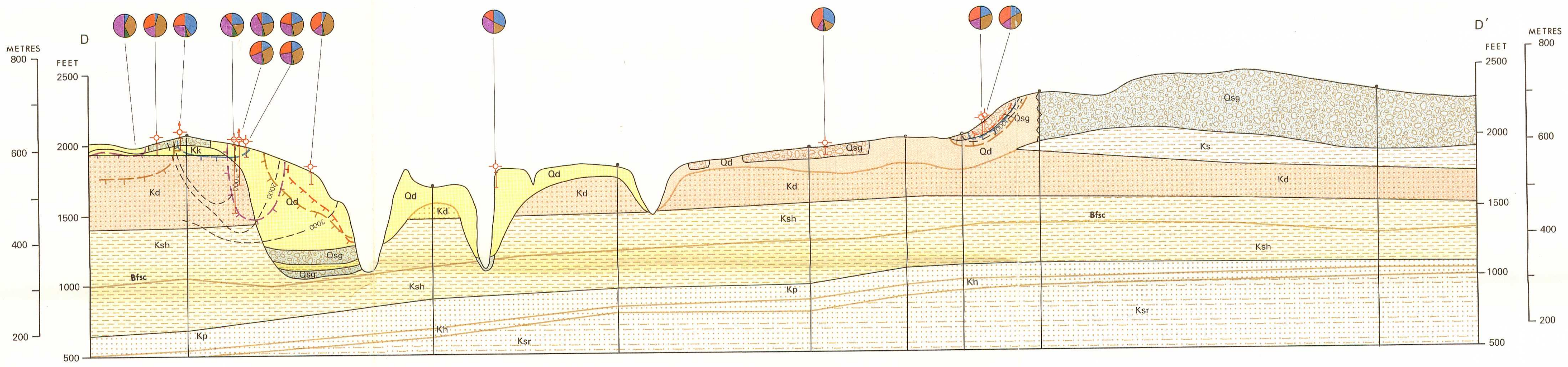


LEGEND

Data control point marking location of a well with a water level information ....
Data control point marking location of a well with yield information ....
Data control point marking location of a surface hydrogeological feature ....

CONVERSION TABLE
LOGARITHMIC SCALE





SCALE 1:250,000
Miles 5 0 5 10 15 20 Miles
Kilometres 5 0 5 10 15 20 25 30 Kilometres

All elevations in feet and/or metres above mean sea level

Vertical exaggeration of the hydrogeological profiles is approximately 40X

An expanded legend and explanatory noted (Earth Sciences Report 72-12) for use with this hydrogeological map series is available from Alberta Research Council, Edmonton, Canada

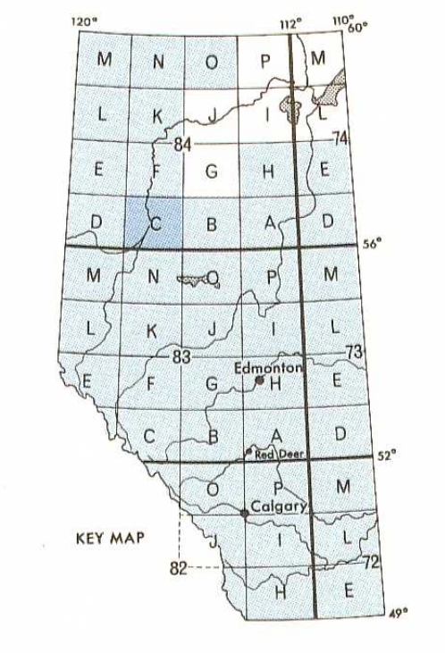
Map to accompany Earth Sciences Report 81-2

Hydrogeology by D. Borneuf

Drafted by J.K. Matthie

HYDROGEOLOGICAL MAP
PEACE RIVER
ALBERTA

NTS 84C



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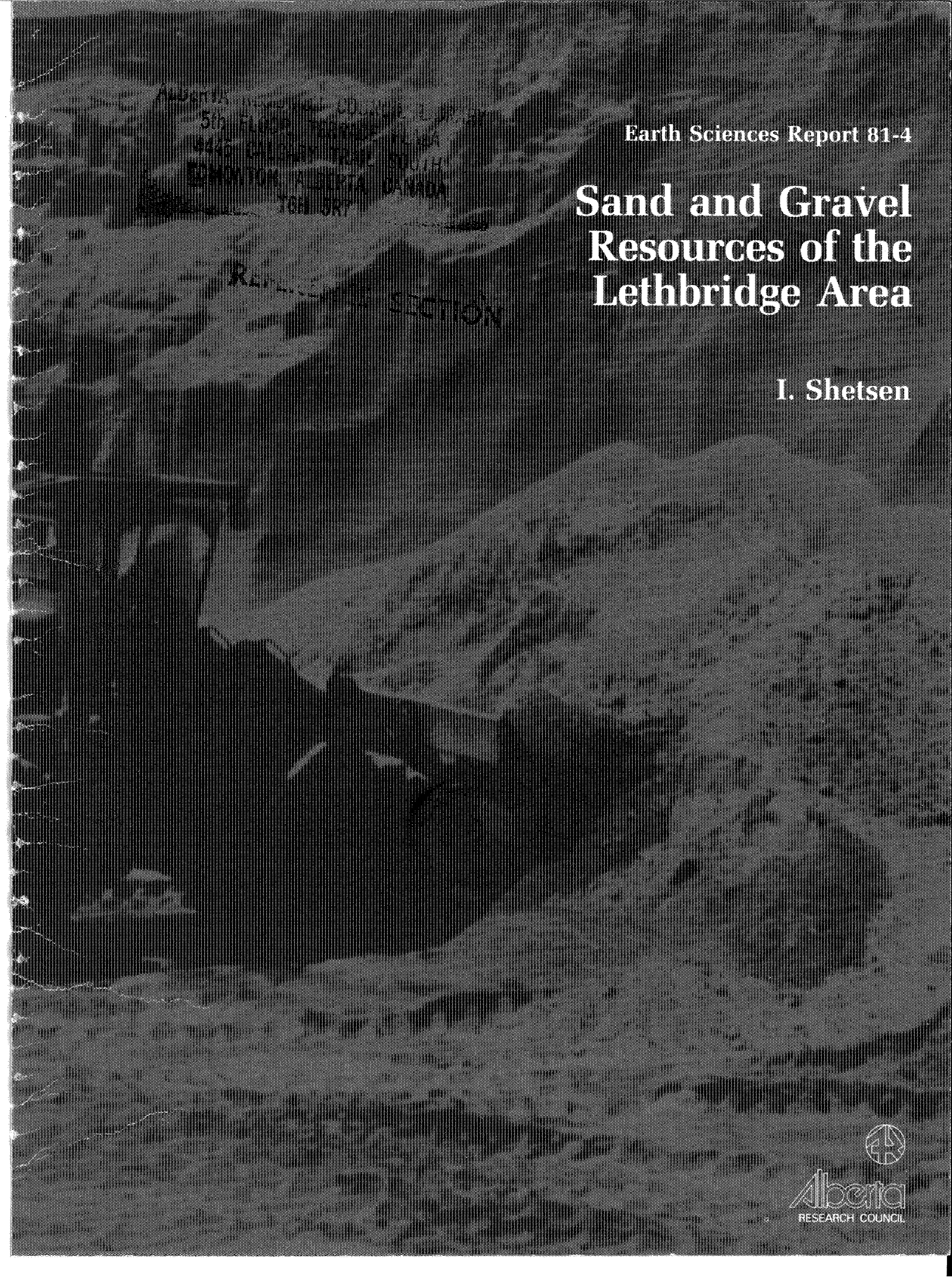
Base map provided by Surveys and Mapping Branch, Department of Energy, Mines and Resources, Ottawa; modified by Surveys Branch, Alberta Transportation, Edmonton

Published in 1983



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Earth Sciences Report 81-4

Sand and Gravel Resources of the Lethbridge Area

I. Shetsen

Alberta
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Earth Sciences Report 81-4

Sand and Gravel Resources of the Lethbridge Area

I. Shetsen

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REFERENCE SECTION

Alberta Research Council
1980

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Publications
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5th Floor, Terrace Plaza
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Edmonton, Alberta
T6H 5R7

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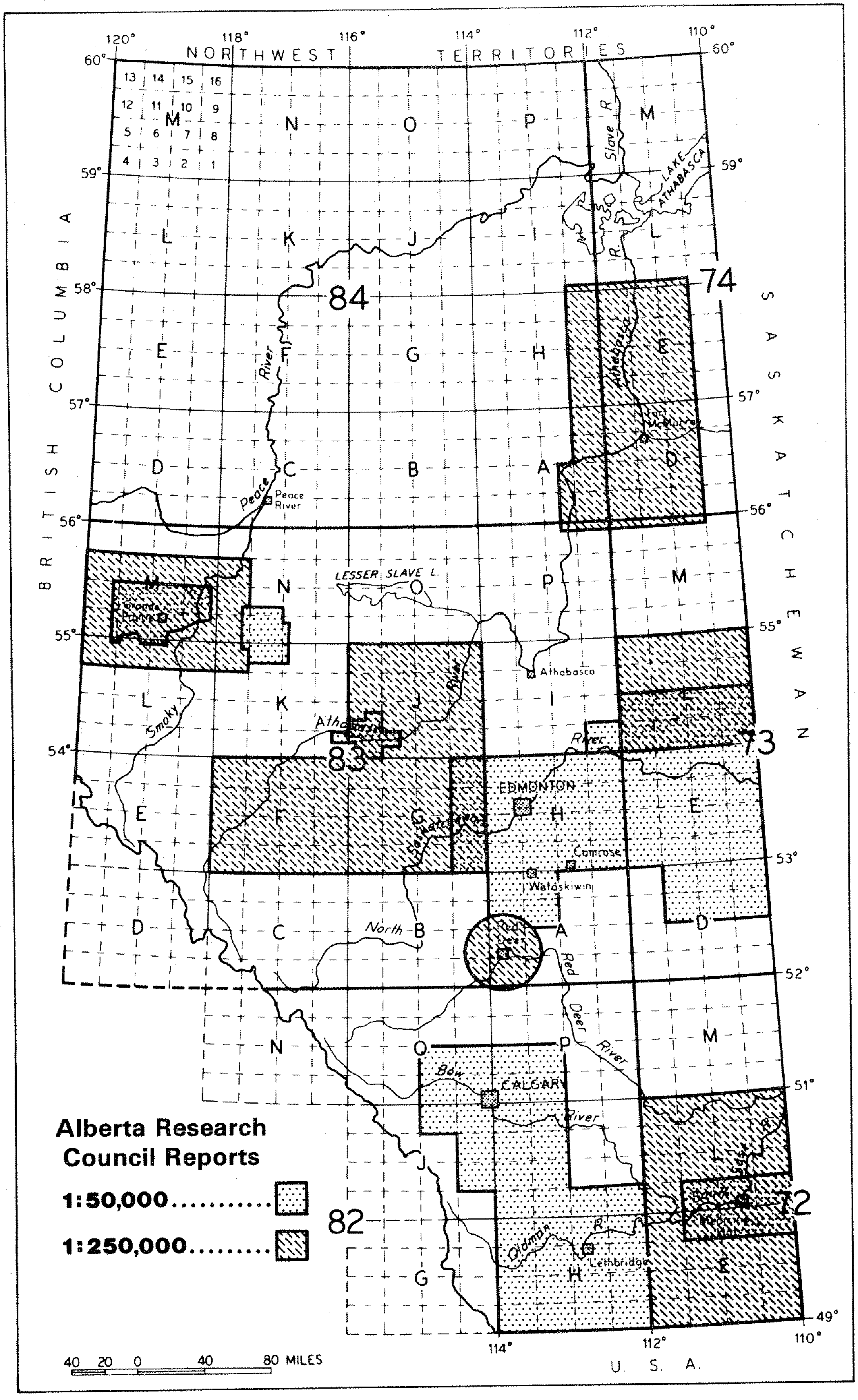
LIST OF ILLUSTRATIONS

PREFACE

Sand and gravel production is often beset with land-use conflicts and environmental problems. The purpose of this series of reports is to provide information about sand and gravel deposits which can help planners make intelligent decisions involving land use and provide a starting point for detailed exploration programs.

This survey concentrates not only on currently exploitable resources, but also on many "untapped" deposits with a foreseeable use. The maps of the deposits have a scale of 1:50 000. The deposits, themselves, have a thickness of at least 1 m, and have a ratio of overburden to sand and gravel of no more than 1:1. Volume or tonnage figures are based on a broad geological knowledge of the deposits and not on detailed sampling or subsurface data. These figures should be used as general estimates only.



Location of the Lethbridge area and the other project study areas.

ABSTRACT

The most important sources of gravel and sand in the Lethbridge area are high and low level alluvial terraces associated with the Oldman River valley. These terraces contain gravel and gravelly sand, exposed at the surface in the case of the high terraces. The low terraces commonly have up to 3 m of fine sand and silt overlying the sand and gravel. The largest of the alluvial deposits, in the vicinity of Fort MacLeod, covers approximately 40 km^2 and is composed of coarse gravel with a consistent thickness of 3.0 to 3.5 m.

Extensive gravel deposits of preglacial age are located in upland areas south of Fort MacLeod, south of Magrath, and in the Del Bonita area. In the vicinity of Del Bonita, 45 km south of Lethbridge, preglacial gravel covers an area of approximately 50 km^2. The material varies in thickness from 3 to 5 m and generally has less than 3 m of overburden. These preglacial deposits are not being widely utilized at present but may become an important source of granular material in the future.

Good sources of coarse and medium sand are found in the kame deposits within hummocky moraine zones along the Rocky Mountain Foothills, in the southwest quarter of the area.

INTRODUCTION

LOCATION

The study area is situated in southern Alberta between 112°00′ and 114°00′ west longitude and 49°00′ and 50°15′ north latitude. It covers Tp 1 to 15 and R 16 to 30, W4th Mer, has a total area of about 18 000 km^2 and includes the counties of Lethbridge and Cardston, and most of the counties of Willow Creek, Taber, Pincher Creek, and Warner. The study area also encompasses part of Waterton Lakes National Park. The study did not include the Blood and Peigan Indian Reserves which are located within the area outlined.

Lethbridge, with a population of about 40 000 is the only city within the study area. The following incorporated towns with populations between 1000 and 5000 are located in the area: Cardston, Claresholm, Fort MacLeod, Granum, Magrath, Milk River, Picture Butte, Pincher Creek, and Taber. With the exception of the southwestern corner, an excellent network of highways and paved and gravelled roads cross the area.

The area divides into three major physiographic units: the Rocky Mountains, in the southwestern corner; the Foothills, bordering the mountains on the southwest; and the Great Plains, which includes most of the area. The general slope of the land surface is towards the northeast. The Oldman River and its tributaries, the St. Mary, Belly, Waterton, and Little Bow Rivers, drain the area, except for the southeastern part which is drained by the Milk River. These rivers flow in valleys 50 to 100 m deep.

PREVIOUS WORK

The surficial geology of the area has been mapped at a scale of 1:250 000 (Stalker, 1957, 1958, 1962, 1965). Hydrogeological surveys have been conducted at a scale of 1:250 000 (Tokarsky, 1974; Ozoray and Lytviak, 1974) and a soil survey at a scale of 1:126 720 (Kocaoglu, 1977). Comprehensive investigations of the sand and gravel resources of the study area had not been undertaken before this study.

PRESENT STUDY

This study was undertaken to determine the distribution, thickness, composition, quality, and reserves of gravel and sand and to provide maps that will aid future development of these resources. The gravel deposits of the entire region were mapped at a scale of 1:125 000 and the main areas of sand and gravel were mapped at a scale of 1:50 000. The results are presented on maps at scale of 1:250 000 (Fig. 1, 2) and 1:50 000 (Fig. 3, 4, 5).

During the winter of 1976–1977 existing information on gravel and sand deposits in the area was synthesized. Data were collected from the following sources: maps of surficial geology, soils, and hydrogeology; water-well logs, seismic shothole logs, and logs of shallow drillholes obtained from Alberta Environment. Airphotos of the entire area were studied.

Fieldwork, in the summer of 1977, included checking geological boundaries delineated on airphotos and surficial maps, and detailed geologic mapping of those areas considered favorable for gravel and sand deposits. Other work included a study of outcrop exposures of alluvial terraces in the Oldman River valley, describing and sampling of 185 pits, and the dry auger drilling of 330 testholes.

A resistivity survey was undertaken to test the efficiency of this method as an aid in prospecting for gravel and sand. The resistivity measurements showed good correlation with drilling data and proved that gravel and sand could be distinguished from other sediments by their electrical properties. The success of the resistivity method depended on the geological setting of the area studied. Gravel-bearing deposits could be located and delineated readily by resistivity measurements alone where they were in contact with till or bedrock. Complementary drilling information was required if gravel lenses were to be traced within areas composed of fine-grained sand. Electrical measurements could not distinguish gravel from pure, medium- to coarse-grained sand because of similar resistivity values. The most cost efficient method of searching for gravel and sand was to combine a resistivity survey with a limited number of drillholes.

Sieve analysis of 172 samples provided the grain-size information on the gravel and sand deposits. The maps and the reports were prepared in the winter and the spring of 1978.

THE MAPS: CONTENTS AND TERMINOLOGY

This report is written to accompany the maps which present the main results of the survey. Below is a description of the contents of the maps and sources of the data that were used to compile the maps.

SURFICIAL GEOLOGY MAP (Figure 1)

Figure 1 (scale: 1:250 000) provides a general picture of the distribution of surficial deposits. Map units are differentiated on the basis of genesis and lithology. Types shown on the map are those that predominate within the areas delineated.

The map was compiled from maps of surficial geology at a scale of 1:250 000 by Stalker (1957, 1958, 1962, 1965). The distribution and areal extent of sand and gravel have been modified from Stalker's maps as have interpretations of the origin of some surficial deposits.

The terminology for genetic types of glacial deposits (glacial drift) is currently not clearly defined. In this report, the terms proposed by R.F. Flint (1957), by C.P. Gravenor and W.O. Kupsch (1959), and by C. Embleton and C. King (1968) are used (Appendix A).

MAP OF DISTRIBUTION OF GRAVEL AND SAND DEPOSITS (Figure 2)

This map, at a scale of 1:250 000, shows all occurrences of gravel and sand observed in the area regardless of quality, extent, and economic importance.

The figure is accompanied by a list of the deposits (Appendix C) which provides information about thickness and areal extent of gravel and sand, thickness of overburden, lithologic and petrographic composition, and a rough estimation of reserves. The gravel and sand deposits on the map are numbered and are classified into seven groups according to their origin.

DETAILED MAPS OF GRAVEL AND SAND DEPOSITS (Figures 3, 4, 5)

These maps, at a scale of 1:50 000, provide detailed information about the distribution, lithology, and thickness of gravel and sand within the "Lethbridge," "Fort MacLeod," and "Del Bonita" areas. The maps are accompanied by eight geological profiles to show the composition of gravel and sand deposits and their relationship with adjacent beds.

The classification of gravel and sand used on the maps and in the report follows the industrial classification of the American Society for Testing and Materials (ASTM) (Appendix B).

Possible gravel and sand deposits shown on the maps are those that have not been defined by drilling or outcrop study because of inaccessibility. The presence of gravel was assumed on the basis of airphoto interpretation.

RELATIONS BETWEEN GRAVEL AND SAND DEPOSITS AND GLACIAL HISTORY

Gravel and sand deposits in the area are abundant and variable. Their composition and origin vary widely, and they are unevenly distributed. Numerous deposits of gravel and sand, some very extensive, occur in the western part of the region and along the Oldman River valley. Only scattered small bodies of gravel, however, have been identified in the eastern part of the area, on the uplands between the Bow and Oldman Rivers, and between the Oldman and the Milk Rivers.

The mantle of unconsolidated sediment that covers the area was deposited during Late Tertiary, Pleistocene, and Holocene time. Gravel and sand were accumulated intermittently during this period, but the rate of the accumulation and the character of the deposits changed repeatedly in response to changes in the source area of coarse material, the direction and type of drainage systems, and the regimen of streams.

Field examination of the lithologic composition of coarse gravel and pebbles has shown that most of the stones originated in the Rocky Mountains. They consist of durable rocks of Late Precambrian and Paleozoic age: limestone and dolomite, quartzite, hard sandstone, and argillite. Some of the coarse fragments were derived from the Precambrian Shield and brought into the area by glacial ice. They consist of igneous and metamorphic rocks, which are mainly granite, diorite, gneiss, and schist. About half the stones derived from the Canadian Shield are weathered and friable. The main source of deleterious material in the coarse fraction of the gravel and sand was local bedrock (late Cretaceous and early Tertiary), consisting of sandstone, siltstone, and shale containing thin coal layers and calcareous concretions.

The pattern of drainage throughout the Quaternary was controlled by large-scale features in the preexisting bedrock surface formed in the Tertiary. The deposits and temporary drainage modifications by glaciation did little to alter this pattern. The bedrock surface rises generally from the northeast to the southwest towards the Rocky Mountains, from elevations of 700 m above sea level to 2500 m above sea level. On the plains, the altitudes increase from 700 m to 1100 m above sea level, with the average gradient 2.5 m/km. The surface of the plains consists of successively higher, flat terraces, separated by gentle slopes. Within the Foothills the altitudes are from 1100 m to 1500 m above sea level, and the average gradient is 15 m/km. In the Rocky Mountains, the average gradient is as much as 80 m/km.

The bedrock surface was cut by valleys which are almost completely buried under the Quaternary deposits and are considered to be of preglacial age (Stalker, 1963). These valleys are as much as 50 to 75 m deep and up to 10 km wide. They extend across the area in a northeastern to eastern direction along the courses of the present Oldman, St. Mary, Belly, Waterton, and Milk Rivers (Geiger, 1965). In some places, the bedrock uplands between the valleys are summits, similar to plateaus, such as Del Bonita Upland and Milk River Ridge in the southern part of the area.

The bedrock terraces and plateaus are believed to represent remnants of old erosional surfaces formed by the action of rivers between Oligocene and late-Pliocene time (Cope, 1891; Collier and Thom, 1918; Alden, 1924). Fluvial sedimentation has left a cover of gravel and sand over bedrock on some of these erosional surfaces. There is evidence for at least three stages of gravel and sand deposition during the late Tertiary. The oldest gravel, covering the flat surface of the Del Bonita Upland, at elevations between 1300 and 1400 m above sea level, could correspond to the Cypress Hills Formation of presumably Oligocene age (Westgate, 1968). Gravel and sand deposits on bedrock terrraces, with elevations between 1080 and 1150 m above sea level, south of Magrath and Fort MacLeod, may be correlated with the Flaxville gravels in Montana and in southeastern Alberta (Collier and Thom, 1918; Westgate, 1968), dated as Miocene to early Pliocene. The youngest preglacial alluvial deposits are known as "Saskatchewan gravel and sand." They fill the bottoms of preglacial channels and are thought to be of late Pliocene to early Pleistocene age (Stalker, 1963). These deposits, which are overlain by drift as much as 80 m thick, are exposed only along the banks of the Belly, St. Mary, and Oldman Rivers, wherever bottoms of the present valleys intersect floors of the ancient streams.

The area was glaciated several times during the Pleistocene (Stalker, 1963; Stalker and Harrison, 1977), but little is known of the details of the pre-Wisconsinan glacial history. During the Wisconsinan most of the region, with the exception of the Del Bonita Upland and the Rocky Mountains, was covered by the Laurentide ice advancing from the northeast and north.

The extent of the final "Classical" Wisconsinan glacier in the area remains controversial. The outer limit of this glaciation, as shown on the map by Westgate (1968), is marked by the well-developed hummocky moraine surrounding the Del Bonita Upland and the Rocky Mountains. Stalker (1977) sets the margin of the Classical Wisconsinan glacier 40 km north of Westgate's boundary, along the southern edge of the hummocky moraine belt that parallels Etzikom Coulee west to Lethbridge and then continues north toward the Traverse Reservoir. Direct evidence does not exist to confirm either of the boundaries, but the morphology of the relief makes the southern boundary appear more likely to represent the extreme maximum of the Classical Wisconsinan ice-sheet. No morphologic differences in the appearance of the hummocky moraines or the river valleys indicate that the relief south of the north boundary is more mature than within it. Thus, it seems logical to assume that the surficial deposits and the landforms of the area were formed during one continuous deglaciation rather than during two deglaciations and one major readvance of ice.

Most of the gravel in the area was deposited in meltwater streams draining the retreating glacier. The glacial drainage systems changed continuously, both in type and direction, as deglaciation proceeded (Fig. 6). Different types of gravel deposits were associated with each of the stages of ice retreat, as illustrated by Figures 6-I, 6-II, 6-III. The glaciofluvial processes also produced different effects southeast and northwest of the line that follows the St. Mary and Oldman Rivers. These differences and the factors involved are discussed below.

The first stage of deglaciation was characterized by a gradual lowering of the ice surface, as a result of a general increase in temperature and conversion of the economy of the ice sheet from positive to negative. At that time the accumulation of gravel and sand took place all along the Foothills belt where at higher elevations the generally thin ice stagnated quickly (Fig. 6-I).

The conditions of drainage differed considerably in the western and eastern parts of the Foothills. West of the St. Mary River, the strongly differentiated bedrock slope was towards the glacier. Meltwater streams, therefore, formed intermittent superglacial and englacial drainage systems. The south, and southwestern, directions of the flow corresponded to the slope of the glacier. The Foothills ridges soon protruded through the downwasting ice and became the sites of numerous small ponds that formed between the ice and the exposed land. These openings on the ice surface presented natural traps for material transported by meltwater flow. The deposits of kame-type origin are widespread within the western part of the Foothills. They are small in area and are generally of a two-storey composition: the lower layers consist of fine, well-sorted sand and silt formed by the initial low velocity flow; the upper layers are composed of coarse, poorly sorted gravel and sand brought in by the later, more rapidly flowing meltwater streams.

East of St. Mary River, meltwater could escape along the slopes of the bedrock uplands, first to the south through a series of marginal and proglacial channels, and later to the east through the pre-existing Milk River valley and its tributaries. Kame deposits are rare in this part of the Foothills, and the main type of glaciofluvial accumulations are meltwater stream deposits, consisting chiefly of fine sands and silt or, more rarely, of unsorted gravel and sand.

Progressive thinning of the ice caused disintegration of the wide marginal part of the ice sheet into fields of dead ice. The glacier terminus was separated into two lobes. One retreated to the northeast, along the Oldman River valley, the other, to the north along the slope of the Foothills.

Southeast of the St. Mary and Oldman Rivers, the glacier terminated at the relatively undifferentiated and steep bedrock slope dipping towards the ice. There the meltwater drained along the slope to the east and southeast carving a series of marginal and submarginal channels. As the melting ice exposed new portions of the slope, successively lower channels were formed. It appears the meltwater streams carried most of their sediment outside the area, since most of the channel terraces are erosional. Only a few terraces contain discontinuous and relatively thin veneers of poorly sorted sand and coarse gravel, largely composed of the rocks derived from the Canadian Shield and the local bedrock.

The conditions of drainage were entirely different in the rest of the area. The ice terminated on the broad lowlands, stretching along the preglacial Oldman, Belly, and St. Mary River valleys, or on the gentle bedrock slopes inclining away, as well as towards, the ice. Here the meltwater streams formed internal drainage systems. These systems were centered in shallow lakes, ponded in the lowlands, in front of the glacier terminus or dead-ice blocks. An absence of shoreline features suggests the lakes did not last long and fluctuated greatly. They drained primarily eastward through the systems of the ice-marginal channels developed in the southeastern part of the area. Part of the sediment the meltwater streams carried into the lakes accumulated as outwash plains, between the ice and the lakes, or between the dead-ice blocks. Fine-grained, well sorted sand is the dominant material in the outwash plains of the area. In some places, however, at the margins of the outwash plains gravel is present. These isolated, relatively small areas of gravel formed where meltwater streams emerging from ice slopes slowed down upon entering the plains. The outwash gravel largely consists of rocks derived from the Rocky Mountains and the Canadian Shield. The local bedrock component is insignificant.

When ice finally disappeared from the area, all the earlier, intermittent drainage systems transformed into the two major drainage basins that exist today, the Oldman River system and the Milk River system. Since that transformation, accumulation of gravel and sand has continued only in the river valleys. Evidence from the Oldman River system indicates there were three different stages of valley development: the initial stage; the late-glacial downcutting; and the period of predominant aggradation, presumably of post-glacial time. The Milk River system is not discussed here, because only a short section of the Milk River valley is within the study area.

Meltwater streams from the Rocky Mountain glaciers formed the Oldman, Waterton, Belly, and St. Mary River valleys and some of their tributary valleys. During early deglaciation, mountain streams merged with the meltwater streams that were draining the glacier on the plains to contribute to glaciofluvial accumulation. They incised deep channels on the steep slopes of the Foothills but made little impression on the Plains where there were low surface gradients and high local base levels controlled by the glacial lakes. As the glacier terminus retreated farther downslope, the meltwater streams from the mountains started to deepen their courses. The rates of downcutting remained low, and the depth of the newly formed valleys did not exceed 15 to 20 m, since the high terraces, all along the valleys, lie at the level of the surrounding plains, or just below it (Fig. 19, Profile R-S). It was the surrounding topography, not changes of the base levels in the lower parts of the valleys, that controlled river accumulation in the area. The stepped, longitudinal profiles of the streams reflected the alternation of the flat surfaces and gentle slopes in the late-glacial topography inherited from the preglacial landscape. The high river terraces have a thick cover of gravel and sand where the streams passed from the slopes to the flat surfaces (Fig. 7). Within the slopes,

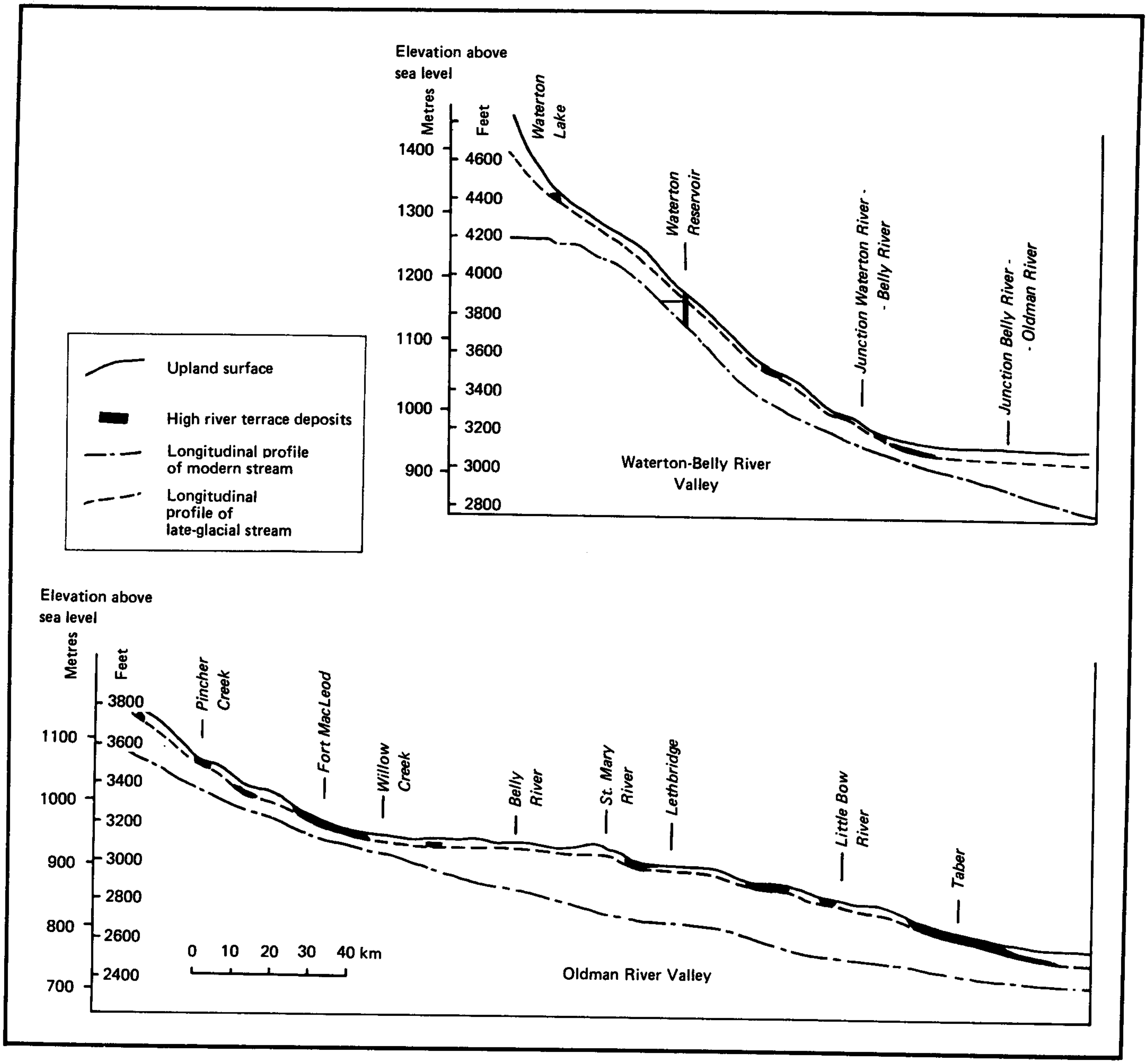


FIGURE 7. Relationship between high river terrace deposits and upland surface of the area.

however, the terraces are absent or are erosional with a thin veneer of lag-gravel over till. The gravel consists largely of rocks derived from the Rocky Mountains. The content of Shield stones in upstream sections of the valleys is relatively low, but increases downstream, with distance away from the mountains. Local bedrock material is usually absent.

The downcutting of valleys in the area took place later in the Pleistocene and, possibly, during the early Holocene. Since the present river valleys are incised into glacial drift and bedrock as much as 100 m deep (Fig. 19, Profile R-S), the erosion rates must have been very high. The valley slopes are mostly steep and non-terraced. Small sites of erosional terraces are found only in some places along the Oldman River valley. Whatever caused the downcutting had to have been of regional character, such as a substantial drop in the base level of the drainage system, a continuous uplift in the upper part of the system, or both. The increased melting of the valley glaciers in the Rocky Mountains intensified the erosional process.

The channel erosion cycle was ended later in the Holocene, by a period of accumulation during which the alluvial fills of the valley bottoms were deposited (Fig. 8; Fig. 19, Profiles K-L, M-N, O-P). Two depositional terraces, at 2.0 to 3.5 m and 5.0 to 7.5 m above river level, can be traced in the major river valleys and in most of the tributary valleys of the area. Remnants of a higher depositional terrace, at 12 to 16 m above stream level, are present only in the Oldman River valley. Each later fill is successively inset in the trench cut in the earlier fill (Fig. 8). The lowest terrace is composed of gravel and sand, fine-grained sand, and silt mixed in variable proportions. The best gravel appears to constitute the lower parts of the fill lying below river level. In the Oldman River valley, downstream from its junction with the St. Mary River valley, this terrace generally has a cover of floodplain deposits which are fine-grained sand and silt, as much as 4.5 m thick. The two upper terraces are composed mainly of floodplain sand and silt. Layers of gravel are near the bottoms of the terraces, although in some places thick lenses of gravel have also been found within these terraces close to the surface. Alluvial gravel consists predominantly of clasts derived from the Rocky

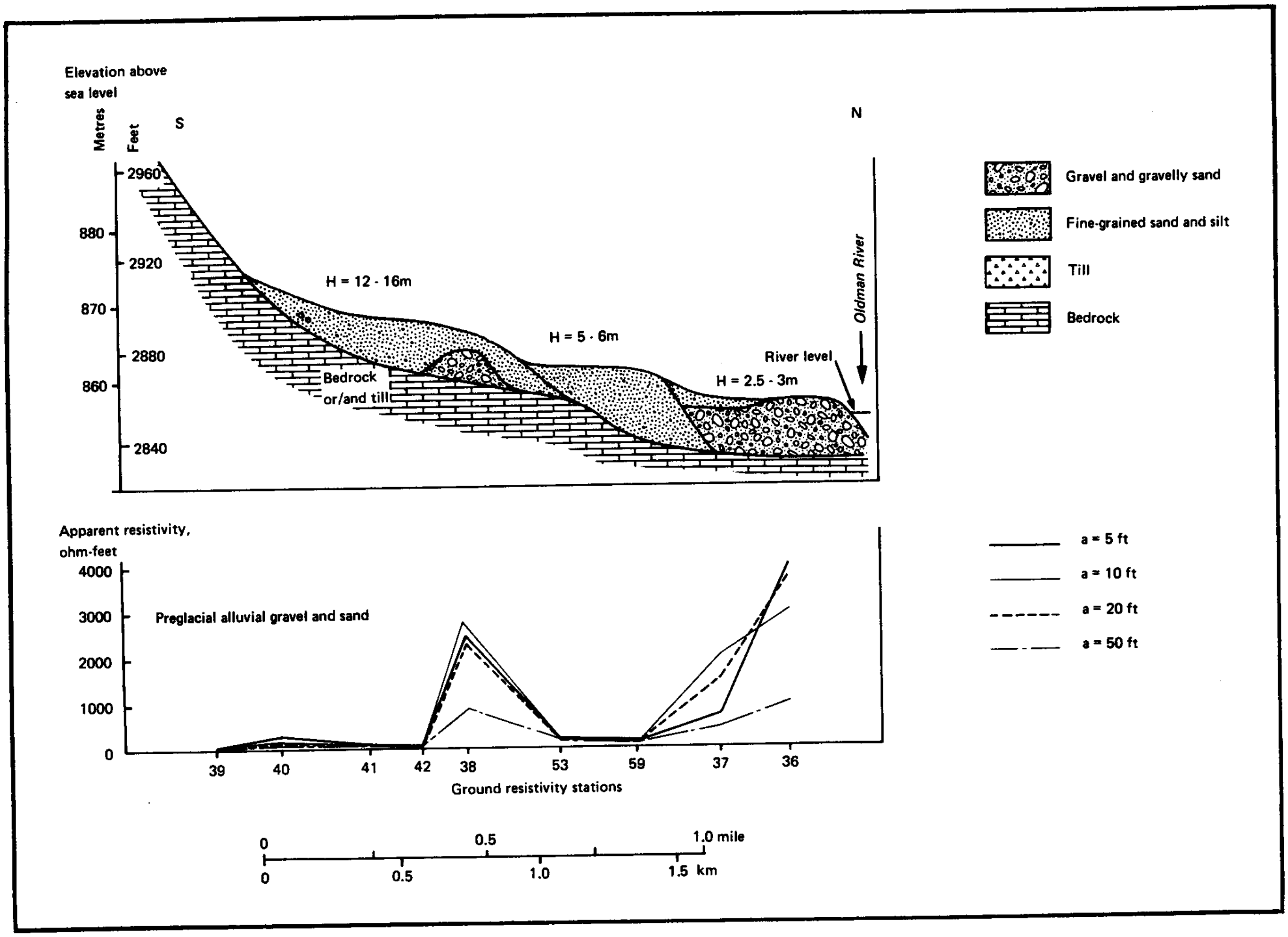


FIGURE 8. Composition of recent alluvial terraces in the Oldman River Valley (Kipp Section).

Mountains. The proportion of Shield and local bedrock material does not exceed 20 percent.

SAND AND GRAVEL DEPOSITS

The gravel-bearing deposits are classified, on the basis of origin, into the seven types listed below:

1. preglacial alluvial deposits;
2. kame deposits;
3. esker deposits;
4. outwash deposits;
5. marginal stream deposits;
6. valley train (high river terrace) deposits;
7. recent alluvial (low river terrace) deposits.

The general characteristics of each type of gravel, and the major deposits within each group, are described in this section. All gravel-bearing deposits found in the area are listed in Appendix C. The bracketed numbers for the deposits refer to the location number given in Figure 2 and Appendix C.

PREGLACIAL ALLUVIAL DEPOSITS

Preglacial gravel and sand constitutes the most extensive aggregate deposit in the area (Deposit 6). It is situated in the southern part of the region near Del Bonita, 70 km south of Lethbridge (see Fig. 5). Approximately 50 km^2 of gravel and sand covers the flat surface of the Del Bonita Upland, between elevations 1300 and 1400 m above sea level. An overburden of silt, interbedded with fine sand, is generally present, but exceeds 2 m in thickness only in a few places. The deposit consists of a fine to coarse, poorly to moderately well-sorted sandy gravel, with layers of fine sand and silt, mainly near the bottom of the deposit. The well-rounded to rounded cobbles and coarse fraction of gravel consist dominantly of quartzite and limestone with a minor amount of arkose and volcanic rocks. The thickness of gravel and sand varies between 1.5 and 15 m. Maximum thickness from 9 to 15 m was recorded in the central part of the upland (Fig. 19, Profile A-B). A minimum estimate of the gravel reserves on the Del Bonita Upland is 2.3 x 10^8 m^3.

Three preglacial gravel and sand deposits, of areas between 2.5 and 4 km^2, have been found on the lower bedrock terraces (Fig. 4) at elevations between 1080 and 1140 m above sea level, 16 and 10 km south of Fort MacLeod (Deposits 81 and 82) and 40 km south of Lethbridge (Deposit 54). The sand and gravel is overlain by stony sandy till. Although the overburden varies greatly in thickness, between 0.6 and 6 m, it is generally less than 2 m. The average thickness of the deposits is between 4.5 and 7.5 m (Fig. 19, Profile H-I). The minimum estimated reserves are 2.3 x 10^7 m^3 (Deposit 81), 1.9 x 10^7 m^3 (Deposit 82), and 5.3 x 10^7 m^3 (Deposit 54).

The Del Bonita deposit and other deposits of preglacial age consist of sandy gravel with the proportion of gravel varying between 55 and 75 percent. The matrix is composed predominantly of fine-grained sand (Fig. 9). The deposits are classified as clean to dirty. The gravel fraction consists of durable rocks derived from the Rocky Mountains. The amount of weak, locally derived, stones does not exceed five percent.

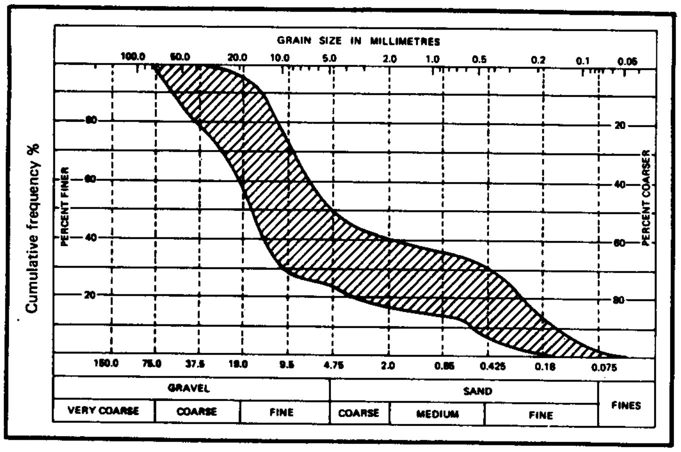


FIGURE 9. Range in grain-size distribution of the preglacial alluvial deposits (8 samples).

The gravel is suitable for most industrial purposes, including concrete and asphalt aggregate, but would require crushing because of its generally coarse nature. At present, a few small pits are contributing to the maintenance of local roads. One pit, 16 km south of Fort MacLeod, is used for asphalt aggregate.

KAME DEPOSITS

Gravel and sand deposits of this origin are scattered throughout the southwestern part of the region, within the Foothills belt. Twenty-two deposits, of areas 1.5 to 50 ha have been recorded in this area. The gravel and sand form mounds, or irregular hills, that stand isolated or in groups. They are situated in low places, between high hills or ridges of bedrock or till. The thickness of the deposits varies within wide limits between 1.5 and 18 m but is generally between 3 and 6 m.

In the northwest portion of the study area, 8 and 16 km to the west of Granum, deposits of this type are also present (Deposits 88, 89, 90). Here they form kame terraces with gently rolling or undulating surfaces. The thicknesses of gravel and sand are up to 17 to 18 m and the areas 26 to 240 ha .

East of the St. Mary River only five gravel-bearing deposits of kame type were found (Deposits 10, 50, 51, 52, 53). Their thicknesses are usually less than 3 m and the areas do not exceed 1.5 ha. The exceptions are the relatively extensive deposits 13 km north of Del Bonita (Deposit 10), and 22 km south of Raymond (Deposit 53), which cover 55 and 50 ha respectively.

The kame gravel and sand deposits are exposed at the surface or have an overburden of silt, fine sand and, in places, till, with thicknesses between 0.3 and 2.4 m. In the western part of the Foothills, the deposits usually consist of two layers. The upper part of the deposits with thicknesses from 1 to 3 m are composed of poorly sorted gravel and sand (Fig. 10), with the content of gravel ranging between 50 and 75 percent (Fig. 11, A). The lower part consists of coarse- and medium-grained clean sand, grading down section into fine-grained sand and silt; proportions of gravel range from 5 to 25 percent (Fig. 11, B). Sand and gravel are horizontally bedded and cross-bedded with a general dip to the south. Lenses and layers of charcoal, up to 5 cm thick, are present in places near the contact between gravel and sand, but generally the amount of

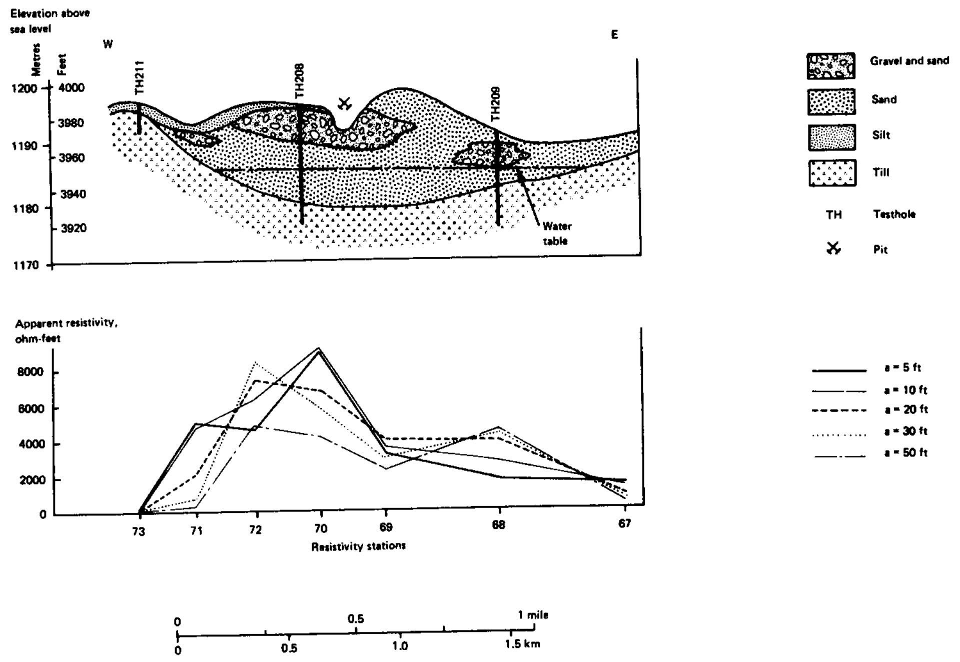


FIGURE 10. Composition of kame, 4 km south-west of Hill Springs (Deposit No. 44).

organic impurities is insignificant and never exceeds 0.1 percent of the volume of the deposit. The deposits in the eastern part of the Foothills are composed of poorly sorted fine- to coarse-grained gravelly sand, with a gravel content of usually 20 to 35 percent. Figures 11 and 12 illustrate the difference in composition and sorting of sand in kame deposits of the southeastern and southwestern parts of the region.

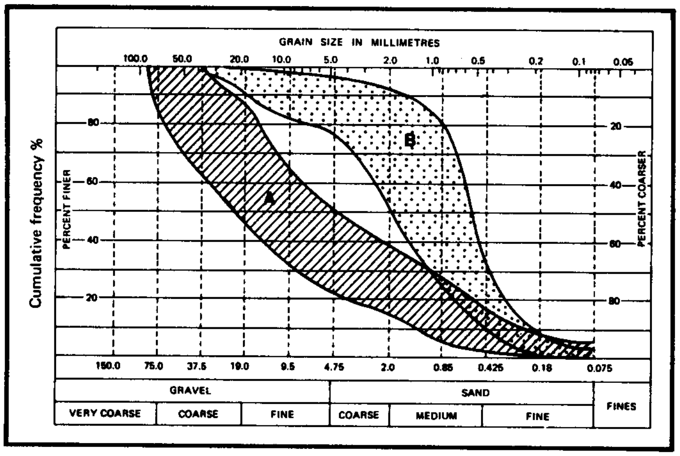


FIGURE 11. Range in grain-size distribution of the kame deposits in the western part of the Foothills:
A - upper gravel and gravelly sand (14 samples)
B - lower sand (9 samples).

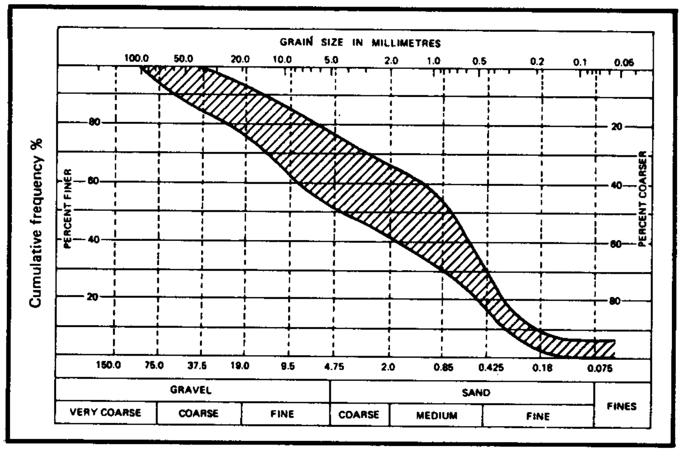


FIGURE 12. Range in grain-size distribution of the kame deposits in the eastern part of the Foothills (5 samples).

The gravel of kame origin consists predominantly (60 to 100 percent) of durable clasts from the Mountains. Deleterious local material generally is absent, or is present in amounts of less than 10 percent, but in places it increases to 20 percent. The content of the rocks derived from the Canadian Shield is small in the west (0 to 12 percent) but is significant in the east (as much as 30 percent).

Minimum estimated reserves of gravel and sand in the individual deposits vary between wide limits, from 7.5 to 10^3 m^3 to 1.1 x 10^7m^3 but generally do not exceed 7.5 x 10^5 m^3. In spite of their relatively small sizes, these deposits are an important source of aggregate material which is being intensively used at present for various purposes: for concrete and asphalt aggregate, for maintenance of gravel roads, and as fill material. The kame deposits are also a good source of clean, coarse- and medium-grained sands that are generally rare in the area.

ESKER DEPOSITS

Only three esker deposits were found within the study area, these are located 9.5 km northeast of Del Bonita, 21 km east of Claresholm, and 11 km east of Parkland.

The deposit near Del Bonita (Deposit 7) forms a short ridge, approximately 2.5 km long and 30 m wide, with a height of 1.5 m. The deposit consists of coarse gravel and cobbles, with a small amount of coarse sand. Dry auger drilling failed to penetrate the gravel below a depth of 1.5 m. The approximate areal extent of the deposit is 28 ha and minimum estimated reserves are 3.8 x 10^5 m^3.

In the northeastern part of the area, esker deposits (Deposits 128, 129) form long narrow ridges as much as 6.5 km long, trending in a southwesterly direction. The heights of the ridges range between 3 and 7.5 m and the widths do not exceed 45 m. The ridges are composed mainly of clean, fine-grained sand, but in places, discontinuous lenses of gravel and poorly sorted fine-, medium-, and coarse-grained sand are present. Their thicknesses vary from 2 to 6 m. The content of gravel in the lenses is between 40 and 55 percent. The coarse fraction of the deposits consists of the rocks derived from the Rocky Mountains (65 to 80 percent) and from the Canadian Shield (20 to 35 percent).

The gravel lenses are scattered within the fine-grained sand deposits and generally are too small to be economically exploited. Thus, the esker deposits, although of good quality, have little use other than for local needs.

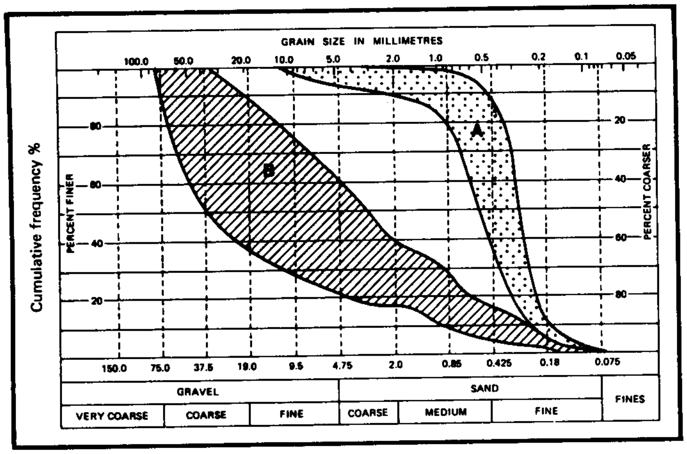


FIGURE 13. Range in grain-size distribution of the outwash deposits:
A - sand (3 samples)
B - gravel and gravelly sand (12 samples).

OUTWASH DEPOSITS

The outwash occurs as sheets composed largely of fine-grained, well-sorted sand with less than 5 percent gravel (Fig. 13, A), which is scattered in the top layers of the sand deposits.

Isolated bodies of sandy gravel and gravelly sand are present in places within ice-contact margins of the outwash plains, where they form low hills or groups of hills of irregular shape (Fig. 19, Profile F-G). Nine gravel-bearing deposits of outwash origin are known in the area. All of them are located within the lowlands extending along the Oldman River and the Little Bow River valleys (Deposits 83, 86, 93, 110, 111, 112, 114, 123, 130).

These deposits are exposed at the surface or buried under silt and fine sand, as much as 1.5 m thick. The thickness of gravel and sand varies from 1.5 to 10.5 m but is mainly between 2 and 4.5 m. The outwash deposits range from clean gravelly sand to sandy gravel, with gravel contents between 30 and 75 percent. The material is generally poorly sorted (Fig. 13, B), and the sorting becomes poorer from the base to the top of the sections. Near the top of the deposits, coarse and unsorted gravel, as much as 1.2 m thick, is generally cemented by calcium carbonate. Sand is mainly medium- and fine-grained although in some deposits coarse-grained sand predominates (Deposits 93, 110).

In the western part of the area (Deposits 86, 93, 130), the gravel largely consists of clasts from the Rocky Mountains (from 70 to 95 percent). The content of stones from the Shield does not exceed 20 percent. Deleterious material derived from local bedrock forms as much as 10 percent of the deposits. In the east, Mountain and Shield rocks are mixed almost in equal proportions: gravel from the Rocky Mountains constitutes from 45 to 65 percent; the Canadian Shield stones, from 35 to 55 percent. The percentages of local bedrock fragments is less than 5 percent.

Deposit areas vary widely between 4 and 97 ha. Their reserves range from 3.0 x 10^5 m^3 to 2.5 x 10^6 m^3.

The outwash gravel and sand is being used mainly for maintenance of gravel roads. They are suitable generally for production of asphalt aggregate, but at present only one deposit located in the western part of the area, 8 km west of Brocket, (Deposit 86) is being used for this purpose.

MARGINAL STREAM DEPOSITS

Gravel and sand deposits of this origin are confirmed to the southeastern quarter of the region, where they form discontinuous terraces on the upper part of the slopes of the ice-marginal channels or, more rarely, are present as channel floor deposits.

Gravel and sand are mostly exposed at the surface; in places, silt overburden is present, up to 1.5 m thick. The thickness of the deposits varies between 1 and 4 m but generally does not exceed 2 m.

The marginal stream deposits are composed mainly of moderately clean gravelly sand or sandy gravel, with a gravel content of 45 to 64 percent. The material is poorly sorted (Fig. 14, A). The gravel is coarse, mainly subangular, and in places roughly horizontally bedded. The content of the Mountain clasts varies between 35 and 55 percent. The content of Shield stones is generally large in these deposits, ranging between 20 and 50 percent. Local bedrock material in places makes up as much as 18 percent of the deposit. Some of the deposits contain lenses and beds composed of angular fragments of shale and sandstone, with a fine sand matrix. Boulders of weathered granite or gneiss are abundant on the surface of the deposits.

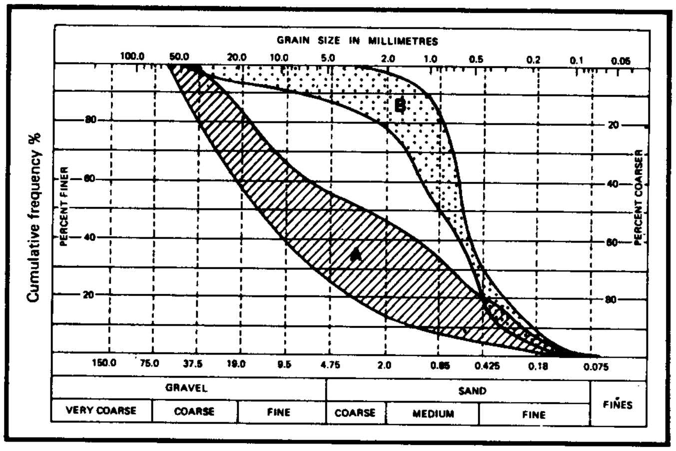


FIGURE 14. Range in grain-size distribution of the marginal stream deposits:
A - gravel and sand (7 samples)
B - sand (2 samples).

A deposit (62) in the western part of the Chin Lake Channel, 25 km east of Lethbridge, differs considerably from the other deposits of this type. Here a small depression on the surface of the generally erosional terrace is filled by well-sorted sand, with a thickness of more than 6 m. The sand is mainly medium-grained (Fig. 14, B), with horizontal layers and lenses of coarse and fine-grained sand, as much as 1 m thick.

The areal extents of the marginal stream deposits vary between 2.5 and 32 ha. The reserves range between 1.9 x 10^5 m^3 and 3.8 x 10^5 m^3.

The gravel and sand of this type are used only for road foundation purposes because of the coarseness of the material and the abundance of deleterious clasts.

VALLEY TRAIN (HIGH RIVER TERRACE) DEPOSITS

The gravel and sand deposits of this origin are the most widespread and variable in composition of all the gravel-bearing deposits.

Forty-one valley train gravel and sand deposits have been reported in the area, varying from minor bodies of area no more than 1.2 ha to extensive mantles covering a few square kilometres.

The deposits are classified into two major subgroups on the basis of their distribution: the deposits of the Oldman River basin, in the western and northern parts of the area; and the deposits of the Milk River basin, confined to the extreme southern part of the region. Vast areas of the divide between the Oldman and Milk Rivers are devoid of gravel and sand of this type.

Deposits of the Oldman River Basin

The valley train terraces have different compositions in the upstream and downstream sections of the basin. The upstream section includes the Waterton and Belly Rivers, Willow Creek, and the upper part of the Oldman River, to its junction with the St. Mary River valley. The downstream section includes the remaining part of the Oldman River and the Little Bow River.

The most extensive upstream deposit is located near Fort MacLeod (Deposit 84) and covers approximately 50 km^2 (Fig. 4). It has an irregular, elongated shape and extends along the Oldman

River for a distance of 16 km. The width of the terrace varies between 2.5 and 4 km. Gravel and sand are exposed at the surface. The deposit has a rather uniform thickness of 3.0 to 3.7 m, increasing in some places near the river to 7.5 m (Fig. 19, Profile C-D).

The material consists of clean gravel and sandy gravel. Fifty-five to 75 percent of the gravel is coarser than 4.6 mm. It ranges from well- to poorly sorted, unbedded or cross-bedded, with bedding dipping to the northeast. The matrix consists of fine and medium sand. In places, the gravel contains lenses of coarse-grained sand. The coarse fraction of the deposit is composed largely of durable rocks derived from the Rocky Mountains (from 20 to 96 percent).

The deposit has four pits in operation for production of asphalt aggregate, road foundation, and fill material. The minimum estimated reserves are approximately 1.5 x 10^8 m^3.

Similar deposits, which cover smaller areas, are also present: in the Willow Creek valley, 3 km west of Claresholm (Deposits 133, 134); the Oldman River valley, 3 km west of Brocket (Deposit 85); and the Waterton and Belly River valleys (Deposits 45, 78, 79, 80). The gravel-bearing material is exposed at the surface or buried under 0.3 to 1.2 m of silt. Gravel content varies between 55 and 75 percent, but is mainly between 60 and 70 percent; the amount of fines does not exceed 3 percent (Fig. 15). The sand matrix is fine- to medium-grained, and more rarely, is coarse- to medium-grained. The gravel is composed mostly of rocks derived from the Rocky Mountains. The thicknesses of the deposits range between 1 and 6 m but mainly between 2 and 4 m. The minimum estimated reserves of the deposits vary between 0.8 x 10^6 m^3 and 2.3 x 10^6 m^3.

The downstream valley train deposits are found along two sections of the Oldman River valley, 16 km north of Lethbridge (Deposits 103 to 108) and in the neighborhood of Taber (Deposits 113, 115 to 121). Four deposits are located in the Little Bow River valley, near the Traverse Reservoir (Deposits 124, 125) and 25 km east of Stavely (Deposits 126, 127). The valley train deposits form elongated, mainly narrow, fill terraces, from 6 to 15 m below the surrounding plain and from 65 to 90 m above the river level.

In the Lethbridge section of the Oldman River, the gravel and sand deposits have an overburden cover of silt, from 0.3 to 1.0 m thick (Fig. 19,

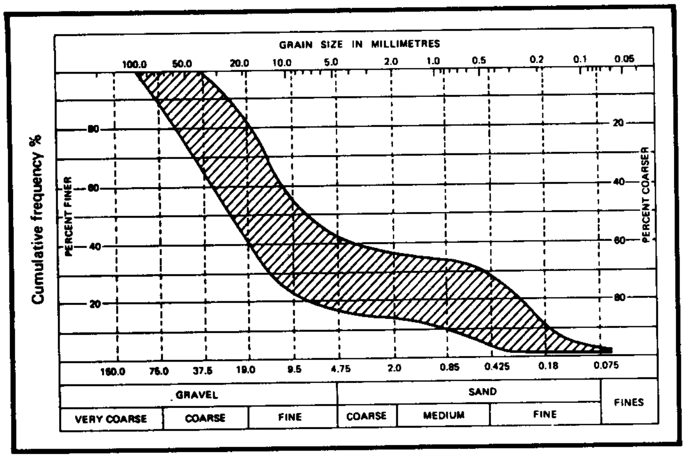


FIGURE 15. Range in grain-size distribution of the valley train (high river terrace) deposits in the Oldman River Basin, upstream sections (16 samples).

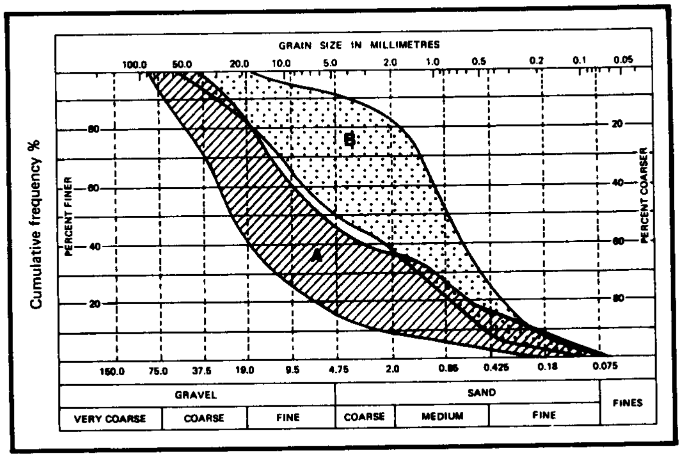


FIGURE 16. Range in grain-size distribution of the valley train (high river terrace) deposits in the Oldman River Basin, downstream sections:
A - Upper gravel (21 samples)
B - Lower sand and gravelly sand (13 samples).

Profile R-S). The thickness of the deposits here varies from 2.5 to 7.5 m. In the Little Bow River valley gravel-bearing material is exposed at the surface and has a thickness between 1.8 and 6 m. In both valleys the deposits generally have a two-layer composition: the top layer, 1.0 to 1.5 m thick, is composed of poorly sorted, clean, coarse and fine gravel, slightly cemented by calcium carbonate (Fig. 16, A); the lower layer consists of moderately to well-sorted, medium to coarse-grained clean sand, (Fig. 16, B) with thin lenses of fine sand and, in places, lenses of soft charcoal. In deposit 105, sand is interbedded with layers of well-rounded, clay and till balls, with diameters between 5 and 15 cm.

In the Taber section gravel-bearing material is exposed at the surface, its thickness varies between 2 and 10 m but averages less than 3 m. The deposits are composed largely of sandy gravel or gravelly sand, from poorly to well-sorted, with gravel content varying widely from 20 to 75 percent.

In the downstream valley train deposits the content of rocks derived from the Canadian Shield is much greater than in the upstream deposits, and constitutes from 10 to 50 percent of the coarse clasts; the content of local bedrock is in most places insignificant, but in some places reaches as much as 15 percent.

The deposits of this type range in area from 1 to 80 ha but are mainly between 20 and 40 ha. The minimum estimated reserves vary from 1.5 x 10^5 m^3 to 5.3 x 10^5 m^3.

Deposits of the Milk River Basin

The valley train deposits of the Milk River valley are confined to the section of the river near the Del Bonita Upland (Deposits 8, 9, 12, 13). Only one deposit (4) was found downstream from the Del Bonita area, 5 km west of Milk River. The gravel and sand deposits are exposed at the surface or have an overburden cover of silt from 0.3 to 1 m thick. Thickness of gravel-bearing material is mainly between 3.0 and 3.5 m.

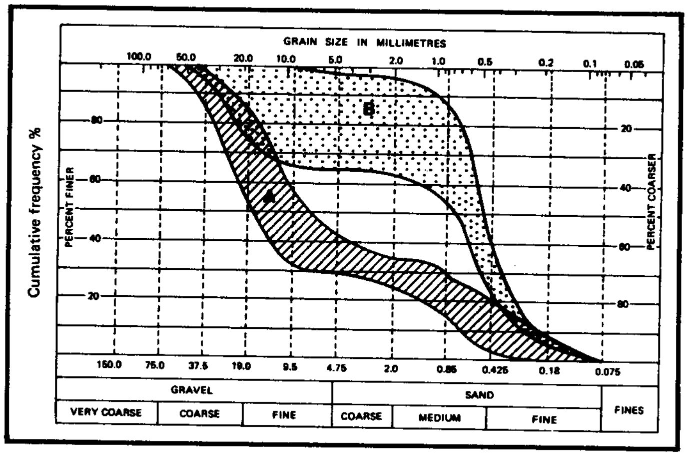


FIGURE 17. Range in grain-size distribution of the valley train (high river terrace) deposits in the Milk River Basin:
A - upstream section - gravel and sand (8 samples)
B - downstream section - mainly sand (2 samples).

The upstream deposits are composed of coarse and fine gravel (60 to 85 percent) and medium- and fine-grained, poorly sorted, clean sand. The downstream deposit (4) has a composition similar to that of the downstream valley train deposits in the Oldman River valley. The upper 1.5 m of the deposit is composed of poorly sorted, slightly cemented gravel (Figure 17, A); the lower layers (4 m) consist of medium-grained sand, with beds of coarse-grained sand and fine gravel (Fig. 17, B).

The gravel consists predominantly of clasts derived from the Mountains (85 to 95 percent) with some Shield-derived stones (5 to 15 percent).

The deposits of the Milk River basin cover from 40 to 120 ha and have reserves between 0.5 x 10^6 m^3 and 2.0 x 10^6 m^3.

The valley train deposits represent one of the best sources of sand and gravel for industry. They are easily accessible and can be readily developed. Coarse material in the upstream river sections is being used at present, after crushing, for asphalt aggregate and for road foundation. Sand from a few of the downstream deposits supplies washed sand for concrete. The operations include screening and washing; the clayey lumps in the sand of deposit 105 have to be removed manually. The gravel material of the downstream sections is being taken from some pits for use as concrete aggregate after screening, crushing, and washing. However, this material is exploited primarily for asphalt aggregate and road foundation, and only crushing is required.

RECENT ALLUVIAL (LOW RIVER TERRACE) DEPOSITS

Gravel-bearing alluvial deposits are believed to be present in most of the depositional terraces in the major river valleys. Generally the gravel is only partly exposed at the surface, and in many areas the gravel and sand deposits are buried under thick covers of floodplain silt and fine sand. Gravel and sand also make up alluvial fans in the Balkiston, Galway, Dunvegan, and Blood Canyon Creek valleys, along the foot of the Rocky Mountains. The composition between upstream and downstream alluvium is not significantly different as was observed for the valley train deposits.

The most extensive deposit of recent alluvial gravel and sand is located near the junction of the Waterton and Belly Rivers, 27 km south of Fort MacLeod (Deposit 49), where the deposit forms a broad terrace with a flat braided surface, 2 to 3 m above the river level, with an areal extent of 14 km^2 (Fig. 4). Gravel and sand are exposed at the surface or, in some places, are buried under fine sand as much as 1.8 m thick. The thickness of the deposit ranges from 1.8 to 4.0 m but is mainly 2.5 m thick. The deposit is composed of poorly sorted, clean, sandy gravel, with 50 to 65 percent of the material greater than 4.6 mm in diameter. It is estimated to contain about 3.0×10^7 m^3 of undeveloped gravel and sand.

Deposits similar in composition are present along the St. Mary, Belly, and Waterton River valleys, (Deposits 16, 17, 28, 32, 33, 37, 47, 48). The gravel generally is poorly sorted, with a considerable amount of coarse material; the matrix consists of fine, medium, and coarse sand. Resistant stones from the Rocky Mountains are predominant (75 to 100 percent); rocks derived from the Canadian Shield compose the remainder of the coarse-grained component; deleterious bedrock material is usually absent. The thickness of the gravel and sand ranges between 1 and 3 m the reserves of the deposits are estimated to vary between 0.5×10^6 m^3 and 2.5×10^6 m.

The alluvial terraces of the Oldman River valley have been best studied along a 55 km section of the river, between Monarch and Diamond City (Fig. 3). Downstream from this section to the eastern boundary of the area the alluvium is composed mainly of silt and fine sand.

Three fill terraces form the bottom of the valley. The highest terrace, with heights between 12 and 16 m above river level, is found only in the upper part of this river section, between Monarch and Kipp. The terrace is generally composed of silt and fine sand, but, in some places, it consists of coarse gravel. The most extensive gravel-bearing deposit within this terrace is located on the south bank of the river, 3 km south of Monarch (Deposit 97). Gravel and sand is exposed at the surface and has a thickness of up to 8 m. The deposit consists of poorly sorted coarse and fine gravel (70 percent) and mainly fine-grained sand. The areal extent is 60 ha; the minimum estimated reserves are about 1.8×10^6 m^3; the deposit has not been developed. Gravel-bearing deposits of the highest fill terrace are being exploited in two pits, No. 33 and No. 37, 3 km west of Kipp (Deposit 99). The resistivity measurements show that the gravel and sand does not extend far beyond these pits.

An intermediate fill terrace was observed in many places along the section described. It has heights between 5.0 and 7.5 m above river level. The terrace is composed mainly of silt and fine sand (Fig. 19; Profiles K-L, M-N, O-P). The gravel-bearing deposits have been recorded in testholes at depths of between 5 and 7 m below surface. The thickness of gravel ranges between 1 and 3 m. These deposits are neither close enough to the surface nor thick enough to be utilized. In places, lenses are present within the upper silt and fine sand deposits. Such lenses are being exploited at present in pits No. 34 and No. 38, about 5 km west of Kipp (Deposit 99). The gravel is exposed at the surface or is buried under silt as much as 3 m thick. The thickness of the deposits varies between 2 and 3 m. The proportion of gravel is about 60 percent. The deposits have a composition similar to the gravel-bearing material of the highest terrace.

The lowest terrace extends along the section described, from Monarch to Diamond City. Its height above the river varies between 2.5 and 3.5 m. The terrace consists of sections built entirely of gravel and sand (Fig. 19, Profiles K-L, M-N) and sections where gravel is covered by fine silty sand and silt (Fig. 19, Profile R-S).

Terraces composed of gravel and gravelly sand prevail in the segment of the valley between Monarch and the junction of the Oldman and St. Mary Rivers. Here the gravel deposits usually are exposed at the surface, or more rarely, have an overburden cover of fine sand, as much as 1.5 m thick (Deposits 73, 75, 76, 95, 96, 97, 99). The gravel is coarse and fine, poorly sorted and clean; the matrix consists mainly of fine and medium sand (Fig. 18). The proportion of gravel varies between 50 and 60 percent, increasing in places to 80 percent. Areal extents range from 20 to 100 ha and the minimum reserves of the deposits are estimated to be between 0.4 x 10^6 m^3 and 3 x 10^6 m^3.

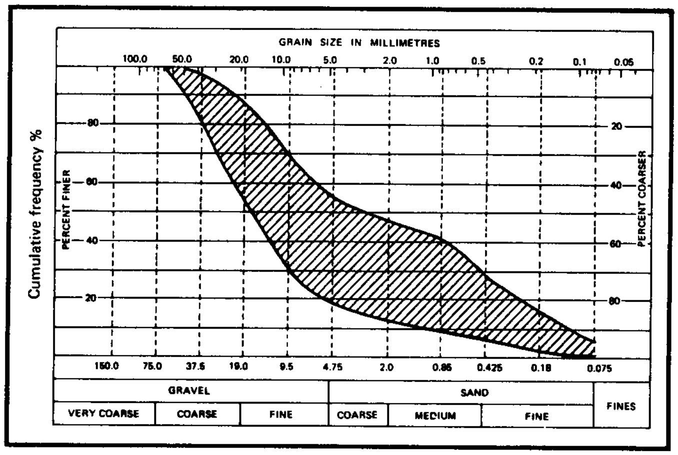


FIGURE 18. Range in grain-size distribution of the recent alluvial deposits (25 samples).

Alluvium with a two-layer composition is present in places in this portion of the river, but it predominates downstream of the junction of the Oldman and St. Mary Rivers. Here the upper part of the lowest terrace is composed of fine-grained sand with scattered lenses of gravel-bearing material. These lenses, varying greatly in extent and thickness, are exploited by a few pits near Lethbridge (Deposits 69, 70, 71, 72, 100). The gravel content in most of the deposits usually does not exceed 25 percent, although the proportion of gravel in some layers may reach as much as 70 percent. The gravel within the lenses is interbedded with fine sand.

The lower beds of the alluvium, generally below the water level, or only a little above, are composed of uniform, coarse and fine, poorly sorted gravel (up to 70 percent) with some fine-grained sand. Beds of gravel have been recorded in the testholes, well logs, and seismic shotholes at depths below surface ranging from 3.0 to 4.5 m. This gravel is believed to extend along the entire river section described. Its thickness varies between 4.5 and 7.5 m. Exploitation of the deposit is complicated, because in large part, it is saturated with water. At present, this gravel is being extracted in two pits, No. 42, 7 km north of Lethbridge, and No. 32, 2.5 km northwest of Kipp. Generally these pits are operated after the high water conditions of spring and early summer have subsided; pumping is used to dewater the pits.

The alluvial gravel consists predominantly of durable rocks derived from the Rocky Mountains (75 to 95 percent). Deleterious materials, such as local bedrock fragments and weathered stones from the Canadian Shield, are practically absent in this type of deposit.

The alluvial deposits are being used for concrete and asphalt aggregate, road-base, and as fill material. The gravel is generally coarse and, for most uses, require crushing and screening.

CONCLUSIONS

The three major groups of gravel and sand deposits in the area are valley train deposits, preglacial deposits, and recent alluvial deposits. Their total reserves are estimated to be hundreds of millions of cubic metres. Most of these deposits are suitable for production of crushed gravel for asphalt aggregate, washed and screened gravel for concrete, crushed gravel for road-base, and gravel for railway ballast. Some of the valley train and recent alluvial deposits supply washed sand for concrete aggregate.

The total reserves of kame, outwash, and marginal stream deposits in the area are estimated to be millions of cubic metres. The outwash and kame gravels are suitable for producing crushed gravel for aggregate and road-base. The marginal stream deposits can serve as a source of crushed gravel for asphalt aggregate and road maintenance.

The esker deposits contain the smallest reserves, estimated to be hundreds of thousands of cubic metres. They can be used as pit-run gravel and sand for local roads. Generally the study area is well provided with gravel for many purposes, but has a shortage of sand of good quality.

Most of the gravel-bearing deposits in the area are now being exploited. Those with limited reserves that will be exhausted within a few years, include: (1) the valley train deposits west and north of Taber; (2) the valley train deposits north of Lethbridge and lenses of alluvial gravel in the vicinity of Lethbridge; (3) the valley train deposit, west of Milk River; (4) most of the kame deposits in Cardston County.

Some of the major deposits which may form the future supplies of gravel in the area are listed below. Some of these deposits are being intensively exploited at present, but have vast reserves, such as the Fort MacLeod deposits. The others are not being utilized because they are located too far from the settlements or are generally unknown.

1. The Fort MacLeod valley train deposit (84): A few pits are being operated at present in the eastern part of the deposit, around Fort MacLeod (Fig. 4): The western part is practically undeveloped.

2. The recent alluvial deposits at Monarch (Deposits 96, 97), 32 km west of Lethbridge (Fig. 3): The deposit has not been developed.

3. The water-bearing alluvial gravel, filling the bottom of the Oldman River valley, between its junctions with the Belly and St. Mary Rivers and near Lethbridge (Fig. 3): It is being extracted at present in two pits.

4. The preglacial alluvial deposit (82), 16 km south of Fort MacLeod (Fig. 4): The deposit has not been developed.

5. The preglacial alluvial deposit (81), 22 km south of Fort MacLeod (Fig. 4): The material is being exploited in two minor pits.

6. The recent alluvial deposit (49), near the junction of the Waterton and Belly Rivers (49), 27 km south of Fort MacLeod (Fig. 4): The deposit has not been developed.

7. The preglacial alluvial deposit (54), 8 km south of Magrath: The deposit has not been developed.

8. The preglacial alluvial deposit at Del Bonita (6), (Fig. 5): Gravel and sand are being exploited in a few minor pits.

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APPENDIX A

GLOSSARY

alluvial: pertaining to material deposited by running water.

alluvial terrace: terrace composed of valley-fill sediments that were originally deposited by stream action and later cut through by the stream, leaving the former floodplain surface some distance above the bed of the present stream.

alluvium: material deposited during relatively recent geological time by running water; includes clay, silt, sand, or gravel in stream beds, floodplains, terraces, alluvial fans, etc.

bedrock: in-place pre-Quaternary material exposed at the surface or underlying the surficial material.

carbonate rocks: sedimentary rocks, mainly limestone and dolomite, consisting chiefly of carbonate minerals.

clast: an individual constituent, grain, or fragment produced by the physical disintegration of rock.

consequent stream: a stream that originates on a newly exposed or recently formed surface and that flows along a course determined entirely by the initial slope and configuration of that surface.

deposit: an accumulation of sediments left in a new location by a natural transportative agent such as water, wind, ice, or gravity.

durable rock: a rock fragment which is hard and inert and can be used as aggregate without breaking, crumbling or reacting with the cementing material.

eolian: pertaining to wind action.

esker: a narrow ridge, often long and sinuous, composed of sand and/or gravel deposited by a meltwater stream flowing in or on glacier ice.

fluvial: pertaining to rivers or streams.

glacial drift: a general term for material moved and deposited by glaciers and by the action of meltwater streams and glacial lakes associated with them.

glaciofluvial deposits: material deposited by streams flowing from, on, or within melting glacier ice, generally composed of sorted, stratified sand and gravel; includes outwash, kame, esker, etc.

glaciolacustrine deposits: material deposited in lakes affected by glacier ice or by meltwater flowing directly from glaciers; composed of well-sorted clay, silt, or sand.

ground moraine: a deposit of till with a flat or undulating surface.

hummocky: an irregular or knob and kettle surface.

hummocky moraine: a deposit of till with a hummocky surface.

ice-contact deposit: material deposited in contact with glacier ice by meltwater; includes kames, eskers, kame terraces, etc.

kame: a round or irregular hill, formed in contact with glacier ice by meltwater; composed of sand and gravel and occasional till blocks.

kame terrace: a terrace formed by the deposition of material from flowing meltwater confined between ice and adjacent high land; usually composed of sorted and stratified sand and gravel.

lacustrine deposit: material deposited in a lake.

marginal stream deposit: discontinuous, narrow body of stratified drift deposited by meltwater streams flowing along the edges of glacial ice.

outwash: a glaciofluvial deposit formed in front of the margin of glacier ice.

plain: a flat to gently undulating surface.

post glacial: pertaining to the time interval since the final disappearance of continental glaciers.

preglacial: pertaining to the time interval prior to the onset of extensive glaciation.

proglacial: the area immediately in front of or beyond the limits of the glacier; proglacial deposits include outwash, glaciolacustrine deposits, etc.

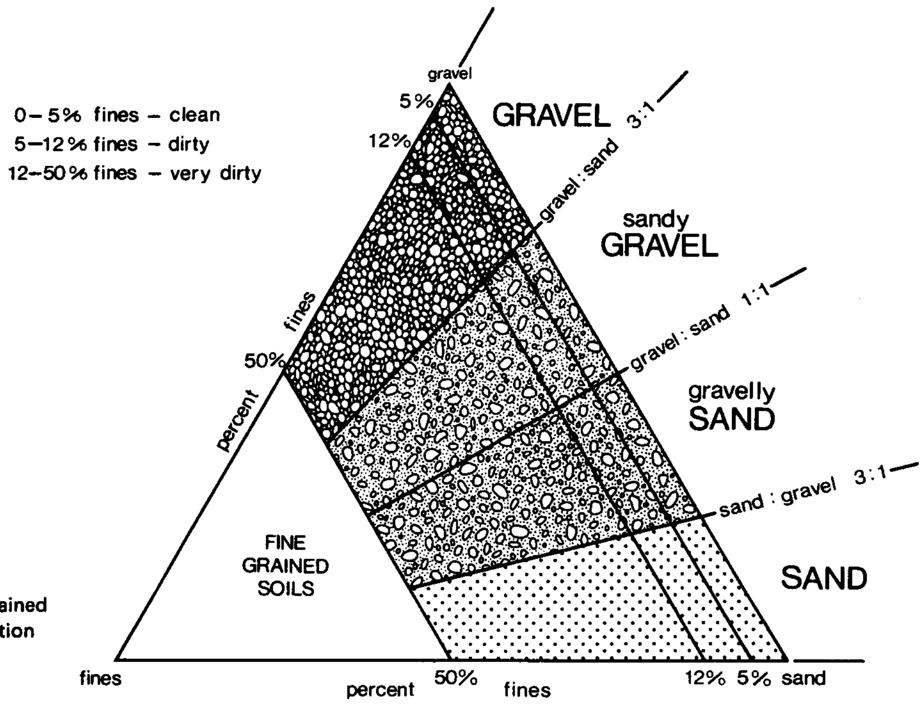
terrace: a relatively flat, stair-stepped, depositional or erosional surface bounded by an ascending slope on one side and a descending slope on the other.

till: unsorted and unstratified sediment deposited directly by glacier ice.

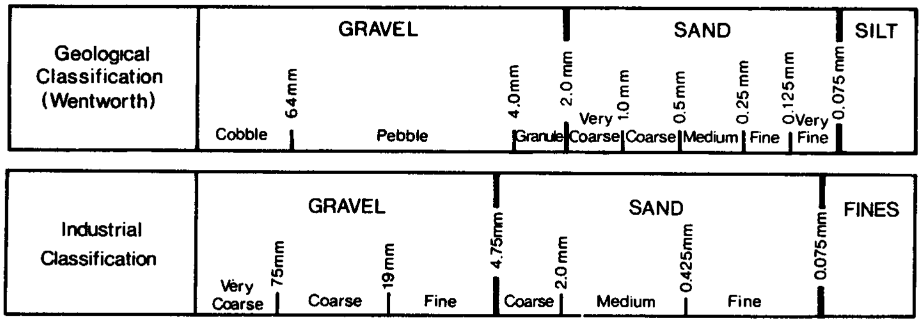
valley train: outwash confined within a valley.

APPENDIX B

CLASSIFICATION OF SEDIMENTS



Classification of unconsolidated, coarse-grained sediments (after the United Soil Classification System).



Geological and Industrial grain-size classification.

APPENDIX C: GRAVEL AND SAND DEPOSITS

Origin	Number on Figure 2	Location (West of 4th Meridian)	Brief Description	Thickness in metres	
				Gravel and Sand	Overburden
Preglacial alluvial deposits	6	**Tp 1, R 21, Secs 3 to 10, 14 to 25, 28 to 31; Tp 1, R 22, Secs 1 to 3, 9 to 16, 21 to 27**	Gravel fine and coarse; sand fine- and medium-grained, clean and moderately clean	1.5 to 15 Avg 4.5	0 to 3 Avg 1.5
Preglacial alluvial deposits	6a	Tp 1, R 23, Sec 36; Tp 2, R 22, Sec 6; Tp 2, R 23, Sec 1	Gravel mainly coarse with some fine, moderately clean; sand fine- and medium-grained	More than 1.5	0.9 to 1.5
Preglacial alluvial deposits	11	TP 3, R 21, Sec 17	Gravel coarse; sand fine- and medium-grained, clean	More than 1.8	2.0
Preglacial alluvial deposits	14	**Tp 2, R 23, Sec 3**	Gravel coarse and fine; sand fine- and medium-grained, clean	More than 1.5	1.2
Preglacial alluvial deposits	54	Tp 5, R 21, Secs 6 to 8; Tp 5, R 22, Sec 1	Gravel fine with some coarse; sand fine-grained, clean	3 to 6 Avg 4.5	0.8 to 4.2 Avg 2.1
Preglacial alluvial deposits	66	Tp 9, R 22, Sec 1	Gravel coarse and fine; sand fine-grained, silty, moderately clean	3 to 6	0 to 3
Preglacial alluvial deposits	67	Tp 9, R 22, Sec 13	Gravel coarse and fine; sand fine-grained, moderately clean	3 to 6	0 to 3
Preglacial alluvial deposits	81	Tp 7, R 26, Secs 4, 9, 10, 15	Gravel coarse; sand fine- and medium-grained, silty, moderately clean	5.5 to 9 Avg 7.5	0.6 to 6 Avg 1.5
Preglacial alluvial deposits	82	Tp 7, R 26, Secs 28, 32, 33, 34,	Gravel coarse and fine; sand fine- and medium-grained, silty, moderately clean	More than 7	1 to 2
Kame deposits	10	**Tp 2, R 21, Secs 8, 17**	Gravel coarse and fine; sand fine- to coarse-grained, clean	1.8 to 2.4	0.3 to 0.5
Kame deposits	15	Tp 1, R 24, Secs 9, 16	Sand fine- and medium-grained, clean with fine gravel	12	0.3 to 1.5
Kame deposits	18	Tp 2, R 25, Secs 22, 23	0 to 2.1 Gravel and sand moderately sorted, clean/ 2.1 to 3.7 Sand medium-grained, clean with some gravel	3	0.6
Kame deposits	19	Tp 2, R 25, Sec 33	Gravel mainly fine; sand fine- to coarse-grained, clean	1.5	

Size Distribution (percentage)			Source of Gravels and Cobbles			Approximate Area in hectares	Minimum Estimated Reserves in cubic metres	Reference Number	
>4.75 mm	0.075 mm to 4.75 mm	<0.075 mm	Rocky Mountains	Canadian Shield	Bedrock			Pits	Testholes
60.4 to 66.3	32.7 to 39.0	0.6 to 1.0	100	0	0	5 000	230 000 000	95 113	175 176 184 to 190 90
56.2	38.6	5.2	100	0	0	240	2 300 000	90	
76.6	22.4	1.0	100	0	0	4	30 000	92	
~70	~30	~0	100	0	0	4	30 000	91	
50.0	49.8	0.2	98	0	2	250	5 300 000		251 to 260
~70	~20	~10	100	0	0	0.2	3 000	16	
~65	~30	~5	100	0	0	0.2	3 000	41	
37 to 55	35 to 54	5 to 10	97	0	3	285	23 000 000	154	27 to 30 265 to 270
~55	~35	~10	95	0	5	365	19 000 000		271 272
75.2	23.2	1.6	92	8	0	55	500 000	93	179 180
7.6	91.3	1.1	60	28	12	35	2 000 000	89	196
53.3	Upper Layer 46.0	1.7	76	4	20	15	200 000	81	
11.2	Lower Layer 87.8	1.0							
65.1	33.4	1.6	92	0	8	7	60 000	80	

Origin	Number on Figure 2	Location (West of 4th Meridian)	Brief Description	Thickness in metres	
				Gravel and Sand	Overburden
Kame deposits	20	Tp 1, R 26, Secs 29, 33	Gravel coarse and fine; sand fine- and medium-grained, clean	2 to 5	1 to 1.5
Kame	21	Tp 2, R 26, Sec 18	0 to 1.2 Gravel coarse and fine; sand fine- to coarse-grained, clean/ 1.2 to 3.0 Interbedding of poorly sorted sand and gravel	3	0
Kame deposits	22	Tp 2, R 26, Sec 7	Gravel coarse and fine; sand fine- to coarse-grained, clean	1.5	0
Kame deposits	23	Tp 1, R 26, Sec 2	Sand medium-grained, well sorted, clean; gravel coarse and fine	1.8	0
Kame deposits	25	Tp 2, R 27 Sec 21, 22	Gravel coarse with some sand; sand medium-grained with layers of fine- and coarse-grained, clean	7.6 to 9.0	1.2 to 2.4
Kame deposits	26	Tp 2, R 27, Sec 17	Gravel fine with lenses of of coarse; sand fine- to coarse-grained, clean	2 to 5.5 Avg 3.7	1.2 to 2.4
Kame deposits	27	Tp 2, R 28, Secs 11, 12	Gravel coarse; sand coarse- and medium-grained	3	0
Kame deposits	30	Tp 2, R 29, Secs 17, 20	Gravel fine and coarse; sand coarse and medium-grained, clean	1.8	0
Kame deposits	31	Tp 2, R 29, Sec 29	Sand fine- to coarse; grained, clean; gravel coarse and fine	10.7	0
Kame deposits	34	Tp 4, R 30, Sec 9	Sand fine- and medium-grained, moderately clean; gravel coarse and fine	1.5 to 2.4	0
Kame deposits	35	Tp 4, R 29, Secs 17, 18, 20	Gravel coarse and fine; sand fine- to coarse-grained, clean	1.8	0
Kame deposits	36	Tp 4, R 29, Sec 21	Gravel coarse and fine; sand medium-grained, clean	3	0
Kame deposits	38	Tp 4, R 29, Secs 14, 15	Gravel fine with some coarse; sand coarse- and medium-grained; clean	4.6 to 9.0 Avg 6	0
Kame deposits	39	Tp 4, R 29, Sec 11	Gravel coarse with some fine; sand coarse- and medium-grained, clean	3 to 5 Avg 3.7	0
Kame deposits	40	Tp 5, R 30, Sec 10	Gravel coarse; sand fine- and medium-grained	1.2	0
Kame deposits	41	Tp 5, R 30, Sec 1	Gravel coarse and fine; sand coarse, clean	2.1 to 4.2 Avg 2.4	0

Size Distribution (percentage)			Source of Gravels and Cobbles			Approximate Area in hectares	Minimum Estimated Reserves in cubic metres	Reference Number	
>4.75 mm	0.075 mm to 4.75 mm	<0.075 mm	Rocky Mountains	Canadian Shield	Bedrock			Pits	Testholes
50.5 to 71.8	25.0 to 48.4	1.1 to 3.2	96	4	0	48	1 000 000	84	200 201
54.6	44.3	1.1	76 to 84	8 to 16	8	5	70 000	82	
~60	~38	~2	---	---	---	3	20 000	83	
~30	~70	--	100	0	0	12	100 000	85	
68.5	sandy gravel 30.4	1.1	88	12	0	40	3 000 000	10	202 203
24.0	sand 75.5	0.5							
63.2	gravel 35.8	1.0	80 to 95	0	5 to 20	23	380 000	7 8 9	
4.0	sand 95.2	0.8							
59.2	39.4	1.4	100	0	0	40	600 000	6	
21.6	78.1	0.3	100	0	0	4	40 000	2	
40.5 to 48.0	50.3 to 59.3	0.2 to 1.7	100	0	0	4	210 000	3	
~35	~55	~10	92	0	8	4	40 000	123	
~60	~40	~0	---	---	---	5	40 000	119	
~65	~35	---	68	20	12	20	300 000	124	
62.8	36.8	0.4	78	10	12	10	300 000	122	
74.1	25.5	0.4	90	10	0	7	130 000	118	
55.8	43.3	0.9	92	0	8	6	35 000	129	
52.1	46.4	1.5	---	---	---	15	330 000	128	214 215

Origin	Number on Figure 2	Location (West of 4th Meridian)	Brief Description	Thickness in metres	
				Gravel and Sand	Overburden
Kame deposits	42	Tp 5, R 29, Secs 5, 6	Gravel coarse and fine; sand fine- to coarse-grained, clean and moderately clean	2.7 to 3.7 Avg 3	0 to 0.6 (0 to 2)
Kame deposits	43	Tp 4, R 28, Secs 2, 3	Gravel fine with lenses of coarse; sand fine- to coarse-grained	2.1	0
Kame deposits	44	Tp 4, R 28, Sec 1	0 to 3 Gravel fine with some coarse; sand coarse and medium-sorted/ 3 to 5.5 Sand medium-grained; gravel fine and coarse	4.6 to 5.5	0 to 1.5
Kame deposits	50	Tp 4, R 23, Secs 3, 4, 9	Sand fine- to coarse-grained; gravel coarse and fine	0.6 to 3 Avg 1.5	0
Kame deposits	51	Tp 4, R 23, Sec 2	Sand fine- to coarse-grained, clean; gravel coarse and fine	2.4	0.5
Kame deposits	52	Tp 4, R 22, Sec 6	Sand fine to coarse-grained, clean; gravel coarse and fine	4.6	0 to 1.5
Kame deposits	53	Tp 4, R 21, Secs 1, 12	Sand fine to coarse-grained, clean; gravel coarse	1.8 to 4.6 Avg 3	0
Kame deposits	56	Tp 6, R 20, Secs 19, 20, 29	Sand medium-grained, well sorted, clean	6	0
Kame deposits	88	Tp 11, R 28, Secs 10, 11, 14, 15	Gravel coarse and fine; sand fine- to coarse-grained, clean	6 to 17 Avg 9	0 to 1
Kame deposits	89	Tp 11, R 28, Sec 25; Tp 11, R 27, Sec 30	Gravel coarse; sand fine-grained, clean and moderately clean	1.2 to 2.7 Avg 1.8	0
Kame deposits	90	Tp 11, R 27, Secs 4, 5	Gravel fine and coarse; sand fine-grained, clean and moderately clean	Up to 18.6	0
Esker deposits	7	Tp 2, R 21, Secs 1, 2, 11, 12	Gravel coarse with pebbles and boulders	More than 1.5	0
Esker deposits	128	Tp 12, R 24, Sec 19, 30; Tp 12, R 25, Secs 25, 35, 36; Tp 13, R 25, Sec 1, 2	Sand fine- and medium-grained; gravel coarse and fine	3 to 10.7 Avg 7.6	0
Esker deposits	129	Tp 15, R 26, Secs 10, 11	Sand fine- and medium-grained; gravel fine and coarse	6	0
Outwash deposits	83	Tp 8, R 26, Secs 17, 18	Sand fine to coarse, clean; gravel mainly fine	10.7	0

Size Distribution (percentage)			Source of Gravels and Cobbles			Approximate Area in hectares	Minimum Estimated Reserves in cubic metres	Reference Number	
>4.75 mm	0.075 mm to 4.75 mm	<0.075 mm	Rocky Mountains	Canadian Shield	Bedrock			Pits	Testholes
41.7 to 76.2	22.9 to 52.3	0.3 to 5.5	88	8	4	35	750 000	125 126	212 213
~60	~39	~1	88	8	4	5	55 000	116	
69.3	Upper layer 29.9	0.8	76	16	8	38	850 000	115	208 to 211
45.4	Lower layer 52.7	1.9							
~25	~73	~2	74	26	0	0.8	7 500	51 52	
21.5	77.7	0.8	65	30	5	0.8	9 000	53	
35.9	63.5	0.6	64	24	12	1.5	35 000	54	
31.5 to 58.7	40.8 to 64.9	0.5 to 3.6	60	36	4	50	750 000	183	123 124
0	100	0	---	---	---	32	1 000 000	55	
66.4	34.7	0.9	78	16	6	240	10 000 000	142 143	53 54
~70	~25	~5	---	---	---	26	200 000	141	
~50	~45	~5	72	20	8	80	7 500 000	144 145	51 52 277, 278
---	---	---	---	---	---	28	380 000		D.H. 177
38.6 to 55.6	42.8 to 60.4	1.0 to 1.6	65 to 80	20 to 35	0	12	300 000	171 172 173	
44.9	54.2	0.9	76	24	0	8	200 000	147	
~0	~30	~70	---	---	---	24	1 400 000		40

Origin	Number on Figure 2	Location (West of 4th Meridian)	Brief Description	Thickness in metres	
				Gravel and Sand	Overburden
Outwash deposits	86	Tp 7, R 29, Secs 9, 10, 16	Gravel coarse and fine; sand coarse- to fine-grained, clean	1.8 to 4.6 Avg 3	0 to 1.5
Outwash deposits	93	Tp 10, R 23, Secs 34; Tp 11, R 23, Sec 2	Gravel coarse; sand fine- to coarse-grained, clean	More than 1	0
Outwash deposits	110	Tp 12, R 20, Sec 10	0 to 1.2 Gravel coarse / 1.2 to 3.7 Sand and gravel; sand coarse and medium-grained, gravel coarse and fine	4 to 9 Avg 7.6	0
Outwash deposits	111	Tp 11, R 20, Secs 26, 35	Sand medium and fine-grained, clean and moderately clean; gravel fine and coarse	1.8	0
Outwash deposits	112	Tp 10, R 18, Secs 14, 23	Sand medium-grained, clean; gravel fine and coarse	2.1	0
Outwash deposits	114	Tp 10, R 17, Secs 9, 16	Gravel fine and coarse; sand fine- to coarse-grained, clean	1.8	0 to 0.6
Outwash deposits	123	Tp 12, R 19, Secs 19, 20, 21, 29, 30	Gravel fine and coarse; sand fine-to coarse-grained, clean grained, clean	1.8 to 6.7 Avg 3.7	0.5
Outwash deposits	130	Tp 15, R 26, Secs 10, 11	Gravel coarse and fine; sand medium-grained, clean	2.1 to 3.7 Avg 2.4	0
Marginal stream deposits	1	Tp 1, R 16, Secs 11, 12	Gravel fine and coarse; sand fine- and medium-grained, clean	1.2	0
Marginal stream deposits	2	Tp 1, R 16, Secs 17, 18	Sand fine-grained, clean; gravel coarse and fine	4	0
Marginal stream deposits	3	Tp 2, R 16, Secs 4, 5	Gravel coarse and fine; sand fine- to coarse-grained, clean	2	0
Marginal stream deposits	5	Tp 1, R 20, Secs 15, 16, 22, 27	Gravel coarse; sand from fine- to coarse-grained, clean	2.4 to 6.4 Avg 3.7	1.2 to 1.5

Size Distribution (percentage)			Source of Gravels and Cobbles			Approximate Area in hectares	Minimum Estimated Reserves in cubic metres	Reference Number	
>4.75 mm	0.075 mm to 4.75 mm	<0.075 mm	Rocky Mountains	Canadian Shield	Bedrock			Pits	Testholes
71.3	28.7	0.3	92	0	8	97	2 500 000	131 132 133 134	45 to 49
67.5	32.0	0.5	70	22	8	10	85 000	103	76
74.9	Upper layer 23.9	1.2	46	54	0	4	300 000	19	D.H. 1 D.H. 2. 87
38.8	Lower layer 59.9	1.3							
5	90	5	50	50	0	12	190 000	20 21	
34.0	65.5	0.5	60	36	4	28	290 000	62	
69.4	29.5	1.1	---	---	---	12	100 000	60	
65.0	34.2	0.8	64	36	0	80	2 500 000	46	85 86
60.2 to 77.2	22.3 to 38.1	0.5 to 1.7	84	16	0	14	350 000	146	
50.6	48.8	0.6	---	---	--	32	190 000	156	
~40	~60	~0	---	---	---	17	350 000	167	
64.0	35.4	0.6	56	26	18	25	230 000	157	
57.3	41.4	1.3	72	28	0	32	190 000	112	171 172

Origin	Number on Figure 2	Location (West of 4th Meridian)	Brief Description	Thickness in metres	
				Gravel and Sand	Overburden
Marginal stream deposits	57	Tp 5, R 19, Sec 36; Tp 5, R 18, Secs 31, 32	Gravel fine and coarse; sand fine- to coarse-grained, with lenses of silt	1.8 to 3	0
Marginal stream deposits	58	Tp 6, R 18, Sec 27	Gravel coarse and fine; sand fine- to coarse-grained, clean and moderately clean	1.2	0
Marginal stream deposits	59	Tp 4, R 17, Sec 35	Gravel coarse and fine; sand fine- and medium-grained	1.2 to 3.7 Avg 2.4	---
Marginal stream deposits	60	Tp 7, R 16, Sec 27, 28	Gravel coarse; sand fine- to coarse-grained, moderately clean	2.1	0.3
Marginal stream deposits	61	Tp 9, R 16, Secs 8, 17, 18	Gravel fine with some coarse; sand fine- to coarse-grained, clean	1.8 to 3 Avg 2.4	0.3
Marginal stream deposits	62	Tp 9, R 19, Sec 1	Sand medium-grained with lenses of fine and coarse sand and fine gravel, clean	More than 6	1
Marginal stream deposits	63	Tp 7, R 19, Sec 5	Gravel fine and coarse; sand fine and medium-grained, clean	1.5	---
Marginal stream deposits	132	Tp 14, R 26, Secs 7, 8	Gravel coarse and fine; sand medium- and coarse-grained, clean and moderately clean	2.1	---
Valley train deposits	4	Tp 2, R 17, Secs 25, 26, 27	0 to 1.5 Gravel fine and coarse with some sand/ 1.5 to 5.5 Sand medium-grained with some coarse sand and gravel	2.4 to 5.5 Avg 3.7	---
Valley train deposits	8	Tp 2, R 21, Secs 10, 11	Gravel fine and coarse; sand fine- to coarse-grained	3	---
Valley train deposits	9	Tp 2, R 21, Secs 5, 8, 9	Sand coarse and medium-grained with layers of organic material; gravel coarse and fine	1.5	1
Valley train deposits	12	Tp 1, R 22, Secs 19, 29, 30	Gravel coarse; sand fine- and medium-grained	3 to 5.2 Avg 3.7	0.3 to 1.2

Size Distribution (percentage)			Source of Gravels and Cobbles			Approximate Area in hectares	Minimum Estimated Reserves in cubic metres	Reference Number	
>4.75 mm	0.075 mm to 4.75 mm	<0.075 mm	Rocky Mountains	Canadian Shield	Bedrock			Pits	Testholes
56.3	43.0	0.7	78	18	4	24	300 000	77 78 79	126 127 128
∼55	∼40	∼5	48	48	4	28	170 000	97 98	129 130
71.3	27.1	1.6	64	24	12	16	380 000	160	135
∼50	∼40	∼10	64	36	0	32	350 000	96	136 137 138
43.7	54.0	2.3	80	20	0	24	290 000	73	
14.8	83.5	1.7	24	76	0	5	115 000	75	
70.8	27.6	1.6	56	44	0	2.5	19 000	76	
∼60	∼35	∼5	72	20	8	32	350 000	136	217
∼30	∼70	∼0	92	8	0	40	760 000	158 159	163 164
66.8	31.1	1.1	84	16	0	77	1 000 000	114	
∼15	∼85	∼0	95	5	0	80	610 000		182 181
61.8 to 77.0	20.7 to 37.0	0.9 to 2.3	96	4	0	120	2 000 000	99	D.H. 192

Origin	Number on Figure 2	Location (West of 4th Meridian)	Brief Description	Thickness in metres	
				Gravel and Sand	Overburden
Valley train deposits	13	Tp 1, R 23, Sec 14	Gravel coarse; sand coarse- to fine-grained, clean	6	1.2
Valley train deposits	24	Tp 2, R 27, Sec 11	Gravel coarse and fine; sand coarse- and medium-grained, clean	5.5	---
Valley train deposits	29	Tp 1, R 29, Sec 31	Gravel fine; sand coarse- and medium-grained, clean	2.7	0.3
Valley train deposits	45	Tp 5, R 27, Sec 35; Tp 6, R 27, Sec 2	Gravel coarse and fine; sand coarse- and medium-grained clean	1.2 to 2.7 Avg 8	---
Valley train deposits	46	Tp 5, R 27, Secs 25, 36; Tp 5, R 26, Secs 30, 31	Gravel coarse and fine; sand medium-grained	1.5 to 2.1	0 to 0.5
Valley train deposits	65	Tp 8, R 21, Secs 17, 20	Sand medium-grained; gravel coarse and fine	2.7 to 6 Avg 3.7	0 to 2.4
Valley train deposits	78	Tp 8, R 25, Secs 11, 14, 15, 23	Gravel coarse and fine with some sand, fine- and medium-grained, clean	1.5	---
Valley train deposits	79	Tp 7, R 25, Secs 23, 25, 26	Gravel coarse and fine; sand fine- and medium-grained, clean	1.8 to 3 Avg 2.1	---
Valley train deposits	80	Tp 6, R 25, Secs 29, 32, 33; Tp 7, R 25, Sec 3	Gravel coarse and fine; sand medium-grained	1 to 2.1 Avg 1.5	---
Valley train deposits	84	Tp 9, R 25, Secs 5 to 16, 17; Tp 9, R 26, Secs 1 to 18, 23, 24; Tp 9, R 27, Secs 1 to 4, 10 to 15	Gravel coarse and fine; sand coarse- to fine-grained, clean	1.5 to 7.6 Avg 3	0
Valley train deposits	85	Tp 7, R 29, Secs 12, 13	Gravel coarse and fine; sand coarse- and medium-grained clean	3 to 4.6 Avg 3.4	0 to 1
Valley train deposits	87	Tp 7, R 30, Secs 24, 25	Gravel coarse; sand coarse- and medium-grained, clean	2.1 to 3.7 Avg 2.4	---

Size Distribution (percentage)			Source of Gravels and Cobbles			Approximate Area in hectares	Minimum Estimated Reserves in cubic metres	Reference Number	
>4.75 mm	0.075 mm to 4.75 mm	≤0.075 mm	Rocky Mountains	Canadian Shield	Bedrock			Pits	Testholes
87.4	11.2	1.4	84	16	0	12	350 000	100	
51.4	47.6	1.0	76	24	0	5	130 000	11	
76.0	23.4	0.6	---	---	---	49	610 000	1	
~60	~37	~3	96	4	0	120	1 000 000		68
51.8 to 75.2	24.0 to 47.0	0.8	88	8	4	60	1 000 000	177 178	70
20.3 to 47.5	51.9 to 79.2	0.5	58	40	2	20	380 000	12 13	107 to 110
~75	~25	~0	---	---	---	305	2 500 000		18 19
75.6	23.2	1.2	96	4	0	35	720 000	175 176	21
69.5	28.3	2.2	100	0	0	160	2 500 000	155	23
57.5 to 77.5	21.1 to 40.5	0.4 to 1.4	90 to 96	6 to 10	0	4,920	150 000 000	106 to 110, 152, 153, 163, 164, 167	1 to 15, 34
69.5 to 74.3	24.9 to 29.4	0.8 to 1.1	96	0	4	77	1 300 000	134 135	43
86.1	13.0	0.9	96	4	0	60	750 000	130	

Origin	Number on Figure 2	Location (West of 4th Meridian)	Brief Description	Thickness in metres	
				Gravel and Sand	Overburden
Valley train deposits	91	Tp 10, R 24, Sec 30	Gravel coarse; sand fine- to coarse-grained	1	0.3
Valley train deposits	92	Tp 10, R 24, Sec 16	Gravel coarse and fine; sand fine- to coarse-grained	2.1	---
Valley train deposits	103	Tp 10, R 21, Secs 15, 16	Gravel coarse and fine; sand fine- to coarse-grained	2.4	0.6
Valley train deposits	104	Tp 10, R 21, Sec 22	0 to 1.5 Gravel coarse; sand fine- to coarse- grained/ 1.5 to 5 Sand medium-grained with fine gravel	5.2	0.3 to 1.2
Valley train deposits	105	Tp 10, R 21, Sec 23	Sand medium-grained with lenses of fine gravel, coarse- and fine-grained sand	6	0.6 to 1.2
Valley train deposits	106	Tp 10, R 21, Secs 24, 25	0 to 1.5 Gravel coarse; sand coarse- to fine- grained/ 1.5 to 4.6 Sand medium-grained with lenses of fine gravel and coarse fine sand	4 to 7 Avg 4.6	0.3 to 1
Valley train deposits	107	Tp 10, R 20, Secs 19, 20	0 to 1.5 Gravel coarse and fine; sand fine- to coarse-grained / 1.5 to 5.8 Sand medium- and coarse-grained with fine gravel	1.2 to 5.8 Avg 4.6	0.3 to 1
Valley train deposits	108	Tp 10, R 20, Sec 26	Gravel fine and coarse; sand coarse- and medium-grained	2.7 to 3.7	0.3 to 0.5
Valley train deposits	109	Tp 10, R 19, Secs 28, 33	Gravel coarse and fine; sand medium-grained	5.6	---
Valley train deposits	113	Tp 10, R 18, Sec 24; Tp 10, R 17, Secs 18, 19	Gravel fine with some coarse; sand medium- and fine-grained	2.1	0 to 0.6
Valley train deposits	115	Tp 10, R 17, Secs 2, 10, 11, 12	Gravel coarse and fine; sand medium-grained	2.4	0 to 0.37
Valley train deposits	116	Tp 10, R 17, Sec 13	Gravel fine and coarse; sand fine- to coarse-grained	1.1	0.5
Valley train deposits	117	Tp 10, R 16, Sec 31; Tp 11, R 16, Sec 5	Gravel fine; sand coarse- and medium-grained	3	0.6

Size Distribution (percentage)			Source of Gravels and Cobbles			Approximate Area in hectares	Minimum Estimated Reserves in cubic metres	Reference Number	
>4.75 mm	0.075 mm to 4.75 mm	<0.075 mm	Rocky Mountains	Canadian Shield	Bedrock			Pits	Testholes
74.9	22.5	2.7	76	24	0	2	15 000	104	75
45.2 to 60.6	52.6 to 38.7	0.7 to 2.2	---	---	---	1.2	14 000	102	72
67.4 to 70.9	29.2 to 30.0	0.9 to 2.6	68	32	0	1.2	15 000	28	225 226
75.6 12.7	gravel 22.6 sand 86.2	1.8 1.1	70	30	0	4	100 000	27	
9.7	87.9	2.4	54	46	0	12	360 000	45	103 104 105
52.3 to 83.2 0 to 33.5	gravel 14.8 to 46.6 sand 65.9 to 10 0	1.1 to 2.1 0 to 0.6	64	36	0	26	600 000	23 24 25 26	90 90a 91 92 93 94
61.3 to 67.5	gravel 31.5 to 35.1	1.0 to 3.6	68	30	2	20	460 000	56	99 100
~65	~30	~5	68	32	---	20	380 000	22	95 96
87.8	11.7	0.5	---	---	---	8	270 000	65	20 21
~70	~30	~0	70	26	4	50	460 000	61	
55.7 to 63.7	34.5 to 43.0	1.3 to 1.8	52 to 54	30 to 48	6 to 16	24	290 000	56 57	
~50	~50	~0	68	32	0	4	19 000	58	
77.9	19.7	2.4	64	36	0	26	380 000	181	149

Origin	Number on Figure 2	Location (West of 4th Meridian)	Brief Description	Thickness in metres	
				Gravel and Sand	Overburden
Valley train deposits	118	Tp 10, R 17, Sec 36; Tp 11, R 16, Sec 6	Gravel fine and coarse; sand medium-grained	9.8	---
Valley train deposits	119	Tp 11, R 16, Secs 31, 32	Sand medium-grained with some gravel	4.6	---
Valley train deposits	120	Tp 12, R 16, Secs 2, 3	Gravel fine and coarse; sand fine- and medium-grained	1.8	0.6
Valley train deposits	121	Tp 11, R 16, Secs 26, 34, 35	Gravel fine and coarse; sand fine- to coarse-grained with lenses of well sorted coarse sand	1.8 to 6 Avg 4.2	0.2 to 0.5
Valley train deposits	122	Tp 15, R 16, Secs 1, 12	Sand fine- and medium-grained; gravel fine- and coarse-grained	2	0.2
Valley train deposits	124	Tp 14, R 20, Secs 17, 18	Gravel fine with some coarse; sand medium- and coarse-grained	4.6	---
Valley train deposits	125	Tp 14, R 20, Sec 4, 9	0 to 1.2 Gravel fine and coarse; sand fine- to coarse- grained/ 1.2 to 6 Sand coarse- and medium-grained with fine gravel	6	---
Valley train deposits	126	Tp 14, R 25, Secs 1, 11, 12, 13	0 to 1 Gravel fine and coarse; sand fine- to coarse-grained/ 1 to 4.6 Sand fine to coarse with fine gravel	2.1 to 4.6 Avg 3	---
Valley train deposits	127	Tp 14, R 25, Secs 23, 26, 27	Gravel coarse and fine; sand medium- and coarse-grained	1.8	---
Valley train deposits	131	Tp 15, R 26, Secs 3, 4, 9, 10	Gravel coarse and fine with lenses of sand, coarse- and medium-grained	2.1 to 3.7 Avg 2.4	---
Valley train deposits	133	Tp 12, R 28, Secs 13, 24	Gravel fine and coarse; sand medium- and coarse-grained	4.3	1.2
Valley train deposits	134	Tp 12, R 28, Secs 23, 26, 35	Gravel fine and coarse; sand medium- and coarse-grained	3.7 to 5.8 Avg 4.3	0.3 to 1

Size Distribution (percentage)			Source of Gravels and Cobbles			Approximate Area in hectares	Minimum Estimated Reserves in cubic metres	Reference Number	
>4.75 mm	0.075 mm to 4.75 mm	<0.075 mm	Rocky Mountains	Canadian Shield	Bedrock			Pits	Testholes
~30	~70	~0	---	---	---	6	290 000		142
~25	~75	~0	---	---	---	32	610 000		145
~25	~75	~0	64	36	0	49	380 000	70	146 147
70.3 to 78.2	20.5 to 29.0	0.3 to 1.3	76 to 92	8 to 24	0	80	1 700 000	67 68 69	
42.8	55.9	1.3	76	24	0	20	200 000	72	156 157
73.5	26.0	0.5	51	49	0	28	650 000	47	81 82
59.7 27.7	gravel 38.8 sand 71.7	1.5 0.6	74	26	0	20	610 000	48	84
72.5 23.3 to 45.6	gravel 25.8 sand 33.6 to 76.0	1.7 0.2 to 0.8	76 to 88	12 to 24	0	36	530 000	149 150 170	222 223
52.7	47.1	0.2	80	20	0	20	180 000	148	221
42.0 to 72.5	26.5 to 57.8	0.2 to 1.0	80	12	8	40	490 000	137	218
62.7	36.4	0.9	84	16	0	36	760 000	139	
52.7	47.1	0.2	96	0	4	60	1 300 000	140	58 216

Origin	Number on Figure 2	Location (West of 4th Meridian)	Brief Description	Thickness in metres	
				Gravel and Sand	Overburden
Recent alluvial deposits	16	Tp 1, R 25, Secs 25, 36; Tp 2, R 25, Sec 1	Sand fine- and medium-grained; gravel coarse and fine	2.1	0.6 to 0.9
Recent alluvial deposits	17	Tp 2, R 25, Secs 11, 12, 13	Sand fine- and medium-grained; gravel coarse and fine	1.8	0.3 to 0.6
Recent alluvial deposits	28	Tp 3, R 27, Secs 18, 19; Tp 3, R 28, Sec 13	Gravel coarse; sand fine- and medium-grained	1.8 to 3.0 Avg 2.4	---
Recent alluvial deposits	32	Tp 3, R 29, Sec 7; Tp 3, R 30, Secs 11, 12	Gravel coarse; sand fine- to coarse-grained	2.1 to 3.7 Avg 3	0.3 to 0.5
Recent alluvial deposits	33	Tp 3, R 30, Secs 21, 22	Gravel coarse; sand fine- to coarse-grained	0.9 to 1.8 Avg 1.5	---
Recent alluvial deposits	37	Tp 4, R 29, Secs 8, 9	Gravel coarse; sand fine- to coarse-grained	1.5	0.5
Recent alluvial deposits	47	Tp 5, R 27, Sec 36; Tp 5, R 26, Sec 31	Gravel coarse; sand fine-grained	2.1	---
Recent alluvial deposits	48	Tp 4, R 26, Secs 31, 32; Tp 5, R 26, Secs 5, 6	Gravel coarse; sand fine- to coarse-grained	2.1	0.9
Recent alluvial deposits	49	Tp 6, R 25, Secs 18 to 21, 27 to 29, 33, 34	Gravel coarse and fine; sand fine- to coarse-grained	1.8 to 4 Avg 2.4	0 to 1.8
Recent alluvial deposits	55	Tp 6, R 23, Secs 13, 14	Sand medium- and coarse-grained; gravel coarse and fine	1.5	---
Recent alluvial deposits	64	Tp 7, R 21, Secs 18, 19	Gravel coarse and fine; sand fine-grained	8.2	2.1
Recent alluvial deposits	68	Tp 7, R 22, Secs 25, 26	Gravel coarse and fine; sand fine-grained	8.5	4
Recent alluvial deposits	69	Tp 8, R 22, Sec 12	Sand fine-grained with lenses of coarse gravel	3	---
Recent alluvial deposits	70	Tp 8, R 21, Sec 18	Sand fine-grained, clean with lenses of coarse gravel	3.7	---
Recent alluvial deposits	71	Tp 9, R 22, Secs 12, 13	Sand fine-grained with coarse gravel	2.4	---

Size Distribution (percentage)			Source of Gravels and Cobbles			Approximate Area in hectares	Minimum Estimated Reserves in cubic metres	Reference Number	
>4.75 mm	0.075 mm to 4.75 mm	<0.075 mm	Rocky Mountains	Canadian Shield	Bedrock			Pits	Testholes
~30	~65	~5	96	4	0	225	2 750 000	88	197
36.0 to 50.5	48.6 to 62.0	0.9 to 2.0	76	16	8	125	1 000 000	87	198
~50	~50	0	---	---	---	90	1 000 000		206
62.4 to 76.1	23.3 to 37.2	0.4 to 0.6	100	0	0	175	2 700 000	4	207
55.0 to 70.0	29.7 to 44.8	0.2 to 0.3	100	0	0	83	610 000	5	
~65	~30	~5	82 to 90	4 to 10	5 to 8	42	300 000	120 121	
72.0	26.4	1.6	88	12	0	170	1 800 000	179	70
~65	~25	~10	---	---	---	48	460 000		261
65.2	31.4	3.4	---	---	---	1400	30 000 000		63, 64 65, 66
48.9	50.5	0.6	74	12	14	1.5	11 000	49 50	116
~50	~50	~0	---	---	---	24	760 000		112
~70	~30	~0	---	---	---	73	1 500 000		111
~10	~90	~0	---	---	---	8	38 000	15	
~25	~75	~0	90	10	~0	10	60 000	14	
~30	~70	~0	86	14	~0	16	76 000	30	

Origin	Number on Figure 2	Location (West of 4th Meridian)	Brief Description	Thickness in metres	
				Gravel and Sand	Overburden
Recent alluvial deposits	72	Tp 9, R 22, Sec 13	Sand fine-grained with fine gravel	1.8	---
Recent alluvial deposits	73	Tp 8, R 22, Secs 9, 10	Gravel coarse; sand fine-grained	7.6	0.3
Recent alluvial deposits	74	Tp 8, R 22, Sec 30; Tp 8, R 23, Sec 25	Gravel coarse; sand fine-grained	>5	0 to 2.5
Recent alluvial deposits	75	Tp 8, R 22, Sec 31; Tp 9, R 22, Sec 6	Gravel coarse and fine; sand fine-grained	4.9 to 7.9 Avg 6	0 to 1.2
Recent alluvial deposits	76	Tp 9, R 23, Sec 24	Gravel coarse; sand fine-grained	More than 1.5	0.6
Recent alluvial deposits	77	Tp 7, R 24, Secs 30, 31; Tp 7, R 25 Secs 35, 36	Gravel fine; sand fine-grained	4	0.6 to 1.5
Recent alluvial deposits	94	Tp 10, R 24, Sec 3	Gravel coarse; sand fine-grained	2.1 to 5.8 Avg 3.7	---
Recent alluvial deposits	95	Tp 9, R 23, Sec 31; Tp 10, R 23, Sec 6; Tp 10, R 24, Sec 1	Gravel coarse and fine; sand fine- and medium-grained	4.6 to 6.1	---
Recent alluvial deposits	96	Tp 9, R 23, Sec 33	Gravel coarse and fine; sand fine-grained	6.5	0.6
Recent alluvial deposits	97	Tp 9, R 23, Sec 33	Gravel coarse and fine; sand fine- and medium-grained	Up to 8.2	0.06
Recent alluvial deposits	98	Tp 9, R 23, Secs 34, 35	Gravel fine and coarse; sand medium- and fine-grained	4.6	0 to 0.9
Recent alluvial deposits	99	Tp 9, R 23, Secs 25, 26, 36	Gravel coarse and fine; sand fine- to coarse-grained	2.4 to 7.6 Avg 4.6	0 to 2.1
Recent alluvial deposits	100	Tp 9, R 22, Sec 24; Tp 9, R 21 Secs 19, 30	Gravel coarse and fine; sand fine-grained	2.1	---
Recent alluvial deposits	101	Tp 9, R 21, Secs 30, 31; Tp 10, R 21, Sec 6	Gravel fine and coarse; sand fine- to coarse-grained	6.1	2.1 to 4.2
Recent alluvial deposits	102	Tp 10, R 21, Secs 9, 10	Gravel coarse and fine; sand fine- to coarse-grained	2.1	---

Size Distribution (percentage)			Source of Gravels and Cobbles			Approximate Area in hectares	Minimum Estimated Reserves in cubic metres	Reference Number	
>4.75 mm	0.075 mm to 4.75 mm	<0.075 mm	Rocky Mountains	Canadian Shield	Bedrock			Pits	Testholes
~20	~80	~0	---	---	---	16	60 000	39	
~60	~40	~0	---	---	---	30	690 000		40 41
~50	~50	~0	---	---	---	20	380 000		
~55	~45	~0	---	---	---	57	1 700 000		43 44 45
60.9	37.7	1.4	96	4	~0	24	340 000	162	
~35	~65	~0	---	---	---	100	1 500 000		20
68.6 to 80.2	18.5 to 30.8	0.6 to 1.3	96	4	~0	22	380 000	101	73 74
68.3	31.3	0.4	80	20	~0	90	2 000 000		236 237 238
~50	~50	~0	---	---	---	100	3 000 000		241 245 246
69.2	29.1	1.7	---	---	---	60	1 800 000		247 248
43.6	55.5	0.9	---	---	---	73	1 500 000		232 233 234 235
47.9 to 79.0	20.0 to 45.7	1.0 to 6.4	76 to 96	2 to 6	2 to 16	485	7 500 000	32 to 38	
~40	~60	~0	88	12	0	20	60 000	43	
71.2	26.6	2.2	96	4	0	100	1 500 000	42	106
81.2	16.6	2.2	80	20	0	36	760 000	29 165	224

GRAVEL AND SAND EXPOSED AT SURFACE OR COVERED BY LESS THAN 10 FEET OF OVERBURDEN

■	Gravel	– gravel 75-100%, sand 0-25%, fines 0-10%
■	Sandy gravel	– gravel 50-75%, sand 25-50%, fines 0-10%
■	Gravelly sand	– gravel 25-50%, sand 50-75%, fines 0-10%
■	Sand	– gravel 0-25%, sand 75-100%, fines 0-10%
□	Possible gravel and sand deposits	

GRAVEL AND SAND COVERED BY MORE THAN 10 FEET OVERBURDEN

▨	Recorded in testholes and well logs
▨	Assumed on basis of geological associations
1	Sandstone, siltstone and shale (bedrock)
2	Till
3	Silty sand, silt and clay
4	Sand fine-grained

Geological boundary; defined, assumed	
Sand and gravel pit, pit number	27
Pit area if it is extensive	
Testhole drilled by ARC, hole number	● 248
Water well log	○
Seismic shothole	▽
Deposit reterence number on map 2 in appendix C	99
Thickness of overburden / Thickness of gravel and sand	13 / 29
Geological profile location	C D
Ground resistivity traverse location	

LEGEND

- River or stream
- Intermittent river or stream
- Lake
- Intermittent lake
- Road, hard surface, all weather 2
- Railway
- Township boundary
- Section line
- Contours definite, approximate 3000

Scale 1:50,000

1 0 1 2 3 Miles

1 0 1 2 3 4 Kilometres

Compiled by I. Shetson
Cartography by A.R.C. Drafting Services

Published 1981

GRAVEL AND SAND DEPOSITS LETHBRIDGE AREA (WEST HALF)

ALBERTA

NTS 82H/11, 82 H/14

QUATERNARY

RECENT

E	Eolian deposits: sand and silt
Atd	Alluvial terraces: gravel, sand and silt
AS	Alluvial fans: gravel and sand

PLEISTOCENE

GLACIOLACUSTRINE

LG	Lacustrine deposits: sand, silt and clay

GLACIOFLUVIAL

Proglacial deposits

AGSt	Valley train (high alluvial terrace) deposits: gravel, sand and silt
AGS	Marginal stream deposits: gravel and sand
AG	Outwash deposits: gravel and sand

Ice-contact deposits

AGK	Kame deposits: gravel, sand and silt
AGE	Esker deposits: gravel and sand

GLACIAL

Th	Hummocky moraine: till with sporadic lenses of gravel, sand and silt
Tr	Ground moraine: till with sporadic lenses of gravel, sand and silt

$\frac{Th}{6}$ * should read $\frac{Tr}{6}$

TERTIARY

Upper Tertiary

PA	Preglacial alluvium: gravel, sand

LITHOLOGIC TYPES

1	Sandstone, siltstone and shale (bedrock)
2	Gravel
3	Sand and gravel
4	Sand and silt
5	Silt and clay
6	Till

Geological boundary: defined, assumed

LEGEND

River or stream

Intermittent river or stream

Lake

Intermittent lake

Road, hard surface, all weather

Railway

Township boundary

Section line

Sources of Information

Surficial geology, High River, Alberta, by A. Mac S. Stalker. Geological Survey of Canada Map No. 14 - 1957.

Surficial geology, Fort MacLeod, Alberta, by A. Mac S. Stalker. Geologicial Survey of Canada Map No. 21 - 1958.

Surficial geology, Lethbridge, Alberta, by A. Mac S. Stalker. Geological Survey of Canada Map No. 41 - 1962.

Surficial geology, Bassano, Alberta, by A. Mac S. Stalker. Geological Survey of Canada Map No. 5 - 1965.

Surficial geology map of the Vauxhall District, Alberta, by L.A. Bayrock and J.F. Jones. Alberta Research Council Preliminary Report 63-2.

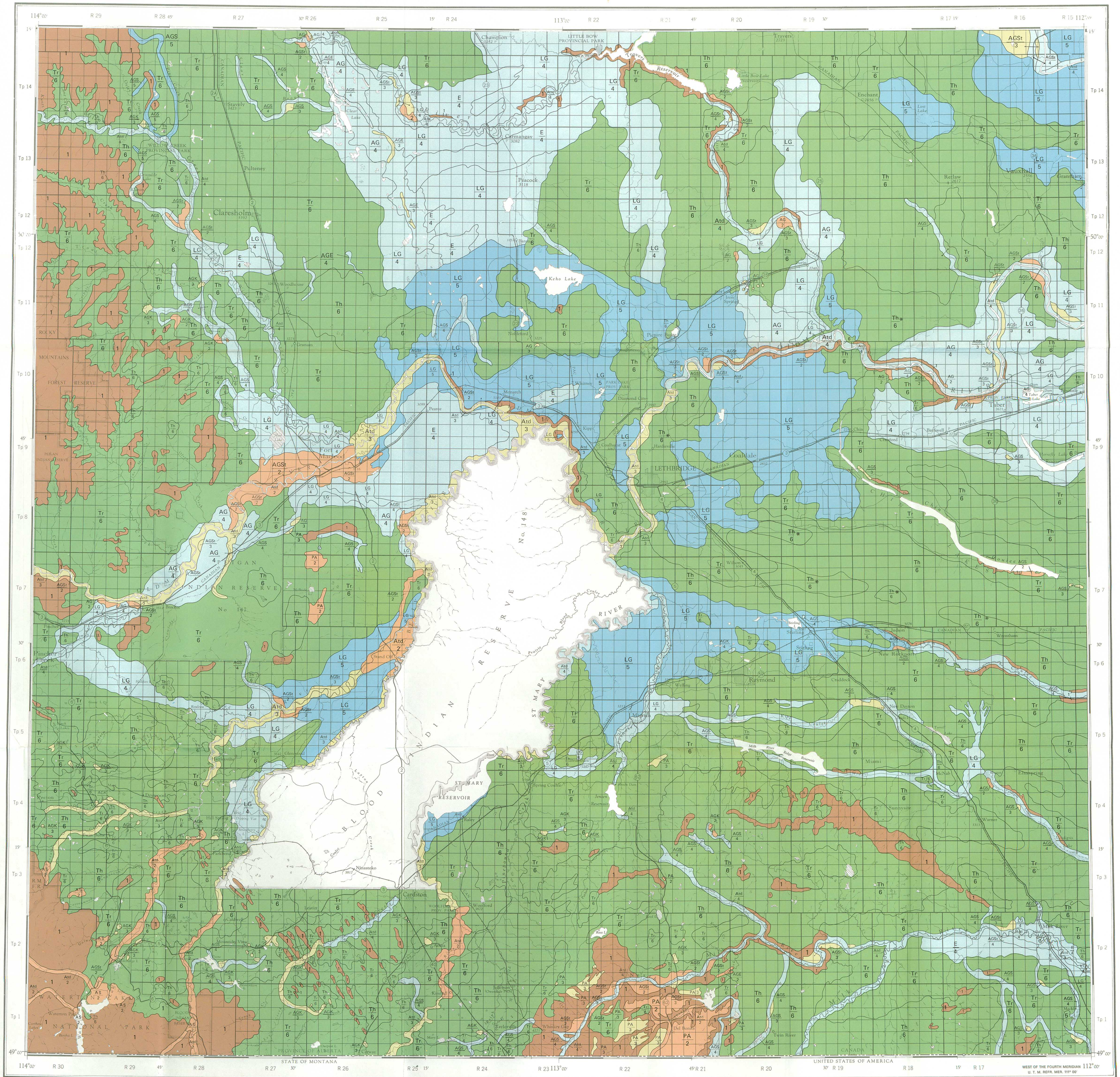
Compiled by I. Shetsen

SCALE 1:250,000

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

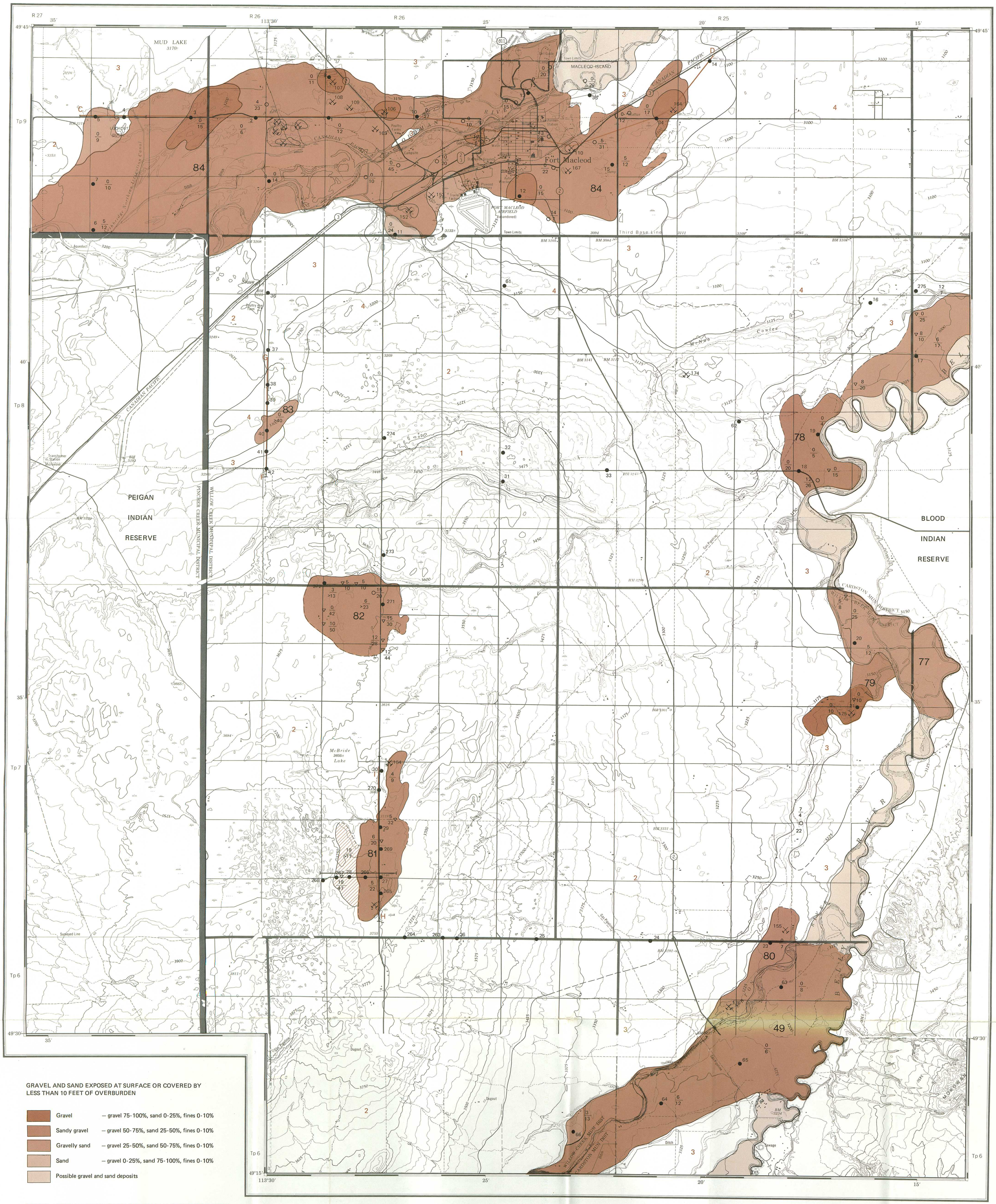
SURFICIAL GEOLOGY
LETHBRIDGE
ALBERTA

NTS 82 H, 82 I



Cartography by A.R.C. Drafting Services

Published 1981



GRAVEL AND SAND EXPOSED AT SURFACE OR COVERED BY LESS THAN 10 FEET OF OVERBURDEN

🟫	Gravel	– gravel 75-100%, sand 0-25%, fines 0-10%
🟫	Sandy gravel	– gravel 50-75%, sand 25-50%, fines 0-10%
🟫	Gravelly sand	– gravel 25-50%, sand 50-75%, fines 0-10%
🟫	Sand	– gravel 0-25%, sand 75-100%, fines 0-10%
🟫	Possible gravel and sand deposits	

GRAVEL AND SAND COVERED BY MORE THAN 10 FEET OVERBURDEN

▨	Recorded in testholes and well logs
▨	Assumed on basis of geological associations
1	Sandstone, siltstone and shale (bedrock)
2	Till
3	Silty sand, silt and clay
4	Sand fine-grained

Geological boundary; defined, assumed

Sand and gravel pit, pit number 74

Pit area if it is extensive

Testhole drilled by ARC, hole number .... ●192

Water well log .... ○

Seismic shothole .... ▽

Deposit reference number on map 2 in appendix C 82

Thickness of overburden / Thickness of gravel and sand .... $\frac{6}{20}$

Geological profile location .... A B

Ground resistivity traverse location

Compiled by I. Shetson
Cartography by A.R.C. Drafting Services

Scale 1:50,000

1 0 1 2 3 Miles
1 0 1 2 3 4 Kilometres

Published 1981

GRAVEL AND SAND DEPOSITS
FORT MACLEOD AREA
ALBERTA

LEGEND

River or stream

Intermittent river or stream

Lake

Intermittent lake

Road, hard surface, all weather 2

Railway

Township boundary

Section line

Contours definite, approximate 3000

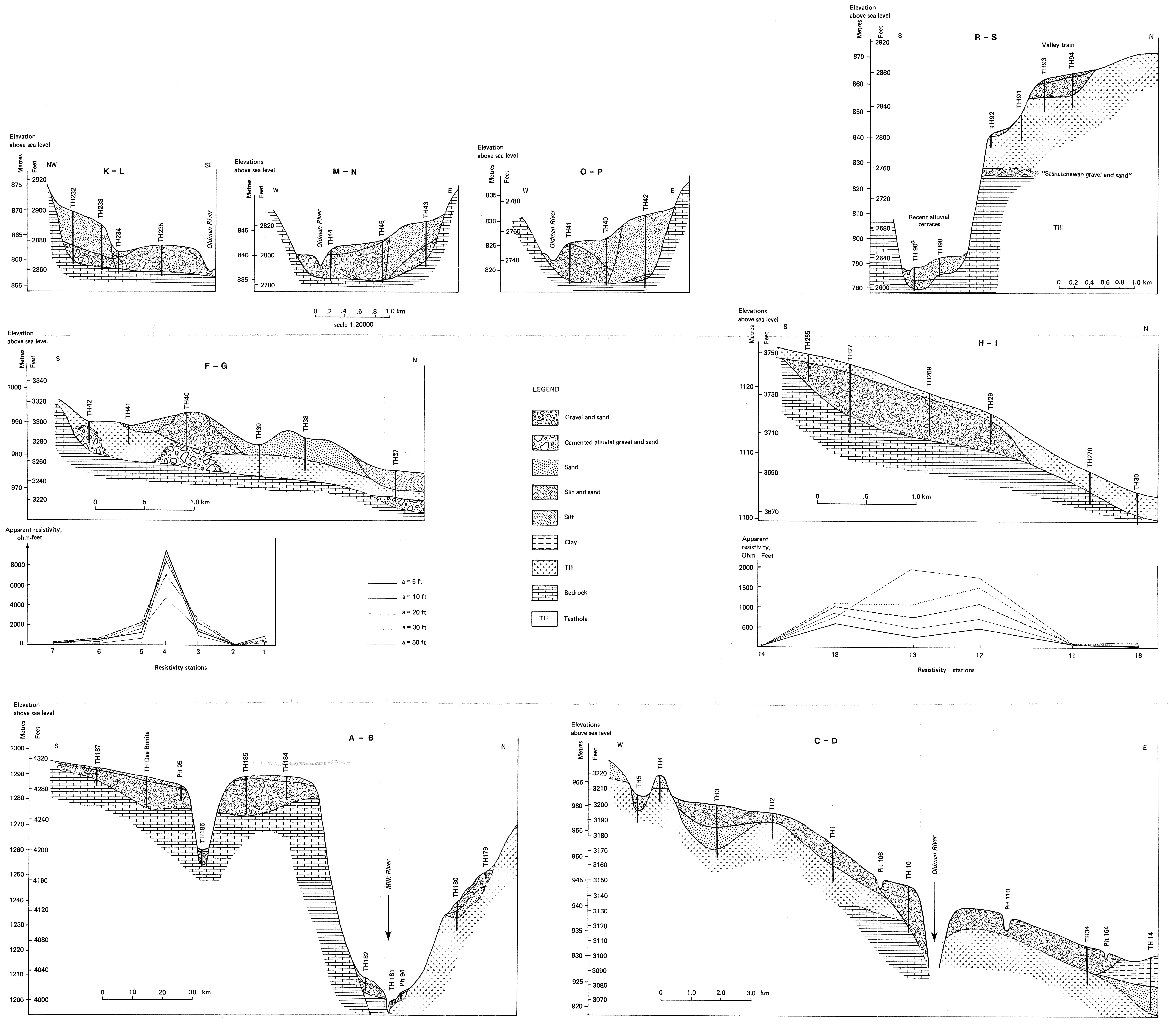


FIGURE 19. Geological profiles

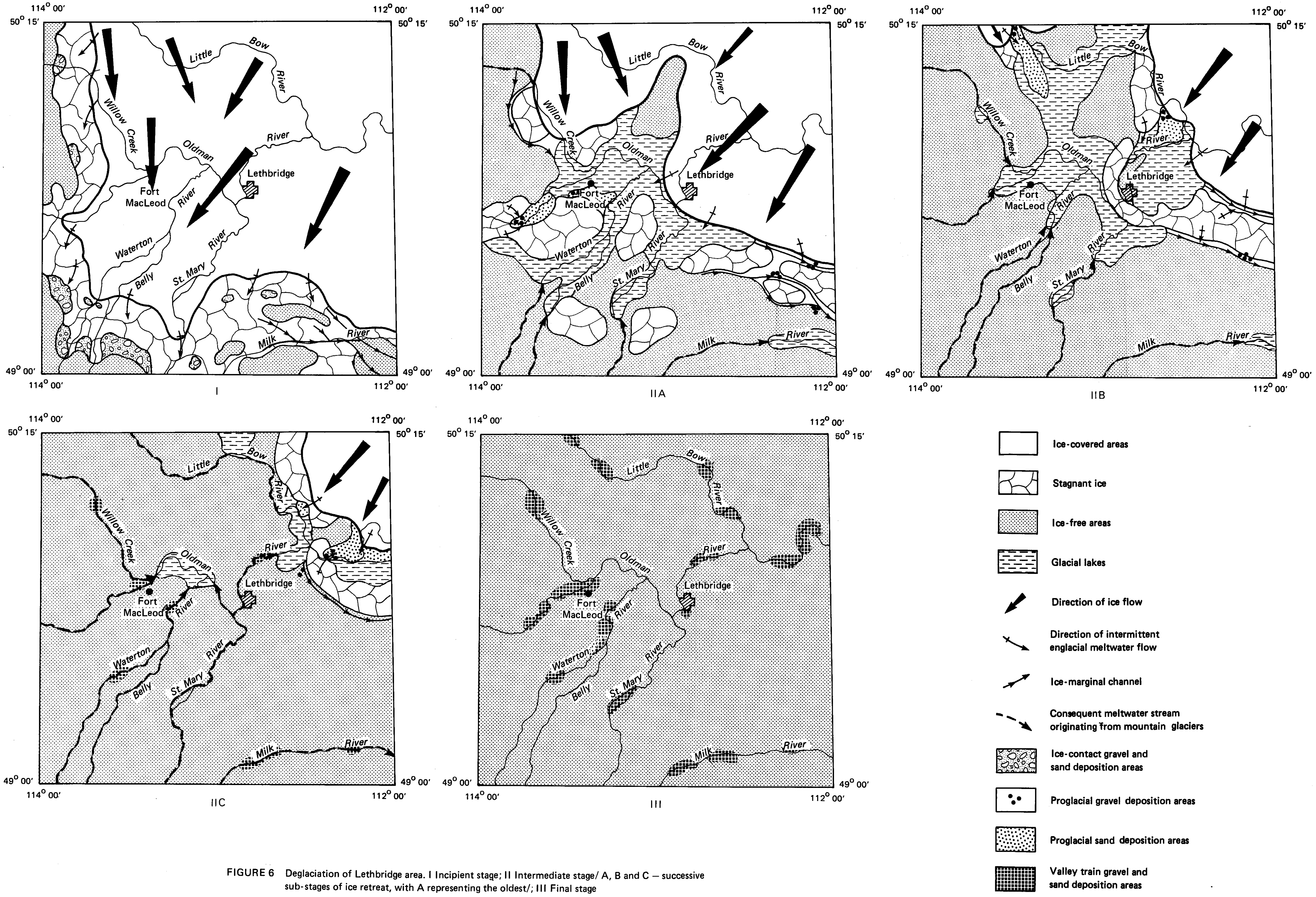
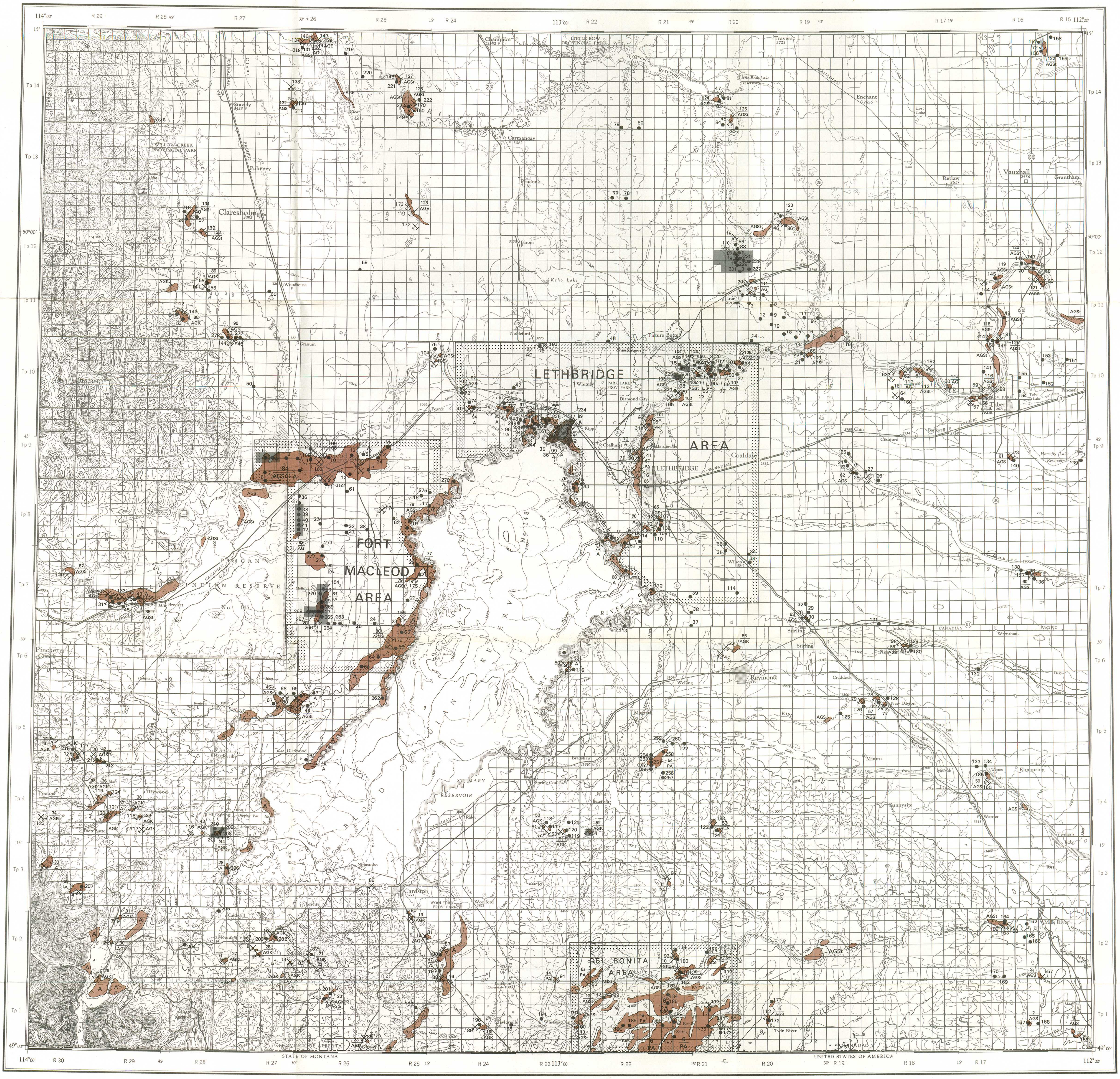


FIGURE 6 Deglaciation of Lethbridge area. I Incipient stage; II Intermediate stage/ A, B and C — successive sub-stages of ice retreat, with A representing the oldest/; III Final stage



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Cartography by A.R.C. Drafting Services

Published 1981

SCALE 1:250,000

Miles 5 0 5 10 15 20 Miles

Kilometres 5 0 5 10 15 20 25 30 Kilometres

DISTRIBUTION OF GRAVEL, SAND DEPOSITS, PITS, TESTHOLES AND RESISTIVITY SITES
LETHBRIDGE – GLEICHEN, ALBERTA

NTS 82H, 82I

GRAVEL AND SAND DEPOSITS

▨	Defined on basis of drilling or outcrop information
▨	Assumed on basis of surface mapping or airphoto interpretation

GENETIC GROUPS

PA	Preglacial alluvial deposits
AGK	Kame deposits
AGE	Esker deposits
AG	Outwash deposits
AGS	Marginal stream deposits
AGSt	Valley train deposits
A	Recent alluvial deposits

Geological boundary ....
Deposit number / Origin .... 65 / AGSt
Sand and gravel pit, number 96
ARC testhole, number .... ● 219
Resistivity site .... ▬
Areas mapped at scale 1:50,000 .... ▨

LEGEND

River or stream ....
Intermittent river or stream ....
Lake ....
Intermittent lake ....
Road, hard surface, all weather 2

Railway ....
Township boundary ....
Section line ....
Contours definite, approximate 2000

GRAVEL AND SAND EXPOSED AT SURFACE OR COVERED BY LESS THAN 10 FEET OF OVERBURDEN

▨	Gravel	— gravel 75-100%, sand 0-25%, fines 0-10%
▨	Sandy gravel	— gravel 50-75%, sand 25-50%, fines 0-10%
▨	Gravelly sand	— gravel 25-50%, sand 50-75%, fines 0-10%
▨	Sand	— gravel 0-25%, sand 75-100%, fines 0-10%
▨	Possible gravel and sand deposits	

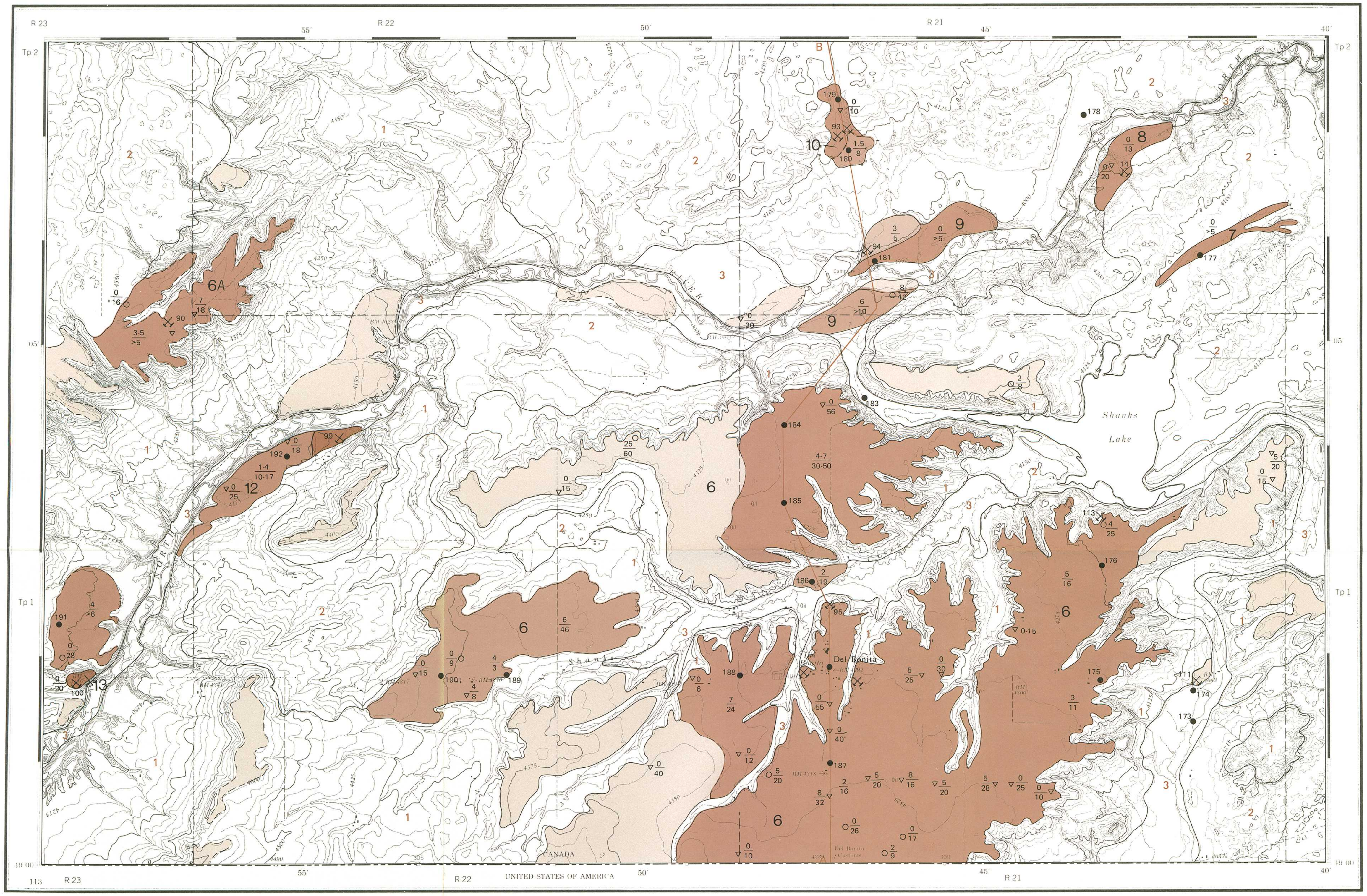
GRAVEL AND SAND COVERED BY MORE THAN 10 FEET OVERBURDEN

▨	Recorded in testholes and well logs
▨	Assumed on basis of geological associations
1	Sandstone, siltstone and shale (bedrock)
2	Till
3	Silty sand, silt and clay
4	Sand fine-grained

Geological boundary; defined, assumed	
Sand and gravel pit, pit number	✕ 91
Pit area if it is extensive	◌
Testhole drilled by ARC, hole number	● 192
Water well log	○
Seismic shothole	▽
Deposit reference number on map 2 in appendix C	3
Thickness of overburden / Thickness of gravel and sand	5/28
Geological profile location	A—B
Ground resistivity traverse location	⊢—⊣

LEGEND

River or stream	
Intermittent river or stream	
Lake	
Intermittent lake	
Road, hard surface, all weather	②
Railway	
Township boundary	
Section line	
Contours definite, approximate	3000



Compiled by I. Shetson
Cartography by A.R.C. Drafting Services

Scale 1:50,000

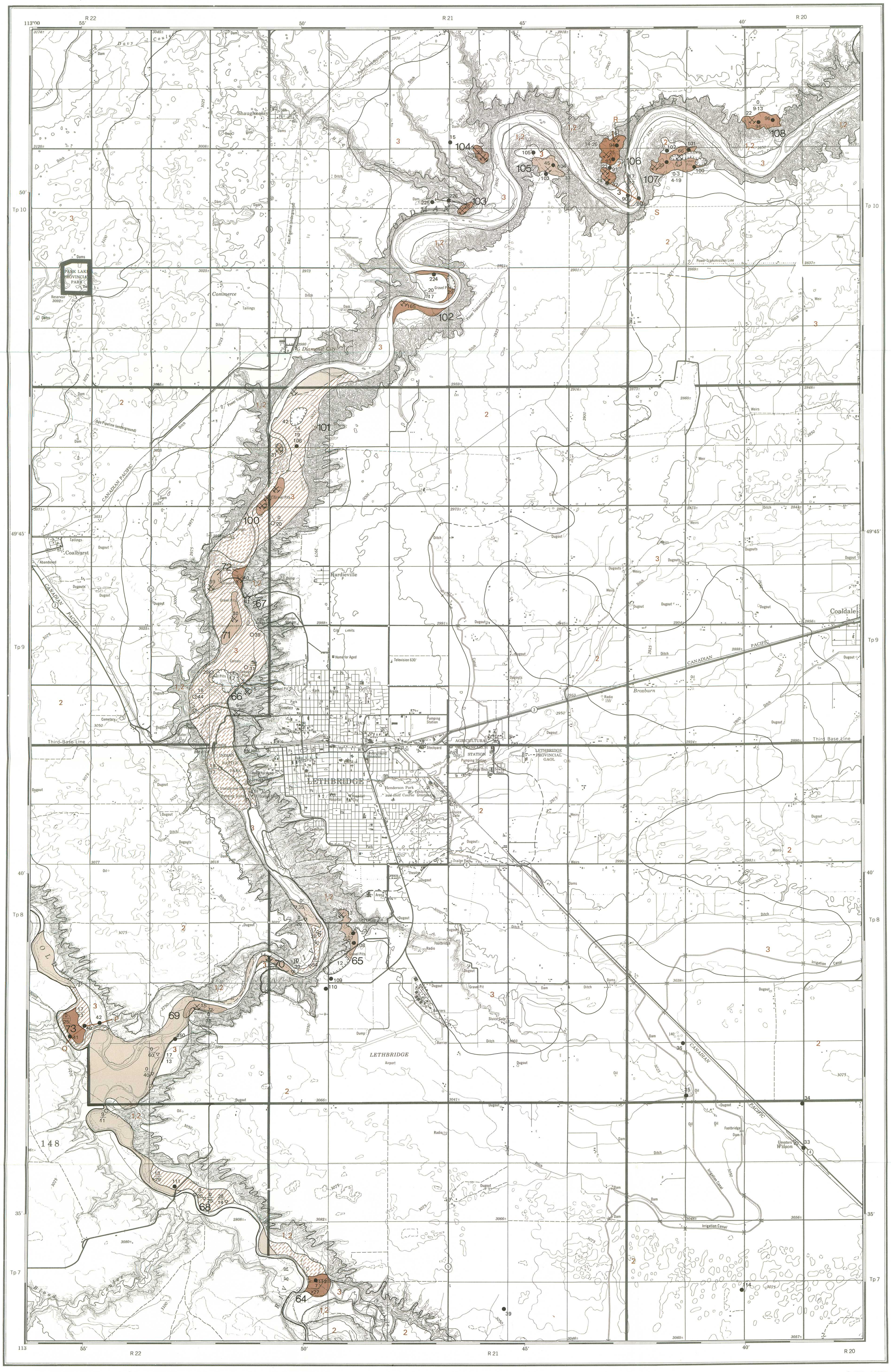
1 0 1 2 3 Miles

1 0 1 2 3 4 Kilometres

Published 1981

GRAVEL AND SAND DEPOSITS
DEL BONITA AREA
ALBERTA

NTS 82H/2



GRAVEL AND SAND EXPOSED AT SURFACE OR COVERED BY LESS THAN 10 FEET OF OVERBURDEN

🟫	Gravel	— gravel 75-100%, sand 0-25%, fines 0-10%
🟫	Sandy gravel	— gravel 50-75%, sand 25-50%, fines 0-10%
🟫	Gravelly sand	— gravel 25-50%, sand 50-75%, fines 0-10%
🟫	Sand	— gravel 0-25%, sand 75-100%, fines 0-10%
☐	Possible gravel and sand deposits	

GRAVEL AND SAND COVERED BY MORE THAN 10 FEET OVERBURDEN

▨	Recorded in testholes and well logs
▨	Assumed on basis of geological associations
1	Sandstone, siltstone and shale (bedrock)
2	Till
3	Silty sand, silt and clay
4	Sand fine-grained

Geological boundary; defined, assumed	
Sand and gravel pit, pit number	81
Pit area if it is extensive	
Testhole drilled by ARC, hole number	●117
Water well log	○
Seismic shothole	▽
Deposit reference number on map 2 in appendix C	70
Thickness of overburden / Thickness of gravel and sand	15 / 25
Geological profile location	A B
Ground resistivity traverse location	

LEGEND

River or stream
Intermittent river or stream
Lake
Intermittent lake
Road, hard surface, all weather
Railway
Township boundary
Section line
Contours definite, approximate

Compiled by I. Shetson
Cartography by A.R.C. Drafting Services

Published 1981

Scale 1:50,000

1 0 1 2 3 Miles
1 0 1 2 3 4 Kilometres

GRAVEL AND SAND DEPOSITS
LETHBRIDGE AREA (EAST HALF)

ALBERTA

NTS 82H/10, 82H/15